

**Narrabri Gas Project (SSD 6456)**  
**Comments on “Submission to IPC following public hearing”**  
**File: “200810 Santos \_Final Submission incl attachments.pdf”**

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21<sup>st</sup> August 2020

To: The Commissioners,

SANTOS submitted to the Independent Planning Commission Narrabri Gas Project the document “Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing” file “200810 Santos \_Final Submission incl attachments.pdf” (the **SANTOS Submission**). In Section 9.2.1 of the *SANTOS Submission*, SANTOS makes a number of incorrect statements in relation to the research presented in the publication Iverach et al. (2020). As leading chief investigator for the research presented in Iverach et al. (2020) and as corresponding author for that manuscript, I would like to address those inaccuracies.

Relevant Experience:

- Associate Professor, UNSW Sydney, School of Biological, Earth and Environmental Sciences
- Joint developer EarthVision geostatistical software ([www.dgi.com](http://www.dgi.com))
- Oil and Gas consulting experience USA, Scotland and Bolivia
- Consulting and training projects for Shell, BP, Total, Chevron, Aera Energy, USGS, US EPA and many more
- Expert reports for the NSW Chief Scientist and Engineer on NSW Geology
- Program director groundwater research Cotton Catchment Communities CRC
- Chief Investigator National Centre for Groundwater Research and Training
- Research scientist for the UNEP managed CCAC Methane Science Studies
- 1989: B.Sc. (Hons), 1995: PhD, Environmental Geophysics, The University of New South Wales, Sydney

The key concerns with the *SANTOS Submission* ordered by importance are:

- Section 9.2.1 Point 3.c – SANTOS used a wrong value (800 ppm) and then used that wrong value to say that one of the conclusions in Iverach et al. (2020) was “erroneous”. The correct rounded value is 800,000 ppm. SANTOS cannot use 800 ppm to make statements about methane concentration changes with depth, because it is the wrong value.
- Section 9.2.1 Point 3.e – SANTOS’s comment about methyl fermentation completely ignores the results graphed in Figure 7, Iverach et al. (2020). Many of the data points in Figure 7 were from Eastern Star Gas reports. Few data points plot in the correct region of the graph to indicate that methyl fermentation is a dominant process in the Lower Namoi Alluvial Aquifer or the coal seam gas wells. By contrast the methane oxidation model proposed in Iverach et al. (2020) is supported by the data in the graph, and most importantly the microbial community composition and abundance data, and the hydrogeochemistry. SANTOS had an opportunity to provide data to support their case, but they did not.
- Section 9.2.1 Point 1 – SANTOS claim the results in Iverach et al. (2020) are not relevant because the groundwater monitoring wells sampled are not within the Narrabri Gas Project boundary. However, Iverach et al. (2020) sampled monitoring wells on the immediate northern boundary of the proposed Narrabri Gas

Project. This included the NSW Government monitoring well (273314) installed to provide new information about the regional hydrogeology and in the future to help evaluate whether there are any impacts from coal seam gas developments.

- Section 9.2.1 Point 2 – SANTOS criticises the fault data presented in Iverach et al. (2020). The research in Iverach et al. (2020) collated the results from past work in the region on faulting, much from the NSW Government DIGS database. SANTOS’s criticism of the fault interpretation in Iverach et al. (2020) is actually saying that the work of past oil and gas companies in the region “does not adequately describe or characterise faults with any rigour”. For example, Iverach et al. (2020) show the fault data from the Wilga Park cross section by Consolidated Petroleum Australia N.L., The Australian Gas Light Company, Peko Oil Limited.
- Section 9.2.1 Point 3.a – SANTOS provided incomplete reference details, making it difficult to check the claims. Discussed in the attachment are the likely documents that SANTOS cite, and they do not contain useable data.
- Section 9.2.1 Point 3.b – SANTOS wrongly focus on faults as the only pathway for methane migration from the coal measures to the Lower Namoi Alluvial Aquifer. No one knows via which pathway the methane has migrated. It could be via faults, joint networks, permeable sedimentary rock zones, or permeable zones adjacent to igneous intrusions (collectively summarised as *other geological pathways*).
- Section 9.2.1 Point 3.d – SANTOS proposed water and geochemical mixing processes not tested against data.

## General Comments

The research published in Iverach et al. (2020) has been subjected to extensive peer review in a high-ranking international scientific journal “Science of the Total Environment”. The research was also submitted as part of a PhD thesis and subjected to further peer review both in Australia and internationally. Our research has been placed in the public domain along with all the data to inform the community and water managers. All data from Iverach et al. (2017) and Iverach et al. (2020) are available in the supplementary information for those papers. The results have ramifications for all groundwater users in the Narrabri region. The many submissions that cited Iverach et al. (2020) are correct – the research results must be considered carefully in the context of assessing the impacts of the proposed Narrabri Gas Project (SSD 6456).

The data and research insights in Iverach et al. (2020) needed to be interpreted in conjunction with the data and research insights in Iverach et al. (2017). Both papers present hydrogeochemical data from the same NSW Government groundwater monitoring wells and were collected during the same groundwater sampling campaigns.

It is concerning that SANTOS made unsubstantiated claims without providing any new data to support their statements. Nor did they reinterpret our data in a rigorous scientific manner and present their interpretation supported by graphs or quantitative justifications. SANTOS did not provide alternative numerical process models to explain the data distributions in Iverach et al. (2017 and 2020). I will also show that some of their statements cannot be supported by the data presented in Iverach et al. (2017 and 2020).

I will show below that SANTOS used a wrong value to make a case against one of the research findings in Iverach et al. (2020). SANTOS do not provide justification for why they refer to the wrong value of 800 ppm rather than the correct methane concentration of 800,000 ppm. SANTOS’s claim against our research using the 800 ppm value is invalid.

Collectively the authors of Iverach et al. (2020) have over 200 peer reviewed publications in international scientific journals. Our research ranks high on international metrics. All data collection, measurements and analysis have been undertaken according to best practice. This is fully documented in our peer reviewed publications Iverach et al. (2017 and 2020). The authorship team in Iverach et al. (2017 and 2020) has provided the community with open data science. The community are correct in citing this research in their public submissions, as it is high quality data, from a high-quality research journal. Our research does inform groundwater management decisions for all sectors: irrigation, stock, domestic and the proposed Narrabri Gas Project.

The community have sought answers for their concerns about the Narrabri Gas Project. The set of publications Iverach et al. (2017 and 2020) have highlighted gaps in our understanding of the hydrogeology and hydrogeochemistry in the

lower Namoi region. Right now, there is inadequate knowledge about the methane concentration and its isotope chemistry in all formations between the target coal seams for coal seam gas production and the Lower Namoi Alluvial Aquifer. There is incomplete knowledge about when methane migrates, at what rate and via which pathways. It could be via faults, or *other geological pathways*. There is simply not enough well log data, or 3D mapping of faults or other hydrogeological or hydrogeochemical data, for anyone to know in detail about pathways of methane migration in the rock formations near the proposed Narrabri Gas Project. The community submissions have focused on faults because it is a clear visual that they understand. But it should be interpreted that when the community focus on faults as pathways of methane migration that it could be via *other geological pathways*. SANTOS must have good data sets for the coal seams of interest for gas production. There have been many studies about the hydrogeology and hydrogeochemistry of the Lower Namoi Alluvial Aquifer, and these are cited in Iverach et al. (2017 and 2020). There is inadequate hydrogeological and hydrogeochemical knowledge for all geological formations in between. For SANTOS to focus on faults as the primary pathway of methane migration given our current scant knowledge about the hydrogeological and hydrogeochemical properties of the geological formations between the targeted coal seam for gas production and the Lower Namoi Alluvial Aquifer is misleading.

SANTOS is correct in saying that the results in Iverach et al. (2020) do not prove that methane has migrated from the targeted coal seams for gas production to the Lower Namoi Alluvial Aquifer. However, SANTOS has not presented data to demonstrate that faults are **not** a pathway for methane migration. SANTOS has not placed adequate data in the public domain similar in quality to the hydrogeochemical or microbial community analysis data presented in Iverach et al. (2017 and 2020), to demonstrate to the community that there is enough information to assess the multi-decadal impact of the Narrabri Gas Project. What the results in Iverach et al. (2017 and 2020) highlight is that there is inadequate information about the hydraulic and hydrogeochemical properties between the targeted coal seams and the Lower Namoi Alluvial Aquifer.

The *SANTOS Submission* was another opportunity for SANTOS to address public concerns with high quality data that others could review to assess the various claims being made about the impact of the Narrabri Gas Project. None of the statements made against Iverach et al. (2020) by SANTOS are supported by high quality public domain data.

The wrong and misleading comments by SANTOS about Iverach et al. (2020) should be considered carefully in the context of the assessment for the proposed Narrabri Gas Project.

Should the Commissioners require any further details or clarifications on the comments I make below I will happily provide additional information.

In the attachment to this letter I outline in more detail my concerns and discuss in detail the errors by SANTOS regarding their statements about Iverach et al. (2020) in the *SANTOS Submission*.

Sincerely



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# ATTACHMENT

## Extended comments about

### Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1

#### Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1, Point 1

1. The area of study is located outside the Project area. The paper considers evidence of connectivity in shallow aquifers located to the north of the Project, not within the Project footprint. Drawdown impacts in the target coal seams due to the Project are not expected to extend more than 5 km beyond the tenement. The area of relatively high fault density studied will not be affected by Project activities. The Project area avoids high density fault areas and also areas of locally intrusive volcanic rock.

#### Comments on, Section 9.2.1, Point 1

The study by Iverach et al. (2020) is along the nearest margin north of the proposed Narrabri Gas Project and the Namoi Alluvium (Figure 1). In Iverach et al. (2020) groundwater samples were collected from NSW Government groundwater monitoring wells immediately adjacent to the Narrabri Gas Project area and within a few hundred metres of Eastern Star Gas exploration wells (Figure 1). The relationship between the sampled groundwater monitoring wells and the Narrabri Gas Project were shown in Figure 1 of Iverach et al. (2017), and the close proximity of the groundwater monitoring wells sampled to the Eastern Star Gas exploration wells is shown in Figure 1 from Iverach et al. (2020). In Figure 1 below the close proximity between NSW Government groundwater monitoring wells 30357-1, 30442-2 (site 13), and CSG well Culgoora 1 (site 21) is highlighted. In Iverach et al. (2020) a groundwater sample was collected and analysed from the newly installed NSW Government groundwater monitoring well 273314 (depth interval 182 to 195 m below the ground surface). Monitoring well 273314 was installed to provide new information about the regional hydrogeology and in the future to help evaluate whether there are any impacts from coal seam gas developments. The groundwater zone sampled in Iverach et al. (2017 and 2020) is critical for quantifying discharge from the Great Artesian Basin into the Lower Namoi Alluvial Aquifer. Hydrogeological impacts from the proposed Narrabri Gas Project will likely extend beyond the surface boundary of the Narrabri Gas Project in future decades. The submissions to the IPC Narrabri Gas Project (SSD 6456) that cited Iverach et al. (2020) are correct – the research findings in Iverach et al. (2020) do have implications for water management by all sectors in the region, including the Narrabri Gas Project.

The statement by SANTOS that Iverach et al. (2020) is outside the Narrabri Gas Project zone of interest is misleading.

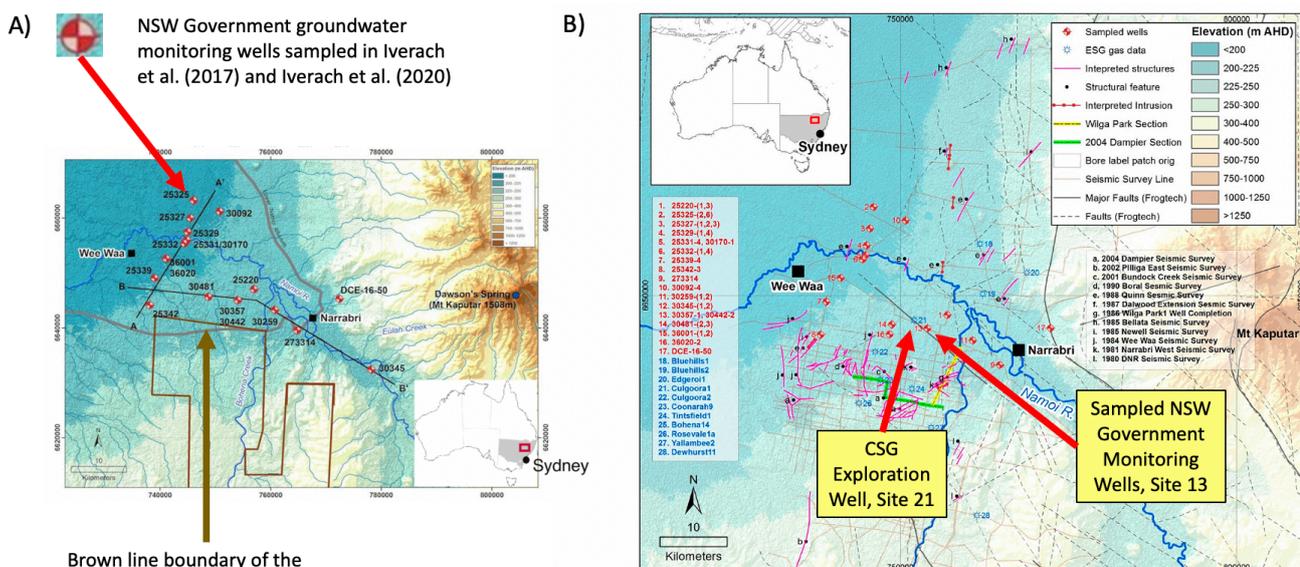


Fig. 1. Map of the study area highlighting groundwater bore locations where samples were collected and major geological structures. The red boxes are the locations of our groundwater samples; the blue wells are locations of gas wells. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 1. Images from Iverach et al. (2017) (A, left) and Iverach et al. (2020) (B, right) that show the proximity of the research presented in those two scientific papers to the proposed Narrabri Gas Project.

## Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1, Point 2

2. The paper's characterisation of faults relies on a qualitative assessment of lineaments and does not adequately describe or characterise faults with any rigour (e.g. fault length, depth, orientation, throw, stress regime, age, formation mechanism, etc.). Based on the information reported in the paper (e.g. a low-resolution and highly stylised geological cross section; uninterpreted seismic data and coarse-scale maps of 'inferred' fault locations), it is not clear whether an adequate and appropriate peer review could have been undertaken regarding geological structures. Cited references do not provide the detail nor supporting investigations to validate the inferences made in the paper regarding fault characterisation and their potential effect on hydrogeological connectivity.

### Comments on Section 9.2.1, Point 2

The study by Iverach et al. (2020) does not focus on fault analysis, but this is not important for the results presented in the paper. The study by Iverach et al. (2020) is a hydrogeochemical study focusing on the Lower Namoi Alluvial Aquifer. In Iverach et al. (2020) it is stated that the pathway of methane migration from depth is not known, and that the methane migration could be via *other geological pathways*. SANTOS's focus on faults as the only pathway of methane migration is misleading. Further research is required by all to understand when and how the methane has migrated from the geological formations beneath the NSW Government groundwater monitoring wells sampled in Iverach et al. (2020). In Iverach et al. (2020) both Figure 1 and supplementary information Figure 1 show a collation of fault data that had been mapped by others. Various oil and gas companies did the fault interpretation, not the authors of Iverach et al. (2020). For example, shown in supplementary information Figure 1 (Iverach et al. 2020) is the section from the well completion report by Consolidated Petroleum Australia N.L., The Australian Gas Light Company, Peko Oil Limited (Figure 2). All the past reports are available in the DIGS database (<https://search.geoscience.nsw.gov.au>). The fault summary presented in Figure 1 in Iverach et al. (2020) is simply to show visually that there are many faults in the region, because faults may or may not have an influence on regional groundwater flow paths and the hydrogeochemistry. SANTOS in their EIS present a similar stylised presentation of the faulting in the region in their EIS submission "Appendix F Groundwater Impact Assessment Figure 4-11".

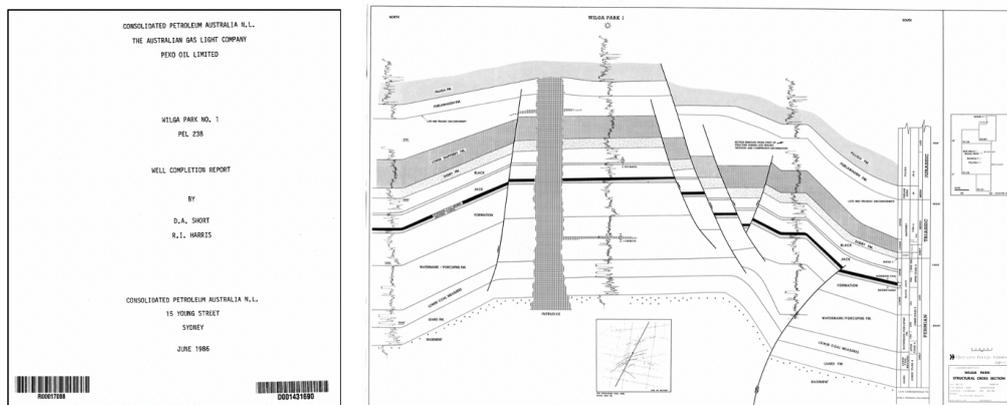


Figure 2. An example well completion report and geological cross-section used in Iverach et al. (2017). Hartogen Wilga Park 1, PEL 238, Gunnedah Basin Appendix C: Wilga Park structural cross section (D001432380).

Submissions to the IPC Narrabri Gas Project (SSD 6456) that made reference to methane migration via faults, or hydraulic pressure transfer via faults cannot be dismissed until SANTOS provides detailed evidence in the public domain about their fault seal analysis, including Allan diagrams, fragmentation studies, capillary pressure diagrams and more (Cervený et al. 2004). Data for a statistically valid number of faults needs to be presented.

Methane migrates from deeper geological formations into the Lower Namoi Alluvial Aquifer. From what source, at what rate, via which pathways and over what timeline needs to be investigated. The statement by SANTOS about Iverach et al. (2020) and fault analysis is irrelevant; it is shifting focus to just one of many geological pathways via which methane has migrated. SANTOS's criticism about the fault interpretation in Iverach et al. (2020) is actually a criticism of the work done by past geologists from various oil and gas companies who defined the Narrabri gas resource.

### Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1, Point 3.a

- a. No data are presented describing dissolved gas isotope signatures of the Pilliga Sandstone or any other aquifers or aquitards of the GAB which are alternative potential sources of methane in the region (e.g. Herzeg & Torgeson, 1991; DMR, 2002).

#### Comments on Section 9.2.1, Point 3.a

When preparing Iverach et al. (2020) an extensive search was undertaken for all available data in the public domain from the NSW DIGS database (<https://search.geoscience.nsw.gov.au>), and that is presented in supplementary information Table 1.b Iverach et al. (2020). SANTOS did not cite any references from their own reports with data to make a case against Iverach et al. (2020), nor did SANTOS provide any data from “Herzeg & Torgeson, (1991)” or “DMR (2002)”. It is difficult to check the relevance of these documents because SANTOS did not provide complete reference details for “Herzeg & Torgeson, (1991)” or “DMR (2002)”. A check in the scientific journal database Scopus does not locate a paper by “Herzeg & Torgeson, 1991”; Herczeg and Torgerson (note the spellings of the names) did publish research on the Great Artesian Basin in 1991 (Herczeg et al. 1991), but this was for groundwater wells in South Australia through to central Queensland. If this is the paper SANTOS intended to cite it is outside the area of interest by hundreds of kilometres (Figure 2).

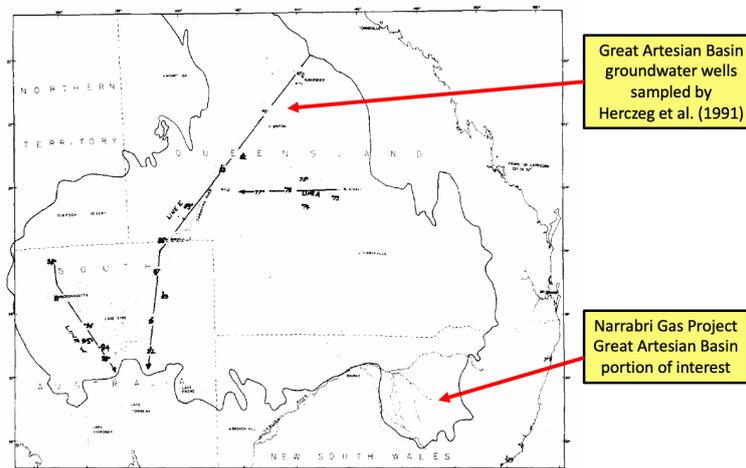


Fig. 3. Location of artesian water wells sampled in May 1985 for this investigation. Sample numbers 73–98 refer to our internal code (see Table 1). The three transects discussed in the text are given here as Line A (wells 73–77), Line E (wells 78–92) and Line W (wells 93–98).

Figure 2. A map from Herczeg et al. (1991) showing that they sampled the Great Artesian Basin far from the region of interest for the Narrabri Gas Project.

Regarding “DMR 2002” it is difficult to know the correct reference. It is likely to be “NSW DMR 2002, Mineral and Petroleum Resources and Potential: NSW Western Regional Assessments, Brigalow Belt South Bioregion (Stage 2) for the Resource & Conservation Division, Planning NSW”. This is a classic reference about the geology of the region, but it has no hydrogeochemical data that can be used to extend the results presented in Iverach et al. (2020). In Iverach et al. (2020) a hypothesis is presented that methane has migrated from the coal measures underlying the Lower Namoi Alluvial Aquifer, and it is concluded that “the dominant source of CH<sub>4</sub> in the alluvial aquifer has been constrained to being primarily from geological formations underlying the LNA.” (LNA: Lower Namoi Alluvium). At present all have incomplete knowledge about methane production and migration for all strata between the Lower Namoi Alluvial Aquifer and the targeted coal seams for coal seam gas production. Further research on this topic is required.

SANTOS cited two references and did not provide comprehensive reference details for either. The first reference, “Herzeg and Torgenson 1991”, is likely to be Herczeg et al. (1991), which is a Great Artesian Basin (GAB) study that extends from central South Australia through to central Queensland. This is in the wrong portion of the GAB and is not relevant. The second reference, “DMR 2002”, likely to be NSW DMR (2002) has no useable hydrogeochemical data to extend the work in Iverach et al. (2020). SANTOS had an opportunity to provide their own data – they did not.

### **Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1, Point 3.b**

- b. There is an absence of supporting groundwater chemistry data to support the conclusion that faults are responsible for upward migration of dissolved methane from the GOB. For example, given there is a natural upward hydraulic gradient (i.e. deeper units are under greater pressure than shallower units), changes in water quality such as increased chloride would be expected because the deeper aquifer units and coal seams of the GOB are far more saline than shallow aquifers.

#### **Comments on Section 9.2.1, Point 3.b**

Section 9.2.1, Point 3.b, can be turned around. One can write - there is an absence of hydrogeological permeability and hydrogeochemical data to support the conclusion that faults are **not** a pathway to enable the upwards migration of methane from the coal measures to the overlying alluvial aquifers. All need to acknowledge that better hydrogeological and hydrogeochemical information is required to assess robustly what does or does not migrate via faults, or *other geological pathways*, in the region of the proposed Narrabri Gas Project.

Further research is needed to determine the true pathway of methane migration. The hydrogeochemical and microbial community composition and abundance reach in Iverach et al. (2020) focuses on the Lower Namoi Alluvial Aquifer. Similar studies are required for the Great Artesian Basin and Gunnedah-Oxley Basin Formations to better characterise all sources of methane, and pathways of methane migration. All anyone can say at the moment is that methane is coming up from below the NSW Government groundwater monitoring well sampled in Iverach et al. (2020). The coal seams being targeted for coal seam gas production cannot be excluded as a potential source of the methane, especially considering that there are commercial quantities of gas in these coal seams. Submissions by others may have focused on faults as a pathway for methane migration because there are many faults in the region as shown in Figure 1 (Iverach et al. (2020)), and as SANTOS show in the SANTOS EIS Appendix F – Groundwater Impact Assessment Figure 4-11. Faults are a very natural visual pathway for the wider community to conceptualise connectivity, methane movement, pressure transfer and fluid movement. When the wider community focus on faults as a pathway of connectivity, it should be read that it could be *via faults, or other geological pathways*. SANTOS had an opportunity as part of the *SANTOS Submission* to present hydrogeological data and hydrogeochemical data for each geological formation overlying the targeted coal seams to clearly demonstrate a lack of methane migration between the geological formations of concern. Until verifiable data are placed in the public domain, the wider community will have ongoing concerns about the multi-decadal impact of the Narrabri Gas Project on groundwater resources in the Lower Namoi Region.

The water quality issues in the region are complex. This is part of the reason why the research in Iverach et al. (2017 and 2020) was undertaken. More research is required before anyone can make robustly defensible statements about the multi-decadal impacts of the proposed Narrabri Gas Project on groundwater resources used throughout the region. Based on a comprehensive data set the authors of Iverach et al. (2017 and 2020) put forth testable hypotheses about discharge from the Great Artesian Basin into the Lower Namoi Alluvial Aquifer, and about methane in the Lower Namoi Alluvial Aquifer being sourced from underlying geological formations.

No one can prove with existing data sets that methane has migrated from the coal measures to the Lower Namoi Alluvial Aquifer via faults. But then again no one can prove that methane has **not** migrated via faults, or *other geological pathways* from the targeted coal seam form coal seam gas production and the Lower Namoi Alluvial Aquifer. Further research is required, and the data need to be placed in the public domain, as done in Iverach et al. (2020).

SANTOS is ignoring that the methane could migrate from formations beneath the groundwater monitoring wells sampled in Iverach et al. (2020) via a number of *geological pathways*, not just faults. The wider community only see faults, so faults should be read in many submissions to infer any *geological pathway* of connectivity. SANTOS had an opportunity to present hydrogeochemical and microbial community composition and abundance studies to support their statements – they did not. There is an absence of supporting hydrogeochemistry data to support the conclusion that faults are **not** a pathway via which methane can migrate.

**Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1, Point 3.c**

c. The paper estimates that the concentration of methane in underlying formations that would be required to explain the changes in methane isotopic signatures in the alluvial sediments is 4,062ppm. Iverach, et al. report (in Table 1b) methane concentrations in the formations underlying the GAB are 800,000ppm and explain that this supports a hypothesis of upward gas migration. However, this appears erroneous, as the data presented appears to have been transcribed incorrectly and actual concentrations are up to 800ppm (i.e. 800,000 µg/L). Hence the reported evidence shows a decrease in methane concentration at depth, not the increase in concentration as described.

**Comments on Section 9.2.1, Point 3.c**

What SANTOS have submitted here is completely wrong. We have transcribed the data correctly (Figure 3). All data presented in supplementary information Table 1.b (Iverach et al. 2020) are taken from Eastern Star Gas well completion reports. The gas concentration analyses for the data presented in Table 1.b (Iverach et al. 2020) were done by Isotech Laboratories, Inc or CSIRO Earth Science and Resource Engineering Gas Geochemistry Laboratory. I assume the reference in the *SANTOS Submission* to the methane concentration of 800,000 ppm is intended to refer to the entry for Culgoora 2, which is 789,900 ppm (Figure 3). Santos provide no justification for the use of 800 ppm for the methane concentration at depth. SANTOS cannot use 800 ppm to make statements about methane concentration changes with depth, because it is the wrong value.

Company Lab No.	Client ID	Depth 1	Depth 2	Well Name	GC Date	H <sub>2</sub> ppm	O <sub>2</sub> +Ar ppm	CO <sub>2</sub> ppm	N <sub>2</sub> ppm	CO ppm	C <sub>1</sub> ppm	C <sub>2</sub> ppm	C <sub>2</sub> H <sub>4</sub> ppm	C <sub>3</sub> ppm	C <sub>3</sub> H <sub>6</sub> ppm	iC <sub>4</sub> ppm	nC <sub>4</sub> ppm	iC <sub>5</sub> ppm	nC <sub>5</sub> ppm	C <sub>6</sub> + ppm	MS Date	δ <sup>13</sup> C <sub>1</sub> ‰	δ <sup>13</sup> C <sub>2</sub> ‰	δ <sup>13</sup> C <sub>3</sub> ‰	δ <sup>13</sup> C <sub>4</sub> ‰	δ <sup>13</sup> nC <sub>4</sub> ‰	δ <sup>13</sup> C <sub>5</sub> ‰	δ <sup>13</sup> nC <sub>5</sub> ‰	δDC <sub>1</sub> ‰	δDC <sub>2</sub> ‰	δDC <sub>3</sub> ‰	δ <sup>17</sup> CO <sub>2</sub> ‰	Comments				
4174-001	CLG002_0090612100622A	748.17	748.97	CLG002	2/17/2011	0	113900	30800	276900	0	577400	978	1	5	0	0	1	0	0	0	2/22/2011	-66.5															
4174-002	CLG002_01114011116551	948.73	949.23	CLG002	2/17/2011	0	34300	5900	168700	0	789900	559	1	3	1	2	1	1	1	660	2/22/2011	-60.1															Raw Total = 89.29

Figure 3. Well Completion Report (WCR) for Culgoora 2, on PEL 238, Narrabri Area. Appendix M Culgoora 2 Isotope Report (DE01453140).

The value of 800,000 ppm is not used for the Rayleigh fractionation modelling and the determination of alpha (α) (Iverach et al. 2020, equation 1, Figure 8). In Iverach et al. (2020) only general comments are made about the higher concentrations of methane at depth reported in supplementary information Table 1.b. The high concentrations reported in the Eastern Star Gas well completion reports agree with the trend predicted by the model presented in Iverach et al. (2020). This offers support for our conceptual model and provides a hypothesis for all to test. The data in Table 1.b are used in Figure 7 (Iverach et al. 2020). The increase in methane concentration with depth is clearly evident in Figure 4 (Iverach et al. 2020). One can establish that there will be higher concentrations of methane at depth simply from the fact that there are commercial quantities of gas in the targeted coal seams for coal seam gas production. There must be a concentration gradient from those commercial concentrations of methane to the lower concentrations of methane in the overlying formations – this is fundamental physics and chemistry.

SANTOS has used a wrong value of 800 ppm to discuss the changes of methane concentration with depth, and they give no justification for why they used this value. They then used this wrong value to say one conclusion in Iverach et al. (2020) was “erroneous”. The correct value is approximately 800,000 ppm. It is SANTOS who made the error, and this reflects poorly on the quality of their data analysis skills and interpretations.

**Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1, Point 3.d**

d. Irrigators on the Namoi Alluvium extract groundwater from the underlying Pilliga Sandstone to irrigate crops. Excess water infiltrates and adds to the alluvium groundwater, hence introducing water with a “GAB signature” into the local alluvial groundwater. This complicates the process of quantitatively assessing the natural flux between the GAB and the alluvium in this region based on water chemistry alone.

**Comments on Section 9.2.1, Point 3.d**

The water chemistry can define the volumetric contributions from each source of water (for example, groundwater from the Great Artesian Basin mixed with river water). SANTOS is correct in saying that the hydrogeochemical results in Iverach et al. (2020) (and Iverach et al. 2017 needs to be added) do not define the flux. However, the water chemistry can be used to calibrate a groundwater flow model. SANTOS have not calibrated their flow models to the hydrogeochemical data sets in the region. This would be a useful next step in validating any water balance model developed for the region to guide water management decisions.

SANTOS’s comments at Section 9.2.1 do not consider the water volumes involved, transit times, the groundwater isotope data used to determine the residence times and rates of mixing between water source endmembers. The irrigators in the region of study obtain most of their water from surface water supplies (Kelly et al. 2007). Most groundwater used by irrigated agriculture is extracted from the freshwater zones of the Lower Namoi Alluvial Aquifer. Irrigators would avoid using water sourced from the Great Artesian Basin, because it can have the wrong sodium adsorption ratio, and it is detrimental to soil structure if applied to the crops (Cotton Info, 2015). Any Great Artesian Basin water would be diluted by “shandyng” lower quality groundwater with good quality surface water (Triantafilis et al. 2013).

Recharge from irrigation returns and rainfall deep drainage is estimated to be at most 0.5% of the aquifer recharge volume (Kelly et al. 2007). Irrigation deep drainage returns (water that moves beyond the root zone) is also discussed in Iverach et al. (2020) - for example *“this is most likely a result of N<sub>2</sub>-based fertilisers leaching into the groundwater during irrigation”*. Any water that does recharge has to migrate to depth past numerous clay layers in the upper 40 m of the Namoi Alluvial sequence (Kelly et al. 2014). Any irrigation deep drainage hydrogeochemical signature would be highly diluted by the time it reaches the depths of the sampling where there is Great Artesian Basin groundwater discharge into the Lower Namoi Alluvial Aquifer.

Iverach et al. (2017) and Iverach et al. (2020) should be read jointly. In Iverach et al. (2017) there is very clean mixing shown on a linear trend between the surface water inputs and the Great Artesian Basin inputs (Figure 7; Iverach et al. 2017). This mixing is due to both natural processes and pumping-induced mixing. Although there is both natural and pumping-induced mixing, such data are still extremely useful for assisting with calibrating regional water balance models, and this is discussed in Iverach et al. (2017).

SANTOS present no scientific evidence to support the claims in Section 9.2.1, Point 3.d. Any Great Artesian Basin water returned to the Lower Namoi Alluvial Aquifer via irrigation deep drainage would be so diluted that its hydrogeochemical signal would not have a significant impact for modelling discharge from the Great Artesian Basin into the Lower Namoi Alluvial Aquifer. The hydrogeochemistry data in Iverach et al. (2017 and 2020) would be a valuable constraint for assisting with calibrating future water balance models to be used to guide groundwater allocations from any aquifer in the region.

## Narrabri Gas Project (SSD 6456) Submission to IPC following public hearing, Section 9.2.1, Point 3.e

- e. Gas isotopes presented for the alluvial groundwaters outline a distinct signature, separate from the Gunnedah Basin groundwaters (Figure 7a in Iverach, et al., 2020), with the former exhibiting a relatively heavier carbon signature in methane for a given carbon dioxide value, reflecting a methyl fermentation origin and not the methane oxidation origin proposed in the paper.

### Comments on Section 9.2.1, Point 3.e

Iverach et al. (2020) does not say there is no methyl fermentation, however it can only be a minor process in the Namoi Alluvium. Data from supplementary information Tables 1.a and 1.b (Iverach et al. 2020) are used in Figure 7 (Figure 4 of this document) to examine methane production and oxidation pathways. The data from Table 1.a are from the sampled NSW Government groundwater monitoring wells and the data from Table 1.b are from Eastern Star Gas well completion reports. These data are presented on  $\delta^{13}\text{C}_{\text{CO}_2}$  vs  $\delta^{13}\text{C}_{\text{CH}_4}$  and  $\delta^{13}\text{C}_{\text{CH}_4}$  vs  $\delta\text{D}_{\text{CH}_4}$  plots (Figure 4). These graphs from Whiticar (1999) are frequently used to determine methane production and oxidation pathways (Whiticar 1999 has been cited over 2300 times).

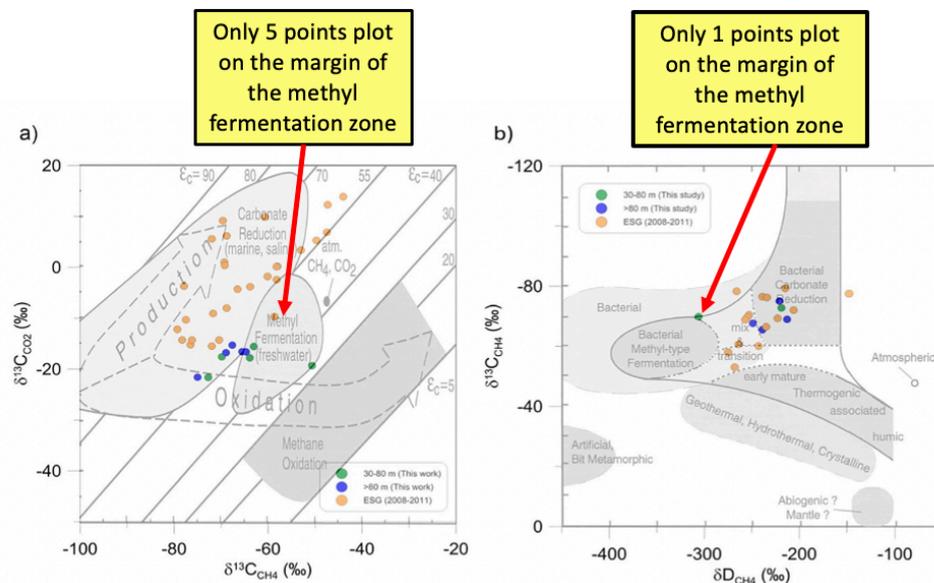


Figure 4. (a) Plot of  $\delta^{13}\text{C}_{\text{CO}_2}$  vs  $\delta^{13}\text{C}_{\text{CH}_4}$  (after Whiticar, 1999) with samples from Iverach et al. (2020)[blue and green points] as well as those collected in the Great Artesian Basin by Eastern Star Gas (2008–2011) [orange points]; (b) plot of  $\delta^{13}\text{C}_{\text{CH}_4}$  vs  $\delta\text{D}_{\text{CH}_4}$  (after Whiticar, 1999). The distribution of points in these graphs do not support the claim by SANTOS that methyl fermentation is a dominant process in the aquifers studied (Originally published in Iverach et al. 2020, Figure 7).

SANTOS do not provide a graph of any data to support the claim that methyl fermentation is a significant active process within the Lower Namoi Alluvial Aquifer or any geological formation. Iverach et al. (2020) present multiple lines of evidence including comprehensive hydrogeochemistry data, methane isotope chemistry data and a microbial community composition and abundance analysis to support the methane oxidation model in the paper. These multiple lines of evidence also show that conditions within the Lower Namoi Alluvial Aquifer are far from optimal for methyl fermentation to be a dominant process. The abundance of methanotrophic bacteria shown in Iverach et al. (2020) Figure 3 suggested that oxidation is a significant process. In addition, the dissolved oxygen levels are in general not anaerobic enough for methanogenesis.

SANTOS provide no evidence that methyl fermentation is a dominant process in the Lower Namoi Alluvium. Iverach et al. (2020) provide multiple lines of evidence that methyl fermentation is not a significant process in the Lower Namoi Alluvial Aquifer. The methane oxidation model proposed in Iverach et al. (2020) is supported by data and the Rayleigh fractionation modelling.

## References

- Cervený, K., Davies, R., Dudley, G., Kaufman, P., Knipe, R., Krantz, B. (2004) Reducing uncertainty in fault seal analysis. *Oilfield Review*. 16(4), pp. 38-51.  
[https://connect.slb.com/~media/Files/resources/oilfield\\_review/ors04/win04/04\\_fault\\_seal\\_analysis.pdf](https://connect.slb.com/~media/Files/resources/oilfield_review/ors04/win04/04_fault_seal_analysis.pdf)
- Cotton Info (2015) Water and Soil Quality, Australian Cotton Industry BMP.  
[https://www.cottoninfo.com.au/sites/default/files/documents/Water%20and%20Soil%20Quality\\_3.pdf](https://www.cottoninfo.com.au/sites/default/files/documents/Water%20and%20Soil%20Quality_3.pdf)
- Herczeg, A.L., Torgersen, T., Chivas, A.R., Habermehl, M.A. (1991) Geochemistry of ground waters from the Great Artesian Basin, Australia. *Journal of Hydrology*, 126(3-4), pp. 225-245.  
[https://doi.org/10.1016/0022-1694\(91\)90158-E](https://doi.org/10.1016/0022-1694(91)90158-E)
- Iverach, C.P., Cendón, D.I., Meredith, K.T., Wilcken, K.M., Hankin, S. I., Andersen, M. S., Kelly, B. F. J. (2017). A multi-tracer approach to constraining artesian groundwater discharge into an alluvial aquifer. *Hydrology and Earth System Sciences*, 21(11), 5953-5969.  
doi:[10.5194/hess-21-5953-2017](https://doi.org/10.5194/hess-21-5953-2017)
- Iverach, C.P., Cendón, D.I., Beckmann, S., Hankin, S.I., Manefield, M., & Kelly, B. F. J. (2020). Constraining source attribution of methane in an alluvial aquifer with multiple recharge pathways. *Science of the Total Environment*, 703.  
doi:[10.1016/j.scitotenv.2019.134927](https://doi.org/10.1016/j.scitotenv.2019.134927)
- Kelly, B., Merrick, N.P., Dent, B., Milne-Home, W. and Yates, D. (2007) “A Scoping Study on Groundwater Knowledge and Gaps in the Namoi Catchment Management Area” for the Cotton Catchment Communities CRC, University of Technology, Sydney - National Centre for Groundwater Management Report, NCGM 2007/1, 62 pages.  
<https://pdfs.semanticscholar.org/7a7e/a13988418dd2fd97d26d6007791dcc58ef99.pdf>
- Kelly, B.F.J., Timms, W., Ralph, T., Giambastiani, B., Comunian, A., McCallum, A., Andersen, M.S., Acworth, R.I., Baker, A. (2014) A reassessment of the Lower Namoi Catchment aquifer architecture and hydraulic connectivity with reference to climate drivers *Australian Journal of Earth Sciences*. 61 (3), pp. 501-511.  
<https://doi.org/10.1080/08120099.2014.900647>
- NSW DMR (2002) Mineral and Petroleum Resources and Potential: NSW Western Regional Assessments, Brigalow Belt South Bioregion (Stage 2). NSW Department of Mineral Resources Geological Survey of New South Wales. A project undertaken for the Resource and Conservation Assessment Council NSW Western Regional Assessments Project Number WRA / 20. ISBN 1 74029 180 8  
<https://www.epa.nsw.gov.au/~media/EPA/Corporate%20Site/resources/forestagreements/wra20.ashx>
- Triantifilis, J., Hulugalle, N., Smith, R., Williams, D., Roth, G. (2013) Irrigation Salinity and Water Quality. *Waterpak*, Section 2, Irrigation Management.  
<https://www.insidecotton.com/jspui/handle/1/555>
- Whiticar, M.J. (1999) Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane. *Chemical Geology*. 161, 291–314.  
[https://doi.org/10.1016/S0009-2541\(99\)00092-3](https://doi.org/10.1016/S0009-2541(99)00092-3)