UNSW SYDNEY

22 May 2017

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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^{o}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 <u>chemical reactions</u>. 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.

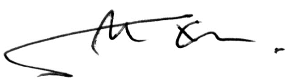
Due to the very long-term nature of some proposed salt landfill operations, the likelihood of contaminating groundwater and surface water over the long term is considerable. The responsibility for managing these risks over the long term will likely be inherited by future generations.

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,



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REFERENCES

Davies, P. J., Gore, D. B. and Khan, S. J. (2015) Managing produced water from coal seam gas projects: Implications for an emerging industry in Australia. *Environ. Sci. Pollut. Res.*, **22**(14), 10981-11000.

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