Environmental, Social and Economic Issues Associated with Coal Seam Methane (CSM) Extraction & Power Generation.

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Australia's untapped reserves of potential coal seam methane beds and the need for a cleaner form of power generation have resulted in numerous gas exploration projects in Australia (Department of Infrastructure and Planning, 2008). But before the energy industry delves head first into a new technology, it must be asked whether there are any negative impacts associated with coal seam methane (CSM).

Numerous social, economic and environmental issues have arisen due to coal seam methane on an international basis (West Coast Environmental Law, 2003: McBeth, *et al,* 2003: Australian Government, 2008: NRW, 2006). These include an average decrease in property prices of 22% (BBC Research and Consulting, 2001), the introduction of harmful chemicals into water sources, causing health problems such as leukaemia, liver and kidney problems, sensory organ and gastrointestinal track problems (Colborn, 2008: Fischer and Bidwell, n.d.) and product water negatively impacting crops (NRW, 2006: Sessoms, *et al.,* 2002: CSIRO, 2006). The use of the product water for farming irrigation purposes can lead to increased runoff, soil erosion and possibly contaminate nearby streams with pesticides, fertilizers and excess nutrients with the potential to cause fishkills (NRW, 2006: Mongillo and Zierdt-Warshaw, 2000).

Regions in Australia that are currently extracting coal seam methane include the Bowen and Surat Basins in Queensland and the Bulga and Wollombi regions in the Hunter Valley of New South Wales (Australian Government, 2008). This study was designed to determine the degrading impacts that coal seam methane would have on Australian farmers' soils. An emphasis was placed on the social and economical impacts that Australian farmers in coal seam methane regions would be subjected to, including compensation, land rights issues, loss of income and a general decrease in quality of life.

*1.0 What is Coal Seam Methane and how is it produced***?**

Methane is a naturally occurring gas (chemical formula of CH_4) that is utilised as a fuel for electricity generation, as it generates less greenhouse gases than coal (West Coast Environmental Law, 2003). This natural gas is formed as a by-product of the coalification process in which organic matter is converted into coal at great depths.

The coalbeds that are formed are saturated with water at high pressures which keeps the methane adsorbed onto the matrix of the coal. CSM projects extract this water at great quantities in order to decrease the pressure and consequently desorb the gas from the coal (these water sources are often drinking water or irrigation aquifers) (McBeth, *et al.,* 2003).

Upon removal of the product water (the water removed from the aquifer) it is stored in pits or dams near the well and allowed to evaporate. Water has also been known to be used for irrigation.

2.0 Exploration.

The exploration stage is an attempt to locate suitable reservoirs of coal seam gas with potential for economically viable gas extraction. Certain economic, social and environmental impacts are presented at this stage.

2.1 Social; In order to determine whether a region of land has sufficient levels of methane reserves for commercial production, gas companies must drill exploration wells and extract samples. If a petroleum lease is granted, then gas companies may enter private property without seeking the approval of the landholder (Department of Infrastructure and Planning, 2008). The exploration stage brings with it numerous trucks and large, drilling equipment detrimental to the land by compacting soils, increasing runoff and damaging previous roads (Coalbed Natural Gas Alliance, 2006: Darin, *et al.,* 2001).

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2.2 Economic; during drilling of farms or ranches, the land is in a state that could not produce crops or support livestock, therefore putting a great financial burden on the owners of the land. If the exploratory stages showed insufficient supplies of methane for production, and the gas companies leave the property, it is not restored to its original productivity (Bond, 2008).

2.3 Environmental; the exploration process requires numerous wells to be drilled in order to estimate the amount of gas available in the coal bed. This method leaves numerous sites open for methane to readily desorb into the atmosphere (as it is wont readily dissolve in water) adding to greenhouse gas emissions. Exploration in Queensland from 06-07 reached a record high with a total of 392 coal seam methane wells drilled for exploratory purposes, in comparison to 171 traditional coal wells (Australian Government, 2008). The Sydney Gas Company's Seismic Exploration caused significant damage to the roads of local residents of the Hunter Valley. After proposing to use a 4WD vehicle in the report submitted to the residents, Sydney Gas used significantly larger vehicles, posing a higher threat to the environment (Australian Government, 2008).

Product Water

3.0 Evaporation ponds

A method widely practiced to dispose of product water was to place the water into an (often unlined) evaporation pond. The water would evaporate from the sun and leave the salts behind (Sessoms, *et al.,* 2003). In Queensland, evaporation ponds are the most common method of disposing of coal seam methane product water (Department of Infrastructure and Planning, 2008).

3.1 Social; negative impacts on soils and vegetation of evaporation ponds leave the land of coal seam methane wells unsuitable for agriculture after the product water has been evaporated (CSIRO, 2006). This leaves the land owner with soil unable to support crop or livestock. The high levels of salt left behind can get picked up by the wind and transported over long distances, creating salt storms that deposit the salts over pasture used by livestock or even over crops, decreasing infiltration and increasing runoff (Sessoms, *et al.,* 2001).

Figure 1; Sand storm from evaporation pit of Dalby site (Source: HBGAG, 2008a).

3.2 Economic; as mentioned above, evaporation pits leave high concentrations of salts, predominantly carbonates, in the soil, making it unsuitable for crops (CSIRO, 2006). Remediating these soils would be a time consuming, costly process (Sessoms, *et al.,* 2002). For more information on the impacts of product water on soil see Irrigation below (6.0).

3.3 Environmental; Evaporating the product water leaves high concentrations of salts behind (carbonates, magnesium, calcium and sodium chloride) which hinders the soil, by increasing osmotic potential. This means that the water outside the plant has a higher salt concentration than the water inside the plant, so the plant secretes water into the soil to decrease the salt concentration, which then dehydrates the plant (CSIRO, 2006). As native flora are generally less salt tolerant than introduced species, evaporation pits promotes an environment where weeds flourish (NRW, 2006). High salinity levels also decreases access to nutrients, restricts rooting depth of plants and therefore impairs root functions (CSIRO, 2006). The salt storms at Chinchilla have introduced a major environmental concern (Wylie, 2006). The Condamine catchment in Dalby is already faced with high levels of salt (Murray-Darling Basin Commission, 2007). Salt storms would increase the levels of salt in this catchment, being detrimental to already susceptible wildlife (Wylie, 2006).

The average salinity of product water was estimated to be 4500ppm, which gives 4.5 tonnes of salt produced per mega litre of product water (HBGAG, 2008a). An average of 0.6 mega litres of product water is expected to be produced per day from one single coal seam well, giving a value of 2,700 tonnes per day for 1,000 wells or 900,000 tonnes of toxic salts per year (HBGAG, 2008a). This is an extremely large amount of hazardous salt, posing a very high risk to the Darling River (HBGAG, 2008a).

4.0 Re-injection

This process includes the re-injection of the product water back into the original aquifer (injection is when the product water is injected into a different aquifer). This process is confined by numerous constraints, such as whether the coal was maintained at saturation or not, and the pressure of the system (Warrence and Bauder, 2008).

4.1 Social; reinjecting water back into the coal seam can contaminate water supplies or aquifers where the water was originally used as part of a chemically enhanced production process (see contamination of groundwater and other subsurface resources). These pollutants pose harmful health concerns such as asphyxia (US EPA, 2008) to severe forms of leukaemia (Clean Water Partners, 2008).

4.2 Economic; re-injecting the product water into the original aquifer is a costly process, requiring compressors, to bring the product water back to the original pressure (Warrence and Bauder, 2008). Re-injection is often constrained by available coal seams, as the operational field cannot be used for re-injection as it would increase pressure and prevent gas desorbing. This means that in most cases re-injection is not feasible.

4.3 Environmental; see social.

5.0 Injection

This process is when the product water is injected into a different aquifer. Problems associated with this include constraints on the location (local climate, existing water quality and hydrogeology) and soil permeability (relatively shallow and unconfined aquifers and sandy soils) (Warrence and Bauder, 2008).

5.1 Social; if the water is reinjected into a different aquifer, a source of drinking water or irrigation water is then depleted from the original aquifer, affecting local property owners (Peacock, 2005: Bond, 2008).

5.2 Economic; removing the water from the original aquifer without replacing it also drops the water table at the original aquifer, which can lead to salt intrusion. This causes the soil to be saline (as shown in figure two) and limiting the crops that can be sewn (Veil, 2006).This negatively impacts the residents of the land that the original aquifer is situated on, making it difficult to produce revenue (Veil, 2002).

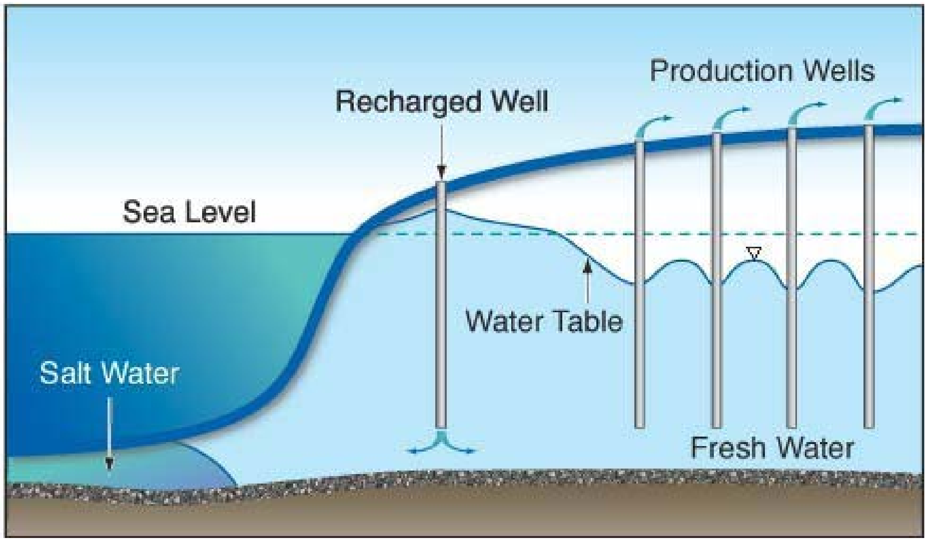

Figure 2: Water table in the presence of a well.
Source:http://www.solinst.com/Res/papers/Salt-Water-Intrusion-2.html

5.3 Environmental; injecting the product water into a different aquifer will cause the water table at the original aquifer to rise, bringing with it high concentrations of salt and therefore polluting the soils (Veil, 2002).

6.0 Irrigation

Product water from coal seam methane sites has often been utilized for irrigating crops (Warrence, *et al.,* 2003), although numerous negative effects resulted from this practice it is still considered a possible disposal method of product water (Warrence, *et al.,* 2003).

6.1 Social; environmental issues discussed below in regards to irrigating crops with product water from coal seam methane sites limit the crops that can grow. These factors include salinity, sodicity, electric conductivity, and pH (Sessoms, *et al.,* 2002). This limits the revenue of the farmers, placing an unnecessary stress on the pockets of farmers. It also reduces the availability of productive farmland.

6.2 Economic; limiting the crops that can grow on land irrigated with coal seam methane product water (NRW, 2006), limits the diversity of produce that comes from areas where coal seam methane mining is common. This also limits farmers' ability to meet supply and demand different produces.

6.3 Environmental; product water in Wyoming was tested to indicate high concentrations of sodium (SAR levels) and salinity levels, which lowers infiltration rates of soils, therefore increasing runoff and erosion (CSIRO, 2006: Hanson, *et al.,* 2003).

Sodicity

Excess sodium levels in soils can cause soils to harden on the surface, preventing infiltration and increasing runoff (Sessoms, *et al.,* 2002).

SAR levels (sodicity levels) can be calculated by using equation 1;

$SAR = Na^+ / \sqrt{[(Ca^{2+} + Mg^{2+})/2]}$ (Sessoms, *et al.,* 2002).
eqn. 1

(Where Na^+ is sodium concentration, Ca^{2+} is calcium concentration and Mg^{2+} is magnesium concentration).
The product water (in this case from the Powder River Basin in Wyoming) at the discharge point had high concentrations of sodium bicarbonate. However in the ponds, the SAR levels increased, therefore the sodic levels increased (Sessoms, *et al.,* 2002). The bicarbonate concentrations also increased in the pond, indicating that equation 2 was occurring;

$NaHCO_3 \rightarrow H^+ + CO_3^{2-} + Na^+$ (Sessoms, *et al.,* 2002). eqn. 2

The sodium carbonate ionizes into hydrogen ions, carbonate ions and sodium ions. The calcium concentrations also decrease from the discharge point to the holding pond (McBeth, *et al.,* 2003). This indicated that calcium carbonate was forming, shown in equation 3.

$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3^+$ (calcite) $+ H_2O + CO_2$ (Sessoms, *et al.,* 2002) eqn. 3

Calcium carbonate was observed to be precipitating out of solution in holding ponds at the Powder River Basin (McBeth, *et al.,* 2003).

These physical components of the product water pose an issue to grounds irrigated with these waters (waters with high SAR levels and excess Na+ concentrations) as this product water can lead to increased erosion via a lowered infiltration rate, especially in clay soils (black, alluvial soils contain >30% clay (Hanson, et al., 1993)).

This occurs as the sodium ions come in between the clay particle, forcing them to disaggregate, which minimizes pore space in the water, therefore decreasing infiltration (and increasing runoff and erosion), decreasing root penetration of crops and lowering crop yield (CSIRO, 2006). In the event of this, previously fertile soil would then become infertile.

A study that simulated product water from the Powder River Basin exposed to the atmosphere, had 5 different samples, and replicated three times each to obtain average values of pH, SAR, and electrical conductivity over a 12 day period (Sessoms, *et al.,* 2002). Over the 12 day period, SAR levels increased by an average of 51% (Sessoms, *et al.,* 2002).

Weeds.
Weed species that are tolerant to coal seam methane product water include salt tolerant species referred to as halophytes (ALL Consulting, 2003). These plants include saltbush (e.g. *Atriplex amnicola, A. nummularia and A. undulata*), reed grasses (e.g. *Phragmites australis*) and saltgrasses (e.g. *Distichlis spicata*) (ALL Consulting, 2003). Salt tolerant weeds that have been linked to coal seam

methane product water such as salt cedar consume large quantities of ground water, jeopardising the survival of native species (May, *et al.,* 1998).

Other weeds that have been found on coal seam methane sites in the United States include Russian knapweed, Canadian thistle, scotch thistle, leafy spurge, black henbane diffused knapweed and spotted knapweed (United States Department of the Interior, 2008a). Salt cedar has been declared a weed of national significance in Australia due to the climate and the salinity in Australian soils (Weeds Australia, 2008), making its prevalence in coal seam methane sites a major issue to Australian farmers. Parthenium has also been declared a weed of national significance and is prominent in areas where coal seam methane production is being carried out, e.g. the Darling Downs, Queensland (Natural Resource Management, 2007). This weed thrives in basic soils that have high clay contents. It is also very competitive with crops and native species and is very successful at colonizing disturbed and cultivated lands (Weeds Australia, 2008a). Parthenium has been found to cause allergic reactions in livestock and humans with increased exposure and is toxic when ingested at any level (Weeds Australia, 2008a). These negative health affects can taint sheep meat and dairy milk. This weed has also been linked to a decrease in property values (Weeds Australia, 2008a).

Conductivity.

The conductivity levels obtained from the Wyoming sites were up to 3.79 dS/m (deciseimens per meter, equivalent to millimhos per cm (mmh/cm), a measurement of electrical conductivity which estimates the total amount of dissolved ions in solution) (McBeth*, et al.,* 2003). This was regarded as a high saline environment and could only be used to irrigate salt tolerant plants (Queensland Water Quality Guidelines, 2007). Crops listed in table 1 include a brief list of the types of crops that could not be irrigated with product water extracted from Wyoming sample sites.

Table 1; Crops Unable to be irrigated with Product Water and the Corresponding Electric Conductivity Tolerance Level.

Crop	EC Tolerance Level
Corn, Grain, Sweet	1.7 dS/m
Cowpea	1.6 dS/m
Cowpea, Caloona	2.0 dS/m
Flax/Linseed	1.7 dS/m
Sugarcane	1.7 dS/m
Lettuce	1.3 dS/m
Sweet Potato	1.5 dS/m
Broadbean	1.6 dS/m

(NRW, 2006)

Different soil types also have different electrical conductivity tolerances, as shown in table 2.

Table 2: Electrical Conductivity tolerance of soil types.

Soil Type	Crops to be grown	Upper EC tolerance (dS/m) for irrigation water
Deep black soils and alluvial soils having a clay content of more than 30 percent. Soils that are fairly to moderately well drained.	Semi-Tolerant	1.5
	Tolerant	2
Heavy textured soils having a clay content of 20-30%. Soils that are well drained internally and have a good surface drainage system.	Semi-Tolerant	2
	Tolerant	4
Medium textured soils having a clay content of 10-20%. Soils that are very well drained internally and have a good surface drainage system.	Semi-Tolerant	4
	Tolerant	6
Light textured soils having a clay content of less than 10%. Soils that have excellent internal and surface drainage.	Semi-Tolerant	6
	Tolerant	8

(Abrol, *et al.,* 1988)

If a farmer was planting corn in deep black soil that was to be irrigated with coal seam methane product water (with EC levels of above 3dS/m), the water would cause swelling of the soils, decreasing infiltration, increasing runoff and erosion possibly polluting nearby water sources.

High electrical conductivity levels also cause soil particles to disaggregate, making the soil less porous, increasing runoff and erosion and also minimizing root penetration (CSIRO, 2006). Salinity levels can also negatively impact crops, as discussed above (see *Evaporation Pit*) (CSIRO, 2006).

Black alluvial soils are commonly found in Dalby and Chinchilla in Southern Queensland, where coal seam methane production has already begun (Australian Government, 2008). These soils are high in clay content and if irrigated with product water would disaggregate as mentioned above, therefore severely impacting crops and potentially polluting waterways with pesticides from erosion and run off (Mongillo and Zierdt-Warshaw, 2000). Circumstances such as these have lead to fishkills (Helfrich and Smith, 2000), where mass moralities of fish occur.

NB: Even if the product water is re-injected, it still needs to be stored directly after extraction; therefore the problems associated with irrigation are also relevant with evaporation ponds and re-injection.

7.0 Desalination Plant

Desalination plants evaporate the water into vapour, leaving the dissolved solids behind (in this case the contaminatants) and condense the water vapour back to its liquid form (US EPA, 2006).

7.1 Social; if the product water is to be desalinated, then either a desalination plant must be constructed on the land or the water must be transported to a desalination plant. If the water is to be transported, this would create unnecessary traffic congestion and potentially damage the roads within the town (BBC Research and Consulting, 2001).

7.2 Economic; This form of product water treatment manages to treat the saline water, however it comes at a great cost and also requires a great deal of energy to be able to do this, making coal seam methane extraction less “green” . One CSM well produces approximately 17,280gallons of water per day (Keith and Bauder, 2003), which is equivalent to 65,404.8L per day. The cost to desalinate the volume of water (at a rate of AU50c per KL of product water) (Australian Institute, 2005) produced in the Powder River Basin by the **16,000 wells (McBeth, *et al.*, 2003) would be approximately AU$523,232. Due to the high costs of desalinating the water, it would also increase in price per kilolitre of water to the consumer.** This indicated that desalination plants are not an economically viable solution to the treatment of product water. The cost of reverse osmosis desalination ranges between AU$0.33-0.63 per KL. Taking an average of AU$0.48, this would give approximately the same values as calculated above. (Clarke, 2008)

7.3 Environmental;
A desalination plant produces 5.2kg of CO_2 per kilolitre of water desalinated (Australian Institute, 2005). This gives a total CO_2 budget per well per day of 340.1 kg. In the Wyoming Basin in 2003, more than 16,000 wells were in production (McBeth, *et al.,* 2003), which equates to **close to 2 billion kilograms of CO_2 emissions in one year.**

8.0 Transportation of Product Water

In order to treat the product water with any of the methods, it must first be transported using either pipelines or heavy duty tanker trucks to the site of treatment (if desalinating or irrigating) (Australian Government, 2008). The transportation of product water induces social, economical and environmental issues detailed below.

8.1 Social; whether the water is being taken to a desalination plant or to a local farm for irrigation, the large quantities of water need to be transported, normally by tanker trucks (Australian Government, 2008: United Nations Environment Programme, 1997). The traffic brought about by these vehicles increased the noise pollution, negatively impacted the roads and increased runoff (CSIRO, 2006: Hanson, *et al.,* 2003)

Figure 3; Trenching for transportation of product water at Yukon,
Source; CPAWS-Yukon, 2008.

8.2 Economic; in order to repair the roads that have been affected by increased heavy vehicle traffic, the residents must pay the local councils to fix them (Australian Government, 2008). Pipelines may also be used to transport the product water; however compressor pipelines (used to transport water against gravity) can be expensive forms of transport (United Nations Environment Programme, 1997). Assuming that the water was being transported in a 50mm pipe a distance of 100km, the total cost of the construction of the pipeline would be AU$22 million (SA Water, 2005).

8.3 Environmental; roads and wildlife are negatively impacted by increased heavy vehicle traffic throughout the area, creating disturbances in ecosystems with the potential to upset predator-prey interactions (Australian Government, 2008). Paving new roads to be used for transportation also increases erosion rates (Australian Government, 2008).

Ground Water

9.0 Contamination of Groundwater and other Subsurface Resources.

Numerous contaminants are present in product water (depending on what processing has occurred), including salts, ammonia, hydrocarbons, heavy metals and even radio nucleotides (Fisher and Bidwell, 2008). Migration of methane (which is increased by exploration and extraction of coal bed methane) has been known to contaminate groundwater supplies and bores located 300m from wells which have been reported to be expelling methane (Atkinson, 2005). Hydraulic fracturing has also introduced numerous environmental pollutants (see 13.0 Primary Production Enhancements below).

9.1 Social; numerous coal seam methane aquifers are located within underground sources of drinking water (USDW). A process called hydraulic fracturing is often carried out in order to maximize the fractures in the coal bed and therefore maximize the flow of product water being pumped out of the aquifer (Palmer, *et al.,* 1993). Hydraulic fracturing can introduce numerous harmful chemicals into the groundwater supply, ranging from benzene (a class A carcinogen linked to both acute and chronic forms of leukaemia) (Clean Water Partners, 2008) to hydrochloric acid (Palmer, *et al.,* 1993). Residents of Mainesburg Pennsylvania reported elevated methane gas levels in water supplies (used for crops and drinking water) caused by methane migration near coal seam methane extraction sites (Tarbell, 2008).

9.2 Economic; the contamination of groundwater with these compounds has led to livestock and residents falling ill (Ardis, 2006). These sources of drinking water are then deemed unusable and another source must be found. This comes at a cost. Pollution of groundwater has led to cattle becoming bloated and ill (Ardis, 2006). This would have a negative impact on the revenue of the cattle farmers in this region. Hydraulic fracturing is another added cost that only adds more contaminants into the water that require treatment to remove, and not all contaminants are removed (EPA, 2000).

9.3 Environmental; Hydraulic fracturing is achieved by pumping water, in conjunction with acids such as hydrochloric acid, water, "slick" water (with a viscosity reducer) and nitrogen foam (Palmer, *et al.,* 1993) at high pressures in order to produce cracks in the coalbed. A number of the added chemicals such as hydrochloric acid are dangerous to humans and livestock when in harmful concentrations. Between 20 and 40% of the chemicals added to the water remain after extraction which may pollute underground sources of drinking water (EPA, 2000). The contamination of groundwater with dangerous compounds such as benzene in the environment has lead to cattle becoming ill (Ardis, 2006).

10.0 Depletion of Groundwater Supply.

When the water is extracted from the aquifers and not replaced, a valuable source of water is then depleted. This occurs when the product water is taken to a desalination plant, used for irrigation, put in an evaporation pond or reinjected into a different aquifer.

10.1 Social: with no groundwater; bores and wells go dry and residents lose a vital drinking water and grey water source (Orr, 2008).

10.2 Economic; Farmers that were utilizing groundwater that was extracted in the CSM process no longer have sufficient supply of water to irrigate crops (Peacock, 2005: Bond, 2008). The product water could be purchased, however the use of this water for irrigation is of no use as it is contaminated and would only negatively impact the soils and therefore the crop and livestock (Sessoms, *et al.,* 2002). The use of the product water for irrigation limits infiltration and increases runoff, therefore increasing pesticide and fertilizer concentrations (CSIRO, 2006: Hanson, *et al.,* 2003).

10.3 Environmental; the decreasing groundwater supplies raise the water table, which raises salts to the soil level (as discussed in *Irrigation* above) (Razowska, 2000). This is detrimental to surrounding flora and fauna that are salt intolerant (Sessoms, *et al,* 2002). Depleting the groundwater supply also interferes with recharge times and discharge as well as changing catchment characteristics (Razowska, 2000).

Production

11.0 Primary Production Enhancements

Most CSM plants don't produce enough energy to meet commercial demand; therefore the sites are injected with CO_2 and sand in order to increase the productivity. This forces the sand in between the seams in order to keep them open and maximize productivity. Some plants also employ hydraulic fracturing. Pumping of excess water into coalbeds at high pressures in order to invoke hydraulic fractures increases the surface area exposed to the water, thus increasing the amount of methane extractable (Nikorama, 2007). This practice however is not controllable and may cause leaks of product water into irrigation and drinking supplies (Natural Resources Defence Council, 2002). Cavitation is another method of primary production enhancement where a cavity is formed near the wellbore portion of the well and is put under pressure until it fractures (Pearson, 2003). CSM, in comparison to other methods of coal extraction (for example coal mining or underground coal gasification) requires significantly more land to produce as much energy.

11.1 Social; Hydraulic fracturing fluids include toxic and carcinogenic chemicals such as benzene, surfactants, potassium chloride (Nikorama, 2007), ammonium chloride, potassium hydroxide and zirconium sulphate (U.S. Department of the Interior, 1998). The chemicals used in hydraulic fracturing include toxicants affecting skin, sensory, respiratory organs, gastrointestinal tracts, liver, kidney, cardiovascular systems blood and neurotoxins (Colborn, 2008). Approximately 92% of the chemicals used in hydraulic fracturing negatively impact the health of residents and wildlife alike (Colborn, 2008). Hydraulic fracturing also uses diesel as a dissolving agent due to its comparatively high carrying capacity (Halliburton, Inc., 2002). The use of diesel in hydraulic fracturing introduces numerous contaminants such as benzene, toluene, ethyl benzene and xylene (Irwin, 1997). These compounds pose health issues such as liver problems, nervous system problems, kidney and eye related health issues, anaemia, temporal nervous system disorders and immune system depression (US EPA, 2006). As CSM demands more land in order to meet the same production rates as alternative methods of power production, more land would be disturbed, also making the budget for compensation to be stretched over more recipients.

11.2 Economic; the combustion of methane is often considered to be an unimportant factor as the probability of combustion is said to be low. In 2001, a cavitation fire caused US$500,000 in damage, as the combustion fire spread to surrounding dry vegetation (Pearson, 2003). Although no residential properties were harmed, local flora and fauna were devastated by this (Pearson, 2003).

Various research indicates that by using alternative extraction techniques, much smaller areas of land can be used to generate similar amounts of energy, thereby negating the negative impacts over large areas.

11.3 Environmental; as mentioned above, hydraulic fracturing can lead to the contamination of groundwater sources including USDW (see 11.0 Contamination of Groundwater and other Subsurface Resources above). Acids are often used in hydraulic fracturing in order to dissolve limestone away from coal (Ely, 1985). The acids used include hydrochloric, formic and acetic acids (Ely, 1985). Surfactants are very resistant to biodegradation and cause environmental issues such as concentrating in marine organisms (Connell, 2005). The majority of the methane that is released in coal mining occurs when the coal seams are fractured (Eliasson, Riemer, Wokaun, 1998) making this process environmentally costly. The cavitation of wells can lead to a build up of methane, running the risk of cavitation fires. This is a serious issue as described above, with the potential to devastate local plant and animal life (Pearson, 2003).

12.0 ***Transportation of Methane.***

This is achieved in pressurized pipelines that are prone to leakage and therefore risk soil contamination, potentially impacting both flora and fauna (HBGAG, 2008) and public safety. These pipelines also risks expulsion of greenhouse gasses, suffocation and possible explosions. Some sites are even located close to endangered species, risking their future (GHD, 2008).

12.1 Social; pipelining methane gas requires the trenching of privately owned land, upturning soils and introducing metals into the soils that may corrode, leaching metals into the soil and contaminating the land (Baker and Pickle, n.d.).

12.2 Economical; Current advancements in pipeline technology have been offset by the increased costs of steel, therefore making pipelines an expensive mode of transport, although still more economical than tanker trucks for long term investment (Chandra, 2008).

12.3 Environmental; leakages from methane pipelines were responsible for high emissions of greenhouse gasses into the atmosphere (US EPA, 2008). These pipelines also risks suffocation and possible explosions (HBGAG, 2008). The Sydney Wollombi site is located within a ten kilometre radius of numerous endangered species, although it continues to operate, risking the fate of these fragile species (GHD, 2008).

13.0 Flaring and Venting

Flaring occurs when there is an excess amount of methane that cannot be conserved. CSG operations in their preliminary stages that produce larger volumes of water and smaller volumes of gas may require more flaring. Venting occurs when it is impractical to flare the excess methane (as there is insufficient gas) and it is vented into the atmosphere (HBGAG, 2008).

13.1 Social; health issues associated with being exposed to methane gases include suffocation, in which oxygen in the respiratory system is displaced by methane (Canadian Centre for Occupational Health and Safety, 2008). This is an issue if methane accumulates in buildings (HBGAG, 2008). Flaring is also a fire hazard, endangering the property, wildlife and residents (CPAWS, 2007).

13. 2; Environmental; flaring of coal seam methane plants is expected to take more time than conventional gas (Harvey, 2002). A study revealed that fossil fuels don't burn effectively, leaving 16-38% of gasses intact (West Coast Environmental Law, 2003) making flaring environmentally hazardous in some situations. Methane is twenty times more effective a greenhouse gas than carbon dioxide (it is twenty times as efficient at trapping heat and also stays in the atmosphere for 9-15 years) (US EPA, 2007). Concentrations of vented methane can accumulate in buildings or natural sinks (such as creeks and dips), reaching explosive levels, with the potential to harm burrowing animals (US EPA, 2007).

14.0 Noise Pollution

With the introduction of industrial equipment to rural areas, large amounts of noise pollution are also brought in, impacting livestock, native fauna and the livelihood of local residents (Darin and Beatie, 2001). One well introduces trucks, earth moving machines, compressors and drilling equipment. This equipment is conglomerated at high densities due to the large number of wells in close proximity over large tracts of land (Darin and Beatie, 2001).

14.1 Social; the quiet, serene, country atmosphere has been bombarded with around the clock drilling equipment and an endless caravan of trucks transporting equipment to and from sites. This has negatively impacted the wellbeing of land owners, adding to the stress of having their properties stripped from them. Some land owners do not have an opportunity to say no (Ardis, 2006).

14.2 Economic; the pressure in CSM wells decreases as gas is extracted over time; therefore compression is required, which generates significant noise pollution (Energy Resources Conservation Board, 2008). Not only does noise pollution decrease the value of the land, it also negatively impacts both livestock and wildlife, making livestock farming during coal seam methane extraction a difficult and costly process (Energy Justice Network). Increased traffic due to transporting product water and industrial equipment created crowding on roads in Wyoming (Darin and Beatie, 2001) which had the potential to impact local tourism (Hunter Bulga Gas Action Group (HBGAG), 2008).

14.3 Environmental; Noise pollution from coal seam methane has been shown to negatively impact wildlife in local areas (Darin and Beatie, 2001). The greater sage-grouse, *Centrocercus urophasianus* has been driven away from the Powder River basin, due to the continuous noise pollution (Walker, *et al.,* 2007). Threats to these animals include decreased sensitivity to mating calls and predator signals putting the future of these birds at risk (Walker, *et al.,* 2007). Areas that were being drilled for methane showed a decrease in population strength (Walker, *et al.,* 2007).

15.0 Loss of Property Values

A Study was conducted by the BBC Research and Consulting group (2001) in order to determine whether there was a link between decreased property values and the vicinity to coal seam methane wells. The results of the study indicated that there was a relationship between these factors (BBC Research and Consulting, 2001).

15.1 Social: Properties located near CSM sites have been evacuated due to risk of explosion and suffocation from methane leaks. These properties are now unable to be sold (BBC Research and Consulting, 2001). Residents are left with mortgages for a house that they cannot live in and cannot sell (BBC Research and Consulting, 2001).

15.2 Economical: A study in La Plata County, USA showed that properties with CSM wells on their land showed a 22% decline in property values (BBC Research and Consulting, 2001). Residential property owners identified factors that impact the values of property which included industrial views and weed propagation (BBC Research and Consulting, 2001). Factors involved with coal seam methane production that may have attributed to the decline in general property value include a decrease in aesthetics due to more roads, heavy vehicle traffic, noise pollution, negatively altering the landscape and soils and the possibility of explosions bought about by methane migration (BBC Research and Consulting, 2001). It was also determined that if a well currently not in use was located on the property, then the probability of drilling on that site was decreased; therefore these properties would increase in price (BBC Research and Consulting, 2001). This is no longer the case, due to Primary Production Enhancements, making it possible to re-visit previously extracted wells and obtain more methane from them (Palmer, *et al.,* 2003). Coal seam methane wells have been spaced closer together in comparison to conventional fuel wells, in order to maximize gas production and recovery (West Coast Environmental Law, 2003: BBC Research and Consulting, 2001) therefore having a negative impact on the aesthetics of the property.

16.0 Laws

In Queensland Australia, the coal seam gas industry developed under 1923 laws until they were revised in 2004, by which time the industry had developed relatively unchecked.

The negative impacts on the land and the people due to this lack of appropriate guidelines and policies were realised and the Queensland Government released the Queensland Coal Seam Management Water Policy (Department of Infrastructure and Planning, 2008).

16.1 Social; due to the fact that all petroleum is owned by the crown (Department of Mines and Engineering, 2008), governments have been resistant to prevent mining companies on privately owned land due to the royalties that the government is entitled to. Some farmers no longer have the right to say no to mining companies extracting coal seam methane from their land (Ardis, 2006). One gentleman from Canada even owned the rights to the coal on his land, however this document was neglected as it is the natural gas that the companies wish to extract, not the coal (Ardis, 2006). In Pennsylvania in the United States, a farmer had 15 acres of land turned into a coal seam methane well site without his permission (Hopey, 2007). This farmer (Bill McConnell) received no compensation for the loss of productivity on his lands, and he is now unable to sell this property (Hopey, 2007). Bill McConnell was left with rates to pay on land that has been stripped of its productivity by coal seam methane exploitation and therefore unable to produce revenue (Hopey, 2007). One rancher in Yukon received compensation of C$30 on a monthly basis which is hardly enough to cover the loss of revenue that he has suffered due to the presence of these wells (CPAWS-Yukon, 2008).

16.2 Economical; Due to some farmers inability to decline the mining companies request to drill their land for coal seam methane, the farmers have no choice but to accept that their property values may decrease by even up to 22% (BBC Research and Consulting, 2001).

If the wells are being drilled on the land, farmers need to make arrangements for compensation immediately. Determining how much compensation is fair is a difficult process as each property is unique and there are many factors that need to be considered. When negotiating for compensation, things to consider include the loss of use of the land (e.g. how much revenue was lost due to inability to sew crops), the decreased value of the property due to the presence of a coal seam methane wells and extra taxes incurred by the upkeep of the well (San Juan Citizens Alliance, 2004).

16.3 Environmental; evaporation ponds were found to be negatively impacting the U.S. soils, flora and fauna and new laws were implemented in an attempt to prevent this, however in Australia up until October 20th, 2008 (Department of Infrastructure and Planning, 2008) no policies were implemented in order to protect Australian vegetation from product water, methane migration and increased greenhouse gases. Evaporation ponds are the most utilized method of disposing of product water in Australia; however they have such deleterious effects on the land (see 3.0 Evaporation Ponds), how can this be a sustainable method of disposing of product water. Evaporation ponds also cause hazardous salt storms, distributing salt over large distances and contaminating soils (HBGAG, 2008a). Laws regarding the drilling of CSM wells were passed in the US which then lead to the closing of specific rivers and lakes from CSM activity in order to prevent contamination (Montana Department of Environmental Quality, 2007). Little action has been taken to protect Australia's rivers.

17.0 **In Conclusion**

The two major issues that lead to a number of the problems discussed above are how to dispose of the large quantities of product water pumped from the aquifers and the need to undertake harmful primary production enhancements in order to make coal seam methane economically viable. The most significant of these issues is the product water issue, leading to depletion of groundwater supplies, saline soils, erosion, loss of productivity of pastures, weed dominated vegetation and much more.

The social, environmental and economic impacts brought about by these factors are too great to ignore. Depletion of groundwater resources has put unnecessary stress on local residents as they attempt to fight a losing battle for the rights to their property. Why must the farmers and local residents pay to have the roads fixed once the coal seam methane companies have left (Australian Government, 2008)?

Pollution sourced from primary production enhancements has lead to residents falling victim to detrimental health effects including chronic forms of leukaemia (Clean Water Partners, 2008). Not to mention the continuous noise pollution sourced from drilling equipment, compressor pipes and trucks, distressing not only the residents but also the wildlife (Darin and Beatie, 2001). The sustainability of agriculture on these lands have been jeopardised by the use of product water as an irrigation source, leaving the land covered in halophytic weeds and endangering native plants and animals (Sessoms, *et al.,* 2002). The increased runoff, caused by irrigation with product water and erosion, has added to the poisoning of the water ways. Farmers lands have been dug up to make way for pipelines to transport methane and product water and their lands left unable to produce crops and now the value of the land has decreased due to the presence of coal seam methane wells. What do the farmers get in return; a monthly payment of C$30 (CPAWS-Yukon, 2008), which is hardly compensation for what they have had to endure. The future of farmers in coal seam methane country is looking bleak. With the depletion of possible sources of drinking water and poisoning of farmers soils, how can this be a sustainable answer to our energy crisis? If farmers can't grow crops because their soils have been poisoned, where will people get their food from?

In the words of a victim of the coal seam methane industry, if a coal seam methane company comes to explore your land, "Get a lawyer the first day!" (Coalbed Methane Watch Group, 2003).

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