



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 1: Australia, Canada and the United States of America, January 2000 to June 2012

This report is the first 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 Snowy Mountains Engineering Corporation (SMEC).

October 2014

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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 is the first 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 and the United States of America (US) during the period January 2000 to June 2012.

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 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 state regulators and industry, with project and citation information, which will enable improved understanding of the water-related impacts of coal seam gas and coal mining.

Main findings

- A total of 55 projects were identified from Australia, Canada, and the US between January 2000 and June 2012.
- Most of the research identified was generated from Australia (54%), with the remaining research originating from the US (33%), and Canada (13%) least of all.
- The dominant research themes on which project have been focusing were: impacts on water quality and quantity; water treatment; effects on land and water resources; and water-dependent ecosystems.
- Research themes that were poorly represented in the search results included: aquifer integrity and disruption of surface water flow pathways.
- In Australia, most relevant research is focused on the Bowen Basin, Surat Basin, Fitzroy Basin and the Murray-Darling Basin in Queensland; the Gippsland Basin in Victoria; and Newnes Plateau, Murray-Darling Basin, Hunter Valley, Namoi Catchment, Wyong and the Southern Coalfield in New South Wales.
- In the US, most research has centred in the Powder River Basin in southeast Montana and northeast Wyoming, Tongue River in Montana, Powell River in southwest Virginia and East Tennessee, Central Appalachian coalfields, and Black Warrior Basin in western Alabama and northern Mississippi.
- In Canada most research is centred on Alberta.
- It has been identified that much recent research focuses on the development of effective water impact monitoring, management, and reporting tools and technologies for application in the coal mining and coal seam gas industries, rather than characterising actual/potential impacts of coal mining and coal seam gas on water-related environmental values.

Abbreviations

General abbreviations	Description
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 operations in 2012)
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
GDE	Groundwater Dependent Ecosystem
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
IMWA	International Mine Water Association
LLS	Local Land Services
OWS	Office of Water Science
UK	United Kingdom
UNSW	University of New South Wales, Australia
US	United States of America
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 water 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 groundwater and gas and generally contain saltier groundwater than aquifers that are used for drinking water or agriculture.
Coal seam gas	a form of natural gas (generally 95-97 per cent pure methane, CH ₄) typically extracted from permeable coal seams at depths of 300–1000 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, causing a dimple, called the cone of depression, to form in the watertable around the well. 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 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.

Term	Description
Hydraulic fracturing	also known as 'fracking', 'fracking' or 'fracture stimulation', is the 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 network of small fractures radiating outwards from the well through which the gas, and any associated water, can flow.
Seismicity (induced)	refers to typically minor earthquakes and tremors that are caused by human activity that alters the stresses and strains on the Earth's crust.
Shale gas	a natural gas found in shale formations.
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.
Water quality	the physical, chemical and biological attributes of water that affects its ability to sustain environmental values.
Well	a human-made hole in the ground, generally created by drilling, to obtain water (also see bore).

1 Introduction

The extractive nature of coal mining and coal seam gas (CSG) 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 fracking chemicals; and groundwater and ecological impacts from enhanced aquifer connectivity.

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 independent, expert scientific advice to decision-makers on the potential 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 is the first in a series of reference list reports commissioned by the Department of the Environment on the advice of the IESC. The complete reference list series will include 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 a number of countries including (but not limited to) Australia, the United States of America (US), Canada, China, India, Russia and the United Kingdom (UK) since January 2000.

The objective of the 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 series will also provide others, including state regulators, with project and citation information, which will enable improved understanding of the water-related impacts of coal seam gas and coal mining.

1.1 Scope

This report (Report 1 in Table 1.1) includes summaries of research projects relating to the water-related impacts of coal seam gas and coal mining developments currently being undertaken or completed during the period January 2000 to June 2012 from Australia, Canada and the US.

Table 1.1 Scope of reports commissioned by OWS regarding water impacts of coal mining and coal seam gas

Report	Country included in 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:
 - water quality and quantity
 - integrity
- R2. disruption of surface water flow pathways:
 - subsidence
 - mine cone of depression
 - infrastructure
- R3. co-produced water and salt management (CSG) and mine water & salt management (coal mines):
 - aquifer injection and/or water treatment (technologies, relative cost benefit)
 - effect on land and water resources (including irrigation)
 - water dependent ecosystems
- R4. integrity of wells- installation, operation, decommissioning
- R5. hydraulic fracturing:
 - chemical – surface and groundwater quality
 - physical – aquitard disruption, borehole collapse
- R6. quality and reliability of irrigation and drinking water supplies.

This report does not include the following types of information:

- research outside of Australia, the US or Canada
- research on other extractive industries
- research not relevant to the impacts on water resources or water-related environmental values from coal seam gas and coal mining
- bibliographic database of completed research
- critical review of the collated material
- research completed prior to January 2000 and after June 2012.

2 Search strategy

2.1 General

The search strategy was three tiered:

- general search engines were utilised to identify research institutions, programs and literature related to the broad topic
- scientific organisation database searches were conducted specific to the research themes
- organisational research programs were targeted.

Table 2.1 summarises the database search methods used and outcomes.

Table 2.1 Search statistics

Database	Search terms [number of results]
Tier 1: General research and literature	
Google < www.google.com.au >	'coal seam gas research' [448 000] 'coal mining water research' [15 000 000] 'coalbed methane research Canada' [4 530 000] 'coal mining research stream flow impact' [4 580 000] 'hydraulic fracturing research' [2 700 000] Review of these results was superficial, the aim being to identify key links/organisations to pursue in more detail
SpringerLink < www.springerlink.com > This database allows export of results to a spreadsheet, where results can then be further filtered/sorted, e.g., by removing titles with reference to 'China' or showing only results with 'Subsidence'	'impact "coal mining" water' [886] 'impact "coal seam gas" water' [14] impact "coalbed methane" water' [84] 'impact "coal bed methane" water' [85] 'impact "coalbed gas" water' [16] 'impact "coal bed gas" water' [9] With filters: years 2000 – 2012 In 'Full Text', with filter: 'Earth and Environmental Science'
ScienceDirect (SciVerse, Elsevier, Scopus) < www.sciencedirect.com >	'impact "coal mining" water' 'impact "coal seam gas" water' impact "coalbed methane" water' 'impact "coal bed methane" water' 'impact "coalbed gas" water' 'impact "coal bed gas" water' With filters: years 2000 – 2012 [Overall results: 100 - 1000s] Allows e-mailing of results, which can then be copied into

Database	Search terms [number of results]
	a document format and searched for key words
Trove (National Library of Australia) < www.trove.nla.gov.au >	'impact "coal mining" water' 'impact "coal seam gas" water' impact "coalbed methane" water' 'impact "coal bed methane" water' 'impact "coalbed gas" water' 'impact "coal bed gas" water' With filters: years 2000 – 2012 [Overall results: 100 - 1000s]
Worldcat (OAIster) < http://oaister.worldcat.org/ >	'impact "coal mining" water' 'impact "coal seam gas" water' impact "coalbed methane" water' 'impact "coal bed methane" water' 'impact "coalbed gas" water' 'impact "coal bed gas" water' With filters: years 2000 – 2012 [Overall results: 10s - 100]
Tier 2 Specific literature	
Geoscience Australia <www.ga.gov.au/oracle/library/catalogue_basic.php > SARIG <sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/cat0/MSearch> InfoMine <www.infomine.com/publications/search.asp> AusGeoRef <www.ausgeoref.org> CSIRO <www.csiro.au/Portals/Publications/Research--Reports.aspx> American Geophysical Union (AGU) <europa.agu.org/?view=search&adv=1> U.S. Geological Survey (USGS) <library.usgs.gov/> U.S. EPA National Service Center for Environmental Publications (NSCEP) <www.epa.gov/nscep/index.html> Geological Survey of Alabama <gsa.state.al.us/publications.aspx> Utah Geological Survey <utsl.sirsi.net/uhtbin/cgisirsi/?ps=KxALjR	"coal seam gas" "coalbed methane" "coal bed methane" "coalbed gas" "coal bed gas" "unconventional gas" "well integrity" "well construction" "aquifer integrity" 'coal water' 'coal impact water' 'coal impact groundwater' 'coal impact ecosystem' 'coal surface water flow' 'coal salinity' "water dependent ecosystem" 'subsidence' "produced water" "hydraulic fracturing" With filter: years 2000 – 2012 [Overall results: 10s (except for UW Libraries, which was 1000s)]

Database	Search terms [number of results]
a8th/USL/39520011/60/1182/X> UW Libraries <www-lib.uwyo.edu/> The Energy Innovation Platform of Alberta (EIPA) <eipa.alberta.ca/> Alberta Environment Information Centre <www.environment.gov.ab.ca/info/home.asp> Alberta Innovates Energy and Environment research database <extranet.aet.alberta.ca/SIIS.public/EIPA/BasicSearch.aspx>	
Tier 3 Specific research	
Australian Coal Association Research Program (ACARP) <www.acarp.com.au/> Research Data Australia <researchdata.ands.org.au/> UQ reSEARCHers <www.uq.edu.au/uqresearchers/search.html?lst_projects=Projects&search_string=coal&type=all> SearchMining.net <www.searchmining.net/>	‘Coal’ and manual search [Results: ≤ 152 (UQ reSEARCHers)]

2.2 Targeted search

Based on the author’s knowledge of research organisations and supplemented by findings from general searches above, the websites of the following institutions were searched for information relating to relevant research projects or programs:

- Australia:
 - Australian Coal Association Research Program (ACARP)
 - Australian Petroleum Production & Exploration Association Ltd (APPEA)
 - Cooperative Research Centre for Coal in Sustainable Development (CCSD)
 - CSIRO
 - Department of Resources, Energy and Tourism
 - Gas Industry Social & Environmental Research Alliance (GISERA)
 - Geoscience Australia
 - National Centre for Groundwater Research and Training (NCGRT)
 - National Water Commission

- Queensland Resources Council
- Queensland Water Commission
- WA:ERA
- Australian National University; AUSCEW, Fenner School of Environment & Society
- Curtin University; Australian Sustainable Development Institute, Oil & Gas Research Portal
- Queensland University of Technology; Water Resources and Geosystems, Earth, Environmental and Biological Sciences
- The University of Queensland (UQ); Sustainable Minerals Institute (SMI)
- University of Newcastle; Newcastle Institute for Energy and Resources
- University of NSW; Water Research Centre, Connected Waters Initiative, School of Mining Engineering
- University of Southern Queensland
- University of Sydney; Institute for Sustainable Solutions
- United States:
 - Geological Survey of Alabama
 - Groundwater Protection Council
 - National Groundwater Association
 - National Research Council
 - U.S. Department of Energy; National Energy Technology Laboratory (NETL)
 - U.S. Environmental Protection Agency
 - U.S. Geological Survey
 - Montana State University
 - University of Wyoming
 - University of Texas at Austin
 - Virginia Tech; Powell River Project
 - Wyoming State Geological Survey
 - Colorado School of Mines
- Canada:
 - Alberta Environment and Sustainable Resource Development
 - Alberta Geological Survey
 - Canada School of Energy and Environment
 - Canadian Association of Petroleum Producers
 - Canadian Natural Gas
 - Canadian Society for Unconventional Resources

- Canadian Water Network
- Centre for Energy
- Government of Alberta Department of Energy
- National Energy Board
- Government of Alberta – Water for Life
- Pembina Institute
- University of Alberta
- University of British Columbia
- University of Calgary
- University of Lethbridge

Where appropriate, key personnel from the above institutions were contacted and asked to provide additional information in specific research projects or programs. Where this information was provided, it has been included in the research profiles in Section 4. Table A1 at Appendix A summarises contacted personnel.

3 Synthesis of search results

A total of 55 research projects from Australia, Canada and the US were found to relate to water impacts and coal seam gas/coal mining, either currently being undertaken or completed, in the period January 2000 to June 2012.

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 research theme.

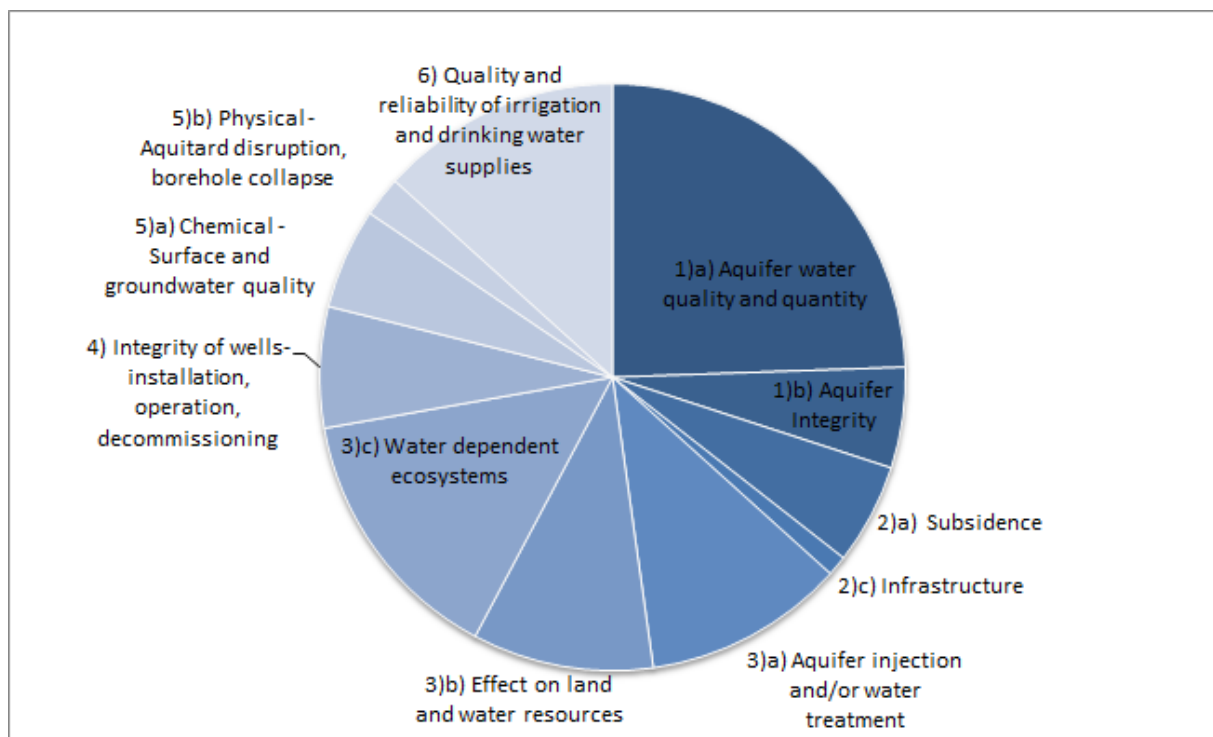


Figure 3.1 Distribution of research themes

The number of projects by research theme were:

R1. aquifer interconnectivity:

- water quality and quantity [22]
- integrity [5]

R2. disruption of surface water flow pathways:

- subsidence [5]
- mine cone of depression [0]
- infrastructure [0]

- R3. co-produced water and salt management (CSG) and mine water & salt management (coal mines):
 - aquifer injection and/or water treatment (technologies, relative cost benefit) [10]
 - effect on land and water resources (including irrigation) [9]
 - water dependent ecosystems [13]
- R4. integrity of wells- installation, operation, decommissioning [6]
- R5. hydraulic fracturing:
 - chemical – surface and groundwater quality [5]
 - physical – aquitard disruption, borehole collapse [2]
- R6. quality and reliability of irrigation and drinking water supplies [12].

The following topics were relevant to the majority of the 55 projects:

- groundwater quality and quantity
- co-produced water from CSG effects and management
- saline mine water effects and management

quality and reliability of irrigation and drinking water supplies. Only a small number of projects related directly to the following topics:

- aquifer Integrity
- mine cone of depression (none)
- disruption of surface water flow pathways from infrastructure
- disruption of surface water flow pathways from subsidence
- integrity of wells- installation, decommissioning
- hydraulic fracturing, physical - aquitard disruption.

Of the 55 projects, 23 related to coal mining and 33 related to coal seam gas, as is displayed in Figure 3.2 and Figure 3.3, respectively.

Two studies (*Coal seam gas, coal and agriculture: water implications*, and *Namoi Catchment water study*) represented both coal mining and coal seam gas.

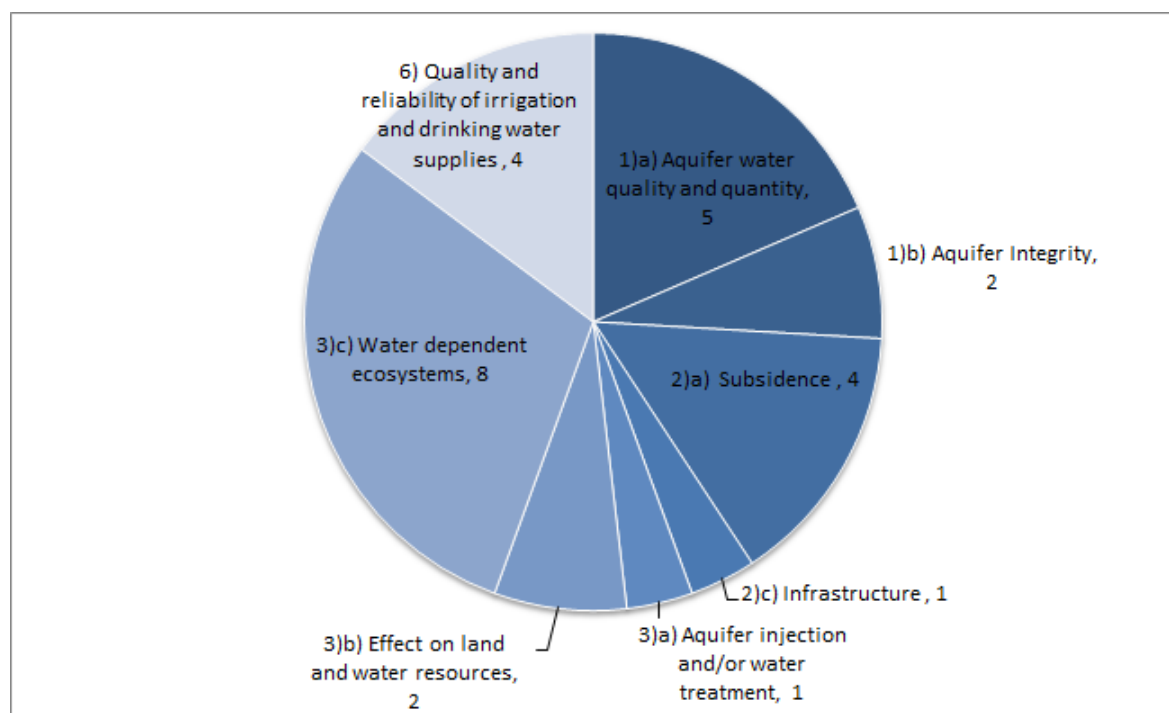


Figure 3.2 Distribution of projects relating to coal mining by research theme

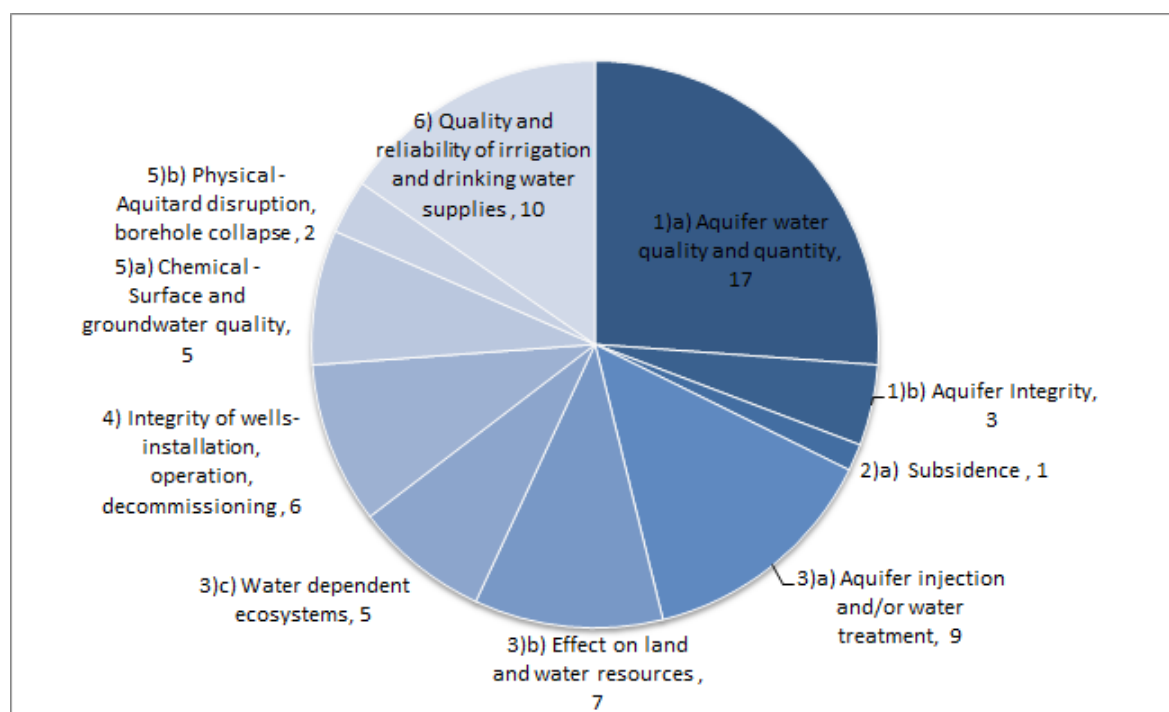


Figure 3.3 Distribution of projects relating to coal seam gas by research theme

3.1.1 Themes outside of review scope

In the process of undertaking this review, it has been identified that much recent research focuses on the development of effective water impact monitoring, management, and reporting tools and technologies for application in the coal mining and CSG industries, rather than characterising actual/potential impacts of coal mining and coal seam gas on water-related environmental values. For example, there has been a shift away from characterising the impacts of produced waters on the receiving environment and toward the development of effective monitoring, treatment and disposal technologies. These “technological” projects were generally not summarised, given the specified research scope; however, examples are provided in the *Centres of research* section of this report should these types of projects be of interest for further follow-up.

Identified projects on hydraulic fracturing and co-produced waters often related to shale gas development and projects in the US. Coal seam gas is well established in the US, while shale gas has emerged recently as a coal energy source. A few summarised projects relate to hydraulic fracturing used in both CSG and shale gas, while those specific to shale gas have not been summarised (see US Geological Survey projects in *Centres of research* section of this report for a summary).

Other research topics returned through the database base searches, but that were not followed up, included:

- carbon capture and sequestration/storage
- seismicity.

3.2 Projects by location

3.2.1 Australia

Several major gas and petroleum companies are extracting or are planning to extract coal seam gas from the Bowen and Surat Basins in Queensland, and other CSG producing areas in New South Wales (NSW).

New South Wales and Queensland are the main black coal producing states with around 97 per cent of Australia's saleable output of black coal, and almost all of Australia's black coal exports. Exports from Western Australia commenced in 2007.

Of the 55 projects identified, 30 were from Australia, mainly relating to the coal mining/coal seam gas areas of Queensland, New South Wales and Victoria.

The distribution of the 30 Australian projects by location is displayed in Figure 3.1.

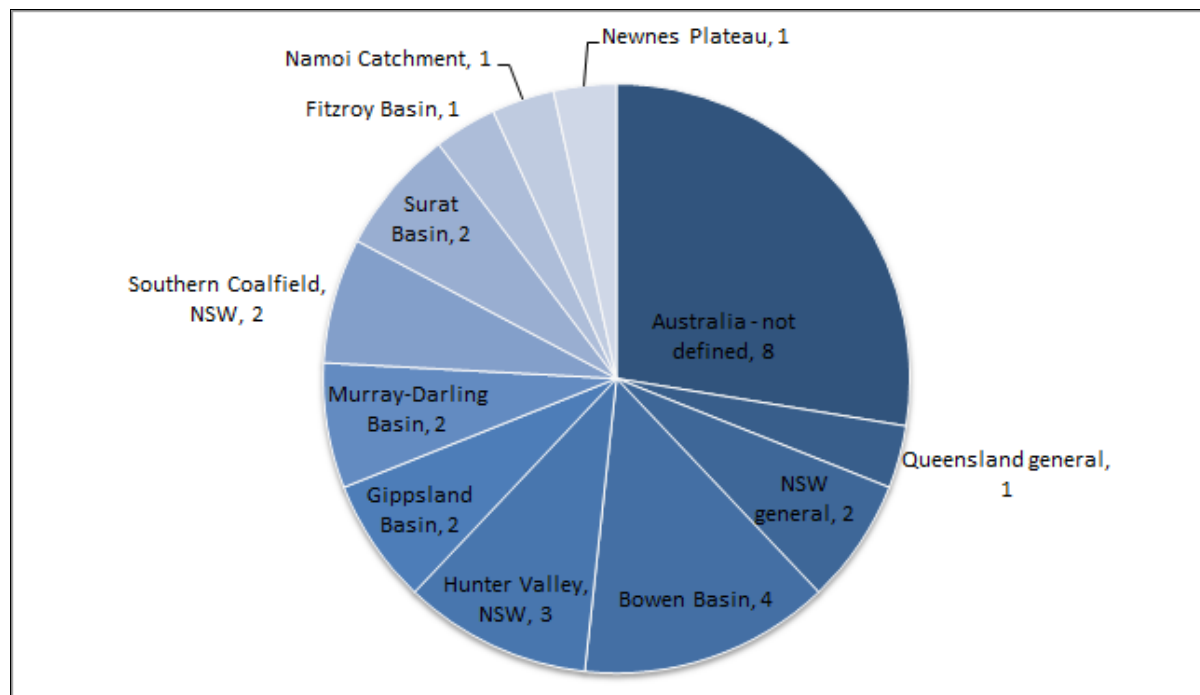


Figure 3.4 Distribution of Australian projects by location

Specific location studies were carried out in the:

- Bowen Basin:
 - coal mining, relating to aquatic ecosystems, infrastructure disruption of flow paths, salinity
- Murray-Darling Basin:
 - coal seam gas, relating to aquifer interconnectivity, water quality and quantity, produced water, aquatic ecosystems, cumulative Impacts
- Newnes Plateau:
 - coal mining, relating to subsidence
- Hunter River Valley:
 - coal mining, relating to salinity, water supply, aquifer interconnectivity, cumulative impacts
- Surat Basin:
 - coal seam gas, relating to aquifer interconnectivity, water supply, cumulative impacts
- Fitzroy Basin:
 - coal mining, relating to water quality and salinity
- Namoi Catchment:
 - coal mining and coal seam gas, relating to surface and groundwater quantity and quality

- Wyong Local Government Area:
 - coal mining, relating to subsidence
- NSW Southern Coalfield:
 - coal seam gas, relating to co-produced water
 - coal mining, relating to subsidence
- Gippsland Basin:
 - coal seam gas, relating to water supply
 - coal mining, relating to water supply

3.2.2 *United States of America*

Of the 55 projects identified, 18 originated from the US. The majority of coal seam gas research in the US has occurred in the Powder River Basin. Other location specific research occurred at the Tongue River, Powell River, Central Appalachian Coalfields and Black Warrior Basin (Figure 3.2).

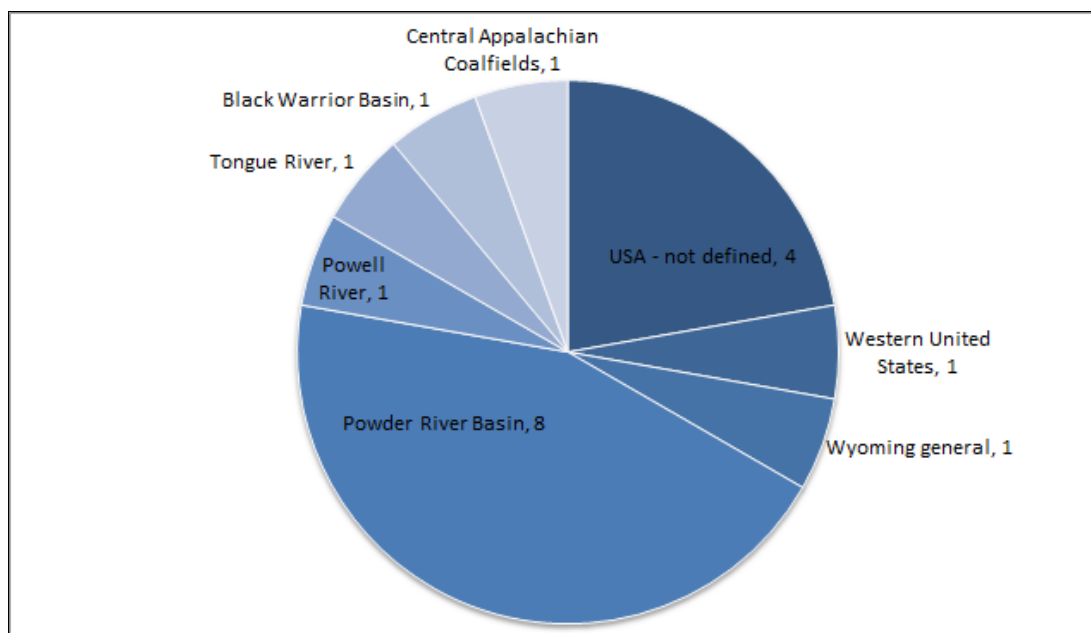


Figure 3.5 Distribution of US projects by location

3.2.3 *Canada*

Of the 55 projects identified, seven were from Canada. Six of the seven originated from Alberta, and one from British Columbia (BC). British Columbia and Alberta represent the main coal producing areas in Canada.

As at March 2002, no large-scale commercial CSG recovery projects existed in Canada¹. In 2003, the Multi-Stakeholder Advisory Committee (MAC) was established as part of a review and consultation initiated by the Department of Energy (DOE) to address public concerns associated with coalbed methane (CBM) development in Alberta. This provided a suite of recommendations associated with CSG development, which have been followed through; this project is summarised in this report.

As at 2006, Alberta was the only province with commercial coalbed methane wells². To date, most of the current shallow CBM development in Alberta has not produced water. Some deeper projects have produced saline water, and some Ardley test wells have produced small amounts of water of varying quality³. Following on from MAC, which addressed CBM development in Alberta, the Oil Sands Sustainable Development Secretariat was created by the Government of Alberta in the summer of 2007 to address rapid growth issues in the oil sands regions of Alberta. Oil sands remain a forefront focus of Alberta Energy and Alberta Environment, along with Carbon Capture and Storage, as part of Alberta's move towards a clean energy future⁴. This is reflected in the recent (since 2007) and current research themes at Alberta research institutes (i.e. Canada School of Energy and Environment; University of Alberta School of Energy and the Environment; University of Calgary Institute for Sustainable Energy, Environment and Economy).

As at 2007, CSG exploration was underway in British Columbia but no commercial operations had commenced. No further information on current CSG development (or research) in British Columbia was found for this review. The British Columbian government website promotes CSG development, along with best practice environmental practices. Of note for this review is British Columbia government's information on produced water; citing experience from the US and a literature review commissioned in October 2001 (outside the scope of this project) on water handling, environmental, and land-use aspects of coalbed gas (CBG) development⁵.

In regards to coal mining, the majority of research identified from Canada was from prior to 2000 and therefore, outside the scope of this project.

3.3 Centres of research

3.3.1 Main sources

The centres of research and programs described below provided much of the compiled information. These also have a significant number of projects occurring that, although were not considered to meet the criteria exactly, related to managing environmental values in the coal mining/coal seam gas industries.

The University of Queensland (UQ): Sustainable Minerals Institute (SMI)

The Centre for Mined Land Rehabilitation (CMLR) provides scientifically rigorous research outcomes for rehabilitation management decisions. Current studies focus on five major areas:

1 Bill Gunter, Alberta Research Council (ARC) Enhanced Coalbed Methane (ECBM) Recovery Project in Alberta, Canada, COAL-SEQ I, Houston, Texas, U.S.A., March 14-15, 2002

2 John Squarek and Mike Dawson, Coalbed methane expands in Canada, Oil & Gas Journal, 24 July 2006, p.37-40

3 <<http://www.energy.alberta.ca/NaturalGas/753.asp>>

4 <<http://oilsands.alberta.ca/cleanenergystory.html>>

5 <<http://www.em.gov.bc.ca/OG/oilandgas/petroleumgeology/CoalbedGas/Pages/ProducedWater.aspx>>

- Stable Landforms & Sustainable Substrates
- Water & Contaminants in the Landscape
- Ecosystem Structure & Function
- Monitoring & Mapping Technologies
- Mine Closure & End Use Planning

The Centre for Coal Seam Gas (CCSG) aims to be a world leading centre of excellence that serves the research and educational needs of industry, government and community stakeholders regarding this emerging industry. This research focuses around the four key areas of:

- water
- geophysics and geochemistry of CSG
- petroleum engineering
- social performance and community impact

The Centre for Water in the Minerals Industry (CWiMI) conducts research towards achieving sustainable water management in the mining industry. It aims to develop key technologies for the measurement, monitoring and modelling of water in the context of mine operations, their surrounding environments and regional communities. Relevant projects include:

- *Understanding salt dynamics to facilitate water reuse on coal mine sites* (summary provided in this report)
- *Assessing impact of sulphate in saline mine site discharge in seasonally flowing streams in the Bowen Basin* (summary provided in this report)
- *Guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams* (summary provided in this report)
- *Coal seam gas & underground coal seam gasification government advice*
- *Environmental offsets: maximising ecosystem services from biodiversity conservation.*

The CWiMI has also developed the following research tools fully capitalise on the benefits of their research into sustainable mine water management and practices:

- Water Miner; a web-based tool that tracks the movement of water into, around and out of mine sites
- Water Value Tool; captures and displays the risks and opportunities associated with mine sites water management practices
- Cumulative Impacts Assessment Tool; captures and displays the groundwater risks and opportunities associated with adding a new project to an existing mined region.

US Geological Survey

Produced water. Researchers in the US Geological Survey (USGS) Energy Resources Program (ERP) and colleagues are actively engaged in examining several aspects related to characterisation, use and impact of produced waters. Currently research is focused in three areas:

- *Assessing impacts of coal bed methane produced waters* – coal bed methane is produced by dewatering coal beds and has become an increasingly important source of energy in the US. The USGS is studying the environmental impacts from use and disposal of related produced waters.
- *Characterisation and sources of Appalachian Basin produced waters* – despite a long history of oil and gas development in the eastern US, sparse compositional data exist for produced waters. This drive, along with renewed interest in Marcellus Shale gas accumulations, is sparking research on the source and chemistry of current and future produced waters from the Appalachian Basin.
- *Water balances for energy resource production* – USGS scientists are developing water budget methods for understanding inputs and outputs from regional oil and gas resources.

Studies related to hydraulic fracturing conducted by USGS water science centres. In August 2012, USGS released a document outlining 41 initiated and proposed projects relating to Hydraulic Fracturing across the US. Mostly these relate to hydraulic fracturing during shale gas development.

US Department of Energy

The National Energy Technology Laboratory (NETL) is owned and operated by the US Department of Energy (DOE) and is part of the DOE national laboratory system. The NETL supports the DOE mission to advance the national, economic and energy security of the US.

NETL implements a broad spectrum of energy and environmental research and development (R&D) programs that will return benefits for generations to come:

- enabling domestic coal, natural gas and oil to economically power US homes, industries, businesses and transportation
- while protecting the US environment and enhancing energy independence.

Many projects are based around technologies to do with management and treatment of produced waters.

University of Wyoming Office of Water Programs, Wyoming Water Research Program

The US State Water Resources Research Institute (WRRI) program places an Institute at the land-grant universities or at another college or university in each of 54 states or territories. Coal seam gas (or coal bed natural gas; CBNG) produced water related issues have been one research theme. A comprehensive list of WRP projects is provided at the following website: <http://www.uwyo.edu/owp/wrp_projects/>.

3.3.2 Industry research

No research projects (other than mandatory environmental assessment and reporting programs) were identified as being independently undertaken by industry companies/corporations on the topic, although a relatively small number of industry companies were targeted for specific search (i.e. BHP Billiton, Australia Pacific LNG, QCG, Santos, Centennial Coal, Hancock Coal Pty Ltd). Industry funded projects being lead by

research institutions were found; the research institutions included: University of Southern Queensland, UQ SMI CMLR, and Western Research Institute (US).

The main industry–research partner organisations identified in Australia were:

- ACARP - Australian black coal producers contribute to a program of collaborative research that is conducted for the benefit of the coal mining industry. Coal producers have committed to pay 5 cents per tonne to fund the ACARP. The funds are paid to Australian Coal Research Ltd (ACR), a company established by the industry to manage all aspects of the program. The ACARP mission is to research, develop and demonstrate technologies that lead to the safe, sustainable production and utilisation of coal.
- GISERA - CSIRO and Australia Pacific LNG Pty Ltd are founding members of the GISERA. An initial investment of more than \$14 million over five years was funding research into the socio-economic and environmental impacts of the natural gas industry. This initial focus was directed at the Queensland CSG-LNG industry, but there was potential to expand to address impacts and opportunities associated with different gas industries and geographies.
- UQ SMI CCSG - the Centre for Coal Seam Gas (also described above) is funded through a membership model, whereby organisations and individuals contribute a minimum of \$500 000 per year for at least five years. The CCSG actively seeks further members, such as junior CSG companies, CSG service providers, international CSG companies and community/environmental groups.
- CCSD - commenced operations on 1 July 2001 and ceased on 30 June 2008, the CCSD was one of 64 Cooperative Research Centres (CRC) established and supported through the Australian Government Cooperative Research Centre Program. The CCSD was an unincorporated joint venture consisting of 18 participating organisations from the black coal producing and using industries and research organisations in Queensland, New South Wales and Western Australia. Research was conducted in six research programs:
 - economic social and environmental assessment
 - current power generation
 - transitional power generation
 - future scenarios and technologies
 - ironmaking
 - by-products and waste.

3.3.3 Other centres

The following research centres were interrogated and, although no project summaries resulted, it is worth noting research being undertaken in regards to water-related environmental values and it's potential application to the coal mining/CSG industries:

- National Centre for Groundwater Research and Training (NCGRT) - groundwater is now recognised as a crucial asset that must be an integral part of Australia's long-term water planning, and to effectively manage this resource requires far more knowledge of sub-surface water systems than is currently available. NCGRT research is expanding this knowledge base through their research programs:
 - Program 1: Innovative Characterisation of Aquifers and Aquitards
 - Program 2: Hydrodynamics and Modelling of Complex Groundwater Systems
 - Program 3: Surface Water - Groundwater Interactions
 - Program 4: Groundwater-Vegetation-Atmosphere Interactions (GVI)
 - Program 5: Integrating Socioeconomics, Policy and Decision Support
- University of New South Wales - the School of Mining Engineering has a new focus on Mining Engineering education on water, dewatering, waste management, and to leading practices for water and environmental issues. DR Wendy Timms and Dr David Laurence recently commenced meeting with stakeholders and researchers to discuss key questions on water in mining and coal seam gas. Some UNSW project examples include:
 - *Assessment of aquitard integrity for agriculture, mining and CSG extraction* (part of NCGRT Project 1B, funded by ARC and NWC, until mid-2014).
 - *Dissolved gases and isotope tracers detecting vertical leakage in a CSG area* (UNSW Connected Waters Initiative, still seeking funding, early stages of 2 year part time project).
 - *Towards best practice in sustainability reporting on water for the mining industry in Australia* (funded by UNSW School of Mining Engineering, early stages of 3 month pilot project). This pilot research will investigate sustainability reporting on water, waste management and land disturbance by the mining industry in Australia 2009 to 2011. Research aims focusing on these indicators are to:
 - review current sustainability reporting practices of mining companies in Australia
 - sustainability indicators used for reporting
 - current best practice internationally.
- QUT Institute for Sustainable Resources - current research projects at the Institute for Sustainable Resources focus on understanding hydrological and hydrogeological systems and interactions. Results may be used as baseline for CSG related projects.

4 Research profiles

This section profiles the 55 recently commissioned or completed research and knowledge acquisition projects found during this review. The project summaries are first ordered by primary theme, then within each theme summaries from Australia are listed first, followed by US and then Canada.

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.

4.1 Aquifer interconnectivity

4.1.1 Water quality and quantity

Table 4.1 Project 1: Assessment of impacts of the proposed coal seam gas operations on surface and groundwater systems in the Murray-Darling Basin

Project characteristics	Details
Project title	Assessment of impacts of the proposed coal seam gas operations on surface and groundwater systems in the Murray-Darling Basin
Project location	Murray-Darling Basin, Queensland, Australia
Principal investigator	Prof Chris Moran, Dr Sue Vink
Lead institution	Centre for Water in the Minerals Industry (CWiMI), Sustainable Minerals Institute (SMI), The University of Queensland (UQ)
Project budget	Not available
Source of funding	Department of Sustainability, Environment, Water, Population and Communities
Project duration	14 October 2010 - 29 November 2010
Current status	Complete
Project summary	This report was commissioned by Department of Sustainability, Environment, Water, Population and Communities on advice in a report by Geoscience Australia and Habermehl (2010) that the location and nature of current and proposed coal seam gas (CSG) activities in Queensland may trigger Section 255AA - Mitigation of unintended diversions - of the Commonwealth <i>Water Act 2007</i> . The scope of this study was to undertake a desktop study to determine the impacts of the proposed CSG operations on the connectivity of groundwater systems, surface water and groundwater flows and water quality in the Murray-Darling Basin. The study scope did not include analysis of engineering structures or solutions such as storage pond design, well completion techniques or brine management strategies.
Objectives	To conduct an independent expert study in relation to development of coal seam gas industry in Queensland and potential for impacts on the Murray-Darling Basin water flows.

Project characteristics	Details
Achievements	<p>A conceptual diagram of flows and processes driving flows in the system was constructed. Imports, exports and hydraulic interactions between the system components were reviewed. Changes to the processes controlling water flows and interactions as a result of CSG activity were categorised according to the relative significance of change and/or local risk. Four interactions are identified as creating significant changes and/or local impacts. Three interactions are categorised as intermediate, six as minor and eight with no changes.</p> <p>Mitigation strategies proposed by the proponents should minimise the risk of water quality compromise to surface waters due principally to potential sediment production from construction activities (APLNG, 2010, Vol 5 Att. 22; QGC, 2010, Vol. 3 Ch.9; Santos, 2010, Section 6.5).</p> <p>Current predicted drawdown of the Condamine Alluvium by CSG proponents suggest that the drawdown of the alluvial aquifer due to CSG activity is likely to be considerably smaller than the drawdown that has occurred over recent decades due to water extraction for agricultural purposes. None-the-less there are significant gaps in knowledge of the system and the numerical models currently being used to assess likely impacts.</p>
Outputs	<p><http://www.environment.gov.au/epbc/notices/assessments/pubs/coal-seam-gas-operations-impacts.pdf></p>
Key personnel	<p>Prof Chris Moran, SMI UQ Dr Sue Vink, SMI UQ</p>
Research themes	<p>Coal seam gas; water quality and quantity; impact management; Murray-Darling Basin</p>

Table 4.2 Project 2: Namoi Catchment water study

Project characteristics	Details
Project title	Namoi Catchment water study
Project location	Namoi Catchment, New South Wales, Australia
Principal investigator	Schlumberger Water Services (Australia) Pty Ltd
Lead institution	Namoi Catchment Water Study Working Group
Project budget	\$4.5 million
Source of funding	\$3 million Mining Industry, \$1.5 million Australian Government
Project duration	September 2010 – July 2012
Current status	Complete
Project summary	<p>The Namoi catchment is located in north-eastern New South Wales (NSW) and is recognised as an agricultural area of significance within Australia that includes one of the most intensively developed groundwater resources in NSW. Coal and potentially economic coal seam gas (CSG) resources exist within the Namoi catchment. Coal is currently extracted from both open-cut and underground operations. Current CSG activity ranges from initial investigations of potential to production from seven small-scale pilot CSG sites. Substantial additional mining and gas projects are planned or being investigated and their development could impact catchment water resources.</p> <p>In response to rising levels of concern within the community, in August 2010 the NSW Government commissioned a study, The Namoi Catchment Water Study (the Study), into the potential effects of coal resource development activities on catchment water resources.</p> <p>The Study included the construction of a three-dimensional numerical model that can be used to develop scenarios of different mining and gas developments and predict their effects on water resources. Since its commencement in 2010, the Study progressed in four phases with each resulting in the publication of separate reports and presentations to the community. The report of the final phase of the Study was released in July 2012.</p>
Objectives	<p>The purpose of the Study was to undertake a strategic assessment of the likelihood of potential impacts posed by coal and gas development in the catchment on the quantity and quality of surface and ground water resources in the catchment.</p> <p>The Study involved establishment of a numerical model addressing surface water and groundwater within the Namoi Catchment. This model will be used to support assessment of risks associated with coal mining and coal seam gas development on water resources within the Catchment.</p> <p>The Study will use existing and new data to develop 3D maps, schematics and models of water and other natural resources in the Catchment. These will be employed to develop scenarios of mining and gas proposals and predict their impact.</p>
Achievements	The Study identified the spatial relationship between the catchment water resources and the potential coal bearing units. It allows the general location and

Project characteristics	Details
	<p>type (open cut mining, underground mining or CSG production) of possible future coal resource development to be inferred. Plausible future mining and CSG production scenarios can then be designed.</p> <p>The integrated assessment of all data resulted in a whole of catchment conceptualisation and qualitative evaluation of the ways that the potential effects from coal resource development activities can propagate away from the source and affect water resources. The assessment also identified the general locations (at a sub-regional scale) of zones which may be most at risk from these activities.</p> <p>The numerical Model constructed for the Study is based on this conceptualisation and is able to incorporate and assess a wide-range of potential future coal resource development activities. The Model provides a robust tool that can be updated with new data, recalibrated as necessary and used to assess alternative scenarios and the effects of changing other inputs and assumptions such as a change in climate.</p> <p>The Model provides predictions of the long-term, cumulative effects of mining and CSG developments on water resources at a catchment-scale and identifies those areas (sub-regionally) that are most at risk from developments and quantifies the potential magnitude of impacts for different coal resource development options. Assessment of the sensitivity of the results to different inputs, and the level of confidence in these predictions, was also undertaken.</p>
Outputs	< http://www.namoiCatchmentWaterStudy.com.au/site/index.cfm?display=317529 >
Key personnel	Steve Cozens, NSW Trade & Investment Sean Murphy, Schlumberger Water Services
Research themes	Coal mining; coal seam gas; Namoi Catchment; water resources; surface and ground water quantity and quality; water resource modelling

Table 4.3 Project 3: Potential local and cumulative impacts of mining on groundwater resources

Project characteristics	Details
Project title	Potential local and cumulative impacts of mining on groundwater resources
Project location	Hunter Valley, NSW, Australia
Principal investigator	Sinclair Knight Merz Pty Ltd (SKM)
Lead institution	National Water Commission
Project budget	\$2 million
Source of funding	National Water Commission, National Groundwater Action Plan
Project duration	September 2008 - August 2011
Current status	Complete
Project summary	<p>The National Water Initiative (NWI) provides a blueprint for the reform of Australia's water management for the next 10 years and beyond. The NWI acknowledges that all water users required an equitable basis from which to share groundwater and surface water resources.</p> <p>In 2007, a National Groundwater Action Plan was initiated by the established National Water Commission (NWC) under the Raising National Water Standards Program to fund projects to progress the groundwater reforms agreed to under the NWI.</p> <p>The NWC recognises that a rigorous and consistent management approach is required for the use of groundwater by mining operations. To address this challenge, NWC contracted SKM in collaboration with the Sustainable Minerals Institute (SMI) to develop a framework for assessing the potential local and cumulative effects of mining on groundwater resources (the Framework) and develop tools to assist prediction and assessment of these effects.</p> <p>The project:</p> <ul style="list-style-type: none"> developed guidelines for environmental impact assessments (EIAs) that outline both general areas and specific items related to water resources, in particular groundwater that should be considered during the assessment of mining proposals developed risk-management based tools to assist planners and developers to predict and minimise the cumulative impact of future mining activities on other water users <p>developed guidelines and tools to enable the integrated management and accounting of water resources across multiple mine sites to minimise the impact on water resources. These will be based on an adaptive management framework to enable improved outcomes as knowledge increases. A number of coal mining regions were shortlisted, including the Gippsland Basin, Perth Basin and Sydney Basin.</p> <p>The Hunter Valley (Sydney Basin) was chosen as the province for Framework testing, principally due to; (i) the scale of development, (ii) the high potential for cumulative effects to arise from mining operations, and (iii) proximity of other anthropological and environmental groundwater users.</p>
Objectives	<p>The project objectives were:</p> <ul style="list-style-type: none"> assist jurisdictions to ensure that their land-use planning and EIA

Project characteristics	Details
	<p>requirements are NWI compliant</p> <ul style="list-style-type: none"> • ensure that the cumulative impacts of mining operations within a watershed or aquifer system are considered in jurisdictional land-use planning processes • enable the local and cumulative impacts on water resources due to mining to be understood, and as far as possible, minimised • assist the mining industry to manage and account for water use at individual mine sites and across multiple mine sites • apply the tools developed under the project in the assessment of the cumulative impact of mining on water resources in up to four regions.
Achievements	<p>The context of mining related groundwater effects was established, and common mining infrastructure was identified in the context of potential to cause groundwater related effects. The interactions of mining operations with natural resources systems was discussed, and major groundwater effects receptors were evaluated, including groundwater dependent ecosystems (GDEs), the community, and economic factors.</p> <p>The ground water effects ranking scheme identified mine water affecting activities derived from the major system components of mining operations. The key water affecting activities have been identified for 5 major mining types including; strip mining, underground, open cut, dredge, and in-situ recovery (ISR). Different mining processes can have a large number of groundwater related impacts ranging from minor, short term effects, through to major long terms effects that may be irreversible. For the identified mining processes, over 30 mine water affecting activities are identified. Within the multi-criteria analysis framework, over 200 potential effects causations are evaluated for the 5 major mining types. Effects to ground water are evaluated for the mining methods considered with aspects ranging from groundwater quality changes, removal of perched aquifers, lowering of groundwater tables and impacts on groundwater dependent ecosystems.</p> <p>A key output of the project was the development of the mining risk framework, which provides a risk-based approach to managing cumulative groundwater affecting activities of mine operators. The risk framework is supported by the tools developed for the project. Groundwater & Resource Information for Development Database (GRIDD); Multi-Mine Water Accounts Tool; and Cumulative Impacts Assessment Tool (CIAT).</p> <p>However, it is recognised that sustainability of project outputs will not be achieved without further effort to address issues such as accessibility of the tools, data sharing and quality and knowledge adoption. The project has provided recommendations to progress these issues.</p>
Outputs	<ul style="list-style-type: none"> • Framework testing – Hunter Valley region, New South Wales <http://nwc.gov.au/__data/assets/pdf_file/0013/11560/Report_9.pdf> • Identification and evaluation of mine water affecting activities in relation to groundwater effects assessments <http://nwc.gov.au/__data/assets/pdf_file/0018/11565/Report_14.pdf>
Key personnel	<p>Paul Howe, SKM Dr Sue Vink, Sustainable Minerals Institute</p>
Research themes	<p>Mining; groundwater supply; groundwater impact assessment; mine water management and planning; cumulative impacts</p>

Table 4.4 Project 4: Hydrodynamic evaluation of Gippsland Basin

Project characteristics	Details
Project title	Hydrodynamic evaluation of Gippsland Basin
Project location	Gippsland Basin, Victoria, Australia
Principal investigator	Sunil Varma, Karsten Michael
Lead institution	CSIRO, Victorian Department of Primary Industries
Project budget	Not available
Source of funding	Not available
Project duration	3 Years to September 2012
Current status	Complete
Project summary	<p>The Latrobe aquifer in the Gippsland Basin in south eastern Australia is a prime example for emerging resource conflicts in Australian sedimentary basins. The Latrobe Group forms a major freshwater aquifer in the onshore Gippsland Basin, and is an important reservoir for oil and gas in both onshore and offshore parts of the basin.</p> <p>The Latrobe Group and overlying formations contain substantial coal resources that are being mined in the onshore part of the basin. These may have coal seam gas potential and, in addition, the basin is considered prospective for its geothermal energy and CO₂ storage potential.</p> <p>The impacts of large-scale groundwater extraction related to open pit coal mine dewatering, public water supply, on the flow of variable density formation water in the Latrobe aquifer has been assessed using equivalent freshwater hydraulic heads and impelling force vectors.</p>
Objectives	To assess impacts of large-scale groundwater extraction related to open pit coal mine dewatering, public water supply, on the flow of variable density formation water in the Latrobe aquifer.
Achievements	<p>The freshwater hydraulic-head distributions suggest that groundwater flows from the northern and western edges towards the central part of the basin. Groundwater discharge occurs offshore along the southern margin and, potentially in the area of the Gippsland Lakes. Freshwater hydraulic gradients in the western part of the basin imply that there is a source of water in the Central Deep where the Latrobe aquifer occurs at depths >2500 m and where the aquifer subcrops beneath the seafloor.</p> <p>However, as shown by the force vector analysis these gradients are largely due to density effects and are probably not solely related to compaction related dewatering of the aquifer as suggested by earlier work. Post-stress hydraulic heads show significant declines near the offshore oil and gas fields, and in the coal mining areas of the Latrobe Valley.</p> <p>A drawdown map constructed using the difference between the pre- and post-stress head distribution shows that the largest drawdowns, of up to 130 m, are in the offshore region near oil and gas fields and onshore in the coal mining areas. A hydrodynamic model of the Latrobe aquifer was used to simulate groundwater recovery in the Latrobe aquifer from different scenarios of cessation of</p>

Project characteristics	Details
	groundwater and other fluid extractions.
Outputs	< https://publications.csiro.au/rpr/pub?list=SEL&pid=csiro:EP106307 >
Key personnel	Dr Karsten Michael, CSIRO Dr Sunil Varma, CSIRO
Research themes	Coal mining; water supply; Gippsland Basin

Table 4.5 Project 5: Coal seam gas water production management

Project characteristics	Details
Project title	Coal seam gas water production management
Project location	Gippsland Basin, Victoria, Australia
Principal investigator	Reem Freij-Ayoub, Julian Strand, Shakil Ahmed
Lead institution	CSIRO
Project budget	\$360 000
Source of funding	CSIRO
Project duration	June 2010 - June 2011
Current status	Complete
Project summary	<p>The predicted large volume and variable quality of Coal Seam Gas (CSG) water make water management a key issue associated with CSG production. Strategies for the management and beneficial use of the water are dictated by water quality and quantity at each CSG development site in addition to the site specifics and the sensitivity of the environmental surroundings.</p> <p>The report:</p> <ul style="list-style-type: none"> contains a review to the factors affecting the environmental and economic viability of CSG production describes a model that simulates primary methane production from coal seams where methane desorption is driven by reservoir pressure depletion provides a case study focussed on predicting the amount of produced methane and water from a selected area in the Gippsland Basin with abundance of coal.
Objectives	<p>The objective of this study is to assess the risks to land and water associated with the production of CSG. The study examines the impact of extracting large quantities of water associated with CSG production on the pressure head in aquifers in or adjacent to the production area. It also examines the risk of land subsidence around production wells. The objective of the report is to assess the risks to land and water associated with the production of CSG in a selected region of the Gippsland Basin.</p>
Achievements	<p>A model that simulates primary methane production from coal seams where methane desorption is driven by reservoir pressure depletion was developed in FLAC3D. The model qualitatively predicts the relative amounts of produced methane and water from one or two coal seams which could be separated by either an aquifer or aquitard. The model can predict the amount of ground subsidence in the region around the wellbore. The production of methane and water from the seams is seen to produce land subsidence in the order of centimetres, which can be considered negligible. Failure in the coal seams has been in shear and tension and was the largest for the case of seams surrounded by aquitards.</p> <p>The report discusses a case study focused on predicting the amount of produced methane and water from a selected area in the Gippsland Basin. The modelling predicts that the drawdown in the aquifer below the produced seam can reach</p>

Project characteristics	Details
	100 m but falls down with production and is localised around the production region.
Outputs	< https://publications.csiro.au/rpr/pub?list=SEA&pid=csiro:EP114078 > < https://publications.csiro.au/rpr/pub?list=SEL&pid=csiro:EP117865 >
Key personnel	Dr Reem Freij-Ayoub, CSIRO
Research themes	Coal seam gas; water supply; subsidence; produced water; Gippsland Basin

Table 4.6 Project 6: A water chemistry atlas for CSG fields - discovering value beyond baseline monitoring

Project characteristics	Details
Project title	A water chemistry atlas for CSG fields - discovering value beyond baseline monitoring
Project location	Australia
Principal investigator	Dr Sue Vink The University of Queensland
Lead institution	Centre for Coal Seam Gas, Sustainable Minerals Institute
Project budget	Not available
Source of funding	Not available
Project duration	Not available
Current status	Not known.
Project summary	<p>Public concern over water quality impacts of coal seam gas industry development are fuelled by the lack of a publicly available, transparent and understandable representation of water chemistry characteristics for the areas under development. A publicly available web-based atlas of water chemistry and the underlying analysis and interpretation can:</p> <ul style="list-style-type: none"> • provide insights into coal seam hydrology and potential interactions with other aquifers • improve our understanding of processes controlling water chemistry in coal seams and other aquifers • lead to the development of a salient and credible data source required for development of indicators of risks and impacts (e.g. on human health, animal health, the environment) <p>refine water monitoring design. This research will produce a publicly available web-based atlas of water chemistry with interpretative layers and risk and opportunity indicators. The atlas will allow stakeholders to search for data and interrogate the data set to show water quality data in relation to relevant standards and other interpretive information.</p> <p>More importantly, analysis and interpretation of water chemistry undertaken in this project can provide insights into coal seam hydrology and potential interactions with other aquifers.</p>
Objectives	<p>To produce a publicly available web-based atlas of water chemistry, that will:</p> <ul style="list-style-type: none"> • incorporate CSG company water chemistry data into a unified database that will extend both the horizontal and depth-related spatial coverage of current data • allow stakeholders to search for water quality data and interrogate the data set • improve gain insights into coal seam hydrology and potential interactions with other aquifers <p>facilitate advances in determining local scale geological controls on hydrological regime and consequent chemical characteristics. A more detailed understanding of water chemistry relationships is needed to inform the assessment of risk indicators and modelling of impacts that could result from the dewatering of coal</p>

Project characteristics	Details
	seams. Knowing the baseline chemistry of different coal seams and aquifers will also enable more effective monitoring of groundwater impacts and identification of key constituents that might act as early warning indicators of changes to connectivity. In addition, the data could be used to determine if there are spatial trends in water chemistry that may be of use in designing operational water management infrastructure and assessing water re-use, treatment and aquifer injection options.
Achievements	Not available
Outputs	< http://www.ccsq.uq.edu.au/Research/waterchemistryatlas.aspx >
Key personnel	Dr Sue Vink, The University of Queensland
Research themes	Coal seam gas; aquifer interconnectivity; water chemistry atlas development; monitoring CSG impacts on water

Table 4.7 Project 7: Powder River Basin drawdown report

Project characteristics	Details
Project title	Powder River Basin drawdown report
Project location	Powder River Basin, Wyoming, US
Principal investigator	Keith E. Clarey, Nikolaus W. Gribb, Richard J. Hays, and J. Fred McLaughlin
Lead institution	Wyoming State Geological Survey
Project budget	Not available
Source of funding	Not available
Project duration	Not available
Current status	Complete, but two additional updates by the WSGS have been commissioned by the BLM and will be completed by 2016.
Project summary	<p>Wyoming State Geological Survey (WSGS) in cooperation with the Bureau of Land Management's (BLM) Buffalo Field Office is publishing an Open-File Report entitled "Coalbed Natural Gas Regional Groundwater Monitoring Report: Powder River Basin (PRB), Wyoming".</p> <p>This project presents data from BLM's deep monitoring well network in the Wyoming PRB along with initial interpretations. This data was collected from a total of 111 monitoring wells from 1993 through 2006.</p> <p>The BLM deep monitoring well network measures the drawdown in the producing zones and provides data with which to evaluate potential leakage between the CBNG water-producing coal deposits and adjacent sandstone aquifers. Groundwater models and drawdown predictions are used to forecast potential hydrogeological impacts of CBNG production in Wyoming. BLM deep monitoring well data can be used to evaluate impact analysis and provide calibration data for future analysis of CBNG drawdown impacts as well as verify the assumptions made in the PRB Final Environmental Impact Statement, 2003.</p>
Objectives	The purpose of this report is to compile, interpret, and evaluate data collected by the BLM deep monitoring well network in the Wyoming portion of the PRB through the end of 2006. This is an initial report and subsequent work will expand upon the first analysis.
Achievements	Groundwater models and drawdown predictions have been used to forecast the potential hydrogeologic impacts of CBNG production in Wyoming. The BLM deep monitoring well data was used to evaluate existing impact analysis models. CBNG impacts to groundwater levels in all of the Fort Union Formation coal wells are less than drawdowns predicted by the 2002 groundwater model, which also predicted a higher rate of CBNG development in the PRB. Aquifer drawdown has been recorded in some of the overlying sandstone beds of the Wasatch Formation.
Outputs	< http://www.wsgs.uwyo.edu/public-info/onlinepubs/docs/PRB-OFR.pdf >
Key personnel	Jim Rodgers, WSGS
Research themes	Coal seam gas; aquifer interconnectivity; groundwater drawdown; Powder River Basin

Table 4.8 Project 8: Research and development concerning coalbed natural gas—Congressional Mandate

Project characteristics	Details
Project title	Research and development concerning coalbed natural gas—Congressional Mandate
Project location	Wyoming, US
Principal investigator	University of Wyoming, Laramie, WY
Lead institution	University of Wyoming
Project budget	DOE Contribution: USD \$1 443 376 Performer Contribution: USD \$490 126 (25% of total)
Source of funding	Funding was provided by a Congressional mandate for research to be conducted through the University of Wyoming at Laramie, WY.
Project duration	2 June 2006 - 30 September 2008
Current status	Complete
Project summary	<p>The research was organised around nine separate, but interrelated, technical project tasks and one administrative task (Task 1). The nine technical project tasks were pursued by separate research teams at the University of Wyoming, but all nine tasks were coordinated to the extent possible in order to maximise information gained about CBNG co-produced waters. In addition to project management in Task (1), the key research tasks included:</p> <ul style="list-style-type: none"> • (task 2) estimating groundwater recharge rates in the PRB • (task 3) groundwater contamination of trace elements from CBNG disposal ponds • (task 4) use of environmental tracers in assessing water quality changes in ground and surface water systems • (task 5) development of a software toolbox to assess CBNG water treatment technologies • (task 6) potential value of CBNG water for enhanced oil recovery using low salinity waterflood • (task 7) evaluation of natural zeolites for low cost CBNG water treatment • (task 8) evaluation of aquatic toxicity testing methods required by regulatory agencies on some CBNG water discharges • (task 9) use of remote sensing to evaluate CBNG water discharges as habitat for West Nile Virus transmitting mosquitoes • (task 10) a summary of lessons learned from historic CBNG management in Wyoming.
Objectives	Coalbed natural gas (CBNG) from the Powder River Basin (PRB) in Wyoming and Montana is a significant component of the US natural gas supply. Environmental concerns over the use of CBNG coproduced water are limiting the development of this important resource. The goal of the 10 tasks in this project is to assist in clearly defining the true environmental issues associated with this water and in developing cost-effective treatment or mitigation technologies that will allow production of the resource without harm to the environment.
Achievements	Some of the conclusions drawn from the research in this project include the following:

Project characteristics	Details
	<ul style="list-style-type: none"> • Investigators estimated that recovery times for PRB groundwater levels from CBNG water production may be as much as 10 times longer than BLM's 2003 EIS estimate of ~30 years – the new estimate is based on researcher's analysis using the Surface Water Assessment Tool (SWAT) to calculate recharge rates and uncertainty levels (Task 2). • Stable isotopes of carbon show excellent potential for tracing CBNG production water, with a signal that is easily distinguished from natural surface waters – this method allowed investigators to identify CBNG contributions to Wyoming surface waters, but also led to their conclusion that Powder River samples from Montana are little affected or unaffected by CBNG production upstream even during low flow conditions (Task 4). • The CBNG treatment toolbox software developed in Task 5 allows cost comparison estimates for 5 demineralisation technologies, showing that treatment costs may range from \$0.036/bbl to \$0.190/bbl depending on technology and local conditions – overall the Toolbox results indicate that treatment cost is directly impacted by the amount of sodium removed regardless of technology used (Task 5). • Injection of CBNG water in Tensleep Formation cores resulted in significantly improved oil recovery following injection of high salinity formation water, supporting a conclusion that, depending on the proximity of CBNG wells and targeted oil reservoirs, use of CBNG water can improve oil recovery in waterflood applications (Task 6). • Wyoming zeolites modified with calcium additions had a much higher CBNG water treatment potential for removal of sodium than natural Ca-zeolites from New Mexico and Idaho, and Task 7 experiments led investigators to estimate Wyoming zeolite material costs at \$0.05/bbl to \$0.10/bbl of treated CBNG water (Task 7). • Chemical constituents in Beaver Creek, Wyoming, CBNG discharge water did not cause acute toxicity to 11- to 15-d-old fathead minnows either in in-stream or lab toxicity tests, and field observations of aquatic plants and animals suggested no overt adverse effects from CBNG effluent discharged to Beaver Creek during 2006-07 study periods (Task 8). • Ammonification of organic nitrogen in CBNG effluents can occur during transport of unpreserved effluent samples, thus potentially biasing Whole Effluent Toxicity tests by increasing ammonia concentrations by the time the samples arrive at the lab (Task 8).
Outputs	http://www.netl.doe.gov/technologies/oil-gas/publications/EPReports/NT15568_FinalReport.pdf http://www.netl.doe.gov/technologies/oil-gas/NaturalGas/Projects_n/EP/AdvDiagnostics/15568_CBNGPowderRiver.html
Key personnel	Dr. Harold Bergman, University of Wyoming Jesse Garcia, NETL
Research themes	Coal seam gas; water quality and quantity (surface and groundwaters); produced water; aquatic ecosystems; Powder River Basin

Table 4.9 Project 9: Unconventional gas – the environmental challenges of coalbed methane development in Alberta

Project characteristics	Details
Project title	Unconventional gas – the environmental challenges of coalbed methane development in Alberta
Project location	Alberta, Canada
Principal investigator	Dr. Mary Griffiths
Lead institution	The Pembina Institute
Project budget	Not available
Source of funding	Not available
Project duration	Not available
Current status	Complete, published June 2003, re-released April 2006
Project summary	<p>The report covers the potential environmental impacts of coalbed methane (CBM) extraction, including hydraulic fracturing, dewatering of coal seams and its impacts on surrounding landowners and potential drainage of wetlands and reduced flows in streams and rivers and disposal of water produced through the dewatering process.</p> <p>Recommendations for improved regulations, environmental impact assessments, and best practices were made in 2003 to show how impacts can be reduced. The Alberta government has started making some changes to regulations, but much of the information in the report is still relevant today.</p> <p>Note: At the time of the study, Alberta Environment did not have sufficient data on aquifers and river basins to determine the cumulative environmental impacts of extracting water from coal seams for CBM projects and there was no provision for a formal EIA of CBM projects in Alberta.</p>
Objectives	To learn from the US experience and avoid or reduce potential impacts in Canada with pro-active, effective regulation and the adoption of best practices by industry.
Achievements	<p>Concludes with a list of recommendations is provided in the interest of reducing the environmental impacts of CBM development in Alberta, covering:</p> <ul style="list-style-type: none"> • adopt the precautionary principle • provide for public input on decisions • improve public information on coalbed methane developments • improve the regulatory process for coalbed development: <ul style="list-style-type: none"> – require non-toxic substances for hydraulic fracturing in non-saline water zones – minimise the land area impacted by development – review the cumulative impacts of dewatering non-saline aquifers – evaluate the optimum method to use/dispose of different grades of non-saline water – avoid or minimise venting and flaring – prevent and respond to problems associated with gas migration – improve reporting on CBM projects – maintain Alberta Environment's role in the management of water and

Project characteristics	Details
	<p>environmental protection Require Environmental Impact Assessments of cumulative effects of large-scale CBM developments</p> <ul style="list-style-type: none"> - avoid “grandfathering” existing CBM projects • adopt best practices for operations: <ul style="list-style-type: none"> - limit surface impacts when exploring for CBM - minimise the surface disturbance “footprint” when drilling for gas - minimise risks associated with hydraulic fracturing - limit emissions from venting and flaring - ensure water conservation and good management - limit noise • evaluate enhanced recovery of coalbed using CO₂.
Outputs	< http://www.pembina.org/pub/157 >
Key personnel	Dr. Mary Griffiths Chris Severson-Baker
Research themes	Coal seam gas; hydraulic fracturing; quality and reliability of irrigation and drinking water supplies; aquifer interconnectivity; integrity of wells; community concern

4.1.2 Aquifer integrity

Table 4.10 Project 10: Hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley

Project characteristics	Details
Project title	Hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley
Project location	Hunter River Valley, New South Wales, Australia
Principal investigator	Pr Ling Li The University of Queensland
Lead institution	The University of Queensland
Project budget	\$415 591
Source of funding	Australian Coal Research Limited
Project duration	2011 - 2015
Current status	Not known. The first field campaign was undertaken from 22/8/2011 to 28/8/2011. Various methods and techniques for the field work had been established and tested. Data collected from the field site have been analysed and presented at the 11 th Coal Operators' Conference (see output below). In the same time, the team has been pursuing the modelling work, currently developing the fracture network generation and flow simulation models. The second field campaign was to take place in October 2012.
Project summary	The work aims to improve understanding of the hydraulic connectivity between mines and adjacent river and groundwater systems in the Hunter River Valley region, and so to develop a set of criteria for assessing the mining impact on the rivers and aquifers, and associated risks.
Objectives	Specific objectives are to: <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	Identification of open active faults and fracture zones is a part of exploration study prior to mining operation. However, detailed mapping of geological discontinuities in an otherwise low permeable overburden is rarely carried out in the mining area. To develop a rapid and feasible survey method, a field campaign was conducted to examine different soil gas survey methods along three transects at the Carrington West Wing extension site of a coal mine, Hunter River Valley, NSW, Australia. Coal seam gas together with Uranium-238 (present in the gas-bearing coal seam) increases the soil gas signal which can be detected with suitable soil gas mapping methods. Three techniques associated with four parameters were tested at the field site. The field experiment has demonstrated the complexity of

Project characteristics	Details
	<p>the soil gas migration and gamma ray emission. Further study is required to understand this complex system, in particular:</p> <ul style="list-style-type: none"> • How to differentiate the geogenic and biogenic sources for methane, carbon dioxide? • How to distinguish the radon origin of deep host rock from that due to uranium mineral in the upper soil layer?
Outputs	<p><http://ro.uow.edu.au/cgi/viewcontent.cgi?article=2090&context=coal> <http://researchers.uq.edu.au/researcher/1153> <http://researchers.uq.edu.au/research-project/13468></p>
Key personnel	<p>Pr Ling Li, The University of Queensland Keith Smith, ACARP</p>
Research themes	<p>Hydraulic connectivity between mines and water resources in the Hunter Valley; mine extension impact on rivers and aquifers; field techniques for identifying faults and fracture zones</p>

Table 4.11 Project 11: 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	Fred Leaney CSIRO Land and Water
Lead institution	Gas Industry Social & Environmental Research Alliance (GISERA)
Project budget	\$667 053
Source of funding	Australia Pacific LNG (80%), CSIRO (20%)
Project duration	July 2011 - April 2015
Current status	In progress
Project summary	<p>The pumping of formation water to facilitate CSG extraction from the Great Artesian Basin (GAB) will likely lead to entrainment and mixing of water from adjacent aquifers. The decrease in pressure from production wells may also affect discharge of deep groundwater to surface water systems and springs. Understanding the source and flux of water involved in these processes can be traced using distinct signatures of various end-member compositions to distinguish pathways and interactions that cannot be done through conventional hydrological monitoring.</p> <p>Effectively monitoring the evolution of these processes requires some prior baseline sampling so that end-member compositions can be well characterised and to develop the most suitable suite of environmental tracers that can meet the criteria for ongoing monitoring. The ideal tracers are those that are conservative and do not react significantly with the aquifer solid matrix (e.g. $2\text{H}/1\text{H}$, $18\text{O}/16\text{O}$, Cl^-, Br^-, noble gases). There are other tracers that have well defined geochemical characteristics that can be used to distinguish the CSG formation water and production water (e.g. major and minor ions, ^{13}C of DIC, ^{34}S of SO_4, $^{87}\text{Sr}/^{86}\text{Sr}$, $^{37}\text{Cl}/^{35}\text{Cl}$, and ^{226}Ra). Furthermore, the use of age tracers such as ^{14}C, ^{36}Cl, ^4He would also be an important component in establishing groundwater residence time and changes in the relative contribution of short and long flow-paths at various sites.</p> <p>The age distribution of various aquifers and formation waters will likely evolve in response to pumping and depressurisation within and adjacent to CSG target sites. Careful monitoring at discrete depth intervals and appropriate spatial scale will allow assessment of altered groundwater flow systems, and the extent of entrainment of 'old' formation water into the main aquifer systems.</p>
Objectives	<p>This project is aimed at:</p> <ul style="list-style-type: none"> • a comprehensive geochemical and isotopic characterisation of groundwater and formation water within the proposed CSG extraction area prior to development • developing protocols for monitoring aquifers and formation water over the time period of extraction and post-development • establishing a set of criteria for ongoing assessment of the monitoring program and implications for aquifer interactions.

Project characteristics	Details
	A practical aim of the project is to provide a means of monitoring the progress and impact of large scale pumping and to inform potential modification of the pumping process to minimise potential impacts on spring-fed or baseflow ecosystems.
Achievements	Not available
Outputs	< http://www.gisera.org.au/research/waterprojects/water-project-4-baseline-monitoring.pdf >
Key personnel	Fred Leaney, CSIRO Land and Water
Research themes	Coal seam gas; aquifer interconnectivity impact on water dependent ecosystems; monitoring of geochemical and isotopic characteristics of CSG formation waters, adjacent aquifers and springs

Table 4.12 Project 12: Reducing the impact of longwall extraction on groundwater systems

Project characteristics	Details
Project title	Reducing the impact of longwall extraction on groundwater systems
Project location	New South Wales, Australia
Principal investigator	Deepak Adhikary
Lead institution	CSIRO
Project budget	\$289 310
Source of funding	Australian Coal Research Limited
Project duration	2009 - August 2012
Current status	Complete
Project summary	<p>The work has focused on physical aspects of the mining impacts on groundwater systems, such as mining-induced overburden fractures, permeability changes, pore pressure changes in aquifers of the overburden, and the spatial extent of these changes.</p> <p>The project has analysed data obtained from both Springvale and Dendrobium collieries and developed numerical models simulating Springvale and Dendrobium colliery geological conditions.</p>
Objectives	<p>The objectives of this project are to:</p> <ul style="list-style-type: none"> • expand the current knowledge base and understanding of the strata deformation, fracturing and caving mechanics • establish the relationships between longwall geometry and intensity of overburden fracturing in different geological environments • quantify the impact of longwall mining on groundwater systems in different geological environments • develop hydrogeological response models for different hydrogeological environments • develop a generic methodology for assessing the hydrogeological impact at other mine sites.
Achievements	Not available
Outputs	< http://www.acarp.com.au/abstracts.aspx?repId=C18016 >
Key personnel	Dr Deepak Adhikary, CSIRO Russell Howarth, ACARP
Research themes	Coal mining; aquifer interconnectivity; strata deformation, fracturing and caving mechanics; hydrogeological response modelling; impacts on groundwater systems

4.2 Disruption of surface water flow pathways

4.2.1 Subsidence

Table 4.13 Project 13: Impacts of mine subsidence on the strata & hydrology of river valleys - management guidelines for undermining cliffs, gorges & river systems

Project characteristics	Details
Project title	Impacts of mine subsidence on the strata & hydrology of river valleys - management guidelines for undermining cliffs, gorges & river systems
Project location	NSW, Australia
Principal investigator	Arthur Waddington
Lead institution	Waddington & Associates, CSIRO and The University of New South Wales
Project budget	Not available
Source of funding	Australian Coal Association Research Program (ACARP)
Project duration	March 1999 - March 2003
Current status	Complete
Project summary	<p>The research work was undertaken by a multi-disciplinary team of researchers and the various aspects of the work were split broadly into the four sections described below:</p> <ul style="list-style-type: none"> • Management of the project, literature search, state-of-the-art review, empirical study, development of empirical predictive techniques and preparation of the final report, incorporating the work of other researchers (Waddington & Associates Pty Limited, trading as Waddington Kay & Associates, using data supplied by collieries, the NSW Dams Safety Committee and Sydney Catchment Authority). • Surveys and monitoring of ground movements, geological investigations and hydrological studies, rock classification and testing and in situ stress measurements (BHP supported by external consultants). • Numerical modelling and development of numerically based predictive methods (CSIRO Petroleum). • Design and construction of a physical scaled model that can be used to illustrate the underlying mechanisms of strata movements for a range of different mining scenarios (The School of Mining Engineering at the University of New South Wales).
Objectives	To gain a better understanding of the impacts of underground coal mining on creeks, river valleys, gorges and cliff lines.
Achievements	The study has provided some additional insight into the valley bulging phenomenon. The major findings arising from the research project provide new methods for the prediction of mining-induced ground movements in creeks, river valleys and gorges. The research reports form the basis of the <i>Management information handbook on the undermining of cliffs, gorges and river systems</i> , for the mining industry, which is also available from Australian Research Administration Pty Ltd.

Project characteristics	Details
Outputs	< http://www.acarp.com.au/abstracts.aspx?repld=C8005 > < http://www.acarp.com.au/abstracts.aspx?repld=C9067 > < http://ro.uow.edu.au/cgi/viewcontent.cgi?article=1164&context=coal >
Key personnel	Arthur Waddington
Research themes	Coal mining; subsidence; surface water flow paths

Table 4.14 Project 14: An assessment of the monitoring programs in the Newnes Plateau shrub swamp communities in the western coalfields of NSW

Project characteristics	Details
Project title	An assessment of the monitoring programs in the Newnes Plateau shrub swamp communities in the western coalfields of NSW
Project location	Newnes Plateau, NSW, Australia
Principal investigator	Dr Peter Erskine and Dr Andrew Fletcher The University of Queensland
Lead institution	The University of Queensland, Sustainable Minerals Institute, Centre for Mined Land Rehabilitation
Project budget	\$1 187 314
Source of funding	Centennial Coal Company Limited
Project duration	2009 - Current
Current status	Active
Project summary	<p>The potential impact of subsidence from underground mining operations in the western Blue Mountains faces broad regulatory and community scrutiny. The Newnes Plateau lies within this region and contains endangered shrub swamp communities, typically above aquitards or where groundwater emerges at the surface.</p> <p>Centennial Coal has three underground operations at the Newnes Plateau. While subsidence has the potential to crack the underlying aquitards and drain swamps, there is controversy over whether this has impacted this swamp community. To address this uncertainty it is important to determine what aspects of the shrub swamp communities should be monitored to detect an impact. If an impact was to occur, how resilient are the shrub swamp communities? What methods are needed to detect an impact? Additionally, are the mapped extents of Newnes Plateau swamps accurate and actually endangered? The CMLR aims to answer these questions amongst many others throughout the course of this research project.</p>
Objectives	<p>The primary aim of this research is to establish if underground mining subsidence is impacting upon the endangered swamp communities of the Newnes Plateau and to monitor their status prior to and after mining has occurred. The assessment process is based on long term monitoring results of condition and cover/abundance of the unique species assemblages within the swamp communities of the Plateau. These are recorded in fixed plots on a seasonal basis. Long-term data is monitored for trends in relation to time since mining which could provide indicators of impact within the swamps. The data collected are assessed over time to identify appropriate indices of impact. Data is provided to both Centennial Coal and their regulators to demonstrate the potential impact of underground mining these plant communities. Further research on the uniqueness of these swamp communities in the upland temperate region of NSW will address and compare assumed vegetation classification systems.</p>
Achievements	Not available
Outputs	Not available

Project characteristics	Details
Key personnel	Dr Peter Erskine (Project Leader) Dr Andrew Fletcher (Project Leader)
Research themes	Coal mining; subsidence; water dependent ecosystems; Newnes Plateau; swamp communities

Table 4.15 Project 15: Potential coal mining impacts in the Wyong LGA - strategic inquiry

Project characteristics	Details
Project title	Potential coal mining impacts in the Wyong LGA - strategic inquiry
Project location	Wyong Local Government Area, NSW
Principal investigator	Kerry Chikarovski (Chair), Emeritus Professor Jim Galvin (Subsidence Expert), Associate Professor Noel Merrick (Groundwater Expert) and Brian Elton (Social and Community Expert).
Lead institution	NSW Department of Planning appointed Panel
Project budget	Not available
Source of funding	NSW Department of Planning
Project duration	5 February 2007 - July 2008
Current status	Complete
Project summary	<p>The NSW Government appointed an Independent Expert Panel to conduct a strategic inquiry into potential coal mining impacts in the Wyong Local Government Area (Wyong LGA).</p> <p>Coal has been mined under the northern coastal sections of Wyong LGA since the 1960s. After the granting of additional exploration licences in 1996, a more intensive coal exploration program took place in the Yarramalong and Dooralong Valleys in the west of the LGA and under the Tuggerah Lakes system in the east of the LGA. In 2006, the Wyong Areas Coal Joint Venture (WACJV) submitted an application to the Department of Planning for approval of the Wallarah 2 Coal Project (Walarah 2), a proposed underground coal mine beneath the Yarramalong and Dooralong Valleys, under Part 3A of the <i>Environmental Planning and Assessment Act 1979</i> (EP&A Act).</p> <p>The Inquiry was established by the Minister for Planning, the Hon Frank Sartor MP, due to concerns held by the community over potential future mining-related impacts on the Central Coast. The Inquiry has reviewed the strategic issues that may arise from future coal mining in Wyong LGA, including the Wallarah 2 proposal, as well as other sites not yet subject to a project application or to current exploration interest. The Inquiry was established against a backdrop of an extended drought across the State and very low levels in the Central Coast's water storages. Consequently, community concerns were particularly related to an ongoing guarantee for the quality and quantity of the region's water supplies. The Yarramalong and Dooralong Valleys and their streams supply 35-40% of the Central Coast's drinking water.</p> <p>The areas of the LGA that were given particular emphasis by the community and interest groups were the Yarramalong and Dooralong Valleys, existing and proposed residential and employment areas east of the F3 Freeway, coastal lakes and wetlands, and areas with threatened species. However, community concerns extended to broader potential impacts on the region's environment, economy and society.</p>
Objectives	<p>The Panel was asked to examine and report on the following terms of reference:</p> <ul style="list-style-type: none"> • whether coal mining under the catchment of the Mardi Dam would compromise, in any significant way, the water supply of the Central Coast • environmental impacts of any underground coal mining, with particular

Project characteristics	Details
	<p>emphasis on:</p> <ul style="list-style-type: none"> – surface and groundwater resources, especially on drinking water supply and flooding – hazards and risks of subsidence impacts – the amenity of the community, including dust and noise impacts <ul style="list-style-type: none"> • social and economic significance of any underground coal mining to the local community, the region and State • areas where mining should not be permitted, or if permitted the conditions under which it may proceed, having regard to the matters listed above and the NSW Government's strategic planning policies that apply to the area.
Achievements	<p>Some findings relating to water-related environmental values include:</p> <ul style="list-style-type: none"> • On the weight of evidence presented to it, longwall mining is likely to cause subsidence-related impacts within the water supply catchments associated with Wyong River and Jilliby Jilliby Creek. However, because of the depth of the coal seams, this subsidence is unlikely to compromise in any significant way the water supply of the Central Coast, since the nature of the geology, geomorphology and depth of the coal seams make it unlikely that underground mining will result in a loss of surface water. With appropriate mine planning, there is also little likelihood for deterioration in the quality of surface waters or contamination from hard rock saline aquifers. In the absence of major, unforeseen geological anomalies (e.g. faults and dykes), subsidence-induced hydraulic connectivity between Wyong River, Jilliby Jilliby Creek or their alluvial systems and any underlying mine workings is extremely unlikely. • There is a lack of information relating to groundwater in the Wyong LGA in general. Of particular concern are a lack of monitoring of aquifer status, lack of metering of groundwater use, the absence of groundwater sharing plans, the lack of government investment in groundwater management and the lack of community involvement in effective monitoring of groundwater. However, based on the available data, while groundwater sourced from the Wyong River and Jilliby Jilliby Creek alluvial systems does make a significant contribution to the water supply of the Central Coast (estimated to be between 3.5 and 6%), any mining activity would not significantly impact on the existing groundwater levels or groundwater availability. • Subsidence impacts are site specific and a lack of sound and comprehensive baseline information limited the ability of the Panel to draw firm conclusions on the hazards and risks of likely impacts of underground mining in the Wyong LGA. However, the Panel categorised these in general terms by identifying three distinct areas within Wyong LGA, namely the Northeastern Area; the Central Area; and the Southern and Western Area. detailed within the report. In the Central Area, underground coal mining is proposed at Wallarah 2 and a substantial coal resource has been identified by the WACJV beneath Tuggerah Lake. The Panel has concerns about the potential for subsidence impacts within the Lake, particularly before more is known about the potential impacts of subsidence on the ecology and hydrology of Tuggerah Lake. <p>The report details Panel recommendations, which should apply to any future coal mine development within Wyong LGA.</p> <p>In addition, the Department on August 17, 2010 released a study of groundwater and surface water baseline information in the western part of the Wyong local government area, to assist in the assessment of the Wallarah 2 coal project.</p>
Outputs	<p><http://www.planning.nsw.gov.au/planningsystem/pdf/report_wyong_coal_final_jul</p>

Project characteristics	Details
	08.pdf> < http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=CvQyheJJuAc%3d&tabid=70&language=en-AU >
Key personnel	Kerry Chikarovski Emeritus Prof Jim Galvin, Galvin and Associates Pty Ltd
Research themes	Coal mining; disruption of surface water flow paths; subsidence; quality and reliability of water supplies; Wyong Local Government Area

Table 4.16 Project 16: Underground coal mining in the Southern Coalfield - strategic inquiry

Project characteristics	Details
Project title	Underground coal mining in the Southern Coalfield - strategic inquiry
Project location	Southern Coalfield, Woronora and Illawarra Plateaus, NSW, Australia
Principal investigator	Professor Bruce Hebblewhite (chair and subsidence expert), Professor Jim Galvin (subsidence expert), Mr Col Mackie (groundwater expert), Associate Professor Ron West (aquatic ecology expert) and Mr Drew Collins (social and economic analysis expert)
Lead institution	NSW Department of Planning appointed Panel
Project budget	Not available
Source of funding	NSW Department of Planning
Project duration	6 December 2006 - July 2008
Current status	Complete
Project summary	<p>The NSW Government established an independent Inquiry into underground coal mining in the Southern Coalfield and appointed an Independent Expert Panel to conduct the Inquiry. The Inquiry was established by the Minister for Planning, the Hon Frank Sartor MP, and the Minister for Primary Industries, the Hon Ian Macdonald MLC.</p> <p>The Inquiry was established because of concerns held by the Government over both past and potential future impacts of mining-induced ground movements on significant natural features in the Southern Coalfield. These concerns first surfaced in the community in 1994 when the bed of the Cataract River suffered cracking and other impacts caused by mine-related subsidence from the underlying Tower Colliery. Sections of the local and broader community have continued to express concerns at further subsidence-related impacts associated with this and other coal mines in the Southern Coalfield.</p> <p>From 2010 all proposed extensions to underground coal mining operations require approval under Part 3A of the <i>Environmental Planning and Assessment Act 1979</i>. Given the community concerns and the changes in the planning system, the Government announced the inquiry to provide a sound technical foundation for assessment under Part 3A (and other regulatory and approval processes) and long term management of underground mining in the Southern Coalfield by both the Department of Planning (DoP) and the Department of Primary Industries (DPI) and other key agencies (such as the Department of Environment and Climate Change (DECC), the Sydney Catchment Authority (SCA) and the Department of Water and Energy (DWE)).</p>
Objectives	<p>The inquiry's Terms of Reference were to:</p> <ul style="list-style-type: none"> • undertake a strategic review of the impacts of underground mining in the Southern Coalfield on significant natural features (i.e. rivers and significant streams, swamps and cliff lines), with particular emphasis on risks to water flows, water quality and aquatic ecosystems • provide advice on best practice in regard to: <ul style="list-style-type: none"> – assessment of subsidence impacts – avoiding and/or minimising adverse impacts on significant natural features – management, monitoring and remediation of subsidence and

Project characteristics	Details
	<p>subsidence-related impacts</p> <ul style="list-style-type: none"> report on the social and economic significance to the region and the state of the coal resources in the Southern Coalfield.
Achievements	<p>Some findings relating to water-related environmental values include:</p> <ul style="list-style-type: none"> Due to the geology and geomorphology of the Southern Coalfield, non-conventional subsidence effects (including valley closure, upsidence and regional far-field horizontal displacement) regularly occur. Since unpredicted impacts of subsidence on rivers and significant streams became apparent, the coal mining industry has made significant advances in its understanding of and ability to predict non-conventional subsidence effects. The majority of subsidence impacts on significant natural features are associated with valley closure and upsidence effects, leading to impacts on rivers and significant streams and in particular the cracking of stream beds and underlying strata. This has the potential, under certain conditions, to result in: <ul style="list-style-type: none"> loss or redirection of surface water flows changes in water quality (particularly ferruginous springs and/or development of iron bacterial mats) loss of ecosystem functionality (e.g. loss of pool integrity and connectivity and changes in water quality) loss of visual amenity. Stream bed cracking is most evident where the stream bed consists of solid rock and is less apparent where the stream bed is covered with sediment (including valley infill swamps) or deep water and sediment (such as the Nepean River). Consequences of stream bed cracking are most severe in streams with significant amounts of exposed bed rock (e.g. in rock bars). The upland swamps of the Southern Coalfield fall into two categories – headwater swamps (which make up the majority) and valley infill swamps. The Panel was not made aware of any significant impacts on headwater swamps caused by mining subsidence. Although it is likely that subsidence impacts observed elsewhere in the landscape are likely to take place beneath such swamps, the Panel was unable to draw any firm conclusions regarding the potential for subsidence to have adverse consequences on these swamps. Most known impacted swamps are valley infill swamps. However, at all sites inspected by the Panel, there had been a range of other environmental factors in play, including evidence of pre-existing scour pools, previous initiation of erosion, concurrent drought, and subsequent heavy rainfall and/or severe bushfires. The sequence of events was not clear in relation to the swamp impacts (drying, erosion and scouring, water table drop, burning, vegetation succession, etc). The Panel therefore cannot be certain that subsidence either initiated or contributed to the damage at these swamps. However, available evidence suggests a significant possibility that undermining of valley infill swamps could cause drainage, water table drop and consequent degradation to swamp water quality and associated vegetation. Further research is required before a definitive conclusion can be reached. No evidence was presented to the Panel to support the view that subsidence impacts on rivers and significant streams, valley infill or headwater swamps, or shallow or deep aquifers have resulted in any measurable reduction in runoff to the water supply system operated by the Sydney Catchment Authority or to otherwise represent a threat to the water supply of Sydney or the Illawarra region. However, this does not discount the possibility that a reduction in runoff may be realised under certain conditions, including

Project characteristics	Details
	<p>downwards leakage to mining operations, especially where a shallow depth of cover prevails or a structural feature provides a conduit for flow.</p> <p>The report details Panel recommendations relating to:</p> <ul style="list-style-type: none"> • assessment and regulatory processes • subsidence impact management • prediction of subsidence effects and impacts • environmental baseline data.
Outputs	< http://www.planning.nsw.gov.au/planningsystem/pdf/report_southern_coalfields_final_jul08.pdf >
Key personnel	<p>Prof Bruce Hebblewhite, University of NSW and Executive Director of Mining Education Australia</p> <p>Prof Jim Galvin, Galvin and Associates</p>
Research themes	Coal mining; disruption of surface water flow paths; subsidence; quality and reliability of water supplies; Wyong Local Government Area

4.2.2 Infrastructure

Table 4.17 Project 17: Criteria for functioning river landscape units in mining and post mining landscapes

Project characteristics	Details
Project title	Criteria for functioning river landscape units in mining and post mining landscapes
Project location	Bowen Basin, Queensland, Australia
Principal investigator	Rohan Lucas Alluvium Consulting (Queensland)
Lead institution	Alluvium Consulting (Queensland)
Project budget	\$255 280
Source of funding	Australian Coal Research Limited
Project duration	2011 - 2014
Current status	Complete. An updated project summary and details of project outputs is provided in report 3 of this reference list series.
Project summary	The project will: <ul style="list-style-type: none"> document best practice river health management in mining and post mining landscapes in Australia and overseas and document emerging issues in the waterway and wetland management industries that will impact on waterway diversion design review the success or otherwise of the existing ACARP diversion parameters (that have been adopted by DERM) establish an agreed set of riverine unit criteria (metrics and performance criteria) for post mining landscapes investigate the issues and risks associated with diversion construction and operation through mine spoil.
Objectives	The objective of this project is to establish the criteria for functioning river landscape units in mining and post mining landscapes. The primary objective of the research will be to define such criteria and describe the performance standards to be achieved for such criteria. It is proposed that the criteria and performance standards be developed in a form suitable for acceptance and adoption by both the mining industry and regulators and provide the mechanism to enable stream diversion licence relinquishment and contribute to orderly mine site closure.
Achievements	The completed literature review and discussions focused on: <ul style="list-style-type: none"> waterway planning, objectives and criteria including the application of trajectory concepts to assist identification of acceptable criteria for relinquishment of diversion licenses constructed waterway design: The literature has identified best practice waterway design. This approach includes both alluvial channel design providing for sediment transport and for a threshold channel design, providing for protection of assets, infrastructure and the watercourse

Project characteristics	Details
	<p>for agreed design flood events</p> <ul style="list-style-type: none"> • monitoring and evaluation: Approaches to waterway monitoring and evaluation.
Outputs	An updated project summary and details of project outputs is provided in report 3 of this reference list series.
Key personnel	Rohan Lucas, Alluvium Consulting (Qld) Keith Smith, ACARP
Research themes	Disruption of surface water flow pathways; infrastructure waterway diversion; constructed waterway design criteria; sediment transport; flooding

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

4.3.1 Aquifer injection and/or water treatment

Table 4.18 Project 18: Understanding salt dynamics to facilitate water reuse on coal mine sites

Project characteristics	Details
Project title	Understanding salt dynamics to facilitate water reuse on coal mine sites
Project location	Australia
Principal investigator	Prof Chris Moran, Dr Sue Vink, Assoc Prof S Golding, Assoc Prof S Phinn, Dr J Esterle
Lead institution	The University of Queensland, Sustainable Minerals Institute (SMI)
Project budget	\$350 000
Source of funding	Australian Research Council, Linkage Project
Project duration	2006 – 2009
Current status	Complete
Project summary	Re-use of water on coal mine sites results in salt concentration and increased coupling of site water reticulation and climate. Salt concentration leads to environmental and operational (coal washing) issues requiring increased effort with water management. This creates a barrier to water reuse. This project will examine two coal mine sites to understand the sources of salt and their introduction into the site water system. A combination of one-off and event-based sampling of chemistry and isotopes, and their integration into a mass balance model will be used. The industry outcome will be guidelines for forecasting water quality signatures given particular mining and climate conditions.
Objectives	Coal mining in Central Queensland occurs in a water scarce region. Coal is a very high value product per unit of water consumed. The industry wishes to expand and to meet current water needs partially by increasing water reuse on site. Difficulties associated with managing salt, in its various forms across a mine site, limit this. This project will produce operational guidelines to overcome these limitations allowing the coal industry to decrease its water footprint by increasing and properly managing water reuse.
Achievements	Not available
Outputs	< http://researchers.uq.edu.au/research-project/7738 >
Key personnel	Prof Chris Moran, Sustainable Minerals Institute Dr Sue Vink, Sustainable Minerals Institute
Research themes	Mine water; salinity

Table 4.19 Project 19: Onshore co-produced water - extent and management

Project characteristics	Details
Project title	Onshore co-produced water - extent and management
Project location	Australia
Principal investigator	RPS Australia East Pty Ltd
Lead institution	National Water Commission
Project budget	\$55 000
Source of funding	National Water Commission, National Groundwater Action Plan
Project duration	March 2010 - September 2011
Current status	Complete
Project summary	<p>Co-produced water is typically saline and can contain other impurities. In other countries there have been a number of management options used for this water including re-injection into isolated aquifer formations, release into streams, use for irrigation and evaporation. In Australia, there have been a number of attempts to use the water beneficially. In Queensland, for example, the water has been used for wash down water in feed lots near Chinchilla.</p> <p>While the Commission recognises that there are possible impacts on other water users - including the environment - at every stage of oil and gas production, the report is intended to objectively review the available information to explore possible water extraction volumes and management options of co-produced water at the surface.</p> <p>These options include a variety of treatment and beneficial use options as well as a limited number of disposal options, each of which may or may not be appropriate for the particular circumstances of individual oil and gas projects.</p>
Objectives	This report was commissioned to raise and discuss issues associated with the management of water produced during oil and gas production, including coal seam gas (CSG) production.
Achievements	<p>There are a number of possible management options for co-produced water, including water supply for urban and industrial consumption, storage for future use (e.g. managed aquifer reinjection) and agricultural use including stock watering and substitution of existing irrigation demand. Most management options will involve some form of water treatment prior to use or disposal due to water quality considerations such as salinity and sodicity.</p> <p>Treatment technologies are available and there appears to be acceptance by CSG producers that untreated water disposal will not be permitted on a large scale and that the costs and responsibility of treatment are borne by the producer. Treated water discharge also requires a licence. The most promising uses of the water are to substitute existing demand for irrigation, mine wash water and power plant cooling. Using co-produced water to provide environmental flows to nationally or internationally important wetland systems (e.g. Narran Lakes) would be limited by the short availability window and system losses, and unlikely to succeed.</p>

Project characteristics	Details
Outputs	< http://www.nwc.gov.au/publications/waterlines/onshore-co-produced-water-extent-and-management >
Key personnel	Bob Pearson, Principal Advisor - Coal Seam Gas, RPS Australia East Pty Ltd National Water Commission
Research themes	Produced water

Table 4.20 Project 20: 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	Leif Wolf CSIRO Land & Water
Lead institution	Gas Industry Social & Environmental Research Alliance (GISERA)
Project budget	\$928 215
Source of funding	Australia Pacific LNG (80%), CSIRO (20%)
Project duration	July 2011 - October 2014
Current status	Active
Project summary	<p>Injection of reverse osmosis treated production water from the coal seams into surrounding aquifers may provide the most viable measure to dispose of production water. A key advantage of this approach compared with other management options is that a local benefit can be created for Great Artesian Basin groundwater users.</p> <p>An envisaged scheme is injecting very large quantities of water (approx. 30-80 GL/a) which is of drinking water quality, into aquifers over a large spatial extent of the CSG development, potentially via a large number of tens to hundreds wells. The extent of the scheme combined with the large numbers of users and existing bores in the target aquifers is such that the risk assessment and operational design of the scheme must specifically account for multiple sources and multiple receptors. APLNG is currently performing a set of injection trials to deliver detailed measurements on local impacts. The groundwater modelling exercise proposed within this project will provide the necessary upscaling of the injection trial findings together with the outputs of the three associated studies in the GISERA water sector and use state of the science modelling techniques to investigate risks perceived by communities, regulators and scientists. In summary the project addresses the feasibility of large scale injection schemes.</p>
Objectives	<ul style="list-style-type: none"> 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 reinjection. 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. 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. Predict cumulative impacts of injection strategies in the Surat & Bowen Basins Predictions of short and long term changes to groundwater quality,

Project characteristics	Details
	<p>both the areal extent of possible changes and the time to equilibrium in terms of general impacts within the basin.</p> <ul style="list-style-type: none"> • 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. • Improving MAR risk assessment procedures for cumulative impacts on hydraulic heads and travel times to extraction wells through the use of probability based modelling. • Model the performance of different layout options for large scale injection to identify suitable well locations/spacing. • Optimum target aquifers in recognition of risk/benefit. • Demonstrate state of the art uncertainty modelling. • 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, exploring which alternative management option will allow such confidence. <p>The demonstration of innovative uncertainty modelling is envisaged to impact on decision making processes in groundwater management by providing a best practice example. If the project can demonstrate the feasibility of large scale injection schemes in CSG water management, this will impact beneficially on Great Artesian Basin water resources.</p>
Achievements	Not available
Outputs	< http://www.gisera.org.au/research/waterprojects/water-project-3-groundwater-modelling.pdf >
Key personnel	Leif Wolf, CSIRO Land & Water
Research themes	Coal seam gas; produced water aquifer re-injection; large scale managed aquifer recharge (MAR)

Table 4.21 Project 21: 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	Dr Peter Dillon CSIRO Land and Water
Lead institution	Gas Industry Social & Environmental Research Alliance (GISERA)
Project budget	\$1 039 989
Source of funding	Australia Pacific LNG (80%), CSIRO (20%)
Project duration	December 2011 - January 2015
Current status	Active
Project summary	<p>Re-injection of CSG water permeate, brine or blends into overlying aquifers, underlying aquifers, and to the coal seams themselves on completion of mining, is a valuable approach to neutralise impacts of mining on water resources, to protect springs and riverine ecosystems, and to allow new and expanded beneficial use of water resources for the wider community. Re-injection requires treatment of injectant to be compatible with the aquifer so as (a) not to clog injection wells and (b) to prevent adverse changes in water quality in the storage zone. The latter issue is addressed by a related proposal. Clogging of injection wells has been the single biggest cause of failure in aquifer storage and recovery (Pavelic and Dillon 1997).</p> <p>This project is aimed at:</p> <ul style="list-style-type: none"> • an advanced characterisation of the physical and hydraulic properties of aquifer material of aquifers targeted for re-injection (relying on the geochemical project for its part for the same samples) • the development of appropriate laboratory experimental procedures that conform where possible to existing standard methods and using them to evaluate the potential for clogging with a range of agreed water types • the field evaluation of clogging using appropriate monitoring to evaluate reliability of lab prediction and to suggest alternative strategies for maintaining high hydraulic conductivity in the near well zone • recommend design of a monitoring program for adoption at all reinjection sites to provide diagnostics in hydraulic conductivity changes in the near-well formation and to enable tracking of operational causes of these to improve redevelopment strategies, and to develop and, if possible, validate a conceptual/analytical model to forecast clogging to design diagnostics and operational procedures for broad application at reinjection sites.
Objectives	<p>Project objectives and outputs include:</p> <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

Project characteristics	Details
	sites similar to that tested.
Achievements	Not available
Outputs	< http://www.gisera.org.au/research/waterprojects/water-project-2-reinjection.pdf >
Key personnel	Dr Peter Dillon, CSIRO Land and Water
Research themes	Coal seam gas; produced water aquifer re-injection; clogging of injection wells

Table 4.22 Project 22: 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	Southern Coalfield, New South Wales, Australia
Principal investigator	Dr Henning Prommer CSIRO Land & Water
Lead institution	Gas Industry Social & Environmental Research Alliance (GISERA)
Project budget	\$881 242
Source of funding	Australia Pacific LNG (80%), CSIRO (20%)
Project duration	July 2011 - October 2014
Current status	Active
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.</p> <p>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 reinjection 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 reinjection of treated CSG waters. Another key objective is to illustrate the use of these techniques such that in the future they can be used on a routine basis for assessments under varying hydrogeological and hydrogeochemical conditions.
Achievements	Not available
Outputs	< http://www.gisera.org.au/research/waterprojects/water-project-1-response-reinjection.pdf >
Key personnel	Dr Henning Prommer, CSIRO Land & Water
Research themes	Coal seam gas; produced water aquifer re-injection; geochemical response to re-injection of CSG water permeates, brines and blends

Table 4.23 Project 23: Geochemistry of CBM retention ponds across the Powder River Basin, Wyoming

Project characteristics	Details
Project title	Geochemistry of CBM retention ponds across the Powder River Basin, Wyoming (2003-2006) Monitoring and modeling of groundwater contamination of trace elements from CBNG disposal ponds across the Powder River Basin, WY (2006-2008)
Project location	Powder River Basin, Wyoming, US
Principal investigator	K.J. Reddy
Lead institution	University of Wyoming, US
Project budget	USD \$209 104 for 2003-2006 USD \$283 398 for 2006-2008
Source of funding	US Geological Survey and Water Research Program (2003-2006) US Department of Energy (2006-2008)
Project duration	2003 – 2006 2006 – 2008
Current status	Complete
Project summary	<p>The Wyoming Water Research Program (2003) funded a project to study geochemical changes of coalbed natural gas (CBNG) disposal pond waters across the Powder River Basin (PRB) in collaboration with the US Geological Survey and the Wyoming Water Development Commission. Objectives of this research were to monitor the geochemical changes and water quality of CBNG disposal ponds in Tongue River Basin (TRB), Powder River Basin (PRB), Little Powder River Basin (LPRB), Belle Fourche River Basin (BFRB), and Cheyenne River Basin (CRB) over a period of 3 years.</p> <p>The more recent research (2006-2008) was built upon the previous CBNG produced water studies and continued with further monitoring of produced water geochemistry changes in the PRB.</p> <p>The CBNG outfall water, disposal pond water, and sediment samples were collected from five sub basins of PRB including Cheyenne River (CR), Belle Fourche River (BFR), Little Powder River (LPR), Powder River (PR), and Tongue River (TR) in 2006 and 2007. Water samples were analyzed for pH, EC (electrical conductivity), TDS (total dissolved solids), major cations, anions, and trace elements. Sediment samples were analyzed for trace elements using toxicity characteristic leaching procedure (TCLP). Geochemical data analysis was performed using MINTEQA2 model to determine speciation, complexation, and mineral saturation processes. Statistical analysis was conducted to determine differences among sediments in watersheds and generate potential descriptive models.</p>
Objectives	<p>The specific objectives of the 2006-2008 study were to:</p> <ul style="list-style-type: none"> • continue to monitor CBNG outfall and disposal pond water in the PRB established by McBeth et al. (2003a) and Jackson and Reddy (2007a) for two more years • determine geochemistry of CBNG outfalls and disposal pond water • investigate changes in pH, SAR (sodium adsorption ratio), and trace elements concentrations over time in CBNG disposal ponds

Project characteristics	Details
	<ul style="list-style-type: none"> determine possible leaching of trace elements from the CBNG disposal pond sediments evaluate potential beneficial uses of CBNG disposal pond water in the PRB, Wyoming.
Achievements	<p>A review of 7 years of water quality monitoring data for CBNG produced water in disposal ponds suggests that in all watersheds pH commonly exceeded the limit for irrigation water, wildlife and livestock, and aquatic life. However, over time it is expected to see a decrease in pH due to reentry of atmospheric CO₂ into the disposal ponds. In some watersheds, such as PR and TR, SAR exceeded the limit for irrigation water. In these watersheds treatment of CBNG produced water with clinoptilolite, a locally available zeolite, or electrodialysis reversal (EDR) process may help lower SAR and maximize the beneficial use of CBNG produced water for irrigation.</p> <p>Major (e.g. Ca, Mg, K) or trace element (e.g. Cr, Fe, Ba, Cu, Mn, Zn, B, Cl, NO₃, PO₄, SO₄, As, and Se) concentrations, except for Al and F, in CBNG produced water in disposal ponds meet water quality criteria for all uses (e.g. irrigation, wildlife and livestock, and aquatic life) in all watersheds in the PRB. Further long-term monitoring of CBNG outfalls, disposal ponds, and sediment leachates in the PRB for geochemical processes will help develop trend analysis to predict toxicity and leaching potential of trace elements from these disposal ponds as well as developing optimum uses for CBNG produced water in the PRB.</p>
Outputs	<p><http://gradworks.umi.com/14/70/1470692.html> <https://www.novapublishers.com/catalog/product_info.php?products_id=14402> <http://www.uwyo.edu/owp/_files/finalreportp10.pdf> <http://deq.state.wy.us/wqd/wypdes_permitting/WYPDES_cbm/Pages/CBM_Watershed_Permitting/Bibliography/BibliographyDownloads/Mcbeth%20UW-JAWRA%202003.pdf></p>
Key personnel	Prof K J Reddy
Research themes	Coal seam gas; produced water disposal ponds; Powder River Basin

Table 4.24 Project 24: Produced water management and beneficial use

Project characteristics	Details
Project title	Produced water management and beneficial use
Project location	Powder River Basin, Wyoming, US
Principal investigator	The project consists of 10 tasks divided among several research Institutions including Argonne National Laboratory, Gas Research Institute, Montana Technical University, PVES Inc., Stanford University, Pennsylvania State University, and the University of Wyoming. The project is being managed by the Colorado Energy Research Institute.
Lead institution	Colorado Energy Research Institute (CERI), Colorado School of Mines (CSM)
Project budget	USD \$2.7 million
Source of funding	DOE Contribution: \$2 176 198 Performer Contribution: \$549 402 (20% of total)
Project duration	June 2005 - October 2007
Current status	Complete
Project summary	<p>This project investigated means to manage and treat co-produced Coal Bed Methane water for beneficial use in the Powder River Basin. The fundamental logic of this project is the recognition that no single treatment can be applied to all co-produced water from Coal Bed Methane (CBM) operations. This project is focused on the Powder River Basin of Wyoming, but the management and treatment procedures can be exported to other CBM areas.</p> <p>A variety of options were to be developed and evaluated to provide CBM operators with the most cost-effective and environmentally sound practices for disposal of co-produced water.</p>
Objectives	This contract is a multi-tasked project with an overall objective of developing a portfolio of technologies to address produced-water issues in a comprehensive manner.
Achievements	<p>The project has been completed. The final report has been completed on the two year Produced Water Management and Beneficial Use project that was overseen by the Colorado Energy Research Institute (CERI) at Colorado School of Mines, Golden, Colorado.</p> <p>There are several unique challenges to the disposal of CBM water. The production of CBM water follows an inverse pattern compared to traditional wells (high to low). CBM wells need to maintain low reservoir pressures to promote gas production making the normal practice of re-injection counterproductive. The unique water chemistry of the produced water can reduce soil permeability, making surface disposal difficult. Finally, the produced water is potable, making it a valuable resource in the western US rather than an undesirable by-product, the usual case in traditional petroleum operations. Therefore, a variety of options were developed and evaluated to provide CBM operators with the most cost-effective and environmentally sound practices for co-produced water. While this project focused on the Powder River Basin of Wyoming, the management and treatment procedures can be exported to other CBM areas in the US.</p>
Outputs	< http://www.netl.doe.gov/technologies/oil-

Project characteristics	Details
	gas/Petroleum/projects/EP/ResChar/15425.htm> <http://www.netl.doe.gov/technologies/oil-gas/publications/EPreports/NT15549_FinalReport.pdf>
Key personnel	Jesse Garcia, NETL Dag Nummedahl, CSM
Research themes	Coal seam gas; produced water management technologies

Table 4.25 Project 25: Coalbed methane research: water management strategies for improved coalbed methane production in the Black Warrior Basin

Project characteristics	Details
Project title	Coalbed methane research: water management strategies for improved coalbed methane production in the Black Warrior Basin
Project location	Black Warrior Basin, Alabama, US
Principal investigator	Jack Pashin
Lead institution	Geological Survey of Alabama
Project budget	Not available
Source of funding	US Department of Energy, National Energy Technology Laboratory
Project duration	1 October 2009 - 30 October 2013
Current status	Complete
Project summary	<p>The Black Warrior Basin of Alabama is a mature province where CBM producers face a range of water management issues. In the eastern CBM fields, fresh water has been disposed safely in streams for decades. Even so, this practice is a subject of increasing scrutiny by environmental groups and agencies, and some of the produced water may have beneficial agricultural and industrial uses. In some fields, where significant potential exists for expansion of the CBM industry, saline formation water limits the ability of producers to pump wells to depressurise coal, which in turn leads to underperforming gas production.</p> <p>This study will employ an integrated, life-cycle approach that draws on a spectrum of geologic disciplines. This investigation employs a spectrum of geologic, hydrologic, geochemical, petrologic, GIS, and other computational techniques to characterise the reservoir geology and basin hydrology of the Black Warrior basin to develop new water management strategies that ensure environmental protection, foster beneficial use of produced waters, and improve reservoir performance.</p>
Objectives	To assist the CBM industry, the Geological Survey of Alabama is conducting a three-year study that provides a conceptual framework for the management of produced water from coal.
Achievements	Water produced from the fresh-water plumes may be disposed safely at the surface, whereas underground injection has been used locally to dispose of highly saline water. Wells in areas that had normal hydrostatic reservoir pressure prior to development tend to produce large volumes of water and may take up to 4 years to reach peak gas production. In contrast, wells drilled in naturally underpressured areas distal to the fresh-water plumes typically produce little water and achieve peak gas rates during the first year of production. Environmental debate has focused largely on issues associated with hydrologic communication between deep reservoir coal beds and shallow aquifers. In the coalbed methane fields of the Black Warrior Basin, a broad range of geologic evidence suggests that flow is effectively confined within coal and that the thick intervals of marine shale separating coal zones limit cross-formational flow (Pashin 2007).
Outputs	This project includes a vigorous technology transfer program that is designed to

Project characteristics	Details
	<p>facilitate the implementation of water management strategies in CBM reservoirs. Results are being presented at technical meetings and workshops and are being published in technical journals and meeting proceedings.</p> <p><http://www.netl.doe.gov/research/oil-and-gas/project-summaries/natural-gas-resources/de-fe0000888></p>
Key personnel	<p>Jack Pashin, Principal Investigator Mac McKinney, Hydrogeology</p>
Research themes	<p>Coal seam gas; produced water aquifer injection; aquifer interconnectivity; management strategies; Black Warrior Basin</p>

4.3.2 Effect on land and water resources

Table 4.26 Project 26: Healthy Headwaters coal seam gas water feasibility study

Project characteristics	Details
Project title	Healthy Headwaters coal seam gas water feasibility study
Project location	Murray-Darling Basin, Queensland, Australia
Principal investigator	Queensland DNRM (formerly DERM) and external consultants
Lead institution	QLD Department of Natural Resources and Mines (DNRM)
Project budget	\$5 million
Source of funding	Commonwealth of Australia Department of Sustainability, Environment, Water, Population and Communities (Water for the Future initiative)
Project duration	December 2010 – April 2013
Current status	Complete
Project summary	<p>In July 2008, the Council of Australian Governments (COAG) signed the Intergovernmental Agreement on Murray-Darling Basin Reform, which establishes new governance arrangements for the Murray-Darling Basin (MDB). The Australian Government also agreed in principle to provide around \$3.7 billion for significant water projects—called priority projects—in MDB states. Subject to agreement between the Australian and Queensland governments, up to \$160 million would be provided over 10 years for Queensland's priority project, known as the Healthy HeadWaters Program. This program was being managed by DERM and funded under the Australian Government's \$12.9 billion Water for the Future initiative.</p> <p>Five million dollars of the Healthy HeadWaters Program funding was allocated to examine the use of CSG water in addressing water sustainability and adjustment issues in the Queensland section of the MDB (QMDB). The Coal Seam Gas Water Feasibility Study would analyse the opportunities for, and the risks and practicability of, using CSG water to assist in achieving the long-term goals in the QMDB of transitioning irrigation communities to lower water use and securing viability of ecological assets. Among other things, the study will consider the feasibility of using CSG water to relieve demand on groundwater for irrigation in heavily committed aquifer systems near the Condamine River.</p>
Objectives	<p>The study was being undertaken as a series of activities:</p> <ul style="list-style-type: none"> • chemistry, origins & hydrogeology of CSG water (activity 1) • CSG water production modelling & forecasting (activity 2) • salinity impacts of using CSG water on landscapes (activity 3) • stream ecosystem health response to CSG water release (activity 4) • groundwater impacts of CSG water extraction (activity 5) • risks and feasibility of injecting CSG water and brines into aquifers (activity 6) • water demand analysis for South-West Queensland (activity 7) • specific proposals for using CSG water in the QMDB (activities 8 & 9). <p>Activities 1 to 7 consisted of investigations to fill knowledge gaps relating to the risks of both extracting and using CSG water, as well as analyses of the likely</p>

Project characteristics	Details
	<p>supply of, and demand for, CSG water. Subject to the risks of using CSG water being acceptable, and the availability of reliable supplies, Activities 8 and 9 would assess specific opportunities for using CSG water to assist in achieving objectives of the Healthy HeadWaters Program.</p> <p>While the primary aim of the study was to determine how CSG water may contribute to the objectives of the Healthy HeadWaters Program, the findings would be invaluable for managing the environmental and resource management risks associated with the rapidly expanding CSG industry both within and outside the QMDB.</p>
Achievements	<p>Activity 1.1 – has undertaken a comprehensive review of all existing data regarding the hydrogeology of the Condamine Alluvium and the underlying and flanking sections of the Walloon Coal Measures. It has developed a new interpretation of these formations and assembled a three-dimensional block model. The findings of this activity provide an improved understanding of the structure of the Walloon Coal Measures and their relationship with the Condamine Alluvium, and also highlight priorities for future research. Outputs of this activity will be used by the Queensland Water Commission in the development of a groundwater flow model to assess impacts of CSG water extraction in the Cumulative Management Area (see Project 1.00).</p> <p>Activity 1.2 – provide an improved understanding of the origins, recharge and flow regimes of coal seam waters in the Surat and Bowen Basins, and an improved ability to identify interconnectivity between coal seams and other aquifers. Results from the assessment of groundwater flow directions and elevation difference between formations, as well as the accompanying water quality assessments, show similar groundwater flow conditions (i.e. direction, rates and artesian conditions) and trends as described by previous researchers (i.e. anion and cation relationships) and have built upon the understanding of basin dynamics.</p> <p>Activity 3 – has developed decision support information for assessing if, where and how CSG water may be used for irrigation in the QMDB without contributing to increases in landscape and stream salinity. This information will be used to develop formal guidelines to assist the preparation and assessment of proposals to irrigate with CSG water.</p> <p>Activity 4 – has developed a decision support system (DSS) to assist the assessment of proposals to discharge CSG water to streams in the QMDB. The DSS features an ecological risk assessment framework which is tailored to the assessment of CSG water releases. It incorporated newly developed ecosystem response models as well as the results of field and laboratory studies of water quality and flow related risks posed by CSG water to aquatic ecosystems. These outputs provide for better management of the potential hazards and any benefits that CSG water presents to aquatic ecosystems in the Surat and southern Bowen Basins.</p> <p>Activity 6.1 – has identified and compared appropriate methods, locations and quantities for the injection of treated CSG water into the Central Condamine Alluvium. Based on physical and hydrochemical analyses of the alluvium, a total of 22 'target areas' were identified, which are being investigated as potential sites for future injection trials. The activity found that matching the water quality of the injected water with that of the receiving aquifer is critical to the success of an injection project. This work will provide the foundation for Activity 8.2, which lay further groundwork for undertaking injection trials in the Central Condamine Alluvium.</p>
Outputs	<p><http://www.dnrm.qld.gov.au/water/catchments-planning/healthy-</p>

Project characteristics	Details
	headwaters/coal-seam-gas-water-feasibility-study>
Key personnel	Joan Meecham, DNRM
Research themes	Coal seam gas; Queensland Murray-Darling Basin; groundwater impacts; co-produced water; aquatic ecosystem health; water resources; management strategy

Table 4.27 Project 27: Fitzroy Basin water quality projects

Project characteristics	Details
Project title	Fitzroy Basin water quality projects
Project location	Fitzroy Basin, Queensland, Australia
Principal investigator	Queensland Department of Environment and Heritage Protection (EHP) (formerly Department of Environment and Resource Management)
Lead institution	Fitzroy Water Quality Advisory Group
Project budget	Not available
Source of funding	Queensland Government
Project duration	Since October 2008
Current status	Not known
Project summary	<p>After major localised flooding in January 2008, some coal mines in the Fitzroy Basin released accumulated contaminated water which impacted on downstream water uses—including drinking water supplies for towns including Tieri, Blackwater, Bluff and Dysart.</p> <p>The Queensland Premier commissioned Professor Barry Hart to review water quality issues in the Fitzroy River after the discharge of 138 gigalitres of mine-affected floodwater from the Ensham Resources Pty Ltd coal mine, located near Emerald in Central Queensland.</p> <p>The government also directed the department to assess and report on the cumulative impacts of coal mine wastewater discharges throughout the Fitzroy Basin. This study examined available data to report on the implications of water discharges from mines on water quality in the Fitzroy River Basin.</p> <p>The study focused on discharges from coal mining operations as the Fitzroy River Basin's large-scale mining activities are dominated by coal mining and planned coal mine expansions. These operations potentially release far greater volumes of water than any other mining source currently operating. They have also operated for long periods of time giving the best opportunity to examine changes in regulation and management of water quality over time.</p> <p>The major water quality parameters of concern associated with coal mining are salinity (based on electrical conductivity), heavy metal ion concentrations and acidity/alkalinity. The study has focused on salinity impacts as these were of major concern to the communities in the areas affected by the mine discharges in 2008 and the available data relates more to salinity than any other contaminant.</p>
Objectives	<p>With the overall purpose being to make recommendations for the management of water discharges from mining activities with respect to water quality, the scope of the study included:</p> <ul style="list-style-type: none"> • providing a brief history of mining development in the Fitzroy River Basin • summarising the regulatory framework for managing the quality of water discharges from mining activities • summarising existing approaches to minimising the impacts of mine-water discharges on water quality • analysing currently authorised water discharges from mining activities • forecasting future mining activities and their potential impact on water quality • reviewing water quality data, how and where it is collected, by whom and to

Project characteristics	Details
	<p>whom it is reported</p> <ul style="list-style-type: none"> analysing trends in water quality and assessing impacts analysing risks associated with changes in water quality recommending ways of improving the collection of water quality, its coordination and management providing recommendations for the future management of water discharges from mining activities.
Achievements	<p>The major findings of this study concluded that in the Fitzroy Basin:</p> <ul style="list-style-type: none"> discharge quality limits and operating requirements for coal mine water discharges are inconsistent the discharge quality limits and operating conditions for some coal mines do not adequately protect the downstream values of the environment background data relating to the quality of the waterways receiving discharge water is extremely limited there is insufficient data to quantify the cumulative impacts of mining water discharges additional and ongoing monitoring and analysis is needed to develop a modelling program for assessing cumulative impacts based on a risk assessment using salinity, six mines were identified as being the highest contributors to potential cumulative impacts (Coppabella, North Goonyella, Goonyella Riverside, Millennium, Peak Downs and Ensham). <p>In May 2009, the government responded to the recommendations of the Review, and the study, and initiated a number of projects, including:</p> <ul style="list-style-type: none"> developing appropriate conditions in environmental authorities for mine water discharges developing local water quality guidelines developing a model for assessing cumulative impacts of mine water discharge across the region. <p>The Queensland Government continues to closely monitor salinity levels in the Fitzroy Basin as part of its independent water quality monitoring program.</p>
Outputs	<p><http://www.fitzroyriver.qld.gov.au/> <http://www.fitzroyriver.qld.gov.au/pdf/cumulativeimpactassessment.pdf> <http://www.fitzroyriver.qld.gov.au/pdf/water-quality-status-report.pdf></p>
Key personnel	Queensland EHP
Research themes	Coal mining; mine water; effect on water resources; salinity; Fitzroy Basin

Table 4.28 Project 28: Management of salinity for closure of open cut coal mines

Project characteristics	Details
Project title	Management of salinity for closure of open cut coal mines
Project location	Hunter Valley, New South Wales, Australia
Principal investigator	K David, S A Prathapar, Bob Creelman, GR Hancock, Tony Voller
Lead institution	NSW Department of Infrastructure, Planning and Natural Resources
Project budget	Not available
Source of funding	Australian Coal Association Research Program (Project No. C11050)
Project duration	Not available
Current status	Complete, published May 2004
Project summary	<p>This project is a scoping study that examines salinity issues facing the mining industry in the Hunter Region that is challenged with mining in a saline environment associated with Permian geological sediments and with the mining process increasing the potential mobilisation of salt.</p> <p>Salinity in the Hunter Valley of New South Wales occurs naturally due to its geological features. Mining activities in the Hunter study area are part of the human disturbance of the landscape with an impact on the dynamic hydrogeochemical equilibrium of the natural state. The mining process increases the potential for the dissolution and mobilisation of salts in the mined landscape. There is also increase in the potential for salt export to the Hunter River, particularly in the medium to long term.</p> <p>During the operational phase of mining this salt is contained on-site with options for subsequent transfer saline water between minesites during approved water sharing arrangements or for controlled release it under the Hunter River Salinity Trading Scheme (HRSTS).</p>
Objectives	The study examines the task of addressing salinity issues, particularly after mining ceases. It examines salt mobilisation processes on mine sites and identifies potential medium to long term problems. It promotes a risk management approach to salinity and the implementation of appropriate guiding principles during the planning and operational phases that will assist with the minimisation of adverse impacts in the post-mining phase.
Achievements	<p>The mine site contribution of salt load to the Hunter River in controlled discharges is estimated at 3% under the HRSTS between 1995 and 2001. The study also estimates that groundwater inflows from the study area contribute 16% of the salt loading in the Hunter River at Singleton.</p> <p>Constructed potentiometric maps of the regional groundwater table highlight a short-term benefit of mining on salinity. The effect of depressurisation of the groundwater table in the vicinity of an active mine pit reduces the risk of the local aquifer system discharging saline groundwaters into the Hunter River that occurs as a natural feature of many Hunter sites.</p> <p>However at mine closure there is a repressurisation of the groundwater tables over time. The options for actively addressing salinity issues are less available following mining. Post mining there is the potential for continued mobilisation of</p>

Project characteristics	Details
	<p>salts within the mined landscape and the progressive accumulation of salts in sink areas like the final void. This study highlights the challenge for the mining industry to minimise the adverse impact of salinity issues post closure through salinity minimisation designs that are incorporated during the planning and mining phases into the mined area.</p> <p>The report includes a proposed groundwater monitoring guideline to standardise the approach to monitoring and data presentation. The use of monitoring to verify EIS predictions will promote the on-going refinement of predictive models that accurately quantify salinity processes on mine sites. This will increase community confidence that the mining industry is addressing salinity issues both in the short and the long term.</p> <p>The minimisation of salinity impacts from mining is essential to ensure the continued sustainable development of the industry in the region. There are many gaps remaining in the knowledge of salinity issues on minesites. This study highlights areas where further work is required.</p>
Outputs	< http://www.acarp.com.au/abstracts.aspx?repId=C11050 >
Key personnel	Not available
Research themes	Coal mining; salinity; groundwater; Hunter Valley

Table 4.29 Project 29: Tongue River water quality study

Project characteristics	Details
Project title	Tongue River water quality study
Project location	Tongue River, Wyoming/Montana, US
Principal investigator	Scott A. Quillinan, J. Fred McLaughlin, and Carol D. Frost
Lead institution	Wyoming State Geological Survey
Project budget	USD \$20 000
Source of funding	Wyoming Department of Environmental Quality, Wyoming State Geological Survey
Project duration	1 year
Current status	Complete 2012
Project summary	The Wyoming State Geological Survey and the University of Wyoming conducted a one-year water quality investigation to determine if an increase in salinity recorded from water samples collected near the Wyoming/Montana border was the result of coalbed natural gas (CBNG) production in the area. Surface water sample sites were chosen to include water samples collected upstream, proximal, and downstream of CBNG development.
Objectives	The purpose of this study is to use water quality data and isotopic ratios of carbon to characterise the water of the Tongue River and associated tributaries, and to determine whether the source of elevated salinity in the early spring is the result of natural processes or human activities.
Achievements	Results of this study show that CBNG produced water can be distinguished from natural surface waters in the Powder River Basin on the basis of water quality and the carbon isotope ratio of dissolved inorganic carbon. The data suggest that natural spring runoff processes within the basin interior are responsible for elevated TDS measured at the Wyoming/Montana state line during late February and early April. Isotopic and geochemical evidence suggests that CBNG production in the area is likely not the cause of high salinities in the early spring in the Tongue River.
Outputs	< http://www.wsgs.uwyo.edu/public-info/onlinepubs/RI-63.aspx >
Key personnel	Scott Quillinan, Wyoming State Geological Survey
Research themes	Coal seam gas; surface water quality; salinity; Tongue River

Table 4.30 Project 30: Western resources project

Project characteristics	Details
Project title	Western resources project
Project location	Powder River Basin, Wyoming, US
Principal investigator	This project included a number of participants including Apache Corporation, Conoco Phillips, Marathon, the Ucross Foundation, Stanford University, the University of Wyoming, Montana Bureau of Mines and Geology, and Western Research Institute.
Lead institution	Western Research Institute (WRI)
Project budget	Management (WRI): USD \$130 000 (DOE) + \$210 000 (Co-sponsor) Hydrologic effects of coal-bed methane development on shallow and deep aquifer systems in the Powder River Basin (D. Saffer): USD \$68 906
Source of funding	Apache Corporation, ConocoPhillips Petroleum Company, and Marathon Oil Company; US Department of Energy, Office of Fossil Energy
Project duration	2002 - 2006
Current status	Complete
Project summary	<p>This project included a comprehensive, basin-wide set of experiments investigating the impacts of coal bed methane (CBM; or coal bed natural gas, CBNG) production on surface and groundwater in the Powder River Basin in Wyoming. This was undertaken by a number of participants including Apache Corporation, Conoco Phillips, Marathon, the Ucross Foundation, Stanford University, the University of Wyoming, Montana Bureau of Mines and Geology, and Western Research Institute.</p> <p>Projects included:</p> <ul style="list-style-type: none"> • Fate and transport of produced water - D. Saffer, University of Wyoming. • Geochemistry of the water resource as the CBM water moves through the hydrologic system - J. Wheaton, Montana Tech/MBMG. • Using Sr isotopes to trace the fate and transport of CBM produced water in the hydrologic system - C. Frost, University of Wyoming. • Beneficial use of CBM produced water for crop production and range improvement - T. Brown, Western Research Institute. • Optimisation of well completion methods to enhance gas production and minimise water production - M. Zoback, Stanford University. • Using seismic methods to monitor spatial and temporal evolution of methane to understand gas flow paths to improve recovery and to show the importance of two-phase flow studies - J. Harris, Stanford University. <p>Field study sites included:</p> <ul style="list-style-type: none"> • Beaver Creek Watershed – In-Channel Pond intensive studies • Coal Creek Site - Out-of-Channel Ponds intensive studies • Piney Creek/Clear Creek - Irrigation with water and land treatment.
Objectives	The overall objective of this jointly sponsored research task was to support the development of CBM resources in the Powder River Basin of Wyoming. Several operators including Apache, Phillips, and Pennaco/Marathon funded and identified the relevant applied research to conduct a comprehensive study of the impact of CBM development on ground and surface water resources through competitive solicitation. Established to provide unbiased, peer reviewed research to fulfill

Project characteristics	Details
	needs of the stakeholders.
Achievements	<p>A report titled Western resources project final report - produced groundwater associated with coalbed natural gas production in the Powder River Basin.</p> <p>It contains six research papers:</p> <ul style="list-style-type: none"> • two studies of surface disposal of produced water (in-channel and out-of-channel) • a study of using produced water for cropland irrigation • a report on using strontium tracers in studying the fate of CBNG waters in the regional hydrologic system • a study of seismic properties of coal reservoirs related to dewatering and gas production, and • a report on methods of wellbore completion methods to optimise CBNG production and minimise water production.
Outputs	<p>Western Resources Project Final Report 2005, 'Produced groundwater associated with coalbed natural gas production in the Powder River Basin, <i>Wyoming State Geological Survey Report of Investigations No. 55</i>.</p> <p>Available at: <http://www.wsgs.uwyo.edu/public-info/news/2006/Mar17_2006.aspx> (or order through online store).</p>
Key personnel	<p>Mark Zoback (Science Director, Editor), Stanford University</p> <p>Terry H. Brown, Western Research Institute</p>
Research themes	Coal seam gas; produced waters; aquifer interconnectivity; water quality; integrity of wells; Powder River Basin

Table 4.31 Project 31: Groundwater chemistry near an impoundment for produced water, Powder River Basin, Wyoming, US

Project characteristics	Details
Project title	Groundwater chemistry near an impoundment for produced water, Powder River Basin, Wyoming, US
Project location	Powder River Basin, Wyoming, US
Principal investigator	Richard Healy and Cynthia Rice US Geological Survey
Lead institution	US Geological Survey
Project budget	Not available
Source of funding	Not available
Project duration	6 Years
Current status	Complete 2008
Project summary	<p>The Powder River Basin is one of the largest producers of coal-bed natural gas (CBNG) in the United States. An important environmental concern in the Basin is the fate of the large amounts of groundwater extracted during CBNG production. Most of this produced water is disposed of in unlined surface impoundments. As of January 2007, permits for more than 4000 impoundments had been issued within Wyoming.</p> <p>A 6-year study of groundwater flow and water chemistry at one impoundment, Skewed Reservoir, has produced the most detailed data set for any impoundment in the Basin.</p>
Objectives	The impact of impoundments for CBNG water on naturally occurring salts stored in sediments and the possible transport of those salts to surface water and groundwater bodies within the Powder River Basin are critical questions. This project studied the fate of CBNG water placed in one such impoundment.
Achievements	Data were collected from a network of 21 observation wells and three suction lysimeters. A groundwater mound formed atop bedrock within initially unsaturated, unconsolidated deposits underlying the reservoir. Heterogeneity in physical and chemical properties of sediments resulted in complex groundwater flow paths and highly variable groundwater chemistry. Sulfate, bicarbonate, sodium, and magnesium were the dominant ions in all areas, but substantial variability existed in relative concentrations; pH varied from less than 3 to more than 9, and total dissolved solids concentrations ranged from less than 5000 to greater than 100 000 mg/L. Selenium was a useful tracer of reservoir water; selenium concentrations exceeded 300 µg/L in samples obtained from 18 of the 24 sampling points. Groundwater travel time from the reservoir to a nearby alluvial aquifer (a linear distance of 177 m) was calculated at 474 days on the basis of selenium concentrations. The produced water is not the primary source of solutes in the groundwater. Naturally occurring salts and minerals within the unsaturated zone, dissolved and mobilised by infiltrating impoundment water, account for most of the solute mass in groundwater. Gypsum dissolution, cation-exchange, and pyrite oxidation appear to be important reactions. The complex geochemistry and groundwater flow paths at the study site underscore the difficulty in assessing

Project characteristics	Details
	<p>effects of surface impoundments on water resources within the Powder River Basin.</p> <p>A surface impoundment for water coproduced with natural gas was studied. Infiltrating impoundment water dissolved naturally occurring salts and minerals. Groundwater was contaminated with selenium, sulfate, and other constituents.</p>
Outputs	<p><http://water.usgs.gov/nrp/proj.bib/Publications/2008/healy_rice_etal_2008.pdf></p> <p><http://www.sciencedirect.com/science/article/pii/S0022169411002228></p>
Key personnel	<p>Richard Healy, US Geological Survey</p> <p>Cynthia Rice, US Geological Survey</p>
Research themes	<p>Coal seam gas; produced water; groundwater quality; salinity; infrastructure; Powder River Basin</p>

Table 4.32 Project 32: Management and effects of coalbed methane development and produced water in the Western United States

Project characteristics	Details
Project title	Management and effects of coalbed methane development and produced water in the Western United States
Project location	Western United States (Colorado, Montana, New Mexico, Utah, North Dakota, and Wyoming)
Principal investigator	Committee on Management and Effects of Coalbed Methane Development and Produced Water in the Western United States
Lead institution	National Research Council, The National Academies
Project budget	USD \$560 000
Source of funding	US Department of Interior, Bureau of Land Management
Project duration	August 2008 - August 2010
Current status	Complete
Project summary	<p>Coalbed Methane (CBM) produced water management can be challenging for regulatory agencies, CBM well operators, water treatment companies, policy makers, landowners, and the public because of differences in the quality and quantity of produced water; available infrastructure; costs to treat, store, and transport produced water; and states' legal consideration of water and produced water. Some states consider produced water as waste, whereas others consider it a beneficial byproduct of methane production. Thus, although current technologies allow CBM produced water to be treated to any desired water quality, the majority of CBM produced water is presently being disposed of at least cost rather than put to beneficial use.</p> <p>The <i>Energy Policy Act</i> of 2005 (P.L. 109-58, Section 1811) noted the relevance of CBM produced water and directed the Bureau of Land Management (BLM) to enter into an agreement with the National Research Council (NRC) to evaluate CBM produced water management in six western states. The NRC established the Committee on Management and Effects of Coalbed Methane Development and Produced Water in the Western United States to develop this report, which addresses the study charge.</p> <p>The report specifically examines the Powder River, San Juan, Raton, Piceance, and Uinta CBM basins in the states of Montana, Wyoming, Colorado, New Mexico, and Utah.</p>
Objectives	<p>To examine the effects of CBM development and produced water on water and soil resources in the western states of Colorado, Montana, New Mexico, Utah, North Dakota, and Wyoming. Specifically:</p> <ul style="list-style-type: none"> • Briefly review existing and ongoing studies by federal agencies related to CBM produced water effects and management including water treatment, use, storage, and disposal; environmental (natural and human) effects; and water quality and quantity. • Identify the major federal and state data resources available for CBM produced water management including those available for topics in (1), above, and identify the major factors influencing CBM produced water chemistry and potential toxicity; the baseline data necessary for effective management of CBM produced water; data gaps, if any, and any

Project characteristics	Details
	<p>additional need for data.</p> <ul style="list-style-type: none"> Identify the major positive and negative effects of CBM produced water treatment, use, storage, and disposal on the quality and quantity of surface and ground water resources, including environmental effects documented by public and private stakeholders. Review existing federal and state regulations that address the management and potential effects of CBM produced water on surface and ground water resources. Evaluate the effectiveness of current and emerging best management practices and production techniques for CBM produced water management options in terms of the minimisation of potential negative impacts to water resources. Discuss the costs for produced water management options, including existing and emerging techniques used in water treatment, use, storage, and disposal.
Achievements	<p>To address the study, the committee reviewed documents produced by federal and state agencies and consultants, peer-reviewed literature, online databases and resources, and information requested from and submitted by external sources, including three public meetings and six public teleconferences.</p> <p>The report's conclusions and recommendations identify:</p> <ul style="list-style-type: none"> gaps in data and information about the natural variations in CBM produced water quality and quantity, baseline conditions and the effects of CBM produced water on the environment, and the degree of connectivity among water-bearing coalbeds, other groundwater aquifers, and surface water; potential beneficial uses of CBM produced water and costs for various water treatment, storage, or use strategies; documented and potential effects of CBM produced water on surface and groundwater resources, soil, and ecological systems and ways in which those effects could be monitored and mitigated; and challenges in the existing regulatory framework for CBM produced water management.
Outputs	<p><http://www8.nationalacademies.org/cp/projectview.aspx?key=48996> <http://www.nap.edu/catalog.php?record_id=12915></p>
Key personnel	<p>William L. Fisher (Committee Chair), The University of Texas at Austin Elizabeth A. Eide (Study Director), National Research Council</p>
Research themes	<p>Coalbed methane; produced waters; US Federal and State regulation; Environmental (natural and human) effects; water quality and quantity</p>

4.3.3 Water dependent ecosystems

Table 4.33 Project 33: Impacts of coal mining on aquatic ecosystems in Central Queensland

Project characteristics	Details
Project title	Impacts of coal mining on aquatic ecosystems in Central Queensland
Project location	Bowen Basin, Queensland, Australia
Principal investigator	Darren Richardson & Ross Bennett
Lead institution	WBM Oceanics Australia
Project budget	Not available
Source of funding	Australian Coal Association Research Program (ACARP Project C11055)
Project duration	2002 - 2005
Current status	Complete
Project summary	<p>The physical and chemical properties of waters can be modified as it flows over and through a mine site. Changes to the physico-chemical properties of mine waters have the potential to modify off-site aquatic ecosystems, by affecting the structure of aquatic habitats, or by directly affecting aquatic flora and fauna species. Although there is a relatively large body of information on Australian aquatic ecosystem responses to water quality changes, there is comparatively little information on the effect of specific pollutant types associated with coal mining activities. This report, together with a companion volume published in 2002, examines the scale and types of impacts on aquatic ecosystems associated with coal mining activities in the Bowen Basin region of central Queensland.</p>
Objectives	The broad aim of the study was to provide an improved understanding of the impact of variations in water quality on the ecology of the catchments within the Bowen Basin.
Achievements	<p>The results of the study provided a case study into the effects of mining on several stream environments, which are representative of conditions experienced in the central Queensland coalmining district. In addition the study identified several key issues and that need to be considered by mine operators.</p> <p>The results show that ephemeral streams are naturally harsh and dynamic environments with biological assemblages showing marked variation in time and space. Superimposed on 'natural' background variation in water quality and biological assemblages are catchment-wide impacts of vegetation clearing and ongoing grazing pressures, which have resulted in irreversible changes to aquatic ecosystems on a regional scale. This has important implications from a mine management perspective, as detailed in the report.</p>
Outputs	< http://www.acarp.com.au/abstracts.aspx?repId=C11055 >
Key personnel	Dr Darren Richardson, BTM WBM
Research themes	Coal mining; mine water; aquatic ecosystems; Bowen Basin

Table 4.34 Project 34: Guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams

Project characteristics	Details
Project title	Guidelines for establishing ecologically sustainable discharge criteria in seasonally flowing streams
Project location	Queensland, Australia
Principal investigator	Dr Sue Vink The University of Queensland
Lead institution	Centre for Water in the Minerals Industry, Sustainable Minerals Institute
Project budget	\$261 800
Source of funding	Australian Coal Research Limited
Project duration	2010 - 2013
Current status	Complete
Project summary	The aim of this project was to provide fundamental knowledge required to design ecologically relevant discharge criteria in seasonally flowing streams. At August 2011, six sampling trips had been conducted to capture changes to the microbial community composition in response to the seasonal changes in environmental conditions and after mine water releases. While more detailed sampling had been undertaken in the Isaac River and Cherwell and Boomerang Creeks, a total of 8 creeks had been sampled upstream and downstream of discharge locations.
Objectives	The specific objectives of this project are: <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	A standard suite of toxicity tests were used to assess the potential toxicity of sulfate and a species sensitivity distribution was derived from this data to define protective concentrations. The concentration of sulfate that should theoretically be protective of 95% of species in the receiving ecosystem was estimated to be 770 mg/L and the concentration of sulfate that should theoretically protect 99% of species in the receiving ecosystem was estimated to be 620 mg/L. This study provides a significant advance in scientific understanding of the potential environmental impacts of sulfate in the Fitzroy River Basin and will help improve licensing and water quality management.
Outputs	< http://www.acarp.com.au/abstracts.aspx?repId=C18033 >
Key personnel	Dr Sue Vink, The University of Queensland Keith Smith, ACARP
Research themes	Coal mining; impact of saline discharge on aquatic ecosystems; guidelines for flow and water quality conditions

Table 4.35 Project 35: Assessing impact of sulphate in saline mine site discharge in seasonally flowing streams in the Bowen Basin

Project characteristics	Details
Project title	Assessing impact of sulphate in saline mine site discharge in seasonally flowing streams in the Bowen Basin
Project location	Bowen Basin, Queensland, Australia
Principal investigator	Dr Sue Vink The University of Queensland
Lead institution	Centre for Water in the Minerals Industry, Sustainable Minerals Institute
Project budget	\$356 956
Source of funding	Australian Coal Research Limited
Project duration	2009 - September 2012
Current status	Complete
Project summary	<p>This project will fill two key knowledge gaps required to improve understanding of the impacts of mining on receiving environments in streams, and in particular seasonally flowing streams. The gaps that will be addressed are:</p> <ul style="list-style-type: none"> • to identify sulphate as a toxicant and define trigger values for aquatic ecosystem protection • to determine the variation in salt concentrations and sulphate composition that occur as a result of discharge during different parts of the seasonal hydrograph. <p>Preliminary experiments have been undertaken using macroinvertebrates collected from the basin. Tests were conducted using a dilution series of artificial mine water. The composition was chosen as representing one of the ion suites present in the basin. A snapshot of the full ion suite present in mine waters across the basin is being conducted by mine sites to help determine representative test solution compositions for additional tests. Acute and chronic tests will also be conducted using commercially available species in accordance with ANZECC/ARMCANZ guidelines.</p>
Objectives	The objective of the work is firstly to develop a locally relevant salinity toxicity data set for aquatic organisms in the Bowen Basin. Secondly to provide an indication of toxicity using test solutions with similar ionic composition to mine waters of the basin.
Achievements	A significant data set was obtained describing the sensitivity of macroinvertebrates to mine waters. Comparison of salinity tolerance of various macroinvertebrate families showed one artificial mine water type being slightly more toxic than the other. Further comparison of artificial mine water tolerance to marine salts, showed mine waters to be more toxic. However, the comparison between mine salts tolerance and marine salts tolerance may not be sufficiently valid as the macroinvertebrates tested with marine salts were not from the same location or region as those tested with mine salts. No previous experiments have been conducted using marine salts with macroinvertebrates collected from the Fitzroy Catchment. While some past studies have reported that salinity tolerance of the same taxon from separate locations can be different, one recent study showed that tolerance to sulfates were similar in macroinvertebrates from Fitzroy

Project characteristics	Details
	<p>Catchment and south-east Queensland.</p> <p>The toxicant trigger values derived from this study can be used to inform the regulation of mine water releases where aquatic ecosystem toxicity from salinity is the primary issue of concern. This could be particularly relevant for management of mixing zones and near-field impacts (such as has traditionally been the case with Transitional Environmental Programs (TEP's)) and where cumulative impacts on aquatic ecosystems or other environmental values are not a major concern.</p>
Outputs	< http://www.acarp.com.au/abstracts.aspx?repld=C18033 >
Key personnel	Dr Sue Vink, University of Queensland Keith Smith, ACARP
Research themes	Coal mining; mine water; salinity; Bowen Basin; surface water; toxicity; water management

Table 4.36 Project 36: Tool to assess mining impacts on river condition

Project characteristics	Details
Project title	Tool to assess mining impacts on river condition
Project location	Bowen Basin, Queensland, Australia
Principal investigator	Dr Claire Sellens Central Queensland University
Lead institution	Central Queensland University
Project budget	\$325 945
Source of funding	Australian Coal Research Limited
Project duration	2012 - November 2014
Current status	The first model was anticipated by the end of November 2012, and anticipated that the collection of additional data would begin in November/December 2012.
Project summary	<p>An AUSRIVAS style predictive model is being developed for the Bowen Basin. This model will assist in the assessment of the health of ephemeral streams, particularly those potentially affected by mining. The project will also evaluate the AUSRIVAS model in terms of ability to detect human impact in ephemeral streams, and evaluate the range of values for macroinvertebrate indices for the Bowen Basin against existing Queensland Water Quality Guidelines for macroinvertebrates.</p> <p>The project is in phase one, and existing data sets are being compiled for the Bowen Basin. Data has been received from Department of Environment Heritage Protection (DEHP), and is in the process of being analysed. This data set contains information from over 200 sites and more than 20 different sample collection dates. This will be combined with data collected in the past year from sites associated with BMA mines. It is expected that data will be added in from additional mines and other stakeholders associated with the Fitzroy Partnership. This is being coordinated with the Fitzroy Basin Association.</p>
Objectives	This purpose of this project is to develop an AUSRIVAS style predictive model for the Bowen Basin. This model will assist in the assessment of the health of ephemeral streams, particularly those potentially affected by mining.
Achievements	Not available
Outputs	Report expected 25/11/2014
Key personnel	Dr Claire Sellens, Central Queensland University Keith Smith, ACARP
Research themes	Coal mining; water dependent ecosystems; modelling; Bowen Basin; ephemeral streams

Table 4.37 Project 37: Total dissolved solids in streams

Project characteristics	Details
Project title	Total dissolved solids in streams
Project location	Virginia, US
Principal investigator	Stephen Schoenholtz Virginia Water Resources Centre, Virginia Tech
Lead institution	Virginia Tech, Powell River Project
Project budget	Not available
Source of funding	Powell River Project; Virginia Department of Mines, Minerals and Energy; Virginia Department of Environmental Quality (past sponsor)
Project duration	2007 - Current
Current status	Active
Project summary	Elevated concentrations of Total Dissolved Solids (TDS) in streams occur due to mining operations and are becoming an environmental quality issue of concern in Virginia and to the US EPA. In 2007-08, Powell River Project developed an innovative and proactive research effort to determine how TDS in streams affects aquatic biota; the research is led by Stephen Schoenholtz of Virginia Water Resources Research Center (VWRRC).
Objectives	Because recent regulatory activity has caused TDS to become a major concern for the coal industry, the dynamics of TDS, SC, and component ions and their effects on aquatic biota in streams receiving mine discharge waters are being studied. The overall research goal is to identify and understand factors responsible for the biological conditions that occur in coalfield streams with elevated TDS.
Achievements	<p>In 2006, VADEQ asked its Academic Advisory Committee for guidance concerning potential regulation of TDS. The resulting study (Zipper and Berenzweig 2007) reviewed scientific literature and analysed water-monitoring data that had been collected by VADEQ. No prior studies that directly addressed aquatic ecosystem effects of elevated TDS or defined protective TDS levels in the Appalachian coalfields were found. Analysis of water monitoring data collected by both VADEQ and West Virginia Department of Environmental Protection found negative associations of SCIs with TDS (Virginia) and with conductivity (West Virginia), despite the fact that the two states calculate their SCIs differently. In other words, SCIs were generally lower for water samples with higher TDS levels in both Virginia and West Virginia datasets. However, those relationships were quite variable. The study also found that sites with high TDS often occurred in association with other water quality problems and/or poor habitat, making existing monitoring data a poor choice for evaluating TDS effects.</p> <p>In mid-2008, a new study of TDS effects in Virginia coalfield streams that are minimally affected by non-TDS water quality problems and have excellent habitat was initiated, with support provided by Powell River Project, VADEQ, and Virginia Department of Mines, Minerals and Energy. An essential activity was location of sampling sites with a range of TDS concentrations that otherwise met the necessary criteria (excellent habitat, minimally affected by non-TDS water quality problems) for the research approach. The study was conducted using VADEQ sampling protocols. Both benthic macroinvertebrate and water samples</p>

Project characteristics	Details
	<p>were obtained during single site visits in fall and spring over a two-year period. Again, a negative relationship between SCI and TDS concentration was observed, despite selecting sites that minimised other non-TDS water and habitat quality problems. Although study results revealed statistically significant relationships between SCI and several water quality measures (TDS, SC, and sulfate), those effects were highly variable even in these carefully selected streams. The interpretation is that one factor causing this variability was the sampling procedure. Whereas the data represented only two days per year, TDS varies throughout the year, and it is likely that the TDS concentrations during weeks and months prior to obtaining a benthic macroinvertebrate sample exert important influence on that sample.</p> <p>Three additional studies have been initiated:</p> <ul style="list-style-type: none"> • A study supported by US Office of Surface Mining is continuing the research at sites with elevated TDS where non-TDS stressors are not evident, as initiated by Timpano (2011). The goal is to determine how potential TDS effects should be measured and monitored as a means of protecting aquatic communities, as indicated by benthic macroinvertebrates as bioindicators. • A study funded by Powell River Project and Virginia Department of Mines, Minerals and Energy to assess biological variability at elevated TDS. This research will: <ul style="list-style-type: none"> – characterise benthic macroinvertebrate community structure on multiple occasions during the period of continuous conductivity measurement described above – enable us to answer questions concerning how benthic macroinvertebrate community structure responds to TDS, when TDS is variable during a time period prior to sampling – help us to determine if the time of sampling macroinvertebrates within a given season influences results. • A third study, funded by Appalachian Regional Initiative for Environmental Science (ARIES), that will attempt to identify environmental factors and in-stream processes that influence response of stream communities to elevated TDS. This will seek answers to the question: What factors vary among streams, both natural and human-caused, influence benthic macroinvertebrate community responses to elevated TDS?
Outputs	< http://www.prp.cses.vt.edu/Research_Results/TDS.html >
Key personnel	Carl Zipper, Director - Powell River Project Stephen Schoenholtz, Virginia Water Resources Centre, Virginia Tech
Research themes	Coal mining; mine watersalinity; water dependent ecosystems; Virginia coalfields

Table 4.38 Project 38: The potential effects of sodium bicarbonate, a major constituent of produced waters from coalbed natural gas production, on aquatic life

Project characteristics	Details
Project title	The potential effects of sodium bicarbonate, a major constituent of produced waters from coalbed natural gas production, on aquatic life
Project location	Powder River Basin, Wyoming and Montana, US
Principal investigator	Edited by Aïda M. Farag and David D. Harper
Lead institution	US Geological Society
Project budget	Not available
Source of funding	Not available
Project duration	Not available
Current status	Published 2012
Project summary	<p>The production water from coalbed natural gas (CBNG) extraction contains many constituents. The US Environmental Protection Agency has established aquatic life criteria for some of these constituents, and it is therefore possible to evaluate their risk to aquatic life. However, of the major ions associated with produced waters, chloride is the only one with an established aquatic life criterion. The focus of this research was NaHCO_3, a compound that is a major constituent of coalbed natural gas produced waters in the Tongue and Powder River Basins. This project included laboratory experiments, field in situ experiments, a field mixing zone study, and a fishery presence/absence assessment.</p> <p>Though this investigation focuses on the Tongue and Powder River Basins, the information is applicable to other watersheds where sodium bicarbonate is a principle component of product water either from CBNG or from traditional or unconventional oil and gas development. These data can also be used to separate effects of saline discharges from those potentially posed by other constituents. Finally, this research effort and the additional collaboration with USGS Water Resources and Mapping, Bureau of Land Management, US Environmental Protection Agency, State of Montana, State of Wyoming, Montana State University, University of Wyoming, and others as part of a Powder River Aquatic Task Group, can be used as a model for successful approaches to studying landscapes with energy development.</p>
Objectives	<p>The objectives of the study were to:</p> <ul style="list-style-type: none"> • define the chronic effects of NaHCO_3, a principle component of CBNG production, on aquatic life • to define sublethal effects at the individual organism level to explain the mechanisms of toxicity during chronic exposure • to define the effect concentrations in relation to concentrations measured in the field so that managers could be more aware of the extent that NaHCO_3 may or may not currently affect aquatic life in the Tongue and Powder River Basins of Montana and Wyoming.
Achievements	The laboratory acute toxicity experiments were completed with a suite of organisms, including 7 species of fish, 5 species of invertebrates, and 1 amphibian species. Experiments performed on these multiple species resulted in

Project characteristics	Details
	<p>LC50s that ranged from 1120 to greater than (>) 8000 milligrams sodium bicarbonate per liter (mg NaHCO₃/L) (also defined as 769 to >8000 milligrams bicarbonate per liter (mg HCO₃-/L) or total alkalinity expressed as 608 to >4181 milligrams calcium carbonate per liter (mg CaCO₃/L)) that varied across species and lifestage within a species. The age at which fish were exposed to NaHCO₃ significantly affected the severity of toxic responses for some organisms. The chronic toxicity of NaHCO₃ was defined in experiments that lasted from 7–60 days post-hatch.</p> <p>For these experiments, sublethal effects such as growth and reproduction, in addition to significant reductions in survival were included in the final determination of effects. Chronic toxicity was observed at concentrations that ranged from 450 to 800mg NaHCO₃/L (also defined as 430 to 657 mg HCO₃-/L or total alkalinity expressed as 354 to 539 mg CaCO₃/L) and the specific concentration depended on the sensitivity of the four species of invertebrates and fish exposed. Sublethal investigations during chronic studies revealed percent decrease in the activity of sodium-potassium adenosine triphosphatase (Na/K ATPase, an enzyme involved in ionoregulation) and the age of the fish at the onset of the decrease may affect the ability of fathead minnow to survive exposures to NaHCO₃. A database of toxicity evaluations of NaHCO₃ on aquatic life has been constructed. Using these data, sample acute and chronic criteria of 459 and 381 mg NaHCO₃/L, respectively, can be calculated for the protection of aquatic life. The final derivation and implementation of such criteria is, of course, left to the discretion of the concerned management agencies.</p> <p>A combination of in situ experiments, static-renewal experiments performed simultaneously with in situ experiments, and static renewal experiments performed with site water in the laboratory, demonstrated that untreated coalbed natural gas (CBNG) product water from the Tongue and Powder River Basins reduces survival of fathead minnow and pallid sturgeon. More precisely, the survival of early-lifestage fathead minnow, especially those less than 6-days post hatch (dph), likely is reduced significantly in the field when concentrations of NaHCO₃ rise above 1500 mg/L. However, age was not a factor for pallid sturgeon and they were sensitive to product water regardless of age.</p> <p>Treatment with the Higgins Loop™ technology and dilution of untreated water increased survival in the laboratory. Both of these situations reduced ammonia in addition to the concentrations of NaHCO₃. These experiments addressed the acute toxicity of effluent waters being added to the main stem rivers, but did not address issues related to the volumes of water that may be added to the watershed. Mixing zones of the three outfalls studied ranged from approximately 800–1200 m below the confluence and the areas within these mixing zones with acutely lethal concentrations of NaHCO₃ (as defined by the presence of concentrated dye) are limited. The areas with concentrations of NaHCO₃ more than the concentrations likely to cause significant mortality, and more than the calculated sample water-quality criteria in the Tongue and Powder River Basins appear to be limited to tributaries and parts of mixing zones with considerable additions of untreated effluent.</p>
Outputs	< http://pubs.usgs.gov/sir/2012/5008/ >
Key personnel	Director, USGS, Columbia Environmental Research Center Aïda Farag, Ph.D.
Research themes	Coal seam gas; produced water; aquatic ecosystems; Powder River Basin

Table 4.39 Project 39: Assessment of ecological conditions and potential effects of water produced from coalbed natural gas development on biological communities in streams of the Powder River Structural Basin, Wyoming and Montana, 2005–08

Project characteristics	Details
Project title	Assessment of ecological conditions and potential effects of water produced from coalbed natural gas development on biological communities in streams of the Powder River Structural Basin, Wyoming and Montana, 2005–08
Project location	Powder River Basin, Wyoming and Montana, US
Principal investigator	David A. Peterson, Melanie L. Clark, Katharine Foster, Peter R. Wright, and Gregory K. Boughton
Lead institution	US Geological Society
Project budget	Not available
Source of funding	Not available
Project duration	Not available
Current status	Published 2008
Project summary	Ongoing development of coalbed natural gas in the Powder River structural basin in Wyoming and Montana led to formation of an interagency task group to address concerns about the effects of the resulting production water on biological communities in streams of the area. The interagency task group developed a monitoring plan and conducted sampling of macroinvertebrate, algal, and fish communities at 47 sites during 2005–08 to document current ecological conditions and determine existing and potential effects of water produced from coalbed natural gas development on biological communities.
Objectives	The purpose of this report is to: <ul style="list-style-type: none"> • assess the current (2005–08) ecological conditions for environmental variables and biological communities, using new data from 2007–08 in conjunction with previously published data from 2005–06 • describe potential effects of natural and anthropogenic environmental variables, including CBNG-produced water, on biological communities to the extent possible from the current conditions data.
Achievements	Macroinvertebrate, algal, and fish community composition varied between drainage basins, among sites within drainage basins, and by year. Macroinvertebrate communities of the main-stem Tongue River were characterised by higher taxa richness and higher abundance of Ephemeroptera, for example, compared to macroinvertebrate communities in plains tributaries of the Tongue River and the main-stem Powder River. Fish communities of the Tongue River were characterised by higher taxa richness and abundance of introduced species compared to the Powder River where native species were dominant. Macroinvertebrate community metric values from sites in the middle reach of the main-stem Powder River, from below Willow Creek to below Crazy Woman Creek, differed from metric values in the upper and lower reaches of the Powder River. Metrics indicative of communitywide differences included measures of taxa richness, relative abundance, feeding mode, and tolerance. Some of the variation

Project characteristics	Details
	<p>in the macroinvertebrate communities could be explained by variation in environmental variables, including physical (turbidity, embeddedness, bed substrate size, and streamflow) and chemical (alkalinity and specific conductance) variables. Of these environmental variables, alkalinity was the best indicator of coalbed natural gas development because of the sodiumbicarbonate signature of the production water.</p> <p>Algal samples from the main-stem Powder River generally confirmed the pattern observed in the macroinvertebrate communities. Algal communities at sites in the middle reach of the Powder River commonly were characterised by dominance by a single taxon and by low biovolume of algae compared to other sites.</p> <p>In contrast to the macroinvertebrate and algal communities, species richness of fish communities was highest in the middle reach of the Powder River. Although a few significant differences in fish metrics were determined along the main-stem Powder River, the differences did not correspond to the pattern observed for the macroinvertebrate and algae communities.</p> <p>Differences in biological communities were noted between years, potentially due to the effects of drought. Macroinvertebrate community metrics, such as Diptera taxa richness, were significantly different in the severe drought year of 2006 from metric values in 2005 and 2007–08. Waterquality data collected during the study indicated that, with few exceptions, water-quality constituents generally did not exceed State or Federal acute and chronic criteria for the protection of aquatic life.</p>
Outputs	< http://pubs.usgs.gov/sir/2010/5124/ >
Key personnel	USGS Wyoming Water Science Center
Research themes	Coal seam gas; produced water; aquatic ecosystems; Powder River Basin

Table 4.40 Project 40: The effects of mountain-top mines and valley fills on aquatic ecosystems of the Central Appalachian Coalfields

Project characteristics	Details
Project title	The effects of mountaintop mines and valley fills on aquatic ecosystems of the Central Appalachian Coalfields
Project location	Central Appalachian Coalfields, US
Principal investigator	Susan B. Norton, Michael Griffith, Laurie Alexander, Amina Pollard, Glenn W. Suter II, Stephen D. LeDuc
Lead institution	US Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment
Project budget	Not available
Source of funding	Not available
Project duration	Not available
Current status	Published December 2009
Project summary	<p>This report assesses the state of the science on the environmental impacts of Mountaintop Mines and Valley Fills (MTM-VF) on streams in the Central Appalachian Coalfields. These coalfields cover about 48 000 square kilometers (122 million acres) in West Virginia, Kentucky, Virginia and Tennessee, US. Reviews focused on the impacts on mountaintop removal coal mining, which as its name suggests, involves removing all or some portion of the top of a mountain or ridge to expose and mine one or more coal seams. The excess overburden is disposed of in constructed fills in small valleys or hollows adjacent to the mining site.</p> <p>The final report reviews literature relevant to evaluating six potential consequences of MTM-VF operations:</p> <ul style="list-style-type: none"> • loss of headwater resources • impacts on water quality • impacts from aquatic toxicity • impacts on aquatic ecosystems • cumulative impacts of multiple mining operations • effectiveness of on-site reclamation and mitigation activities.
Objectives	To better understand the ecological impacts of mountaintop mining.
Achievements	<p>The conclusions, based on evidence from the peer-reviewed literature and from the US Environmental Protection Agency's Programmatic Environmental Impact Statement released in 2005, were that Mountaintop Mines and Valley Fills lead directly to five principal alterations of stream ecosystems:</p> <ul style="list-style-type: none"> • springs and ephemeral, intermittent and perennial streams are permanently lost with the removal of the mountain and from burial under fill • concentrations of major chemical ions are persistently elevated downstream • degraded water quality reaches levels that are acutely lethal to organisms in standard aquatic toxicity tests • selenium concentrations are elevated, reaching concentrations that have caused toxic effects in fish and birds • macroinvertebrate and fish communities are consistently degraded.

Project characteristics	Details
Outputs	< http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=225743#Download >
Key personnel	Mntntop/condct Reports tm-cond@epa.gov
Research themes	Coal mining; mine water; water levels; mine water; aquatic ecosystems; Central Appalachian Coalfields

Table 4.41 Project 41: Aquatic studies in the McLeod and Upper Smoky River systems

Project characteristics	Details
Project title	Aquatic studies in the McLeod and Upper Smoky River systems
Project location	Alberta, Canada
Principal investigator	Richard Casey
Lead institution	Alberta Environment
Project budget	Not specified
Source of funding	Alberta Environment
Project duration	September 2000 - August 2005
Current status	Complete
Project summary	<p>At the time of this study, there were limited studies that have examined the fate and effects of selenium in flowing and standing water ecosystems at northern latitudes. Concerns related to the fate and effects of selenium in aquatic ecosystems near mountain coal mines in west-central Alberta arose in the late-1990s. Sampling by Alberta Environment in 1998 and 1999 confirmed that selenium concentrations at “exposed” stream sites (i.e. downstream of mine activities) were often an order of magnitude greater than Canadian and US water quality guidelines for the protection of freshwater aquatic life. In comparison, selenium levels at reference or background sites, not affected by mines or other major disturbances, were typically less than the most stringent water quality guideline. Mobilisation of selenium from geologic sources into surface water due to mining has occurred at three coal mines in the upper McLeod River and upper Smoky River systems. Selenium concentrations at exposed sites near the mines are comparable to those that have shown adverse effects on aquatic life in published studies.</p> <p>In September 2000, experts on the effects of selenium on fish and wildlife in North America were invited to a two-day technical workshop in Hinton, Alberta. The main goals of the workshop were to review the Alberta results and develop work plans to address data and knowledge gaps. Alberta Environment initiated several studies based on the workshop and discussions in the Selenium Working Group. The focus of the Alberta Environment studies was to conduct ambient monitoring and determine the fate and potential effects of selenium in flowing-water systems surrounding the mines.</p> <p>This report is a compilation and summary of data collected in the Alberta Environment studies from 1998 to 2003. Available data before 1998 are also used to illustrate longer-term trends for selenium at key sites in the McLeod River, and limited samples from lakes are included for comparative information.</p>
Objectives	<p>Specific objectives of the studies were to:</p> <ul style="list-style-type: none"> • continue and establish new ambient monitoring of selenium and other metals at sites near the CRC, Gregg River and Smoky River mines, including pairs of reference and exposed sites in stream systems that flow through the mines • determine the concentrations of selenium in surface water and components of the aquatic food web (i.e. sediment, biofilm, benthic macroinvertebrates and other non-fish biota in flowing-water systems, and to compare these

Project characteristics	Details
	<p>data in a conceptual food web for streams near the mines</p> <ul style="list-style-type: none"> conduct a pilot study to determine selenium concentrations at old, closed or abandoned coal mines in the Rocky Mountain foothills of south-western Alberta.
Achievements	<p>Overall, selenium concentrations generally remained stable (with no overall increase or decrease) from 1998 to 2003 at key reference and exposed stream sites near the three mountain mines. Surface water data for 28 metals from 1998 to 2003 showed most concentrations were higher at the exposed sites compared to reference sites in stream systems intersecting the mines. Concentrations increased by 10-fold for 11 metals and by 100-fold for four metals at the exposed sites compared to the corresponding reference sites. Comparing the metal data to available water quality guidelines, selenium was the only one that exceeded the guidelines at all exposed sites in the six stream systems examined.</p> <p>Comparisons of the conceptual food web data to toxicity effects thresholds from the literature showed selenium concentrations in the diet and rainbow trout tissues, especially ovary, were usually above the thresholds in exposed streams compared to reference streams. These results for rainbow trout and data from other Alberta studies (comparing selenium concentrations in fish tissues to toxicity effects thresholds) near the mountain mines indicate that adverse effects on various fish species are expected in exposed streams compared to reference streams. Results of laboratory toxicity studies support this conclusion in part by demonstrating adverse effects (increased teratogenesis and edema) on rainbow trout offspring (fry) from the exposed stream, compared to the reference stream. The adult fish used in these studies were taken from the same streams and sample period used in the food web evaluation. Brook trout were not as sensitive to selenium. A related experimental study proposed a physiological mechanism for selenium bioaccumulation causing teratogenesis in rainbow trout.</p> <p>Results of a pilot study at old, closed or abandoned coal mines in south-western Alberta indicated selenium concentrations do not appear to be presently elevated at the sites sampled. However, it is not known if selenium was ever at higher levels than those currently observed. Overall, results of the Alberta Environment studies and data from other fish studies from west central Alberta show concern with potential influences of selenium in exposed streams near the mountain coal mines. Additional monitoring and research are required to fully evaluate the fate and effects of selenium at the mines, including aquatic ecosystems such as end pit lakes or wetlands in the reclaimed landscape.</p> <p>Further from this research, Microbial Technologies, Inc. reviewed the environmental chemistry of selenium and technologies for its treatment at the three mountain coal mines in West-Central Alberta. These include physically-based technologies (reverse osmosis, nanofiltration, and ion exchange), chemically-based technologies (iron precipitation and catalyzed cementation), and biologically-based technologies (algal volatilization, biological treatment plant, in-situ treatment, Biopass and other passive treatment systems, treatment wetlands, and evaporation ponds). Several of these technologies have been tested at a pilot-scale or implemented as treatment facilities: Evaluation of Treatment Options to Reduce Water-Borne Selenium at Coal Mines in West-Central Alberta < http://environment.gov.ab.ca/info/library/7766.pdf ></p>
Outputs	< http://environment.gov.ab.ca/info/posting.asp?assetid=7743&categoryid=5 >
Key personnel	Richard Casey, Alberta Environment & Sustainable Resource Development Curtis Brock

Project characteristics	Details
Research themes	Coal mining; selenium concentrations; aquatic ecology

Table 4.42 Project 42: Environmental investigation of the Quinsam Watershed

Project characteristics	Details
Project title	Environmental investigation of the Quinsam Watershed
Project location	Quinsam River, Canada
Principal investigator	Dr. William R. Cullen and Vivian W-M. Lai
Lead institution	University of British Columbia and Environmental Sciences Group Royal Military College
Project budget	Not specified
Source of funding	Variety of sources, Canadian Water Network/Réseau Canadien de l'Eau
Project duration	2008 - 2012
Current status	Results currently being written up for publication
Project summary	<p>A previous study conducted in 2006 by British Columbia's Ministry of Environment had established that the arsenic concentration in sediments in Long Lake near the coal mine was elevated, but it was unclear whether the high arsenic levels were natural or if the Quinsam Coal mine's activities might be responsible. The matter took on new urgency when Quinsam Coal applied to BC's Ministry of Energy, Mines and Petroleum Resources to expand the mine to extract 1.7 million tonnes of raw coal from 2011 to 2014.</p> <p>This study was initiated to investigate whether the mine was introducing arsenic into the watershed and if so, what the effects of arsenic input were on biota in the watershed. To determine natural and anthropogenic elemental loadings in sediments in the area, sediments were collected from a number of background lakes and lakes on the mine property, including the lake of highest concern, Long Lake. These results were compared with waste material from the mine site. The uptake of arsenic was investigated by using mussels in both short and long-term monitoring studies. A short-term caged mussel experiment was designed to investigate the potential for arsenic uptake, while long-term monitoring of mussels downriver of the mine was used to investigate current and historical arsenic loading in mussels.</p>
Objectives	This study was initiated to investigate whether the mine was introducing arsenic into the watershed and if so, what the effects of arsenic input were on biota in the watershed.
Achievements	<p>In particular, Long Lake sediments were found to be elevated in arsenic. Further speciation analysis and bioaccessibility, or solubility, testing indicated that the introduced arsenic contamination can be easily solubilized and is more soluble than arsenic in the waste rock from the mine site. These speciation and bioaccessibility tests indicate that Long Lake sediments have forms and solubilities of arsenic similar to those from surrounding lakes. Further study is required to identify which of many potential sources around Long Lake is responsible for the elevated arsenic concentrations. The lake that flows into Long Lake, No Name Lake, was previously identified as also having elevated arsenic concentrations and the current study obtained similar results.</p> <p>Elevated arsenic concentrations in sediments were found to correlate with</p>

Project characteristics	Details
	<p>elevated arsenic concentrations in biota. During the short-term caged mussels experiment higher arsenic loadings were found in mussels in Long Lake than in surrounding Quinsam watershed lakes. Higher loadings were seen in mussels collected from the Quinsam River in relation to the same species of mussel monitored in a nearby watershed, Simms Creek.</p> <p>Arsenic concentrations are elevated in Long Lake as a result of acid rock drainage and other chemical process associated with mine waste. The high arsenic levels are associated with high concentrations of sulphate. The arsenic is available to bivalves, and presumably other biota. Further studies were recommended to identify the points of arsenic input should be undertaken to allow for corrective action. In particular sediment cores would provide evidence of the extent of anthropogenic arsenic inputs since the mine opening.</p> <p>This study led to the mine's expansion being placed on hold until mine officials respond to CWN's findings. The source of a lot of the arsenic turned out to be abandoned flooded mine workings that leaked into the lake via what was euphemistically named the "Long Lake Seep". The mine was required to develop a treatment process for this underground water and has submitted a revised expansion plan.</p>
Outputs	<p>An Environmental Investigation of the Quinsam Watershed http://www.cwn-rce.ca/wp-content/uploads/2011/07/environmental-investigation-of-quinsam-watershed.pdf</p>
Key personnel	<p>William R. Cullen, Professor Emeritus at the University of British Columbia's Department of Chemistry</p>
Research themes	<p>Coal mining; surface water quality; arsenic; toxicity; Quinsam Watershed</p>

4.4 Integrity of wells

Table 4.43 Project 43: Potential for gas migration due to coalbed methane development

Project characteristics	Details
Project title	Potential for gas migration due to coalbed methane development
Project location	Alberta, Canada
Principal investigator	James Armstrong
Lead institution	Worley Parsons
Project budget	Not available
Source of funding	Alberta Environment
Project duration	Not available
Current status	Published March 2009
Project summary	<p>Recognition of coal bed gas (CBG) as an increasingly important energy resource has led to rapid expansion of exploration activity. Rapid development started in the 1980s in the western United States of America (US), and has spread over the last six years to the Western Canadian Sedimentary Basin (WCSB). Increased production activities have brought increased awareness of environmental issues surrounding CBG development. In particular, reports of negative experiences associated with early CBG development in the US have raised stakeholder concerns in Canada.</p> <p>Alberta CBG development has largely avoided the water resources issues experienced in the US from CBG exploitation for two reasons. The major CBG resource plays in Canada to date have been in 'dry' coals, while 'wet' CBG coals developed in the US required dewatering in order to recover the gas. Secondly, the rapid increase in Alberta CBG development occurred after Alberta regulators had already implemented protective legislation to address environmental concerns associated with protection of groundwater resources.</p> <p>The report includes the background with respect to Alberta geology, a discussion on coal gas migration including natural pathways and potential pathways related to energy and water well construction, a conceptual risk assessment, and a summary of CBG development experiences in the US.</p>
Objectives	<p>The report was prepared for Alberta Environment to address public concerns regarding a lack of Alberta-based information about potential impacts associated with CBG development.</p> <p>The report is intended to summarise information in four areas, including:</p> <ul style="list-style-type: none"> • how gas moves within natural systems • potential impacts related to CBG development • differences in gas migration potential associated with CBG production intervals • experiences from outer jurisdictions.
Achievements	Three principal pathways for gas migration to surface were identified in relation to CBG development. The first pathway is along older or abandoned boreholes with

Project characteristics	Details
	<p>inadequate or decaying seals across shallow coal beds. A second pathway is within water wells completed across water-bearing coal zones and/or adjacent sandstone units. The third pathway is in areas where coal zones approach ground surface.</p> <p>Perspectives on environmental issues for gas migration from CBG development vary between stakeholders. Risk summarises the combination of the probability of an event and its resulting negative consequences. A sample risk review related to gas migration was used to illustrate this point. A comprehensive assessment would require much more input from all affected stakeholders.</p> <p>Further development of a risk model with broader stakeholder input and all risks (not just gas migration) may also help raise awareness of the technical details, different perspectives, and mitigation alternatives.</p> <p>Gas migration problems related to CBG development in the 'dry' Horseshoe Canyon Formation coals are unlikely to occur, given the hydrogeological conditions coupled with present regulatory requirements. Anticipated CBG development in shallower, 'wet' Ardley coal zones will require dewatering, and will benefit from risk management experiences learned from CBG development in the US. The deeper, 'wet' Mannville coals require removing saline water, a strictly regulated activity. The potential for CBG leakage associated with historical oilfield wells (i.e. drilled prior to the mid-1970's) needs further assessment, by looking at surveyed locations relative to existing water wells and by using geochemical and stable isotopic gas analyses.</p> <p>Water well owners need to be educated about their responsibility for well installation and maintenance, including proper abandonment of old and unused water wells.</p>
Outputs	< http://environment.gov.ab.ca/info/posting.asp?assetid=8172&searchtype=asset&txtsearch=gas%20migration >
Key personnel	Alberta Environment env.infocent@gov.ab.ca
Research themes	Coal seam gas; well integrity; aquifer interconnectivity

4.5 Hydraulic fracturing

4.5.1 Chemical – surface and groundwater quality

Table 4.44 Project 44: Assessing potential effects of hydraulic fracturing for energy development on water resources

Project characteristics	Details
Project title	Assessing potential effects of hydraulic fracturing for energy development on water resources
Project location	US
Principal investigator	29 scientists representing 14 USGS water science centers, the National Center, the National Research Program, the Central Energy Resources Center, the Central Region National Water-Quality Assessment Program, FORT, the Columbia Environmental Research Center, Duke University, and an eastern Colorado water conservation district
Lead institution	US Geological Survey's Powell Center for Analysis and Synthesis
Project budget	USD \$116 000
Source of funding	US Geological Survey
Project duration	2012 - Current
Current status	Active
Project summary	<p>The US Geological Survey (USGS) John Wesley Powell Center for Analysis and Synthesis is hosting an interdisciplinary working group of USGS scientists to conduct a temporal and spatial analysis of surface-water and groundwater quality in areas of unconventional oil and gas development. The analysis uses existing national and regional datasets to describe water quality, evaluate water-quality changes over time where there are sufficient data, and evaluate spatial and temporal data gaps.</p> <p>The Powell Center study is a collaboration with the USGS National Water-Quality Assessment (NAWQA) Program, which provided water-quality data from the USGS National Water Information System (NWIS) and US Environmental Protection Agency (EPA) Modern Storage and Retrieval (STORET) databases.</p>
Objectives	<p>The objectives of the USGS Powell Center work group are to:</p> <ul style="list-style-type: none"> • better understand hydraulic fracturing in the United States • broadly assess the quality of surface water and groundwater in areas of unconventional oil and gas production • evaluate potential changes in water quality over time • determine current baseline concentrations of major ions in surface water and groundwater in areas of unconventional oil and gas production • identify spatial and temporal data gaps where further information is needed to evaluate existing water quality and water-quality trends • identify future research needed to better understand the effects of oil and gas production and hydraulic fracturing on surface-water and groundwater quality.

Project characteristics	Details
Achievements	Preliminary data compilation for areas of unconventional oil and gas production from the USGS and EPA databases yielded 754 000 water-quality samples collected from 78 000 groundwater sampling sites and 32 000 surface water sampling sites. Major ions, including calcium, magnesium, sodium, bicarbonate (alkalinity), chloride, and sulfate, are the most commonly determined constituents for most water quality samples. Concentrations of these constituents can be affected by oil and gas development and are typically elevated in produced waters. Spatial and temporal analyses will include summary statistics for major-ion concentrations in samples of surface water, shallow groundwater (within about 100 feet of land surface), and deep groundwater for selected time periods in selected unconventional oil and gas production areas. Where sufficient data are available, changes in water quality over time will be evaluated and described for each area. Areas and time periods for which sufficient data are unavailable will be identified as data gaps where additional data collection may be warranted to evaluate water quality and water-quality trends.
Outputs	< http://pubs.usgs.gov/fs/2012/3049/ > < http://www.fort.usgs.gov/Research/research_tasks.asp?TaskID=2417 >
Key personnel	Mr Zack Bowen, U.S. Geological Survey
Research themes	Hydraulic fracturing; surface water quality; groundwater quality; unconventional gas

Table 4.45 Project 45: Hydraulic fracturing and water resources: separating the frack from the fiction

Project characteristics	Details
Project title	Hydraulic fracturing and water resources: separating the frack from the fiction
Project location	US
Principal investigator	Heather Cooley Pacific Institute
Lead institution	Pacific Institute Water Program
Project budget	Not available
Source of funding	The 11th Hour Project
Project duration	Not available
Current status	Completed June 2012
Project summary	The report <i>Hydraulic fracturing and water resources: separating the frack from the fiction</i> is a detailed assessment and synthesis of existing research on fracking as well as the results of interviews with representatives from state and federal agencies, industry, academia, environmental groups, and community-based organisations from across the United States. Interviewees identified a broad set of social, economic, and environmental concerns, foremost among which are impacts of hydraulic fracturing on the availability and quality of water resources.
Objectives	To better identify and understand what the key issues are, examine the impacts of hydraulic fracturing and unconventional natural gas extraction on water resources, and identify areas where more information is needed.
Achievements	The study finds that while chemical disclosure can be useful for tracking contamination, risks associated with fracking chemicals are not the only issues that must be addressed. The massive water requirements for fracking and the potential conflicts with other water needs, including for agriculture and for ecosystems, pose major challenges. Methane contamination of drinking water wells is also a concern according to some field studies, as are the serious challenges associated with storing, transporting, treating, and disposing of wastewater.
Outputs	< http://pacinst.org/publication/hydraulic-fracturing-and-water-resources-separating-the-frack-from-the-fiction/ >
Key personnel	Heather Cooley, Pacific Institute Kristina Donnelly, Pacific Institute
Research themes	Hydraulic fracturing; impacts on water resources; stakeholder engagement

Table 4.46 Project 46: Evaluation of impacts to underground sources of drinking water by hydraulic fracturing of coalbed methane reservoirs

Project characteristics	Details
Project title	Evaluation of impacts to underground sources of drinking water by hydraulic fracturing of coalbed methane reservoirs
Project location	US
Principal investigator	Office of Water, Office of Ground Water and Drinking Water
Lead institution	United States Environmental Protection Agency
Project budget	Not available
Source of funding	Not available
Project duration	2000 - 2004
Current status	Complete
Project summary	<p>US EPA published a final report summarising a study to evaluate the potential threat to underground sources of drinking water (USDWs) from the injection of hydraulic fracturing fluids into coalbed methane (CBM) production wells. In 1997, in <i>LEAF v. EPA</i>, the Eleventh Circuit Court ruled that, because hydraulic fracturing of coalbeds to produce methane gas is a form of underground injection, Alabama's EPA-approved underground injection control (UIC) program must effectively regulate this practice. In response to the Eleventh Circuit's decision, citizen complaints, and Congressional interest, EPA made the determination to investigate the potential for hydraulic fracturing of CBM wells to contaminate USDWs.</p> <p>In addition to reviewing more than 200 peer-reviewed publications, EPA also interviewed 50 employees from state or local government agencies and communicated with approximately 40 citizens who were concerned that CBM production impacted their drinking water wells.</p>
Objectives	The purpose of the fact-finding study was to assist EPA in determining if hydraulic fracturing of coalbed methane wells poses a threat to underground sources of drinking water, and complete the study before making regulatory or policy decisions regarding hydraulic fracturing.
Achievements	<p>In its review of incidents of drinking water well contamination believed to be associated with hydraulic fracturing, EPA found no confirmed cases that are linked to fracturing fluid injection into CBM wells or subsequent underground movement of fracturing fluids. Further, although thousands of CBM wells are fractured annually, EPA did not find confirmed evidence that drinking water wells have been contaminated by hydraulic fracturing fluid injection into CBM wells. Where fluids are injected, EPA believes that groundwater production, combined with mitigating effects of dilution and dispersion, adsorption, and biodegradation, minimise the possibility that chemicals included in fracturing fluids would adversely affect USDWs.</p> <p>In the course of conducting the study, EPA found that diesel fuel, which may pose some environmental concerns, was sometimes used in fluids for hydraulic fracturing within USDWs. To address any environmental concerns, EPA worked</p>

Project characteristics	Details
	with the three service companies that perform 95% of the hydraulic fracturing projects in the US to voluntarily remove diesel fuel from CBM fracturing fluids injected into USDWs.
Outputs	< http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_coalbedmethanestudy.cfm >
Key personnel	US Environmental Protection Agency, Office of Ground Water and Drinking Water +1 202 564 3750
Research themes	Hydraulic fracturing; drinking water

Table 4.47 Project 47: EPA study of hydraulic fracturing and its potential impact on drinking water resources

Project characteristics	Details
Project title	EPA study of hydraulic fracturing and its potential impact on drinking water resources
Project location	Washington, DC, United States
Principal investigator	US Environmental Protection Agency Office of Research and Development
Lead institution	US Environmental Protection Agency Office of Research and Development
Project budget	FY 2010 Enacted USD \$1.9 million FY 2011 Enacted USD \$4.3 million FY 2012 Enacted USD \$6.1 million FY 2013 Pres Bud USD \$14.2 million
Source of funding	US Government
Project duration	2010 to 2014
Current status	A first progress report is planned for late 2012. A final draft report is expected to be released for public comment and peer review in late 2014.
Project summary	At the request of Congress, EPA is conducting a study to better understand any potential impacts of hydraulic fracturing on drinking water and ground water. The scope of the research includes the full lifespan of water in hydraulic fracturing, from acquisition of the water, through the mixing of chemicals and actual fracturing, to the post-fracturing stage, including the management of flowback and produced water and its ultimate treatment and disposal.
Objectives	The overarching goal of this research is to answer the following questions: <ul style="list-style-type: none"> • Can hydraulic fracturing impact drinking water resources? • If so, what conditions are associated with these potential impacts?
Achievements	Not available
Outputs	< http://www2.epa.gov/hfstudy > < http://www2.epa.gov/hfstudy/study-potential-impacts-hydraulic-fracturing-drinking-water-resources-progress-report-0 >
Key personnel	US Environmental Protection Agency, Office of Ground Water and Drinking Water +1 202 564 3750 Edward Hanlon
Research themes	Impacts of hydraulic fracturing on drinking water resources; hydraulic fracturing process

4.6 Quality and reliability of irrigation and drinking water supplies

Table 4.48 Project 48: Preliminary assessment of cumulative drawdown impacts in the Surat Basin associated with the coal seam gas industry

Project characteristics	Details
Project title	Preliminary assessment of cumulative drawdown impacts in the Surat Basin associated with the coal seam gas industry
Project location	Surat Basin, Qld, Australia
Principal investigator	RPS Aquaterra
Lead institution	University of Southern Queensland
Project budget	Not available
Source of funding	Arrow Energy, Origin Energy, Queensland Gas Corporation, Santos Ltd
Project duration	September 2010 - March 2011
Current status	Complete
Project summary	During 2010, the four major CSG companies operating in the Surat Basin identified that there was significant community concern regarding the cumulative groundwater impacts of CSG operations in this area. In an industry first, these companies agreed to pool their resources to review the approaches taken to the individual assessments, and provide a preliminary independent assessment of cumulative groundwater impacts associated with CSG operations. The University of Southern Queensland (USQ) was commissioned in September 2010 to manage this study, with RPS Aquaterra engaged to undertake the independent assessment of cumulative impacts, based on information from published impact assessment reports and other information made available to USQ and RPS Aquaterra by the four CSG companies to undertake the study.
Objectives	The overarching aim was to collate and present the existing groundwater modelling data to provide both the Government and the public with a greater level of understanding and confidence regarding the cumulative groundwater impacts from the development of CSG projects within the Surat Basin. This preliminary study was designed to provide a first estimate of impacts based on existing modelling.
Achievements	This study has collated groundwater information from the four major CSG companies operating in the Surat Basin to provide a preliminary but over-conservative assessment of the groundwater areas expected to be impacted by depressurisation of the Walloon Coal Measures. In the low impact case, cumulative drawdowns in the Precipice Sandstone never exceed 5m in any location, reaching a maximum of only 3.5 m; whereas using the high end of the predicted range, a relatively large area of greater than 5m cumulative drawdown is apparent. Likewise, the predicted area of greater than 5 m cumulative drawdown in the Hutton Sandstone is significantly larger using the high end of the predicted impact range, compared with the low end.

Project characteristics	Details
	<p>The extent of > 5 m drawdown is similar in both the Bungil/Mooga and the Gubberamunda Aquifers. Maximum extent of > 5 m drawdown in the Springbok Sandstone is intermediate between the higher and lower aquifer units. In all cases, the region of > 5 m cumulative drawdown is limited to the general proximity of the CSG developments. The drawdown is more extensive in the down dip direction in all cases, with impacts in the updip direction constrained not only by the outcrop limits, but presumably also due to influence of ongoing recharge to updip areas.</p> <p>The study provides recommendations for further research.</p>
Outputs	< http://eprints.usq.edu.au/19462/ >
Key personnel	Prof Steven Raine, University of Southern Queensland
Research themes	Coal seam gas; groundwater supply; groundwater modelling; cumulative impacts; Surat Basin

Table 4.49 Project 49: Coal seam gas, coal and agriculture: water implications

Project characteristics	Details
Project title	Coal seam gas, coal and agriculture: water implications
Project location	Australia
Principal investigator	Prof Damien Barrett The University of Queensland
Lead institution	Centre for Water in the Minerals Industry, Sustainable Minerals Institute
Project budget	\$227 810
Source of funding	Australian Coal Research Limited
Project duration	2011 - 2012
Current status	Complete
Project summary	<p>The external drivers and differential rate of expansion of three sectors; coal mining, agriculture and Coal Seam Gas (CSG), are determining potential conflict for water resources and land access. Many community members and the media do not distinguish between coal mining and the emerging CSG sector. Coupled with the uncertainty regarding cumulative impacts of multiple CSG projects, potential for conflict over water resources and negative environmental impacts these factors represent a risk to the coal industry's 'social licence to operate', even if they emanate from another sector.</p> <p>The project aimed to identify and define water-related issues within the coal mining, CSG and agriculture sectors; explore the regional character of these issues; identify cross-sector risks to the coal mining industry and generate a spatial data product that locates where competition and conflict are most intense between these sectors.</p>
Objectives	The objective of this project is to improve understanding of the potential conflict for water resources between coal mining, agriculture and the rapidly expanding CSG industry.
Achievements	The spatial distribution of CSG, coal mining and agriculture show that the risk of adverse community reaction to CSG and mining activities is dependent on the spatial (horizontal and vertical) adjacency of the different sectors, water availability and use, soil quality, hydrology and presence of environmental and agricultural assets.
Outputs	< http://www.acarp.com.au/abstracts.aspx?repId=C21006 >
Key personnel	Prof Damien Barrett, The University of Queensland Keith Smith, ACARP
Research themes	Coal seam gas; coal mining; water supply; water impacts; cumulative impacts; spatial database; conflict for water resources within coal mining, CSG and agricultural sectors

Table 4.50 Project 50: Modelling the water, energy and economic nexus

Project characteristics	Details
Project title	Modelling the water, energy and economic nexus
Project location	Australia
Principal investigator	Dr Alan Woodley The University of Queensland
Lead institution	The University of Queensland
Project budget	\$194 750
Source of funding	Australian Coal Research Limited
Project duration	2012 - February 2014
Current status	Complete
Project summary	<p>The mining industry faces three long term strategic risks in relation to its water and energy use:</p> <ul style="list-style-type: none"> • securing enough water and energy to meet increased demand • reducing its water use, energy consumption and emissions due to social, environmental and economic pressures • fully understanding the link between water and energy, so that an improvement in one area does not simply create a greater adverse affect in the other. <p>This project aims to help the industry analyse these risks by creating a tool that models the interactions of water and energy on a site wide level.</p>
Objectives	This tool will allow sites to quantify their water and energy use and associated synergies and tradeoffs.
Achievements	The project is in the initial stages. However, the major energy uses and emissions on mine sites have been identified and are in the process of adding them to a water systems model. The next stages of the project are to identify the offsite impacts of water and energy use and to incorporate them inside a risk framework, allowing sites to better understand the 'true' value of water and energy.
Outputs	< http://www.acarp.com.au/abstracts.aspx?repId=c21033 >
Key personnel	Dr Alan Woodley, The University of Queensland Keith Smith, ACARP
Research themes	Coal mining; water supply; water and energy modelling

Table 4.51 Project 51: Underground water impact report, Surat Cumulative Management Area

Project characteristics	Details
Project title	Underground water impact report, Surat Cumulative Management Area
Project location	Queensland, Australia
Principal investigator	Coal Seam Gas Water, Queensland Water Commission (QWC)
Lead institution	Coal Seam Gas Water, QWC
Project budget	Not available
Source of funding	Queensland Government
Project duration	March 2011 - ongoing
Current status	The <i>Surat underground water impact report</i> (UWIR) was approved by the Department of Environment and Heritage Protection. The approved report is a statutory instrument under the <i>Water Act 2000</i> (Qld). Tenure holders have responsibilities for directly implementing specific aspects of the report, while various government agencies have roles in ensuring proper implementation of the report.
Project summary	<p>The Surat Basin extends over 180 000 square kilometres of southern and central Queensland where it overlies parts of the Bowen Basin. Coal Seam Gas (CSG) is produced from the Walloon Coal Measures of the Surat Basin and the Bandanna Formation of the Bowen Basin.</p> <p>With the Surat and southern Bowen Basin undergoing a major expansion in CSG production, the region was declared a Cumulative Management Area (CMA) under the Queensland <i>Water Act 2000</i>, which gave the Queensland Water Commission (QWC) the responsibility of preparing an Underground Water Impact Report (UWIR).</p>
Objectives	<p>When water is extracted from a gas well, the groundwater levels fall in the area surrounding the well. Where a petroleum well field is established, the impacts extend laterally beyond the extent of the well field. If there are multiple well fields adjacent to each other, the impacts of water extraction from the fields on water levels will overlap. In these situations, a cumulative approach is required for the assessment and management of water level impacts.</p> <p>The Queensland regulatory framework provides that an area of concentrated petroleum development where there are likely to be overlapping impacts on water levels from multiple petroleum operations, can be declared a CMA. In those areas, the QWC is responsible for:</p> <ul style="list-style-type: none"> • predicting the regional impacts on water levels • developing appropriate water monitoring and spring management strategies • assigning responsibility to individual petroleum tenure holders for implementing specific parts of the strategies. <p>The regulatory framework provides that the QWC set out these assessments, strategies and responsibilities in an UWIR.</p>
Achievements	There are some 21 000 water bores within the Surat CMA with bore water used for grazing, irrigation, industrial and urban consumption. Of these, there are 528 bores which are expected to experience a decline in water level of more than the

Project characteristics	Details
	<p>trigger threshold as a result of CSG water extraction.</p> <p>A regional water monitoring network with 498 monitor points will be put in place to gather data on water levels and quality. There are 71 spring complexes within the Surat CMA. In the long term the impact on water levels in the source aquifer is expected exceed 0.2 metres at five of those sites. As it will be some years before any potential impacts occur, there is time to plan and implement mitigation actions for these springs.</p> <p>In assessing impacts, the UWIR has not taken into account any re-use of CSG water in substitution for water extraction by existing users or the injection of treated CSG water back into aquifers. Such measures have the potential to mitigate the impact of CSG water extraction on water levels in aquifers.</p>
Outputs	<p><http://www.dnrm.qld.gov.au/ogia/surat-underground-water-impact-report/implementation-of-the-report></p> <p>The Queensland Water Commission will report annually, continue to undertake and promote research to improve knowledge, and update the model and the Underground Water Impact Report every three years to incorporate new knowledge.</p>
Key personnel	Mr Sanjeev Pandey, QWC
Research themes	Coal seam gas; groundwater supplies; beneficial users; groundwater bores; springs

Table 4.52 Project 52: Organic compounds in produced waters from coalbed natural gas wells in the Powder River Basin, Wyoming, US

Project characteristics	Details
Project title	Organic compounds in produced waters from coalbed natural gas wells in the Powder River Basin, Wyoming, US
Project location	Powder River Basin, Wyoming, US
Principal investigator	William Orem
Lead institution	US Geological Survey
Project budget	Part of a larger project with total project budget of approximately USD \$500 000 per annum. The produced water part estimated at about USD \$100 000 per annum.
Source of funding	US Geological Survey Energy Resources Program
Project duration	2005 - ongoing
Current status	Active
Project summary	<p>The organic composition of produced water samples from coalbed natural gas (CBNG) wells in the Powder River Basin, WY, sampled in 2001 and 2002 are reported as part of a larger study of the potential health and environmental effects of organic compounds derived from coal; "Impacts of Energy Resources on Human Health and Environmental Quality."</p> <p>In this part, the USGS undertook an examination of organic compounds present in CBNG produced water, with initial work conducted in the Powder River Basin, Wyoming, US. Ongoing work has been undertaken in the Black Warrior Basin, Alabama on organic compounds in produced water from CBNG, and on organics in produced water and hydrofracking fluid from the Marcellus Shale in Pennsylvania.</p>
Objectives	<p>The overall project is intended to provide policymakers and the public with the scientific information needed to weigh the human health and environmental consequences of meeting our energy needs.</p> <p>The quality of CBNG produced waters is a potential environmental concern and disposal problem for CBNG producers, and no previous studies of organic compounds in CBNG produced water had been published.</p>
Achievements	<p>Organic compounds identified in the produced water samples included: phenols, biphenyls, N-, O-, and S-containing heterocyclic compounds, polycyclic aromatic hydrocarbons (PAHs), aromatic amines, various non-aromatic compounds, and phthalates. Many of the identified organic compounds (phenols, heterocyclic compounds, PAHs) are probably coal-derived. PAHs represented the group of organic compounds most commonly observed. Concentrations of total PAHs ranged up to 23 µg/L. Concentrations of individual compounds ranged from about 18 to <0.01 µg/L. Temporal variability of organic compound concentrations was documented, as two wells with relatively high organic compound contents in produced water in 2001 had much lower concentrations in 2002.</p> <p>In many areas, including the Powder River Basin, coal strata provide aquifers for drinking water wells. Organic compounds observed in produced water are also</p>

Project characteristics	Details
	likely present in drinking water supplied from wells in the coal. Some of the organic compounds identified in the produced water samples are potentially toxic, but at the levels measured in these samples are unlikely to have acute health effects. The human health effects of low-level, chronic exposure to coal-derived organic compounds in drinking water are currently unknown. Continuing studies will evaluate possible toxic effects from low level, chronic exposure to coal-derived organic compounds in drinking water supplies.
Outputs	< http://pubs.er.usgs.gov/publication/70029891 > < http://pubs.usgs.gov/fs/2009/3096/pdf/fs2009-3096.pdf >
Key personnel	William Orem, U.S. Geological Survey
Research themes	Coal seam gas; produced water; quality of drinking water supplies; Powder River Basin

Table 4.53 Project 53: An independent review of coalbed methane related water well complaints filed with Alberta Environment

Project characteristics	Details
Project title	An independent review of coalbed methane related water well complaints filed with Alberta Environment
Project location	Alberta, Canada
Principal investigator	Dr. Alexander Blyth
Lead institution	Alberta Research Council
Project budget	Not available
Source of funding	Alberta Environment
Project duration	Not available
Current status	Complete, published 16 January 2008
Project summary	<p>Alberta Research Council (ARC) was contracted by Alberta Environment (AENV) to conduct four reviews of complaints about coalbed methane (CBM) activities affecting private water wells.</p> <p>All the water well complaints reviewed by ARC were water quality related. Specific water quality complaints included:</p> <ul style="list-style-type: none"> • livestock refusing water • methane gas in water • increased methane gas in water (pipes banging and taps "spurting" more) • mineral and bacteria deposits in well and plumbing system <p>ARC used several lines of evidence to evaluate the water well complaints, including:</p> <ul style="list-style-type: none"> • local and regional geology and hydrogeology • surrounding energy well information • water well construction and maintenance • major ion chemistry • dissolved organic chemistry • free gas composition and carbon isotope geochemistry
Objectives	ARC undertook these reviews for AENV to independently assess the scientific evidence and provide conclusions identifying whether or not the water wells had been impacted by CBM extraction activities.
Achievements	The ARC's overall conclusion of the evidence from the reviews of the AENV and AEUB files, along with a new review and evaluation of additional data and aspects, is that energy development projects in the areas most likely have not adversely affected the complainant water wells.
Outputs	< http://www.environment.gov.ab.ca/info/posting.asp?assetid=8136&categoryid=5 >
Key personnel	Alec Blyth, ARC
Research themes	Coal seam gas; quality and quantity of water supplies; well integrity; aquifer interconnectivity; public complaints

Table 4.54 Project 54: Coalbed methane/ natural gas in coal

Project characteristics	Details
Project title	Coalbed methane/natural gas in coal
Project location	Alberta, Canada
Principal investigator	The CBM/NGC Multi-Stakeholder Advisory Committee (MAC)
Lead institution	The CBM/NGC Multi-Stakeholder Advisory Committee (MAC)
Project budget	Not available
Source of funding	Not available
Project duration	2003 - 2009
Current status	Complete
Project summary	<p>MAC was originally formed in November 2003 as part of a review and consultation initiated by the Department of Energy (DOE) to address public concerns associated with coalbed methane (CBM) development in Alberta. The MAC's Final Report, released to the public in May 2006, contained 44 recommendations to improve existing rules and regulations related to CBM development in Alberta and identified areas for further study.</p> <p>A multi-stakeholder group, the MAC II was formed in September 2006 in response to a Final Report recommendation for annual reviews for three years to assess progress on the recommendations. MAC II stakeholder membership was identical to the MAC although individual stakeholders may differ.</p> <p>In December 2009 the MAC II concluded with the release of the third and last annual progress update report on recommendations made to the Alberta government to help ensure the safe and responsible development of coalbed methane in the province.</p>
Objectives	<p>The purpose of the MAC is to:</p> <ul style="list-style-type: none"> • guide the consultation process, including the development of a consultation framework to ensure issues are adequately addressed • determine the specific CBM/NGC issues to be addressed • coordinate, consolidate, evaluate and submit recommendations to the government
Achievements	<p>In 2004 about 90 percent of the 3575 CBM/NGC wells drilled in Alberta and about the same percentage of CBM/NGC wells with production were in the dry coal seams of the Horseshoe Canyon/Belly River coals. These dry coal seams are extremely under-pressured and are usually not connected to any underground water source; consequently, they produce little or no water. The remaining CBM/NGC wells in Alberta as at December 2004 mainly targeted seams that usually contain water. These coals are more normally pressured and may be wet – saturated with saline or non-saline water – and are sometimes used as a source of water supply.</p> <p>The MAC concluded that the continuing protection of aquifers, water bodies and non-saline water users by the provincial government is critical for the appropriate development of CBM/NGC, especially in coal zones containing non-saline groundwater. The MAC found that the risk to non-saline groundwater from deeper</p>

Project characteristics	Details
	<p>saline CBM/NGC and intermediate dry CBM/NGC development was low, but additional care and study are still required.</p> <p>As of 15 August 2009, progress has been made on all 42 accepted recommendations from the 206 MAC Final Report, including all nine recommendations that had been identified as early action items. A total of 29 recommendations had been completed, six were on schedule, six were behind schedule and one was reviewed and not actioned. Several of the outstanding recommendations were scheduled for completion by the end of 2009, but no further publication in relation to this was available.</p> <p>Outcome of MAC recommendations [Alberta Environment]:</p> <ul style="list-style-type: none"> • baseline water well testing, from 2006 • groundwater monitoring –gas and water sampling in existing monitoring network and 16 new monitoring wells in CBM area • guidelines for Groundwater Diversion for Coalbed Methane/Natural Gas in Coal Development, 2004, to be updated • partnered with Alberta Geological Survey –groundwater mapping in Edmonton-Calgary corridor (main CBM area) • study, Potential for Gas Migration Due to Coalbed Methane Development, March 2009. <p>Outcome of MAC recommendations [Energy Resources Conservation Board]:</p> <ul style="list-style-type: none"> • Bulletin 2007-10: updates Alberta's Base of Groundwater Protection Information • Directive 27 –on shallow fracturing operations, 2006 <ul style="list-style-type: none"> – Limitation on fracturing at less than 200 metres deep – Set up technical review committee to learn more about shallow fracturing – Directive updated in 2009, with increase in restrictions to protect adjacent water wells • Directive 35 –implements Alberta Environment standard for baseline water well testing, 2006 • Directive 36 – updated in 2006 to prohibit use of oil-based or potentially toxic substances when drilling wells above base of groundwater protection, 2006 • Directive 43 – requires industry to conduct shallow logging to provide additional information for groundwater mapping, 2006 • Directive 44 – requires reporting and analysis of water produced in oil and gas wells completed above base of groundwater protection, 2006 • report: Risk to water wells of pathogens in drilling fluids, 2009 (see research summary Risk to water wells of pathogens in drilling fluids below) • ERCB/Alberta Geological Survey Open File Report, 2009-16 into natural hydraulic pathways between two shallow geological formations and the implications for CBM production.
Outputs	<p><http://www.energy.gov.ab.ca/NaturalGas/Gas_Pdfs/MACFinalReportJan06.pdf> <http://www.energy.gov.ab.ca/NaturalGas/1239.asp></p>
Key personnel	List of MAC members provided in appendices of each output report.
Research themes	Coal seam gas; hydraulic fracturing; quality and reliability of irrigation and drinking water supplies; aquifer interconnectivity; integrity of wells; regulatory requirements

Table 4.55 Project 55: Risk to water wells of pathogens in drilling fluids

Project characteristics	Details
Project title	Risk to water wells of pathogens in drilling fluids
Project location	Alberta, Canada
Principal investigator	Dr Abimbola Abiola and Dr Cathryn Ryan
Lead institution	Olds College and University of Calgary
Project budget	Not available
Source of funding	Energy Resources Conservation Board
Project duration	Not available
Current status	Published 2009
Project summary	In response to MAC recommendations (see project Coalbed Methane/ Natural Gas in Coal above), the ERCB retained the third-party expertise of Dr. Abimbola Abiola, microbiologist from Olds College, and Dr. Cathryn Ryan, hydrogeologist from the University of Calgary, to prepare a report on the abundance of pathogens in surface waters and evaluate whether pathogens in surface waters that are used in drilling fluids in Alberta have the ability to survive in or be transported through a groundwater system and to report their findings. The report is a professional opinion based on an extensive review of literature and professional experience.
Objectives	To prepare a report on the abundance of pathogens in surface waters and evaluate whether pathogens in surface waters that are used in drilling fluids in Alberta have the ability to survive in or be transported through a groundwater system and to report their findings.
Achievements	A summary of the key findings presented in their report is as follows: <ul style="list-style-type: none"> • The subsurface presents a hostile environment to surface water pathogens given its lower temperatures, lower oxygen levels, and fewer nutrients. • Pathogens can be introduced into surface waters through animal wastes, sewage, and industrial or agricultural effluents. • The types of pathogens typically found in Alberta surface waters are unlikely to survive the salt levels found in nontoxic drilling fluids. • Pathogen transport into the subsurface is unlikely, even over short distances, due to the typically low infiltration distance of drilling fluids from the wellbore.
Outputs	< https://ercb.andornot.com/Record/ERCB32559 > < http://groundwork.iogcc.org/topics-index/hydraulic-fracturing/topic-resources/risk-to-water-wells-of-pathogens-in-drilling-fluid >
Key personnel	Energy Resources Conservation Board 1-403-297-8311 infoservices@ercb.ca
Research themes	Coal seam gas; Quality and reliability of irrigation and drinking water supplies; Aquifer interconnectivity; Pathogens

Appendix A - Project contacts

Where appropriate, key personnel from research institutions were contacted and asked to provide additional information on specific research projects or programs. Where this information was provided, it has been included in the research profiles in Section 4. Table A1 summarises the contacted personnel.

Table B1 Contacted personnel

Country	Research institution	Contact name	Response received
Australia	The University of Queensland; Sustainable Minerals Institute	Alistair Innes-Walker Prof Chris Moran Dr Sue Vink	Yes
Australia	University of New South Wales; School of Mining Engineering	Dr Wendy Timms	Yes
Australia	CSIRO; Earth Science and Resource Engineering	Dr Sunil Varma	Yes
Australia	CSIRO; Petroleum	Dr Reem Freij-Ayoub	
Australia	University of Southern Queensland; Faculty of Engineering and Surveying	Prof Steven Raine	No
Australia	NSW Department of Trade and Investment, Regional Infrastructure and Services	Steve Cozens	Yes
Australia	Geoscience Australia; Environmental Geoscience Division	Kriton Glenn, Ph.D	Yes
Australia	Queensland University of Technology; School of Earth, Environmental & Biological Sciences,	Prof Mal Cox Dr Maree Corkeron	Yes
Australia	Curtin University; Australian Sustainable Development Institute, Department of Petroleum Engineering Oil & Gas Research Portal, and Water Quality Research Centre	Kelly Pilgrim-Byrne, Prof Prof Brian Evans, Jeff Charrois	Yes – no relevant research
Australia	University of Newcastle; School of Engineering	Prof Garry Willgoose Prof Stephen Fityus	No
Australia	Healthy Headwaters CSG Water Feasibility Study	Angus Veitch	Yes
Australia	Queensland Water Commission	Sanjeev Pandey	No
Australia	Fenner School of Environment and Society	Public access request	No
US	University of Wyoming; Carbon Management Institute	Scott A. Quillinan P.G.	Yes
US	Virginia Tech; Powell River Project	Carl Zipper	Yes

Country	Research institution	Contact name	Response received
US	University of Wyoming; College of Agriculture and Natural Resources, Department of Renewable Resources	Prof K J Reddy	Yes
US	Wyoming State Geological Survey	Jim Rodgers	No
US	Geological Survey of Alabama	Jack Pashin, Ph.D.	No
US	US Geological Survey	Richard W. Healy	No
US	US Geological Survey	Zack Bowen	Yes
US	US Geological Survey	William Orem	Yes
US	US Geological Survey	Mark Engle, Ph.D	Yes
US	Office of Research Development, US EPA	Dayna Gibbons	Yes
US	National Research Council, The National Academies	Public access request	Yes
US	Groundwater Protection Council	Public access request	No
Canada	Alberta Environment & Sustainable Resource Development	Richard Casey	Yes
Canada	Alberta Environment & Sustainable Resource Development	Curtis Brock	No
Canada	University of British Columbia; Department of Chemistry	William R. Cullen	Yes