



Reply to: Sally Hunter, Baan Baa
by email: sallyhunter030508@gmail.com

22 May 2017

Submission: Environmental Impact Statement for the Narrabri CSG gasfield

Thank you for the opportunity to make a submission to the Environmental Impact Statement for the proposed CSG gasfield at Narrabri.

The North West Alliance is an affiliation of groups across North West NSW who have an interest in education and advocacy around extractive industries projects. It is comprised of local, regional and state-wide community groups including groups based in Narrabri, Bellata, Maules Creek, Coonabarabran, Gilgandra, Dubbo, Coonamble, Burren Junction, Walgett, Tamworth, Armidale, Mullaley and the Liverpool Plains.

Members of the North West Alliance are united in our opposition to this gasfield and its associated infrastructure and pipeline. These developments are a wholly inappropriate land use for the Pilliga Forest and its surrounding productive farmland and poses unacceptable risks to the Great Artesian Basin and Namoi alluvium upon which the agricultural industries and towns of our region rely.

The gasfield is an industrial development in an area that is one of 15 biodiversity hotspots around the country, and an important refuge for declining woodland birds and migratory species. The Pilliga is also a crucial part of the cultural and spiritual life of the Gomeroi people and a beloved natural place of recreation and exploration for the broader community.

We are disappointed with the poor quality of the Environmental Impact Statement which includes information that is out of date and indicates poor attention to detail and a general lack of thorough data collection and analysis. It is unfortunate that community groups must commission independent review of the various parts of the Environmental Impact Statement in order to obtain accurate and objective analysis of the likely impacts of this gasfield on our communities, environment and economy. Nevertheless, we have obtained a series of expert reviews of the material provided by Santos which we append to this report.

We provide a summary here of some of our key objections and the most glaring problems with the EIS and Santos' proposal, but seek the assurance of the Department of Planning that the problems, questions and gaps raised by the expert reviews we provide with this submission will be addressed in full.

Sincerely,

Nicky Chirlian
Willow Tree

Peter Small
Coonabarabran

Jan Robertson
Gilgandra

Sally Hunter
Baan Baa

Megan Kuhn
Bundella

On behalf of the North West Alliance

Summary

Water

- All member groups of the North West Alliance have expressed major concerns regarding the risk to ground water. As our three expert reviews on this subject make clear, the material presented by Santos is inadequate for the purpose of assessing the impact of this gasfield and has not accurately characterised the risk.
- Of critical importance to the North West Alliance is the recognition in the EIS that the effects of pumping CSG production water will impact the area on a regional scale.
- More than one reviewer identified a basic lack of data on hydraulic head measurements prior to the development proceeding. This will make any landholder's attempt to secure "make good" actions from Santos next to impossible and is unacceptable. A baseline of the pressure, height and quality of water in the overlying productive aquifers must be established.
- The appended reviews should be read in conjunction with each other. Hayley's review was strictly limited to the adequacy of the model and its inputs and is augmented by the detailed local knowledge and knowledge of research literature relevant to the local area in Broughton.
- Andrea Broughton's expert review (Appendix C) provides detailed responses to Santos's EIS for the Narrabri Gas Project which provide specific information as to lack of data, paucity of modelling and predictions based on a model with a low level of confidence.
- Dr Matthew Currell (Appendix B) found that the risk of ground and surface water contamination as a result of the gasfield activities is high, and the potential impact of this contamination severe, given the unusually high quality of water in the Pilliga sandstone, the unusually poor quality of water in the target coal seams and the high rate of spills and leaks evident in research into unconventional gas drilling in several states in the US.
- Currell also found that there was little to no consideration of fugitive gas migration into aquifers overlying the target coal seams, posing a groundwater contamination and safety hazard as well as a greenhouse and air pollution risk.
- These are important risks, identified early by local communities that could lead to detrimental impacts to the environment and/or water users, if not appropriately managed. Decision-makers reviewing the EIS should carefully evaluate these risks, given the reliance of agricultural industries and communities on good quality and available groundwater. We seek assurance from the Department of Planning that the problems, data gaps and inadequacies identified in these reviews will be addressed in full.
- Section 7.6 of Appendix F Part 1 refers to make good provisions "that *may* be followed" (our emphasis) and these appear to only be offered for "unanticipated consequences."
- In the absence of baseline data on water being provided with the EIS, this commitment is worth nothing. It will be impossible and expensive for landholders to have to demonstrate that the water loss they experience is a result of the gasfield and this wafer-thin "commitment" to make good any losses is no commitment at all.

Social and economic

- Rigorous community-based, neighbour to neighbour, surveys have been diligently conducted by individual communities for over four years across our North West region. Community survey teams visited every house in their district, to invite residents to respond to the question, "Do you want your land/road gasfield free?" To date, over 100 communities in the North West have overwhelmingly rejected gasfield expansion on their lands and rural communities.

- Comprehensive data from these surveys has been carefully collected and collated. Community survey teams were diligent in visiting every house in their locality, with an overwhelming response: 96% of respondents want their homes, farms and communities gasfield free. To express their determination and solidarity, these communities have subsequently declared themselves gasfield free “by the will of the people” in an area covering 3.28 million hectares encircling the Pilliga, across nine local government areas.
- Six local government areas in the North West region have adopted moratoria in regard to coal seam gas and associated infrastructure.
- The social impacts of this gasfield are of profound concern to our network and have been inadequately described and assessed in the EIS. Lockie (Appendix F) found that the report is not transparent with the evidence on which claims about social impact significance, likelihood and consequences are made.
- Lockie concluded that the impact predictions and mitigation measures proposed in the SIA could not be comprehensively reviewed because insufficient detail has been provided outlining how impact significance has actually been assessed.
- We are very disappointed in the Social Impact Assessment in the EIS and its failure to address the new guidelines for such assessments prepared by the Department of Planning. Much of the information is out of date and inadequate consultation has been undertaken to discuss the ramifications of this project with people in Narrabri and surrounding districts.
- A review by The Australia Institute of the economics sections of the EIS found that it has heavily understated the costs of the project and is misleading (Appendix D).
- We do not believe that the operation of the world-renowned Siding Spring Observatory should be put at risk by the introduction of coal seam gas into the region, given the spatial intensity of the industry, its use of flares and the likelihood that one gasfield will be the beginning of further CSG expansion in the region.

Biodiversity

- A review of the ecological assessment and impact on vertebrate fauna by David Milledge (Appendix G) found that the EIS does not provide an appropriate and adequate assessment of the likely impacts of the project on vertebrate fauna, particularly threatened species.
- Specifically, Milledge asserts that the importance of the Pilliga forest and woodland nationally, and the severe environmental stress it is already experiencing, have not been given adequate consideration. In addition, the small number of species recorded means the EIS has failed to identify areas and habitat features of importance to local populations of endangered species.
- We believe that the threatened species flora surveys have also been inadequate and weed threats had been poorly considered. Decisions of this gravity, establishing a huge unconventional industrial gasfield in forest and farmland near a growing regional town cannot be made on the strength of the meagre data gathered for this EIS.
- We note that ecologist David Paull has also identified serious omissions and inadequacies in methodology of direct and indirect impacts and survey deficiencies for some key fauna species. Specifically, the assertion that there are no koala in the study area (despite 3 independent studies finding evidence) is not supported, though we concede that Koalas are under considerable stress in the Pilliga and should therefore be granted the highest possible protection and care in management of their habitat.
- Ian Campbell (Appendix E) reviewed the Aquatic ecology assessment and found that the EIS failed to conduct adequate aquatic ecology surveys and analysis. In particular, targeted surveys are required for the critically endangered river snail *Notopala sublineata*. He also found glaring problems with the water quality assessment.

Waste, toxics and pollution

- We provide a review of the produced water and waste assessment of the EIS by Associate Professor Stuart Khan.
- Khan notes that expressing salinity as electrical conductivity introduces significant uncertainty about the actual concentrations of salt in the produced water. This information should be provided.
- Khan also identifies that the EIS has clearly identified or discussed the risk of brine pond leakage which has the potential to lead to mobilisation of metals in soil, including uranium.
- Santos proposes to irrigate with treated produced water, but the treatment process does not appear to include removal of metals and other contaminants. We note that AGL was forced to abandon a CSG wastewater irrigation trial in Gloucester because of unacceptably high levels of salt and heavy metals.
- There is no indication that any treatment disposal mechanism or licenced facilities exist that have capacity to take the solid salt waste produced by the water treatment plant, nor any analysis of the chemical composition of this waste. There is no information about how much of this salt will be stored at any one time at the Leewood site.
- Khan identifies landfill of salt waste brings potential of seepage of saline leachate to ground and surface water and that such storage must be maintained permanently, saying there is considerable likelihood of such a facility contaminating groundwater and surface water over the long term. This is not discussed at all in the EIS.
- There is no chemical analysis provided of the water that has already been brought to the surface as part of Santos' drilling activities in the Pilliga.
- We believe that the use of flaring poses unacceptable air quality risk and poses the unacceptable serious bushfire risk. We also believe the Rural Fire Act should be changed so that the petroleum industry must adhere to local fire conditions set by the RFS, and not flare in conditions above high fire danger.
- Given that the US EPA has banned flaring and that this practice produces toxic air pollutants, we seek the Department's support in ensuring there will be no flaring used at this gasfield and that other means will be used to deal with gas.
- The EIS notes that the project is considered to be a potentially hazardous industry due to large volumes of Class 2.1 flammable gases being present i.e. methane. The EIS notes that there is a medium risk of fire and explosion resulting in a large scale bushfire. This is an unacceptable level of risk to the community.
- Santos refer to a "health impact assessment" in the EIS but there is no health impact assessment in evidence, rather there is initial evidence of identification of areas to screen. It is frankly appalling that a document purporting to be or contain such an assessment would be exhibited by the Department of Planning for a coal seam gas project, given the known and suspected health impacts of unconventional gas.
- The NSW Chief Scientist's report into CSG found that there are human health risks at all stages of CSG extraction, with exposure via water, soil and air pollution and health effects including respiratory, cardiovascular and reproductive effects.
- Crucial work identified by that report has not been completed, including creation of an insurance mechanism and work to identify exposure pathways that affect human health. Meanwhile, considerable additional evidence has been documented in peer-reviewed studies demonstrating the health effects of unconventional gas.
- The National Toxics Network submission includes myriad specific questions and problems with the way chemicals and the risks associated with drilling, handling, recovery and disposal are dealt with

in the Environmental Impact Statement that the members of the North West Alliance likewise want addressed.

- Gas migration is a serious issue for coal seam gas operations and recent research has indicated that it may be dramatically underestimated. We urge the Department to seek independent analysis of this risk as there is little to no evidence that the EIS has adequately dealt with it.

Aboriginal cultural heritage

- We include in the appendices a review of the Aboriginal cultural heritage assessment and management plan by Peter Kuskie.
- Kuskie raises serious problems with the approach taken by Santos in mapping and modelling cultural heritage significance and recommends that the mapping should be set aside.
- We note deficiencies identified in the consultation process, the transparency of Santos' assessment and in the proposed management plan.
- We believe that decisions about the protection and management of Aboriginal cultural heritage should be in the control of Gomeroi people and urge the Department of Planning to ensure that there is free and informed consent by Gomeroi people in decisions about the management of the Pilliga.

The points above are a summary of the material provided to the North West Alliance in review of Santos' Environmental Impact Statement. The detailed reviews are attached and we look forward to each of them being addressed in detail by the Department of Planning and Santos.

Appendix A: Kevin Hayley, Groundwater Solutions, review of the numerical groundwater modelling component of the Narrabri Gas Project EIS.

Appendix B: Dr Matthew Currell, review of ground and surface water quality

Appendix C: Andrea Broughton, review of groundwater impact assessment

Appendix D: Rod Campbell for The Australia Institute, review of economic impact assessment

Appendix E: Ian Campbell, review of aquatic ecology assessment

Appendix F: Prof Stewart Lockie, review of social impact assessment

Appendix G: David Milledge, review of vertebrate fauna

Appendix H: Ass Prof Stuart Khan, review of produced water management and waste

Appendix I: Peter Kuskie, review of Aboriginal cultural heritage and management plan



Groundwater Solutions

Review of Santos Narrabri Gas Project Environmental Impact Statement

Kevin Hayley

May, 2017

1 Executive Summary

This report is the result of independent review of the numerical groundwater modelling component of the Narrabri Gas Project (the Project) Environmental Impact Statement (EIS). Construction of the numerical groundwater model is deemed to be based on sound reasoning and consideration of background information, and is consistent with standard industry practice and relevant guidelines. There is a lack of observation data used to calibrate the model parameters with the exception of the net flux to groundwater over the Naomi Alluvium aquifer. As a result, the selected model parameters are based on expert review of background information and as such, have greater uncertainty than model parameters calibrated to observation data. The key model parameters and predictive model stresses influencing predictions of groundwater impact, have a large level of uncertainty, which results in high uncertainty in the model predictions.

The predictive uncertainty analysis presented in the EIS is deemed to be inadequate for two main reasons:

The uncertainty analysis lacks statistical rigour to be able to assess the likelihood of adverse impacts to groundwater receptors.

A conservative predictive simulation is not run or presented. A conservative simulation is one that adopts combinations of model parameter values and representation of development stress that would produce the largest impact on receptors, while maintaining parameter values that are within a plausible range given existing system understanding and observations. This is a worst-case scenario that cannot be discounted on the basis of currently available understanding and observation data.

Recommendations for further work on predictive uncertainty analysis are given in Section 12.

2 Reviewer Qualifications

Kevin Hayley is a consulting geophysicist and groundwater modeler with 13 years of experience in the construction and calibration of numerical models of groundwater flow and contaminant transport, and in using geophysical methods for environmental monitoring and mineral exploration. He received his Ph.D. from the University of Calgary in 2010 where he conducted research into monitoring salt-impacted soil using time-lapse geophysics. He has strengths in numerical methods, inverse problems and uncertainty analysis. He has authored more than 20 peer reviewed journal and conference papers on topics ranging from geophysical inversion methods to computational hydrogeology with cloud computing. He has conducted several groundwater modelling projects with large transient datasets involving calibration and uncertainty analysis for environmental impact assessments of Oil sands extraction in Alberta Canada, mine planning, and large infrastructure projects in Victoria Australia. He holds accreditation as a professional Geophysicist and Geoscientist with governing bodies in the Canadian provinces of Alberta and British Columbia.

3 Introduction

Groundwater Solutions Pty. Ltd. was retained by the NSW EDO on behalf of the North West Alliance community group to review, and provide expert professional opinion on the groundwater modelling

component of the EIS for the Project submitted to the New South Wales (NSW) Government by Santos Ltd. [Santos Ltd., 2017]

Specifically, Groundwater Solutions was requested to address the following questions:

In your opinion are the groundwater conceptual and numerical models, including design, construction, uncertainty, sensitivity analysis and data inputs, adequate?

In your opinion are the predictive modelling and potential groundwater impacts identified in the EIS appropriate?

Provide any further observations or opinions which you consider to be relevant, including in relation to the potential impacts of the Project on groundwater.

To address these questions, Appendix F of the EIS the Project Groundwater Impact Assessment (GIA) [Santos Ltd., 2017], and Chapter 11 of the EIS were reviewed with respect to the Australian Groundwater Modelling Guidelines [Barnett et al., 2012] and other relevant technical literature.

Results of the review of the groundwater modelling work completed for the Project application are discussed below, and are subdivided into the main components of a groundwater modelling project to allow evaluation of each stage of the modelling process. The questions outlined above form the basis of the discussion section.

This review has been conducted in accordance with the 'Expert witness code of conduct' (Schedule 7, Uniform Civil Procedure Rules 2005).

4 Background

The proposed development of the Project, involves installation of up to 850 gas wells on 425 pads over an area of 950 km². Gas extraction wells will target coal seams at 500m to 1,200m below ground surface, and water will be pumped to depressurize the coal seam and allow for gas development. As part of the investigation into potential environmental impacts of the project, a numerical model of groundwater flow was built for Santos by hydrogeological consultants CDM Smith, in order to simulate the impact on near surface water supply aquifers that are connected to sensitive Groundwater Dependent Ecosystems.

The predictions of interest from this model are the propagation of pressure changes from the targeted coal seams in the Gunnedah-Oxley Basin, to shallow water supply aquifers including the Namoi Alluvium and Great Artesian Basin (GAB) Pilliga Sandstone.

5 Model Objectives

The stated objectives of the Project modelling component as outlined in Section 6.1 of the GIA are as follows:

- *Estimate changes in hydraulic head in the target coal seams, and water table elevations in connected hydro-stratigraphic units due to the proposed coal seam gas field development activities;*
- *In areas where drawdown is predicted, estimate the recovery time for hydraulic head to return to pre- coal seam gas development levels;*
- *Identify and quantify the potential groundwater loss or gain in each Water Sharing Plan zone due to intra and inter-formational flows; and*

- *Identify those landholders who may potentially be impacted by coal seam gas activities and quantify the predicted impacts.*

A notable amount of effort has been expended to review available data sources, conceptualize the groundwater system and develop a numerical model of groundwater flow. The model is based on a logical review of available data, reasonable simplifying assumptions, and consistent with best industry practices. The numerical model developed for the Project is deemed fit for the purpose of meeting the stated objectives.

However, in the absence of a calibration dataset that could inform predictions, or a statistically rigorous predictive uncertainty analysis, the model predictions are a qualitative expression of expert opinion consistent with the physics of groundwater flow rather than a quantification of predicted impacts.

Moreover, Pre-coal seam gas development levels in the target seams are unknown due to absence of baseline hydraulic head measurements, and any estimate of change in hydraulic head in that unit will be uncertain as a result of this data paucity.

Therefore, the achievement of modelling objectives is limited by lack of calibration and baseline data, and lack of statistical rigour in uncertainty analysis.

6 Conceptual Model

A conceptual model is a qualitative description and understanding of a groundwater flow system based on current knowledge of geology, climate, observable aspects of the hydrologic system in surface water features and wells, and expert opinion.

In a numerical groundwater modelling study, a conceptual model is used as the basis for a numerical model that can simulate the flow of groundwater through the subsurface. This section is structured to assess the main parts of the conceptual model which include hydro-stratigraphy, parameter selection, data review, and interpretation of likely groundwater flow.

6.1 Hydro-stratigraphy

A critical review of the hydro-stratigraphic conceptual model would require location specific knowledge and experience that is outside this reviewer's area of expertise, and as such, a review of the hydro-stratigraphic conceptual model is outside the scope of this review.

It is noted that only one hydro-stratigraphic conceptual model was created and alternative geometries were not considered. Hydro-stratigraphic conceptual models based on point observations from borehole data have uncertainty due to the interpretation and interpolation that must be performed between observation data locations, even with studies based on a relatively large geological dataset such as this one. Although it requires substantial additional effort, and as a result, is rarely done in practice, the consideration of alternative conceptual models is recommended by the Australian Groundwater Modelling Guidelines [Barnett *et al.*, 2012]. Uncertainty in conceptual models and the resulting numerical model geometry, is not incorporated into commonly used parameter uncertainty methods [Doherty, 2015], and as a result can introduce uncertainty and bias into model predictions that are difficult to quantify. Previous studies investigating the topic of conceptual model uncertainty [Refsgaard *et al.*, 2012], suggests that conceptual model uncertainty is a dominant source of predictive uncertainty in modelling projects lacking calibration data such as this one. Different geological interpretations about how the

Gunnedah-Oxley Basin sub-crops beneath the Namoi Alluvium could have a large impact on model predictions.

6.2 Hydraulic Parameters

A key parameter for the predictions of propagating pressure changes due to the depressurisation of the target coal seams, is the vertical hydraulic conductivity (K_v) of stratigraphic layers between the coal seams in the Gunnedah-Oxley Basin and the receptors in the Namoi Alluvium and GAB Pilliga Sandstone. As discussed in the GIA, K_v parameters can assume a large range of values for sedimentary rocks, up to seven orders of magnitude for sandstones, and as stated in the GIA: “*The existing ranges of values for K_v adopted for strata of the GAB and Gunnedah-Oxley Basin vary over almost four orders of magnitude from 1E-6m/d to 4E-3m/d.*” (P 5-10 of the GIA). Based on the geological interpretation of laterally continuous aquitards, CDM Smith, formed an expert opinion that the most likely value of K_v is on the low end of the existing estimates. This opinion is supported by reasonable arguments based on literature review of typical rock property values [Bear, 1972; Freeze and Cherry, 1979], and observed pressure and salinity changes between deep Gunnedah-Oxley Basin strata and shallow aquifers. However, the application of literature values for a rock type to a numerical model layer representing several hydro-stratigraphic units lumped is subject to uncertainty as discussed further in Section 8.2.

6.3 Data Review

A thorough assessment of publicly available water table data was conducted by CDM Smith to develop a conceptual model of groundwater flow. Deeper pressure measurements from drill stem tests (DST) were discounted based on observations of pressure increasing at a rate greater than hydrostatic pressure with depth. The higher-pressure observations in the DST data were used to support the qualitative interpretation that the deep groundwater system is well confined and resistant to rapid pressure propagation to overlying units including the shallow water supply aquifers. The absence of hydraulic head measurements in the deeper hydro-stratigraphic units from wells installed as part of pilot projects is a limitation of the groundwater flow system assessment. Transient observation of hydraulic head in deeper Gunnedah-Oxley Basin strata above the Bibblewindi 9-Spot Pilot location were reviewed by CDM Smith. The observed hydraulic head changes were interpreted to be not responding to the groundwater extraction during the one year time span of observation, this interpretation was also used to support of the qualitative interpretation of a confined deep groundwater system, which is reasonable for the area near the Pilot location.

6.4 Groundwater Flow System

Based on the geological interpretation and the available hydraulic data, a conceptual model of flow was formed that contains a shallow Alluvial system, the Namoi Alluvium, consisting of sands and gravels interacting with a deeper bedrock system, the GAB and Gunnedah-Oxley Basin, which consists of layered sandstones, mudstones, shales and coal seams. In regions where the permeable bedrock aquifers are in contact with the alluvial sediments, some connectivity and interaction exists between the units.

6.4.1 Faulting

CDM Smith contends that faults in the area do not contribute to groundwater flow based on seismic data leading to the interpretation that faulting is Permian to Triassic (>200 Million years) in age.

This is a reasonable assumption, and a more critical analysis would require detailed knowledge of the regional geology which is outside this reviewer's area of expertise.

6.4.2 Implications

The key implication for the predictions of impacts to the Naomi Alluvium is identified on page 5-40 of the GIA, *"Connections between the target coal seams and alluvial units will control the potential magnitudes and locations of impacts on shallow groundwater sources in the alluvium."*

The above statement also applies to predictions of impacts in the GAB Aquifers. A hydraulic connection between the target coal seams and the GAB Pilliga Sandstone or Namoi Alluvium could occur through heterogeneity (holes) in confining layers, faulting, or the connection at the interface between the Gunnedah-Oxley Basin strata and the Namoi Alluvium. If a hydraulic connection exists, the pressure changes due to coal seam gas development could propagate at a faster rate and higher magnitude, causing a larger degree of impact to the water supply aquifers.

7 Numerical Model Design and Construction

7.1 Model Code

MODFLOW-SURFACTTM was selected as a modelling code for the Project due to its numerical stability when simulating unconfined conditions. The open source MODFLOW USG code [Panday *et al.*, 2013] would also have been a valid alternative. However, MODFLOW-SURFACTTM is deemed to be an appropriate choice.

7.2 Model Discretization and Layers

To make predictions of groundwater impacts, a numerical model requires that a region of interest be broken up into discrete cells or elements, where the partial differential equations governing groundwater flow are solved.

The discretization interval of 1 to 5 km is appropriate for a model of this large regional scale (53,000 km²). The simplification of the hydro-stratigraphic conceptual model into aquifers and aquitards is reasonable for the predictions of interest, and the vertical discretization of the model layers is appropriate.

7.3 Boundary conditions

Boundary conditions applied at the model lateral extents are derived from consideration of the conceptual model of groundwater flow, they are far enough from the area of simulated stress to avoid influence. The application of a river boundary condition is reasonable, and recharge outside the Namoi Alluvium is estimated based on logical assumptions of climate and geology. The net flux over the Namoi Alluvium is estimated based on an observation dataset of water table elevations discussed in Section 8.

8 Numerical Model Calibration and Sensitivity Analysis

Model calibration is a process of estimating model parameters that cause a model to best reproduce historical observations. Models with a large amount of calibration data that is similar to the predictions being made, and with a calibration time frame larger than the prediction time frame are considered to have a lower degree of extrapolation and a lower degree of predictive uncertainty

[Barnett *et al.*, 2012]. Models with limited calibration data that is similar to predictions being made are considered to have a high degree of extrapolation and higher predictive uncertainty.

8.1 Model Calibration

CDM Smith used an inverse modelling technique to estimate steady net flux into the Namoi Alluvium based on water table elevation observations. This flux is a combination of recharge, evapotranspiration, pumping, and surface water interaction not captured by the river boundary condition. As stated in the GIA, the focus of the calibration procedure was to produce an initial head distribution for the predictive modelling that was consistent with the observed water table elevations and the results of a steady state equilibrium model. All model parameters other than the net flux over the Namoi Alluvium were fixed at initial estimates.

With respect to all model parameters other than the net flux over the Namoi Alluvium, the model is uncalibrated.

No deeper hydraulic head measurements or transient observations from pilot projects were used to constrain model parameters. As a result, the parameterization of the model other than the net flux over the Namoi Alluvium is not constrained by any hydraulic observation data and will have a higher degree of uncertainty.

8.2 Adopted Hydraulic Parameters

The adopted values of hydraulic parameters used for predictive modelling are discussed in Section 6.7 of the GIA, and are based on a reasonable review of existing data, previous studies, geological interpretations and literature values. A key comment on this section concerns selection of the K_v of the aquitard layers, because these layers are the dominant controls on the connectivity between the target coal seams and the receptors in the Namoi Alluvium and GAB aquifers this parameter will control the speed and magnitude of pressure propagation from the target coal seams to the water supply aquifers. CDM Smith argues for the adoption of values that are on the low end of the existing estimates, based on literature values for clay and shale aquitards, and evidence based on pressure and groundwater salinity changes with depth. In the simplification of the hydro-stratigraphic conceptual model into numerical model layers, several distinct hydrogeological units ranging from sandstone, coal, and clay to marine shales were lumped together as an aquitard. This could lead to an underestimation of drawdown propagation to receptors if there is spatial heterogeneity in the presence, thickness and competence of the interpreted low conductivity hydro-stratigraphic units. Adopting aquitard literature values for the bulk rock property of the combined unit on a regional scale may be an underestimate of vertical conductivity. The key point is that the vertical hydraulic conductivity parameters that control the predictions of interest have a relatively high level of uncertainty.

9 Predictive Modelling

Predictive modelling is based on the simulation of historical production of water from Gunnedah-Oxley Basin coal seam gas Pilot Projects in the region and the planned Project development. As with all simulations, a level of uncertainty is associated with the future scenarios as the final actual development of the field is likely to differ from current plans in timing, location, and magnitude of pumping, due to unforeseen events and additional information gained during development.

9.1 Coal seam development simulation

Simulation of groundwater extraction in the target coal seams is conducted by extracting water from the system at a specified rate from grid cells designated as pumping wells. The specified rates are based on results of reservoir modelling simulations that account for the complexities of coal desaturation that cannot be included in a regional groundwater model, due to scale and computational difficulty. Uncertainty in coal porosity in the reservoir simulation extends into the specified rates, and has been accounted for by providing three alternative levels of water extraction: base, high and low, to represent uncertainty in water extraction rates. Additionally, the reservoir modelling will not necessarily account for leakage into the reservoir from surrounding strata which will predominantly be controlled by the permeability of the rock closest to the coal seam.

If the hydraulic conductivity of layers surrounding target coal seams is high, the application of well boundary conditions to represent coal seam desaturation may undervalue the total water extracted from the system due to under estimation of leakage into the coal seams. This will result in under-prediction of impacts at receptors. However, in the absence of a large degree of leakage into the reservoir, application of the specified rates to a groundwater model unable to simulate buffering of pressure changes by coal desaturation, may be conservative with respect to predicting impacts at receptors.

The three alternate levels of water extraction presented (base, high and low), do not account for uncertainty in leakage into the reservoir. Simulation of coal seam depressurization is a complex process that cannot be simulated in a regional groundwater model due to the high computational burden of simulating multiphase flow. The simplification of the processes required to approximate it in a groundwater model, results in subjective decisions with inherent uncertainty. Thus, the range of the three extraction rate values produced by the reservoir modelling may not span the full range of appropriate extraction rates to apply to a groundwater model to capture the uncertainty in simulating coal desaturation.

The variability and uncertainty in possible extraction rates is not included in any of the simulations investigating the effect of the Narrabri Coal Mine adjacent to the Project or parameter uncertainty, so the combined effect of higher than base case extraction and higher K_v layers or cumulative effect of the Narrabri Coal Mine is never presented.

9.2 Cumulative effects

Other projects in the region were reviewed for the potential for significant cumulative impacts. The development of Narrabri Coal Mine Stage 2 Longwall Project was identified as having the potential for cumulative impacts, other regional development projects were not considered because the effects on predictions were anticipated to be negligible.

The development of Narrabri Coal Mine Stage 2 Longwall Project was simulated in two scenarios: mine development in isolation, and mine development combined with the base extraction rate representation of the Project.

The results of the two Narrabri Coal Mine simulations were compared to infer the relative additional impact of the Project which was deemed to be small relative to the impact of the Narrabri Coal Mine. However, cumulative effects of the Narrabri Coal Mine are not considered in any of the other simulations exploring the effect of higher or lower water production for the Project or hydraulic parameter uncertainty.

10 Predictive Uncertainty Analysis

An informal qualitative predictive uncertainty analysis was conducted by CDM Smith to examine the sensitivity of predicted impacts to variations of hydraulic parameters. The K_v of hydro-stratigraphic units between the targeted coal seams and the receptors was varied by one order of magnitude. The K_v controls the rate and magnitude of upward propagation of pressure changes, higher K_v leads to faster and larger pressure propagation.

The specific storage of the conductivity of the hydro-stratigraphic units between the targeted coal seams and the receptors was varied by one order of magnitude. Specific storage controls the amount of water released from compressed storage due to pressure changes. A low storage system will allow larger magnitude pressure changes due to coal seam dewatering to propagate more quickly.

The equivalent parameter for unconfined units is specific yield, which controls how much water comes out of a unit due to decline in the water table. Groundwater extraction from low specific yield systems will cause greater drawdown at the water table than high specific yield systems.

Only one simulation considered combined effects of parameter changes (BCS-5) which used a higher K_v and lower specific storage. All predictive uncertainty simulations used the base level of water extraction and neglected cumulative effects, so, as discussed in section 9.1, the combined effect of higher than base case extraction, higher K_v and lower specific storage is not presented.

11 Discussion

11.1 Conceptual Model, Numerical Model Design and Construction

In this reviewer's professional opinion the groundwater conceptual model, numerical model design and construction are adequate for the stated modelling objectives and meet the standards outlined in the Australian Groundwater Modelling Guidelines [Barnett *et al.*, 2012] and other technical references e.g. [Anderson and Woessner, 1992].

11.2 Model Calibration

The calibration data used for the Project are near surface water levels which will provide some information about the regional directions of groundwater flow. However, near surface water levels will provide no constraint on the aspects of the model that control the connectivity between the targeted coal seams and shallow receptors in the Namoi Alluvium and Pilliga Sandstone. The regional direction of groundwater flow is fairly irrelevant with respect to predictions of drawdown and capture [Leake, 2011]. Therefore, the existing hydraulic head dataset provides no constraint on predictions and the model is effectively uncalibrated.

As discussed in section 5.3.2 of the Australian Groundwater Modelling Guidelines [Barnett *et al.*, 2012], modelling without calibration is of value, and predictive uncertainty analysis can still be undertaken using the initial parameter estimates and uncertainties, although there is a lower degree of confidence in predictions. For data input to provide a meaningful reduction in predictive uncertainty it needs to be similar in nature to the predictions of interest [Christensen *et al.*, 2006; Watson *et al.*, 2013; White *et al.*, 2014]. An example of this type of dataset would be long term depressurization of the target coal seam and transient observation of drawdown in overlying layers. Thus, truly useful data for constraining predictions of impact will not be available until the project has been constructed and operating.

11.3 Uncertainty analysis

A widely adopted philosophy of science is that a theory can never be proven correct only disproven by data [Popper, 2005]. The existing model can be thought of as expressing the most likely outcome based on the prior understanding of the model system, however there are an infinite number of alternative models consistent with all observations and background knowledge [Tarantola, 2006]. The acceptance of alternative models is a guiding principal of the Australian Groundwater Modelling Guidelines [Barnett *et al.*, 2012]. The combination of this philosophy with Bayes statistical theorem [Bayes, 1763] forms the basis of most applied uncertainty analysis methods.

Section 1.5.5 of the Australian Groundwater Modelling Guidelines [Barnett *et al.*, 2012] states:

“The level of effort applied to uncertainty analysis is a decision that is a function of the risk being managed. A limited analysis, such as an heuristic assessment with relative rankings of prediction uncertainty, or through use of the confidence-level classification, as described in section 2.5, may be sufficient where consequences are judged to be lower. More detailed and robust analysis (e.g. those based on statistical theory) is advisable where consequences of decisions informed by model predictions are greater.”

Given that the Project involves installation of substantial infrastructure, and groundwater extractions from bedrock units in areas where current extraction levels have reached, or exceeded, sustainable groundwater diversion limits (Section 2.13 of the GIA), the consequences of the decisions made by this model are deemed to be large. Considering, the model predictions are unconstrained by a calibration dataset, quantification of predictive uncertainty is the only quantitative analysis that can be performed.

In the uncertainty analysis conducted by CDM Smith, simulations to assess the sensitivity of model predictions to variations in extraction rate and model parameter values are done independently. The sensitivity simulation BC-S5 varied both vertical hydraulic conductivity and specific storage parameters. However, base case water extraction rates were used which are less than half the total volume of the high case water extraction rates, specific yield was held steady and cumulative effects from the Narrabri Coal Mine were not simulated. A conservative simulation that includes high vertical hydraulic conductivity, low storage, low specific yield, high water extraction rates, and cumulative effects from the Narrabri Coal Mine is not presented as part of this assessment.

The existing heuristic predictive uncertainty analysis is deemed to be inadequate. A discussion of alternative approaches is provided in Section 12.

11.4 Predictive Modelling

The predictive scenarios were based on the representation of coal seam gas development as specified pumping rates derived from reservoir simulations. As discussed in section 6.1 of this report, representation of coal seam gas development in a groundwater model is challenging, requires subjective simplifications and has a high degree of uncertainty. Simulations were run to assess the predicted impact of a base, high and low level of water extraction. It is this reviewer's professional opinion that the range of uncertainty in water extraction rates should be expanded to account for the absence of formation leakage in the reservoir simulation. The extraction rates should also be included as an adjustable parameter in any further uncertainty analysis

11.5 Cumulative Effects

Simulations were conducted to assess cumulative effects of the Narrabri Coal Mine, combined with the Project using the adopted model parameters and the base case extraction rates. There is limited guidance in Australia on the appropriate way to address cumulative effects in application modelling [Nelson, 2016]. The cumulative effects simulations demonstrate that the predicted effects in a simulation of the Narrabri Coal Mine and this Project are dominated by the effect of the Mine that is not part of this assessment. Based on this, further simulations and reported results considered the Project in isolation.

A simulation of the Project in isolation is not a true representation of the actual water extraction and subsequent impacts, and the assessment of cumulative effects did not consider the uncertainty in model parameters or water extraction volumes.

A more rigorous assessment of cumulative impacts would require that the simulation of the existing and approved Narrabri Coal Mine be adopted as a 'Null Scenario' as described in [Barnett *et al.*, 2012], all simulations addressing model parameter and extraction rate uncertainty include cumulative effects assessment, and that all discussion of simulated impacts include discussion of the combined cumulative impact as well as the additive component to the impacts from the Project.

12 Recommendations

It is recommended by this reviewer that additional effort be placed on predictive uncertainty analysis.

A formal predictive uncertainty analysis can be undertaken by assessing the uncertainty in each of the initial parameter estimates, and assigning appropriate standard deviations and bounds. Unconstrained Monte Carlo sampling of parameter values followed by predictive simulations, would allow drawdown at selected locations to be quantitatively assessed in a way that could inform a discussion about the likelihood of adverse impacts.

Alternatively, linear methods of uncertainty propagation are applicable to uncalibrated models [Doherty, 2015].

The processes of water level data matching used in the Project could be challenging for formal uncertainty analysis. However, this is a result of a technical choice of calibration technique and could potentially be automated with Python scripting [Bakker, 2014], and applied to realizations of alternative hydraulic parameter sets.

It is recommended that uncertainty in the extraction rates be included in formal uncertainty analysis.

The aquitard layers in the numerical model are representations of several distinct hydro-stratigraphic units and are likely to have significant heterogeneity laterally and vertically. It is recommended that the uncertainty analysis include spatial variability in the vertical hydraulic conductivity of the aquitard layers either on a model cell by cell basis or through pilot points [Doherty *et al.*, 2011], to capture the possibility of locally distinct zones of higher K_v . Additionally, it is recommended to increase the range of possible vertical hydraulic conductivity values beyond the one order of magnitude range in values assessed in the current analysis and based on the discussion presented in Section 6.2 and 8.2 of this report.

An ideal analysis of predictive uncertainty would consider alternative conceptual models and numerical model geometries, particularly with respect to the connection between the Gunnedah-Oxley Basin and Namoi Alluvium. However, it is recognised that consideration of alternative conceptual models represents a large degree of effort and is not common industry practice. In this case, alternative conceptual models should be considered if they lead to orientations of layers representing permeable sediments in contact with target coal seams, such as the Black Jack Group, that sub crop under the Namoi Alluvium in a way that causes a larger hydraulic connection than the current model but cannot be ruled out by the existing geological dataset. However, the consideration of spatially variable aquitards discussed above will serve as a surrogate for alternative conceptual models.

It is recommended that a conservative simulation be run consisting of high vertical hydraulic conductivity, low specific storage, low specific yield, and high water use case.

Finally, as discussed in Section 11.5, it is recommended that the base model, conservative model, and uncertainty analysis be run on representation of the Narrabri Coal Mine alone and the combined simulation of the Project and the Narrabri Coal Mine, and that all discussion of impacts and uncertainty include both the predicted cumulative impact and the component of that impact caused by the Project obtained by differencing simulation results.

On this basis of this type of uncertainty analysis, an informed risk-based decision about the potential impacts of the Project can be made, by considering a most likely outcome (the current model), a high impact case that is less likely but cannot be discounted on the basis of the current observation dataset, and a histogram of predictions from formal uncertainty analysis that could provide a measure of the likelihood of higher impact results.

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Review of Environmental Impact Statement – Santos Narrabri Gas Project

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Introduction

I was briefed by EDO NSW on behalf of the North West Alliance to provide expert advice on the Narrabri Gas Project. The following report outlines my opinions regarding the environmental impact statement (EIS) that has been prepared for Santos' Narrabri Gas Project, particularly regarding issues related to groundwater and surface water quality. I have prepared this report in accordance with the Expert Witness Code of Conduct.

Background and relevant expertise

I am a Senior Lecturer in the School of Engineering at RMIT University, in Melbourne, Australia. I received my PhD from Monash University in 2011, on the use of environmental isotopes and geochemistry to assess the sustainability of groundwater usage and controls on groundwater quality in a water-stressed region of northern China. For the last 6 years while employed at RMIT I have taught hydrogeology, geochemistry and groundwater modelling to environmental and civil engineering students, and supervised Masters and PhD projects in applied hydrogeology research. I have been awarded more than half a million dollars in research funding as a lead chief investigator on more than 10 research grants, which have supported projects examining groundwater sustainability and contamination issues in Australia and China. I have published more than 25 peer-reviewed international journal articles, which have been cited more than 400 times, and I am on the editorial board of the *Hydrogeology Journal* (the journal of the International Association of Hydrogeologists).

I acted as an independent scientific expert witness regarding hydrogeology and groundwater quality issues during the Victorian Parliamentary Inquiry into unconventional gas in 2015. My submission to the inquiry was extensively cited in the committee's final report (Parliament of Victoria, 2015). I was also commissioned by the then Department of Environment and Primary Industries (DEPI) to carry out baseline monitoring of methane and isotopic indicators in groundwater in areas of potential future unconventional gas activity (Currell et al, 2016).

Summary of my opinion

It is my opinion that there are significant potential environmental impacts that could arise from Santos' proposed Narrabri Gas Project, and that the risk of these impacts occurring has not been given full and adequate consideration in the relevant sections of the EIS. Specifically, two major environmental risks associated with the project are:

1. Groundwater and surface water contamination, particularly with coal seam gas (CSG) produced water and/or other wastewater produced as a result of the project; and
2. Fugitive gas migration into aquifers overlying the target coal seams (a groundwater contamination and safety hazard) and/or to the atmosphere (a greenhouse gas and/or air pollution risk).

In my view, these are important risks that could lead to detrimental impacts to the environment and/or water users, if not appropriately managed. Decision-makers reviewing the EIS should be aware that these potential risks exist, and should be presented with detailed discussion, analysis and datasets to inform rigorous assessment of their potential magnitude and consequences, including:

- Careful analysis and discussion of both of these specific risks (1 and 2), drawing on:
 - a) lessons learned from international and local experience with similar unconventional gas projects (e.g., based on appropriate literature);
 - b) scientific information regarding the particular environmental features and factors in the project area that may cause these risks to be of greater or lesser significance; such as detailed information on groundwater recharge rates and mechanisms and the geochemical processes controlling groundwater quality.
- Appropriate baseline data related to these issues specifically, in order to characterise the pre-development levels of potential contaminants of concern (including fugitive gas and those present in produced water), and understand natural variability and drivers of changes in these;
- Detailed risk assessments and predictive modelling to inform a rigorous analysis of likelihood and consequence of various risk pathways that could result in groundwater contamination and/or fugitive methane impacts;
- Detailed management and mitigation strategies to rapidly detect, diagnose and respond to instances of environmental contamination from these mechanisms through the life of the project.

These two major risk areas are discussed further in detail below, referring to relevant literature and experience from other unconventional gas projects around the world, and examining the level to which the issues have been investigated, discussed and accounted for in the baseline data, monitoring programs, mitigation and management strategies presented in the EIS.

1. Groundwater and surface water contamination

Contamination of groundwater and surface water are major environmental risks that require careful management in any unconventional¹ gas operation (Hamawand et al, 2013; Vengosh et al, 2014; Vidic et al, 2013; Jackson et al, 2014). The major pathways by which contamination of surface and/or groundwater can take place, regardless of whether hydraulic fracturing is involved or not, are:

- a) Contamination by wastewater (e.g. produced water or drilling fluids) that is spilled, leaked and/or inappropriately managed as it is brought to the surface and subsequently stored, treated and transported around the site;
- b) Contamination due to well integrity failures, or legacy/abandoned boreholes, which allow gas and/or fluids to escape from unconventional gas reservoirs and cross-contaminate other aquifers.

According to Professor Robert Jackson (from the Stanford University School of Earth Sciences) and his colleagues, who have published extensively on the topic of environmental impacts of unconventional gas in the United States:

“Maintaining well integrity and reducing surface spills and improper wastewater disposal are central to minimizing contamination from...naturally occurring contaminants such as salts, metals, and radioactivity found in oil and gas wastewaters. Several recent reviews have discussed the potential water risks of unconventional energy development” (Jackson et al, 2014, p.241).

For coal CSG projects such as the Narrabri Gas Project, the major potential contamination source is ‘produced water’ that would be pumped from the coal seams in order to de-pressurise these and allow gas to de-sorb and flow freely (via the gas wells) to the surface. CSG produced water typically exhibits poor

¹ Note: In this report (as is standard in the research literature), the term ‘unconventional gas’ covers any project that extracts gas from onshore areas using directional (e.g., horizontal) drilling, in geological formations that do not have significant natural permeability, including coal, shale or other ‘tight’ sedimentary rocks. The term ‘unconventional’ includes gas developments in these settings, with or without hydraulic fracturing – which is not proposed to be adopted in the Narrabri Gas Project.

quality, due to its extended periods of residence within coals (Hamawand et al, 2013; Khan and Kordek, 2014). Contaminants that are characteristic of CSG produced water include high levels of sodium, heavy metals and other trace elements (such as barium and boron); high levels of salinity (e.g., total dissolved ion contents of >5g/L, in some cases up to 30g/L); fluoride, ammonia, organic carbon and other potential contaminants (APLNG, 2012; Biggs et al, 2012; Hamawand et al, 2013; Khan and Kordek, 2014).

The risks associated with potential groundwater and/or surface water contamination with produced CSG water are of particular significance in the Narrabri Gas Project (in comparison with other gas projects), due to:

- a) The apparently unusually poor water quality associated with the particular coal seams targeted in the project (Gunnedah Basin coals), and
- b) The unusually high quality of the shallow groundwater and surface water in the project area, which covers areas of potential recharge for the Pilliga Sandstone² – one of the main aquifers in the southern Great Artesian Basin (as is further discussed below in section 1.3), as well as the importance of water in the Namoi Alluvium (which also occurs within or close to the project area) to local water users.

To this end, the EIS should contain:

1. Detailed chemical characterisation of produced waters sampled during gas exploration activity in the project area to date, and detailed baseline groundwater chemistry data in overlying aquifers which may be affected by contamination with such water, such as the Pilliga Sandstone and Namoi Alluvium;
2. Discussion and analysis of the potential pathways and mechanisms by which contamination of shallow aquifers by produced water could occur, such as surface spills at CSG wells, pipeline leaks or leakage/overflow from storage dams;
3. Discussion and analysis of previous incidents where spillage or leakage of produced water has taken place in the project area (e.g. in association with previous CSG exploration);
4. Risk assessment strategies, whereby the hazard, likelihood and consequence of contamination associated with the produced water stream (prior, during and following water treatment) are assessed, with detailed supporting assumptions and relevant data;
5. Extensive baseline datasets, extensive physical monitoring infrastructure and detailed ongoing monitoring plans to rapidly detect any incidences of groundwater contamination associated with produced water as they occur;
6. Detailed strategies to minimise and mitigate the impacts associated with produced water contamination of shallow groundwater, soil and surface water in the project area.

While some limited baseline data, and basic information covering these topics is included within various parts of the EIS (e.g. Chapter 7, Chapter 11, Chapter 14, Chapter 28, Appendix F, Appendix G3 and Appendix G4), the information provided relating to assessment and management of groundwater and surface water contamination lacks detail and/or critical supporting data commensurate with the significance of the risks and the potentially impacted receptors.

1.1 Relevant project activities

Gas will be extracted from up to 850 wells drilled throughout the life of the project³. It is estimated that approximately 37.5 billion litres (GL) of water (up to 80GL) will be produced from the target coal seams via these wells during the life of the Narrabri Gas Project (see EIS Chapter 11), or approximately 1.5 GL per year. It is documented in the EIS (Chapter 7) that this water is saline – with TDS values said to be

² The executive summary to the EIS claims that the project is “not located in a major recharge area for the GAB”; however this statement is made in the absence of detailed field-based investigations of groundwater recharge rates, and it is questionable based on a number of lines of evidence, as discussed in section 1.3 of this report.

³ According to Chapter 2, wells already drilled for exploration/pilot CSG operations within the project area may also be operated on top of the 850 new wells proposed.

‘around 14,000 $\mu\text{S}/\text{cm}$ ’ (approximately 9 g/L), although raw data showing the range of salinities and detailed chemical composition of produced waters is not included in this chapter, or the Water baseline report (Appendix G4). The quoted salinity value in the EIS is also lower than previously published estimates of the produced waters from coal seams in the project area, based on testing of produced waters from the Bibblewindi Gas Exploration Pilot project (see Khan and Kordek, 2014 who cite an average total dissolved solids content of 18 g/L and a range from 14.5 to 31 g/L).

These salinity levels are significantly higher than typical CSG production water – for example the water extracted from coal seams in the Surat and Bowen basins of Queensland, which are the largest existing CSG projects in Australia (these typically produce water with TDS contents below 5 g/L, see Biggs et al, 2012). As documented in a 2014 report to the Office of the Chief Scientist and Engineer (Khan and Kordek, 2014), in addition to having high salinity, the water produced from the coal seams in the Narrabri region also contains significant levels of heavy metals, boron and fluoride, which could make the water an environmental and human health hazard, and a major potential source of groundwater and surface water contamination in the area.

Produced water will be generated at all CSG wells drilled for the project - potentially 850 new wells, plus existing wells drilled during exploration - throughout their operating life (see figure 7-2 of Chapter 7 of the EIS). The produced water pumped from the target coal seams is planned to be managed through a ‘network of water gathering lines and in-field balance tanks’ (Chapter 7 of the EIS). Prior to treatment, the water will be stored in (lined) above ground ponds. Water production from the CSG wells is expected to peak at approximately 10 ML/day, within the first 5 years of the project, and then decline – this is typical of CSG projects (e.g. QGC, 2012). The produced water from each CSG well will be collected and piped through a network of gathering lines and pipes, and transported to water treatment facilities (Leewood and Bibblewindi), where it will be treated by reverse osmosis and a range of other standard water treatment techniques. Treated water will then be amended with gypsum salt, to reduce the sodium absorption ratio, in an effort to make the resulting water suitable for irrigation in the region (Chapter 7 of the EIS).

This water treatment system, whereby wastewater from each CSG well is transported to the Leewood facility and Bibblewindi site, means that there will be hundreds of potential sites of contamination. Point-source contamination with produced water could occur by spills and/or leaks at each CSG well-head and all of the gathering lines, pipelines and joins in the network. Above ground dams which store the produced water may also leak and/or overflow, for example in the event of major storms. Any spills or leaks of produced water that occur en-route to or during storage at the water treatment facilities, could potentially detrimentally affect the surrounding land and shallow groundwater in the uppermost unconfined water table aquifer(s).

The treatment of produced water will result in two major products being produced continuously through the life of the project:

1. Treated water (in an amount similar or equal in volume to the amount of raw produced water from the CSG wells), which will be made available for irrigation in the area. It is estimated that the treated water will have an electrical conductivity of approximately 370 $\mu\text{S}/\text{cm}$, following amendment with gypsum salt. Excess treated water is also proposed to be disposed of via direct discharge into Bohena Creek (during high-flow events). It is unclear from the produced water management plan (Chapter 7) exactly how much of this water will be stored at the Leewood facility at a given point in time, and also not clear what the proponent plans to do if there is insufficient irrigation demand or capacity to discharge to the environment (e.g. enough high-flow events to allow this), in order to absorb the volumes being produced by the gas wells and treatment plant at a given time. There are potential environmental impacts from the widespread introduction of treated wastewater into the environment, either as irrigation return flow - which would seep through the soil profile and partly re-infiltrate the water table aquifer, or as surface water discharged to Bohena Creek. While the salinity of the treated water is proposed to be relatively fresh, and similar to much of the native shallow groundwater and surface water in the area, there may be issues that arise due to the different chemistry of this water compared to the natural surface

runoff and shallow groundwater (e.g. differences in the redox, pH, alkalinity and sodicity parameters).

2. Waste brine (salt) produced from the reverse osmosis process. In the EIS it is estimated that ~41,000 tonnes of salt per year (115t per day) will be produced in the early stages of the project (see Chapter 7). However, this estimate should be viewed as somewhat uncertain, as it depends on both the volume of produced water that ultimately comes from the gas wells, and the salinity of this water. Based on the TDS estimates of produced water associated with CSG exploration in the project area provided in Khan and Kordek, 2014 (e.g., approximately 18 g/L rather than 9 g/L, as is quoted in the EIS), the overall volume of salt may be under-estimated by a factor of two. The brine produced from the Leewood facility will be a hazardous material, enriched in the chemical elements that occur in the produced water. No detailed chemical assay of this waste brine was provided in the project EIS to aid a detailed risk assessment of the production, handling and disposal of the material.

While Chapter 7 of the EIS details plans to transport the waste brine to a licensed facility, at a rate of approximately '2 to 3 B-double truck-loads' per day, outstanding questions that are not addressed in the produced water management plan include:

- Has a suitable facility been identified and have they agreed to accept the material in the estimated volumes proposed?
- How much brine can be accepted per day by the facility, and what is the total capacity of the facility (e.g. is it adequate to accept all of the waste through the project life – on the order of 1Mt of brine)?
- How much brine will be allowed to be stored at any one time at the Leewood facility awaiting transport?
- Have detailed chemical analyses and hazard assessment of the brine material been conducted, based on the wastes produced during the Bibblewindi Pilot project ?

An additional risk associated with the project (in terms of groundwater and surface water quality) is the disposal of drilling fluids. The EIS estimates (in Chapter 28) that approximately 178,000 m³ of drilling fluid will be produced throughout the life of the project. Such fluids are generally saline, turbid and contain high levels of elements used to control density, such as potassium and barium. The proponent plans to recycle as much of the drilling fluid as possible, which is a sound principle. Like produced water however, such drilling fluid is a potential land and/or shallow groundwater contamination risk if not managed appropriately and thus detailed storage, transport and management protocols should be outlined in the EIS.

1.2 Potential mechanisms of groundwater and surface water contamination

Based on international experience with unconventional gas, the size of the Narrabri Gas Project (e.g. number of wells and required infrastructure to collect, transport and store the produced water) and the past track record of CSG operations in the Pilliga region (e.g. Khan and Kordek, 2014), there is a strong likelihood that leaks and/or spills of produced water will occur throughout the life of the Narrabri Gas Project, risking contamination of shallow aquifers and surface water bodies in the area. This conclusion is based on an assessment of international literature reporting experience with numerous gas projects of similar size, for which large empirical datasets on the rates of wastewater spills and leaks have now been collected, predominantly in the United States (U.S. EPA, 2016; Patterson et al, 2017). The U.S. is a valuable example to study in this context, as it now has well over a decade of experience with unconventional gas development, and has hundreds of thousands of operating gas wells across many states and project types (shale gas, coal seam gas, tight gas). While arguably, the risks associated with wastewater spills and leaks are of a different nature in the Narrabri Gas Project (and CSG projects generally) in comparison to shale gas, which is the more common form of unconventional gas in the U.S., the risks are in some regards greater in the case of CSG, as volumes of wastewater produced per well for CSG are typically larger (Hamawand et al, 2013).

A recent study by Duke University and the United States Geological Survey (Patterson et al, 2017), showed that some form of spillage or leakage of wastewater has occurred at between 2 and 16% of unconventional gas wells drilled and operated in the United States (regardless of whether the wells are subject to hydraulic fracturing or not). Their survey included a large, representative dataset, including tens of thousands of individual wells across different states and types of unconventional gas projects. According to the data, the risk of such spillage/leakage incidents is greatest within the first 3 years of drilling and development of a given gas well. The US EPA's 5-year nation-wide review of impacts of hydraulic fracturing on drinking water (US EPA, 2016), estimated a similar percentage of spillage incidents (on the basis of smaller sample size), associated with hydraulic fracturing fluids specifically (it is noted that hydraulic fracturing will not be conducted in the Narrabri Gas Project). The Patterson et al, (2017) study included both wells that were subject to hydraulic fracturing and those that weren't, had a larger sample size, and looked at the full unconventional gas lifecycle from drilling through to decommissioning of wells, and is therefore more relevant to the Narrabri Gas Project.

Spills and leakage of wastewater at unconventional gas wells occur due to a variety of reasons, including storage and movement of wastewater via flow lines, as well as equipment failure and human error:

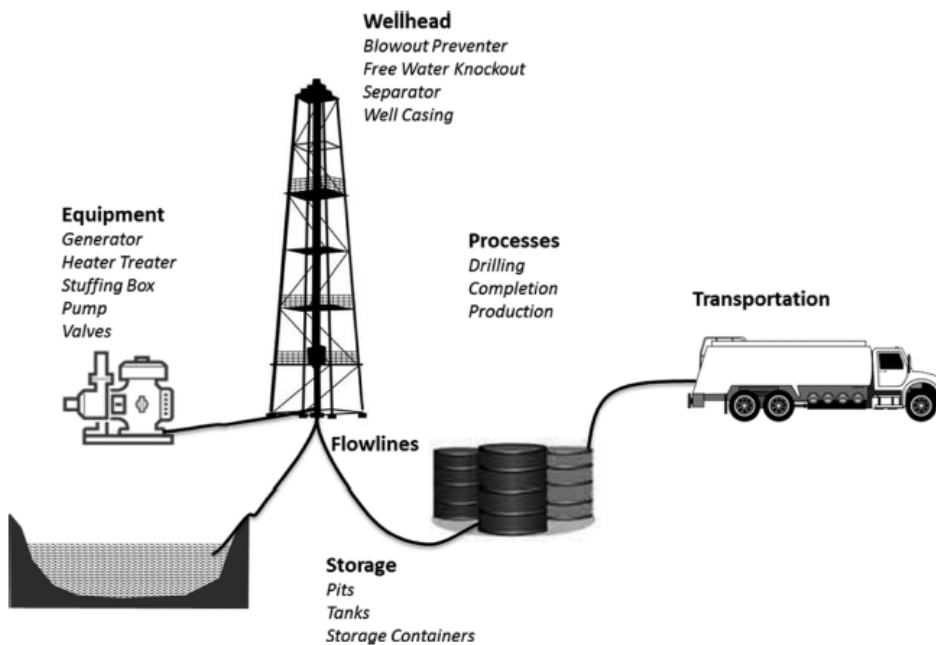


Figure 1 – conceptual diagram of unconventional gas set-up, showing points at which spillage/leakage of waste water commonly occur. From: Patterson et al, 2017.

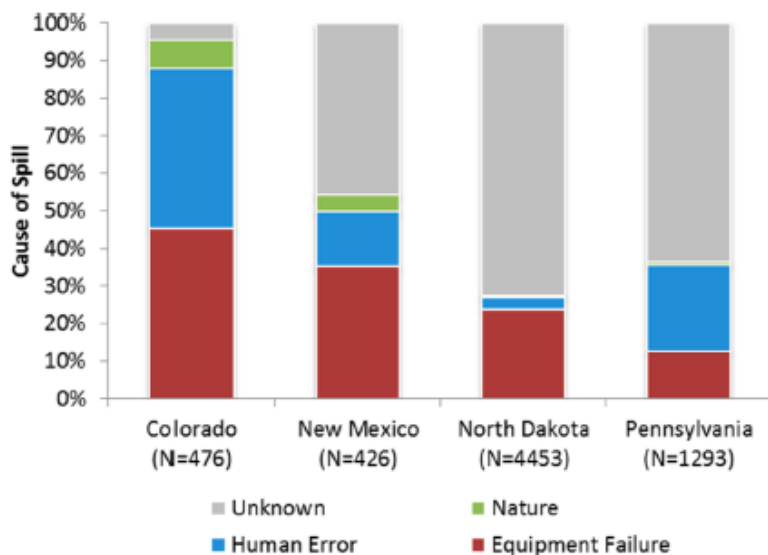


Figure 2 – breakdown of the number and cause of waste water spills from unconventional gas operations in four states in the U.S. From: Patterson et al, 2017.

Using these spill rates, which are based on tens of thousands of wells across the U.S., something on the order of 15 to 130 spills of wastewater could be expected to occur in association with the Narrabri Gas Project, if the planned 850 wells are drilled. For example, taking a conservative spill rate of 3.5% of all wells, this would equate to approximately 30 spill incidents arising from the project. As is shown in figure 3 below, the overall annual spill rate from unconventional gas and oil wells in the U.S., based on the best available data, is approximately 5%, which would equate to more than 40 spills for the Narrabri Gas Project if all 850 wells are drilled.

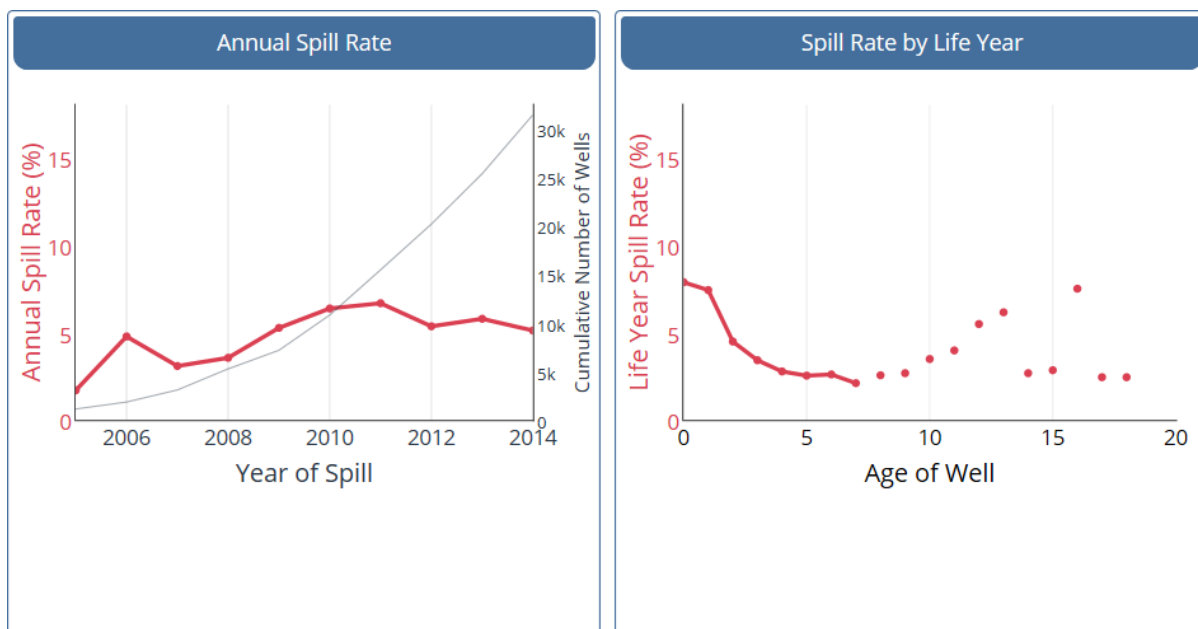


Figure 3 - Wastewater spill rates in the United States per number of wells in shale, coal and tight gas & oil operations. Data sourced from the National Center for Ecological Analysis and Synthesis spills data visualization tool: <http://snappartnership.net/groups/hydraulic-fracturing/webapp/spills.html>

On the basis of these data it is reasonable to conclude that regardless of the level of care, and the desire of project operators to minimise spills and leaks, there will inevitably be some wastewater spillage/leakage incidents, whereby produced water can potentially contaminate the environment. A cautious and conservative approach to this issue, which recognises that spills and leaks will inevitably happen is

therefore warranted. This shifts the question from not *whether* wastewater spills and leaks will occur throughout the life of the Narrabri Gas Project, but rather:

- a) *how to minimise* the incidence of these events to the greatest extent possible (so that the number approaches the low end of the range, say 2% of wells rather 15%);
- b) *how to detect* as rapidly as possible when these events do take place, through leak/spill detection systems and an extensive network of shallow groundwater monitoring wells; and
- c) *how to contain and mitigate* the consequences of these events so that they have minimal impact on the environment.

Based on Chapter 7 (Produced Water Management), Chapter 14 (Soils and Land Contamination) and Appendix G4 (Water Monitoring Plan) it appears the proponent may be under-estimating the risk of wastewater spills and leaks, which could leave the project vulnerable and poorly equipped to respond to the incidents that do arise. For example, there is no reference to the literature or data cited above, characterising typical spill rates and mechanisms associated with unconventional gas in the United States (or elsewhere in the world) and only descriptive information (rather than detailed analysis) regarding previous spill incidents involving produced water in the project area (see Chapter 14). All tanks, gathering lines, ponds and well-heads which are storing and transmitting CSG produced water have some potential to act as sites of spills and/or leaks (e.g. Figure 1), and as such a detailed life-cycle risk assessment, and monitoring plans to detect and isolate contamination should be included in the EIS (e.g. in Chapter 7 and/or Chapter 11).

Of some concern is the fact that there is already a track-record of spills and leaks of produced water having occurred in the Narrabri Gas Project area, associated with CSG activity carried out prior to 2012. At least one major spill incident and a number of other smaller incidents have taken place associated with production, handling and treatment of produced water from pilot CSG exploration activities (e.g., the Bibblewindi Pilot project). These incidents are recorded in the EIS (Chapter 14, pages 11 and 12).

Additional information regarding these incidents is provided in the report by Khan and Kordek (2014) to the NSW Office of the Chief Scientist and Engineer:

“In June 2011, approximately 10,000 litres of untreated saline water leaked from a pipe near the reverse osmosis plant at Bibblewindi. Operations at the Bibblewindi Water Management Facility were subsequently suspended. Santos is currently undertaking a \$20 million rehabilitation of the Bibblewindi Water Management Facility site. The plant was decommissioned and removed from the site in December 2012. The three storage ponds located at the Bibblewindi facility were also found to be unsuitable for long term use and Santos has commenced their removal and subsequent rehabilitation of the site. A number of other storage ponds in the Pilliga, including at Bohena have already been removed and site rehabilitation initiated.”

Also noted in this report are similar instances, where:

- ‘Multiple leaks and spills at the Bibblewindi Water Management Facility’ occurred during 2009 to early 2011,
- ‘An unknown volume of produced water overtopped a tank at the Bibblewindi Water Management Facility and spilled into the Pilliga and an ephemeral watercourse that was flowing at the time’ in 2010⁴

The contamination issues that have already been experienced to date at the site, when only a fraction of the number of wells proposed in the Narrabri Gas Project had been drilled and tested, underlines the significant possibility that future incidents of a similar nature (or other mechanisms highlighted in Figures 1 & 2) will occur over the 25-year life of the project. While Chapter 14 describes these prior incidents with produced water, as well as additional issues encountered at the Tintfield Water Treatment Facility, there is little analysis of the mechanisms of failure, and steps that should be taken to ensure the risk of similar incidents

⁴ Khan and Kordek, 2014, p.17.

occurring in future is minimised. The EIS includes some basic information about steps that will be taken but little detail:

“The risk of a recurrence of these types of incidents going forward has been significantly reduced through the design, construction and operation of new infrastructure, changes to operational procedures and ongoing monitoring.”

And:

“The recently constructed Leewood Water Management Facility now contains the majority of the produced water and brine associated with the Narrabri operations. The Leewood facility includes two double lined ponds with leak detection equipment installed. The facility meets the requirements of the NSW *Produced Water Management, Storage and Transfer* (NSW Department of Industry, Skills and Regional Development 2015c). Small volumes of produced water are also stored at the Tintfield Water Management Facility which now operates under a Liner Integrity Management Program, as outlined above. These changes, together with the extensive infrastructure and groundwater monitoring undertaken across the activities and the implementation of Santos systems for infrastructure operation and environmental management, minimises the risk of potential pollution incidents.”

Further:

“The likelihood of leaks or spills of produced water are considered low given the design and operational engineering controls and extensive monitoring and management systems that would form part of the project.

- the produced water and brine storages at the Leewood Water Management Facility include double lined ponds that have leak detection equipment installed. The ponds meet the requirements of the *Exploration Code of Practice: Produced Water Management, Storage and Transfer* (NSW Department of Industry, Skills and Regional Development 2015c)
- continuous pressure monitoring of produced water pipelines for indications of a leak. Water pressures at well heads and within water gathering lines is low
- programmed inspections and maintenance of plant and equipment
- all facilities would be designed and operated under the applicable Australian safety standard and protocols
- operations in accordance with the requirements of the Environment Protection Licence and a Produced Water Management Plan
- the ability to remotely operate and shut in wells if required.

In the unlikely event that a spill or leak did occur the risk of human health and the environment is negligible. Design and engineering controls along with monitoring systems would enable leaks to be detected and rectified quickly. Additionally, there is a low risk that bores would be affected as these generally take from sources that are over 50 metres below perched or shallow water bodies that could be impacted by a spill. In addition, the presence of relatively impermeable geological units in addition to perched water bodies having very low transmissivity further minimises the risk.”
– page 14-20 of Chapter 14.

The risk assessment outlined in Table 14-2 also indicates that the proponent believes both the pre and post-mitigated significance of the risk from produced water leaks or spills to be ‘moderate’ sensitivity, and ‘low’ magnitude and significance, which warrants some careful consideration. While these engineering techniques and management protocols described are warranted, they would be aided by in-depth discussion of the mechanism(s) of past wastewater spills and leaks in the project area, and in other similar incidents overseas or elsewhere in Australia. This is particularly given that the scale of the Narrabri Gas Project is an order of magnitude larger than the previous CSG activities at the site, during which the prior incidents of spills and leaks arose. Details regarding the ‘perched water bodies’, ‘relatively impermeable geological

units' or the site specific groundwater monitoring related to these previous contamination incidents, are not readily available to examine in the EIS, and should be included (e.g. in technical appendices).

As discussed further below, the current monitoring network for shallow groundwater outlined in Appendix G3 includes six monitoring sites (with bores screened at one or more depths) in the Pilliga Sandstone in the project area boundary (see Fig 3-5 of Appendix G3) and four monitoring sites in the Alluvium in the project area (Figure 3-4), as well as additional bores in these aquifers outside the project area. This network is highly unlikely to be adequate in order to rapidly detect shallow groundwater contamination incidents resulting from produced water spills and leaks in the project area. Given that there will potentially be 850 operating CSG wells across more than 400 well-pads, there will be a ratio of more than 50 gas wells for every shallow monitoring site in the project area, meaning only a fraction of the area potentially affected by produced water leaks and spills will have any baseline groundwater quality data or be actively monitored throughout the project (discussed further below in section 1.4).

The past incidents of spillage and leakage of wastewater are discussed in the 'Soils and Land Contamination' chapter (Chapter 14) of the EIS. The risk of shallow groundwater contamination by this mechanism is given minimal consideration in the 'Groundwater and geology' (Chapter 11) and Appendix G3 'Water Monitoring Plan'. The Water Monitoring Plan (Appendix G3) does not acknowledge the risk of groundwater contamination from produced water leakage and spills as one of its listed 'NGP water-affecting activities and potential effects that may be caused to groundwater sources addressed by this WMP' (Table 2-5). Hence, there is no indication that groundwater monitoring will be undertaken specifically to address this risk. Such contamination is one of the primary risk pathways which could impact the environment and water users, and should thus be carefully monitored and managed throughout the life of the project.

Another potential mechanism of groundwater contamination is well-faults, which may arise during construction, operation and following de-commissioning of the project. Improper sealing of gas wells and/or the presence of legacy or abandoned oil, gas or water exploration or production wells in an area of unconventional gas can potentially create pathways for cross-contamination between aquifers, for both fluids and fugitive gases (Vidic et al, 2013; Darrah et al, 2014; Jackson et al, 2014).

Regarding this issue, the EIS states:

"Losses of drilling fluid into the soil profile is very unlikely due to the drilling methodology and engineering and operational controls that would be implemented. Drilling would comply with the Code of Practice for Coal Seam Gas: Well Integrity (DTIRIS 2012) which sets out the design, construction and maintenance requirements for gas wells to ensure the safe and environmentally sound production of gas. Under the conventional overbalanced drilling fluid system that would be used for the project, the pressure of the column of drilling fluid is equal to, or greater than, the pressure of the various downhole formations through which they are drilled. This prevents influx of water or gas into the well bore whilst drilling. Surface drilling occurs to allow a steel pipe, called a conductor, to be cemented into the ground generally to 10 to 20 metres below the surface. This isolates loose or unconsolidated rock near the surface and prevents any impacts to the surface soils during the rest of the drilling process and the ongoing operation of the well. Well integrity will be monitored throughout the life of the well in accordance with the requirements of the Code of Practice."

The Executive Summary also states that drilling will be conducted in accordance with the Code of Practice. Well integrity is an issue throughout all phases of unconventional gas development, and must be carefully monitored and managed throughout the full life-cycle, including drilling, operation and decommissioning of gas wells (Jackson et al, 2014). Detailed protocols and mechanisms to minimise well integrity risks are not discussed in the EIS, for example, descriptions of what steps will be taken to monitor build-up of sustained casing pressure in the gas wells during the drilling and operational phases (see further discussion in section 2, below).

1.3 Particular risks to receptors, and relevant environmental values in the Narrabri Gas Project area

The combination of significant volumes (e.g. >1GL/yr) of poor quality water being produced and managed across hundreds of sites in the project area over a period of 25 years, and the otherwise high quality of the groundwater hosted in the Pilliga Sandstone Aquifer (the predominant shallow aquifer in the region), and Alluvium, raises significant concerns from an environmental and water management perspective.

From the data contained in the EIS it is clear that groundwater is of an unusually high quality in the Pilliga Sandstone aquifer (e.g., Table 4-10 of the baseline water data shows the aquifer has average EC values around 400 $\mu\text{S}/\text{cm}$, or approximately 250mg/L), which makes it a viable potable water source for landholders in the region (most shallow aquifers on the Australian continent do not contain water so fresh and suitable for potable use – e.g., see Harrington and Cook, 2014).

The project area includes land on which the Pilliga Sandstone aquifer outcrops (is directly exposed) or sub-crops at the surface, and therefore can be expected to receive direct groundwater recharge via rainfall runoff in some areas, where hydraulic gradients permit this (Figure 11-3 of Chapter 11 and Table 2-2 of Appendix G3 notes that the Pilliga Sandstone: “Represents a GAB recharge bed”). In spite of this being shown on the geological map of the project in Chapter 11 and acknowledged in Table 2-2, in the executive summary of the EIS, it is stated that the project area is: “not located in a major recharge area for the GAB”. This statement is made without detailed supporting evidence (such as a field-based investigation of groundwater recharge rates, hydraulic gradients or detailed lithological logs), and is questionable in the absence of such data. Evidence that is consistent with parts of the project area being a significant recharge area for this Great Artesian Basin (GAB) aquifer includes:

- the fact that the geological map shows that the project area is one of the few major areas where the Pilliga Sandstone (a GAB aquifer) is exposed at the surface, and that previous studies of the Great Artesian Basin (E.g. Habermahl et al, 1997; Brownbill, 2000; Herczeg et al, 2008; Ransley and Smerdon, 2012), map the area as a region of recharge and subsequent north-westerly groundwater flow to the wider Great Artesian Basin (see figure 4 below):

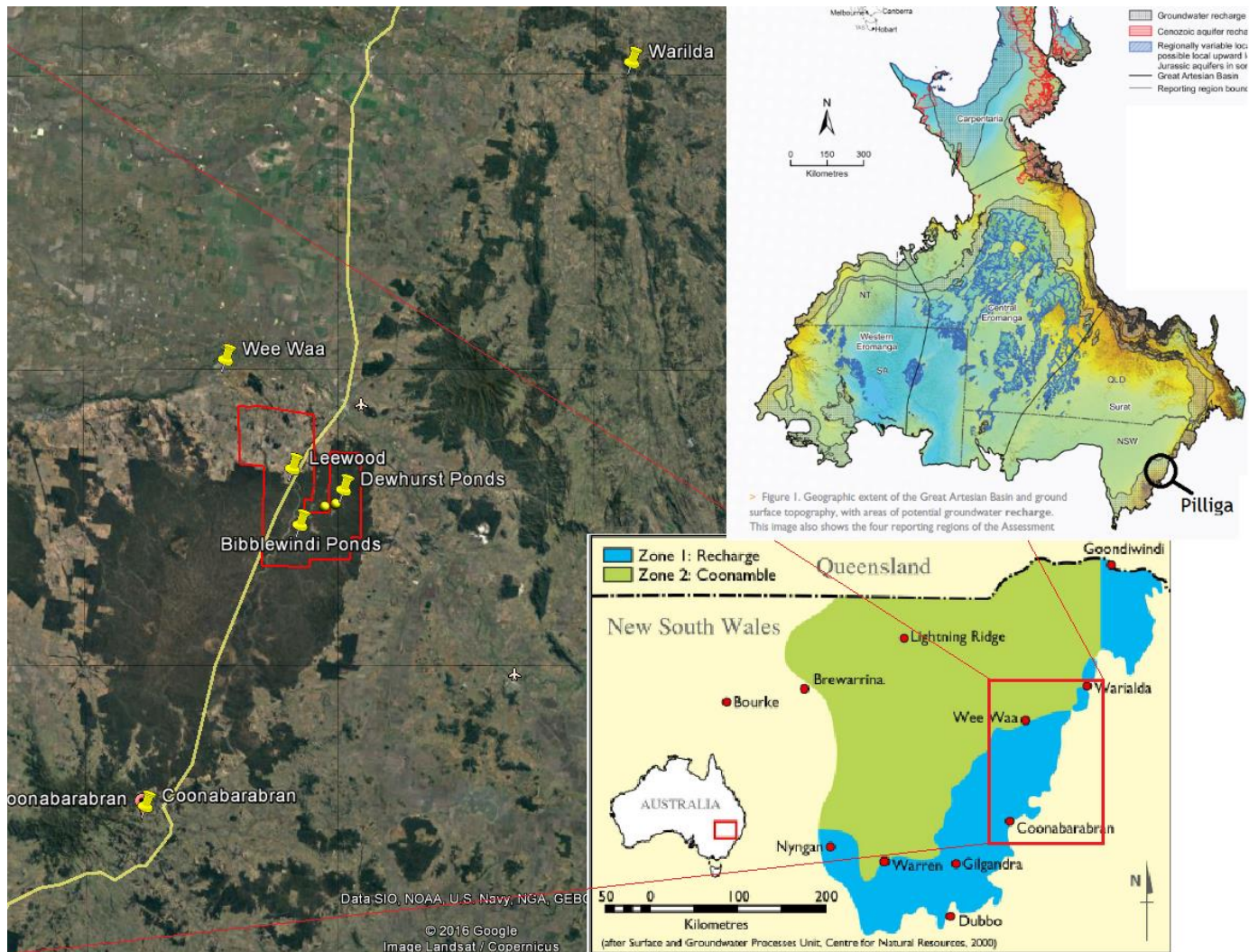


Figure 4 – Google Earth image showing project area (red outline) and mapped recharge areas for the southern Great Artesian Basin according to Herczeg, 2008 and Ransley and Smerdon, 2012. In both instances the project area is mapped within one of the restricted geographic areas of groundwater recharge to the southern GAB aquifers.

- The fact that ‘rejected recharge springs’ occur in the nearby area (as described in Chapter 11 of the EIS). Such springs are characteristic of GAB recharge areas (see Fensham et al., 2010)
- The unusual freshness of the groundwater. One of the standard techniques of recharge estimation used in Australia and worldwide is the Chloride Mass Balance method (e.g. Scanlon et al, 2002; Crosbie et al, 2010, Healy, 2010). According to this method, the chloride content of groundwater is inversely proportional to the recharge rate; hence a low chloride concentration (as is reported in the baseline water quality monitoring for the Pilliga Sandstone in Appendix G4) corresponds to high recharge rates.

1.3.1 Recharge estimation in the project area

Estimation of groundwater recharge is of vital importance to any hydrogeological study, from both groundwater quality and quantity perspectives (Healy, 2010). Within the EIS conceptual and numerical hydrogeological models, there is some limited attempt to estimate recharge to the various aquifers in the project area, including the Pilliga Sandstone, however the methods adopted provide a low level of confidence regarding actual rates. Additional data contained in the EIS could have been used to provide further estimates of recharge, as follows:

Using the Chloride mass balance method, under the assumption of steady state recharge (e.g. Crosbie et al, 2010), the amount of recharge to a groundwater aquifer that is unconfined (e.g. exposed to the surface and

in which the water table occurs) can be estimated as the ratio of chloride delivered in rainfall per unit time, to the amount of chloride in groundwater:

$$P \times Cl_P = R \times Cl_R$$

P = Precipitation, R = Recharge, Cl_P = Chloride delivered by precipitation, Cl_R chloride in recharging groundwater

Rainfall chloride concentrations in the study area are likely to be approximately 1.5mg/L, as Biggs (2006) determined rainfall chloride concentrations to be 1.41 mg/L to the north of the project area, at an equivalent distance from the coastline (at Goondiwindi). Distance from the coast is the primary determinant on chloride deposition in rainfall – see Crosbie et al, (2012). Given an average rainfall of 639mm/year at (Chapter 13 of the EIS), and that groundwater in the Pilliga Sandstone contains chloride concentrations averaging 31.5 mg/L (from Table 4-4 of Appendix G4 of the EIS), an average recharge of approximately 28.5 mm/year can be expected. This is a significant recharge volume, and higher than most of the Australian continent (see Herczeg, 2011 p.52) and most of the Great Artesian Basin (e.g., Ransley and Smerdon, 2012).

This estimated recharge value is also higher than what is provided in the conceptual hydrogeological model included in the Groundwater Impact Assessment of the EIS (Appendix F), which instead uses the ‘method of last resort’ to estimate recharge as being in the broad range 1 to 20 mm/year. It should be noted that the estimates of recharge presented in the EIS using this method are:

- a) acknowledged by the authors of the method (Crosbie et al, 2010) to be a highly uncertain method with low reliability, and only to be used as a starting point in the absence of better data (such as chloride values in groundwater and rainfall).
- b) not sufficiently spatially resolved to be applied to the project area (see Figure 5-14 of Appendix F, in which the project area is hardly discernible, and the contour increments too large to give meaningful data on local recharge rates).

As the authors of the ‘method of last resort’ recharge estimation technique noted when they described their method (quoting from Crosbie et al, 2010):

“The intention of this work was to provide a simple means of estimating recharge in data-poor areas where detailed work was not warranted.” – Crosbie et al, 2010 p.2035

Clearly, the study area does represent one in which detailed work is warranted, given the size and significance of the Narrabri Gas Project. Also quoting from Crosbie et al, 2010:

“This comparison of methods has shown that different methods can give recharge estimates that appear to be very different, but with an understanding of what was actually being measured they can provide complimentary information. This again highlights the need for using multiple methods of estimating recharge as not all methods are suitable for all purposes.” – Crosbie et al, (2010) p.2029

The approach taken in the Groundwater Impact Assessment (Appendix F) has made little attempt to cross-compare different methods, or verify estimates based on additional data collection and field work. The chloride mass balance based estimate above is based on easily available data that is included in the EIS; it is not clear why this was not used to complement the lower reliability method that was selected in the EIS.

Further, within the groundwater model (Appendix F), recharge to the Pilliga Sandstone (and other aquifers outside the Namoi Alluvium) is estimated as a flat percentage of rainfall – in the case of the Pilliga Sandstone, 1% of rainfall or 8 mm/year has been used, according to Figure 6-14. A flat percentage of

rainfall is another method that should be considered as having low reliability. Little justification is given in the modelling documentation (e.g. section 6.4.5 of Appendix F) as to why a value of 1% of rainfall was considered appropriate for estimating recharge to this aquifer.

The lack of any further study of recharge processes and rates using field-based techniques is a major oversight, given the significance of the Pilliga Sandstone as a southern GAB aquifer, and the potential for water quality (and possibly, quantity) impacts associated with CSG development. Techniques that can and should be used in areas where detailed study is warranted to better determine the rates, mechanisms and specific locations of recharge (as reviewed in Healy, 2010) include:

- Chloride mass balance analysis (using saturated and/or unsaturated zone data)
- Water table fluctuation monitoring;
- Double-ring infiltrometer or lysimeter testing
- Sampling for 'young' environmental tracers, such as tritium or SF₆

The fact that the area is likely to (or at least plausibly may) contain areas of significant recharge, and that no attempt has been made to understand recharge in the area using the above techniques, is concerning. It indicates that the groundwater impact assessment is missing rigorous estimates of a fundamental water balance parameter, and suggests that the risk of groundwater contamination (due to the mechanisms described in section 1.2) occurring in an area containing high quality groundwater resources, is not being given sufficient attention in the scientific program or design of the monitoring and management programs.

In a recharge area, any impact to groundwater quality (e.g. due to CSG wastewater spills or leaks) will in the long term affect groundwater further down-gradient in the aquifer— in the case of the Narrabri Gas Project area, this means the GAB aquifers to the northwest of the project. The restricted geographic areas where aquifer units are exposed at the surface and where direct groundwater recharge occurs are the hydrogeological equivalent to the 'headwaters' of a river catchment. Impacts to water quality occurring in such areas affect groundwater in the aquifer downstream of these regions eventually as well. The fact that to date the Pilliga is a relatively pristine area, with few existing land-use impacts threatening groundwater quality, means that the project area is one where particularly high quality water can be ensured to enter the GAB. As such, a greater than normal level of protection (e.g. restriction of potentially polluting land-use activities) may be warranted - as is standard practice for many drinking water catchments. This argument is further outlined in relation to the Pilliga region in Currell, (2015).

If spillage/leakage of wastewater occurs at rates that are standard for unconventional gas around the world (e.g. Patterson et al, 2017, see section 1.2) this could have a significant material impact on the quality of groundwater in the area, and threaten the viability of the aquifer as a potable water source, as well as the long-term quality of the groundwater recharge entering the Pilliga sandstone.

1.4 Adequacy of baseline groundwater quality data

Groundwater quality baseline data is a critical requirement for assessing current water quality and chemistry, determining the factors and processes controlling groundwater quality, and assessing future impacts due to CSG.

Some baseline data are included within Appendix F (Groundwater Impact Assessment) and Appendix G4 (Water Baseline Report) of the EIS. These data contain significant gaps and deficiencies, and do not constitute a rigorous baseline with which to assess existing groundwater geochemical conditions, document natural variability in groundwater quality (and the processes governing changes in quality) and/or adequately determine in future whether the gas project is causing impacts to groundwater quality through mechanisms such as those described above and below (section 2). Deficiencies include:

1. The relatively low number of bores in each aquifer, and the geographical spread of monitoring sites throughout the project area. In total, there are 58 groundwater monitoring bores installed, with a further 8 bores planned for monitoring water level and water quality. This total number is divided among the various aquifers, for example according to Table 4-1 of Appendix G4, there are 17

monitoring bores in total in the Pilliga Sandstone, and only some of these bores (confined to six localities) are within the project area (additional monitoring bores are located outside the project boundary). There are a similar number of bores in the Namoi alluvium, and fewer within the Gunnedah-Oxley Basin. This compares with up to 850 CSG wells that will be drilled; a very high ratio of gas bores to monitoring bores (e.g. tens of gas wells for every monitoring well). It is highly questionable whether this coverage is adequate, and concerning that there are large areas (such as the central and eastern parts of the project area) in which there appears to be no monitoring bore coverage at all (see figures 3-3 through 3-6 in Appendix G3). Particular areas, such as those surrounding the Leewood treatment plant (where a significant amount of wastewater will be transported and managed) should be extensively installed with shallow monitoring wells to reflect the fact that large volumes of wastewater will be transported to and stored at this site. Likewise all major areas in which the proposed CSG well pads are constructed need to be covered by a network of shallow and deep monitoring bores, including sites both up-gradient and down-gradient of the pads, to make a proper assessments of whether any groundwater quality impacts are occurring.

2. An inadequate number of parameters and constituents analysed in the baseline groundwater quality samples taken to date, and in particular, contaminants that may be present in CSG produced water or fugitive gas are absent in the groundwater baseline datasets in Appendix G4. Tables 4.3-4.7 provide summary statistics of water quality characteristics in four main aquifers in the project area. Missing from these are any analysis of the dissolved oxygen or redox potential (e.g. Eh/ORP), which are critical 'master parameters', vital to any assessment of the geochemistry of the groundwater, such as the level of saturation with respect to minerals and gases, the speciation of particular ions, the amount of organic matter and potential for redox reactions – all of which are important controls on groundwater quality (e.g. Appelo and Postma, 2005). It is not clear whether the metals analysis reported in these tables represents dissolved or total metals. This is an important consideration when assessing the form and likely behaviour of metals in the groundwater.

Other important analytes that are missing from these tables, and which may be future contaminants impacting the groundwater due to CSG activity (e.g. via wastewater spills or fugitive gas migration), include:

- Iron (as both total and dissolved; $\text{Fe}^{2+}/\text{Fe}^{3+}$)
- Arsenic
- Aluminium
- Ammonia
- Dissolved and Total organic carbon
- Dissolved methane
- Hydrogen sulfide
- Uranium & other radionuclides (e.g. ^{222}Rn , radium)

Without any baseline data on these particular species that could be present in significant quantities in produced water and/or which may be sensitive to changes in the geochemistry brought about by CSG-related activity, any future assessment of whether groundwater quality has been impacted by CSG (and the causal mechanism of such impacts) will be extremely difficult.

3. A lack of time-series data showing any trends in groundwater chemistry/quality through time at individual sites, or any maps showing spatial trends in groundwater quality through the region (e.g. salinity contour maps or element maps in each unit). Such trend analysis is vital to understanding the current influences controlling groundwater quality and assessing future change.
4. A lack of any reported baseline information on the chemical composition of produced water from the target coal seams, which was generated during exploration for CSG in the region. A detailed analysis of the geochemistry of water produced from the coal seams is a vital pre-requisite for assessing future possible impacts from spills or leaks associated with the storage, transport and

treatment of produced water (see section 1.2), and for determining whether such incidents are impacting groundwater quality during operation of the gas project. Some basic information about water quality from two monitoring sites in the Gunnedah-Oxley basin sequences is included in Tables 4-8 and 4-9 of Appendix G4. However, these data are again missing key analytes (e.g., those listed above) and give little indication of the variability and range of geochemistry and water quality of fluids that will be extracted from the coal seams in these sequences specifically. It is unclear whether the water quality data for these sequences represents water extracted from just the coal seams in the overall sequence (which would be representative of future produced waters coming from CSG wells) or whether it includes water intersected from horizons of other geological material hosting different quality groundwater, that might be intersected by long-screen monitoring wells in addition to water in the coal seams themselves.

5. A lack of microbiological characterisation of the groundwater and produced water. Particular microbial communities may occur in the produced water (as is documented for oil and gas wastewaters – see Van Stempvoort et al, 2005), and these and other bacterial communities may impact groundwater quality if they are introduced to aquifers in which they were previously absent (e.g. through leaks or spills of produced water).
6. Lack of an indication of where exactly the CSG wells will be drilled, and where pipelines for gas and produced water will be constructed. The groundwater monitoring network and baseline data should complement the layout of the well pads and pipelines to ensure all areas of active CSG extraction are adequately covered.

2. Fugitive gas contamination of shallow groundwater and the surface atmosphere

Methane is a potent greenhouse gas (when emitted to the atmosphere) and a potential groundwater contaminant that can lead to pump failures and potential explosion hazards in landholder bores (Walker and Mallants, 2014). When a gas reservoir is disturbed by drilling, hydraulic fracturing, de-watering or any combination of these, gas may potentially migrate from the reservoir to other parts of the sub-surface, such as aquifers above the gas deposit (which may be used for water supply), and/or the surface atmosphere. Some researchers argue that fugitive methane emissions associated with gas drilling, production and processing potentially render unconventional gas an equal or worse source of greenhouse gas pollution in comparison to coal (Howarth et al., 2011; McJeon et al, 2014, Howarth, 2014; Melbourne Energy Institute, 2016).

Leakage of methane into shallow aquifers and/or the atmosphere is now a well-documented phenomenon associated with unconventional gas development (Osborne et al, 2011; Howarth et al, 2011; Jackson et al, 2013b; Darrah et al, 2014; Vengosh et al, 2014; Jackson et al, 2014). Detailed analysis of the potential pathways for fugitive methane to enter shallow aquifers and/or the atmosphere as a result of CSG, and detailed strategies to minimise fugitive methane pathways, monitor fugitive methane, and address any impacts that are detected are thus needed to ensure this risk is properly managed. At present, there is very limited discussion or acknowledgement of this risk in the EIS, and limited (or no) baseline data regarding methane and other dissolved gas contents in groundwater, to allow future assessment of changes to shallow groundwater or surface atmospheric methane concentrations that might arise as a result of the project.

2.1 Relevant project activities

Fugitive methane release to either the atmosphere or shallow aquifers is a risk associated with all parts of the unconventional gas lifecycle, including drilling of the gas wells (Caulton et al, 2014), operation of the gas wells (Day et al, 2014), management and transport of wastewater (e.g. methane may de-gas from wastewater stored in dams at the surface) (Kort et al, 2014; Iverach et al, 2015) and gas distribution and processing (e.g. leakage of gas from pipelines into shallow groundwater; venting of gas that includes

methane). In the case of the Narrabri Gas Project, the fugitive methane to shallow groundwater and/or the atmosphere could occur during all of these activities.

2.2 *Mechanisms of stray/fugitive gas contamination*

2.2.1 *Groundwater contamination with fugitive methane*

It is now well documented that contamination of shallow aquifers with ‘stray gas’ (fugitive methane) has occurred in a number of areas of the United States due to unconventional gas development (Bair, 2010, Osborn et al 2011, Ground Water Protection Council, 2012, Jackson et al, 2013, Darrah et al, 2014, Jackson et al 2014).

As is noted in the review by Professor Robert Jackson and colleagues, most instances of fugitive gas contamination impacting shallow groundwater due to unconventional gas have to date taken place due to problems with the casing and cementing of gas and/or water wells in the project areas. Abandoned (legacy) wells are another possible conduit for cross-contamination of aquifers with fugitive methane:

“In well leakage, fluids (liquids or gases) can migrate through holes or defects in the steel casing, through joints between casing, and through defective mechanical seals or cement inside or outside the well. A build-up of pressure inside the well annulus is called sustained casing pressure (SCP) and can force fluids out of the wellbore and into the environment. In external leaks, fluids escape between the tubing and the rock wall where cement is absent or incompletely applied. The leaking fluids can then reach shallow groundwater or the atmosphere.⁵”

In some extreme cases, gas contamination of shallow aquifers can result due to major well-failure incidents such as ‘blow-outs’, which take place when there is a significant build-up of sustained casing pressure in the well. Bair (2010) describe the findings of an expert panel appointed to document the mechanism of one such incident in Bainbridge County, Ohio, which resulted in methane contamination of shallow water bores, and an explosion in a home basement from fugitive methane build-up (Figure 5):

⁵ Jackson, R. et al, 2014 p. 337

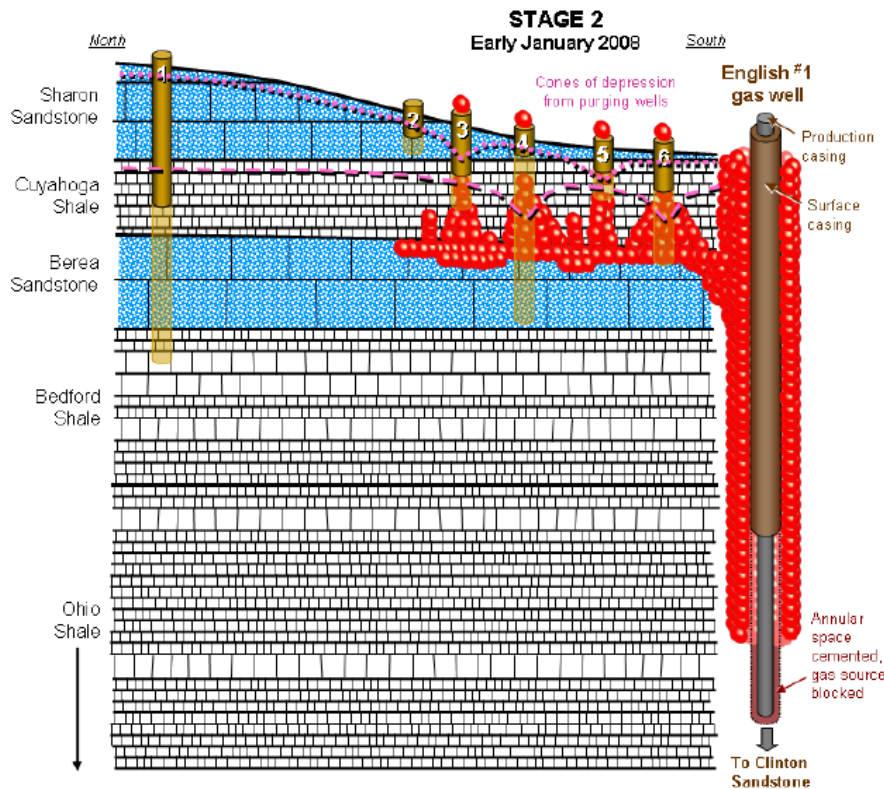


Figure 5 - Schematic diagram showing mechanism of gas contamination of shallow aquifers, based on a case study in Bainbridge County, Ohio (Bair, 2010).

As with surface leaks of unconventional gas wastewater (such as CSG produced water), it is acknowledged in the technical and research literature that faults in a small percentage of gas wells are inevitable, and as such it is not possible to eliminate the risk of stray gas (or fluid) contamination associated with well faults entirely - particularly in a gas project with a large number of wells (such as the Narrabri Gas Project). Jackson et al, (2014) cite data showing that between 3 and 6% of wells in the Marcellus Shale in Pennsylvania (a highly developed shale gas resource in the United States) experienced failures within the first 3 years of operation. Similar rates of failure are reported for wells drilled for conventional or unconventional oil and gas projects in the United States (Jackson et al, 2013b).

In the case of the Narrabri Gas Project, it is therefore important to recognise that well failures and faults will be likely to occur at some stage. Clear protocols and plans to monitor, rapidly detect and mitigate such problems as quickly as possible thus need to be in place before the first gas well is drilled. These protocols and plans must be carefully observed and independently monitored throughout the full lifecycle of the project, through to decommissioning of the gas wells and ongoing monitoring of the site after gas has been extracted.

So far, the EIS contains limited information regarding methods by which well integrity will be monitored and ensured throughout the life of the project, other than reference to the fact that the NSW *Code of Practice for Coal Seam Gas Well Integrity* (DTIRIS, 2012) will be followed during construction of the gas wells (e.g. see the EIS executive summary and Chapter 14). Whether all wells (water, gas, oil, active, inactive, abandoned) in the project area can be effectively identified, monitored, maintained and prevented from acting as pathways for fugitive methane contamination, is a question of critical importance to understanding fugitive gas contamination risks.

As with CSG wastewater contamination of groundwater from the surface, a rigorous assessment and management plan for possible fugitive gas contamination via well faults requires that extensive and detailed baseline groundwater chemistry datasets be collected prior to development of the project. As

discussed in section 1.4, such baseline groundwater chemistry data is a pre-requisite for effectively monitoring and detecting any possible leakage of gas (or fluids) into shallow groundwater as a result of CSG activity. An example of a baseline monitoring program which included repeated measurements of methane in shallow (and deep) groundwater above gas-bearing geological formations is the Victorian Water Science Studies, carried out in 2015 in association with the Gippsland Bioregional Assessment project (e.g., Jacobs, 2015). This program used specialised groundwater and gas sampling techniques to determine levels of methane in the Gippsland and Otway basins – which at the time of the survey were considered potential future areas of unconventional gas development. The baseline data served to document pre-existing levels of gas in groundwater, and coupled with isotopic sampling conducted by Currell et al (2016), allowed the existing sources of methane and associated geochemical processes in the gas-bearing aquifers and overlying units to be understood. A similar program has been carried out in the Richmond River catchment in northern NSW (Atkins et al, 2015) and overseas (e.g., Humez et al, 2016).

Such monitoring programs (reporting methane concentrations and isotopic compositions in groundwater in areas of possible unconventional gas development) should be standard practice for any CSG project of significant size, to ensure a rigorous baseline exists for assessing any future fugitive methane contamination of groundwater. This would also allow existing sources of methane and associated geochemical processes in aquifers overlying gas deposits to be better understood. Isotopic characterisation allows for ‘fingerprinting’ of gases from particular sources- such as naturally occurring bacterial methane produced in relatively shallow sedimentary formations, and thermogenic gases produced at great depth, which are the typical targets for gas development. As an example, an increase in the concentrations of thermogenic type gas in water wells containing little pre-existing methane and/or methane with a different isotopic signature (such as biogenic gas), would be a clear indication of contamination by fugitive gas, which may be more difficult to establish without the isotope data in addition to baseline concentrations.

Examples of the type of data that can be produced from this type of sampling in an area of potential future unconventional gas development are shown below in Figures 6 to 8 (based on data collected by Currell et al, 2016 in the Gippsland Basin in Victoria):

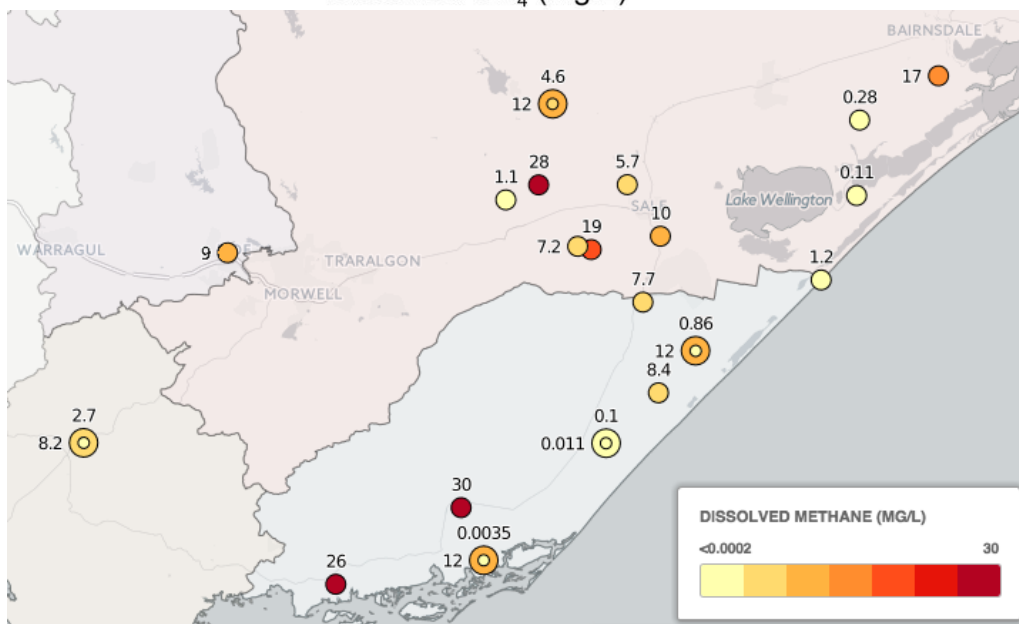
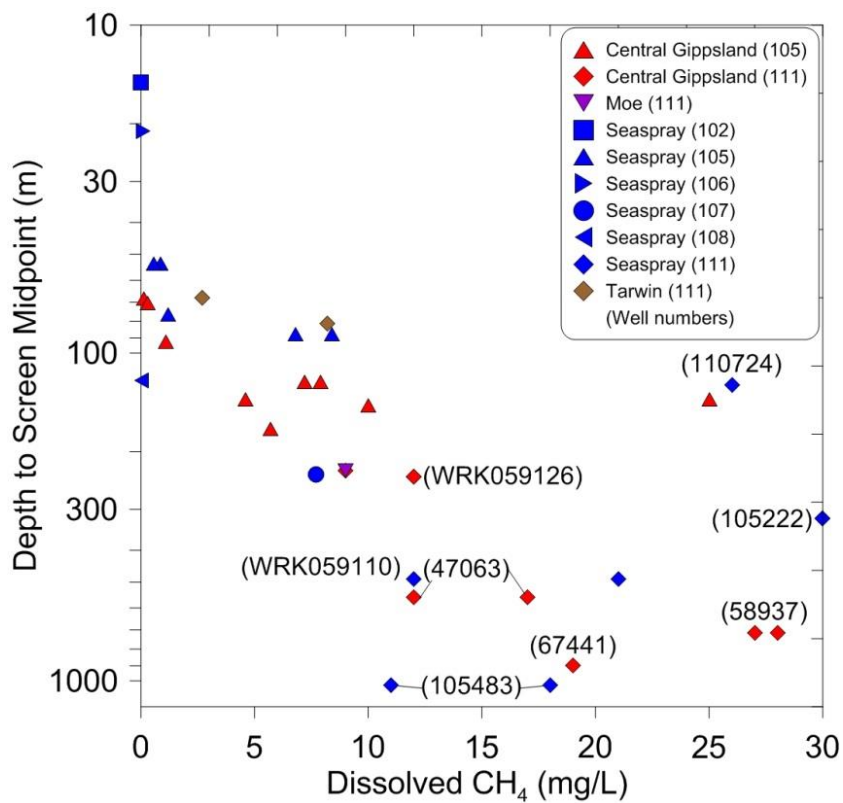


Figure 6 – Example of baseline data collected in Gippsland basin, showing concentrations of dissolved methane in groundwater at different depths and aquifers overlying potential unconventional gas target (Currell et al, 2016)

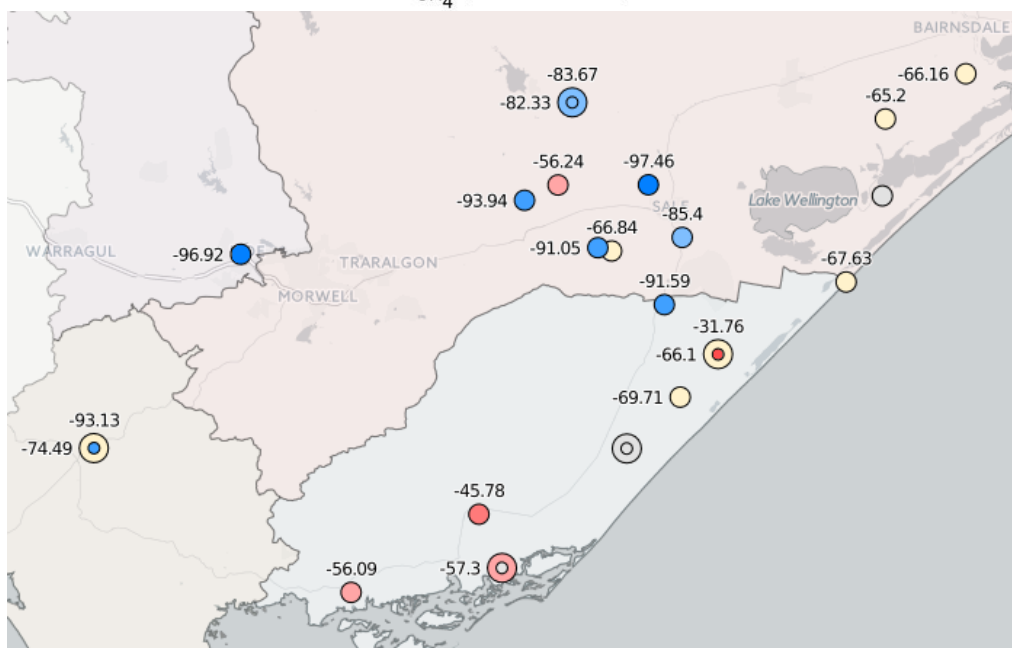
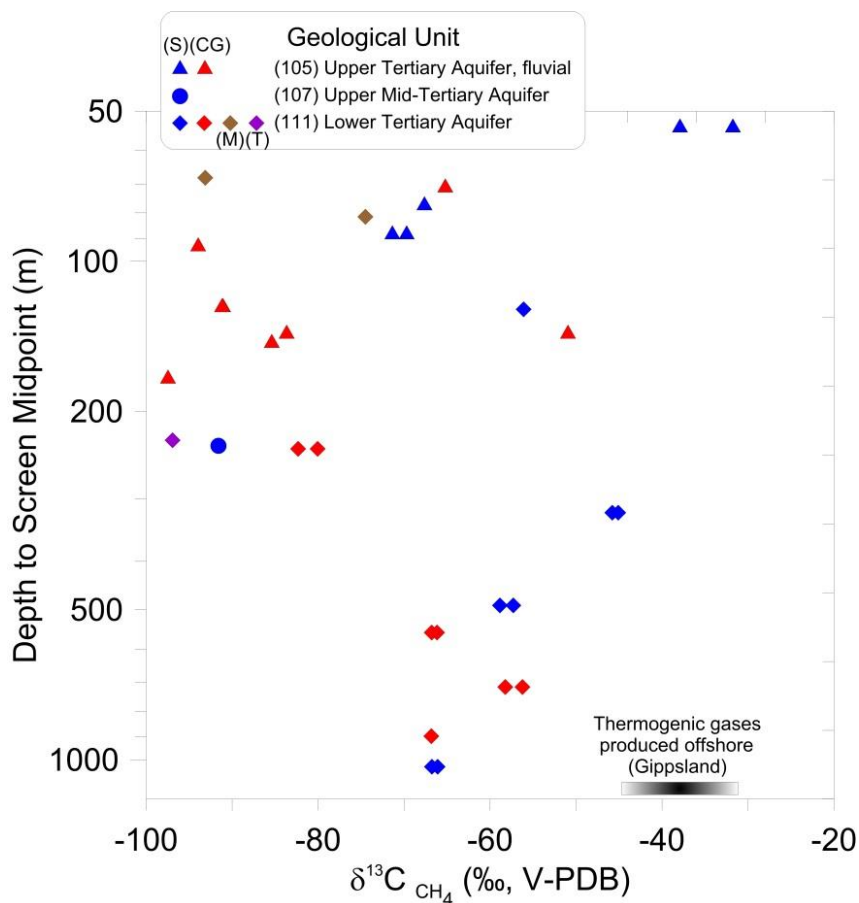


Figure 7 – Baseline isotopic characterisation of methane in groundwater in the Gippsland Basin (Currell et al, 2016).

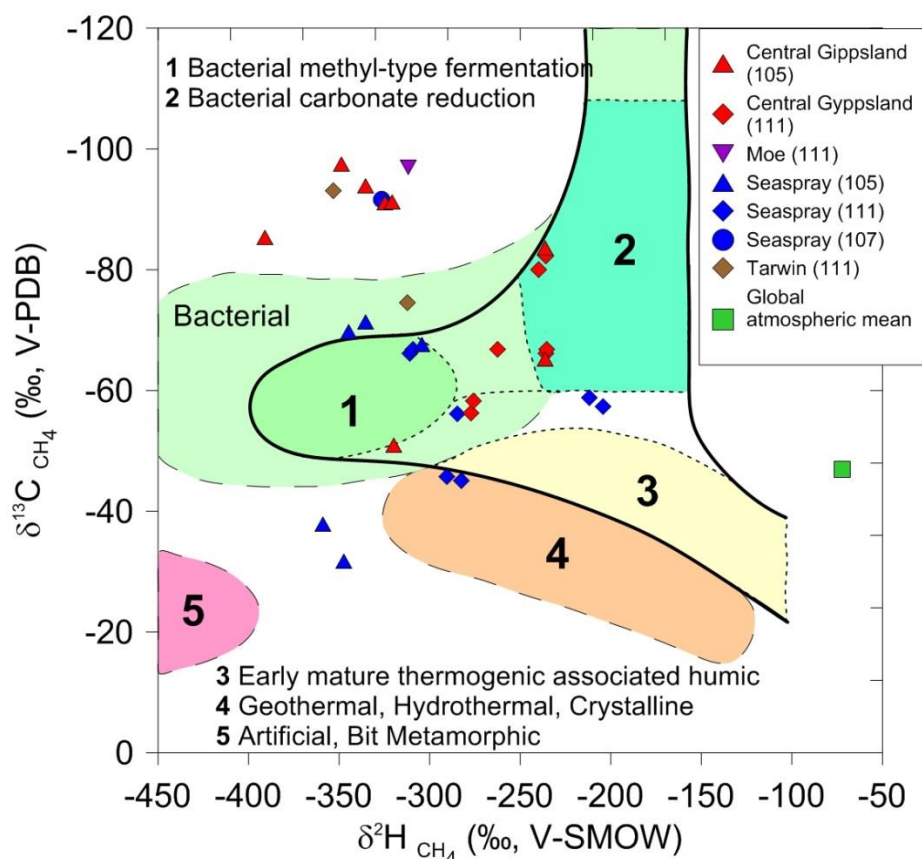


Figure 8 - Baseline isotopic characterisation of dissolved methane in groundwater from the Gippsland basin, showing likely sources of dissolved gases under current conditions. Isotopic compositions can fingerprint gases from different sources (Currell et al, 2016).

At present, the baseline data reported in the EIS are not adequate for the purpose of managing the risk of fugitive gas contamination in groundwater. In particular, the water baseline report (Appendix G3) contains no data reporting methane concentrations or other hydrocarbons in groundwater from any monitoring wells, and hence there is no baseline with which to detect and assess any changes in methane levels in groundwater, e.g., due to fugitive gas or fluid migration. As is discussed in the report on the inquiry into onshore unconventional gas in Victoria (Parliament of Victoria, 2015), and other literature (e.g. Walker and Mallants, 2014; Humez et al, 2016), determination of dissolved and/or 'free' methane concentrations in groundwater needs to be done in order to detect any fugitive gas contamination of aquifers in regions of unconventional gas. Additional sampling to determine the isotope composition of methane in the coal seams, and other aquifers where it may naturally occur is also a valuable tool to determine different sources of methane, and accurately delineate the source of any increases in methane concentrations observed during groundwater monitoring (Iverach et al, 2015; Currell et al, 2016; Humez et al, 2016). The fact that methane has not been included in the water baseline report (Appendix G3) and does not appear to be included in the list of analytes to be regularly sampled in the project area to date is thus a major oversight in the EIS.

2.2.2 Fugitive methane release to the surface atmosphere

In addition to the risk of contaminating water supply aquifers with gas, emissions of methane to the atmosphere during unconventional gas development are a significant potential source of greenhouse gas emissions. Within the EIS Chapter on greenhouse gas emissions (Chapter 24), the proponent does not discuss some of the common potential sources of fugitive methane emissions to the atmosphere from unconventional gas development within its Scope 1 emissions sources (direct emissions). These sources include leaks from gas well-heads (e.g. leaking valves or joins) – e.g. see Day et al, (2014); leakage that occurs during gas well drilling – which has recently been determined to be a significant source of fugitive

methane associated with shale gas drilling in the United State (see Caulton et al, 2014); and de-gassing of methane from produced water stored in above-ground dams (e.g., see Iverach et al, 2015).

The assessment of greenhouse gas emissions for the Narrabri Gas Project appears to down-play the importance of these sources of methane emissions to the atmosphere, ignoring the recent international research which shows that these emission sources can be significant (Caulton et al, 2014; Kort et al, 2014; Howarth, 2014; Melbourne Energy Institute, 2016). Quoting from the EIS page 24-5:

“upstream emissions for fossil fuel supplies are those emitted in the extraction, processing and transportation of the fuel product (i.e. coal or gas)

downstream emissions are those emitted from the combustion of the fuel by the end-user.

Upstream emissions form only a small proportion of the total lifecycle emissions for energy generation. Consequently, it is the downstream emissions that have by far the greatest bearing on the emissions intensity of the energy.”

Contrary to this opinion, in 2011 William Howarth (a professor at Cornell University) proposed that fugitive methane to the atmosphere from unconventional gas development due to well, pipeline and other leaks in the United States was being systematically under-estimated by national greenhouse gas inventories, and constitutes a significant greenhouse gas emission source. Subsequently, a number of studies looked to quantify fugitive methane to the atmosphere in areas inside and outside unconventional gas fields, including Australian CSG fields (e.g. Kort et al, 2014, Leifer et al, 2013; Maher et al, 2014; Day et al, 2014; Caulton et al, 2014; Melbourne Energy Institute, 2016). These studies have largely confirmed the hypothesis that direct leakage of methane to the atmosphere during the ‘upstream’ part of the unconventional gas process can be a significant GHG source, and potentially, negate the relatively lower CO₂ equivalent emissions associated with the ‘downstream’ burning of natural gas for energy (as compared to coal or oil).

In Australia, Maher et al, (2014) monitored near-surface methane concentrations in northern New South Wales and southeast Queensland, comparing areas within CSG development (the Tara gas field) with areas outside gas fields. They showed that near-surface atmospheric methane concentrations were elevated in CSG fields (up to 6.5 parts per million, and consistently above 2ppm) relative to areas of no CSG development and equivalent geology. Possible explanations are leaks around gas well production and collection infrastructure, increased soil gas emissions and/or de-gassing from produced water stored in above-ground ponds containing dissolved methane.

Work by Day et al., (2014), examined gas leaks in some of Queensland’s CSG fields, using similar technology. They targeted gas production wells and pipelines, looking to identify leakage to the atmosphere. They found that the majority of operating CSG wells showed little or no evidence of any methane leakage, and that in general gas contents were at background atmospheric levels. However, one well was identified with increased levels of methane emission to the atmosphere, associated with a valve on the well which periodically vented gas containing methane to the atmosphere.

A recent study by Dana Caulton and colleagues published in the *Proceedings of the National Academy of Sciences, USA* used both ‘top down’ estimates (using aircraft-based measurements of greenhouse gases) and ‘bottom up’ estimates (using ground based monitoring instruments) to determine fluxes of fugitive methane to the atmosphere in areas of unconventional gas in the Marcellus Shale of Pennsylvania. This work showed significantly higher fluxes associated with gas drilling, transport and processing than previously documented (and used in industry and government inventories of fugitive methane emissions), and highlighted the significance of emissions during drilling and well-pad development:

“The identification and quantification of methane emissions from natural gas production has become increasingly important owing to the increase in the natural gas component of the energy sector. An instrumented aircraft platform was used to identify large sources of methane and quantify emission rates in southwestern PA in June 2012. A large regional flux, 2.0–14 g CH₄ s⁻¹ km⁻², was quantified for a ~2,800-km² area, which did not differ statistically from a

bottom-up inventory, $2.3\text{--}4.6 \text{ g CH}_4 \text{ s}^{-1} \text{ km}^{-2}$. Large emissions averaging $34 \text{ g CH}_4/\text{s}$ per well were observed from seven well pads determined to be in the drilling phase, 2 to 3 orders of magnitude greater than US Environmental Protection Agency estimates for this operational phase. The emissions from these well pads, representing $\sim 1\%$ of the total number of wells, account for 4–30% of the observed regional flux. More work is needed to determine all of the sources of methane emissions from natural gas production, to ascertain why these emissions occur and to evaluate their climate and atmospheric chemistry impacts”⁶ (Caulton et al, 2014).

Other methods including satellite-based estimation of atmospheric methane fluxes have highlighted significant emissions from CSG (called ‘coalbed methane’ in the US) in New Mexico (Kort et al, 2014). The significant methane emission anomaly identified in this area was attributed to either leaks from CSG wells and/or de-gassing from produced water stored in open ponds at the surface. The estimates of methane flux from the satellite derived methods also showed higher levels of emission than those previously accounted for by the US EPA.

These studies highlight that increased methane emissions to the atmosphere are a common problem associated with unconventional gas development, which may cause significant under-estimation of the greenhouse gas emissions from these projects.

In the EIS chapter on greenhouse gas (Chapter 24) there is no detailed discussion of these issues, and only a brief indication that fugitive methane to the atmosphere in the ‘upstream’ part of the project will be monitored and managed; section 24.2:

“A leak detection and repair program approved by the NSW Environment Protection Authority will be implemented to identify and minimise fugitive emissions.”

However, no baseline data for atmospheric levels of methane in and around the proposed project area are presented. The collection of baseline data on methane concentrations (and preferably isotopic compositions) in the near surface atmosphere (as for groundwater) in areas of potential unconventional gas development is a critical step in ensuring fugitive methane resulting from CSG projects can be accurately assessed and quantified. An example of such a program conducted in Australia is AGL’s Camden gas project. In this program, methane levels in the atmosphere were collected using portable infrared mass spectrometers deployed at a range of locations up-wind and down-wind of the CSG operations, and data on both the atmospheric concentrations, and isotopic compositions of methane were collected (Pacific Environment, 2014). This study allowed non-CSG related sources (such as landfills and livestock) to be measured and accounted for as well as CSG related emissions – in this case one event of significant methane emissions from the gas operation was detected, due to gas processing activities at the AGL plant.

A similar monitoring program with baseline data and ongoing monitoring should be carried out as part of the management strategy for detecting and minimising fugitive methane to the atmosphere due to the Narrabri Gas Project. While this may be planned (e.g. in conjunction with the ‘leak detection and repair program’), as yet there appears to have been no such program designed or conducted. While a baseline air quality monitoring program was carried out in the project area in 2014 (see Appendix L of the EIS), methane monitoring was not included in this program.

Appendix R (Greenhouse Gas Assessment) of the EIS mentions the issue of fugitive methane emissions, and makes estimates of total emissions through the life of the project (see Table 2-3). This is based on National Greenhouse and Energy Reporting (Measurement) Determination 2008 and the American Petroleum Institute compendium of 2009. This assessment includes a number of assumptions. For example, in Table 2-3 of Appendix R, it is stated:

“No material methane venting is expected to occur during the (well) completion phase”

This contradicts the findings of Caulton et al, (2014) and other studies described above. It is also not clear whether or not de-gassing of methane from CSG produced water storage dams has or will be monitored or

⁶ Caulton et al, 2014, p.6237.

accounted for; given evidence that this may constitute a significant source (Kort et al, 2014; Iverach et al, 2015) it should be part of the baseline data and monitoring program.

Importantly, while it is proposed that methane emissions will be monitored and reported in the Greenhouse Gas Assessment (Appendix R), there is no detail of whether or how emissions of methane from the fugitive sources listed above will be monitored and reported. The EIS should thus outline detailed strategies for:

- a) Monitoring groundwater and near surface atmospheric methane concentrations and isotopic compositions regularly, in order to detect any changes and establish the cause (whether related to a contamination problem or natural influences); and
- b) Rapid and effective response plans to address any detected contamination of groundwater or the atmosphere with fugitive methane and other pollutants, to quickly cut the contamination pathway(s).

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Santos NSW (Eastern) Pty Ltd - NARRABRI GAS PROJECT

Expert Review of Environmental Impact Statement

May 2017

Andrea Broughton, Groundwater Solutions International

Introduction

I have been briefed by EDO NSW, on behalf of the North West Alliance, to provide my expert opinion on the groundwater impact assessment of the Santos Narrabri Gas Project (**NGP**).

I am a Senior Hydrogeologist trading under the name Groundwater Solutions International as part of Gradient Limited. I worked for the formerly named Department of Water Resources, NSW, from 1992 until 1995 as a Project Hydrogeologist and was located in Gunnedah/Sydney. As a result of my work I obtained a good understanding of the hydrogeological processes that occur within, and between, the southern Surat Basin and Gunnedah Basin geological units, having undertaken an intense property-by-property three year study of bores. Data collected and reviewed included bore and well hydrographic and water quality records; geological records from both the bores, wells and mining exploratory bores; hydrological data from creeks and rivers; and climatic data. I ran educational workshops for property owners and government employees working in the area. Since leaving Australia I have reviewed groundwater impacts of mining operations at the request of community groups. I maintain a keen interest in respect to any hydrogeological investigations, and other relevant scientific studies, undertaken in the Namoi Valley Catchment.

In providing my expert opinion, I have reviewed the following documents written by CDM Smith Australia Pty Ltd “**CDM Smith**” consultant to Santos NSW (Eastern) Pty Ltd “**Santos**,” which forms part of the Environmental Impact Statement for the NGP (**Santos EIS**):

- Executive Summary
- Chapter 11: Groundwater and Geology
- Appendix F: Groundwater Impact Assessment (**GIA**) (CDM Smith 2016a, *Narrabri Gas Project Groundwater Impact Assessment*, prepared for Santos NSW (Eastern) Pty Ltd, October 2016).
- Appendix G3: Water monitoring plan (**WMP**) (CDM Smith 2016b, *Narrabri Gas Project Water Monitoring Plan*, prepared for Santos NSW (Eastern) Pty Ltd, October 2016).
- Appendix G4: Water baseline report (**WBR**) (CDM Smith 2016c, *Narrabri Gas Project Baseline Report*, prepared for Santos NSW (Eastern) Pty Ltd, October 2016)

In preparing my expert opinion I have read and agree to be bound by the ‘*Expert witness code of conduct*’ (Schedule 7, Uniform Civil Procedure Rules 2005).

ISSUE 1

Is the groundwater conceptual model, including baseline data, hydrostratigraphy, hydrogeological properties of aquifers and aquitards, and groundwater flow systems, adequate?

The conceptual groundwater model forms the hydrogeological framework and philosophy, or the platform, on which the numerical groundwater model is based. The numerical groundwater model is then used for the GIA. Therefore it is imperative that the conceptual groundwater model, even if it is simplified, represents the region the NGP is proposed to operate within.

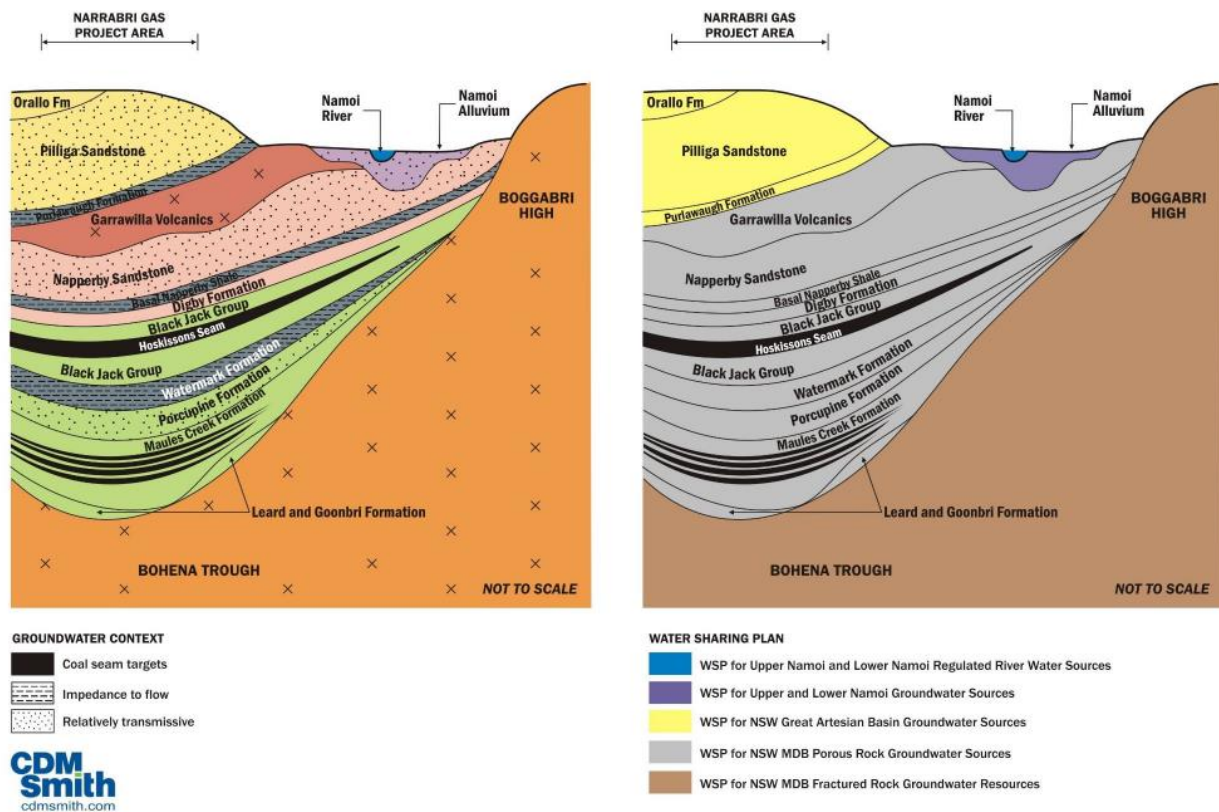
I have reviewed the conceptual groundwater model, based on my local knowledge of the Namoi Valley Catchment. In my opinion, the model is mostly appropriate with the exception of critical information regarding the ability, or inability, of a hydrostratigraphic unit (HSU) to transmit, store and yield groundwater.

CDM Smith developed the conceptual groundwater model utilising data collected by Santos and the Department of Primary Industries (DPI): Water, and adopts concepts from previous groundwater modelling within and near the GIA study area. For full details of these models please refer to Section 5.0 of the GIA (Appendix F, Santos EIS).

This data was used to develop a hydrogeological conceptual model to encapsulate the current understanding of the groundwater systems in the GIA study area (Appendix F, Santos EIS). The NGP conceptual groundwater model is a simplified representation of the key features of the groundwater systems that has been built based on the interpretation of available data and information (Appendix F, Santos EIS).

To assist with understanding the locations of different formations I have reproduced Figure 2.1 from the Water Monitoring Plan. I provide additional information on each of the components of the conceptual groundwater model below.

Figure 2-1 Project area schematic showing lithology and WSPs



Baseline Data

Summary

In my opinion the baseline data for the aquitards in the groundwater conceptual model are inadequate.

CDM Smith stated 'the Gunnedah-Oxley Basin and the Great Artesian Basin aquitards play an essential role protecting the overlying GAB Pilliga Sandstone and alluvial aquifers, by dampening the amplitude and time frame of drawdown in the overlying GAB from pumping influences resulting from CSG dewatering in the GOB' (Appendix G4, Santos EIS).

In my opinion, I do not consider the baseline data representing the following key aquitards to be adequate:

- Gunnedah-Oxley Basin (**GOB**) Permian aged Upper Maules Creek, Porcupine and Watermark Formations,
- GOB Triassic aged Digby and Basal Napperby Shale Formations, and
- Great Artesian Basin (**GAB**) Jurassic Purlawaugh Formation.

The baseline dataset is not statistically viable (which would require at least 6 samples per bore). Given the importance of understanding the baseline water level and water quality of these aquitards, they are not sufficiently represented in the Narrabri Gas Field dataset.

Baseline data for the GAB Pilliga Sandstone consolidated aquifer and the Namoi Alluvial unconsolidated aquifer are well represented for the Narrabri Gas Field. However, the shallow Bohena Alluvium is not adequately represented in the eastern portion of the NGP where leakages and spillages can occur from the Leewood Water Treatment Plant, brine ponds, irrigation fields, and pipeline infrastructure.

Hydrostratigraphic Unit Descriptions

CDM Smith presented baseline data for both water level and water quality for the main HSUs in the Narrabri Gas Field.

The stratigraphic units *'have been grouped into hydrostratigraphic units according to the capacities of the strata to transmit or inhibit the movement of groundwater'*. These are as follows:

- Significant transmissive units (STUs).
- Less significant transmissive units (LSTU).
- Probable negligibly transmissive units (PNTU).
- Negligibly transmissive units (NTU).

'These definitions identify the relative significance of each stratigraphic unit with respect to the expected hydrogeological response to the subsurface to coal seam gas development. Thus, a very conductive and high-yielding stratum is considered to be a STU, a low-yielding stratum is considered to be a LSTU, and leaky strata and aquitards are considered to be PNTUs and NTUs.'

Freeze and Cherry (1979) describe aquitards as *'a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water (AGI, 1980).'*

CDM Smith stated that the GOB aquitards (Digby and Napperby Formations) and the GAB Jurassic aquitard (Purlawaugh Beds) play an essential role protecting the overlying GAB Pilliga Sandstone and alluvial aquifers by dampening the amplitude and time frame of drawdown in the overlying GAB from pumping influences resulting from Coal Seam Gas (**CSG**) dewatering in the GOB.

Given the importance of understanding the baseline water level and water quality of these aquitards, the very limited baseline dataset, which is not statistically viable; indicates that these HSUs are not sufficiently represented in the Narrabri Gas Field.

Groundwater Baseline Hydraulic Head and Pressure

General overview

CDM Smith presented statistical summaries of the baseline data for the hydraulic head and pressure at the monitoring locations within the GOB and GAB. These were summarised in Table 4-1 of Appendix G4, Santos EIS.

Baseline hydraulic head datasets were collated from Santos and DPI Water bores and presented as hydrographs. All bore screen intervals are presented. The baseline data temporal and spatial viability is discussed in the following sections.

Permian and Triassic HSUs (GOB monitoring bores)

Nested monitoring bores are located at two locations:

- Santos nested bore site at Dewhurst 8; and
- DPI bore site GW036546 37km SSE of Dewhurst 8, and outside of the NGP.

Single bores were located at:

- Santos' Bibblewindi site bore BWD6; and bore TULPRDGY02 located ~15 km WSW of Dewhurst 8.
- DPI bore site GW036497-1 located outside of NGP near the 30km Buffer Zone (located 48km SSE of Dewhurst 8).

Hydrographs for each bore were given in the WBR (Appendix G4, Santos EIS).

POINT ONE: There is a lack of geological borelogs, or comment by CDM Smith, indicating where the bore screen intervals are located in some of the GOB formations (as to whether they in aquifers or aquicludes) as follows:

- DPI bore GW036546-3 is screened over interval 87m – 91m bgl, in the Black Jack Formation. However, the Black Jack Formation includes aquifers and aquitards. Without the provision of a geological borelog indicating the part of the formation in which the bore is screened, any baseline hydraulic head data are meaningless.
- DPI bore GW036546-2 is screened over interval 27-29m bgl, in the Napperby Formation. However, the Napperby Formation includes the Napperby Sandstone and Basal Napperby Shale, the latter being an important aquitard.

POINT TWO: Variation in hydraulic head conditions in the five Santos bores was very limited (one year).

The baseline dataset is not representative of the temporal variation in groundwater pressure head in the GOB bores. It can take a number of years for the deep HSUs to show the effects of a drought (a lag effect). Therefore, predictions using a numerical model based on a lack of temporal variation will not predict realistic drawdown effects in the deep HSUs as a result of drought conditions during CSG dewatering, where the recharge is less, surface water sources are less available and likelihood of increased groundwater pumping. However, DPI bores do achieve this.

POINT THREE: Spatially, the baseline bores represent less than half the NGP site.

Two locations in the western (Biblewindi West Field) and north western (Bohena Field) portion of the NGP should have been incorporated into the baseline dataset. However, having said this, the main Permo-Triassic HSUs of interest are represented by at least two bores each (with the exception of Maules Creek Fm). The baseline dataset would benefit from a nested bore accessing the Napperby Sandstone and Basal Napperby Shale in the Dewhurst 8 bore site (see further comments regarding this below).

Jurassic HSUs (GAB monitoring bores)

Only two bores represent the basal Jurassic Purlawaugh Formation aquitard, DWH14PRPUR03 and BWD28QGPUR01. DWH14PRPUR03 has data for just over one year only which is not a sufficient baseline dataset against which to compare future data.

The Jurassic HSUs are well represented spatially within and outside of the NGP. However, the Santos bores lack temporal coverage within the NGP. Only two bores have at least two years of data with the remaining having 1 to 1.5 years of data. This is not sufficient to form a temporally representative baseline dataset as these formations have lag periods measured in years. That is, effects from drought could take more than a year to manifest a change in the deeper Pilliga Sandstone unit in the Recharge Area of the GAB. Hydraulic conductivities have been estimated to be

around 1-5 m/year in the recharge area (Habermehl, 1980, in 'GABCC 2016. *Great Artesian Basin Resource Study 2014*. Report by the Great Artesian Basin Coordinating Committee'). Groundwater flow rates based on Carbon-14 and Chlorine-36 studies range from less than one metre to about five metres (Habermehl, 2002, , in 'GABCC 2016. *Great Artesian Basin Resource Study 2014*. Report by the Great Artesian Basin Coordinating Committee'). Numerical modelling will not include monitoring data representing drought periods, therefore, Santos cannot effectively predict the effects of CSG dewatering in this portion of the GAB recharge area.

These bores do establish baseline hydraulic head conditions between GAB HSUs. In saying this, it is unfortunate there was no baseline data given for the Orallo Formation in the Bibblewindi Field area as there are certainly positive hydraulic gradients between the Lower and Upper Pilliga Sandstone at bore sites BWD26, BWD 27 and BWD 28. Although Figure 3-2 in the WBR (Appendix G4, Santos EIS) suggested bore BWD27PRORA02 (Orallo Fm) existed, there were no details given in Table 4-1 of the WBR (Appendix G4, Santos EIS). The Keelindi Beds are a 'Negligibly Transmissive Unit' (aquitard) which serve to protect the Upper Pilliga Sandstone from lower quality water which may be present in the Bohena Alluvial aquifer due to past contamination events (depending on the hydraulic gradient).

DPI bores are located outside the NGP. Data from these bores adequately represented spatial and temporal trends in groundwater head; however, these bores did not establish baseline hydraulic head conditions between GAB HSUs.

Two Santos bore sites situated very close to each other, DWH14 and DW8, represent almost the entire suite of HSUs of interest to the NGP - Maules Creek, Porcupine Fm, Digby Fm, Purlawaugh Fm, Lower Pilliga and Upper Pilliga. Unfortunately Santos has not used a bore to provide baseline data for the Napperby Fm (Napperby Shale Beds).

Hydrographs from nested bore sites at DWH14 and at DW8 overlap for a three month time period only, and there is no overlap at all for the Purlawaugh Formation data. If these two nested bore sites had been measured concurrently a very useful baseline groundwater pressure head dataset for Permo-Triassic-Jurassic HSUs would have been provided.

Namoi Alluvium

Baseline data has been collated for 16 DPI bores located outside the NGP. These bores are spatially and temporally viable and hydrographs are presented in the WBR (Appendix G4, Santos EIS). Four bore sites have nested piezometers allowing a baseline dataset of hydraulic pressure head conditions (upward or downward) to be established.

Bohena Alluvium

No baseline water level dataset has been established from the four Santos bores drilled along Bohena Creek, in the Bohena Alluvium, and no private bores have been included. No reason was given in the WBR as to why this has not been done. The Bohena Alluvium is not be viewed by Santos as a high-valued groundwater resource. However, local property owners rely on the Bohena alluvial aquifer as the Namoi alluvium is absent.

No baseline water level dataset was presented from the Bohena bores located in the NGP Leewood Water Treatment Plant, brine ponds and irrigation fields. Monitoring groundwater levels will establish the likely fluctuation in water levels so that any groundwater mounding can be detected.

The WMP (Appendix G3, Santos EIS) has included these four Santos bores as part of the 'sentinel bores' network located in the shallow groundwater resources. However, this is inadequate for monitoring of leakages and spillages that can occur at the Leewood Water Treatment Plant, brine ponds, irrigation fields, and pipeline infrastructure.

CDM Smith state in the WMP that the 'alluvial aquifers is considered to be a form of 'lagging resource condition indicator' in the sense that unexpected adverse changes observed at these locations would indicated that an impact to the water source has already occurred'. CDM Smith state 'the purpose of monitoring in the high-valued

groundwater sources is to demonstrate that observed changes in resource condition are not an effect of the NGP'. CDM Smith contends that NGP effects on groundwater levels will be overshadowed by climatic and consumptive use conditions. However, Santos has no baseline dataset from the Bohena Alluvium to measure the 'lagging' results against. Therefore, this approach is unacceptable for the Bohena Alluvial aquifer.

Summary

- GOB baseline datasets are lacking temporal and spatial data for key HSUs.
- The Black Jack and Napperby Formations include aquifers and aquitards. However, the strata in which the baseline monitoring bore is screened has not been identified, and therefore this does not allow for a meaningful baseline hydraulic head dataset.
- Variation in hydraulic head conditions in the five Santos bores located in the GOB HSUs are temporally limited (one year) and therefore do not give representative baseline conditions in these deep hydrostratigraphic units especially since these units experience lag effects measured in years.
- GAB hydrostratigraphic units are well represented spatially, but not temporally, for the Pilliga Sandstone, Orallo and Mooga Formations which are part of the Keelindi Beds.
- The Namoi alluvium is well represented spatially and temporally.
- The Bohena alluvium has no baseline water table dataset to measure the WMP against.

The implications of the above mean the conceptual model is based on a lack of data from the GOB and GAB aquitards. This affects the Numerical Model which provides the drawdown estimations from pumping influences resulting from CSG dewatering in the GOB.

Groundwater Baseline Chemistry

General overview

CDM Smith presented statistical summaries of the baseline data for the groundwater quality at the monitoring locations within the GOB and GAB. These were summarised in Table 4-2 of Appendix G4.

CDM Smith made two conclusions:

1. 'Overall, the water quality of groundwater in each stratigraphic unit is similar with respect to the major cation compositions (sodium-potassium dominant) and anion compositions (bicarbonate dominant).'
2. 'Groundwater in the Permo-Triassic strata of the Gunnedah Basin is distinguishable by larger salinity (EC) and acidity (pH) compared to groundwater in the GAB and alluvial groundwater sources.'

The Jurassic Pilliga Sandstone consolidated aquifer, Orallo Formation and Namoi Alluvial unconsolidated aquifers are well represented in the baseline chemistry. However, the Bohena Alluvial unconsolidated aquifer is not well represented. No baseline water quality datasets were presented from the Bohena bores constructed prior to the establishment of the NGP Leewood Water Treatment Plant, brine ponds and irrigation fields. Monitoring groundwater quality in these areas will establish background chemistry levels so future monitoring datasets from the WMP can be made, allowing the early detection of contamination events.

The underlying GOB is not well represented and is misleading. The reasons for this are discussed below. The lack of any bore logs to show which part of the Digby and Napperby Formations are monitored is an oversight.

Permian and Triassic HSUs (GOB Monitoring Bores)

The GOB Permo-Triassic strata baseline chemistry dataset is presented in Table 4-3 Appendix G4. Table 4-3 is a summary of data from Table 4-8 (Triassic Digby Formation), Table 4-9 (Triassic Napperby Formation) and Table 4-10 (Jurassic Purlawaugh Beds). CDM Smith stated all these tables are "statistical summaries of the baseline data for groundwater quality at monitoring locations within the Gunnedah-Oxley Basin".

POINT ONE: The major ion dataset given in Table 4-3 does not represent the Permian to Triassic HSUs and as a consequence is not statistically viable.

CDM Smith chose three monitoring bores to represent the Permian-Triassic HSU baseline chemistry:

- Two GOB monitoring bores: one located in the Triassic-aged Digby Formation aquitard (bore TULPRDGY02) and the other located in the overlying Triassic Napperby Formation aquitard (bore TULPRDGY01). This nested bore site is located to the east and outside of the Narrabri Gas Field.
- One GAB monitoring bore (DWH14PRPUR03) located in the Purlawaugh Beds within the Dewhurst CSG Exploration Field.

No Permian data is represented in Table 4-3. The GAB Purlawaugh Bed aquitard underlying the Pilliga Sandstone aquifer is Jurassic-aged and therefore should not be included in Table 4-3.

Table 4-8 and Table 4-10 have insufficient sample sizes, and therefore are not statistically viable, to determine the groundwater type.

POINT TWO: Table 4-3 is not representative of groundwater salinity (EC) in Permo-Triassic HSUs

The Permo-Triassic dataset in Table 4-3 (Appendix G4), and Tables 4-8 through to 4-10, report salinity as Electrical Conductivity (EC). CDM Smith report EC in two forms EC (field) and EC @ 25°C (lab).

EC is a measure of the groundwater's capability to pass electrical flow in microsiemens per centimetre (uS/cm). Therefore EC is directly related to the concentration of ions in the groundwater. The conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulphides and carbonate compounds. The more ions that are present the higher the EC of the groundwater. **However, conductivity is also affected by temperature** and the warmer the groundwater, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25°C (or specific conductance). As the temperature of the groundwater will affect the conductivity readings, reporting conductivity at 25°C allows data to be easily compared between datasets.

Comparing field EC from the various hydrostratigraphic units in the GOB and GAB becomes difficult as it depends on the temperature of the groundwater when measurements were taken. EC (field) is affected by temperature which is why hydrogeologists compare EC @ 25°C (lab or field if equipment allows for this), so that equivalent datasets can be properly compared.

The following points are noted:

- With the exception of the Triassic-aged strata, EC (field) and EC @ 25°C (lab) datasets in Tables 4-8, 4-9 and 4-10 are not statistically viable but have been combined to produce a 'statistically viable' dataset in Table 4-3. However, Table 4-3 is not representative of the Permo-Triassic HSUs. There is quite a difference in EC @ 25°C (lab) between the three HSUs which is lost when averaged in Table 4-3. This may have important ramifications when using this baseline data against future monitoring and in developing the conceptual groundwater model.
- The mean EC (field) is quite distinctive in all three HSUs as follows:
 - Digby Formation Aquiclude: Mean ~9161 uS/cm (16 percentile - 84 percentile: 6736 uS/cm - 10657 uS/cm).
 - Napperby Formation Aquiclude: Mean ~5721 uS/cm (16%-84%: 3396 uS/cm - 7151 uS/cm).
 - Purlawaugh Beds Aquiclude: Mean ~575 uS/cm (not a statistically viable data set).

So the distinctive EC for each formation is lost when averaged to produce Table 4-3 Mean EC (field) ~5397 uS/cm (16% - 84%: 573 uS/cm - 10103 uS/cm).

- Salinity, reported as EC, is misleading. There is a relationship between EC and Total Dissolved Solids. However, electrical conductivity can be elevated in groundwater with clay and silt particles in suspension but this does not mean the groundwater is saline. These aquitards are primarily made up of mudstone and siltstone.

POINT THREE: Table 4-3 is not representative of groundwater acidity (pH) in the Permo-Triassic HSUs.

CDM Smith presented a statistically viable field pH dataset in Table 4-3, and Tables 4-8 through to 4-10. Each formation has a distinctive field pH signature as follows:

- Digby Formation Aquitard: Mean 11 (16% - 84%: 6.6 – 12.9).
- Napperby Formation Aquitard: Mean 6.7 (16% - 84%: 6.2 – 6.9).
- Purlawaugh Formation Aquitard: Mean 10.5 (16% - 84%: 10.1 – 10.9)

The difference in pH between the three HSUs is lost when averaged in Table 4-3. This may have important ramifications when using this baseline data against future monitoring and in developing the conceptual groundwater model.

POINT FOUR: The Permo-Triassic monitoring bores are only located in the north eastern area of the NGP, so the dataset is not spatially representative.

In my opinion, Santos should have been aware of the need to drill bores through these formations knowing it would require spatially representative bores for baseline studies and for the ongoing monitoring plan. This has not been done.

Jurassic HSUs (GAB Monitoring Bores)

CDM Smith presented 20 bores to represent the GAB Jurassic hydrostratigraphy. This consisted of:

Pilliga Sandstone (Table 4-4 of WBR, Appendix G4, Santos EIS)

- Ten Santos bores which adequately represent, temporally and spatially, the Upper and Lower Pilliga Sandstone aquifer in the NGP area. These consist of:
 - 4 bores from the Lower Pilliga Sandstone consolidated aquifer (bore screen intervals between 140m and 219m below ground level (bgl)).
 - 6 bores from the Upper Pilliga Sandstone consolidated aquifer (4 bore screen intervals between 60m and 100m bgl, and two between 207m and 218m bgl).

The dataset has statistically viable sample sizes (6 or more samples to determine mean, 16% and 84% percentiles) for major ion, EC and pH analyses. Laboratory EC at 25°C measurements were made, therefore comparisons can be made with other aquifers and aquitards (including the deeper Permo-Triassic bores).

- Two Santos bores (BWD1WB and BWD5WB), with unknown screen intervals. Only two samples were collected from each bore for major ions, EC (field and lab EC @25°C), and pH over a time period of 1 year and 10 days, for each bore respectively. Therefore I do not consider baseline conditions at these sites to be representative of the Pilliga Sandstone.
- Three DPI bores with known screen intervals, between 60.6 and 112.8m bgl. Only one bore has statistically viable lab EC @25°C and field pH (GW030400-1) measurements so the data can be compared with other hydrostratigraphic units. The other two had very limited measurements in this respect. All bores had limited major ion data. Even though the data from these bores span between 12 – 28 years (1971 – 1999) the data is over 18 years old.

Orallo Formation (part of the Keelindi Beds) (Table 4-5 of WBR, Appendix G4, Santos EIS)

- Two Santos bores are representative, temporally and spatially. Bore screen intervals are between 109m and 153m bgl. Data collected is statistically representative for major ions, EC (field and lab EC @25°C), pH (field and lab) over a time period of 2.5 – 2.75 years.
- Three private bores (7703, 7705, 7706), which have unknown bore screen intervals. Two samples have been collected from each bore with data for major ions, EC (field and lab EC @25°C), pH (field and lab) representing a two year period. These bores are located close to each other, so I consider their combined datasets are statistically viable.

CDM Smith reported the groundwater quality in the Pilliga Sandstone aquifer to be ‘generally fresh to slightly brackish and suitable for domestic, stock and irrigation purposes’ (WMP, Appendix G4). The Pilliga dataset recorded a mean EC @25°C of 402.2 uS/cm and 68% of the data lies within a range of 127.5 to 1200 uS/cm (1 standard deviation away from the mean); and a mean field pH of 6.2 with 68% of the dataset with a range of 5.2 to 8.0. The Orallo Formation dataset recorded a mean EC @25°C of 1029.8 uS/cm and 68% of the data lies within a range of 484.6 to 1351.2 uS/cm (1 standard deviation away from the mean); and a mean field pH of 7.4 with 68% of the dataset with a range of 6.8 to 8.2 (WBR, Appendix G4).

Namoi Alluvium HSU (Alluvial Monitoring Bores)

CDM Smith presented 13 bores to represent the Namoi Alluvial aquifers, with known screen intervals. This database consisted entirely of DPI monitoring bores, which are located downgradient of the NGP area, and are spatially and temporally adequate. Six of these bores provided statistically viable datasets for major ions, EC (field and lab EC @25°C), and pH (field and lab) representing a two year period. The remaining 7 bores had field EC and pH data only, with limited major ion data.

CDM Smith reported the Namoi alluvial aquifers produce groundwater that is fresh to slightly brackish and suitable for multiple uses including town drinking supply, stock and domestic use and irrigation (WMP, Appendix G3, Santos EIS). The Namoi Alluvium dataset recorded a mean EC @25°C of 696.7 uS/cm and 68% of the data lies within a range of 330.6 to 1109 uS/cm (1 standard deviation away from the mean); and a mean field pH of 7.9 with 68% of the dataset with a range of 7.5 to 8.4 (Table 4-6, WBR, Appendix G4).

Bohena Creek Alluvium HSU (Alluvial Monitoring Bores)

CDM Smith presented four Santos bores located along Bohena Creek within the NGP. These bores have only 2 samples each including major ions, EC (field and lab EC @25°C), and pH (field and lab) representing a ‘two year period’. However, an examination of the individual datasets for each of these four bores indicates that for three of the bores the sampling period was only three months between 17/7/2013 and 25/10/2013, and only one week for monitoring bore BHNCKMW3 (please refer to Tables 4-44 to 4-47 in WBR, Appendix G4, Santos EIS). This sampling period needs to be verified by CDM Smith.

The Bohena Alluvium dataset recorded a mean EC @25°C of 559.4 uS/cm and 68% of the data lies within a range of 148 to 1314 uS/cm (1 standard deviation away from the mean); and a mean field pH of 6.8 with 68% of the dataset with a range of 6.4 to 7.9 (Table 4-7, WBR, Appendix G4).

No baseline water quality datasets were presented from the Bohena bores constructed prior to the establishment of the NGP Leewood Water Treatment Plant, brine ponds and irrigation fields. Monitoring groundwater quality in these areas will establish background chemistry levels so future monitoring datasets from the WMP can be made, allowing the early detection of contamination events.

Summary

Santos presented Table 11-6 (Chapter 11, Santos EIS) summarising the water quality in the HSUs. The mean EC and pH values presented are from values of lab EC @25°C and pH (field) taken from statistically viable datasets found in WBR Appendix G4.

As discussed above, the GOB Permo-Triassic water quality data is not representative and is misleading. The GAB Purlawaugh Formation leaky aquitard chemical characteristics are not statistically viable and have become hidden as a result of the incorrect incorporation of its dataset into the Permo-Triassic HSU dataset, which is also not representative. Aquitard groundwater chemistry can provide important datasets showing how leaky the aquitard can be perceived. Although the Purlawaugh Formation aquitard dataset is not statistically viable there is evidence that it has relatively low EC (at least an order of magnitude than the underlying Triassic aquitards) which indicates it may be able to transmit water more easily than is reflected in the conceptual model.

The GAB Pilliga Sandstone consolidated aquifer and Quaternary Namoi Alluvial aquifer datasets are spatially and temporally statistically viable. The Bohena Alluvial aquifer dataset needs verification. The dataset is not representative of the eastern portion of the NGP in the vicinity of the Leewood Water Treatment Plant. No baseline datasets were presented from the Bohena bores constructed prior to the establishment of the NGP Leewood Water Treatment Plant, brine ponds and irrigation fields. Monitoring groundwater quality in these areas will establish background chemistry levels so future monitoring datasets from the WMP can be made, allowing the early detection of contamination events.

In addition, the *Australia and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC 2000 Guidelines) suggest there should be an assessment of organic compounds (eg methane) or of the radiological quality. This has not been carried out by CDM Smith/Santos, or if so, it has not been presented in the WBR for any of the HSUs. The implication of this is that there is no baseline data to compare any future monitoring data against, should buoyant methane gas (fugitive methane gas) that is not affected by the low pressure zone artificially created at the exploration/production wells, migrate to other low pressure zones, such as faults and poorly constructed bores.

Surface Water Baseline Data

Streamflow

CDM Smith presented baseline data for six DPI operated river gauging stations - five stations on the Namoi River/Namoi Creek and one located on Bohena Creek.

Baseline data for the Namoi River/Namoi Creek are presented in Table 5-2 in the WBR (Appendix G4, Santos EIS). Namoi River is perennial where streamflow exceeds 1ML/day 90% of the time. DPI stream gauging data is well represented for the Namoi River and Namoi Creek as seen in Figure 5-2 of the WBR.

Baseline data from Bohena Creek stream gauging station is presented in Table 5-3 of the WBR. Records of data are very sparse. This is due to the intermittent streamflow (ephemeral) of Bohena Creek where 1ML/day is exceeded 10% - 90% of the time. CDM Smith stated: 'Flows were recorded on only 15 percent of days between September 1995 and June 2005' and 'Flow records end in 2010; however, water level has been recorded since then but not converted to flows' (WBR, Appendix G4, Santos EIS). This information should have been completed and presented as part of the Santos EIS.

Surface Water Quality

The water quality data for the Namoi River and Bohena Creek is spatially and temporally (2 years between 2012 and 2104) representative of the NGP and surrounding area. For full water chemistry results refer to Tables 5-10 to 5-15 in the WBR (Appendix G4, Santos EIS).

Summary

Bohena Creek is ephemeral so water quality will be quite different during times of continuous streamflow against times where individual ponds will exist during prolonged dry periods or drought. I expect the baseline dataset would be significantly skewed if the ephemeral creek presents as individual ponds for significant periods of time. As such, I consider that it would be better if the baseline dataset was split into continuous streamflow and ceased flow. These two baseline datasets would then serve a better purpose to measure any inflow of CSG contaminated surface or groundwater (depending on groundwater – surface water connectivity).

Hydrostratigraphic unit representation

In my opinion the HSUs are adequately discussed in the Section 5.2 of the GIA for the Permian coal measures, Jurassic Pilliga Sandstone and Alluvial aquifers. However, discussions are limited for the Triassic Formations and early Jurassic Purlawaugh Formation. As the Triassic and early Jurassic HSUs are important aquitards I do not consider this to be adequate for the conceptual model.

The main HSUs of interest in this report and indicative thicknesses were given in Table 4-4 of the GIA (Appendix F, Santos EIS). There is a wealth of information that has been gathered from private and DPI bores located in the Namoi Alluvium and Pilliga Sandstone, and Santos and other CSG/coal mining proponents' investigations in the Permian coal measures and adjacent strata. However, only two bores each of the Triassic Digby and Napperby Formations, and only one from the early Jurassic Purlawaugh Formation, have been monitored. Neither CDM Smith nor DPI stated which part of the Napperby and Digby Formations these bores are screened in.

Santos had to drill through the Triassic HSUs many times as part of their Narrabri Gas Field drilling programme. CDM Smith has not presented any geological borelogs, interpreted downhole geophysical logs or photographic evidence of core samples from these bores.

Figure 11-4 provided the hydrostratigraphic classification (Chapter 11, Santos EIS). It showed the classification of aquifers and aquitards. The aquitards are classified as follow:

'Probable negligible transmissive units (PNTUs) include much of the late Permian and late Triassic Age strata in the Gunnedah Basin. Negligibly transmissive units (NTUs) include the early and mid-Permian and early and mid-Triassic Age strata, which closely correlate with the most effective aquitards.'

'Overall, the hydrostratigraphic sequence consists of significant transmissive units at depth within the coal seams of the Gunnedah Basin, which are hydrologically isolated from the overlying portion of the Pilliga Sandstone aquifer of the Surat Basin and the shallow Namoi Alluvium aquifer by thick aquitard sequences. The adopted classification system therefore recognises aquifers (e.g. Namoi Alluvium, Pilliga Sandstone) and aquitards (e.g. Purlawaugh Formation, basal Napperby Shale, Digby Formation and the Watermark Formation) but prefers to identify coal seams as STUs rather than aquifers because they generally do not yield economic quantities of water to wells, and would not normally be referred to as aquifers.'

CDM Smith (2016a) discussed the thicknesses of the aquitards in a misleading light as it is the hydraulic properties of these leaky, low transmissivity HSUs that will mostly influence whether they are effective aquitards or not. I agree the Triassic Digby basal Bomera Conglomerate and the Triassic basal Napperby Shales can be effectively conceptualised as a negligibly transmissive unit due to the degree of cementation and diagenesis. However, I am not convinced this is the case for the remaining Digby Formation and the Napperby Sandstone.

Hydrogeological properties representation

In my opinion, hydrogeological properties, and in particular vertical hydraulic conductivity (Kv), of the Triassic Digby and basal Napperby Shale and early Jurassic Purlawaugh Formation aquitards are not adequately represented in the conceptual model.

CDM Smith made the following observations from the compiled data (GIA Appendix F, Santos EIS):

- 'The existing ranges of values for Kv that have been adopted for strata of the GAB and GOB did not clearly distinguish between more or less transmissive units. Values of Kv for the Pilliga Sandstone (a major regional aquifer), the Permian coal seams (known water producing units) and strata considered to be aquitards (probable/negligibly transmissive units)'; for example similar to values of Kv for the Purlawaugh Formation aquitard (classified as a negligible transmissive unit by CDM Smith/Santos).
- 'The existing ranges of values of Kv adopted for strata of the GAB and GOB vary over almost four orders of magnitude from 1E-6 m/d to 4E-3 m/d.'
- 'When considered within the context of the HSU classifications (Table 5.1 GIA, Appendix F) there are some anomalies in the existing adopted values of Kv; for example, the Blythesdale Group (Keelindi Beds) has been assigned values of Kv typical of a poor aquifer while it is generally considered to be an aquitard consisting of clayey sandstone, siltstone and conglomerate.'
- 'The existing ranges of values for Kv adopted for all strata of the GAB and GOB are mainly typical of consolidated sandstones, and do not reflect literature values for aquitards containing shale, mudstone and siltstone, which are typically within the range 1E-8 to 1E-4 m/d.'

In my opinion Santos should have measured the Kv of the critical units (Purlawaugh Formation, Basal Napperby Shales, Digby Formation, Watermark-Porcupine-Upper Maules Ck Formations), which are relied upon to protect the Pilliga Sandstone and alluvial aquifers. Instead, Santos second guessed Kv values from other investigations and has used text book Kv values in the conceptual groundwater model. These measurements may not be representative and therefore may impact on the GIA outcomes.

Hydrographs from the BWD28 set of bores located in the Purlawaugh Formation, Lower and Upper Pilliga Sandstone, show similar characteristics in a time frame of months, not years. Likewise hydrographs from DPI nested bores GW036546 located in the Black Jack Formation, Digby and Napperby Formations showed similar characteristics in a timeframe measured in months. Hydrographs from Santos' set of bores at DWH14 showed the Purlawaugh Formation aquitard fluctuated ~0.5m, although the overlying Pilliga bores did not seem to fluctuate significantly. However, CDM Smith have provided hydrographs of the Pilliga Sandstone monitoring bores at a smaller scale giving the appearance the bores do not fluctuate in a similar fashion to the underlying Purlawaugh Formation bore DWH14PRPUR03. In conclusion, the aquitards (especially the Purlawaugh Formation aquitard) may be leakier than has been conceptualised in CDM Smith's model. In addition, it should be questioned whether the 'lower end' and 'text book' vertical hydrogeological conductivities assigned to the Purlawaugh Formation aquitard are representative.

CDM Smith and Santos also stated the thickness of the aquitards as being a major factor in protecting the overlying high quality Pilliga Sandstone and alluvial aquifers, and groundwater dependent ecosystems (GDEs). Dr Wendy Timms, Connected Waters Initiative, UNSW, has researched many factors affecting aquitard potential, including that the permeability of the aquitard is relatively more important than thickness (Timms et al. Leading practices for assessing the integrity of confining strata: application to mining and coal-seam-gas extraction. *IMWA Conference*, 139-148, 2012).

Sensitivity analyses on varying Kv values have been undertaken, as part of the groundwater numerical modelling, and this will determine how much of an impact there is on the overlying Pilliga Sandstone and Alluvial aquifers.

Groundwater flow systems representation

In my opinion, CDM Smith mostly adequately conceptualise flow systems across the model domain in which the NGP is located.

Sections 5.6, 5.6.1, 5.6.2, 5.6.3 and 5.6.4 of the GIA adequately explain the concepts of the groundwater flow systems in the model domain. The effects of pumping CSG production water will impact the area on a regional scale, before it could affect the local alluvial groundwater sources.

I agree with the following CDM Smith statements: 'Within the context of predicting impacts of coal seam gas developments spanning tens to hundreds of years, it followsthat relatively short-lived fluctuations of water levels in rivers and shallow groundwater sources do not influence these predictions.'

'The inclusion of relatively high-frequency, cyclic stresses in the modelling domain would make the detection of delayed and extended responses to coal seam gas development difficult to discern.'

'Cyclic stresses and responses in streams and shallow groundwater sources are neglected so that changes in hydraulic head and groundwater flow are directly attributable to coal seam gas development.'

However, there is a long term decline in groundwater levels in the Namoi Alluvium. I have concerns as to whether the model has adequately conceptualised this long term groundwater loss in the Namoi Alluvium as part of the model domain.

I consider that the main problem with the conceptualisation of the groundwater flow system is the representation of the aquitards ability to transmit groundwater vertically.

ISSUE TWO

Are the predictive modelling and potential groundwater impacts identified in the Santos EIS appropriate?

In my opinion, the predictive modelling is not entirely appropriate as it is based on a Numerical Model which has a low model confidence level classification of 'Level 1'.

The resultant NGP numerical groundwater model determined the groundwater impacts from predicted depressurisation and drawdown from the GIA, as summarised in Table 3-1 (WMP, Appendix G3, Santos EIS) .

Figure 3-2 of the WMP (Appendix G3, Santos EIS) showed the predicted maximum extent of drawdown that exceeded 1m within Late Permian coal seams (CDM Smith 2016b) which occurs at mid-depth within the GOB and immediately below Triassic Age strata that are the focus for early-detection monitoring (WMP, Appendix G3, Santos EIS).

In Table 2-5 of the WMP (Appendix G3, Santos EIS) CDM Smith stated the predicted impacts of gas extraction will be 'Not Measurable' in changes of water level, and aquifer connectivity between aquifers supporting GDEs and other users. In my opinion, this is not in keeping with predictive depressurisation and drawdown determined from the GIA (Appendix F, Santos EIS) which stated in the summary:

'...no impacts on hydraulic head or water supply works in the Pilliga Sandstone exceeding 0.5m drawdown are predicted as a consequence of the Narrabri Gas Project'. (Tables 11.9 and 11.10 stated <0.5m and 0.6m, respectively for base case and high case predictions).

'...no impacts on water table elevation or water supply works in the Namoi alluvium exceeding 0.5m drawdown are predicted as a consequence of the Narrabri Gas Project'.

No comment was made regarding the Bohena alluvium in the immediate vicinity of the NGP which is an oversight.

These predictions were based on a Numerical Model with the lowest model confidence level classification of 'Level 1' from Table 2-1 of the Australian Groundwater Modelling Guidelines (Barnett *et al.* 2012). The implication being there is not enough spatial and temporal data for some of the major HSUs to allow transient calibration to be undertaken for those units (only calibrated for Namoi Alluvium). Therefore, long term predictions of drawdown effects due to CSG dewatering cannot be made reliably. That is, the Numerical Model is not fit for purpose. It was not in my brief to review and comment on the Numerical Model; however, I state the following in support of my opinion:

- The model is calibrated only for steady state flow in the Namoi alluvial aquifer and not for transient state flow.
- The predictive model time frame far exceeds that of calibration time based on the transient data period.
- The model is based on inadequate hydraulic properties and very limited data representing the deeper groundwater system (Jurassic, Triassic and upper Permian).
- CDM Smith did not undertake a Monte Carlo assessment to see what potential outcomes could occur with a range of hydraulic conditions and scenarios.
- Given that CDM Smith state the aquitards are critically important, serving to physically dampen drawdown effects and temporally retard the pumping production water from the Permian coal seam measures, in my opinion, the predictive modelling is not entirely appropriate.

ISSUE THREE

Is the proposed groundwater monitoring plan appropriate?

In my opinion, the WMP is mostly appropriate; however please note the comments below.

Summary

Key principles of the WMP are summarised as follows and shown in Figure 3-1 of the WMP (Appendix G3, Santos EIS).

- Monitoring activities are designed to inform, to the extent possible, an understanding of whether the NGP is contributing to changes in water quantity or quality within high-valued groundwater sources in the GAB and alluvial aquifers.
- Where possible, 'leading' resource condition indicators for quality and quantity are used for early warning of potential changes to water resource conditions arising from the NGP. Sentinel monitoring bores are nominated within the Triassic HSUs (Napperby and Digby Formations) in the GOB to detect unexpected changes prior to potential impacts on receptors within the GAB Pilliga Sandstone and Namoi Alluvial aquifers.
- 'Lagging' resource condition indicators for quantity and quality are nominated to assess trends in water resource conditions associated with non-NGP activities (i.e climatic and consumptive use). The nominated sites are DPI bores located in the Pilliga Sandstone and Namoi Alluvial aquifers where the NGP baseline data exhibit historical effects from variations in climate and consumptive water use patterns. This data is proposed to be used to demonstrate that observed changes in resource condition are not an effect of the NGP.

The concept of a monitoring for 'leading' and 'lagging' effects is prudent and sound.

GOB WMP

The nominated GOB groundwater monitoring plan is appropriate for monitoring the effects of the CSG depressurisation in the Permian coal measures on the Triassic and Jurassic HSUs. However, there is no adequate baseline dataset to compare it with. This monitoring bore configuration includes three proposed new bores representing the Triassic Digby and Napperby Formation aquitards and Jurassic Purlawaugh Formation aquitard. This monitoring bore configuration should have existed for the WBR. The baseline data should cover temporal and spatial variation. CDM Smith (and Santos) should have provided data which indicates what a 'typical temporal variation' is, and then collected statistically viable data covering that time period. The fact that Santos spent less than two years gathering this data is questionable. There is little baseline data for the GOB Triassic HSUs with which to measure the WMP bores against, for both water quality and hydraulic head.

GAB WMP

The nominated GAB groundwater monitoring bores and programme should adequately represent the Purlawaugh, Pilliga, Orallo and Mooga Formations in the NGP and surrounding area. However, there are Level 2 bores which in my opinion should be Level 1 bores. The proposed WMP for the GAB bores will have an inadequate baseline dataset due to limited temporal coverage within the NGP. Only two bores have at least two years of data with the remaining having 1 to 1.5 years of data. This is not sufficient to form a temporally representative baseline dataset as these formations have lag periods measured in years. That is, effects from drought could take more than a year to manifest a change in the Pilliga Sandstone unit in the Recharge Area of the GAB.

Unfortunately, there was no baseline data given for the Orallo Formation in the Bibblewindi Field area. There is an upward hydraulic gradient between the Lower and Upper Pilliga Sandstone at bore sites BWD26, BWD 27 and BWD 28. CDM Smith Figure 3-2 in the WBR showed bore BWD27PRORA02 (Orallo Fm) existed but for some reason there was no data presented. The Orallo Formation (part of the Keelindi Beds) is a 'Negligibly Transmissive Unit' (aquitard), which serves to protect the Upper Pilliga Sandstone from lower quality water which may be present in the Bohena Alluvial aquifer due to past contamination events (depending on the hydraulic gradient).

Namoi and Bohena Alluvium

The nominated bores represent the Bohena alluvium (Santos bores), within the NGP; and the Namoi alluvium (DPI bores) in the surrounding area. CDM Smith did not state which part of the Namoi Alluvium the bores are screened in – Narrabri or Gunnedah subsystems. This is significant as these systems behave differently.

Most of the Level 1 bores will be measured against limited baseline data collected and presented in the WBR (CDM Smith, Appendix G4 of the EIS). The best baseline data was collected from DPI bores at sites GW025338, GW021266, GW025343 and GW036005, yet they are Level 2 bores. There is no baseline data collected for the Level 1 bore GW025340, and so there is no dataset against which it can be measured.

These bores lie adjacent and along Bohena Creek. In my opinion, four more bores should be established to adequately monitor the NGP activities that may impact on the Bohena alluvium should the Leewood ponds or pipelines leak, or irrigation field deep drainage occur:

- Two bores located down gradient NW of the Leewood Water Treatment Facility ponds.
- Two bores located NE on the eastern side of Bohena Creek. Leewood's irrigation fields are located along a local structural ridge. Shallow groundwater could flow either NW and/or NE from the site.

There is a discrepancy in the WBR. It is not clear whether the baseline water quality data from the four Bohena alluvium bores was collected over a three month period or over a two year period. There has been no baseline water level data collected from the four Bohena alluvium bores as part of the WBR. This monitoring network is not able to be measured against an established baseline dataset.

Review of WMP (Appendix G3, Santos EIS)

Introduction

Chapter 11: Groundwater of the Santos EIS states that a regional groundwater monitoring network of 58 monitoring locations was already in place across, and beyond, the NGP area to measure and track potential impacts to groundwater sources. This network is to be further developed with an additional 8 monitoring bores proposed to be installed to operate as part of the NGP.

‘The Water Monitoring Plan (WMP) included trend analysis, with monitoring results assessed against background data (Water Baseline Report), a response framework and reporting arrangements.’

Reporting included:

- Groundwater levels.
- Groundwater pressure.
- Groundwater quality.
- Real time monitoring of some parameters (but Santos had not stated which ones).

The existing baseline will be complemented by information collected as part of the ongoing monitoring outlined in the Santos Groundwater Monitoring Plan.

The WMP has been developed by Santos having regard to the policy intent and requirements of the overall NSW Aquifer Interference Policy (AIP; NSW DPI 2012) including:

- Considering the levels of the risks posed to water resources, and users of those resources, by the NGP, which are assessed in the GIA to be low to very low (CDM Smith 2016b).
- Ensuring minimal impact requirements (Table 1 of the AIP) can be met, noting the minimal impact considerations include the water needs of dependent ecosystems, culturally significant sites and water users.
- Having appropriate response mechanisms in place should observed changes to water resources (e.g. water table or stream flow decline) found to exceed the predicted effects or the minimal impact considerations.

To achieve this purpose the WMP included:

- Design of a monitoring program to support early detection and identification of unexpected impacts from the NGP should they occur.
- Identification of thresholds for observed adverse changes in the condition of water resources at which appropriate actions may be taken to manage and mitigate these effects, taking into account the minimal impact considerations of the AIP.
- Validation of the predicted effects of the NGP on water resources presented in the GIA (CDM Smith 2015b) and adaptive management that will be followed if the predictions are found to be substantially less than observations and need to be revised.
- Design of appropriate methods for reporting and analysing data from the monitoring program to identify when adverse changes that were not predicted may be related to the NGP.

CDM Smith provided Table 2-2 and Table 2-3 (WMP, Appendix G3, Santos EIS) which lists ‘water dependent assets and receptors that are identified as having the potential to be impacted by the NGP.’ Table 2-4 and 2-5 outline the water-affecting activities of the NGP that CDM Smith considered to be addressed in the WMP.

CDM Smith (2016b) stated:

‘Risks posed to these assets from the project are assessed in the GIA to be low to very low.’

‘Potential interactions between the target coal seams for gas production, in which direct depressurisation will be induced, and the shallow high-valued groundwater and surface water sources that host potentially sensitive receptors are assessed in the GIA to be negligible.’

In Table 2-5 CDM Smith predicted gas extraction impacts would be considered ‘Not Measurable’ in changes of water level, and aquifer connectivity between aquifers supporting GDEs and other users. This is not in keeping with predictive depressurisation and drawdown determined from the GIA.

CDM Smith stated in Table 2-5 that ‘changes to groundwater-surface water interactions due to reduction in aquifer pressures would be considered ‘Not Measurable’. However, in my opinion, even a low induced flow rate from Bohena Creek could impact on sensitive GDEs along the hyporheic zone of Bohena Creek.

In addition, in my view, the impacts of un-managed leaks from ponds and pipelines should have been considered.

Key Principles

The key principles of the WMP are summarised as follows (as shown in Figure 3-1 of the WMP):

- Monitoring activities are designed to inform, to the extent possible, an understanding of whether or not the NGP is contributing to changes in water quantity or quality within high-valued groundwater sources in the GAB and alluvial aquifers.
- Where possible, ‘leading’ resource condition indicators for quality and quantity are used for early warning of potential changes to water resource conditions arising from the NGP. Sentinel monitoring bores are nominated within the Triassic hydrostratigraphic units (Napperby and Digby Formations) in the GOB to detect unexpected changes prior to potential impacts on receptors within the GAB Pilliga Sandstone and Namoi Alluvial aquifers.
- ‘Lagging’ resource condition indicators (quantity and quality) are nominated to assess trends in water resource conditions associated with non-NGP activities (i.e climatic and consumptive use). The nominated sites are DPI bores located in the Pilliga Sandstone and Namoi Alluvial aquifers where the NGP baseline data exhibit historical effects from variations in climate and consumptive water use patterns. This is to demonstrate that observed changes in resource condition are not an effect of the NGP.

Permian and Triassic HSUs (GOB monitoring bores)

The WMP (CDM Smith, 2016b) shows the proposed Water Sharing Plan (**WSP**) for NSW Porous Rock Groundwater Sources in the GOB groundwater monitoring bore network (Figure 3-6, Appendix G3 of EIS). Tables B-1 and B-3 (Appendix B in the WMP) and Table 3-6 present the groundwater pressure head and water quality monitoring programme.

In my view, the WMP monitoring network for the GOB should have been in place for the WBR. There are only two baseline water quality monitoring datasets provided in the WBR (nested bores TULPRDGY01 - Napperby Fm and TULPRDGY01 - Digby Fm) against which to measure the WMP data. Groundwater pressure head baseline dataset, in the NGP area, has only been monitored for one year. In my opinion, this is not acceptable. Santos has provided an inadequate and misleading groundwater baseline water quality dataset for formations which are considered to be very important in protecting the GAB high value aquifers. In my opinion, at least two years of baseline monitoring, aiming for a temporally representative dataset, should occur using the WMP monitoring bores before the Santos EIS can be considered adequate and the NGP approved.

Jurassic HSUs (GAB monitoring bores)

The nominated GAB groundwater monitoring bores and programme should adequately represent the Purlawaugh, Pilliga, Orallo and Mooga Formations in the NGP and surrounding area (refer to Figure 3-5 and Table 3-5 of the WMP).

There is a discrepancy as to whether Santos' nested bore BWD28 is a Level 1 or Level 2 monitoring bore (it is a Level 1 bore in Figure 3-5 but a Level 2 bore in Table 3-5). In my view, it should be a Level 1 bore.

In my view, a new monitoring bore should be constructed near WBR baseline bore site 7705/7703 as this would be beneficial to monitor Purlawaugh, Upper and Lower Pilliga downgradient of Leewood Water Treatment Plant.

Nested bores NYOPRORA01 and NYOPRUPS02 should be Level 1 bores. The DPI Level 1 monitoring bores GW030121-1, GW030121-2, GW030121-3 have been proposed for water level monitoring only, with CDM Smith stating these DPI bores are not equipped for water quality sampling. However, GW030121-1 was sampled as part of the baseline studies for field EC and lab pH with the results given in the WBR. Similarly, proposed Level 2 DPI bores GW030310-2 was sampled for full major ion chemistry, lab EC and pH; and GW030400-1 was sampled for anion and some cation analyses, lab EC and field pH. Accordingly, there is no clear reason provided as to why these bores are not equipped to be used for water quality sampling in the future.

The proposed monitoring bores will have an inadequate baseline dataset to measure against due to limited temporal coverage within the NGP. Only two bores have at least two years of data with the remaining having 1 to 1.5 years of data. This is not sufficient to form a temporally representative baseline dataset as these formations have lag periods measured in years. That is, effects from drought could take more than a year to manifest a change in the deeper Pilliga Sandstone unit in the Recharge Area of the GAB.

Unfortunately, there is no baseline data given for the Orallo Formation in the Bibblewindi Field area. There is an upward hydraulic gradient between the Lower and Upper Pilliga Sandstone at bore sites BWD26, BWD 27 and BWD 28. CDM Smith Figure 3-2 in the WBR suggested bore BWD27PRORA02 (Orallo Fm) existed but no data has been included in the Santos EIS. The Orallo Formation (part of the Keelindi Beds) in a 'Negligibly Transmissive Unit' (aquitard) which serves to protect the Upper Pilliga Sandstone from lower quality water which may be present in the Bohena Alluvial aquifer due to past contamination events (depending on the hydraulic gradient). Accordingly, the lack of baseline data is significant.

Namoi and Bohena Alluvium Monitoring Bores

The nominated alluvial aquifer groundwater monitoring bores are presented in Figure 3-4 (Appendix G3, Santos EIS). The bores represent the Bohena alluvium (Santos bores), within the NGP; and the Namoi alluvium (DPI bores) in the surrounding area. CDM Smith has not stated which part of the Namoi Alluvium the bores are screened in – Narrabri or Gunnedah subsystems. This is significant as these systems behave differently.

The Namoi Alluvium WMP monitoring programme is given in Table 3-3. Most of the Level 1 bores will be measured against limited baseline data collected and presented in WBR (CDM Smith, Appendix G4, Santos EIS). The best baseline data was collected from DPI bores at sites GW025338, GW021266, GW025343 and GW036005, yet they are Level 2 bores. No baseline data has been collected for Level 1 bore GW025340 and therefore there is no dataset to measure it against.

The WMP bores nominated for the Bohena Alluvium are those that were used for the WBR and are given in Table 3-4. They lie adjacent and along Bohena Creek. In addition to the Bohena bores installed prior to the establishment of the Leewood Water Treatment Plant, brine ponds and irrigation fields, I suggest four more bores should be established to adequately monitor the NGP activities that may impact on the Bohena alluvium should the Leewood ponds or pipelines leak, or irrigation field deep drainage occur:

- Two bores located down gradient NW of the Leewood Water Treatment Facility ponds.
- Two bores located NE on the eastern side of Bohena Creek. Leewood's irrigation fields are located along a local structural ridge and shallow groundwater could flow either NW and/or NE from the site.

There is a discrepancy in the WBR. It is not clear whether the baseline water quality data was collected over a three month period or over a two year period. There has been no baseline water level data collected as part of the WBR. Therefore, the Bohena alluvium monitoring network is not able to be measured against an established water level baseline dataset.

In addition, the *Australia and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC 2000 Guidelines) suggest there should be an assessment of organic compounds (eg methane) or of the radiological quality. CDM Smith has not included these in the WMP for any of the HSUs. Should buoyant methane gas (fugitive methane gas) be present, or increase, in the HSUs overlying the CSG target zone then it will not be picked up until the environment is impacted which is unacceptable.

ISSUE FOUR

Further observations

Commonwealth Requirements

The GIA was prepared by CDM Smith taking into consideration the Commonwealth Department of the Environment's EPBC Act policy statement *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources* (Commonwealth of Australia 2013). The significant impact guidelines cover a range of criteria, but those pertinent to baseline monitoring include:

- Changes to hydrological characteristics – potential significant impacts on the hydrological characteristics of a water resource as a result of the action;
- Changes in water quantity, including timing of variations on water quantity;
- Changes in integrity of hydrological and hydrogeological connections;
- Changes in the area or extent of a water resource; and
- Changes to water quality.

In order to measure changes in hydrological characteristics and water quality, a sound knowledge of baseline conditions is required. Baseline conditions require statistically significant data which characterise the hydraulic nature of each HSU (including aquifers and aquitards), and the quality of the groundwater within each HSU, over typical temporal and spatial variations. In my opinion, the Santos EIS does not demonstrate that baseline conditions are currently well known.

NSW Secretary's Environmental Assessment Requirements (SEARS)

The NSW SEARS for the NGP included advice and recommendations from DPI Water. These were given in Table 1-2 in the GIA (Appendix F, Santos EIS).

Pertinent to baseline data, DPI Water recommended the Santos EIS provide:

*'Sufficient baseline monitoring for groundwater quantity and quality for all aquifers and GDEs to establish a baseline incorporating **typical temporal and spatial variations.***

In my opinion, CDM Smith (and Santos) should have provided baseline data that indicated 'typical temporal variations,' and then collected statistically viable data covering that time period. However, the Santos EIS fails to

provide this baseline data for the GAB and GOB. On the other hand, baseline data in respect of spatial variation, which is easier to collect, has been adequately provided for the GAB but not the GOB.

This letter report has been prepared by Andrea Broughton, Senior Hydrogeologist, and provided to NW Alliance solely for use in their submission to the Santos EIS, with my expert review on Santos (Eastern) Pty Ltd: *Environmental Impact Statement - Executive Summary; Chapter 11; Appendix F Groundwater Impact Assessment and supporting appendices G3 and G4* (CDM Smith 2016a, b and c). Neither this report nor its contents may be referred to or quoted in any statement, study, report, application, prospectus, loan, other agreement or document, without the express approval of Andrea Broughton, Groundwater Solutions International (part of Gradient Limited).

Disclaimer

The information contained in this desktop review is based on the contents of the *Narrabri Gas Field Environmental Impact Assessment* (Santos Eastern Pty Ltd, October 2016), and my own professional experience. I accept no responsibility for the results of actions taken as a result of information contained herein and any damage or loss, howsoever caused, suffered by any individual or corporation.

The findings and opinions in this report are based on a desk top review undertaken by myself, Andrea Broughton, Senior Hydrogeologist, BSc Geology, BSc Geology (Hons), MAppSci Hydrogeology and Groundwater Management, of Groundwater Solutions International (part of Gradient Ltd).

Narrabri Gas Project Submission

The economic assessment of the Narrabri Gas Project is misleading and does not comply with NSW assessment guidelines. The benefit cost analysis by consultants GHD is contradicted by the proponents' financial statements and analysis commissioned by the Australian Energy Market Operator.

Tony Shields
Rod Campbell
May 2017

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Summary

The economic assessment of the Santos Narrabri Gas Project is misleading, heavily understating the costs of the project. This is evident from the fact that both proponents, Santos and CLP Group, have written off the entire value of the project in their financial statements, effectively valuing the project at zero.

In December 2015 Santos was forced to “write down the remaining book value” of its Narrabri stake and in December 2016, classified the project as a ‘non-core asset’. This is in stark contrast to the economic assessment written by consultants GHD, that estimates the net present value of the project at \$1.54 billion to Australian stakeholders, implying a total value of \$2.2 billion.

The main factor behind GHD’s optimistic evaluation is assumed capital and operating costs far below published estimates by other analysts. In 2015 the Australian Energy Market Operator (AEMO) commissioned analysis that included estimates of gas production costs in the Gunnedah Basin which includes the Narrabri Gas Project area. AEMO’s estimates are between \$6.53 and \$7.98 per gigajoule (GJ), with a central estimate of \$7.25/GJ.

Even without allowing for inflation or any discounting of future costs, GHD’s costs per gigajoule are lower than AEMO’s most optimistic scenario, \$6.25/GJ compared to \$6.53/GJ. As soon as any inflation, financing costs, risk and uncertainty are considered through a discount rate, GHD’s costs are far lower than those commissioned by AEMO. Exact comparison is difficult without more information on both studies, but GHD’s central present value cost per gigajoule is just 34% of AEMO’s central value, at \$2.48/GJ.

This large difference in costs must be explained by GHD and Santos. In our opinion this is the main factor resulting in the wildly different project values estimated by financial analysts compared to the benefit cost analysis performed by GHD.

GHD note in their report:

GHD has prepared this report on the basis of information provided by Santos which GHD has not independently verified or checked beyond the agreed scope of work...It was outside the scope of this analysis to independently appraise project parameters such as forecast gas prices, capital and operating costs and gas production estimates.

The *NSW Guidelines for the Economic Assessment of Mining and Coal Seam Gas Proposals* with which this benefit cost analysis should comply require the economic assessment to 'be based on rigorous, transparent and accountable evidence that is open to scrutiny'. Cost and production data in the GHD analysis is not rigorous or transparent and has not been subject to scrutiny even by GHD, contrary to the NSW Guidelines.

Other problems with GHD's analysis include:

- Optimistic gas prices. Santos has a history of making over-optimistic oil and gas price forecasts and this appears present in the gas price forecast it has supplied to GHD.
- No discussion of the pipeline required to facilitate the project.
- Minimal consideration of costs of potential impacts on water resources.
- No consideration of costs of potential impacts on human health.
- Underestimate of greenhouse gas emissions, ignoring fugitive and migratory emissions.

The flaws in GHD's analysis are typical of assessments of 'megaprojects'. Nobel Prize for Economics winner, Daniel Kahneman, and Amos Tversky, have outlined the systematic biases that are common in such assessments, including optimism bias, strategic misrepresentation and principal-agent misalignment of objectives. The world's most cited scholar on megaprojects, Bent Flyvbjerg writes:

When cost and demand forecasts are combined, for instance in the cost-benefit analyses that are typically used to justify large infrastructure investments, the consequence is inaccuracy to the second degree. Benefit-cost ratios are often wrong, not only by a few percent but by several factors. As a consequence, estimates of viability are often misleading, as are socio-economic and environmental appraisals, the accuracy of which are heavily dependent on demand and cost forecasts. These results point to a significant problem in policy and planning: More often than not the information that promoters and planners use to decide whether to invest in new projects is highly inaccurate and biased making plans and projects very risky.

Recent changes to NSW project assessment guidelines have not improved the quality of assessment provided by proponents such as Santos and consultants such as GHD, which continue to include glaring errors and inconsistency with market evaluations and independent assessments. NSW guidelines must continue to evolve and deal with the biases and strategic misrepresentation of projects that are rife within the planning system.

The Narrabri Gas Project will not affect rising gas prices in eastern Australia. Now that Australia is linked to world gas markets via export terminals in Gladstone, Queensland, Australian prices will largely reflect world market prices.

Benefits to the local area are likely to be minimal. Gas industry-funded research in Queensland finds that local businesses in unconventional gas regions believe that gas development led to deterioration in their finances, local infrastructure, social connections and labour force skills.

The Narrabri Gas Project is financially dubious, with uncertain benefits and costs that have not been properly assessed by GHD. It is likely that its costs outweigh its benefits and it should be rejected by NSW planning authorities on this basis.

Introduction

Santos is proposing to extract coal seam gas in the Gunnedah Basin of New South Wales, southwest of Narrabri. The project is referred to as the Narrabri Gas Project (Project). Santos has lodged an Environmental Impact Statement (EIS) for the Project, which includes a benefit cost analysis prepared by GHD.¹ This document is our submission concerning the benefit cost analysis and other economic aspects of the EIS.

The Project is a large project covering 950 square kilometres and includes the installation of up to 850 new wells, new access tracks, a gas processing facility, a water management facility and various buildings. First production is scheduled for 2019/20, with the Project having an estimated life of 25 years.

The Project area includes a portion of the region known as the Pilliga. Nearly half of the Pilliga is set aside for conservation.² The Pilliga has spiritual meaning and cultural significance for the Aboriginal people of the region. Other parts of the Pilliga are State Forest set aside for forestry, recreation and mineral extraction. Much of the Project area is within this State Forest, with the remaining Project area on agricultural land that supports dry land cropping and grazing.

The benefit cost analysis states that the net present value of the Project is \$1.54 billion and that the Project is expected to generate approximately 1,300 jobs during construction and 200 jobs during operation. The benefit cost analysis estimates that the Project will generate \$293 million in royalties for the NSW Government and \$60 million in payroll taxes (in net present value terms). Our view is that the benefits of the Project are heavily overstated, while costs are understated. Many projects in the NSW planning system have suffered from these problems, as is common internationally. International literature on megaproject assessment outlines why these over-optimistic estimations arise again and again.

We confirm that in preparing this submission we have read the Expert Witness Code of Conduct under the *Uniform Civil Procedure Rules 2005* and agree to be bound by it.

¹ GHD (2016) *Narrabri Gas Project – Environment Impact Statement Economic Assessment*

² *Ibid*, p3.

Project value in proponent accounts

The net present value (NPV) of the Project estimated by GHD in the EIS is \$1.54 billion. This estimate is contradicted by values in the proponents' financial statements.

The Project is 80% owned by Santos and 20% owned by the Hong Kong based CLP Group via its subsidiary EnergyAustralia. Santos itself is 87% domestic owned and 13% foreign owned. The Project is therefore 30% foreign owned.

GHD's benefit cost analysis calculates the net present value of this project to the *Australian community*. Taking into account the 30% foreign owned stake, the estimated net present value of the Project to *all* stakeholders would be \$2.2 billion.³

In contrast, Santos values the Project at zero in its financial accounts. In December 2015 Santos was forced to "write down the remaining book value" of its stake in the Project due to the "low oil price environment and the fact that the rate of investment in the Narrabri Gas Project will be slowed".⁴ In December 2016, Santos classified its stake in the Project as a 'non-core asset stoking speculation that it would sell the venture'.⁵ CLP Group also values the Project at zero.^{6 7}

There are significant differences between economic benefit cost analysis and financial analysis. However, the contrast of zero book value with \$2.2 billion NPV points to over-optimism and strategic misrepresentation in the benefit cost analysis.

Benefit cost analysis includes more items in its calculations than financial accounts, such as social and environmental costs – the GHD analysis includes for example a social

³ The benefit cost analysis estimate of \$1.5 billion in net present value to Australian shareholders divided by 70% (1-30%).

⁴ Santos (2016), *Statement on Santos NSW assets*, <https://narrabrigasproject.com.au/2016/02/statement-on-santos-nsw-assets/>

⁵ Hannam (2016) *Santos signals possible NSW CSG exit, raising doubts about government gas plan*, Newcastle Herald, 8 December 2016, <http://www.theherald.com.au/story/4345321/santos-signals-possible-nsw-csg-exit-raising-doubts-about-government-gas-plan/?cs=12>

⁶ CLP Group (2015) CLP Group (2015) *Annual Report 2014*, p224, [https://www.clpgroup.com/en/Investors-Information-site/Documents/Financial%20Report%20PDF/e_Annual%20Report%202014%20\(full%20version\).pdf](https://www.clpgroup.com/en/Investors-Information-site/Documents/Financial%20Report%20PDF/e_Annual%20Report%202014%20(full%20version).pdf)

⁷ Chambers (2015) *CLP writes off stake in Santos project*. The Australian, 28 February 2015, <http://www.theaustralian.com.au/business/mining-energy/clp-writes-off-stake-in-santos-project/news-story/2619e923515725685b4b4fb0222af101>

cost of carbon. Company financial accounts do not include such costs. These items should lower the NPV compared to the value in the financial accounts. However the reverse is the case here, the NPV is much higher.

Financial analysis and benefit cost analysis also approach discounting differently. However, in the sensitivity analysis GHD's benefit cost analysis calculates the value of the Project under the alternative assumption of a 10% discount rate which would be closer to the discount rate used in the financial accounts. This 10% discount rate implies that the NPV of the Project to all shareholders is \$1.1 billion, which far from explains this difference.⁸

CLP Group wrote down the value of the Project to zero in December 2014. In doing so, it valued its stake in the Project using a discount rate of 13% and assumed 2.5% inflation.⁹ This implies a real maximum discount rate of 10.5% which is very close to the 10% (real) discount rate used in the benefit cost analysis. In other words when CLP used a discount rate similar to that used in GHD's analysis (10.5% vs 10%), CLP valued the Project at zero compared to the benefit cost analysis estimate of \$1.1 billion.¹⁰

Santos has been more optimistic than its partner CLP Group in valuing the Project over time. Both Santos and CLP Group reduced their valuation of the Project in December 2014. However while CLP Group wrote down its stake to zero, Santos only wrote down its Narrabri stake to \$543 million.¹¹ It was not until a year later in December 2015 that Santos wrote down its stake in the Project to zero stating it was due to the 'low oil price environment and the fact that the rate of investment in the Narrabri Gas Project will be slowed'.¹²

Santos' optimism compared to its partner, CLP Group, raises concern that this benefit cost analysis, which is based on Santos assumptions, is subject to optimism bias.

⁸ The alternative scenario of a 10% discount rate results in NPV of \$770 million to Australian shareholders. \$770 million divided by 70% (domestic ownership of the Project) equals \$1.1 billion.

⁹ CLP Group (2015) *Annual Report 2014*, pp224, 204, [https://www.clpgroup.com/en/Investors-Information-site/Documents/Financial%20Report%20PDF/e_Annual%20Report%202014%20\(full%20version\).pdf](https://www.clpgroup.com/en/Investors-Information-site/Documents/Financial%20Report%20PDF/e_Annual%20Report%202014%20(full%20version).pdf)

¹⁰ The assumptions used to calculate this NPV calculation may have moved favourably since December 2014 when CLP Group's valuation was done, but this is unlikely. Oil and gas prices have halved (see below). Neither Santos nor EnergyAustralia have revised upwards their estimation of the Narrabri gas reserves and forecast costs are unlikely to have decreased much, if at all.

¹¹ Chambers (2015) *CLP writes off stake in Santos project*. The Australian, 28 February 2015, <http://www.theaustralian.com.au/business/mining-energy/clp-writes-off-stake-in-santos-project/news-story/2619e923515725685b4b4fb0222af101>

¹² Santos (2016), *Statement on Santos NSW assets*, <https://narrabrigasproject.com.au/2016/02/statement-on-santos-nsw-assets/>

Cost assumptions

Capital and operating costs used in the GHD benefit cost analysis appear unrealistic when compared to estimates of these costs in research commissioned by the Australian Energy Market Operator (AEMO). In February 2015 AEMO commissioned Core Energy Group to analyse gas production costs for the Eastern Australian market, including the Gunnedah Basin (i.e. the Project).

Core Energy estimated costs in the Gunnedah Basin under three scenarios relating to the gas production, low, reference and high, as shown in Table 4 below:

Table 4: Core Energy estimates of Gunnedah Basin supply costs, AUD/GJ

Low production	Reference	High production
7.98	7.25	6.53

These costs estimated by Core Energy are far higher than those estimated by Santos and provided to GHD. As discussed above, GHD made no effort to verify Santos' estimates. Exact comparison between Core Energy's cost estimates and GHD's cost estimates are difficult due to the way information is presented in the EIS. Core's estimates represent:

Breakeven price of gas (expressed as AUD/GJ) required to cover the net present value of full lifecycle costs of producing reserves for a defined supply area and to resource owner with a 10% real return on capital.¹³

GHD provide several estimates of nominal and real capital and operating costs at different discount rates (GHD pp 19, 23 and 25), and an incomplete production schedule from 2019 to 2041 (p 19). Assuming production between 2026 and 2041 tapers in a linear manner, total production would be 1,447 GJ of gas. In terms of costs per gigajoule of production, costs used by GHD are far lower than those estimated by Core Energy for AEMO, as shown in the table below:

¹³ Core Energy Group (2015) *Gas Production and Transmission Costs: Eastern and South Eastern Australia*, p9, https://aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2015/Core--Gas-Production-and-Transmission-Costs.ashx page III

Table 5: GHD costs per gigajoule of production

	Undiscounted nominal	Undiscounted real	Discount rate 4%	Discount rate 7%	Discount rate 10%
Capital costs (AUD\$m)	3,570.0	2,980.0	2,333.7	2,004.3	1,757.4
Operating costs (AUD\$m)	5,470.0	3,790.0	2,229.7	1,578.0	1,161.5
Production (GJ)	1,447	1,447	1,447	1,447	1,447
Break-even price per GJ	\$6.25	\$4.68	\$3.15	\$2.48	\$2.02

As shown in the table above, even without allowing for inflation or any discounting of future costs, GHD's costs per gigajoule are lower than Core Energy's most optimistic scenario, \$6.25/GJ to \$6.53. As soon as any inflation, financing costs, risk and uncertainty are considered through a discount rate, GHD's estimated costs are far lower than those published by AEMO. Exact comparison is difficult without more information on both studies, but GHD's central present value cost per gigajoule is just 34% of AEMO's central value. This major difference in assumed costs must be explained by GHD and Santos. In our opinion this is likely to be the main factor in the wildly different Project values estimated by financial analysts compared to the benefit cost analysis performed by GHD.

GHD assumes a gas price received of \$8.70 per GJ. There is little margin between this price and a cost of \$7.25 per GJ. Only a small deviation in gas prices, gas production and/or costs is required to render the Project unviable in this case. As discussed earlier, the GHD assumed price of \$8.70 per GJ is optimistic compared to current world gas prices. If we assume the price received is the current Japanese gas price (net of export costs) of approximately \$A7.16 per GJ¹⁴ then the Project is uneconomic compared to the Core Energy production cost estimate of \$7.25 per GJ.

Santos' massive asset write-downs have caused it to use funds to repay debt instead of making investments. This raises the question of whether Santos could proceed with the Project if it was approved and whether Santos has the ability to continue with the Project if/when forecasts prove to be overly-optimistic.¹⁵

¹⁴ See Table 3 above.

¹⁵ Santos (2016), *Santos announces a new strategy to drive shareholder value*, 8 December 2016, <https://www.santos.com/media/3476/2016-investor-day-asx-presentation-final.pdf>

Analysis relies on data from proponent

In considering the potential biases in the data used by GHD, we note that their analysis is very largely based on assumptions which Santos has given to GHD. These assumptions include capital and operating cost estimates, discussed above, as well as production, gas price, tax and royalty estimates considered later in this submission.

GHD notes “it was outside the scope of this analysis to independently appraise project parameters such as forecast gas prices, capital and operating costs and gas production costs,” and “GHD does not accept liability in connection with such unverified information”.¹⁶

The *NSW Guidelines for the Economic Assessment of Mining and Coal Seam Gas Proposals (NSW Guidelines)*, with which this benefit cost analysis should comply, require the economic assessment to ‘be based on rigorous, transparent and accountable evidence that is open to scrutiny’.¹⁷ However this benefit cost analysis does not contain evidence to support the assumptions supplied by Santos, and GHD has not independently appraised them.

¹⁶ GHD (2017) Narrabri Gas Project Benefit Cost Analysis, p6

¹⁷ NSW Government (2015) *NSW Guidelines for the Economic Assessment of Mining and Coal Seam Gas Proposals*, p3, http://www.planning.nsw.gov.au/Policy-and-Legislation/Mining-and-Resources/~/_media/C34250AF72674275836541CD48CBEC49.ashx

Megaprojects - over cost, over time, over and over again

The flaws and biases that appear to be present in the GHD assessment are often seen in megaproject assessment. These systematic biases have become well documented and well known, particularly due to the work of Bent Flyvbjerg, but also due to the work of Nobel Prize Winner for Economics, Daniel Kahneman, together with Amos Tversky. These biases include:

- optimism bias;
- the planning fallacy;
- strategic misrepresentation; and
- principal agent theory.

Kahneman and Tversky are credited with demonstrating the over-optimistic bias of humans. People underestimate the costs, completion times and risk of planned actions, whereas they overestimate the benefits of the same actions.¹⁸ Kahneman and Tversky also highlighted the planning fallacy which is the tendency for people involved in a project to underestimate the costs and risks of a project simply because they do not foresee what can go wrong. They base their forecasts of the future on the best case rather than the likely case. Kahneman and Tversky say those involved with a project take *the inside view*. People who take the inside view:

- make forecasts by focusing tightly on the project at hand, considering its objective, the resources they brought to it, and the obstacles to its completion; and
- construct in their minds scenarios of their coming progress and extrapolate current trends into the future.

This results in overly optimistic forecasts.¹⁹

¹⁸ Kahneman, D. & Tversky, A. (1979a) *Prospect theory: An analysis of decisions under risk*, *Econometrica*, 47, pp. 313–327. Kahneman, D. & Tversky, A. (1979b) *Intuitive prediction: Biases and corrective procedures*, in: S. Makridakis & S. C. Wheelwright (Eds) *Studies in the Management Sciences: Forecasting*, vol. 12 (Amsterdam: North Holland).

¹⁹ Flyvbjerg (2008) *Curbing Optimism Bias and Strategic Misrepresentation in Planning: Reference Class Forecasting in Practice*, *European Planning Studies* 16:3-21, p9

Kahneman and Tversky contrast the inside view with taking the much more accurate *outside view*. The outside view examines the experiences of a class of similar projects, lays out a rough distribution of outcomes for this reference class, and then positions the current project in that distribution.²⁰

Flyvbjerg also highlights strategic misrepresentation and the principal agent theory.²¹ These theories suggest that there are strong incentives that cause project proponents to deliberately overstate the benefits and underestimate the costs and risks of projects. For example, politicians may want to have projects built to meet policy objectives. Managers may want to have projects built because there are tangible and intangible rewards for getting them underway and for running a bigger company than a smaller company. If senior managers are keen on a project, company employees may also reap the benefits of supporting the project progressing. Employees' ownership of a company (for example, ownership of company shares) is often small compared to their salary and potential bonus, consequently their losses if a project fails are small but their rewards for success are much greater. Managers and employees may also rightly reason that they will have another job elsewhere by the time a project fails and that the blame for the failure will be diffused.

Many of these theoretical issues may be influencing this estimation of net present value of the Project. The Project is strongly opposed by many people. Therefore the Project proponents have stronger reasons to overestimate the benefits and underestimate the costs of the Project compared to if the Project had little opposition. These overestimations or underestimations may be difficult to detect at the proposal phase, and if the Project goes ahead, it will be some years before the forecasts would be shown to be wrong.

Flyvbjerg has collected statistics on megaprojects from around the world. He summarises:

“Success in megaproject management is typically defined as projects being delivered on budget, on time, and with the promised benefits. If, as the evidence indicates, approximately one out of ten megaprojects is on budget, one out of ten is on schedule, and one out of ten delivers the promised benefits, then approximately **one in one thousand projects is a success**, defined as “on target” for all three. Even if the numbers were wrong by a factor of

https://www.researchgate.net/publication/233258056_Curbing_Optimism_Bias_and_Strategic_Misrepresentation_in_Planning_Reference_Class_Forecasting_in_Practice

²⁰ Paraphrasing Flyvbjerg (2008) *Curbing Optimism Bias and Strategic Misrepresentation in Planning* ..., p9.

²¹ Flyvbjerg (2008) *Curbing Optimism Bias and Strategic Misrepresentation in Planning...*

two—so that two, instead of one out of ten projects were on target for cost, schedule, and benefits, respectively— the success rate would still be dismal, now eight in one thousand. This serves to illustrate what may be called the “iron law of megaprojects”: ***Over budget, over time, over and over again. Best practice is an outlier, average practice a disaster*** in this interesting and very costly area of management.”²²

In reference to benefit cost analyses, Flyvbjerg further writes that:

“When cost and demand forecasts are combined, for instance in the cost-benefit analyses that are typically used to justify large infrastructure investments, the consequence is inaccuracy to the second degree. ***Benefit-cost ratios are often wrong, not only by a few percent but by several factors.*** As a consequence, estimates of viability are often misleading, as are socio-economic and environmental appraisals, the accuracy of which are heavily dependent on demand and cost forecasts. These results point to a significant problem in policy and planning: ***More often than not the information that promoters and planners use to decide whether to invest in new projects is highly inaccurate and biased making plans and projects very risky.***”²³

The oil and gas sector is not immune from the problem. Westney is a Houston-based engineering and risk consultant to the oil and gas industry. They estimate that the probability of oil and gas projects running on time and on cost is only between 5% and 25%.²⁴ Westney also quote Independent Project Analysis who found only 22% of large oil and gas projects were on time and on budget.²⁵ Both these estimations leave aside the question of whether the projects also achieved their stated benefits (i.e. revenue). To help answer this question Westney quote a PricewaterhouseCoopers study that found only 2.5% of megaprojects met their objectives of scope, cost, schedule *and* benefits.²⁶

Worldwide consulting firm EY analysed 365 oil and gas megaprojects and found 65% were over-budget and 73% over schedule. The budget overruns were not small – current project estimated costs were, on average, 59% above the initial estimate. EY

²² Flyvbjerg (2014) *What you should know about megaprojects and why....*, p11, emphasis added.

²³ Flyvbjerg (2008) *Curbing Optimism Bias and Strategic Misrepresentation in Planning...*, p5, emphasis added.

²⁴ Briel, Luan and Westney (2014) *Built-in Bias Jeopardises Project Success*, p2, <http://www.westney.com/wp-content/uploads/2014/04/Built-in-Bias-article-SPE-as-published.pdf>

²⁵ Boschee (2012) *Panel Session Looks at Lessons Learned from Megaprojects*. SPE Today, 10 October 2012. Quoted in Briel, Luan and Westney (2012).

²⁶ PricewaterhouseCoopers (PwC) (2009) *Need to know: Delivering capital project value in the downturn*. Quoted in Briel, Luan and Westney (2012). Note this study refers to all megaprojects, not just oil and gas megaprojects.

noted these estimates were likely to understate poor performance as a substantial amount of the projects were still underway. Once again, EY only looked at cost performance and did not cover revenue performance.²⁷

Closer to home is the building of Australia's eight newest Liquid Natural Gas (LNG) plants (including Santos's Gladstone LNG plant) which have totalled up \$45 billion in cost overruns.²⁸

Revenue forecasts are subject to the same biases that make cost forecasts so optimistic. Flyvbjerg estimates 84% of rail projects overestimate demand by more than 20%, and 72% of projects overestimate demand by more than 40%. For roads, 50% of projects overestimate demand by more than 20%, and 25% by more than 40%.²⁹ For oil and gas projects, revenue projection is made doubly difficult because of the difficulty of forecasting both reserves under the ground *and* also forecasting oil and gas prices which can fluctuate wildly from year to year. Recently Santos' Gladstone LNG plant has had to buy gas to meet contracts because Santos overestimated its gas reserves.³⁰

As Flyvbjerg writes, when optimistic forecasts of cost are combined with optimistic forecasts of demand, it is very risky to place much weight on the resulting estimation of net benefit. Take a generous estimate of the likelihood of oil and gas projects running on cost: say 1/3 of projects run on budget or better as opposed to the 1 in 10 figure quoted by Flyvbjerg, the 5-25% quoted by Westney and the 22% quoted by Independent Economic Analysis. Combine it with a generous estimate of the probability of revenue running as forecast: say 1/3 of projects deliver their estimated revenue. The result is still only a 1 in 9 chance that a project will meet both its cost and revenue projections. Moreover as Flyvbjerg notes, there is also a good likelihood that if a project fails to meet its projections, it will not be off by just 10 or 20 per cent, but much more, possibly hundreds of per cent.

²⁷ EY (n.d.) *Spotlight on oil and gas projects*, p4-5, [http://www.ey.com/Publication/vwLUAssets/EY-spotlight-on-oil-and-gas-megaprojects/\\$FILE/EY-spotlight-on-oil-and-gas-megaprojects.pdf](http://www.ey.com/Publication/vwLUAssets/EY-spotlight-on-oil-and-gas-megaprojects/$FILE/EY-spotlight-on-oil-and-gas-megaprojects.pdf)

²⁸ Fickling (2017) *Devil's bargain on gas means nobody is winning*, Sydney Morning Herald, 27 March 2017, <http://www.smh.com.au/business/energy/devils-bargain-on-gas-means-nobody-is-winning-20170326-gv6za7.html>

²⁹ Flyvbjerg (2008) *Curbing Optimism Bias and Strategic Misrepresentation in Planning...*, p5.

³⁰ McDonald-Smith (2016) *Santos under pressure as GLNG performance questioned*, Australian Financial Review, 12 October 2016, <http://www.afr.com/business/energy/gas/santos-under-pressure-as-glng-performance-questioned-20161012-gs0ddd>

While GHD estimates that the Project will provide a net benefit to Australia of \$1.54 billion in net present value terms, based on analysis of other projects, there is at least a 90% probability that the net present value will be less than this and a high likelihood that the net present value will be *much* less than this and may be negative.

NSW legislation and guidelines largely ignore the systemic biases that cause projections for projects, particularly megaprojects, to overestimate their benefits and underestimate their costs. With a capital cost of over \$2 billion and operating costs of over \$1.5 billion, the Project can be defined as a megaproject.³¹ Bent Flyvbjerg is the world's most cited scholar on megaprojects. He has advised the UK Government on its "Green Book" used to evaluate projects, the US Government and several corporations.³² Systemic biases have caused Flyvbjerg to propose the *iron law of megaprojects: over cost, over time, over and over again*.

³¹ Flyvbjerg defines a megaproject as a project with cost of over US\$1 billion. Flyvbjerg (2014) *What you should know about megaprojects and why: an Overview*, p1, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2424835

³² Said Business School (2017) *Bent Flyvbjerg* <http://www.sbs.ox.ac.uk/community/people/bent-flyvbjerg>

Oil and gas price assumptions

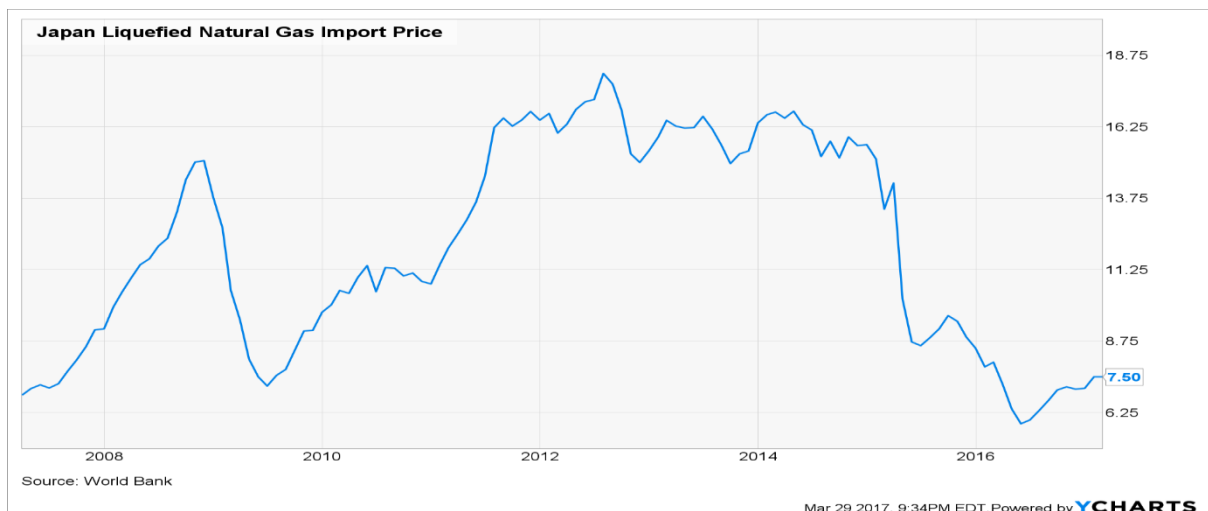
The discussion above indicates the difficulties in making forecasts in order to value projects. The further into the future those predictions are made, the more precarious those forecasts become. Only three years ago, Santos valued its Narrabri holding at \$1,351 million. Its financial accounts now value it as worthless. The energy market is undergoing what has been regarded as an energy revolution. This makes oil and gas price forecasts very uncertain. The US shale oil boom has caused a halving of the oil and gas prices, which oil and gas companies did not forecast, and has caused them to make massive asset write-downs (see Figures 1 and 2 below).

Figure 1 Brent Crude Oil Price (US\$ per barrel)



Source: <http://www.nasdaq.com/markets/crude-oil-brent.aspx?timeframe=10y>

Figure 2 Japan Liquefied LNG Natural Gas Import Chart (US\$/mmBTu)



Source: https://ycharts.com/indicators/japan_liquefied_natural_gas_import_price

Figures 1 and 2 show the impact of the US shale oil boom, which oil companies failed to consider. This is an example of the limitations of the insider view highlighted by Kahneman and Tversky, discussed above. In this case, oil and gas companies took prices over recent years as a given and failed to foresee the competition from the US shale oil boom.

The long term outlook for energy continues to be for downward pressure on prices as renewable energy decreases in cost and increases in availability. While it is easy to be sceptical of the impact of renewable energy - “renewable energy has always been coming” – the train is clearly pulling into the station now. In October 2016, International Energy Agency (IEA) reported that for the first time renewable energy passed coal as the world’s biggest source of power-generating capacity. In China, in the first half of 2016, more grid-connected solar energy was installed than in the whole of 2015.³³ In April 2017, Great Britain went a full day without burning coal for electricity for the first time since the 1800s.³⁴

Renewable energy can be produced at very little marginal cost making it hard for other energy sources to compete. The EIS forecasts a revenue stream from the Project based on a constant gas price of \$A8.70 per GJ received over the 25 year life of the Project. Making such a prediction so far into the future given the likely downward pressure on energy prices from renewable energy appears optimistic at best.

The important assumptions in the benefit cost analysis are sourced from Santos however Santos does not have a good record as a forecaster. Its assumptions about oil and gas prices have proven to be overly-optimistic, and still appear overly-optimistic. These overly-optimistic price assumptions have caused Santos to make massive asset write-downs.

Over the last three years Santos incurred \$8.4 billion in asset write-offs, as shown in Table 1 below. This is thirteen times the underlying profits it has reported over those three years.

³³ The Economist (2016) *Wind and solar advance in the power war against coal*, 27 October 2016 , <https://www.economist.com/news/finance-and-economics/21709355-clean-energy-surges-so-does-price-coal-wind-and-solar-advance-power>

³⁴ Bennhold (2017) *For first time since 1800s, Britain goes a day without burning coal for electricity*, Sydney Morning Herald, <http://www.smh.com.au/environment/global-warming/for-first-time-since-1800s-britain-goes-a-day-without-burning-coal-for-electricity-20170422-gvqamv.html>

Table 1: Santos asset write-downs

Santos financial year	Asset write-down A\$m	Underlying profit A\$m
2014	2,356	533
2015	3,924	50
2016	2,156	63
Total 2014-2016	8,436	646

Sources: Santos Annual Reports 2014-2016. Santos (2015), p7. Santos (2016), pp5,82. Santos (2017), p4,78,59. <https://www.santos.com/investors/company-reporting/>

Part of the reason for the write-downs shown in Table 1 is that Santos writes contracts for its gas sales in which the prices paid are linked to the oil price. As such, Santos makes predictions about future oil prices to value its assets. For 2015 and 2016 these forecasts have proven to be reasonably accurate for the coming year, but beyond that its forecasts have been overly-optimistic and Santos has had to revise them downwards as time has passed. They still appear overly-optimistic. Santos' 2016 Annual Report, released in February 2017, forecasts gas prices of \$US75/barrel for 2019 and onwards. This is 30% more than the futures market, which forecasts a price of only \$US54-58/barrel for the years out to 2025. This raises questions about whether the price assumptions from Santos are similarly optimistic.

Table 2: Santos oil price forecasts

	Brent oil price: \$US/barrel					
	2015	2016	2017	2018	2019	2020 onwards
Santos oil price forecast Dec 2014	\$55	\$70	\$80	\$90	\$90	\$90
Santos oil price forecast Dec 2015		\$40	\$60	\$0	\$75	\$75
Santos oil price forecast Dec 2016			\$60	\$70	\$75	\$75
Actual average price for the year	\$52	\$44				
Brent Oil Financial Futures April 2017			\$53	\$54	\$54	\$57

Sources: Santos (2015) Santos Annual Report 2014, p52, Santos (2016) Santos Annual Report 2015, p60. Santos (2017) Santos Annual Report 2016, p77. Statista (2017) UK Brent Oil Price Changes since 1976 <https://www.statista.com/statistics/262860/uk-brent-crude-oil-price-changes-since-1976/>. CME Group (2017) Brent Last Day Financial Futures Quotes. Price quoted for June each year. 2020 onwards is an average of the forecast June price for years 2020-2025. <http://www.cmegroup.com/trading/energy/crude-oil/brent-crude-oil-last-day.html>.

The over-optimism that Santos has displayed in its financial accounts appears present in the price assumption it has provided to the benefit cost analysis. Santos estimates that the Project will receive \$8.70 per GJ.

With the building of LNG plants at Gladstone the Australian gas price will, over time, equal the world gas price (net of the costs of export).³⁵ At 30 April 2017 the imported LNG price into Japan was US\$7.75/mmBTu. We calculate this equates to around \$7.16 per GJ (see Table 3), which is 18% less than the \$8.70 price assumed by Santos. Once again, Santos appears over-optimistic in its price forecasts.

Table 3: Estimate of gas price received by Australian producer in \$A/GJ

Japan 30 April 2017 imported LNG price	USD /mmBTu	\$7.75
Convert to GJ (divide by .9478)		
Japan current imported LNG price /GJ	USD/GJ	\$8.18
Cost to transport from Australia to Japan	USD/GJ	-\$0.75
Cost to liquefy	USD/GJ	-\$1.50
Cost to transport in Australia	USD/GJ	-\$0.56
Price received by Australian producer	USD/GJ	\$5.37
AUD/USD exchange rate end April = 0.75		
Price received by Australian producer	AUD/GJ	\$7.16
Price assumed in benefit cost analysis	AUD/GJ	\$8.70

Sources: Ycharts (2017) *Japan Liquefied Natural Gas Import Price*, https://ycharts.com/indicators/japan_liquefied_natural_gas_import_price Accessed 10 May 2017. Costs to transport gas to Japan and cost to liquefy from Robertson and West (2016) *It's a gas! Australian gas is a bargain ... if you're Japanese*, <https://www.michaelwest.com.au/its-a-gas-australian-gas-prices-are-a-bargain-in-japan/> Cost to transport in Australia estimated based on assumption of cost of transport gas from Narrabri to Sydney of \$A0.75 per GJ from Buckley (2014) *Briefing Note: The Narrabri Gas Project*, December 2014, Institute for Energy Economics and Financial Analysis, p13, <http://www.ieefa.org/wp-content/uploads/2014/12/IEEFANarrabriCSGproject.pdf>. AUD/USD exchange rate from <http://www.rba.gov.au/statistics/historical-data.html>

If approval for the Project is granted, gas production is not scheduled to start until 2020 at 12.8 million GJ per annum, and not reach full production of 74.1 million GJ per annum until 2025.³⁶ This is a considerable number of years away and, as discussed above, megaprojects like this one rarely run on schedule. The downward impact of renewable energy on energy prices will only increase over time. These time lags make predicting the future oil price even more precarious than if production was to start immediately.

³⁵ For more discussion of this see 'Energy context' later in this submission.

³⁶ GHD (2016) *Narrabri Gas Project – Environment Impact Statement Economic Assessment*, p13.

Market access - pipeline

The benefit cost analysis focusses on the Project itself. However, the Project also requires a \$450 million, 450 kilometre gas pipeline to be built so that the gas can be sold. This requires government approvals, negotiation with landholders and communities in seven local government areas, negotiations with APA Group, who will build the pipeline, and the actual building of the pipeline itself, which will cross rivers, wetlands, highways and major roads. These are all potential sources of delay and increased costs, which would reduce the NPV of the Project.³⁷

³⁷ Ferguson and Clift (2017) *Pipeline worth \$450m proposed to support controversial Narrabri Gas Project in NSW*, 31 March 2017, <http://www.abc.net.au/news/2017-03-31/pipeline-proposed-for-narrabri-gas-project/8404188>

External costs

There are major concerns about groundwater contamination with the Project. Groundwater contamination could be regarded as a low probability high impact event. It would have a devastating impact on neighbouring farms. It is difficult to predict the probability of a low probability event precisely because these events occur infrequently and we have difficulty appreciating their magnitude. With such events, we also reach the limit of our knowledge, we simply do not know what can go wrong and how serious it could be, i.e. so-called ‘unknown unknowns’. As Taleb wrote in his book, *The Black Swan*, ‘Left to our own devices we tend to think what happens every decade in fact only happens every century and, furthermore, that we know what’s going on’.³⁸ The risk of groundwater contamination is simply considered low and ignored in this benefit cost analysis.³⁹ It should not be. Just because something cannot be measured easily, does not mean it is unimportant or that it should be ignored.

There are similar concerns about the disposal of waste water, health impacts and possible drawdown of the Great Artesian Basin.⁴⁰ These are also low probability, high impact events where the effects are uncertain because of the limitations of our knowledge. They are also ignored in this benefit cost analysis.

Concerns about coal seam gas were important enough for the Australian Medical Association to pass a resolution saying:

*“... all future proposals for coal seam gas mining are subject to rigorous and independent health risk assessments, which take into account the potential for exposure to pollutants through air and groundwater and any likely associated health risks. In circumstances where there is insufficient evidence to ensure safety, **the precautionary principle should apply.**”*⁴¹

³⁸ Taleb (2010), *The Black Swan*, Random House, p141.

³⁹ GHD (2016) *Narrabri Gas Project – Environment Impact Statement Economic Assessment*, p10.

⁴⁰ Thomas and Reading (2017) *Experts to assist with Narrabri Gas Project assessment*, Australian Broadcasting Commission, <http://www.abc.net.au/news/2017-02-21/experts-to-assist-with-narrabri-gas-project-assessment/8290146> . See also Grudnoff (2014) *Fracking the Future*, The Australia Institute, p43-49, http://www.tai.org.au/sites/default/files/IP%2016%20Fracking%20the%20future%20-%20amended_0.pdf

⁴¹ AMA (2013) *AMA calls for coal seam gas health check*. Emphasis added <https://ama.com.au/media/ama-calls-coal-seam-gas-health-checks>

Greenhouse gas emissions are likely to be underestimated

There is increasing concern about carbon emissions from coal seam gas with research from overseas and by University of Melbourne researchers finding that emissions which occur as part of the coal seam gas production process (termed ‘fugitive emissions’) may be significantly underestimated. This is particularly due to methane which is emitted as part of the production process. Methane is a powerful contributor to greenhouse gas emissions. University of Melbourne research found that:

- Several major potential sources of methane emissions are assumed to be zero under Australia’s accounting and reporting of unconventional gas.
- Methane measurements at US unconventional gas fields have found leakage rates in the order of 10-25 times higher than the Australian Government reports to the United Nations, and up to 170 times those claimed by the gas industry.
- If leakage rates comparable to those found in the US are found at Australian unconventional gas fields it will have serious implications for Australia meeting its emission reduction commitments under the Paris Agreement.⁴²

Other research by the University of Melbourne has found that coal seam gas extraction in Queensland’s Surat Basin could be significantly increasing methane emissions from underground gas deposits.⁴³

Given these findings, this benefit cost analysis research is likely to be underestimating carbon gas emissions and thereby underestimating the carbon costs of this project.

⁴² Lafleur, Forcey, Saddler and Sandiford (2016) *A review of current and future methane emissions from Australian unconventional oil and gas production*, The University of Melbourne – Melbourne Energy Institute. Research was funded by the Australia Institute.

⁴³ Lafleur and Sandiford (2016) *The risk of migratory methane emissions resulting from the development of Queensland coal seam gas*, The University of Melbourne – Melbourne Energy Institute. Research was funded by the Australia Institute.

Sensitivity analysis

The analysis above indicates that there are strong grounds to believe that the forecasts in this benefit cost analysis are over-optimistic, and quite possibly very over-optimistic. Even with this likely over-optimism, only small changes in the benefit cost analysis forecasts are required to make the Project marginal. Roughly speaking a cumulative detrimental change of only approximately 30% in a combination of the price, production and cost forecasts will make the Project marginal. For example: a 30% decline in the gas price; or a 20% decline in the gas price combined with 10% decline in gas production; or a 10% decline in the gas price, a 10% decline in production and a 10% increase in cost would all make the Project marginal. As Flyvbjerg noted, benefit cost ratios for megaprojects 'are often wrong, not only by a few percent but by several factors'. A cumulative detrimental change of more than 30% is quite likely.

As discussed above, Core Energy Group forecasts the cost of production of the Project at \$7.25 per GJ. There is even less margin for error between this cost and the \$8.70 gas price assumed in the benefit cost analysis. It only takes roughly a 20% cumulative negative change in forecasts to make the Project marginal. And if we assume the gas price is the current Japanese imported LNG price (net of export costs) of \$7.16 per GJ, as per Table 3, then the Project is uneconomic.

Benefits to New South Wales are required to be assessed

The NSW Guidelines require project proposals to estimate their benefit to NSW.⁴⁴ However, the benefit cost analysis for the Project estimates a benefit to Australia of \$1.5 billion in NPV terms. The benefit cost analysis explains why this was done.⁴⁵ The NSW Guidelines recommend using 32% as the proportion of the NSW population to the Australian population to estimate benefits to NSW.⁴⁶ On this basis the NPV to NSW is \$490 million. This is the figure that should be of most concern to NSW decision makers under the Guidelines.

⁴⁴ NSW Government (2015) *NSW Guidelines for the Economic Assessment of Mining and Coal Seam Gas Proposals*, p1, http://www.planning.nsw.gov.au/Policy-and-Legislation/Mining-and-Resources/~/_media/C34250AF72674275836541CD48CBEC49.ashx

⁴⁵ GHD (2016) *Narrabri Gas Project – Environment Impact Statement Economic Assessment*, p8.

⁴⁶ NSW Government (2015) *NSW Guidelines ...*, p10,

Energy context

There is currently extensive commentary about increases in gas prices in Australia. Unfortunately the Project will be of little use in addressing this issue.

For many years Australian gas prices were substantially lower than the world gas prices because Australian gas producers could not easily export gas to the world. However the construction of LNG plants has meant that Australian gas producers can now sell to the world and receive the world gas price. Consequently, Australian gas prices have more than doubled to match world gas price parity.⁴⁷ Increased gas from the Project will not lower gas prices, as Australian producers (e.g. Santos) will sell to the world market if they can receive a higher price there. Matt Grudnoff, of The Australia Institute, examined this issue four years ago and forecast the substantial rises in Australian gas prices that have since occurred.⁴⁸

While the gas price rise was predicted, as the transition to Australia being the world's largest gas exporter takes place, spot gas prices in particular, have spiked as industrial users' gas contracts set at lower prices expire and LNG plants source gas in the domestic market to meet their export contracts, because their own gas fields have not produced as much gas as forecast.⁴⁹ Unfortunately the genie cannot be put back in the bottle, now that producers have the option of selling at the world price the Australian gas price will not fall back below the world gas price parity. The Project cannot change this.

Nor can the Project help to ease the price spikes during the current transition period because it will be at least some five or six years before the Project could add to Australia's gas supply in a meaningful way. The Project is not forecast to start production until at least 2020, production takes five years to ramp up and, as discussed previously, there is a high likelihood that the Project will run over-schedule. In those five or six years or more, the current transitory price spike will have passed due to a combination of one or all of the following:

⁴⁷ Oakley Greenwood (2016) *Gas Price Trends Review*, <https://industry.gov.au/Energy/Energy-information/Documents/Gas-Price-Trends-Report.pdf>

⁴⁸ Grudnoff (2013) *Cooking up a price rise*, The Australia Institute, <http://www.tai.org.au/sites/default/files/PB%2053%20Cooking%20up%20a%20price%20rise.pdf>

⁴⁹ Macrobusiness (2017) *Credit Suisse: Gas solutions do not convince a 5-year old*, <https://www.macrobusiness.com.au/2017/04/credit-suisse-gas-solutions-not-convince-5-year-old/>

- The higher gas price will cause users to reduce demand, either by using gas more efficiently, using other energy sources or deciding they can make more money by selling their contracted gas supply to another gas user. As discussed above, falling renewable energy and battery prices make these energy sources more and more attractive. Higher gas prices also make it more attractive for alternative energy sources to supply the market;
- LNG producers who currently export gas instead choosing to supply the domestic market;
- Government action requiring LNG producers to supply/reserve gas for the domestic market. Credit Suisse has proposed that the third party gas currently used in the Santos Gladstone LNG plant should be directed to the domestic market.⁵⁰ Professor Ross Garnaut has suggested similarly;⁵¹ and
- Changes in government regulation. For instance changing electricity market rules and regulations could reduce the need for gas-fired electricity plants by making it more attractive for other energy sources to supply the market.⁵² Similarly the Australian Competition and Consumer Commission has raised the issue of monopoly pricing by gas pipelines and argued for better regulation of gas pipelines to reduce gas prices.⁵³

The EIS claims that the Project will add substantially to the NSW gas supply.⁵⁴ However this makes little sense as the existence of gas pipelines across Eastern Australia means that there is really no isolated NSW market. Instead, there is an East Australian gas market and the price of gas in this market depends on the world gas price. There is simply no shortage of gas in Australia, just a shortage of gas at prices Australians are accustomed to.

⁵⁰ Stevens (2017) *GLNG partners clash over gas plan*, Australian Financial Review, 24 April 2017, <http://www.afr.com/business/glng-partners-clash-over-domestic-gas-plan-20170421-gvpw04>

⁵¹ Stevens (2017) *Ross Garnaut says LNG cutbacks only answer to gas crisis*, Australian Financial Review, 21 April 2017, <http://www.afr.com/business/energy/gas/ross-garnaut-says-lng-export-cutbacks-only-answer-to-gas-crisis-20170420-gvp7gb#ixzz4f0dh3BgJ>

⁵² For instance changing electricity pricing to the five minute rule as recommended by the Australian Energy Market Operator. The Australia Institute (2017) *Open Letter calls for straightforward changes to fix 'energy trilemma'* <http://www.tai.org.au/content/open-letter-calls-straightforward-changes-fix-%E2%80%98energy-trilemma%E2%80%99-0>

⁵³ Stevens (2017) *Sims excited by gas watchdog invitation*, Australian Financial Review, 20 April 2017, <http://www.afr.com/business/energy/rod-sims-excited-by-pms-gas-watchdog-invitation-20170420-gvoqeq>

Robinson (2016) *It's a gas*, Australian gas prices are a bargain in Japan, <http://www.michaelwest.com.au/its-a-gas-australian-gas-prices-are-a-bargain-in-japan/>

⁵⁴ Santos (2016) Narrabri Gas Project – Environmental Impact Statement, 32-3.

Benefits to the Narrabri community are uncertain

The benefit cost analysis highlights the benefits of the Project to the local community.⁵⁵ In contrast, a report by The Australia Institute based mostly on gas industry-funded research found that local businesses in unconventional gas regions in Queensland believe that gas development led to deterioration in their finances, local infrastructure, social connections and labour force skills.⁵⁶ Key findings of the report:

- Local business stakeholders reported a deterioration in:
 - Financial capital;
 - Local Infrastructure;
 - Local skills;
 - Social cohesion; and
 - The local environment.
- Unconventional gas reduced community wellbeing:
 - Fewer than one in four local people approved of the unconventional gas industry, with less than 6% believing it would “lead to something better”.
- Unconventional gas created few additional jobs:
 - There were virtually no spillover jobs created in local retail or manufacturing; and
 - Gas jobs will be reduced by 80% at the end of the construction period.
- For every 10 unconventional gas jobs created, 7 service sector jobs were lost.

When regional towns become service centres for the gas industry, existing businesses often lose their skilled staff, have to compete with inflated gas industry wages and face higher costs for rent and services. Workers work long shifts in self-contained camps and have little opportunity to spend money locally, and companies often bypass local suppliers.

⁵⁵ GHD (2016) *Narrabri Gas Project – Environment Impact Statement Economic Assessment*, p21-22.

⁵⁶ Ogge (2015) *Be careful of what you wish for*, The Australia Institute.

Recommendations

The benefits and costs of the Project have been misrepresented in the GHD assessment. Proponent financial statements and research published by AEMO suggest the project is economically marginal. Considering the likelihood of significant external costs, the project should be rejected on this basis.

The NSW Guidelines which prescribe this benefit cost analysis do not appear to have incorporated the work of Kahneman and Tversky, and also of Flyvbjerg, that highlights the very high likelihood of over-optimism and strategic misrepresentation in benefit cost analysis. This is disturbing given that these biases are well known. The UK Government has considered these biases in their project guidelines since 2003.⁵⁷ The Victorian Parliament considered them in a 2012 Parliamentary Inquiry.⁵⁸ Switzerland, Denmark and The Netherlands have also considered them.⁵⁹

Beyond the inadequacies of the benefit cost analysis for the Project discussed above, we make three general recommendations to improve the use of benefit cost analysis in assessing mining and coal seam gas projects:

- 1. Revise the NSW Guidelines**

The NSW Guidelines need to be urgently revised to consider over-optimism and strategic misrepresentation.

- 2. Incorporate reference class forecasting**

Kahneman and Flyvbjerg urge the use of reference class forecasting to better estimate the benefits and costs of projects. This is done by comparing the costs and benefits to what similar projects have achieved rather than relying on assessments by the project proponents, that is, taking the *outside view* rather than the *inside view*. Terrell also recommends that Australian Governments do this when assessing infrastructure projects.⁶⁰ We also recommend that reference class forecasting be used to evaluate mining and coal seam gas

⁵⁷ Flyvbjerg (2008) *Curbing optimism bias and Strategic Misrepresentation in Planning*, p11.

⁵⁸ Parliament of Victoria (2012) *Inquiry into Effective Decision Making for the Successful Delivery of Significant Infrastructure Projects*,
http://www.parliament.vic.gov.au/images/stories/committees/paec/reports/PAEC_InfrastructureInquiry_FINAL-Report.pdf

⁵⁹ Flyvbjerg (2014) *What you should know about megaprojects and why....*, p16.

⁶⁰ Terrill (2016) *Cost overruns in transport infrastructure*, Grattan Institute, p22,
<https://grattan.edu.au/wp-content/uploads/2016/10/878-Cost-overruns-on-transport-infrastructure.pdf>

proposals.

3. Develop a database of projects for use in reference forecasting

Terrell recommends that, 'The Commonwealth Department of Infrastructure should be required to publish to data.gov.au the post-completion report it already requires from state governments as a condition of providing final milestone payments for transport infrastructure projects. Reports should detail any scope changes and their justification, agreed and actual construction start and finish dates, actual project costs, reasons for overruns or under-runs, and progress against performance indicators.'⁶¹ In addition, Flyvbjerg has developed a database of transport projects for the UK Treasury to use in reference forecasting of new transport proposals.⁶²

Mining and gas proposals, such as the Project, are becoming increasingly controversial as communities grow concerned about risks to their community and the environment. Similar to infrastructure projects, we recommend that the NSW Government work with other state governments and the federal government to develop a database of approved mining and coal seam gas proposals, which highlights their outcomes versus their forecast benefits and costs. This can then be used to carry out reference class forecasting so that project appraisals are much less vulnerable to the optimism bias and strategic misrepresentation that occurs when the project proponents provide their own benefit cost analysis.

⁶¹ *ibid*, p24.

⁶² Flyvbjerg (2008) *Curbing optimism bias and strategic misrepresentation in planning*, p11.

Review of the Water Quality and Aquatic Ecology components of the Narrabri Gas Project Environmental Impact Assessment

by

Dr Ian Campbell

May 2017



1. Introduction

I confirm that in preparing this report I have read the Expert Witness Code of Conduct under the *Uniform Civil Procedure Rules 2005* and I agree to be bound by it. The documents I have utilised in preparing this report are listed under the references section at the end of the report.

2. Chapter 12. Surface Water Quality & Appendix G4 Water Baseline Report

2.1 Methods

The EIS states:

“Methodology from ANZECC/ARMCANZ (2000) was used for the project to generate water quality baseline statistics for the purpose of impact assessment. The regional baseline water quality data that have been collected over several years for the project provide an understanding of water quality within the Namoi River and Bohena Creek (refer to Appendix G4). These data would be used as comparative (sic) during ongoing water quality monitoring throughout all project phases using trend analysis over time so that identified significant variance from the norm can be investigated.

The method above was then interpreted for the purposes of impact assessment as described in Chapter 10. This method considers the sensitivity of the receiving environment (Bohena Creek for example) and when multiplied by a magnitude rating, determines likely impact significance.” (Page 12.4)

It is unclear what this means. ANZECC/ARMCANZ (2000) does not include a method to “generate water quality baseline statistics”. It does, however, include recommendations on data collection at reference sites which specify “*a minimum of two years of contiguous monthly data ...is required*” (ANZECC 2000 page 7.4-5). None of the data sets for either the Namoi River or Bohena Creek fulfil this criterion. While that is understandable for Bohena Creek which is not a perennially flowing stream, that is not the case for the Namoi River. The only data set provided which extends over 2 years is that for site 7511 which included only 12 sampling occasions over that period.

It is unclear what “*significant variance from the norm*” means. It seems to be phrased in pseudo-statistical language. Water chemistry in rivers is highly variable both spatially and temporally. Does the “norm” mean the mean (average) or the median or something else? The “variance” in statistics is a measure of the deviations of a set of measurements from the mean and is determined from the equation:

$$\sigma^2 = \frac{\sum(x_i - \mu)^2}{N}$$

I assume that what is meant here is a “significant difference” from the median or mean. It is unclear if that means a statistically significant difference. If so a power analysis would need to be conducted on the existing data to establish how many samples would need to be collected and analysed in order to establish that there was a statistically significant difference. From the data included in the tables here it is not possible to conduct such an analysis. To do such an analysis it is necessary to know the mean and standard error or standard deviation of the data set at a site. Using just the mean values for the 6 Namoi River sites (which will be an underestimation) and the maximum and minimum values (which will be an overestimation) for TDS and Calcium the number of samples necessary to detect a 25% change in either of those analytes, with 95% confidence, would be between 4 and 75 samples based on a power analysis conducted with SYSTAT software.

2.2 Statistical Analysis

“As new surface water quality data are collected, these will continue to be added to the dataset, which undergoes statistical analysis to ensure it is spatially and temporally representative such that it provides confidence when assessing trends in water quality analytes. This is important so that outlying data points or spikes can be identified during operational water quality monitoring that may flag potential issues.

All field-based surface water monitoring data and laboratory results are captured in a centralised database. This methodology allows for automated trend analysis and comparison of data against baseline information and threshold values.” P 12-7.

Despite what is stated in the excerpt above, appendix G4 has no statistical analysis, and results are presented for various analytes together with minimum, maximum, mean and median values, and the number of samples. No explanation is given as to how the proponent intends to ensure the data is spatially and temporally representative, or how trends are to be detected. The data set is quite sparse, particularly in terms of temporal patterns, with the most frequent sampling apparently being once every two months. Certainly the data set is inadequate to ascertain patterns of change during high flow events, and the sampling frequency is totally inadequate to detect spills.

2.3 Summary on Namoi River

The Summary section (page 12-15) on the Namoi River is inadequate. There is no evidence to support the statement that *“a variety of chemical constituents are recognised as a product of activities within the greater Namoi Catchment, with the main source of total dissolved solids being agriculture and residential runoff”*. There is no evidence of agriculture or residential runoff contributing to TDS.

“(M)ajor ions include sodium, chloride, and calcium, which reflect the dominant water type of the Namoi River” (Page 12-15). In as far as it means anything, this statement appears to be incorrect. Converting the mean ionic concentrations from Table 12.1 to milliequivalents (mEq) gives 1.43 for each of Na and Ca (the two predominant cations). For chloride (the major anion measured) the mEq value is 0.9. The sums of the mEq values for anions and cations should be identical (since river water is electrically neutral). So the sum of the

positive charges is about 2.86, but for negative charges is only 0.9, leaving a large component of the anions not accounted for. The sites tables in appendix G4 indicate quite high levels of sulphate (e.g site 7529 had 24mg/L = 0.54 mEq), but if that is representative that still only accounts for about 54% the anionic component. So what is the rest? Is it carbonate and bicarbonate? If so that has very significant implications for the “dominant water type” – and for the biota which occur in the river. If natural, it also means that maintaining the pH in the river is very important. It also means that the Namoi is very different to Bohena Creek which appears to be sodium and chloride dominated with lower pH.

2.4 Cause of High EC

The statement that *“The background electrical conductivity values may be attributed to agricultural and dryland cropping activities in which accumulated salts can be mobilised and discharged into surface water during rainfall events”* (Page 12-15) is incorrect. Indeed, we know that some western NSW rivers were at times too salty for humans and stock to consume when first encountered by Europeans, long before there were any substantial agricultural or dryland farming activities in the catchment.

2.5 Water Chemistry of Bohena Creek

There is far less data for Bohena Creek than for the Namoi River, partly because the creek is not perennial. The water chemistry data are quite variable. In order to detect a 25% change in conductivity with 95% confidence would require between 25 and 75 samples, and to detect the same level of change in calcium concentration would require between 35 and 150 samples. So far only 40 samples in total have been collected from this creek. In contrast to the Namoi River, the chloride in Bohena Creek accounts for 77% of the anionic component required to match the Na and Ca components. It is interesting that the ratio of Na/Ca in Bohena Creek is 3.17, indicating a predominance of Na, while that in the Namoi River is 1.11, indicating an approximate gravimetric equivalence.

It is most disturbing that the EIS makes no mention of the obvious chemical differences between the two water bodies. Differences in water chemistry may have substantial impacts on the biota of streams (molluscs, for example are favoured by high calcium levels such as the Namoi River), and on the impact of toxicants such as metals (which are more toxic in acidic, lower calcium streams such as Bohena Creek). However, this is not discussed under either water quality or aquatic ecology.

2.6 Need for Release to the Creek

According to Figure 12.2 on page 12.5 the treated water to be released to Bohena Creek during the peak years will amount to 418 ML each year for 2 years. That amounts to approximately 12% of the water produced. That amount of water would be utilized if an additional 100ha were to be irrigated or by a 65% increase in dust suppression usage. Should there be dry years, such as the period 2001-2004 there would be no flows in the creek, much less flows > 100 ML per day, so there would be no possibility to discharge and some other disposal route would need to be found. I note that zero flow years occurred for

40% of the years used as a basis for the design of the project (1995-2005), and that the period from 2005-2012 was excluded from consideration because it had “far fewer incidences of flow” (Managed Release Study p 22). That suggests that there may be far fewer opportunities to release water than is suggested by the earlier data. The fewer incidences of flow are attributed to a change in the rating curve, but the post-2005 rating curve is presumably the rating curve used currently. It would seem to be unnecessary to discharge to the Creek and preferable, therefore, to plan from the outset not to discharge any of the water extracted in the gas extraction process.

3. Chapter 16. Aquatic Ecology

Most of the details of the aquatic ecology work on which this section is based are included under the Managed Release Study and so are discussed below.

3.1 Aquatic Habitat

It is curious that the stream habitat structure is discussed on page 16.10 under “Riparian Habitat” with a different description being provided on page 16.11 under “Aquatic Habitat”.

3.2 Water Quality

The discussion of water quality is very disappointing, as demonstrated by comments regarding turbidity, such as *“One reason for the high turbidity was the large volume of sediment suspended in the water column”*. Yes, high turbidity is virtually always caused by high levels of suspended sediment, there are only two other possible factors, the nature of the sediment particles, and large volumes of organic particles. However, the comment that *“the high turbidity probably contributes to the low dissolved oxygen concentrations”* is incorrect. Low dissolved oxygen concentrations are primarily a product of the availability of organic material which is utilised by microorganisms, and a low re-aeration rate in the standing waters of the remnant pools.

4. Appendix G3: Water Monitoring Plan

4.1 Absence of Water Quality Monitoring Design

On page 3-20 of the Water Monitoring Plan the proponents suggest that surface water quality monitoring will be conducted at 6 sites (4 on Bohena Creek and two on the Namoi River). No indication is given of the frequency of sampling. Would it be only during releases, or would it commence during periods of flow prior to releases? How frequently during the release? Would samples be taken on a single occasion, or weekly or daily? How many samples would be collected at each time, one, or five or ten? This appears to me to be totally inadequate as a monitoring plan. There is sufficient existing data to determine how many samples are needed to detect effects of identified sizes, so I would expect a discussion of the frequency and number of samples at the very least.

5. Appendix G1: Managed Release Study

5.1 Treated Water Quality

The assessment of the impact on the water quality of Bohena Creek of the treated water release at p33 is based on modelled predictions of the composition of the treated water. However, we are given little indication of the confidence limits of the model. Predicted concentrations of various components in the treated water are presented in Table 5.1 (p 34). The mean concentration of phosphorus is predicted to be 0.01 mg/L, but the maximum concentration will be less than 0.01 mg/L. The level of total nitrogen, a key nutrient potentially stimulating algal blooms in freshwater systems, cannot be calculated although the concentration of ammonia, a nitrogen-based compound, will be up to 50 µg/L. Predictions of the consequences of the released water for Bohena Creek depend on composition of the released water, but I have a low level of confidence in this modelling.

5.2 Aquatic Ecology and Stygofauna Assessment

Within the Managed Release Study documents, the section on macroinvertebrates is particularly weak. It is troubling that sites in Bohena Creek were compared with sites in the Namoi River (p 12) given that one stream is intermittent and the other is perennial, and that one is apparently sodium chloride dominated and the other calcium carbonate dominated – both factors which would lead to substantial faunal differences. The Namoi is not a suitable reference system for a BACI type design to detect any impact.

5.3 Indicative Invertebrate Taxa

The comment that *“the presence of Leptoceridae and Acarinae are indicative of severe to moderate impairment”* (p 29) is untrue. In fact impairment is characterised by the absence of intolerant taxa, not the presence of tolerant taxa. Both Leptoceridae and Acarinae occur, and may be abundant, at sites with as close as is possible to no human impact. We are told that *“Hydropsychidae, Telephleidae (sic) and Protoneuridae occurred in the Namoi River but not in Bohena Creek”* (p66 Aquatic Ecology and Stygofauna Assessment) which is perhaps not surprising in the case of the Hydropsychids since they are obligate passive filterers requiring flowing water to survive. I assume that “Telephleidae” is a mis-spelling of “Telephebiidae” throughout the document.

5.4 Water Quality, Electrical Conductivity (EC)

In the Aquatic Ecology and Stygofauna Assessment appendix of the Managed Release Study we are informed that:

“EC was within the recommended ANZECC range for all sites, although temporarily fell below the minimum at Nuable Creek and Middle Creek in Autumn and at Spring Creek in spring (Table 12)”.

The same point is made on Page 62.

In Table 12 the document claims that ANZECC (2000) included a recommended range for EC of 125-2200 $\mu\text{S}/\text{cm}$. This is a complete misunderstanding of the ANZECC document. The value of 125 $\mu\text{S}/\text{cm}$ is not a lower limit trigger value, but rather an upper limit for lowland streams in the eastern highlands of Victoria which have naturally low conductivity, as ANZECC states “*Low values are found in eastern highlands of Vic. (125 μScm^{-1}) and higher values in western lowlands and northern plains of Vic (2200 μScm^{-1})*”.

5.5 River snail *Notopala sublineata*

On page 72 the document cites NSW DPI (2007) as a source for a statement that this species has “*not been collected for more than 15 years in natural environments*”. The DPI document does comment that “*Over the last decade living specimens have only been recorded from water supply irrigation pipelines*”, but this does not appear to have been intended as a definitive statement. The species has been detected in irrigation pipelines because it is a pest in those locations, where it may block the pipeline. It has not been detected elsewhere, but it has rarely been sought. DPI (2007) note that “*There have been no extensive dedicated surveys for the river snail in NSW. However, some survey work has been done as part of a postgraduate research project at Macquarie University*”. There are very few freshwater malacologists in Australia, so there are very few people looking for freshwater snails, and since most aquatic invertebrate surveys (such as the one conducted here) only identify taxa to the level of family, it is not surprising that the species has not been detected. Given that there is an historical record of the species from this area I would have expected that the proponent would have conducted a targeted survey for the species conducted by an appropriately experienced freshwater invertebrate specialist.

6. Appendix C of Appendix G1: Aquatic Ecology and Stygofauna Assessment

6.1 Macroinvertebrate Assessments

It is stated in sections 4.24 and 4.3.4 that SIGNAL scores from Bohena Creek indicate pollution or poor condition. On page 47 “*SIGNAL scores below 4 indicate severe pollution, or poor condition*” and on page 66 “*These scores are indicative of high to moderate levels of disturbance*”. SIGNAL scores, and most other indicators, need to be interpreted by a specialist with some expertise in the field. Taxa with high SIGNAL scores are generally those intolerant of low concentrations of dissolved oxygen. In flowing waters oxygen concentrations are maintained by the entrainment of oxygen through the turbulent flow. When flow ceases, the pools remaining in non-perennial streams generally contain high loads of organic material, in the form of terrestrial plant litter which has fallen into the stream. Microbial processing of this material consumes oxygen, and water temperatures are often higher than during flow periods, which also reduces dissolved oxygen concentrations, and there is less oxygen diffusion into the water because of the reduced level of turbulence. Consequently, even in non-perennial streams without human influence the fauna tends to be dominated by taxa which are tolerant of low dissolved oxygen concentrations, and which have low SIGNAL scores. Examples include air-breathing taxa such as Corixidae, Notonectidae, Nepidae, Dystiscidae, Veliidae and Culicidae, as well as

species which have mechanisms, such as blood pigments, to assist them in living in low oxygen environments such as some Chironomidae and oligochaets. All of these occurred in the pools of Bohena Creek and lowered the SIGNAL score. However, in these circumstances they are not necessarily indicative of pollution or other anthropogenic disturbance, but simply that the stream had ceased to flow, and they were the taxa able to survive in the remnant pools.

7. Executive Summary

The executive summary states (p ES 16) that:

The project's Water Monitoring Plan would be implemented to monitor the managed release, including upstream and downstream water chemistry, hydrology and toxicity assessment.

However, as noted above there is insufficient information provided to indicate that the monitoring plan would be effective, or even to assure us that the proponents are aware of what is required to effectively detect and monitor for environmental impacts.

8. Conclusion

In general I found the components of the report dealing with water quality and aquatic ecology below the standard that I would expect.

From the point of view of surface water quality, chapter 12, on water quality, and the supporting appendices G1 and G4, are extremely disappointing. Data collection has been inadequate, the “statistical analysis” is superficial in the extreme, the interpretation is shallow and unscientific, and the documents are replete with vague and meaningless reassurances such as *“It is assumed that treated water temperatures at the point of release would be as close to Bohena Creek ambient temperatures as possible”* (Managed Release Study p13). If that is the criterion, treated water can be released at any temperature the proponent wishes, simply by stating that it wasn’t possible to cool the water any further. I would expect that a competent management plan would specify a numerical goal, such as released treated water being within 2°C of the temperature in Bohena Creek. Again, in regard to the released water, the proponent states it would *“target a SAR similar to Bohena Creek if long duration releases are required”* (Managed Release Study p 82). It is unclear what “similar” means - within 5%? 10%? 20%?

The results, and implications of the water quality work do not seem to have been considered by those conducting the aquatic ecology work, and there has been no targeted search for the snail *Notopala sublineata*.

There has not been adequate consideration given to the design of post-impact monitoring, and the number of samples, and sampling frequency, which would be required, just as there has not been adequate consideration given to the sampling design for water quality in the existing work.

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Export report: Social impact assessment of the Narrabri Gas Project

Prof Stewart Lockie

26 April 2017

1. Declaration

I have read the Uniform Civil Procedures Rules 2005: Schedule 7 Expert Witness Code of Conduct and agree to be bound by the provisions under the code.

I have made all inquiries which I believe desirable and appropriate to matters addressed in this report. No matters of significance, to my knowledge, have been withheld.

2. About the author

2.1 Contact details

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2.2 Highest academic qualification

Doctor of Philosophy (Rural Sociology), Charles Sturt University, 1997

2.3 Current appointments

- Distinguished Professor of Sociology and Director of the Cairns Institute at James Cook University
- Fellow of the Academy of the Social Sciences in Australia
- International Council for Science (ICSU) Committee for Scientific Planning and Review.
- Adjunct Professorial appointments at the Australian National University and Charles Darwin University
- Foundation Editor, *Environmental Sociology*
- Editorial Board member: *International Journal of Comparative Sociology*, *Sociology of Development* and *Ecosystem Health and Sustainability*

2.4 Relevant experience

Prof Lockie has undertaken social impact assessments on behalf of government agencies, community groups and development proponents in the resources sector. More details are available on request. His contributions to the theory and practice of social impact assessment are evident in:

- Membership of the International Principles for Social Impact Assessment Project Team.¹
- Inclusion of Prof Lockie's publications in the International Association for Impact Assessment's *Key Citations Series: Social Impact Assessment*² and *Guidance for Assessing and Managing the Social Impacts of Projects*.³
- Contribution of four chapters to *Developments in Social Impact Assessment*.⁴

3. Adequacy of the Narrabri Gas Project SIA

This section addresses the adequacy of the methodology and evidence base that underpin the Narrabri Gas Project Social Impact Assessment.

According to Appendix T1 of the Project EIS, the SIA is based on:

- The Secretary's Environmental Impact Assessment Requirements for the project.
- *International Principles for Social Impact Assessment* published by the International Association for Impact Assessment (IAIA).

Additionally, as stated in Chapter 10 Approach to the Impact Assessment, the Narrabri Gas Project SIA incorporates a qualitative risk assessment based on *AS/NZS ISO 31000:2009 Risk Management – Principles and Guidelines*.

While none of these documents prescribe specific assessment methodologies and techniques they do provide criteria against which the adequacy of SIAs might be assessed. For example, the *AS/NZS ISO 31000:2009* standard outlines 11 principles of risk management including requirements that they explicitly address uncertainty, are based on the best available information, and are transparent and inclusive.

Insight into SIA methodology can be drawn from IAIA's recent *Guidance for Assessing and Managing the Social Impacts of Projects* (2015) which summarises the phases of SIA as:

- i. Understand the issues: understand social area of influence, assemble baseline data, initiate participatory processes, scope issues etc.
- ii. Predict, analyse and assess the likely impact pathways: social changes and impacts, indirect impacts, cumulative impacts, affected party responses, significance of changes and project alternatives.
- iii. Develop and implement strategies: address negative impacts, enhance benefits and opportunities etc.

¹ www.iaia.org/uploads/pdf/IAIA-SIA-International-Principles.pdf

² www.iaia.org/uploads/pdf/KeyCitations_SIA.pdf

³ www.iaia.org/uploads/pdf/SIA_Guidance_Document_IAIA.pdf

⁴ www.e-elgar.com/shop/developments-in-social-impact-assessment

- iv. Design and implement monitoring programs: indicators to monitor change, evaluation and periodic review etc.

This guidance document does not prescribe specific methodologies or techniques for use in project SIAs but highlights those considered typical of best practice social impact assessment.

Methodological steps undertaken in the Narrabri Gas Project SIA are broadly consistent with the IAIA guidance document. These steps included: (1) scoping; (2) establishing a social baseline; (3) impact identification and management; and (4) development of mitigation measures and management strategies. A number of stakeholders were consulted concerning potential issues and management strategies related to their respective areas of interest.

Through these steps, the Narrabri Gas Project SIA profiles impacted communities and identifies a range of impacts and management strategies plausibly relevant to the project.

The social baseline documented in Appendix T1, Section 4 draws on ABS data, other (unspecified) SIA reports and local planning documents. It would benefit from integration of material generated by the Gas Industry Social and Environmental Research Alliance (GISERA) funded project *Social Baseline Assessment of the Narrabri Region of NSW in Relation to CSG Development*.⁵ While this project is not yet complete, the Phase 2 report released early 2017 provides more comprehensive information on community expectations and perceptions than that detailed in the Narrabri Gas Project SIA.⁶

However, while the sources of baseline data reported in the Narrabri Gas Project SIA are generally clear, the report is not transparent in relation to the evidence on which many subsequent claims about impact significance, likelihood and consequences are made, nor who has been involved in making these assessments.⁷ This lack of transparency makes it difficult to evaluate whether the assessment of impacts is based on the best available information or inclusive of all stakeholders with an interest in the project. As IAIA's SIA guidance document states:

“Research methods and analytical procedures must be fully disclosed to: enable replication of the research by another practitioner; enable peer review of the adequacy and ethicality of the methodology; and to encourage critical self-reflection on the limitations of the methodology and any implications for the results and conclusions (p. 33).”

SIA requires practitioners to make predictions that cannot be extrapolated directly from baseline conditions and trends. To assess the potential implications of development for impacted communities they use a range of tools including impact pathway analysis, multi-criteria analysis and (as used in the Narrabri Gas Project SIA) risk analysis. These tools rely, in turn, on expert judgement, local knowledge and, importantly, post-development studies of

⁵ <https://gisera.org.au/project/social-baseline-assessment-narrabri-region-nsw-relation-csg-development/>

⁶ Walton, A., McCrea, R., Taylor, B. and Jeanneret, T. (2017) *Understanding local community expectations and perceptions of the CSG sector: Social baseline assessment: Narrabri project – Phase 2*. CSIRO Report: CSIRO Australia.

⁷ Exceptions to this observation include the attribution of expectations concerning the likely impact of this project on crime and antisocial behaviour to police.

similar projects implemented elsewhere.⁸ It is possible the Narrabri Gas Project SIA has used one or more of these. However:

- If expert judgement has been used it is important to specify who these experts were (including EIS team members) and what qualifies them to exercise judgement in this context.
- If local knowledge has been used it is important, again, to specify which stakeholder groups have contributed local knowledge and in relation to which impacts.
- If comparative analysis of other studies has been undertaken a comprehensive list of sources should be provided.

4. Social impact predictions and mitigation measures

In the absence of more detail concerning how impact significance has been assessed, and by whom, it is not possible to provide a comprehensive review of the impact predictions and mitigation measures identified in the SIA. This section will comment, therefore, on several issues in respect of which I believe more information is required before the possibility of more significant social impacts can be ruled out.

4.1 Cumulative impacts

Of particular importance is the need for more detail on developments in the region likely to generate cumulative impacts given their potential to amplify the magnitude and significance of those arising from the Narrabri Gas Project and to undermine, as a consequence, the adequacy of impact mitigation measures identified in the SIA.

The Secretary's Environmental Assessment Requirements for the project include:

“assessment of the likely impacts of all stages of the development, including any *cumulative impacts*, taking into consideration any relevant laws, environmental planning instruments, guidelines, policies, plans and industry codes of practice... (emphasis added).”

Appendix T1, Section 6.3.8 identifies several other resource extraction projects proposed for the region and notes the potential for these to create competition for labour and housing, particularly during the construction phase (see also Chapter 29 Cumulative Impacts).

The potential, however, for cumulative impacts on labour and housing markets appears not to have been considered further in the assessment of risk or in the identification of mitigation strategies (Appendix T1, Section 7). These consider only those demands for labour and accommodation associated directly with the Narrabri Gas Project.

Other issues in relation to which cumulative social impacts might plausibly be expected but which are not addressed in the SIA include the demographic profile of affected communities,

⁸ Burdge, R. (2003) The practice of social impact assessment – background. *Impact Assessment and Project Appraisal* 21(2): 84–88. Available at www.tandfonline.com/doi/abs/10.3152/147154603781766356

demands on social infrastructure, changes to community identity, stress and anxiety associated with uncertainty, and the prevalence of crime and other antisocial behaviour – each of which were important foci for interactive and cumulative impacts during the recent expansion of coal mining in Queensland’s Bowen Basin.⁹

Again, I am not claiming that these do present significant risks in relation to the Narrabri Gas Project but that the evidence presented in the SIA is not sufficient either to rule them out or to evaluate the adequacy of management and mitigation strategies.

4.2 Social cohesion

The GISERA funded research cited above into Narrabri community expectations and perceptions of the CSG sector (Walton et al. 2017) suggests that water is the dominant concern among community members and that many hold positive attitudes towards the project and project proponent. Those with negative attitudes towards the project tend to consider the risks to water and other values unmanageable and/or the proponent and government untrustworthy. Participants in the study described the community as polarized and reported feeling pressure to adopt particular views, feeling maligned for their own views, and so on.

I do not wish to express a view on whether Narrabri residents ought to hold positive, neutral or negative attitudes towards the Gas Project. The key issue here is that conflict over the project should be acknowledged in the SIA and the risk this presents, longer term, to social cohesion should also be acknowledged and managed proactively.

Adherence to the Agreed Principles of Land Access along with regular communication through various channels as identified in Appendix D, Section 6 are both relevant and proactive steps to reduce conflict and subsequent risks to social cohesion. However, given the polarization already evident in the community it would be reasonable to conclude that additional strategies are warranted. Walton et al. (2017) identify a number of considerations relevant to the development of such strategies. These include ongoing support for independent research, respect for differing views, taking steps to ensure local capture of benefits, and attention to the long-term future of the Narrabri community.

The Community Benefit Fund identified in the SIA ought to provide opportunities to implement strategies for fostering community cohesion and, indeed, Appendix T1, Section 7.8 does foreshadow use of the fund to support environmental activities, research, community events etc. However, no detail is provided on governance and decision-making arrangements for the fund nor what ‘\$120 million through the life of the project’ might mean in the short to medium term. Transparency in relation to such matters is needed to build trust in the proponent and to reduce anxiety among those concerned about community impacts.¹⁰

⁹ Petkova, V., Lockie, S., Rolfe, J. And Ivanova, G. (2009) Mining developments and social impacts on communities: Bowen Basin Case Studies’, *Rural Society*, 19(3): 211–228. Available at

www.bowenbasin.cqu.edu.au/Petkova%20et%20al.%20Rural%20Society%2009.pdf.

¹⁰ Porter, M., Franks, D. and Everingham, J-A. (2013) Cultivating collaboration lessons from initiatives to understand and manage cumulative impacts in Australian resource regions.

4.3 Life of project planning including closure

Project closure is identified in the Narrabri Gas Project EIS as a potential source of social impacts including loss of employment, business opportunities and population (subject to socioeconomic conditions at the time). Experience elsewhere suggests that key conditions will include the level of economic dependence on the project, the adequacy of environmental rehabilitation, and the extent to which the project has shaped local and regional population flows.¹¹

Appendix T1, Section 7.10 of the EIS states that prediction and management of social impacts arising from closure will be addressed through the closure planning process. Closure planning is treated, in other words, as beyond the scope of the EIS.

However, as the above quote taken from the Secretary's Environmental Assessment Requirements for the project states, assessment is required "of the likely impacts of *all stages of the development*" (emphasis added). The Secretary also refers to two relevant guidance documents on project closure including *Mine Closure and Completion – Leading Practice Sustainable Development Program for the Mining Industry* (Commonwealth Government)¹² and the *Strategic Framework for Mine Closure* (ANZMEC-MCA).¹³ Both documents stress that closure planning is integral to the full project life cycle and that consultation should occur throughout the full life cycle.

Treating closure as an integral part of the whole project life cycle is reflective of international best practice. The IAIA *Guidance for Assessing and Managing the Social Impacts of Projects* (2015) states that, projects are, by definition, fixed term activities. While uncertainty over the lifespan of extractive projects is inevitable due to commodity market volatility, closure strategies should be in place at project commencement and plans should be updated regularly to reflect changes in the project and the operating environment. Failure to plan for closure from the earliest stages of project development risks undermining trust in project proponents and missing opportunities to leave a positive legacy.

Appendix T1, Section 7.10 of the EIS expresses the expectation that sustained benefits will arise from the Community Benefit Fund and that these benefits will continue beyond the life of the project. This may well be the case. However, clear consideration of closure in the

Resources Policy 38: 657–669. Available at

www.sciencedirect.com/science/article/pii/S0301420713000184.

¹¹ Lockie, S., Franetovich, M., Petkova-Timmer, V., Rolfe, J. and Ivanova, G. (2009) 'Coal Mining and the Resource Community Cycle: A Longitudinal Assessment of the Social Impacts of the Coppabella Coal Mine', *Environmental Impact Assessment Review*, 29, 330–339. Available at

www.bowenbasin.cqu.edu.au/Lockie%20et%20al%20Env%20Impact%20Assess%20Review%202009.pdf.

¹² www.industry.gov.au/resource/Documents/LPSDP/LPSDP-MineClosureCompletionHandbook.pdf.

¹³ www.sernageomin.cl/pdf/mineria/cierrefaena/DocumentosRelacionados/Strategic-Framework-Mine-Closure.pdf.

design of the fund and in design of impact mitigation strategies more generally will improve the chances of this happening.

4.4 Positive impacts for Indigenous residents

The EIS documents outline a comprehensive approach to managing cultural heritage and commit the proponent to negotiating suitable agreements with native title holders. Additionally, the SIA (Appendix T1, Section 7.3) notes opportunities to generate positive social impacts through support for Aboriginal employment and business opportunities. These might be considered particularly important to the social legacy of the Narrabri Gas Project given comparatively low incomes and employment levels among Indigenous residents.

Despite stated commitment to implement a *Diversity and Equal Opportunity Policy* to ‘maximise Aboriginal employment including for contractors’ no detail is provided as to the concrete measures that will be taken to ensure this goal is realised. Again, this is not to say the project will not generate positive social outcomes for Indigenous residents but that the mechanisms intended to generate these benefits are not clear.

5. Further observations

Unconventional gas development can have positive social impacts including a reversal of the net out-migration of young people evident in many rural areas.¹⁴ Concern and conflict in relation to the potential for negative impacts, moreover, tends to be highest during the construction phase of resources projects with concern then shifting to longer-term considerations of community viability.¹⁵

As noted above, a lack of transparency in relation to how social impacts have been assessed in the Narrabri Gas Project EIS makes it difficult to evaluate the adequacy of their assessment or of management and mitigation measures. This is just as true, moreover, of opportunities to maximise positive social impacts as it is of strategies to avoid or minimise negative social impacts.

¹⁴ Measham T.G. and Fleming D.A. (2013) Impacts of unconventional gas development on rural community decline: working paper, November 2013, CSIRO, Australia. Available at <https://gisera.org.au/wp-content/uploads/2016/04/socioeco-proj-1-rural-decline-workingpaper.pdf>.

¹⁵ Walton, A., Williams, R. and Leonard, R. (2017) Community perspectives on coal seam gas development during two phases of industry activity: construction and post-construction. *Rural Society* 26(1): 85–101. Available at www.tandfonline.com/doi/full/10.1080/10371656.2017.1293546



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Report on the adequacy of the Environmental Impact Statement for the Narrabri Gas Project in assessing and mitigating impacts on the vertebrate fauna of the Project Area

David Milledge

16 May 2017

1. I have been asked by EDO NSW, on behalf of the North West Alliance, to prepare a report based on a review of the Environmental Impact Statement (EIS) for the Narrabri Gas Project (Project) in relation to likely impacts on the vertebrate fauna of the Project Area and on the adequacy of the EIS in assessing and mitigating these impacts.
2. In this regard I have been provided with a copy of Division 2, Part 31 of the *Uniform Civil Procedure Rules 2005* and the *Expert Witness Code of Conduct* (Code of Conduct) in Schedule 7 of those rules. I have read the Code of Conduct and have adhered to those rules in preparing this report.
3. Also in preparing this report, I have read the following documents that comprise part of the EIS for the Project:
 - a) Executive Summary
 - b) Chapter 15 - Terrestrial ecology
 - c) Chapter 29 - Cumulative impact
 - d) Chapter 30 - Environmental management and monitoring
 - e) Appendix C - Field Development Protocol
 - f) Appendix J1 - Ecological impact assessment) Appendix J2 - Biodiversity assessment report
 - i) Appendix V - Rehabilitation strategy
4. I have had considerable field experience in the Pilliga forests and woodlands and associated habitats, including the EIS Project Area, having conducted a survey for large forest owls at 500 sites throughout the Pilliga in 2001. This survey demonstrated that the area supported the most significant population

of the Barking Owl *Ninox connivens* in NSW, a species listed as Vulnerable on the Schedules of the NSW *Threatened Species Conservation (TSC) Act 1995*.

5. I also took part in a comprehensive targeted survey of Threatened fauna species in the majority of the Project Area in 2011, when 20 Threatened species (*TSC Act 1995*) were recorded. These included the South-eastern Long-eared Bat *Nyctophilus corbeni* and Pilliga Mouse *Pseudomys pilligaensis*, both also listed as Vulnerable under the Commonwealth's *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*.
6. The results of the large forest owl survey have been published in Milledge (2002), Milledge (2004) and Milledge (2009).
7. Results of the targeted Threatened fauna survey in the Project Area have been published in NICE and CUCCLG (2012), and in Paull *et al.* (2014) in relation to the Pilliga Mouse.

Overall appropriateness and adequacy of the assessment of impacts on vertebrate fauna

8. A review of the EIS assessment of impacts on vertebrate fauna (Appendix J1, summarised in Chapter 15) shows that the EIS has not appropriately and adequately assessed potential impacts on vertebrate species and on key Threatened species in particular, despite a substantial amount of field survey effort. This is due to a number of factors, consisting of:
 - a) a failure to acknowledge the overall significance of the Pilliga forests and woodlands for biodiversity conservation and of the importance of the Project Area in this context;
 - b) a failure to acknowledge the high level of environmental stress already operating on the Pilliga forests and woodlands, and to take into account the potential additional impacts of climate change;
 - c) a failure to obtain a sufficient number of records of most key Threatened species, precluding the identification of important local populations of these species in the Project Area, that are necessary to implement effective protective measures;
 - d) a failure to acknowledge the likely high level of impact on vertebrate fauna from the Project, particularly from indirect and cumulative impacts, together with the dismissal of the potential for a likely significant effect on key Threatened species.

Significance of the Pilliga forests for biodiversity conservation and of the importance of the Project Area in this context

9. The Pilliga forests and woodlands represent the largest, relatively intact, unfragmented block of dry sclerophyll forest and woodland in eastern Australia. As such they provide a crucial refuge for biodiversity in a landscape

largely cleared for agriculture (NICE and CUCCLG 2012, Lunney *et al. submitted 2017*).

10. They comprise part of one of 15 National Biodiversity Hotspots recognised by the Commonwealth (Australian Government Department of Environment and Energy website, accessed 14 May 2017) and a globally significant Important Bird Area (now termed Key Biodiversity Area, Birdlife Australia website, accessed 14 May 2017).
11. The Pilliga forests and woodlands also constitute a stronghold for numerous declining woodland bird species (e.g. Birds Australia 2005) as well as many other Threatened vertebrates (NICE and CUCCLG 2012, Milledge 2013) and constitute part of the eastern Australian bird migration system, providing seasonal foraging and movement habitat (NICE and CUCCLG. 2012, Milledge 2013).
12. These attributes have been virtually ignored in the EIS and do not appear to have been considered as background or context (Chapter 15, Appendices J1 and J2) in assessing the biodiversity significance of the area, the potential for significant impacts and the mitigation of such impacts.
13. The Project Area falls mainly within a landscape unit known as the Pilliga Outwash Province (Provinces of the Brigalow Belt South Bioregion, NSW EPA Forests Agreement, Western Regional Assessment, website accessed 14 May 2017). This Province has generally higher soil nutrient status, increased plant productivity, and a higher vertebrate carrying capacity than the adjoining Pilliga Province (Milledge 2004), which encompasses the greater proportion of the Pilliga forests and woodlands.
14. Much of the National Park and Nature Reserve estate in the Pilliga lies in the eastern and southern sections within the Pilliga Province with its poorer soils and higher incidence of wildfire (Milledge 2004). These reserves provide relatively poor quality habitat for vertebrate fauna compared with conservation areas in the Outwash Province, which although containing more productive soils, comprise Community Conservation Areas that provide lower levels of protection. This is because they are subject to a range of activities excluded from National Parks and Nature Reserves that diminish their biodiversity conservation values.
15. Consequently it is inaccurate to imply that the approximately 50% of the Pilliga allocated to conservation (EIS Executive Summary, What is proposed?; Chapter 15, s.15.2.1) is of equal value in this regard.
16. The lack of consideration and acknowledgement of these attributes and values refutes the claim that the Project Area has been evaluated in the wider Pilliga context (EIS Chapter 15, s.15.1) and that the "ecology of the project area is well understood" (EIS Executive Summary, Terrestrial and aquatic ecology).

17. Although the "high ecological and landscape value" of the Pilliga forests and woodlands is noted (EIS Chapter 15, s15.2.1) and that the area comprises a "unique biological, geological and geographic unit" (EIS Appendix J1, s4.11.3), this is not carried through to any analyses or mitigation measures. Neglecting consideration of the specific ecological values of the Project Area in a regional and national context have contributed to the inappropriateness and inadequacy of the impact assessment and to the lack of identification of particular areas requiring the application of precise protection and mitigation measures.

High level of environmental stress already operating on the Pilliga forests and woodlands, and the potential additional impacts of climate change

18. The Pilliga forests and woodlands have been subject to severe environmental stress over the past few decades, including prolonged drought, extreme temperatures, wildfire and losses of significant fauna habitat elements (Lunney *et al. submitted 2017*, Niche Environment and Heritage 2004, Parnaby *et al.* 2010, Milledge 2004).
19. This situation should have been taken into account in assessing the impact of the Project, particularly in relation to cumulative impacts. However, as with the Pilliga's overall biodiversity conservation significance and the Project Area's values in the wider Pilliga context, it has generally been overlooked.
20. The failure to detect any live Koalas *Phascolarctos cinereus* in the Project Area over the four year survey period (EIS Chapter 15, Appendix J1) in areas where the species had previously been recorded (NICE and CUCCLG 2012, Niche Environment and Heritage 2014) should have raised concern and served to inform the impact assessment process.
21. The status of the formerly extensive and healthy Koala population in the Pilliga forests and woodlands, now considered to be on an extinction trajectory (Lunney *et al. submitted 2017*), is an indication of the level of environmental stress currently impacting the Pilliga's ecosystems.
22. The potential for even greater detrimental impacts on these systems posed by anthropogenic climate change has similarly received little consideration in the EIS's assessment of the Project's impacts, again particularly with respect to cumulative impacts. Predictions for climate changes in the Pilliga area include frequent extended extreme temperatures, altered rainfall with longer periods of drought and increased fire frequency and intensity (Lunney *et al. submitted 2017*, Niche Environment and Heritage 2014).
23. These effects, although discussed in the supporting documents in the EIS (Appendix J1), have not been adequately considered, particularly in identifying refuges and designing specific measures to mitigate impacts likely to be exacerbated as the climate changes.

Lack of a sufficient number of records of most key Threatened species to enable identification of important local populations of these species in order to implement protective measures

24. An examination of the locations and numbers of individuals of most key Threatened species (species with significant populations in the Pilliga forests and woodlands) detected in the Project Area over the four year survey period (EIS Appendix J1, Figs 20, 21; Appendix C) indicates that the field surveys failed to obtain a sufficient number of records of these species to adequately inform the assessment and mitigation of impacts likely from the Project.
25. Examples of the low numbers of locations and individuals of such Threatened species that were obtained in the Project Area comprise:
 - a) no records of the Pale-headed Snake *Hoplocephalus bitorquatus* from the State Forests (the main area of forest and woodland in the Project Area) and only four locations outside these Forests;
 - b) no records of the Barking Owl from the State Forests and only four locations outside State Forests;
 - c) only one location for the Eastern Pygmy-possum *Cercartetus nanus* within the Project Area and one outside;
 - d) only one location for the Squirrel Glider in the Project Area;
 - e) only four locations in the Project Area for the South-eastern Long-eared Bat with only four to five individuals captured;
 - f) only three locations in the Project Area for the Pilliga Mouse with only five individuals captured.
26. These results, from surveys conducted over four years contrast markedly with those obtained by NICE and CUCCLG (2012) in and closely adjacent to the Project Area over only approximately 10 days, when for example, 21 individuals of the South-eastern Long-eared Bat and 25 individuals of the Pilliga Mouse were captured at 8 and 7 separate locations respectively.
27. Perhaps the low number of records of these Threatened species from EIS field surveys reflected the environmental stresses experienced in the Pilliga prior to and during the survey period (paras 18-23 above), or perhaps they also reflected additional impacts operating as a result of previous and on-going gas mining exploration activities. However, the NICE and CUCCLG (2012) surveys were undertaken within the same period with sharply contrasting results (para 26 above).
28. Whatever the reasons for these low numbers, such a paucity of information has resulted in an inability to accurately demonstrate the occurrence of important populations of key Threatened species in the Project area,

preventing an adequate assessment of potential impacts and severely restricting the ability to formulate effective mitigation measures.

29. The identification of specific habitats and habitat elements being used by the key Threatened species is required prior to planning the locations for siting gas wells and well pads to facilitate avoidance and buffering of these attributes.
30. For example, the locations of hollow-bearing trees used by the hollow-dependent Pale-headed Snake, Barking Owl, Eastern Pygmy-possum, Squirrel Glider, Yellow-bellied Sheath-tailed Bat *Saccolaimus flaviventris* and South-eastern Long-eared Bat in the Project Area should have been determined to enable protection measures to have been precisely applied.
31. In addition, the paucity of survey records of key Threatened species is also likely to have compromised the modelling of their habitats (EIS Appendices J1, J2), as indicated by the use of only five Pilliga Mouse captures at three sites to inform derivation of the Pilliga Mouse habitat model (EIS Appendix J1, F5).

Likely high level of impact from the Project and particularly from indirect and cumulative impacts, and dismissal of potential for a likely significant effect

32. It is difficult to accept, as the EIS has found, that there would not be a major significant adverse effect on the vertebrate fauna, including a number of Threatened species (EIS Executive Summary, Terrestrial and aquatic ecology), from the installation and operation of up to 850 gas wells on up to 250 well pads over a 20 year period as proposed by the Project.
33. The installation and operation of these pads and wells will result in the following detrimental impacts over approximately 15% of the higher quality vertebrate habitat in the Pilliga forests and woodlands:
 - a) increased fragmentation of a landscape already under severe environmental stress;
 - b) the creation of wide, effectively permanent barriers to vertebrate movement resulting from construction of linear corridors and bushfire asset protection zones; these will have an associated effect of increased exposure of vulnerable species to predation from introduced vertebrates including the Red Fox *Vulpes vulpes*, Feral Cat *Felis catus* and Feral Pig *Sus scrofa*;
 - c) increased sedimentation of already silted up, ephemeral waterways and the reduced availability of surface water essential to the maintenance of many vertebrate populations;
 - d) increased disturbance from an exponential increase in vehicle movements, dust, noise and lighting associated with gas mining operations;

e) continuing detrimental impacts on high value riparian habitat crucial for vertebrate refuges and movements;

f) increased adverse impacts on vertebrate habitats from pest vertebrate species such as the Feral Pig and Feral Goat *Capra hircus*;

g) cumulative impacts resulting from the exacerbation of perturbations already operating in the Project Area due to now intensive forestry operations (Niche Environment and Heritage 2014) and climate change, particularly the loss of hollow-bearing trees (Parnaby *et al.* 2010), vegetation loss and increased fire frequency (Lunney *et al. submitted 2017*).

34. The statement that the Project would not have a significant impact on Threatened vertebrate species (EIS Executive Summary, Terrestrial and aquatic ecology) is based primarily on the claim that it would only impact on a very small area of habitat, and on largely untested mitigation measures intended to alleviate the direct and indirect impacts listed above (para 33).
35. Mitigation measures relied on to reduce these impacts include the employment of an "Ecological Scouting Framework" (EIS Executive Summary, Chapter 15, Appendix J1), but this appears untested and should have been developed and validated prior to the field surveys to demonstrate its usefulness. Further, its effectiveness is likely to be highly compromised as the "avoidance, management and mitigation measures" proposed to protect the values it might identify will only be implemented "where practicable" (EIS Executive Summary, Terrestrial and aquatic ecology).
36. Another mitigation measure is the proposed progressive rehabilitation of well pads (EIS Executive Summary, How will the project be developed?, Fig. ES 2) but the benefits of this measure have not been demonstrated, despite the rehabilitation of exploration well pads having been underway for at least two years (EIS Executive Summary, Fig. ES 2).
37. It could also have been expected that permanent monitoring plots would have been established to gauge the effectiveness of proposed mitigation measures. These should have initially been installed to collect baseline data and allow for adaptive management, and to engender confidence in the mitigation measures proposed, but such plots do not appear to have been established.
38. Similarly, vertebrate pest control programs could also have been established to inform this proposed mitigation measure, as pest animal impacts have been ongoing during the past years of exploration activities in the Project Area (NICE and CUCCLG 2012), but again this does not appear to have been trialled.
39. **In summary, the EIS does not provide an appropriate and adequate assessment of the likely impacts of the proposed Project on vertebrate fauna, and particularly on Threatened species (TSC Act 1995, EPBC Act 1999), or of adequate mitigation of these impacts.**

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22 May 2017

Brendan Dobbie
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Australia

Dear Mr Dobbie,

Re: Narrabri Gas Project

This letter was prepared in response to your request, on behalf of the North West Alliance, to provide independent expert advice regarding the Narrabri Gas Project. That request was the subject of the letter that I received from you dated 31 March 2017.

As requested by you, I have now reviewed the following sections of the Environmental Impact Statement (EIS) for The Narrabri Gas Project ("project"), prepared by the project proponent, Santos.

- a) Executive summary;
- b) Chapter 7 - Produced water management;
- c) Chapter 28 - Waste management;
- d) Appendix G1 - Managed release study _Bohena Creek;
- e) Appendix G2 - Concept irrigation design;
- f) Appendix T3 - Chemical risk assessment; and
- g) Appendix W - Decommissioning report.

Please find below, my advice in response to the following three specific questions, labelled a), b) and c).

I confirm that in preparing this report I have read the Expert Witness Code of Conduct under the *Uniform Civil Procedure Rules 2005* and agree to be bound by it.

a) In your opinion, is the assessment of the produced water management system described in the EIS appropriate?

I have previously reviewed the issues associated with the production and management of produced water from coal seam gas (CSG) activities for the NSW Office of the Chief Scientist and Engineer (Khan & Kordek, 2014). The report that I prepared for that purpose is publically available and, I believe, still highly relevant to the issues currently being considered and described in this EIS. Some of the key issues were later summarised in peer-reviewed academic research paper (Davies *et al.*, 2015).

According to the EIS, around 37.5 gigalitres of water would be extracted from the target coal seams over the life of the project. Water production is generally not consistent over the life of a CSG well, but much greater volumes are extracted during the first few years, with significant declines thereafter.

The EIS describes the quality and management of produced water in Chapter 7. Somewhat unhelpfully, the salinity of the produced water is described in terms of electrical conductivity (in units of microSiemens per centimetre), rather than an actual salt concentration (in units of mg/L). It is stated that the average salinity is around 14,000 microSiemens per centimetre. The EIS states that “this level of salinity is approximately 30 percent of the salinity of seawater, which is around 50,000 microSiemens per centimetre”.

The actual conversion from electrical conductivity to salt concentration in mass terms is dependent upon the precise chemical composition of the salt. Produced water from CSG wells is predominantly composed of sodium bicarbonate, whereas sea water is predominantly composed of sodium chloride. Consequently, the conversion from electrical conductivity to salt concentration is significantly different for the two saline solutions.

At 25°C, 14,000 microSiemens per centimetre would equate to approximately 7000 mg/L sodium chloride, but would equate to approximately 14,000 mg/L sodium bicarbonate. On this basis, it is not accurate to state that the salinity is approximately 30 percent of the salinity of seawater. Seawater contains around 35,000 mg/L of salt, hence the produced water is approximately 40% the salinity of seawater.

I note that in previous personal discussions (in 2014) with Santos Water Management Leader, Glen Toogood, I was informed that the overall average salt concentration was expected to be 18,000 mg/L. On that basis, the salinity would be approximately 50% the salinity of seawater. In order to avoid this ambiguity, the EIS should simply provide the actual expected salt concentration –in mg/L- in Chapter 7.

It is stated in the EIS that the Leewood water treatment plant would have a maximum design capacity of 14 ML/day during the predicted water peak. This is much larger than information previously provided by Santos, which indicated that the plant would treat up to 1.5 ML day, producing up to 1.0 ML/day of reverse osmosis (RO) permeate.

The EIS indicates that produced water volumes are projected to peak at around 10 ML/day during around years two to four.

The key water treatment processes at the Leewood water treatment plant are described in the EIS as follows:

- Stage 1: Removal of solids using dissolved air flotation, strainer and microfiltration/ultrafiltration (membrane) technologies. This stage would use ion exchange technology to remove certain cations that can otherwise interfere with

reverse osmosis (refer to Stage 2). Biocide would be used to control the growth of organisms through the treatment process.

- Stage 2: Removal of salt using reverse osmosis technology. About two-thirds of produced water would exit reverse osmosis as treated water (permeate), with the remaining one-third being brine.
- Stage 3: Recovery of treated water (distillate) from brine using thermal evaporation technologies. The distillate would be recombined with the treated water.
- Stage 4: Removal of a solid salt product from concentrated brine using salt crystallisation technology. The solid salt product would be stored on site prior to being removed for off-site disposal at a licensed facility. Residual distillate would also be recovered by thermal evaporation and recombined with the treated water.
- Stage 5: Removal of ammonia by chlorination. This would be followed by dechlorination and pH adjustment.
- Stage 6: Amendment of the treated water. Calcium sulfate would be added to adjust the sodium adsorption ratio.

While the EIS does not provide more detailed design specifications, I consider that this is –in concept– a water treatment plant that can be expected to produce very high quality treated water. It is my opinion that with appropriate design and management, such a water treatment processes could reliably produce water suitable for the intended beneficial reuse applications, which are stated to be “irrigation, stock watering, dust suppression and construction”.

Similarly, I consider that these treatment processes could produce water of a quality suitable for managed release to the environment. However, two important points should be noted in this case:

1. I have not considered the issues relating to the variable flow volumes of water in Bohena Creek and how these releases may impact upon them;
2. Some previous studies regarding the release RO-treated water to freshwater systems have raised concerns that such water may be “too clean”, depriving the waterways of minerals and organic substances, necessary to maintain aquatic ecology. While this may not prove to be a major obstacle, it would be appropriate to closely investigate this issue and ensure an appropriate level of management is in place.

The overview of the water treatment process (Figure 7-4) indicates that significant volumes of brine concentrator distillate and salt crystalliser distillate will be blended with RO permeate. I have not identified information describing the expected water quality of these distillates. If they are significantly lower than that of RO permeate, it may be more appropriate for those distillates to be blended into the RO feed, rather than the RO permeate.

Major sources of potential environmental risk are the produced water storage ponds and the brine storage ponds. Such ponds will always present risks in terms of potential

leakage, thus contaminating the groundwater supplies below. Previous experience with brine ponds at this location has revealed that the leakage of brine from brine ponds may lead to the mobilisation of some metals in soil, including uranium. This risk does not appear to be clearly identified or discussed.

In addition to leakage from ponds, a further risk is from spillage during flooding events. Such events have the potential to wash very large loads of salt from the ponds onto soil, as well as into waterways. Stringent and effective risk management practices will need to be in place to manage these risks.

b) In your opinion, have the produced water management plans as described in the EIS adequately considered patterns of production, high energy proposal, salt management, and irrigation water quality?

In section 7.8.1 “Salt Volumes”, it is stated that “produced water was heated in the laboratory to 180 degrees Celsius to simulate the thermal process used during water treatment. During heating, some salt in the produced water decompose, while the remainder become a solid salt product. After taking into account decomposition resulting from heating, the typical mass of salt produced is 11,700 milligrams per litre of water fed to the water treatment process”.

The fact that the initial salt concentration (in mg/L) does not seem to be provided, makes it difficult to understand the mass balance for the above paragraph. However, it is clearly implied that some chemical change is understood to take place. In my opinion, this needs to be supported with some clear and balanced chemical reactions. In addition, the EIS needs to answer the following questions:

- What salts are being changed and into what products?
- What is the mass loss of salt relative to the initial mass?
- How is that loss accounted for?
- Does this change produce gaseous products?

In Chapter 28 “Waste Management”, it is stated that 430,500 tonnes of salt are projected to be produced over the 25 year life of the project.

I understand that this 430,500 tonnes of salt would be disposed of at a licensed landfill facility. The operation of the licensed landfill facility appears to be outside the scope of this EIS. However, it is appropriate to consider the lifecycle impacts of all products produced from the proposed CSG operation. Salt-filled landfills are subject to a number of potential hazardous events, which effectively compound the environmental risks that flow from the CSG operation.

One potential hazardous event involves the failure of the landfill liner and seepage of saline water (leachate) to groundwater and surface water. There are measures that are normally proposed to be in place to manage this risk, but these measures will not completely eliminate the risk. Importantly, the lifespan of this salt storage will need to be properly considered. Salt does not biodegrade in the environment and has an infinite

environmental residence time. Consequently, salt storages will need to be maintained on a permanent basis (decades or longer) or until the salt is re-mined and removed from the facility. Failure to do so will guarantee that the salt will eventually contaminate the local environment including groundwater and surface water. Unless satisfactory measures are in place to manage this risk over many decades (or longer), the risk is not managed.

A further important potential hazardous event is that of flooding, which can impact an open landfill monocell (one that is still in the process of being filled) and well as the existing stock-piles of salt, being prepared for landfill (or being prepared to be transported to the landfill site). These stock-piles will be relatively uncontained, and therefore, much more prone to causing environmental contamination during flooding or large wet weather events.

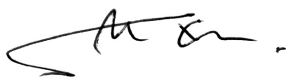
Due to the very long-term nature of some proposed salt landfill operations, the likelihood of contaminating groundwater and surface water over the long term is considerable. The responsibility for managing these risks over the long term will likely be inherited by future generations.

I have not paid specific attention to the energy requirements associated with this water treatment plan. However, a number of the proposed processes, including reverse osmosis, brine concentration and brine crystallisation are highly energy intensive. Consequently, the operation of this water treatment plant will add substantially to the overall energy footprint of the CSG operation.

c) Provide any further observations or opinions which you consider to be relevant, including in relation to the potential impacts of the Project on produced water management.

I have no further comments to add.

I hope you will find these comments to be helpful,



Stuart Khan
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