

Santos NSW (Eastern) Pty Ltd - NARRABRI GAS PROJECT

Expert Review of Environmental Impact Statement, including the Response to Submissions

28 June 2018

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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 Response To Submissions (**RTS**) produced by Santos NSW (Eastern) Pty Ltd (**Santos**) in response to community and expert submissions made on the Narrabri Gas Project (**NGP**). This report examines the Groundwater Impact Assessment (**GIA**) and associated response. This report follows on from an expert report completed by me in response to the original GIA in May 2017.

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 professional 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, which forms part of the Environmental Impact Statement for the NGP (**Santos EIS**):

NGP RTS Part A:

- Executive Summary
- The Project
- Response to IESC
- Response to DPI Water
- Response to EPA
- Response to Gilgandra Shire Council
- Response to non-agency submissions

NGP RTS Part B Appendices A-D:

- Appendix B Project Commitments
- Appendix D Water Baseline Report

NGP RTS Part D Appendices I-L:

- Appendix L Errata

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*).

The report has been structured to provide comments on whether the concerns expressed in my report of May 2017 have been addressed by Santos or CDM Smith, or if my concerns are still valid. I have included quotes from my previous report in italics.

EXECUTIVE SUMMARY

CDM Smith stated 'the Gunnedah-Oxley Basin and the Great Artesian Basin aquitards play an essential role protecting the overlying [Great Artesian Basin] 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 [Gunnedah-Oxley Basin] GOB' (Appendix G4, Santos EIS).

In my opinion, the baseline data representing the following key aquitard hydrostratigraphic units (**HSU**) is temporally and spatially inadequate to draw this conclusion:

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

Previously I stated '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.e. it is not the thickness that determines aquitards. I agree the Triassic Digby basal Bomera Conglomerate and the Triassic basal Napperby Shales have a high degree of cementation and diagenesis, but I am concerned the degree of fracturing in these HSUs has not been adequately explored. Therefore I am still unconvinced these HSUs can be effectively conceptualised as negligibly transmissive units. I have also not seen any hydraulic evidence from Santos regarding the remaining strata within the Digby Formation, and the Napperby Sandstone, and whether they should be treated as low transmissivity HSUs.

In my opinion the main problem with CDM Smith's conceptualisation of the groundwater flow system is the representation of the aquitards ability to transmit groundwater vertically. CDM Smith and Santos state in their RTS that their model sensitivity analysis indicates vertical hydraulic conductivity is not sensitive. That is, by applying a wide range of vertical hydraulic conductivities the model didn't respond by showing significant changes in flux across the HSUs. However Santos did not say which HSU aquitard's vertical hydraulic conductivity is not sensitive. In my opinion the Triassic and Jurassic aquitards ability to transmit groundwater vertically has still not been adequately conceptualised and represented in the conceptual groundwater model. This could lead to an underestimation of the decrease in pressure head in the GAB HSUs and water levels in the alluvium.

CDM Smith state that because they believe the derived parameterisation for the GAB HSUs were in comparable ranges to those reported in the literature for comparable lithologies, this has provided Santos with confidence that, where there is insufficient field data, then they can use theoretical values in the numerical modelling exercise. However, CDM Smith did not specifically discuss the GOB aquitards except to comment that the aquitards in some cases seemed to possess similar hydraulic characteristics as poor aquifers, which they don't believe is the case. In my opinion the parameterisation of the Triassic Digby Conglomerate and basal Napperby Shale, and early Jurassic Purlawaugh Bed aquitards are still not adequately represented in the conceptual model. Instead, theoretical values are being used by CDM Smith to derive hydraulic parameters for the numerical modelling exercise with CDM Smith ignoring what they see as insufficient 'local scale' field measurements which they believe do not 'scale' well to the regional numerical model cells. In my opinion the numerical model needs to be reassessed as to whether a regional scale model is appropriate for its end use and whether actual field data recorded from critical aquitard HSUs should be used.

CDM Smith states '...it is not practical to 'cookie cut' a local scale model since the local boundary conditions over time are not defined. More generally, there is no advantage in developing a local-scale model unless additional local-scale data are available to inform better representation of geometry or better representation of the proposed

stresses on the local water source. Neither of these circumstances applies to the EIS groundwater modelling.’ However, in my opinion Santos should be developing a local-scale model.

I understand the conceptual and groundwater model is based at a regional scale and the effects of the depressurisation of the GOB target coal beds will also occur at a regional scale in the GOB HSUs, before any flow on effect of this depressurisation is felt in the GAB HSUs in the Narrabri area. Santos and CDM Smith clearly believe that it is important to represent the GOB and GAB aquitards with more than a few monitoring bores in the NGP, as evidenced in their proposed Water Monitoring Plan (**WMP**) (which includes drilling more GOB and GAB monitoring bores). Therefore, in my opinion, this should have been completed as part of the Water Baseline Report (**WBR**), given the highly variable nature of the GOB HSUs. A credible statistically viable dataset representing these critical GOB and GAB aquitards is essential so that the hydraulic properties can be effectively modelled to determine groundwater impacts to the GAB.

In my opinion the Namoi and Bohenia alluvial aquifers have been inadequately represented as a result of the regional scale of the conceptual and numerical model. I understand it is impossible to model the highly variable nature of the Namoi alluvial groundwater system but in my opinion, the shallow alluvial groundwater system has been oversimplified.

I stated in my previous report that the lowest model confidence level classification of ‘Level 1’ is because there is not enough spatial and temporal data for some of the major deep GOB and GAB HSUs to allow transient calibration to be undertaken for those units (the model is only calibrated for Namoi Alluvium). Despite what CSIRO state in their review of the CDM Smith groundwater model, long term predictions of drawdown effects due to CSG dewatering cannot be made reliably. That is, the Numerical Model is currently not fit for purpose.

The Permian and Triassic HSUs are even less represented now since the bore database has been updated to exclude the DPI Water bores that were misinterpreted by CDM Smith/Santos as representing GOB and GAB HSUs, as stated in the RTS. Some of these bores have been reassigned as Namoi Alluvial bores in the WBR dataset. The implication of this is that critical GOB HSUs are not represented in the baseline dataset which impacts on the validity of the groundwater model setup.

There is a lack of geological borelogs, or comment by CDM Smith, indicating where the bore screen intervals are located in the Permian Black Jack and Maules Creek formations, and the Triassic Digby and Napperby formations as to whether they in aquifers or aquicludes. These units are not uniform ‘aquicludes’, at best they are ‘aquitards’ with highly variable transmissivities.

The baseline dataset is not representative of the temporal variation in groundwater pressure head in the Santos GOB and deep GAB bores. It can take a number of years for these deep GOB 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 there is increased likelihood of groundwater pumping.

Spatially, the baseline bores represent only the north-east corner of the NGP site.

There is still no Permian GOB HSUs water quality baseline data presented in the updated WBR; and water quality from only one nested bore site representing the Napperby and Digby Formation HSUs. Santos continues to average the electrical conductivity (EC) and pH readings, which are different in both HSUs, to form the baseline dataset which, in my opinion, may have important ramifications when using this averaged value as the baseline to compare future monitoring data against.

The Jurassic Purlawaugh Bed aquitard is only represented by two bores and one of these bores has data for just over one year only which is not a sufficient baseline dataset against which to compare future data. Water quality is only monitored in one bore which in my opinion is insufficient to be referred to as representative of this HSU. The low EC (at least an order of magnitude less than the underlying Triassic aquitards) indicates it may be able to transmit water more easily than is reflected in the conceptual model.

The Jurassic Pilliga Sandstone HSU is still well represented spatially within the NGP. However, with the removal of three DPI Water bores representing the Pilliga Sandstone; and three bores representing the Orallo Formation and Mooga Sandstone belonging to the Keelindi Beds, the Jurassic HSUs are now not well represented outside the NGP.

The Quaternary Namoi Alluvium is well represented spatially and temporally using the DPI Water monitoring bores outside the NGP.

The shallow Holocene Bohena Alluvium is not adequately represented in the western portion of the NGP where leakages and spillages can occur from the Leewood Water Treatment Plant, brine ponds, irrigation fields, and pipeline infrastructure. 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.

No baseline water level dataset has been established from the four Santos bores drilled along Bohena Creek, in the Bohena Alluvium. The Bohena Alluvium is still not being viewed by Santos as a high-valued groundwater resource. However, in my experience, local property owners rely on both the Pilliga Sandstone and the Bohena alluvial aquifer where the Namoi alluvium is absent.

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.

The Bohena Creek has been determined to be disconnected from the underlying Bohena Alluvial groundwater system. Therefore my point in my previous report concerning establishing a baseline dataset for both continuous streamflow and ceased flow would not be necessary from a CSG contaminated groundwater point of view. However CDM Smith has not provided any evidence to support this position (by way of comparing streamflow hydrographs with the adjacent Bohena Creek bores hydrographs, any isotope or geochemical investigations). Therefore my concern is still valid for any inflow of contaminated surface water from previously contaminated shallow groundwater from prior spill incidences in the Bohena Alluvium by Eastern Star Gas.

The WMP provided by CDM Smith and Santos has not been updated in light of the misinterpreted borelogs. There are a number of GOB and GAB DPI Water bores which are not able to be incorporated into the WMP. Santos or CDM Smith has not addressed the issues I previously raised in regard to the WMP.

Santos RTS did not address the fact they now have less than adequate monitoring bore network nominated for Level 2 response trigger in Triassic/Late Permian Age strata of the GOB. CDM Smith and Santos have not provided any information on how they are going to rectify this gap in data (including the lack of baseline data that is also required to provide a comparison for water levels).

Santos states a number of times that they will work with DPI Water to ensure the WMPs are robust. I understand from reading the RTS that DPI Water has seriously questioned Santos' WMP and therefore the WMP is still to be finalised.

CDM Smith and the RTS has still not stated which part of the Namoi Alluvium the WMP bores are screened in – Narrabri or Gunnedah subsystems. This is significant as these systems behave differently.

Santos has still not addressed 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.

In conclusion, one requirement on Santos is to provide an environmental assessment based on '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 my opinion, the Santos RTS still does not demonstrate that baseline conditions are currently well known in the Permo-Triassic HSUs and the Holocene Bohena Alluvial HSU.

The NSW Secretary's Environmental Assessment Requirements (**SEARS**) for the NGP included advice and recommendations from DPI Water. 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. Santos has not defined what a 'typical temporal variation' would be. I have reviewed the baseline data in light of the most recent droughts, that being 2012 to 2014 and the Millennial Drought. The RTS still fails to provide temporally and spatially viable baseline data for the GOB and deep GAB HSUs.

The following sections provide a review on whether Santos has addressed the issues raised in my previous report.

ISSUE 1

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

'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.'

This comment is still valid.

Baseline Data

Summary

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

This point is still valid.

I previously wrote the following comment which is still valid:

'CDM Smith stated 'the Gunnedah-Oxley Basin and the Great Artesian Basin aquitards play an essential role protecting the overlying [Great Artesian Basin] 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 [Gunnedah-Oxley Basin] 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.'*

Santos stated in the Executive Summary of the RTS:

In addition, the Water Baseline Report has been revised and updated to reflect additional water monitoring data collected up to July 2017 and to provide information on the characteristics of produced water, treated water and the brine following successful commissioning of the Leewood Water and Brine Treatment Plant in mid-2016. The updated Water Baseline Report is contained at Appendix D.

The bore database has also been updated to exclude the DPI Water bores that were misinterpreted by CDM Smith/Santos as representing GOB and GAB HSUs as stated in the RTS page 5-40 and 5-41. Some of these bores have been reassigned as Namoi Alluvial bores in the WBR dataset.

The water level and quality dataset collected from bores representing HSUs is presented in the updated Water Baseline Report (WBR), and is now temporally statistically viable. However, bores which were meant to represent critical GOB HSUs have been removed, creating an even less spatially representative dataset. Critical GOB aquitard hydraulic characteristics are not represented at all for the Triassic Napperby and Permian Black Jack formations. Given the importance of understanding the baseline water level and water quality of these aquitards, these aquitards 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.'

This comment is still valid.

Hydrostratigraphic Unit Descriptions

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

CDM Smith has grouped the stratigraphic units 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).

CDM Smith stated: *'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 even more limited baseline dataset since the removal of five bores which were misinterpreted by CDM Smith indicates that these HSUs are not sufficiently represented in the Narrabri Gas Field. This continues to be a valid point which has not been addressed by either CDM Smith or Santos in the RTS (Dec 2017).

Groundwater Baseline Hydraulic Head and Pressure

General overview

CDM Smith has presented an update of the statistical summaries of the baseline data for the hydraulic head and pressure at the monitoring locations within the GOB and GAB (Santos RTS, Dec 2017). These are summarised in Table 4-1 of the NGP RTS WBR. This table includes more data collected up to mid-2017, allowing the dataset to be mostly statistically viable, and removes data from DPI Water bores that were incorrectly interpreted in the original EIS WBR.

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 were discussed in my previous report and are included again here in following sections with my comment on whether my points are still valid.

Permian and Triassic HSUs (GOB monitoring bores)

There were nine bores in the EIS WBR. These included:

Nested monitoring bores located at two locations:

- Santos nested bore site at Dewhurst 8 DWH8AQGDGYF01 (Triassic Digby Fm), DWH8AQGPOR03 (Permian Porcupine Fm), DWH8AQGMCF04 (Permian Maules Creek Fm); and
- DPI bore nested bore site GW036546-1 (Triassic Digby Fm), GW036546-2 (Triassic Napperby Fm), and GW036546-3 (Permian Black Jack Fm) which is located 37km SSE of Dewhurst 8, and outside of the NGP.

DPI Water stated in their submission that these bores have been incorrectly interpreted in the WBR Appendix G4, Santos EIS. These bores are considered by DPI to be representative of the Lower Namoi Alluvium located in the Upper Namoi Zone 2 alluvium.

Single bores were located at:

- Santos' Bibblewindi site bore BWD6 (Permian Porcupine Fm); and bore TULPRDGY02 (Triassic Digby Fm) located ~15 km WSW of Dewhurst 8 and outside of the NGP.
- DPI bore site GW036497-1 (Triassic Napperby Fm) located outside of NGP near the 30km Buffer Zone (located 48km SSE of Dewhurst 8). This bore was also wrongly interpreted by CDM Smith as representative of the Napperby Formation. DPI Water has stated in their comments that it belongs to Upper Namoi Zone 2 alluvium and is considered to be Lower Namoi Alluvium.

As a result of removing the DPI Water bores Santos' GOB monitoring bore network has been reduced to five bores. These bores are located at two sites within, and one site outside of, the NGP as shown in Figure 3.1 RTS WBR.

The following points in italics were stated in my previous review and are repeated here with further comments on whether they are still valid.

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.*

As Santos has now removed DPI Water nested monitoring bore GW036546 from the baseline dataset, point one above is no longer relevant to DPI bore GW036546-3. However, it still applies to the remaining baseline bores as it is important to see exactly where in the Black Jack, Maules Creek and Digby formations the monitoring bores are screened. These units are not uniform aquicludes; at best they are aquitards with highly variable transmissivities.

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.

This point is still valid for the deep GOB and GAB HSUs. All six bores have at least two years of continuous monitoring but I do not consider this to be representative of temporal variation in hydraulic head (groundwater pressure) in the deep GOB and GAB bores. Please note that the data entry in Table 4-1 (shown below) for Bore BWD6 is incorrect, as the data presented in Figure 4-3 below indicates data has been collected continuously until at least 01 September 2017.

BWD6	Santos	Porcupine Fm	GOB	427	5/15	6/16	354.2	369.7	362.3	362.6
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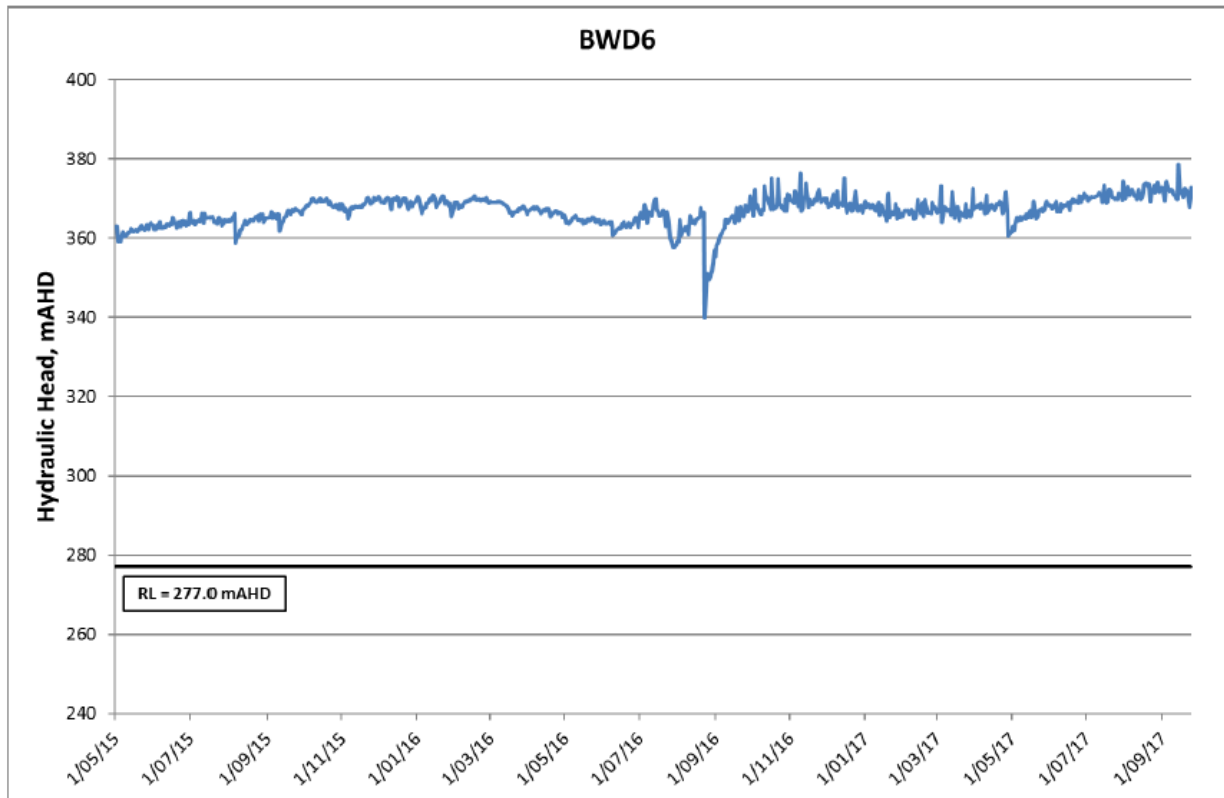


Figure 4-3 Hydrograph for monitoring bore BWD6 (Porcupine Formation)

Santos' predicted early depressurisation estimates were realistic. However, in my opinion these depressurisation estimates cannot be predicted with the present incomplete baseline dataset for the GOB and deep GAB HSUs.

The DPI Water bores are now not part of this dataset. The implication of this is that critical GOB HSUs are not represented in the baseline dataset which impacts on the validity of the groundwater model setup.

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

Two locations in the western (Bibbiewindi 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).

This point is considered to be even more valid now as spatially, the baseline bores mostly represent only the north east corner of the NGP site.

With the removal of the incorrectly interpreted DPI Water bores, there is no baseline monitoring data for the Triassic Napperby Sandstone and Basal Napperby Shales. The baseline dataset would benefit from a nested bore accessing the Napperby Sandstone and Basal Napperby Shale in the Dewhurst 8 bore site. A further bore site should be established each in the western (Bibbiewindi West Field) and north western (Bohena Field) portion of the NGP.

The Triassic Digby Formation has two monitoring bore sites but these are located only in the north eastern portion of the NGP. The baseline monitoring plan would be more robust if a monitoring bore site was located each in the western (Bibblawindi West Field) and north western (Bohena Field) portion of the NGP.

With the removal of the incorrectly interpreted DPI Water bores, there is no baseline monitoring data for the Permian Black Jack Formation. This is concerning as this formation was to be monitored to see if predicted early depressurisation estimates were credible.

There is still only one monitoring bore for the Permian Maules Creek Formation. A further monitoring bore site should be established each in the western (Bibblawindi West Field) and north western (Bohena Field) portion of the NGP.

The Permian Porcupine Formations has two monitoring bore sites. A third site should be located in the north western (Bohena Field) portion of the NGP.

Santos currently has a spatially non-representative, baseline hydraulic head dataset for Permo-Triassic formations. Santos are planning to construct more monitoring bores, as part of the WMP, to gather more hydraulic head data and to monitor whether future adverse changes to water resources may be related to the Project.

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.

This point is still valid. Given DWH14PR nested pipes for the Upper and Lower Pilliga are continuously monitored from 2014 until the end of 2017, it is unclear why has the nested pipe for the Purlawaugh Bed aquitard only been monitored for one year (refer to Figure 4-7 below). Groundwater level variation may be small, but it still provides insight into hydraulic pressure head variation when compared with other formation hydrographs. Baseline information from this aquitard is critical for setting up baseline conditions in the numerical model, and for comparing

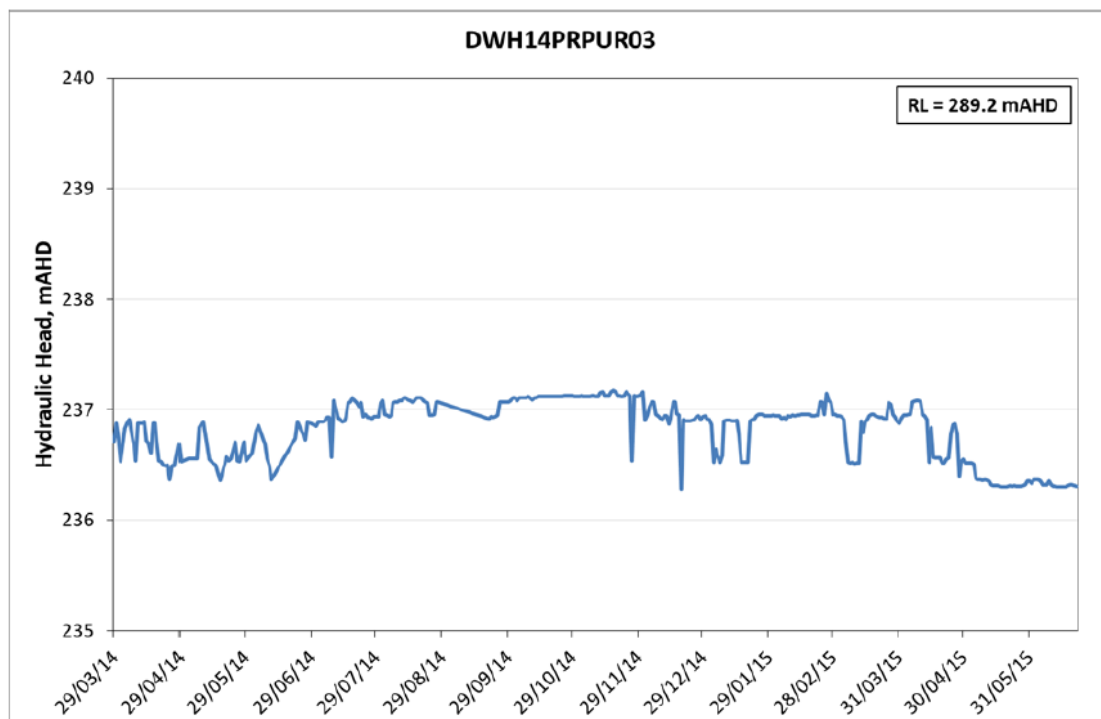


Figure 4-7 Hydrograph for monitoring bore DWH14PRPUR03 (Purlawaugh Formation)

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').

The Jurassic HSUs are still well represented spatially within the NGP. However, with the removal of three DPI Water bores representing the Pilliga Sandstone; and three bores representing the Orallo Formation and Mooga Sandstone belonging to the Keelindi Beds, the Jurassic HSUs are now not well represented outside the NGP. Bore GW098011-1 (Pilliga Sandstone aquifer) is given in Table 4-1 but is not shown on the GAB map in Figure 3-2.

I believe the baseline dataset has sufficient temporal coverage within the NGP. The effects of the 2012-14 drought are more than likely represented in the dataset. Although this dataset has been presented by CDM Hill for baseline dataset purposes, I believe some interpretation should be made in comparison to rainfall data to show whether the hydrographs presented are responding to pumping in the vicinity of and/or long term drawdown effects. CDM Hill stated the following:

'Pressure heads have been corrected for barometric changes, but have not been smoothed to remove technical aberrations. This provides an indication of the competency of the respective probes and allows consideration of data variability that may reasonably be expected at each location.'

Although I believe it is appropriate to provide hydrographs of the baseline dataset which include technical aberrations (before smoothing) and data variability, it would be helpful if CDM Smith could have provided some interpretation as to which variability is due to instrumentation issues, pumping activities in the NGP area and compared with low rainfall/drought conditions. This would allow us to see a real snapshot of meaningful variability.

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.

Contrary to my previous advice and in light of further consideration of the data, I now believe there is monitoring data representing a period of drought (namely 2012-2014). Taking into account the fact that groundwater moves through the GAB at a velocity of 1-5 metres per year (Habermehl, 1980, in 'GABCC 2016, Great Artesian Basin Resource Study 2014. Report by the Great Artesian Basin Coordinating Committee'), then the effects of drought would be expected to be picked up in the monitoring bores constructed in the upper Pilliga Sandstone aquifer. Santos' monitoring bores in the Upper Pilliga Sandstone have been recording water levels mostly since the beginning of 2014 and I would expect that the effects of this dry period should be seen in these hydrographs. If this dry period hasn't shown up yet then the previous Millennium Drought from late 1990s to the arrival of the La Nina in 2010 will have.

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).

This point is still valid. In the updated WBR CDM Smith has removed bore BWD27PRORA02 (Orallo Fm) from Figure 3-2. More information should be provided on why this has been done as it would be good to see the hydraulic relationship between Orallo and the underlying Upper Pilliga Sandstone.

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.

Six of the eight DPI bores located outside of the NGP have been removed due to CDM Smith incorrectly interpreting the borelogs. The point made above is still valid for the two remaining bores GW030121-3 (Pilliga Sandstone aquifer) and GW025338-3 (Orallo Fm). Bore GW098011-1 (Pilliga Sandstone aquifer) has been included in Table 4-1 but is not shown on the GAB map in Figure 3-2 and therefore I don't know where it is located to comment.

Two Santos nested 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).

These comments are still valid. This is unfortunate as this suite of nested bores would give a very good insight into the hydraulic relationship between the main suites of HSUs of interest in the NGP.

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.

This comment has mostly been addressed as there are now two years of overlapping data, except of the Purlawaugh Bed bore. It is unclear why Santos has not and is continuing to not monitor DWH14PRPUR03.

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.

This comment is still valid. Santos has increased its alluvial bore monitoring network to 25 DPI Water bores, including 7 nested bores. CDM Smith needs to update Figure 3-3 to show the additional alluvial monitoring bore sites.

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 being 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.

The above points are still valid and have not been addressed by Santos in their revised WBR.

Summary

- *GOB baseline datasets are lacking temporal and spatial data for key HSUs.*

The GOB baseline dataset is still lacking spatial data for key HSUs but the existing few baseline bores have enough data (greater than two years) to be temporally representative.

- *The Black Jack and Napperby Formations include aquifers and aquitards. However, the stratum 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.*

There is now no existing baseline dataset for the Black Jack and Napperby Formations.

- *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.*

This comment has been addressed but there is a lack of spatially representative hydraulic head conditions for the GOB HSUs.

- *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 Pilliga Sandstone bores are both spatially and temporally representative inside the NGP. The Purlawaugh Beds are not temporally or spatially representative in the NGP. This is now not the case for Pilliga and Keelindi Bed bores located outside the NGP, as six out of the eight DPI Water bores have been removed from the baseline monitoring database.

- *The Namoi alluvium is well represented spatially and temporally.*

This is still valid.

- *The Bohena alluvium has no baseline water table dataset to measure the WMP against.*

This is still valid.

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.

This comment is still valid.

Groundwater Baseline Chemistry

General overview

CDM Smith has presented updated 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 the RTS WBR.

CDM Smith in the EIS WBR 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.'

These conclusions are still valid.

My previous comments are presented below in italics including further comments as to whether they are still valid in light of Santos' updated WBR (Dec 2017).

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.

This underlying GOB is still not well represented spatially. The two bores, each within the Napperby and Digby formations, are now temporally representative (greater than two years of data).

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 Jurassic Pilliga Sandstone and Orallo Formation are still well represented in the baseline chemistry within the NGP. However these HSUs are not well represented outside of the NGP due to these bores being removed from the baseline dataset as a result of CDM Smith misinterpreting the DPI Water borelogs.

The Namoi Alluvial baseline chemistry is well represented outside the NGP but the Bohena Alluvial aquifer, the main alluvial aquifer within the NGP, remains unrepresented in the NGP Leewood Water Treatment Plant brine ponds and irrigation field areas. My previous comments remain valid. The baseline groundwater quality dataset for the four bores located along Bohena Creek have a representative baseline dataset (two years). Santos plans to discharge treated wastewater into Bohena Creek when it is flowing at rates greater than 100 ML/day. The representative baseline chemistry dataset will ensure future monitoring of the Bohena Alluvial aquifer is meaningful.

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".

CDM Smith has now removed the Jurassic Purlawaugh Beds as part of the GOB baseline water quality dataset.

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.*

The GAB Purlawaugh Bed monitoring bore DWH14PRPUR03 has now been removed from the GOB water quality monitoring network. However, there is still no Permian data represented in Table 4-3.

Table 4-8 and Table 4-9 in the updated WBR now has sufficient sample sizes, and are statistically viable to determine the groundwater type. Only values for lithium (Li) and sodium absorption ratio (SAR) are not statistically viable but this does not affect determining groundwater type.

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

This point is still valid. Although the Jurassic Purlawaugh Bed dataset has been removed this point is still valid as there is no Permian water quality data included. The data is representative of Triassic strata at one location east of the NGP. I believe one sampling location is not representative of the Triassic 'aquicludes' in the NGP.

The following points were made in my previous report:

- *With the exception of the Triassic-aged strata, EC (field) and EC @ 25°C (lab) datasets in Tables 4-8, 4-9 and 4-10 are not statistically viable but have been combined to produce a 'statistically viable' dataset in Table 4-3. However, Table 4-3 is not representative of the Permo-Triassic HSUs. There is quite a difference in EC @ 25°C (lab) between the three HSUs which is lost when averaged in Table 4-3. This may have important ramifications when using this baseline data against future monitoring and in developing the conceptual groundwater model.*

The EC (field) and EC @ 25°C (lab) datasets in Tables 4-8 and 4-9 are now statistically viable. However, I still believe the EC characteristics for the two HSUs are lost when averaged in Table 4-3 and this may still have important ramifications when using this average values as the baseline to compare future monitoring data against.

- *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).*

This is still valid for both the Digby and Napperby Formations (I will discuss the Purlawaugh Beds below). The following tables are from the updated WBR. However, future sampling will confirm or otherwise as to whether averaging EC values for both the Digby and Napperby formations is a concern.

Digby Formation (Table 4.8):

Water Quality Measure	No. of Samples	No. of Samples >LOR	Min.	Max.	Mean	Percentile 16%	Percentile 84%
EC @ 25C (lab) (µS/cm)	6	6	7220	10300	8820	7236	9996

Napperby Formation (Table 4.9):

Water Quality Measure	No. of Samples	No. of Samples >LOR	Min.	Max.	Mean	Percentile 16%	Percentile 84%
EC @ 25C (lab) (µS/cm)	6	6	3640	7820	6645	6120	7484

So the distinctive EC for each formation is lost when averaged to produce **Table 4-3**:

Water Quality Measure	No. of Samples	No. of Samples >LOR	Min.	Max.	Mean	Percentile 16%	Percentile 84%
EC @ 25C (lab) (µS/cm)	12	12	3640	10300	7732	7013	9410

- *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.*

This point is still valid.

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

In my previous report I stated the following:

CDM Smith presented a statistically viable field pH dataset in Table 4-3, and Tables 4-8 and 4-9. 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.

In the updated WBR report the following pH values are given:

Digby Formation Aquitard (Table 4-8):

Water Quality Measure	No. of Samples	No. of Samples >LOR	Min.	Max.	Mean	Percentile 16%	Percentile 84%
pH (field)	11	11	6.5	13.0	9.41	6.67	12.8

Napperby Formation Aquitard (Table 4-9):

Water Quality Measure	No. of Samples	No. of Samples >LOR	Min.	Max.	Mean	Percentile 16%	Percentile 84%
pH (field)	13	13	5.8	7.0	6.7	6.7	6.9

Again the distinctive pH for each formation is lost when averaged to produce Table 4-3:

Water Quality Measure	No. of Samples	No. of Samples >LOR	Min.	Max.	Mean	Percentile 16%	Percentile 84%
pH (field)	24	24	5.8	13.0	8.0	6.7	12

My concern is still valid.

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.

This comment is still valid.

Jurassic HSUs (GAB Monitoring Bores)

CDM Smith previously presented 20 bores to represent the GAB Jurassic hydrostratigraphy. I have included my previous comments in italics and stated whether my concerns are still valid.

Purlawaugh Beds has now been incorporated correctly into the Jurassic HSU GAB water quality monitoring bore network. In my previous report I stated only one bore represented the Purlawaugh Beds as follows:

- *One GAB monitoring bore (DWH14PRPUR03) located in the Purlawaugh Beds within the Dewhurst CSG Exploration Field.*

This is still valid. There is a sufficient number of samples over a nearly three year monitoring period (29/10/2013 – 5/7/2016). No further bores have been chosen to represent the important Purlawaugh Beds hydrochemistry which is still an oversight. It is unclear why Santos could not incorporate bore BWD28QGPUR01 into their water quality monitoring network.

Pilliga Sandstone (Table 4-4 of EIS WBR)

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

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

This is still valid.

- *Two Santos bores (BWD1WB and BWD5WB), with unknown screen intervals. Only two samples were collected from each bore for major ions, EC (field and lab EC @25°C), and pH over a time period of 1 year and 10 days, for each bore respectively. Therefore I do not consider baseline conditions at these sites to be representative of the Pilliga Sandstone.*

This is still valid. However there is now one more sample for field pH and EC.

- *Three DPI bores with known screen intervals, between 60.6 and 112.8m bgl. Only one bore has statistically viable lab EC @25°C and field pH (GW030400-1) measurements so the data can be compared with other hydrostratigraphic units. The other two had very limited measurements in this respect. All bores had limited major ion data. Even though the data from these bores span between 12 – 28 years (1971 – 1999) the data is over 18 years old.*

GW030121-1, GW030310-2, and GW030400-1 which were interpreted by CDM Smith to be representative of Pilliga Sandstone aquifers were reassigned as Lower Namoi Alluvium after comments made by DPI Water in their submission.

GW030121-1 Pilliga Ss - Geologist, driller logs and depth indicate this pipe is located the Lower Naomi Alluvium	Reassign from Pilliga Sandstone to Lower Namoi Alluvium (logged as gravel and coarse sand).
GW030121-3 Pilliga Ss - Sandstone based on drillers log only. No geologist log available could be in Lower Naomi Alluvium	Keep as top of Pilliga Sandstone (logged as sandstone).
GW030310-2 Pilliga Ss - Geologist and driller logs indicate this pipe is located the Lower Naomi Alluvium	Reassign from Pilliga Sandstone to Lower Namoi Alluvium (logged as large gravel and stones).
GW030400-1 Pilliga Ss - Geologist and driller logs indicate this pipe is located the Lower Naomi Alluvium	Reassign from Pilliga Sandstone to Lower Namoi Alluvium (logged as gravelly clay).

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.*

This is still valid. Bore BHN14PRORA01 is located inside the NGP and NYOPRORA01 is located outside of the NGP to the northwest.

- *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.*

This is still valid.

Namoi Alluvium HSU (Alluvial Monitoring Bores)

CDM Smith previously presented 13 bores to determine the baseline data for water quality in the Namoi Alluvial aquifers. This has now been increased to 16 bores to include GW030121-1, GW030310-2 and GW030400-1 which

were previously misinterpreted as GAB Pilliga Sandstone bores. Figure 3-3 of the updated WBR needs to be updated to include these additional bores. This database consists entirely of DPI monitoring bores, which are located downgradient of the NGP area, and are spatially and temporally adequate. Previously I stated the following:

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.

There are still only six bores out of the sixteen bores with statistically viable datasets for major ions, EC (field and lab EC @25°C), and pH (field and lab) representing a period greater than two years.

Bohena Creek Alluvium HSU (Alluvial Monitoring Bores)

Previously I noted the following:

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.

This comment is still valid with CDM Smith having not clarified the sampling period.

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.

This has not been addressed by the RTS.

Summary

I discussed previously that the GOB Permo-Triassic water quality data is not representative and is misleading. This is still the case as no Permian HSUs have been included. In the updated WBR, CDM Smith has moved the Purlawaugh Beds into the GAB HSU water quality dataset.

The GAB Purlawaugh Formation leaky aquitard chemical characteristics are not statistically viable. As a result they have not been included in Figure 4-50 Durov diagram of average groundwater quality for monitoring locations. 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 less than the underlying Triassic aquitards) which indicates it may be able to transmit water more easily than is reflected in the conceptual model.

In my previous report I stated the following:

*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.*

These statements are still valid except that I meant to say the western portion, not the eastern portion, of the NGP.

In my previous report I stated the following

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.

This statement has been addressed.

Methane data has now been included for all Santos bores representing the HSUs. CDM Smith noted that 'all Namoi Alluvium bores are State monitoring bores. No trace gases have been reported for any of the GW-series bores. Local landholder bores accessing groundwater from the Namoi Alluvium were sampled by Santos. Variable levels of methane were detected in these bores. Some recorded no methane and others reported methane up to 0.6 mg/L. Stable isotopes indicated a thermogenic source for this gas.'

The proponent notes that most gas data from waters have been collected recently by the proponent via its network of dedicated monitoring bores, augmented by sampling of local landholder bores and DPI Water monitoring bores. This data is incorporated into the revised Water Baseline Report (EIS Appendix G4 and Appendix D to this RTS).

In general, methane is observed at low and varying levels in all formations above the target formations, though most groundwater samples from across the monitoring network do not record hydrocarbons above limits of reporting. There is no spatial coincidence between elevated levels in different formations, though elevated levels in deeper formations may relate to underlying conventional gas reserves or seepage losses from deeper coal measures.

Alluvium groundwaters with elevated methane occur along the Namoi River, north-east of the project. Alluvium- and colluvium-sourced groundwaters above and adjacent to gas exploration sites show negligible to below background methane levels, indicating that gas is not escaping to the surface related to these development activities.

Surface Water Baseline Data

Streamflow

In my previous report I reported CDM Smith stating:

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.

This concern is still valid.

Surface Water Quality

The water quality data for the Namoi River and Bohena Creek is spatially and temporally (two years between 2012 and 2014) representative of the NGP and surrounding area. CDM Smith/Santos have only kept monitoring Bohena Creek site 7506, which is located near where Santos intend to discharge treated produced water when flows are greater than 100 ML/day.

Summary

Previously I stated the following:

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).

CDM Hill has discussed in their updated report that they believe the Bohena Creek is not connected to the underlying Bohena Alluvial groundwater system. Therefore my point above concerning establishing a baseline dataset for both continuous streamflow and ceased flow would not be necessary from a CSG contaminated groundwater point of view. However CDM Smith has not provided any evidence to support this position (by way of comparing streamflow hydrographs with the adjacent Bohena Creek bores hydrographs, any isotope or geochemical investigations). Therefore my concern is still valid for any inflow of contaminated surface water.

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.'

This comment is still valid as the RTS has not discussed the Triassic GOB and Jurassic GAB aquitards in any further detail. I believe this is due to the continuing lack of hydraulic and water quality data informing CDM Smith and Santos. As a result of misinterpreting the DPI Water borehole logs there is now even less information to inform the assessment.

I do understand the conceptual and groundwater model is based at a regional scale and the effects of the depressurisation of the GOB target coal beds will also occur at a regional scale in the GOB HSUs, before any flow on effect of this depressurisation is felt in the GAB HSUs in the Narrabri area. Santos and CDM Smith clearly believe that it is important to represent the GOB and GAB aquitards with more than a few monitoring bores in the NGP, as evidenced in their proposed WMP (which includes drilling more GOB and GAB monitoring bores). Therefore, in my opinion, this should have been completed as part of the WBR, given the highly variable nature of the GOB HSUs. A credible statistically viable dataset representing these critical GOB and GAB aquitards is essential so that the hydraulic properties can be effectively modelled to determine groundwater impacts to the GAB.

I discuss individual HSUs and my ongoing concerns that have not been addressed in the RTS in the following sections.

I noted in my previous report that:

'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.'

The RTS states that it is not possible to establish hydraulic properties for HSUs in the same manner as for pump testing water bores. I understand this but hydrogeology was born out of the Canadian petroleum well fields and there are other ways to establish hydraulic properties such as detailed analysis of borehole cores and interpreted downhole geophysical logs.

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

'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.'

In my previous report I stated that:

'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. Not the thicknesses.'

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.

In my opinion the Namoi and Bohena alluvial aquifers have been inadequately represented as a result of the regional scale of the conceptual and numerical model. I understand it is impossible to model the highly variable nature of the Namoi alluvial groundwater system but in my opinion, the shallow alluvial groundwater system has been oversimplified. The RTS has not discussed how they have represented the Bohena alluvial aquifer connectivity with Bohena Creek. I understand CDM Smith believe they are hydraulically disconnected. This leads to considerably different groundwater modelling scenarios when investigating the effects of surface water contamination. It also affects the modelling of controlled discharges of treated produced water into Bohena Creek.

Hydrogeological properties representation

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

Santos provided the following general comment in the RTS:

Numerous lines of evidence were used to derive values that could best parameterise the formations and zonation in the groundwater model. After consideration of all available information and comparison to previous studies and models for the region, it was determined that many of the derived parameters were in comparable ranges to those reported in the literature for comparable lithologies. This realisation provided both confidence that regional and local modelling studies are in agreement with theoretical considerations and that parameterisation of units for which there are insufficient field data is likely to be appropriate for the numerical modelling exercise.

To provide further justification and explanation for the specific parameterisation of the numerical model, this question is best answered by separate consideration of the Great Artesian Basin and alluvial aquifers, as discussed below.

Great Artesian Basin

A review of groundwater modelling of the Great Artesian Basin (Smith and Welsh 2011) found that there is no available data on the spatial distribution of hydrogeological properties within the project area. Subsequent modelling of the Great Artesian Basin and Gunnedah-Oxley Basin for the Namoi Catchment Water Study (SWS 2012) adopted uniform hydrogeological properties in the Great Artesian Basin of this area. More recent groundwater modelling, specifically considering the project area by GISERA (Sreekanth *et al.* 2017 – published subsequent to the project EIS), implemented a spatially-uniform, but depth-dependent, relationship for horizontal hydraulic conductivity and specific storage in

the Great Artesian Basin and Gunnedah-Oxley Basin. The spatial distribution of vertical hydraulic conductivity was not described in that report.

Within the EIS, Table 5-2 in the Groundwater Impact Assessment (EIS Appendix F) describes a limited number of very localised (falling head) measurements of hydraulic conductivity in Great Artesian Basin and Gunnedah Basin strata. These, however, are local-scale point measurements that do not directly scale to model cells, which represent a minimum area of one square kilometre in the EIS groundwater model.

There are, thus, insufficient data to support a defensible regional-scale interpolation of the spatial distributions of hydrogeological properties in the Great Artesian Basin.

In this circumstance, order-of-magnitude values of hydrogeological properties informed by existing estimates is considered the only practicable choice for groundwater modelling. It is worthwhile noting that while hydraulic conductivity and specific storativity are assigned as uniform values within aquifer layers, the transmissivity and storage coefficients for the layers derived from these properties are not uniform because they also depend on layer thickness, which varies spatially.

Estimates of hydrogeological properties in Table 5-3 of the Groundwater Impact Assessment, therefore, are values adopted specifically for groundwater modelling studies and do not constitute measurements or field-based estimates of these parameters.

Santos is stating that because they believe the derived parameterisation for the GAB HSUs were in comparable ranges to those reported in the literature for comparable lithologies, this has provided Santos with confidence that where there is insufficient field data then they can use theoretical values in the numerical modelling exercise. That may be so for the GAB HSUs (excluding the basal Purlawaugh Bed aquitard) as there is a greater dataset, however, this line of thought can not be transferred to the GOB aquitards with confidence as there has been little work carried out to allow such confidence in using test book parameterisation for the GOB aquitards. Santos has not addressed the critical GOB HSUs in this discussion. In my opinion the parameterisation of the Triassic Digby and basal Napperby Shale, and early Jurassic Purlawaugh formation aquitards remains inadequately and inappropriately represented in the conceptual model.

Santos states that local-scale measurements do not scale to model cells, which represent a minimum of one square kilometre in the EIS numerical groundwater model. Santos also states there is insufficient data to support a

defensible regional-scale representation of the spatial distribution of hydrogeological properties in the GAB. However, in my opinion that is the point of gathering the baseline data, to find the gaps in knowledge and to rectify this for the EIS.

I previously noted that CDM Smith made the following observations from the compiled data (GIA Appendix F, EIS):

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

'In my opinion Santos should have measured the Kv of the critical units (Purlawaugh Formation, Basal Napperby Shales, Digby Formation, Watermark-Porcupine-Upper Maules Ck Formations), which are relied upon to protect the Pilliga Sandstone and alluvial aquifers. Instead, Santos second guessed Kv values from other investigations and has used text book Kv values in the conceptual groundwater model. These measurements may not be representative and therefore may impact on the GIA outcomes.' Neither Santos nor CDM Smith has made any comments regarding this.

'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).'

Santos states in their RTS that they carried out sensitivity analyses on varying Kv values, as part of the groundwater numerical modelling, and found there was little difference to the drawdown scenarios.

Groundwater flow systems representation

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

I commented in my previous report that:

- *'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.*

The first point has been addressed by CDM Smith stating they were able to calibrate the Namoi Alluvium using the DPI Water GW-series hydrographs which date back to the early 1970s.

With regards to my second point it appears CDM Smith have represented the aquitards based on text book hydraulic parameters for the aquitards, as their field evidence did not fit their idea of how the aquitards should perform. The RTS states that their model sensitivity analysis indicates vertical hydraulic conductivity is not sensitive. That is, by applying a wide range of vertical hydraulic conductivities the model didn't respond by showing significant changes in flux across the HSUs. However the RTS did not say which HSU aquitard's vertical hydraulic conductivity is not sensitive. In my opinion the Triassic and Jurassic aquitards ability to transmit groundwater vertically has still not been adequately conceptualised and represented in the conceptual groundwater model. This could lead to an underestimation of the decrease in pressure head in the GAB HSUs and water levels in the alluvium.

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'. '

Santos RTS response to this was:

'The EIS groundwater model has been reviewed by the CSIRO against the review criteria established in the Australian Groundwater Modelling Guidelines (Barnett et al 2012). In relation to whether the model was considered fit for purpose, the review stated:'

- "The groundwater flow model presented is an adequate representation of the regional groundwater flow system in the Gunnedah Basin and the model is suited to make simulations to meet the above stated model objectives"; and
- "The reported impacts are a good summary of, and true to, the model simulated values. Considering the availability of data and the limitations of numerical modelling, the reported conclusions on the impacts of the proposed coal seam gas development of the proponent on changes in water balance, pressure head and water table are justified."

I stated in my previous report that the lowest model confidence level classification of 'Level 1' is because 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. I also stated the following:

- *The model is calibrated only for steady state flow in the Namoi alluvial aquifer and not for transient state flow.*
- *The predictive model time frame far exceeds that of calibration time based on the transient data period.*
- *The model is based on inadequate hydraulic properties and very limited data representing the deeper groundwater system (Jurassic, Triassic and upper Permian).*
- *CDM Smith did not undertake a Monte Carlo, probabilistic analysis/assessment to see what potential outcomes could occur with a range of hydraulic conditions and scenarios – a sensitivity analysis.*

CDM Smith did not comment on the first three points but did respond regarding GISERA (Sreekanth et al. 2017) undertaking a probabilistic assessment to see how sensitive the model was for a range of hydraulic conditions. CDM Smith stated the following:

The method used for assessing predictive uncertainty in the EIS groundwater modelling is presented in Section 6.10 “Model Uncertainty and Sensitivity” of the Groundwater Impact Assessment (EIS Appendix F).

The independent review of the EIS groundwater modelling by CSIRO states “The sensitivity analysis can be considered a qualitative uncertainty analysis, showing the extremes of the plausible ranges of parameter values. In this case, it is a valid alternative to a formal uncertainty analysis in which estimates of the probability of each prediction (corresponding to a particular plausible combination of parameter set and water production curve) are provided.”

A more recent groundwater modelling exercise of the project by GISERA (Sreekanth et al. 2017) considered probabilistic results based on 500 realisations of the model parameters. For a range of water production volumes between 4.4 gigalitres and 107 gigalitres (compared to the EIS Base Case of 37.5 gigalitres) the GISERA report concluded “...changes to the water balance components induced by the gas development are relatively small compared to the probabilistic estimates of their baseline values.” Overall, the findings and conclusions of the GISERA report regarding potential impacts of the project on high-valued water sources are consistent with the conclusions in the project EIS.

The implication of this modelling exercise indicated that for a range of hydraulic conditions the overall change in flux across the HSUs as a result of depressurisation in the Permian coal measures was relatively small in comparison with their baseline values. That is, the water pressure change in the Pilliga Sandstone and alluvial aquifers are small as discussed in EIS. Without knowing which HSUs hydraulic conditions were changed it is difficult for me to comment further.

ISSUE THREE

‘Is the proposed groundwater monitoring plan appropriate?’

I previously stated...

‘in my opinion, I believe the WMP is mostly appropriate’.

CDM Smith and Santos have not provided an updated WMP in light of the misinterpreted borelogs. There is now a number of GOB and GAB DPI Water bores which are not able to be incorporated into the WMP.

GOB WMP

Table 3-13 from the EIS WMP is presented below. Four DPI Water bores representing key GOB HSUs were destined to be included as sentinel monitoring bores (these are highlighted in blue). These DPI Water bores have now been excluded due to the misinterpretation of the borelogs.

However, Part A Section 6.11.5 of the RTS did not address the fact they now have less than adequate monitoring bore network nominated for Level 2 response trigger in Triassic/Late Permian Age strata of the GOB. CDM Smith and Santos have not provided any information on how they are going to rectify this gap in data (including the lack of baseline data that is also required to provide a comparison for water levels).

Table 3-13 Nominated Level 2 response trigger in Triassic Age strata of the Gunnedah-Oxley Basin

Monitoring bore	Formation	Predicted maximum drawdown [m]	Predicted time of maximum drawdown [y]
GW036546-3	Upper Black Jack Group	< 0.5	571
DWH8AQGDGY01	Digby Formation	2.4	191
GW036546-1	Digby Formation	< 0.5	571
MPDGY-01	Digby Formation	< 0.5	371
MPDGY-02	Digby Formation	< 0.5	821
MPDGY-03	Digby Formation	3.2	161
TULPRDGY02	Digby Formation	1.2	201
GW036497-1	Napperby Formation	< 0.5	1021
GW036546-2	Napperby Formation	< 0.5	621
MPNAP-01	Napperby Formation	< 0.5	371
MPNAP-02	Napperby Formation	< 0.5	821
MPNAP-03	Napperby Formation	1.9	191
MPNAP-04	Napperby Formation	1.5	151
TULPRNAP01	Napperby Formation	0.7	221

GAB WMP

Previously I stated...

The nominated GAB groundwater monitoring bores and programme should adequately represent the Purlawaugh, Pilliga, Orallo and Mooga Formations in the NGP and surrounding area.

In light of the misinterpreted borelogs the GAB monitoring bore network needs revising. The remaining bores now have sufficient baseline data to compare monitoring water levels against.

The following comment was made as, in my opinion; there was a gap in the baseline and monitoring database:

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).

This was not addressed in the RTS and in my opinion is still valid.

I also questioned whether some of the Level 2 bores should actually be Level 1 bores to ensure a more robust monitoring network as follows:

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.

These comments were not addressed by the RTS. The only exception is that the RTS states a number of times that they will work with DPI Water to ensure the WMPs are robust. I understand from reading the RTS that DPI Water has seriously questioned Santos' WMP and therefore the WMP is still to be finalised.

Table 3-5 Monitoring program details - WSP for NSW Great Artesian Basin Groundwater Sources

Location	Bore category	Form of measurement		Management Objective ^[1]	Baseline / control data
		Water quantity	Water quality		
BHN14PRORA01 BHN14PRUPS02 DWH14PRUPS01 DWH14PRLPS02 DWH14PRPUR03 GW025340-3	Level 1	<ul style="list-style-type: none"> Field measured ⇒ water level (reduced to mAHD), using calibrated pressure transducers Frequency ⇒ Continuous (recording interval set to 24 hrs) 	<ul style="list-style-type: none"> Field measured ⇒ EC, pH, DO, Eh Frequency ⇒ Quarterly Laboratory ⇒ pH, salinity (as EC and TDS), major ions, and other analytes as appropriate Frequency ⇒ Biennial 	Quantity a) No adverse change to spring discharges or wetted areas ^[3] b) No adverse change to pressure heads in GAB aquifers ^[3] Quality a) No adverse change to existing beneficial use of groundwater sourced from GAB aquifers ^[3]	WBR data ^[2]
GW030121-1 GW030121-2 GW030121-3 GW098011-1			(bores not equipped for water quality sampling)	Quantity As above	

Notes: 1. Refer Section 3.2
2. CDM Smith (2016a and 2016b)
3. Other than those attributed to climate variability (seasonal and inter-annual), irrigation, mining and other anthropogenic influences

Table 3-5 Monitoring program details – WSP for NSW Great Artesian Basin Groundwater Sources (cont.)

Location	Bore category	Form of measurement		Management objective ^[1]	Baseline / control data
		Water quantity	Water quality		
BWD26PRUPS01 BWD26PRLPS02 BWD27PRUPS02 BWD27PRLPS03 BWD28QGLPS01 BWD28QGUPS01 BWD28QGPUR01 DWH3PRUPS01 DWH3PRLPS02 NYOPRORA01 NYOPRUPS02	Level 2	<ul style="list-style-type: none"> Field measured ⇒ water level (reduced to mAHD), using manual techniques Frequency ⇒ Biennial (unless equipped with pressure transducers) 	<ul style="list-style-type: none"> Field measured ⇒ EC, pH, DO, Eh Frequency ⇒ Biennial Laboratory ⇒ pH, salinity (as EC and TDS), major ions, and other analytes as appropriate Frequency ⇒ Biennial, but only if and when pressure declines attributed to NGP are observed 	Quantity a) No adverse change to spring discharges or wetted areas ^[3] b) No adverse change to pressure heads in GAB aquifers ^[3] Quality a) No adverse change to existing beneficial use of groundwater sourced from GAB aquifers ^[3]	WBR data ^[2]
GW030310-2 GW030400-1 GW021266-4 GW025343-2 GW025338-3			(bores not equipped for water quality sampling)	Quantity As above	

Notes: 1. Refer Section 3.2
2. CDM Smith (2016a and 2016b)
3. Other than those attributed to climate variability (seasonal and inter-annual), irrigation, mining and other anthropogenic influences

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.

This point has not been addressed in the RTS and is still valid.

Most of the Level 1 bores will be measured against limited baseline data collected and presented in the WBR. The best baseline data was collected from DPI bores at sites GW025338, GW021266, GW025343 and GW036005, yet they are Level 2 bores. Water quality baseline data was not presented in the updated WBR for the Level 1 bore GW025340, and so there is no dataset against which it can be measured.

I stated in my previous report that four more Bohena Alluvial aquifer bores should be established in the Leewood Water Treatment area:

‘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.

I stated in my previous report that:

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.

Santos has included baseline methane concentrations for their bores. There was no methane data included in the DPI Water alluvial bores. Santos measured methane in some local landholder bores accessing groundwater from the Namoi Alluvium. Santos reported ‘variable levels of methane were detected in these bores. Some recorded no methane and others reported methane up to 0.6mg/L. Stable isotopes indicated a thermogenic source for this gas.’

Santos did not state whether the methane levels were thermogenic in the Purlawaugh, Pilliga Sandstone and Orallo Formations. Santos did not say if any isotopic work was undertaken to determine the origin of the methane in these deeper GAB HSUs, like they did for the alluvial aquifer bores. This would have been a valuable comparison of methane sources between the HSUs.

I stated the following in my previous report:

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.

I stated in my previous report that this was not in keeping with predictive depressurisation and a drawdown in the order of 0.5m which was determined from the GIA. Santos believes the 0.5m is within model error and is not likely to affect GDEs. CDM Smith previously 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.

I raised the issue that

'impacts of un-managed leaks from ponds and pipelines should have been considered'.

Santos provided the following comment which is evidence they have considered it:

All facilities including gas and water gathering lines would be designed to the relevant Australian Standards and protocols, including the Australian Pipeline Industry Association (APGA) *Code of Practice for Upstream Polyethylene Gathering Networks-CSG Industry*. In the unlikely event that a spill or leak did occur, design and engineering controls along with monitoring systems would enable leaks to be detected and rectified quickly.

The design of the Leewood and Bibblewindi produced water ponds would comply with the NSW Government's *Code of Practice* requirements with double lined ponds, leak detection and seepage collection and an engineered spillway as standard. Ponds are designed as multi cell facilities which improves maintenance ability and limits volume release in the event of an issue. Pond levels and collection sumps are monitored with telemetry to a control centre and in addition there are several shallow monitoring bores installed adjacent to the ponds as part of the monitoring network.

There is continuous pressure monitoring of produced water pipelines for indications of a leak and wells can be shut in remotely if required to minimise volumes of water released in the event of a leak. Note that water pressures at well heads and within water gathering lines is low.

Regular plant, equipment and pipeline checks and inspections and an Equipment Maintenance Plan would be developed that includes the proactive programmed maintenance of produced water transfer and storage infrastructure.

Chemicals will be stored and handled in accordance with the relevant Australian Standards, including AS1940. Maintenance requirements would be carried out in accordance with operational procedures

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 RTS still does not demonstrate that baseline conditions are currently well known in the Permo-Triassic HSUs and the Holocene Bohena Alluvial HSU.

NSW Secretary's Environmental Assessment Requirements

The SEARS for the NGP included advice and recommendations from DPI Water. These were given in Table 1-2 in the GIA.

Pertinent to baseline data, DPI Water recommended the 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, Santos should have provided baseline data that indicated 'typical temporal variations,' and then collected statistically viable data covering that time period. Santos has not defined what a 'typical temporal variation' would be. The RTS still fails to provide this baseline data for the GOB. On the other hand, baseline data in respect of spatial variation, which is easier to collect, has been adequately provided for the GAB and alluvial HSUs but not the GOB HSUs.

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) and the *NGP Response to Submissions Part A, Part B (Appendices B and D) and Part D (Appendix L)*. 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), the *NGP Response To Submissions* 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).