Review of Santos Narrabri Gas Project Response to EIS Submissions

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Introduction

I was briefed by EDO NSW on behalf of the North West Alliance to provide an expert report addressing the Response to Submissions prepared by Santos (the Proponent) as part of their proposal to develop the Narrabri Gas Project (Project). The following report should be read in conjunction with my original expert report of May 16th 2017 (herein referred to as Currell, 2017), which analysed potential groundwater (and to a lesser extent surface water) impacts of the Project. A copy of that report is provided as Appendix 1. The current report provides my opinion with respect to whether or not the concerns, deficiencies and risks outlined in that report have been addressed by the Response to Submissions, and if so, to what degree.

This report is based on my review of the following documents prepared by Santos, as well as other literature cited in the references section:

- Narrabri Gas Project: Response to Submissions (Part A), particularly responses to non-agency submissions (including Currell, 2017), but also the responses to IESC, Department of Primary Industries – Water (DPI Water) and NSW Environment Protection Authority (EPA); and
- Appendix D Water Baseline Report.

I have prepared the report in accordance with the NSW Land and Environment Court Expert Witness Code of Conduct.

Background and relevant expertise

I am a Senior Lecturer in the School of Engineering at RMIT University, Melbourne, Australia. I received my PhD from Monash University in 2011, on the use of environmental isotopes and geochemistry to assess controls on groundwater quality. For the last 7 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, supporting projects examining groundwater sustainability and contamination issues in Australia and China. I have published more than 35 peer-reviewed international journal articles, which have been cited more than 650 times, and served on the editorial board of the *Hydrogeology Journal* (the journal of the International Association of Hydrogeologists) from 2014 to 2018. I acted as an independent expert witness regarding hydrogeological and groundwater quality issues during the Victorian Parliamentary Inquiry into Unconventional Gas in 2015 and my evidence 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, 2017).

Summary of my opinion

Most of the concerns raised in my original expert report (Currell, 2017) remain unchanged, and have not been adequately addressed in the Proponent's Response to Submissions. In cases where additional data or information have been provided, these data are of value but they raise further concerns (particularly regarding the risk of groundwater contamination to the Great Artesian Basin (GAB)) and do not alleviate the concerns outlined in my original report regarding the issues discussed. There appears to have been no substantial revision or re-design of the Project to account for the risks raised in Currell, (2017) relating to groundwater impacts of the Project, despite these and other relevant issues being raised in numerous other submissions from key agencies and non-agency submissions.

Of particular concern are the following issues:

1. The Proponent has made little or no attempt to update the Project design in light of further data (included in the updated Water Baseline Report) regarding the composition of coal seam gas (CSG) produced water, including the significantly higher average salinity of this water compared to what was reported in the Environmental Impact Statement (EIS), and the presence of multiple hazardous constituents in this water (including concentrations of arsenic, barium, fluoride, cadmium and organic carbon that are highly elevated relative to typical ranges in groundwater). Based on new data provided in the Water Baseline Report, it is also clear that significantly elevated levels of particular elements (e.g. barium, boron, fluoride) are present within the produced waste brine which results from treatment of the produced water. Given that high volumes of produced water (in the order of 35 gigalitres over the project's life) are proposed to be generated, transported, stored and treated throughout the Project area, significant additional attention and further detail should have been given regarding how the Project can be designed and managed such that the risks of groundwater and surface water contamination are minimised. However, in the Response to Submissions, the Proponent states that the Produced Water Management Plan is essentially un-changed from that described in Chapter 7 and Appendix G of the original EIS. This is in spite of the additional data, and the high level of concern regarding this issue that was indicated in many of the submissions.

2. Baseline groundwater quality data provided in the updated Water Baseline Report are still inadequate with respect to characterising the water quality and developing a robust monitoring program to detect and remediate any impacts related to produced water leaks and spills, and other possible groundwater contamination mechanisms (e.g. migration of fugitive gases). The significance of these omissions has increased given the new data presented relating to produced water and waste brine chemistry; which show that the produced water is of higher salinity than previously reported, and containing significant concentrations of arsenic and other hazardous constituents. For example, the groundwater quality baseline data are still missing important analytes (e.g. arsenic, iron, total organic carbon, ammonia, uranium and other radio-nuclides), despite this issue being raised in Currell, (2017) and despite evidence that some of these elements occur in high concentrations in the produced water and/or brine.

3. The proponent has failed to properly acknowledge and take into account the extensive literature now available regarding the incidence of unconventional oil and gas wastewater leaks and spills, drawing on the experience of extensive onshore oil and gas development (conventional and unconventional) in the United States of America (e.g. Patterson et al., 2017). The existence of the large database of wastewater spill incidents, which indicates that spills typically occur at 3 to 5% of unconventional gas wells, appears not to have been analysed to assist with updating the Produced Water Management Plan. The Proponent appears to still hold the belief that wastewater spills and leaks will not happen (citing a lack of incidents of this kind occurring at Leewood over the last 4-5 years), and has not significantly updated its groundwater and surface water quality monitoring network to account for the information regarding the prevalence of spills in onshore oil and gas operations. Importantly, references to the Proponent's current track-record with respect to produced water management at Leewood should also acknowledge:

   a) that spills and leaks of CSG wastewater in the Project area have taken place in the past, at the Bibblewindi treatment plant;

b) that the current project size and volumes of produced water generated to date are a very small fraction of what would be produced under the proposed Project and thus the risk of spills and leaks would be significantly heightened under the proposal to drill 850 wells.

4. In my opinion, the spatial coverage of the groundwater monitoring regime required to adequately detect, characterise and mitigate such impacts as soon as they occur is poorly developed and at this stage is nowhere near commensurate with the size, numbers of wells and volumes of wastewater that would be produced. No significant change or update to the details of the groundwater monitoring program outlined in Appendix G3 of the EIS has been proposed, in response to the issues raised by Currell, (2017) and other submissions on the topic of groundwater monitoring in key agency submissions (such as the IESC and NSW EPA) and many non-agency submissions (e.g. see page 6-96 of the Response to Submissions Part A).

5. No additional field data have been collected to more accurately determine the rates and mechanisms of groundwater recharge in the Project area - particularly to the GAB aquifer system. This is in spite of the acknowledgement (in accordance with Currell, 2017) that the entire Project area appears to sit within a recharge zone for the GAB. No revision of the Project design to account for the fact that the area clearly has a strong potential to recharge the GAB and that the generation, transport and management of large volumes of poor quality wastewater in this area presents a significant groundwater contamination risk to the GAB. Similarly, there has been little attempt to further understand the geochemical, microbiological and hydrological controls which govern groundwater quality within the area, and their relationship to groundwater recharge, flow-paths, inter-aquifer mixing, water-rock interactions and geo-microbiological reactions in the aquifers. Such information is vital in the development of a robust conceptual model of pre-development groundwater conditions (including an understanding of processes controlling groundwater quality). Such information could be gained through collecting further environmental tracer data in the area.

Style of the Response to Submissions:
The Response to Submissions is written in such a way as to preclude analysis of whether specific concerns raised in non-agency submissions (including Currell, 2017) have been addressed. The response has selected a series of broad issues that were raised in multiple submissions and addressed these issues in a general manner, grouping related concerns from (at times) a large number of submissions. Most of the statements under sub-topics in the response (Part A) begin with the phrase ‘Submissions stated…’ or ‘One submission stated..’ with no citations given to indicate which submission(s) highlighted the issue(s). This makes it almost impossible to verify whether the issues raised in these submissions have been accurately portrayed and/or properly addressed in the Proponent’s response. In my opinion, this is a poor scientific writing style and it limits the ability for a reviewer to interrogate various claims and arguments made in the document. In the case of my previous submission (Currell, 2017) it appears that this method of responding to the submissions ‘in bulk’ has allowed some concerns to be left out or selectively ignored (for example there is no mention of the issue of a lack of a convincing conceptual model with respect to the major controls on groundwater quality in the study area based on mapping of hydrochemical data and collection of further environmental tracer data).

While it may be impractical for the Proponent to address every submission point by point in their response, there should in my view have been much greater effort put into pulling out specific issues raised in these submissions (e.g. quoting and or citing these submissions directly) to ensure that the key details of these concerns are not lost by the process of grouping, generalisation and simplification of the response.

Degree to which identified concerns have been addressed

This section discusses the degree to which concerns raised in Currell, (2017) have been addressed in the Response to Submissions, for example through the inclusion of additional data, re-assessment of particular risks, or re-design of the Project proposal.

1. Groundwater and surface water contamination risk (section 1 of Currell, 2017)

1.1 Further data and findings regarding volumes of produced water/treated water

The response to concerns regarding the ability of Santos's produced water gathering, transport, storage and treatment processes to adequately manage the volumes of produced water generated by the Project (6-38 to 6-39) indicate that no significant change has been made with respect to the Produced Water Management Plan outlined in the EIS (in Chapter 7, Appendix G1 and G2). The response refers readers back to original information already presented in the EIS. Given that a number of submissions raised this issue, it is disappointing to see that alternative approaches to produced water management (including the treated water) have not been considered, investigated and/or modelled. Strategies could have included attempting to reduce volumes of produced water by reducing the overall number of gas wells; seeking alternative/additional measures to de-centralise the produced water treatment system (in case of a major failure at Leewood); finding additional beneficial uses (apart from the proposed irrigation scheme and discharge to Bohena Creek).

1.2 Updated water baseline data: Produced water, treated water and brine

1.2.1 Produced water composition

With respect to the quality of the produced water, the updated Water Baseline Report (Section 6 of Appendix D) confirms that the data provided in the EIS regarding average salinity of the produced water was inaccurate and under-estimated the true average salinity of this water (as was hypothesised in Currell, 2017). While this is acknowledged in the Response to Submissions (p 6-40) there has been no discussion of the additional implications of this difference – such as the fact that it will likely result in an increase in the volume of waste brine produced by the Project (probably by 50% or more given the additional load of dissolved salts). It would appear that there has not been any update to the estimated quantities of salt that would be produced by the Project - see page 6-269 'Quantification of waste salt', which refers readers back to the original estimates in the EIS.

Additional data have also been provided in Appendix D regarding the chemical composition of produced water, based on samples from the Leewood facility. On the basis of these data, there are clearly additional contaminants of significant potential concern within the produced water that were not flagged in the EIS and are not given any further substantial discussion in the Response to Submissions. These include:

> *Arsenic:* the mean arsenic content of produced water is 100 µg/L (maximum concentration of 1 mg/L). These levels are well above those known to be hazardous to human health, e.g., they are far above NHMRC Health Guideline Values used in the Australian Drinking Water Guidelines, and are at or above ANZECC trigger values for long-term irrigation. Concentrations of arsenic at this level (depending on speciation) may also be expected to result in significant impacts to surficial or sub-surface ecosystems (e.g. exceed ANZECC freshwater ecosystem trigger values). It is very concerning in this context that no baseline data on current arsenic concentrations in groundwater or surface water have been reported in the updated Water Baseline Report (Appendix D).
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> *Barium:* the mean concentration of barium in the produced water is 3.35 mg/L (maximum 14.5 mg/L); which is above the health guideline value in the Australian Drinking Water Guidelines.
>
> *Cadmium:* the mean concentration in samples where cadmium was detected above the limit of reporting is 20 µg/L, with a maximum of 140 µg/L. These concentrations are above NHMRC health guideline levels.

Dissolved Organic Carbon (DOC): The mean concentration of DOC is 196 mg/L, while the maximum is 1330 mg/L. This is a very significant load of organic carbon which may be expected to create in-direct water quality problems, such as catalysing microbially mediated reactions in any impacted groundwater or surface water that can produce harmful by-products (e.g. hydrogen sulphide, increased dissolved iron and manganese concentrations, methane).

Ammonia-N: The mean concentration of ammonia-N is 0.79 mg/L, with a maximum of 3.9 mg/L. This is above the aesthetic guideline values in the Australian Drinking Water Guidelines (ADWGs).

Fluoride: Mean concentration of fluoride is 7.64 mg/L, with a maximum of 11.8 mg/L. This far exceeds the health guideline value in the ADWGs; drinking water containing this level of fluoride would create a significant risk of fluorosis – a serious long term health condition.

Methane: Mean concentration of methane 35.5 µg/L; maximum 98 µg/L. While concentrations at this level are not expected to result in any health or aesthetic issues with the water; the presence of methane, in conjunction may catalyse microbial activity and lead to indirect water quality effects.

All of these analytes warrant further attention in terms of risk assessment from potential spills and leaks of produced water, inclusion within the baseline groundwater monitoring program, and other potential mitigation/management strategies to prevent contamination of groundwater and/or surface water with these constituents.

Additional analytes which were recommended to be reported from the produced water (Currell, 2017) but which are still missing from the updated Water Baseline Report include: speciation of iron (e.g. Total, Fe^{2+}, Fe^{3+}) hydrogen sulphide, and radionuclides other than uranium (e.g. radium, radon). There are potential health, ecological and aesthetic risks associated with these species, depending on concentration levels.

Treated water composition

Treated water compositions from the Leewood facility are also included in the updated Water Baseline Report (Section 7). In general most of the contaminants listed are at concentrations well below the guideline values for drinking, recreational and irrigation usage – although data for methane and organic carbon are not included in the table.

Waste brine composition

Of significance is data concerning the Reverse Osmosis (RO) brine composition produced from the Leewood treatment plant (data contained in section 7). The brine exhibits concentrations of many of the contaminants noted above (e.g., arsenic, barium, fluoride) as well as other constituents (chloride, boron) exceeding guideline values and potentially hazardous to human and ecological health.

This underscores an argument in Currell, (2017) that the management of waste from the Leewood facility is not simply a matter of disposal or re-use of ‘salt’ in the sense this term is normally used (e.g. for relatively pure sodium and/or potassium chloride). Rather the ‘salt’ produced by the water treatment facility is a concentrated brine solution which contains high levels of many elements that are hazardous at high concentrations.

Further concerns which arise from the new data include:

- Whether estimates of salt disposal requirements and waste management protocol been thoroughly revised in light of the information (this appears not to have been done)
- Whether updated risk assessment and management strategies for the production, transport, treatment and disposal of produced water and waste brine have been conducted in light of these additional data (It appears this has not been done)

- Whether specific monitoring of groundwater will be done to determine baseline concentrations of these elements in all potentially impacted areas (e.g. anywhere that a spill or leak of produced water and/or waste brine could take place) and to ensure that no contamination with these elements occurs. (This appears not to have been addressed – see next section below).

1.3 Baseline groundwater quality data and monitoring program

Currell (2017) flagged a number of deficiencies in the baseline groundwater quality data presented in the EIS. In particular, there were a number of analytes which were hypothesised to be probable constituents of the produced water, which it was argued would need to be analysed in groundwater prior to the Project commencing in order to properly assess possible contamination with these elements as a result of CSG development. The suggested analytes (in section 1.4 of Currell 2017) included:

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

Apart from dissolved methane (which is now included in section 4.2 of the updated Water Baseline Report), none of these analytes have been monitored or reported from the monitoring bore network.

Additional analytes that should be reported in light of the data showing the produced water chemistry include arsenic (found at concentrations up to 1 mg/L), cadmium (up to 0.14 mg/L) and lead (found in one sample at 0.48 mg/L), which exceed health and/or recreational guideline levels in some reported produced waters. Given the occurrence of significant levels of arsenic in the CSG produced water along with other contaminants which may be deemed of potential concern, baseline data and an updated groundwater quality monitoring program with significant additional spatial coverage should have been developed and this remains a critical oversight.

The statement on Page 6-67 of the Response to Submissions regarding baseline groundwater quality:

> "Further, analysis of the chemistry of the groundwaters, presented in the revised and updated Water Baseline Report…demonstrates that there are no contaminants of concern in coal measures waters…"

ignores the presence of a mean arsenic concentration in the produced water from coal seams of 0.1 mg/L (and maximum value of 1 mg/L); as well as the periodically elevated cadmium and lead concentrations, which are hazardous to human health. In my view this statement is therefore not accurate nor consistent with the new data presented in the water baseline report.

1.4 Further assessment of groundwater recharge to the Great Artesian Basin (GAB) system within the Project area.

The likelihood that the Project occurs in a region of recharge ('intake') area for groundwater in the GAB aquifer(s) (as proposed in Currell, 2017) is discussed in the Response to Submissions (page 6-68-6-70). The contention that the area is indeed a recharge area for the GAB is further supported by the recent work done to aid updated groundwater modelling by CSIRO (e.g., Figure 2 of Sreekanth et al., 2017 shows the Project region is entirely within the GAB 'intake' area); as well as other information cited in the response from Geoscience Australia (Page 6-70).

In the context of the overall highly restricted area within which recharge to the GAB system takes place (Ransley and Smerdon, 2012), this issue is of great significance. The Project occurs in an area mapped by the Geoscience Australia and CSIRO reports as being one of *relatively* low recharge to the GAB (e.g. shown in Fig 6-15), however in the context of very restricted recharge to the overall basin – the vast majority of land area underlain by the GAB provides no recharge to the system at all - and the generally low recharge rates which occur on most of the Australian continent due to aridity and soil type (see Crosbie et al., 2010), the estimated rates shown (in the order of 5 mm/year) are still significant. Moreover, these estimates are acknowledged to be of low reliability by the authors of these source reports, as they are not based on specific field data collected from the study area (rather, they are from regional-scale assessments).

What is most concerning with respect to this issue is that there appears to have been no attempt to collect further field evidence to verify the degree to which groundwater recharge actually occurs within the Project area, and/or the mechanism(s) and rates of recharge. As demonstrated in Currell (2017), evidence presented elsewhere in the EIS (chloride concentrations in groundwater from Pilliga Sandstone baseline data) indicates recharge rates of approximately 5 times the suggested rates – e.g. between 20 to 30mm/year. This additional line of evidence has not been acknowledged in the Response to Submissions, and no further data collection has been conducted to verify or disprove the alternative estimates provided in Currell (2017). A series of suggested recharge estimation techniques were provided in Currell (2017) (section 1.3.1) which are known to provide reliable information regarding the location(s), mechanisms and rates of groundwater recharge (Healy, 2010). These techniques include the use of infiltrometer testing and monitoring of soil moisture profiles, as well as sampling for tritium, CFCs, SF_6 and other 'young' groundwater age tracers. It appears that none of these techniques have been employed to look further into the critical issue of groundwater recharge to the GAB in the Project area.

Irrespective of the recharge *rate*, the proposal to produce, transport and process more than one gigalitre per year of very poor quality wastewater (see section 1.2 above), over an area which constitutes one of the few zones where recharge to the GAB can occur, is of major concern. Recharge areas are characterised by downwards hydraulic gradients, meaning any spills or leaks of wastewater at the surface will naturally flow through the unsaturated zone to the water table, potentially contaminating the upper aquifer(s). In the Response to Submissions, Santos argues that one of the reasons the area has previously been mapped as having relatively low recharge rates (5mm/year) is due to low rainfall amount. This correctly implies that if additional sources of water are introduced at the surface (such as wastewater holding ponds and/or spills and leaks of produced water), then the rates of recharge may significantly increase over the short term (adding significant amounts of contaminated water to the aquifer), as low surface moisture may currently limit recharge (e.g. actual recharge is well below potential recharge but could increase with the addition of new water sources at/near the surface).

As noted above, there appears to have been little or no attempt to modify the produced water storage, transport and treatment system or revise the Project (e.g. by reducing the number of wells) to account for this issue; nor has any substantial proposal been put forward to increase the number of monitoring wells, frequency of monitoring or analytes monitored within the Pilliga Sandstone aquifer as part of the groundwater monitoring program. These remain significant oversights.

1.5 Other issues raised in Currell, 2017 regarding produced water management and groundwater/surface water contamination risk that remain un-addressed:

Evidence regarding the likelihood of spills and leaks of produced water:

Currell, (2017) presented extensive data from the United States of America regarding the frequency of wastewater spills and leaks associated with on-shore unconventional and conventional oil and gas operations (drawing on Patterson et al., 2017 and the associated database of spills compiled as part of that project). These data indicate that spill rates in the order of 3-5% of wells are common and I argued that the current Project is unlikely to be an exception to this general pattern (Currell, 2017, section 1.2). It appears however that there have been no significant changes to the risk assessment, monitoring strategies or produced water management plan in light of these data. The database and extensive literature regarding wastewater spill incidents associated with onshore oil and gas appears not to have been consulted or analysed with respect to re-assessing the likelihood and significance of this risk. Rather, the Proponent appears to still hold the belief that wastewater spills and leaks will simply not happen (in spite of the extensive experience and data from elsewhere around the world). The Proponent cites a lack of any reported spill or leak incidents occurring at the Leewood facility over the last 4-5 years in support of this opinion. Importantly, the current track-record with respect to produced water management at Leewood needs to acknowledge:

a) that spills and leaks of CSG wastewater in the Project area have taken place at the Bibblewindi treatment plant in the past;
b) that the current size of the Proponent's operations utilising the Leewood facility, and the volumes of produced water generated to date, are a very small fraction of what would be produced under the proposed Project.

The risks associated with produced water spills and leaks would clearly increase significantly under the scenario of drilling and producing gas from 850 wells, and transporting, storing and treating more than one gigalitre of water per year from the Project as opposed to the small-scale pilot CSG activities conducted to date.

Further details about the design of the Project, such as proposed gas well locations
In order to determine the adequacy of the proposed groundwater monitoring network and assess groundwater contamination risks (e.g. associated with produced water management), further detail regarding the proposed locations of wells, pipelines, storage and treatment infrastructure is, in my view, required (this view was also expressed in other submissions). This type of detail is essential for assessing key factors such as the proximity between areas where significant groundwater recharge takes place and infrastructure such as gas production wells, produced water gathering and transport pipelines, and the proposed groundwater monitoring. Appendix C provides an outline of how the Project design will be approached, but provides no further guidance in terms of where CSG wells might be located with respected to the proposed groundwater monitoring network. The lack of such detail increases the level of uncertainty regarding the risks associated with groundwater contamination.

Conceptual hydrogeological model (with respect to groundwater quality)
No attempt has been made (as was suggested in Currell, 2017) to map the concentrations of key water quality constituents in the region, in order to gain a better understanding of the relationship between groundwater quality and groundwater recharge, flow-paths in each aquifer, inter-aquifer mixing and discharge, as well as the key geochemical and microbiological reactions taking place in the aquifers controlling groundwater chemistry under current conditions. Such information is vital in the development of a robust conceptual model of pre-development groundwater conditions (including an understanding of processes controlling groundwater quality). Such information could be gained through collecting further environmental tracer data in the area and integration of such data with maps of water quality indicators and groundwater flow patterns. Without such information, proper interpretation of groundwater quality monitoring results from the Project area will likely suffer from ambiguities and uncertainty in terms of the reasons for any observed changes in groundwater quality.

No revision to the proposed monitoring network for groundwater quality in the region
In spite of the high level of concern with respect to impacts on groundwater quality in the region expressed in Currell (2017) and many other submissions (including the IESC, NSW EPA and DPI), there has so far been no update or revision of the groundwater monitoring plan outlined in Appendix G3 of the EIS, and no drilling of additional groundwater monitoring wells to improve the poor spatial coverage highlighted in these submissions. The high ratio of gas production bores to groundwater monitoring bores, and the difficulty in assessing the proper siting of monitoring bores without further detail about gas well and other infrastructure locations, were flagged as major issues, yet these have not been addressed in the Response to Submissions in any substantial way. The Proponent responds to

concerns raised in many of the submissions regarding the adequacy of the groundwater monitoring program by referring back to the original groundwater monitoring plan (Appendix G3) – see page 6-96 of the Response to Submissions Part A and indicating that a ‘refined’ plan will be developed in future with the aid of DPI Water.

Section 2: Fugitive gas contamination risk (e.g. enhanced methane leakage to groundwater)
The issue of the potential for the Project to create new pathways for fugitive gas migration to shallow aquifers is discussed within the Response to Submissions Part A (e.g. page 6-74). To address this issue, baseline data on groundwater methane concentrations have been included in the updated Water Baseline Report (Appendix D). These data are valuable in terms of providing a baseline of methane in groundwater prior to any significant gas development. Importantly, however, it should be acknowledged that the spatial and temporal coverage of these data are limited, which is likely to make future trend identification (and distinguishing natural changes from contamination due to gas development) difficult. This is compounded by the fact that methane concentrations in groundwater are by nature quite variable through time in most settings (e.g. Humez et al., 2016).

The recommendation to analyse the isotopic composition of methane in various aquifers (Currell, 2017), and in particular, the produced CSG wastewater has unfortunately not been acted upon (despite the recommendation being acknowledged on page 6-74). Without isotopic data, determining the source(s) of any observed change in methane concentrations during monitoring of groundwater will be considerably more difficult than otherwise. In conjunction with the relatively poor spatial coverage of the groundwater monitoring network, the ability to adequately monitor and detect any fugitive gas migration into shallow aquifers as a result of the Project will be limited, and in my view the current proposed monitoring program will not adequately guard against this potential risk.

In general the risk of increasing migration of fugitive methane into shallow aquifers above the gas deposits has been given limited additional consideration, and the Proponent relies on the assumption that gas well integrity will be maintained throughout the life of the Project and beyond, preventing this from becoming a major issue.

Section 3: Other issues in agency submissions
A number of other issues related to potential impacts of the Project on groundwater were raised by agency submissions, and those which are within my expertise are briefly discussed below:

Baseline data and possible impacts to groundwater dependent ecosystems
The issue of inadequate baseline data and characterisation of groundwater dependent ecosystems (GDEs) was pointed out by the IESC in its advice on the Project in 2017. In response, the Proponent has done little, if any, additional field-based research to further characterise GDEs in the region and has maintained their belief that the risk of impacts to GDEs will be negligible. This relies on assumptions made on the basis of the groundwater modelling from the site – namely that shallow aquifers are not expected to experience drawdown of greater than 0.5m. This is problematic in two respects:

1. without proper characterisation of GDEs to begin with, there is no way to investigate whether a drawdown level of up to 0.5m will have a significant impact on such systems;
2. given that the modelling is highly parameterised and complex, there is likely to be a significant degree of uncertainty regarding the drawdown impacts.

While the modelling might provide an indication of the most likely range of impacts, of itself it does nothing to guard against greater than expected impacts in fact taking place within parts of the study area (which may be home to GDEs). Without detailed baseline data relating groundwater levels, fluxes and quality to ecosystem health, it will not be possible to assess, during Project operations, whether and to what degree GDE health is changing and whether or not this is related to the Project. To this end, it is very concerning that the Water Monitoring Plan does not propose to conduct any direct monitoring of GDEs (page 5-12 of Response to Submissions Part A).

Groundwater monitoring plan & prediction of groundwater (quantity) impacts
As discussed above in Section 1, my opinion is that the proposed groundwater monitoring plan is not adequate to guard against water quality related impacts that could arise from the Project. I believe the same applies to the monitoring of groundwater quantity impacts. The IESC (page 5-13), DPI Water (page 5-44) and NSW EPA (page 5-56) also express this view in their submissions, and recommend that a more detailed and comprehensive groundwater monitoring plan be developed, including additional groundwater monitoring wells.

Rather than drill additional groundwater monitoring wells in areas where the spatial coverage and baseline data are lacking and/or produce a revised and more detailed groundwater monitoring plan, the Proponent has pledged to work with DPI Water and other stakeholders to 'refine' the existing monitoring plan. A statement is made regarding the monitoring plan being targeted towards monitoring in areas 'that are most likely to see changes as a result of the project' (presumably on the basis of the groundwater modelling results). Similar to the approach to GDE impacts outlined above, this relies on *a priori* assumptions about the nature and magnitude of likely impacts from the Project, which are unsubstantiated by field-based evidence. There is a great degree of risk inherent in this approach.

With respect to modelling and monitoring of impacts on groundwater quantity, the Proponent argues that the emphasis has been and should be on estimating volumetric changes in water fluxes within the relevant aquifers, as opposed to drawdown impacts (e.g. p.5-14). The two impacts are related, however estimation and/or monitoring of one does not necessarily provide a sound indication of the other – see Currell, (2016). The relationship between flux and drawdown can be better understood with the aid of reliable (e.g. field-based) estimates of the storage coefficients and hydraulic conductivity of the aquifers in question – this is an area however where further data collection appears not to have been conducted since the EIS. The assumption that water volume change is the primary concern (rather than drawdown) overlooks important drawdown-related impacts that can occur in response to mining development, such as bore interference (e.g. water levels falling below the depth of water users' pump intakes) or level thresholds which may be required to sustain groundwater dependent ecosystem function.

With respect to groundwater quality monitoring, the lack of coverage of the monitoring network to guard against issues such as produced water leaks and spills has been highlighted above in section 1 of this report. The NSW EPA also indicated in their submission that the groundwater monitoring network was inadequate and that additional monitoring at produced water storage facilities should be agreed with NSW EPA. The Proponent relies on the assumption that 'seepage detection' monitoring at such facilities will be adequate to protect against any impact on groundwater quality. This ignores other important issues such as:

- Storage facilities are not the only place where produced water may leak into groundwater. Pipelines transporting the water may also leak, and spills and leaks may occur at the gas well-head.
- Overflow from produced water storage facilities (e.g. during extreme weather) may also cause contamination of groundwater.
- Seepage detection may be able to detect losses of produced water to groundwater, however without baseline groundwater quality data, it will be impossible to determine the effect of any detected seepage incidents on the shallow aquifer.

Development of local-scale groundwater models
The IESC recommended that local-scale daughter models be considered to evaluate impacts that occur at the local (as opposed to regional) scale as a result of the Project. The justifications given as to why this was not attempted are in my opinion weak. Firstly, the Proponent cites a lack of impacts occurring in high value groundwater sources predicted in the existing modelling for not looking further at local scale impacts. Presumably one of the purposes of local scale modelling would be to

look in greater detail at the possibility of such impacts when the resolution or detail of the modelling is enhanced in these regions. Such modelling could test (using a range of scenarios) what possible levels of impact occurring more regionally might result in impacts to key receptors at the local level. Such modelling need not necessarily involve ‘cookie cutting’ from the existing model – it could utilise alternative simplified modelling approaches, as appropriate.

Secondly, the Proponent argues that a lack of local-scale field data will make it difficult to inform accurate local-scale modelling. This is consistent with the interpretation in Currell (2017) and the IESC advice that the field data and monitoring program carried out to date are inadequate to properly characterise groundwater conditions and conduct rigorous predictions of impact. It is to a large degree within the Proponent’s control as to how much additional field data is collected and for what purpose; further examination of the many submissions reveals some key concerns which warrant further field data collection and (if appropriate) local scale modelling.

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