Santos NSW (Eastern) Pty Ltd - NARRABRI GAS PROJECT

Expert Review of Environmental Impact Statement

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Introduction

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

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

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

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

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

ISSUE 1

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

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

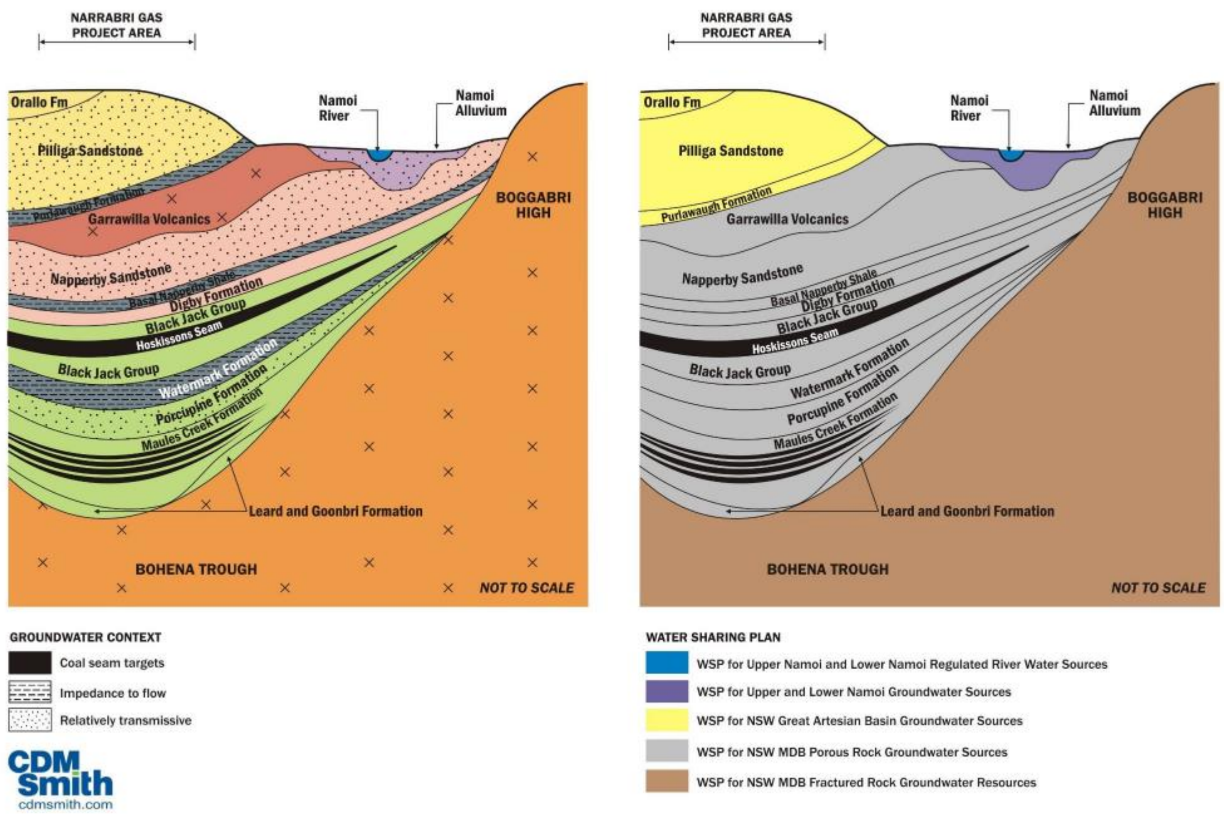
I have reviewed the conceptual groundwater model, based on my local knowledge of the Namoi Valley Catchment. In my opinion, the model is mostly appropriate with the exception of critical information regarding the ability, or inability, of a hydrostratigraphic unit (**HSU**) to transmit, store and yield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

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

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

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

Figure 2-1 Project area schematic showing lithology and WSPs



Baseline Data

Summary

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

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

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

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

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

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

Hydrostratigraphic Unit Descriptions

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

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

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

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

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

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

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

Groundwater Baseline Hydraulic Head and Pressure

General overview

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

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

Permian and Triassic HSUs (GOB monitoring bores)

Nested monitoring bores are located at two locations:

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

Single bores were located at:

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

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

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

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

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

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

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

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

Jurassic HSUs (GAB monitoring bores)

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

The Jurassic HSUs are well represented spatially within and outside of the NGP. However, the Santos bores lack temporal coverage within the NGP. Only two bores have at least two years of data with the remaining having 1 to 1.5 years of data. This is not sufficient to form a temporally representative baseline dataset as these formations have lag periods measured in years. That is, effects from drought could take more than a year to manifest a change in the deeper Pilliga Sandstone unit in the Recharge Area of the GAB. Hydraulic conductivities have been estimated to be around 1-5 m/year in the recharge area (Habermehl, 1980, *in* 'GABCC 2016. *Great Artesian Basin Resource Study 2014*. Report by the Great Artesian Basin Coordinating Committee'). Groundwater flow rates based on Carbon-14 and Chlorine-36 studies range from less than one metre to about five metres (Habermehl, 2002, , *in* 'GABCC 2016. *Great Artesian Basin Resource Study 2014*. Report by the Great Artesian Basin Coordinating Committee'). Numerical modelling will not include monitoring data representing drought periods, therefore, Santos cannot effectively predict the effects of CSG dewatering in this portion of the GAB recharge area.

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

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

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

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

Namoi Alluvium

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

Bohena Alluvium

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

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

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

CDM Smith state in the WMP that the 'alluvial aquifers is considered to be a form of 'lagging resource condition indicator' in the sense that unexpected adverse changes observed at these locations would indicated that an impact to the water source has already occurred'. CDM Smith state 'the purpose of monitoring in the high-valued groundwater sources is to demonstrate that observed changes in resource condition are not an effect of the NGP'. CDM Smith contends that NGP effects on groundwater levels will be overshadowed by climatic and consumptive use conditions. However, Santos has no baseline dataset from the Bohena Alluvium to measure the 'lagging' results against. Therefore, this approach is unacceptable for the Bohena Alluvial aquifer.

Summary

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

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

Groundwater Baseline Chemistry

General overview

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

CDM Smith made two conclusions:

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

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

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

Permian and Triassic HSUs (GOB Monitoring Bores)

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

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

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

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

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

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

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

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

EC is a measure of the groundwater's capability to pass electrical flow in microsiemens per centimetre (uS/cm). Therefore EC is directly related to the concentration of ions in the groundwater. The conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulphides and carbonate compounds. The more ions that are present the higher the EC of the groundwater. **However, conductivity is also affected by temperature** and the warmer the groundwater, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25^{o}C (or specific conductance). As the temperature of the groundwater will affect the conductivity readings, reporting conductivity at 25^{0}C allows data to be easily compared between datasets.

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

The following points are noted:

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

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

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

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

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

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

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

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

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

Jurassic HSUs (GAB Monitoring Bores)

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

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

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

  The dataset has statistically viable sample sizes (6 or more samples to determine mean, 16% and 84% percentiles) for major ion, EC and pH analyses. Laboratory EC at 25^{o}C measurements were made, therefore comparisons can be made with other aquifers and aquitards (including the deeper Permo-Triassic bores).
- Two Santos bores (BWD1WB and BWD5WB), with unknown screen intervals. Only two samples were collected from each bore for major ions, EC (field and lab EC @25^{o}C), and pH over a time period of 1 year and 10 days, for each bore respectively. Therefore I do not consider baseline conditions at these sites to be representative of the Pilliga Sandstone.
- Three DPI bores with known screen intervals, between 60.6 and 112.8m bgl. Only one bore has statistically viable lab EC @25^{o}C and field pH (GW030400-1) measurements so the data can be compared with other hydrostratigraphic units. The other two had very limited measurements in this respect. All bores had limited major ion data. Even though the data from these bores span between 12 – 28 years (1971 – 1999) the data is over 18 years old.

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

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

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

Namoi Alluvium HSU (Alluvial Monitoring Bores)

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

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

Bohena Creek Alluvium HSU (Alluvial Monitoring Bores)

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

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

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

Summary

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

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

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

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

Surface Water Baseline Data

Streamflow

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

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

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

Surface Water Quality

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

Summary

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

Hydrostratigraphic unit representation

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

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

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

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

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

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

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

Hydrogeological properties representation

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

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

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

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

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

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

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

Groundwater flow systems representation

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

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

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

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

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

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

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

ISSUE TWO

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

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

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

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

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

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

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

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

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

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

ISSUE THREE

Is the proposed groundwater monitoring plan appropriate?

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

Summary

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

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

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

GOB WMP

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

GAB WMP

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

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

Namoi and Bohena Alluvium

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

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

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

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

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

Review of WMP (Appendix G3, Santos EIS)

Introduction

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

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

Reporting included:

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

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

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

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

To achieve this purpose the WMP included:

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

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

CDM Smith (2016b) stated:

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

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

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

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

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

Key Principles

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

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

Permian and Triassic HSUs (GOB monitoring bores)

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

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

Jurassic HSUs (GAB monitoring bores)

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

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

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

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

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

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

Namoi and Bohena Alluvium Monitoring Bores

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

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

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

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

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

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

ISSUE FOUR

Further observations

Commonwealth Requirements

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

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

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

NSW Secretary's Environmental Assessment Requirements (SEARS)

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

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

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

In my opinion, CDM Smith (and Santos) should have provided baseline data that indicated 'typical temporal variations,' and then collected statistically viable data covering that time period. However, the Santos EIS fails to provide this baseline data for the GAB and GOB. On the other hand, baseline data in respect of spatial variation, which is easier to collect, has been adequately provided for the GAB but not the GOB.

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

Disclaimer

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

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