

Advice to decision maker on coal seam gas project

IESC 2017-086: Narrabri Gas Project (EPBC 2014/7376; SSD 6456) – New Development

Requesting agency	The Australian Government Department of the Environment and Energy The New South Wales Department of Planning and Environment
Date of request	15 June 2017
Date request accepted	16 June 2017
Advice stage	Assessment

Summary

The proposed Narrabri Gas Project is a coal seam gas project of up to 850 production wells from 425 well pads located south-west of Narrabri, NSW. Estimated gas production is 200 TJ/day, with a project life of 25 years.

The IESC provides the following summary based on information provided in the assessment documentation. This summary should be read in conjunction with the specific response to questions posed by State and Commonwealth regulators.

Key potential risks of the project include: salt and chemical management and disposal; groundwater depressurisation and drawdown in aquifers within the project area and surrounds that may impact groundwater dependent ecosystems (GDEs) and other groundwater users; and changes to surface water flow and quality as a result of discharges to Bohena Creek. Potential areas at risk from these impacts include: landowner bores in the northern portion of the project area, outside the Pilliga State Forest, overlying areas of gas extraction from the Hoskissons Seam; Hardys and Eather Springs; Bohena Creek downstream of the discharge location; and areas of co-produced brine, salt and waste are stored.

Baseline groundwater information has been collected to inform the environmental impact assessment for this project. However, the IESC considers that further data is required to determine the full range of potential impacts to groundwater resources and associated users. The proponent's groundwater model underpins much of the assessment of the impacts to water resources and associated users in the region. As expected when modelling complex environments, there are limitations associated with the groundwater model that introduce a level of uncertainty with the model outputs. Ongoing collection of hydrogeological information and data will be needed to confirm the preliminary predictions of impacts to groundwater resources within the region. The current surface water and groundwater modelling will need to be continually audited and reviewed in light of this information to ensure impacts are adequately predicted and measures are in place to monitor, manage, and if required,

mitigate impacts. Should the project be approved, this will be an important aspect in the ongoing adaptive management of impacts to surface water and groundwater resources.

The IESC acknowledges the early stage of the proposed project and understands that the proponent will have to undertake further work as the assessment progresses. Knowledge gaps, uncertainties and data limitations within the Environmental Impact Statement (EIS) have been identified by the IESC. In order to reduce associated uncertainties with these knowledge gaps, as soon as possible the proponent should consider:

- providing detail on the reservoir modelling, including confirmation that gas extraction will be limited to 5% from the Hoskissons seam and 95% from the Maules Creek Formation.
- providing a groundwater monitoring plan detailing a groundwater impact early warning monitoring system that includes management, mitigation and contingency measures.
- identifying hydrogeological characteristics and source aquifers for Hardys and Eather Springs (identified as high priority GDEs by the NSW state government).
- undertaking appropriate field assessment of further GDEs.
- clarifying the nature of long and short term salt storages, including associated monitoring and management measures.
- upgrading the surface water gauging infrastructure to be used to determine commencement and cessation of proposed discharges into Bohena Creek.
- clarifying the proposed treatment and monitoring regime to be undertaken prior to and/or during discharges to Bohena Creek, particularly for ammonia.
- improving the water balance modelling to ensure sufficient options exist for management of co-produced water during extreme weather events.

Specific details on the above matters are discussed within this advice in the responses to the questions posed by the State and Commonwealth regulators.

Context

The IESC was requested by the Australian Government Department of the Environment and Energy and the New South Wales Department of Planning and Environment to provide advice on the Santos Narrabri Gas Project in NSW.

This advice draws upon aspects of information in the Environmental Impact Statement, information provided within the request for advice, information from the Namoi sub-region Bioregional Assessment and relevant research undertaken in the region, together with the expert deliberations of the IESC. The project documentation and information accessed by the IESC are listed in the source documentation at the end of this advice.

The proposed project will comprise up to 850 production wells on 425 well pads. The estimated water production ranges from 34 GL ('Low Case') to 87 GL ('High Case') for the project life of 25 years. Project infrastructure includes a central gas processing facility for the compression, dehydration and treatment of the gas to commercial quality. Supporting infrastructure includes treatment, beneficial reuse, power generation, water and gas distribution and operational management facilities.

The northern part of the project area is located within an agricultural area and the southern part of the project area (approximately 66%) is occupied by the Pilliga State Forest. Within the region, the main

source of surface water is the Namoi River, while groundwater is sourced from the Namoi Alluvium and Great Artesian Basin (GAB). Groundwater is used for a range of purposes including agriculture, stock, domestic and industry. The project area and surrounds also contains groundwater dependent ecosystems (GDEs), including Hardys and Eather Springs (identified as high priority GDEs by the NSW state government) and riparian vegetation along Bohena Creek. State and Commonwealth listed endangered ecological communities within the project area include Weeping Myall Woodlands, Brigalow, Fuzzy Box Woodland and Carbeen Open Forest. Fuzzy Box Woodland and Carbeen Open Forest, in particular, are located along streams in the project area.

Key potential impacts

The key potential impacts of the project include:

- long-term release of salt to the environment and the ongoing management of brine and salt waste. There is uncertainty in the quantities of salt that will be produced. There is also limited information in relation to the location and process for storage, and the containment and monitoring measures at the point of disposal.
- declines in groundwater level in landholder bores as a result of depressurisation and drawdown in the medium- to long-term (greater than 10 years).
- reductions in water availability to springs and other GDEs as a result of groundwater depressurisation and drawdown. These reductions may also impact surface water and groundwater connectivity, particularly along Bohena Creek.
- changes in surface water flow as a result of proposed discharges into Bohena Creek and uncertainties in the management of water during project operations in the short term (less than 10 years).
- changes to surface water and groundwater quality as a result of inappropriately stored or unintentional release of chemicals or untreated co-produced water.

These impacts could occur at a range of timescales, as indicated above, and monitoring and management measures need to take this into consideration. For example, given the potential long timeframes for groundwater impact, groundwater monitoring (at key locations and timings) will be important to continually assess if impacts are as predicted and to be capable of identifying any change to the timeframes for impacts. Where monitoring indicates shorter timeframes for impacts to occur or impacts of greater magnitude, contingency measures need to be in place to mitigate and manage impacts.

Appraisal of data and methodologies

The EIS provides sufficient baseline water quality monitoring for the Namoi River. Baseline data for the Namoi River extends over two years which can be used to derive local water quality guidelines (WQGs).

The groundwater model is regional in nature, as acknowledged by the proponent, and classified as class 1 (Barnett et al. 2012) due to limited data to constrain parameterisation. This yielded preliminary regional scale predictions of the extent and magnitude of groundwater drawdown and flux at indicative locations within the area.

The IESC notes that pilot investigations have been undertaken within the project area dating back to 1998 and small-scale production for electricity generation since 2004. The presentation of details of these investigations and production history is limited. In particular, information in relation to groundwater pressure and head data would provide an early indication as to how the groundwater

system responds during these periods of stress. The rates of groundwater extraction used in the model simulations are based on estimates derived from the historical water production from conventional and coal seam gas (CSG) pilot wells in the Gunnedah Basin. However, information in relation to assumptions and values that have been used in the reservoir model is not provided.

There is low confidence in the water balance modelling and therefore the produced water management system. Contingency actions are not provided to address the possibility of excess water storage if other beneficial reuse options are not available.

In contrast to recommended approaches (e.g. Richardson et al. 2011; Serov et al. 2012), desktop analyses were used to exclude most of the Type 2 and Type 3 GDEs from field assessment. The GDE assessment was further limited as the risk assessment assigned low ecological values to many potential GDEs within the project area, based on scant or no field data collected by the proponent. Therefore, the risk assessment potentially under-estimates the potential impacts on GDEs in the project area.

Monitoring and management plans for surface water, groundwater and waste management are inadequate and conceptual in nature. The current proposed groundwater monitoring network is not suitable as its limited spatial coverage would not provide an early warning of groundwater depressurisation and potential impacts to landowner bores and GDEs.

Response to questions

The IESC's advice, in response to the requesting agencies' specific questions, is provided below.

Question 1: Groundwater Model

a) Does the IESC agree that the model is fit for purpose, and that any uncertainties can be adequately managed through appropriate monitoring to verify and refine the groundwater model over time?

1. For a project of this scale and complexity, the IESC considers that the groundwater model would need to fulfil two purposes. It would need to both estimate the rate of groundwater flow (i.e. flux) between aquifers and provide an indication of the location and magnitude of groundwater impact (i.e. drawdown) that would result in the loss or reduced availability of groundwater to users (e.g. landowner bores and GDEs).
2. The proponent has stated that the model "is considered to be fit for purpose for predicting potential regional impacts on groundwater and surface water from proposed water extraction" (EIS, Appendix F, p. 16). Compared to the modelling used in the Queensland CSG fields where groundwater is drawn down to a specified head, this model uses a specified flux based on water production history from pilot well production in the area. Both approaches are valid and the approach used in this model is considered adequate to provide reasonable estimates of groundwater take from water resource units. However, further confidence in these estimates would be obtained if modelled heads in target seams resulting from the imposed range of extraction rates could be verified as suitable to enable gas desorption and subsequent production. This is not clear from the information provided in the EIS documentation, which is lacking imposed head data and data from pilot projects in the project area.
3. The model is not capable of robustly determining the full range of the magnitude of potential local impacts on GDEs and landholder bores, limiting its ability to be used as a tool for risk assessment under the *EPBC Act 1999* and the NSW Aquifer Interference Policy (AIP) (DPI, 2012). In order to assess the model's ability to predict local scale impacts near receptors, it is important to confirm that modelling abstraction in production bores as a flux does not under-estimate drawdown impacts at a distance from the points of abstraction. The limited capability of the model to quantify local scale impacts has also been flagged by the NSW Department of Primary Industries (DPI)

Water who conclude that the model is not able to provide output at the scale and accuracy required to assess the project's impacts against the NSW Aquifer Interference Policy without additional data collection and model refinement.

4. The key risks of the project include impacts to landholder bores and GDEs utilising groundwater from the Namoi Alluvium, Pilliga Sandstone and the alluvium associated with Bohena Creek. These long-term risks are due to potential groundwater depressurisation propagating from target coal seams. While the groundwater model has some degree of predictive capability in providing an early indication of the general location of impacts, it is not able to reliably indicate the magnitude of impact. The use of small scale 'daughter models' in areas of particular concern could be considered to address this limitation. While the current modelling indicates a low likelihood and severity of impact to most receptors, further verification of model inputs (including suitability of imposed extraction rates) and other refinements of the model are needed to improve confidence in model predictions. These refinements of the model are discussed further in the response to Question 1b below.
5. The IESC notes that DPI Water have requested that the proponent provide a calibrated model for assessment and review at year five of the development. This includes an ongoing commitment to validate and recalibrate the model every five years using the data collected over the previous five years. This approach is reasonable; however, it could be further improved by:
 - a. undertaking annual data reviews, data trend analyses and reporting on changes to the development (e.g. footprint, layout and timeframes) to identify any deviations from predicted volumes of extracted water or impacts on water resources (including aquifers, GDEs and surrounding landholder bores) as reported in the proponent's EIS.
 - b. using the information gathered by the above reviews and the proponent's ongoing monitoring to review the model two to three years after the commencement of groundwater and/or gas production.
 - c. undertaking validation and calibration of the model. If impacts predicted by the model that is calibrated to annual monitoring data are less than those predicted in the EIS, then the model review period could be extended to five years utilising data collected over the preceding years.
 - d. concurrently reviewing and revising all relevant management plans to ensure early prediction of impacts and the implementation of adequate monitoring, management and contingency measures.

Question 1

b) If not, can the IESC identify what aspects of the modelling are not adequate, and whether any uncertainties are likely to result in any material impacts over and above those predicted in the EIS, and what should be done to address these uncertainties?

6. While the approach to groundwater modelling at a regional scale is reasonable for this type and stage of project, aspects in relation to data, parameterisation, calibration and uncertainty/sensitivity analysis require further consideration in order to improve model confidence as they may have a material influence on predictions at the local scale.
 - a. The proponent should provide evidence that the imposed extraction rates are suitable to enable gas desorption and subsequent production. Where modelled groundwater heads are not within the appropriate range expected for desorption, potential groundwater impacts may be over- or under-estimated. As mentioned above, provision of modelled imposed head data at extraction wells, and well extraction and head data from pilot gas production, will improve

confidence in the suitability of current imposed extraction rates. The groundwater impact predictions are based on the representation of these groundwater extraction volumes. If extraction volumes and fluxes are to change, then the groundwater impacts will also change, especially if greater extraction occurs within the shallower late Permian Hoskissons coal seam than currently predicted and modelled. Gas extraction from the Hoskissons seam is currently stated to comprise 5% of total production.

- b. The measuring of head directly above and below the tightest aquitard strata, together with groundwater production rates, would allow constraint of aquitard hydraulic properties (refer to paragraph 8b).
- c. Characterisation of fault displacements and provision of fault and geological/stratigraphic analyses and data to support the geological conceptualisation are required. Further consideration is needed with respect to the scale and extent of faulting in the region and the likely impact on groundwater during and post CSG extraction to justify excluding faulting from the groundwater model.
- d. The groundwater model adopted hydraulic conductivity values for aquitards at the low end of the range of previous modelling studies. However, Turnadge et al. (in press; 2017) report a method which up-scales aquitard core permeability tests using wireline logs of bores across the project area and also accounts for spatial variability. Turnadge et al. (2017) report shorter timeframes for the propagation of depressurisation and greater medians of maximum drawdowns in localised areas using this method. Consideration should be given to these and similar methods, including the collection of site-specific data, in assessing the effects of changing permeability and storativity, particularly in areas with overlying sensitive receptors.
- e. There is some justification provided for the lack of sensitivity testing for recharge; however, recharge could be negligible, particularly over the western areas of the Lower Namoi Alluvium (Timms et al. 2012). In addition, work completed by Iverach et al. (2017) suggests that groundwater from the GAB to certain areas of the Namoi alluvium could be up to 70% of total contribution. These variations indicate that a range of different hydrogeological conceptualisations and testing methods should be used to address uncertainties associated with recharge to various hydrogeological units within the region.
- f. The model has not been adequately calibrated due to the lack of data. To address model uncertainties associated with an uncalibrated model, a probabilistic uncertainty analysis could also be undertaken as this will provide the bounds and likelihood of groundwater impacts. The location of further monitoring points and the necessity for specific data collection (e.g. pressure, etc.) could then be identified based on this uncertainty analysis which would enable a more robust transient calibration. This information will also help improve the understanding of the current conceptual model of the groundwater flow system. An ongoing uncertainty analysis should be included in all model updates.
- g. Consideration should be given to inclusion of the Bohena Creek alluvium as a model layer. Riparian vegetation communities along Bohena Creek are stated to be GDEs. Potential impacts to this area should be represented and accounted for in the groundwater model or, preferably, in a separate smaller scale (daughter) model that enables time-variable localised impacts to be considered.
- h. The Pilliga State Forest covers approximately 66% of the project site. Prior studies in the region have identified extensive areas of the Pilliga that are likely to have evapotranspiration rates in excess of local rainfall and hence are likely to utilise groundwater (Welsh et al. 2014). To ensure this process is adequately accounted for in the model, a suggested approach would be analysis of remotely sensed data through the use of surface energy balances such

as the Sebal algorithm (e.g. Bastiaanssen et al. 1998) to provide robust estimates of evapotranspiration in these areas of the model.

7. Uncertainties associated with each of these aspects have the potential to result in different predicted impacts to those presented in the EIS. Ongoing data collection and model refinement will reduce uncertainties in the model and improve confidence in model predictions.

Question 1

c) Does the IESC recommend any specific monitoring and data collection that should be undertaken, and when this monitoring should occur?

8. Strategic groundwater monitoring should be undertaken initially in areas of early field development to inform the ongoing adaptive management of project impacts. The monitoring network should include:
 - a. the collection of extraction rates and subsequent head data at production wells.
 - b. targeted groundwater monitoring wells at adequate depths and spatial variation, close to areas of early gas extraction to monitor the early propagation of groundwater depressurisation during production. This should also include monitoring of hydraulic head directly above and below the tightest formations (i.e. aquitards) to provide realistic observations of hydraulic gradients (refer to paragraph 6b).
 - c. monitoring bores within the Triassic units of the Gunnedah Basin, in particular within the Napperby and Digby Formations and targeted in areas of early development, to provide early warning triggers of the timing and extent of groundwater depressurisation.
9. The IESC agree with DPI Water that further field hydrogeological information should be obtained for the purpose of constraining model parameterisation. This groundwater monitoring network should be installed as soon as possible, prior to production, to further validate current baseline groundwater level, pressure and quality conditions and add to the existing baseline dataset for impact assessment.
10. During field installation of monitoring wells and ongoing field-based groundwater data collection, additional information on faults (e.g. presence or absence of gas shows in the Jurassic sequence), storativity and strata sub-crop should also be collected to improve the geological conceptualisation of structures and features that may influence the flow and flux of groundwater.
11. Primary data collection of aquifer hydraulic parameters through pump testing should also be undertaken to verify parameterisation in the model, with a particular focus on hydraulic conductivity and storativity. The measurement for realistic variations of storativity in the model, based on scaling up of in-situ measured storativity (Acworth et al. 2017, David et al. 2017) is particularly important as these values are a source of uncertainty in the model that has the potential to affect the magnitude and timing of drawdown.
12. The collection and analysis of isotope data could provide more confidence in the overall water balance, mixing, and conceptual models of geology and associated connectivity. Should outcomes of this analysis indicate a larger role of geological features of different/various scales on groundwater flow in the region, further consideration could be given to geophysical methods to inform the conceptual and geological model.

Question 2: Groundwater Impacts – Gunnedah-Oxley Basin

a) Does the IESC agree that the water extraction volumes have been adequately assessed, noting that it is likely to be small compared to the sustainable diversion limits?

13. The scenarios used in the groundwater model predictions are based on extraction volumes predicted from reservoir modelling (EIS, Appendix F, p. 8-2). As stated previously, details of reservoir modelling (e.g. gas saturation, porosity) associated with water production are not provided or discussed. Therefore, the IESC is unable to assess the veracity of the reservoir modelling and associated groundwater abstraction rates that have been subsequently employed in the groundwater model predictive simulations.

Question 2

b) If not, can the IESC identify whether any uncertainties in the assessment would result in a material impact in the context of the NSW Aquifer Interference Policy and other applicable regulatory requirements?

14. While predicted groundwater take from the Gunnedah-Oxley Basin may be small when compared to sustainable diversion limits, uncertainties (e.g. reservoir modelling values that have been transferred to the groundwater model) could have implications for model predictions of groundwater drawdown propagation into shallow aquifers and ultimately groundwater that would be utilised by GDEs and other users. In addition, if groundwater is extracted at a greater rate from a particular area or level, it has the potential to result in greater impacts than predicted.

15. If the extraction rate is greater than predicted in the groundwater model, there is potential for greater drawdown and flux that potentially could impact groundwater users and the GAB. Uncertainties which have the potential to lead to greater impacts than predicted in the assessment include:

- a. additional gas extraction in the shallower late Permian (Hoskissons seam) and areas where target formations sub-crop. This has the potential to result in larger areas of groundwater drawdown and depressurisation than currently predicted. This may have implications for the NSW AIP and relevant water sharing plans (also see responses to Questions 3 and 4).
- b. hydrogeological parameters that result in increased horizontal and vertical groundwater flux, which could result in larger magnitude and shorter timeframes of groundwater impact.
- c. the differences in modelling flux in production bores versus pressure head and whether modelling flux may potentially under-estimate impacts, especially at a distance from extraction points.

Question 2

c) Does the IESC recommend any additional measures to monitor and manage extraction of water from this water source?

16. The collection and use of actual flux and head data will be important to validate model predictions and ensure groundwater extraction volumes are within predicted estimates. If extraction exceeds predictions, the re-assessment of potential groundwater impacts may be required.

17. As noted in paragraph 6b and 8b, measuring of head directly above and below aquitard series would provide realistic observations of hydraulic gradients and help constrain aquitard hydraulic properties.

Question 3: Groundwater Impacts – Great Artesian Basin and Alluvial Aquifers

a) Does the IESC agree that the drawdown and induced water flows from these groundwater sources has been adequately assessed, noting that predicted induced flow is likely to be small compared to the sustainable diversion limits?

18. As mentioned in the response to Question 1a, the type and nature of modelling chosen for this project was to provide consistent water production (flux) estimates. While a valid method, this approach comes at the expense of accurate predictions of drawdown. To simulate predictions, pumping bores were assigned within the model layers representing the coal seam gas targets and the rates and volumes of extraction from the pumping bores were set equal to the rates and volumes of water production in the reservoir modelling. By their nature, reservoir models are generally designed to account for local scale, near well field conditions (i.e. dual porosity effects, dual phase flow and gas liberation). The extent to which near well field processes influence hydraulic head at a regional scale will depend on conditions that are specific to the well field and how they relate to the wider geological environment (Commonwealth of Australia, 2014). Measuring head directly above and below the tightest aquitard strata, together with production groundwater rates, would help constrain aquitard hydraulic properties.
19. The magnitude and severity of impact on the Pilliga Sandstone and Namoi Alluvium are dependent on the vertical hydraulic conductivity of aquitards in limiting the propagation of groundwater depressurisation. Changes to groundwater flux are likely to be reasonably predicted in the regional model; however, predictions of drawdown may not be adequately predicted at a local scale.

Question 3

b) If not, can the IESC identify whether any uncertainties in the assessment would result in a material impact in the context of the NSW Aquifer Interference Policy and other applicable regulatory requirements?

20. Uncertainties identified are associated with the conceptual model that is the basis for the numerical model; the presence and nature of faults as barrier or conduits for groundwater flow; hydraulic characterisation and parameterisation of all aquitards and inter-burden between coal seams; and recharge that influences groundwater flux and drawdown within the model. These uncertainties have the potential to result in a material impact in the context of the NSW Aquifer Interference Policy (AIP) as drawdown magnitude appears to be materially more important and uncertain than induced water flows. For example, research by Turnadge et al. (2017) to characterise aquitard properties has indicated that drawdown in the parts of the Pilliga Sandstone could be greater than the 2 metre threshold of the AIP where variable heterogeneous vertical hydraulic conductivity parameters for aquitards are considered.
21. In areas where the target formations subcrop beneath or adjacent to the alluvium, or where the Hoskissons seam is targeted in the north-western corner of the lease, there is potential for impacts on groundwater users of the GAB and Namoi alluvium. In the north-western section of the project area the Hoskissons seams is shallower compared to the Maules Creek Formation. Given the reduced depth to the Hoskissons seam, the north-western project area has the potential to have an increased risk of impact on groundwater users in this area.

Question 3

c) Does the IESC recommend any additional measures to monitor and manage potential impacts on these water sources?

22. Impacts to landholder bores are stated to be managed through 'make good' arrangements, but options for mitigating impacts on springs which are likely to be sourced from the Pilliga Sandstone are limited. To monitor potential impacts on springs, the installation of monitoring wells in locations along the likely groundwater flow paths to these springs for the purpose of early detection of potential impacts should be considered.
23. Measures to monitor and manage potential impacts on the GAB and alluvial aquifers include:
- a. additional monitoring in the vicinity of early extraction, with wells located near and above the extraction area to gain data on propagation rates to validate model predictions. In addition to monitoring wells in the Napperby Formation (refer to paragraphs 6b and 8b), further consideration could also be given to additional early warning monitoring bores within the Purlawaugh Formation (if possible), and the base of the Pilliga Sandstone located above the centre of the initial CSG production areas.
 - b. further interrogation of existing hydraulic conductivity and fault data to develop improved understanding of heterogeneity. This will help identify areas where depressurisation may propagate towards the Pilliga Sandstone and shallower aquifers, improving predictions and enabling early identification of areas at highest risk. This will also provide assurance that the extraction of groundwater from the late Permian will be as predicted in the EIS.
 - c. the model undergoing further pressure testing, including determining/evaluating which hydraulic conductivity parameters could lead to an impact exceeding the NSW AIP 2 metre minimum impact thresholds.
 - d. consideration given to the development of local scale daughter models.
24. Given the presence of other mining in the region, particularly the Narrabri Underground Coal mine and CSG production associated with the former Eastern Star development, model assumptions could be better further tested with existing drawdown associated with this mining. This would also provide further assessment of cumulative impacts in the area.
25. Should monitoring indicate larger impacts and short timeframes to impacts, the Water Management Plan should consider appropriate Trigger Action Response Plans (TARPs) and contingency measures. TARPs should be in place before the commencement of gas production and should not involve long investigative phases but rather consider immediate response measures.

Question 4: Surface Water Impacts – Produced Water Management

a) Does the IESC agree that produced water is able to be stored, treated and managed in a manner that would adequately minimise risks to surface water resources?

26. The management measures and facilities identified by the proponent appear to be generally appropriate for the management of co-produced water. However, further consideration in relation to the management options for the beneficial reuse and release of water and the management of salt and brine is needed to ensure risks to surface water and groundwater resources are adequately managed.

Question 4

b) If not, can the IESC identify material residual risks, and recommended any additional measures that should be implemented to address these matters?

27. The IESC considers there are remaining residual risks associated with the discharge of treated water, storage and potential unintentional releases of untreated water into nearby surface water or leakage into shallow groundwater. In addition, risks remain in relation to long-term legacy issues caused by the storage of salt and brine.

Discharge to Bohena Creek – Risk assessment

28. Treatment of produced water for discharge (as well as drilling, construction, dust suppression in forested areas and stock watering) includes removal of solids, reverse osmosis, removal of ammonia by chlorination followed by dechlorination and pH adjustment. To mitigate potential impacts of discharges to the environmental values of Bohena Creek, it is proposed that discharge of treated water will only occur during high flow, defined as 100 ML/day (at the Bureau of Meteorology (BoM) station number 419905). These discharge conditions will most likely coincide with wet weather when other beneficial reuse options are unavailable.
29. The empirical mixing zone model “CORMIX”, assumes at least a 1:10 dilution of treated discharge water after mixing with Bohena Creek (EIS, Appendix G1, Appendix E). However, the chemical risk assessment is based on achieving a 1:40 dilution (EIS, Appendix T3, p. 82). Therefore, the calculated exposure concentrations used in the risk assessment are 4 times lower than those assessed in the mixing zone study. Clarification in relation to this inconsistency is needed as this may have implications for the Hazard Quotients (HQ) and level of estimated risk to downstream ecosystems.
30. Of particular concern is the estimated concentration of ammonia. Tables 6-4, 6-6 and F-1 within EIS, Appendix T3 estimate ammonia to be 6-10 mg/L in treated discharge water as well as after mixing with Bohena Creek, despite a dilution factor of 40. These concentrations are an order of magnitude above the ANZECC/ARMCANZ (2000) ammonia guideline value. It is noted that the mixing zone study only considers 10 water quality parameters, of which ammonia is not included (EIS, Appendix G1, Appendix E, Table 3).
31. Further limitations of the risk assessment and direct toxicity assessment include:
- a. an absence of aquatic biota data used in the effects assessment (only data on mammals and birds were used to derive HQs)
 - b. site-specific guidelines for boron and fluoride were derived incorrectly. This has resulted in more conservative values than if undertaken appropriately, although less conservative for boron than the current ANZECC/ARMCANZ (2000) guideline value.

Discharge to Bohena Creek – Characterising discharge events

32. The Managed Release Study (EIS, Appendix G1, p. 41) notes that predicted releases per release event are most likely less than 200 ML total (or 16 ML/day over 12 days), but higher volume releases are possible. The volume and duration limits (including proposed daily maximum discharge) of discharge events should be specified as this will alter the amount of contaminant dilution. These limits should be provided in daily and cumulative totals and as a proportion of total flows in Bohena Creek during discharge (e.g. ratio of discharge to natural creek water). This will be especially relevant on the falling limb of the Bohena Creek hydrograph where residual discharges and decreasing creek flows could result in a rise in contaminant concentration.

33. The proponent does not provide predictions of temporal variation in contaminants (e.g. ammonia, mercury, copper, boron, fluoride) to Bohena Creek. Contaminants percolating through the alluvial sediments and leaving residues behind can cause subsequent first flow pulses containing high contaminant concentrations that pose a potential water quality risk.

Water balance modelling

34. Confidence in the water balance modelling is low for the reasons listed in paragraphs 35 to 39 below.
35. The volume of water to be used for irrigation, dust suppression, drilling and release during the first four years is entirely dependent on the groundwater model's water extraction volume input but it was not possible for the IESC to assess the veracity of this value as the reservoir modelling report was not provided. The water balance is run with an assumed treated water volume of 12 ML/day, which is marginally greater than the 10 ML/day of co-produced water predicted to be extracted under the groundwater model 'Base Case' simulation. Conducting sensitivity analyses on parameters used in the water balance would reduce uncertainty in the water balance predictions by providing upper and lower ranges of conditions under which discharge (and other beneficial uses of treated water) could potentially occur. In addition, running the water balance to test the management system's ability to handle produced water volumes up to the 'High Case' of approximately 20 ML/day would provide an upper limit of water management requirements.
36. Reports provided for the water balance assume that if all beneficial uses (drilling, construction, irrigation, stock watering, dust suppression and discharge) are unavailable to the proponent, water will be stored in the proposed 200 ML storage or at the Leewood storage. Limited detail is provided regarding the storage and transfer of produced water and its associated waste products. The proponent has not identified alternative or contingency actions if all storages (Leewood, Bibblewindi and the proposed storage dam) are at maximum capacity.
37. The water balance presents results in terms of monthly probabilities, based on 50 years of rainfall data. There are at least three different rainfall gauges (BoM stations 054120, 053026, 053016) close to the Narrabri West Post Office (station 053030) which could be used to provide more than 100 years of daily rainfall. Using more than 100 years of rainfall data would provide a greater statistical range of probable weather conditions to estimate the regularity of flows greater than 100 ML/day in Bohena Creek.
38. The Runoff-Flow model frequently over-predicts the length of flow durations in Bohena Creek (for flows greater than 100 ML, EIS, Appendix G1, p. 53). Presenting the water balance as the daily probability of being able to discharge rather than the monthly probability would improve confidence in the water balance results. This would in turn reduce uncertainty in the proposed water management system's ability to adequately cope with produced water under a greater range of potential climatic conditions.
39. The flood monitoring gauge in Bohena Creek needs to be updated to ensure it is adequate to determine when flows in Bohena Creek are greater than 100 ML/day and trigger a start or stop of release. The NSW EPA has highlighted that the location of the gauge is 6 to 8 km downstream from the discharge location and it is not located in an appropriate location within the stream channel. The IESC supports the NSW EPA recommendations to upgrade the gauge, including moving it to the centre of the flow channel and, when automatic flow logging commences, reducing the flow velocity trigger to below 100 ML/day (currently at 1000 ML/day). The IESC considers that an additional gauge located closer to the discharge location, preferably just upstream of the outflow, should be installed and used to determine flow conditions suitable for commencement and cessation of discharges.

Salt management

40. The long-term salt storage and management requirements of the proposed project need to be clearly resolved by the proponent. These should include:
 - a. consideration of other contaminants of concern (e.g. metals, organics, radionuclides that might be present within salt crystallised during the brine management process) to ensure that salt waste is appropriately classified for management and disposal.
 - b. assessing the potential risks associated with leaching of residual salt stored on-site and potentially disposed of within landfills. This has not been addressed apart from the statement that salt waste is to be stored in a weather-proof structure.
 - c. identification of all potential options (including preferred, available and contingency options) for long-term disposal of salt waste, which is estimated to peak at 115 tonnes per day in years two to four. The assessment relies on the assumption that landfills appropriately licensed to accept this waste exist nearby. The proponent has identified potential landfill facilities for disposal in the region but notes that most have limited capacity for additional waste.

Co-produced water and waste management

41. The IESC notes that at the Leewood Water Management Facility, produced water would be treated via a number of processes and reused for drilling, construction, dust suppression in forested areas, and irrigation, with releases to Bohena Creek occurring infrequently. Post-treatment water quality amendment for sodium adsorption ratio (SAR) or pH would also be undertaken for irrigation, as well as dust suppression in non-forested areas, drilling and stock watering, but not for direct discharge into Bohena Creek.
42. Used drilling fluid is proposed to be stored and treated at a previously approved drilling fluid treatment facility at the Narrabri Operations Centre. Prior to reuse, drilling fluid will be tested and amended according to a Fluids Management Plan. To determine the potential risks associated with management of drilling fluids, the proponent needs to provide or detail the key measures proposed to be included in the Fluids Management Plan.
43. The approximate quantities of drilling waste, produced water and its associated waste products (e.g. brine, salt, filter solids etc.) are listed in Table 28-3 and Table 28-6 of the EIS. The storage, collection and disposal of these substances and the potential risks to water resources associated with these activities also need to be assessed and detailed within the EIS.
44. The IESC suggests the following measures to manage risks associated with waste streams.
 - a. Drilling fluid should be kept separate from co-produced water waste streams, with appropriate monitoring, onsite management and disposal. Monitoring of relevant analytes should be undertaken to inform appropriate management options and waste classification.
 - b. Water used for dust suppression should be at a quality that will not degrade nearby surface water features and terrestrial vegetation.
 - c. The proponent states that water application rates to land through irrigation would be consistent with or better than bore water. The irrigation model also indicates that small amounts of sediment and nutrients would be carried in run-off which would be mitigated by an Irrigation Management Plan. Limitations identified in the water balance model (paragraphs 35 to 39) and the lack of site-specific soil studies should be addressed to support this.

Drilling chemicals

45. While the IESC acknowledges that some or all of the chemicals proposed to be utilised while drilling coal seam gas extraction are also utilised for other (including potentially civil) drilling activities, these chemicals are considered to be industrial chemicals and should have their hazards and risks rigorously and transparently assessed. Where required, appropriate risk mitigation processes should be implemented. Chemical risk assessments should be informed by appropriate physio-chemical, ecotoxicological and site-specific monitoring data. The use of any chemicals that have not had their risks assessed should be avoided until an assessment has been undertaken. In particular:
- a. a range of water management chemicals identified in the EIS (Appendix T3, pp. 35 – 36) do not have their Chemical Abstract Service (CAS) registered number presented. These numbers are needed to determine the environmental risks associated with their use.
 - b. the drilling chemicals crystalline silica, tridymite (CAS RN 15468-32-3) and cellophane (CAS RN 9005-81-6) have not been listed in the Australian Inventory of Chemical Substances (AICS) maintained by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS). The proponent should confirm with NICNAS that these chemicals are able to be imported for use in Australia.
 - c. the chemicals below identified by the proponent predate the *Industrial Chemicals (Notification and Assessment) Act 1989* and therefore their risks (if any) may not have yet been assessed or characterised.
 - i. Copolymer of acrylamide and potassium acrylate (CAS RN 31212-13-2);
 - ii. Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione (Dazomet) (CAS RN 533-74-4);
 - iii. Methylisothiocyanate (MITC) (CAS RN 556-61-6); and
 - iv. Polyalkylene (CAS RN 9038-95-3).

Question 4

c) Does the IESC recommend any additional measures for the storage, treatment, management and/or monitoring of produced water to address residual risks?

46. The IESC has identified in the response to Question 4b measures additional to those proposed for the management of waste generated by the project.
47. To address residual risks due to discharges into Bohena Creek, the following measures could be considered:
- a. To confirm modelled predictions of mixed water quality, monitoring of potential contaminants should be undertaken with “Limits of Detection” sensitive enough to detect adopted trigger values.
 - b. Be consistent with ANZECC/ARMCANZ (2000), until a complete dataset is available to derive site-specific trigger values, it is preferable to adopt an interim trigger value for electrical conductivity using the existing 80th percentile (i.e. approximately 200 $\mu\text{S}/\text{cm}$ rather than the default upland river trigger value of 350 $\mu\text{S}/\text{cm}$).
 - c. The managed release study risk estimation considers the potential for the ionic composition of mixed water to be inconsistent with that of the receiving environment. The proponent states that “since treated water will be released under flowing conditions with dilution levels at a

mixing ratio of a minimum of approximately 10:1, the negative effects of ion imbalance are unlikely to occur, and risks are considered low” (EIS, Appendix A of Appendix G1, p. 30). The proponent should verify this conclusion with future monitoring data.

48. The proponent proposes to amend treated water to improve SAR prior to irrigation but has not committed to amending treated water prior to discharge. The IESC considers that the quality of water proposed to be discharged should be amended to an equivalent quality (including SAR), or better, to the quality conditions of receiving waters in Bohena Creek.
49. Table 9-2 also specifies mitigation measures for treated water exceedances of trigger values for contaminants such as ammonia, mercury, copper, boron, fluoride, and other parameters (EIS, Appendix G1, pp. 81-82). These measures should be further detailed in the Water Monitoring Plan.
50. The water monitoring plan identifies monitoring parameters and frequencies that should be refined commensurate with the risk of impact to the receiving environment. Receiving environment monitoring parameters include physio-chemical, major ions and “other analytes as appropriate”. The proponent should specify all monitoring parameters, and include key contaminants (e.g. mercury, boron, ammonia) identified in the impact assessment. Monitoring should be undertaken before, during and after release, not just after release.
51. One Bohena Creek water sample was tested for toxicity on one occasion when it was used as the diluent and control water in the boron and fluoride tests to derive site-specific guidelines for these elements. In Appendix G1 (p. 85), the proponent suggests they will “reappraise the toxicity of treated water for release to the creek ... annually for 5 years post commissioning”; however, this has not been included in the monitoring plan. The IESC suggests that the proponent should consider ecotoxicity testing of Bohena Creek water immediately after discharge (upstream and downstream comparison), as well as toxicity testing of treated water before discharge.

Question 5: Groundwater Dependent Ecosystems

a) Does the IESC agree that the potential impacts to GDEs have been adequately assessed, and that the project is unlikely to have a significant impact on GDEs in the locality?

52. The adequacy of the impact assessments for the range of GDEs within the project area varies. The uneven risk assessment and survey effort result in uncertainties in impact predictions as the proponent did not consistently consider all potential GDEs within the project area.

Type 1 GDEs (aquifer and stygofauna ecosystems)

53. The limited field sampling (from five shallow pits and nine bores that were sampled only once, Table 4 in EIS, Appendix C of Appendix G1) in the project area yielded no stygofauna. As stated by the proponent, stygofauna generally occur in low densities and the lack of animals does not conclusively indicate their absence from the site. At least 7 taxa of stygofauna have been collected from 15 monitoring bores in the Namoi River alluvial aquifer near Wee Waa, approximately 50 km west-northwest (and downstream) of Narrabri (Korbel 2012). Further stygofaunal sampling should be undertaken, especially in the hyporheic zone of Bohena Creek and associated alluvium.
54. Although stygofauna probably do not inhabit saline waters at great depths (greater than 500 metres below ground level) in the project area, they are likely to occur in shallow freshwater and alluvial aquifers where groundwater or colonization sources persist (e.g. connected alluvial systems). Changes to groundwater quality (e.g. temperature, chemical composition), organic matter supply and subsurface flow paths (e.g. away from colonists’ source habitats) have the potential to impact on these Type 1 GDEs.

Type 2 GDEs (ecosystems that depend on surface expression of groundwater)

55. Based on desktop analysis followed by hydrogeological conceptualisations of the sites, the proponent reduced 54 potential Type 2 GDEs down to nine (EIS, Table 5.1, Fig. 5.1, Appendix B of Appendix F). These nine GDEs were judged to have 'low ecological values' because the sites were modified and lacked protected or important wetland species. However, DPI Water classifies two of these GDEs (Hardys Spring and Eather Spring) as high priority GDEs due to the value of the groundwater source from which they originate, and both springs are identified by the Nature Conservancy Australia as having high ecological value (EIS, Table 5-1, Appendix B of Appendix F). Neither GDE was visited. The remaining seven Type 2 GDEs were either sampled once or not at all.
56. Field sampling at each of these nominated Type 2 GDEs was inadequate to fully assess site-specific potential impacts or to provide suitable baseline data for monitoring ecological responses due to altered groundwater regimes that may be caused by the project. Given that several of the nine Type 2 GDE sites were not sampled, the absence of important or threatened species has been inferred rather than verified from field assessment.
57. The identification of the source(s) of water to high priority GDEs (e.g. Hardys and Eather Springs) should include isotope and geochemical tracer studies. Field data on water level and/or flow to these spring GDEs should be obtained under baseline conditions along with estimated sensitivity to changes attributed to variable climatic conditions and/or CSG related impacts.
58. The proponent states that it is likely that shallow groundwater in the alluvium of Bohena Creek and Jacks Creek provides base flow during dry periods and is most likely a source of water to riparian vegetation and aquatic flora and fauna associated with pools in these creeks. However, no evidence is provided to support the subsequent claim that less than 0.5 metres drawdown in the shallow alluvium will result in no significant ecological impacts to low flows, the persistence of remnant pools, or groundwater levels adjacent to ephemeral creeks. In pools connected by subsurface flow along low-gradient stream beds (e.g. Bohena Creek and Jacks Creek), a drawdown of 0.2-0.5 metres may alter low flows and the persistence of pools connected by subsurface flow potentially impacting biota that rely on shallow refugial pools as drought refuges. To assess the likelihood and severity of these potential impacts, the proponent needs to undertake field analysis targeting locations identified by detailed hydrogeological and ecological conceptualisations that are likely to be inhabited by Type 2 GDEs.

Type 3 GDEs (ecosystems such as vegetation that depend on subsurface presence of groundwater)

59. The Type 3 GDEs identified by the proponent were considered 'potential' GDEs because there was no field data to verify whether the vegetation communities access groundwater (EIS, p 4-32, Appendix F). Two vegetation communities (Fuzzy Box Woodland and Carbeen Open Forest community), predominantly occurring in riparian areas of Bohena Creek and its tributaries, are listed as Endangered under the NSW *Threatened Species Conservation Act 1995* (TSC Act). There are several other Type 3 GDE communities mapped along Bohena Creek and its tributaries (EIS, Fig 5-2 in Appendix B of Appendix F). Given the likely changes to the flow regime in Bohena Creek due to water releases, the groundwater regime supplying these Type 3 GDEs may be altered and potentially impair recruitment and/or persistence of these vegetation communities.
60. The riparian Type 3 GDEs along Bohena and its tributaries are disproportionately important in the landscape because they are in moderate-good condition and provide crucial ecological connectivity to the broader Pilliga State Forest (EIS, p 71 Appendix C of Appendix G1). These riparian zones also included most of the potential habitat for Koalas (EIS, Chap. 15, Fig 15-7). Therefore, their accurate field-mapping is crucial, and assessment should span the full GDE study area illustrated in the EIS, Fig 5-2 (Appendix B of Appendix F). Given the limited field assessment

and lack of knowledge about obligate and facultative groundwater dependency of the Type 3 GDEs in the project area, there is not enough information to assert that a drawdown of greater than 0.5 metres is unlikely to have an impact on these GDEs.

61. The potential combined impacts of disruption of surface runoff and vegetation fragmentation caused by the construction of 425 well pads and the interconnecting network of roads, especially in the Pilliga State Forest, has not been adequately assessed. Although this vegetation might not all be Type 3 GDEs, the impacts of altered runoff and vegetation fragmentation should be considered by the proponent.

Question 5

b) If not, can the IESC identify whether any uncertainties in the assessment would result in a material change to the potential impacts on GDEs?

62. The proponent states that there are no potential Type 1 GDEs identified in the project area (EIS, Appendix B of Appendix F, p.vi). This claim is based on very limited field sampling (paragraph 53); however, other studies (e.g. Korbel 2012) have recorded stygofauna in the Namoi River alluvial aquifer approximately 50 km from the project area. If additional sampling (see response to Question 5c) collected stygofauna, then assessment of potential impacts on this GDE, especially in the shallow alluvium and hyporheic zone of Bohena Creek, is warranted.
63. Mapping of potential Type 2 and Type 3 GDEs in the project area relies primarily on desktop assessments. All desktop assessments are prone to uncertainty, and there is a risk that GDEs may have been missed in the absence of detailed field surveys, especially outside the project area and within the projected zone of potential groundwater drawdown. The proponent admits that the degree of groundwater dependency is frequently unknown, reducing reliability of assessments on the likelihood of impacts to Type 2 and Type 3 GDEs caused by a drawdown of less than 0.5 metres and/or altered flow regimes in Bohena Creek. As some of these GDEs (e.g. Fuzzy Box Woodland and Carbeen Open Forest community) are listed as Endangered, these uncertainties in field assessment may hamper the development of effective management measures to protect these important GDEs.
64. Consideration of alternative hydrogeological conceptualisations and their incorporation into ecological conceptual models is needed to identify priority areas where vegetation GDEs (Type 3) potentially occur. This would help rule out areas where GDEs could not occur. Consideration should be given to determining if vegetation in the Pilliga Forest (both in State Forest and the National Park) is preferentially utilising perched aquifers, as opposed to the regional groundwater system, where surface water systems are not a key water source.

Question 5

c) Does the IESC recommend any specific additional monitoring and management measures for GDEs?

65. The IESC considers that additional monitoring and management measures are needed to test the proponent's predictions that the project presents a low risk to GDEs.
- a. Groundwater monitoring locations should be closer to relevant GDEs. The only intended monitoring is of groundwater level and pressure within the groundwater monitoring network through the Water Monitoring Plan. The monitoring locations (EIS, Fig 3-9, Appendix G3, p. 3-23) for shallow groundwater (the assumed source for potential GDEs) are too far from the locations of most of the GDEs (EIS, Ch. 11, Fig 11-8, p. 11-43).

- b. Baseline field-based ecological monitoring (especially of the Fuzzy Box Woodland and Carbeen Open Forest community) in conjunction with remote sensing (e.g. methods outlined in Emelyanova et al. (in press)) needs to be undertaken, with suitable management measures tailored for implementation based on the results of the monitoring program.
- c. The proponent claims that the nine potential Type 2 GDEs identified in the project area have 'low ecological values'. However, the GDE risk assessment guidelines by Serov et al. (2012) recommend continued long-term monitoring for GDEs deemed to have low ecological values and low risk. Although the proponent commits to monitoring groundwater level and pressure within its groundwater monitoring network through the NGP Water Monitoring Plan, the IESC considers:
 - i. monitoring programs for these nine GDEs, along with Bohena Creek and its tributaries, should also sample suitable ecological parameters and include indicators likely to provide early warning of deteriorating condition due to altered groundwater regimes. These monitoring data would guide implementation of appropriate adaptive management measures as well as provide important baseline data against which to judge temporal trends in ecological condition of these GDEs, including changes in response to water releases in Bohena Creek.
 - ii. trigger levels based on groundwater data collected close to GDEs and matched with concurrent monitoring of the structure and composition of the ecological communities are needed. For all GDEs, there is no monitoring planned for detecting potential changes in the structure or composition of the ecological communities. Proposed triggers are only for groundwater level and pressure in general and are not related to site specific changes at any of the potential GDEs. Given the long time-lag for these triggers (three or more consecutive years of higher produced water rates than predicted (Level 1), or a greater decline in groundwater pressure in the Gunnedah Oxley Basin Triassic aged sediments than predicted by modelling (Level 2) (EIS, Appendix G3, Table 3-10, p. 3-27)), there may be irreversible impacts to GDEs.

Date of advice	8 August 2017
Source documentation available to the IESC in the formulation of this advice	<p>Santos, 2017. Narrabri Gas Project, Environmental Impact Statement.</p> <p>Santos, 2017. Appendices to Narrabri Gas Project, Environmental Impact Statement.</p> <p>NSW Department of Primary Industries (Water), 2017. Narrabri Gas Project (SSD 6456) Comment on the Environmental Impact Statement (EIS).</p> <p>NSW Environment Protection Authority, 2017. Narrabri Gas Project (SSD 6456) Comment on the Environmental Impact Statement (EIS).</p> <p>NSW Department of Planning and Environment (Resources and Geoscience), 2017. Narrabri Gas Project – Environmental Impact Statement Review.</p>
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