Submission to Santos EIS April 24, 2017

Attn: Executive Director, Resource Assessments

Department of Planning and Environment

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April 24 , 2017

Dear Sir / Madam,

For her 2014 review of coal seam gas (CSG), the NSW Chief Scientist and Engineer Professor Mary O'Kane spent many hours in consultation with many experts discussing possible risks to the environment and human health posed by the CSG industry.

The document that was published by the Chief Scientist in September 2014 is a scientific and legislative blueprint for reducing and hopefully eliminating such risks.

My submission to the Santos EIS deals only with scientific data regarding possible impacts of the proposed Narrabri Gas Project (NGP) on artesian water in the Namoi valley.

I am focusing on three areas: (1) Drawdown (2) Connectivity (3) Well integrity

I have no political, philosophical or ideological objection to the mining of CSG as such, just a concern about long – term effects on water resources required for agricultural and domestic purposes.

………..

(1) Drawdown.

To produce CSG, water is pumped from the coal seams 500 to 1000 metres below the surface for several months to release methane trapped in the coal.

This will alter pressure in the Surat basin, where the NGP is located. Water from the great artesian basin (GAB) will obey the laws of gravity and attempt to fill the void below.

The GAB underlies and "controls" the two artesian aquifers used in the valley for town water supplies and agricultural pursuits.

The resultant fall in the level of the water table is called "drawdown". The extent of drawdown depends on the degree of connectivity between the GAB and the coal seams.

The process of drawdown is explained comprehensively by Dr Philip Pells (2013) in his submission to the Chief Scientist's CSG review. Dr Pells constructed a physical model to demonstrate drawdown and displayed the Newtonian equations that underpin the process.

Banks (2014, p. 3) uses CSIRO data to examine drawdown:

> There is proven downwards connection between sub basins of the GAB and many of its underlying petrochemical rich basins (Surat has 10% connection; Eromanga has up to 50% connection). It follows that dewatering of aquifers under the GAB where some connection exists will

ultimately reduce pressure heads in the GAB and reduce water flow at its numerous bores and springs.

Banks takes a broad view of the GAB and its recharge processes, concerned that 79% of the GAB is covered by gas and petroleum licences:

> Approximately 2.1% of the total area of the GAB provides more than 5 – 30 mm/year recharge to the basin, and only 0.2% of the GAB provides greater than 30 mm/year of recharge. These very high recharge areas are rare and widely separated. The main one in NSW is in the East Pilliga Forest between Narrabri and Coonabarabran.

The NGP is situated in a major recharge area.

(2) Connectivity

The CSG industry claims there is almost zero connection between the GAB and coal seams based on research using mathematical modelling. Such modelling requires large amounts of accurate data and is far from being a precise tool as the NSW Chief Scientist & Engineer has already noted in her 2014 report on CSG mining (O'Kane 2014, p. 9):

> While numerical models have an important role to play in guiding the initial risk assessment process, they cannot be relied on to predict the true local impacts for hydrological processes that are multi-decadal in nature such as the impacts from seam depressurisation.

The IESC (2014, p. 63) agrees:

> The uncertainty associated with predictive models stems from two main sources: field measurements and the model. The field observations that are used to constrain and calibrate the model are inherently uncertain due to the errors associated with the measurement methods. Although this error can be reduced through improved field techniques and frequency of data collection, it cannot be eliminated.

Furthermore (IESC 2014, p. 79):

Uncertainty lies in what happens to the natural system as operations come online over time (i.e. cumulative impact) and after the resources have been exhausted and the infrastructure is decommissioned.

Santos, nevertheless, insist that their numerical model MODFLOW is" state of the art" (Santos EIS 2017 Appendix F (2 of 2) Appendix D page 4)

A team from UNSW has proved connectivity in the northern section of the Surat Basin using established science based on the isotopic signature of methane. CSG has been found in water bores, having travelled upwards through cracks and fissures in the strata. These same cracks and fissures will provide downward pathways for GAB water following depressurisation.

An outline of the UNSW results can be seen at Iverach, Charlotte P. (2015)

Team leader, Associate Professor Bryce Kelly supervised collection of water samples in the Namoi Valley early in the new year. He is hoping to quantify the connectivity between the GAB and the two alluvial aquifers it supports.

The job of determining connectivity between the GAB and coal seams has been handed to GISERA, who have several projects in the area scheduled for completion in 2018 and 2019.

(3) Well Integrity

Gas wells can fail during the first year of production, leaking methane through their cement casing. Ingraffea (2012, p. 7) offers percentage failure rates from the Marcellus field in Pennsylvania:

"2010: 6.2% 2011: 6.2% 2012: 7.2%"

If these rates held for the NGP, that would equate to 60 wells failing in their first year of production.

Five different universities represented by Darraha, Vengosha, Jackson, Warner and Poreda (2013) summarised their research:

Hydrocarbon production from unconventional sources is growing rapidly, accompanied by concerns about drinking-water contamination and other environmental risks. Using noble gas and hydrocarbon tracers, we distinguish natural sources of methane from anthropogenic contamination and evaluate the mechanisms that cause elevated hydrocarbon concentrations in drinking water near natural-gas wells. We document fugitive gases in eight clusters of domestic water wells overlying the Marcellus and Barnett Shales, including declining water quality through time over the Barnett. Gas geochemistry data implicate leaks through annulus cement.

Camden in NSW is a recent Australian example of leaking CSG wells. In a survey of 128 wellheads in 2015, Heath Pipeline Services found a total of 41 leaks. Three were classified as significant (> 50,000 parts per million), twelve as major (10,000 to 50,000 ppm) and twenty-six as minor (1000 to 10,000 ppm)

Wells leaking so early in the production process does not inspire confidence in long – term integrity, when wells have been plugged and abandoned. There are conflicting laboratory simulations of the effect of carbon dioxide on casing cement, but there is still research to be done taking on – site conditions into account. In the Abandoned Wells section of her CSG review, O'Kane (2014, p. 12) states:

> If an area of uncertainty were to exist in relation to the integrity of petroleum wells, it would be in relation to the potential long-term impacts. Studies exist for CO2 subsurface storage wells, which suggest that cement would be able to isolate CO2 and upper aquifers over the long-term (1,000+ years). Although comparisons can be made linking long-term CSG well integrity to that of the CO2 storage wells, with a potentially more aggressive environment, there is scope for additional research to assess specifically the impact of abandoned CSG wells over extended timeframes.

Some CSG wells may leak early in production because of mechanical pressures placed on their casings. In abandoned wells, cement casing can be corroded by chemicals in the strata, most likely carbon dioxide. The iconic high school experiment of bubbling CO2 into limewater to produce a precipitate of calcium carbonate will be re-enacted underground.
Where carbon dioxide is present and reacts with calcium hydroxide in the cement the carbonate will fall out of the matrix allowing shrinkage and cracking in the casing.

It is reasonably certain that CO2 will be present in the Surat Basin applying the work of Thomson. S, Thomson. D and Flood. P (2015) in the Sydney Basin:

> Gas content and gas composition trends with depth have been investigated for the Sydney Basin. Four distinct zones have been identified, which can be classified according to depth below ground surface. An upper low gas zone (Zone 1, 0–100 m), dominated by CO2 and with very low gas contents (<0.7 m3/t), is underlain by a biogenic methane-rich zone (Zone 2, 100 to250 m), with a rapid rate of increase in gas content with depth, followed by a mixed gas zone (Zone 3, 250 to 600 m), comprising biogenic and thermogenic methane and magmatic CO2, and having a lower rate of

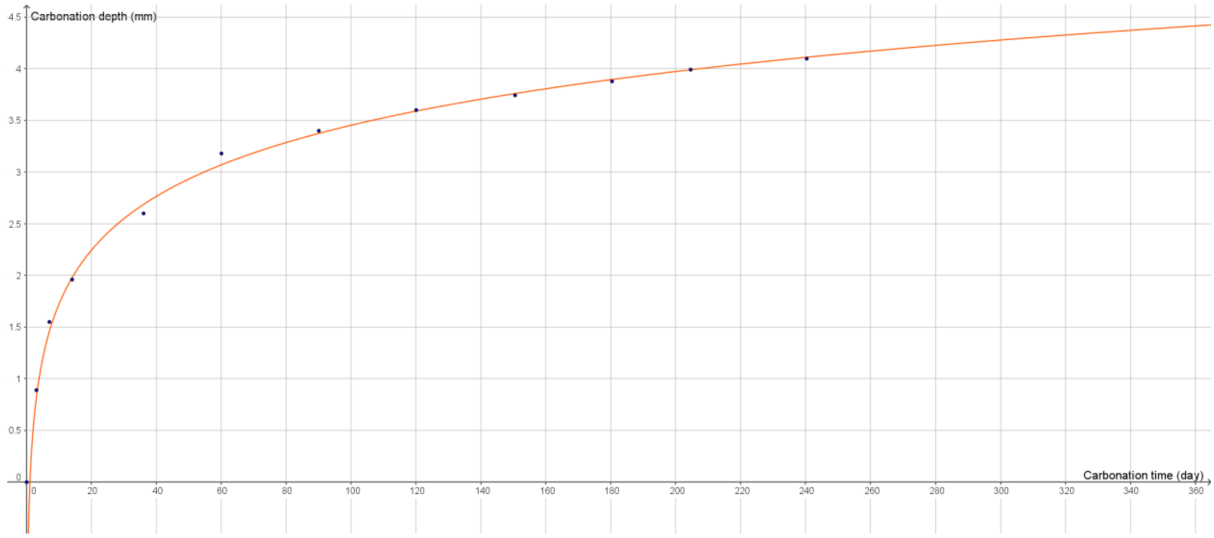
gas content increase with depth relative to Zone 2, and Zone 4 (>600 m), which contains thermogenic methane and other 'wet gases.' A model is proposed that provides a rationale for the origin and timing of emplacement of the various coal seam gases in the Sydney Basin.

If carbonation of the cement casing occurs then the simulation by Dong, Qiu, Xiang, Huang, Xing and Han (2014, p. 227) and the electrochemical method they devised should provide an idea of the rate of degradation: (The table of results is graphed below.)

Table 2. The average carbonation depth for mortars with different Cement/Sand ratio (1:2, 1:3, 1:4)

CARBONATION DEPTHS (MM)

Carbonation time (Days)	C/S = 1: 2	C/S = 1: 3	C/S = 1: 4
0	0.00	0.00	0.00
3	0.89	1.80	1.02
7	1.55	2.54	2.18
14	1.96	2.67	3.29
36	2.60	3.68	3.94
60	3.18	4.32	4.61
90	3.40	5.53	5.62
120	3.60	5.80	6.46



Extrapolation is a risky business (as it is with Santos software). At the rate shown, the depth of carbonation would be about half of the concrete production sheath's thickness (13 mm) in ten years.

Theoretically, a section of the cement casing pipe will shrink to half of its original diameter leaving an annular pathway down which water can flow.

The length of the pipe and the degree of shrinkage will depend on the presence and strength of corrosive substances present in the strata. Perhaps a scale model could be built to simulate local conditions and processes.

Rawling and Sandiford (2013,) provide a neat diagram of possible leakage pathways from an abandoned well in a background paper for the NSW Chief Scientist.

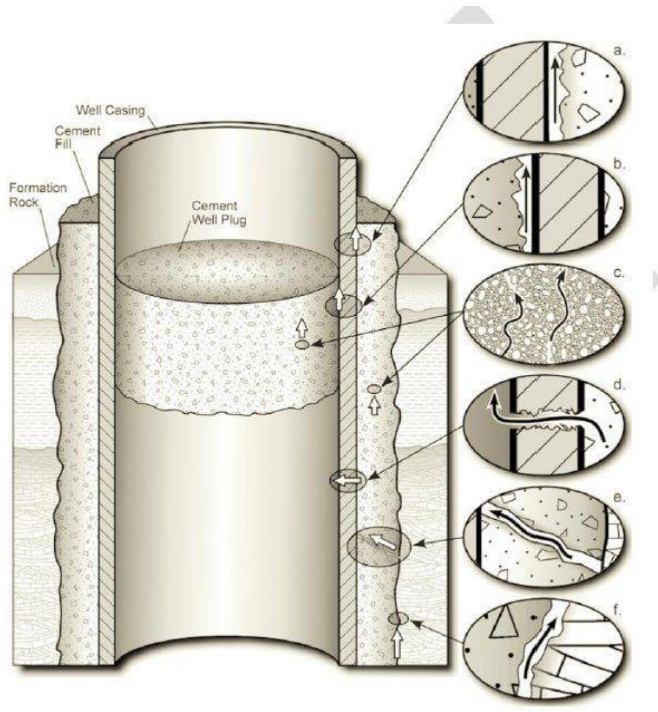


Figure 1: Diagrammatic representation of possible leakage pathways from a cased and abandoned bore or well (Gasda et al, 2004). a) Between casing and cement; b) between cement plug and casing; c) through the cement pore space as a result of degradation; d) through casing as a result of corrosion; e) through fractures in cement; and f) between cement and rock.

Davies, Almond, Ward, Jackson, Adams, Worrall, Herringshaw, Gluyas, Whitehead. (2014} took a virtual field tour of wells around the world:

> Data from around the world (Australia, Austria, Bahrain, Brazil, Canada, the Netherlands, Poland, the UK and the USA) show that more than four million onshore hydrocarbon wells have been drilled globally. Here we assess all the reliable datasets (25) on well barrier and integrity failure in the published literature and online. These datasets include production, injection, idle and abandoned wells, both onshore and offshore, exploiting both conventional and unconventional reservoirs. The datasets vary considerably in terms of the number of wells examined, their age and their designs. Therefore, the percentage of wells that have had some form of well barrier or integrity failure is highly variable (1.9%–75%). Of the 8030 wells targeting the Marcellus shale inspected in Pennsylvania between 2005 and 2013, 6.3% of these have been reported to the authorities for infringements related to well barrier or integrity failure. In a separate study of 3533 Pennsylvanian wells monitored between 2008 and 2011, there were 85 examples of cement or casing failures, 4 blowouts and 2 examples of gas venting.

The authors explain during the introduction to their project how deteriorating wells may become pathways to natural or man-made fluids, thus aiding pollution or increasing the rate of drawdown:

> Some of the shallower strata may contain groundwater used for human consumption or which supports surface water flows and wetland ecosystems. Although it has been routine practice to seal wells passing through such layers, they remain a potential source of fluid mixing in the subsurface and potential contamination (King and King, 2013). This can occur for many reasons, including poor well completion practices, the corrosion of steel casing, and the deterioration of cement during production or after well abandonment. Boreholes can then become high-permeability potential conduits for both natural and man-made fluids (e.g. Watson and Bachu, 2009), and vertical pressure gradients in the subsurface can drive movement of fluids along these flow paths. The potential importance of wellbore

integrity to the protection of shallow groundwater has recently been highlighted in research papers and reports (e.g. Osborn et al., 2011)

Table 3 (P. 246) is a list of countries, their wells and the percentage of these wells that have had integrity problems:

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Table 3
Compilation of published statistics on well barrier and well integrity failure, including information on well age, number of wells included in study, well location, and te minology used to describe nature of well barrier or integrity failures.

Country	Location	No. Wells studied	% Wells with barrier failure or well integrity failure	Additional information	Published source
USA	ONSHORE Operational wells in the Santa Fe Springs Oilfield (discovered ~1921), California, USA	>50	75	Well Integrity failures. Leakage based on the 'observation of gas bubbles seeping to the surface along well casing'.	Chillingar and Endres (2005)
USA	ONSHORE Ann Mag Field, South Texas, USA (wells drilled 1998–2011)	18	61	Wells drilled 1998–2011. Well barrier failures mainly in shale zones.	Yuan et al. (2013)
USA	OFFSHORE Gulf of Mexico (wells drilled ~1973–2003)	15,500	43	Wells drilled ~1973–2003. Barrier failure. 26.2% in surface casing.	Brufato et al. (2003)
Offshore Norway	OFFSHORE Norway, 8 Companies, Abandoned Wells (wells drilled 1970–2011)	193	38	Wells drilled 1970–2011. Well integrity and barrier failure. 2 wells with likely leak to surface.	Vignes (2011)
China	ONSHORE Kenxi Resevoir, China (dates unknown)	160	31.3	Well barrier failure	Peng et al. (2007)
China	ONSHORE Gudao Resevoir, China (wells drilled 1978–1999)	3461	30.4	Wells drilled 1978–1999. Barrier failure in oil-bearing layer.	Peng et al. (2007)
Offshore Norway	OFFSHORE Norway, 8 Fields (dates unknown)	217	25	Wells monitored 1998–2007. Well integrity and barrier failure. 32% leaks occurred at well head.	Randhol and Carlsen (2007)
Canada	ONSHORE Saskatchewan, Canada (dates unknown)	435	22	Wells monitored 1987–1993. Well integrity failure: SCVF and GM	Erno and Schmitz (1996)
Offshore Norway	OFFSHORE Internal Audit, Location Unknown (dates unknown)	711	20	Barrier failure	Nilsen (2007)
Offshore Norway	OFFSHORE Norway, 12 Offshore Facilities (wells drilled 1977–2006)	406	18	Wells drilled 1977–2006. Well integrity and barrier failure. 1% had well head failure.	Vignes and Aadnøy (2010)
China	ONSHORE Daqing Field, China (wells drilled ~1980–1999)	6860	16.3	Wells drilled ~1980–1999. Barrier failure	Zhongxiao et al. (2000)
Bahrain	ONSHORE Bahrain (wells drilled 1932–2004)	750	13.1	Wells drilled 1932–2004. Failure of surface casing with some leaks to surface	Sivakumar and Janahi (2004)
Netherlands	ONSHORE Netherlands (dates unknown)	31	13	Barrier failure	Vignes (2011)
UK	OFFSHORE UK Continental Shelf (dates unknown)	6137	10	Well integrity and barrier failure.	Burton (2005)
USA	ONSHORE Marcellus Shale, Pennsylvania, USA (wells drilled 1958–2013)	8030	6.26	Well reports 2005–2013. Well integrity and barrier failure. 1.27% leak to surface.	This study
China	ONSHORE Gunan Reservoir, China (dates unknown)	132	6.1	Barrier failure	Peng et al. (2007)
USA	ONSHORE Nationwide Gas Storage Facilities (<1965–1988)	6953	6.1	Wells drilled <1965–1988. Well integrity and barrier failure.	Marlow, 1989
China	ONSHORE Hetan Reservoir, China (dates unknown)	128	5.5	Barrier failure	Peng et al. (2007)
USA	ONSHORE Marcellus Shale, Pennsylvania, USA (wells drilled 2010–2012)	4602	4.8	Wells drilled 2010–2012. Well barrier and integrity failure.	Ingraffea (2012)
Canada	ONSHORE Alberta, Canada (wells drilled 1910–2004)	316,439	4.6	Wells drilled 1910–2004. Monitored 1970–2004. Well integrity failure: SCVF and GM	Watson and Bachu (2009)
Indonesia	ON/OFFSHORE Malacca Strait (wells drilled ~1980–2004)	164	4.3	Wells drilled ~1980–2010. Both well integrity and barrier failures. Further 41.4% of wells identified as high risk of failure.	Calosa and Sadarta (2010)
USA	ONSHORE Pennsylvania, USA (wells drilled 2008–2013)	6466	3.4	Wells drilled 2005–2012. Well integrity and barrier issues. Leak to surface in 0.24% wells.	Vidic et al. (2013)
China	ONSHORE Kenli Resevoir, China (dates unknown)	173	2.9	Barrier failure	Peng et al. (2007)
USA	ONSHORE Marcellus Shale, Pennsylvania, USA (wells drilled 2008–2011)	3533	2.58	Wells drilled 2008–2011. Well integrity and barrier failure	Considine et al. (2013)
USA	ONSHORE Nationwide CCS/Natural Gas Storage Facilities (dates unknown)	470	1.9	Well integrity failure. Described as significant gas loss.	IPCC (2005)

The IESC (2014, page 36) is similarly concerned about well integrity since decaying CSG wells could provide preferred pathways for GAB water responding to depressurisation and so accelerate drawdown.

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Even wells with adequate casing and backfilling may fail after a long time due to corrosion of the casing materials or chemical alteration of the grout.

Experimental and field evidence suggest that cement casing in some CSG wells will fail, either in the short term during production or in the long term after plugging and abandonment. Wells may become conduits for water movement in a depressurised basin. Drawdown may be accelerated.

Drawdown is not an accident. It is induced during CSG mining by the pumping of large volumes of water from coal seams. Drawdown is gravity at work. Once started, drawdown cannot be stopped.

In her 2014 CSG Review, the NSW Chief Scientist and Engineer presented a blueprint for scientists and legislators to follow. The plan was to reduce any threat to human health and the environment that drilling holes through the GAB may cause.
Leaking wells at Camden are proof that regulations to improve well construction have not worked, have partially worked or have not been thoroughly monitored.
Scientists are still researching drawdown, connectivity and well integrity. Some brilliant work has been done, particularly with the isotopic signature of methane, but researchers have not yet been able to fill all knowledge gaps mentioned in the blueprint.

Santos has submitted a huge EIS with a gigantic flaw. Despite warnings from the IESC and the NSW Chief Scientist & Engineer they have insisted on measuring connectivity and predicting the extent of drawdown using mathematical modelling.
So, the threat to artesian water remains from a project that NSW and Australia do not need and cannot afford. Santos is diverting natural gas from Bass Strait and Gippsland, NSW's long time providers, to their LNG plant at Gladstone for export.
Santos also sold gas to Sydney through a pipeline from Moomba, now diverted to Gladstone as well, These actions have driven the price of domestic gas from around $4 per GJ to $20, hurting households and industry. That's a problem for the federal government to handle.
Santos gambled with Gladstone and lost to a price war between OPEC and US shale oil, and a world awash with relatively cheaper methane from Qatar, USA, Israel and Russia.
CSG gas has the highest wellhead cost of all (about $7 per GJ compared to the US cost of about $3) Factor in transport and conversion to LNG and it appears Santos will struggle to be competitive or even profitable if they continue to mine coal seam gas.
The NGP is a costly mistake for Santos and becoming more expensive as global oil and gas prices remain low.
Current and future residents of the Namoi valley should not be expected to risk water resources on a corporate bungle.
Yours faithfully,

Bill Newell.

W J Newell

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