

THE ENVIRONMENTAL CONCERNS OF COAL SEAM GAS EXPLORATION IN AUSTRALIA-LESSONS LEARNED

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ABSTRACT

BACKGROUND: Both South Africa and Australia (as well as other countries) have vast reserves of methane gas trapped either in coal or shales up to 1 km or more below the surface. Some of these seams are not pervious (tight gas) and need to be fraced (fracturing is also used) to release the gas. This is a process where high pressure water, sand and fracturing fluids are injected into the wells to open up the coal or shale to release the gas. Unfortunately in most instances because of the depth of the gas it is at a level where groundwater is present which has to be pumped down to a level where the gas can be release to the surface.

ISSUES: The method for fracturing because of previous bad publicity has raised the following concerns from the farming community:

- a possible reduction in available groundwater for farming activities
- the fracturing fluids used might contaminate the available groundwater or aquifers, making it unfit for farming activities
- as most of these produced waters contain dissolved solids because of the coal or shale from which it has been released from, it has to be treated with high cost systems such as Reverse Osmosis (RO) to enable it to be reused for farming activities or released in streams.

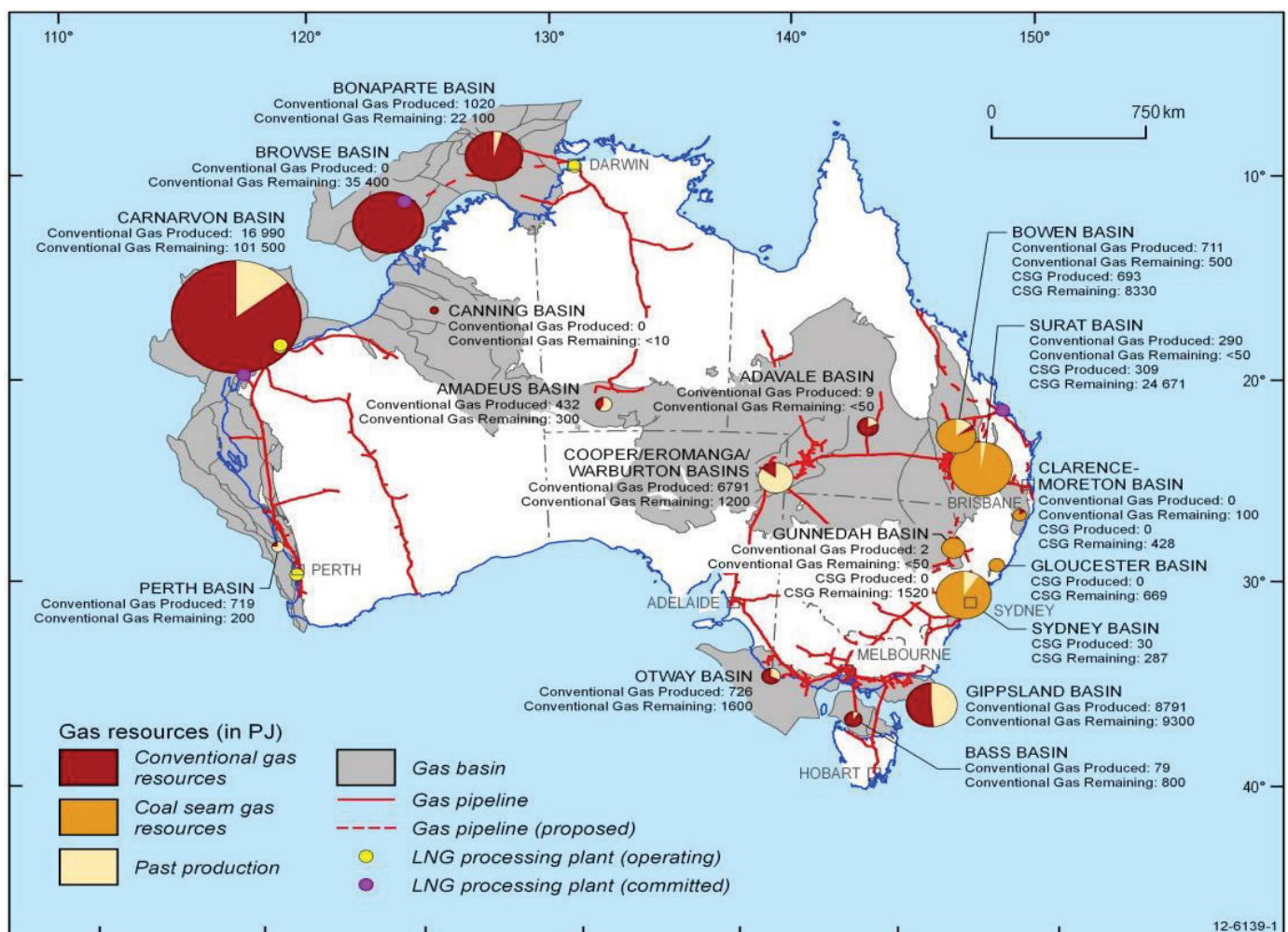
AUSTRALIAN LEGISLATION: The Australian legislation calls for the removal of dissolved solids to a level that is environmentally acceptable before it can be released. It also calls for containment of all salts removed from the RO process as it cannot be released into the environment. This is termed a Zero Liquid Discharge (ZLD) and salt formation from the brine released by the RO process is extremely expensive and special equipment has to be used.

CONCLUSION: It takes huge investments from gas companies to take the Governments and the community along the journey and prove conclusively that this type of development does not have an adverse impact on the environment.

THE ISSUE

Coal and shale seam gas reserves are likely to make a major contribution to future energy needs. However, the new technology for exploiting these reserves, termed hydraulic fracturing or fracturing raises several environmental issues. Australia and South Africa has significant exploitable reserves of natural gas from coals and shale seams, primarily located in the coal basins in QLD and NSW (Australia) but with production potential in most states and territories. Commercial production commenced in Australia in 1996 with slow production growth for its first decade. As with the development of other extractive resource industries, the sustainable development of the sector requires balanced consideration of

FIGURE 1 Location of Australia's gas resources and infrastructure (RET et al, 2012)



its environmental, social and economic impacts, benefits and costs. Activities associated with the development of natural gas from coal seams will affect the environments in which it occurs. Potential environmental issues such as groundwater depletion, produced water management, surface disruption from activities associated with the drilling of wells and the construction of pipelines, and chemical use associated with well drilling and hydraulic fracturing must be managed to minimise environmental impacts.

Australian governments are focused on achieving a balance between developing a world-class industry, protecting the environment, water resources and human health while delivering opportunities and benefits to the Australian community. It is the responsibility of governments to understand and address both the risks and community perceptions involved in the development of natural gas from coal and shale seams and adopt positions that address and respond equally to these risks and perceptions. Governments should aim to provide policies and regulations that encourage the growth of the industry within a regime of relevant, enforced conditions and legislation to protect the environment, human health and facilitate social development and sustainability.

WHAT IS FRACTURING

The methane, formed both by biogenic processes as well as the thermal decomposition of organics, becomes trapped within the high surface area pore networks within the coal. The recovery process involves drilling typically up to 1000 m (and deeper, e.g. 2000 m for shale gas) to locate naturally occurring fractures within the formation and increasing the porosity within the formation to provide conduits for gas migration.

Hydraulic fracturing has been widely used in Australia for more than 40 years to increase the rate and amount of oil and gas extracted from reservoirs. The process of hydraulic fracturing is applied to a minority of operations in Australia.

A sound understanding of the geology, hydrology, hydrogeology and geomechanics is essential to plan the fracturing process and ensure fracture stimulation activities are conducted in a safe manner that protects communities, the environment and water resources. Baseline and ongoing monitoring underpin evidence-based decision-making which ensures that actions taken by regulators and operators on hydraulic fracturing are accountable and enduring.

Hydraulic fracturing is also known as fracture stimulation, fracking or fracking. Hydraulic fracturing is the process through which fractures are produced in geological formations. Most commonly, a fluid made up of water, sand and additives is injected under high pressure through a perforated cased well into a geological formation. The pressure caused by

the fluid injection under pressure creates fractures in the coal or shale seam where the well is perforated.

For a vertical well treatment, a fracture might typically extend to a distance between 20 and 250 metres from the well. The fractures grow slowly; for example the initial average velocity may be less than 10 metres per minute and slow to less than 1 metre per minute at the end of the treatment. The 'proppant' in the hydraulic fracturing fluid acts to keep the fracture open after injection stops, and forms a conductive channel in the coal through which the water and gas can travel back to the well. After the fracturing is complete, the majority of the hydraulic fracturing fluid is brought back to the surface over time and treated before being reused or disposed of in accordance with the regulations applying in that jurisdiction. Well integrity standards include arrangements for hydraulic fracturing and are the key mechanism for managing potential impacts. The impacts that arise generally relate to potential aquifer interconnectivity, intersection of induced fractures with existing faults/fractures and/or existing wells, and the potential for chemical contamination.

Prior to obtaining an authorisation to undertake hydraulic fracturing activities, legislation requires operators to:

- provide details of their proposed hydraulic fracturing operations including the location of wells
- detail the chemicals to be used and the toxicity of ingredients and mixtures
- develop a risk assessment that must be carried out for any well prior to it being hydraulically fractured to ensure that the activity is managed to prevent environmental harm.

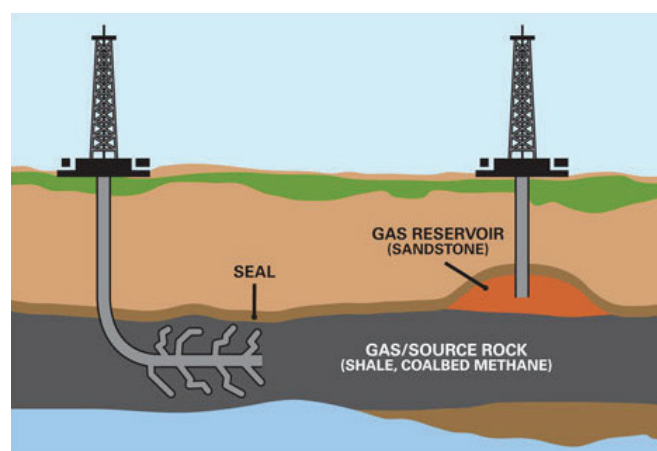
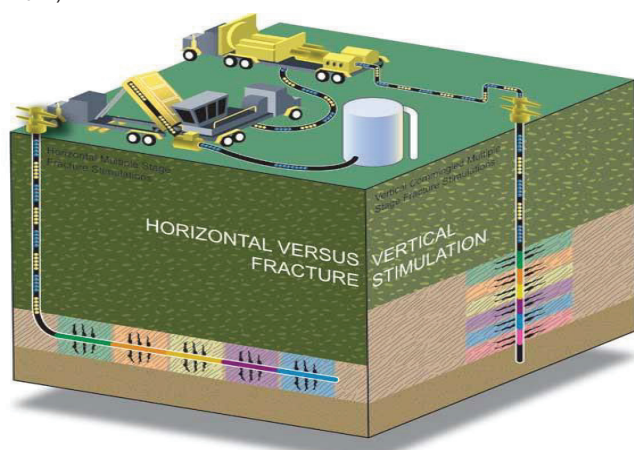


FIGURE 3 Schematic diagram of the differences between Unconventional and Conventional gas extraction

Some commonly-used chemical additives and their uses in hydraulic fracturing fluids include:

- gelling agents (commonly guar gum), cross-linkers, and flocculants – additives used to increase the viscosity of the fracturing fluid as it is pumped under pressure into the crack and joints in the coal, to allow more proppant to be carried into fractures
- breakers – which dissolve the hydraulic fracturing gels such as guar gum so that the fractures can transmit water and gas to the well
- friction reducers and clay controllers – chemicals used to reduce any friction between the fracturing fluid and the bore casing and to control any swelling in clay
- bactericides – such as sodium hypochlorite and sodium hydroxide, which are used to control the introduction of outside bacteria to the coal seam which may restrict gas flow to the well
- surfactants – such as ethanol and the cleaning agent orange oil, which are used to increase fluid recovery from the fracture

FIGURE 2 Schematic diagram of the hydraulic fracturing process (June et al 2012)



- scale and corrosion inhibitors and iron controllers – to prevent the build of scale and rust in the bore
- acids and alkalis – acids injected to dissolve calcite from within the natural cracks and joints in the coal before the fracturing fluids are injected and to balance the acidity of the hydraulic fracturing fluid; and
- monitoring isotopes – isotopes occasionally used to monitor the growth of the fractures in the coal seam.

INFLUENCE ON THE COMMUNITY

Coal seam gas reserves represent a major contribution to energy needs, however, gas recovery by hydraulic fracturing (fracking or fraccing), requires careful management to minimise any possible environmental effects. Although the industry is adapting where possible to more benign fracking chemicals, there is still a lack of information on exposure to natural and added chemicals, and their fate and ecotoxicity in both the discharged produced and flow-back waters. Geogenic contaminants mobilised from the coal seams during fracking may add to the mixture of chemicals with the potential to affect both ground and surface water quality.

The potential impact of developments to extract natural gas from coal seams has on groundwater resources is a significant source of community concern. The issues that arise can be broadly categorised as depletion and contamination of water resources, each of which could affect existing groundwater users, inter-aquifer connectivity, groundwater to surface water interactions and groundwater-dependent ecosystems. The responsible management and use of chemicals in operations associated with the production of natural gas from coal seams and potential human health and environmental impacts are key concerns for many communities and a high priority for governments and industry. Industry has developed and continues to research environmentally benign chemicals and formulations for use in operations. Governments are working with industry to better understand potential impacts on human health and the environment through the national chemical assessment process.



FIGURE 4 Community protests against fracturing

- In Australia communities have responded with (See Figure 4):
- Guerrilla style protests
 - Coordinated grass root groups
 - Savvy, well resourced media campaigns and websites, for example:
 - Australia – Lock the Gate Alliance lockthegate.org.au
 - Britain – Frack Off frack-off.org.uk and No Dash for Gas nodashforgas.org.uk
 - Canada – Stop Fracking Ontario stopfrackingontario.wordpress.com
 - USA – Americans Against Fracking americansagainstfracking.org and Food and Water Watch foodandwaterwatch.org
 - Global Frackdown – globalfrackdown.org

Thus like other locations, community concerns around fracking in Queensland and NSW has led to:

- the formation of lobby groups and ongoing activities
- community legal action
- extensive campaigns involving TV, radio, internet, rallies, letter box drops
- concerts
- landowners blocking land
- calls for an investigations into the impacts of fracking and CSG.

Surveys completed in Australia for the Centre for Coal Seam Gas (CSG) found that of 1007 respondents:

- people lack knowledge of CSG but were interested in finding out more
- those who knew a lot about CSG were likely to indicate that it was having a positive impact on the State, those who knew a little indicated that CSG was having a negative impact
- people's perceptions were guided by stories in the media rather than balanced factual information
- despite the lack of knowledge people were not confident that the environmental impacts of CSG were well managed, regulated and understood.

The growth of fracking and the CSG industry has led to the establishment of regulations around:

- land access
- social impact management and engagement
- housing
- strategic cropping land
- CSG water management.

The government has undertaken a number of initiatives including:

- undertaking extensive community road shows and meetings
- creating a CSG Enforcement Unit
- establishing a Gasfields Commission and community reference groups
- establishing a Land Access Implementation Committee
- deploying technical specialists to directly liaise with communities
- senate hearings
- independent expert scientific committees.

ENVIRONMENTAL ISSUES

The selection of a CSG water beneficial use route or disposal route is largely dependent on the proximity of the CSG producer to disposal or beneficial use locations, the cost and complexity of the treatment process (if required) and whether or not water from several producers or sites. The production of coal seam gas (CSG) involves the pumping of water from coal formations to reduce water pressure and release the gas. This can affect overlying and underlying aquifers because of interconnectivity between the formations. A regional groundwater flow model was constructed to predict the impacts of current and planned CSG development on water pressures in aquifers.

As with any large mining or industrial operation, consideration needs to be given to the environmental effects of fracking. The number of hydraulic fracturing products is not trivial. It has been suggested that in the US, between 2005 and 2009, oil and gas service companies used more than 2 500 products containing some 750 chemicals (US House of Representatives Committee 2011). The number used in coal seam gas fracking is considerably less, and in Australia, the Australian Petroleum Production and Exploration Association Limited recently released a list of 45 chemicals that supposedly comprised for that time, 'all chemicals used in Australian coal seam gas fracking fluids' (Australian Petroleum production and Exploration Association Ltd 2010).

In Australia, regulatory agencies can require companies to provide details of proprietary chemicals used in fracking, and as a consequence many coal seam gas companies have proactively listed such chemicals



(and Material Safety Data Sheets MSDSs) in some cases) on their websites. Data are also available in publically available EICs. A listing of commonly used fracking chemicals from these sources is as discussed previously, however their use is rapidly changing with a view to choosing more environmentally friendly chemicals.

The detection of benzene in discharge waters has led to bans on the use of BTEX compounds (benzene, toluene, ethylbenzene and xylenes) in fracking fluids. Other geogenic contaminants include metals and radionuclides (Cheung et al 2009, Rice et al 2000). Ecologically Sustainable Development (ESD) is widely used in state and federal legislation that regulates activities such as mining and environmental impacts. ESD aims to balance the environmental, economic and social costs and benefits of a proposed activity. However, the appropriate balance can be difficult to achieve when there is uncertainty about the costs and benefits of particular developments.

Risk management is a necessary addition to the precautionary principle. The application of the precautionary principle should be a proportionate and reasonable response to:

- the level of potential impact (e.g. the principle is most applicable to potential catastrophic or irreversible harm)
- the likelihood of a potential impact occurring (is the risk plausible and reasonably likely to occur)
- the costs of regulatory action, and the opportunity cost of not proceeding.

Environmental legislation provides a robust mechanism to manage projects at the state and federal level. The three LNG projects currently under construction in QLD have approximately 1 000 state conditions and more than 300 federal conditions each.

LEGISLATION

In Australia all underground assets such as coal, gas, gold etc. is owned by the Government and not the farmer. Also most of the CSG field are below some of the most productive farms in Australia which makes it difficult to explore for gas whilst not be detrimental to the farming operations.

Under the Queensland regulatory framework, petroleum and gas tenure holders have rights and responsibilities in relation to the extraction of groundwater in the process of producing petroleum and gas. These responsibilities are to 'make good' impairment of private groundwater supplies caused by the water extraction activities and to carry out monitoring and other management activities.

In practice, different approaches to the management of produced water operate in Australia although natural gas from coals seams is currently only produced in QLD and NSW. There are moves in NSW, VIC and SA to ensure that the extraction of water during petroleum operations is incorporated into water resource planning mechanisms, often by licensing the use of water through the allocation of water entitlements within a planning regime to ensure the sustainable management of Australia's water resources.

Australia's existing development planning framework requires environmental impact approvals from the relevant state or territory and under Commonwealth legislation if they impact on matters of national environmental significance.

For operations, the regulator should ensure that the environmental impact assessment process includes consideration of:

- drilling operations which includes water resource protection, noise management and dust minimisation
- potential impacts of operations to extract natural gas from coal seams on the hydrogeological environment (ideally through a numerical groundwater flow model developed with consideration of the Australian Groundwater Modelling Guidelines - subject to peer review and independent audit) and provide for ongoing monitoring to determine any changes that may impact existing users and the environment

- the requirements for ongoing monitoring, evaluation, and reporting of hydraulic fracturing activities including the use of chemicals (storage, handling, processing, transport, and disposal) with respect to potential human health or environmental impacts
- the implementation of impact mitigation controls and compliance with relevant legislation, standards, and codes of practice as part of the operation.

Queensland (Qld) stipulates that operators are required to undertake a risk assessment to identify the risks that may occur during well construction, operation and abandonment within the state's Code of Practice for Constructing and Abandoning Coal Seam Gas Wells. As previously mentioned, applications for site specific activities in Qld must provide the following information: the quantity of water that is expected to be produced; the flow rate at which the water is expected to be produced; the quality of the water; and the proposed management strategies (in accordance with the Coal Seam Gas Water Management Policy 2012).

This information is collectively known as the water management plan. Operators are also required under the Water Act 2000 to undertake baseline monitoring, spring surveys where applicable, and prepare and submit an underground water impact report which includes a water management strategy and spring impact management strategy.

NSW has similar requirements as part of its Aquifer Interference Policy, which requires applicants to address potential water impacts (including aquifer compaction, deterioration of ambient water quality and significant soil erosion). In all jurisdictions, the management of risks associated with chemicals used in activities to extract natural gas from coal seams is stipulated in safety management plan requirements through both the environmental management plan requirements and health and safety legislation.

Australia's legislative approach to well integrity has been developed from extensive experience in onshore and offshore oil and gas production. It is based on international best practice for well design, construction, maintenance and rehabilitation.

WATER TREATMENT AND DISPOSAL

Water and salt management are major issues associated with coal seam gas production (ALL Consulting 2003). The water pumped into wells (0.2–0.6 ML per well) for hydraulic fracturing returns to the surface as the pressure is reduced (Rutovitz et al 2011). The chemistry of this water is altered as it interacts with the coal seam minerals. In addition, there is water associated with the coal deposits that becomes mobilised as part of the drilling operation. This is generally termed produced water or formation water. It is typically quite saline as well as containing other constituents, both inorganic and organic, of the minerals and coal with which it has been associated in the deposits.

The water used in fracking mixes with produced water during the fracking process, with the composition gradually becoming more characteristic of the produced water. The industry typically refers to 'flow-back water' as the water produced within a few days of the fracking, and 'produced water' after that, even though it may still have characteristics of both types of water. Volumes of produced water can be up to 100 kL day per well, but this typically diminishes over the lifetime of a well which may be as long as 10 years (Refer to Figure 5).

Natural gas is held in coal seams by water pressure. As water is pumped from the coal seams (a process called depressurisation), the pressure is lowered and the gas is released. As water pressure is reduced, gas flow increases and water flow rates decrease from each well, typically to around a quarter to a third of the initial flow over a period of a few months to a few years, depending on the hydrogeological conditions of the seam.

The volume of produced water extracted from each well can vary considerably between wells and regions. The quality of produced water also varies significantly, from near potable to brackish (moderately saline).

Typically, produced water is of a quality that significantly restricts its potential use or disposal unless treated.

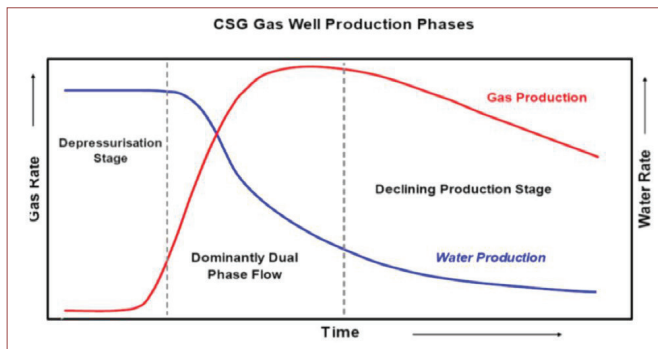


FIGURE 5 Typical gas and water flow in production of natural gas from coal seams (QWC 2012b)

The development of natural gas from coal seams and associated potential impacts on groundwater resources is a significant source of community concern. The issues that arise can be broadly categorised as depletion and contamination of water resources, each of which could affect existing groundwater users; inter-aquifer connectivity; groundwater to surface water interactions; and groundwater-dependent ecosystems.

The key inter-related issues for water management are associated with:

- depressurisation of coal seams potentially affecting surrounding aquifers
- contamination of surface water or groundwater
- management (recovery, storage, transport, treatment and disposal) of produced water and post-treatment wastes and by-products
- beneficial use of produced water (including reinjection)
- safe decommissioning of wells ensuring long-term aquifer integrity.

In addition to lowering groundwater pressures and water levels in bores, the large-scale depressurisation of the coal seams has the potential to release gas into water bores that have been drilled through the coal seams. However, in many cases the water bores tend to be relatively shallow (that is, less than 100 metres) compared to wells, which will limit the

potential for gas migration into water bores. In Australia, the CSG Water Management Policy encourages the beneficial use of recycled produced water as a preferred management option. Beneficial uses of treated produced water identified include substitution for water for existing irrigation schemes, new irrigation use, with a focus on sustainable irrigation projects, livestock watering and release to the environment in a manner that improves local environmental values.

In NSW, the Aquifer Interference Policy outlines preferred disposal options to include reinjection to an aquifer, discharge to a river, on-selling to a nearby industry, agricultural development or potable water supply. Any option requires treatment of produced water to an appropriate water quality standard to have minimal impact on any proposed receiving land and waters. Consideration must also be given to pollution issues, which are regulated under the Protection of the Environment Operations Act 1997 (NSW). In a change from past practices, jurisdictions with the most significant developments have moved to either completely ban or prevent the use of evaporation dams unless there is no feasible alternative. In addition to removing the risk of spills or uncontrolled discharges in the event of flooding, the policy is directed toward maximising the potential beneficial use of produced water and minimising the impact of the production of natural gas from coal seams on other water users in the short and long term.

Water quality from CSG dewatering:

- typically TDS values 1 200 mg/l to 10 000 mg/l
- typically high Sodium, Bi carbonate, carbonate and chloride ions
- high Alkalinity and pH

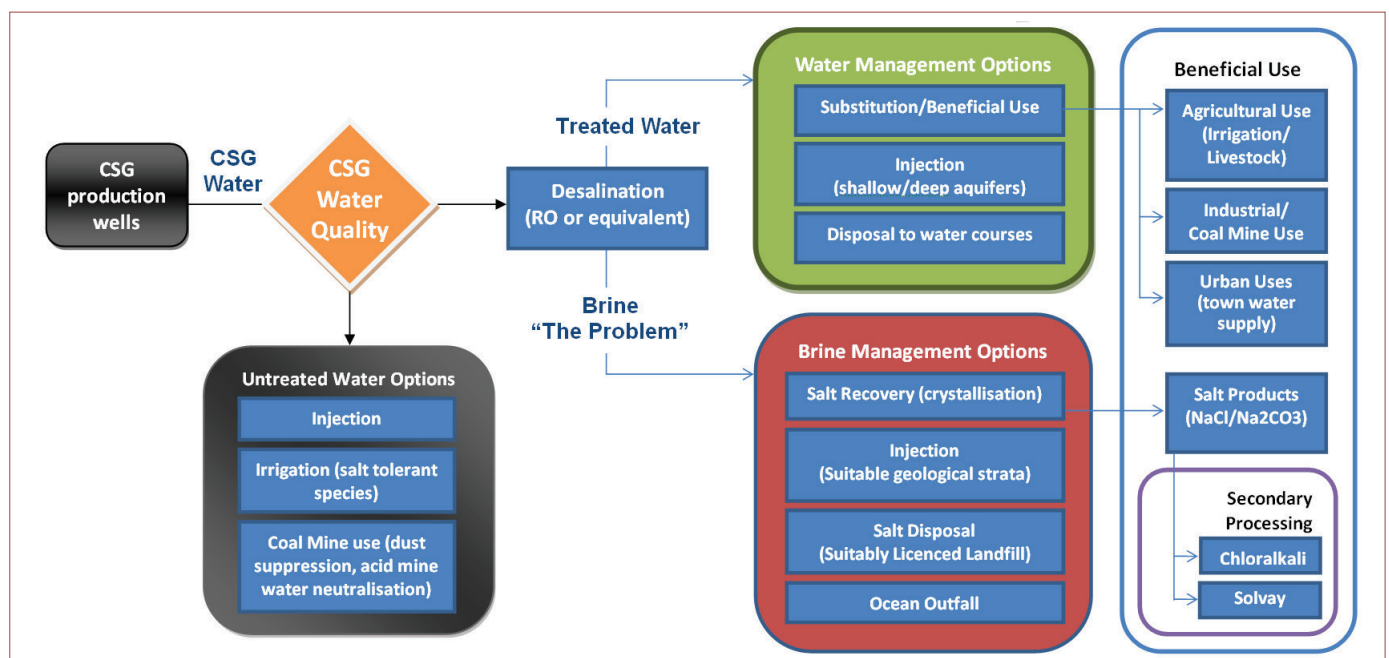
Significant species:

- Cations – K, Ca, Mg, B, Sr, Ba
- Anions – SiO₂, F, Br
- High Sodium Adsorption ratio

What can be produced from these ions:

- Sodium Chloride
- Sodium Carbonate
- Sodium Bicarbonate
- Calcium Carbonate
- Magnesium Carbonate, Magnesium Hydroxide

FIGURE 6 Conceptual CSG water management strategy



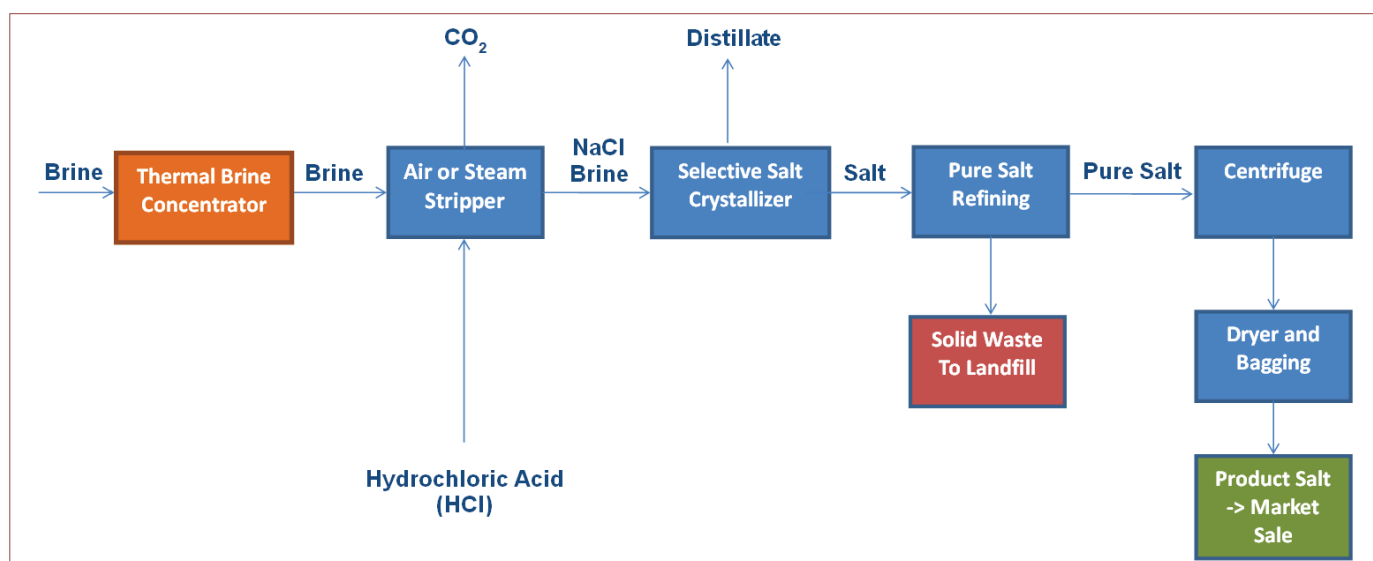


FIGURE 7 Salt recovery facility using enhanced selective crystallization for NaCl recovery—process flow diagram.

- Smaller quantities, Strontium sulphate, strontium carbonate, barium sulphate etc.

Beneficial use of the treated water:

- Aquaculture
- Coal washing
- Dust suppression
- Industrial use
- Irrigation
- Livestock watering

Specific application for water is available under the Environmental Protection (Waste Management) Regulation 2000. Specific application required for Potable/Public water supply. Also RO permeate for Flood Clean-up.

Need to manage excess, produced or associated water implies managing both the “pure” water itself and dissolved ions (salts) it contains. Tendency to focus on the immediate problem, water first and then think about how to manage the salts. Almost always Reverse Osmosis is required to treat the produced water (potentially EDR can also be used, but generally salinity too low for economic thermal desalination as first step). Partial treatment and blending may be an option (See Figure 6).

Reverse Osmosis is a predictable process provided constant feed conditions are achieved. Pre-treatment is a critical design issue. Probable a need exist for up front buffering /storage to aid consistency. There will a brine stream to be managed (See Figure 7).

Several Possibilities to manage the brine stream:

- disposal as brine (to ocean)
- use as brine (feedstock)
- irrigate low salinity or blended
- injection where no detrimental impact
- deep well where containment can be assured
- blend and inject into aquifer.

The range of possible products increased if additional chemicals added. The top minimisation technologies in terms of cost-effectiveness and robustness include enhanced recovery reverse osmosis, solar evaporation ponds and mechanical evaporation/crystallisation. The recovery of salt and deep well injection appears to be the front runners in terms of providing a sustainable and cost-effective disposal route for brine. Brine injection may be accomplished by injecting into deep wells in the immediate vicinity of the CSG production area, injection into the coal seams

from where the associated water originated and/or piping of brine to distant aquifers or depleted gas fields. Salt recovery of sodium carbonate/bicarbonate salts and/or sodium chloride may be undertaken via various means, with the most likely method incorporating mechanical vapour compression evaporation and crystallisation.

CONCLUSION

It can be concluded that although technical feasible to conduct environmentally sensitive fracturing (depend on specific site conditions) it is the community that has to be convinced that the fracturing process can be done without any detriment to their farms, houses and ground water assets. This is a long and protracted journey and takes several years to be resolved to the satisfaction of all parties involved. From an Australian perspective it only works if the community and possibly the Government are taken along the journey from the start as all minerals and metals below the surface belongs to the Governments and not to the land owners.

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