



Narrabri Gas Project

State Significant Development

SSD 6367

June 2020

Published by the NSW Department of Planning, Industry and Environment

dpie.nsw.gov.au

Title: Narrabri Gas Project

Cover image: *Gas well, courtesy of Santos*

© State of New South Wales through Department of Planning, Industry and Environment 2020. You may copy, distribute, display, download and otherwise freely deal with this publication for any purpose, provided that you attribute the Department of Planning, Industry and Environment as the owner. However, you must obtain permission if you wish to charge others for access to the publication (other than at cost); include the publication in advertising or a product for sale; modify the publication; or republish the publication on a website. You may freely link to the publication on a departmental website.

Disclaimer: The information contained in this publication is based on knowledge and understanding at the time of writing (June 2020) and may not be accurate, current or complete. The State of New South Wales (including the NSW Department of Planning, Industry and Environment), the author and the publisher take no responsibility, and will accept no liability, for the accuracy, currency, reliability or correctness of any information included in the document (including material provided by third parties). Readers should make their own inquiries and rely on their own advice when making decisions related to material contained in this publication.

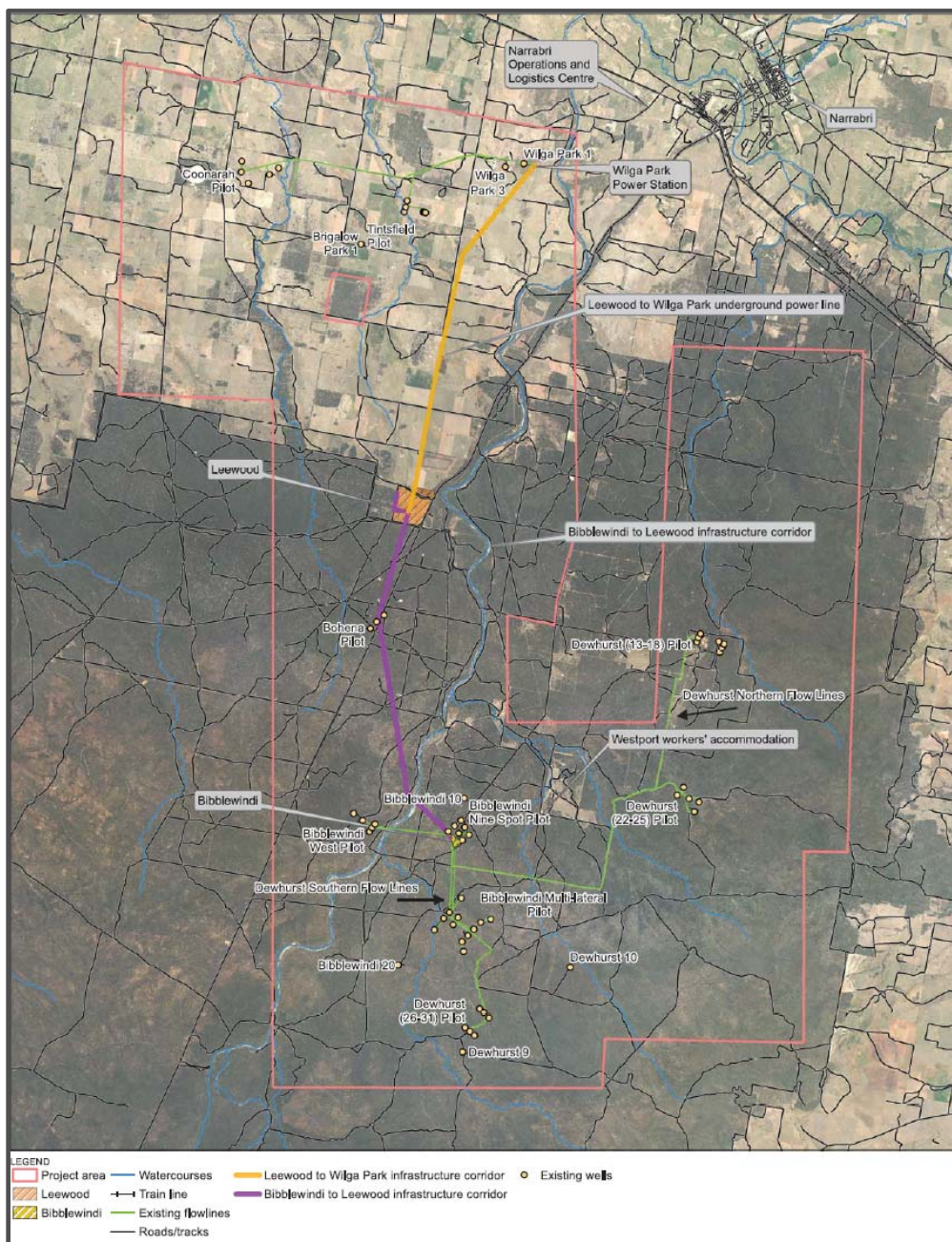
Executive Summary

Overview

Santos proposes to develop the Narrabri Gas Project on around 1,000 hectares of a larger 95,000-hectare site in the Pilliga State Forest and on adjoining grazing land in north-western NSW about 25 kilometres to the south-west of Narrabri.

The project involves drilling up to 850 coal seam gas wells to produce up to 200 terajoules (TJ) of gas a day for the domestic gas market over a period of at least 20 years, which is enough to supply up to 50% of NSW's gas demand.

It is classified as a Strategic Energy Project and has a capital investment value of \$3.6 billion and would create 1,300 jobs during construction and 200 jobs during operations.



The community has raised significant concerns about the project saying it would damage the region's water resources, cause significant biodiversity impacts on the Pilliga State Forest, generate substantial greenhouse gas emissions, and adversely affect the health, safety and cohesion of the local community. Following extensive community consultation and investigations, the Department of Planning, Industry and Environment (Department) has completed its detailed assessment of the merits of the project.

This assessment was informed by advice from Narrabri Shire Council, government agencies and independent experts, including a Water Expert Panel which was specifically set up for the project, and has concluded that the project:

- is critical for energy security and reliability in NSW as it would:
 - provide essential gas supplies to the domestic market to address forecast shortfalls from 2024;
 - facilitate the extension of the existing gas pipeline network to northern NSW, bringing it closer to the strategic gas supplies in both Queensland and the Northern Territory;
 - support the development of gas-fired power stations in NSW to provide dispatchable energy to the National Electricity Market (NEM) as it transitions away from a long-term reliance on coal-fired power stations to a greater reliance on renewable energy; and
 - put downward pressure on gas prices;
- deliver significant economic benefits to NSW and the Narrabri region and stimulate the economic recovery from the effects of the COVID-19 pandemic, including:
 - creating jobs and attracting investment to the region;
 - providing up to \$14.5 million to Narrabri Shire Council for community projects and infrastructure;
 - setting up a Community Benefit Fund with up to \$120 million to share the benefits of the project with the local community; and
 - facilitating economic development in Narrabri, including the development of a new industrial estate;
- has been designed to minimise any impacts on the region's significant water resources, including the Great Artesian Basin, the biodiversity and heritage values of the Pilliga State Forest, and the health and safety of the local community;
- would comply with the relevant requirements and standards in government legislation, policies and guidelines;
- would not result in any significant impacts on people or the environment; and that
- any residual impacts of the project can be reduced to an acceptable level by capping total water extraction to 37.5 gigalitres (GL) over the life of the project and requiring Santos to comply with strict standards, rehabilitate the site to a high standard and offset the biodiversity impacts of the project.

The Department has recommended a comprehensive suite of strict conditions, which have been developed in consultation with key government agencies and independent experts, to ensure this occurs.

Based on this assessment, the Department considers the project is in the public interest and is approvable subject to strict conditions.

Narrabri Gas Project

The Narrabri Gas Project involves developing a new coal seam gas field and associated infrastructure over 95,000 hectares in north-western NSW near Narrabri over 25 years.

This includes:

- drilling up to 850 gas wells on up to 425 well pads to extract the extensive gas resources trapped within the deep coal seams of the Gunnedah Basin, with 95% of this extraction to come from the Maules Creek Formation (800-1,200 metres below ground), and the remainder to come from the Black Jack Group (around 500 metres below ground);
- producing up to 200 TJ of gas a day for the domestic market;
- expanding the existing gas exploration infrastructure on site, including the Bibblewindi and Leewood gas and water processing facilities;
- extracting up to 37.5 GL of saline water from the coal seams over the life of the project, at an average of around 4 megalitres (ML) a day to enable the gas to flow to the surface;
- treating all this produced water to a suitable standard to enable its reuse (for dust suppression, production or irrigation) or discharge to Bohena Creek under high flows;
- implementing mitigation measures to minimise the economic, social and environmental impacts of the project, including:
 - avoiding carrying out development in sensitive areas, such as the Brigalow State Conservation Area and Brigalow Nature Reserve;
 - locating well pads in accordance with a detailed Field Development Protocol, and avoiding (to the greatest extent practicable) heritage items, endangered ecological communities and threatened species habitat;
 - only developing wells and infrastructure on privately-owned land with the agreement of the landowner; and
 - drilling, operating and abandoning all gas wells in strict accordance with the NSW Government's *Code of Practice for Coal Seam Gas Well Integrity* (Well Integrity Code), which reflects international best practice and has been designed to protect land and water resources from any adverse impacts in perpetuity;
- progressively rehabilitating the site; and
- offsetting any residual biodiversity impacts in accordance with the *NSW Biodiversity Offsets Policy for Major Projects 2014* (Major Projects Offsets Policy).

Although the Narrabri Gas Project requires a connection to the existing pipeline network in NSW, Santos is not seeking approval for this pipeline as part of the project as it is likely to be delivered by another party and to be subject to a separate approvals process.

At present, there are two options:

- connecting the project to the approved Queensland-Hunter gas pipeline located to the east of the site; or
- developing the proposed Western Slopes Pipeline, which would connect the project to the Moomba-Sydney pipeline to the west of the site.

Given the uncertainties with both options, Santos has agreed to accept a condition requiring it to ensure there is an approved pipeline connection for the project prior to construction and that the pipeline is in place prior to starting any gas production.

The Department has included this in the recommended conditions.

State Significant Development

The project is classified as State Significant Development and requires the approval of the Independent Planning Commission of NSW (Commission) under the *Environmental Planning & Assessment Act 1979* before it may proceed.

The Minister for Planning and Public Spaces has asked the Commission to hold a public hearing prior to making a final decision on the project.

This report is designed to inform the community about the detailed assessment and to assist the Commission weigh up the merits of the project in accordance with the requirements of the EP&A Act.

Commonwealth Approval

The project is a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) because it could have significant impacts on Commonwealth-listed threatened species and communities, water resources and the Siding Springs Observatory.

Consequently, it requires the approval of the Commonwealth Minister for the Environment in addition to any State approvals.

Under the Bilateral Agreement between the NSW and Commonwealth governments, all Commonwealth matters will be assessed under the State process, and the Commonwealth Minister will consider the Department's assessment report prior to making a final decision under the EPBC Act.

Engagement

The Department has consulted widely with the community, special interest groups and government agencies during the assessment of the Narrabri Gas Project.

This consultation has included:

- making all the information on the project publicly available on the Department's website;
- exhibiting the EIS from 21 February to 22 May 2017 (90 days);
- holding several public information sessions in Narrabri during the exhibition;
- publishing copies of all the submissions received online;
- requiring Santos to provide a formal response to the issues raised in submissions;
- holding meetings with key stakeholders, including:
 - Narrabri Shire Council;
 - the community consultative committee for the project;
 - landholders in the project area;
 - several special interest groups, including the North West Alliance, People for the Plains, Lock the Gate, Environment Defenders Office, Artesian Water Users Group, Namoi Water, NSW Farmers Association, NSW Country Women's Association, and Nature Conservation Council; and
 - Aboriginal groups, including the Narrabri Local Aboriginal Land Council (LALC), Wee Waa LALC and Dharriwaa Elders Group;
- meeting with the Commonwealth Independent Expert Scientific Committee (IESC); and
- working closely with government agencies on the assessment of key issues.

During this consultation, the Department has gained a better understanding of key issues and the community's concerns about the project which has informed its detailed assessment of the merits of the project.

Submissions

During exhibition, the Department received nearly 23,000 submissions on the project, including 17 from government agencies, 133 from special interest groups, and 22,721 from the general public.

Over 70% of the submissions were form letters, however there were several submissions from special interest groups that included detailed reports from technical experts.

Most of the submissions (98%) were against the project, although a breakdown of submissions from the local area shows a broader spectrum of views with nearly 37% of these submissions supporting the project.

In summary, the submissions raised three key strategic concerns.

First, they were almost universally opposed to gas development in NSW. They argued that urgent action is required to address climate change, and that NSW should be doing everything it can to transition away from fossil fuels, such as coal and gas, towards a greater reliance on renewable energy (wind, solar, battery storage and pumped hydro).

Second, they were concerned about the risks of non-conventional gas development more generally, reiterating many of the concerns that were raised during the NSW Chief Scientist and Engineer's review of coal seam gas development in NSW in 2013-14 and in other jurisdictions across Australia and overseas.

This included concerns about the:

- impacts on land and water resources, including the impacts of fracking;
- health and safety risks for local communities, including the air emissions and exposure to toxic chemicals;
- the trustworthiness of the gas industry; and
- the ability of government to properly regulate the industry.

Third, they criticised the strategic justification for the Narrabri Gas Project and the assessment of its impacts, including the:

- strategic benefits of the project, saying there was no guarantee the gas would go to the domestic market;
- design of the project and lack of certainty about the layout given the location of the gas wells would only be finalised following approval and further appraisal;
- technical studies assessing the impacts of the project including the baseline data; assumptions and methods used; predictions; uncertainties involved and inadequate assessment of cumulative impacts assessment; and
- likely impacts of the project.

In terms of impacts, the submissions focused on four key issues: the impacts of the project on the region's significant water resources; its impacts on the biodiversity values of the Pilliga State Forest; the greenhouse gas emissions of the project; and its impacts on the local community.

Santos has provided a formal response to the issues raised in submissions and maintains the project should be approved subject to the proposed mitigation measures and offsets.

Assessment

The Department has completed a detailed assessment of the merits of the project.

This assessment has included examining the findings of several studies, inquiries, assessments, policies and guidelines that are relevant to the Narrabri Gas Project, including:

- reviewing the experience of other jurisdictions in Australia and overseas in assessing and regulating the impacts of non-conventional gas development, including the findings of several major public inquiries;
- conducting a field trip to the gas fields in the Surat Basin in Queensland to meet with Queensland regulatory agencies and landholders, inspect several coal seam gas operations, and get a better understanding of some of the challenges associated with the rapid growth of coal seam gas in this region and the impacts of this development;
- considering the findings and detailed recommendations of the NSW Chief Scientist and Engineer's review into coal seam gas activities in NSW and the Government's response to these recommendations, including the *NSW Gas Plan* which sets the strategic framework for gas development in NSW;
- analysing several large-scale environmental studies, regional data sets and coal seam gas research papers, including the:
 - Commonwealth's *Bioregional Assessment of the Northern Inland Catchments*, which collects a range of scientific information on the land and water resources in the region;
 - *Namoi Catchment Water Study*, which considered the potential cumulative impacts of coal seam gas and mining activities within the Namoi catchment;
 - studies undertaken by the CSIRO's Gas Industry Social and Environmental Research Alliance (GISERA), some of which were directly related to the Narrabri Gas Project; and
 - research on coal seam gas published by the IESC; and
 - having regard to key legislation, policies and guidelines that set standards for acceptable environmental performance in NSW, including the
 - *NSW Aquifer Interference Policy* and applicable Water Sharing Plans under the *Water Management Act 2000*;
 - NSW codes of practice for coal seam gas, including the Well Integrity Code;
 - Major Projects Offsets Policy;
 - *NSW Noise Policy for Industry*; and
 - *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales*.

It also included visiting the site and surrounds several times, meeting with landholders in the project area and reviewing Santos' EIS, specialist studies, community concerns, Santos' response to submissions and technical advice from key government agencies.

Finally, the Department obtained advice from independent experts.

Due to significant community concerns about land and water impacts, the Department established an independent Water Expert Panel (WEP) for the project. The panel was chaired by Professor Peter Cook (geologist) from the University of Melbourne and was comprised of Professor John Carter (geotechnical engineer), Professor Chris Fell (chemical engineer) and Michael Williams (hydrogeologist).

The WEP reviewed the experience gained from non-conventional gas development in Australia and internationally, the findings of prior coal seam gas investigations in the Narrabri area, and the detailed specialist studies carried out for the Narrabri Gas Project. It met with experts in government agencies, special interest groups, industry, community leaders, farmers, landholders, regulators, and Santos' employees and consultants. It also undertook field inspections of the site and surrounds.

In its detailed investigations, the WEP did not identify any land or water issues that were likely to result in significant impacts on people or the environment or that could not be managed to ensure all applicable government standards or codes are met.

While the WEP identified some uncertainties, principally due to the lack of detailed information about the deeper geological substrata, it concluded these uncertainties “*could be addressed through ongoing monitoring, adaptive management and a robust regulatory regime that is rigorously and effectively enforced.*”

The final WEP report included 32 recommendations and 27 observations, which have been incorporated into the recommended conditions. The WEP has subsequently reviewed and endorsed the recommended conditions.

In addition to the WEP, the Department sought independent expert advice on the potential Aboriginal heritage, hazard, social and economic impacts of the project, and has considered this advice in its detailed assessment in developing the recommended conditions.

During its detailed assessment, the Department has found it difficult to reconcile the significant community concerns about the Narrabri Gas Project with the technical advice from experts that the risk of any significant impacts occurring is generally low and can be controlled using standard engineering practice and imposing strict conditions on Santos.

One of the reasons for this dichotomy may be the limited exposure the community has had to coal seam gas in NSW and its reliance on reports about the actual or perceived impacts of non-conventional gas development in other jurisdictions without appreciating the important differences between these jurisdictions and the Narrabri Gas Project.

At a general level, however, there are at least five factors in favour of the Narrabri Gas Project.

First, it is a relatively small project compared to coal seam gas development in other jurisdictions with up to 850 gas wells to be drilled over 25 years compared to the over 6,800 wells that have been drilled in Queensland over the last decade and the thousands of additional wells that are likely to be drilled in that State over the same period as the Narrabri Gas Project.

Second, there is limited scope for cumulative impacts with the Narrabri Gas Project as it is the only coal seam gas project in the region and there are unlikely to be any significant interactions with the coal mines in the area, including the Narrabri underground mine which is located on the eastern border of the project. This is different to what is happening in other jurisdictions, such as Queensland, where several large projects are being operated side by side and there is a detailed regulatory regime in place to manage the cumulative impacts of these projects on the region’s water resources.

Third, the Gunnedah Basin where the Narrabri Gas Project is located has fundamentally different geology and hydrogeology compared to several other jurisdictions with coal seam gas development, and these differences substantially reduce any risks to land and water resources.

Fourth, the site and surrounds comprise predominately the Pilliga State Forest and broad-acre grazing land, and Santos has committed to only undertaking project-related activities on privately-owned land with the agreement of the landowner. It has also committed to meeting the Environment Protection Authority’s (EPA) air quality, noise and other environmental criteria at sensitive receiver locations, unless the applicable landowner agrees otherwise; and has demonstrated in its technical studies that this can be achieved.

Finally, the NSW Government has introduced strict regulatory controls for coal seam gas development which would be applied to the Narrabri Gas Project. These include:

- strict development consent, petroleum production lease and environmental protection licence requirements;
- requirements to obtain separate water licences for all water take (compared to Queensland and Northern Territory where this is not required);
- appointing the EPA as the lead regulator for coal seam gas in NSW;
- specific codes of practice for coal seam gas development;

- outcomes-based regulation with monitoring and adaptive management, including the ability to shutdown wells if necessary; and
- measures for ongoing community engagement during the project, including establishing Community Consultative Committees and making all relevant information public available of the Department's website and other data portals.

Energy Security & Reliability

The Narrabri Gas Project has been declared a Strategic Energy Project because of the crucial role it could play in strengthening energy security and reliability in NSW.

NSW currently uses around 125 PJ of gas each year.

This gas is used by around 500 heavy industrial facilities (smelters, paper mills, abattoirs), 33,000 business, gas-fired power stations, and 1.4 million households (for cooking and heating); and it supports around 300,000 jobs.

Although NSW is rich in gas resources, it currently imports 95% of its gas from other states, with around 40% historically coming from South Australia and 55% from Victoria. The remaining 5% comes from the Camden Gas Project in Sydney.

The Australian Energy Market Operator (AEMO) forecasts that domestic gas demand is likely to remain stable or decline slightly over the next 20-30 years, depending on the security of gas supply and gas prices.

The domestic gas market has experienced significant changes over the last decade, largely due to the development of a major coal seam gas export industry in Queensland. This has exposed the domestic gas market to international prices and seen domestic gas prices nearly double in the space of a few years. It has also increased the competition for domestic gas supply with almost 70% of domestic gas now going to export markets.

Due to the scheduled closure of the Camden Gas Project in 2023 and likely decline in supplies from South Australia and Victoria, AEMO forecasts that the long-term outlook for the domestic gas market is "tight and uncertain" and indicates there are likely to be supply shortfalls in the southern states, including NSW, from 2024 unless new supplies are brought online.

Any shortfalls in gas supply or increases in gas prices could have significant economic consequences for NSW: it may result in the closure of several major industrial facilities and businesses, resulting in significant job losses in regional areas.

Importantly, it may also discourage the development of peaking gas-fired power stations, which AEMO predicts could play a critical role in providing dispatchable energy to the NEM over the next few decades as it transitions to a greater reliance on renewable energy (wind, solar and pumped hydro).

The Narrabri Gas Project would produce up to 200 TJ of gas a day over at least 20 years, which is enough to supply up to 50% of NSW's forecast gas demand.

Further, Santos has committed to providing all this gas to the domestic market and agreed to accept a condition to this effect on any petroleum production lease granted for the project under the *Petroleum (Onshore) Act 1991*.

Following detailed assessment, the Department has concluded that the Narrabri Gas Project is critical for energy security and reliability in NSW as it would:

- provide essential gas supplies to NSW over the next few decades to address forecast shortfalls from 2024, which could result in significant job losses;
- facilitate critical extensions of the existing gas pipeline network to the northern parts NSW, connecting major gas users (Sydney, Newcastle, Wollongong) to the most prospective gas resources in NSW, and bringing them closer to the strategic gas resources in Queensland and the

North Territory, which are likely to play a major role in supplying gas to the domestic market in the future;

- encourage the development of peaking gas-fired power stations in NSW to compensate for the scheduled closure of several coal-fired power stations in the next 20 years (Liddell, Vales Point, Eraring and Bayswater) and reduce greenhouse gas emissions in NSW;
- increase competition in the domestic gas market and put downward pressure on gas prices; and
- promote economic development in northern NSW by creating jobs and supporting the creation of new businesses, including the development of a new industrial hub outside Narrabri adjoining the Inland Rail Project.

Groundwater

The region has significant groundwater resources which support a valuable agricultural industry, including extensive irrigation in the alluvial floodplains of the Namoi River.

These resources are contained in the shallower aquifers of the Gunnedah Basin, particularly the Namoi Alluvials and Pilliga Sandstone, which form part of the Great Artesian Basin. Groundwater use from these aquifers is currently around 165 GL a year.

The local community has significant concerns that the Narrabri Gas Project would damage these resources, principally by:

- drawing water away from the shallow aquifers to the deeper geological strata following the depressurisation of the target coal seams and gas extraction, and reducing the water available to farmers; and
- contaminating the water in the shallow aquifers with saline water, gas or other pollutants from the deeper coal seams or drilling fluids via the gas wells or other geological pathways (such as faults).

Over the last decade, extensive work has been undertaken to investigate the risks of coal seam gas development on water resources and to estimate the likely cumulative impacts of coal seam gas and mining development in the Namoi Water Catchment.

This work has been supplemented with a detailed assessment of the potential water impacts of the Narrabri Gas Project, which has now been extensively reviewed by some of the most respected experts in Australia, including the independent WEP.

Despite some uncertainties, mostly due to a lack of detailed information about the deeper geological strata as a result of its limited development potential to date, these experts agree the geology and hydrogeology of the area is generally well-known at a regional scale.

Santos has addressed these uncertainties by using conservative assumptions in its modelling. Both the IESC and WEP are satisfied that the project's ground water model is fit for purpose; however, they say Santos should be required to upgrade the model over time to incorporate new information collected for the project and to improve the accuracy of its predictions.

There are at least ten reasons why the Narrabri Gas Project is unlikely to adversely affect the region's groundwater resources.

First, the target coal seams are very deep, generally between 800 and 1,200 metres below ground although some seams (5%) are located around 500 metres below ground, and at least 350-650 metres deeper than most (97%) of the productive groundwater bores in the shallower aquifers overlying the project area.

Second, these coal seams are physically separated from the shallower aquifers by several aquitards (impermeable layers) that would significantly reduce the potential flow or drawdown of any water from the shallower aquifers to the deeper strata.

Third, there is no evidence of any geological structure that could create a pathway between the shallower aquifers and the coal seams so the risk of regional-scale water impacts is generally low, even though some localised impacts could still occur due to minor faults and structures.

Fourth, the target coal seams are reasonably permeable, and the exploration undertaken by Santos has demonstrated that no fracking is required to stimulate the flow of gas from these coal seams. This significantly reduces the risk of any major disruption to the geological strata surrounding the coal seams.

Fifth, the project would only extract water from the deep coal seams. This water is highly saline and currently has no beneficial use.

Sixth, a key mitigation measure of the project is to limit the extraction of water from the coal seams to 37.5 GL of water over the life of the project, or to an average of 1.5 GL a year. This restriction, coupled with the favourable geology, would significantly reduce any risk of drawdown from the shallower aquifers.

For comparative purposes, the project would extract an average of 1.5 GL of saline water from the coal seams each year. The extraction of this water is predicted to result in the annual leakage of a maximum of 60 ML of water a year from the shallower aquifers (about 200-250 years from now), which is a low volume of water compared with the 165 GL of water currently being extracted from these aquifers by other water users each year, or compared to an average cotton farm which uses around 4 GL of water a year.

Under the water legislation, Santos would need to obtain water licences for all the project's predicted water take, including the direct take from the coal seam aquifers and indirect take from the shallower aquifers, just like any other water user in the region.

Seventh, the project is reasonably isolated from other industrial uses, including the coal mines in the region, and is unlikely to result in any significant cumulative impacts on the shallow aquifers.

Eighth, the risks of the project can be reduced further by:

- carrying out investigations over time to improve the understanding of the deeper strata and using this information to upgrade the groundwater model and refine the location and design of gas wells to avoid and/or minimise any local impacts (due to local faults, or to variations in the composition of gas that may require changes to the specifications of the casings and cement used in wells); and
- ensuring that all gas wells are designed, drilled, operated, maintained and abandoned in strict accordance with the Well Integrity Code, which represents current international best practice and will be updated over time to incorporate any improvements in practice.

Ninth, Santos would be required to carry out extensive monitoring during operations and following the abandonment of any gas wells to ensure that the actual impacts of the project on the shallower aquifers is negligible, and consistent with current predictions.

This monitoring would be supplemented by further monitoring carried out by the Department's Water Group, including the installation of government-owned monitoring bores.

Santos would also be required to prepare and implement a detailed trigger, action and response plan for the project and to take prompt action to address any risks of adverse impacts identified during this monitoring.

Finally, several actions could be implemented (if necessary) to reduce the water impacts of the project in the unlikely event of any adverse impacts being detected during monitoring. These actions include reducing groundwater extraction rates from the coal seams; shutting down the operation of gas wells, prohibiting the drilling of gas wells in certain areas (where the local geology is unfavourable, for instance); refining the design of gas wells, particularly the specifications of the casings and cement; and repairing gas wells.

Following detailed assessment, the project is expected to comfortably comply with the minimal harm criteria in the *NSW Aquifer Interference Policy* and the non-discretionary standards for aquifer interference in the *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (Mining SEPP).

Peak drawdown (the lowering of the groundwater table) in both the Namoi Alluvials and Pilliga Sandstone is predicted to be less than 0.5 metres, which is within the range of natural fluctuation, and is unlikely to be noticed by groundwater users.

Peak groundwater take (volumetric groundwater loss due to induced drawdown) from these groundwater sources is also predicted to be minor, at well below one percent of the Sustainable Diversion Limits (or long term annual average extraction limits) for all relevant water sources.

The Department has recommended a comprehensive suite of conditions to ensure Santos avoids and/or minimises the water impacts of the project.

These conditions include requiring Santos to:

- restrict produced water extraction to 37.5 GL over the life of the project;
- not undertake any fracking;
- prepare detailed Field Development Plans for the approval of the Planning Secretary prior to carry out any gas field development on site;
- design, construct, operate, maintain and abandon all wells in strict accordance with the NSW Well Integrity Code;
- establish a water technical advisory group, including independent experts and local groundwater users, to review and advise on water-related matters;
- comply with a range of water performance measures;
- secure water licences for all predicted water take;
- provide compensatory water supplies to affected water users, in the unlikely event this occurs;
- regularly update the groundwater model; and
- monitor and publicly report on water impacts.

Finally, consistent with the recommendations in the NSW Chief Scientist & Engineer's review of coal seam gas activities in NSW, the Department would work with the EPA and the Department of Regional NSW – Mining, Exploration and Geoscience to ensure there are suitable safeguards in place under the planning, environmental protection and petroleum legislation to avoid and/or minimise any long-term risks of the project.

These safeguards would include using:

- security deposits to ensure the gas wells are abandoned properly and the site is rehabilitated to a high standard;
- financial insurance/assurance to manage any residual risks during operations and following the closure of the gas field; and
- the Legacy Mines Program to deal with any potential long-term impacts of the project in the unlikely event that they occur.

With all these measures in place, the Department has concluded that the project is unlikely to result in any adverse impacts on the region's groundwater resources.

Produced Water Management

Several submissions were concerned that the 37.5 GL of saline groundwater extracted during the project would pollute the region's surface water resources and contaminate land on the site and surrounds.

Santos is proposing to avoid this by:

- collecting all saline water directly from the gas wells and conveying it in buried water gathering lines with leak detection systems to the Bibblewindi and Leewood facilities for storage and treatment;
- storing all produced water, treated water and any associated wastes (brine and salt) in specially designed storages;
- treating all water to a suitable standard in accordance with applicable guidelines;
- reusing treated water for production, dust suppression, rehabilitation and irrigation;
- discharging any excess treated water to Bohena Creek during high flows; and
- sending all salt recovered during the water treatment process to a licenced waste facility for disposal.

The WEP has reviewed Santos' proposed produced water treatment system in detail and concluded that it represents current best practice, and that any risks can be effectively managed subject to strict conditions.

The WEP also concluded that the:

- treated and amended water from the Leewood treatment facility would meet both the Australian Drinking Water standards and ANZECC guidelines for long-term irrigation; and
- the water quality of any discharges to Bohena Creek in times of high rainfall would be "*better than that measures in Bohena Creek, the Namoi River and local bores*", but that some temperature matching should occur prior to any discharge.

In relation to the production of wastes, the WEP noted that although average salt extraction rates would be high given the salinity levels of the produced water, total salt volumes (around 33,600 tonnes a year) would be relatively small compared to other coal seam gas projects in Australia and the Murray Darling Basin Authority's salt interception scheme, which generates about 500,000 tonnes of salt a year.

The WEP found that the recovered salt would be comprised primarily of sodium carbonate and would be low in heavy metals and other undesirable components when compared to the EPA's Waste Classification guidelines. Consequently, the salt is likely to be classified as general solid waste which can routinely be disposed of at one of the 11 licenced waste facilities within 150 kilometres of the site.

Nevertheless, the WEP noted that the salt may be suitable for beneficial reuse, and that Santos should be required to further investigate options for beneficial use prior to disposal. The Department has included this in the recommended conditions.

The recommended conditions also require Santos to:

- ensure the project causes no water pollution;
- locate all water-related infrastructure in accordance with the Field Development Protocol;
- treat all produced water to a suitable standard in accordance with the applicable guidelines;
- seek further approvals from the EPA prior to using any treated water for irrigation;
- meet strict criteria for any water discharges to Bohena Creek (volume, quality and temperature);
- comply with water performance measures; and
- prepare and implement a detailed Water Management Plan for the project, which includes monitoring and public reporting of any water impacts.

Biodiversity

Submissions raised four key issues about the potential biodiversity impacts of the project.

First, they criticised the adequacy of Santos' assessment, particularly the method used to determine the likely vegetation clearing of the project given the final layout of the project would only be finalised during construction following further resource appraisal.

Following detailed investigations, the Department considers that Santos has taken a conservative approach to estimating the potential biodiversity impacts of the project, and that this assessment has been carried out in accordance with the requirements in the Major Projects Offsets Policy.

Second, submissions argued the Pilliga State Forest - where around two-thirds of the project is located – has significant regional biodiversity values and should be protected from the project.

However, in 2005, the NSW Government undertook a comprehensive review of all its landholdings in the Pilliga region. This review resulted in the permanent protection of 240,000 hectares of land, including the establishment of the Brigalow State Conservation Area and Brigalow Nature Reserve within the project area. Santos has committed to avoiding all impacts on the biodiversity values of these conservation areas during the project.

The rest of the State-owned land in the Pilliga region was zoned for different uses under the *Brigalow and Nandewar Community Conservation Act 2005*; and under this zoning system, the project area was expressly zoned for forestry, recreation and mineral extraction.

Consequently, there is greater strategic support for the use of this land for the project than there is for its permanent protection for conservation.

Third, submissions claimed the project would have unacceptable impacts on both Commonwealth and State-listed threatened species and communities.

Based on its conservative assessment, Santos estimates that around 1,000 hectares of native vegetation would be cleared across the 95,000-hectare site. However, actual clearing rates are expected to be much lower (250-630 hectares) depending on the final layout of the gas field, and are likely to be no greater than 70% of the worst-case predictions.

Santos has also committed to further reduce any biodiversity impacts by:

- setting limits for the clearing of each vegetation community and key habitat;
- carrying out detailed flora and fauna surveys prior to locating any well pads and gas-related infrastructure;
- using the results of these surveys to inform the detailed design of the gas field and avoid (to the greatest extent possible) clearing endangered ecological communities or the removal of threatened species habitat;
- implementing several mitigation measures to minimise the impacts on flora and fauna, including conducting pre-clearance surveys;
- rehabilitating the site to a high standard after construction; and
- offsetting the residual biodiversity offsets of the project in accordance with the Major Projects Offsets Policy.

The Department supports these measures and notes that there is extensive scope to reduce the biodiversity impacts of the project during detailed design; and particularly to avoid impacts on threatened species and communities, principally through the careful siting of well pads and associated infrastructure and use of directional-drilling. In this regard, the Department notes that, on average, there would be one well pad of approximately one hectare for every 225 hectares of the site.

It also notes that the biodiversity impacts of the project are likely to be distributed broadly across the large project area and are likely to be mitigated, to a large extent, by the progressive rehabilitation of the site.

Finally, submissions contended that Santos' proposed biodiversity offsets were inadequate.

Under the Major Projects Offsets Policy, the total offset liability for the project is:

- 66,630 ecosystem credits;
- 1.525 million species credits.

Santos has demonstrated that there is more than enough land in the region that could be used to retire these credits, but has argued that it should be allowed to use feral pest control within the project area and the rehabilitation of the site to reduce its offset liability for the project.

The Department has recommended conditions requiring Santos to retire at least 70% of its total offset liability prior to the construction of the project. This is to provide Santos with an incentive to reduce the vegetation clearing and habitat removal during the detailed design of the gas field, and ideally limit the clearing to no more than 630 hectares so no further offsets would be necessary.

If further clearing is required, the conditions require Santos to address any residual offset liability prior to undertaking the clearing.

The Department agrees with criticisms in public submissions that feral pest control is a standard mitigation measure for projects and is not a suitable biodiversity offset for the project.

While there is policy support for using rehabilitation to reduce offset obligations – to encourage good rehabilitation – Santos has not yet demonstrated that it can achieve high quality rehabilitation on the site; and even though the Department considers adequate rehabilitation is possible, it is likely to take some time to achieve.

Consequently, the Department has significantly restricted the potential use of rehabilitation as a biodiversity offset for the project. Under the recommended conditions, Santos can only use rehabilitation to retire the remaining 30% of offsets (if they are required), and only if the actual rehabilitation of the site has been carried out to a suitable standard.

In summary, the Department has concluded that the project is unlikely to have any significant biodiversity offsets, and that any residual biodiversity impacts can be offset in accordance with the requirements in the NSW Offsets Policy.

Greenhouse Gas Emissions

Submissions about the greenhouse gas emissions of the Narrabri Gas Project were as much about the ongoing use of fossil fuels and gas in Australia as they were about the project.

The NSW energy market is changing rapidly as more renewable energy is built and is likely to change even more rapidly over the next two decades as most of the remaining power stations in NSW are closed.

Extensive work undertaken by AEMO, however, has consistently shown that the transition of the NEM to a greater reliance on renewable energy requires significant investment in new transmission infrastructure as well as dispatchable energy (pumped hydro, battery storage and gas), and is likely to take many years.

In the interim, AEMO forecasts that gas use in NSW is likely to remain strong; and that peaking-gas fired power stations are likely to play a significant role in providing dispatchable energy to the NEM assuring a reliable and reasonably-priced supply of gas – such as the Narrabri Gas Project – can be secured.

Consequently, the greenhouse gas emissions associated with gas use in NSW are likely to continue, whether the Narrabri Gas Project is approved or not.

Using gas to generate dispatchable energy is also likely to help reduce total greenhouse gas emissions in NSW as coal use is phased out.

Recent research undertaken by the CSIRO indicates that fugitive emissions from coal seam gas projects in Australia are lower than previously thought, and that on a life cycle basis, domestic coal seam gas-fired electricity would produce up to 50% less carbon emissions compared to coal-fired production.

In relative terms, the emissions of the project are expected to be low: background levels of methane and carbon-dioxide are low in the area; the target coal seams are very deep and generally sealed off

from the surface by several aquitards; and the leakage from gas wells is expected to be very low given they would be drilled in accordance with the Well Integrity Code and fitted with leak detection systems.

Finally, the project's direct and indirect greenhouse gas emissions, including emissions from the downstream burning of the gas, would be minor, at less than 1% of the Australia's total emissions. This is despite the project potentially supplying up to 50% of NSW gas demand.

Consequently, the Department does not support calls to refuse the Narrabri Gas Project due to its greenhouse gas emissions. Essentially, this would be a decision against the future use of gas in NSW, which would make it harder to transition to a low emissions economy.

On the contrary, the *NSW Gas Plan* seeks to create a sustainable gas industry in NSW that addresses community concerns and provides vital gas supplies to NSW, including industry, businesses and the over one million households who rely on gas across NSW.

Consistent with the requirements in the Mining SEPP, the Department has recommended conditions requiring Santos to minimise the greenhouse gas emissions of the project.

Community

Most submissions raised concerns about the impacts of the Narrabri Gas Project on the local community, highlighting the complex interaction between the potential economic, environmental and social impacts of the project. In particular, they were concerned that the project would adversely affect the health, safety and livelihood of many people, disrupt community cohesion, and diminish the community's sense of place.

The Department has investigated these concerns in detail over the last three years in consultation with Narrabri Shire Council, landholders in the project area, members of the local community, the Community Consultative Committee, key government agencies and independent experts.

Following these detailed investigations, the Department has reached three broad conclusions.

First, the project would result in significant economic benefits for both NSW and the local community.

These benefits include:

- attracting \$3.6 billion of capital investment to the region and \$5.5 billion of spending during operations;
- creating 1,300 jobs during construction, 200 jobs during operations, and up to 500 jobs in associated industries that provide goods and services to the project;
- increasing NSW's real economic output by around \$12 billion;
- strengthening energy security and reliability in NSW by providing up to 200 TJ of gas a day to the domestic market and putting downward pressure on gas prices;
- generating more than \$3 billion for the NSW Government in royalties and taxes; and
- facilitating local economic development, including the proposed industrial hub in Narrabri adjoining the proposed Inland Rail Project.

Consistent with the *NSW Gas Plan*, the benefits of the project would be shared with the local community.

Landholders in the project area who agree to gas development on their land would be fairly compensated in general accordance with the compensation benchmarks set by the NSW Government, which are regularly reviewed by the Independent Pricing and Regulatory Tribunal. This would provide additional income to farmers in the project area with minimal risk of any adverse environmental impacts.

Further, up to \$120 million would go into a Community Benefit Fund set up for the project under the *Petroleum (Onshore) Act 1991*. This fund would ensure that a dedicated share of royalties linked to the production of gas would go to the local community for spending on a broad array of community projects.

Together, these benefit-sharing schemes are likely to result in long-term economic benefits for the local community and to foster prosperity in the region.

Second, with suitable controls, the Narrabri Gas Project is unlikely to harm the environment or adversely affect the health and safety of the local community.

This is largely because the project has favourable geology, is located primarily in the Pilliga State Forest, and there is considerable flexibility to avoid and/or minimise any adverse impacts of the project during detailed design. In short, it should be possible to locate gas wells away from residences and sensitive natural features, including State Conservation Areas, Yarrie Lake, threatened species and communities and areas and areas of high cultural heritage value to local Aboriginal groups.

Key findings in this regard, include:

- the air and noise emissions of the project would comfortably comply with the relevant criteria (incremental and cumulative) set by the EPA at all residences, and construction dust and noise impacts could be reduced to acceptable levels with the implementation of standard controls;
- the risk of any adverse fugitive air toxin emissions is low;
- the project would comply with the relevant hazards criteria set by the Department, including the criteria for fire and explosions and uncontrolled discharges from storage facilities on site;
- bushfire risks can be reduced to an acceptable level by designing the project to comply with applicable guidelines, including *Planning for Bushfire Protection*, minimising ignition risk and having detailed procedures in place to respond to any emergencies both on the site and in the surrounding area;
- impacts on the region's heritage, biodiversity and landscape values would be mitigated, to a large extent, by avoiding sensitive features with conservation value and by the dispersed nature of the project; and
- the project is unlikely to have any significant impacts on the natural resources of the area, including the land and water resources which are so highly valued by the local community.

Finally, like all major projects, the Narrabri Gas Project is likely to result in both positive and negative social impacts in the region. These impacts could be tangible, in terms of putting pressure on public infrastructure and services, adversely affecting the housing and rental market, and increasing labour costs; but they could also be intangible, in terms of affecting community cohesion, the mental health of certain people, and peoples' sense of place.

These impacts are always difficult to weigh up and come to a definitive conclusion about, however, the Department considers that any adverse social impacts of the Narrabri Gas Project can be mitigated to a large extent by ensuring that Santos:

- carries out extensive community engagement to build social licence and establish relationships with the local community, to keep the community informed, to publicly report on environmental monitoring data, and to promptly resolve any problems that may arise;
- reduces any pressure on public infrastructure and services by contributing \$14.5 million to Narrabri Shire Council for spending on local community projects and services and working with State government service providers to ensure essential services (health, education, police, community) are maintained;
- mitigates any adverse impacts on the housing market by providing workers accommodation on site and expanding this accommodation over time if necessary;
- promotes local economic development by employing local workers, including workers from vulnerable communities, providing suitable training, purchasing local goods and services and supporting the development of the proposed industrial hub in Narrabri; and

- complies with the strict controls in the recommended conditions to ensure there are no significant impacts on any private properties or residences or the natural resources that the local community relies on.

It also recognises that the NSW Government has a crucial role to play in ensuring this occurs by engaging with the local community, providing accurate information on the impacts of the project, monitoring Santos' performance and strictly enforcing the recommended conditions.

Based on these conclusions, the Department considers that, on balance, the Narrabri Gas Project is likely to make a positive contribution to the community, resulting in long term economic benefits, and that any adverse impacts can be avoided and/or minimised through a combination of effective community engagement, detailed design, strict controls and prompt action to address any problems if they occur.

Conclusion

The Narrabri Gas Project is critical for energy security and reliability in NSW as it would deliver up to 200 TJ of gas a day to the domestic gas market for a period of at least 20 years, addressing any forecast shortfalls in gas supply from 2024 and putting downward pressure on gas prices.

It would also deliver significant economic benefits for NSW and the local community, including attracting \$3.5 billion of capital investment to the region, creating up to 1,300 jobs during construction and 200 jobs during operations, and sharing the benefits of the project with the local community by contributing up to \$120 million to a Community Benefit Fund for community projects.

Following extensive consultation and investigations, the Department has completed its detailed assessment of the merits of the project.

Based on this assessment, the Department has concluded that the project would not adversely affect the region's valuable groundwater resources; that the project can be designed to avoid and/or minimise impacts, including reducing the predicted footprint by as much as 30%; and that any residual impacts can be reduced to an acceptable level through effective community engagement, compliance with strict conditions and prompt action to address any problems. Consequently, the project is unlikely to result in any significant impacts on the local community or the environment.

On balance, the Department has concluded that the project is in the public interest and is approvable subject to strict conditions.

Contents

1	INTRODUCTION	1
1.1	OVERVIEW	1
1.2	EXPLORATION	2
2	PROJECT	6
2.1	SUMMARY	6
2.2	COAL SEAM GAS FIELD.....	8
2.3	GAS AND WATER MANAGEMENT	13
2.4	ANCILLARY INFRASTRUCTURE.....	18
2.5	VOLUNTARY PLANNING AGREEMENT	18
2.6	TIMING.....	18
2.7	RELATED MATTERS	19
3	STRATEGIC CONTEXT	22
3.1	ENERGY SECURITY & RELIABILITY.....	22
3.2	COAL SEAM GAS REVIEW & REFORMS.....	24
3.3	REGIONAL SETTING	26
4	STATUTORY CONTEXT	30
4.1	APPROVAL UNDER THE EP&A ACT	30
4.2	OTHER NSW APPROVALS	34
4.3	COMMONWEALTH APPROVAL	35
5	ENGAGEMENT	37
5.1	DEPARTMENT'S ENGAGEMENT	37
5.2	SUBMISSIONS	38
5.3	KEY COMMUNITY ISSUES.....	40
5.4	SANTOS'S RESPONSES	41
5.5	AGENCY ADVICE.....	42
6	ASSESSMENT	47
6.1	OVERVIEW	47
6.2	GROUNDWATER.....	50
6.3	PRODUCED WATER MANAGEMENT	73
6.4	BIODIVERSITY.....	82
6.5	ABORIGINAL HERITAGE	99
6.6	GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE	104
6.7	ECONOMIC AND SOCIAL IMPACTS	108
6.8	OTHER ISSUES	115
7	EVALUATION	122
	APPENDICES	124
	APPENDIX A: ENVIRONMENTAL IMPACT STATEMENT	
	APPENDIX B: STATUTORY CHECKLIST	
	APPENDIX C: IESC ADVICE	
	APPENDIX D: PUBLIC SUBMISSIONS	
	APPENDIX E: SANTOS' RESPONSES	
	APPENDIX F: AGENCY ADVICE	
	APPENDIX G: WATER EXPERT PANEL REPORT	
	APPENDIX H: EXPERT ADVICE	
	APPENDIX I: CONDITIONS	

1 Introduction

1.1 Overview

1. Santos proposes to develop the Narrabri Gas Project over 95,000 hectares (ha) of land to the south west of Narrabri in the Narrabri local government area (see **Figure 1**).
2. About two thirds of this land is in the Pilliga State Forest, and is reserved for forestry, recreation and mining. The rest is privately-owned agricultural land to the north of the forest, which is used for dryland cropping and grazing.

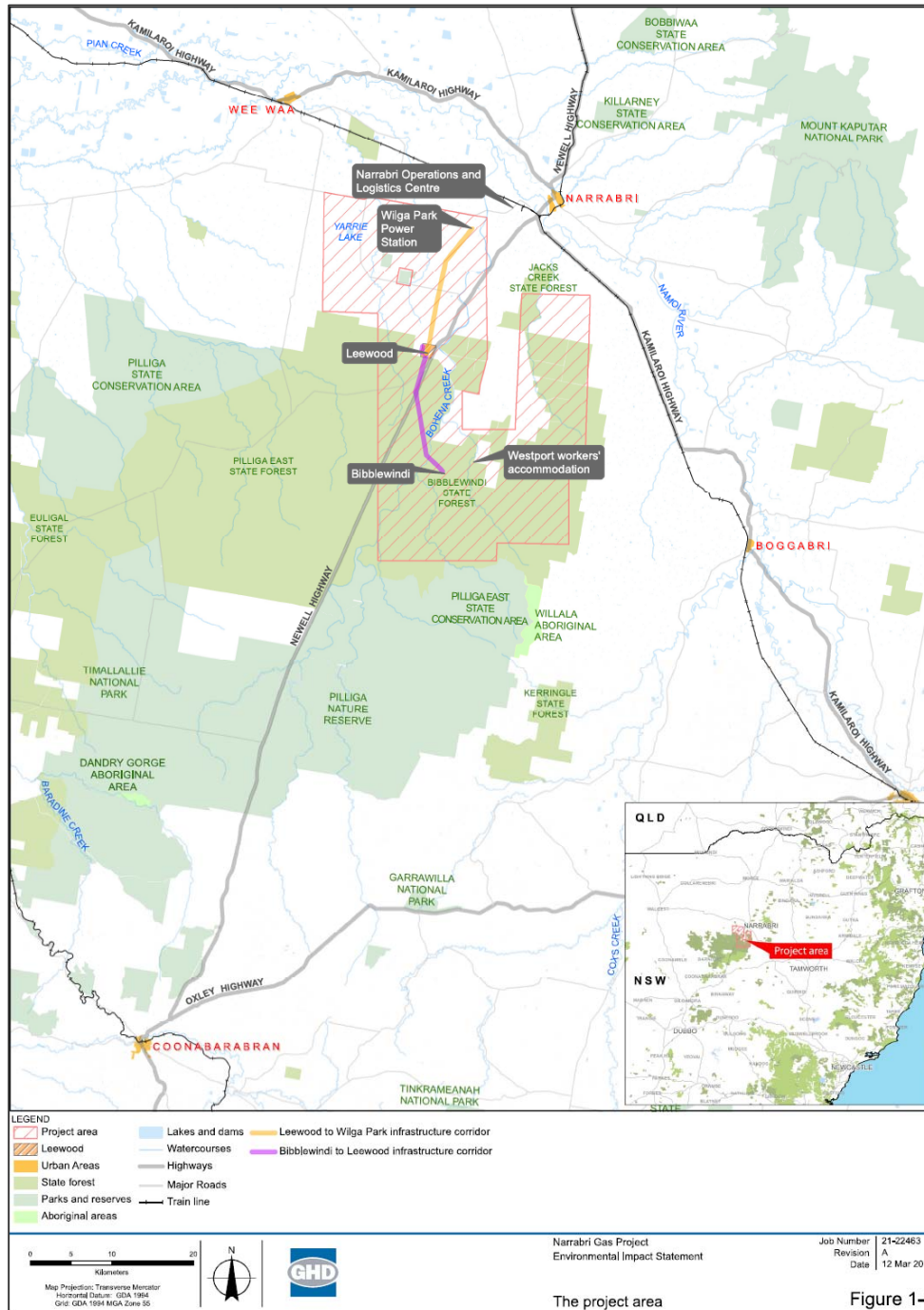


Figure 1 | Regional Context

3. The project involves developing a coal seam gas field and associated infrastructure, including gas and water processing facilities, on about 1,000 ha of the broader 95,000 hectare site and producing up to 200 terajoules (TJ) of gas a day for around 20 years.
4. Santos would provide all this gas – which is enough to supply up to 50% of NSW's demand – to the domestic market.
5. The project has a capital investment value of \$3.6 billion and would create 1,300 jobs during construction and 200 jobs during operations.

1.2 Exploration

6. The site forms part of the Gunnedah Basin and has been subject to extensive gas exploration since the early 1960s (see **Table 1** and **Figure 2**).

Table 1 | Gas Exploration History

Period	Key Activities
1960s	<ul style="list-style-type: none"> • Exploration drilling for oil and gas starts
1980s	<ul style="list-style-type: none"> • Petroleum Exploration Licence (PEL) 238 granted
1990s	<ul style="list-style-type: none"> • Non-conventional gas exploration starts in PEL 238
1998	<ul style="list-style-type: none"> • Conventional and non-conventional gas wells drilled at Bohena by Eastern Star Gas
2002	<ul style="list-style-type: none"> • Approval granted to Eastern Star Gas for conventional gas production at Coonarah • Approval granted to Eastern Star Gas for 12 megawatt (MW) gas fired power station near Narrabri, later moved to Wilga Park
2004	<ul style="list-style-type: none"> • Petroleum Production Lease (PPL) 3 granted for the Coonarah gas field • Wilga Park Power Station starts operations using gas from the Coonarah gas field
2006	<ul style="list-style-type: none"> • Exploration shifts to coal seam gas in the Pilliga State Forest, focusing on the Bohena and then Bibblewindi and Dewhurst areas
2007	<ul style="list-style-type: none"> • Petroleum Assessment Lease (PAL) 2 granted to Eastern Star Gas
2008	<ul style="list-style-type: none"> • Approval granted by the then Minister for Planning to upgrade the Wilga Park Power Station to 40 MW and use exploration gas to generate electricity
2011	<ul style="list-style-type: none"> • Santos acquires Eastern Star Gas
2013	<ul style="list-style-type: none"> • Santos develops the Leewood Water Processing Facility to treat all water collected from the exploration gas wells

7. This exploration concentrated initially on finding oil and conventional gas resources, but later shifted to finding non-conventional – or coal seam – gas resources.
8. In 2002, Eastern Star Gas started producing gas from conventional gas wells at Coonarah in the northern part of the site and using this gas to produce electricity at the Wilga Park Power Station near Narrabri. However, production was poor and the Coonarah gas field was subsequently closed.
9. Since then, exploration has focused mainly on finding coal seam gas resources in the Pilliga State Forest and drilling gas wells at Bohena, Bibblewindi and Dewhurst (see **Figure 2**).
10. This exploration has discovered a prospective coal seam gas resource of around 1,500 petajoules (PJ) in the deep coal seams of the Gunnedah Basin – mainly between 800 and 1,200 metres (m) below the surface. Santos is now proposing to extract this resource.
11. The target coal seams are thick and reasonably permeable and do not require hydraulic fracturing (fracking) to stimulate gas production from the coal seams.

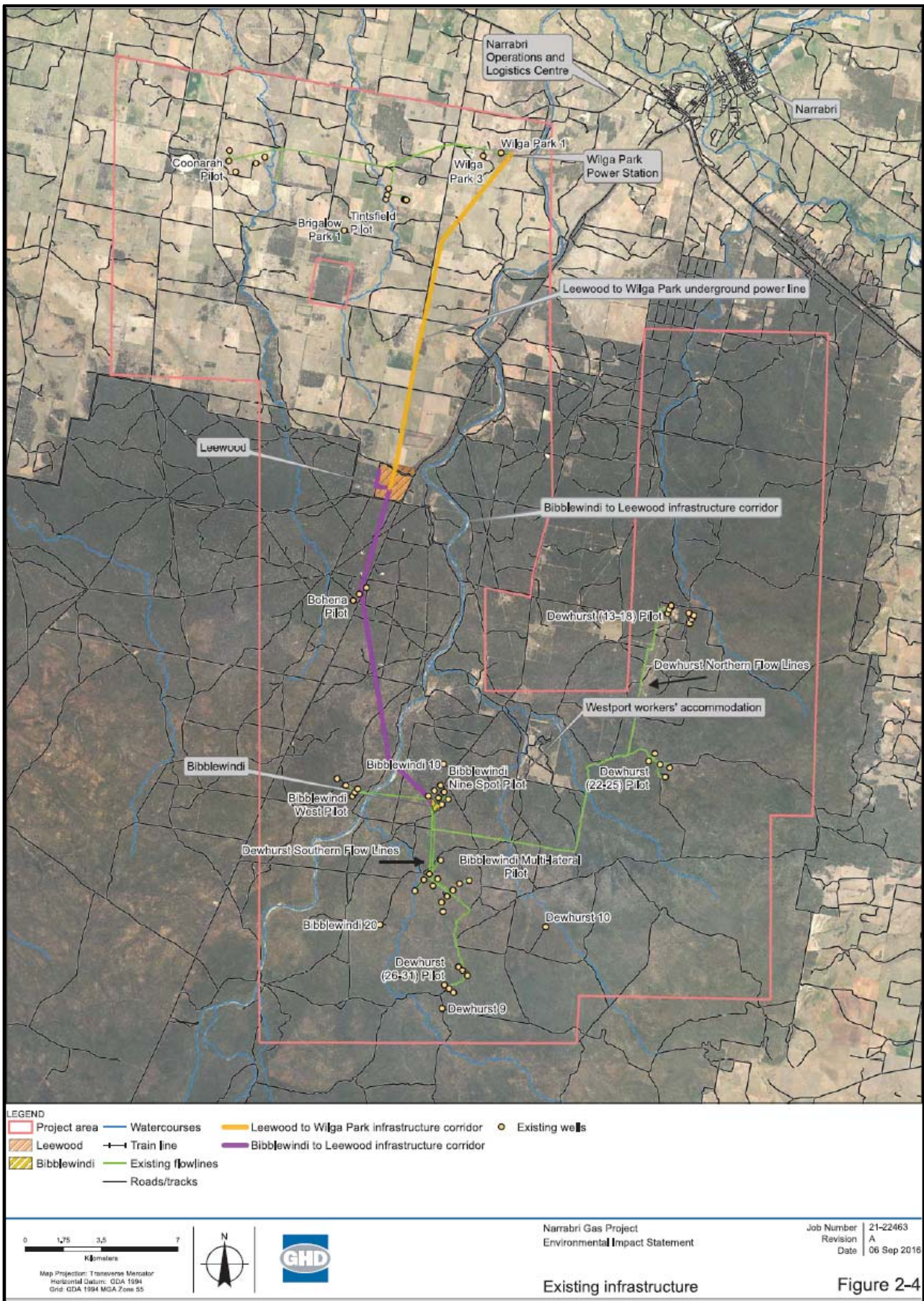


Figure 2 | Existing and Approved Infrastructure

Existing Gas-Related Development

12. During exploration, a range of gas-related development has been developed on the site (**Figure 2** and **Table 2**).

Table 2 | Existing Gas-Related Development

Development		Approval	Future Use
Gas Field Infrastructure			
Gas wells	• Coonarah wells (5 wells)	2002 & 2005	Yes
	• Tintfield wells and safety flare (9 wells)	2013	
	• Brigalow Park well	2004	
	• Wilga Park wells (2 wells)	1998	
	• Bohena wells (4 wells)	1998 & 2004	
	• Bibblewindi wells (28 wells)	2008, 2009 & 2014	
	• Dewhurst wells (20 wells)	2009, 2013 & 2014	
Gas gathering lines	• Connecting the gas wells to the main gas and water pipelines in the infrastructure corridor	Various	Yes
Associated Infrastructure			
Leewood facility	• Water treatment facility • Water and brine storage ponds	2013 & 2015	Yes
Bibblewindi facility	• Gas compression station • Safety flare • Water storage ponds	2006 & 2013	Yes
Wilga Park Power Station	• 40 MW power station	2008	Yes – separate consent
Infrastructure corridor	• Gas and water pipelines • Associated infrastructure	2008	Yes
Narrabri Operations & Logistics Centre	• Offices • Drilling fluids treatment facility	2013	Yes - separate consent
Westport workers accommodation facility	• Temporary accommodation - 64 workers	2012	Lapsed
Wilga Park drillers camp	• Temporary accommodation – 64 workers	2012	Lapsed

13. This infrastructure includes:
 - gas wells at several drilling pads across the site, including:
 - the Wilga Park, Brigalow Park and Tintsville gas wells located on the agricultural land to the north of the site; and
 - the Bohena, Bibblewindi and Dewhurst gas wells located in the Pilliga State Forest;
 - underground gas gathering lines, which convey all the gas and water extracted from these gas wells to the Bibblewindi and Leewood processing facilities for storage and/or treatment;
 - the Bibblewindi and Leewood processing facilities, which include:
 - a gas compression station and safety flare;
 - a state-of-the-art water treatment plant; and
 - water and brine storage ponds;
 - an infrastructure corridor, which includes a large pipeline connecting the Bibblewindi and Leewood processing facilities to the Wilga Park Power Station;
 - the Wilga Park Power Station, which is currently capable of generating around 22 MW of electricity using gas from the exploration wells but has approval to generate up to 40 MW of electricity; and
 - the Narrabri Operations and Logistics Centre, including offices and a drilling fluids treatment facility.
14. Although Santos received development consent from Narrabri Shire Council to establish two temporary workers accommodation facilities on site, it only developed and used the Westport facility for a short period. Both of these development consents have now lapsed.
15. Santos plans to continue to use most of the gas-related development as part of the Narrabri Gas Project and surrender all the relevant development consents for this development so that there would be a single development consent for all its operations on site.
16. The only exceptions would be the Wilga Park Power Station and Narrabri Operations & Logistics Centre, which would continue to operate under the existing development consents.

Table 3 | Key Components of the Project

Component	Development
Project Summary	Development of the Narrabri Gas Project, including: <ul style="list-style-type: none"> • a coal seam gas field with up to 850 gas wells; • associated infrastructure, including gas and water processing facilities; and • progressively rehabilitating the site
Project Life	25 years, with around 20 years of gas production
Gas Reserves	1,500 PJ
Target Coal Seams	Coal seams of the Bohena Trough within the Gunnedah Basin, including: <ul style="list-style-type: none"> • the Maules Creek Formation (800 to 1,200 m deep); and • Hoskissons Seam (around 500 m deep)
Gas Production	Up to 200 TJ a day for the domestic market
Gas Field	Progressive development of the coal seam gas field, including: <ul style="list-style-type: none"> • up to 450 well pads located in accordance with Field Development Protocol; • each well pad up to 1 ha for construction, reducing to 2,500m² for operations; • up to 850 new gas wells and continued operation of existing wells: <ul style="list-style-type: none"> ○ developed in accordance with the <i>Code of Practice for Coal Seam Gas Well Integrity</i> (Well Integrity Code); ○ vertical, deviated and lateral wells; and ○ no fracking • ancillary infrastructure, including: <ul style="list-style-type: none"> ○ access tracks; ○ gas and water separators, gas flares and water tanks; ○ underground gas and water gathering lines; ○ diesel/gas generators; and ○ remote sensing telemetry units
Gas & Water Processing Facilities	Upgrade the existing gas and water processing facilities on site, including the: <ul style="list-style-type: none"> • Bibblewindi facility: <ul style="list-style-type: none"> ○ in field gas compression facility and safety flare; ○ drilling support facility; and ○ ancillary infrastructure (including staff amenities; car parking, diesel and chemical storage, and utilities) • Leewood facility, including: <ul style="list-style-type: none"> ○ gas processing facility; ○ gas-fired power station (optional); ○ produced water treatment facility and associated storage ponds; and ○ ancillary infrastructure (including diesel and chemical storages, laydown areas, offices; car parking, workshops, telecommunication tower, and utilities) • Infrastructure Corridor for major gas and water pipelines and utilities, connecting the Bibblewindi and Leewood facilities to the Wilga Park Power Station
Water & Waste Management	<ul style="list-style-type: none"> • Extract up to 37.5 gigalitres (GL) over the project at a rate of up to 10 megalitres (ML) a day • Treat all this water at the Leewood facility using a reverse osmosis plant for: <ul style="list-style-type: none"> ○ reuse on site (drilling, dust suppression, rehabilitation); ○ crop irrigation or stock watering in surrounding areas; or ○ discharge to Bohena Creek favourable conditions (if reuse is unavailable); • Extract up to 840,000 tonnes of salt from the produced water, which would be reused off-site or sent to a licenced waste facility; • Produce up to 1.1 million cubic metres (m³) of drill cuttings, which would be mixed, turned and buried on-site or sent to a licenced waste facility
Ancillary Infrastructure	<ul style="list-style-type: none"> • Westport workers accommodation facility – up to 200 workers; • Upgrade intersections off Newell Highway
Capital Cost	\$3.6 billion
Employment	Up to 1,300 jobs during construction and 200 jobs during operations
Voluntary Planning Agreement	\$14.5 million to Narrabri Shire Council for infrastructure and services

2.2 Coal Seam Gas Field

Gas Reserves

20. Gas exploration over several decades has discovered a prospective coal seam gas resource on site of around 1,500 PJ.
21. Gas extraction for the Narrabri Gas Project would target mainly the Rutley, Namoi, Parkes and Bohena coal seams within the Maules Creek Formation and the Hoskissons coal seam in the Black Jack Group.
22. These seams (see **Figure 4**) are generally very deep, with the Maules Creek Formation coal seams located between 800 m and 1,200 m below the ground and the Hoskissons coal seam located around 500 m below ground.

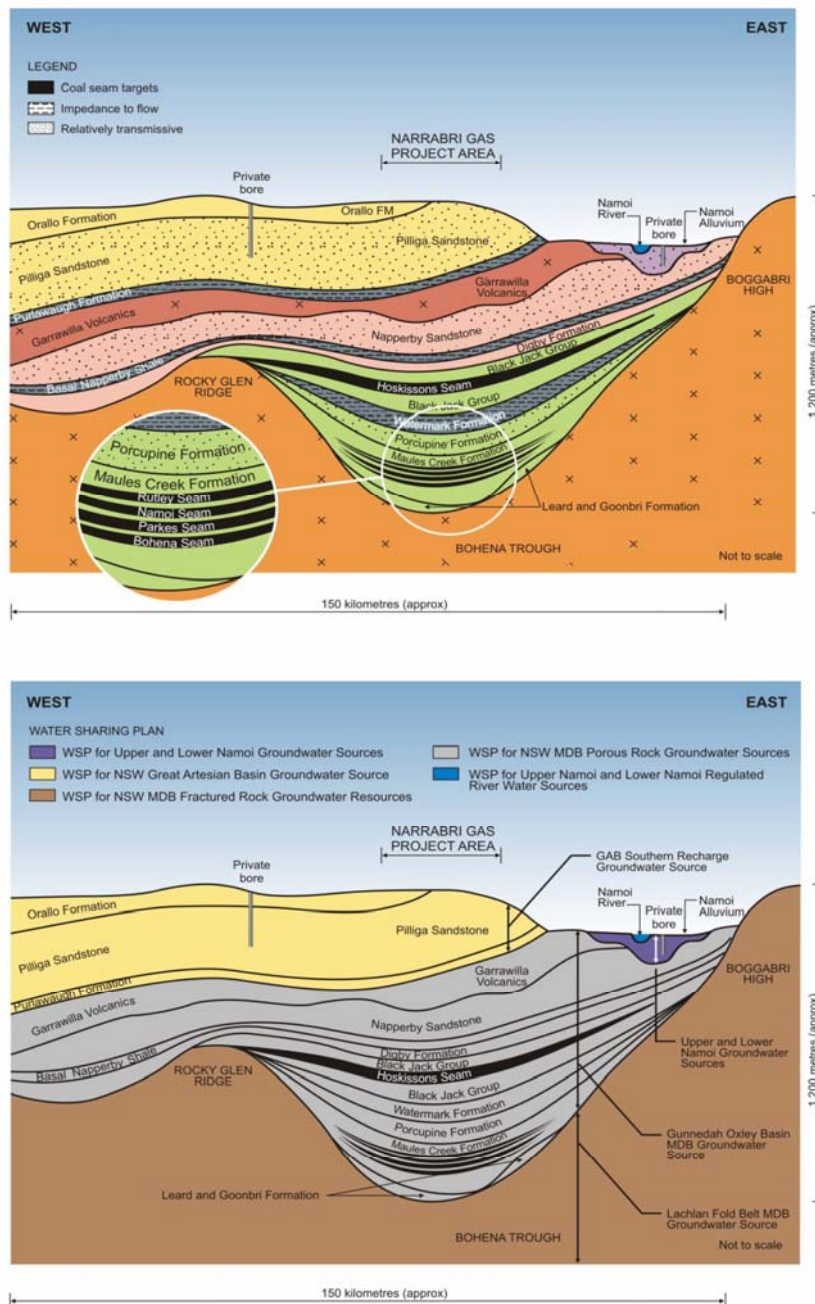


Figure 4 | Geology and Hydrogeology

Well Pads

23. Up to 850 gas wells would be established on up to 425 well pads.
24. On average, there would be one well pad per 225 ha of the site, so the development of the gas field would be relatively dispersed across the site. However, the concentration of wells would be greater in areas where gas flow rates are high.
25. Typically, each well pad would be around 1 ha during construction so there is enough space to drill the well and install any gas-related infrastructure (see **Figure 5**). After construction, however, the well pad would be partially rehabilitated leaving an area of around 2,500 m² for operations.
26. Consistent with other gas development, the specific location of these well pads would be determined during operations:
 - following further consultation with landowners and key stakeholders;
 - following the collection of further information on the gas resource (seismic surveys, drilling core and chip holes, and establishing pilot wells), water resources and sensitive features within the site; and
 - in accordance with the Field Development Protocol (see **Table 4**).
27. The Field Development Protocol has been developed to avoid and/or minimise the potential health, safety and environmental impacts of the project and to protect people and any sensitive natural features (houses, heritage items, key infrastructure, etc.) from any significant impacts.
28. Further, Santos has indicated that it would only develop gas wells or gas-related infrastructure on privately-owned land if it can secure the agreement of the landowner.
29. The final location of the wells would need to be approved by the Department of Planning, Industry and Environment (Department) before they could be developed.

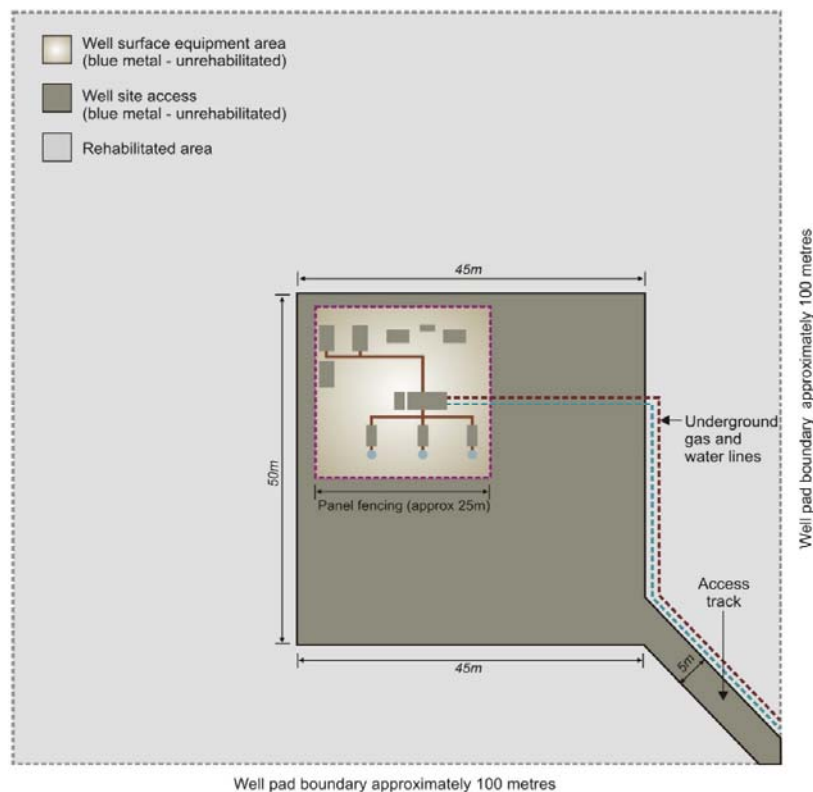


Figure 5 | Typical Well Pad Layout (3 Gas Wells)

Table 4 | Field Development Protocol

Aspect	Protocol
Landowners	<ul style="list-style-type: none"> • All pilot well pads to be spaced at least 250 m apart, and all production well pads at least 750 m apart • No development on privately-owned land without the agreement of the landowner • When the landowner agrees, all development to be located on-site in consultation with the landowner and to be covered by a detailed access agreement • No development within 200 m of an unoccupied residence • Comply with government standards at all occupied residences – noise, air quality, safety – unless the landowner agrees otherwise • Minimise visual impacts on residences on adjoining properties through the micro-siting of well pads
Water	<ul style="list-style-type: none"> • No development within 200 m of Yarrie Lake • No development in buffer areas around watercourses (based on the stream order) within the project area, apart from linear infrastructure (pipelines, communication cables, etc.) crossings of these watercourses when this is unavoidable • Large dams and storage ponds to be located outside the 1% annual exceedance probability (AEP) (unless this is expressly approved) • All gas wells to be developed in accordance with the Well Integrity Code • No fracking • Collect all gas and water from the gas wells and send it to the Leewood facility for processing and treatment • Use standard erosion and sediment controls
Biodiversity	<ul style="list-style-type: none"> • No development on the surface or under the Brigalow Nature Reserve • No development on the surface or to a depth of 100 m under the Brigalow Conservation Area • Comply with strict clearing limits • Carry out further flora and fauna surveys to inform the micro-siting of well pads • Avoid and minimise the clearing of endangered ecological communities, threatened flora and threatened species habitat • Implement standard mitigation measures during clearing and operations, including: <ul style="list-style-type: none"> ○ pre-clearance surveys; ○ progressive rehabilitation of well pads following construction; and ○ decommissioning and final rehabilitation of wells following operations • Offset all residual biodiversity impacts
Heritage	<ul style="list-style-type: none"> • Carry out further heritage surveys in consultation with representatives of the Aboriginal community to inform the micro-siting of wells • Avoid: <ul style="list-style-type: none"> ○ all known Aboriginal and other heritage sites; and ○ any heritage sites with high conservation value that are found during the further surveys • Implement standard mitigation measures to protect known heritage sites from adverse impacts
General	<ul style="list-style-type: none"> • Collect additional data to inform the siting of the well pads, including geophysical (seismic) surveys, further geological assessment (pilot wells, core and chip holes), hydrological assessment • Monitor and publicly report on environmental performance • Adaptive management

Gas Wells

30. Each well pad could have up to three gas wells.
31. These gas wells would be drilled from the well pad to the target coal seam in either vertical, deviated or lateral configurations. In addition, some coal seams may have multi-lateral wells running horizontally within the same seam (see **Figure 6**).

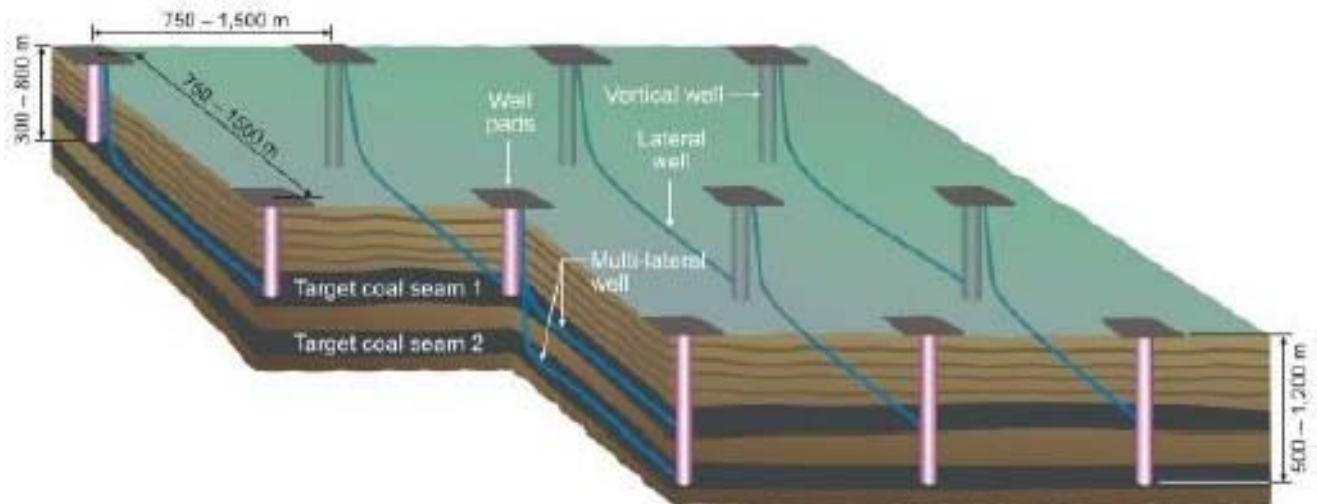


Figure 6 | Possible Gas Well Configurations

32. All gas wells would be developed in strict accordance with the NSW Government's Well Integrity Code (see <https://www.resourcesandgeoscience.nsw.gov.au/landholders-and-community/coal-seam-gas/codes-and-policies/code-of-practice-for-coal-seam-gas-well-integrity>).
33. The main purpose of the Well Integrity Code is to protect land and water resources, particularly beneficial water aquifers, by ensuring gas, water and other fluids are contained inside the well casings and cannot leak into the surrounding strata and contaminate productive groundwater resources.
34. The key components of a typical gas well are shown in **Figure 7**.
35. The Well Integrity Code outlines a range of mandatory best practice standards for the design, construction, operation, maintenance and, ultimately, decommissioning of coal seam gas wells. This includes detailed advice on:
 - incorporating key locational factors into the design of the well;
 - selecting, designing, installing and testing gas well casings, the cement in wells, well heads, drilling fluids and logs;
 - monitoring and maintaining gas wells during production;
 - suspending during production; and
 - abandoning the wells following production.
36. At present, the target coal seams are saturated with water and the gas is bound to the coal by water pressure. To enable the gas to flow, water has to first be extracted from the coal seams to reduce the water pressure.

NOTE that A section would normally be set below GL. Shown above GL for illustration purposes only.

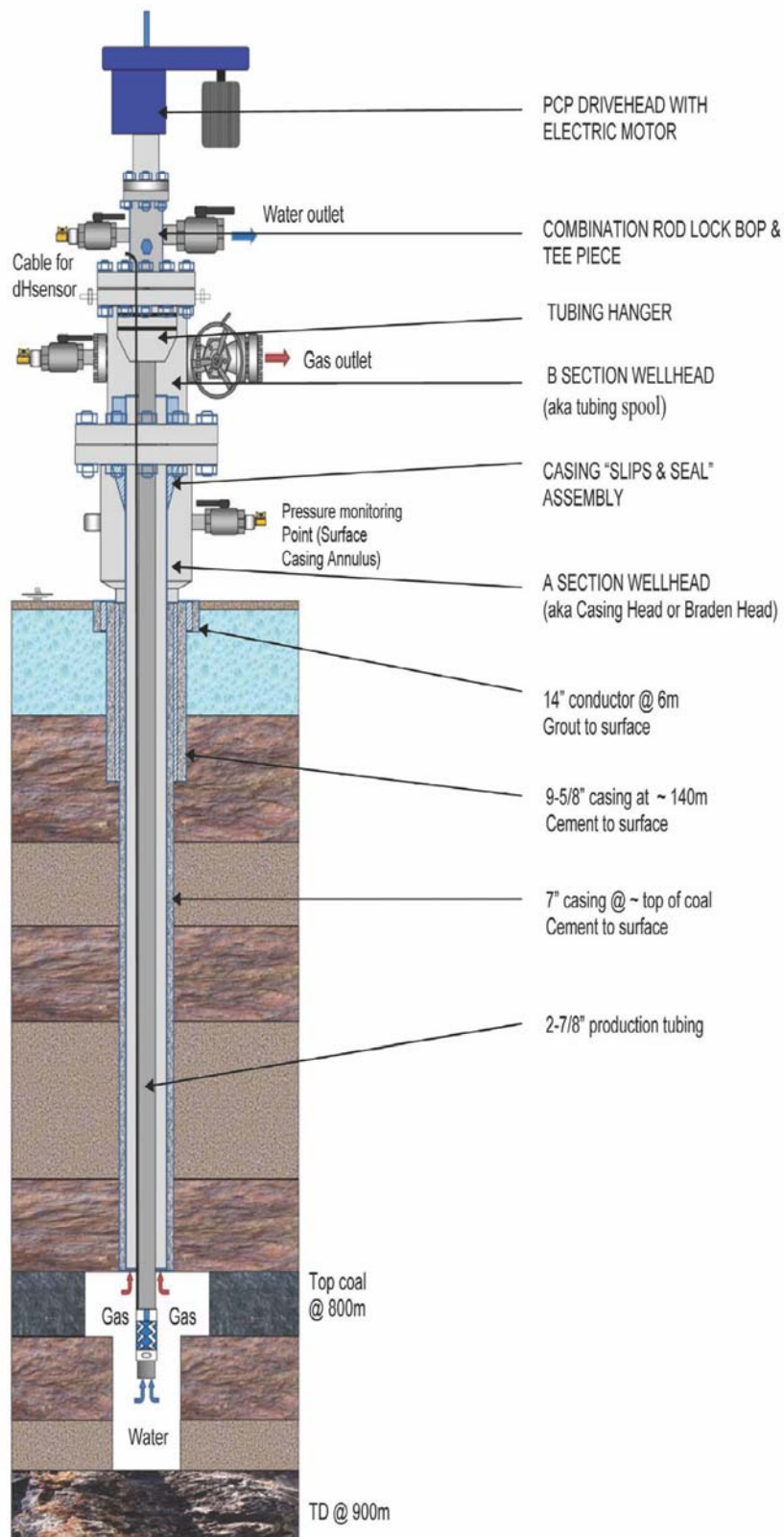


Figure 7 | Typical Coal Seam Gas Well

37. In simple terms, the gas extraction process involves the following steps:
- drilling to the target coal seams through the overlying rock strata;
 - installing the gas well;
 - extracting the groundwater – which is known as produced water - from the coal seam to reduce water pressure;
 - extracting gas; and
 - collecting all produced water and gas from the well and transferring it by underground gathering lines via the infrastructure corridor to the processing facilities on site.
38. As the target coal seams are thick and reasonably permeable, they do not require any fracking to stimulate gas production. Consequently, Santos is not seeking approval for fracking and has indicated that it will accept a condition on any development consent for the project prohibiting any fracking.

2.3 Gas and Water Management

39. Following extraction, all gas and produced water would be transferred to the Bibblewindi and/or Leewood facilities (see **Figure 8**) for further processing. This would include:
- compressing and treating the gas prior to exporting it from the site; and
 - treating the produced water to a suitable standard (Australian drinking water guidelines; or the applicable guidelines for irrigation or stock and domestic use) either for beneficial use (dust suppression, crop irrigation, stock dewatering) or discharge from the Leewood processing facility to Bohena Creek under favourable conditions (flows > 100 ML a day).

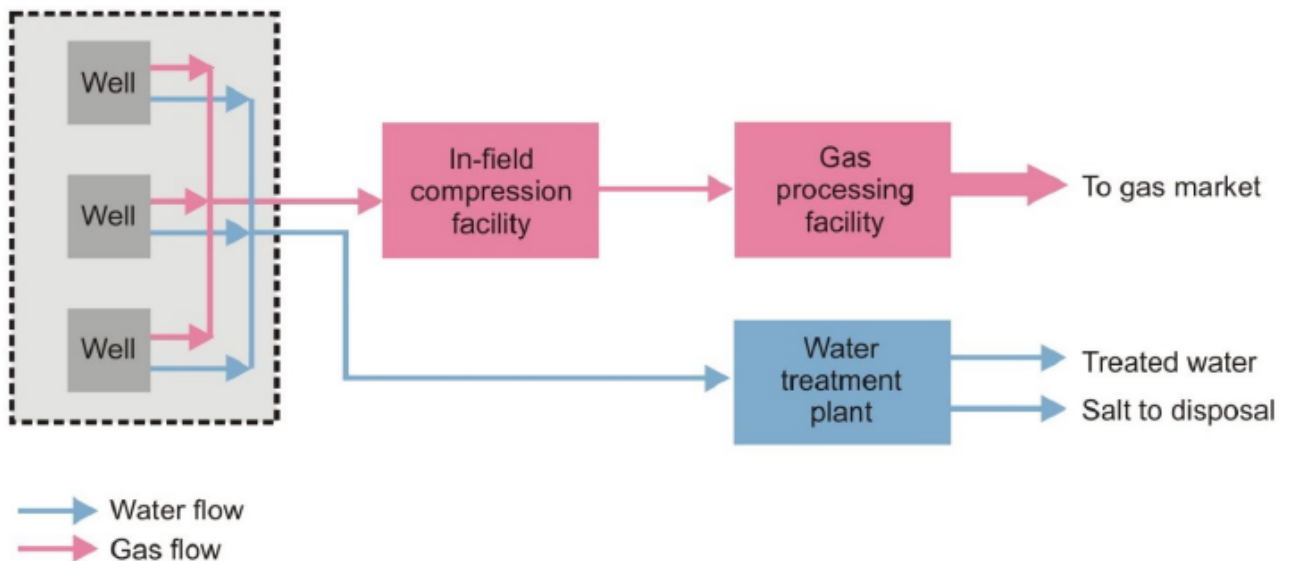
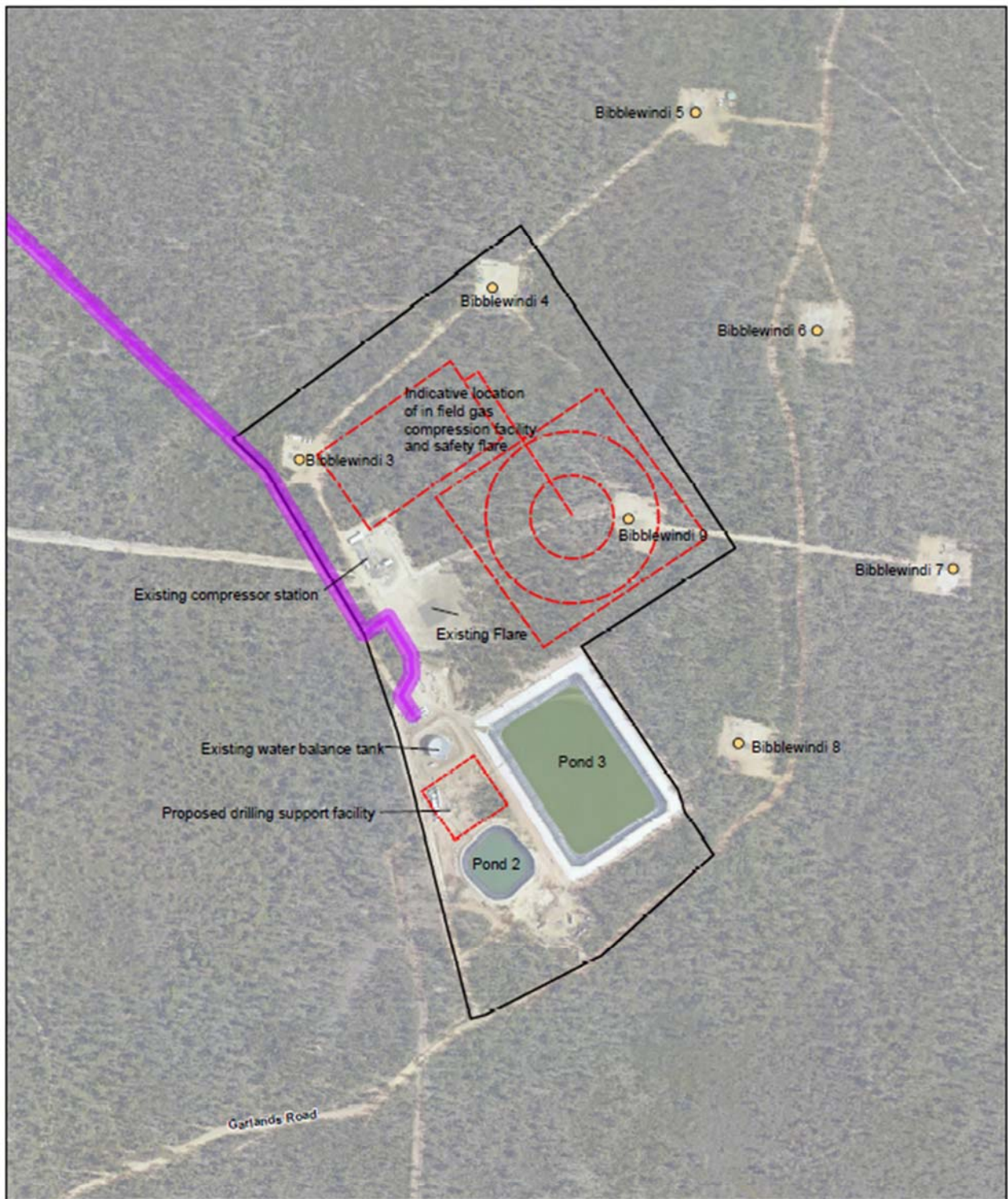


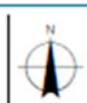
Figure 8 | Typical Gas and Produced Water Management

40. Both the existing Bibblewindi and Leewood facilities and infrastructure corridor would require substantial upgrades to support the project, which are shown in **Figures 3, 9 and 10**.



Aerial Imagery: Dec 2013

- LEGEND
- Indicative Bibblewindi site boundary
 - Indicative Infrastructure location
 - Bibblewindi to Leewood Infrastructure corridor
 - Existing wells



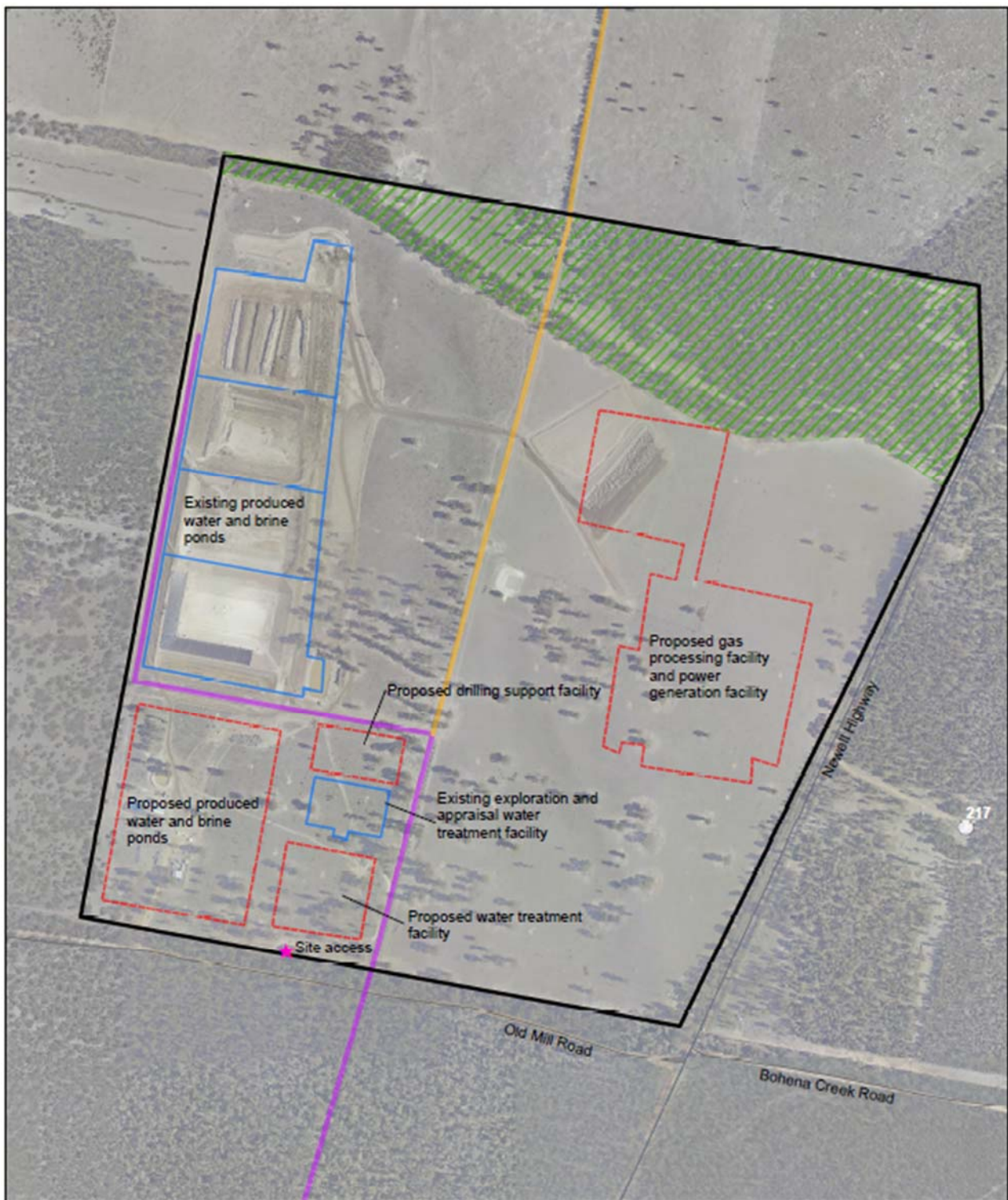
Narrabri Gas Project
Response to submissions

Job Number | 21-22483
Revision | A
Date | 10 Apr 2018

Existing and proposed infrastructure
at Bibblewindi

Figure 4-4

Figure 9 | Bibblewindi Facility



Aerial Imagery: Dec 2013

- LEGEND**
- Leewood
 - Existing facilities
 - Proposed infrastructure
 - Vegetation to remain
 - Leewood to Wilga Park infrastructure corridor
 - Bibblewindi to Leewood infrastructure corridor
 - Roads

<p>0 0.075 0.15 0.3 Kilometers</p> <p>Map Projection: Transverse Mercator Horizontal Datum: GDA 1984 Grid: GCA 1984 UTM Zone 55</p>			<p>Narrabri Gas Project Response to submissions</p> <p>Existing and proposed infrastructure at Leewood</p>	<p>Job Number 21-22483 Revision A Date 10 Apr 2018</p>
---	--	--	---	--

Figure 4-3

Figure 10 | Leewood Facility

Gas Processing

41. Gas collected from the production wells would be transported via underground gas gathering lines and pipelines to the Leewood central gas processing facility. Gas from the southern parts of the site would first go to the Bibblewindi facility for compression before being sent to the Leewood facility.
42. At Leewood, the gas would be processed in the central gas processing facility. This would involve additional compression, carbon dioxide removal and dehydration.
43. The processed gas would then be:
 - used on-site to generate electricity for the project at the proposed small gas-fired power station at Leewood (if it is built); or
 - exported off-site via gas pipeline to:
 - the Wilga Park Power Station;
 - local customers; and/or
 - the domestic gas market.
44. Both the Bibblewindi and Leewood facilities would include gas safety flares with a stack height of up to 50 m to manage gas releases during commissioning, maintenance or emergencies.

Produced Water Management

45. Up to 37.5 gigalitres of produced water would be extracted during the life of the project. Water volumes would peak at approximately 10 ML/day in Years 2 to 4 when extensive drilling would occur. They would then average around 4.5 ML/day during production before declining gradually towards the end of the project as the gas wells are progressively decommissioned (see **Figure 11**).

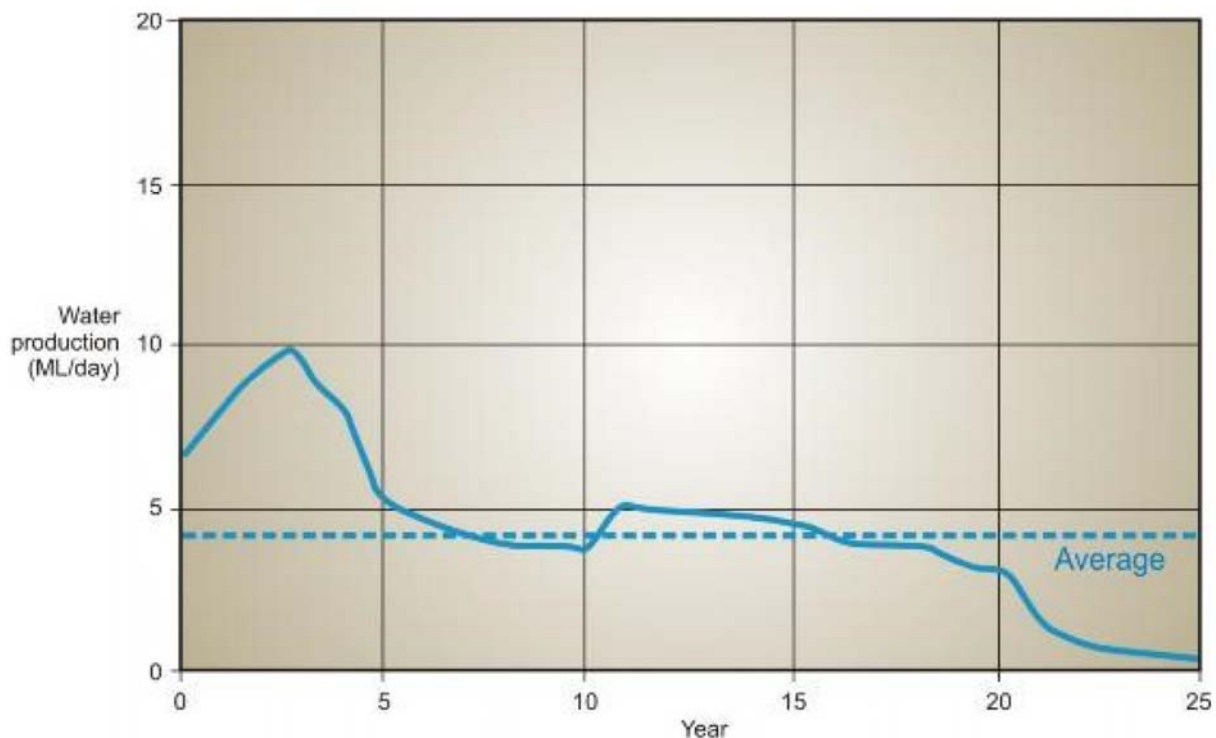


Figure 11 | Indicative Produced Water Rates

46. This water would be saline, at about 40% the salinity of seawater, and would require treatment to a suitable standard before it could be reused or discharged off-site.
47. Most of this water would be stored in specially built water storage ponds at the Biblewindi and Leewood facilities (see **Figures 9** and **10**). However, up to five 5 ML water tanks would be located across the site to manage high and low flows of produced water and to facilitate the effective transfer of water from the gas field to the ponds at Leewood or Biblewindi.
48. Ultimately, all produced water would be pumped to the water treatment plant at Leewood, where it would undergo a multi-stage treatment process, using reverse osmosis (and other systems) to produce treated water that meets Australian drinking water guidelines and irrigation and stock watering guidelines.
49. Treated water would be used beneficially for irrigation, stock watering, construction, dust suppression and/or drilling activities. A treated water transfer pipeline/s would connect Leewood to the irrigation area(s), and treated water storage dams (up to 200 ML capacity) would to be constructed across the irrigation areas.
50. During prolonged wet weather periods when irrigation and other beneficial uses are not available, excess treated water would be released to Bohena Creek via a managed release pipeline and diffuser (see **Figure 12**), but only when the creek is flowing at 100 ML or more a day.

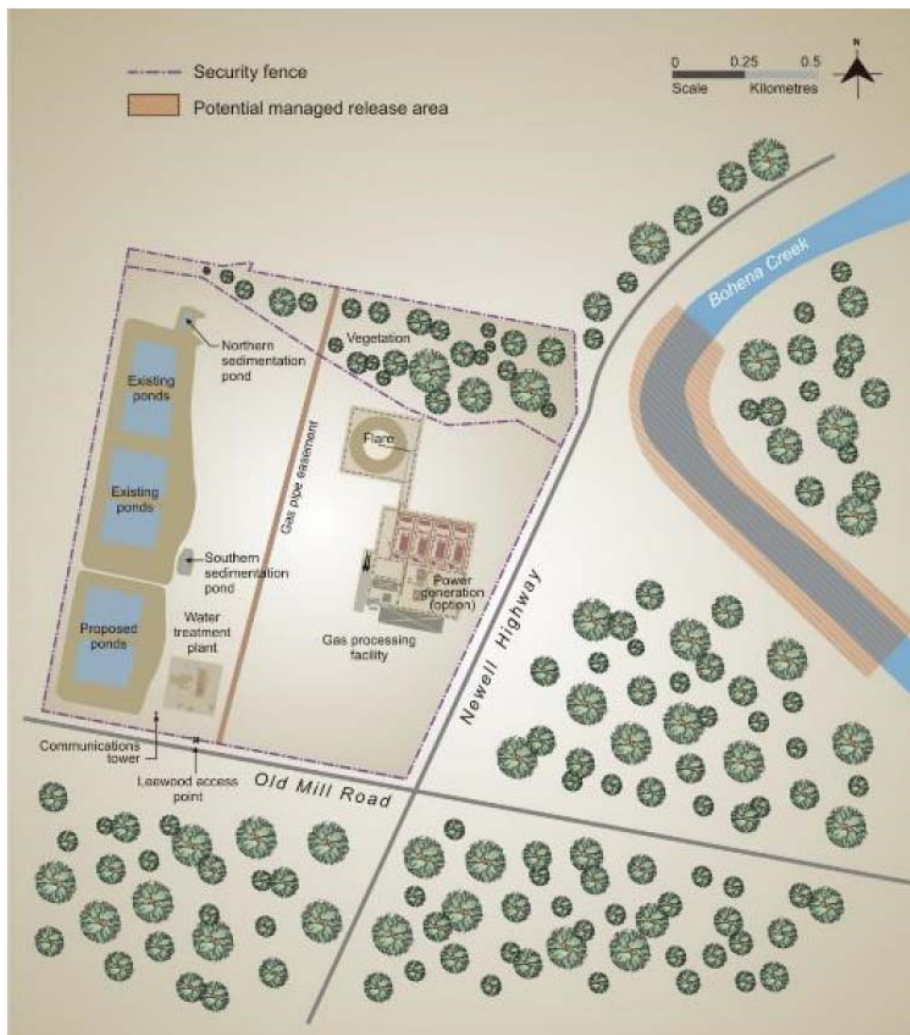


Figure 12 | Bohena Creek Managed Release Area

Waste Management

51. The brine generated during produced water treatment would initially be stored in brine ponds at Leewood, and ultimately concentrated and passed through a salt crystalliser to produce a solid salt product.
52. Up to 840,000 tonnes of salt may be produced during the project, with around 33,600 tonnes produced each year.
53. The salt would be stored in a covered interim storage facility while on site, before being transported off-site for beneficial reuse (if this is feasible and reasonable) or disposed of at a licenced waste facility. Santos would investigate potential beneficial reuse options for the material.
54. Rock-based drill cuttings from the construction of wells (approximately 400,000 m³) would be buried on site or disposed of off-site at a licensed disposal facility. Coal-based drill cuttings (approximately 720,000 m³) would be temporarily stored on site in containers before being disposed of off-site at a licenced waste facility.
55. Drilling fluids, cement slurry and other waste generated by the project would also be disposed of at licenced waste facilities.

2.4 Ancillary Infrastructure

56. The project includes developing a range of ancillary infrastructure, including:
 - upgrading the former Westport workers accommodation facility to provide accommodation for up to 200 workers, including:
 - installing demountable buildings for sleeping quarters;
 - kitchen and dining facilities; and
 - amenities and services;
 - upgrading two intersections on the Newell Highway (Old Mill Road and X-Line Road) to provide safe access to the site;
 - utilities to support the project, including telecommunications and electricity supply; and
 - water-related infrastructure to support water irrigation and the discharge of water from the site.

2.5 Voluntary Planning Agreement

57. Santos and Narrabri Shire Council have agreed to the terms of a Voluntary Planning Agreement (VPA) for the project, involving the payment of \$14.5 million of contributions.
58. These contributions would be used to fund the delivery of local infrastructure and services in the Narrabri LGA, including:
 - \$10 million for special projects to help drive economic development;
 - \$3 million for community initiatives or local infrastructure; and
 - \$1.5 million towards local roads maintenance.

2.6 Timing

59. The project would be developed in four phases, some of which would occur concurrently.

60. Phase 1 would involve carrying out further exploration and appraisal activities, including:
- seismic surveys;
 - core and chip holes;
 - drilling up to 25 pilot wells; and
 - installing ancillary infrastructure to support these activities (access tracks, gas and water gathering lines, flaring infrastructure).
61. Phase 2 would involve developing the gas field and related infrastructure, including:
- drilling production wells (up to 850 wells on up to 425 well pads);
 - installing ancillary infrastructure to support the drilling of the gas wells, including access tracks, gas and water gathering lines, water balance tanks, flaring infrastructure, utilities and services;
 - upgrading the key infrastructure on site, including the infrastructure corridor and Leewood and Bibblewindi facilities;
 - developing the water and gas processing infrastructure;
 - building the Westport workers accommodation facility; and
 - installing the ancillary infrastructure.
62. Phase 3 would involve operating the gas field and associated infrastructure and producing gas for the domestic market.
63. Phase 4 would involve decommissioning the gas field and associated infrastructure and the final rehabilitation of the site.

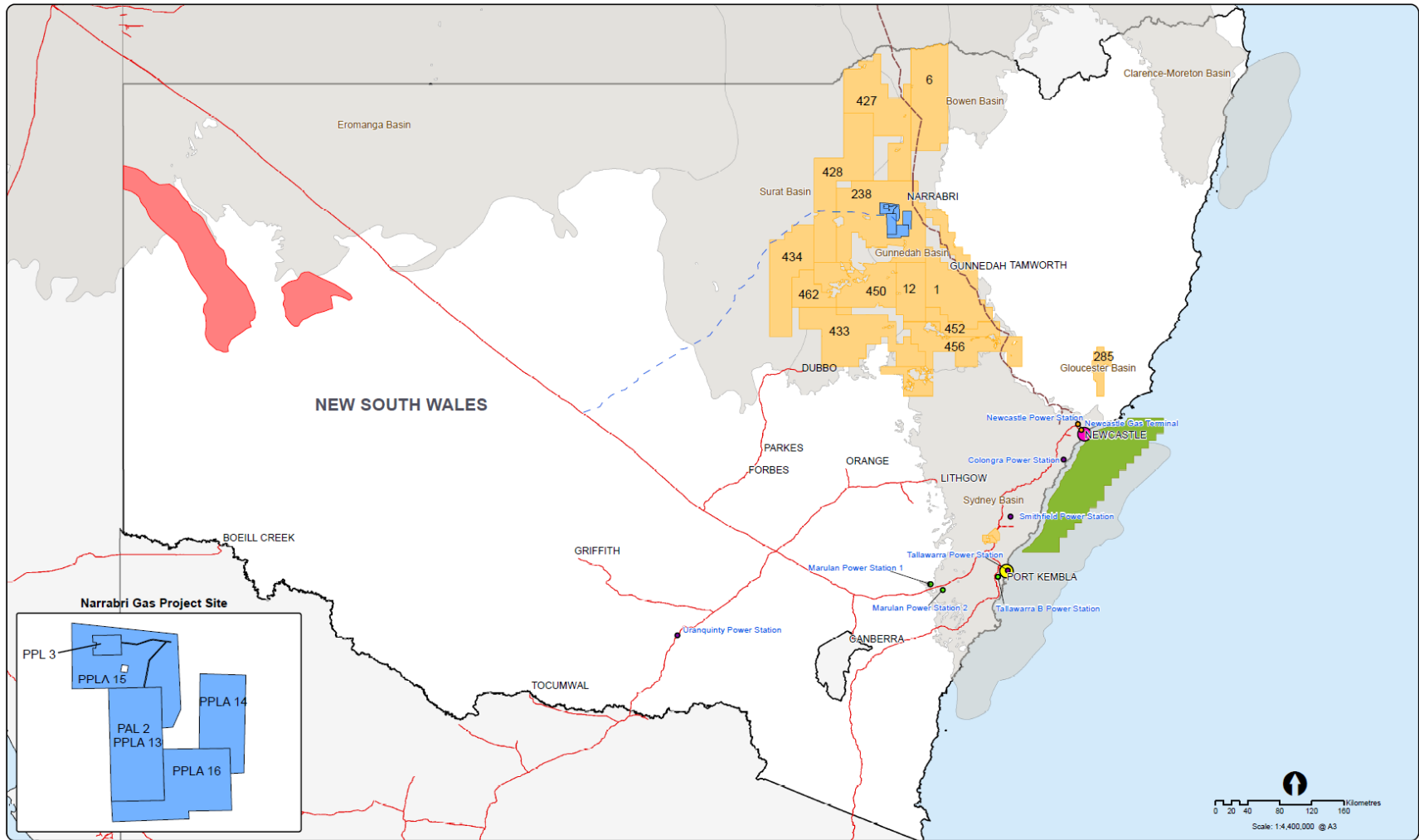
2.7 Related Matters

Community Benefit Fund

64. One of the key drivers in the NSW Gas Plan is to share the benefits of any gas development with the local community.
65. The key mechanism to deliver these benefits is through establishing a Community Benefit Fund (CBF) for gas projects under the *Petroleum (Onshore) Act 1991*.
66. The CBF will receive contributions from gas companies and the NSW Government (a share of royalties), normally linked to the production of gas, and these contributions would be used to fund community projects in the local community.
67. Mining, Exploration and Geoscience (MEG) has published guidelines for the establishment and operation of CBFs, and is currently consulting with Santos, Narrabri Shire Council and other key stakeholders about establishing a CBF for the Narrabri Gas Project, including establishing the detailed governance and administrative arrangements of the fund.
68. Santos has committed to contributing 10% of any royalties paid for the Narrabri Gas Project to this CBF, which would result in contributions of around \$120 million to the fund over the life of the project.
69. These funds could make a major contribution to the economic and social development of the region over the next 20-30 years.

Gas Pipeline

70. Prior to producing gas, Santos would need to connect the Narrabri Gas Project to the existing regional gas pipeline network, which is currently located several hundred km to the south of the site (**Figure 13**).
71. Although this connection is essential for the project, Santos is not seeking approval for this pipeline as part of the Narrabri Gas Project. The pipeline is likely to be delivered by another party and subject to a separate approvals process under the State Significant Infrastructure provisions of the *Environmental Planning and Assessment Act 1979* (EP&A Act).
72. At present, there are two possible options for the pipeline connection.
73. The first option involves connecting the project to the approved Queensland-Hunter gas pipeline located to the east of the site (see **Figure 13**).
74. This pipeline is classified as Critical State Significant Infrastructure because it would extend the existing gas pipeline network in NSW to the north and improve the ability of NSW to secure gas from Queensland and the Northern Territory. It would also drive greater competition in the domestic market and put downward pressure on gas prices.
75. Although the pipeline was approved in 2009, it has not been built yet due to uncertainties in the gas market over the last decade. However, the proponent has until 15 October 2024 to physically commence the construction of the pipeline, and the approval of the Narrabri Gas Project could facilitate the development of this pipeline.
76. If the Queensland-Hunter gas pipeline is built, then further approvals would be required to connect the Narrabri Gas Project to the pipeline. Given the relatively short distance between the project and the pipeline, the Department cannot see any constraints – from a strategic perspective – with securing a suitable alignment for such a connection.
77. The second option involves developing the proposed Western Slopes Pipeline, which would connect the project to the Moomba-Sydney pipeline to the west of the site (see **Figure 13**).
78. This pipeline, which is being proposed by the APA Group, is classified as State Significant Infrastructure under the EP&A Act and is in the early stages of the approvals process. The Department has issued the requirements for the EIS and is now waiting for the APA Group to complete the EIS before it starts public consultation and assessing the merits of the project.
79. Given the uncertainties with both options, Santos has agreed to accept a condition on any development consent for the Narrabri Gas Project requiring it to ensure there is an approved pipeline connection to the project prior to starting to construct the project (Phase 2) and that this connection is in place prior to starting any gas production (Phase 3).



- Legend**
- Newcastle Gas Import Terminal (Proposed)
 - Port Kembla Gas Import Terminal (Approved)
 - Gas Fired Power Stations**
 - Operating
 - Approved
 - Proposed
 - National Onshore Gas Pipelines
 - QLD Hunter Pipeline (Approved)
 - Western Slopes Pipeline (Proposed)
 - Narrabri Gas Project Site
 - Petroleum Applications and Titles
 - Preliminary Regional Issues Assessment Troughs
 - Petroleum Exploration Permit 11
 - Basins

Gas Infrastructure NSW



Document Path: G:\EPLANNING\Business_Data\lad_hoc\Map_Request\20190624_Rose_Anne_Hawkeswood\Maps\MXD\NSW_Gas_Industry_NSW_Only_20190701.mxd
 Document Name: NSW_Gas_Industry_NSW_Only_20190701
 Date Saved: 1/07/2019 10:31:45 AM

Figure 13 | Gas Pipeline Network

3 Strategic Context

3.1 Energy Security & Reliability

Domestic Gas Market

- 80. NSW forms part of the east coast gas market, which is comprised of a series of gas fields and pipelines in South Australia (Cooper Basin), Victoria (Otway and Gippsland Basins), Queensland (Surat and Bowen Basins) and the Northern Territory (Beetaloo Basin).
- 81. This market has experienced significant changes over the last decade, largely due to the development of a major non-conventional (coal seam gas) gas export industry in Queensland, including several liquified natural gas export terminals at Gladstone. This has exposed the domestic gas market to international prices and seen gas prices nearly double in the space of a few years. It has also increased the competition for domestic gas supply, with almost 70% of domestic gas now going to export markets.
- 82. The increasing prices, coupled with concerns about future supply, have made it increasingly difficult for local industries in NSW to remain competitive, and has also discouraged the development of peaking gas-fired power stations in to help manage the transition of the National Electricity Market (NEM) from a reliance on coal-fired power stations to a greater reliance on renewable energy.
- 83. In its 2019 *Gas Statement of Opportunities*, the Australian Energy Market Operator (AEMO) indicates the long-term outlook for the domestic gas market remains “tight and uncertain” and forecasts supply shortfalls in southern states, including NSW, from 2024 unless new supplies are brought online (see **Figure 14**).

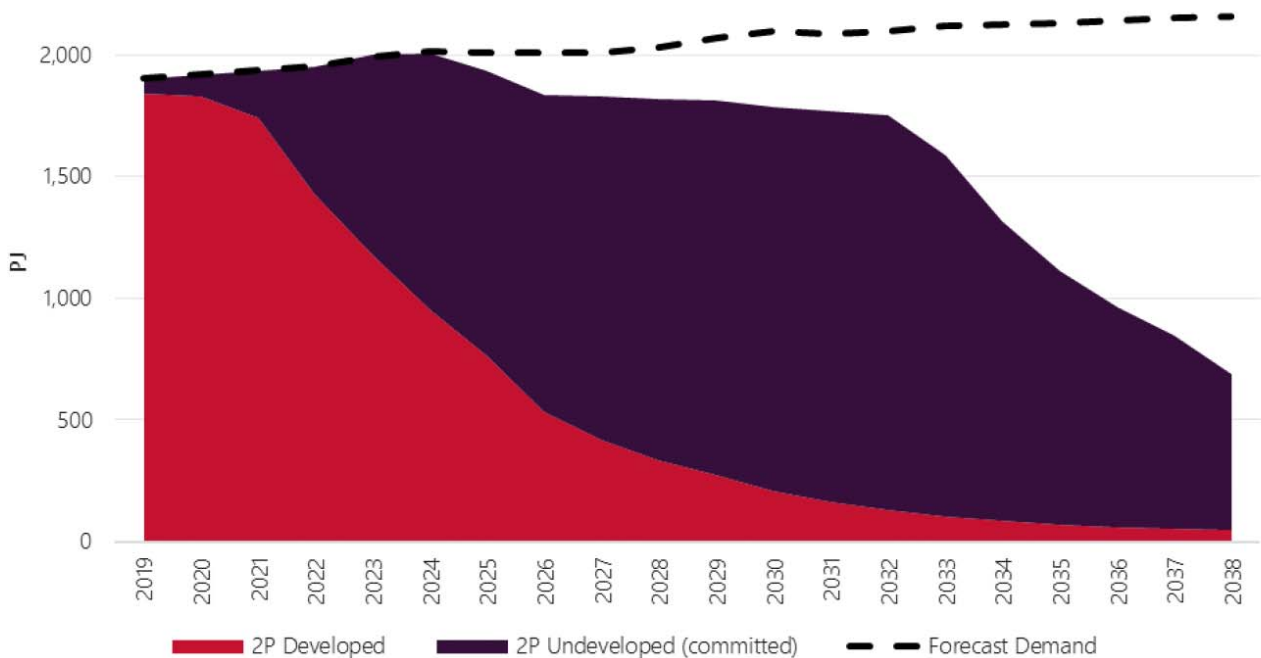


Figure 14 | Forecast East Coast Gas Market Supply and Demand

- 84. Both the Commonwealth and NSW government are seeking to avoid any shortfalls in gas supply by:

- encouraging greater supply, principally by developing new gas resources but also potentially by importing gas through new import terminals;
- facilitating expansions to the existing pipeline network to improve the integration of the gas market and make it easier to move gas supplies between states;
- increasing competition in the gas market to drive down gas prices.

NSW Gas Demand & Supply

85. NSW currently uses around 125 PJ of gas a year.
86. This gas is used by around 500 heavy industrial facilities (smelters, paper mills, abattoirs, etc.), 33,000 other business, gas fired power stations, and more than 1.4 million households (for cooking and heating); and supports around 300,000 jobs.
87. Although NSW is rich in gas resources, it currently imports more than 95% of its gas from other states with around 40% of this gas coming historically from South Australia and 55% from Victoria. The remaining 5% comes from the Camden Gas Project in Sydney, which is due to cease operations in 2023.
88. Current forecasts predict a small decline in demand over the next two decades as domestic users adjust to higher gas prices. However, the closure of several coal-fired power stations in NSW (Liddell, Vales Point, Eraring and Bayswater) could increase the demand for gas in the electricity sector as new gas-peaking power stations are built to provide dispatchable energy to the NEM.
89. While gas demand is likely to remain constant or to increase slightly over this period, additional supply will be required to compensate for the closure of the Camden Gas Project and the likely major decline in supplies from traditional sources in Victoria and South Australia from 2023.
90. These additional supplies could come from:
 - Queensland and the Northern Territory, although this would require significant extensions to the existing gas pipeline network in NSW;
 - imports, either through the approved Port Kembla gas import terminal (which has not been built yet) or the proposed Newcastle gas import terminal (which is still in the early stages of the planning approvals process); or
 - the Narrabri Gas Project.
91. Any shortfalls in gas supply or increases in gas prices is likely to have significant economic consequences for the NSW economy. It would result in the closure of several key industrial facilities and businesses, resulting in significant job losses in regional areas. It would also discourage the development of peaking gas-fired power stations which are forecast to play a critical role in helping the NEM transition over the next few decades to a greater reliance on renewal energy.

Strategic Energy Project

92. The Narrabri Gas Project would produce up to 200 TJ of gas a day for about 20 years, enough to supply 50% of NSW's forecast gas demand.
93. Further, Santos has committed to providing all the gas produced by the project to the domestic market and has agreed to accept a condition to this effect on any petroleum production licence granted for the project under the *Petroleum (Onshore) Act 1991*.

94. Consequently, the NSW Government has declared the Narrabri Gas Project to be a Strategic Energy Project. This is principally because the project would strengthen energy security and reliability in NSW by:
- providing essential gas supplies to NSW over the next few decades to address forecast shortfalls in gas supply from 2023-4, which could result in significant job losses;
 - facilitating critical extensions of the existing gas pipeline network to northern parts NSW, connecting major gas users (Sydney, Newcastle, Wollongong) to the most prospective gas resources in NSW, and bringing them closer to the strategic gas resources in Queensland and the North Territory, which are likely to play a major role in supplying gas to the domestic market in the future;
 - encouraging the development of peaking gas-fired power stations in NSW to compensate for the closure of several coal-fired power stations in the next 20 years and help the NEM to transition to a greater reliance on renewable energy and reduce greenhouse gas emissions in NSW;
 - increasing competition in the domestic gas market and putting downward pressure on gas prices; and
 - promoting economic development in northern NSW by creating jobs and supporting the creation of new businesses, including the development of a new industrial hub outside Narrabri adjoining the approved Inland Rail Project.

3.2 Coal Seam Gas Review & Reforms

95. The rapid increase in non-conventional gas development (coal seam gas, shale gas and tight gas) overseas and across the east coast of Australia, particularly in Queensland, in recent years has fueled community concerns about the impacts of this development.
96. This includes concerns about:
- impacts on land and water resources, principally due to fracking depleting aquifers and contaminating water resources;
 - impacts on the health and safety of the community due to air emissions from the extraction and processing of gas and the handling of any associated wastes;
 - the management and disposal of wastes generated during gas development, particularly the management and disposal of saline produced water and its associated waste streams including brine and salt;
 - the greenhouse gas emissions of the development, particularly the fugitive emissions from gas wells and processing facilities;
 - the conduct of certain gas companies and the way they treat local landholders; and
 - social impacts on local communities where the gas is extracted.
97. These concerns have led to calls for moratoriums or bans on non-conventional gas development in several jurisdictions.
98. They have also led to major public inquiries into the carrying out of this development in Victoria, South Australia, Western Australia, the Northern Territory as well as NSW; and to major reforms in the way this development is assessed and regulated in these jurisdictions.

Chief Scientist & Engineer Review

99. In 2013, the NSW Government asked the Chief Scientist and Engineer to conduct a comprehensive review of coal seam gas activities in NSW.

100. This review included a comprehensive study of industry compliance, risks, best practice, benchmarking against national and international standards, scientific research and extensive community consultation.
101. The Chief Scientist and Engineer released her final report in September 2014.
102. While this report acknowledged community concerns about the coal seam gas industry, it concluded that the industry could provide significant economic benefits to the community, and that the risks associated with the industry could be effectively managed with detailed community consultation, the right regulation, engineering solutions, and constant monitoring and research.
103. The report contained 16 recommendations to deliver “world’s best practice regulation” for coal seam gas development in NSW, which were all adopted by the NSW Government in the *NSW Gas Plan*.
104. The Department has considered these recommendations in its detailed assessment of the merits of the Narrabri Gas Project.

NSW Gas Plan

105. The *NSW Gas Plan* was released in 2014 and sets a strategic framework for gas development in NSW.
106. It builds on the Chief Scientist and Engineer’s recommendations and seeks to secure vital gas supplies for the State by:
 - using better science and information to inform decision-making;
 - rationalising gas exploration and developing the most prospective resources with the fewest risks;
 - providing strong and certain regulation; and
 - sharing the benefits of the industry with local landholders and the community.

NSW Reforms

107. The coal seam gas review and *NSW Gas Plan* have led to several reforms in NSW.
108. First, coal seam gas development has been banned in sensitive areas, including National Parks, Sydney’s drinking water catchment, critical industry clusters, and within 2 km of residential areas.
109. Second, there has been a significant rationalisation of gas exploration licences across NSW. Through buybacks and cancellations, only 7% of NSW is now subject to gas exploration licences; existing titleholders are subject to a use it or lose it policy; and new licences can only be issued after detailed strategic assessment and community consultation. Remaining licences are concentrated in north-western NSW (see **Figure 13**) where the target coal seams are generally deep and isolated from any beneficial aquifers.
110. Third, the NSW Government has released several policies and guidelines to minimise the impacts of coal seam gas development, including:
 - the *NSW Aquifer Interference Policy* (AIP) in 2012 to protect aquifers;
 - codes of practice for the coal seam gas industry covering well integrity (to protect the cross-contamination of aquifers), managing produced water and fracking;
 - banning evaporation ponds and the use of BTEX (benzene, toluene, ethylbenzene and xylene) chemicals and requiring all other chemicals to meet Australian drinking water health guidelines; and
 - introducing the “gateway process” to protect strategic agricultural land.

111. Fourth, reforms have been made to ensure landholders and the local community share in the benefits of any gas development, including changes to the land access and arbitration process, benchmarking of landholder compensation rates, and creating a regulatory framework and guidelines for the establishment of Community Benefit Funds for gas projects.
112. Fifth, actions have been taken to improve community engagement, including appointing a NSW Land & Water Commissioner, establishing community consultative committees for coal seam gas projects, and making it easier for the community to get access to key information on specific projects via the Department's Major Projects Portal and key scientific databases, including the SEED, DIG and Common Ground databases.
113. Further, all projects, including the Narrabri Gas Project, are classified as State significant projects and must undergo comprehensive assessment and obtain approval under the EP&A Act before they may proceed.
114. Finally, the Environment Protection Authority (EPA) has been appointed as the lead regulator for all coal seam gas development in NSW and is responsible for monitoring and enforcing compliance with any conditions of approval.

3.3 Regional Setting

115. The Narrabri Gas Project is located approximately 20 km south-west of Narrabri (population approximately 13,000) and covers an area of approximately 95,000 ha. Land use in the project area is dominated by the State Forest in the southern part of the site (66% of the project area) and privately-owned agricultural land in the northern part of the site (see **Figure 15**).
116. The forested areas form part of the 'Pilliga', which covers an area of approximately 500,000 ha. Almost half of this area (240,000 ha) was protected as reserves under the *National Parks and Wildlife Act 1974* following a comprehensive review in 2005. The rest of the area, including the project area, were dedicated as State Forest and set aside for forestry, recreation and mineral extraction.
117. The agricultural areas within the site do not include any strategic agricultural land. They are generally used for broad acre grazing and dryland cropping; the soils have low to moderate soil fertility; and there is no irrigated cropping land in the project area. From a regional perspective, the higher quality agricultural land that is subject to extensive irrigation tends to be concentrated in the alluvial floodplains of the Namoi River and its associated tributaries, which are located several kilometres to the north and north-east of the site.
118. There are 114 residences in the project area, and a further 103 residences within 3 km of the site (see **Figure 16**). Santos has committed to only undertaking project development on privately-owned land if the landowner agrees.
119. The target coal seams in the project form part of the Gunnedah geological formation and are generally located between 800 m and 1,200 m below ground level. These coal seams and their associated aquifers are well below, and physically separated from, the highly valued shallower aquifers in the region as well as major watercourses such as the Namoi River.
120. The shallow aquifers, some of which form part of the Great Artesian Basin, are widely used to supply water for agricultural, town and environmental purposes. The coal seam aquifers, on the other hand, contain poor quality (saline) groundwater and are separated from the shallow aquifers by approximately 250 m to 400 m of relatively impervious rock known as 'aquitards'. The coal seam aquifers do not form part of the Great Artesian Basin and are not used for productive purposes in the region due to their saline nature.

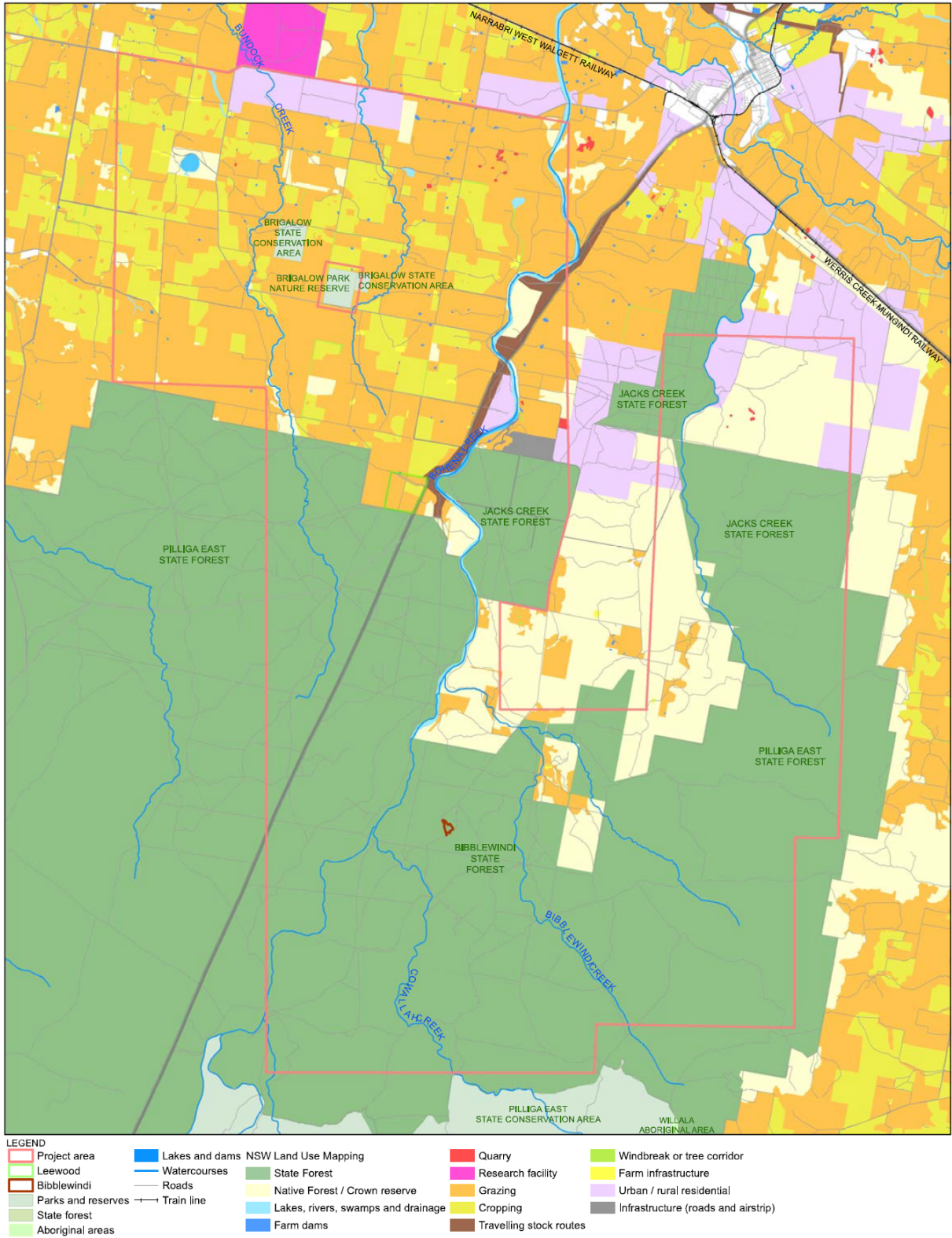
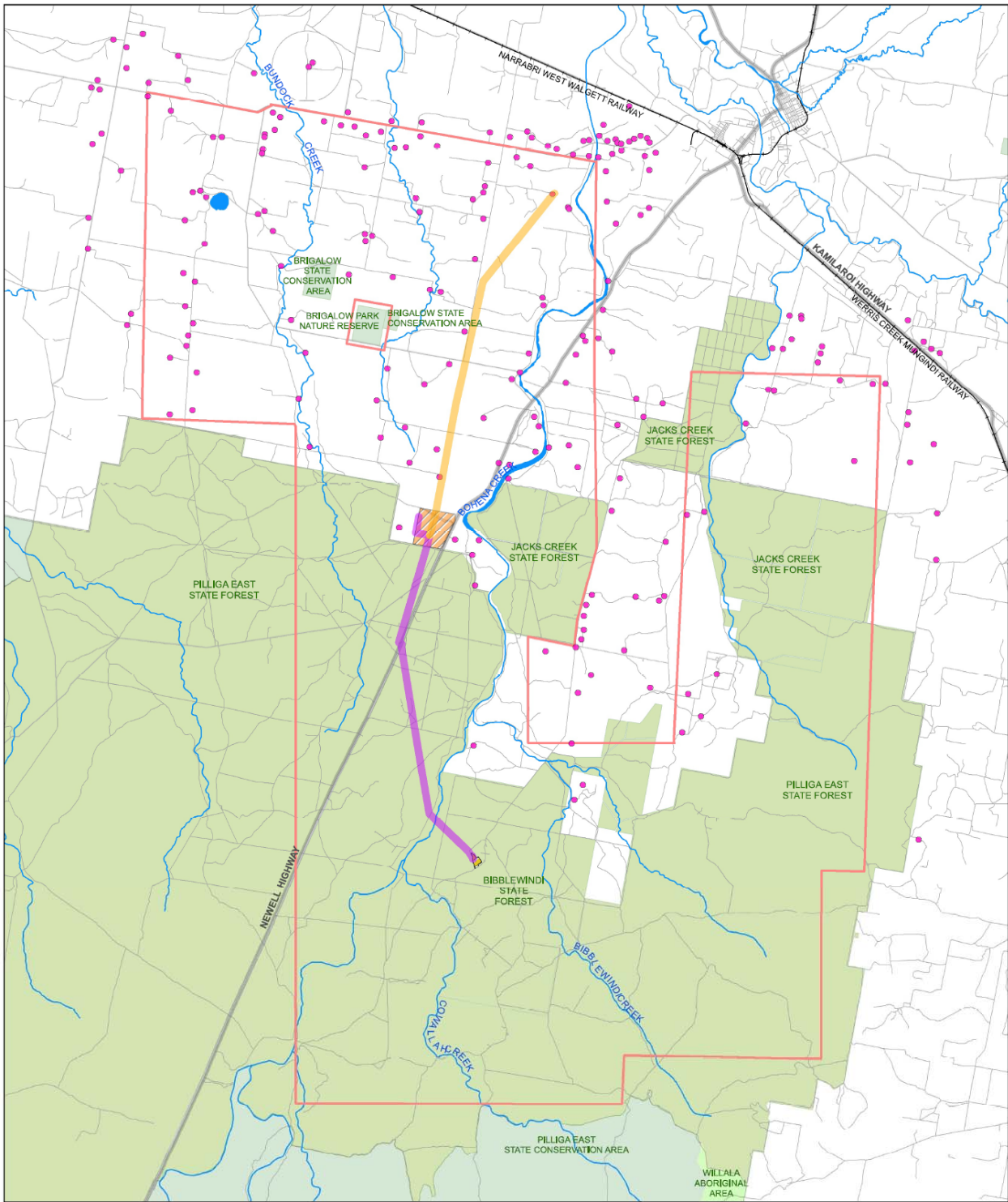


Figure 15 | Land Use



- LEGEND
- Project area
 - Lakes and dams
 - Leewood to Wilga Park infrastructure corridor
 - Leewood
 - Watercourses
 - Bibblewindi to Leewood infrastructure corridor
 - Bibblewindi
 - Roads
 - Parks and reserves
 - Train line
 - State forest
 - Sensitive receivers
 - Aboriginal areas

Figure 16 | Local Landowners

121. Key natural features in the project area includes the Brigalow State Conservation Area and Brigalow Nature Reserve. Santos has committed to protecting both of these areas with high conservation value by undertaking no development on the surface or under the Brigalow Nature Reserve and no development on the surface or to a depth of below 100 m under the Brigalow State Conservation area.
122. Santos has also agreed to protect several other key natural features from adverse impacts under its proposed Field Development Protocol (see **Table 4**), including Yarrie Lake which is a popular recreational facility in the region.
123. There are several coal mines in the region. However, apart from the Narrabri underground coal mine which is located on the eastern boundary of the project area, these mines are long way from the project area in and around the Leard State Forest or to the south of Gunnedah, and are unlikely to generate any cumulative impacts with the project.
124. Key infrastructure in the region includes the:
 - major towns and villages in the region, including Narrabri, Wee Waa and Gunnedah;
 - Kamilaroi and Newell Highways;
 - several local and forestry roads, including Old Mill Road, Yarrie Road, Old Gunnedah Road;
 - the Wilga Park Power Station (see **Figure 3**);
 - the approved Queensland-Hunter gas pipeline (see **Figure 13**);
 - the approved inland railway line, which adjoins the northern part of the site; and
 - the proposal to establish a new industrial are to the north of the site to take advantage of the proposed inland rail and a secure gas supply from the Narrabri Gas Project.

4 Statutory Context

4.1 Approval Under the EP&A Act

State Significant Development

125. The project is classified as State Significant Development (SSD) under Section 4.36 of the EP&A Act because it is 'development for the purposes of petroleum production', which is listed as SSD under Clause 6 of Schedule 1 of *State Environmental Planning Policy (State and Regional Development) 2011* (State and Regional Development SEPP).
126. Consequently, the project requires development consent under Division 4.7 of the EP&A Act before it may proceed.
127. Under Section 4.5(a) of the EP&A Act and Clause 8A (1) of State and Regional Development SEPP, the Independent Planning Commission is the consent authority for the development application (DA) because the Department received over 25 public objections to the project during the exhibition period.

Permissibility

128. The project is permissible with development consent under a combination of the *Narrabri Local Environmental Plan 2012* (Narrabri LEP), *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (Mining SEPP) and Section 4.38 of the EP&A Act.
129. The project area is located wholly within the Narrabri local government area.
130. Under the Narrabri LEP (see **Figure 17**) the:
 - northern part of the site is zoned RU1 – Primary Production;
 - southern part of the project area is zoned RU3 – Forestry; and
 - Brigalow State Conservation Area and Brigalow Nature Reserve are zoned E1 – National Parks and Nature Reserves.
131. Under Clause 7(2)(a) of the Mining SEPP, the project is permissible with development consent in the RU1 zone because it is development for the purposes of petroleum production on land where both agriculture and industry are permissible with and without development consent under the Narrabri LEP.
132. The project is permissible without development consent in the RU3 zone under the Narrabri LEP because the Forestry Corporation of NSW is satisfied that it is a commercial activity that is compatible with forestry and is prepared to authorise it under Part 5 of the *Forestry Act 2012*.
133. Although the project is permissible with development consent in the E1 zone under Clause 7(2)(e) of the Mining SEPP, Santos is not proposing to carry out any surface development in either of these zones, and has committed to drilling at least 100 m below the surface of the Brigalow State Conservation Area to avoid any adverse impacts on the biodiversity values of this area.
134. Consequently, the project is permissible either with or without consent on all of the land within the project area. Under Section 4.38(4) of the EP&A Act, however, the entire project is permissible with development consent.

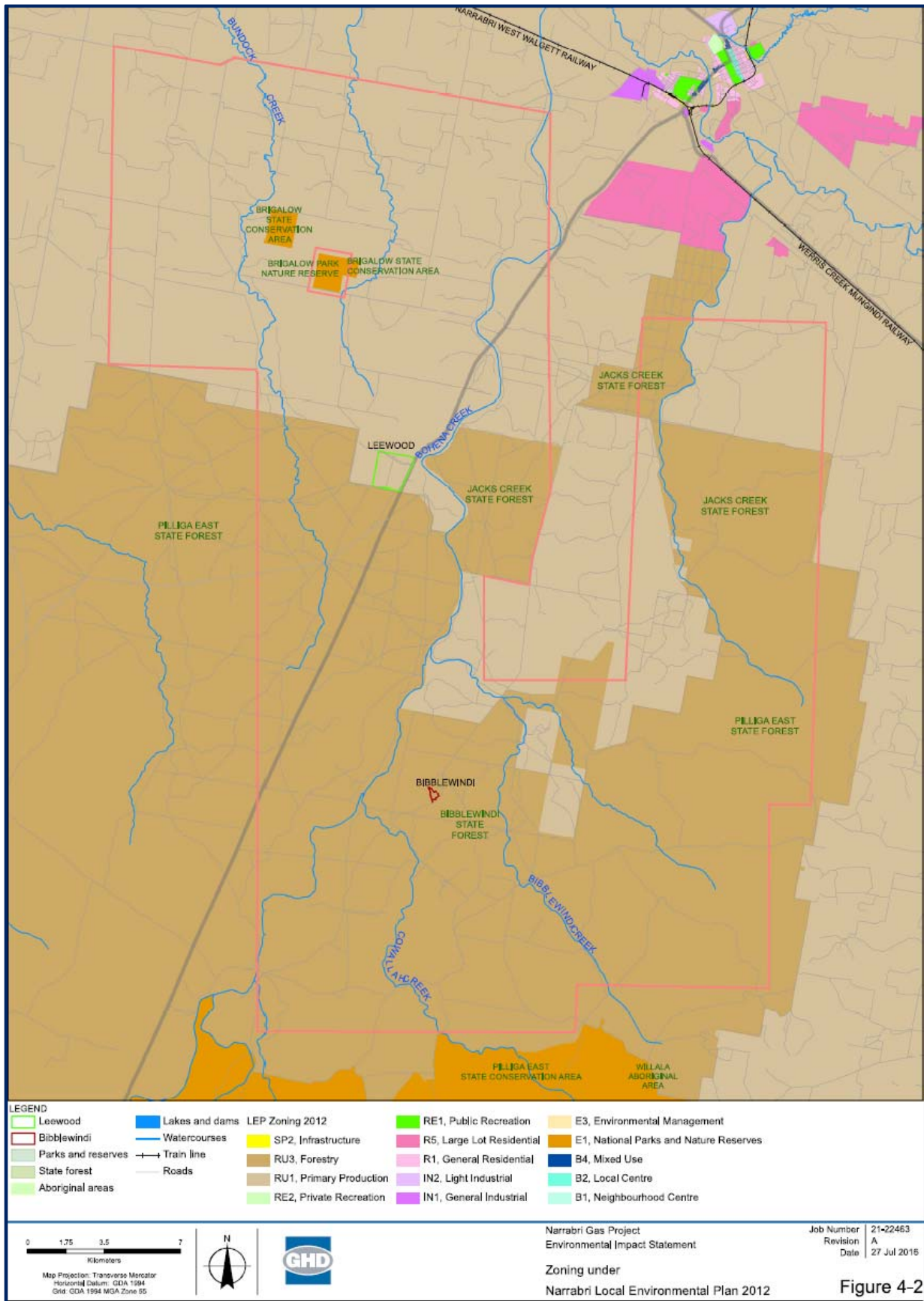


Figure 17 | Land Zoning under Narrabri LEP 2012

Exempt Approvals

135. Under Section 4.41 of the EP&A Act, the following approvals are not required for the project:
- various heritage-related approvals under the National Parks and Wildlife Act 1974 and Heritage Act 1997;
 - a permit under Section 219 of the Fisheries Management Act 1994;
 - a bushfire safety authority under Section 100B of the Rural Fires Act 1997; and
 - various water-related approvals under Sections 89-91 of the Water Management Act 2000.
136. The Department has integrated the assessment of these matters into its detailed assessment of all other matters under the EP&A Act, consulted with the agencies responsible for administering these approvals, and recommended conditions requiring Santos to minimise the heritage, fish, bushfire and water impacts of the project.

Application of the Biodiversity Conservation Act 2016

137. Under Section 1.7 of the EP&A Act, the provisions of Part 7 of the *Biodiversity Conservation Act 2016* (BC Act) apply to the assessment of SSD DAs under the relevant transitional arrangements of Part 7 of the *Biodiversity Conservation (Savings and Transitional) Regulation 2017* (S&T Regulation), as the DA for the project was lodged with the Department before the BC Act commenced on 25 August 2017.
138. Consequently, the former planning provisions continue to apply to the project, and the terrestrial biodiversity impacts of the project must be assessed under the *NSW Biodiversity Offsets Policy for Major Projects* (Major Projects Offsets Policy), which is underpinned by the Framework for Biodiversity Assessment (FBA), rather than under the BC Act.
139. The FBA sets out the process for:
- assessing the biodiversity impacts of SSD projects; and
 - determining the biodiversity offset requirements for these impacts.
140. Santos has carried out a detailed assessment of the biodiversity impacts of the project in accordance with the NSW Offsets Policy, which is considered further in Section 6.4.
141. If the project is approved, any obligations imposed on Santos to retire biodiversity credits established using the FBA will become obligations to retire credits under the BC Act under Clause 22 of the S&T Regulation, and the Department will translate these credits into “reasonably equivalent” credits for the purposes of the BC Act.

Assessment of Existing & Approved Infrastructure

142. As indicated in Section 1, Santos proposes to use most of the existing and/or approved petroleum-related development on site for the Narrabri Gas Project. It is seeking approval for the continued use of this development as part of the DA and proposes to surrender any existing development consents for this development if the project is approved.
143. Under Section 4.63 of the EP&A Act, a consent authority is not required to reassess the likely impact associated with the continued use of this development or to re-determine whether to authorise the development under the new development consent. However, the consent authority may modify the way the continued development is to be carried out for the purpose of the consolidation of the development consents.

144. This is intended to make it easy to consolidate multiple development consents into a single development consent without having to re-assess the impacts of what has already been approved, and to simplify the regulatory controls for a project.
145. The Department has included recommended conditions for the project to minimise the impacts associated with the continued use of this development, and to ensure it is removed following operations and the land is rehabilitated to a suitable standard.

Administrative and Procedural Requirements

146. Under the EP&A Act and Regulation, several administrative and procedural requirements must be met before a consent authority can determine a development application for SSD.
147. These requirements include:
- making the DA in the correct manner;
 - exhibiting the DA and EIS for at least 28 days;
 - publicly notifying the exhibition;
 - providing a copy of the submissions to the applicant;
 - making all relevant information on the DA publicly available on the Department's website.
148. The Department has reviewed the steps taken in the assessment of the Narrabri Gas Project and is satisfied that all relevant requirements have been met (see checklist in **Appendix B**).

Public Hearings

149. On 3 March 2020, the Minister for Planning and Public Spaces asked the Commission to hold a public hearing into the Narrabri Gas Project under Section 2.9(1)(d) of the EP&A Act. This was principally due to the significant level of public interest in the project and the complex technical issues associated with assessing the likely impacts of the project.
150. Under the terms of reference, the Commission is required to:
- Conduct a public hearing into the carrying out of the Narrabri Gas Project (SSD 6456) prior to determining the development application for the project under the Environmental Planning and Assessment Act 1979, paying particular attention to:
 - a) *the Department of Planning, Industry and Environment's assessment report, including any recommended conditions of consent;*
 - b) *key issues raised in public submissions during the public hearing; and*
 - c) *any other documents or information relevant to the determination of the development application.*
 - Complete the public hearing and make its determination of the development application within 12 weeks of receiving the Department's assessment report in respect of the project, unless the Planning Secretary agrees otherwise.
151. The public hearing is meant to give the public another opportunity to have another say on the project and to provide detailed feedback to the Commission on the Department's assessment report and any recommendations. It is also meant to give the Commission an opportunity to ask questions and seek clarifications on key issues to ensure it is fully informed prior to making its final decision on the merits of the project.
152. Following the public hearing, the Commission will determine the DA for the project in accordance with the requirements of the EP&A Act.

Mandatory Matters for Consideration

153. Under Section 4.40 of the EP&A Act, the Commission is required to evaluate the merits of the Narrabri Gas Project against the relevant matters for consideration set out in Section 4.15 of the Act prior to determining the development application for the project.
154. This includes:
 - (a) the provisions of any environmental planning instruments;
 - (b) the terms of any offer to enter into a planning agreement under Division 7.1 of the EP&A Act;
 - (c) the prescribed matters for consideration in Division 8 of the EP&A Regulation;
 - (d) the likely impacts of the project, including the environmental impacts on both the natural and built environments, and social and economic impacts in the locality;
 - (e) the suitability of the site for the project;
 - (f) the issues raised in any submissions on the project; and
 - (g) the public interest, including any relevant objects of the EP&A Act.
155. The Department has considered all of these matters in detail (see checklist in **Appendix B**), and summarised the findings of this review in this assessment report and the recommended conditions (see **Appendix I**).
156. The report has been prepared following extensive consultation with several government agencies (Commonwealth, State and local), independent experts and key stakeholders; and reflects the State Government's position on these matters.
157. The primary purpose of the assessment report is to help the Commission to evaluate the relevant matters required under the EP&A Act and determine the DA.

4.2 Other NSW Approvals

158. In addition to development consent under the EP&A Act, the Narrabri Gas Project requires several other approvals under NSW legislation.

Consistent Approvals

159. The project requires the following approvals:
 - a production lease under the *Petroleum (Onshore) Act 1991*;
 - an environment protection licence under the Protection of the Environment Operations Act 1997;
 - a licence under the *Pipelines Act 1967*; and
 - consent under Section 138 of the *Roads Act 1993* for road works including intersection upgrades and drilling under the road network.
160. Under Section 4.42 of the EP&A the assessment of these matters has been integrated into the assessment of all other matters under the EP&A Act.
161. Consequently, if the development application for the project is approved then these approvals cannot be refused, and the terms of these approvals must be substantially consistent with the terms of the development consent.
162. This reflects the government's commitment to provide an integrated, efficient and effective regulatory approvals process for State significant projects in NSW.
163. However, this restriction does not apply to subsequent renewals of these approvals; and in particular, to renewals of environmental protection licences following their first review. This is to

ensure that these licences remain current and incorporate any relevant changes to environmental standards and policies over time.

164. The Department has worked closely with the agencies responsible for administering these approvals during the assessment of the Narrabri Gas Project to minimise the impacts of the development. These agencies have advised the Department that they would be willing to grant the necessary approvals subject to conditions, which have been incorporated into the recommended conditions for the project.

Other Legislative Requirements

165. The project is subject to other requirements under NSW legislation that are not formally integrated into the assessment process under the EP&A Act.
166. These include:
- commercial agreements for the use of certain State-owned land under the *Crown Lands Act 1989* and *Forestry Act 2012*;
 - complying with the requirements in the *Work Health and Safety (Mines and Petroleum Sites) Act 2013* and *Dams Safety Act 2015* to ensure the safety of workers and the general public;
 - obtaining licences for relocating any threatened species under the *National Parks and Wildlife Act 1974*; and
 - obtaining surface water and groundwater licences for any water take of the project under the *Water Act 1912* and the *Water Management Act 2000*.
167. The Department has consulted the agencies responsible for administering this legislation during the assessment of the Narrabri Gas Project, and none of these agencies has identified any constraints to Santos being able to comply with these requirements, or secure these necessary authorisations, for the project.

4.3 Commonwealth Approval

Controlled Action

168. On 23 March 2015, the Narrabri Gas Project (EPBC 2014/7376) was declared to be a “controlled action” under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). This declaration was made because the project:
- is likely to have a significant impact on listed threatened species and communities (Sections 18 and 18A) and water resources (Sections 24D and 24E); and
 - includes activities involving Commonwealth land (Sections 26 and 27A): in this case, it could have significant impacts on the operation of the Siding Springs Observatory
169. Consequently, the project requires the approval of the Commonwealth Minister for the Environment in addition to any State approvals before it may proceed.

Bilateral Agreement

170. Under the Bilateral Agreement between the NSW and Commonwealth governments, all Commonwealth matters will be assessed under the State approvals process.
171. Under this agreement, the Department is required to:
- seek advice from the Commonwealth Independent Expert Scientific Committee on Coal Seam Gas and Large Mining Development (IESC) about the potential impacts of the project

on water resources and ground water dependent ecosystems, and the adequacy of the measures proposed to mitigate and monitor the impacts of the project;

- assess the likely impacts of the project on Commonwealth matters in accordance with any relevant agreement, policies or guidelines; and
- prepare an assessment report for the Commonwealth Minister, including any recommended conditions.

172. The Commonwealth Minister will then consider the Department's assessment report and make a final decision on the project under the EPBC Act.

IESC Advice

173. The Department has consulted the IESC during the assessment of the Narrabri Gas Project. This included attending an IESC meeting in Brisbane to provide a detailed briefing on the project to members of the committee and identify key issues for further advice.

174. The IESC has provided technical advice to the Department (see **Appendix C**), which has been fully considered in the assessment of all water-related impacts and incorporated into the recommended conditions for the project.

5 Engagement

5.1 Department's Engagement

175. The Department has consulted widely with the community, special interest groups and government agencies during its detailed assessment of the Narrabri Gas Project.
176. This consultation has included:
- making all the information on the project publicly available on the Department's website;
 - exhibiting the EIS from 21 February to 22 May 2017 (90 days);
 - holding several public information sessions in Narrabri during the exhibition;
 - publishing copies of all the submissions received online;
 - requiring Santos to provide a formal response to the issues raised in submissions;
 - holding meetings with key stakeholders, including:
 - Narrabri Shire Council;
 - the community consultative committee for the project;
 - landholders in the project area;
 - several special interest groups, including the North West Alliance, People for the Plains, Lock the Gate, Environment Defenders Office, Artesian Water Users Group, Namoi Water, NSW Farmers Association, NSW Country Women's Association, and Nature Conservation Council; and
 - Aboriginal groups, including the Narrabri Local Aboriginal Land Council (LALC), Wee Waa LALC and Dharriwaa Elders Group;
 - inspecting the site and surrounds;
 - conducting a field trip to the gas fields in the Surat Basin in Queensland to meet with Queensland regulatory agencies and landholders, inspect several coal seam gas operations, and get a better understanding of some of the challenges associated with the rapid growth of coal seam gas in this region; community concerns; any impacts, and the policy and regulatory responses taken to address these impacts; and
 - appointing independent experts to provide advice on key issues, and arranging meetings between these experts and key stakeholders to ensure they are fully informed of community and other expert opinions on the Narrabri Gas Project;
 - meeting with the Commonwealth Independent Expert Scientific Committee; and
 - working closely with government agencies on the assessment of key issues, including the:
 - Commonwealth Department of Water, Agriculture and the Environment;
 - Environment Protection Authority, Regional NSW, NSW Health, Transport for NSW, and other expert groups within the Department;
 - Narrabri Shire Council and Gunnedah Shire Council.
177. During this consultation, the Department has gained a much better understanding of key issues and concerns about the project. It has also used this information to inform its detailed assessment of the merits of the project.

5.2 Submissions

178. There is significant public interest in the Narrabri Gas Project.
179. During exhibition, the Department received nearly 23,000 submissions (see **Table 5**), the largest number of submissions ever received on a State significant project in NSW.

Table 5 | Summary of Submissions

Area	Submissions	Support	Object	Comment	Form
Agency	17			17	
Special Interest Groups	133	18	106	9	
General Public					
Local Area	470	173	295	2	182
NSW	15,921	70	15,756	95	11,742
Rest of Australia	5,034	36	4,943	55	3,387
Overseas	200	1	192	7	125
Unknown	1096		1,096		1,088
Public Submissions Total	22,721	280	22,282	159	16,524

Note: Numbers exclude duplicate submissions.

180. In broad terms:
- 17 of these submissions were from agencies, including the Narrabri Shire Council, EPA, NSW Health, Transport for NSW;
 - 133 submissions were from special interest groups, including the North West Alliance, People for the Plains, Artesian Bore Water User's Association, Namoi Water, Lock the Gate, Nature Conservation Council, Wilderness Society, and Environment Defenders Office; and
 - around 22,721 submissions were from the general public.
181. These submissions came from far and wide, with 470 submissions coming from the local area, nearly 16,000 from other parts of NSW, and 5,234 from other parts of Australia and overseas.
182. Over 70% of the submissions were form letters, and the product of a concerted campaign against the project. However, there were several substantial submissions from special interest groups, including submissions from the North West Alliance, Artesian Bore Water User's Association and People for the Plains which included detailed reports from technical experts criticising the assessment of the impacts of the project.
183. Most of the public submissions (98%) were overwhelmingly against the project, although the breakdown of submissions shows a greater divergence of views in the local area with 37% of the submissions supporting the project even though the majority were still against it.
184. **Appendix D** contains a copy of all the submissions received on the project.
185. Conceptually, these submissions had three key themes.

186. First, they were almost universally opposed to gas development in NSW. They argued that urgent action is required to address climate change, and that NSW should be doing everything it can to transition away from fossil fuels, such as coal and gas, towards a greater reliance on renewable energy (wind, solar, battery storage and pumped hydro).
187. They were critical of arguments that gas could play an important role in any such transition, saying gas may end up generating more greenhouse gas emissions once fugitive methane emissions are included.
188. Finally, they argued that the project would either generate or facilitate the generation of significant greenhouse gas emissions during the extraction and production of gas and at the factories, businesses and households where it is used.
189. Second, these submissions were concerned about the risks of non-conventional gas development more generally, reiterating many of the concerns that were raised during the Chief Scientist and Engineer's review of coal seam gas development in NSW in 2013-14 and in other jurisdictions across Australia and overseas, particularly in the USA where there has been a boom in shale gas development over the last decade.
190. This included concerns about the:
- impacts on land and water resources, including the impacts of fracking;
 - health and safety risks for local communities, including the air emissions and exposure to toxic chemicals;
 - the social divisions created in communities where gas development occurs;
 - the trustworthiness of the gas industry; and
 - the ability of government to properly regulate the industry.
191. Many of these submissions cited research and findings from gas development all over the world without explaining their applicability to the Narrabri Gas Project, and often ignored the significant differences between different types of gas development in terms of the scale, the nature of the resource, the depth of extraction, the geology, the methods used to extract the resource, the proximity of people to any operations, and the measures used to manage the water extracted from the gas operations and associated by products.
192. This is understandable given the Narrabri Gas Project is the first major project to be assessed in NSW following the completion of the Chief Scientist and Engineer's review, and the fact that there is very little coal seam gas development in NSW at this stage: consequently, there is a tendency for people to look for examples beyond NSW to try and get a better understanding of what may happen if the Narrabri Gas Project proceeds.
193. Finally, these submissions attacked almost every aspect of the Narrabri Gas Project, including:
- the strategic benefits of the project, saying there was no guarantee the gas would go to the domestic market;
 - the design of the project and lack of certainty about the layout given the location of the gas wells would only be finalised following approval and further appraisal;
 - technical studies assessing the impacts of the project including the baseline data; assumptions and methods used; predictions; uncertainties involved and inadequate assessment of cumulative impacts assessment; and
 - the likely impacts of the project.
194. Essentially, they argued that the impacts of the project would be unacceptable and that it should be refused.

5.3 Key Community Issues

195. Despite the broad array of concerns raised by the community in public submissions, there were essentially three key issues.

Water

196. The region is one of the most productive agricultural areas in Australia and local farmers are heavily reliant on the region's water resources, particularly the shallow groundwater resources in the Namoi and Surat aquifers but also the surface water resources in the Namoi River and its associated tributaries.

197. The community believes the project poses significant risks to the region's water resources, particularly the shallower aquifers as it could:

- dewater the shallower aquifers and reduce the groundwater currently available to farmers for agricultural production; and
- contaminate groundwater resources, principally by facilitating the migration of pollutants from the deeper strata to the beneficial water resources through the gas wells or by creating new pathways for these pollutants to move through the geological strata.

198. They also believe the poses a significant risk to the region's surface water resources as up to 37.5 GL of highly saline water would be extracted from the deeper strata and brought to the surface to allow the extraction of gas from the coal seams.

199. The community is concerned that it may not be possible to treat the produced water to a suitable standard and that the proposed reuse of this water for dust suppression or irrigation may result in the contamination of land in the area, and the proposed discharge of excess water to Bohena Creek may result in the pollution of the region's surface water resources. They are also concerned that the large water storage ponds at the Bibblewindi and Leewood facilities may fail, resulting in uncontrolled discharges to the environment which could pollute the region's land and water resources.

200. Finally, the treatment of the produced water would generate several by-products, including up to 840,000 tonnes of salt. The community is concerned about where this salt would be sent to for disposal.

Biodiversity

201. The project is located mostly in the Pilliga State Forest.

202. Several conservation groups argued that the Pilliga is the largest undisturbed remnant area of dry sclerophyll forest in NSW with significant conservation values and should be protected.

203. They claimed the project would have significant impacts on the conservation values of the Pilliga and several threatened species and communities within the project area by clearing native vegetation and removing habitat; reducing the connectivity between forested areas; creating additional noise, dust and light for fauna; and spreading weeds and feral pests.

204. Finally, they argued the proposed offsets for the project are inadequate, and that Santos should not be allowed to use feral pest control or the rehabilitation of the site to reduce its offset liability for the project.

Impacts on the Local Community

205. Some submissions felt the project would have a positive impact on the region, producing a secure supply of gas for NSW, creating jobs, attracting investment, promoting local economic development, generating royalties and taxes, and providing community benefits through the proposed voluntary planning agreement and community benefit fund.
206. However, these submissions were in the minority.
207. Most submissions thought the project would have unacceptable impacts on the local community, including:
- affecting peoples' livelihood by damaging the land and water resources of the region;
 - affecting peoples' health by exposing them to toxic air emissions, chemicals and other pollutants;
 - jeopardising peoples' safety by increasing hazards and bushfire risks in the region;
 - adversely affecting the amenity of the area by creating additional dust, noise and traffic;
 - industrialising the rural landscape;
 - diminishing the heritage values of the region, including the intangible cultural heritage values of the Aboriginal community and their connection to country;
 - compromising the operations of the Siding Springs Observatory;
 - discouraging tourism and recreation;
 - putting pressure on local infrastructure and services (housing, medical services, schools);
 - affecting property values and the ability of landowners to secure insurance;
 - creating divisions within the community; and
 - disrupting the social fabric of the community.
208. The Department has considered these issues in its detailed assessment of the merits of the project, and summarised the findings of this assessment in Section 6.

5.4 Santos's Responses

209. Since the exhibition of the EIS, Santos has:
- responded to the issues raised in submissions; and
 - provided additional information to the Department to address technical matters raised by agencies, the Department's independent experts and the experts working for some of the special interest groups who are opposed to the project.
210. **Appendix E** contains copies of these responses and this additional information.

5.5 Agency Advice

211. During the exhibition of the EIS, none of the agencies objected to the project.
212. However, most of these agencies sought clarifications, further assessment and/or additional information on several technical issues, including:
- geological conditions, including the presence of faults or geological structures;
 - the composition of the gas;
 - the groundwater model and plans to upgrade, validate and calibrate the model over time as more information is collected;
 - produced water management and any contingency measures for handling excess water;
 - waste management, including the potential reuse or disposal of salt;
 - air emissions, including fugitive emissions, air toxics and other pollutants;
 - the biodiversity assessment and proposed offsets;
 - hazards, particularly the fire and explosion risks of the Leewood gas processing plant;
 - bushfire risks;
 - Aboriginal heritage consultation;
 - impacts of flaring on the dark skies of the Siding Spring Observatory;
 - the cost benefit analysis; and
 - the social impact assessment.
213. **Appendix F** contains copies of the agencies' submissions and requests, and **Appendix E** contains a copy of Santos' responses to these matters.
214. After reviewing these responses, all agencies are now satisfied that the impacts of the project can be controlled to comply with the standards in applicable government legislation, policies and guidelines subject to the imposition of strict conditions (see **Table 6**).

Table 6 | Agency Advice

Agency	Advice	Conditions
State		
Department of Planning, Industry and Environment		
Water Group	<ul style="list-style-type: none"> • Groundwater model is fit for purpose for a planning decision but should be upgraded, validated and calibrated over time as further information is collected. • Supports cap on extraction rates as a key mitigation measure. • Santos should be required to: <ul style="list-style-type: none"> - secure water licences for all predicted water take prior to construction (Phase 2); - reduce all water-related risks during detailed design; - monitor and report on all water impacts; - develop a detailed trigger, action and response plan to address any unexpected impacts (if necessary); and - prepare a detailed Water Management Plan for the project. 	Supports recommended conditions
Biodiversity Conservation Division	<ul style="list-style-type: none"> • The biodiversity impact assessment of the project is suitably conservative and has been carried out in accordance with the requirements of the NSW Biodiversity Offsets Policy for Major Projects. • Santos should be required to: <ul style="list-style-type: none"> - reduce the biodiversity impacts of the project even further during the detailed design; - prepare a detailed Biodiversity Management Plan for the project to avoid and/or minimise any impacts on threatened communities and species; - offset the residual biodiversity impacts of the project in accordance with the offset policy, and to retire at least 70% of the offset liability for the project prior to construction (Phase 2). • Only supports the use of rehabilitation to retire offset credits if it is carried out to a high standard and relates to the last 30% of the project's offset liability; and it does not support Santos' proposal to use feral animal control to reduce its offset liability. • Santos has complied with the Aboriginal cultural heritage consultation requirements and should be able to avoid most of heritage items in the project area. • Santos should be required to prepare a detailed Heritage Management Plan for the project in consultation with the Aboriginal community, and work with community groups to avoid and/or minimise the Aboriginal heritage impacts of the project. 	Supports recommended conditions
Crown Land	<ul style="list-style-type: none"> • Prior to disturbing any Crown land, Santos must obtain the necessary approvals. 	Statutory requirement

Agency	Advice	Conditions
State		
Environment Protection Authority	<ul style="list-style-type: none"> Following detailed investigations into several matters – including noise, air quality, water impacts and waste (particularly produced salt, produced water and drill cuttings) - the EPA has no outstanding concerns about the project. The project is predicted to comply with the relevant standards and criteria, and any residual issues can be addressed through the recommended conditions. 	Supports recommended conditions
NSW Health	<ul style="list-style-type: none"> The project is predicted to comply with all applicable health-based criteria, but this should be validated through detailed monitoring. The risks to human health from contamination of water is low, but Santos should be required to comply with strict conditions to ensure the proposed safeguards are effective. 	Supports recommended conditions
Department of Regional NSW		
Mining, Exploration & Geoscience	<ul style="list-style-type: none"> Supports the project as it would deliver a secure, reliable and affordable gas supply to NSW. Santos' resource estimates are robust, and the resource can be extracted viably without fracking. All wells must comply with the relevant codes of practice for coal seam gas, particularly the Well Integrity Code. Santos should avoid sterilising any mineral resources in the region when it secures offsets for the project. 	Supports recommended conditions
Forestry Corporation	<ul style="list-style-type: none"> Has no residual concerns about the project and has entered into a commercial agreement with Santos for the use of all forestry land in the project area. 	Commercial agreement in place
NW Local Land Services	<ul style="list-style-type: none"> Santos should be required to minimise the project's impacts on travelling stock reserves and biodiversity and to control the spread of weeds and pests. 	Addressed in recommended conditions
Transport for NSW	<ul style="list-style-type: none"> The road network is suitable for the project subject to minor upgrades to the two intersections. Santos will require further approval from TfNSW prior to carrying out any works in the State road corridor. Santos should be required to prepare a detailed Traffic Management Plan for the project. 	Supports recommended conditions
NSW Rural Fire Service	<ul style="list-style-type: none"> Santos should be required to: <ul style="list-style-type: none"> reduce the bushfire risks of the project further during detailed design; have suitable measures in place to respond quickly to any fires; and prepare a detailed Bushfire Management Plan for the project. 	Addressed in recommended conditions

Agency	Advice	Conditions
State		
Heritage NSW	<ul style="list-style-type: none"> Acknowledged that the project would have minimal heritage impacts but recommended measures to further reduce the heritage impacts of the project. Santos should be required to prepare a detailed Heritage Management Plan for the project. 	Supports recommended conditions
Council		
Narrabri Shire Council	<ul style="list-style-type: none"> Supports the project subject to strict conditions: <ul style="list-style-type: none"> - requiring Santos to enter a VPA with Council involving the payment of \$14.5 million for community projects and road maintenance; - prohibiting the disposal of salt at any local waste facilities; - requiring safeguards for the rehabilitation and long-term management of gas wells; - requiring insurance against pollution; and - independent monitoring; Council has asked for changes to the proposed Community Benefit Fund for the project, and is in discussions with Mining, Exploration and Geoscience on the final terms of the fund. This fund will be formalised in conjunction with the grant of any production lease for the project under the <i>Petroleum (Onshore) Act 1991</i>. 	Addressed in recommended conditions
Gunnedah Shire Council	<ul style="list-style-type: none"> No residual concerns subject to the imposition of strict conditions to minimise adverse impacts Santos should be required to review the social impacts of the project over time and implement any recommendations arising from the review. 	
Warrumbungle Shire Council	<ul style="list-style-type: none"> Noted its opposition to coal seam gas mining in general and asked where the biodiversity offset areas would be located and where the salt would be taken to for disposal. 	Considered in assessment
Gilgandra Shire Council	<ul style="list-style-type: none"> Raised concerns about the potential contamination of groundwater, impacts to other Great Artesian Basin users, and light pollution on Siding Spring Observatory. 	Addressed in recommended conditions
Commonwealth		
Australian Astronomical Observatory	<ul style="list-style-type: none"> Acknowledged the project is unlikely to adversely affect the operations of the Siding Springs Observatory. Santos should be required to minimise routine flaring when the moon is more than 50% full. Asked to be kept informed of changes that could affect the sky lighting. 	Addressed in recommended conditions

Agency	Advice	Conditions
State		
Australian Rail Track Corporation	<ul style="list-style-type: none"> The project is unlikely to affect the proposed Inland Rail Project 	-

6 Assessment

6.1 Overview

215. The Department has completed a detailed assessment of the merits of the project.
216. This assessment has included examining the findings of several studies, inquiries, assessments, policies and guidelines that are relevant to the Narrabri Gas Project, including:
- reviewing the experience of other jurisdictions in Australia and overseas in assessing and regulating the impacts of non-conventional gas development, including the findings of several major public inquiries;
 - conducting a field trip to the gas fields in the Surat Basin in Queensland to meet with Queensland regulatory agencies and landholders, inspect several coal seam gas operations, and get a better understanding of some of the challenges associated with the rapid growth of coal seam gas in this region and the impacts of this development;
 - considering the findings and detailed recommendations of the Chief Scientist and Engineer's review into coal seam gas activities in NSW in 2014-5, and the Government's response to these recommendations of the review, including the NSW Gas Plan which sets the strategic framework for gas development in NSW;
 - analysing a number of large-scale environmental studies, regional data sets and coal seam gas research papers, including the:
 - Commonwealth's Bioregional Assessment of the Northern Inland Catchments, which collects a range of scientific information on the land and water resources in the region;
 - Namoi Catchment Water Study, which considered the potential cumulative impacts of coal seam gas and mining activities within the Namoi catchment;
 - studies undertaken by the CSIRO's Gas Industry Social and Environmental Research Alliance (GISERA), some of which were directly related to the Narrabri Gas Project; and
 - research on coal seam gas published by the IESC; and
 - having regard to key legislation, policies and guidelines that set standards for acceptable environmental performance in NSW, including the
 - AIP and applicable Water Sharing Plans under the Water Management Act 2000;
 - NSW codes of practice for coal seam gas, including the Well Integrity Code and the *Exploration Code of Practice: Produced Water Storage and Transfer* (Produced Water Management Code);
 - Major Projects Offsets Policy;
 - NSW Noise Policy for Industry; and
 - Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales.
217. It has also included visiting the site and surrounds several times, meeting with landholders in the project area and reviewing Santos' EIS, specialist studies, community concerns, Santos' response to submissions and technical advice from key government agencies.
218. Finally, the Department obtained advice from several independent experts.
219. Due to significant community concerns about land and water impacts, the Department established an independent Water Expert Panel (WEP) for the project. The WEP was chaired by

Professor Peter Cook (geologist) from the University of Melbourne and was comprised of Professor John Carter (geotechnical engineer), Professor Chris Fell (chemical engineer) and Michael Williams (hydrogeologist).

220. The WEP reviewed the experience gained from coal seam gas development in Australia and internationally, the findings of prior coal seam gas investigations in the Narrabri area, and the detailed specialist studies carried out for the Narrabri Gas Project. It met with experts in government agencies, special interest groups, industry, community leaders, farmers, landholders, regulators, and Santos' employee's and consultants. It also undertook field inspections in the Narrabri and Pilliga Forest areas.
221. In its detailed investigations, the WEP did not identify any land or water issues that were likely to result in significant impacts on people or the environment or that could not be managed to ensure all applicable government standards or codes are met.
222. While the WEP identified some uncertainties, principally due to the lack of detailed information about the deeper substrata, it concluded they "could be addressed through ongoing monitoring, adaptive management and a robust regulatory regime that is rigorously and effectively enforced."
223. The final WEP report included 32 recommendations and 27 observations, which have been incorporated into the recommended conditions. The WEP has subsequently reviewed and endorsed the recommended conditions.
224. **Appendix G** contains a full copy of the WEP report.
225. In addition to the WEP, the Department sought independent expert advice on the potential Aboriginal heritage, hazard, social and economic impacts of the project, and has considered this advice in its detailed assessment and developing the recommended conditions.
226. During its detailed assessment, the Department has found it difficult to reconcile the significant community concerns about the Narrabri Gas Project with the technical advice from experts that the risk of any significant impacts occurring is generally low and can be controlled using standard engineering practice and imposing strict conditions on Santos.
227. One of the reasons for this dichotomy may be the limited exposure the community has had to coal seam gas in NSW and its reliance on reports about the actual or perceived impacts of non-conventional gas development in other jurisdictions, without appreciating the important differences between these jurisdictions and the Narrabri Gas Project.
228. At a general level, however, there at least five factors in favour of the Narrabri Gas Project.
229. First, it is a relatively small project compared to coal seam gas development in other jurisdictions, with up to 850 gas wells to be drilled over 25 years compared to the over 6,800 wells that have been drilled in Queensland over the last decade, and thousands of additional wells that are likely to be drilled in Queensland over the same period as the Narrabri Gas Project.
230. Second, there is limited scope for cumulative impacts with the Narrabri Gas Project as it is the only coal seam gas project in the region and there are unlikely to be any significant interactions with the coal mines in the area, including the Narrabri underground mine which is located on the eastern border of the project. This is totally different to what is happening in other jurisdictions, such as Queensland, where several large projects are being operated side by side and there is a detailed regulatory regime in place to manage the cumulative impacts of these projects on the region's water resources.

231. Third, the Gunnedah Basin where the Narrabri Gas Project is located has favourable geology and hydrogeology for coal seam gas development compared to several other jurisdictions, which reduces any risks considerably. These attributes include:
- the target coal seams are deep (generally 500 to 1,200 m below ground level);
 - no fracking is required or proposed to extract the gas;
 - the target coal seam aquifers are saline and are not used for productive purposes in the region;
 - the coal seam aquifers are physically separated from the shallower, better quality aquifers by thick layers of relatively impermeable rock (known as aquitards) which limits impacts to the shallow aquifers;
 - the project area is not a major recharge area for the Great Artesian Basin; and
 - the project area has low seismic activity and no major structural faults, further limiting the potential for connectivity between the hydrogeological layers.
232. Fourth, the project area and surrounds is sparsely populated, and Santos has committed to only undertaking project-related activities on privately-owned land with the agreement of the landowner. It has also committed to meeting key air quality, noise and other environmental criteria at sensitive receiver locations, unless the applicable landowner agrees otherwise; and has demonstrated in its technical studies that this can be achieved.
233. Finally, the NSW Government has introduced strict regulatory controls for coal seam gas development which would be applied to the Narrabri Gas Project. These include:
- strict development consent, mining lease and environmental protection licence requirements;
 - requirements to obtain separate water licences for all water take (compared to Queensland and Northern Territory where this is not required);
 - appointing the EPA as the lead regulator for coal seam gas;
 - best practice coal seam gas codes of practice, policies and guidelines;
 - outcomes-based regulation with adaptive management, including the ability to shutdown wells if necessary; and
 - measures for ongoing community engagement during the project, including establishing Community Consultative Committees and making all relevant information public available on the Department's website and other data portals.
234. Consequently, following its detailed assessment the Department has concluded that the project is unlikely to result in any significant impacts on people or the environment, notwithstanding the community's concerns, and that any impacts can be suitably controlled with strict conditions.

6.2 Groundwater

Summary

The coal seams and associated aquifers targeted by the project differ from many contemporary coal seam gas projects in Australia (mainly Queensland) and overseas, in that they are deeper and more saline, and are consequently not used for beneficial purposes such as agriculture or town water supply.

These target aquifers are geologically separated from the shallower, more highly valued aquifers by thick layers of rock known as aquitards, which limit the potential for impact.

Notwithstanding, the shallower aquifers do comprise important groundwater resources for the region. They include the Namoi alluvial aquifers and aquifers associated with the Surat Basin (Pilliga Sandstone), which form part of the Great Artesian Basin. These aquifers are generally productive and contain good quality water, and are consequently widely used for agricultural and domestic supplies in the region.

The project would not extract any water directly from these aquifers. However, it does have the potential to indirectly affect them through induced drawdown from the underlying coal seam groundwater extraction, and/or through otherwise contaminating the aquifers.

A substantial body of work has now been undertaken to model and assess whether such impacts would occur. This work includes regional groundwater modelling undertaken by the NSW Government, peer reviewed modelling undertaken by Santos, independent assessment by the WEP, and additional groundwater modelling undertaken by CSIRO.

Based on this work, the relevant NSW Government agencies and the WEP believe that the groundwater modelling work is 'fit for purpose', and is adequate and appropriate to assess the broad land and water-related impacts of the project.

The assessment indicates that, due to the depth of the target coal seams and the overlying aquitards, the impacts on the highly valued aquifers would be minimal, and would not occur until many years after mining commences.

Peak drawdown (i.e. groundwater table lowering) in both the Namoi alluvials and the Pilliga Sandstone (Great Artesian Basin) is predicted to be less than 0.5 m, which is within the range of natural fluctuation and the minimal harm considerations in the AIP, and therefore meets the applicable non-discretionary development standard for aquifer interference under the Mining SEPP. The changes are unlikely to be noticed by groundwater users in the area.

Peak groundwater take (i.e. volumetric groundwater loss through induced drawdown) from these groundwater sources is also predicted to be minor, at well below one percent of the Sustainable Diversion Limits (or long term annual average extraction limits) for each of the relevant water sources.

The WEP and the NSW Government have considered the project's potential to contaminate or otherwise affect groundwater resources in a number of other ways, such as subsurface contamination from drilling fluids, below ground methane or carbon dioxide leakage, cross contamination of aquifers, and long-term legacy issues following well decommissioning.

The WEP and the NSW Government have considered these potential impacts in detail, and found that the risks are able to be effectively managed, and are unlikely to result in any significant impacts to regional land and water resources.

The WEP concluded that the current regulatory framework for coal seam gas well integrity provides reassurance that the likelihood for potential harm to humans and the environment is low, subject to the implementation and enforcement of these regulations.

Introduction

235. Potential impacts on water resources in the Namoi Catchment has long been recognised as one of the key risks associated with coal seam gas development in the region.
236. In 2010, the NSW Government commissioned the Namoi Catchment Water Study in response to community concerns about the potential impacts of the growing mining and coal seam gas industry on the significant groundwater and surface water resources in the region.
237. The comprehensive study found that although mining and coal seam gas developments in the Namoi Catchment are unlikely to have significant regional-scale impacts on water resources – even with very substantial coal and coal seam gas development scenarios – there could be local impacts. The study noted that these local impacts could not be determined by a catchment wide study (such as the Namoi Water Study), and stressed the need for detailed project-specific investigations, supplemented by comprehensive monitoring and operational management plans for approved projects.
238. In 2013, the NSW Government asked the then NSW Chief Scientist and Engineer, Professor Mary O’Kane, to undertake a comprehensive review of coal seam gas activities in NSW, focusing on potential human health and environmental impacts.
239. The Chief Scientist’s review included a series of technical reviews by experts that related specifically to the potential impacts of coal seam gas development on water resources, including:
- groundwater resources;
 - geological resources;
 - produced water and solids management;
 - water treatment;
 - seismicity and subsidence;
 - abandoned wells;
 - fracture stimulation;
 - methane origins and behaviour; and
 - environmental risks.
240. As outlined in Section 4, the review concluded that provided drilling occurs in areas where the geology and hydrogeology can be characterised adequately, and provided that appropriate engineering and scientific practices are used to manage the storage, transport, reuse or disposal of produced water and salts, the risks associated with coal seam gas development can be appropriately managed.
241. In addition to the review, the NSW Government introduced three important codes of practice specifically aimed at minimising any risks to water resources from coal seam gas development, including the *Code of Practice for Coal Seam Gas Well Integrity* (Well Integrity Code).
242. The Well Integrity Code establishes a best practice framework for coal seam gas wells, including:
- mandatory standards for well design and construction, based on a number of best practice industry standards;
 - well monitoring and maintenance;
 - management of produced water; and

- that the design of wells guarantees the safe and environmentally sound production of gas by:
 - preventing interconnection between coal seams and aquifers;
 - ensuring gas is appropriately contained without leakage;
 - ensuring isolation between different aquifers and water bearing zones;
 - not introducing substances that may cause environmental harm; and
 - requiring all chemicals to be used to be disclosed during the approval process.
243. Based on this research work and regulatory framework, several specialist water resource assessments and reviews have now been undertaken for the Narrabri Gas Project to assess the incremental and cumulative effects of the project and any other mining development in the region.
244. First, the EIS includes specialist groundwater and surface water assessments undertaken by CDM Smith and GHD, respectively. The groundwater assessment includes detailed modelling of the potential groundwater-related impacts of the project.
245. Second, the EIS includes a peer review of the groundwater assessment and model, undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO).
246. Third, the EIS includes a number of related assessments to supplement the water resource assessments, including a:
- managed release (of treated water) study, undertaken by Eco Logical;
 - irrigation concept design, undertaken by Beneterra;
 - water monitoring plan, undertaken by CDM Smith;
 - water baseline report, undertaken by CDM Smith (and updated in the RTS);
 - interpretive soils report, undertaken by GHD; and
 - contaminated land assessment, undertaken by GHD.
247. Fourth, the CSIRO's Gas Industry Social and Environmental Research Alliance (GISERA) is undertaking several coal seam gas research projects in NSW, some of which are directly related to the Narrabri Gas Project. These include projects on:
- impacts of coal seam gas depressurisation on the Great Artesian Basin flux (or flow);
 - spatial design of groundwater monitoring network in the Narrabri Gas Project area;
 - improving the representation of the impact of coal seam gas development in groundwater models; and
 - groundwater contamination risk assessment.
248. These projects, which are now complete or nearing completion, have generated several technical reports and papers, which can be found on GISERA's website (<https://gisera.csiro.au>).
249. Fifth, the project's water resource impacts have been reviewed by specialist hydrologists and hydrogeologists within government, including the Department's Water Group and the Commonwealth's Independent Expert Scientific Committee. They have also been reviewed by a number of technical experts engaged by special interest groups, such as the North West Alliance.

250. Finally, as explained in the previous section, the Department established the WEP to undertake an independent review of the land and water impacts of the Narrabri Gas Project, including all previous studies, technical assessments, expert reviews and the issues raised in submissions (see **Appendix G** for a full copy of the WEP report).
251. The Department believes that the body of work undertaken to assess the potential land and water resource impacts of the project is substantial and has involved reviews by some of the country's most respected water specialists.
252. Despite the comprehensive nature of this work, there are still some unknowns about the hydrogeology of the project area, particularly in the deeper stratigraphic layers that will be the target of the Narrabri Gas Project. This is principally because the deep strata have not been subject to significant water extraction in the past due to their depth and poor (saline) water quality, which has made them unattractive for agricultural and other water users.
253. These uncertainties relate to how the water resources in different hydrogeological layers will react to coal seam gas development, particularly at a local scale; and to how the pumping of large amounts of water from the coal seams to enable the gas to be extracted could affect the shallower, more highly valued, aquifers. Some of this information is unable to be determined until pumping commences from the gas wells and the water pressure in the coal seams is reduced.
254. To address the uncertainties, the groundwater modelling for the project, as well as research undertaken by independent bodies such as the CSIRO's GISERA, has had to make a number of conservative assumptions based on field observations and/or the available literature. This is consistent with what happens on any large-scale modelling exercise where there are always uncertainties involved.
255. In relation to the Narrabri Gas project, however, these uncertainties have been kept to a minimum and/or mitigated as far as practicable through the:
- substantial modelling work undertaken by Santos and independent bodies;
 - conservative nature of the assumptions used;
 - uncertainty analyses undertaken as part of the modelling, which tested different 'worst case' assumptions; and
 - ability to control groundwater extraction by capping groundwater extraction rates and/or stopping the pumping from gas wells if necessary.
256. Based on this work, the Department, EPA, IESC and the WEP all believe that the Santos' modelling work is 'fit for purpose', and that there is adequate information available to assess the land and water-related impacts of the project and to make a final decision about whether the project should proceed under the EP&A Act.

Groundwater Context

257. Understanding the geology and hydrogeology of the project area is fundamental to any investigation of the coal seam gas resource, and to assessing the potential impacts of any coal seam gas development. As outlined in Section 1, exploration and appraisal work has been ongoing in the area since the 1960s, and there is now a good understanding of the gas resource and its host geology and hydrogeology, particularly at a regional level.
258. A schematic showing the geology of the project area and the hydrogeological layers or units associated with these geological strata are shown in **Figure 18**.

Province	Period/ Epoch	Division	Group	Sub- group	Formation	Lithology and hydrogeological classification	Trans- missivity	
Namoi Alluvium Volcanics	Pleistocene				Narrabri Fm	Clay and silt with sand lenses	LSTU	
	Pliocene				Gunnedah Fm	Gravel and sand with clay lenses	STU	
	Miocene				Cubbaroo Fm	Gravel and sand with clay lenses	STU	
	Eocene				Warrumbungle Vol	Basalt, dolerite	PNTU	
	Eocene				Liverpool Range Vol	Basalt, dolerite	PNTU	
Surat Basin	Cretaceous	Middle	Blythesdale Gp (Keelindi Beds)		Bungil Fm, Mooga Ss, Orallo Fm	Clayey to Quartzose sandstone, subordinate siltstone and conglomerate	NTU	
		Early			Pilliga Ss	Fluvial, medium to very coarse grained, quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone and fine grained sandstone and coal	STU	
	Jurassic	Late					STU	
		Middle			Purlawaugh Fm	Fine to medium grained sandstone thinly interbedded with siltstone, mudstone and thin coal seams	NTU	
		Early		Garrawilla Volcanics			LSTU	
	Late					LSTU		
Gunnedah Basin	Triassic				Deriah Fm	Sandstone	PNTU	
					Napperby Fm	Interbedded fine sandstone, claystone and siltstone	PNTU	
						Basal Napperby Shale	NTU	
					Digby Fm	Quartzose sandstone (Ulinda Ss)	NTU	
					Lithic sandstone	NTU		
					Lithic conglomerate (Bomera Conglomerate)	NTU		
				Nea	Trinke Fm	Coal measures - siltstone, fine sandstone, tuffs, stony coal	PNTU	
					Wallala Fm	Conglomerate, sandstone, siltstone, minor coal bands	PNTU	
					Breeza Coal	Coal and claystone	PNTU	
					Clare Ss	Medium to coarse-grained quartzose sandstone, quartzose conglomerate	LSTU	
				Coogal	Hows Hill Coal	Coal	PNTU	
					Benalabri	Claystone, siltstone and sandstone, fining up cycles; more sandy towards top	PNTU	
					Hoskissons Coal	Potential target coal seam	STU	
				Brothers	Brigalow Fm	Fining-up sequence of medium to coarse-grained quartzose sandstone and siltstone	PNTU	
					Arkarula Fm	Sandstone and siltstone	PNTU	
					Melvilles Coal Mb	Coal	PNTU	
					Pamboola Fm	Sandstone, siltstone, minor claystone and coal	PNTU	
		Permian	Middle	Millie		Watermark Fm	Marine siltstone, shales and sandstone	NTU
						Porcupine Fm	Fining upward sequence of conglomerate and sandstone to mudstone	NTU
						Upper Maules Creek Fm	Sandstone and conglomerate, siltstone, mudstone and coal	NTU
				Rutley Seam	Potential target coal seam	STU		
				Interburden	Sandstone and conglomerate, siltstone, mudstone	PNTU		
				Namoi Seam	Potential target coal seam	STU		
				Interburden	Siltstone and conglomerate, siltstone, mudstone	PNTU		
	Early	Bellata		Parkes Seam	Potential target coal seam	STU		
					Interburden	Siltstone and conglomerate, siltstone, mudstone	PNTU	
					Bohena Seam	Potential target coal seam	STU	
					Lower Maules Creek Fm	Sandstone and conglomerate, siltstone, mudstone and coal	NTU	
				Goonbri Fm	Siltstone, sandstone and coal	NTU		
				Leard Fm	Flinty claystone	NTU		
Basement					Werrie Basalt and Boggabri Volcanics (Basement)	Rhyolitic to dacitic lavas and ashflow	LSTU	
						Tuffs with interbedded shale. Rare trachyte and andesite. Weathered basic lavas	NTU	

LEGEND
 Aquitard
 Coal seam

Figure 18 | Hydrogeological Units Showing the Aquifers and Aquitards

259. There are a number of water resources within these hydrological units, and the use of this water is regulated under several Water Sharing Plans established in accordance with the *Water Management Act 2000*. The main applicable water resources include (from the ground surface downwards) the:
- surface water of the Namoi River and its tributaries, regulated under the Water Sharing Plan for *Upper Namoi and Lower Namoi Regulated River Water Sources*;
 - shallow alluvial deposits associated with the Namoi River (Namoi Alluvials), regulated under the Water Sharing Plan for *Upper Lower Namoi Groundwater Sources*;
 - aquifers associated with the Surat Basin (Pilliga Sandstone), which forms part of the Great Artesian Basin, regulated under the Water Sharing Plan for *NSW Great Artesian Basin Groundwater Sources*; and
 - deep aquifers associated with the Gunnedah Oxley Basin (GOB) strata of the Bohena Trough, regulated under the Water Sharing Plan for *Murray Darling Basin Porous Rock Groundwater Sources*.
260. The aquifers are separated by various layers of less transmissive layers (or units), known as aquitards (see **Figure 18**). The aquitards have low permeabilities, and therefore restrict or slow the ability of groundwater to move between one aquifer and another.
261. The shallow aquifers, including the Namoi Alluvials and Pilliga Sandstone, are generally productive and contain good quality water. Consequently, these units are widely used by groundwater users and are highly valued in the region.
262. There are some 4,682 registered bores within 30 km of the project area. Most of these bores (approximately 97%) are less than 150 m deep and tap into the shallow groundwater resources within the Namoi Alluvium and the Pilliga Sandstone.
263. Most of the bores deeper than 150 m also tap into the Pilliga Sandstone, which is typically 150 to 300 m thick in the project area.
264. The Narrabri Gas Project does not propose to extract any water from these valuable aquifers.
265. The coal seams targeted by the project are located well below these highly productive aquifers, at around 500 m to 1,200 m depth, and are physically separated from the productive aquifers by the aquitards. The coal seam aquifers are highly saline, and as such are not beneficially used or targeted by groundwater users in the region.
266. Whilst the project would not directly extract water from the valuable shallower aquifers, it could indirectly affect them through depressurising the coal seam aquifers, which could cause some drawdown of the shallower aquifers. It also has the potential to affect the shallow aquifers by creating pathways between the aquifers, through gas well or geological faults and structures, that could lead to the cross-contamination of these aquifers.
267. These potential impacts have been assessed and considered in detail by Santos, by submitters, by government agencies (including the Department's Water Group, EPA and IESC), by independent organisations including the CSIRO's GISERA, and by the WEP.
268. A summary of the key aspects of this assessment is provided below.
269. As outlined before, the assessment concludes that the indirect impacts on valuable aquifers would be very small, due largely to the presence of the aquitards separating the deeper saline coal seam aquifers from the shallower, good quality aquifers.

Avoidance and Mitigation Measures

270. As outlined in Section 2, Santos proposes to locate gas field infrastructure for the project in accordance with a Field Development Protocol (see **Table 4**), which includes a number of restrictions (or rules) for avoiding impacts on identified resources. Some of these relate to avoiding impacts on water resources, including:
- no surface infrastructure within 200 m of Yarrie Lake;
 - no non-linear infrastructure within watercourses and buffer areas (as defined by stream order classification); and
 - locating ponds and dams above the 100-year flood level.
271. Santos has also committed to siting bores on privately-owned land only with the agreement of the landowner, and to not undertaking any fracking for the project.
272. With regard to groundwater extraction, Santos has sought approval for capped extraction of 37.5 GL of water over the 25-year project life, or an average of about 1.5 GL per year, from the target coal seams. As outlined above, this groundwater is deep, saline (at about 40% the salinity of seawater), and not currently used by groundwater users in the region.
273. This extraction quantity is consistent with Santos' 'Base Case' predictions in its groundwater modelling (see below). In and of itself, this extraction cap is an important mitigation measure, as it means that Santos is willing to restrict itself (in the planning approval) as to how much it can pump from the target coal seams. It indicates that Santos is confident in its model predictions and is willing to accept the associated commercial risks if the required extraction proves to be underestimated.
274. Any extraction beyond 37.5 GL (or an average of over 1.5 GL/yr) would require separate planning approval, which would require revised environmental assessments of any impacts, including cumulative assessment. There is no guarantee that such an approval would be granted.
275. Santos has also proposed a range of other measures to avoid, minimise, mitigate and/or compensate for the water-related impacts of the project. These measures include:
- drilling, completion and rehabilitation of wells in compliance with the NSW Well Integrity Code, which includes mandatory provisions for (amongst other things):
 - preventing interconnection between hydrogeological formations and aquifers;
 - ensuring gas is contained within the well and associated infrastructure without leakage;
 - ensuring zonal isolation between different aquifers; and
 - not introducing substances that may cause environmental harm;
 - compliance with New South Wales and or Commonwealth policies relating to drilling fluids, including a restriction on using oil-based muds (as per the Well Integrity Code);
 - extraction ('take') of groundwater in compliance with the water sharing regulations of the *Water Management Act 2000*, including procurement of appropriate water access licences;
 - using lined pits during drilling, with removal of drilling fluids and cuttings that are not able to be beneficially reused;
 - implementation of a groundwater monitoring network in accordance with a detailed Water Monitoring Plan;
 - treatment of produced water via reverse osmosis to meet or exceed Australian drinking water quality guidelines, and irrigation and stock watering guidelines, with beneficial reuse of treated water for:

- crop irrigation;
- stock watering;
- dust suppression; and
- drilling, construction and rehabilitation activities;
- managed release of treated water to Bohena Creek under appropriate flow conditions, in the event that beneficial reuse is unavailable;
- siting gas and water gathering lines below ground (with greater depth at watercourse crossings), with leak detection systems;
- construction of produced water infrastructure at Leewood and Bibblewindi in accordance with applicable Australian standards and codes, with produced water/brine ponds having:
 - appropriate capacity (to withstand a 72-hour 100-year storm event);
 - double-lined construction;
 - seepage collection pumps between the liners and below the secondary layer; and
 - leak detection and groundwater monitoring systems;
- incident protocols, including the option of well shutdown (or ‘shut in’) should an incident occur;
- a Produced Water Management Plan, including trigger action response plan and pollution incident response management plan; and
- crystallisation of saline water from the treatment system into solid salt product, with disposal to off-site licensed landfills in accordance with regulatory requirements, and investigation into beneficial reuse opportunities.

Groundwater Model

276. Santos has developed a regional-scale groundwater model for the project using the MODFLOW-SURFACT modelling software.
277. The model considers three different cases (or scenarios) for water extraction over the 25-year project life, including¹:
- Base Case water production – 37.5 GL;
 - Low Case water production – 35 GL; and
 - High Case water production – 87.1 GL.
278. Santos notes that the Base Case is conservative in that it assumes greater water extraction than anticipated, based on experience from its existing appraisal wells.
279. As outlined above, Santos has only sought approval for water extraction up to the Base Case (i.e. 37.5 GL). As such, the water extraction associated with the High Case (or any extraction above the Base Case) does not form part of the proposal and is only provided as a hypothetical worst-case water prediction only. The Department has recommended conditions restricting water extraction to the Base Case only, with annual extraction generally consistent with the extraction curve indicated in the EIS and averaging around 1.5 GL a year.

¹ The production amounts for the cases are based on the ranges from Santos’ pilot wells and the observed variation in porosity of coals.

280. The model simulation spans approximately 1,520 years, which includes historical production from pilot wells, the proposed production during the project, and a recovery period of approximately 1,475 years after the project ceases.
281. The model assumes 95% of water extraction would occur from the Maules Creek Formation (Early Permian coal seams), and 5% from the higher Hoskissons Formation (Late Permian coal seams), with extraction from the Late Permian seams occurring only later in the project life (i.e. from around Year 10).
282. The model includes assessment of cumulative impacts associated with other mining and resource projects in the region, including the Narrabri underground coal mine. Other coal projects were found to have only a minor influence.
283. The model also includes a number of sensitivity analyses to investigate the sensitivity of the model results to changes in the inputs and assumptions used in the modelling. These include varying the assumed properties of the aquifers and aquitards, as well as testing the Low Case and High Case estimates for water production from the target coal seams.
284. Concerns about the groundwater model, and the inputs to the model, were raised in several submissions. Key issues included the adequacy of the:
- conceptual hydrogeological model – including the ability of the aquitards to restrict flow, the heterogeneity (or diversity) of the geological layers, and the potential presence of faults;
 - baseline data;
 - uncertainty analysis; and
 - overall model confidence level, including the regional scale of the model.
285. These and other model-related issues have been considered in detail by the WEP (see **Appendix G**). The model findings have also been confirmed by recent GISERA studies, which have derived findings that are broadly similar to Santos' findings.
286. The WEP notes that heterogeneity is a feature of all geological scales and is to be expected. It also notes that the number of wells and core logs is limited in some layers and consequently there is a high level of uncertainty attached to extrapolation between wells.
287. Notwithstanding, the WEP concludes that these knowledge gaps and the resulting risks and uncertainties are similar to many other onshore gas projects, and that the risk of unintended groundwater movement, contamination or gas leakage remains small.
288. The WEP also concludes that it is unlikely that faulting constitutes a major risk to the project, with any such faulting unlikely to have a major impact on groundwater flows.
289. Overall, the WEP concludes that whilst the baseline data is lacking in some areas and is based on literature values in some layers, particularly in the deeper layers, the analysis undertaken provides confidence in the parameters used in the modelling. The WEP considers that the coal seam gas development is very likely to be hydraulically isolated from the surrounding geological units and expects that this would be confirmed once production-scale pumping commences.
290. Several submissions criticised the overall confidence level of the groundwater model, contending that the model has the attributes of a lower class 'Class 1' model using the classifications in the *Australian Groundwater Modelling Guidelines*.
291. Santos accepts that the model is a Class 1 model under the guidelines but notes that it is not technically feasible to achieve all of the Class 2 or Class 3 model attributes within the project

lifetime. This is because achieving a higher-class model requires calibration against actual pressure responses to coal seam gas water extraction occurring in the highly valued water sources (i.e. Great Artesian Basin and Namoi Alluvium). This is not predicted to occur for tens or hundreds of years after the start of coal seam gas production (see below).

292. Irrespective of the level of model confidence, the WEP agrees with CSIRO and the IESC that the model is 'fit for purpose'.
293. However, the WEP recommends that Santos should be required to:
 - upgrade the model to a transient model, based on ongoing monitoring, within 3 years;
 - make this update available for public comment; and
 - update the model every 3 years thereafter.
294. The Department has reflected this in the recommended conditions for the project.

Groundwater Quantity Impacts

295. Due to the depth of the target coal seams, and the presence of overlying aquitards separating the saline coal seam aquifers from the shallow highly valued aquifers, the groundwater assessment indicates that impacts on the highly valued aquifers would be minimal over time, and would not occur until many years after mining commences.
296. Two key indicators for gauging the significance of impacts on the overall groundwater resources are the 'drawdown' (i.e. water table lowering) caused by the project in the various aquifers, and the water 'take' (i.e. water either directly extracted or indirectly lost due to drawdown).
297. Predicted drawdown can be compared against the 'minimal harm considerations' in the AIP.
298. Predicted water take in each aquifer can be compared against the Sustainable Diversion Limits (SDLs) established in the respective Water Sharing Plans. These SDLs have been established to determine sustainable amounts of groundwater that can be extracted from a water source without adversely affecting the resource or the environment over the long term.

Groundwater Drawdown

299. The extent of drawdown predicted within the target coal seam aquifers (i.e. Permian targets) and the highly-valued aquifers (Pilliga Sandstone and Namoi Alluvium) for the Base Case and High Case pumping scenarios is shown in **Table 7**, and the Base Case drawdown extent is shown on **Figure 19**. As outlined above, Santos has only sought approval for groundwater extraction associated with the Base Case, and therefore the High Case is shown for indicative purposes only.

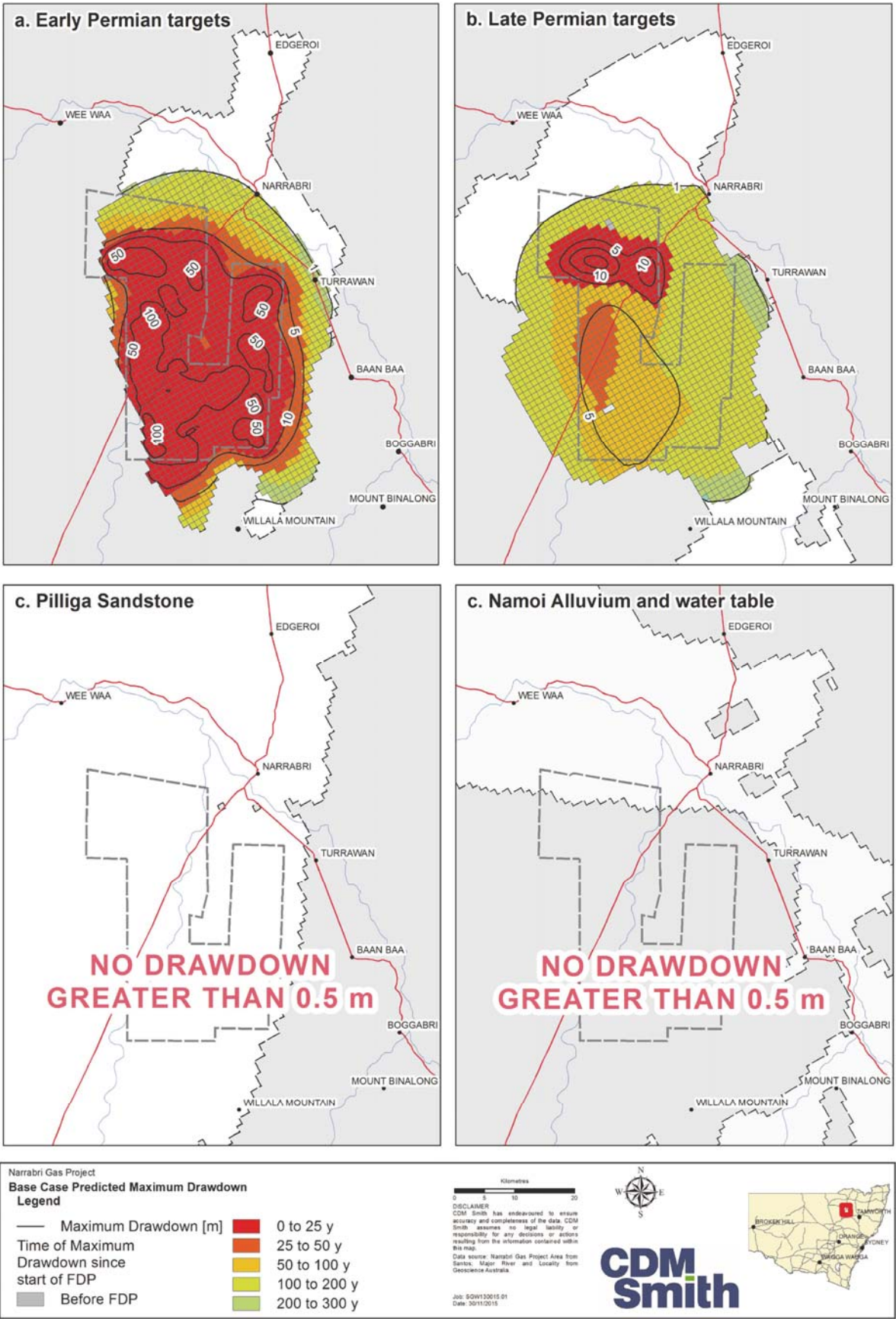


Figure 19 | Predicted Maximum Drawdown - Base Case

Table 7 | Maximum Predicted Drawdown for Key Aquifers

Aquifer	Maximum Drawdown (m)		Time to Reach Max. Drawdown (years)	
	Base Case	High Case	Base Case	High Case
Namoi Alluvium	<0.5	<0.5	-	-
Pilliga Sandstone	<0.5	0.6	-	190-200
Late Permian Targets	16.4	32.3	0-300	0-350
Early Permian Targets	153	224	1-300	2-500

300. As outlined in the table, the predicted drawdown in the highly valued shallow aquifers is less than 0.6 m for both the Base and High Case scenarios. This drawdown is well within the range of natural fluctuation and the minimal harm considerations in the AIP (i.e. 2 m) and is unlikely to be noticeable by groundwater users in the area.
301. The predicted drawdown also complies within the minimal impact considerations in the AIP for all of the sensitivity and uncertainty scenarios modelled for the Base Case in the groundwater assessment.
302. Consequently, the project meets the non-discretionary development standard for aquifer interference under the Mining SEPP.
303. Groundwater drawdown in the deeper (saline) target coal seams is more significant. As outlined above though, these aquifers are not beneficially used in the region.
304. Ultimately, the water extracted for the project (37.5 GL) would be replenished by downward induced flows from overlying water sources. This recovery is expected to occur over a period of approximately 1,500 years.

Groundwater Take

305. The predicted peak water take from the applicable water sources is shown in **Table 8**. This take includes direct take as a result of water extraction (i.e. from the Gunnedah Oxley Basin water sources), and indirect take as a result of induced flow (i.e. all other water sources).
306. As indicated in the table, the predicted water take is low relative to the SDLs (or Long Term Annual Average Extraction Limits) for all water sources.
307. The largest take occurs from the Gunnedah Oxley Basin (GOB) water source (i.e. the saline water source including the coal seams), with maximum take representing some 1.8% of the SDL, or 0.4% of the average annual recharge to the GOB aquifer. As outlined above, this water source is not significantly used in the region due to its depth and poor water quality.
308. Peak predicted take from the highly valued water sources is very low, at well less than 1% of the SDLs.

Table 8 | Predicted Water Take (Base Case)

Water Source	Peak Annual Water Take (ML/yr)	Peak Year (after project start)	Years to Reach >1 ML/yr	Santos Share Components Held (units/ML)	Total Share Components Issued	Sustainable Diversion Limit (ML/yr)
Upper Namoi	1.0	250	250	Nil	109,804 aquifer 6,280 local utility	122,100
Lower Namoi	4.19	250	56	Nil	81,586 aquifer 4,407 local utility	86,000
GAB Southern Recharge	57.3	190	19	10	24,432 aquifer 3,066 local utility	29,680
GAB Surat	0.16	950	-	Nil	5,502 aquifer 3,318 local utility	35,097
Gunnedah Oxley Basin	3,553 (1,500)	2-4 (Long Term Average)	1	600	23,109 aquifer 480 local utility	205,640

309. Consequently, the Department accepts that there is adequate depth in the market for all affected water sources to accommodate the relatively small water take associated with the project.
310. The WEP also considers that the water take in comparison to the SDLs for each water source is small, and that there appears to be sufficient depth in the water trading market for Santos to obtain the necessary entitlements, but notes that this may still have some localised effects given the existing level of development of some water sources (such as the Lower Namoi Water Source and the GAB). Further, current conditions in some water sources are such that the regulator may decide to restrict access to groundwater.
311. As shown in **Table 8**, Santos does not currently hold adequate water licences to account for the water take in any of the affected water sources. However, apart from the GOB water source, the predicted water take is not expected to occur for many years, including at least:
- 19 years to reach >1 ML/yr take for the GAB Southern Recharge water source; and
 - 56 years to reach >1 ML/yr take for the other applicable water sources.
312. Santos notes that the *Water Management Act 2000* requires a water licence to be held at the time of take, and not in respect of future or anticipated type. However, Santos also acknowledges that the AIP states that the preferred approach for mining activities is that proponents hold water access licences for the maximum predicted take, from the commencement of the project regardless of when water will actually begin to be taken.
313. Based on the existing regulations, and given the long timeframes before water take is predicted to occur, Santos has proposed that it obtain water access licences for the water take from the:
- GOB water source, for actual take in a particular year;
 - GAB Southern Recharge water source, within 5 years after production commences; and
 - GAB Surat water source and Upper and Lower Namoi water sources, no later than 25 years after project commencement.

314. The Department has carefully considered the approach to water licencing for the project.
315. On one hand, it is common practice for regulators to require water access licences to be obtained by mining proponents for the maximum predicted water take before projects commence, to ensure security of supply arrangements are in place before water take occurs. However, on the other hand this requirement may act as a supply constraint in the water market, particularly if the water take is unlikely to occur for many years after the licence is obtained, and could lead to increased prices on the open market.
316. Given the sensitive nature of the project and the need to ensure security of supply, the Department has recommended conditions requiring Santos to demonstrate that it has adequate water licences to account for the maximum predicted water take, prior to the commencement of each phase of the project (i.e. ongoing exploration, construction, operation and decommissioning). It has also recommended conditions requiring Santos to ensure that it has sufficient licenced water at all stages, and to adjust the scale of the development to match its available water supply if necessary.

Great Artesian Basin Recharge

317. Some submissions raised concerns that the project could have significant impacts on the Great Artesian Basin, in part because the project area is believed by submitters to be a major recharge area for the basin.
318. The Great Artesian Basin covers a large part of the Australian continent, with the project area located at the south-eastern boundary of the Basin, as shown in **Figure 20**. This part of the Basin (known as the Coonamble Embayment) has little connection to the remainder of the Great Artesian Basin outside NSW.
319. Coal seam gas wells would be installed through the Great Artesian Basin (GAB) aquifers, into the underlying Gunnedah Oxley Basin (GOB). There would be no direct water extraction from the GAB. However, there would be some indirect loss of water from the GAB, which as outlined above, is predicted to be minor compared to the established SDLs.
320. The project area, as with the entire region, is within a recharge area for the GAB. However, recent modelling by GISERA indicates that the project area is located within a comparatively low recharge zone (less than 5 mm per year), as the Pilliga Sandstone outcropping is limited in the area and rainfall is relatively low. Primary recharge in the region (more than 40 mm/yr) occurs via the Warrumbungles, located to the south of the project area, where higher rainfall and greater outcropping exists (see **Figure 21** and **Figure 22**).
321. The WEP accepts that the project area is not a significant recharge zone for the GAB. Notwithstanding, as outlined above Santos would be required to obtain adequate water licences to account for the small induced water loss from the GAB water source prior to this loss occurring just like any other water user operating under the Water Sharing Plan.

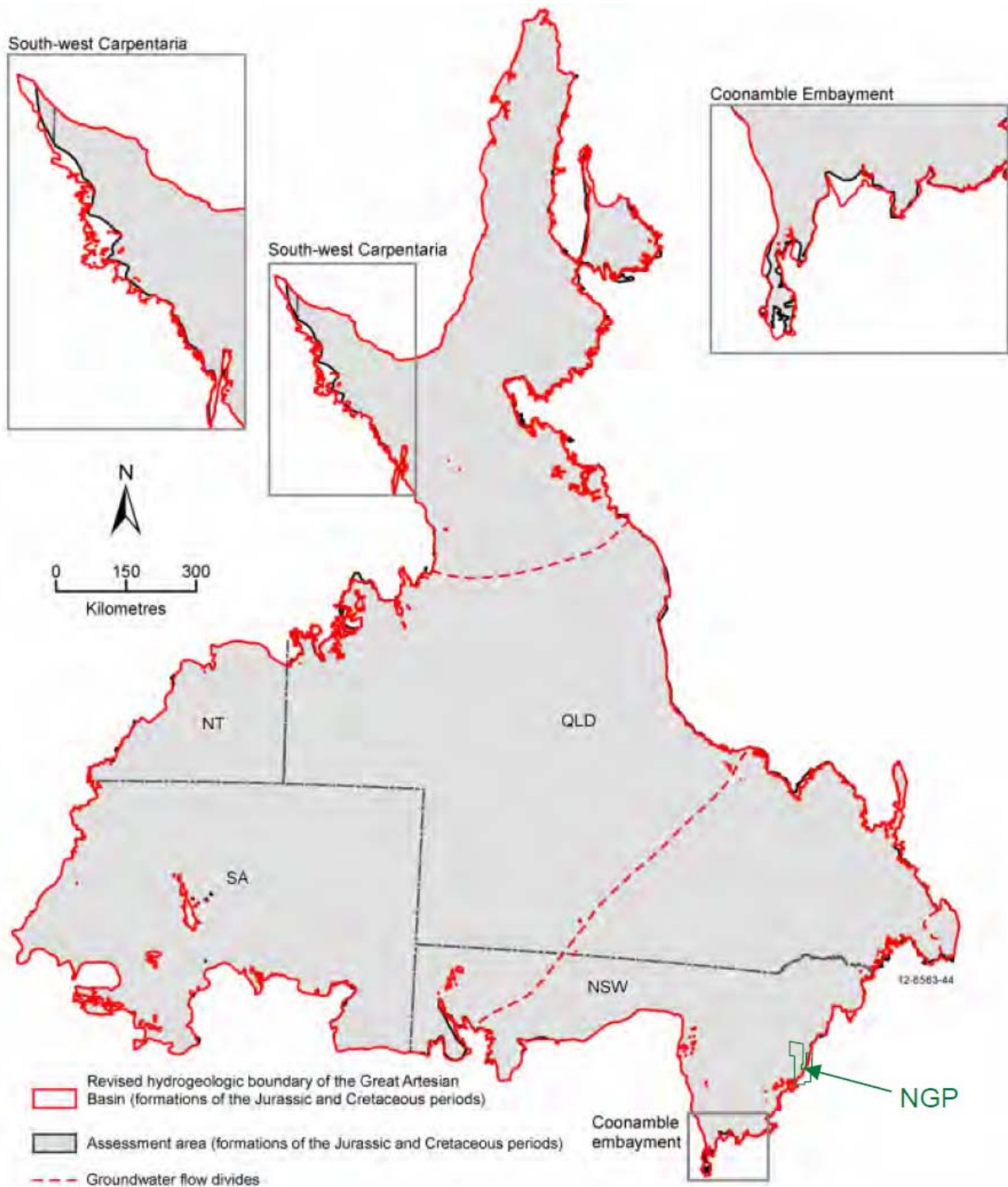


Figure 20 | Great Artesian Basin

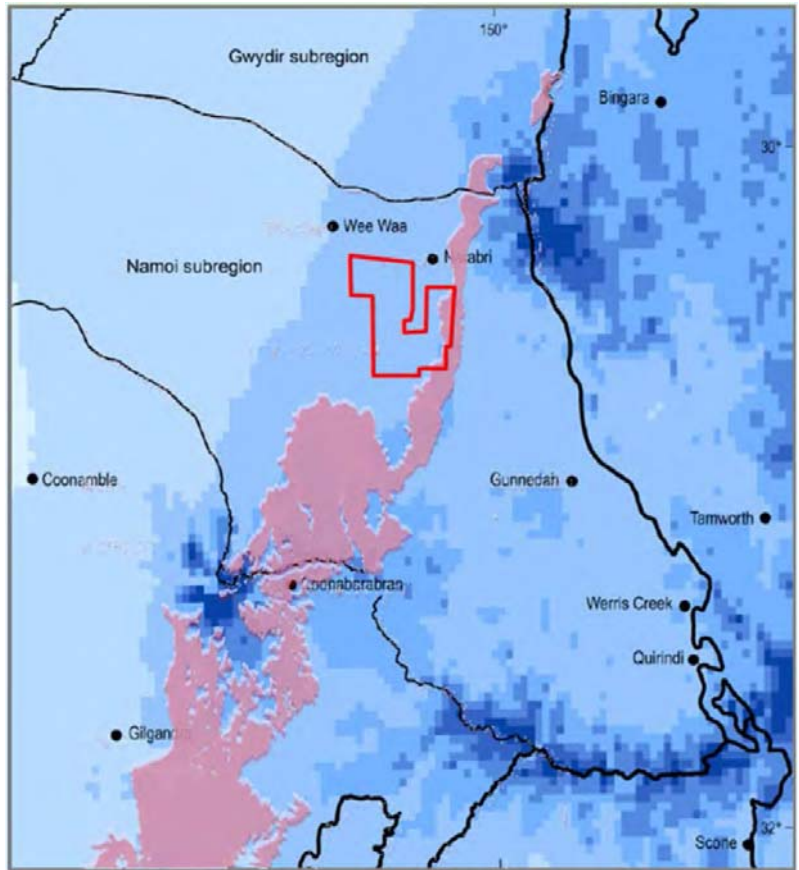


Figure 21 | Rainfall (Blue Gradient) and Pilliga Sandstone Outcrop (Pink Shading)

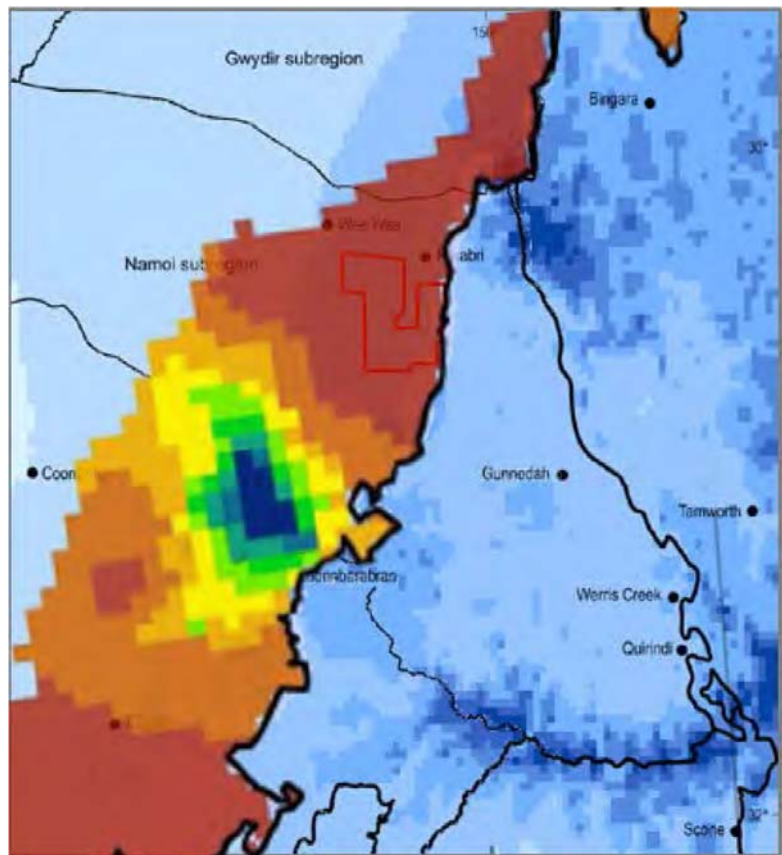


Figure 22 | Recharge to Pilliga Sandstone - Blue Areas of High Recharge (40 mm/yr) Grading to Low Areas in Brown (5 mm/yr)

Groundwater Dependent Ecosystems

322. Groundwater dependent ecosystems (GDEs) are ecosystems which require access to groundwater (beyond soil-based groundwater from rainfall) to meet some or all of their water requirements.
323. Groundwater dependent ecosystems within the project area include waterholes on Bohena Creek and other watercourses (Type 2 GDEs), riparian vegetation (Type 3 GDEs), as well as potential stygofauna (subterranean fauna) (Type 1 GDEs).
324. While the studies for the EIS did not identify any stygofauna in the project area, submitters noted that stygofauna have been identified in the Pilliga Sandstone and alluvial aquifers, and Santos acknowledges that further studies may identify stygofauna in the project area.
325. Notwithstanding, Santos notes that the project is not expected to have any significant impacts on these groundwater units, and therefore is not expected to have any significant impact on stygofauna or other GDEs.
326. The WEP agrees that the project is unlikely to adversely affect GDEs, and notes that compliance with the minimal harm criteria in the AIP would ensure that even if there are high-value GDEs in the project area, they would be protected from any unacceptable cumulative impacts associated with coal seam gas production and other groundwater activities (mostly agriculture but also mining) in the region.

Subsurface Contamination

327. Submissions raised concerns about the potential for the project to contaminate land and water resources. This could occur via several mechanisms, with the key subsurface hazards including:
 - contamination of groundwater from drilling fluids;
 - migration of methane or carbon dioxide leakage from below ground;
 - cross-contamination of the different aquifers penetrated by drilling, principally the pollution of the shallower aquifers by the saline water and other contaminants in the deeper aquifers when they are brought the surface in the gas wells; and
 - long-term legacy issues if the gas wells are not abandoned properly.

Drilling Fluids

328. The use of oil-based drilling fluids is prohibited in New South Wales under the Well Integrity Code.
329. The EIS states that water-based drilling fluids would be used for the project, comprising either bentonite or a polymer to aid the drilling process. The fluid would comprise non-hazardous constituents and meet drinking water guidelines for benzene, toluene, ethyl-benzene and xylene (BTEX) compounds.
330. The WEP noted that synthetic-based drilling muds have been banned in some Queensland coal seam gas operations and suggests that this should be considered by the NSW regulators. The Well Integrity Code will be reviewed shortly, and this will be considered during the review.
331. Nonetheless, the WEP considers that adherence to the Well Integrity Code would appropriately mitigate the risk of drilling fluids escaping into and contaminating the surrounding soil/rock profile.

Methane Migration

332. Submissions raised concerns about the potential for methane to migrate into surrounding strata, groundwater bores and other water supplies, as claimed in some high-profile cases in the US and in Queensland.
333. Subject to the construction and maintenance of wells in accordance with the Well Integrity Code, the WEP considers that significant subsurface migration should not occur and is unlikely to result in significant impacts.
334. The WEP notes that good baseline data is necessary to assist in evaluating any concerns and disputes in the future about levels of methane in groundwater and acknowledged that Santos has provided additional information on this matter.
335. In this regard, Santos has reported that 'background' methane is observed at low and varying levels in all formations above the target coal seam formations. However, most of the groundwater samples from across the monitoring network did not record hydrocarbons above the level of reporting.
336. All recorded cases of methane in groundwater outside the coal measures have been below 10 parts per million (ppm), and Santos notes that successful ignition of gas in water can only be achieved when concentrations are in excess of 50,000 ppm (i.e. when methane exists as a separate gas phase).

Reservoir Cross Contamination

337. The WEP also considered the potential for cross-contamination and other contamination of reservoirs and aquifers, which could occur from induced flows via a number of mechanisms including:
- geological faults;
 - compromised gas well integrity;
 - coal seam gas well leakage, particularly in abandoned wells;
 - historical conventional gas wells and coal mining core holes; and
 - existing groundwater bores.
338. The analysis, which included consideration of independent particle tracking assessment undertaken by GISERA, found that any cross-contamination through faults or gas wells, if it were to occur, would be very localised and is unlikely to result in significant impacts to highly valued groundwater resources.
339. Contamination via groundwater bores is unlikely, given that bores in the area do not extend into the target coal seams or the immediately overlying formations.
340. Further, any leakage along well bores, if it were to occur, is likely to be downward during the life of the project and the recovery period (i.e. for around 1,500 years after), which would minimise the risk of impacts on the higher, valuable aquifer systems.
341. The WEP concludes that, overall, the risk of indirect induced and enhanced aquifer connectivity via groundwater and coal seam gas production bores is likely to be very low. The WEP noted that it is unable to conclude whether faults would provide preferred hydraulic pathways in the area and recommended that detailed geological mapping and seismic investigation be conducted prior to selecting final well locations. The Department has included this in the recommended conditions.

342. The Department has incorporated several other of the WEP's recommendations into the recommended conditions, including requiring Santos to develop and monitor all wells in accordance with the Well Integrity Code, carry out detailed groundwater monitoring to detect any cross-contamination, and take corrective action if the unlikely event that any cross-contamination is detected..

Well Drilling and Well Integrity

343. The WEP considered the potential hazards associated with drilling wells, including:
- the possibility of encountering conventional gas (which could cause overpressure);
 - the possibility of well blow outs; and
 - inadequate well integrity.
344. The WEP notes that while some conventional gas is known to occur in the region, the likelihood of encountering conventional gas is relatively low and could be managed via standard well design and safety measures, consistent with the Well Integrity Code. The WEP considers the risk of well blow out is very low.
345. Well integrity is fundamental to the safe operation of a coal seam gas well, and to ensure that aquifers are not contaminated over the long term. In NSW, well construction is regulated by the Well Integrity Code, which outlines a range of best practice mandatory standards for the design, construction, maintenance and monitoring of coal seam gas wells.
346. The WEP report includes discussion on the potential failure mechanisms associated with gas wells, including failure during drilling, failure of the casing, and failure of the cement.
347. While some submissions claimed that studies in the US indicate that failure rates for gas wells are relatively high, the WEP notes that CSIRO studies have found that the rate of well integrity failures that have the potential to cause environmental contamination is in the order of 0.1%, with several well studies finding no well integrity failures at all.
348. The WEP considered the potential corrosion risks to wells, including the potential for acid attack due to carbon dioxide or sulphate-reducing bacteria. Given the very low presence of sulphate in the target aquifers, and the availability of corrosion resistant materials, the WEP does not believe that corrosion presents a significant risk to the project, and could be effectively mitigated by using suitable corrosion-resistant casings and cements if necessary, in accordance with the applicable guidelines.

Decommissioning and Legacy

349. The Well Integrity Code requires that, upon decommissioning of gas wells (also known as 'plug and abandonment'), the entire vertical or near-vertical section of the coal seam gas well is completely filled with a suitable cement plug, from the bottom of the vertical section to the ground surface.
350. Whilst cementing of horizontal sections has not been required in the past, in part due to difficulties in sealing the horizontal section, the WEP notes that cementing technology is improving to the point that it can now be applied to sub-vertical sections.
351. Consequently, the WEP suggests that Santos be required to consider whether sub-vertical sections should also be sealed with cement prior to decommissioning of gas wells. The Department has included this in the recommended conditions, and notes that this matter will also be considered in the review of the Well Integrity Code.

352. The WEP believes that long term risks to groundwater resources after decommissioning are low, and supports the findings of the recent Northern Territory inquiry into hydraulic fracturing which found that:

“The combination of small cross-sectional areas, long vertical lengths of flow pathways and low driving pressure differentials means that overall, there is a low likelihood of substantial vertical movement of fluids post decommissioning.”

353. Given the low risks, the WEP considers that the primary strategy for decommissioning should be to ensure that wells are plugged and abandoned using the best available technology, and to the satisfaction of the regulator.

354. The Department notes that the NSW Government has committed to a three-layered policy to provide suitable safeguards for any short and long term risks associated with coal seam gas activities, and that this would be implemented for the project if it is approved. The three layers comprise:

- security deposits for rehabilitation under the PO Act;
- insurance/assurance mechanisms required under the POEO Act; and
- ongoing implementation of the Legacy Mine Program to deal with any impacts associated with legacy wells.

355. These measures would largely be addressed through the rehabilitation requirements under the mining lease and the operational requirements under the EPL.

356. Nonetheless, the Department has recommended conditions requiring Santos to:

- rehabilitate the project area progressively;
- ensure all rehabilitation is carried out to a high standard;
- comply with several rehabilitation objectives, including requirements to:
 - decommission all wells in accordance with the Well Integrity Code, the Produced Water Management Code, and the *Exploration Code of Practice: Rehabilitation*; and
 - cement sub-vertical and horizontal well sections, where this is reasonable and feasible; and
- prepare and implement a detailed Rehabilitation Management Plan, that addresses all aspects of rehabilitation including closure, as well as a program to monitor, independently audit and report on the effectiveness of the rehabilitation measures.

Other Impacts

357. The WEP considered a number of other potential land and water related issues associated with the project, including the potential for induced seismicity (earthquakes) associated with the project, subsidence caused by the project, and flooding-related matters.

358. The WEP concluded that the risk of seismicity associated with the project is very low, and that the risk of a damaging seismic event is extremely low.

359. The WEP considers that the risk of subsidence associated with the project is low, but recommended that a subsidence baseline survey be undertaken, with periodic subsidence monitoring. The Department has included this in the recommended conditions.

360. With regards to flooding, the WEP noted that the storage ponds are required to maintain sufficient freeboard to handle a 72-hour 1-in-100-year flood without overflowing, and that the EIS indicates that all ponds would be located above the flood level.

Monitoring and Management

361. The detailed assessment of the project by government authorities and the WEP indicates that the Narrabri Gas Project is able to be undertaken in a manner that would not result in any significant groundwater-related impacts to water users or the environment, provided Santos is required to comply with strict conditions.
362. Several submissions argued that all the necessary monitoring and management plans should be developed prior to any approval of the project. However, this is contrary to current practice and unnecessary. The assessment has shown that the water-related risks of the project are suitably low and that there are several reasonable and feasible measures that could be implemented to further reduce these risks and take corrective action, if necessary, in the unlikely event that subsequent monitoring detects any adverse impacts in local areas.
363. Further the management plans are likely to be developed in stages as the project is rolled out progressively and would only need to cover the specific requirements of the stage rather than the whole project. They would also be subject to regular independent audits and review by experts and updated over time to incorporate any new information collected during monitoring.
364. The Department has recommended a comprehensive suite of conditions to minimize the water impacts of the Narrabri Gas Project.
365. These conditions are consistent with the WEP's recommendations and those of key government agencies, and include:
- clear standards and performance measures for compliance;
 - consultation with applicable stakeholders, including the community;
 - review by independent experts;
 - adequate baseline data to be obtained, prior to production;
 - the implementation of comprehensive monitoring and management measures, based on best practice;
 - early detection of any adverse or unpredicted impacts;
 - prompt incident response and complaints management;
 - compensatory water supplies, in the unlikely event that these are required;
 - public access to information, including monitoring results, incidents and management plans; and
 - ongoing independent auditing, review and updating based on continual improvement.
366. In accordance with the NSW Government's standard best practice conditions for mining projects, the Department has recommended conditions requiring Santos to:
- Water Supply:
 - extract no more than 37.5 GL of produced water over the life of the project, with water extraction generally matching the predicted water production curve (see **Figure 11**);
 - ensure that it has adequate water for all stages of the project, and if necessary, adjust operations to match available water supply;
 - obtain water access licences prior to each project phase;

- Compensatory Water Supply:
 - provide compensatory water supplies to any landowner whose water supplies are adversely impacted as a result of the project to a greater extent than the minimal harm considerations in the AIP;
- Water Pollution:
 - not discharge any water from the site, except in accordance with an Environmental Protection Licence (EPL) under the *Protection of the Environment Operations Act 1997*;
 - not pollute any water;
- Water Management Performance Measures
 - comply with a number of performance measures consistent with the predictions in the EIS and/or minimal harm criteria and applicable standards, including:
 - no fracking to be undertaken;
 - measures relating to protection of the Namoi Alluvial aquifers;
 - measures relating to protection of the Great Artesian Basin aquifers;
 - drawdown in the Gunnedah Oxley Basin aquifer to match predictions;
 - wells, pipelines, storages and other infrastructure to be constructed, monitored and maintained in accordance with applicable standards and codes, including the Well Integrity Code and Produced Water Management Code;
 - gas field infrastructure and other infrastructure to be sited in accordance with the Field Development Protocol (see Section 2.2), with:
 - no surface infrastructure within 200 m of Lake Yarra;
 - no non-linear infrastructure within watercourses and buffer areas as defined by stream order classification; and
 - storage ponds and dams above the 72-hour 1-in-100-year flood level;
 - produced water quality to be treated to meet applicable standards;
 - beneficial use of treated water, with discharge to Bohena Creek the least preferred option;
 - irrigation and beneficial use of treated water in accordance with applicable guidelines;
 - discharge of treated water to Bohena Creek only under appropriate flow conditions (i.e. at least 100 ML/day);
 - protection of aquatic and riparian ecosystems, including groundwater dependent ecosystems; and
 - appropriate storage, handling and disposal of salt product, with investigation of beneficial use options;
- Groundwater Model:
 - update the groundwater model prior to the commencement of construction, and every 3 years thereafter;

- Water Technical Advisory Group:
 - establish a technical advisory group to advise on project-related land and water management issues; and
 - advisory group to comprise a range of water-related experts from government, the scientific community and local interest groups and landowners;
- Water Management Plan:
 - prepare and implement a comprehensive water management plan in consultation with the technical advisory group and applicable stakeholders;
 - prepare and implement a range of subsidiary management and monitoring plans, including a:
 - Erosion and Sediment Control Plan;
 - Water Balance;
 - Surface Water Management Plan;
 - Groundwater Management Plan;
 - Produced Water Management Plan;
 - Irrigation Management Plan;
 - Dust Suppression Protocol;
 - Salt Management Plan; and
 - Pollution Incident Response Management Plan;
 - ensure adequate baseline data is obtained, prior to production;
- Other Environmental Management Measures:
 - undertake annual reviews;
 - regularly review and revise management plans and monitoring programs;
 - maintain a Community Consultative Committee;
 - promptly report incidents;
 - undertake 3 yearly independent environmental audits; and
 - provide public access to a range of information, including monitoring results and management plans.

6.3 Produced Water Management

Summary

The WEP has reviewed Santos' proposed produced water treatment system in detail. It concludes that the system represents best current international practice, and that risks are able to be effectively managed subject to stringent design, management and monitoring. The WEP is also satisfied that the treated water can be beneficially reused and/or released to Bohena Creek without causing any significant adverse impacts on water users or the environment.

The produced water treatment system would generate up to 840,000 tonnes of salt over the project life, or an average of around 35,000 tonnes per year. As a comparison, the Murray Darling Basin Authority's salt interception scheme generates about 500,000 tonnes of salt per year.

The WEP accepts that the salt product would likely classify as general solid waste under the EPA's waste classification guidelines, and could be disposed of at appropriately licensed solid waste facilities. It notes that the salt product does have the potential for beneficial reuse given its composition, and Santos has committed to investigating beneficial reuse options.

The project also has the potential to contaminate or otherwise affect surface water and land resources in a number of other ways, such as surface spills and leaks, and via irrigation and/or discharge of treated water.

The WEP and the NSW Government have considered these potential impacts in detail, and found that the risks can be effectively managed, and are unlikely to result in any significant impacts to regional land and water resources.

The WEP concluded that the current regulatory framework for produced water management provides reassurance that the likelihood for potential harm to humans and the environment is low.

Surface Water Context

367. The project is located in the Namoi River catchment, which forms part of the Murray Darling Basin. The project area lies predominantly in the Lower Namoi sub-catchment (see **Figure 23**), with most of the project area draining north via ephemeral creeks including (see **Figure 24**):
- Bohena Creek;
 - Jacks Creek;
 - Bundock Creek; and
 - Mollee Creek.
368. Bohena Creek is the main ephemeral watercourse in the project area and flows generally in a northerly direction through the project area to the Namoi River, which is located approximately 10 km north of the project area.
369. Bohena Creek only flows in response to heavy rainfall events and contributes little inflow to the Namoi River under normal conditions. However, it contributes significant flood inflows during protracted wet conditions.
370. Water quality in Bohena Creek is generally fresh, with average electrical conductivity of 216 μ S/cm, and total dissolved solids (TDS) of around 200 mg/L. The water is generally neutral with an average pH of 7.1.

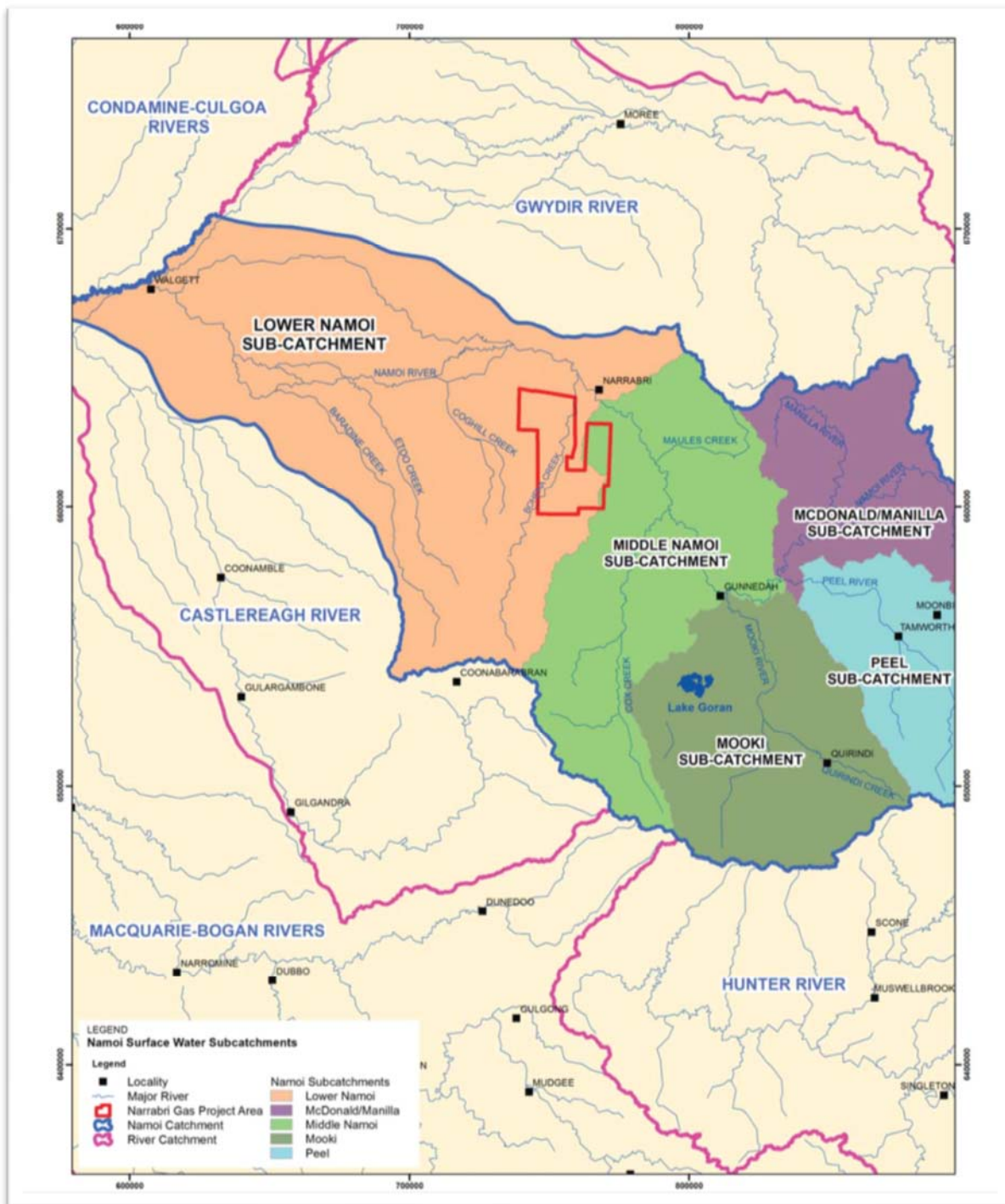


Figure 23 | Surface Water Catchments

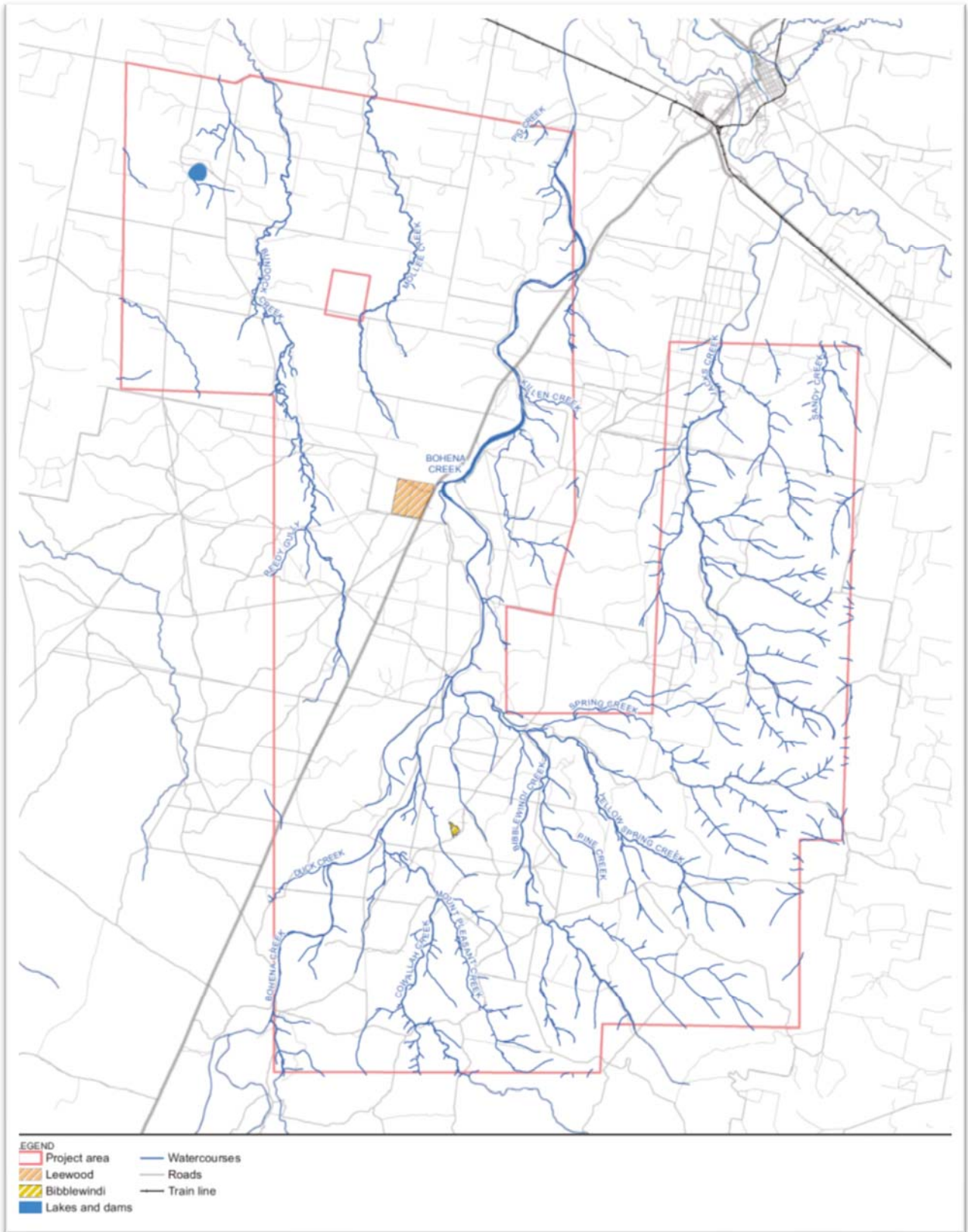


Figure 24 | Watercourses

Produced Water Management

371. Removal of water from the coal seams is a fundamental component of any coal seam gas development. By removing water, the pressure in the coal seams is lowered, which allows the natural gas to flow.
372. The Narrabri Gas Project involves extracting up to 37.5 GL of produced water over the project life at an average of 1.5 GL per year. Produced water volumes would peak at approximately 10 ML/day in Years 2 to 4, and gradually decline over the remaining life of the project to approximately 4 ML/day (see **Figure 11**).
373. Management of produced water has come a long way since the early days of non-conventional gas development in the US and Australia where evaporation ponds, often poorly designed and/or constructed, were used. This practice is now banned in New South Wales and Queensland, and appropriate regulations have been imposed (including the Produced Water Management Code).
374. Santos proposes to treat produced water extracted from the project to meet drinking water and other applicable standards, and to beneficially reuse the treated water for agricultural irrigation and other activities such as dust suppression. During extended wet periods when irrigation and other beneficial reuse are not available, Santos proposes to discharge excess treated water to Bohena Creek under appropriate flow conditions (i.e. at least 100 ML/day flow in the creek).
375. The produced water management process is shown on **Figure 25**, and involves the following key steps:
- pumping water from the gas wells (via underground pipelines) to storage ponds at Leewood and Bibblewindi;
 - produced water treatment in 6 main stages, including:
 - Stage 1 – removal of solids and ion exchange;
 - Stage 2 – removal of salt via reverse osmosis;
 - Stage 3 – recovery of treated water from brine, with interim brine storage in ponds;
 - Stage 4 – removal of solid salt product from brine;
 - Stage 5 – removal of ammonia and pH adjustment to produce a final treated water product suitable for:
 - construction and drilling;
 - dust suppression;
 - stock watering;
 - managed release to Bohena Creek; and
 - Stage 6 – amendment of treated water (via calcium addition) to make it suitable for agricultural irrigation; and
 - storage and off-site disposal of the solid salt waste product to licensed landfill.

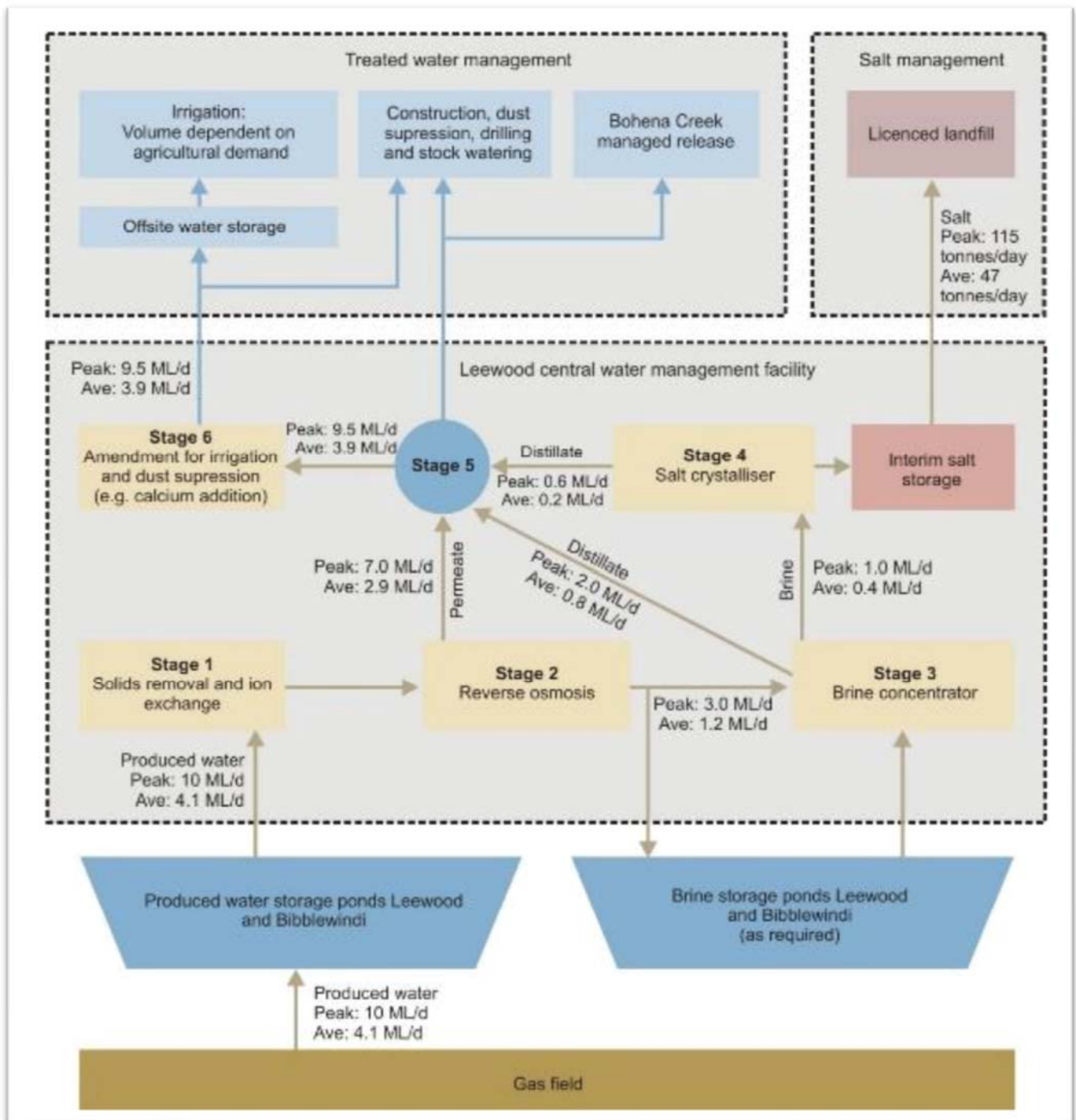


Figure 25 | Produced Water Treatment Process

376. Key issues raised in submissions in relation to produced water management included the:
- composition of produced water and the adequacy of the treatment plant to appropriately treat potential contaminants within the water;
 - capacity of the water storages and water treatment plant;
 - risk of spills, leaks or uncontrolled discharges during operations;
 - impacts to soil and water resources associated with irrigation of treated water; and
 - impacts to Bohena Creek associated with treated water discharges to the creek.

377. The WEP has considered these and other issues associated with the proposed produced water management system (see **Appendix G**).
378. With regard to produced water flows and composition, the WEP found that the amount of water produced by the project is likely to be relatively low (as a ratio of energy produced) compared to other non-conventional gas operations in Queensland and the US. However, produced water from the project is likely to be more saline (as total dissolved solids). The WEP notes that this is not necessarily a disadvantage, but it does affect the design of the treatment system and the ultimate composition and quality of salt product.
379. The WEP acknowledged the concerns of various submissions about the possible presence of constituents of potential concern (COPCs) in the produced water, such as organics derived from coal seams and radionuclides. However, after reviewing the proposed water treatment system (including Santos' pilot plant), the WEP accepts that these COPC's and other potential contaminants are able to be effectively treated with the proposed reverse osmosis treatment system, and that risks are able to be effectively managed subject to stringent design, management and monitoring.
380. The WEP notes that the system represents best current international practice, is modular in design, and can be readily adapted to meet requirements and address risks as required. It also notes that the gas wells can be shut in if necessary (i.e. flow stopped) to avoid any adverse impacts.
381. The WEP notes that the water storages are consistent with applicable best practice standards, including the Produced Water Management Code. These include requirements for:
- appropriate pond storage capacity (i.e. ability to maintain sufficient freeboard to handle a 72-hour 1-in-100-year flood event without overflowing);
 - double geomembrane liners for open ponds;
 - leak detection systems;
 - groundwater monitoring; and
 - trigger action response plans (TARPs) to address potential incidents.
382. As outlined above, treated water is proposed to be beneficially reused for:
- Irrigation – up to 10 ML/day; and
 - stock watering, dust suppression, construction and drilling – approximately 1 to 2 ML/day.
383. Analysis indicates that there is ample land in and around the project area which could be used for irrigation of treated water. The WEP notes that the treated water would impose a small salt burden on the irrigated land, but that the composition of water is likely to be similar to the water quality from existing (alluvial) aquifer bores in the region and the Namoi River system.
384. The WEP concludes that the water would be suitable for irrigation and on-site use, subject to appropriate soil studies of irrigation sites, and irrigation management and monitoring. The Department has included this in the recommended conditions.
385. In times of extended rainfall, when beneficial use cannot occur or would be constrained, Santos proposes to discharge treated water to Bohena Creek. Water would be discharged only when the creek is flowing at greater than 100 ML per day, with the flow measured at the gauging station on the Newell Highway. During the peak predicted water production (i.e. Years 2 to 4), this could occur on up to 44 days a year.

386. The WEP considered the potential impacts associated with this release and found that the concentration of constituents in the treated water are generally below those reported in Bohena Creek. Consequently, it is unlikely to have any adverse impacts on the creek system. Boron and zinc levels could be slightly higher than the concentrations in the creek, however this is unlikely to result in any adverse impacts.
387. Some submitters suggested that the flows in Bohena Creek should be monitored closer to the release site, rather than at the Newell Highway which is approximately 8 km downstream. However, Santos noted that locating the gauging station closer to the release site would be difficult due to the sparse and ill-defined nature of the stream near the release site. The WEP agreed that this is a reasonable justification for using the Newell highway gauging station, which would need to be upgraded to provide the required measurement sensitivity for the project. Santos would finalise the location of the gauging station in consultation with the EPA prior to any discharges occurring from the site.
388. The Department agrees that the managed release of excess treated water to Bohena Creek can be appropriately managed. However, it believes that Santos should be required to maximise the reuse of water treated before discharging it to the creek, and has incorporated this into the recommended conditions. It has also recommended conditions requiring Santos to comply with a number of performance measures in relation to produced water management, and to prepare and implement a detailed Produced Water Management Plan.

Salt Management

389. As outlined above, the proposed produced water treatment system would generate a by-product comprising a solid mass of salt crystals, which could be reused or sent to a licensed landfill for disposal.
390. Submissions raised several issues in relation to salt generation and management, including concerns about the:
- volume of salt produced;
 - potential environmental risks associated with salt production and management on site;
 - composition of the salt product and potential contaminants; and
 - lack of detailed consideration of options for beneficial reuse or disposal.
391. With regards to the salt recovery process itself, the WEP considers that the technology is state-of-the-art and should function effectively subject to competent operation.
392. The EIS predicted that some 430,500 tonnes of salt would be produced over the life of the project, or an average of around 47 tonnes per day (about two B-double truck loads). However, based on updated water baseline information in the RTS, the WEP considers that salt production could be up to approximately 850,000 tonnes over the project life.
393. The WEP notes that the salt quantity produced as a ratio of produced water would be considerably higher for the project (average 11.5 tonnes per ML of produced water) compared to existing Queensland operations (between 3.8 to 4.6 tonnes per ML). However, the total amount of salt produced by the project would be much smaller than these operations (i.e. up to 5.5 million tonnes) due to the smaller size of the project relative to Queensland projects.
394. To further illustrate the predicted salt volume, the WEP notes that the total volume over the 25-year project would be equivalent to the volume of a large aircraft hangar. In comparison, the Department notes that the Murray Darling Basin Authority's salt interception scheme generates about 500,000 tonnes of salt per year.

395. The WEP also considered the composition of the salt product, noting that the available data suggests that it would be low in heavy metals and other pollutants, when compared to the EPA's *Waste Classification Guidelines*. The WEP agrees with Santos that the salt waste is likely to be classified as general solid waste under the waste classification guidelines and could be disposed of at several licenced waste facilities in NSW. However, the WEP recommends that Santos be required to confirm whether any COPC's are present in the salt product on an ongoing basis, as this may affect the salt waste classification and disposal requirements.
396. With regards to disposal, Santos proposes to temporarily store the salt product on site in a weather-proof structure, before off-site disposal at an appropriately licensed waste facility(ies). Santos reports that there are 11 licensed solid waste disposal facilities within a 150 kilometre radius of the site.
397. Some submitters argued that Santos should be required to undertake a full life cycle assessment of the potential impacts associated with any salt disposal. However, this is unnecessary. Both the Department and the EPA are satisfied that any salt produced by the project can be managed in accordance with the applicable guidelines and disposed of at suitably licenced facilities, which have been specifically designed to accommodate such wastes on a routine basis.
398. Although the WEP acknowledges that using recovered salt beneficially has had limited success in other coal seam gas operations, it notes that the higher sodium carbonate concentration in the project's salt product could make it more attractive for starting a small salt-based industry. Consequently, the WEP recommends that further work should be done on the potential beneficial uses for the product.
399. The Department agrees and has recommended conditions requiring Santos to investigate beneficial use options for the salt product. It has also recommended conditions requiring Santos to comply with a number of performance measures in relation to salt management, and to prepare and implement a detailed Salt Management Plan.

Surface Spills and Contamination

400. Several submissions raised concerns about the potential for the project to contaminate land and water resources. This could occur in several ways, with the key surface-related hazards including:
- surface spills or uncontrolled discharges of produced water, retentate (concentrate) and brine, either at the well pads, pipelines or production plant;
 - surface spills of chemicals and other fluids used in the drilling and gas production process; and
 - contamination associated with irrigation and/or disposal of treated water (addressed in proceeding section).
401. Submissions raised concerns about previous spills on site, which occurred mostly during historical operations by Eastern Star Gas, as well as spills at certain Queensland operations and overseas.
402. Santos proposes to implement several measures to avoid and/or minimise any spills, leaks or uncontrolled discharges from its surface facilities and operations. This includes ensuring design of key infrastructure complies with best practice and the relevant codes of practice. It also proposes to develop several monitoring, management and incident response plans, including a:
- Trigger Action Response Plan;
 - Produced Water Management Plan;
 - Pollution Incident Response Management Plan;

- Irrigation Management Plan; and
- Dam Safety Emergency Plan.

403. The WEP has reviewed the hazards and risks to land and water resources associated with surface spills from the project, noting that the hazards are similar to those for other large industrial facilities such as chemical process plants, water treatment plants and sewage treatment plants.
404. The WEP indicated that Santos' measures for spill management are appropriate, and that while potential spills could have significant localised impacts, they are unlikely to have any significant impact on the regional water resources given the likely relatively low spill volumes and their composition.
405. The WEP concluded that the current regulatory framework for handling chemicals used in the project provides reassurance that the likelihood for potential harm to humans and the environment is low, subject to the implementation and enforcement of these regulations.
406. The WEP recommended that Santos be required to detail appropriate fail-safe measures, containment measures and effective response measures during the detailed design of key infrastructure, and the Department has included this in the recommended conditions.

6.4 Biodiversity

Summary

The 95,000 ha project area contains some 80,398 ha of native vegetation.

Based on a range of potential field development scenarios, the likely extent of native vegetation clearing required for the gas-field is expected to be between 247 to 626 ha. However, Santos has conservatively estimated clearing of 921 ha based on a maximum clearing limit for each vegetation community. A further 78 ha would be cleared for fixed infrastructure, such as at the Leewood and Bibblewindi sites.

That is, there is only a small area (around 1%) of clearing within the project area and only a very small area (around 0.2%) of clearing within the broader Pilliga Forest, comprising some 500,000 ha of remnant woodland.

Three endangered ecological communities (EECs) would potentially be disturbed, conservatively including up to 19.3 ha of Brigalow, up to 5.9 ha of Fuzzy Box Woodland, and up to 0.1 ha of Weeping Myall Woodland. A number of threatened flora and fauna species occur or have the potential to occur in the project area, including 27 listed plant species and 57 listed fauna species.

Santos has developed a Field Development Protocol that sets 'rules' for avoiding impacts on threatened species and key habitat. These rules include avoiding development in ecologically sensitive areas and riparian areas, setting maximum disturbance limits for each plant community type and threatened flora species, and undertaking micro-siting surveys for project-related infrastructure.

Santos has also committed to offsetting the residual biodiversity impacts through a combination of land-based offsets, supplementary measures, payments into the Biodiversity Offsets Fund, and rehabilitation of disturbed areas. The Department has recommended that offsets be staged with a focus on land-based offsets

The Department is satisfied that Santos' proposed measures to minimise biodiversity impacts are reasonable, and importantly that the most sensitive biodiversity values can be avoided. The Department is satisfied that the project is unlikely to have any significant impacts on the broader biodiversity values of the Pilliga and surrounding region, subject to recommended conditions.

Introduction

407. Around two thirds, or some 62,750 ha, of the project area is located within 'the Pilliga', a 500,000 ha contiguous area of remnant native forest, the largest in western NSW (see **Figure 15**).
408. The EIS includes a specialist biodiversity assessment undertaken by Eco Logical Australia. The assessment was supplemented by additional information in Santos' RTS and Supplementary RTS.
409. The biodiversity assessment was carried out under the *NSW Biodiversity Offsets Policy for Major Projects 2014* (Major Projects Offsets Policy) using the *Framework for Biodiversity Assessment* (FBA).
410. Key issues on biodiversity highlighted in submissions included:
 - the adequacy of the biodiversity assessment;
 - the importance of the Pilliga Forest;
 - unacceptable impact on threatened communities and species; and
 - the adequacy of proposed offsets for residual impacts

Figure 17: Vegetation mapping – Endangered Ecological Communities

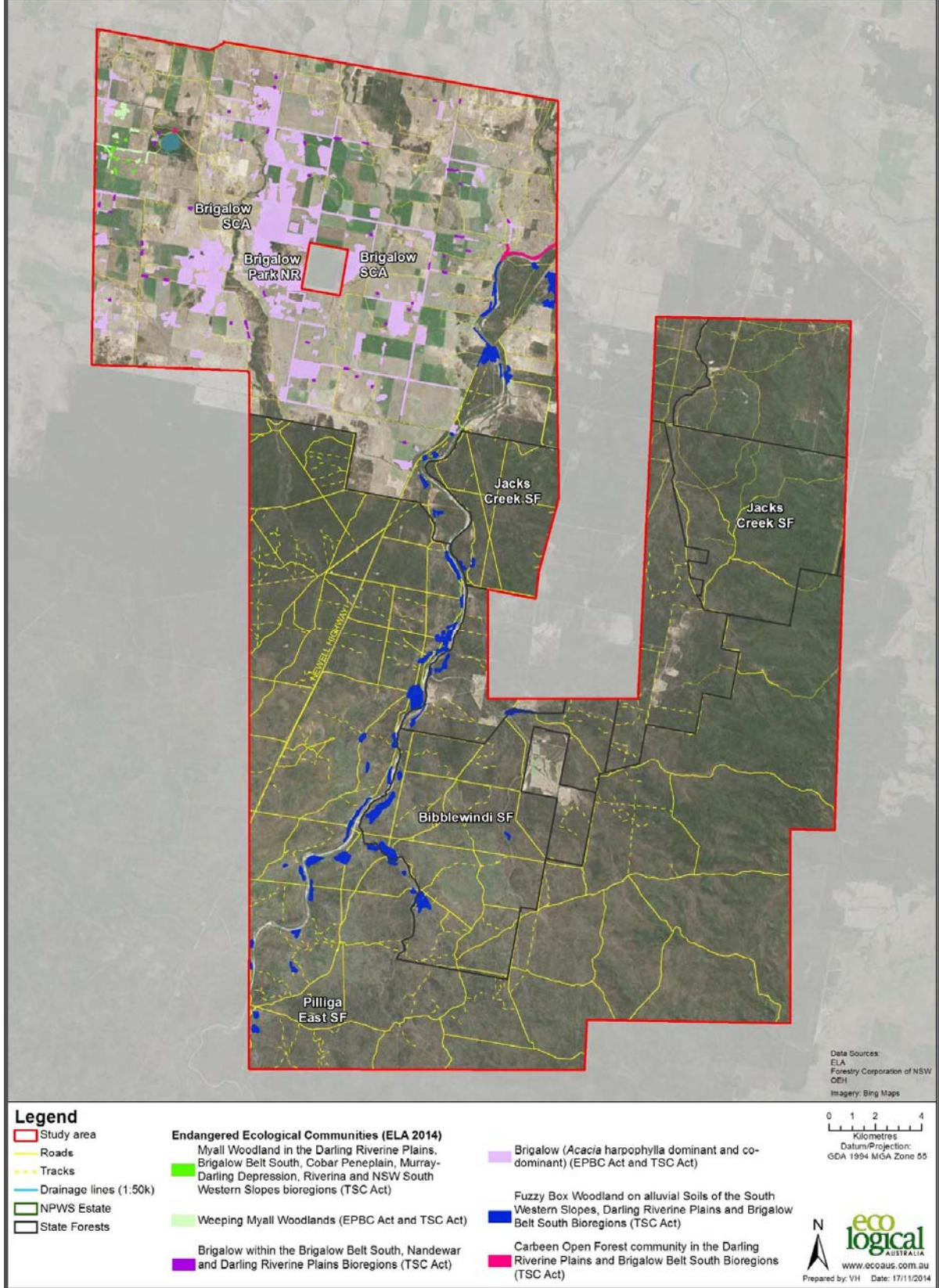


Figure 26 | EECs - Narrabri Gas Project

Adequacy of Assessment

411. As discussed in Section 2, apart from the major infrastructure sites such as Leewood and Bibblewindi, the exact location of gas field infrastructure (including well pads and associated linear infrastructure) has not been confirmed at this stage, and would be subject to detailed investigation and assessment during the project life, in accordance with the Field Development Protocol.
412. Santos' draft Field Development Protocol includes a number of restrictions (or rules) for avoiding impacts on identified resources. Some of these relate to avoiding impacts on biodiversity values, including:
 - excluding Brigalow Park Nature Reserve from the project area;
 - excluding surface infrastructure from the Brigalow SCA;
 - no surface infrastructure within 200 m of Yarrie Lake;
 - placing large ponds and dams in areas of low ecological sensitivity;
 - excluding non-linear infrastructure from riparian corridors;
 - setting maximum disturbance limits for each Plant Community Type (PCT);
 - setting maximum disturbance limits for threatened flora species; and
 - maximising the use of existing roads, tracks and disturbance corridors.
413. Additional avoidance and mitigation measures proposed by Santos include avoiding impacts to EECs to the greatest extent possible, co-locating linear infrastructure such as gas and water pipes and access tracks with existing roads, tracks and disturbance corridors, and placing infrastructure in previously cleared areas.
414. Based on these rules, the Field Development Protocol includes a detailed process for siting gas field infrastructure, which would include:
 - detailed constraints and avoidance analysis;
 - incremental and cumulative disturbance review;
 - in-field micro-siting, including ground-truthing survey; and
 - detailed infrastructure design.
415. The outcomes of these investigations would be used to develop the Field Development Plans, which would include, amongst other things, detailed designs for the proposed gas field infrastructure in a manner that avoids, to the greatest extent possible, biodiversity resources.
416. This approach to siting gas field infrastructure is standard for the gas industry, where a level of flexibility is required in the placement of gas wells as the field develops over time, driven by project information collected on the gas resource and geology.
417. To enable assessment of the potential biodiversity impacts associated with the project, the biodiversity assessment was based on conservative estimates of the upper disturbance limits for each vegetation community, based on a number of different gas field development scenarios, and the rules of the Field Development Protocol.
418. In essence, this method provides an overly conservative estimate of total vegetation clearing, as it provides a worst case estimate for each vegetation type coupled with a worst case scenario of gas field development, which would not be realised in practice (as only one development scenario would be implemented).

419. Nonetheless, the predicted total native vegetation clearing for each of the gas field development scenarios is provided in **Table 9** below. The highest value from each of these different development scenarios was then used to estimate maximum clearing for each PCT.

Table 9 | Field Development Scenarios Used to Determine Maximum Individual PCT Clearing Limits

Scenario	Description	% Area	Clearing (ha)
A	Even distribution of wells across project area	100%	534-556
B2	Focus southern part of Pilliga Forest	37%	598-614
B3	Focus western part of Pilliga Forest	37%	557-572
B4	Focus on cleared farmland	40%	247-252
C	Wells located in selected water extraction areas	31%	567-588
D	Wells distributed across all water extraction areas	100%	608-626
E	Wells located in areas with the highest resource potential	35%	539-590
Gas-field clearing when summed by maximum for each individual PCT			921

420. As indicated in the table the estimated maximum clearing for the gas field, based on summing the worst case for each PCT, is 921 ha, or less than 1 percent of the project area. However, the maximum clearing for the gas field, based on the various development scenarios, ranges from only 247 to 626 ha, or between 27 and 68 percent of the assumed worst case clearing.
421. While the exact footprint of the gas field infrastructure is not known, the Department is satisfied with the biodiversity assessment methodology used in the assessment, and acknowledge that the assessment provides a conservative estimate of biodiversity impacts for the project.
422. Some submitters raised concerns about the adequacy of field surveys and the classification of vegetation into the identified PCTs.
423. A key concern raised in the Upper Mooki Landcare submission and subsequent advice was that some PCT's are better categorised as representing Box Gum Woodland EEC. In response, Eco Logical undertook a detailed analysis of field data vegetation plots, including an assessment of soil and geology, landscape and vegetation mapping data. The additional analysis concluded that the assemblage of species and soil type was not consistent with listing advice for the Box Gum Woodland EEC. The Department accepts this conclusion and notes that ground truthing forms part of the development of the Field Development Plans, which would be subject to consultation and the approval of the Department.
424. The Department considers that the survey effort and identification of PCTs adequately informs the biodiversity assessment and that further detailed surveys undertaken during the FDP to inform avoidance in conjunction with maximum clearing limits set for each PCT provides a robust platform for managing and regulating biodiversity impacts.

Protection of the Pilliga

425. The Department notes community views that the Pilliga Forest should be protected from resource extraction due to its conservation value and that it is the largest intact remnant forest in western NSW.
426. These concerns were acknowledged in 2005, when the NSW Government completed comprehensive strategic land use planning for the Pilliga and surrounding region.
427. The land use planning involved extensive consultation with a wide range of stakeholders, including leading conservation groups, striking a balance between competing land uses including biodiversity and cultural heritage conservation, recreation, forestry and mining.
428. This strategic land use planning is addressed in the *Brigalow and Nandewar Community Conservation Area Act 2005* (BNCCA Act). The Act allocated areas of pre-existing state forest into four different zonings, including:
- Zone 1 – Conservation and Recreation areas (National Park);
 - Zone 2 – Conservation and Aboriginal cultural areas (Aboriginal Areas);
 - Zone 3 – Conservation, recreation and mineral extraction (State Conservation Areas); and
 - Zone 4 – Forestry, recreation and mineral extraction (State Forests).
429. Almost half (or 240,000 ha) of the Pilliga was protected as reserves for biodiversity and/or cultural heritage conservation (Zones 1 to 3), with these areas permanently protected under the *National Parks and Wildlife Act 1974*.
430. The project area is located within Zone 4, which was specifically set aside for forestry, recreation and mineral extraction, subject to appropriate merit assessment. It includes parts of the Pilliga East, Bibblewindi and Jacks Creek State Forests. These areas have historically been logged, and have an extensive network of forestry roads and tracks through the forested areas.
431. There are two conservation areas within the area bounded by the project area, including Brigalow Nature Reserve (Zone 2) and Brigalow State Conservation Area² (Zone 3). These areas have been excluded from the project area and would be protected from any impacts from the project.
432. As outlined above, the project would clear in the order of 1% of native vegetation within the project area and about 0.2% of the total Pilliga Forest area with the main infrastructure area at Leewood located outside the forest.
433. Well pads and associated infrastructure would also be progressively rehabilitated back to the surrounding native vegetation communities following construction and decommissioning.
434. The Department is satisfied that the Narrabri Gas Project has been planned in a manner that is consistent with this comprehensive strategic land use planning for the Pilliga and surrounding region. It is noted that the development of the natural gas resource was specifically identified and considered in the development of the BNCCA Act.

² The Brigalow SCA is subject to a surface exclusion zone (including a 50m buffer), and reserved to a depth of 100m. Santos proposes that any sub-surface infrastructure would be at a depth of more than 110 m below the SCA.

Impacts on Threatened Species & Communities

Communities

435. The biodiversity assessment identified 22 plant community types (PCTs) in the project area, including approximately 71,000 ha of woodland communities (75% of project area), 9,500 ha of derived native grassland (DNG) (10% of project area), and 3,100 ha of EECs (3% of project area). The balance of the project area comprises mainly agricultural areas and disturbed land. The PCTs are listed in **Table 10** and EECs also shown on **Figure 27** below.
436. The project would disturb up to 989 ha of native vegetation, of which 921 ha is associated with the gas field development, noting that this is a conservative estimated based on maximum clearing limits for each PCT, and 68 ha is associated with the known infrastructure locations. No PCT would be impacted by more than 3% of its occurrence in the project area.
437. The project is designed to avoid as far as practicable direct clearing of the 4 EECs identified in the project area with a maximum clearing of around 25 ha of the 3,100 ha (<1%) of EEC's, with avoidance measures proposed during the implementation of the Field Development Protocol to further reduce this predicted impact.
438. Santos has committed to avoiding all impacts on the Carbeen Open Forest EEC, and only a minor 0.1 ha area of Weeping Myall Woodland EEC is predicted to be potentially impacted. Complete avoidance of the Weeping Myall EEC may not be possible (subject to detailed design), as linear infrastructure is required to pass through road-side corridors where the EEC is located. Similarly, the Fuzzy Box EEC is located mainly along riparian areas of Bohena Creek in the Pilliga Forest and some small amount of clearing (5.9 ha) of this EEC would be required to facilitate linear infrastructure.
439. The Department has recommended conditions imposing upper clearing limits for all vegetation types predicted to be impacted, as well as requirements for Santos to undertake micro-siting surveys as part of the development of the Field Development Plans. In accordance with this framework, if micro-siting surveys were to subsequently identify different PCTs (such as Box Gum woodland EEC) that are not permitted to be disturbed, then Santos would need to avoid the impact, or seek separate approval for the clearing.
440. The biodiversity assessment includes significance assessments for all of the potentially affected EECs³. The assessments conclude that clearing up to the maximum clearing limits is unlikely to significantly impact any EECs, as the vegetation being removed would be a small proportion of that being retained in the project area, and the removal would not be at a scale that would isolate or fragment populations.
441. The Department accepts this conclusion, subject to implementation of the identified avoidance and mitigation measures, and suitable biodiversity offsetting arrangements (as discussed separately below).

³ When the EIS was lodged, former Sections 5A-5D of the EP&A Act applied which related to threatened species assessment and management, including taking into account the significance of impacts on threatened species (ie the '7 part test'). Due to amendments to the EP&A Act in August 2017, these provisions do not now apply to the project. Nonetheless, the Department considered the significance assessments completed by Eco Logical on State listed threatened species using the 7-part test. Further, the Department also considered Eco Logical's significance assessments on Commonwealth listed species using the methodology outlined in *Matters of National Environmental Significance Significant Impact Guidelines 1.1 (2013)*.

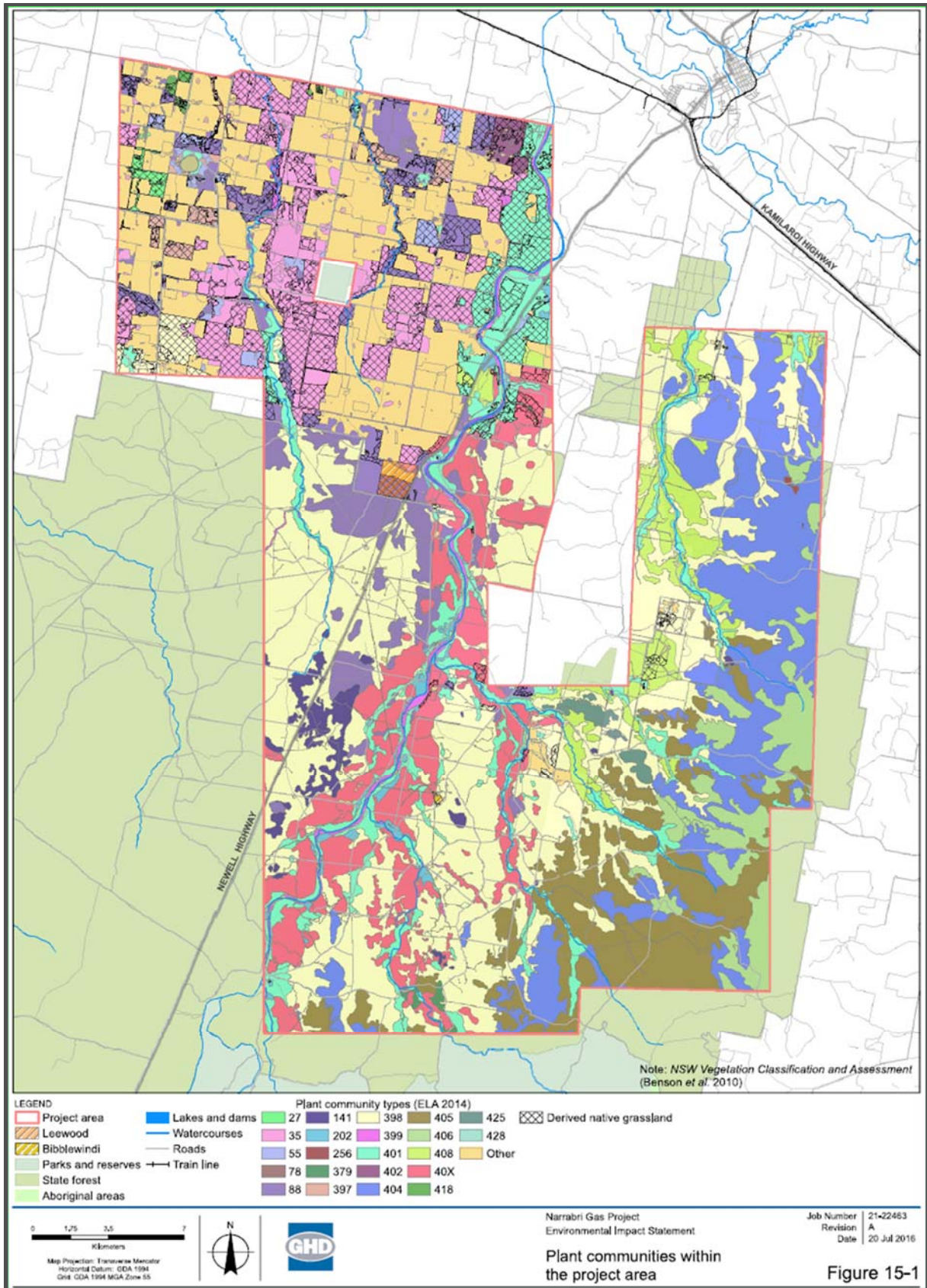


Figure 27 | Vegetation Communities – Narrabri Gas Project

Table 10 | Native Vegetation Communities Within the Project Area (endangered ecological communities shown in blue)

PCT	Plant Community Type Name	Condition Class	Total Area Mapped within Project Area (ha)	Direct Impacts	% Cleared	Indirect Impacts	Cumulative Impacts	Total Impact	Credits
				Area (ha)		Area (ha)	Area (ha)	Area (ha)	
27	Weeping myall open woodland of the Darling Riverine Plains Bioregion and Brigalow Belt South Bioregion	Native Vegetation	36	0.1	0.28	0	0	0.1	5
27	Weeping myall open woodland of the Darling Riverine Plains Bioregion and Brigalow Belt South Bioregion	DNG	173.3	0.5	0.29	0	0	0.5	20
35	Brigalow - belah open forest / woodland on alluvial often gilgaied clay from Pilliga Scrub to Goondiwindi, Brigalow Belt South Bioregion	Native Vegetation	2468	19.3	0.78	3.9	0	23.2	1,303.50
35	Brigalow - belah open forest / woodland on alluvial often gilgaied clay from Pilliga Scrub to Goondiwindi, Brigalow Belt South Bioregion	DNG	4,228.50	37.2	0.88	0	0	37.2	1,301
55	Belah woodland on alluvial plains and low rises in the central NSW wheatbelt to Pilliga and Liverpool Plains regions – woodland	Native Vegetation	362.5	3.9	1.08	0.8	0	4.7	219.7
55	Belah woodland on alluvial plains and low rises in the central NSW wheatbelt to Pilliga and Liverpool Plains regions	DNG	322.9	1.7	0.53	0	0	1.7	65
78	River red gum riparian tall woodland / open forest wetland in the Nandewar and Brigalow Belt South Bioregions	Native Vegetation	10.5	0	0				
88	Pilliga box - white cypress pine – Buloke shrubby woodland in the Brigalow Belt South Bioregion – Woodland	Native vegetation	4,456.40	40.8	0.92	8.2	0	49	2,845.60
88	Pilliga Box - white cypress pine – Buloke shrubby woodland in the Brigalow Belt South Bioregion	DNG	1,526.90	8.8	0.58	0	0	8.8	283
141	Broombush - wattle very tall shrubland of the Pilliga to Goonoo regions, Brigalow Belt South Bioregion	Native vegetation	1,035.60	19.5	1.88	4	0.5	24	761.5
202	Fuzzy box woodland on colluvium and alluvial flats in the Brigalow Belt South Bioregion (including Pilliga) and Nandewar Bioregion	Native vegetation	588.9	5.9	1	1.2	2.1	9.2	648.5
202	Fuzzy box woodland on colluvium and alluvial flats in the Brigalow Belt South Bioregion (including Pilliga) and Nandewar Bioregion	DNG	1.4	0	0				
256	Green mallee tall mallee woodland on rises in the Pilliga - Goonoo regions, southern Brigalow Belt South Bioregion	Native vegetation	20.3	0.3	1.48	0.1	0	0.4	15.4
408	Dirty gum (Baradine gum) - black cypress pine - white bloodwood shrubby woodland on of the Pilliga forests and surrounding region – Woodland	Native vegetation	3,084.80	33.3	1.08	6.8	3.4	43.5	2,410.50
408	Dirty gum (Baradine gum) - black cypress pine - white bloodwood shrubby woodland on of the Pilliga forests and surrounding region	DNG	103.5	0.4	0.39	0	0	0.4	10
398	Narrow-leaved ironbark - white cypress pine - Buloke tall open forest on lower slopes and flats in the Pilliga Scrub and surrounding forests in the central north Brigalow Belt South Bioregion – Woodland	Native vegetation	23,492	323.4	1.38	63.4	57.5	444.2	23,651.40
398	Narrow-leaved ironbark - white cypress pine - Buloke tall open forest on lower slopes and flats in the Pilliga Scrub and surrounding forests in the central north Brigalow Belt South Bioregion	DNG	494.9	3.9	0.79	0	0	3.9	184
399	Red gum - rough-barked apple +/- tea tree sandy creek woodland (wetland) in the Pilliga - Goonoo sandstone forests, Brigalow Belt South Bioregion- Woodland	Native vegetation	1,048	3.4	0.32	0.7	0.1	4.2	220.2
399	Red gum - rough-barked apple +/- tea tree sandy creek woodland (wetland) in the Pilliga - Goonoo sandstone forests, Brigalow Belt South Bioregion	DNG	47.1	0.2	0.42	0	0	0.2	0
402	Mugga ironbark - white cypress pine - gum tall woodland on flats in the Pilliga forests and surrounding regions, Brigalow Belt South Bioregion – woodland	Native vegetation	177.7	1.6	0.9	0.3	0	1.9	93
402	Mugga ironbark - white cypress Pine - gum tall woodland on flats in the Pilliga forests and surrounding regions, Brigalow Belt South Bioregion	DNG	189.7	1.6	0.84	0	0	1.6	0
379	Inland scribbly gum - white bloodwood - red stringybark - black cypress pine shrubby sandstone woodland mainly of the Warrumbungle NP - Pilliga region in the Brigalow Belt South Bioregion – Woodland	Native vegetation	103.6	2.7	2.61	0.5	0	3.2	207.9
397	Poplar box - white cypress pine shrub grass tall woodland of the Pilliga – Warialda region, Brigalow Belt South Bioregion – woodland	Native vegetation	326.7	1	0.31	0.2	0	1.2	63.6
397	Poplar box - white cypress pine shrub grass tall woodland of the Pilliga – Warialda region, Brigalow Belt South Bioregion	DNG	446.3	1.3	0.29	0	0	1.3	33
401	Rough-barked apple - Blakely's red gum - black cypress pine woodland on sandy flats, mainly in the Pilliga Scrub region – woodland	Native vegetation	5,954.90	46.4	0.78	9.2	2.3	58	3,649.30
401	Rough-barked apple - Blakely's red gum - black cypress pine woodland on sandy flats, mainly in the Pilliga Scrub region	DNG	1,641.20	18.1	1.1	0	0	18.1	646
404	Red ironbark - white bloodwood +/- burrows wattle heathy woodland on sandy soil in the Pilliga forests – woodland	Native vegetation	9,993.90	86.6	0.87	17.6	0	104.2	6,295.80
405	White bloodwood - red ironbark – black cypress pine shrubby sandstone woodland of the Pilliga Scrub and surrounding regions – Woodland	Native vegetation	6,652.10	108.7	1.63	48.5	13.3	308.9	16,799.20
406	White bloodwood - motherumbah – red ironbark shrubby sandstone hill woodland / open forest mainly in east Pilliga forests – Woodland	Native vegetation	3,239.20	69	3902.13	14	0	83	4,243.50
40X ¹	White bloodwood – dirty gum – rough barked apple – black cypress pine heathy open woodland on deep sand in the Pilliga forests	Native vegetation	7,534.90	138.4	1.84	-	-	-	-
405 ²	White bloodwood – dirty gum – rough barked apple – black cypress pine heathy open woodland on deep sand in the Pilliga forests	DNG	239.5	1.9	0.79	0	0	1.9	72
418	White cypress pine - silver-leaved ironbark - wilga shrub grass woodland of the Narrabri-Yetman region, Brigalow Belt South Bioregion – woodland	Native vegetation	66.2	0.2	0.3	0.1	0	0.3	14.9
418	White cypress pine - silver-leaved ironbark - wilga shrub grass woodland of the Narrabri-Yetman region, Brigalow Belt South Bioregion	DNG	69.6	0.3	0.43	0	0	0.3	8
425	Spur-wing wattle heath on sandstone substrates in the Goonoo - Pilliga forests, Brigalow Belt South Bioregion	Native vegetation	366.7	8.4	2.29	1.7	0.1	10.2	562.7
428	Carbeen - white cypress pine - curracabah - white box tall woodland on sand in the Narrabri - Warialda region of the Brigalow Belt South Bioregion	Native vegetation	15	0	0				
TOTAL		Total	80518.7						
		Total Woodland	71018.9	988.8	3931.19	181.2	79.3	1249.3	66633.2
		Total DNG	9484.8						

Note 1: Eco Logical argued in the EIS that PCT 40X was a new PCT, as it represented a unique assemblage of species on a particular landform in the Pilliga. BCD advised that the FBA required that the PCT's conformed to the mapping to plant PCTs according to the NSW PCT classification as described in the VIS Classification Database and that PCT 40X should be incorporated into PCT 405. For the purposes of FBA offsetting calculations, this vegetation community is included in PCT 405.

Note 2: Eco Logical classified this as PCT 40X in the EIS

442. In addition to direct vegetation clearing, Santos has assessed indirect impacts to account for the fragmented nature of the clearing and associated edge and other indirect effects created at a landscape level.
443. Further, whilst not required under the Major Projects Offsets Policy, Santos is also proposing to offset indirect and cumulative biodiversity impacts to compensate for the effects of fragmentation, noise, light, weeds, feral animals, and previously approved petroleum activities.
444. Eco Logical estimates that the indirectly affected area would amount to some 181 ha. This is based on a 10% buffer around all linear infrastructure and 10% of a 50 m buffer around well pads, Bibblewindi and the workers accommodation facility.
445. The cumulative impacts include those associated with 79.3 ha of native vegetation cleared for existing approved exploration infrastructure that would continue to be used for the project where offsets were not previously required. This includes exploration appraisal pads and gas and water gathering lines.
446. To calculate the credit liability for indirect and cumulative credits, Eco Logical used the Major Projects Credit Calculator to establish the credit liability for the direct impacts for each PCT. The credit liability of each impact type is summarised in **Table 11**.

Table 11 | Total Ecosystem Credits

Type of Impact	Area (ha)	Ecosystem Credits
Direct Impacts	988.8	58,522
Indirect Impacts	181.1	3,327*
Cumulative Impacts	79.3	4,784
Total	1,249.2	66,633

* The total credits for indirect impacts were multiplied by 0.3, based on the assumption that impacts would occur over 30 years only, being the life of the project and 10 years for the establishment of rehabilitated vegetation.

Flora

447. A total of 27 threatened plant species have been recorded or are predicted to occur in the study area (i.e. project area and surrounds). Ten of these were recorded during field surveys, while the remaining 17 species are considered unlikely to occur in the project area due to a lack of suitable habitat.
448. The predicted worst-case impacts on the 10 recorded threatened flora species are summarised in **Table 12** below. The impact estimates are based on habitat modelling using the maximum area of PCTs that would to be impacted under the worst-case development scenario. As with the PCTs, the impact estimates are likely to overstate the actual impacts.
449. Santos has committed to avoiding any impacts on the identified critically endangered species, *Myriophyllum implicatum*, which is a creeping matted herb with a habitat preference for shallow wetlands. It was recorded at one location in the study area.

Table 12 | Threatened Flora Impacts and Species Credits

Species	Status ¹		Population (individuals)	Maximum Impact (individuals ²)	Offset Credits
	BC Act	EPBC Act			
<i>Bertya opposens</i> (coolabah bertya)	V	V	956,861	10,309	144,326
<i>Commersonia procumbens</i> (listed as <i>Androcalva procumbens</i> in the EPBC Act)³	V	V	240,274	3,716	55,740
<i>Diuris Tricolor</i> (pine donkey orchid)	V	-	3,353	52	676
<i>Lepidium aschersonii</i> (spiny pepperpress)	V	V	8,264,623	77,691	1,087,674
<i>Lepidium monoplacoides</i> (winged pepperpress)	E	E	218,265	1,116	16,740
<i>Polygala linariifolia</i> (native milkwort)	E	-	16,317	252	3,780
<i>Pomaderris queenslandica</i> (scant pomaderris)	E	-	45,518	467	6,538
<i>Pterostylis cobarensis</i> (Greenhood Orchid)	V	-	431,718	6,658	95,732
<i>Tylophora linearis</i>	V	E	33,154	513	7,722
<i>Myriophyllum implicatum</i>	CE	-	1	0	-

Notes:

1. V = vulnerable; E = endangered; M = migratory; CE = critically endangered.
2. Based on a habitat modelling calculation or from estimated area of occupancy
3. Also known as *Rulingia procumbens*

450. For the other nine species, the maximum predicted impacts are relatively minor compared to the estimated population of the species across the study area, representing up to approximately 1.5% of the estimated populations within the study area. The biodiversity assessment includes significance assessments for all of the potentially affected species, which conclude that the project is unlikely to significantly impact any of the identified threatened flora species.
451. The Department is satisfied that these worst case potential impacts are likely to be conservative, and that the project is unlikely to significantly impact any of the identified threatened flora species⁴, subject to implementation of the identified avoidance and mitigation measures, and suitable biodiversity offsetting arrangements (as discussed below).

⁴ Including additional EPBC Act listed species identified by the Commonwealth Department of the Environment and Energy (DoEE)

Fauna

452. A total of 35 threatened fauna species were recorded in the project area, and a further 22 species are considered to have the potential to occur based on available habitat and regional site records. The species are summarised in **Table 13** below.
453. The majority of these species are identified as ecosystem credit species under the FBA. This means that, for the purposes of biodiversity offsetting, the impacts on these species are accounted for in the impact ecosystem credits identified above. That is because the vegetation communities provide suitable habitat for these species.
454. However, 6 of the fauna species are identified as species credit species under the FBA. These include the regent honeyeater, black-striped wallaby, eastern pygmy-possum, pale-headed snake, squirrel glider and koala. However, under the BC Act, the regent honeyeater is now identified as an ecosystem credit species as “Important Habitat” mapping completed by BCD does not identify core habitat of the regent honeyeater within the project boundary⁵.
455. The biodiversity assessment includes significance assessments for all of the potentially affected species, which conclude that the project is unlikely to significantly impact any of the identified threatened fauna species, given the relatively small area of habitat removal and the presence of large areas of suitable habitat in the region.
456. The Department is satisfied that the project can be managed such that it would not result in a significant impact to any of the identified threatened fauna species⁶, subject to implementation of the identified avoidance and mitigation measures, and suitable biodiversity offsetting arrangements (as discussed below).
457. In regards the koala, the Department notes that *State Environmental Planning Policy (Koala Habitat Protection) SEPP 2019* replaced *SEPP 44 – Koala Habitat Protection*. However, under transitional arrangements SEPP 44 continues to apply to the project. The project area contains koala habitat but not core koala habitat as a resident breeding population of koalas was not identified. Consequently, a Koala Plan of Management is not required for the project.
458. Santos proposes to fund a Koala research program aimed at determining the location and sizes of remnant Koala populations in the broader Pilliga region to inform conservation efforts for the species. Santos proposes that this program would offset up to 10% of the offset liability of the project.
459. The Department is supportive of the research program, however as a mitigation measure in addition to the retirement of the identified 30,454 species credits required for the koala.
460. The Department has therefore recommended that a Koala research program be prepared as a component of the Biodiversity Management Plan that includes measures for:
- determining the location and size of remnant Koala populations in the Pilliga Forest;
 - investigating why suitable areas of habitat may not be occupied by Koalas; and
 - guiding adaptive management of the Koala population in the project area and any land-based offset areas.

⁵ In this instance, the FBA credits could be converted into reasonably equivalent credits under the provisions of the BC Act and retired as ecosystem credits. This process is undertaken at the time of retiring these credits.

⁶ Including additional EPBC Act listed species identified by the Commonwealth DoEE.

Table 13 | Threatened Fauna Species

Group	Species	Status ¹		Recorded	Maximum Impact Area (ha)	Species Credits
		BC Act	EPBC Act			
Birds	Black-necked stork	E	-	Yes	-	-
	Barking owl, black falcon, diamond firetail, dusky woodswallow, glossy black cockatoo, grey crowned babbler, hooded robin, little eagle, little lorikeet, masked owl, speckled warbler, spotted harrier, square tailed kite, turquoise parrot, varied sitella	V	-	Yes	-	-
	Painted honeyeater	V	V	Yes	-	-
	Cattle egret, glossy ibis, fork-tailed swift, great egret, rainbow bee-eater, satin flycatcher, white throated needletail	-	M	Yes	-	-
	Regent honeyeater (S)	CE	CE	Potential	48	4,255
	Swift parrot	E	CE	Potential	-	-
	Brolga, black-breasted buzzard, black-chinned honeyeater, blue-billed duck, freckled duck, Gilbert's whistler, scarlet robin	V	-	Potential	-	-
	Magpie goose	V	Mar	Potential	-	-
	Sharp-tailed sandpiper, Latham's snipe	-	M, Mar	Potential	-	-
	Australian bustard, bush stone-curlew, grey falcon	E		Potential	-	-
	Australasian bittern, Australian painted snipe,	E	E	Potential	-	-
	Superb parrot	V	V	Potential	-	-
Mammals	Black-striped wallaby (S)	E	-		989	30,455
	Eastern bent-wing bat, Eastern cave bat, Little pied bat, Yellow-bellied sheath-tail-bat	V	-	Yes		
	Eastern pygmy possum (S)	V	-	Yes	775	17,950
	Squirrel glider (S)	V	-	Yes	862	21,952
	Koala (S)	V	V	Yes	989	30,454
	Pilliga mouse, south-eastern long-eared bat	V	V	Yes	-	-
	Spotted-tailed quoll	V	E	Potential	-	-
	Large-eared pied bat	V	V	Potential	-	-
	Rufous bettong, stripe-faced dunnart	V	-	Potential	-	-
Reptiles	Pale-headed snake (S)	V	-	Yes	-	30,454

Notes:

1. V = vulnerable; E = endangered; M = migratory; CE = critically endangered.
 2. Based on a habitat modelling calculations or from estimated area of occupancy
 3. Also known as *Rulingia procumbens*
- (S) Species Credit Species

Aquatic

461. Two fish species and one invertebrate species listed under the NSW *Fisheries Management Act 1994* (FM Act) and / or the EPBC Act are present or may occur in the project area. These are:
- Silver perch (listed under the FM Act and the EPBC Act);
 - Murray cod (listed under the EPBC Act); and
 - River snail (listed under the FM Act).
 - The Murray-Darling Basin population of eel-tailed catfish, listed under the FM Act, is also considered likely to occur in the project area.
462. Increases in the volume of water or changes to water quality as a result of discharges to Bohena Creek are the key potential impacts on these species. However, as none of these species are likely to occur in Bohena Creek due to lack of suitable habitat, the impacts would be negligible.
463. Impacts on the species inhabiting the Namoi River would also be unlikely due to the distance between the proposed release point and the confluence of the river, and as the water would be treated in accordance with strict discharge limit conditions, and only released during high flow conditions.

Biodiversity Offsets

464. In summary, Santos conservatively estimated that, following adoption of avoidance measures to minimise direct clearing, the residual impact credit liability required to be offset includes:
- 66,633 ecosystem credits;
 - 1,418,928 flora species credits; and
 - 135,520 fauna species credits.
465. Santos proposed to offset the impacts of the project in accordance with the provisions of the Major Projects Offsets Policy including a combination of:
- like-for-like land-based offsets, which would be required to be secured through a Biodiversity Stewardship Agreement under the BC Act;
 - supplementary and compensatory measures (now called biodiversity conservation actions under the BC Act), proposed to include a nil-tenure feral animal control program and funding a Koala research program;
 - rehabilitation of disturbed areas; and
 - payment into the NSW Government Biodiversity Conservation Fund, if required for any residual credits.
466. Santos argued that the proposed supplementary measures and the rehabilitation would reduce the total offset liability by around 30% with the remaining approximately 70% of offsets retired through land-based offsets.
467. The Department does not support this approach as outlined below and recommends staged retirement of credits with a focus on like for like land-based offsets and payment into the Biodiversity Conservation Fund.

Land-based Offsets

468. If land-based offsets were used to meet all the offsetting requirements, Santos estimates that around 6,408 ha of land would be required to meet its ecosystem credit liability (less estimated rehabilitation credits)⁷.
469. Santos has investigated the availability and suitability of potential land-based offset sites in the region, and identified a total of around 282,000 ha of potential offset land held on freehold title, which includes land with like-for-like vegetation that would likely also provide suitable habitat for 'species credit' species.
470. This indicates that there is sufficient land in the region to satisfy the ecosystem and species credit liabilities associated with the project, if land-based offsets were used.
471. The Department acknowledges that the total offset liability has been calculated based on a very conservative estimate that 989 ha of vegetation would be cleared. As outlined above, the realistic maximum clearing is likely to be between 247 and 626 ha, or between 27% and 67% of the upper disturbance limit for all vegetation.
472. On this basis, the Department recommends staged offsetting as follows:
- Prior to Phase 1 (ongoing exploration and appraisal) – retire any ecosystem and species credits liability generated by the works proposed in a Field Development Plan for that phase;
 - Prior to Phase 2 (construction of production wells and major infrastructure) – retire 70%⁸ of the ecosystem and species credit liability for all ecosystems/species (less any credits retired as part of Phase 1 activities); and
 - Prior to exceeding these 'Phase 2' credits liabilities – retire the remaining (or 'residual') credit liability for that ecosystem or species.
473. This staging would address the likely offset liability for each ecosystem/species prior to the main construction phase, while providing an incentive for Santos to minimise the amount of clearing associated with the project.
474. The Department recommends that the credits retired prior to commencement of Phase 2 can only be retired through like for like land-based offsets managed through a Stewardship Agreement under the BC Act or payment into the Biodiversity Conservation Fund or through biodiversity conservation actions approved under the BC Act.

Feral Pest Control

475. Santos proposed a nil-tenure feral animal control program as a supplementary measure to offset up to one third of the offset liability for the project.
476. While there would be clear benefits in undertaking a broader funded control program in close consultation with other land managers in and around the Pilliga, the Department is not satisfied that Santos had demonstrated that the program would lead to long-term biodiversity benefits, given it would only be carried out over the life of the project.
477. Further, it was not clear how the feral animal control program would equally benefit all threatened species impacted by the project and there was no agreement between the Department and

⁷ Based on 9.3 credits/ ha, the average number of credits that a Biobanking site generates.

⁸ The Department has recommended that 100% of the ecosystem credit liability for the two EPBC listed EEC's (Weeping Myall and Brigalow) be retired before the commencement of Phase 2.

Santos on an appropriate credit value for the program to calculate an appropriate level of funding over the life of the project. These concerns were also raised in public submissions on the project.

478. The Department notes that under the Major Projects Offsets Policy, supplementary measures can only be used as a last resort where appropriate like-for-like offset sites cannot be found. Given the availability of potential offset land, the Department considers that most of the credit liability should be retired using land-based offsets.
479. The Department also notes that Santos would be required to undertake targeted feral animal control in the land it occupies as a mitigation measure during the life of the project in consultation with the NSW Forests. The Department has recommended conditions requiring Santos to undertake feral animal and weed control as a component of the Biodiversity Management Plan.
480. Further, under the EPBC Act direct offsets must be used for at least 90% of the offsets, unless it can be clearly demonstrated that other compensatory measures provide an increased benefit, and must be directed to providing biodiversity outcomes for the threatened species, population, EEC or habitat impacted.
481. On this basis, the Department considers that the proposed nil-tenure feral animal control program should not be included in the biodiversity offsets strategy and the focus should be on securing land-based offsets for the upfront retirement of the Phase 2 credits as outline above.

Rehabilitation

482. As outlined in Section 2, the well pads would initially have an area of approximately 1 ha during construction, with this area reduced to approximately 0.25 ha during operations, with the balance rehabilitated. Gas and watering line corridors would also be rehabilitated following construction.
483. In the EIS, Santos proposed to use ecological rehabilitation of well pads and linear infrastructure to reduce its overall impact credit liability. The Department and BCD did not accept this approach given the uncertainties and timeframes associated with rehabilitation, and required Santos to recalculate its overall impact credit liability (the updated credit liabilities are outlined above).
484. Nonetheless, Santos estimates that the rehabilitation activities would rehabilitate approximately half of the disturbed areas soon after construction. This would amount to a progressive rehabilitation area of approximately 587 ha following construction activities.
485. Based on the results of previous rehabilitation efforts in the project area, Santos is seeking to retire some of its ecosystem credits through ecological rehabilitation. It has calculated the credit value of the rehabilitation of the 587 ha of short-term rehabilitation at 7,040 credits (approximately 10.5 % of the total ecosystem credit liability)⁹.
486. Concerns about the effectiveness of rehabilitation was raised in a number of agency and public submissions, particularly from the North West Alliance which references poor rehabilitation outcomes at some well pads and infrastructure areas, including from spills requiring extensive soil remediation as part of rehabilitation.
487. Santos acknowledges that there are legacy rehabilitation issues at some sites under the previous operator's management, but that more recent rehabilitation monitoring of sites, commenced under its control, shows that the rehabilitation targets can be met.

⁹ Santos argues that previously rehabilitated sites within the project area have approximated 72% of the condition of reference sites, and is seeking 12 credits/ha for ecosystem credits.

488. Santos argues that disturbance of soils for construction of linear infrastructure and well pads would be short term, with the natural seed bank remaining largely intact. Given this, and the results of rehabilitation monitoring, Santos considers that natural regeneration in these circumstances is likely to be successful.
489. The Department accepts that rehabilitation could be used to offset ecosystem credits, but only where it can be demonstrated that the rehabilitation is trending towards a recognisable PCT, as demonstrated through meeting detailed performance and completion criteria. This would provide an incentive for Santos to ensure good and prompt rehabilitation practices.
490. Santos is also seeking to use ecological rehabilitation credits towards retiring species credits for six flora and one fauna species. Santos considers, based on expert advice and literature review, that these species are likely to respond positively following disturbance, and therefore have a reasonable prospect of successful rehabilitation to provide suitable habitat for the species¹⁰.
491. However, the Department questioned whether the proposed rehabilitation would be effective and able to generate species credits for some of these species, particularly for three flora species and one fauna species that it considered would be unlikely to respond positively to disturbance. Consequently, the Department did not accept Santos' approach in this regard.
492. The Department considers a precautionary approach is warranted in the use of ecological rehabilitation credits. In this regard, the Department's recommended conditions would not allow Santos to use ecological rehabilitation credits for the up-front staged retirement of the Phase 2 credit liability. However, if Santos could demonstrate that its rehabilitation meets performance and completion criteria, then it may use rehabilitated land to retire some of the residual credit liability (if required) for the relevant PCTs and/or species (i.e. those considered by BCD as likely to respond positively to rehabilitation) later in the project life.

Conclusion

493. Santos has sought to avoid, mitigate, manage and/or offset the residual biodiversity impacts of the project in accordance with the Major Projects Offsets Policy, so that biodiversity values would be enhanced or maintained over the medium to long term.
494. The Department is satisfied that the measures proposed to minimise impacts to biodiversity are reasonable, and that the most sensitive biodiversity values can be avoided.
495. The Department is further satisfied that the residual biodiversity impacts of the project can be offset in accordance with NSW Government policy.
496. The Department has recommended a broad suite of conditions to ensure that biodiversity impacts are minimised and, where the impacts are unavoidable, to ensure that the residual impacts are accounted for and offset in accordance with government policy.
497. The recommended conditions require Santo to:
- comply with disturbance limits on vegetation communities and threatened species;
 - undertake detailed micro-siting investigations for all gas field infrastructure to ensure the commitments set out in the Field Development Protocol are implemented and high value

¹⁰ Santos estimates that rehabilitation for species credits would provide 7.1 credits/individual for flora species and 7.1 credits/ha for fauna species.

ecological features (including threatened flora and hollow-bearing trees) are avoided where feasible and reasonable;

- include detailed analysis of incremental and cumulative biodiversity disturbance as part of the Field Development Plans;
- retire applicable ecosystem and species credits in a staged manner to the satisfaction of the BCD, in accordance with a detailed Biodiversity Offsets Strategy;
- prepare and implement a comprehensive Biodiversity Management Plan, that includes measures for (amongst other things):
 - avoiding and/or minimising impacts on threatened flora and fauna;
 - enhancing the quality of vegetation, vegetation connectivity and wildlife corridors through assisted and/or targeted revegetation;
 - introducing naturally scarce fauna habitat features such as nest boxes and salvaged tree hollows;
 - controlling weeds and pests;
 - protecting vegetation and habitat outside approved disturbance areas;
 - prepare and implement a detailed Koala Research Program; and
 - meet a number of rehabilitation objectives and performance criteria, and prepare and implement a detailed Rehabilitation Management Plan.

6.5 Aboriginal Heritage

Summary

Aboriginal cultural heritage assessment identified 90 known Aboriginal cultural heritage sites in the project area, as well as areas of potential cultural heritage sensitivity.

Santos has committed to avoiding all known Aboriginal (and non-Aboriginal) heritage items in the project area. It has also committed to undertaking additional Aboriginal heritage surveys, in consultation with key Aboriginal stakeholders, prior to the construction of gas field infrastructure, and to avoiding any sites of significance identified in these surveys.

The Department and BCD are satisfied that Santos' commitments to avoidance would appropriately mitigate the project's potential Aboriginal cultural heritage impacts. The Department has recommended a number of conditions to ensure this occurs, including requiring Santos to establish an Aboriginal Cultural Heritage Advisory Group for the project.

Aboriginal cultural heritage assessment identified 90 known Aboriginal cultural heritage sites in the project area, as well as areas of potential cultural heritage sensitivity.

Santos has committed to avoiding all known Aboriginal (and non-Aboriginal) heritage items in the project area. It has also committed to undertaking additional Aboriginal heritage surveys, in consultation with key Aboriginal stakeholders, prior to the construction of gas field infrastructure, and to avoiding any sites of significance identified in these surveys.

The Department and BCD are satisfied that Santos' commitments to avoidance would appropriately mitigate the project's potential Aboriginal cultural heritage impacts. The Department has recommended a number of conditions to ensure this occurs, including requiring Santos to establish an Aboriginal Cultural Heritage Advisory Group for the project.

Introduction

498. The EIS includes an Aboriginal Cultural Heritage Assessment undertaken by Central Queensland Cultural Heritage Management.
499. The Department engaged an independent archaeologist, Dr Andrew Sneddon of The University of Queensland, to undertake a review of the Aboriginal cultural heritage impacts associated with the project, and the draft ACHMP. Dr Sneddon's report is attached in **Appendix H**
500. The Aboriginal Heritage Assessment and ACHMP were undertaken in consultation with applicable Aboriginal stakeholders including the Narrabri Local Aboriginal Land Council (LALC), Wee Waa LALC, Red Chief LALC, the Gomeroi native title claimants, and other Registered Aboriginal Parties (RAPs). Over 550 RAPs have been involved in the consultation process, which included:
 - letters and advertisements;
 - a number of meetings;
 - field survey trips;
 - requests for comments; and
 - invitations for review of the draft assessment report and management plan.
501. All RAPs were invited to participate in the consultation process.
502. Some submissions, including from the Gomeroi traditional custodians and the Dharriwaa elders group, raised concerns about the adequacy of the consultation, including that the EIS did not contain detailed information on the consultation undertaken.

503. BCD, Dr Sneddon and the Department have reviewed the consultation process, and are satisfied that the assessment and consultation has been undertaken generally in accordance with applicable guidelines, including the BCD's *Aboriginal Cultural Heritage Consultation Requirements for Proponents* (2010).
504. The project area is located within Kamilaroi Country, the traditional homelands of the Gomeroi People.
505. The project area is predominantly within the administrative area of the Narrabri LALC, although a small portion lies within the administrative area of the Wee Waa LALC. Red chief LALC, whose administrative area covers the Gunnedah locality to the east of the project area, also nominated as a RAP for the project.

Assessment Approach and Avoidance Principle

506. Given the large size of the project area (95,000 ha), and that the location of the gas field infrastructure is yet to be determined, the assessment focused on consultation, audit of existing data, limited field survey to verify existing known sites, land and cultural sensitivity mapping, and preparation of the draft ACHMP. Detailed field surveys are proposed to be undertaken prior to finalisation of the locations of all gas field infrastructure, as part of micro-siting investigations for the relevant infrastructure.
507. The assessment identified 90 known Aboriginal cultural heritage sites in the project area. A summary of the site types is presented in the following table.

Table 14 | Known Aboriginal Sites in the Project Area

Site Type	Number of Sites	Percentage	Scientific Archaeological Significance
Stone artefact scatter	17	18.9%	Medium-High
Isolated stone artefact	31	34.4%	Low-High
Scarred tree	34	37.8%	Low-High
Grinding grooves	1	1.1%	Medium-High
Historic camp	1	1.1%	Medium-High
Hearth	1	1.1%	Medium-High
Historic burial	1	1.1%	Medium-High
Other historic place	1	1.1%	Medium-High
Resource place	2	2.2%	High
Rock shelter / stone artefact scatter	1	1.1%	High
Total	90	100%	

508. Santos has also prepared landscape mapping which identifies potential cultural heritage sensitivity zones within the project area (see **Figure 28**). This mapping would be used to guide

gas field infrastructure planning and micro-siting field surveys. The Aboriginal Cultural Heritage Assessment and Dr Sneddon cautioned that the sensitivity mapping has limitations given the large project area and limited existing cultural heritage surveys, and noted that it would be refined over time as surveys are undertaken for the gas field infrastructure.

- 509. The limitations of the sensitivity mapping would be mitigated to a large degree by application of the 'avoidance principle'. In this regard, Santos has committed to avoiding all of the known Aboriginal sites within the project area, regardless of their archaeological or cultural heritage significance. Santos has also committed to avoiding all sites of higher significance identified during subsequent micro-siting surveys, with avoidance by site type as shown in the following table.

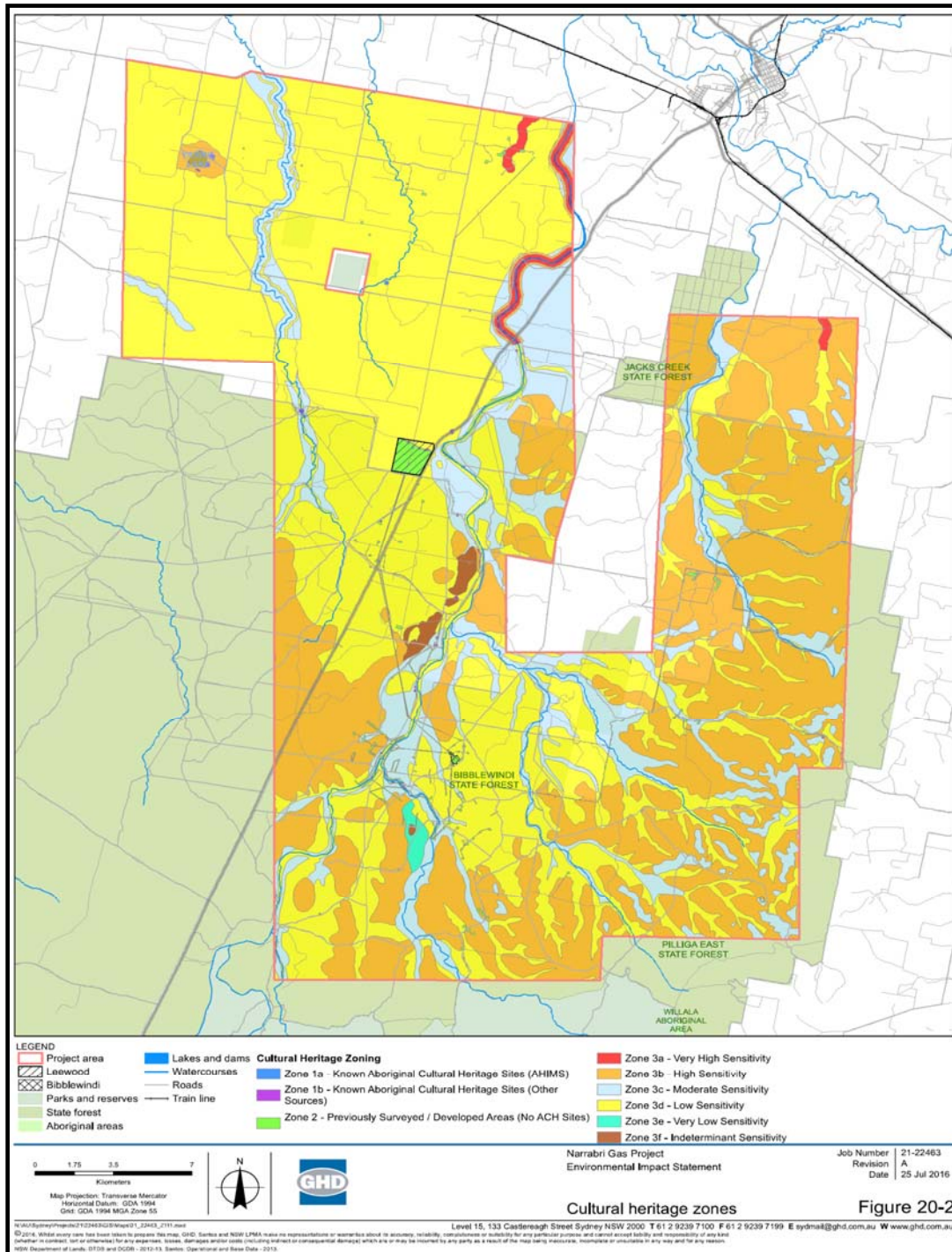


Figure 28 | Aboriginal Cultural Heritage Sensitivity Mapping (nb. known sites not shown)

Table 15 | Management of Aboriginal Sites Identified in Field Survey

Site Type	Management Commitment
Burials	Avoid
Stone arrangements and earthen circles	Avoid
Carved trees	Avoid
Rock shelters	Avoid
Grinding grooves	Avoid
Quarries	Avoid
Earthen mounds	Avoid, if confirmed as cultural feature
Scarred trees	Avoid, if confirmed as cultural feature
Hearths and ovens	Avoid, if confirmed as cultural feature
Places of traditional or anthropological significance	Avoid, if confirmed as cultural feature
Recent historic and contact sites	Avoid, if confirmed as cultural feature
Stone artefact concentrations	Maximise avoidance, where reasonable and reasonable
Shell middens	Maximise avoidance, where reasonable and reasonable
Subsurface cultural material	Maximise avoidance, where reasonable and reasonable
Isolated stone artefacts	Maximise avoidance, where reasonable and reasonable

510. Santos has also committed to implementing buffers to culturally sensitive areas such as watercourses and Yarrie Lake (see Section 2.2).
511. The Department and BCD accept that Santos' commitments to avoiding all known Aboriginal sites and all higher significance sites identified during field surveys, as well as avoiding all other sites as far as practicable, would appropriately mitigate the project's impacts on Aboriginal cultural heritage sites within the project area.
512. BCD and the Department also accept that the project is able to be managed such that it would not significantly impact the wider cultural heritage values of the project area and region, subject to the implementation of a number of mitigation measures. Dr Sneddon did not raise any significant concerns about the cultural heritage impacts of the project, subject to a number of recommendations in relation to ongoing assessment and management.
513. The Department has recommended conditions consistent with BCD and Dr Sneddon's recommendations and Santos' commitments, including conditions requiring Santos to avoid all direct and indirect disturbance of known Aboriginal sites, and higher significance sites identified in micro-siting surveys, and to avoiding other sites where reasonable and feasible.
514. The Department has also recommended conditions requiring Santos to finalise and implement the comprehensive ACHMP, and to establish and maintain an Aboriginal Cultural Heritage Advisory Group for the project.

515. The advisory group would comprise representatives from BCD, the scientific community (suitably qualified archaeologists), the Narrabri LALC, Wee Waa LALC, and Gomeroi native title claimants, and provide advice on project-related cultural heritage management issues. This would include preparation and implementation of the ACHMP and Field Development Plans, including involvement in micro-siting survey investigations.
516. In this regard, the Department accepts that it would be impractical and unnecessary to have all 550-odd RAPs involved in micro-siting investigations for gas field infrastructure, particularly given Santos' commitments to avoidance.
517. However, the Department has recommended conditions requiring the ongoing involvement of all RAPs and other local knowledge holders in project-related activities, including requirements on Santos to consult with RAPs and other applicable Aboriginal stakeholders in relation to:
- establishment of the Aboriginal Cultural Heritage Advisory Group representatives;
 - finalisation of the ACHMP;
 - assessing and managing any Aboriginal sites identified during micro-siting investigations that are not able to be avoided; and
 - conservation and management of cultural heritage in any Santos-managed biodiversity offset areas.
518. The Department has also recommended conditions requiring Santos to make relevant information and documents publicly available, including all management plans (including Field Development Plans) and monitoring results, and minutes from advisory group meetings.

6.6 Greenhouse Gas Emissions and Climate Change

Summary

Strategic energy planning indicates that there is a demonstrable need for the ongoing production and development of natural gas resources such as the Narrabri Gas Project to meet society's basic energy needs, and that project can be seen as being consistent with NSW's and Australia's commitments to a low carbon future.

The project's direct 'Scope 1' greenhouse gas emissions (including fugitive emissions from the gas field) would be small, representing less than 0.2% of total Australian emissions. Total project-related Scope 1 to 3 emissions (including emissions from the downstream burning of the gas resource) would also be low relative to Australian emissions, at approximately 0.9% of the nation's total emissions. This is despite the project potentially supplying up to 50% of NSW gas demand.

Recent research projects undertaken by the CSIRO indicate that fugitive emissions from coal seam gas mining projects in Australia are lower than previously thought, and that on a life cycle basis, domestic coal seam gas produced electricity would produce up to 50% less carbon emissions compared to coal fired electricity production.

In his regard, CSIRO's research indicates that the project has the potential to assist in reducing NSW's greenhouse emissions intensity, and be a key component of NSW's future energy supply mix.

519. The EIS includes a greenhouse gas (GHG) emissions assessment, undertaken by Santos and GHD. The assessment was undertaken in accordance with applicable GHG assessment guidelines, including the National Greenhouse and Energy Reporting (Measurement) Determination 2008 and the National Greenhouse Accounts Factors, 2016.
520. The assessment calculates direct and indirect GHG emissions associated with the project, including 'Scope 1' emissions (i.e. direct GHG emissions from sources controlled by Santos), 'Scope 2' emissions (i.e. indirect emissions associated with the import of electricity) and 'Scope 3' emissions (i.e. other indirect emissions, such as those associated with the downstream combustion of product gas).
521. The assessment considered all direct and indirect GHG emissions from the project, and conservatively assumed that peak gas production (i.e. 200 TJ/day to market) would be maintained for the entire 25 year operational life of the project, which would not occur in practice. The assessment also considered the two power supply options for the project – with Option 1 comprising on-site gas-fired power supply, and Option 2 comprising electricity supply from the grid.
522. A summary of the calculated GHG emissions associated with the project is presented in the following table.

Table 16 | Direct and Indirect GHG Emissions

Scope	GHG Source	Total Project GHG Emissions (Mt CO ₂ -e)		Typical Year Project GHG Emissions (Mt CO ₂ -e)	
		Option 1 – On-site Power	Option 2 – Grid Power	Option 1 – On-site Power	Option 2 – Grid Power
Scope 1	Fuel Use	12.0	2.2	0.47	0.08
	Gas Flaring	2.0	2.0	0.005	0.004
	Gas Venting	0.1	0.1	0.005	0.004
	CO ₂ Venting	12.0	10.9	0.48	0.44
	Fugitive Emissions	0.1	0.05	0.002	0.002
	Vegetation Clearance	0.2	0.2	0	0
	Total Scope 1	26.3	15.5	0.96	0.53
Scope 2	Electricity	0	18	0	0.72
Scope 3	Downstream Gas Use	94.3	94.3	3.77	3.77
Total		120.6	127.8	4.73	5.02

523. As indicated in the table, the main direct GHG emission sources associated with the project are CO₂ venting from the gas processing operations (45% of Scope 1 emissions for Option 1, and 70% for Option 2), and fuel use if Option 1 is chosen (45% of Scope 1 emissions for Option 1). While Option 2 would generate less direct emissions on site, it would generate more indirect (Scope 2) emissions through electricity import and use.
524. Overall, the bulk of emissions associated with the project are indirect emissions associated with the downstream burning of the gas resource (i.e. Scope 3 emissions), which account for some 75% to 80% of the total direct and indirect GHG emissions generated by the project.
525. To put these emissions into context, a comparison between the total direct and indirect project-related emissions and total Australian GHG emissions is presented in **Table 17**.
526. As indicated in the table, the direct (Scope 1) GHG emissions from the project are small in comparison to total Australian emissions, representing up to 0.22% of Australia’s energy sector emissions and up to 0.18% of total Australian emissions.
527. Total project-related GHG emissions (Scopes 1 to 3) emissions are also low relative to Australian emissions, at approximately 0.9% of the nation’s total emissions. This is despite the project potentially supplying up to 50% of NSW’s gas needs. On a global scale, the project related emissions (Scopes 1 to 3) represent some 0.009% of current global GHG emissions (i.e. 53.5 GT CO₂-e).

Table 17 | Project GHG Emissions Compared to Australian GHG Emissions (2018)

	Total Australian GHG Emissions (Mt CO ₂ -e)	Project Scope 1 GHG Emissions (% of Australian total)		Project Total (Scopes 1-3) GHG Emissions (% of Australian total)	
		Option 1 – On-site Power	Option 2 – Grid Power	Option 1 – On-site Power	Option 2 – Grid Power
Australian Energy Sector	441.6	0.22	0.12	1.1	1.1
Total Australian	538.2	0.18	0.1	0.9	0.9

528. A number of submissions raised concerns that the GHG assessment omitted or underestimated some emissions, particularly fugitive emissions of methane and CO₂ from gas extraction and processing operations. Submitters cited studies from the US and elsewhere (including Australia) that indicate that fugitive methane constitutes a significant GHG emission source from coal seam gas mining, potentially negating the relatively lower CO₂ emissions associated with the downstream burning of gas for energy compared to coal or oil.
529. Santos has confirmed that the emissions factors used in the assessment are consistent with the National Greenhouse Accounts Factors and industry standards.
530. Further, CSIRO has been undertaking a range of research programs in recent years to provide detailed estimates of natural and fugitive emissions from coal seam gas mining in Australia. This research indicates that fugitive methane emissions from gas production in Queensland are lower than previously thought, at less than 0.5% of coal seam gas production. This is well below the thresholds cited in previous studies where the benefits of coal seam gas would be negated relative to coal.
531. CSIRO's Queensland study also found that the largest contributor to total methane in the region was cattle grazing (54%), followed by a feedlots (24%), and coal seam gas processing (8%). GHG emission rates from various land uses included:
- coal seam gas well (median) – 1 kg/day;
 - coal seam gas water treatment plant – 18 to 32 kg/day;
 - coal seam gas compression plant – 780 kg/day;
 - urban sewage treatment plant – 45 kg/day;
 - medium sized landfill – 400 kg/day; and
 - cattle feedlot – 2,600 kg/day.
532. CSIRO has also recently undertaken a life cycle analysis of coal seam gas electricity production compared to coal-fired electricity production¹¹. The study indicates that if Queensland Surat

¹¹ Whole of life greenhouse gas emissions assessment of a coal seam gas to liquefied natural gas project in the Surat Basin, Queensland Australia (July 2019).

Basin gas was used to displace domestic coal fired electricity generation, the GHG emission reduction relative to coal-fired electricity generation would be up to 50%.

533. CSIRO's research indicates that coal seam gas has the potential to significantly reduce NSW's and domestic total GHG emissions intensity, if it displaces local coal-fired electricity generation. If the gas were to be exported as liquefied natural gas (LNG), emissions intensity savings would be less, due to the liquefaction, shipping and regasification processes required for export.
534. In this regard, Santos has committed to preserving all gas generated by the project for the domestic (East Coast) market. The Department considers this to be a key commitment, as it would assist significantly in:
- shoring up NSW gas supplies, given that New South Wales currently produces less than 5% of its current gas needs;
 - boosting NSW energy security, through provision of flexible dispatchable energy; and
 - driving down NSW GHG emissions and working towards a low carbon future, by providing a flexible, local, scalable dispatchable energy source that can work with renewables to reduce energy-sector GHG emissions.
535. The Department notes that the regulation of Santos' commitment to domestic supply would occur through the petroleum mining licencing for the project under the *Petroleum (Onshore) Act 1991*.
536. The NSW Government has committed to an aspirational long-term objective of achieving net zero greenhouse gas emissions by 2050. This objective is consistent with the IPCC's projected requirements to maintain average global warming to 1.5°C, as committed to by the Australian government in the Paris Agreement.
537. As outlined in Section 3.1 strategic energy planning by the AEMO indicates that natural gas will continue to be an important component of the dispatchable energy supply mix for the foreseeable future, particularly as it is 'flexible' (i.e. can be turned on and off quickly), and can complement variable renewable sources at times of low wind and solar availability (eg. at night).
538. This strategic energy planning indicates that there is a demonstrable need for the ongoing production and development of natural gas resources such as the Narrabri Gas Project to meet society's basic energy requirements.
539. For the above reasons, and in particular Santos' commitment to preserving gas generation from the project for the domestic market only, the Department considers that there is a demonstrable need for the gas generated by the project, and that the project is consistent with NSW's and Australia's commitments to a low carbon future.
540. The Department has recommended conditions Santos to:
- minimise point source and fugitive GHG emissions to the greatest extent possible;
 - ensure that the project does not result in any material change to background methane and carbon dioxide levels at sensitive receiver locations in the project area;
 - implement a comprehensive leak detection and repair program; and
 - implement all reasonable and feasible measures to improve energy use efficiency and reduce GHG emissions.

6.7 Economic and Social Impacts

Summary

Economic assessment indicates that the Narrabri Gas Project would provide major economic and social benefits for Narrabri, the North West region and to NSW, including:

- a direct capital investment of \$3.6 billion, and a further \$5.5 billion in operating costs over the life of the project;
- generating 1,300 jobs during peak construction, 200 jobs at the project during operations, and over 500 direct and indirect jobs in the surrounding region and NSW;
- increasing NSW real economic output by approximately \$12 billion;
- generating more than \$3 billion in direct revenue for the NSW Government through royalties and taxes; and
- providing significant funding for local infrastructure and community service projects over the life of the project, including via a:
 - Community Benefit Fund with a value of around \$120 million; and
 - Voluntary Planning Agreement and Road Maintenance Agreement with Narrabri Council, with a value of approximately \$14.5 million.

Detailed cost benefit analysis, including consideration all environmental impacts and downstream externalities, indicates that the project's economic benefits would significantly outweigh its costs, with a net economic benefit of between \$1.5 and \$1.6 billion.

Social assessment indicates that the project would result in a range of positive and negative social risks and/or impacts, but that the negative risks are able to appropriately managed.

Economics

541. The EIS includes economic assessments, including a Cost Benefit Analysis undertaken by GHD and a Macroeconomic Assessment undertaken by Acil Allen Consulting.
542. The Department engaged an independent economist, Dr Brian Fisher of BAEconomics, to undertake a review of the economic assessments and economic impact associated with the project. Dr Fisher's review is attached in **Appendix H**.
543. Following the provision of some additional information provided by Santos in its responses to submissions, Dr Fisher confirmed that the assessments had been undertaken in accordance with applicable economic guidelines and give reasonable estimates of the likely impacts of the project.

Regional Economic and Socio-Economic Impacts

544. The macroeconomic assessment, using a computable general equilibrium model, indicates that the project would provide very significant direct and indirect socio-economic benefits for the locality, region and State, including:
 - For the local Narrabri LGA economy:
 - up to 1,300 jobs at the project during construction, and 200 direct jobs at the project during operations;
 - 127 average full-time equivalent jobs in the LGA;

- \$3.6 billion (\$2 billion net present value¹²) direct capital investment value for construction, and \$5.5 billion (\$1.6 net present value) operating costs over the life of the project;
- \$11 billion (\$4.5 billion net present value) in real economic output; and
- \$526 million (\$250 million net present value) in real income.
- For the wider regional economy¹³:
 - 162 average full-time equivalent jobs in the wider region;
 - \$572 million (\$348 million net present value) in real economic output; and
 - \$690 million (\$396 million net present value) in real income.
- For the State economy:
 - 224 average full-time equivalent jobs in the rest of NSW;
 - \$384 million (\$295 million net present value) in real economic output;
 - \$4.8 billion (\$2.1 billion net present value) in real income; and
 - \$3.1 billion (\$1.2 billion net present value) in royalties and tax revenue to the NSW Government.
- Total economic output:
 - 224 average full-time equivalent jobs in the rest of NSW;
 - \$11.9 billion (\$5.1 billion net present value) in real economic output; and
 - \$6 billion (\$2.8 billion net present value) in real income.

545. To put these numbers into perspective, the total real economic output of the project represents approximately 1 percent of NSW's gross State product.

546. Dr Fisher has reviewed the general equilibrium analysis, and considers that the analysis has been carefully done and provides plausible estimates of the likely impacts of the project.

Cost Benefit Analysis

547. The macroeconomic assessment outlined above provides an estimate of the overall economic stimulus of the project. However it does not include, and is not intended to provide, consideration of externalities (i.e. consequential benefits and costs) associated with the project (for example, loss of agricultural production or downstream greenhouse gas impacts).

548. To assess the net economic benefits of the project, the economic assessment includes a Cost Benefit Analysis, which seeks to identify and weigh up all of the project's benefits and costs based on its full range of environmental, social and economic impacts and benefits.

549. A summary of the cost benefit analysis is provided in the following table.

¹² Net present values assume an annual discount rate of 7%

¹³ Including Gunnedah, Tamworth Regional, Armidale Dumaresq, Coonamble, Inverell, Moree Plains, Dubbo, Gilgandra, Glen Innes Severn, Gwydir, Liverpool Plains, Uralla, Walgett and Warrumbungle LGAs. A supplementary economic assessment provided at the request of Dr Fisher provided an additional consideration of regional impacts based on the Moree-Narrabri Statistical Area Level 3.

Table 18 | Project Costs and Benefits

Items	Value (net present value)	
	On-site gas-fired electricity generation option	Connection to grid electricity option
Costs <ul style="list-style-type: none"> • Capital project construction • Operating costs • Decommissioning and rehabilitation • Loss of agricultural production • Loss of forestry production • Public infrastructure maintenance and renewal • Biodiversity offsetting • Noise and vibration impacts • Greenhouse gas impacts 	\$3.9 billion	\$3.8 billion
Benefits <ul style="list-style-type: none"> • Gas sales revenue • Agricultural production from treated water • Compensation to landowners 	\$5.4 billion	\$5.4 billion
Net value	\$1.5 billion	\$1.6 billion
Benefit-cost ratio	1.39	1.43

550. As outlined in the table, the analysis indicates that the project would have a net economic benefit of between \$1.5 and \$1.6 billion, or a benefit to cost ratio of between 1.39 and 1.43, depending on the electricity option.
551. The assessment included a number of sensitivity analyses based on varying discount rates, gas production, gas prices and capital costs. The sensitivity analysis showed positive outcomes under all modelled analyses with the exception of a 30% gas price reduction, in which the project would be marginally negative (0.98), with a net loss of \$85 million.
552. Dr Fisher noted that the cost benefit analysis did not include estimates of the net benefits to NSW, and Santos subsequently provided additional calculations of the project's benefits to the State and to Australia. The additional analysis indicates that the project would have a net positive benefit for both NSW (1.11 to 1.12 benefit-cost ratio) and Australia (1.34 to 1.38 benefit-cost ratio), with sensitivity analyses deriving similar results as the overall assessment.
553. Based on the additional assessment, Dr Fisher concluded that it is highly likely that the net benefits to the NSW community flowing from the development would be positive.
554. Dr Fisher noted that key concerns raised in submissions – including long term demand for LNG and the economic viability of the project in light of impairment charges adopted by Santos – do not affect the outcomes of the assessment, and/or do not appear to be consistent with recent ACCC forecasts for gas network prices in the East Coast gas market.
555. The Department acknowledges that there are different views on the value that should be placed on various costs and benefits, particularly the externalities (impacts on third parties not directly related to the project) when conducting an economic assessment. This was raised in many of the submissions from individuals and special interest groups and organisations. However, based

on the cost benefit analysis undertaken for the project (and similar cost benefit analyses undertaken for other resource projects in the region and elsewhere in NSW), the Department accepts the findings of Santos's economic assessment and the independent expert advice from Dr Fisher that the project's benefits to society (especially to the State and region) would significantly outweigh its costs, including externalities.

Social Impacts

556. The project would generate a range of major positive social impacts in the local community through job creation and economic opportunities, and facilitate flow-on local economic development including the proposed industrial hub in Narrabri adjoining the proposed Inland Rail Project.
557. It would also have major positive social impacts for the wider region and State, through bolstering domestic and industrial gas supplies, and generating significant tax and royalty revenues.
558. Nevertheless, the project also has the potential to have negative social impacts in the local community and the wider area, by putting pressure on local services and facilities and affecting social dynamics and other land users.
559. The EIS includes a detailed social assessment, undertaken by GHD, that considers the social impacts of the project on infrastructure and community health and wellbeing.
560. The Department engaged Professor Deanna Kemp, Director of the University of Queensland's Centre for Social Responsibility in Mining Sustainable Minerals Institute, to provide advice on the social assessment and impacts of the project.
561. Professor Kemp identified some issues with aspects of Santos' social assessment, including assumptions used in the assessment, the assessment of distribution of benefits and potential social conflict and division, and the response to community concerns. Public submissions also raised a number of issues, including concerns about impacts on vulnerable groups, community fears and health, impacts associated with a fly-in-fly-out (FIFO) workforce, and impacts following closure of the project.
562. Nevertheless, Prof Kemp considers that, overall, the negative social impacts of the project can be appropriately managed, and that many of the residual issues can be dealt with through a Social Impact Management Plan (SIMP) and appropriate conditions of consent.
563. A summary of the social assessment and the Department's consideration of the social impacts is provided below.

Accommodation

564. Around 1,300 workers would be employed during the peak construction period of 3 to 4 years. This would reduce to around 345 workers during operations, of which around 95 are likely to already live in the region (within an hour of the project) and 50 would be working in Santos' offices in other cities.
565. Most of the project workforce would be accommodated in workers accommodation facilities in Narrabri and at the Westport workers accommodation facility. There are already around 1,000 beds available (1,500 approved) in existing workers camps around Narrabri, and Santos is proposing to increase the capacity of Westport workers accommodation facility from 64 to 200 beds.
566. Santos estimates that short-term accommodation in Narrabri would also be used by about 130 FIFO workers during the peak construction period and 10 FIFO workers during operations.

567. In this regard, Narrabri has around 11 motels and four hotels as well as a range of other holiday accommodation (e.g. bed and breakfast, farm stays, serviced apartments, camp grounds etc.) with over 300 beds available.
568. Consequently, the Department is satisfied that there is adequate existing and planned supply available in the locality to accommodate the peak construction phase without causing significant adverse impacts on tourism and trade.
569. With regard to the operational phase, around 50 workers and their families (assumed to be approximately 130 people) are expected to relocate more permanently to Narrabri for the project. Based on an assessment of properties advertised for rent and sale, the social assessment concluded there would be sufficient housing capacity to absorb the new permanent residents during operations.
570. Professor Kemp did note that the project has the potential for additional demand related to third party contractors and other flow-on services such as teachers moving to the town because of the increase in workers with school-age children.
571. However, there are three future housing developments identified for the town, which are able to accommodate additional demand generated by the project.
572. The Department is satisfied that there is sufficient existing and planned housing availability in the locality to accommodate the project.

Services and Infrastructure

573. The assessment includes consideration of the project's demands on local services and community infrastructure, including health services, emergency services and other essential services, recreational and leisure facilities, roads etc.
574. The assessment indicates that the project is unlikely to place significant undue demands on these services. Santos anticipates that the FIFO workforce would generally use health services at their place of permanent residence and would not significantly increase the demand for health services near the project.
575. Notwithstanding this, there would be some additional demand for services. However, the socio-economic benefits generated by the project, including the monetary contributions to Council through the VPA (see Section 2.5) would assist in mitigating the additional demand for services.
576. Further, as outlined in Section 2.7, Santos has committed to contributing to a Community Benefit Fund (CBF) for the project, which will be established under the *Petroleum (Onshore) Act 1991*.
577. Under the CBF, Santos would contribute 10% of the royalties from the project into the fund for disbursement to community projects in the region. The value of payments into this fund is estimated to be around \$120 million over the life of the project.
578. These funds could make a major contribution to the economic and social development of the region over the next 20-30 years.

Recreational Values

579. Yarrie Lake is a visitor attraction within the project area that is highly valued by the community. Santos has committed to not placing surface infrastructure within 200 m of the lake and its reserve area to minimise any impacts on visitors to the lake. The environmental assessment indicates that the project is unlikely to have any significant adverse impacts on the recreational values of the lake or other recreation areas in the project area and locality.

Distributive Equity

580. The project would have significant benefits for the local community by stimulating the local economy and directly and indirectly creating work and training opportunities, as well as through the direct distribution of funds into community projects from the CBF and VPA.
581. However, the benefits and impacts would not necessarily be distributed equitably, and some groups within the community may be disproportionately impacted.
582. In particular, landholders hosting infrastructure are likely to be specifically affected, as the infrastructure would potentially impact landholder's use, access and management of the land, and the productivity and economic viability of the land. Other potential impacts to landholders include loss of privacy due to the presence of the project workforce, uncertainty related to the timing of project activities, and amenity impacts. The sum of these impacts has the potential to disrupt the values that contribute to the lifestyle of landholders.
583. To address these issues, Santos has committed to only locating gas field infrastructure on properties with the written agreement of the landholder. This agreement would include compensation provisions, establish mutually acceptable conditions for siting of infrastructure, and document the nature and indicative timing of activities (by both the landholder and Santos) to ensure project and farming activities can co-exist effectively. It also means that amenity impacts can be largely avoided or offset through the compensation plan.
584. Neighbouring landholders that don't host infrastructure may also be subject to loss of amenity but would not necessarily benefit from any of the compensation arrangements discussed above. However, as outlined in Section 2.2, Santos has committed to meeting applicable noise and air quality criteria at all privately-owned residences, and the Department has recommended conditions formalising these commitments. The Department has also recommended conditions requiring Santos to comply with a number of other locational criteria, including:
- no project-related infrastructure within 200 m of any residence, unless otherwise agreed;
 - no well pads within 100 m of privately-owned land, unless otherwise agreed;
 - production wells to be spaced at least 750 m apart; and
 - no telecommunications towers within 500 m of any residence, unless otherwise agreed.
585. The Northwest Alliance submission and Professor Kemp noted that other vulnerable and disadvantaged groups may also be disproportionately impacted by the project. While Santos has not specifically identified all vulnerable groups in the social assessment, it proposes to offset the impacts through contributions into the CBF and sponsorships and donations. Santos is also proposing to implement a Diversity and Equal Opportunity Policy to increase participation of Indigenous people in the project.

Community Characteristics

586. Submissions raised concerns about the project increasing competition for local labour, causing wage inflation and putting pressure on other industries. Submissions also raised concerns about the FIFO workforce during peak construction resulting in antisocial behaviour and gender imbalance.
587. With regard to labour competition, the assessment indicates that these effects would be confined mainly within the mining sector, because workers in the mining industry possess skills that match the needs of the project.

588. The impacts would also be generally limited to the peak construction phase. During operations, the impacts on labour supply are predicted to be relatively minor given the large labour pool and high unemployment in the region.
589. To minimise other potential impacts associated with antisocial behaviour and gender imbalance, Santos has committed to implementing a workforce management plan and code of conduct to manage workforce and community related impacts. These measures are consistent with contemporary mining projects, and the Department is satisfied that any adverse impacts can be appropriately managed through the SIMP.

Social Cohesion and Community Wellbeing

590. A survey of community wellbeing and attitudes to coal seam gas was conducted by GISERA in 2018. This found that attitudes towards coal seam gas development varied widely, with 30% of residents indicating they would reject coal seam gas development, 27% indicating they would tolerate it, 15% indicating they would be ok with it, 13% approving of it, and 15% embracing it. It also found that people who lived in Narrabri and surrounds held more favourable views than those who lived in other subregions of the Shire.
591. These opposing and often strongly held views of the project have caused, and are likely to continue to cause, social divisions in the community.
592. Whilst the assessment of the project indicates that it is unlikely to result in any significant health and amenity impacts, the Department acknowledges that 'intangible' fears may persist, which may lead to increased stress and anxiety in the community, and affect certain people's mental health and sense of place.
593. To help address these issues, Professor Kemp observes that leading practice involves transparent information sharing and stakeholder involvement.
594. The Department agrees, and has recommended conditions requiring Santos to continue to consult with the community through a Community Consultative Committee (CCC) to ensure that the views and concerns of the community through its representatives are considered during the life of the project.
595. The Department has also recommended that Santos be required to prepare and implement a comprehensive and adaptive Social Impact Management Plan for the project, in consultation with Council, the CCC and the local community. The plan would (amongst other things):
- identify negative social impacts resulting from the project during construction, operations and following closure in both a local and regional context;
 - include an adaptive management and mitigation program to minimise and/or mitigate negative social impacts during the life of and following the cessation of the project; and
 - include a program to monitor, review and report on the effectiveness of these measures.

Conclusion

596. The Department's assessment of the Narrabri Gas Project indicates that it would generally meet all relevant health and amenity criteria, and result in major socio-economic benefits for the locality, region, and the State.
597. Nevertheless, as with other contemporary mining projects, the project does have the potential to result in some negative social impacts, particularly at the local level. The Department is satisfied that these residual impacts can be appropriately minimised and managed.

598. The Department has recommended a number of conditions to ensure this occurs, including requiring Santos to:
- establish and maintain a Community Consultative Committee (CCC) to ensure that the views and concerns of the community through its representatives are considered during the life of the project;
 - enter into a VPA with Narrabri Council to provide contributions to community services and facilities;
 - prepare a detailed Social Impact Management Plan in consultation with Council, the CCC, affected communities and other relevant stakeholders;
 - prepare Field Development Plans in consultation with the CCC and applicable landholders;
 - prepare Property Management Plans as part of the Field Development Plans to manage impacts on privately-owned land upon which infrastructure is proposed to be located, in consultation with landholders;
 - prepare Public Safety Management Plans as part of the Field Development Plans to ensure public safety and manage access in the project area;
 - prepare noise and air quality management plans in consultation with the CCC;
 - establish a Water Technical Advisory Group and Aboriginal Cultural Heritage Advisory Group, with representatives from local water users and local Aboriginal groups, respectively;
 - independently review potential exceedances of applicable environmental criteria, at the request of applicable landowners;
 - maintain complaints and incident management and reporting systems; and
 - make a range of project-related information publicly available, including:
 - the EIS and related information;
 - management plans;
 - monitoring results;
 - minutes of CCC and advisory group meetings;
 - annual reviews and audit reports; and
 - complaints and incidents.
599. The Department also acknowledges that Santos has committed to a range of other measures that would offset the social impacts of the project. These include:
- a diversity and equal opportunity policy that includes capacity building strategies for Indigenous people to encourage Indigenous participation in the project;
 - sponsorships and donations; and
 - contributions to the CBF (to be administered via the production lease under the *Petroleum (Onshore) Act 1991*).

6.8 Other issues

600. The Department has also considered a range of other issues in its assessment. These issues are summarised in **Table 20** below.

Table 19 | Other Issues

Issue	Findings	Recommended Conditions
<p>Noise and Vibration</p>	<p>Noise assessment indicates that the noise emissions during the operation of the project – including the project, existing pilot wells and the Wilga Park Power Station – would comply with the applicable noise criterion (i.e. 35 dBA) at all sensitive receivers and at all time periods, during routine operations.</p> <p>Santos has committed to locating all wells to comply with the 35 dBA criterion, unless otherwise agreed by the landowner.</p> <p>Some exceedances are predicted during non-routine operations at Leewood and Bibblewindi, when the safety flare is operating at maximum flow. These exceedances would range from 1dB to 20dB at the closest receivers, with up to 15 receivers affected at Leewood, and 2 receivers affected at Bibblewindi.</p> <p>These non-routine operations would occur infrequently, during emergencies and scheduled maintenance activities only. Scheduled maintenance requiring total plant outage would occur once every two years, during which time the safety flare may be required to operate at or near capacity for approximately 3 days.</p> <p>To manage these exceedances, Santos would:</p> <ul style="list-style-type: none"> • schedule maintenance activities during standard construction hours as far as practicable; • keep affected receivers informed of the potential noise levels; and • seek to use the Bibblewindi safety flare during scheduled maintenance where practicable to reduce use of the Leewood safety flare. <p>Given the infrequency and short-term nature of maintenance activities, the EPA and Department accept that the predicted exceedances are unlikely to significantly impact the amenity of surrounding receivers. However, the Department has recommended a number of conditions to mitigate noise impacts on these receivers.</p> <p>Some noise exceedances are also predicted during construction works, however these would be of short duration only. Santos has committed to meeting the applicable construction criteria at all receivers for works undertaken outside standard construction hours.</p>	<p>The recommended conditions require Santos to:</p> <ul style="list-style-type: none"> • comply with applicable noise and vibration criteria at all receivers during routine operations; • implement all reasonable and feasible measures to comply with applicable noise criteria during non-routine safety flaring operations; • schedule safety flaring activities to the least sensitive times of the day (i.e. daytime), where practicable; • keep the public informed of the scheduled safety flaring activities; • implement additional noise mitigation measures at the receivers most affected by non-routine safety flaring activities (i.e. those predicted to experience exceedances of 10 dBA or more), at the landowner's request. These measures could include provision of short-term alternative accommodation during non-routine safety flaring operations, and/or acoustic treatments to residences (eg. double glazing, insulation); • comply with operational noise criteria for construction works outside standard construction hours, unless otherwise agreed with the affected receiver; • implement all reasonable and feasible measures to comply with applicable construction criteria (i.e. 40 dBA) during standard construction hours; and • prepare and implement a detailed Noise Management Plan for the project, including a noise monitoring program.

Issue	Findings	Recommended Conditions
Air Quality	<p>Detailed air quality modelling indicates that all pollutant emissions associated with the project would comply with applicable incremental and cumulative criteria at all sensitive receivers for all scenarios, including routine operations and non-routine operations (i.e. during operation of safety flares at maximum output).</p> <p>Air quality is also predicted to comply at the boundary of the Leewood and Bibblewindi facilities, as well as at the boundary of the well pads.</p> <p>Detailed analysis of fugitive emissions of methane, carbon dioxide and other trace elements indicates that such emissions would comfortably comply with applicable impact assessment criteria, and are unlikely to result in any significant environmental impacts or contribution to greenhouse gas emissions.</p> <p>The Department and the EPA are satisfied that the air quality risks associated with the project are low, and can be effectively managed subject to conditions.</p>	<p>The recommended conditions require Santos to:</p> <ul style="list-style-type: none"> • comply with the applicable air quality criteria at all receivers; • undertake additional air quality assessment and modelling demonstrating this compliance prior to the commencement of the project; • minimise point source and fugitive emissions of methane, carbon dioxide and other pollutants, and ensure negligible contribution to baseline pollutant levels in the area and in groundwater users bores; • implement a detailed leak detection and repair system; and • prepare and implement a detailed Air Quality Management Plan and undertake periodic independent audits.
Visual and Landscape	<p>Visual assessment indicates that the major facilities, including Leewood and Bibblewindi, are unlikely to result in any significant visual impacts given the location of the facilities, the sparsely populated nature of the area, and intervening vegetation.</p> <p>Some minor glimpses of Leewood infrastructure may be available through intervening vegetation from the Newell Highway and one receiver to the east, although impacts are expected to be negligible.</p> <p>The gas field is also not expected to result in any significant visual or landscape impacts, given the low density of wells across the landscape (i.e. average of one well pad per 224 ha), the relatively small size and height of the well pad infrastructure (i.e. generally 2,500m² in area and up to 2 to 3 m high), and the relatively flat landscape of the site and lack of significant regional views.</p> <p>Some gas field infrastructure, such as telecommunications towers, would be more visible, although these would be sparsely located, and would present as similar to other electrical and telecommunications infrastructure in the region.</p> <p>Siding Springs Observatory initially raised concerns about potential lighting impacts (particularly from safety flaring) on the Observatory, which is located approximately 90 km and 100 km from Bibblewindi and Leewood, respectively.</p>	<p>The recommended conditions require Santos to:</p> <ul style="list-style-type: none"> • locate project-related infrastructure to minimise impacts on sensitive receivers, including: <ul style="list-style-type: none"> – no infrastructure within 200 m of any residence, unless otherwise agreed with the landowner; – no well pads within 100 m of any privately-owned land, unless otherwise agreed with the landowner; – production well pads to be spaced at least 750 m apart; – no telecommunications towers within 500 m of any residence, unless otherwise agreed with the landowner; and – no applicable infrastructure in proximity to conservation areas and riparian areas; – undertake additional landscape screening along the Newell Highway frontage to screen views to the Leewood Facility; and – minimise visual and lighting impacts on surrounding receivers and the Siding Spring Observatory,

Issue	Findings	Recommended Conditions
	<p>However, following additional lighting assessment, which demonstrated that the flaring operations would comfortably meet the applicable sky glow guidelines, the Observatory subsequently confirmed that its concerns had been addressed. The Observatory nonetheless requested that Santos considers performing maintenance-related flaring when the moon is more than 50% illuminated (i.e. a gibbous moon), which Santos has agreed to.</p>	<p>including undertaking scheduled flaring activities during a gibbous moon.</p>
<p>Hazards and Risk</p>	<p>Santos has undertaken detailed hazards assessments, including a Preliminary Hazard Analysis (PHA), and a Quantitative Risk Assessment (QRA) for the Leewood Central Gas Processing Facility (CGPF) and medium pressure gas trunkline between Leewood and Bibblewindi.</p> <p>The assessments have been reviewed by the Department's Hazards Unit, as well as independent hazards and risk expert, Phillip Skinner of Arriscar.</p> <p>The assessments identified the key hazards associated with the project as:</p> <ul style="list-style-type: none"> • sudden loss of containment of significant quantities of water from catastrophic failure of a pond wall; • uncontrolled loss of liquid chemicals or dangerous goods; • uncontrolled loss of containment of gas leading to a fire or explosion; and • large-scale bushfire, caused by project activities or other activities. <p>Residual risks associated with the first two of these hazards were found to be low, and can be appropriately managed through design, construction and maintenance of facilities in accordance with applicable standards and guidelines.</p> <p>With regard to fire and explosion risk, modelling in the QRA found that the project would comply with relevant fatality and injury risk criteria at all surrounding receivers, subject to the Leewood CGPF being relocated 75 m to the west of the location as originally proposed in the EIS (but still within the Leewood boundary).</p> <p>Despite this relocation, the injury risk criterion would still be exceeded over a small area to the east of the Leewood site. However, Mr Skinner acknowledged that this exceedance should be able to be designed out through the implementation of technically feasible risk reduction measures during the final design of the plant. He recommended that this be required to be demonstrated in the Final Hazard Analysis (FHA) for the project.</p>	<p>The recommended conditions require Santos to:</p> <ul style="list-style-type: none"> • prepare and implement a: <ul style="list-style-type: none"> - Hazard and Operability (HAZOP) Study; - Final Hazard Analysis (FHA); - Fire Safety Study; - Construction Safety Study; - Pipeline Safety Management Study; - Emergency Plan; - Safety Management System; and - Fire Management Plan; and - undertake periodic Independent Hazards Audits, as part of wider Independent Environmental Audits.

Issue	Findings	Recommended Conditions
	<p>Mr Skinner and the Department's Hazard Unit are satisfied that hazards can be appropriately managed, and have recommended a number of conditions to manage these risks, including requiring Santos to prepare and implement a number of hazard-related analyses, plans and studies, and undertake periodic independent hazards audits. The Department has recommended conditions consistent with Mr Skinner's and the Hazard Unit's recommendations.</p>	
<p>Fire</p>	<p>With regard to bushfire risk, the assessment indicates that, subject to the implementation of Asset Protection Zones (APZs) and other proposed measures, these risks are able to be effectively managed.</p> <p>Gas flaring activities in the forested areas were identified as one of the key bushfire-related risks. Modelling indicates that the maximum radiant heat at the nearest vegetation in a catastrophic fire event would be 6.3 kW/m², which is comfortably below the RFS recommended standard of 10 kW/m².</p> <p>Mr Skinner and the Department's Hazard Unit are satisfied that hazards can be appropriately managed, and have recommended a number of conditions to manage these risks, including requiring Santos to comply with the asset protection requirements in the RFS' <i>Planning for Bushfire Protection</i> guidelines, and maintain suitable equipment to respond to any fires in the project area.</p> <p>The Department has recommended conditions consistent with Mr Skinner's and the Hazard Unit's recommendations.</p>	<p>The recommended conditions require Santos to:</p> <ul style="list-style-type: none"> • prepare and implement a detailed Fire Management Plan; • undertake periodic Independent Hazards Audits, as part of wider Independent Environmental Audits; • comply with the asset protection requirements in the RFS' <i>Planning for Bushfire Protection</i> guidelines; and • maintain suitable equipment to respond to any fires in the project area.

Issue	Findings	Recommended Conditions
Historic Heritage	<p>Heritage assessment for the project identified a total of 53 sites of some heritage potential. Collectively, these sites were assessed as being of local heritage significance as part of the Pilliga East Logging Cultural Landscape, which demonstrates the history of logging in the Pilliga forest area.</p> <p>Of these sites, 21 sites were assessed as having local heritage significance in their own right. These sites include a sawmill, logging camps and other logging infrastructure, habitation structures, an oil well and two Giant Air-shower Recorder Pits¹⁴.</p> <p>Santos has committed to avoiding disturbance of all of these 21 heritage items, through the development and implementation of the Field Development Plans.</p> <p>With these avoidance measures, the Department and the Heritage Division accept that the project is unlikely to result in any significant impact to historic heritage values of the region, including the Pilliga East Logging Cultural Landscape.</p> <p>The Heritage Division recommended that an additional site, Johnston’s Albion Sawmill, be mapped and undergo photographic archival recording, notwithstanding its disturbed nature. Santos subsequently noted that this site does not contain any cultural heritage material, and is heavily disturbed. The Department accepts that archival recording of this site is not warranted if it is not proposed to be impacted.</p>	<p>The recommended conditions require Santos to:</p> <ul style="list-style-type: none"> • avoid the identified heritage items; • appropriately manage any additional heritage items discovered during the project; and • prepare and implement a Historic Heritage Management Plan.

¹⁴ Ground pits used by Sydney University in the late 1960s and 70s to record giant cosmic ray air-showers. The sites are assessed as having State social significance.

Issue	Findings	Recommended Conditions
Traffic and Transport	<p>Santos proposes to upgrade two intersections to provide safe and efficient access to Leewood, Bibblewindi and other project components. These upgrades include the:</p> <ul style="list-style-type: none"> • Newell Highway / X-Line Road intersection; and • Newell Highway / Old Mill Road intersection. <p>With these upgrades, traffic assessment indicates that the peak traffic associated with the project (which would occur during the main 3-year construction phase) would remain well below the capacity of local roads and intersections, and is unlikely to result in any significant traffic safety impacts.</p> <p>During the operational phase of the project, traffic volumes would be much less than during the construction phase, and are not expected to result in any significant traffic impacts.</p> <p>The RMS and Narrabri Council did not raise any significant concerns about traffic-related impacts of the project, subject to Santos undertaking the required upgrades and entering into a road maintenance agreement to meet the expected increase cost of rural road maintenance resulting from the project.</p> <p>Santos and Council have since agreed to the terms of a VPA for the project, which includes contributions towards road maintenance.</p> <p>Santos has also agreed to the terms of an occupancy agreement with FCNSW, which would address ongoing impacts on forestry roads.</p>	<p>The recommended conditions require Santos to:</p> <ul style="list-style-type: none"> • undertake the required road upgrades to the satisfaction of RMS; and • enter into road maintenance agreements with RMS and Council, prior to the commencement of construction.

7 Evaluation

601. The Department has assessed the development application, EIS, submissions, Santos' responses to submissions, the independent expert reports, and a range of additional information provided by Santos and relevant government agencies. The Department has also considered the objectives and relevant considerations under Section 4.15 of the EP&A Act.
602. Based on this assessment, the Department considers that Santos has designed the project in a manner that achieves a reasonable balance between maximising the recovery of a recognised gas resource of State significance and minimising the potential impacts on surrounding land users and the environment as far as is practicable, particularly through:
- only developing gas-related infrastructure on privately-owned land with landowner agreement;
 - not undertaking any fracking for the project;
 - developing all gas wells in accordance with the best practice Well Integrity Code;
 - restricting groundwater extraction to the 'base case' volumes modelled for the project, with no extraction from the highly valued shallow aquifers used in the region;
 - providing setbacks to key water resources and conservation areas;
 - minimising disturbance to native vegetation as far as practicable; and
 - avoiding impacts to all known Aboriginal and non-Aboriginal heritage items, and any additional items of significance discovered during the project.
603. The Department has recommended a comprehensive and precautionary suite of conditions to ensure that the project complies with relevant criteria and standards, that the impacts are consistent with those predicted in the EIS, and that residual impacts are effectively minimised, managed and/or at least compensated for.
604. The recommended conditions have been reviewed and accepted by the key NSW Government authorities, and the Department believes that the conditions reflect current best practice for the regulation of coal seam gas projects.
605. The Department recognises that the project would provide major economic and social benefits for Narrabri, the North West region and to NSW, including:
- a direct capital investment in the project of \$3.6 billion, and ongoing operational investment of \$5.5 billion over the life of the project;
 - generation of 1,300 jobs during peak construction, 200 jobs at the project during operations, and over 500 direct and indirect jobs in the surrounding region and NSW;
 - increasing NSW real economic output by approximately \$12 billion;
 - funding for local infrastructure and community service projects; and
 - direct revenue for the NSW State Government, including more than \$3 billion in royalties and taxes.
606. Importantly, the project would produce enough natural gas to supply up to half of New South Wales' gas demand, which would bolster NSW's energy security, and put downward pressure on gas prices.
607. The project is also consistent with long term strategic energy planning and has the potential to assist in driving down NSW greenhouse gas emissions and working towards a low carbon future,

by providing a flexible, local, scalable dispatchable energy source that can work with renewables to reduce energy-sector GHG emissions.

- 608. The Department has carefully weighed the impacts of the project against the significance of the resource and the socio-economic impacts benefits. On balance, the Department believes that the project's benefits outweigh its residual costs, and that is in the public interest and is approvable, subject to stringent conditions.
- 609. This assessment report is hereby presented to the Independent Planning Commission to determine the application.



11/06/2020

Stephen O'Donoghue
Director
Resource Assessments



11/06/2020

Mike Young
Executive Director
Energy, Resources and Compliance



11/06/2020







David Kitto
Executive Director
Special Projects

Appendices

Appendix A: Environmental Impact Statement

See the Department's website at: <https://www.planningportal.nsw.gov.au/major-projects/project/10716>

Appendix B: Statutory Checklist

Administrative & Procedural Requirements		
1.	<p>DA made in accordance with relevant requirements</p> <ul style="list-style-type: none"> • Completed DA form • Provided information required under Part 1 Schedule 1 of the EP&A Regulation • Land owner's consent is not required as the project is classified as public notification development under Clause 49(2) of the EP&A Regulation, and the applicant gave notice of the application in accordance with the requirements in Clause 49(2)(a) & (b) • Fee paid in accordance with the requirements in Part 15 of the EP&A Regulation • EIS prepared in accordance with the: <ul style="list-style-type: none"> - Secretary's environmental assessment requirements - Form and content requirements in Schedule 2 of the EP&A Regulation • Site Verification Certificate submitted with the DA in accordance with the requirements in Clause 50A of the EP&A Regulation 	
2.	DA exhibited for at least 28 days in accordance with the community participation requirements in Part 1 Schedule 1 of the EP&A Act	
3.	<p>Exhibition of the DA & EIS publicly notified in accordance with relevant requirements</p> <ul style="list-style-type: none"> • Clause 50(5) of the EP&A Regulation • Clause 77 of the EP&A Regulation • Clause 16(2) of the Mining SEPP • The consultation requirements in the Infrastructure SEPP 	
4.	Submissions provided to applicant with request for a response to the issues raised in submissions in accordance with Clause 82 of the EP&A Regulation	
5.	Response to submissions provided	
6.	All relevant information made publicly available on the Department's website in accordance with Clause 82(3) of the EP&A Regulation	

Appendix C: IESC Advice

See the Department's website at: <https://www.planningportal.nsw.gov.au/major-projects/project/10716>

Appendix D: Public Submissions

The Department received around 23,000 submissions from individuals and 133 submissions from special interest groups (including private businesses). These are listed in the table below, and the submissions may be viewed on the Department's website at <https://www.planningportal.nsw.gov.au/major-projects/project/10716> under 'Submissions'.

Submissions from some special interest groups included independent expert advice on aspects of the EIS. Some experts also provided follow up advice on the Response to Submissions on behalf of the special interest groups. That advice is available on the Department's website at <https://www.planningportal.nsw.gov.au/major-projects/project/10716> under 'Response to Submissions'.

Submissions on EIS	
Public Submissions (See the Department's website under Submissions)	<ul style="list-style-type: none"> • Form Letters • Individual Submissions
Special Interest Groups (See the Department's website under Submissions)	<ul style="list-style-type: none"> • North West Alliance, including expert reviews • Artesian Bore Water Users Association Inc, including expert reviews • Upper Mooki Landcare Inc, including expert review • Pets and Wildlife of Pottsville Beach • Northern Inland Council for the Environment • Mulgoa Valley Landcare Group • Artesian Bore Water Users Association of NSW Inc • Koala Action Inc. • Running Stream Water Users Association • Great Artesian Basin Protection Group • Coal & coal seam gas free Mirboo North • Friends of the Earth Sydney • NSW Bush Carers • Dharriwaa Elders Group • Birding NSW • Maules Creek Community Council • ECCO • Bayside Climate Change Action Group • Ryde Gladesville Climate Change Action Group • National Parks Association NSW Southern Sydney Branch • National Toxics Network • Gomeri Traditional Custodians • Stop Coal Seam Gas Blue Mountains • coal seam gas Free Shoalhaven • Lismore Community Sustainability Forum • Australian Plants Society Northern Beaches • Australian Beef Group • North Coast Environment Council • Hastings Birdwatchers • GasFieldFreeDubboRegion

Objecting

Submissions on EIS

- CountryMinded
- S.A.F.O.K. INC Securing Australia's Future for Our Kids
- BirdLife Northern NSW
- Friends of the Pilliga
- New England Greens
- Hornsby Ku-ring-gai Greens
- Groundswell Gloucester Inc.
- Stop coal seam gas Sydney Inc.
- Ryde Hunters Hill Flora and Fauna Preservation Society
- Lock the Gate Alliance
- Blacktown & District Environment Group
- Kalang Progress Association
- Wando Conservation and Cultural Centre
- Blue Mountains Bird Observers
- No coal seam gas Gilgandra District Inc
- Clarence Valley Conservation Coalition Inc
- Collectif Causse Méjean - Gaz de Schiste NON !
- Grafton Loop, Knitting Nannas Against Gas
- Armidale Action on Coal Seam Gas & Mining
- Nature Conservation Council of NSW
- Knitting Nannas Against Gas NENW
- Climate Rights Newcastle and Hunter
- New England Greens Armidale Tamworth
- BirdLife Australia
- Gloucester Knitting Nannas
- People for the Plains
- Maules Creek Branch of the Country Women's Association of NSW
- POWER
- Dubbo Field Naturalist and Conservation Society Inc
- SOS Liverpool Plains
- The Colong Foundation for Wilderness Ltd
- Farmers for Climate Action
- Clarence Environment Centre Inc
- The Wilderness Society
- Rivers SOS
- Armidale NPA
- Friends of the Koalas Inc.
- Mullaley Gas and Pipeline Accord Inc
- Coonabarabran Residents Against coal seam gas
- Evans Head Residents for Sustainable Development Inc.
- Friends of Siding Spring Observatory
- Sustainable Living Armidale
- Lismore Environment Centre
- Orange and Region Water Security Alliance
- Cumberland Bird Observers Club Inc
- Namoi Water
- Kyogle Group Against Gas
- NSW Nurses and Midwives Association

Submissions on EIS

- Northern beaches Greens
- North West Plains Sustainability Group
- Concerned Communities of Falkirk
- Clarence Valley Astronomical Society
- IEEFA.org
- The Mullum Trust
- Knitting Nannas Against Coal and Coal Seam Gas - Dubbo loop
- Climate Change Action Network

- Think Brick Australia
- Narrabri Local Aboriginal Land Council
- Yarrie Lake Flora and Fauna Trust
- The Norwood Resource
- RDA NSW
- Narrabri Cycle and Triathlon Club
- RDA Northern Inland NSW
- Yes2Gas
- NSW Business Chamber
- Narrabri and District Chamber of Commerce

Supporting

- RECC
- Australian Air Quality Group
- Country Women's Association of NSW
- Doctors for the Environment Australia
- Cotton Australia

Commenting

Organisations

(See the Department's website under [Submissions](#))

- A & T Painting
- Alana Fairchild Pty Ltd
- Anderton & Fleck
- Andy Gheorghiu Consulting
- Antony Christian & Associates
- Art Box Workshops
- BG and LM Hawke
- Black Knight Marketing Group
- Crop & Nursery Services
- divaland lights
- FESTEROO
- HealthyLife
- Kingfisher Law
- Marylou Potts Pty Ltd
- Medical Device Research Australia
- Netcom IT
- OzEnvironmental Pty Ltd
- Polygon Heritage
- Return To Light
- Rimshot Music Aust PTY LTD

Commenting

- Busfox
- EnergyQuest
- Narrabri Coal Mine (Whitehaven)
- NU4YU WHOLE BODY HEALTH

Supporting

Submissions on EIS

- Power Beyond Hydraulics
- Remapak
- Weston Aluminium Pty Limited
- Winangali Infusion

- ECOCERN P/L
- Hunter Gas Pipeline Pty Ltd
- Ledline
- Mulbury

Commenting

Submissions on Response to Submission

Special Interest Groups

(See the Department's website under [Response to Submissions](#))

- North West Alliance, including reviews by:
 - Mr Hayley – Groundwater
 - Dr Currell – Groundwater
 - Mr Kuskie – Aboriginal cultural heritage
 - Dr Lawrence and Dr Ziller – Social impacts
 - The Australia Institute – Economics
 - Mr Paull – Terrestrial Ecology
 - Dr Saddler – Greenhouse gas
 - Mr Milledge - Biodiversity
 - Associate Prof. Hose - GDEs
 - Ms Broughton – Groundwater modelling
 - Associate Prof. Khan – Produced water
- Mr. Paull on behalf of Upper Mooki Landcare

Appendix E: Santos' Responses

Additional information provided by Santos during the assessment process may be viewed on the Department's website at <https://www.planningportal.nsw.gov.au/major-projects/project/10716> under 'Additional Information'.

RTS (See the Department's website under Response to Submissions)	https://www.planningportal.nsw.gov.au/major-projects/project/10716
Supplementary RTS (See the Department's website under Additional Information)	https://www.planningportal.nsw.gov.au/major-projects/project/10716
Additional Information (See the Department's website under Additional Information)	<ul style="list-style-type: none">• E1 - Leewood Central Gas Processing Facility• E2 - Leewood QRA Assumption Register• E3 - Air Quality Impact Assessment Supplementary Report• E4 - Response to RFS Issues• E5 - Bushfire Ignition Frequency• E6 - Operation of Leewood Safety Flare• E7 - Strategic Context Update• E8 - Response to Narrabri Shire Council

Appendix F: Agency Advice

Advice received from public authorities is listed in the table below. The advice may be viewed on the Department's website at <https://www.planningportal.nsw.gov.au/major-projects/project/10716> under 'Agency Advice'.

Agency	Advice
Planning, Industry and Environment	
Biodiversity Conservation Division	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Advice on Supplementary RTS • Advice on MNES
Water	<ul style="list-style-type: none"> • Advice on EIS • Water Advice on RTS • Advice on Supplementary RTS • Advice on Conditions • Final Advice
Environment Protection Authority	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Advice on Supplementary RTS • Final Advice • Supplementary Final Advice – Fugitive Emissions
Regional NSW	
Mining, Exploration and Geoscience	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Advice on Supplementary RTS
Resource Regulator	<ul style="list-style-type: none"> • Advice on RTS
Forestry Corporation of NSW	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Final Advice
North West Local Land Services	<ul style="list-style-type: none"> • Advice on EIS
Premier and Cabinet	
Heritage Council of NSW	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS
Transport for NSW	
Transport for NSW	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Advice on Supplementary RTS
RMS	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Advice on Supplementary RTS

NSW Health	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS
Customer Service	
NSW Rural Fire Service	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Advice on Supplementary RTS
Councils	
Narrabri Shire Council	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS • Advice on Supplementary RTS • Final Advice
Gunnedah Shire Council	<ul style="list-style-type: none"> • Advice on EIS
Warrumbungle Shire Council	<ul style="list-style-type: none"> • Advice on EIS
Gilgandra Shire Council	<ul style="list-style-type: none"> • Advice on EIS
Commonwealth Agencies	
Australian Astronomical Observatory	<ul style="list-style-type: none"> • Advice on EIS • Advice on RTS
Australian Rail Track Corporation	<ul style="list-style-type: none"> • Advice on EIS

Appendix G: Water Expert Panel Report

REPORT OF THE WATER EXPERT PANEL

REVIEW OF THE NARRABRI GAS PROJECT

February 2020



Contents

EXECUTIVE SUMMARY	iv
ACKNOWLEDGEMENTS.....	ix
GLOSSARY	x
1. INTRODUCTION.....	1
1.1 Terms of reference	1
1.2 Scope of the report	2
1.3 Membership of the WEP.....	2
1.4 Consultations undertaken by the WEP	2
1.5 Prior CSG investigations in the Narrabri area.....	4
1.5.1 Groundwater.....	5
1.5.2 What is groundwater	5
1.5.3 Water management in NSW	5
1.5.4 Surface / groundwater interaction	6
1.5.5 Groundwater modelling.....	7
1.6 Experience from CSG developments in Australia and internationally	8
1.6.1 Unconventional gas.....	8
1.6.2 International and Australian experience of CSG exploration and production.....	10
1.7 Conclusions.....	16
1.8 References	16
2. GEOLOGY	18
2.1 Background.....	18
2.2 Structural geology	20
2.3 Sedimentary geology.....	20
2.3.1 Gunnedah Basin sediments	22
2.3.2 Surat Basin sediments.....	22
2.3.3 Surficial sediments	23
2.3.4 Hydrogeology	23
2.5 Geological risk and uncertainty.....	24
2.6 Gas occurrence and composition	25
2.7 Geological heterogeneity.....	27
2.8 Subsidence.....	29
2.9 Faulting.....	30
2.10 Induced seismicity.....	35
2.11 Conclusion	36
2.12 References.....	37
3. GROUNDWATER	38
3.1 Background.....	38
3.2 Groundwater in the Namoi region	38
3.3 Data availability	39
3.4 NGP EIS groundwater model.....	42
3.5 Modelled water balance.....	49
3.6 Groundwater management	52
3.7 Groundwater dependent ecosystems	56
3.8 Groundwater monitoring and modelling plan.....	59
3.9 Hoskissons Seam	60
3.10 Conclusion	61

3.11	References	62
4.	PRODUCED WATER	64
4.1	Background.....	64
4.2	Produced water flows and composition	65
4.2.1	Flow as a ratio of gas yields	65
4.2.2	Time variance over operating life of site	65
4.2.3	Compositional variation of produced water at NGP.....	66
4.2.4	Comparison with Australian and international sites.....	68
4.3	Treatment process	70
4.3.1	Treatment processes used elsewhere	70
4.3.2	Evaluation of proposed treatment process for NGP site.....	71
4.4	Site water balance.....	74
4.5	Treated water for irrigation and on-site use.....	77
4.5.1	Volumes and composition of treated water.....	77
4.5.2	Evaluation of on-site use.....	78
4.6	Disposal to water courses.....	78
4.6.1	Evaluation of disposal to Bohena Creek	78
4.6.2	Other possible treatment options	79
4.7	Conclusions.....	79
4.8	References.....	79
5.	SALT	82
5.1	Background.....	82
5.2	Salt recovery process.....	83
5.2.1	Salt recovery processes used elsewhere	83
5.2.2	Evaluation of proposed salt recovery process in NGP EIS	83
5.3	Quantity of salts in produced water	83
5.4	Calculation of salt production	85
5.5	Chemical composition of salt	87
5.6	Possible uses of recovered salt	88
5.7	Disposal of salt to landfill	89
5.7.1	Secure landfill options in the region	90
5.8	Potential hazards associated with on-site storage and transportation.....	90
5.9	Conclusions.....	91
5.10	References.....	91
6.	POTENTIAL CONTAMINATION	93
6.1	Potential contamination hazards	93
6.2	Surface spills of fluids.....	93
6.2.1	Likelihood of liquid leakages and spills from process plant.....	95
6.2.2	Likely intensity and contaminant concentrations.....	96
6.3.3	Preventative measures in process plant design.....	96
6.4	Subsurface contamination	98
6.4.1	Loss of drilling fluids.....	98
6.4.2	Methane migration	99
6.4.3	Reservoir cross-contamination	100
6.4.4	CSG wells.....	102
6.4.5	Conventional gas wells.....	104
6.4.6	Coal mine core holes.....	105
6.4.7	Groundwater bores.....	106
6.4.8	Wellbore leakage	106

6.4.9	Faulting pathways	107
6.5	Well drilling	108
6.5.1	Conventional gas.....	108
6.5.2	Well blowout.....	109
6.6	Well integrity	110
6.7	Well completion.....	116
6.8	Plug and abandonment	116
6.9	Conclusions.....	118
6.10	References	119
7.	MONITORING, MANAGEMENT AND REGULATION.....	121
7.1	Monitoring networks	121
7.1.1	Groundwater monitoring.....	121
7.1.2	Released water.....	122
7.1.3	Boreholes	122
7.1.4	Fugitive emissions	123
7.1.5	Other monitoring	124
7.2	Management plans and incident response provisions.....	125
7.3	Regulation compliance	126
7.4	References	127
8.	CONCLUSIONS, RECOMMENDATIONS AND KEY OBSERVATIONS	128
	Summary table of recommendations	128
	Summary table of key observations	132
	APPENDIX A – EXPERT PANEL	135
	APPENDIX B – CONSULTATION UNDERTAKEN BY THE WEP.....	137
	APPENDIX C – WEP QUESTIONS TO SANTOS	138
	C1 – WEP QUESTIONS TO SANTOS	138
	C2 – SANTOS RESPONSE TO WEP QUESTIONS.....	138
	C3 – WEP RESIDUAL QUESTIONS TO SANTOS.....	138
	C4 – SANTOS RESIDUAL RESPONSES.....	138
	APPENDIX D – TREATED AND AMENDED WATER QUALITY.....	139
	APPENDIX E – POTENTIAL LEAKAGE VIA WELLBORES	142

Cover Photo – DPIE 2017 – gas well infrastructure - Water Expert Panel site visit August 2017

EXECUTIVE SUMMARY

This report has been prepared by the Water Expert Panel (WEP) in response to a request by the Department of Planning and Environment (now Department of Planning, Industry and Environment) for expert advice on a proposal by the proponent, Santos, to undertake the Narrabri Gas Project (NGP). The report considers in particular, land and water issues, drawing on the scientific and engineering expertise of the WEP, along with insights gained by the WEP through its discussions with other experts and key agencies, as well as with special interest groups and with Santos. Field inspections undertaken by the WEP and meetings the WEP held in Narrabri also provided valuable input into this report.

In the twenty years since production commenced first in Queensland and then NSW, much has been learned about coal seam gas, both in terms of how to optimise gas production and how to minimise adverse environmental impacts. Gas is now an important part of Australia's energy portfolio, with many industries and households in NSW reliant on affordable and available gas. Nonetheless there continue to be community concerns, regarding unintended impacts from gas production, notably on groundwater. It is therefore important to ensure such concerns are addressed in a transparent and evidence-based manner.

Extensive Australian and international experience in coal seam gas production has led to an understanding of risk and of how to mitigate any adverse impacts. This in turn has resulted in the development of best practice in gas production and an appropriate regulatory regime. Overall, CSG exploration and production can be conducted in a manner that produces significant economic and community benefits with minimal impact on the environment.

Much is already known about the geology and hydrogeology of the Narrabri region and this provides a basis for confidently predicting the gas resources and the manner in which they might be produced. However, as in all natural systems and especially those involving the subsurface, there are knowledge gaps that only become evident and get resolved as a project proceeds.

Underlying the NGP area are sediments, including extensive coals, of the Gunnedah-Oxley Basin. While the coal seams outcrop west from the Mooki River, the proposed gas production will be mainly from the Maules Creek coals from as deep as 1,200 m below the surface, with some minor production from the shallower Hoskissons seam which rises to depths of about 300 m in some areas. The old rocks of the Gunnedah Basin are overlain by younger Surat Basin sediments including sediments of the Great Artesian Basin, notably the high permeability Pilliga Sandstone. The WEP identified some confusion regarding the nomenclature of the Pilliga Sandstone that requires resolution. The youngest sediments are the unconsolidated sands and gravels of the Namoi Valley, which include the most significant low salinity high yield aquifers in the region.

In its consideration of the geology, the WEP sees a need for more publicly available information on gas composition and suggests that more detailed information on rock heterogeneity would be valuable for future subsurface modelling. The prospect of subsidence or induced seismic activity associated with gas production is regarded as low, given the considerable depth from which the gas will be extracted. No geological

structures were identified that are likely to adversely impact of gas production or groundwater movement. Nonetheless, the WEP recommends Santos undertake more detailed fault analysis and structural assessment should the project be approved and it should be required to make this information publicly available.

Groundwater is a vital resource on which irrigation, farming and urban water supply in the Narrabri region is dependent. Consequently, it is no surprise that many of the concerns expressed by individuals and special interest groups regarding the NGP, relate to its potential impact on groundwater. The aquifers, along with the rivers, constitute important water 'sources' that are carefully regulated. Assigned entitlements held by private interests can be traded. Unassigned and environmental entitlements are held by the government. In the Narrabri area, the NSW Government has responsibility for those entitlements, taking into account its commitment to the National Water Initiative. As part of the NSW Government's \$22.8 million Water Monitoring Strategy new bores have been constructed recently in the Gunnedah Basin to enhance the existing groundwater monitoring network in the Namoi catchment.

There are a number of groundwater systems in the Narrabri region. These vary in terms of water quality, quantity and use. Unlike Queensland, where the gas-producing Walloon Coal Measures are also an important aquifer and a major intake area for the Great Artesian Basin, the coals in the NGP region are separated from the major aquifers of the Great Artesian Basin and the alluvium by aquitards. Additionally, the hydraulic connectivity between the Gunnedah-Oxley Basin and the Great Artesian Basin is very low. These factors greatly reduce the likelihood of any impact on the major freshwater aquifers arising from the production of gas. The WEP notes that over the anticipated 25-year life of the NGP, the predicted total volume of groundwater extracted from Gunnedah Basin gas wells, is of the same order as the annual groundwater savings being reported from GABSI. The total volume of gas-related produced groundwater is also minor compared to annual volumes currently extracted from the Namoi alluvium. Nonetheless, there is a risk that small impacts from connected water sources can potentially have cumulatively significant local impacts. It is therefore important to ensure that an effective water management system is put in place to mitigate this impact risk.

The WEP notes that Santos will have to hold entitlements in each of the water sources impacted after the approval of the NGP. Although trading with existing entitlement holders offers a potential way forward, this may also require negotiation with the regulator, given that most water sources are effectively fully allocated. However, the Gunnedah-Oxley source does have significant unassigned water.

In addition to impacting on existing water sources, it has been suggested that the NGP might impact upon Groundwater Dependent Ecosystems. The WEP is of the view that application of the current Aquifer Interference Policy in the NGP region will protect these systems from unacceptable cumulative impacts. Concerns have also been expressed about potential impacts on stygofauna, but given the extent to which the aquifers in the region have been utilised over many years, there are unlikely to be any significant 'natural' fauna remaining, and, in any case their recognition would be quite problematic.

There is much discussion on groundwater models in the EIS and in this report. Groundwater models are simplified (conceptual and mathematical) representations of the groundwater system and are important tools in the management of groundwater resources. They can range from quite simple models to highly complex 3-dimensional numerical models used for simulating steady state and transient (variable) groundwater flow. The EIS uses a finite difference approach, the widely used and well regarded MODFLOW software platform. Overall the WEP believes that the model used for the NGP is fit for purpose, but a number of recommendations are made regarding future use of the model and also data input in the model that will increase the future level of confidence in its predictive capabilities. As part of this, recommendations are made regarding the need to improve groundwater monitoring in the NGP region. Some of this improvement will happen as the NGP moves forward, but in some areas there will be a need for additional government action.

The NGP development is likely to be hydraulically isolated from the surrounding geological units, including the highest value sources of fresh groundwater. Consequently, the anticipated drawdown and overall impact resulting from coal seam gas production is likely to be very minor. Nonetheless it is important to ensure that the impact on individual bores will not be significant, or can be satisfactorily ameliorated, or the owner adequately compensated.

As a consequence of coal seam gas extraction, significant volumes of brackish or saline groundwater will be produced and a common concern is that this could contaminate surface water, soils and groundwater. Consequently, it is important that produced water is stored, treated and used or disposed of, in an environmentally acceptable manner. In some early projects, evaporation ponds and deep disposal into saline brines were commonly used, but these are now banned in NSW. Fortunately, a number of innovative and effective techniques have been developed for treating produced water, including so that it can be used beneficially.

Large storage ponds will be used in the initial stages of treatment of NGP produced water and it is important for the regulator to be satisfied that these ponds are of sufficient capacity to handle a range of potential incidents, such as process plant outages and extreme weather events. Also, it is important that Santos clarifies the necessary operational measures that are in place, if the safe operating level of the pond were to be exceeded. Studies by Santos have shown that a well can be shut in for a period, thereby stopping feed flow of both gas and produced water, should adverse processing conditions be encountered, without adversely impacting on the future production of the well.

The WEP was concerned about the lack of some compositional data for produced water in the EIS, but for the most part those concerns were addressed by the provision of additional chemical data by Santos along with more comprehensive baseline data. However, it does consider that it would be valuable to provide more data on chemicals of potential concern. It also suggests that if the project proceeds, regular analyses of produced and treated water should be undertaken and that the results should be made publicly available.

The current NGP plan is to treat produced water to meet Australian Drinking Water Standards, using a reverse osmosis facility, with the treated water then being used for

irrigation and other beneficial purposes, or disposal to Bohena Creek. The WEP notes that the level of salt removal in the small-scale reverse osmosis unit now installed at Leewood, is noticeably better than that predicted in the EIS and this, together with Santos' record in produced water treatment in Queensland, gives the WEP confidence that production water can be treated so that it can be beneficially used, including for irrigation. The WEP recommends that prior to the commencement of irrigation, the advice of an agricultural expert be sought in order to determine the appropriate process settings for process water amendment.

There are a number of potential risks attached to treating produced water and these are outlined in this report, but none is seen to represent an unacceptable risk to the project, or the environment, and all can be managed. The single biggest risk lies in ensuring that there is no storage pond over-topping. The WEP benefitted from visiting the Leewood facility and discussing the measures taken at the facility to carefully monitor the performance of the facility and the design and operation of the pond. It concluded from that visit and further information provided, that the facility was well constructed, fit for purpose and represented best practice.

A component of the handling of produced water at the NGP is intermittent disposal of treated water to Bohena Creek, on an estimated 44 days per year in periods of peak production when the creek is flowing at 100 ML/day. Concerns have been expressed about the effect of such managed release on the ecology of the creek, and its impact on nearby groundwater and ultimately the Namoi River. With the high performance of the reverse osmosis plant, the WEP considers it unlikely that the proposed discharge of treated produced water into Bohena Creek at the scale proposed will adversely affect the ecology of the creek. However, it did consider that temperature matching of discharged and creek water will be desirable and that it may be preferable to monitor stream flows closer to the NGP site than is currently the case.

At its peak the NGP will produce an estimated 47 tonnes of salt a day and a total of 430,000 tonnes over the lifetime of the project, although analysis indicates that this volume could be greater. A number of plants around the world are now using a process similar to that proposed for the NGP in order to maximise recovery of useable water (up to 98%). Concerns have been expressed regarding the impact of the recovered salt on the environment and the possibility that the process may concentrate some undesirable species. The WEP considered these and other issues. It concludes that the proposed process for recovering salts from the reverse osmosis concentrate is appropriate and should function effectively.

In terms of the actual composition and the quantity of salt produced, the WEP felt it would have been helpful to have more comprehensive analyses, in order to better assess the prospects for beneficial use of the salt, including providing clarity on any chemicals of potential concern. The recovered salt is expected to be primarily sodium carbonate, which has some potential for use in the chemical industry. The alternative is disposal of the salt at licenced sites. There is a need for certainty that there are suitable licenced waste disposal sites in NSW willing to accept NGP salt and with enough assured collective capacity to handle the anticipated volumes. Along with this will be a need for ongoing monitoring of the salt composition over the life of the project.

Risks can arise in coal seam gas projects due to surface spills or leakage of produced water or brine concentrate, or treatment chemicals. They can also occur in the subsurface from loss of drilling fluids, cross contamination from a saline aquifer or leakage of produced gases. If not remediated such incidents can leave a legacy of contaminated soils, surface water or groundwater. There are, however, a series of established good-practice codes covering these aspects and government agencies such as the NSW Environment Protection Authority and DPIE (Water) that set required standards and monitor performance. In their responses to the EIS and the Santos Response to Submissions, these agencies have detailed their particular concerns and requested that, should the project proceed, Santos works with the particular agency in the development of appropriate management plans. The WEP supports this approach and calls for adequate government resourcing of agencies to allow this and subsequent monitoring of performance to occur.

Particular issues raised by the WEP and discussed in detail in this report include spillage of process liquids and drilling muds, construction and monitoring of NGP wells to prevent well failure and possible well blowout. Should the project proceed, Santos should provide adequate confirmation that wells can be safely abandoned at the end of their productive life by ensuring that both vertical and horizontal sections can be effectively sealed. The WEP also agreed on the need for further baseline data, particularly in relation to the presence of background levels of methane in existing bores.

Monitoring, management and regulation compliance is emphasised throughout the EIS and are central to many of the issues considered by the WEP. Whilst discussions have already occurred between the agencies and Santos about monitoring protocols, adequate monitoring of groundwater heads, concentration of chemicals in aquifers throughout the project area and measurements of methane and CO₂ will allow early detection of problems and issues of concern. In particular, concerns such as cross-aquifer contamination, environmental impact on surface water and greenhouse gas emissions can be tracked. Early detection of problems and issues of concern will allow effective controls and remediation measures to be implemented. Should the project proceed, the WEP is strongly in favour of the adoption of this approach termed 'adaptive control', with public availability of key monitored parameters and regular reporting to the appropriate agency.

The report contains Key Observations and Recommendations, and these are summarised at the end of the Report.

In conclusion, the WEP did not identify any land and water issues that were likely to result in significant impacts on people or the environment or that could not be managed to ensure all applicable government standards or codes would be met. However, it did identify a number of questions and concerns arising from a current lack of information, or uncertainty regarding an interpretation or a model. If the NGP is to proceed, these can be addressed through ongoing monitoring, adaptive management and a robust regulatory regime that is vigorously and effectively enforced.

ACKNOWLEDGEMENTS

The WEP acknowledges with thanks the many valuable and informative meetings it had with Santos, representatives of government departments and agencies, GISERA, representatives of Special Interest Groups and with the broader Narrabri community.

- NSW Government agencies
- Santos
- Experts engaged by Santos:
 - Tony Smith
 - Richard Cresswell
 - Thomas Neame
 - David Chubb
- Landowners in Narrabri
- Namoi Water
- People for the Plains
- North West Alliance
- Experts engaged by North West Alliance:
 - Dr Mathew Currell
 - Ms Andrea Broughton
 - Dr Kevin Hayley
- Lock the Gate Alliance
- Wilderness Society
- Artesian Borewater Users Association
- Great Artesian Basin Protection Group
- Narrabri Gas Project Community Consultative Committee members, including representatives from:
 - Narrabri Council
 - Lower Namoi Cotton Growers Association
 - North West Local Land Services
 - Country Women's Association
 - People for the Plains
 - Narrabri Chamber of Commerce
 - Narrabri Local Aboriginal Land Council
 - NSW Famers
 - Namoi Water
- GISERA

GLOSSARY

Abbreviation	Meaning
2D	Two-dimensional
3D	Three-dimensional
ABWUA	Artesian Bore Water Users Association
ACOLA	Australian Council of Learned Academies
Aquifer	An underground layer of water-bearing permeable rock or soil
Aquitard	A zone within the earth's crust that restricts the flow of groundwater from one aquifer to another
CGP	Camden Gas Project
COAG	Council of Australian Governments
COPC	Chemicals of potential Concern
CSG	Coal seam gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSS	Culturally significant site
DPE	NSW Department of Planning and Environment
DPI	NSW Department of Primary Industry
EIS	Environmental impact statement
EPA	NSW Environment Protection Authority
FEED	Front-end engineering design
Fracking	Hydraulic fracturing (usually of rock)
GAB	Great Artesian Basin
GABS	GAB Shallow Groundwater Source
GDE	Groundwater dependent ecosystems
GIA	Groundwater impact assessment
GISERA	CSIRO/Gas Industry Social and Environmental Research Alliance
GL	Gigalitres = 10^9 Litres (a unit of volume)
GOB	Gunnedah Oxley Basin
Hydrostratigraphy	Structure of subsurface porous materials
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
Km	Kilometre(s) (a unit of length)
L	Litre(s) (a unit of volume)
LNA	Lower Namoi Alluvium
M	Metre(s) (a unit of length)
Mg	Milligram(s) (a unit of mass)
mg/L	Milligrams per litre (a measure of concentration)
ML	Megalitres = 10^6 Litres (a unit of volume)
mm	Millimetre(s) (a unit of length)
MPa	Megapascal(s) (a unit of pressure)
NGP	Narrabri Gas Project
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NOW	New South Wales Office of Water
NSW	New South Wales
PJ	Petajoule = 10^{15} J (a unit of energy)
ppm	Parts per million
Produced water	A two-phase mixture of gas and water extracted from coal seams
RREO	Recovery Exemption Order
RSC	Residual sodium carbonate
RTS	Response to submissions
SAR	Sodium adsorption ratio
SDL	Sustainable Diversion Limit
SIGs	Special Interest Groups

Abbreviation	Meaning
Stratigraphy	Rock layering, usually in sedimentary or igneous rocks
Stygofauna	Fauna that live in groundwater systems or aquifers
tcf	Trillion cubic feet
TDS	Total dissolved solids

1. INTRODUCTION

For some years, the Narrabri region of NSW has been an area of interest to oil and gas companies and a number of gas developments based on coal seam gas (CSG) have been proposed, most recently, the Narrabri Gas Project (NGP). In September 2016, the Government revised the Secretary's Environmental Assessment Requirements for Development Application SSD 14_6456 for the proposed NGP.

Based on those requirements, in January 2017 Santos submitted an Environmental Impact Statement (NGP EIS) to the Department of Planning and Environment, (DPE) Subsequently, DPE commissioned a number of experts to provide advice on the NGP EIS. In 2019, DPE was restructured to form the Department of Planning Industry and Environment (DPIE), but throughout this Report the name DPE is used, as that was the commissioning Department. This report provides advice on land and water aspects of the NGP EIS.

1.1 Terms of reference

In order to assist the DPE in progressing consideration of the NGP EIS, experts in the fields of land and water, social issues, economic matters, hazards and risk, and aboriginal heritage were appointed by the Department. An Expert Panel, focussed on Land and Water (the Water Expert Panel or WEP), was established by the Department, with terms of reference that included:

- Provision of advice to DPE on land and water issues as required
- Review of the NGP EIS and other relevant documents
- Consultation with key agencies
- Review of key submissions
- Consideration of submissions and consultations
- Meetings with community groups, special interest groups and experts
- Consultations with Santos
- Field visits to the area of the NGP
- Identification of key questions, issues or knowledge gaps requiring further consideration
- Preparation of a report for DPE as input into its preliminary assessment of the Project
- Provision of advice to the Independent Planning Commission (IPC), if required
- Review of, and recommendations to DPE regarding the IPCN Report, if required
- Provision of reports for inclusion in the Final Assessment Report

1.2 Scope of the report

Given its terms of reference, this report by the WEP is focused on land and water issues. Key areas of science and engineering falling under the remit of the WEP include geology, geophysics, geochemistry, hydrogeology, groundwater modelling, monitoring, reservoir engineering, production engineering, drilling operations, water treatment and salt recovery, water use, risk and uncertainty, contamination, spillage, well integrity and regulations relating to these topics.

The WEP has sought to avoid topics covered by other DPE-appointed experts and/or the authorities. Some of these were quite clearly 'out of scope' for the WEP, such as health and safety, indigenous issues, light pollution, leakage from gas lines, and social issues. Some topics are less 'cut and dried'. For example, the WEP decided that for the most part, it was appropriate to leave consideration of fugitive emissions to experts in the EPA, although related topics such as gas composition and leakage have geological and geochemical aspects that are considered in this Report. Groundwater Dependant Ecosystems (GDE) are important biological or ecological systems, but they also fall within the remit of the WEP to some extent, because of the essential part played by groundwater in maintaining the ecological viability of GDEs.

Groundwater was obviously a particular focus of the WEP review process, but groundwater also has a very important social and economic dimension, which falls outside the scope of the WEP and needs to be dealt with by the appropriate experts and authorities. In the case of risk, above-ground operations of the proposed NGP, were formally assessed by a DPE-appointed expert in risk. The WEP considered it appropriate to focus on subsurface risk and uncertainty.

1.3 Membership of the WEP

Professor Peter J Cook, CBE FTSE Geologist (Chair)

Professor John Carter, AM FAA FTSE FRSN FAIB CPEng Geotechnical Engineer

Professor Chris Fell, AM FTSE FRSN CPEng Chemical Engineer

Mr R. Michael Williams, PSM Hydrogeologist

Detailed biographies are provided in **Appendix A**.

1.4 Consultations undertaken by the WEP

The WEP considered it essential to consult widely with a range of stakeholders, to ensure that it fully understood the scope of the proposed NGP and any community concerns regarding the proposal. It also needed to be clear on what is known, what is uncertain and what is unknown, in terms of the science underpinning the Project. More than 22,000 written submissions on the NGP were received by DPE. It was not possible for the WEP to read all of these, but it did read a wide cross section of submissions. It also had the benefit of access to the Report on the NPG by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC).

Importantly, it met with a range of officials, experts, special interest groups, industry, community leaders, farmers, landholders, regulators, coal seam gas (CSG) company employees and consultants. It held meetings in Sydney and in Narrabri and undertook field and facilities inspections in the Narrabri and Pilliga Forest areas.

Meetings were held with the following organisations:

Government and Agencies

- NSW Department of Planning and Environment (DPE) including the Division of Resources and Geoscience
- NSW Department of Industry Lands and Water
- NSW Environment Protection Authority (EPA)
- CSIRO/Gas Industry Social and Environmental Research Alliance (GISERA)

Special Interest Groups

- People for the Plains
- Artesian Bore Water Users Association
- Great Artesian Basin Protection Group
- North West Alliance, including experts
- Namoi Water
- Lock the Gate Alliance
- Wilderness Society
- Industry
- Santos

A detailed list of consultation undertaken by the WEP is provided in **Appendix B**.

Following the release of the NGP EIS and the subsequent consultation period, in February 2018, Government Agencies and Special Interest Groups formally wrote to DPE, seeking additional information or clarification from Santos on some issues considered in the NGP EIS. The WEP, separately also raised a number of issues, where it too sought further clarification from Santos (see **Appendix C1 and C3**).

Santos formally responded to these various enquiries (see **Appendix C2 and C4**). The WEP recognised that some issues of interest to the Panel, might also be of commercial relevance. Where such issues potentially arose, the WEP sought to ensure that commercially sensitive-site specific data was not necessary to address its queries. However, in rare instances, Santos was of the view that there were still commercially sensitive issues surrounding a few of the questions and felt unable to respond to the WEP on these.

The WEP therefore sought to take up these pending issues and others, with Santos in June 2018, for further consideration. Santos finally responded to a number of these issues in May 2019.

Most recently, the WEP has had the benefit of seeing the submissions of the EPA, the Department of Industry – Land & Water and the DPE Resource Regulator. Comments arising from consideration of these submissions are incorporated in this Report. Finally, the WEP attended a meeting with GISERA (and received a copy of its reports; see GISERA, 2018 a, b) on potential water impacts of CSG production and some of the matters raised by GISERA are considered in this WEP Report.

1.5 Prior CSG investigations in the Narrabri area

Coal was first discovered in the Sydney Basin in early colonial days and the Gunnedah Basin was known to contain coal more than 100 years ago (David, 1887). Investigations by the NSW Government in the Narrabri area (Harper 1926; Kenny, 1928) showed the extent of the coals and pointed to their commercial significance, although it was to be some years before there was any large-scale mining. During the 1960s extending into the 1970s, some exploration for oil and gas was undertaken in the region, with gas (occasionally oil) shows being encountered, although they were largely non-commercial.

In 1976, exploration for CSG was initiated in Queensland, with commercial CSG production commencing in 1996. In NSW, exploration for CSG started in 1998, with commercial production commencing in 2001 in the Camden area. The Narrabri area was considered by exploration companies to have CSG potential and by 2009 the area had been assessed to have significant CSG resources. This provided the basis for Santos to plan its proposed NGP with a twenty-five-year time frame for the project.

Along with some existing appraisal and exploration wells, which will potentially be converted to production wells, it is proposed to drill up to 850 new gas wells on approximately 425 well pads. There will also be associated construction and operation of gas processing and water treatment facilities as part of the Project.

At much the same time that plans were being developed for the NGP, a number of questions arose regarding the potential impact of CSG exploration and production, on the environment and on human health. The New South Wales Government therefore commissioned the NSW Chief Scientist and Engineer, Professor Mary O’Kane, to undertake a comprehensive review of CSG-related activities in the State. A range of reports was subsequently issued by the Office of the Chief Scientist and Engineer (<http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review>) and a Final Report was released in September 2014 (O’ Kane, 2014).

The Review found that in general, the technical challenges and risks posed by the CSG industry can be managed through a range of measures (see later). Sixteen recommendations were made by the Review, all of which were supported by the Government through the NSW Gas Plan. This then provided a very important starting point and a useful yardstick for the WEP, when assessing the NGP EIS.

Through the joint action of the Australian Government Department of Environment and Energy and the NSW Department of Planning and Environment, the IESC provided advice on the Project (IESC, August 2017) noting that “ *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”.

The IESC also considered that whilst baseline groundwater information had been collected, *“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...Ongoing collection of hydrogeological information and data will be needed to confirm the preliminary predictions of impacts to groundwater resources within the region”.*

In 2017 and 2018 GISERA (<https://gisera.org.au>) produced a number of reports relating to land and water issues in the Narrabri area including monitoring and potential groundwater changes in the GAB aquifer (Sreekanth et al., 2018 a and b).

The opportunity for the public to comment on the NGP EIS resulted in a number of written submissions from Special Interest Groups, which have been valuable to the WEP in drawing attention to particular issues of concern.

1.5.1 Groundwater

Groundwater is a vital natural resource in the Narrabri and adjacent areas and a major concern expressed in the submissions to the Department and the WEP was the extent to which CSG developments would impact on it. With this in mind it is useful to provide some background on groundwater to enable an improved understanding of how the groundwater is managed.

1.5.2 What is groundwater

Water that fills the saturated pores and fractures in soil and rock below the ground surface is called groundwater. An aquifer is a geological formation or interval that can yield a usable quantity of groundwater to suitably constructed bores. An aquitard is a less permeable geological formation or interval that significantly impedes the flow of groundwater rather than completely stopping it.

1.5.3 Water management in NSW

The 1994 Council of Australian Governments’ (COAG’s) Water Reforms drove the replacement of the Water Act 1912 with the Water Management Act 2000 (WMA). The WMA requires water sharing plans to be developed for regulated rivers, unregulated rivers and groundwater. This was completed in 2009. The area and aquifers included in each plan are referred to as a water source. The plans are valid for 10 years although they can be amended to assist with implementation or to reflect changes in legislation.

The reforms resulted in all assigned entitlements being held by private interests. Any unassigned entitlements and environmental water are held by the government. Under these conditions, access to entitlement by new entrants can be by trade with existing entitlement holders or by application to government should unassigned water be available. Trade between water sources is not permitted.

In areas where data on long term groundwater levels and usage was available, an understanding of the water balance has been developed through groundwater flow

models. These areas, primarily large alluvial inland basins, include the Upper and Lower Namoi alluvium, where plans for the sustainable use of their water resources could be implemented relatively quickly.

However, as part of its commitment to implement the National Water Initiative (2004), NSW developed water sharing plans for the whole State. These plans are based on a percentage of rainfall recharge (ranging between 5 and 70%) over the entire water source being made available for consumptive use. All the water sources impacted by the proposed CGS development have active groundwater management.

All water sharing plans have a volumetric limit for consumptive use which is referred to in the regulations as the Long Term Average Extraction Limit or locally, as the Sustainable Diversion Limit (SDL). At the commencement of each plan, shares in the water source are issued to landholders with the “value” of a share being 1 ML/year.

Water sharing plans provide the framework and rules for managing shares in water sources and extraction under an access licence. For groundwater, the plans contain many generic rules that apply to all water sources. They also contain some specific management rules to manage known issues such as local impacts.

To manage trade and other new entrants, extraction points require a works approval for the proposed volume to be extracted by the entitlement holder, that specifies the bore location, site geology, screened interval depths and pumping capacity. It is noted that State-significant developments do not require a works approval. The regulator assesses the local impacts of such extraction against the rules in the water sharing plan before issuing an approval for all or part of the proposed extraction.

1.5.4 Surface / groundwater interaction

If the surface and groundwater are connected, interchange of water will occur in some form and consequently the extraction of groundwater for CSG production may have an impact on the water available for stream flow. The key challenge in modelling surface and groundwater interaction is the difference in the time scale between each of the processes. Groundwater movement is generally several orders of magnitude slower than surface water movement. Consequently, the responses of groundwater systems to hydrological drivers such as climate variability and groundwater extraction can be subtle and take a long time to move through all the aquifers and aquitards. Hence, a key requirement in modelling surface and groundwater interactions in river system models is to account for the time lags. However, this is not straightforward and it has to be said that the modelling of surface and groundwater interactions in river system models is still very much in its infancy. Nor is there any consensus on how best to incorporate this interaction into river systems models.

The exchange flow (or ‘flux’) between surface and groundwater has four components:

- river stage fluctuations (low flow conditions in bank and high flow overbank);
- changes in aquifer recharge;
- changes in evapotranspiration; and
- groundwater extraction or interception.

Until the spatial scale of any proposed model is defined, the data requirements for each of these components are unclear. The spatial scale will dictate the level of complexity and thus the processes that can be included. Large-scale models invariably take a 'lumped' (low resolution) approach that requires less local detail, whereas smaller scale physically-based models explicitly account for more local (higher resolution) processes. Temporal 'lumping' will mask shorter term hydrological events as they average out over the larger time interval. At a whole-of-river scale, readily available data can only support a low fidelity model, as is the case for the model development in the Santos EIS.

1.5.5 Groundwater modelling

A groundwater model is a simplified (usually mathematical) representation of the groundwater system. Models can take many forms (simple, analytical and numerical) depending on the complexity of information required.

Simple water balance or 'bucket' models involve only volumes for each of the inputs, outputs and any changes in storage across the whole of a surface/groundwater system for a given time period.

An analytical model is generally used to estimate aquifer properties within a set of assumptions such as the boundary conditions that relate to the groundwater system. They are generally used to make predictions in either one or two dimensions. For instance, they are used in pumping tests (with and without observation bores) to estimate a single set of hydraulic parameters for the aquifer and aquitard.

Numerical models are used for simulation of three-dimensional, steady state and transient (variable) groundwater flow. Steady state flow occurs when the magnitude and direction of flow is constant with time throughout the entire model domain. The amount of water within the model domain remains the same, so inflow to, and out flow from the model is constant. As time is not an independent variable there is no storage term in the groundwater flow equation. Transient flow occurs when the magnitude and direction of the flow change with time.

Barnett et al. (2012) describe how numerical groundwater models are constructed and calibrated. As such models tend to be multilayered with spatially distributed parameters, the input data requirements are significantly higher. They can provide the basis for making predictions and establishing the level of associated uncertainty or confidence in three dimensions across an entire groundwater system.

The Santos EIS compares the finite difference and finite element approaches to understand and predict groundwater flow. The finite element approach can accurately represent complex aquifer geometry but may have difficulty in accurately quantifying internal water movements. The finite difference approach was selected as it provides a more accurate accounting of internal flows, which is one of the EIS objectives. It uses the MODFLOW platform, software developed by the US Geological Survey (Panday et al., 2013), which is widely used and accepted by governing and regulatory bodies.

1.6 Experience from CSG developments in Australia and internationally

1.6.1 Unconventional gas

Major accumulations of natural gas are found in sedimentary basins, in a range of geological settings, which serve to define whether the gas is regarded as 'conventional' or 'unconventional'. In almost all cases, the gas (whether conventional or unconventional) is composed predominantly of methane (CH₄) but with minor quantities of other hydrocarbons sometimes present. There can also be trace contaminants in the gas as well as inert gases, the most significant usually being carbon dioxide (CO₂). Information on the various categories of natural gas occurrences is summarised in Table 1.1 and discussed in more detail in the ACOLA Review (Cook et al, 2013).

Conventional gas has usually migrated out of organic-rich source rocks and then been trapped. This trap can be in porous and permeable reservoir rocks such as sandstones (often overlain by a low permeability seal), in structural traps such as anticlines or fault traps or in stratigraphic traps where the reservoir is 'pinched out'. Conventional gas, which occurs over a wide range of depths, often under high pressure in the reservoir, is fairly simple to extract and has provided most of the world's commercial gas production to date. Some basins contain both conventional and unconventional gas.

Unconventional gas is mostly found in low permeability rocks and includes shale gas, tight gas, CSG and gas hydrates. Gas hydrates are found offshore under the seafloor. These are not presently exploited but may be an important future resource for some countries.

Tight gas is similar to conventional gas in that it is most commonly found in sandstones into which the gas has migrated. But they are sandstones with low permeability that require various reservoir engineering techniques to stimulate the production of the gas (or oil).

Shale gas is mostly found in the deeper parts of sedimentary basins in low permeability rocks such as mudstones or shales, which require hydraulic fracturing (fracking) of the rock before gas can be produced in commercial quantities.

CSG, the other 'unconventional gas', occurs within coal seams, where the gas is adsorbed onto the fine organic particles making up the coal, or trapped in cleats, fractures or cracks within the coal. CSG is mainly composed of methane with variable, though usually minor amounts of heavier hydrocarbons, nitrogen, and carbon dioxide. It is usually produced from much shallower depths than shale gas or tight gas.

The methane is generated by biogenic (microbial) or thermogenic (thermal) processes. Biogenic methane is formed when microbes act upon shallow coals, whereas thermogenic methane is formed at greater depths, as the temperature of the coal bed increases with increasing depth of burial. Methane drainage from coal mines has been used for many years in Australia as a safety measure. Some coals have a low permeability and may require hydraulic fracturing to produce the methane; most have natural permeability relating to the fractures or cleats, which facilitates the production of gas.

For large-scale production of methane, it is usually necessary to dewater the coal. This is done by pumping out the formation water, thereby lowering the water table in the vicinity of the drill hole, depressurising the coal and inducing gas flow.

Because they are lumped together as “unconventional gas”, people can confuse shale gas and CSG, but in terms of their depth of occurrence, the manner in which the methane is trapped, the technologies used to produce the gas and the extent to which fluids are injected (shale gas) or groundwater withdrawn (CSG), there are many important differences. Table 1.1 summarises the distinctions between them.

Table 1.1: Characteristics of unconventional gas (from Table 3.1 ACOLA Report, Cook et al, 2013)

	Coal seam gas	Shale gas	Tight gas
Location	Particularly in Qld and NSW.	Includes remote locations in WA, Qld, NT and SA.	Onshore WA, SA and Vic. Largest known resources are in the Perth (WA), Cooper and Gippsland basins.
Commercial production	Significant exploration and characterisation of known resources. First commercial production of CSG began in 1996. CSG contributes about 10% of Australia's total gas production and greater than 70% of Qld's gas production.	Currently minor commercial production and resources are currently poorly understood and quantified.	Known tight gas reserves in existing conventional reservoirs that are well characterised will be primary targets for production.
Source rock	Coal seams (also the reservoir rock).	Low permeability, fine grained sedimentary rocks (also the reservoir rock).	Various source rocks that have generated gas, which has migrated into low permeability sandstone and limestone reservoirs.
Gas occurrence	Primarily adsorbed within organic matter.	Contained within the pores and fractures ('free gas') and adsorbed within organic matter.	Contained in pores
Typical depth	300-1000 metres (shallow compared to conventional and other unconventional gas). Deeper coals exist but are not currently economic as CSG reservoirs.	1000-2000 plus metres	Depths greater than 1000 metres
Composition	Mostly methane (>95%). CO ₂ can be present but makes production less economic. Minor 'higher' hydrocarbons, nitrogen and inert gases.	Mostly methane. The presence of other hydrocarbons could make the resource more valuable.	Mostly methane.
Estimated Resource volume (for Australia)	Total identified resources estimated to be 203 tcf (DRET, 2012).	Total identified resources (discovered and undiscovered) are approximately 396 tcf (11.2 tcm) (IEA, 2011).	The in-place resources (total discovered) are 20 tcf (0.566 tcm), which is expected to increase with further exploration. (GA, 2012)
Transport and market network	Existing infrastructure for transportation and established market structures, particularly in Qld.	Cooper Basin region has existing gas infrastructure, however resources in WA and NT are generally in remote locations with limited infrastructure. Use by local mines is being considered in some cases.	Existing tight gas resources have been located in established conventional gas producing basins (Cooper and Perth basins), close to established infrastructure for commercial production. Other tight gas resources are in more remote locations.
Technology/ Infrastructure required	Hydraulic fracturing used for less than half of the wells but this use is expected to increase as lower permeability seams are targeted.	Hydraulic fracturing and horizontal wells commonly required.	Large scale hydraulic fracturing treatments and/or horizontal wells required.
Water usage	Water produced from dewatering (pumping water out of the reservoir to reduce reservoir pressure and allow gas flow). Water required for hydraulic fracturing if used.	Water required for hydraulic fracturing	Water required for hydraulic fracturing
Key extraction challenges	Removal of water and recycling or disposal of produced water necessary.	Overcoming low permeability Minimising amounts of water to be sourced for hydraulic fracturing. Reducing infrastructure footprint.	Reducing infrastructure footprint.

1.6.2 International and Australian experience of CSG exploration and production

The CSG potential of numerous sedimentary basins has been assessed for many parts of the world over the past twenty years or so. But it has only been in the United States and Canada and more recently in Queensland, that large scale production of CSG has been undertaken. Whilst every sedimentary basin is different, it is useful to draw on that North American and Australian experience, when considering the NGP. In doing so, it is important to make the point that most recent media comment regarding the US experience with unconventional gas, relates to shale gas, not CSG.

To again summarise key differences: shale gas generally occurs deep in sedimentary basins; it is produced from shales and mudstones through injection of fracking fluids to induce production; it often contains heavier hydrocarbons and generally involves producing formation water (usually quite saline) only for the first year or two of production.

CSG is generally produced from quite shallow depths; it seldom contains heavy hydrocarbons; coals may, but often do not require fracking; and pumping of formation water (fresh or brackish water in many cases) to produce “de-gassing”, often continuing for some years, is an integral part of most operations. The proposed NGP involves the production of CSG and not shale gas.

A modest quantity of conventional gas has been produced in the NGP area and the possibility of encountering more cannot be discounted. Nonetheless it is likely that if conventional gas were to be encountered it would not be a significant contributor to NGP gas production and would be unlikely to raise any additional technical, environmental or other issues outside the scope of the NGP EIS.

North America

CSG is commercially exploited in a number of areas, notably in Alabama, New Mexico, Wyoming and Alberta.

Wyoming

The single largest CSG development in North America to date, has been in the Powder River Basin of Wyoming extending into Montana. The Basin began CSG production in 1989, providing an average of 8-9% of total US gas production since that time. During the peak exploration phase, up to 2000 wells a year were drilled. The coals of the Powder River Basin are interbedded with mudstones, sandstones and limestones, which have produced conventional gas in places. The main CSG-producing coals occur in the lower Tertiary Wasatch and Fort Union Formations and the Upper Cretaceous Lance Formation at depths ranging from 300-400 m. The coalbeds in these three formations also serve as important aquifers (Flores, 2004).

The Basin has potential CSG reserves of 100 tcf and resources of 700 tcf. However, the advent of cheap shale gas over the past decade has resulted in a major drop in Powder River CSG production in recent years. Approximately 24,000 CSG wells have been drilled in the basin in the past 20 years, over several thousand square kilometres (km²). The State has benefitted from royalties, increased economic activity and ready access to a new energy source, and the US economy more broadly has benefitted.

Many landowners have also benefitted because of their ownership of the mineral rights. But there have been a number of problems (USGS, 2000), including inadequate management of large volumes of produced saline water, with adverse effects on soils, rangeland and crops in some areas (Rice et al., 2000). The migration of methane into some domestic and farm wells has also proved to be a concern.

Bleizeffer (2015) states that there are “*approximately 3000 wells left orphaned – a liability for the state to clean up*”. It is unclear if all these are CSG wells. So, a number of problems have arisen from the early days of CSG development, but much has been learned in terms of remediation, monitoring, regulation, exploration, understanding gas-bearing coals and optimising production. Perhaps most significant, has been the recognition of how important it is to understand the hydrogeology of the Basin and the role and potential impact of co-produced water in any CSG development (Myers, 2009; Rice et al., 2000; Johnston et al., 2008).

Alberta

CSG developments in the Western Canadian Sedimentary Basin target a shallow 200-800 m depth interval that produces a “dry gas” with little or no water and a deeper 900-1500 m interval (Cretaceous) that contains wetter gas and substantial quantities of saline water. Most production has been from the shallower interval. Perhaps because Alberta had the opportunity to learn from some of the problems that became apparent in the Powder River Basin, a robust regulatory regime was put in place at an early stage (Alberta Energy, 2017).

Much of the regulatory regime is focussed on water and aquifer protection in a basin with fairly complex hydraulic pathways (Park, 2009). It clearly differentiates between saline and non-saline produced water and regulates the manner in which they are handled. Most of the CSG production to date has been of “dry gas” with only a small amount of fresh water produced. Alberta also regulates well spacing and has implemented best practice in many areas to minimise environmental impact. It has a well-defined “orphan well” system in place. As in the Powder River Basin, exploration in Western Canada has now turned more to shale gas, but CSG production continues, not least because reserves are large and it provides a clean readily-useable gas with few contaminants.

The geological, hydrological, environmental and economic setting of the Narrabri region is quite different to that of the North American CSG-producing basins and care needs to be taken in extrapolating US or Canadian CSG lessons to Australia. Nevertheless, much has been learned from these overseas developments. First, they have highlighted problems that can arise from intense, inadequately regulated CSG production. But through those problems, approaches have been developed to avoid or minimise or remediate impacts.

Regulations have been put in place from which we can learn and where appropriate, apply. Not all of them are appropriate to Australian conditions, but some are. A great deal of excellent science and engineering has been generated as a result of CSG activities in North America and particularly regarding sub-surface processes; much of that knowledge can be applied in Australia.

In some instances, claims of adverse effects from CSG have been upheld overseas; in other instances, they have not. In addition, the North American CSG experience has produced new technologies that can be used for CSG production in Australia to bring down costs, enhance production and minimise impacts. This includes directional drilling, improved monitoring techniques, the use of multi-well pads and more secure well completions.

Australia

There are a number of sedimentary basins in Australia (Figure 1.1) with the potential to produce CSG. However, currently the only commercial production is from Queensland, which produces in excess of 1,000 PJ of gas a year (2015-16), and NSW which produces a modest 5 PJ of gas a year.

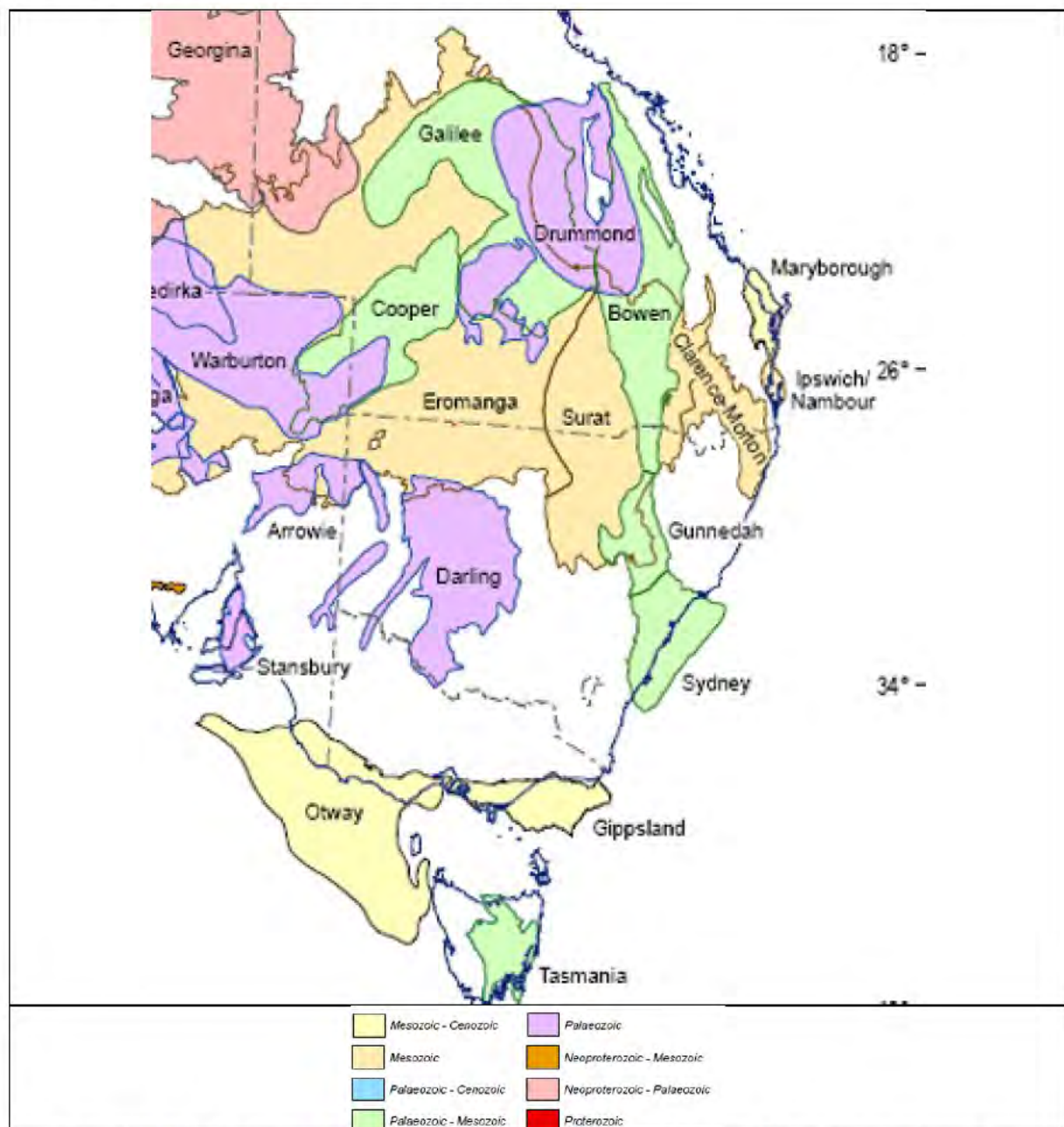


Figure 1.1: Sedimentary basins of eastern Australia (Source Geoscience Australia)

Queensland

There are two distinct CSG provinces in Queensland; the Bowen Basin and the Surat Basin (Towler et al., 2016).

The Bowen Basin is part of a massive eastern Australian coal-bearing sedimentary basin extending from southern NSW to central Queensland (Harrington, 1989). Coal mining has been underway in the Basin since 1890, but commercial exploitation of CSG did not get underway until 1995. The CSG focus has been on the late Permian coals of which the Baralaba Coal Measures and the Bandanna Formation are the most important. Initially, attention was focussed on the Moura and Fairview areas, but extending into the Scotia and other parts of the Basin in recent years.

The total area of the Basin is approximately 200,000 km², with CSG activities extending over more than 10,000 km². Production is generally from a depth range of 300-800 m, with extensive dewatering required. Because the Bowen coals are mature, their permeability is low which has meant that in-seam drilling, multi-directional wells and in some cases fracking, has been important. However, in anticlinal areas such as Fairview, the permeability of the coal is much higher, which in turn improves rates of gas production. Total CSG reserves in the Basin are approximately 10,000 PJ and annual production was 146 PJ in 2015-2016.

The Surat Basin is a large (300,000 km²) relatively thin (2500m of sediments) Mesozoic basin in SE Queensland - N NSW, extending west into the deeper Eromanga Basin and the Great Artesian Basin (GAB). It contains a number of small conventional gas accumulations, but in recent years the focus has been very much on CSG. The sediments range in age from early Jurassic to early Cretaceous. The coals are relatively low rank (immature), occur at shallow depths and are of Cretaceous age. In 2000, following a promising pilot well, and the Powder River experience, it was concluded that that low rank coals could produce CSG.

The attention of gas explorers then became focussed on the Surat Basin and in particular the Walloon Coal Measures lying between 200-600 m depth. The Walloon coals have a lower gas content than the Bowen coals, but also have a higher permeability, making it easier and more cost effective to produce their CSG. In 2014 alone, 1600 CSG wells were drilled in the Surat Basin and gas production in the Basin overtook Bowen production. By 2016, the Surat Basin had about 80% of Queensland's proven CSG reserves and was producing more than 60% of the State's CSG.

As with most other CSG basins, to produce the CSG it was necessary to bring water from the coal seams to the surface, to reduce the formation pressure and release the gas. However, the Walloon Coal Measures are also an important aquifer and a major intake area for the GAB. Therefore, managing the produced water has been a major issue for the Surat Basin gas producers and the Government.

A range of water management measures have been taken, with the number one priority being to beneficially use the produced water. Salinities range from 200 to 10,000 parts per million of Total Dissolved Solids (TDS) and a range of methods have been successfully applied to treat the produced water to a quality where it can be used for irrigation. If that is not feasible, because of the water quality or because of the large

volume of water extracted, then disposal is allowed, including re-injection, with a requirement to minimise and mitigate any impacts on environmental values.

Lowering of the water table has been a significant issue in some areas, with adverse impacts on domestic and stock wells, which has required a number of wells to be deepened or redrilled. Additionally, because the coals and interbedded sands are discontinuous, there have been concerns regarding pollution of some aquifers, including possible escape of methane.

Despite this range of potential issues, many landholders and farmers have been willing to have CSG activities on their land, in no small measure because of the financial benefits of doing so. There are also economic benefits to the wider Queensland community. At the same time, some community concerns continue to arise regarding groundwater, environmental and other impacts.

So, are there lessons for the NGP from the Queensland CSG experience? The Surat experience has highlighted the importance of having good systems and regulations in place to minimise any adverse effects arising from de-watering. At the same time, it is important to point out there are major differences between the Surat Basin and the Narrabri area, in that Narrabri coal measures are deeper and do not constitute a major water intake area nor are they a major aquifer. Consequently, the types of water issues that have arisen in the Surat Basin are unlikely to arise in the Narrabri area.

Nevertheless, the lessons learned for Queensland in terms of handling produced water will be valuable to the NGP. The Bowen experience is more relevant to the NGP in that in both basins, the CSG is from high rank coals, with low permeability, fairly continuous seams and relatively low water contents. Depths of extraction are also quite similar.

New South Wales

A number of basins in NSW have been explored for CSG, but currently the only producing area is around Camden in the southern part of the Sydney Basin. The Camden Gas Project (CGP) is a relatively small CSG project, with a total of 144 wells drilled, of which 92 still produce gas. There are a number of coal beds in the Permian Illawarra Group, with the dominant CSG sources being the relatively thin Bulli and Balmain coals, occurring at 600-700 m depth. They are overlain by a series of Triassic sediments, including a number of aquitards and several producing aquifers, the most significant being the Hawkesbury Sandstone and the Wianamatta Group.

The coals are high grade, with low permeability and relatively high salinities. After the first stimulation period, the coals produce very little water and therefore disposal of saline water has not been a major problem for the CGP. Because of their low permeability the coals have required stimulation and extensive inclined and long reach wells, to initiate and maintain gas flow.

There have been a small number of surface spills relating to CGP activities that have required remedial action. Leakage or accidental release of methane is carefully monitored by the EPA. Overall, the CGP has demonstrated that it is feasible to undertake a CSG project on the margins of an urban area but has also shown the difficulties that can arise as urban areas expand into pre-existing rural CSG-producing areas. The CGP plans to shut down its operations in 2023.

So, what is the relevance of the current NSW experience and the CGP to Narrabri? The coals of the Camden and Narrabri areas are similar, in that they are both Permian in age, comparatively dry and relatively high grade. However, the coals of the Narrabri area are thicker and have somewhat higher permeability. Consequently, fracking is not seen as a requirement to produce Narrabri gas.

In both areas, the CSG is extracted from depths of several hundred metres; there are then overlying aquitards before significant aquifers are encountered. In both areas, protection of groundwater is important, but the groundwater settings are somewhat different in that there is no significant groundwater intake in the CGP area, whereas the NGP includes an intake zone for the GAB, once again re-enforcing the message that every CSG project is different.

In considering the NSW experience, there is one initiative that warrants particular mention, which is in part an outgrowth of NSW experience but also reflects the wider experience of CSG elsewhere in Australia and internationally. The Report of the Independent Review of Coal Seam Gas Activities in NSW, undertaken by the NSW Chief Scientist and Engineer in 2013-2014, was an important milestone in terms of developing a state-wide, evidence-based approach to the approval and regulation of CSG developments.

The Report considers that the technical challenges and risks posed by the CSG industry can in general be managed through measures such as:

- careful designation of areas appropriate in geological and land-use terms for CSG extraction;
- high standards of engineering and professionalism in CSG companies;
- creation of a State Whole-of-Environment Data Repository;
- comprehensive monitoring of CSG operations with ongoing automatic scrutiny of the resulting data;
- a well-trained and certified workforce;
- application of new technological developments as they become available, and which can make CSG production safer and more efficient; and
- a clear, revised, legislative framework supported by an effective and transparent reporting and compliance regime.

The Review recognises that in areas where the detailed hydrogeology is not yet fully characterised, there could be unexpected events, learnings, or accidents and that therefore it was important for Government and industry *“to approach these issues with eyes wide open, a full appreciation of the risks, complete transparency, rigorous compliance, and a commitment to addressing any problems promptly with rapid emergency response and effective remediation”*.

A comprehensive EIS is obviously an important part of identifying any such concerns. The Independent Review, along with the NSW Government response, provides a clear basis for consideration of the land and water issues raised in the NGP EIS and these are discussed in the subsequent Chapters of this Report.

1.7 Conclusions

There is a wealth of experience in CSG production from existing operations in North America and Queensland that can be applied to the NGP. Some of that experience relates to problems that have arisen and which the NGP must avoid. Some of the early operations of the industry in particular resulted in adverse environmental impacts. But overall, with a few exceptions (from which important lessons have been learned), operations internationally and in Australia have shown that provided industry best practice is followed, CSG exploration and production can be conducted in a manner that produces significant economic and community benefits with minimal impact on the environment.

1.8 References

Alberta Energy 2017 Coalbed methane development 5p
<http://www.energy.alberta.ca/OurBusiness/753.asp>

Bleizeffer D, 2015 Coalbed Methane: boom, bust and hard lessons. Wyoming State Historical Society
www.wyomohistory.org

Barnett B, Townley L R, Post V, Evans R E, Hunt R J, Peeters L, Richardson S, Werner A D, Knapp A and Boronkay A (2012) – Australian Groundwater Modelling Guidelines, Waterlines report, National Water Commission, Canberra.

Cook, PJ, Beck V, Clark R, Fisher B, Kentish S, Toomey J, Williams J 2013 Engineering Energy – unconventional gas production Report of the Australian Council of Learned Academies Melbourne 250p
www.acola.org.au

David, T.W.E, 1887 Report on coal recently discovered near Gunnedah. New South Wales Department of Mines, Annual Report for 1886, 151-152.

Flores R M 2004 Coalbed methane in the Powder River Basin, Wyoming and Montana: An assessment of the Tertiary-Upper Cretaceous coalbed methane total petroleum system. USGS Digital Data Series DDS-69-C https://pubs.usgs.gov/dds/dds-069/dds-069-c/REPORTS/Chapter_2.pdf

GISERA 2018 Potential water impacts of coal seam gas in the Pilliga Sandstone
https://gisera.csiro.au/wp-content/uploads/2018/08/18-00384_GISERA_FACTSHEET_SGW-GABFluxFinalReport2pp_WEB_180807.pdf

Hanlon, F.N., 1950 Geology of the North-Western Coalfield—Part VIII. Geology of the Narrabri district. Royal Society of New South Wales, Journal and Proceedings, 82(4), 302-308.

Harper, L.F., 1926 Gunnedah Coalfield. New South Wales Department of Mines, Annual Report for 1925, 109-110.

Harrington, H J, et al. 1989 Permian coals of eastern Australia. Bureau of Mineral Resources, Canberra Bull 231

Johnston, C R, Vance G F, Ganjgunte GK, 2008 Irrigation with coalbed natural gas co-produced water
Agricultural Water Management 95 1243– 1252
http://ftp.musette.cr.usgs.gov/tmp/PRB_USGS/16ohnson_cbm_irrigation_2008.pdf

Kenny, E.J, 1928 Geological Survey of the Coonabarabran-Gunnedah district with special reference to the occurrence of subsurface water. New South Wales Annual Report for 1927, 130.

Myers, Tom. 2009. Groundwater management and coal bed methane development in the Powder River Basin of Montana. Journal of Hydrology – J Hydrol. 368. 178- 193

O’Kane M, 2014 Final Report of the Independent Review of Coal Seam Gas Activities in NSW
www.chiefscientist.nsw.gov.au/coal-seam-gas-review

See also <http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/csg-background-papers>

Panday, Sorab, Langevin, C.D., Niswonger, R.G., Ibaraki, Motomu, and Hughes, J.D., 2013, MODFLOW–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater

flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Techniques and Methods, Book 6, chapter. A45, 66 p

Parks K, Andriashek L D, 2009 Preliminary Investigation of Potential Natural Hydraulic Pathways Between the Scollard and Paskapoo Formations in Alberta: Implications for Coalbed Methane Production Alberta energy Regulator Report 2009-16 http://ags.aer.ca/publications/OFR_2009_16.html

Powder River Basin Resources Council 2009 Coalbed methane

<http://www.powderriverbasin.org/coalbed-methane/>

Rice C A, Ellis M S, Bullock J H, 2000 Water co-produced with coalbed methane in the Powder River Basin, Wyoming: preliminary compositional data USGS Open File Report 00-372

Sreekanth, J, Gladish D, Gonzalez D, Pagendam D, Pickett T, Cui T 2018a CSG-induced groundwater impacts in the Pilliga region: prediction uncertainty, data-worth and optimal monitoring strategies. CSIRO, Australia <https://gisera.csiro.au/wp-content/uploads/2018/06/Water-8-Final-Report.pdf>

Sreekanth J, Cui T, Pickett T, Barrett D 2018b Uncertainty analysis of CSG-induced GAB flux and water balance changes in the Narrabri Gas Project area. CSIRO, Australia <https://gisera.csiro.au/wp-content/uploads/2018/08/Water-7-Final-Report.pdf>

Swindell G S, 2007 Powder River Basin Coalbed Methane Wells – Reserves and Rates Society of Petroleum Engineers <https://www.onepetro.org/conference-paper/SPE-107308-MS>

Towler B, Firouzi M, Underschultz J, Granett A, Schultz H, Esterle J, Tyson S, Witt K 2016 An overview of the coal seam gas developments in Queensland. Journal of Natural Gas science and Engineering

https://www.researchgate.net/publication/304350462_An_overview_of_the_coal_seam_gas_developments_in_Queensland

USGS, 2000 Coal-bed methane: potential and concerns. USGS Fact Sheet PS-123-00 <https://pubs.usgs.gov/fs/fs123-00>

2. GEOLOGY

If the mineral, energy, groundwater and other natural resources of the Narrabri region are to be conserved or used beneficially, it is essential that the geology of the region is comprehensively documented and well understood. Without this knowledge, the exploitation of gas resources could have unintended consequences on the groundwater resources. This chapter describes the geological framework of the NGP area and the region around it and explains how that framework influences the occurrence and behaviour of CSG and groundwater.

2.1 Background

Some of the early history of geological exploration and the discovery of coal in the Gunnedah Basin is summarised in Chapter 1. In 1971, the first Narrabri 1:250,000 geological map was published (Wallis, 1971). Subsequently, the development of several coal mines in the district, coupled with oil and gas exploration, greatly enhanced our knowledge of the Permian-Triassic Gunnedah-Oxley Basin (GOB) sequence. The increased use of the water resources of the area, particularly for irrigation, in turn provided the opportunity to better understand the overlying sediments of the Mesozoic Surat Basin (especially the GAB), and the superficial sediments of Tertiary and Quaternary age as well as the Tertiary volcanic rocks that occur in the Narrabri region.

Section 4.5 Appendix F of the NGP EIS provides valuable information on the regional geological setting of the NGP. There are topics such as the extent of sedimentary heterogeneity, gas composition and structural considerations, where Santos has subsequently provided some additional information to the WEP. But there is a need for further consideration of these and related topics, which is addressed below.

The geology of the area is shown in Figure 2.1. Geological properties such as connectivity, rock type, bed thickness, heterogeneity and structure have a major influence on hydraulic conductivity and the manner in which resources can be extracted, the type of wells that need to be drilled and the risks that might arise from such activities. Risks such as enhanced leakage of water or gas from coal seams or aquifers or through aquitards, or the risk of lowering the water table in overlying aquifers all need to be considered.

The geological architecture provides the framework within which any ‘real-world’ hydrogeological modelling must be undertaken. For all these reasons, it is essential to have a comprehensive understanding of the geology of the area of the NPG and any surrounding areas that might be impacted by the proposed project.

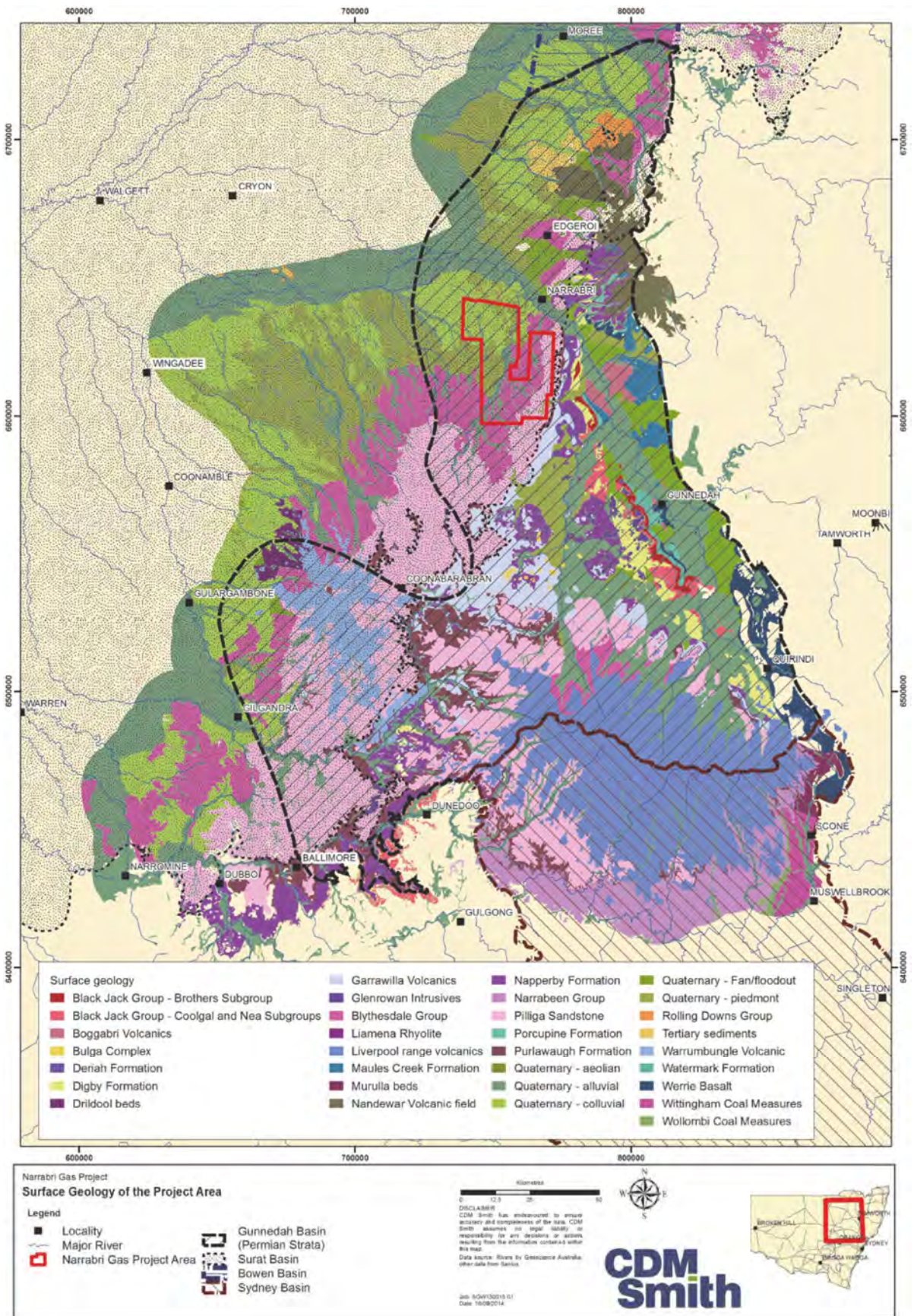


Figure 2.1: Regional geology of the Narrabri area (Source – NGP EIS Figure 11-3)

2.2 Structural geology

As documented in the NGP EIS, extensively folded and faulted Palaeozoic Lachlan Fold Belt rocks form the basement throughout much of Eastern Australia. In the early Permian, structural deformation produced the north-south trending Bowen-Sydney Basin and its series of related sub-basins, including the GOB, which in turn contain small troughs, such as the Bohena Trough, in the vicinity of the NGP. These troughs are filled with 1-2 km thick sediments of middle Permian-middle Triassic age (Tadros, 1993; Korsch and Totterdell, 2009), which then underwent late Triassic rifting, volcanism, folding, faulting and uplift.

This tectonism produced a regional unconformity on which the sediments of the Surat Basin were deposited. Tadros (1993) observes that the western part of the Gunnedah Basin retains elements of its early rift geometry, in that it is divided into north-south blocks by major cross-faults. But for the most part, the major late Triassic-age faulting and thrusting evident in the GOB does not extend up into the overlying Jurassic-Cretaceous Surat or GAB (O'Neill & Danis, 2013).

There is minor faulting and folding in the GAB which impacts on groundwater flow in some places. The Surat sequence is overlain by thin Cenozoic (late Tertiary – Quaternary) sediments (with some volcanics) in the Namoi Valley. Korsch & Totterdell (2009) note: *“To some extent fault reactivation has also continued into the Cenozoic with Surat Basin sedimentary rocks being folded and faulted, although penetration by reactivated faults is not extensive”*. The Geoscience Australia earthquake database indicates no earthquakes in the Narrabri area exceeding 1.5 magnitude.

The NGP EIS states: *“A key conclusion of the faulting study is that strata located between the target coal seams and the overlying Surat and superficial sediments are largely unaffected by faulting”*. The issue of faulting in the NGP area is taken up later in this chapter.

2.3 Sedimentary geology

The sediments of the Gunnedah, Surat and Namoi sequences within the Bohena and Bellata Troughs, are discussed in some detail in the NGP EIS and the sedimentary sequences of the NGP area are summarised in Figure 2.2 below.

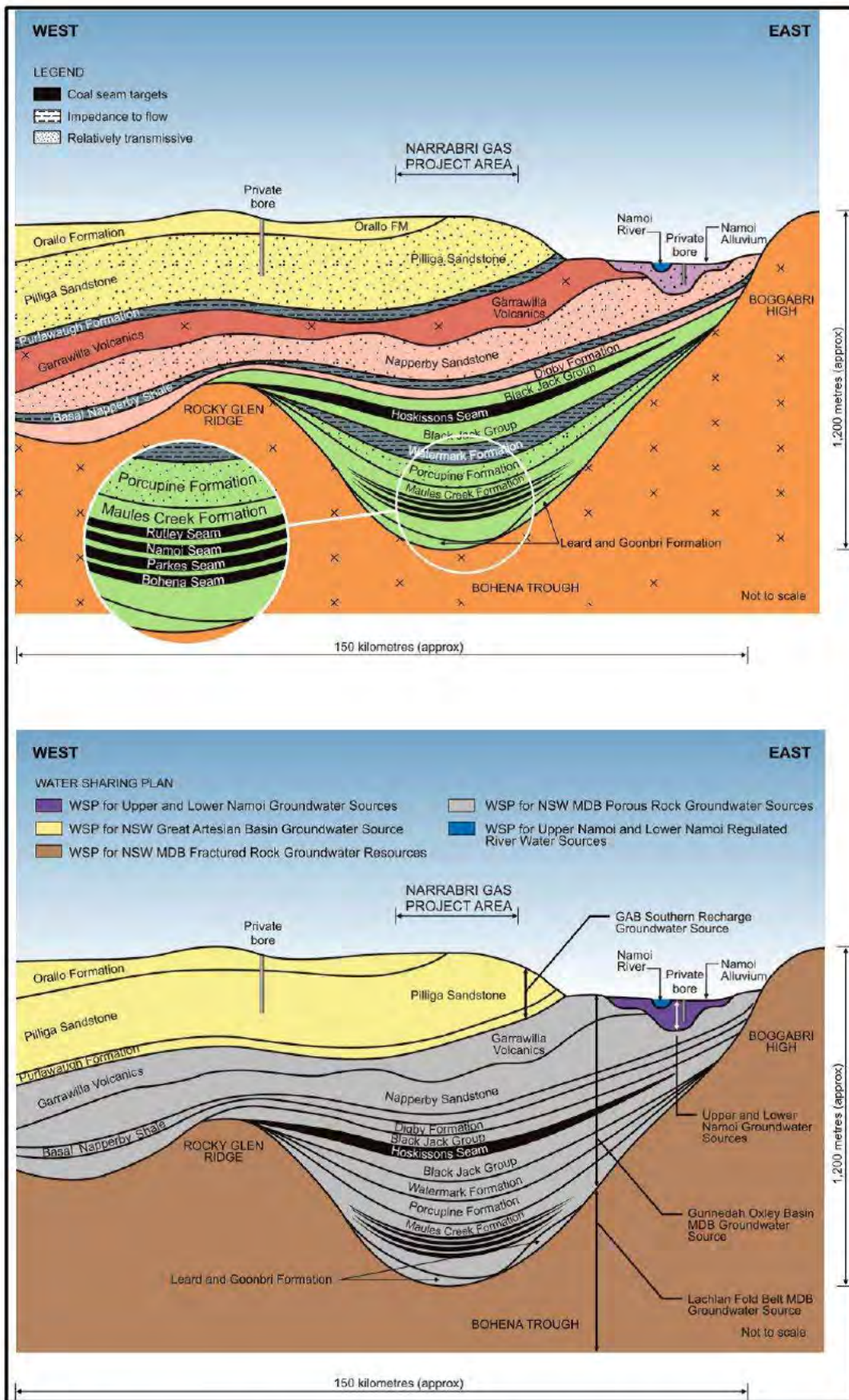


Figure 2.2: The geology of the Narrabri Gas Project area including the target coal seams and water sources (Source NGP EIS ES-4)

2.3.1 Gunnedah Basin sediments

The Late Permian - late Triassic sediments, which are up to 1000 m thick, are dominated by sequences of coals, sandstones, siltstones and mudstones of fluvial-alluvial-delta-swamp origin in the lower and upper formations and more marine-nearshore environments in the middle. As a consequence of their depositional environments, the sediments are quite variable in thickness, composition and geometry, although individual coal beds can be uniform over some distance.

Properties such as grain size, porosity and permeability in the sandy parts of the section are variable, producing a high level of heterogeneity at a range of scales, in many parts of the sequence. Laterally the sediments are highly variable in thickness; the coals tend to be more uniform, although properties such as cleating, fracturing and grade, do vary. The coal seams of the Maules Creek Formation, which are up to 8 m thick, constitute around 10% of the sequence. They range in depth below the surface from 500-1000 m and are the primary target of the NGP.

The younger and shallower Hoskissons Coal Member of the Black Jack Group, which includes coal seams up to 5 m thick, is also a target for the NGP, although it is anticipated that it will only provide 5% of total gas production. This is factored into the amount of water likely to be extracted as part of the CSG operations (Appendix F of the NGP EIS).

2.3.2 Surat Basin sediments

The Jurassic-Cretaceous sequence, which is up to 300 m thick in the NGP area includes some thin volcanics at the base, but is dominated by clastic sediments including siltstones, mudstones, sandstones and conglomerates, with a few thin and discontinuous coals. Heterogeneity is a feature of the sequence; some of the sandstones have high permeability.

The Middle Jurassic Pilliga Sandstone is a significant aquifer in the GAB. It is mapped by Pratt (1998 a and b) to extend well beyond the eastern boundary of the GAB reaching to the south of Gunnedah. However, the sandstones east of the GAB are not time equivalents of the Pilliga Sandstone. As part of a state government drilling program in the Spring Ridge area, these sandstones were dated by palynology as being Early Cretaceous in age as discussed by Martin (1980). This distinction is important, as the 'lumping together' of these rocks has led to community misunderstanding of likely impacts from the proposed NGP development, with some submissions suggesting that the whole of the NGP area is a major recharge zone for the GAB. That misunderstanding is perhaps exacerbated by public confusion regarding the locations, areal extent and recharge relevance of the Pilliga Forest, the Pilliga National Park and the NGP. As discussed in Chapter 3, this region is part of the intake beds of the Great Artesian Basin and therefore it is important to have greater clarity on the distribution of the Pilliga Sandstone, its geological and hydrogeological properties and its importance as an intake zone for the GAB. One thing that is evident from GISERA studies presented to the WEP in August 2018 and largely covered in Sreekanth et al. (2017, 2018a, 2018b), is that overall, horizontal movement of groundwater in the Pilliga Sandstone is small, being of the order of a few metres a year. The recharge rates were estimated to be less than 5 mm per year in Santos-

impacted area as compared to rates up to 45 mm per year for localised areas on the eastern side of the Coonamble Embayment to the south (Smerdon and Ransley, 2012).

Key Observation 1

The volume of water that provides the recharge in the NGP area to be developed by Santos is relatively small compared to that of the dominant area of recharge in NSW to the south along the eastern flank of the Coonamble Embayment of the GAB.

Recommendation 1

The WEP recommends to Government that when the Narrabri region is next mapped, consideration should be given by the Geological Survey of NSW to remapping and renaming the time-discordant Pilliga Sandstone east of the GAB, to better reflect its setting, age and lithological properties and to eliminate the current confusion regarding its geographic and geological distribution and its significance to GAB recharge.

2.3.3 Surficial sediments

Within and adjacent to the Namoi Valley and overlying the Gunnedah and Surat sequences, there is up to 170 m of Pliocene to Recent unconsolidated, alluvial, high permeability channel sands and gravels (important aquifers in places) with interbedded clays.

The transmissivity of these geological formations exerts a major control on the hydrogeology of the NGP area and is considered at length in Chapter 3.

2.3.4 Hydrogeology

The Gunnedah sequence is typically low in permeability and does not contain any major aquifers. However, the occurrence of the Wilga Park 1 conventional gas well located 12 km WSW of Narrabri, in the upper Digby Formation (a medium to coarse grained quartzose sandstone) and the Coonarah 1/1A gas well located 23 km west of Narrabri, with porosities of up to 13% and permeability of over 700 millidarcies (Cadman & Pain 1998), indicates that there is some transmissivity within the Basin.

Amongst the coal seams, the Hoskissons Seam has somewhat higher permeability than the deeper seams and could perhaps be regarded as a low yield aquifer, although its water quality is poor. The stratigraphic control on the hydrogeology is evident in Table 1.2, with marked variations in the hydrochemistry of the various geological formations.

The basal Purlawaugh Formation of the Surat sequence is regarded as an aquitard. The overlying Pilliga Sandstone is an important regional aquifer in the vicinity of the NGP and further west. But its importance in terms of GAB recharge is a disputed issue,

in that the NGP EIS considers it to be insignificant, whereas a number of Special Interest Groups (SIGs) consider it to be very significant (see Chapter 3).

The degree of connectivity in the NGP area, between the GOB, the GAB and the surficial sediments, is an important issue that is also considered in Chapter 3.

2.5 Geological risk and uncertainty

It is apparent from the discussion above and from the NGP EIS, as in other geologically-based projects in the NGP area, there are knowledge gaps regarding the subsurface geology and hydrogeology. Again, as with other similar projects the knowledge base will be greatly enhanced as work proceeds, new data collected and uncertainties resolved. Some of these geological uncertainties may in turn translate into geological risks, which can be mitigated by obtaining more information or re-analysing existing information or by adaptive management. It is important to emphasize that uncertainties and risks are an inevitable feature of every resource project. Their management is an integral part of, and standard practice in every resource project, for there are always some knowledge gaps and uncertainties that can only be resolved by collecting new information as a project proceeds.

The O’Kane Review considered the risks associated with the CSG industry in depth and concluded *“provided drilling is allowed only in areas where the geology and hydrogeology can be characterised adequately, and provided that appropriate engineering and scientific solutions are in place to manage the storage, transport, reuse or disposal of produced water and salts – the risks associated with CSG exploration and production can be managed”*.

Consistent with that conclusion, this WEP review of geology and hydrogeology, aims to identify any key areas of uncertainty that need to be resolved, in order to decrease or manage risk. Perceived geological uncertainties or risks which are addressed in the remainder of this chapter, include:

- geological data relating to lithology (porosity, permeability, composition, etc.) of the sediments;
- composition and possible subsurface behaviour of gas;
- extent and nature of sedimentary heterogeneity and its potential influence on transmissivity/connectivity on CSG production and on groundwater extraction;
- occurrence and extent of faulting or other discontinuities and any risks arising from them;
- prospect of ground movement associated with CSG operations;
- geological connection between the various basins (also discussed in the next Chapter); and
- possibility of induced seismicity.

These and related issues are considered in some detail in the NGP EIS. The remainder of this chapter considers whether additional information might be required and what additional steps might be taken to manage uncertainty or risk.

2.6 Gas occurrence and composition

Unlike conventional gas, CSG usually has very little ethane and no higher hydrocarbons; it is generally low in nitrogen; hydrogen sulphide can be present in minor amounts in some sulphur-rich coals. Rarely, radon has reported to be associated with some CSG occurrences (Ko, Ko and Ward, 1996). The carbon dioxide content of CSG can be quite variable, from as little as 1% or less, up to 20% or more, at which stage it may be uneconomical to produce the gas.

The focus of the NGP is on CSG from the coals of the Maules Creek and Hoskissons intervals. A number of concerns were raised in submissions by SIGs regarding gas composition and implications to pollution, safety and other issues. There are known to be some high-CO₂ wells in the Gunnedah Basin, but overall, there is little publicly available information on CO₂ in the NGP area. In many basins, CO₂ concentrations in CSG vary from one coal seam to the next, depending on depth or type of coal, or on the impact of post depositional processes such as thermal or microbiological events.

For example, it is likely the composition of CSG in the Maules Creek coals will be somewhat different to that of the shallower Hoskissons coals. The concentration of carbon dioxide in CSG can be a significant economic issue. The economic aspects of the NGP are not the concern of the WEP. Fugitive emissions to the atmosphere, including CO₂, are monitored by the EPA and do not fall within the terms of reference of the WEP. But there can also be subsurface consequences arising from the occurrence of CO₂ in CSG.

High concentrations of CO₂ in groundwater or produced water may have implications for water treatment and water quality. It may also have implications in terms of gas-rock-water interactions, which can increase or decrease permeability for example. The occurrence of CO₂-rich CSG can also have implications for the choice of steel or the need for CO₂-resistant cements for well completions and abandonments and this is considered further in Chapter 6.

The WEP (Water Expert Panel) sought information about gas composition, especially carbon dioxide, from Santos but the company has declined to provide such information on the grounds that “*detailed spatial information of gas is commercial in confidence*”. The WEP recognises the commercial relevance of the gas composition. For that reason, it has not sought detailed spatial or compositional information, suggesting instead that Santos provide an average value and an indication of variability in CO₂ concentration so that the WEP might comment.

Santos has stated it “*will design, construct, operate and, plug and decommission wells in accordance with the Code of practice for CSG well integrity (NSW Government 2012) and industry best practice to ensure their integrity throughout the life of the development and into perpetuity (once decommissioned).*” Also “*While the CO₂ concentration can be variable across the Narrabri Gas Project area, it is understood by Santos what impact this will have on the well design. This understanding allows Santos to analyse, and if required build in additional control measures to the*

engineering design and operating procedures throughout the life of the development and into perpetuity”.

The WEP finds this statement reassuring but is nonetheless of a view that there would be benefit in a more transparent approach to the issue of gas composition given the level of interest in this topic, evidenced by the fact that it was raised in a number of submissions.

A number of submissions from SIGs expressed concern about the possible presence of hydrogen sulphide and the impact on CSG if it were to be high in hydrogen sulphide. Monitoring for H₂S, like CO₂ falls within the remit of the EPA, but it does have potential significance to corrosion of subsurface equipment and to water treatment. As indicated above, hydrogen sulphide is seldom present in CSG, but biogenic H₂S can occur in sulphate-rich groundwater due to the action of sulphate-reducing bacteria. The NGP EIS (Appendix F) provides data on the composition of groundwater in the Maules Creek and Hoskissons Formations. Table 5-15 gives a sulphate value for the Maules Creek Formation of 68.9 ppm, with a maximum value of 1,305 ppm. Given the elevated pH and relatively low sulphate concentrations, H₂S in the CSG is considered by the WEP to be unlikely to be a significant issue for the NGP target formations. This is supported by further information provided by Santos in response to a question from the WEP. This indicated that the sulphate ion concentration in the produced water is low, being in the range 2-213 ppm, with the pH being high.

In its response to WEP questions regarding gas composition, Santos stated that *“the composition of gas from coal seams (is) almost entirely comprised of methane (CH₄) carbon dioxide (CO₂) nitrogen (N₂) water vapour (H₂O) and small traces of ethane (C₂H₆).”* Based on Santos’ track record elsewhere, of successfully and safely producing and processing gas with a range of compositions, the WEP considers that Santos is well equipped to deal with the range of gas compositions likely to encountered in the NGP.

Recommendation 2

The WEP recommends Santos makes comprehensive data on the composition of CSG available to Government on a regular basis because of its implications to subsurface equipment and processes and to related regulations.

The other area of potential concern regarding gas relates to the unanticipated migration of CSG to the surface or into water wells or standing bodies of surface water. In Queensland for example, the leakage of methane into the Condamine River near Chinchilla has received a great deal of media and public attention, although the extent to which the leak is directly tied to large scale CSG production in the Surat Basin is not clear. A number of deep water wells in the GAB have been known to leak methane over many years which clearly has no relation to CSG production. Additionally, high CO₂-CSG has a different risk profile (CO₂ is an asphyxiant) to ‘pure’ CSG, which needs to be factored into a risk management strategy. In the unlikely event that gas high in H₂S, were to occur within the NGP area, this would have health and safety implications that would be managed as part of normal gas field procedures.

Key Observation 2

Based on the evidence presented in the EIS and the depth from which the CSG will be produced, provided the wells are completed to industry best practice the WEP considers the risk of migration of methane into overlying aquifers is low to very low.

An initial difficulty for the WEP in seeking to evaluate any of these potential concerns regarding gas composition was that the NGP EIS provided little information on existing surface or near surface occurrences of gas. However, in response to questioning by the WEP, Santos has provided information on methane occurrences in some bores. It is unclear how representative of existing bores these particular bores are. The depth of the CSG coals and the low permeability of the coals and the adjacent sediments suggests that unanticipated leakage of CSG to the surface is not likely to be a major issue, but it cannot be totally discounted at this stage, given the limited baseline information on gas occurrences.

Elevated levels of methane in some of the deeper non-coal Triassic formations is not unexpected and may relate to seepage from deeper coals or from conventional gas accumulations. The occurrence of relatively high concentrations of methane in some of the groundwater derived from the Namoi alluvium is also not entirely unexpected. However, it would be prudent to fully document these occurrences and determine their likely source, prior to major CSG developments in the area.

Additionally, it may be prudent to document known occurrences of methane at the surface or in wells or water bodies in the Narrabri region, prior to commencement of the NGP, not because migration of gas from CSG operation is seen by the WEP as a high risk, but because it would provide a base against which any future concerns regarding gas leakage or migration, could be evaluated. Santos has indicated new data has now been collected that may help to address this gap.

Recommendation 3

The WEP recommends that Santos enhances its documentation of natural leaks and accumulations of methane in wells, at the surface and in water bodies in and around the area of the NGP prior to commencement of any large-scale gas production. This will provide a comprehensive baseline against which environmental changes might be assessed. It also recommends that this information be made publicly available.

2.7 Geological heterogeneity

Heterogeneity in sediments can have a major influence on groundwater and produced water, the engineering of production wells and the migration of gas. It is evident from the NGP EIS and other information available on the coal-bearing sediments of the Gunnedah Basin, that geological heterogeneity is a feature at all scales. This can

impact on the level of confidence in the geological model and in turn, on the groundwater model.

This level of heterogeneity is to be expected, given the Permian-Triassic depositional environments that prevailed in the Gunnedah Basin area included fluvial, alluvial, delta and nearshore, which typically produce channelling, washouts and seam splits. Related to this, there is likely to be a high degree of lateral and vertical variability in the surrounding sediments. Much of the fine heterogeneity will be below the level of seismic resolution presently available to the NGP but can be seen in cores and well logs.

The number of wells currently available in Gunnedah sediments is limited and consequently in most areas, there is a high level of uncertainty attached to any extrapolations between wells. The cross sections provided in the NGP EIS are low resolution and not optimal for providing an indication of heterogeneity. This could be improved through high resolution seismic profiling or more drilling, or both.

In the NGP EIS, the project has used standard depositional models for the Gunnedah and Surat sedimentary systems and in the hydrogeological models, which is a realistic approach given the level of data availability. However, given the presence of a number of coal mines in the area, the WEP suggests the opportunity may exist to take a more quantitative approach to modelling heterogeneity in the coal measures in particular. This could be done by inspecting and documenting rock exposures within the mines, which could be used to develop more quantitative geological models which can then be extrapolated to areas of the NGP.

It would be useful also to have greater certainty regarding variability and heterogeneity in the Surat sequence. The major aquifers are generally taken to be fairly homogeneous within the GAB, but as pointed out below, discontinuities such as faults can have an impact. Additionally, there is some dispute regarding the geometry of the base of the Surat Basin. For example, in some areas, the Purlawaugh Formation, an aquitard, occurs at the base of the formation, but this is not the case everywhere, which in turn may have implications to connectivity.

There is known to be a high degree of heterogeneity within the Namoi sequence – a function of its alluvial depositional environment. This has an impact on groundwater flow, but the fact that the Namoi sequence is dealt with as a single hydrogeological unit (or as Upper and lower Namoi) and the scale at which it is modelled, probably means that the level of knowledge is adequate.

It is a concern to the WEP that according to the NGP EIS (Appendix F, 5.3.1), there have only been measurements of permeability on 30 rock samples from the project area although some indirect values have been obtained via drill stem tests. This small number of measurements does place some constraints on understanding heterogeneity in the Project area. Nonetheless, Appendix F (particularly Sections 4 and 5) does provide an extensive discussion of how permeability and sorption coefficients were chosen and demonstrates the sensitivity of the model's predictions to different permeabilities.

The NGP EIS approach of bounding the problem based on extrapolation of existing data is seen as plausible. This suggests that even with higher assumed permeability,

drawdown can be predicted with a reasonable level of confidence. Nonetheless, few actual porosity and permeability measurements have been built into the NGP models, with some of the values used being generic, or from places far removed from the Narrabri area.

The risk of unintended groundwater movement or contamination or gas leakage, is small (as documented in the NGP EIS). But any residual uncertainty could perhaps be further decreased if there was greater confidence in the magnitude and nature of heterogeneity and in the geological model. For example, it would be beneficial to have more measured GOB, GAB and Namoi porosity and permeability values used in future modelling as the NGP progresses.

Recommendation 4

The WEP recommends that as a wider range of sub surface samples becomes available during further appraisal work, Santos obtains additional reliable data on geological heterogeneity and on rock properties such as permeability, especially for the Gunnedah and Surat Basins. This additional information should be used in future modelling and be made publicly available.

2.8 Subsidence

The large-scale extraction of oil and gas has resulted in significant ground subsidence in some parts of the world, for example California. Similarly, where there has been extensive extraction of groundwater for irrigation or for urban or industrial use (Bear, 1979) there has been major subsidence in some areas, especially where the sediments are poorly consolidated. In NSW, some subsidence is known to have occurred in association with groundwater extraction from alluvial aquifers in the lower Namoi Valley (Ross and Jeffery, 1990).

It is well known that subsidence can occur when pore pressures are reduced, the pore space reduced and the weight of the overburden then borne by the grain matrix (e.g., Pineda and Sheng, 2013). This can result in deformation, compression, changes in the rock stress and surface sag. The process is time dependent on the rate at which the groundwater or pore water is withdrawn and the rate at which the rocks compact.

Depending on its magnitude, subsidence can impact on flow paths and on infrastructure. However, the magnitude is also highly dependent on the compressibility, not only of the coal seams from which the CSG is extracted but also of the overlying sediments. Little information is provided in the NGP EIS on the mechanical properties of the rocks in the NGP area, but it can reasonably be assumed that the deep sediments of the Gunnedah Basin are strongly indurated, have high mechanical strength and stiffness and are relatively incompressible, with the possible exception of the coals.

The shallow surficial sediments of the Namoi Valley are unconsolidated and likely to have low compressive strength. The Surat sediments probably lie between these two extremes. As already noted, subsidence has occurred in the surficial sediments of the Namoi Valley, where there has been extensive near-surface groundwater extraction.

In contrast, CSG production and associated groundwater abstraction (which can be of an order of magnitude less than the volumes of water extracted for irrigation), will be undertaken at much greater depths, from Gunnedah sediments likely to be characterised by high mechanical strength and stiffness and low compressibility.

A number of submissions expressed concern that dewatering/depressurising of the coals, could result in subsidence. In its response Santos states: *“the potential for the project to cause subsidence at depth and at the land surface due to depressurisation of the targeted coal seams was assessed in the groundwater impact assessment (EIS Appendix F). The assessment concluded the potential magnitude of subsidence due to the project is likely to be minor and not a concern. The maximum predicted compaction at the depth of extraction is 205 mm and is not likely to cause subsidence at the land surface”*.

The WEP agrees with this assessment and regards the risk of significant surface subsidence associated with best-practice CSG operations within the area of the NGP as very low. It is technically feasible to manage and mitigate subsidence associated with CSG by reinjection of produced water back into the coal seam to restore the formation pressure. But it is judged unlikely that this will be necessary.

Were any subsidence to occur in the NGP area, it would more likely to be associated with groundwater abstraction from the high-yield unconsolidated surficial sediments of the Namoi Valley. However, the rules of the Water Sharing Plan to ensure sustainable take of water would serve to limit the likelihood of this occurring.

Recommendation 5

The WEP considers that the risk of subsidence associated with the NGP is low to very low. However, consideration could be given by Government and Santos to establishing an accurate topographic baseline survey in the Narrabri region via interferometric synthetic aperture radar (INSAR) with periodic re-runs, to monitor any subsidence associated with large scale irrigation or CSG extraction.

2.9 Faulting

The NGP EIS (Appendix F, p4-29) states *“the majority of faults in the project area are Permian to Triassic in age and mainly displaced Permian and (to a lesser extent) Triassic strata. The amount of displacement is less than 100 m. From the seismic data no evidence was found of large post-Jurassic faults that displace Jurassic strata and extend into underlying Triassic and Permian strata. Where it is present, surface faulting and displacement in the Jurassic strata was found to be minor.”* On the same page of the NGP EIS, it is stated that during the Tertiary there was *“gentle folding of Jurassic rocks with very minor fault reactivation”*.

In the same section of the NGP EIS (p 4-28) it is observed that *“Information provided by Santos on major faulting in the project area, including fault types, their extents and probable ages (Figure 4-11) show a relatively poor correlation between these results and the existing large-scale mapping of faults in the OZSEEBASE datasets”*.

In section 7.4.3 of Appendix F, it is stated *“On the basis of the faulting investigation and associated interpretation, the individual fault zones within the project area are considered to be unlikely to act as conduits for preferential groundwater flow or gas migration between hydrostratigraphic units in the Gunnedah-Oxley Basin (Triassic to Permian age) or between groundwater sources in the GAB (Cretaceous to Jurassic age) or shallow alluvial systems (Cenozoic age).”*

A number of submissions such as that of the North West Alliance, considered that there was insufficient information provided on faulting. The submission from the IESC recommended that further consideration of the scale and extent of faulting in the region was needed. It also recommended that there was a need to consider the likely impact on groundwater and on post-gas extraction, arising from the exclusion of faulting from the groundwater model.

Turnadge et al. (2018) document faults, intrusive structures (mud volcanoes, sandstone dykes, igneous intrusions) and pipes within the Gunnedah Basin, which have the potential to disrupt seals and permeability. The EIS reports that in the vicinity of the NGP, faults are the most common of these features, though there are some pipes.

Sreekanth et al. (2017), state: *“Further studies are required to quantify the presence of faults on the flux changes induced by CSG development”*. In Appendix F (section 6.4.2) of the NGP EIS, it is stated *“Faults are omitted from the geological model on the basis of recent assessment of the potential for faults to provide preferential pathways for leaking of water and hydrocarbons between coal seam targets within the Gunnedah Basin and the overlying shallow groundwater sources in the Surat basin and Namoi alluvium. Based on the current interpretation of faulting within the study area it is thought that individual faults are unlikely to act as conduits for induced preferential flow under coal seam development and therefore they do not need to be specifically represented in the groundwater flow model.”*

Although dealing with a very different geological environment to that of the NGP region, Cohen and Sitar (1999) make the observation *“2-D cross-sectional models traditionally used to examine flow in faulted formations may not be appropriate. In addition, the influence of a particular type of fault cannot be generalized; depending on the location where contaminants enter the saturated zone, faults may either enhance or inhibit vertical dispersion”*. Their comments serve to highlight the problems encountered in modelling the hydrogeological impact of faulting or excluding faults from the model.

The WEP does not suggest that one model should be used for the NGP in preference to another. However, it is concerned that the exclusion of faulting from the hydrogeological models, could have some impact in terms of predicting flow paths and that this needs further consideration.

In its response to a number of submissions relating to modelling undertaken for the NGP, Santos states: *“the conceptual hydrogeology of the project area is not disputed by the hydrogeological community and the use of alternative groundwater conceptual models for the project area is therefore not justified”*. Santos also comments in its response to the submissions *“multiple lines of evidence indicate most known faulting within the project area is of small-scale and doesn’t extend into the overlying*

formations. Potential impacts on groundwater flow due to faulting is therefore considered to be highly unlikely. There is no evidence to contradict this view.”

In its response to the comments of the IESC, Santos states: *“In general faulting within the project area is small-scale and sparse with most structures only identifiable on single seismic lines with associated fault throws of 5 to 40 m compared to 50 to 100 m of total formation thickness. There is no evidence that the faults extended into the overlying formations.”*

The NGP EIS does not provide any detailed cross sections or structure maps that might serve to clarify the fault pattern. Figure 4-11 in the EIS Appendix, does provide a map showing fault patterns, but at very small scale. Additionally, there are no seismic cross sections to illustrate the nature and magnitude of faults within the area of the NGP. The schematic of the hydrostratigraphy of the project area (Figure 6-12 of the NGP EIS) shows a simplistic ‘layer cake’ approach with no faulting indicated.

The NGP EIS suggests there is evidence of some reactivation of faults but gives no quantification of the scale (other than to describe it as minor). Nor does it indicate whether these reactivated faults or any other faults are likely to be transmissive. If the faults reflect a compressive regime, it is likely that they are for the most part sealing (non-transmissive) faults (there is no information provided on the stress field in the NGP EIS to confirm this).

The response of Santos to comments from the IESC is that *“Most faulting within the project area is considered to be compressional and is believed to be associated with the closure of the Bowen Gunnedah Sydney basinal system during a middle Triassic”*. It is unlikely that the “original” compressional stress field would have remained unchanged since the Upper Palaeozoic, given that there was a major subsequent change in the stress field in eastern Australia.

There is evidence of neotectonics in the region, with a recent fault with a scarp of about 4m affecting the Namoi downstream from Narrabri. This fault is probably an example of reactivation of a much deeper and older fault, possibly initiated in the GOB sediments. It is known from the Surat Basin in Queensland that neotectonics and the related stress field can have a major impact on the transmissivity of faults, on the productivity of CSG wells and on the occurrence of natural leakage of methane. It is unclear if this might be the case in the NGP region, but it does suggest that the issue needs consideration.

But it is not just the issue of the transmissivity of the actual fault; there is also the issue of vertical displacement and whether or not that displacement might juxtapose two transmissive intervals with formation water of different salinities? The NGP EIS suggests that most faults have vertical displacements in the range of 5-40 m compared to hydrostatic formation thicknesses, which are in the range of 50-100 m. However, given the probability of heterogeneity within thick ‘bundles’ of sediment in the defined hydrostratigraphic units, it is still possible that a throw of say 40 m on a fault, could juxtapose different transmissive units, producing an impact on groundwater flow that would not be evident from the model.

The issue raised in the NGP EIS of a poor correlation between the Santos fault data and the patterns of faulting evident in the OZSEEBASE data set is attributed to

differences of scale, but again serves to highlight the need for further consideration of the nature and extent of faulting in the NGP area.

The O’Kane Review was rightly concerned to ensure that *“drilling is allowed only in areas where the geology and hydrogeology can be characterised adequately”*. Based on the information available to date, the WEP is not confident that the information provided in the NGP EIS on the structural setting of the NGP, meets the threshold of being “adequately characterised”.

Why is this of concern? The presence, or absence of faulting can have an impact not only on groundwater flow but also on the risk of gas migration and pollution of aquifers. As stated earlier, if the area is within a compressive regime, then the faults may not be transmissive, but the lack of evidence to support the compressive model, for example through geomechanical analysis of core or downhole measurements, is seen as a weakness.

Geological faulting in the Gunnedah Basin has the potential to enhance the hydraulic connectivity between rock layers, if there are major fault zones that extend through multiple formations that could channel the flow of groundwater, particularly in the vertical direction.

According to the NGP EIS: *“the majority of faults in the project area are Permian to Triassic in age and mainly displace Permian and, to a lesser extent, Triassic strata.”* (Section 4.5.11 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017). It is therefore reasonable to assume that if these faults and fault zones provide preferred pathways for the migration of dissolved salts, then significant migration, at least by diffusion through the fault zones (but also possibly by advection through this zone), would have occurred already. However, the vast differences in TDS values for the upper and lower aquifers provide strong evidence that diffusion (or even advection) via the faulting (or through the rock layers themselves) has probably not been significant in the past.

Nevertheless, the question remains of whether migration through the fault zones could occur in the future, particularly by advection if there was a preferential hydraulic gradient for flow upwards from the more saline coal bearing strata to the less saline GAB.

For a considerable period of time after decommissioning of the Project the overall hydraulic gradient in the sediments is predicted in the NGP EIS to favour downward flow of groundwater. Therefore, it is unlikely that there would be any significant migration of dissolved salts upward by advective flow, at least for a very long period of time after decommissioning.

Furthermore, in addition to the likelihood of advective flow being downward, osmotic effects are also likely to favour the downward migration of groundwater to the more saline aquifers at depth. For example, if the salt content of these aquifers is one-third that of seawater, the osmotic pressure exerted on non-saline water is perhaps as large as 15 atmospheres, or approximately 150 m of head.

The NGP EIS concludes that the individual fault zones within the project area are *“unlikely to act as conduits for preferential groundwater flow or gas migration between hydrostratigraphic units in the Gunnedah-Oxley Basin (Triassic to Permian age) or*

between groundwater sources in the GAB (Cretaceous to Jurassic age) or shallow alluvial systems (Cenozoic age). Overall, the risk of changes in the vertical connectivity between groundwater sources due to activation of vertical groundwater flow in faults that could be induced by depressurisation of coal seams was assessed by Santos to be very low.” (Page 7-7 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017).

Santos considers that whilst there are some larger fault structures on the margins of the basin or associated with intrusive activity, these “*generally do not extend into the overlying Jurassic strata which remains largely unstructured*”. Santos has interpreted thousands of kilometres of 2D seismic lines of various vintages (from the 1960’s onwards) and believes there is no evidence of faults displacing key aquitard layers and states “*there is no evidence that deep faults extend up through the overlying formations*”, i.e., faults that extend from the GOB into the GAB. Nonetheless, faults have been identified on single seismic lines by Santos with throws of 5-40 m. As pointed out by Smerdon and Turnadge (2015), faults vertical to the flow path with a displacement of 25-50 m in the GAB can have a major impact on hydraulic head.

In the NGP EIS (Appendix F, Section 7.4.3) it is stated “*on the basis of faulting investigations and associated interpretation, the individual fault zones within the project area are considered to be unlikely to act as conduits for preferential groundwater flow or gas migration between hydrostatic units*”. Whilst this may be so, the evidence in support of this view is not presented. In its submission, the Department of Industry – Water, considers “*there is a need for more detailed cross-sections of the whole geological/hydrogeological profile from the geological model and the groundwater model*”. If this were to be done it could serve to address the concerns of the WEP.

Santos provided the WEP with a high resolution image of a seismic line (EB08-06) acquired in the project area, with key seismic horizons interpreted. In the image, both the Gunnedah and Surat Basin strata show a relatively simple structure in the Dewhurst area of the Bohena Trough, where the project is proposed. Also, basic structure maps for the top Maules Creek formation and Base Jurassic interpreted horizons respectively suggest that there are no faults that affect the overlying Cretaceous and Jurassic strata (Surat Basin) which contains the main aquifer zones.

Key Observation 3

Based on the evidence presented in the EIS, the WEP considers it unlikely that faulting constitutes a major risk to the NGP or is likely to have a major impact on groundwater flow

Santos also points out that “*reservoir pressure data indicates that the early Permian (Maules Creek formation) and overlying late Permian (Black Jack Group) and younger strata have different pressure gradients and are therefore isolated from one another*”. Also, Santos states “*Two separate pressure trends are apparent in this data for the Late Permian Black Jack Group and Early Permian Maules Creek Formation respectively. The two trends are separated by an average of approximately 50 psi.*

The data indicates that the Black Jack coals are normally pressured for their depth, and the deeper Maules Creek coals are over-pressured by an average of 50 psi”.

Based on the information provided in the NGP EIS, and the large amount of seismic interpretation undertaken by Santos, the WEP accepts it is unlikely there are major unrecognised faults in the NGP area that have displaced Jurassic sediments and that would have a major impact on CSG operations or groundwater flow. Nonetheless, the possibility exists that more subtle structures could have a significant local impact. Such structures are unlikely to be evident from 1960's vintage surveys. The WEP is also of the view that an assessment of neotectonic features in the NGP region could be a valuable addition to the existing structural data sets.

Recommendation 6

Although the WEP does not believe there is evidence of any major geological structures that would adversely impact on CSG production, it recommends that as the project proceeds and as new information emerges, Santos:

- undertakes a more detailed structural assessment at a resolution that meets modern petroleum industry standards;
- undertakes an assessment of neotectonics and the stress field in the NGP and adjacent areas;
- assesses the impact of excluding faulting from groundwater modelling (supporting the recommendation of the IESC); and
- makes new structural information publicly available.

2.10 Induced seismicity

Induced seismicity can occur as a result of a range of sub-surface - near surface activities including hydraulic fracturing, subsurface disposal of wastewater from industrial or gas and oil activities, the development of enhanced geothermal systems (by injecting water into hot, low-permeability rocks) or loading due to large dams. Some of the submissions express concern about the prospect of fracking being undertaken as part of the NGP. However, Santos is clear that it will not undertake fracking.

The issue of induced seismicity associated with unconventional gas production has commanded a great deal of attention in the USA in recent years. Some oil and gas activities have produced small, mostly non-damaging seismic events and fracking is often held out as the likely cause, though as pointed out by Baptie et al. (2016) *“the probability of felt earthquakes caused by hydraulic fracturing for recovery of hydrocarbons is very small. Over 1.8 million hydraulic fracturing operations have been carried out in the US in ~1 million wells and there are only three documented cases of induced earthquakes conclusively linked to hydraulic fracturing for shale gas recovery. The largest of these earthquakes had a magnitude of 3.0”.*

A more likely trigger is the injection of produced water. For example, in Oklahoma, there has been a massive increase in seismic activity in the past decade, compared to the historic record of seismicity. This is related to fluid injection and optimally oriented faults in crystalline basement (McCarr, 2014).

In the case of the NGP, there is no intention to hydraulically frack the coal seams or any other formations. Additionally, there is no plan (nor would it be approved under current NSW regulations) to dispose of any produced water into or below the GOB.

In the absence of hydraulic fracturing and deep reinjection of produced water, are there any other circumstances where production of groundwater or CSG could produce microseismic events? It is conceivable that there could be some small-scale displacement of GOB rocks during extraction of groundwater, but the quantities of water extracted as part of the NGP are quite modest compared to the quantities extracted for irrigation for example.

Consequently, even if there were to be any detectable seismic events, there is no reason to believe they would be damaging events. Could there be reactivation of existing faults within the GOB or GAB sediments? Assessing this risk is inhibited to some extent by the very limited amount of information on faulting in the region, although the area is characterised by low seismic activity at the present day. Nonetheless, as discussed previously there are neotectonic features in the region.

Key Observation 4

The WEP considers, in the absence of any deep reinjection of produced water, the probability of induced seismic activity associated with the production of CSG in the NGP area, is very low and the risk of a damaging seismic event associated with CSG production to be extremely low.

2.11 Conclusion

The sort of risks and uncertainties facing the NGP, because of geological data or knowledge gaps, are much the same as those facing many other onshore gas projects. As is standard industry practice, these gaps will need to be addressed and the risks progressively managed if the project proceeds. Based on its successful record of gas exploration and production to date, the WEP believes that Santos has the capability to successfully address current NGP geological uncertainties and to manage ones that might arise in the future.

2.12 References

Baptie B, Segou M, Ellen R, Monaghan A 2016 Unconventional Oil and Gas Development: Understanding and Monitoring Induced Seismic Activity. *British Geological Survey Open Report*, OR/16/042. 92pp.

<https://beta.gov.scot/publications/unconventional-oil-gas-understanding-monitoring-induced-seismic-activity/pages/3/>

Cadman, S.J. and Pain, L, 1998 Bowen and Surat Basins, Clarence-Moreton Basin, Gunnedah Basin, and other minor onshore basins, Queensland, NSW and NT. Australian Petroleum Accumulations Report 11, Bureau of Resource Sciences, Canberra.

Cohen, A.J.B. and Sitar, N. 1999 Influence of faults on groundwater flow and transport at Yucca Mountain <https://www.osti.gov/servlets/purl/926686>

IESC 2014 Aquifer connectivity within the Great Artesian Basin and the Surat, Bowen and Galilee Basins. Department of Environment, Canberra http://www.environment.gov.au/system/files/resources/004450a8-cf4f-4666-96b2-7be88a10add3/files/background-review-aquifer-connectivity_0.pdf

Korsch RJ and Totterdell JM 2009 Subsidence history and basin phases of the Bowen, Gunnedah and Surat Basins, eastern Australia. *Australian Journal of Earth Sciences*

Martin H A, 1980 – Report on the Year's work as Post Doctoral Fellow. School of Botany. UNSW (unpubl.).

McGarr, A. 2014 Maximum magnitude earthquakes induced by fluid injection. *J. Geophys. Res. Solid Earth*. Vol 119 No 2

McNamara, DE et al. 2015 Efforts to monitor and characterize the recent increasing seismicity in central Oklahoma. *The Leading Edge* June 2015 9 special volume on Injection-induced seismicity 56, 335–353

O'Neill C, and Danis C, 2013 – The geology of NSW. Report commissioned for the NSW Chief Scientist's Office May 2013 114p http://www.chiefscientist.nsw.gov.au/data/assets/pdf_file/0005/32972/NSW-Geology-Paper-ONeill-and-Danis-MQU.pdf

Pineda JA, & Sheng, D, 2013 Subsidence: an overview of causes, risks and future development of coal seam gas production. Report commissioned for the NSW Chief Scientist's Office July 2013 54p

http://www.chiefscientist.nsw.gov.au/data/assets/pdf_file/0017/31274/Subsidence_Cause_OCSE_Final_Aug2013.pdf

Pratt W 1998a – Gunnedah Coalfield (North) regional geology 1:100,000 First Edition. Geological Survey of New South Wales, Sydney

Pratt W 1998b – Gunnedah Coalfield (South) regional geology 1:100,000 First Edition. Geological Survey of New South Wales, Sydney

Smerdon B D, Turnadge C, 2015 Considering the potential effect of faulting on regional-scale groundwater flow: an illustrative example from Australia's Great Artesian Basin. *Hydrogeology Journal* 23 (5) 949-960

Tadros NZ 1993 The Gunnedah Basin, New South Wales, Memoir 12. Geological Survey of New South Wales, Sydney.

Turnadge C, Esteban L, Emelyanov I, Nguyen D, Pervukhina M, Han T, Mallants D, 2018 Multiscale aquitard hydraulic conductivity characterisation and inclusion in groundwater flow models: Application to the Gunnedah Basin CSIRO 53p

Wallis G R, 1971 Narrabri 1:250,000 Geological Sheet First Edition. Geological Survey of New South Wales

3. GROUNDWATER

This chapter describes the importance of groundwater in the Namoi region and the way it is managed. It discusses the modelling of the potential impact of CSG production on existing groundwater users and resources and on the natural environment in the region of the Narrabri Gas Project.

3.1 Background

CSG production requires bores to be drilled into the coal seams and some of the groundwater within the seams to be removed by pumping. This lowers the groundwater pressure in the coal seams allowing gas to desorb. A mixture of groundwater and gas is then transported to the surface via the bore, where they are then separated.

The coal seams act like aquifers in that the lowering groundwater pressure rapidly radiates along the coal seams. However, because the coal aquifer is separated from the over and underlying rock by low permeability aquitards the groundwater pressure loss in the surrounding rock units is muted. In the Namoi region there is a sequence of overlying aquifers and aquitards, so that while the pressure decline of the groundwater in the coal seam is predicted to be hundreds of metres, the pressure loss in the shallower productive zones is less than a few metres. This readjustment in groundwater pressure can take decades to be detected in the shallow zones and up to centuries to reach a new equilibrium. This is somewhat different to the situation in areas of the Surat Basin in Queensland, where CSG production can result in very significant and rapid drawdown in major aquifers, largely because, unlike the NGP region, the important aquifers and the coal seams in Queensland, are in close proximity.

The Namoi Valley is subject to water sharing plans. All water sharing plans, including that for the Namoi Valley, have a volumetric limit for consumptive use, which is referred to in the regulations as the Long Term Average Extraction Limit, or locally, as the Sustainable Diversion Limit (SDL). The groundwater usage is further controlled by rules that limit the impacts on other users, stream flow and high value ecosystems, as well as on the aquifer itself. Significant government and community funds are expended annually on monitoring and reporting, with parameters such as water levels, water quality and metered water usage being monitored and assessed.

CSG production will impact to varying degrees on the alluvial near-surface aquifers associated with the Namoi River and the underlying Great Artesian Basin. The groundwater users in these systems have made hard financial decisions and surrendered water entitlement over the last decades to ensure there is environmentally sustainable access. There are community concerns that these hard won conditions should not be undermined by the NGP or any other project that impacts the groundwater.

3.2 Groundwater in the Namoi region

Groundwater is a highly valued resource in the Namoi region, although the spatial and temporal availability of groundwater data for the region is highly variable, being largely

dependent on the level of development of the resource. To date, groundwater quality and quantity monitoring has generally only been implemented once a groundwater development has commenced commensurate with the level of annual usage, which is in turn related to the SDL of each Groundwater Source.

Pena–Arancibia et al. (2016) provide an overview of the water usage in the Namoi Valley which shows that 43% of the annual water usage is groundwater. The mean annual diverted surface water for the period 2004–05 to 2011–12 was 278 GL, with 271 GL/year (97%) used in irrigation and 7 GL/year (3%) used for domestic and stock consumption or by local water utilities. While 3 GL/year of general security water entitlements and 0.03 GL/year of low security water entitlements are held by water users, the actual level of their use is not reported. The mean annual groundwater usage in the Namoi Valley from 2006–07 to 2013–14 was 165 GL/year.

Groundwater extraction for basic water rights such as for stock or domestic use, does not require a water access licence, but is estimated to be 46.4 GL/year. Mining and other industrial users held 3.7 GL/year in groundwater entitlements, all of which are in the non-alluvial water sources discussed by Green et al. (2010).

The groundwater flow model in the NGP EIS groups the geological units discussed in Chapter 2, into 25 hydrostratigraphic units that may be potentially impacted by CSG-related pumping from the Gunnedah-Oxley Basin coal seams, as shown in Table 3.1.

As previously mentioned, the groundwater is managed by Water Sharing Plans that further group hydrostratigraphic units into “groundwater sources”. The attributes, level of development and monitoring in each of the groundwater sources are discussed in <http://www.water.nsw.gov.au/water-management/groundwater>.

Each of the groundwater sources has different policy and management responses, largely based on the aquifer type, the relationship with the river system and the level of groundwater development. The predicted (modelled) impacts on these groundwater sources are a focus of the NGP EIS.

3.3 Data availability

As previously indicated the groundwater data available in the study area is highly variable, both spatially and temporally.

Data collection has largely been undertaken by the NSW government in response to various development and water availability issues. Early recognition of the problem of rapidly falling groundwater yields and pressure levels in aquifers associated with the Pilliga Sandstone in the GAB, resulted in the construction and strata details of bores being archived from as early as the late 1800s. From the early 1900s all bores were monitored 1 - 4 times per year for pressure, flow, temperature, chemistry and bore head condition. Once the cause of the decline in flows and pressures was established (a high rate of groundwater extraction leading to a new hydraulic equilibrium), a more limited network of monitoring bores was established in the GAB, though with the same monitoring frequency of 1 - 4 times a year.

In the early 1950s all water bores constructed in NSW were required to be registered, with their geology, construction, yield and some basic groundwater parameters recorded.

In the early 1980s due to increased groundwater extraction from the main alluvial aquifers for town water supplies and irrigation, the annual groundwater produced from each bore was first estimated and then metered. This included extraction from the Upper and Lower Namoi alluvium, shown in Table 3.1 as Narrabri, Gunnedah and Cubaroo Formations. Later, other high yield aquifers, such as the Pilliga Sandstone east of the study area were managed more closely.

The government monitoring network was developed to assess the impact of groundwater flow due to extraction by high yield bores, with most piezometers (instruments that measure water pressure) located within the higher permeability zones. The hydraulic characteristics of the aquitards have tended to be assessed from pumping tests rather than through direct measurement of hydraulic parameters.

From the 1920s onwards, pressure levels in the Surat Basin of the GAB were on a long-term trajectory toward a new equilibrium that reflected the level of development, i.e., water extraction, acceptable to all stakeholders. Coupled with this, there was some control of flowing bores and elimination of wasteful bore drains. Since 1999, a series of coordinated joint investments to limit wasteful groundwater production have been made by government and the community under the umbrella of the Great Artesian Basin Sustainability Initiative (GABSI).

The main thrust of GABSI has been to increase artesian pressures by controlling bore flows through bore rehabilitation, and by stopping waste by replacing inefficient delivery systems. GABSI has resulted in water savings of 78.5 GL/year in NSW (ABWUA 2017). It is unclear how long this level of water savings can continue, given the finite storage volume available in this groundwater system.

The NGP EIS documents the existing bores which source groundwater within GOB sediments that are target formations for CSG production (Table 3.1). The number of these bores is limited, because of the ready availability of alternative water sources and the generally low (stock quality) grade of the GOB groundwater. The GOB bores currently in use are supplemented by some mineral exploration and mining bores.

Table 3.1: Hydrostratigraphic Unit Classification (after Table 5.1 in Appendix F Santos (2017))

Province	Period/ Epoch	Division	Group	Sub-group	Formation	Lithology and Hydrogeological Classification	
Namoi Alluvium	Pleistocene				Narrabri fm	Clay and silt with sand lenses	
	Pliocene				Gunnedah fm	Gravel and sand with clay lenses	
	Miocene				Cubbaroo fm	Gravel and sand with clay lenses	
					Warrumbungle Vol	Basalt, dolerite	
Vocanics	Eocene			Liverpool Range Vol	Basalt, dolerite		
Surat Basin	Cretaceous	Middle	Blythesdale Gp (Keelindi Beds)		Bungil Fm Mooga Ss Orallo Fm	Clayey to quartzose sandstone, subordinate siltstone and conglomerate	
		Early			Pilliga Ss	Fluvial, medium to very coarse grained, quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone and fine grained sandstone and coal.	
	Jurassic	Late					
		Middle			Purlawaugh Fm	Fine to medium grained sandstone thinly interbedded with siltstone, mudstone and thin coal seams	
		Early	Garrawilla Volcanics				
Late				Dolerite, basalt, trachyte, tuff, breccia			
Gunnedah Basin	Triassic	Middle			Deriah Fm	Sandstone	
					Napperby Fm	Interbedded fine sandstone, claystone and siltstone Basal Napperby Shale	
		Early			Digby Fm	Quartzose sandstone (Ulinda Ss) Lithic sandstone Lithic conglomerate (Bomera Conglomerate)	
	Permian	Late	Black Jack	Nea	Trinkeby Fm	Coal measures - siltstone, fine sandstone, tuffs, stony coal	
					Wallala Fm	Conglomerate, sandstone, siltstone, minor coal bands	
				Coogal	Breeza Coal	Coal and claystone	
					Clare Ss	Medium to coarse-grained quartzose sandstone; quartzose conglomerate	
					Hows Hill Coal	Coal	
					Benelabri	Claystone, siltstone and sandstone; fining up cycles; more sandy towards top	
				Brothers	Hoskissons Coal	Potential target coal seam	
					Brigalow Fm	Fining-up sequence of medium to coarse-grained quartzose sandstone and siltstone	
					Arkarula Fm	Sandstone and siltstone	
					Melvilles Coal Mb	Coal	
					Pamboola Fm	Sandstone, siltstone, minor claystone & coal	
				Middle	Millie	Watermark Fm	Marine siltstone, shales and sandstone
		Porcupine Fm	Fining upward sequence of conglomerate and sandstone to mudstone				
		Early	Bellata	Upper Maules Creek Fm	Sandstone and conglomerate, siltstone, mudstone and coal		
				Rutley seam	Potential target coal seam		
				Interburden	Sandstone and conglomerate, siltstone, mudstone		
	Namoi seam			Potential target coal seam			
	Interburden			Sandstone and conglomerate, siltstone, mudstone			
	Parkes seam			Potential target coal seam			
	Interburden			Sandstone and conglomerate, siltstone, mudstone			
	Bohena seam			Potential target coal seam			
	Lower Maules Creek Fm			Sandstone and conglomerate, siltstone, mudstone and coal			
	Goonbri Fm			Siltstone, sandstone and coal			
Leard Fm	Flinty claystone						
Basement			Werrie Basalt and Boggabri Volcanics (Basement)	Rhyolitic to dacitic lavas and ashflow Tuffs with interbedded shale. Rare trachyte and andesite. Weathered basic lavas			
Colour code key:	STU – Significantly Transmissive Unit						
	LSTU – Less Significantly Transmissive Unit						
	PNTU – Probable Negligibly Transmissive Unit						
	NTU – Negligibly Transmissive Unit						

The NSW government is now expanding its regional groundwater monitoring network to include piezometers in the deeper aquifers that are predicted to be impacted by CSG production (DPI 2017). The construction activity for this network is programmed to run to 2020. Given the potential increase in CSG activity in NSW, it is anticipated that more of the \$22.8 million allocated to water monitoring will be assigned to the Narrabri area.

There are significant aquitards in the Narrabri area as shown in Table 3.2. However, the nature of the hydraulic connection between the GAB and GOB aquifers is critical in assessing the likely future impact of CSG production. In Queensland, CSG production within the GAB, is predicted to cause several hundreds of metres of drawdown of the water table. In contrast, the NGP production will be from within the GOB and is unlikely to cause significant drawdown in aquifers overlying the GOB. The relationship of the aquitards to the other hydrostratigraphic units and with the water sources is shown schematically in Figure 2.2.

Smerdon, Marston and Ransley (2012) indicate that the connectivity between the GOB and the GAB is very low or negligible due to the generally low permeabilities of the GOB in this area. This is supported by the production trials at Bibblewindi, where the production pad is said to have produced gas without pump priming after a 2-year period of closure.

With the possible exception of information about faulting, there is sufficient geological information available on which to base a high-level assessment of the proposed CSG development. The current information available is suitable for impact assessment prior to development. However, in the case of hydrogeological information, the current piezometer network is not sufficient either in plan position or vertically, to provide data for the groundwater flow models in order to predict future impacts of CSG activities particularly relating to water licensing considerations. The requirements for a groundwater monitoring plan and future transient groundwater flow modelling are discussed in Section 3.8.

3.4 NGP EIS groundwater model

The NGP EIS groundwater model was developed by Santos to predict the impact of CSG production on the surrounding groundwater and surface water systems. It is based on MODFLOW-Surfact software (Pandley et al., 2013). In the first instance output from the model was matched to interpolated data sets taken from measured data for a single period of time, notionally the year 2000 as discussed in EIS Chapter 11 Section 6.5.1. The model, thus calibrated, was then used to predict the effect of the removal of production water from the target coal seams on groundwater behaviour.

The model conceptualisation is based largely on the geological units whose framework is well known. Hydrostratigraphic units are defined from the geological units on the basis of perceived hydraulic permeability, i.e., the capability of the rock or sediment to permit the flow of fluids through its pore spaces, which in turn is used to classify the units into aquifers and aquitards. A basin scale groundwater flow system is then applied. This approach is consistent with the available data and the EIS objectives.

The NGP EIS model domain covers an area of over 53,200 km² within which the project area (957 km²) is centrally positioned to ensure that negligible pumping

impacts reach the model boundaries shown in EIS Chapter 11, Appendix F (Figure 6.9). The domain is much larger than one required solely for the NGP EIS of the proposed CSG development because the proponent was required to examine broader cumulative impacts as well as the impact of NGP CSG production. Ultimately, the only additional impact was that of the Narrabri Coal Mine, as all other proposed projects lapsed. No attempt was made by the NGP to model the impact of future hypothetical projects in the Narrabri region, nor could such a requirement reasonably be placed on the NGP.

O’Kane (2014), in Recommendation 13(4), called for government-commissioned models to comprehensively examine cumulative impacts for CSG developments. As the EIS model predicts that the aquifers in the Namoi are connected when CSG production occurs, such a model should be considered. However, as Santos is the only proposed CSG operator in this region, a move to a comprehensive model now, would be premature. If such a model were to be developed in the future, the recently released Namoi subregion by Sreekanth et al (2017) may be an appropriate starting point. It covers an area significantly larger than the Namoi Valley catchment. The model platform is MODFLOW USG, so in principle, smaller area models (“daughters”), developed for local issues could be integrated into the subregional model. There are currently calibrated models for town water supply and irrigation (LNA and UNA), stock and domestic (GAB) and mining (Narrabri Coal among others), which cover different aquifers vertically that could be the ‘daughter’ models integrated with the impacts of the proposed CSG activity. The impacts of CSG production are likely to be small and therefore the WEP does not see regional model development as a requirement for approval although it does commend such a model for future consideration.

The NGP EIS model adopted uses 45 geological units (defined in Table 3.1) as the basis for 25 model layers (Table 3.2). The hydraulic properties of these layers were derived from the literature (Santos, 2018) based on the dominant lithology. While the Namoi subregional model does not provide the details of groundwater impacts in the GOB units, it does allow the impacts of NGP production on the Pilliga Sandstone aquifer to be assessed (Sreekanth et al., 2017a).

Turnadge et al. (2018) have subsequently measured continuous vertical hydraulic conductivities (Kv) on cores from 97 bore sites in the model domain for four of the key aquitards (Purlawaugh Formation, Napperby Formation, Watermark Formation and Porcupine Formation). They used harmonic means to produce a probability distribution for values of Kv for each of the hydrostratigraphic units. The information derived is consistent with that used in the NGP EIS model. While the study did not indicate any discontinuity in low permeability values which would cause increased drawdown in overlying formations, this cannot be ruled out, given the method of sampling used in the study and the extent of heterogeneity.

Table 3.2: Correlation of Hydrostratigraphic Units to NGP EIS Model Layers (Source: Table 6.4 in Appendix F Santos (2017))

Basin	Period	Stratigraphic Unit			Geological Model Layer	HSU	Model Layers		
		Group	Sub-group	Formation					
Surat GAB	Cenozoic			Narrabri (informal)	1	Aquifer	1		
				Gunnedah (informal)					
				Liverpool Range Volcanics					
	Cretaceous	Rolling Downs Gp		Wallumbilla Fm	2	Aquitard	2		
		Blythesdale Gp (Keelindi Beds)	Bungil Fm	3			3		
			Mooga Ss		4				
			Orallo Fm		5				
				Pilliga Ss	4		Aquifer	6	
	Jurassic			Puriawaugh Fm	5	Aquitard	7		
				Garrawilla Volcanics	6				
Triassic			Deriah Fm	7	8				
			Napperby Fm						
Gunnedah	Late Permian	Black Jack Group	Nea	Trinkekey Fm	9		Aquitard	9	
				Waltala Fm					
			Coogal	Breeza Coal Mbr				10	10
				Clare Ss					
				Howes Hill seam					
				Benelabri Fm					
				Hoskissons Coal (Late Permian coal seam targets)		10			Aquifer
			Brothers	Brigalow Fm		11		Aquitard	14
				Arkarula Fm					15
				Melvilles Coal Mbr					16
	Pamboola Fm	17							
	Middle Permian	Millie			12	Aquitard	18		
							19		
Early Permian	Bellata			13	Aquitard	20			
						21			
		Early Permian coal seam targets		13	Aquifer	22			
		Maules Creek Fm		13	Aquitard	23			
						24			
				Goonbri Fm	Model Basement				
		Leard Fm							
		Boggabri Volcanics							
		Werrie Basalt							
Base	Basement								

Key Observation 5

Hydraulic parameters (such as hydraulic conductivity) used in the EIS groundwater flow model are based on literature values. Subsequent laboratory analysis and upscaling of the regional model provides confidence in the parameter selection for the GOB and GAB layers used in the NGP EIS model.

The Pilliga Sandstone is modelled in the EIS as a composite hydrostratigraphic unit that covers the Middle Jurassic zone of the GAB and the Early Cretaceous sandstones to the east, as discussed in Chapter 2 and shown in Table 3.1. However, this composite approach to the Pilliga Sandstone in the NGP EIS does not conform with conventional geological or hydrogeological usage. This may have implications for the

model, as implied by the extent of the composite unit (shown in Figure 6.6 of Appendix F of the NGP EIS) in that the east and west sandstone units are not hydraulically connected. This lumping together of the units is significant for the model in that the eastern Early Cretaceous sandstones are significantly more permeable than those of the GAB to the west and are capable of yielding large irrigation and town water supplies via suitably constructed bores.

Given the variability of data within each modelled unit, the use of average measured heads was adopted in the NGP EIS groundwater model and used for the calibration of the steady state model. In future model development, consideration could be given to using temperature-corrected heads, as there is a significant temperature gradient between deep and shallow aquifers. This would likely increase the impact of the CSG development on the shallower aquifers by increasing the predicted downward head gradient.

Calibration of the groundwater model was achieved in the NGP EIS by matching the composite water table and pressure surfaces developed, nominally for the year 2000, and by adjusting groundwater input and output. This is a reasonable approach, given there are no significant pumping stresses on the hydrostratigraphic units assigned to the Gunnedah Oxley Basin and the high level of pumping from the alluvium associated with the Namoi River is close to the extraction limit (SDL) and relatively constant. The alluvial units associated with the Upper and Lower Namoi Groundwater Sources are made up of multi-aquifer alluvial intervals, which have 12 and 1 management zones, respectively.

In an independent study, the regulator (DPI Water – now DPIE Water) has made use of separate groundwater flow models used for water resource management studies in the Lower Namoi Alluvium (LNA) and the Upper Namoi Alluvium (UNA). In these models, all input material parameters were spatially distributed and time series were either measured or calculated for all input and output parameters. In one of the models, Merrick (2001) found the fixed head approach (akin to the average heads approach) predicted flow from the GAB to LNA of 10.3 GL/year compared to 7.9 GL/year for the observed dynamic heads. This indicates that the flow from the GAB to the LNA is particularly sensitive to the head difference between the two water sources. For the period modelled, the GAB head must have been lower than the current value, because the impact of re-pressurisation due to GABSI activities was yet to occur.

Three scenarios for CSG pumping were considered in the calibrated NGP EIS model. These involve the extraction of a total of 35, 37.5 and 87.1 GL over 25 years, representing the low, base and high water extraction cases, respectively. The pumping rates were input to the model as an annual time series, so that the peak rates were 9, 10 and 20 ML/year, (EIS Appendix F, Figures A6.23, A6.24 and A6.25).

The NGP EIS groundwater flow model does not directly consider GAB extraction. The GAB pressure surface modelled was for around the year 2000, as discussed in the EIS (Appendix F Section A6.5.1 and Figure A5.12). The GAB pressure levels for a limited selection of bores (Appendix F, Figure A5.12) are relatively stable for the period prior to the year 2000. However, for the one bore with data after this period, an upward spike is evident, consistent with the impact of the groundwater savings arising from

GABSI, which serves to highlight the importance of including GABSI savings in the modelling.

The annual GAB water saving reported for NSW (as discussed in Section 3.2) is the same quantum as the total volume of water predicted to be extracted by CSG wells from the GOB Groundwater Source over the 25 year life of the NGP. Given that the GABSI activities are fully reported and publicly available for all proposed bores, these changes should be included in any future predictive modelling of CSG impacts. This addition is likely to decrease the predicted impact of CSG development on the alluvial aquifers.

As the GAB pressures are generally rising due to the water savings, the impact of the CSG development on the overlying water sources, in terms of observed water levels, should be less than predicted in the NGP EIS modelling to date. This GAB “buffering”, resulting from the GABSI savings and the associated pressure increase, should also increase the GAB volumetric loss to the deeper layers, and proportionately decrease the LNA loss.

In other words, the NGP EIS groundwater model assumes that groundwater extraction from each of the water sources does not change significantly over time. However, since the calibration period, GABSI in NSW is annually adding a similar quantum of water to that proposed to be extracted for the entire 25-year life of CSG production.

Recommendation 7

The WEP recommends to Santos that the impact on GAB pressure levels from the GABSI rehabilitated bore and water saving measures (that are monitored by the NSW Government groundwater network), be included in all future modelling and the results made publicly available.

There clearly have been significant changes to the level of groundwater access and use in each of the Namoi groundwater sources that are significantly greater volumetrically than the modelled groundwater extraction due to the NGP. However, the projected impact of the NGP, while small, may be significant in some locations. Such impacts should be identified after determination, so that mitigation or avoidance can be planned in a timely manner should they be required.

The current NGP EIS steady state model was calibrated on a static set of groundwater levels. Predictions were then made on the impact of the NGP over time.

However due to the level of development and groundwater trading there have been significant annual use changes in the GAB and LNA. The drawdown pattern experienced in those water sources changed quite radically both within and between water years. The proposed extraction pattern from the GOB by the NGP will complicate those changes even more. A transient groundwater flow model uses temporal groundwater and climatic information that reflect the changes in groundwater storage to predict the resultant impacts over time. The temporal predictions will be required to adequately manage the interaction between the water sources.

Recommendation 8

The WEP recommends that should the NGP proceed, Santos:

- develops a transient groundwater flow model with no less than the steady state model layers, based on the monitoring network to be agreed with the relevant regulator, including other sources of data that are available in the model domain.
- presents a report on the transient model for public comment within 3 years of commencing the project if approved.
- updates and presents the transient model every 3 years thereafter, for the life of the project unless otherwise advised.

In the North West Alliance submission, Hayley (2017) identified an unquantified but high degree of predictive uncertainty and recommended additional work be carried out to provide greater clarity. He demonstrated the advantages of alternative conceptual models and numerical model geometry. Hayley also conceded that this would require a significant additional effort that is not consistent with current industry practice.

Several submissions suggest that the NGP EIS groundwater flow model has the attributes of a lower class of confidence as applied to the classification developed for the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). In the view of the WEP this issue was adequately addressed by Santos (2019) in its supplementary response to submissions (pages 2.7 – 2.8). Santos accepts that the model should be classified as Class 1 but contends that the low confidence in the accuracy and location of small impacts is not significant, as it does not reflect uncertainty in the magnitude of the impacts. Santos has agreed to undertake piezometer construction and associated data collection and as a consequence, the WEP is of the view that there will be an increase in model confidence as the production phase of the Project commences.

The NGP EIS groundwater model has been reviewed by CSIRO (2015) using the checklist in the Guidelines from the Australian Groundwater Modelling Guidelines (Barnett et al., 2012), which is accepted industry practice. They found the model ‘fit for purpose’ (EIS, Appendix F) . This conclusion is reasonable, as many of the attributes needed to increase model certainty require monitoring or long-term production activity. However, this check list is largely based on process rather than outcomes. Consequently, while the 3rd objective in the check list “*identify and quantify the potential groundwater loss or gain in each Water Sharing Plan zone due to intra- and inter-formational flows*” was met, the mismatch in the predicted GAB flux contribution to the alluvial aquifers, cited for the LNA model, was not discussed.

Key Observation 6

The WEP notes that the NGP EIS steady state model was found by CSIRO to be a suitable platform on which to make decisions for the purposes of the EIS, but prior to construction, the model-improved predictions will be required.

Santos (2019) states that “In summary the low risk of significant impact stems from the depth of the target coal seams and the relatively small volumes of proposed extraction from the Gunnedah Basin compared to the larger existing uses extracting directly from the overlying high-values water sources”. The WEP recognises that small impacts between connected water sources can have cumulatively more significant impacts (particularly if the water source is fully allocated and has high annual use), but believes that the water management system in NSW can be applied to mitigate this impact risk.

The GISERA modelling was aimed at examining the impact of the NGP on the connected shallower aquifers and providing an assessment of the uncertainty of the NGP EIS model predictions. As it is not directly relevant to the impact of the NGP development, the GISERA modelling discussed by Sreekanth et al. (2017a) does not include the hydraulically disconnected Pilliga Sandstone to the east of the GAB intake beds, south and west of Gunnedah, as shown in Figure 3.1. However, the bioregional assessment modelling reported by Sreekanth (2017), appears to include it, as it is relevant to obtaining a water balance for the Namoi River catchment.

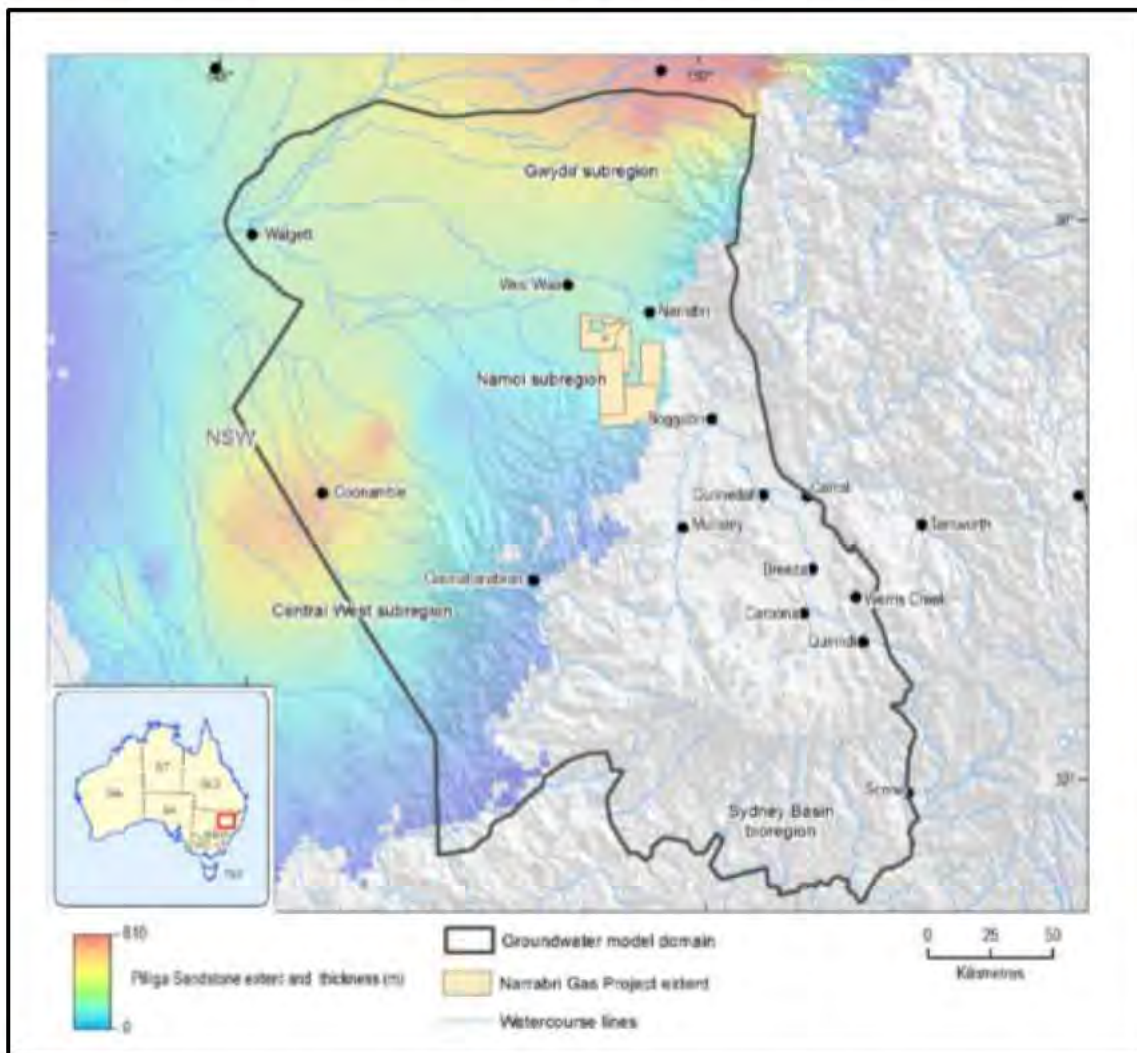


Figure 3.1: Extent and thickness of the Pilliga Sandstone (after Sreekanth et al., 2017a)

Sreekanth et al. (2018a) have recently used probabilistic groundwater modelling to assess the uncertainties of water balance changes due to CSG production from the Pilliga Sandstone aquifer of the GAB. Their model was not designed for management purposes. While the CSG pumping ratio between the Maules Creek Formation and Hoskissons Seam is different from that assumed in the NGP EIS, the model is essentially the same as the NGP EIS model and therefore comparisons can be made.

Sreekanth et al. (2017) developed an impact envelope which indicates that the maximum water loss from the GAB is between 0.28 and 2,300 ML/year, with a median of 84.5 ML/year. They also report on the uncertainty of total water produced by CSG production as being in the range 4.4 to 107.9 GL, which encompasses the high, low and base cases considered in the NGP EIS. They concluded that it was '*likely that the maximum CSG flux impact (between the GAB and the GOB) will be around 80 ML/year*'. This envelope, together with assessment of likely flux, provides a level of confidence in the NGP EIS predictions.

3.5 Modelled water balance

In groundwater modelling it is important to demonstrate that a model water balance is achieved, as all inflows and outflows should be in balance, both within each of the modelled units and within the model as a whole. Further, it is water volumes for which entitlements are held and are consumed and traded that are most important. Water levels tend to be managed as secondary impacts on water management plans, e.g., they may be used as drawdown triggers.

The steady state condition referred to in the NGP EIS (which also outlines how the impacts are quantified) is defined as (Appendix F, paragraph 3, page A11.16), - "*The Groundwater Impact Assessment derives a steady state condition for groundwater as the starting point for model prediction. The steady state condition of groundwater was derived from an analysis of DPI Water data to reveal those years with the most prevalent spatial data array, considered to be representative of the study area. The model was then used to make predictions of the impact of the project activities (primarily the extraction of groundwater to depressurize the target coal seams) on the groundwater environment. The model quantified impact to groundwater pressures and levels.*"

The NSW government UNA and LNA groundwater flow models used for water management of the impacted Namoi alluvium are transient, being calibrated against water levels and the large metered pumped volumes over the last 30 years, as discussed in the EIS (Section 3.2). The predicted fluxes (or flows) derived from these models are likely to have significantly more certainty than those predicted by the Santos (2017) model. However, as pointed out by Santos (2018), both these fluxes are modelled quantities and measurement of them is not practical.

A revised resultant steady state water balance has been presented by Santos (2018 Figure 6.13). The calibrated steady state model of the NGP EIS model was used to predict the temporal pressure level changes due to NGP operations. The accuracy of these predictions is difficult to assess given the lack of flux information that would allow a comparison of predicted and actual fluxes to be made. However, the water source interchange volumes can be compared with those from the models for the UNA and

LNA given in the EIS (Appendix F, Table A5.9). Within the model domain, the area of the UNA is outside the area of influence of the proposed CSG development, so the groundwater balance provided in the EIS is applicable to the region rather than to just the project. For the LNA, leakage from the artesian aquifer is estimated by Merrick (2001) at 7.9 GL/year compared to 1.6 GL/year predicted by the revised NGP EIS model. As noted earlier when comparing the fixed groundwater head methods used in the NGP EIS model, this volume is calculated by Merrick et al. (1986) to be 10.3 GL/year. It should be noted that these volumes are very small compared to the annual SDL and water usage from all the Namoi water sources.

The UNA model for the Upper and Lower Namoi Groundwater Sharing Plan assumes no leakage between the underlying rocks including the Pilliga Sandstone (attributed in the EIS to McNeilage, 2006). However, the UNA model only covers Zones 2, 3, 4, 5, 11, and 12 of the EIS groundwater model. McNeilage (2016) has considered the full UNA area model. He showed that the southern Zones 6, 7 and 9 in the Mooki River and Cox's Creek valleys have exposure to sediments of the GAB. The water balance in the revised NGP EIS model has leakage of 7.2 GL/year from the GAB (Pilliga Sandstone), the vast majority of which is outside the area of influence of the CSG development.

As discussed earlier, the rocks modelled as Pilliga Sandstone in this area are hydraulically disconnected from the GAB. The location of the 'Pilliga sandstone' in question is shown in Figure 3.2 (identified as Spring Ridge/ Mooki River Pilliga Sandstone outcrop).

There are numerous springs arising from sandstones and basalts in the headwaters of the Mooki River that are based largely on local flow systems. There are no quantitative estimates or measurements of such flow as the modelled leakage is subject to significant uncertainty.

The leakage from the GAB into the LNA occurs in a specific area west of Narrabri that is controlled by the pre-Tertiary geology. The exposure of the UNA to the GAB is extremely limited, to the extent that no groundwater exchange between them has been observed or modelled. However, the UNA does have significant exposure to the Pilliga Sandstone hydrostratigraphic unit in the upper reaches of Cox's Creek and the Mooki River valleys.

In that region, the Pilliga Sandstone is assigned to the GOB Water Source with the Spring Ridge Management Zone covering much of its outcrop. It may be that if the NGP EIS model is to be used in the future, then the Pilliga Sandstone of the GAB should be reported separately from the unit in this area, as this would allow direct comparison with the water sharing plans and assist the community in understanding potential impacts. In their reporting of the GAB, Sreekanth et al. (2018b) do not refer to the eastern unit or include it in their GAB assessments.

This difference in the modelled flows into the LNA is significant and appears to arise primarily from the assumed homogeneity of the model layers in the NGP EIS and the heterogeneity in the NSW government model. The method used in Merrick (2001) was adopted for the latter model used to estimate the LNA SDL and for ongoing management purposes. The difference is important - as this is the only independently-assessed flux against which the NGP EIS model predictions can be tested. Santos

(2018) indicates no direct measurement of the flux has been made; rather, measured parameters are used to provide modelled estimates of the flux. Santos provides a discussion of eight methods used to estimate this flux. When assessing the impact for water management purposes the WEP believes it would be prudent to use the changes in GAB heads predicted for the CSG development in the NSW government alluvial models, to assess changes in groundwater flows.

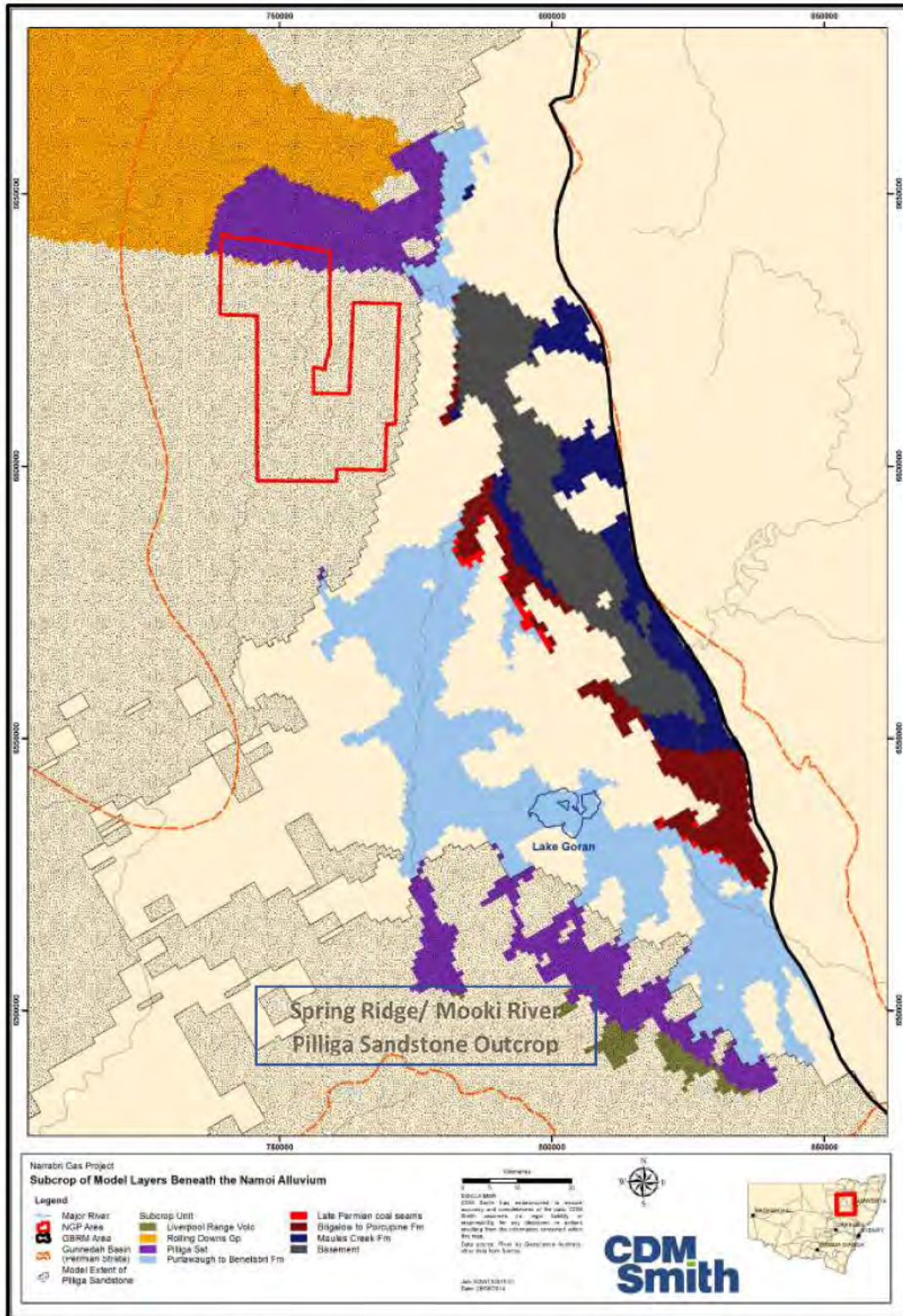


Figure 3.2: Subcrop of NGP EIS Model Layers beneath the Namoi alluvium (Source Figure 6.12 in Appendix F Santos (2017))

Key Observation 7

The NGP EIS steady state groundwater model predicts a very small volumetric impact on flows between the GAB and the LNA. However, these flows are different to those published for the Lower Namoi Groundwater Source, which indicates some uncertainty in the NGP predictions.

Recommendation 9

The WEP recommends to Santos that the GAB heads predicted by the EIS model should be used from hereon in the LNA groundwater flow model, to provide an improved estimate of the impact on leakage from the GAB to the Lower Namoi Groundwater Source.

Recommendation 10

The WEP recommends that if the project is approved and prior to construction, Santos specifies the level of entitlement required from the LNA and assesses the potential impact of that entitlement on access of existing users and groundwater trading under a range of climatic conditions.

3.6 Groundwater management

Produced water quality can vary significantly in space and time from that predicted through the groundwater monitoring network. The quality of the groundwater in the aquifers relevant to the NGP is highly variable. Santos reports the quality of groundwater within each of the main aquifer groupings as:

- Alluvium is generally fresh (<500 mg/L TDS) to brackish (500 to 3500 mg/L TDS) and alkaline (pH about 8)
- Pilliga Sandstone is fresh and neutral (pH about 7)
- Permo-Triassic units of the Gunnedah Oxley Basin are brackish to saline (3500 to 35,000 mg/L TDS and alkaline (pH about 9)
- Target coal seams are saline and alkaline (pH about 8)

Under CSG operating conditions, inter-aquifer vertical flux is predicted to be very low and the quality of produced water is expected to reflect primarily the horizontal journey of groundwater during recharge. Groundwater quality may vary across the project and will be monitored.

Under the current NSW policy and management framework, Santos will have to hold entitlement in each of the water sources impacted prior to commencement of CSG production. Relevant water sources are shown schematically in Figure 2.2. The Water

Sharing Plans and Water Sources that lie within the model domain are indicated in Table 3.4. It is noted that Upper Namoi Groundwater Management Area (GMA) Zone 12 (Kelvin) is outside the model domain and Zone 11 (Maules Creek) has only partial representation. Further, the modelling indicates the GAB Shallow Groundwater Source will be impacted.

Table 3.4: Water Sharing Plan Reporting Area (Source: Table 6.14 Appendix F Santos (2017))

Water Sharing Plan	Groundwater Source	WSPRA	Description
Upper and Lower Namoi (2003)	Lower Namoi	1	Flux from base of alluvium to GAB Surat
		2	Flux from base of alluvium to GAB Southern Recharge
	Upper Namoi	3	Flux from base of alluvium to GOB in GMA zone 1
		4	" " " " GMA zone 2
		5	" " " " GMA zone 3
		6	" " " " GMA zone 4
		7	" " " " GMA zone 5
		8	" " " " GMA zone 6
		9	" " " " GMA zone 7
		10	" " " " GMA zone 8
		11	" " " " GMA zone 9
		12	" " " " GMA zone 10
		13	" " " " GMA zone 11
NSW MDB Fractured Rock (2011)	Liverpool Ranges Basalt	14	Base of basalt to Oxley Basin
		15	Base of basalt to Gunnedah Basin
	Warrumbungle Basalt	16	Base of basalt to GAB Southern Recharge
NSW MDB Porous Rock (2011)	Gunnedah-Oxley Basin	17	Oxley Basin to Late Permian coal seam targets
		18	Gunnedah Basin to Late Permian coal seam targets
		19	Gunnedah Basin to Early Permian coal seam targets
NSW Great Artesian Basin (2008)	Southern Recharge	20	GAB Southern Recharge to Gunnedah Basin
	Surat	21	GAB Surat to Gunnedah Basin

GAB – Great Artesian Basin, GOB – Gunnedah-Oxley Basin

The level of current development for all the Water Sources (except the GAB Shallow Groundwater Source) is shown in Table 3.5. Due to the predicted large lag times between groundwater production and impact, the use of many management measures, such as “cease to pump”, would probably not be appropriate for this development. Each of the water sources illustrated in Figure 2.2, from which Santos will have to gain an entitlement, has a different level of development and different management characteristics. The entitlements would need to be sufficient to cover the annual maximum amount of water used from each source during the life of the NGP. Determining these entitlements will not be straightforward under the current licencing regime and may need assistance from the Regulator.

Table 3.5: Groundwater Source Level of Development (Source: Table 4.5 in Appendix F Santos, 2017)

Relevant Water Sharing Plan	Groundwater Source	Total Number of Licences Issued	Total Share Components Issued	LTAEL* [ML/y]
NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011	Gunnedah-Oxley MDB	142 aquifer 3 local utility	23,109 aquifer 480 local utility	205,640
NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011	Liverpool Ranges Basalt MDB	12 aquifer	422 aquifer	19,075
	Warrumbungle Basalt	4 aquifer	71 aquifer	5,710
NSW Great Artesian Basin Groundwater Sources 2008	GAB Surat	51 aquifer 10 local utility 1 Aquifer (TW)	5,502 aquifer 3,318 local utility 25 aquifer (TW)	35,097**
	Southern Recharge	148 aquifer 9 local utility	24,432 aquifer 3,066 local utility	29,680
Upper and Lower Namoi Groundwater Sources 2003	Upper Namoi	562 aquifer 9 local utility	109,804 aquifer 6,280 local utility	122,100
	Lower Namoi	213 aquifer 3 local utility	81,586 aquifer 4,407 local utility	86,000

Source: NSW Water Register, DPI Water 2016/17

*Long Term Annual Average Extraction Limit

** As at 30 June 2014 as advised by DPI Water on 27 July 2016

The Basin Plan 2012 sets out the current Sustainable Diversion Limit (SDL) for the NSW groundwater sources in the Basin, excluding the GAB, which is not addressed in the Plan. The SDL for the latest compilation of the Plan in 2018 is given for groundwater in Schedule 4 (Australian Government, 2018).

It is perhaps useful to illustrate the complexity of the current system using some examples from the Narrabri region.

The *GOB Groundwater Source* has a Sustainable Diversion Limit (SDL) of 127.5 GL/year and significant unassigned water which may be available to the proponent.

The *Great Artesian Groundwater Source* is effectively fully allocated so that Santos would need to go to the market to obtain entitlement to draw water from the GAB for two of the groundwater sources that are indicated as impacted in the NGP EIS.

The *Southern Recharge Groundwater Source* is the primary area in the GAB impacted most by the NGP. It has an SDL of 29.75 GL/year based on estimates of direct rainfall recharge, as it has no groundwater sources overlying it. At the commencement of the Plan, 25 GL/year of tradable aquifer access licences were held. All GABSI water savings are retained in the SDL.

The *Surat Groundwater Source* had an SDL of 46.6 GL/year at the commencement of the Water Sharing Plan in 2008. However only 15.1 GL/year was held as tradeable aquifer access licences (based on the sustainable pressure estimate). This is accomplished by returning 70% of the GABSI water savings to the environment from aquifer access licenses only, i.e., 30% of water savings from this license type are returned to the SDL. The SDL in 2014 (Table 3.5) was 35.1 GL/year of which 5.527 GL/year was accounted for by aquifer access licences. However, the current ownership of the entitlement and the current size of the SDL is unclear. It is also noted

that the 25 ML/year assigned to the town water supply is subject to access rules that make it unavailable to the NGP.

The *GAB Shallow Groundwater Source* (GABS) “manages” the Cretaceous and surficial sediments above the Pilliga Sandstone to a depth of 60 m below ground surface. The GABS has not been addressed in the NGP EIS (Tables 3.4, 3.5), although it is defined by model layers 2 to 5 (Table 3.2). The entitlement required from this water source to account for the CSG impact should be defined. It is noted that the Surat Basin portion of the GABS has an SDL of 15.5 GL/year and there is unassigned water. Consequently, access by the NGP should not be an issue.

The *Lower Namoi Groundwater Source*, is very important and as discussed in Section 3.4 the Santos groundwater model is adequate for assessing impact on deeper zones. But as it is a steady state model and does not match the GAB to LNA fluxes modelled by independent transient alluvial models. Consequently, while it is adequate for assessing impact, it should not be used for assessing the entitlement required to cover any water take from the GAB or the LNA.

The modelled changes in GAB heads predicted for the CSG development should be used in the independent alluvial models when assessing entitlement required for those water sources. The SDL for the LNA is 88.3 GL/year plus basic rights and for the UNA it is 123.4 GL/year. Both systems are currently fully allocated, so access to entitlement for Santos can presently only be through the market.

The surface water plans are not addressed in the NGP EIS even though the surface water is a recharge source and may be impacted. However, as indicated by Sreekanth et al. (2017), the predicted volumes are only a maximum of a few ML/year. Property rights are held as water entitlements that are also subject to the annual announced allocation. The latter may reduce the value of the entitlement to something less than 100% of the notional entitlement.

Announced allocations of less than 100% have occurred in both the UNA and LNA in recent years. The LNA has drawdown level triggers and trade zones which restrict access to new entitlement holders, as discussed by Smithson (2009). Entitlements are tradable although their activation at any specific groundwater work is subject to impact rules. The groundwater is managed by rules set out in each plan so that adverse impacts can be avoided or at least recognised and managed.

Key Observation 8

For the LNA, the drawdown triggers in the local management rules are currently being approached by the existing users by the end of the pumping season in each water year. This may restrict future access to the groundwater.

In summary, the impact the predicted small drawdown from CSG production will have on trade zone boundaries is presently unclear. However, observation bores presented in <http://www.water.nsw.gov.au/realtime-data/groundwater> indicate that current end-of-season pressure levels are close to the level where the regulator may decide to restrict access to groundwater. Added to this, the entitlement that Santos is seeking,

or likely to seek for the Lower Namoi Groundwater Source, is large in comparison to the record of historic trading patterns provided by Aither (2017).

So, what conclusions can be drawn regarding the steps that would need to be taken to manage the potential impact of the NGP on existing water resources and on current users of that water? First, there is a need for ongoing dialogue between the Regulator and the project proponent, as it would be risky for the project to assume whatever allocations the NGP requires will be available. As pointed out above, some of the potential sources are already fully allocated. Whilst the market offers a way forward to meet some of the required water entitlements, it cannot be assumed that the market would necessarily deliver the allocations required.

In addition, whilst the WEP considers that the overall water requirements of the NGP will be quite small compared to existing use for irrigation, as evident from Figure 2.2, the project does impact, albeit at a very modest level for the most part, on a large number of hydrogeological units. Consequently, the process of providing water entitlements to address those impacts could prove to be complex and time consuming. Such negotiations usually occur after approval but before any impact.

Given that CSG production will impact a number of groundwater sources and will need to be managed, is the NGP EIS model adequate to assess the impact? As discussed in Section 3.4, the model is adequate for assessing impacts on the GOB and the GAB but as it is a steady state model and does not match the GAB to LNA fluxes modelled by independent transient alluvial models, it should not be used for management purposes when assessing impacts on the shallower zones and required entitlements. The modelled changes in GAB heads predicted for the CSG development should be used in the independent alluvial models when assessing entitlement required for those water sources.

Key Observation 9

There is currently a high level of entitlement and use in both the surface and shallower groundwater systems. The water entitlement that Santos is seeking from the LNA, whilst not large compared to current groundwater usage, is likely to be large in comparison to the historic trading patterns.

3.7 Groundwater dependent ecosystems

As the name implies, groundwater dependent ecosystems (GDE) are ecosystems that rely on groundwater, whether directly or indirectly for some or all of their water requirements. Changes in groundwater quantity and quality can have a significant impact on the ecology of GDEs. Potential GDEs in the NGP region have been identified in the EIS (Eco Logical Australia, 2016).

High value GDEs are protected from the impact of groundwater extraction by rules in the water sharing plans for each of the water sources, as shown in Figures 3.3 and 3.4. None of the water table declines predicted by the NGP EIS model would breach these conditions. GDE health and diversity are also likely to be heavily influenced by

climate variability, which may mask longer-term change caused by variations in the water table.

- GDE-related targets in the minimal harm criteria of the Aquifer Interference Policy are (NSW Office of Water 2013) no more than 10% cumulative change in the depth of the water table about either a GDE or culturally significant site (CSS);
- no change to the River Condition Index or less than 1% increase in average salinity; and
- no change to the beneficial use category (based on water quality) at a distance of 40 metres from the activity (unless this change will not prevent the long-term viability of GDE, CSS or water supply works).

The minimal harm criteria for the alluvial groundwater sources are presented in Figures 3.3 and 3.4. The criteria for other sources can be found in NOW (2013).

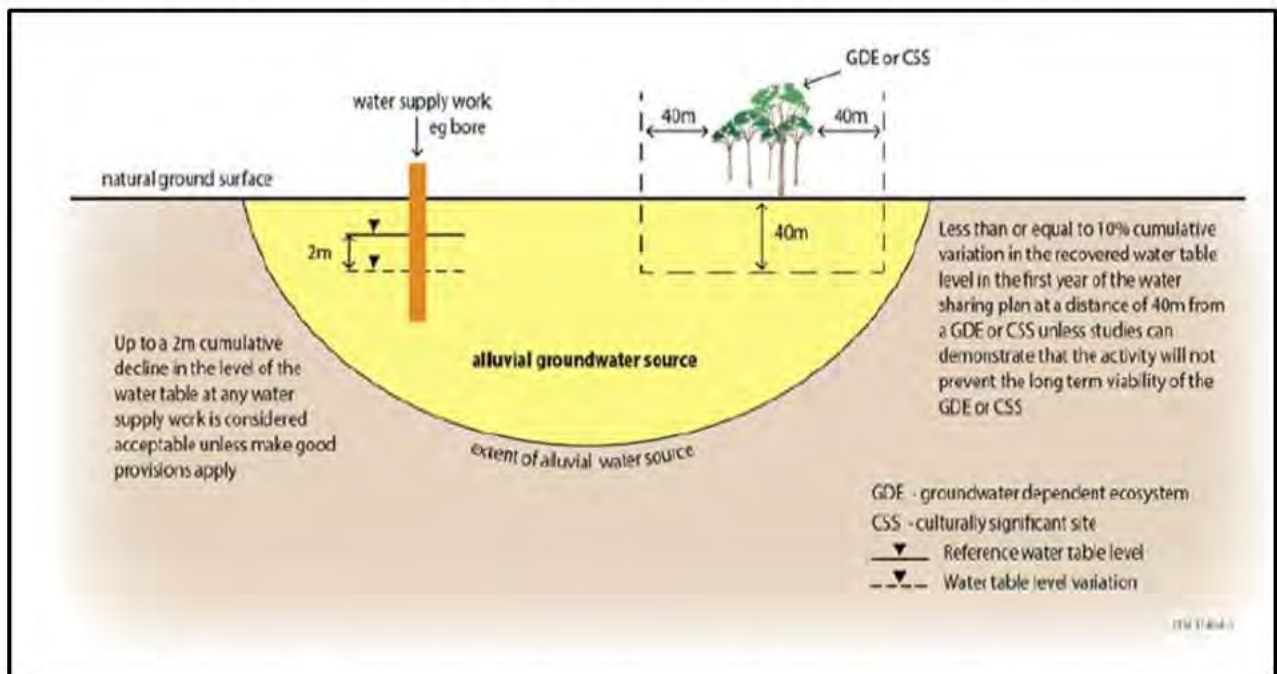


Figure 3.3: Minimal Harm Groundwater Level Criteria for Alluvial Aquifers (after NSW Office of Water 2013)

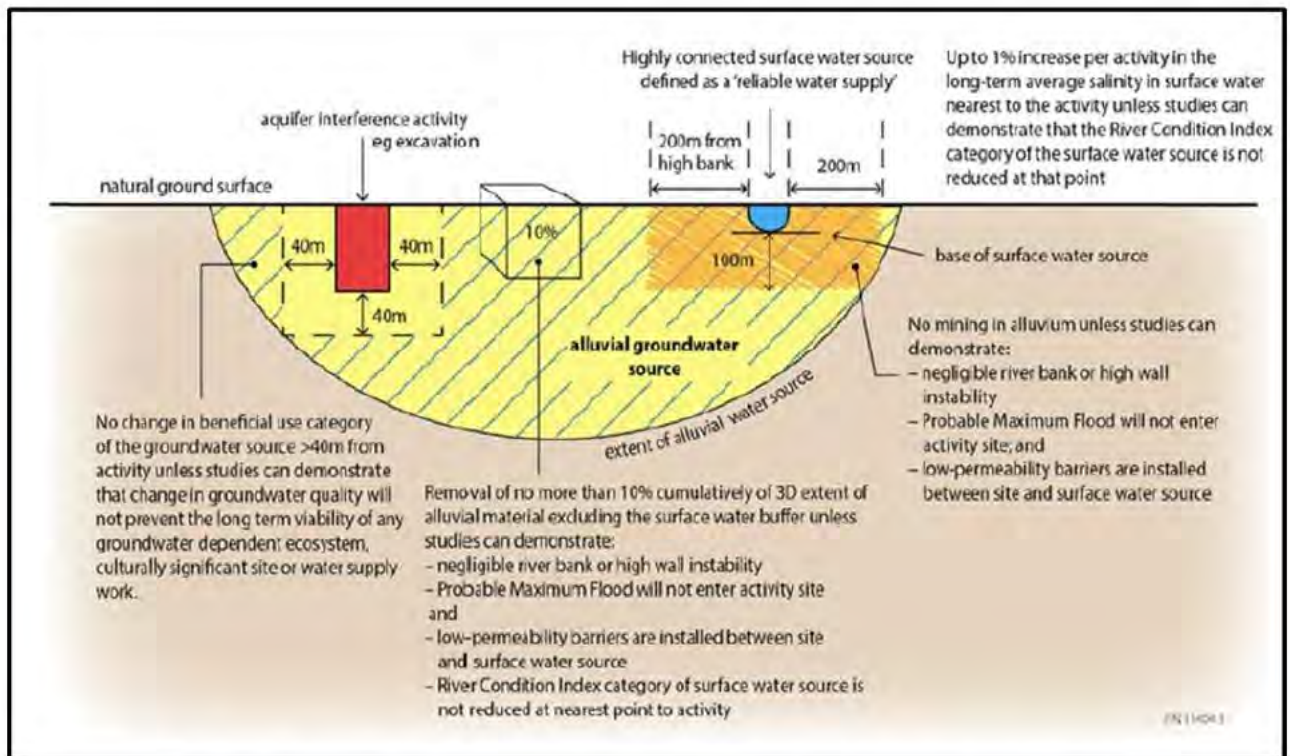


Figure 3.4: Minimal Harm Groundwater Quality Criteria for Alluvial aquifers (after NOW 2013)

Key Observation 10

Adherence to the minimal impact consideration of the Aquifer Interference Policy in the NGP region, will ensure that high value GDEs will be protected from any unacceptable cumulative impacts associated with CSG production and other groundwater-based activities in the region.

Hose (2018) has suggested the need for investigation of stygofauna in the GAB and alluvial aquifers. However, these water sources have been heavily pumped over the last 120 and 50 years, respectively. The water level changes resulting from this prior extraction far exceed any impact predicted for the NGP. The exception may be Bohena Creek, a shallow sandy-bedded, non-perennial creek with occasional refuge pools. In braided stream systems there is considerable exchange between surface and groundwater volumes with macro-invertebrates being moved into and out of the sediment. This makes the definition and recognition of stygofauna problematic. Recognition that Bohena Creek flows are only augmented by treated production water in times of high creek flow suggests that GDEs present in the creek are unlikely to be adversely affected by this proposal.

3.8 Groundwater monitoring and modelling plan

Santos indicated that as the locations of the production wells are uncertain, a specific plan is not appropriate or possible at this stage. Rather, Santos proposes to negotiate a groundwater monitoring regime with the regulator after approval.

This is a practical approach from the perspective of the NGP but provides little certainty to other stakeholders. Broughton in her Issue 3 (Broughton, 2018) questions the proposed monitoring plan following the reassignment of several piezometers to different hydrostratigraphic units. The WEP considers that a generic monitoring plan that can be used to condition approval would be more appropriate.

A generic plan would specify the hydrostratigraphic units to be monitored and the periods and methodologies to be employed. Factors such as a bore characterisation, piezometer construction, spacing and parameters to be monitored, would be defined in that plan. Data storage and reporting timeframes could also be addressed in the groundwater monitoring plan.

The generic monitoring plan should address the complementary government monitoring that is generally undertaken outside the CSG project area, on which impact assessment will rely. The adequacy of the coverage of the deeper bores that are programmed to be constructed needs to be addressed to ensure continuity in coverage.

Recommendation 11

The WEP recommends that, Santos develop a groundwater monitoring plan (to be applied once the phasing of the production well sites is identified). It should include what government–conducted monitoring might be required outside the CSG production area.

Sreekanth et al. (2018a; and summarised in <https://gisera.csiro.au/wp-content/uploads/2018/09/KTS-presentation.pdf>) have recently provided a suggested monitoring network. It is based on the Namoi Bioregional Assessment, presented by Sreekanth et al. (2017), and uses two different approaches to conceptualise the hydraulic parameters. The first uses the calibrated model and the second includes the parameterisation (a method of approximating complex systems) of key aquitards, as discussed by Turnadge et al. (2017) in the calibrated model.

The parameterisation of key aquitards approach was adopted by the NSW government for groundwater monitoring network review and rationalisation, as it is not biased by the assumptions and limitations of the groundwater flow model. Further, it is not limited to the modelling data set; rather, it is able to use all data that can be accessed. This is particularly important in this case, as much of the GAB information is held outside the government database.

In NSW, the probabilistic (the likelihood of something happening) framework and rank-reduced spatial distribution methods have been applied in alluvial and GAB groundwater network reviews since the late 1980s (Merrick 1999). However, in those

cases, observed aquifer responses rather than modelled outputs were used as data for the assessment.

The NGP EIS uses MODFLOW-SURFACT as the modelling platform, which met the objectives at that time. However, migration to the MODFLOW-USG platform or a platform with similar capabilities, should be considered when a transient groundwater flow model is developed. As MODFLOW-USG has an unstructured grid it would allow a more flexible approach for new information to be included.

This platform would be more compatible with the adaptive management approach proposed for the NGP. In that, as a gas field develops, there is a significant potential for knowledge of layer and spatial complexity to increase, which can be readily incorporated into the model. This flexibility could extend to including near-gas well conditions and faulting, should they become matters of concern.

Recommendation 12

The WEP recommends to Santos and to Government that prior to construction the groundwater modelling be migrated from the current MODFLOW-SURFACT software to a more flexible package, such as MODFLOW-USG or a similar unstructured grid.

3.9 Hoskissons Seam

In its NGP EIS, Santos indicated that at a later stage of the NGP, some gas will be extracted from the Hoskissons coal seam and that this might represent typically 5% of the total gas extracted over the life of the project. This coal seam, which rises to around 300 m below ground level, is much closer to the GAB than the lower coal seams, from which it is proposed to extract the majority of the gas. This then raises the question of whether extraction of gas from the Hoskisson Seam will have a greater impact on groundwater aquifers because of its closer proximity to the GAB.

Accordingly, the WEP asked the following questions of Santos (under the heading Question 21 – Hoskissons Seam) (see Appendix C).

- A) What will be the impact of gas production from the Hoskissons Seam on the GAB and other shallower aquifers in terms of drawdown and flux?
- B) What would be the impact(s) on the GAB and shallower aquifers if pumping from the Hoskissons seam was shut down during production?

The Santos response indicated an overall extraction of 1.89 GL of water from the Hoskissons seam (compared to 35.6 GL from the Maules Creek Formation) but did not include a specific estimate of the effect of this extraction on drawdown. The extraction from this seam is proposed to be later in the project development. The predictions will therefore be updated using a transient groundwater model and any drawdown issues could be handles at that stage.

Santos also responded to WEP question 21B indicating that overall the effect on the GAB and shallower aquifers of a shutdown in production from the Hoskissons seam would be negligible at a project scale. Such action would “*only have a potential to*

reduce overall water extraction by a maximum of 5% and more likely only a few percent". The WEP is of the view that based on current data, this is a realistic response.

3.10 Conclusion

The potential impact of the NGP on the groundwater resources of the Narrabri region is undoubtedly one of the most important issues facing the project. Related questions include whether the modelling and the data that underpin that modelling are 'fit for purpose' and do they, for example, provide confidence that the anticipated drawdown as a result of CSG production will be very minor compared to rates of drawdown associated with current groundwater uses?

On the basis of the information available, the WEP considers the NGP EIS model to be fit for purpose and the predicted impacts minor. However, whilst the overall impact might be very minor, it is important to ensure that the impact on individual bores will not be significant or can be ameliorated to the satisfaction of the owner of the bore. This will need to be managed carefully by the Regulator and Santos.

As is evident from the earlier discussion in this Chapter, these questions raise complex scientific issues, which often play an important part in an equally complex regulatory regime.

What can be said is that the NGP development, as proposed in the EIS, is considered by the WEP to be very likely to be hydraulically isolated from the surrounding geological units, in particular the shallow Pilliga Sandstone and alluvial aquifers. The WEP expects this will be confirmed once production scale pumping commences. There will also be some low range flux and drawdown impacts that will be less than the minimal harm thresholds of the Aquifer Interference Policy.

The drawdown levels predicted by the NGP EIS are reasonable, with a level of confidence provided by the later GISERA modelling and WEP observations of the field trials at Bibblewindi. The project as proposed, is consistent with the water trading regime established under the Water Management Act 2000. There appears to be sufficient depth in the water trading market for NGP to obtain entitlements in each of the water sources for the volumes likely to be required.

However, given the existing level of development of the GAB and LNA Groundwater Sources in particular, while the volumes consequent on the CSG developments will be small, they may have localised impact on some existing groundwater users. The importance of this is that even if Santos is to hold the appropriate entitlement their impact may activate local area draw-down rules that will restrict access for all users in the trading zone. This may require some resolution by the regulator after consultation with the relevant stakeholder groups.

3.11 References

Aither 2017 – Water markets in New South Wales: Improving understanding of market fundamentals, development, and current status. A final report prepared for NSW Department of Primary Industries Water. Aither Pty Ltd

Artesian Bore Water Users Association 2017 – Submission Regarding the NGP EIS for the Proposed Narrabri Gas Project (SSD 14_6456)

Australian Government 2018 – Basin Plan 2012. Compilation No. 6. <https://www.legislation.gov.au/Details/F2018C00451>

Barnett B, Townley L R, Post V, Evans R E, Hunt R J, Peeters L, Richardson S, Werner A D, Knpton A and Boronkay A, 2012– Australian Groundwater Modelling Guidelines, Waterlines report, National Water Commission, Canberra.

Broughton A 2018 – Narrabri Gas project. Expert Review of Environmental Impact Statement, including the Response to Submissions on behalf of the North West Alliance.

Calf G E 1978 – An investigation of recharge to the Namoi Valley aquifers using environmental isotopes. Aust. J Soil Res 16: 197 – 207

CSIRO 2015 – Review Narrabri Gas Project Groundwater Modelling Report. CSIRO Land and Water Flagship, Adelaide

Department of Primary Industry 2017 – Water Monitoring Strategy for Coal Basins in NSW. Gunnedah Basin Update.

Green D, Petrovic J, Moss P, and Burrell M. 2011 Water resources and management overview: Namoi catchment, NSW Office of Water, Sydney

Hayley K 2017– Review of the numerical groundwater modelling. Santos Narrabri Gas Project Environmental Impact Statement Groundwater Solutions for North West Alliance.

Howes G C 2018 – Expert Review. Narrabri Gas Project Environmental Impact Statement and Response to Submissions on behalf of the North West Alliance.

Iverach C P, Cendón D I, Meredith K T, Wilcken K M, Hankin S I, Andersen M S and Kelly B F J (in discussion) – A multi-tracer approach to constraining artesian groundwater discharge into an alluvial aquifer. Hydrol. Earth Syst. Sci

Kelly B F J, Timms W A, Andersen M S, McCallum A M, Blakers R S, Smith R, Rau G C, Badenhop A, Ludowici K and Acworth R I 2013 – Aquifer heterogeneity and response time: the challenge for groundwater management. Crop and Pasture Science CSIRO.

Lamontagne S., Taylor A.R., Cook P.G., Smithson A. 2011. Interconnection of surface and groundwater systems – River losses from losing/disconnected streams. Namoi River site report. CSIRO: Water for a Healthy Country National Research Flagship, Adelaide. 33pp.

McNeillage C 2006 – Upper Namoi Groundwater Flow Model: Groundwater Management Area 004; Zones 2,3,4, 5, 11 and 12 (draft) NSW Department of Natural Resources.

McNeillage C 2016– Upper Namoi Groundwater Flow Model for Zones 1 -12. NSW Department of Primary Industries, Office of Water (in draft).

Merrick N.P., Ross J.B. and Williams R.M. 1986 – Groundwater in the Lower Namoi Valley, New South Wales. AWRC Conference Groundwater Systems under Stress, Brisbane, 1986. Pp 461 – 471

Merrick N P 1999 – A preliminary assessment of the Great Artesian Basin groundwater monitoring network. UTS (Insearch) for DLWC NSW Project Number E97/44/002.

Merrick N P 2001 – Lower Namoi Groundwater Flow Model Calibration 1980 – 1998 UTS INSEARCH for Department of Land and Water C99/44/001

NSW Office of Water 2013 – NSW Aquifer Interference Policy. Fact Sheet 4: Assessing the Impacts. Available Online at:

http://www.water.nsw.gov.au/data/assets/pdf_file/0007/548890/law_key_aquifer_interference_factsheet_4_assessing_the_impacts.pdf

O’Kane M 2014 – Final Report of the Independent Review of Coal Seam Gas Activities in NSW, www.chiefscientist.nsw.gov.au/coal-seam-gas-review

Pena-Arancibia J, Slatter E, Northey J and Cassel R 2016 – Current water accounts and water quality for the Namoi subregion. Product 1.5 for the Namoi subregion from the Northern Inland Catchments Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia. <http://data.bioregionalassessments.gov.au/product/NIC/NAM/1.5>.

Panday, Sorab, Langevin, C.D., Niswonger, R.G., Ibaraki, Motomu, and Hughes, J.D., 2013, MODFLOW–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Techniques and Methods, Book 6, chapter. A45, 66 p.

Santos 2017– Narrabri Gas Project – Environmental Impact Statement.

Santos 2018 – Narrabri Gas Project. Response to Submissions.

Santos 2019 Introduction Narrabri Gas Project. Supplementary response to submissions

Sreekanth, J., Crosbie, R., Pickett, T., Cui, T., Peeters, L., Slatter, E., Northey, J., Merrin, L.E., Davies, P., Miotlinski, K., Schmid, W. and Herr, A. 2017 – Groundwater numerical modelling for the Namoi subregion. Product 2.6.2 for the Namoi subregion from the Northern Inland Catchments Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Sreekanth J, Cui T, Pickett T, and Barrett D 2018a – Uncertainty analysis of CSG-induced GAB flux and water balance changes in the Narrabri Gas Project area. CSIRO, Australia. <https://gisera.csiro.au/wp-content/uploads/2018/08/Water-7-Final-Report.pdf>

Sreekanth J, Gladish D, Gonzalez D, Pagendam D, Pickett T, Cui T 2018b – CSG-induced groundwater impacts in the Pilliga region: prediction uncertainty, data-worth and optimal monitoring strategies. CSIRO, Australia.

Smerdon BD, Marston FM and Ransley TR 2012 – Water resource assessment for the Great Artesian Basin. Synthesis of a report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Smithson, A., 2009 – Lower Namoi Groundwater Source: Groundwater Management Area 001 Groundwater Status Report 2008, NSW Department of Water and Energy, Sydney

Turnadge C, Esteban L, Emelyanova I, Nguyen D, Pervukhina M, Han T and Mallants D 2018 – Multiscale aquitard hydraulic conductivity characterisation and inclusion in groundwater flow models: Application to the Gunnedah Basin, New South Wales, prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Canberra.

Williams R M, Riley G T, Calaitzis P, Ross J B and Lennon J 1995 The History of Community Involvement in Groundwater Policy Development – Lower Namoi Valley New South Wales. AWWA 16th Federal Conference. Vol 1 pp 549 – 556

4. PRODUCED WATER

This chapter examines the proposed treatment of groundwater produced as a consequence of CSG extraction and compares it with good practice elsewhere.

4.1 Background

CSG is released from deep coals by removing water from the coal seam and this in turn allows the gas to desorb from the coal. A two-phase mixture of gas and water (termed “produced water”) then flows up the drill bore to be separated at the surface and subsequently processed separately. A key to the economic success and environmental acceptability of CSG recovery is the beneficial use of produced water, especially so in a dry continent like Australia. So too, is operation of produced water processing plants so that spillages are absolutely minimised and contained, and the salts recovered from produced water are effectively removed from site and handled so as to prevent environmental hazard.

Handling of produced water has had a mixed history in the US and in the early days of the industry in Australia, where evaporation ponds were initially used. This practice is now banned in Queensland and NSW and appropriate regulations have been imposed. These prescribe how treated produced water may be most advantageously used and have led, in the Queensland context, to extensive state-of-art treatment plants that deliver quality water to townships, recharge of aquifers used for potable water supply, for irrigation agriculture and for stock watering. Disposal of treated produced water to streams is considered a less desirable option, but one that can be accessed if the environmental impact of this is considered sufficiently benign.

The possibility of disposal of concentrated produced water (brine) to deep aquifers having a high salt content is common practice in the USA and is being explored in the Queensland context, but is not currently permissible in NSW, nor is it proposed for the NGP.

Details of produced water and its treatment have been provided in several discussion papers (Khan and Kordek, 2014; Fell, 2014) developed for the NSW Chief Scientist and Engineer’s report on the CSG industry (O’Kane, 2014) and in many publications accessible on the internet, including those examining the Australian situation (IESC, 2014; Qld Gas Fields Commission, 2014; APPEA, 2016).

Within the responses to the NGP EIS a common theme has been fears of contamination of the water in the GAB and surface waters surrounding the produced water processing plant from inadvertent spills, improper use of treated water for agriculture and road de-dusting, and intermittent release of treated produced water to Bohena Creek.

Other concerns relate to failure of produced water storage facilities by breaching of dam walls or the overtopping of dams caused by heavy rain events. How Santos plans to minimise such risks by plant design and careful operation is discussed later in this chapter. It is noted that there are NSW regulations applying to the design, operation and monitoring of storage dams and there is the opportunity to draw on the experience of these in action in Queensland where similar regulations apply.

As a result of the many submissions raising issues about the treatment of produced water and a set of questions raised by the WEP, Santos has provided further information (Santos, 2018a and 2018b). In particular, this includes an updated Water Baseline Report (WBR) and performance characteristics of the Leewood reverse osmosis facility now that it has been brought into operation. Data on this unit provided in the NGP EIS was based on modelling using Hydranautics software. The Leewood plant uses Osmonics membrane cartridges and these are reported as significantly improving the quality of treated water (reverse osmosis permeate) over that originally predicted.

4.2 Produced water flows and composition

4.2.1 Flow as a ratio of gas yields

The NGP EIS estimates that the volume of produced water removed over the 25-year life of the NGP will be 37.5 GL. The quantity of gas recovered will be an average of 200 TJ/day or a total of 1.83×10^6 PJ, giving a co-produced water to energy ratio of 50 ML/PJ. This is compared with the long-term averages for other CSG sites in Table 4.1.

Table 4.1: Co-Produced Water to Energy Ratio for CSG Sites

Basin	Location	Produced Water to Energy Ratio ML/PJ
Sydney	NSW	1
Gunnedah-Oxley	NSW (NGP)	50
Bowen	Qld	63
Surat	Qld	260
US (various)	USA	5 – 415

From the viewpoint of gas yield per unit of produced water to be treated, the Santos project, based on the GOB, is attractive. Exploratory studies by Santos to date have been used to establish the quoted quantity of produced water for the given gas recovery. There is likely to be some uncertainty in the figure, but advice from the NSW Department of Resources and Energy (NSW DRE, 2017) and GISERA (GISERA, 2017) suggests that it is a reasonable estimate at this stage of process development and a sound one on which to base the detailed design of the produced water treatment plant. The 37.5 GL drawdown over the life of the project represents a relatively small percentage of the allowable water take from the GOB. The produced water treatment plant is essentially modular in design and can be adapted relatively easily to meet higher feed requirements if needed.

4.2.2 Time variance over operating life of site

The flow of produced water from a CSG site varies with time. From a steady increase in an initial stage where wells are brought into production, it reaches a maximum at the Year 2-4 stage and then declines as sufficient water has been removed from early wells to ensure their continued production of gas. In Figure 7.2 of the NGP EIS, reproduced here as Figure 4.1, Santos has provided an indicative produced water profile showing flow peaking at 10 ML/day in year 3 and declining thereafter, with the average over the life of the project being 4 ML/day. This type of profile is consonant with CSG experience elsewhere and is dependent on the rapidity of establishment of new wells and their individual behaviour. Santos has indicated that it will develop a

Field Development Protocol to ensure an orderly development of the NGP gas field. This protocol will be refined as the results from newly established wells are assessed.

Of significance is Santos' advice to the WEP from its exploratory studies that a well can be shut in (i.e., its flow stopped) for a period and then continue to yield gas at former rates when flow is re-started. This observation is important in terms of the operator's ability to take action to stop feed flow of both gas and produced water if adverse processing conditions are experienced.

The time variance of produced water flow means that the treatment plant and its storages have to be designed to handle peak flow, but components can be removed or held as spares once the period of peak flow has passed. The NGP EIS indicates that the produced water processing plant is to be designed for a feed flow of 14 ML/day and significant storage is to be provided (see later).

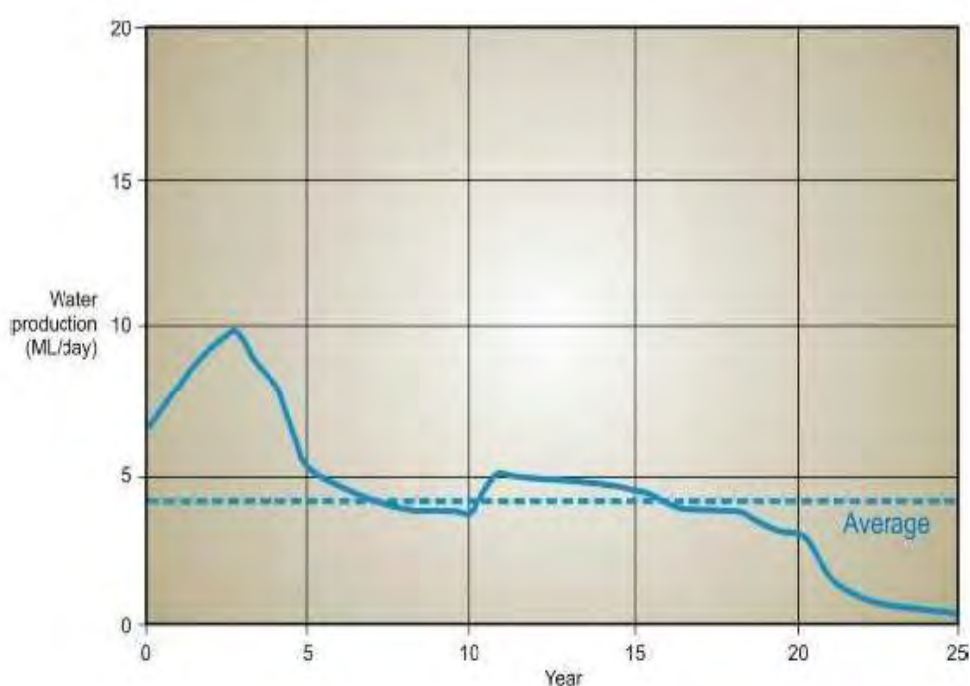


Figure 4.1: Produced water take over time (From Santos EIS Fig.7.2)

4.2.3 Compositional variation of produced water at NGP

It is usual for the composition of produced water to vary somewhat across a CSG site, and with time. In its presentation to the WEP in 2017, Santos reported that *“Natural carbonate and silicate reactive processes are actively taking place as recharge becomes groundwater and groundwater moves through the formations of the project area. This results in: generally increasing salinity with distance (from source) and depth; decreasing chloride to bicarbonate ratio with distance along groundwater flow paths, and a significant increase in the sodium adsorption ratio”*. In turn, this is reflected in the chemical composition of the produced water recovered from target coal seams.

In the same 2017 presentation, Santos stated that *“hydrocarbons are generally not above detection limits for most non-coal seam samples analysed. There are, however, isolated and unrelated exceptions in all formations”*. Much depends on the ability of

the analytical instruments used to detect and record levels of the species present with modern instruments having detection limits below component health specifications for environmental water.

Table 4.2 compares some characteristics of NGP-produced water with the specifications for drinking water (ADWG, 2017) and target levels for water in lowland streams (AWA, 2000). The figures for mean concentrations in the Leewood ponds are taken by the WEP to be a surrogate for feed concentrations to the treatment plant. The Water Baseline Report provides the ranges of each of these chemicals, taken from all available data for the region. The ranges reported are substantial and reflect in part old data taken under uncertain conditions and situations where possible sample contamination from drilling fluids has occurred (Santos, 2018a).

Table 4.2: NGP produced water compared with advice in the NGP EIS and Standards for Drinking and Environmental Water for non-organic species

Component (Concentrations in mg/L unless otherwise indicated)	Mean Concentration in Leewood Ponds (Santos, 2018a)	Santos Advised Produced Water Concentrations In EIS (Appendix T3 Table 6-3)	Australian Drinking Water Standard (ADWG, 2017)	ANZECC Environmental Target (AWA, 2000)
pH	9.4	8.57	6.5 – 8.5	6.5 – 7.5
Conductivity μ S/cm	22,613	5,310	n/a	125 – 2,200
Total Dissolved Solids mg/L	14,668	23,800	< 600	
Sodium	7,059	6,500	< 180	18
Chloride	1,457	2,100	< 250	
Barium	3.35	15	< 2	
Sulphate	42.7	18	< 250	
Boron	0.95	1.3	< 4	1.8
Fluoride	7.64	6.4	< 1.5	0.46
Silica	12.9	24	< 80	
Manganese	0.01	0.18	< 0.5	1.9
Aluminium	0.13	6.1	< 0.2	0.055
Ammonia as N	0.79	16	< 0.5	
Uranium	na	0.001	<0.0017	
Mercury	0.00013	0.00071	< 0.001	0.0006
Cadmium	0.02	0.0053	<0.002	0.002
Copper	0.0037	0.022	< 2	0.0014
Zinc	0.099	0.023	< 3	0.008
Selenium	0.043	0.015	< 0.01	0.011
Carbonate alkalinity as CaCO ₃	5,195	730	n/a	n/a
Bicarbonate alkalinity as CaCO ₃	7,797	12,400	n/a	n/a

n/a Not available

Of the 63 produced water quality parameters reported by Santos (Santos, 2018a and 2018b), 17 do not meet drinking water or irrigation standards. It is not intended by Santos to use produced water before treatment. Exceedances of chemicals of possible concern such as fluoride, cadmium, zinc and selenium are relatively low. It is the function of the treatment plant to lower these to acceptable levels in terms of the standards for drinking water and irrigation.

It is noted that the mean values of Leewood pond data have a lower TDS concentration than in the NGP EIS but the electrical conductivity is much higher, possibly reflecting the role of pH in the carbonate to bicarbonate transition. The ratio of total carbonate to chloride in the Leewood pond data is also higher.

In recent responses by Santos (Santos, 2018a, 2019) to comment by the Department of Industry, Division of Lands and Water (DOIW, 2018) on water quality, historic analyses of groundwater quality are provided for the Gunnedah-Oxley Basin, with samples taken at well-heads across the project areas. Means and 16th and 84th percentile figures are given for a range of analytes. The mean values for Leewood pond data provided in Table 4.2 above lie generally within the ranges reported for the new data. The NGP EIS indicates that treated produced water will meet drinking water standards. Later information (Santos, 2018a, 2018b, 2019) provides information on treated water from the now-operating Leewood plant. Summarised data (Table D1, Appendix D) compares component concentrations with those in local bores, in Bohena Creek and in the Namoi River.

Treated and amended water from the Leewood plant meets both Australian Drinking Water Standards and ANZECC Guidelines for long-term irrigation. With regard to its potential disposal to Bohena Creek in times of high rainfall, the concentration of all reported chemical constituents is better than that measured in Bohena Creek, the Namoi River and local bores, with the possible exception of the levels of boron and zinc. The differences are very small. More is said of this later in this chapter where beneficial uses of the treated water are considered.

4.2.4 Comparison with Australian and international sites

The composition of produced water at the NGP can be compared with that at other Australian CSG sites (QCLNG, GLNG, APLNG and Arrow Energy in Queensland and AGL at Camden, NSW) and with established sites in the USA. This can conveniently be done using a variation of a Piper diagram, as in Figure 4.2 (Dahm et al, 2010). Representative data for Queensland operations has been taken from Queensland data (Qld DNR, 2012), noting that some CSG-producing companies regard this information as commercial-in-confidence. It is noted that, in most situations more than 95% of the TDS are accounted for by the sodium, chloride and bicarbonate ions.

Examination of the data reveals that produced water at the NGP site is generally higher in TDS than at the Queensland CSG sites with a higher proportion of bicarbonate ions present. This is not necessarily a disadvantage but does affect the design and performance of the produced water treatment process and the ultimate composition of the salt product and its possible commercial potential.

CSG recovery in the USA is a well-established technology and, over time, produced water treatment processes have evolved to make better beneficial use of treated produced water in areas that are customarily arid, with stream disposal no longer considered acceptable.

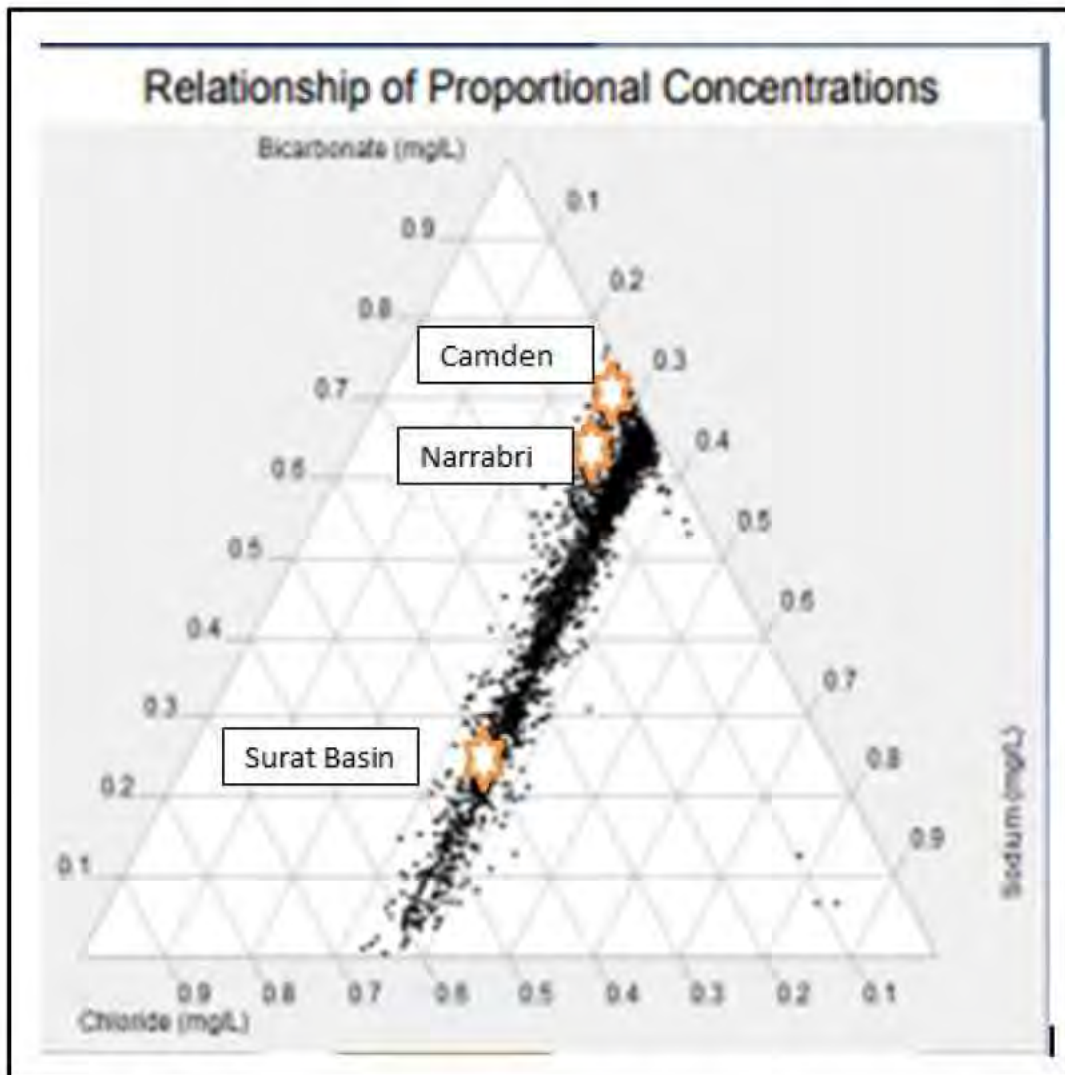


Figure 4.2: Sodium, Chloride and Bicarbonate Concentrations in Produced Water (After Ref 30 for US sites with Australian data added by the WEP)

In various submissions in response to the NGP EIS, concerns have been expressed about the possible presence of constituents of potential concern (COPCs), the levels of which are not reported in the NGP EIS. These include organics derived from coal seams and radionuclides. Several Australian studies (Shearman et al., 2014; Coordinator-General, 2015; Santos, 2013) have identified trace levels of PAHs, high molecular weight hydrocarbons and some nuclear species in produced water from various sources but the levels are below those of concern for drinking water. The treatment of produced water removes these from reverse osmosis permeate, with the newly available information provided in the updated Water Baseline Report and the Response to Submissions (RTS) by Santos (Santos, 2018a), confirming this.

Santos (2018a) has indicated that it will continuously monitor the pH and electrical conductivity of treated water and have a detailed analysis performed on a monthly basis. Inclusion of the levels of the components (identified in the NGP EIS and RTS and summarised in Table A1.1) would be appropriate, augmented by less frequent analyses to check for the presence of radionuclides and higher organic species though these have not appeared in detectable levels in exploratory wells to date. Data collected should be made publicly available.

Recommendation 13

The WEP recommends that Santos conducts regular analyses of production and treated water and makes the results of these analyses publicly available. Analyses should include chemicals of potential concern.

4.3 Treatment process

The treatment of produced water to render it fit for beneficial use has spawned an extensive technical literature. Dependent on the quantity and nature of the dissolved solids content, the combination of separation processes used reflects the need for process efficiency and reliability. Membrane technology has come to play an extensive role in most treatment processes, with pre-treatment of the process feed to minimise membrane fouling and increase membrane longevity.

As an operator of one of the key CSG plants in Queensland that practices produced water treatment and beneficial use, Santos has extensive experience in the operation of produced water processing plant and the proposed NGP operation is clearly modelled on this. Key to the successful operation of a reverse osmosis plant is the lowering of the level of alkaline earth species (calcium and magnesium in particular, by ion exchange) that would otherwise form insoluble carbonates at the membrane surface.

Conventional treatment is to first subject the feed water that has been stored in a produced water holding pond where algal growth might occur, to biocide addition, coarse filtration and then to microfiltration. This is followed by weak acid ion exchange and pH adjustment to prevent the silica content fouling the surface of the membrane in the subsequent reverse osmosis step. Permeate from the reverse osmosis unit is referred to as “treated water” and may have its characteristics changed (“amended”) to make it suitable for beneficial uses. Concentrate (“retentate”) from the reverse osmosis unit is stored in holding ponds before being further processed to recover salts present.

There is significant know-how in the effective operation of a large-scale membrane plant. Through its large investment in seawater desalination plants and membrane facilities at mining and CSG ventures, Australia has a significant body of experience in the area.

4.3.1 Treatment processes used elsewhere

As an aid to evaluating the proposed NGP produced water treatment facility, Table 4.3 summarises facilities in operation or proposed at Queensland CSG establishments. Plants are generally sized to handle peak flows in the first few years of project life, with significant storage provided for produced water feed, concentrate and treated water.

Table 4.3: Produced Water Treatment Facilities at Queensland CSG Operations

Name	Operator	Plant Capacity ML/day	Comment
GLNG	Santos	82	Spread over Fairview (40 ML/d), Roma (28 ML/d), Arcadia and Scotia (Santos, 2013). Rising to 82 ML/day (Shearman et al., 2014). Mean TDS 2,850-9,310 mg/L.
QCLNG	QGC	192	Central and Southern Fields [Kenya] (92 ML/d); Northern Fields [Wandoan] (100 ML/d) (Santos, 2013; QGC, 2017)
APLNG	Origin	112	(APLNG, 2017)

QCLNG’s Kenya plant delivers potable water to the town of Chinchilla. The international water company, Veolia, has recently been awarded a 20-year contract to operate this facility (QGC, 2017). QCLNG’s Northern Fields plant at Wandoan was named Industrial Water Project of the Year at the 2016 Global Water Awards (Global Water Awards, 2016). The award is for the most impressive technical or environmental achievement worldwide in a given year in the field of industrial water and illustrates the advanced state of development of the technology.

Queensland facilities for the treatment of produced water, operate on a significantly larger scale than the proposed NGP development (14 ML/d), partly because of the scale of the Queensland operations and partly because the water to gas ratio of the Queensland CSG fields is significantly higher. The success to date of the Queensland operations is a source of confidence about the technical competence of Australian operators.

4.3.2 Evaluation of proposed treatment process for NGP site

The proposed treatment process for produced water at the NGP is given in Chapter 7 of the NGP EIS. Figure 4.2 below outlines the processing steps. They closely follow what has been found to be effective in Queensland and internationally. Produced water taken from a holding pond is subject to an initial clean-up by dissolved air flotation and straining. This removes algae and larger suspended solids. It is then put through a microfiltration unit with the permeate from this unit subjected to ion exchange and pH adjustment to minimise fouling of the membranes in the subsequent reverse osmosis plant. Permeate from the reverse osmosis plant is de-ammoniated and dechlorinated and has its pH adjusted to give “treated” water. Retentate (concentrate) from the reverse osmosis plant is subjected to two stages of salt concentration to give a crystalline salt product and recovered water that is added to the treated water.

Figure 4.3 shows a peak flow of produced water of 10 ML/d. As earlier indicated, the reverse osmosis unit will be designed to handle 14 ML/d, giving a level of spare capacity to handle plant outages, rainfall or other events.

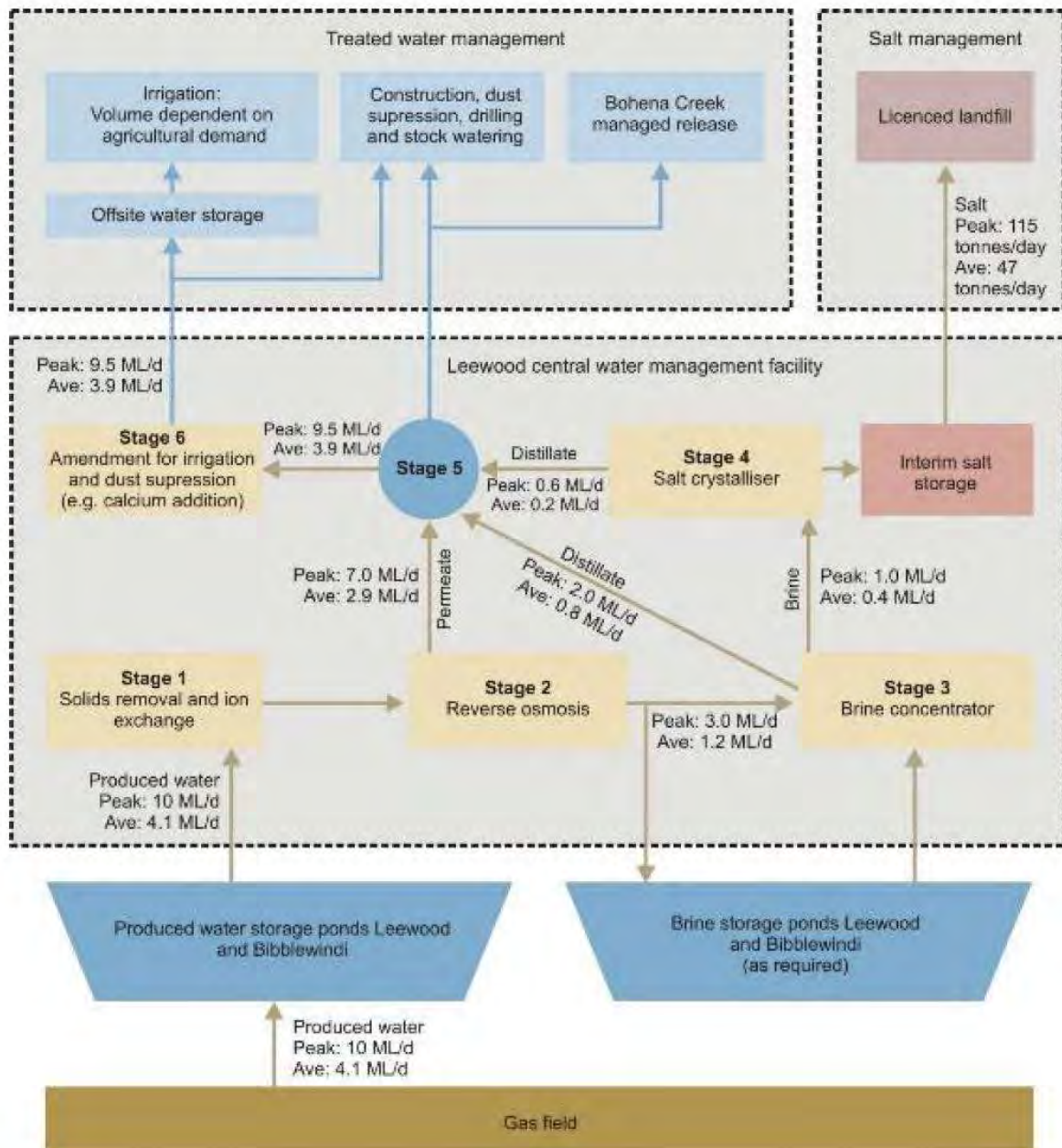


Figure 4.3: Produced Water Treatment Process in NGP (Source Figure 7-4 NGP EIS)

Notable in the flowsheet is the recovery of permeate in the reverse osmosis unit. 70% of the feed to this unit will be recovered as permeate with the remainder becoming concentrate. For the process overall, 95% of the water in the feed is shown as being recovered. This is a little lower than the 97% claimed in some Queensland operations and probably reflects the substantially higher dissolved solids content in the produced water obtained in the NGP operation. Because of the higher feed salt content, the recovery in the reverse osmosis step is relatively low because of concentration polarisation, placing an energy burden on subsequent concentration and crystallisation steps.

In arriving at the levels of salts and other species anticipated in the treated water, the NGP EIS has relied on calculations using membrane-plant supplier Hydranautics software. Since June 2017 the reverse osmosis plant at the Leewood water treatment plant has been in operation. The proponent has included operating data on this plant in its response to submissions (Santos, 2018a,b). The plant uses Osmonics

membrane cartridges and produces a much improved permeate than originally anticipated in the NGP EIS.

Operations at this site were inspected during a visit by the WEP on 8 August 2017. They were judged to be effective, with close attention paid to the prevention of leaks and spills. Reverse osmosis technology is essentially modular and a combination of operating experience at the pilot scale at the NGP and large-scale operations in Queensland lend confidence to the ability of Santos to design and operate a suitable full-scale produced water treatment plant at the NGP.

Key Observation 11

On the basis of operating experience on a pilot-scale unit at the NGP and at large-scale in Queensland, the WEP believes Santos has the capacity to commission the design and to operate a successful process for the treatment of CSG-produced water such as likely to be experienced at the NGP.

Uncertainties associated with the operation of a membrane-based process such as that described, are summarised in the following table, together with commentary on how the approach described in the NGP EIS matches best international practice.

Table 4.4: Operational risks Associated with membrane plant

Parameter	Impact	Comment on Mitigation and Management Measures Proposed in EIS
Quantity of produced water to be processed.	This will occur in the shorter term as more wells are brought on stream and in the longer term as flow from wells declines.	Santos is providing substantial holding capacity for produced water to allow feed flow to plant to be regulated to match plant capacity.
Quality of produced water	Components of produced water will change with time and source well location. This may in turn impact on quality of treated water and plant operations.	Range of historical concentrations in Leewood ponds provided in updated Water Baseline Report (Santos, 2018a). These suggest that full-scale RO plant can be designed to cope at the FEED stage.
Temperature of produced water	Seasonal variations can occur. These affect the rejection performance of the membrane system and may impact on system maintenance.	This aspect should be able to be appropriately handled by membrane selection at the FEED stage.
Algal growth and suspended matter in produced water pond	Fouling of the RO membranes can occur.	Treatment flowsheet counters this problem by biocide addition, dissolved air flotation, straining and microfiltration. This is best current practice.
Precipitation of calcium and magnesium salts at surface of membrane caused by hardness of produced water	Membranes foul or require frequent chemical cleaning.	EIS shows ion exchange to counter this problem. This step is widely used in Australia and overseas and is appropriate.

Parameter	Impact	Comment on Mitigation and Management Measures Proposed in EIS
Silica in the feed water may cause precipitation at the RO membrane surface	This can lead to fouling of the membrane that cannot be removed by membrane cleaning processes.	The EIS indicates that pH will be adjusted prior to the RO plant to mitigate this problem. This step is appropriate.
RO membrane failure	Can be caused by non-reversible fouling of the membrane surface or ageing of the membrane leading to declining membrane performance.	Leewood plant operational experience will assist in allowing appropriate equipment redundancy at the FEED stage, together with a multiple-train design which allows on-line membrane replacement.
Ancillary equipment failure	Failure of pumps, dosing equipment and transfer facilities can lead to plant outages and spills.	Santos response to WEP submissions (Santos, 2018b) indicates a 95% overall membrane plant reliability.

FEED - Front End Engineering Design (Detailed plant design stage once operational details are settled)

Being essentially a modular process, many of the operating problems experienced in membrane technology identified in Table 4.4 can be resolved by carrying spare capacity and having access to replacement membrane modules and ancillary plant. In the case of CSG-produced water treatment, the declining flow of feed water with time means that spare capacity becomes available and declines in membrane performance are less critical.

One ongoing problem, that of silica fouling (which can cause irreversible fouling of the membrane surface), is now the subject of a concerted joint effort by Australian CSG companies who are sponsoring a major Australian Research Council Linkage Grant supporting university R&D in this area. Recent studies (Lunevich, 2015)) suggests that the silica fouling problem could be overcome by selective precipitation and/or the use of an intermediate nanofiltration step in a dual stage reverse osmosis system (Blair et al., 2017).

More is said on the question of plant availability in the section below that deals with the process water balance.

4.4 Site water balance

Key to the environmentally acceptable operation of the produced water treatment in the NGP, is balancing the capacity of the treatment plant and storages provided, so that there is no risk of storages over-topping because of inlet flows, plant capacity limitations or inclement weather. The NGP EIS indicates that a total of three 300 ML storage dams will be made available, with each dam divided into two 150 ML cells. The NGP EIS is not specific on the designation of these storages and it would be good process practice to have them capable of being interconnected, but it is expected that 600 ML will be available for storage of produced water and 300 ML being made available for reverse osmosis concentrate. In addition, there will be a storage capacity of 200 ML of treated water and smaller storages at source and use locations.

The large storages will be constructed according to regulations prevailing in NSW for produced water management (NSW DISRG, 2015) and a Produced Water Management Plan will be required prior to commencement of operations. The

regulations provide requirements for double geomembrane liners for open ponds, monitoring of leaks or failures in pond walls and the development of a Trigger Action Response Plan indicating steps to be taken should adverse findings occur. Ponds are required to maintain sufficient freeboard to handle a 72-hour deluge associated with a 1-in-100 year flood without overflowing. In the case of the ponds at Leewood, it is indicated in the NGP EIS that these are constructed above the flood plain.

The WEP inspected the existing ponds at Leewood during the August 2017 inspection tour. It is judged that if existing and new storage ponds on the NGP site meet the requirements indicated in the regulation (NSW DISRG, 2015) and an appropriate Produced Water Management Plan is developed, then the engineering and environmental aspects of produced water storage will be met.

Key Observation 12

Existing storage ponds at Leewood appear to be appropriately constructed. Adherence to the appropriate NSW Codes of Practice and close attention at the FEED stage to the requirement for environmentally safe operation, should ensure that any risks associated with storage of produced, treated and concentrated produced water are met.

Operation of the produced water treatment plant and of associated storage, calls for decisions above-and-beyond those required under the Code of Practice. Factors that will affect treatment of produced water and gas production during times of peak water (years 2-4) are summarised in **Table 4.5** below.

Table 4.5: Issues Associated with Operation of Produced Water Processing Plant

Issue	Impact
Volume of produced water is significantly higher than expected for required flow of gas.	Will affect the number of days of production water storage available.
Treatment plant outages caused by membrane plant failure, extended cleaning or equipment failure.	Will cause backup in feed storage.
Wet weather causes cessation of irrigation.	Temporary build-up in treated water storage unless conditions allow disposal to Bohena Creek.
Prolonged wet weather but insufficient flow in Bohena Creek to allow disposal there.	Back-up in treated water storage and possibility that produced water treatment has to be shut down.
Extreme weather event, 1 in a 100 year exceedance for 72 hour.	Should be coped with by pond operating practice but may force cessation of produced water treatment.

The plant would appear likely to have produced water storage for approximately 30-45 days and treated water storage for perhaps 10 days once allowance is made for requirements under the Code.

While operating conditions, treated water usage and prevailing weather patterns are not the same as the Queensland operations, figures in Table 4.6 suggest that the storage provided at the NGP (estimated 600 ML, equivalent to 43 days of treatment

capacity) is somewhat higher than that at the Queensland operations. The figures below are taken from (Hagströma et al., 2016).

Table 4.6: Storages Provided at Santos Queensland GLNG CSG Operations

Gas Field	Treatment Capacity ML/day	Produced Water Storage ML (days)	Treated Water Storage ML	RO Concentrate Storage ML
Roma	28	580 (21)	975	1,685
Fairview	40	545 (14)	675	2,030
Arcadia	3	75 (25)	55	665
Scotia	10	120 (12)	145	775

Santos (2013) comments for the Queensland operation that *“GLNG’s adaptive water management procedures are designed to prevent the need for any emergency discharge. There has been no emergency discharge required to date. All water management and brine containment ponds are designed in accordance with DEHP’s regulated dam guidelines (similar to those in NSW). This includes a requirement for the Design Allowance, which is the 1 in 100 year, 3 month wet season rainfall volume to be available on 1 November each year to contain the wet season rainfall”*.

These comments should also apply to the NGP. The NGP EIS reports a maximum rainfall of 407 mm in the month of December on nearby Rosewood Farm. The Water Management Plan prepared after approval (if this should eventuate) should indicate how this and the issues covered in Table 4.5 will be allowed for, in deciding on storage capacity.

The WEP is somewhat reassured by the observation on exploratory wells at the NGP that the flow of gas and attendant water could be stopped for a period without the stoppage affecting gas and water flows when the operation was restarted. In an extreme weather situation this allows for the possibility of emergency discharge to be minimised.

In its response to submissions, Santos (2018a, b) has given details of how its water holding systems will cope with plant outages and periods of heavy rain. Santos indicated that its Queensland plants have been operated without overtopping or pond failure and that operating practices to avoid spillages are well established.

Recommendation 14

The WEP recommends to Government that the proposed Water Management Plan should provide further information to the EPA on the adequacy of the Leewood storage ponds to cope with any process plant outages and extreme weather events. In addition, Santos should clarify what operational steps would be taken in the event that a storage facility exceeds its safe operating level. The preparation of the Plan should be undertaken in consultation with the EPA prior to commencement of production.

4.5 Treated water for irrigation and on-site use

4.5.1 Volumes and composition of treated water

The NGP EIS indicates a peak flow of treated water of 9.5 ML/day with the long-term (25 year) average being 3.9 ML/day. Because of its sodium content, treated water would not be suitable for use on agricultural land. Treated water for this purpose would have calcium chloride added to reduce the Sodium Adsorption Ratio (SAR), to produce “amended” water that would be more suitable for irrigation. The anticipated chemical composition of both treated and amended water is given in Table D1, Appendix D. For operating flexibility Santos has assumed that the peak total of treated and amended water used for downstream design purposes will be 12 ML/day.

Treated and amended water will be beneficially used for irrigation (estimated use 10 ML/day), stock watering, dust suppression, construction and drilling (estimated use 1– 2 ML/day). Depending on the application either treated or amended water will be used. Santos does not propose to irrigate forest areas (Santos, 2018a).

The value for irrigation use corresponds to a 750 mm/year application to 500 ha of Lucerne (Section 14.4.3 of NGP EIS). Elsewhere in the NGP EIS, it is suggested that up to 60 ML/day could be used on this application if conditions were right. The use of amended water for irrigation and dust suppression depends on the weather. If consistent rain prevents that use, Santos seeks permission to discharge suitably treated water into Bohena Creek as discussed in the next section.

Table D2, Appendix D compares the properties of amended water taken from the updated Baseline Water Report (Santos, 2018a) with the ANZECC Guidelines for irrigation water (AWA, 2000). The amended water meets ANZECC guidelines for short and long-term irrigation. From Table D1 it can be seen that it has characteristics similar to those of water from nearby aquifer bores and the Namoi river system.

Nonetheless, it does impose a small salt burden on the irrigated land. The use of groundwater for irrigation is regulated by the relevant authorities and the NGP proposal will need to meet their requirements. For general irrigation the user must meet water licence volumetric limits. For irrigation on Santos property, it would be regulated under the Environment Protection Licence (EPL) granted by the NSW EPA. If use is off-site by a third party, the regulatory path is likely to be via a specific Resource Recovery Exemption Order (RREO) granted by the NSW EPA, otherwise an EPL would be required.

The two parameters used to evaluate the suitability of irrigation water are SAR and Residual Sodium Carbonate (RSC) (AWA, 2000). The NGP EIS indicates that treated water is to be amended by the addition of calcium chloride to bring it to a satisfactory SAR, such that it does not damage the irrigated soil. Although the ANZECC guidelines do not specifically mention a trigger bicarbonate level, the presence of a high bicarbonate load can become of concern for higher pH values. pH adjustment does occur in the proposed amendment process. With the much lower bicarbonate level in the treated water from the Leewood plant (Santos, 2018a), RSC is not seen as a problem.

Recommendation 15

The WEP recommends to Santos that prior to the commencement of irrigation using treated water, a study be undertaken by an agricultural expert to determine the appropriate process settings for process water amendment and the preferred soil types to be irrigated, so as to preserve the agricultural integrity of the irrigated land.

4.5.2 Evaluation of on-site use

The NGP EIS indicates the protocols it would use for application of water for dust suppression and rehabilitation, matching quality to land use (forest or agriculture) and avoiding saturation or run-off and avoiding application during rainy periods. These protocols are appropriate.

4.6 Disposal to water courses

A key component of the handling of produced water at the NGP will be the intermittent disposal of treated water to Bohena Creek. During the peak produced water flow period (years 2–4), this is estimated to occur on 44 days per year when the creek is flowing at 100 ML/day. The proposed release will then be up to 12 ML/day or, on a yearly average basis, 14% of the produced water entering the treatment plant. Being able to release water in this way means that rainy periods, when irrigation cannot occur, can be managed without overtopping storage ponds.

Responses to the NGP EIS expressed concern about the effect of such managed release on the ecology of the creek, its effect on nearby groundwater and ultimately the Namoi River of which Bohena Creek is an ephemeral tributary. In dry periods Bohena Creek can revert to a series of ponds.

4.6.1 Evaluation of disposal to Bohena Creek

Mixing of discharged water with flowing water in Bohena Creek during rain events will lead to minimum nine-fold dilution of components in the discharged water. With the much improved performance of the reverse osmosis plant (Santos, 2018a), concentrations of components in the amended water lie below those reported for Bohena Creek (Table A1.1) with the possible exception of boron and zinc. In the case of zinc, the resolution of the analytical instrument is insufficient to determine whether the value for water proposed to be discharged lies below that for the creek. Whilst the figure for boron lies slightly above that reported for the creek, the combined flow after amended water discharge will have a boron level of 0.054 mg/L versus the 0.05 mg/L in creek water, the difference is considered unlikely to affect the ecology of the creek provided the discharged water and creek water are effectively mixed. Temperature matching of discharged and creek water will be desirable and this possibility is implied in the RTS (Santos, 2018a).

The NGP proposal is to release amended water to Bohena Creek when the creek is flowing at 100 ML/day, with the flow to be determined by the gauging station at the Newell Highway. Flows within Bohena Creek are likely to be influenced by the interaction of surface water with groundwater and the WEP suggests that it would be

preferable, for the purposes of discharge, to monitor stream flows much closer to the NGP site. In the RTS the proponent has argued that the Newell Highway flow station be maintained but the instrument be upgraded, giving as a reason the ill-defined nature of the river bed further upstream. This argument seems reasonable.

4.6.2 Other possible treatment options

The treatment of produced water from conventional and unconventional natural gas recovery and from mining enterprises, is an active field of engineering and scientific study and possible alternative processes are continuing to evolve. Processes such as electrodialysis, capacitative deionisation, ion exchange (Fell, 2014) each have their proponents and are evaluated in terms of cost. Because of their essentially modular nature, they can be used to replace elements of an existing scheme and should be kept under surveillance for application by the NGP operator as time passes. At this stage none is considered by the WEP to offer a better alternative than that proposed in the NGP EIS.

4.7 Conclusions

The process proposed in the NGP EIS for the treatment of CSG produced water, represents best current international practice. It is also a technology that Santos and other Australian operators have in practice in Queensland CSG ventures. Updated operating data from the Leewood plant suggests that its performance is substantially better than anticipated in the Santos EIS giving permeate that once amended, is suitable for irrigation and onsite use. The intermittent release of treated produced water to Bohena Creek during periods of high rainfall appears acceptable in terms of the chemical composition of the water but temperature matching would be appropriate.

4.8 References

ADWG, 2017: Australian Drinking Water Guidelines (2011) - Updated October 2017, National Health and Medical Research Council, 2017

APLNG, 2017: Australia Pacific LNG,

<https://www.aplng.com.au/topics/water-and-csg.html>

APPEA, 2016: Water from Coal, Australian Petroleum Production and Exploration Association (APPEA), November 2016

<https://www.appea.com.au/tech-drill/water-from-coal/>

AWA, 2000: Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian Water Association, 2000

<http://www.agriculture.gov.au/SiteCollectionDocuments/water/nwqms-guidelines-4-vol2.pdf> [There has been a 2018 Revision of these guidelines to improve their utility. At this stage the quantitative aspects of the guidelines for individual analytes of interest to the NGP are essentially unchanged from those in the 2000 version.]

Arrow Energy, 2013: Coal Seam Gas Water and Salt Management Strategy, Arrow Energy, 2013
https://www.arrowenergy.com.au/data/assets/pdf_file/0004/8653/7040_12_Att05_Rev1.pdf

Blair et al., 2017: Enhanced water recovery in the coal seam gas industry using a dual reverse osmosis system, [D Blair](#), [D T. Alexander](#), [S Couperthwaite](#), [M Darestani](#) and [G J. Millar](#), Environmental Science: Water Research & Technology, 2017,3 278-292

<http://pubs.rsc.org/-/content/articlelanding/2017/ew/c6ew00266h/unauth#!divAbstract>

Co-ordinator-General, 2015: Santos GLNG Gas Field: Coordinator-General's evaluation report on the environmental impact statement December 2015

<https://www.statedevelopment.qld.gov.au/resources/project/santos-glng/santos-glng-report-on-final-eis.pdf>

Dahm et al., 2010: Coalbed Methane Produced Water Usability Through Characterization, K Dahm, K Guerra, P Xu, X Mayer, N Hancock, D Heil, T Cath, and J Drewes, Colorado School of Mines, 2010

http://aqwatec.mines.edu/produced_water/new/IPEC2010/2.IPEC2010_WaterQuality.pdf

Doctors, 2017: Submission from Doctors for Environment in response to NGP EIS, 2017

DOIW, 2018: Comment by Department of Industry, Lands and Water Division, on Santos Response to Submissions

Fell, 2014: Water Treatment and Coal Seam Gas, C Fell, Fell Consulting Pty Ltd 2014

http://www.chiefscientist.nsw.gov.au/data/assets/pdf_file/0005/56858/Water-treatment-and-CSG_Final.pdf

GISERA, 2017: Presentation to WEP by Gas Industry Social Environmental Research Alliance (GISERA), 2017

Global Water Awards, 2016: Australian Water Treatment Plant Named Industrial Water Project of the Year <http://www.genewsroom.com/press-releases/australian-water-treatment-plant-named-industrial-water-project-year-282886>

Hagströma et al., 2016: Produced Water—Emerging Challenges, Risks, and Opportunities E L. Hagströma, C Lylesb, M Pattanayekb, B DeShields, and M. Berkman, Environmental Claims Journal, 2016, Vol 28, No.2, 122-139

http://www.brattle.com/system/publications/pdfs/000/005/282/original/Produced_Water_Emerging_Challenges_Risks_and_Opportunities.pdf?1462473734

IESC, 2014: Fact sheet - Coal seam gas extraction and co-produced water, Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, 2014

<http://www.iesc.environment.gov.au/publications/csg-extraction-and-co-produced-water>

Khan and Kordek, 2014: Coal Seam Gas: Produced Water and Solids, S Khan and G Kordek, UNSW 2014

http://www.chiefscientist.nsw.gov.au/data/assets/pdf_file/0017/44081/OCSE-Final-Report-Stuart-Khan-Final-28-May-2014.pdf

Lunevich, 2015: Silica Fouling in Coal Seam Gas Water in Reverse Osmosis Desalination, L. Lunevich, PhD thesis, Victoria University 2015

<http://vuir.vu.edu.au/29720/1/Lyudmila%20Lunevich.pdf>

National Toxics Network, 2017: Response of National Toxics Network to NGP EIS, 2017

NSW DISRG, 2015: Exploration Code of Practice: Produced Water Management, Storage and Transfer, NSW Department of Industry, Skills and Regional Development, 2015

https://www.resourcesandenergy.nsw.gov.au/data/assets/pdf_file/0005/565952/Exploration-Code-of-Practice-Produced-Water-Management-Storage-and-Transfer.pdf

NSW DRE, 2017: Advice to WEP from NSW Department of Resources and Energy, 2017

O'Kane, 2014: Final Report of the Independent Review of Coal Seam Gas Activities in NSW, NSW Chief Scientist and Engineer, 2014

http://www.chiefscientist.nsw.gov.au/data/assets/pdf_file/0005/56912/140930-CSG-Final-Report.pdf

QGC, 2017: QGC's Kenya Water Treatment Plant, Queensland, Australia

<http://www.water-technology.net/projects/-qgc-kenya-water-treatment-plant-queensland/>

Qld DNRM, 2012: Stream ecosystem health response to coal seam gas water release: Hazard characterisation, Healthy HeadWaters Coal Seam Gas Water Feasibility Study, Queensland Department of Natural Resources and Mines, 2012

https://www.dnrm.qld.gov.au/data/assets/pdf_file/0012/106104/stream-ecosystem-health_hazard-characterisation.pdf

Qld GasFields Commission, 2014: CSG Water Treatment and Beneficial Use in Queensland, Australia, GasFields Commission Queensland, November 2014

file:///C:/Users/User/Downloads/Sub_121_Att%2032.pdf

Santos, 2013: Santos GLNG Project: CSG Water Monitoring and Management Plan, Produced Water Management, Stage 2, Revision 2, 2013

<https://www.santos.com/media/3755/csg-water-monitoring-and-management-plan-summary-plan-stage-2.pdf>

Santos, 2018a: Response to Submissions, Santos, 2018

Santos, 2018b: Response to Questions Raised by Water Expert Panel, Department of Planning and Environment, Santos, 2018

Santos, 2019 Narrabri Gas Project, Supplementary Response to Submissions.

Shearman et al., 2014: Assessment of Geogenic Contaminants in Water Co-Produced with Coal Seam Gas Extraction in Queensland, Australia: Implications for Human Health Risk, W Stearman, M Taulis, J Smith and M Corkeron, Geosciences, 2014, 1, 2

[file:///C:/Users/User/Downloads/geosciences-04-00219%20\(5\).pdf](file:///C:/Users/User/Downloads/geosciences-04-00219%20(5).pdf)

Spectrum Analysis, 2017: Guide to Interpreting Irrigation Water Analysis, Spectrum Analysis Inc., USA

http://www.spectrumanalytic.com/support/library/pdf/guide_to_interpreting_irrigation_water_analysis.pdf

5. SALT

This chapter examines the processes proposed for the NGP for the recovery and disposal of salt resulting from treatment of produced water and it compares them with good practice elsewhere. It also considers the prospects for their beneficial use or failing that, options for disposing of the salt in an environmentally acceptable manner.

5.1 Background

Soluble salts and other species are contained in the produced water from CSG recovery. They are substantially removed in the reverse osmosis section of the produced water treatment plant, with the concentration of salts in the concentrate stream (retentate or brine) determined by the level of recovery practiced. Subsequent salt recovery consists of two unit operations: brine concentration and brine crystallisation. The end product is a solid mass of crystals (containing some water), fit for possible beneficial use or disposal in a licensed landfill.

Figure 5.1 (taken from figure 7.4 of Chapter 7 of the NGP EIS) illustrates the recovery process and anticipated flows for the peak years (2-4) of the project. It has been amended for this report to show the notional increases of salt concentrations in process streams in sections of the treatment process. The actual concentration multipliers are slightly less than these, as the rejection of salts in the reverse osmosis section is incomplete and a small amount of salt is lost in the distillates from the brine concentrator and crystalliser, which are added to treated produced water.

Of the peak 48.5 tonnes/day of salt in the produced water, as reported in the NGP EIS, 97% (47.1 tonnes/day) is estimated as end-product salt, with the remainder appearing in low concentrations in water used on site for irrigation, drilling and dust suppression. Over the life of the project it is estimated that 430,500 tonnes of salt will be produced (NGP EIS Chapter 28, Table 28.6).

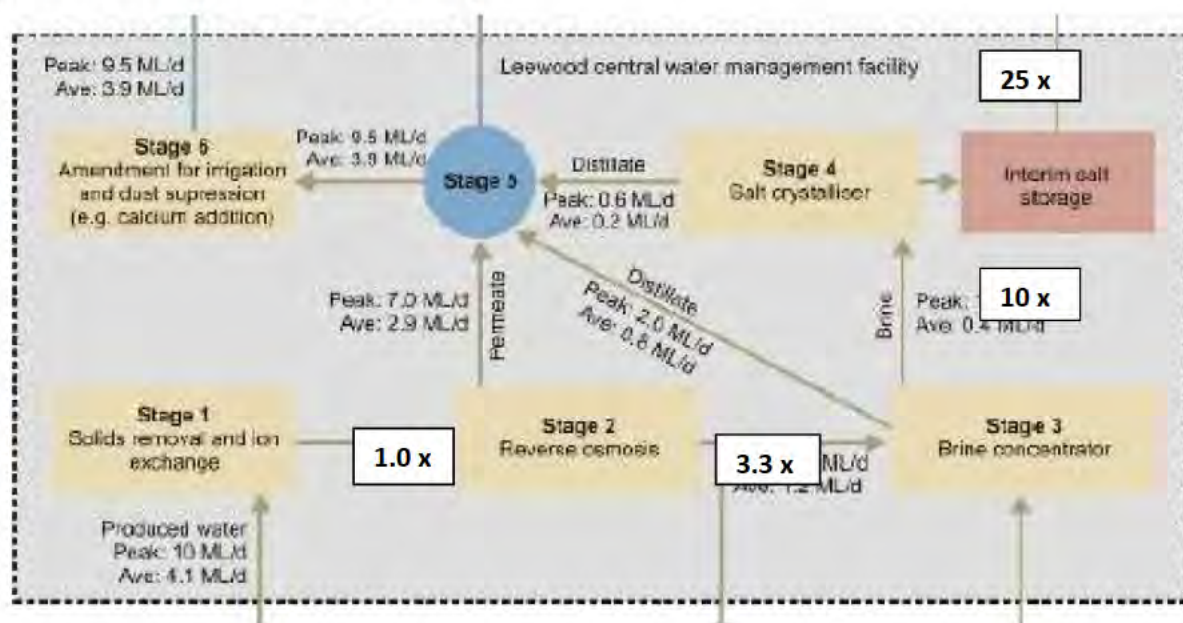


Figure 5.1: Salt recovery process showing sectional increases in salt concentration (multipliers added by WEP)

Issues raised by responders to the NGP EIS (Responses, 2017) included concern about the volume of salt produced, the possibility of it imposing an environmental risk to surface and groundwater at the NGP, its composition and the possibility that some species present may make it a prescribed waste, and the failure to explore opportunities for beneficial use.

5.2 Salt recovery process

5.2.1 Salt recovery processes used elsewhere

The proposed salt recovery process closely follows in format that now being increasingly implemented across the world in zero liquid discharge (ZLD) facilities (Modern Water, 2017; Suez, 2017a,b; Pancrantz, 2015; Tong et al., 2016; Veolia, 2013 and 2017a,b). The steps in a ZLD process comprise brine concentration, which uses mechanical vapour compression to raise salinity up to 250,000 mg/L with a subsequent crystallisation step in a specially designed crystalliser that delivers a solid product. Together, water recoveries of up to 98% can be achieved.

Suez (2017b) notes that there are about 15 large facilities now operating in the USA. Notable examples in Australia are at the Ranger uranium plant of Energy Resources of Australia that is of similar size to the one proposed at the NGP (Veolia, 2013), and that at the QCLNG facility (General Electric, 2016), which concentrates brine for disposal.

There are challenges in the effective operation of ZLD plants. These include foaming caused by any organic species present, the corrosive nature of boiling salt solutions requiring expensive materials of construction, and scaling requiring regular 2-6-week “boilouts” (Suez, 2017b).

5.2.2 Evaluation of proposed salt recovery process in NGP EIS

The technology proposed in the NGP EIS for the recovery of salt from the concentrate from the reverse osmosis section is judged to be state-of-art and should provide relatively trouble-free operation, provided an experienced contractor is involved in equipment supply and operation.

Key Observation 13

The proposed process for recovering salt from reverse osmosis concentrate, represents state-of-art technology and should function effectively when allied with sound equipment purchase and competent operation.

5.3 Quantity of salts in produced water

Whilst the technology for salt recovery at the NGP is sound, plant design and energy requirements will depend on the salt concentration in the feed to the brine concentrator, and ultimately on the salt concentration in the produced water.

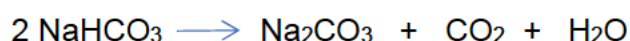
In the NGP EIS Santos has predicted that 430,500 tonnes of “salt” will be produced over the life of the project. This is based on the salt content of the produced water and

a recognition that the soluble material in produced water in part comprises sodium bicarbonate that is broken down to sodium carbonate in the salt recovery process.

In section 7.8.1 of Chapter 7 of the NGP EIS, it is noted that:

“To determine the volume of solid salt product the project would generate, laboratory work was undertaken to imitate the Leewood water treatment process (explained in Section 6.2.1 of Chapter 6), using conditions likely to achieve a similar level of decomposition. Specifically, the produced water was heated in the laboratory to 180 degrees Celsius to simulate the thermal process used during water treatment. During heating, some salt in the produced water decomposes, while the remainder becomes a solid salt product. After taking into account decomposition resulting from heating, the typical mass of salt produced is 11,700 milligrams per litre of water fed to the water treatment process. This factor has been used to determine the estimated salt production rates below.”

Sodium bicarbonate breaks down according to the following formula:



This results in an approximate halving in the mass associated with the bicarbonate ions formerly present.

Santos has reported a TDS in produced water of 23,800 mg/L (NGP EIS Appendix T3, Table 6-3) and bicarbonate ions comprise 64% of salts initially present. Accounting for the breakdown of bicarbonate, the calculated mass of salt produced per litre of water fed to the water treatment process is closer to 16,000 milligrams. However, it is clear that substantially all of the bicarbonate will be converted to carbonate in the brine concentration and crystallisation sections of the plant, with the emission of carbon dioxide. This emission should be counted in the total CO₂ emissions from the plant.

Key Observation 14

Essentially all the bicarbonate present in the produced water is converted to carbonate in the salt concentration and crystallisation sections of the treatment plant.

In providing further information in its updated Water Baseline Report, Santos appears to have provided conflicting information. Table 5.1 compares the properties of produced water given in the NGP EIS with the mean properties of water in the Leewood ponds. This latter water could be considered to be representative of the current produced water feed to go to the salt recovery plant. However, the concentrations in the Leewood pond water could also reflect in part past transfers from the Bibblewindi operation. The Leewood ponds information gives ranges and means for concentrations of component chemicals. Figures for total dissolved solids and electrical conductivity are given. The mean values taken together do not constitute a representative analysis of produced water that would allow a mass balance over the reverse osmosis unit to be performed or the analysis to be checked for ionic balance. But as four ions dominate (sodium, chloride, bicarbonate and carbonate), the analysis can be regarded as indicative.

Table 5.1: Properties of Produced water

Property	Mean in Leewood ponds - Updated Water Baseline Report, 2018	NGP EIS, 2017 Table 6.3 Appendix T3
pH	9.4	8.57
Conductivity ($\mu\text{S}/\text{cm}$)*	27,613	14,000
TDS (mg/L)	14,668	23,800
Sodium (mg/L)	7059	6500
Chloride (mg/L)	1,457	2,100
Total alkalinity as CaCO_3 (mg/L)	12,993	n/a
Bicarbonate (Calculated as $1.22 \times \text{CaCO}_3$ equivalent (mg/L)	9512	15,128
Carbonate (Calculated as $0.6 \times \text{CaCO}_3$ equivalent) (mg/L)	3117	438
Bicarbonate/Carbonate Split Calculated from Above	75%/25%	97%/3%
Bicarbonate/Carbonate Split Based on pH and Figure 1	90%/10%	98%/2%

*Conductivity of 0.5% solutions at 20°C: NaHCO_3 4,200 $\mu\text{S}/\text{cm}$; Na_2CO_3 7,000 $\mu\text{S}/\text{cm}$; NaCl 8,200 $\mu\text{S}/\text{cm}$, reference:

https://sites.chem.colostate.edu/diverdi/all_courses/CRC%20reference%20data/electrical%20conductivity%20of%20aqueous%20solutions.pdf

There would appear to be a discrepancy between the conductivities and TDS in Table 5.1 that is not explained by the different pH values or slightly different temperatures of measurement.

It is also noted that the mean of the field TDS values for the Leewood ponds (14,668 mg/L) after heating to 180°C increases to 16,392 mg/L. Heating to 180°C will convert all bicarbonate to carbonate and yield an anhydrous product, so this is also an apparently anomalous result.

Recommendation 16

The WEP recommends to Santos that a full analysis be undertaken, of representative produced water, and its ranges and means, as this would allow a mass balance to be established across the reverse osmosis and salt recovery units.

5.4 Calculation of salt production

Literature sources (Wiki, 2018) indicate that sodium carbonate will crystallise from solution as the hexahydrate ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$) that, on storage, deliquesces to give the monohydrate ($\text{Na}_2\text{CO}_3 \cdot 1\text{H}_2\text{O}$) which is stable to about 50°C, after which the water of crystallisation is lost.

Total salt output over the life of the Project can be calculated using concentration in produced water values in the EIS. This entails multiplying the TDS by the volume of produced water over the life of the project and subtracting the solids lost in the reverse osmosis permeate and the loss in mass of bicarbonate converted to carbonate in the salt recovery step. The final salt product is assumed to be sodium carbonate monohydrate.

Alternatively, total salt output can be calculated from Brine (RO Concentrate) data in the updated water baseline report provided by Santos. The bicarbonate/carbonate split in this stream has not been provided, but has been estimated by the WEP from the prevailing pH as 90%/10%, with the concentrations of bicarbonate and carbonate species then calculated from total alkalinity. The calculation then takes into account the conversion of bicarbonate to carbonate monohydrate and assumes a 70/30 split of permeate to retentate in the reverse osmosis unit, which may not necessarily be the case for the data supplied.

Estimates of total salt production are provided in Table 5.2.

Table 5.2: Salt Production Estimate

Calculation Strategy	Predicted Salt Production Over Project as Na ₂ CO ₃ .1H ₂ O
From Concentration in Produced Water in NGP EIS	700,000 tonnes
From Concentration in Leewood Ponds in updated Baseline Water Report	430,000 tonnes
From Concentration in Brine in updated Baseline Water Report	854,000 tonnes

The calculations reveal that there is uncertainty over the amount of salt likely to be produced over the life of the project. Whilst the salt recovery plant will be designed for peak produced water flows, it would be desirable if Santos were to clarify figures provided, to allow a mass balance to be conducted around the salt recovery section based on data now available from the Leewood operation.

Recommendation 17

The WEP recommends that Santos provides current information on Leewood Plant operations that gives a clear basis for an estimate of likely salt production, recognising that this may change as more wells are commissioned.

It is instructive to compare the estimated amount of salt recovered in the NGP with that at other CSG sites. This is done in Table 5.3

The higher tonnage of salt per ML of produced water for the proposed NGP operation reflects the higher salt content in NGP produced water. It is noted that the total quantity of salt recovered by the NGP will be significantly lower than at the Queensland sites because of the scale of the Queensland projects in terms of gas recovered. The figures quoted in Table 5.3 are those appearing in the original EISs for the projects or the Queensland Coordinator-General's appraisals of these EISs.

Table 5.3: Tonnes of salt recovered over operating life for different CSG projects

Site	Tonnes of Salt Over Life of Project	Average tonnes salt produced per Megalitre of produced water extracted over life of project	References
Narrabri NGP	430,500	11.5	NGP EIS
Santos Qld (GLNG)	824,500	3.8	Co-ordinator-General, 2015
Arrow Energy –Qld (Surat Basin)	2,970,000	4.5	Arrow, 2017 Arrow, 2013
Australia Pacific LNG (Surat Basin)	2,000,000	4.0	APLNG, 2009 APLNG, 2010
GCLNG - Qld (Surat Basin)	5,500,000	4.6	QCLNG, 2009,2010

5.5 Chemical composition of salt

The NGP EIS does not give a breakdown of the constituents of the salt recovered from the treatment process, referring to it only as ‘salt’. It is possible to infer the likely composition from the constituent concentrations provided in produced water and treated water (see Chapter 4). For non-volatile soluble species the concentration factor will be 25 x, modified slightly by the rejection characteristics of the reverse osmosis membrane. Typically, 97-99% of soluble species is rejected.

Table 5.4 gives the estimated concentrations of the principal inorganic species in the salt. The values in this table are relative and do not allow for any water of crystallisation remaining after the salt recovery process.

Table 5.4: Principal components in recovered salt

Component	Percentage of component present
Sodium carbonate	78
Sodium chloride	21
Other	<0.6

By mass balance it is possible to estimate the quantities of lesser components including COPCs in the salt produced by NGP (117 tonnes) each day during the period of peak produced water flows (years 2-4). They are expressed in parts per million (mg/kg) in Table 5.5.

Table 5.5: Lesser components in solid salt waste

Component	Parts per Million* mg/kg
Barium	1,282
Sulphate	1,539
Boron	111
Fluoride	547
Silica	2,052
Manganese	1.5
Aluminium	522
Uranium	0.009
Mercury	0.06

Component	Parts per Million* mg/kg
Cadmium	0.45
Copper	1.9
Zinc	2.0
Selenium	1.3
Aluminium	521

*under peak flow conditions

Table 5.5 suggests that the salt produced is low in heavy metals and other undesirable components, when compared to the EPA waste classification guidelines.

Labile organic compounds derived from the coal seam, having been removed by the reverse osmosis unit, will appear in the overheads from the brine concentrator and brine crystalliser. There is a risk that over time, they will build up in the salt recovery circuit and will have to be purged lest they dissolve in the condensate that is returned to the treated water stream. This is an aspect that should be considered at the FEED stage of plant design.

Recommendation 18

The WEP recommends to Santos that the likely composition of lesser components in the recovered salt be more closely studied prior to Front End Engineering Design (FEED), as it may impact on the attractiveness for beneficial use of the salt and operation of the salt recovery circuit.

5.6 Possible uses of recovered salt

Using recovered salt beneficially is a problem that has confronted all Australian operators of CSG facilities. Various EIS and Water and Salt Management Plans (Coordinator-General, 2015; Arrow, 2013; APLNG, 2009; QCLNG, 2009 and 2010) have examined the problem, with some companies exploring injection of brine concentrate into deep aquifers, with others including salt recovery sections in produced water treatment plants with the short-term proposal to store solid salt and the longer term proposition of initiating a salt-based industry. In the latter regard, the Queensland operators (including Santos) are jointly sponsoring R&D on selective crystallisation to produce purified salt products (UQ, 2017).

As an example, sodium carbonate will be a significant component of the produced salt at the NGP. The world production of sodium carbonate from sea-water or mined sodium chloride by the Solvay process is approximately 40 million tonnes/year (Carbonate, 2015). This may be compared with the 11 million tonnes of salt produced over the life of Australian CSG plants. Australia uses approximately 0.4 million tonnes/year of the chemical in glass making and mineral processing. Australia's only producer of sodium carbonate by the Solvay process (Penrice Soda) ceased operations in 2014. At that time, it produced 330,000 tonnes/year. Sodium carbonate can readily be converted to sodium bicarbonate which has a host of other uses. For example, one international company (SOLVAir, 2017) reports on its successful use in the reduction of acid gas stack emissions.

Currently the NGP EIS proposes storage on site, followed by disposal to a licensed solid disposal facility. By way of illustration, the quantity of salt produced over the life of the NGP (430,500 tonnes) would require a storage volume equivalent to a large aircraft hangar (180 m length, 60 m width, 20 m high).

The salt recovered at the NGP will be significantly higher in sodium carbonate than at the Queensland CSG operations. It may therefore be a more attractive starting material for a salt-based industry than that from Queensland CSG facilities, provided the smaller scale can be accommodated. Alternatively, consideration might be given to trucking the NGP salt to a central salt processing facility in Queensland, should one eventuate.

Recommendation 19

The WEP recommends to Government and to Santos that, recognising the recovered salt from the NGP is primarily sodium carbonate, further consideration be given to options for its beneficial use.

5.7 Disposal of salt to landfill

The NGP EIS proposes that the salt produced at the NGP be disposed of at a waste disposal site. The disposal of solid waste to licenced landfill sites in NSW falls under the jurisdiction of the NSW EPA. As in Queensland, the waste must meet certain requirements with respect to potential toxicity and the likelihood that components could be leached into groundwater.

The NSW EPA provides specific guidelines (NSW EPA, 2017) on the classification of wastes. Based on the concentrations in Table 5.4 and the criteria in Table 1 of the EPA guidelines, it would appear that the salt produced at the NGP would meet the requirements to be classified as General Solid Waste. However, it is noted that concentration levels of some compounds of interest in the produced water and their fate in the treatment process are not provided in the NGP EIS. Were the levels of these to be such that the salt product contains higher than accepted levels, the salt may have to be classified as a hazardous waste and handled accordingly.

Key Observation 15

Information provided in the NGP EIS, suggests the salt product will meet the requirements to be treated as a general solid waste and to be categorised as “non-trackable”.

Recommendation 20

The WEP recommends that prior to construction Santos provides the regulator with any data available on chemicals of potential concern (COPCs), including their likely concentration in the recovered salt, and that such data be provided on an ongoing basis if the project proceeds

5.7.1 Secure landfill options in the region

Comment in this section is predicated on the salt product being classified as a general solid waste. Chapter 28 of the NGP EIS indicates that there are 11 licensed solid waste disposal sites within 150 km of the project boundary. Under the relevant Act, this is the maximum allowable distance that waste can be transported unless it is transported into a regulated area (coastal/metro) and an additional waste levy paid.

In the NGP EIS it is indicated that: *'The proponent has held discussions with a number of major waste disposal organisations and they have indicated that they have the capacity and capability to dispose of the salt waste at a number of their appropriately licensed facilities.'* Such licensed premises would, under NSW legislation, be required to have met design objectives for cell leachate controls with any leachate from rainfall being pumped to leachate ponds where it is safely handled.

Key Observation 16

In lieu of a proposal to make beneficial use of the salt product, the proposal in the NGP EIS to transfer salt to a licensed disposal site capable of long-term storage of leachable solids is considered acceptable.

Recommendation 21

The WEP recommends that Santos provides to the EPA formal statements from licensed waste disposal operators, confirming that they have available the necessary storage facilities for salt or are willing to develop them.

5.8 Potential hazards associated with on-site storage and transportation

The unintended spillage of solid salt is not a major problem if it is quickly cleaned up and not wet by rain or other sources of water. However, the salt is readily soluble and concentrated salt solutions will cause die-back of flora in affected areas and the possible release of in situ chemical species from the soil. The NGP EIS has indicated on Table 28.6 that the salt will be stored in 'bins or other contained area' for transport and disposal. It would be good practice for salt loading to be conducted in a covered area with an impermeable floor, with adequate protection from surface water and rainwater ingress.

The transport of salt by truck to licensed disposal premises should take place under closely controlled conditions, whereby any spills are promptly attended to with a minimum use of water.

5.9 Conclusions

The salt recovery process proposed in the NGP EIS reflects best international practice in zero liquid discharge technology. The solid salt product is primarily sodium carbonate that can either be beneficially used or disposed of to a licensed solid waste disposal site. The estimated quantity of salt produced is broadly compatible with the solids content of produced water at the NGP but apparent anomalies in data provided should be explained. Trace components and chemicals of possible concern in the salt will need to be monitored over the life of the project.

5.10 References

- Arrow, 2017a: Coal Seam Gas Water and Salt Management Strategy, Arrow Energy, https://www.arrowenergy.com.au/data/assets/pdf_file/0004/8653/7040_12_Att05_Rev1.pdf
- Arrow, 2017b: Surat Gas Project EIS, Arrow Energy, 2013 https://www.arrowenergy.com.au/data/assets/pdf_file/0017/1664/Chapter200520-20Project20Description.pdf
- APLNG, 2009: Environmental Impact Statement, Australia Pacific LNG, 2009 <https://www.aplng.com.au/about-us/compliance/eis.html>
- APLNG, 2010: Australia Pacific LNG Project: Coordinator-General's report on the environmental impact statement, Queensland, 2010 <https://www.aplng.com.au/content/dam/aplng/compliance/government-approvals/CG-Report-Australia-Pacific-LNG-Project.pdf>
- Carbonate, 2015: Sodium Carbonate, The Essential Chemical Industry Online, 2015 <http://www.essentialchemicalindustry.org/chemicals/sodium-carbonate.html>
- Coordinator-General, 2015: Santos GLNG Gas Field: Coordinator-General's evaluation report on the environmental impact statement, 2015 <https://www.statedevelopment.qld.gov.au/resources/project/santos-glng/santos-glng-report-on-final-eis.pdf>
- General Electric, 2016: Australian Water Treatment Plant Named Industrial Water Project of the Year, General Electric, 2016 <http://www.genewsroom.com/press-releases/australian-water-treatment-plant-named-industrial-water-project-year-282886>
- Modern Water, 2017: Brine Concentration, Modern Water 2017 https://www.modernwater.com/pdf/MW_Factsheet_brine_concentration_highres.pdf
- NSW EPA, 2017: Waste Classification Guidelines, NSW EPA, 2017 <http://www.epa.nsw.gov.au/your-environment/waste/classifying-waste/waste-classification-guidelines>
- Pancratz, 2015: Brine Management and Zero Liquid Discharge (ZLD) Options, T Pancratz, DesalTech 2015 http://www.desaltech2015.com/assets/presenters/Pankratz_Tom.pdf
- QCLNG, 2009: Queensland Curtis EIS, Executive Summary, 2009 <https://www.statedevelopment.qld.gov.au/resources/project/queensland-curtis-liquefied-natural-gas-project/executive-summary-eis.pdf>
- QCLNG, 2010: Queensland Curtis LNG Project: Coordinator-General's report on the environmental impact statement, 2010 <https://www.statedevelopment.qld.gov.au/resources/project/queensland-curtis-liquefied-natural-gas-project/queensland-curtis-lng-project-cg-report.pdf>
- SOLVAir, 2017: SOLVAir Select 300 Sodium Bicarbonate

https://www.pollutiononline.com/doc/solvair-select-300-sodium-bicarbonate-0002?vm_tld=2028856&user=95a8803b-5cbe-46ee-a849-eb9bbadbdb0c&utm_source=et_6214185&utm_medium=email&utm_campaign=POL_10-18-2017&utm_term=95a8803b-5cbe-46ee-a849-eb9bbadbdb0c&utm_content=SOLVAir+Select+300+Sodium+Bicarbonate

Suez, 2017a: Recover up to 95% of industrial wastewater as high purity distillate, Suez Water Technologies (formerly General Electric Water Division), 2017

<https://www.suezwatertechnologies.com/products/industrial-fixed-wastewater-evaporators>

Suez, 2017b: The advantage of mixed salt crystallizers in zero liquid discharge (ZLD) wastewater treatment systems, Suez Technical Paper, 2017

<file:///C:/Users/User/Downloads/TP1028EN.pdf>

Tong, 2016: The Global Rise of Zero Liquid Discharge for Wastewater Management: Drivers, Technologies, and Future Directions, T Tong and M Elimelech, Environ. Sci. Technol. 2016, 50, 6846–6855 <http://pubs.acs.org/doi/pdf/10.1021/acs.est.6b01000>

UQ, 2017: Brine Management, Centre for Coal Seam Gas, University of Queensland, 2017 <http://research.ccsq.uq.edu.au/keywords/brine-management>

Veolia, 2013: ERA Brine Concentrator Startup Marks Unique Approach to Mine Water Management, Veolia Water Systems and Technologies, 2013

<http://www.veoliawatertech.com/news-resources/press-releases/2013-11-13,era-brine-concentrator-startup.htm>

Veolia, 2017a: Total Water & Wastewater Management for Shale Gas Production. Veolia Water Technology, 2017

<http://www.veoliawatertech.com/markets/upstream-onshore/unconventional-gas-water-treatment/>

Veolia, 2017b: MBD™ Modular Brine Crystallization System, Veolia Water Technology, 2017

<http://www.veoliawatertech.com/news-resources/datasheets/MBD-wastewater-crystallizer.htm>

Vobis, 2017: Vobis LLC Crystallisers , 2017 <http://www.vobisllc.com/crystallizers/>

Wiki, 2018 *Wikipedia*, 2018 https://en.wikipedia.org/wiki/Sodium_carbonate

6. POTENTIAL CONTAMINATION

This chapter addresses some of the potential water-related contamination issues that may arise during the life of the NGP, i.e., in the development and operational and decommissioning phases of the project, and the possible legacy issues that may become important after the project has ceased, i.e., in the post-decommissioning phase. Discussion of each of the issues is provided, covering briefly the associated hazards and risks identified by Santos and the recommendations of the WEP on further mitigation management, where appropriate.

6.1 Potential contamination hazards

The potential contamination hazards that pose risks to the quality of surface and ground water include the following:

- surface spills of produced water, retentate from the reverse osmosis treatment of the produced water and salt recovery concentrates, chemicals stored on well pads, and any other fluids used in the drilling and gas production process; and
- subsurface contamination of groundwater from drilling fluids, methane or carbon dioxide leakage below ground, or the intrusion of salt and other substances from cross-contamination of the different aquifers that will be penetrated by well drilling.

Each of these hazards is discussed in detail in the following sub-sections, together with consideration of the mitigation strategies proposed in the NGP EIS to control the risks posed by these hazards. Some of the hazards and risks discussed below have already been identified and discussed in Chapters 4 and 5 from a process plant perspective. This has included the possible incidence of spills and leaks in the discussion of the produced water treatment process. The emphasis of the discussion of these issues in this chapter is on their potential impact and mitigation of the associated risks to surface and ground water.

6.2 Surface spills of fluids

The likelihood of surface spills and leakage of fluids during all stages of the project have been considered in the NGP EIS and various stakeholders have also noted the potentially detrimental consequences of such spills and leaks. In particular, concern over the possibility of leaks and spills from the produced water processing plant was a feature of many of the responses to the NGP EIS. In the NGP, produced water spills could also occur at either the bore head and from pipelines. Such concerns about spills are commonplace with regard to plants processing chemicals and, less frequently, to water treatment and sewerage plants.

Spills and leaks could also be composed of retentate from the reverse osmosis process used to treat the produced water, salt recovery concentrates, stored chemicals and also other production fluids. These all have the potential to contaminate both surface water and groundwater.

The NGP EIS relies on Tadros (1993) for the geological framework, although Pratt (1998) provides more detail within the study area. The groundwater sources impacted by a surface spill would be Shallow GAB or GAB (Southern Recharge Zone). The impact of a spill event on groundwater will be governed by local conditions, although it is likely to mobilise any salt bulge present in the unsaturated zone below the surface.

The hydrostratigraphic units defined in the NGP EIS are of only generalized assistance in predicting the impact of such spills. For instance, the Blythesdale Group (Keelindi Beds) are defined as an aquitard, but this unit is composed of the shales of the Orallo Formation and Bungil Formation, as well as the Mooga Sandstone aquifer which is a locally important water source.

Due to the salinity of the produced water, any spill of this water is likely to have significant impact on the local ecosystem, but given the likely volume, it is unlikely to have an impact on the regional groundwater system. There is also uncertainty about whether a spill could mobilise undesirable chemicals in the soil, leading to the appearance in surrounding bores of potentially toxic substances.

Within NSW, the Environment Protection Authority maintains regulatory oversight of process plant operations and issues an Environment Protection Licence (EPL) under the *Protection of Environment Operations Act 1997* which will include conditions to ensure environmental protection.

As noted by Patterson et al. (2017), most spills that occur in unconventional gas projects are related to the storing of water and materials in tanks and pits, and in moving wastewaters between equipment in pipelines and other forms of transport (e.g., road tankers). Perhaps unsurprisingly, the incidence of spills has been found to be greatest within the first three years of well life, when 75–94% of spills occurred. This is the period during which wells are drilled and generally have their largest water production volumes. It is noted that Santos has indicated in the NGP EIS that it expects a peak flow of produced water of 10 ML/day to occur in year 3 after project commencement, with flow rates declining thereafter.

According to the NGP EIS: *“The risk of impacts from produced water, chemical and hydrocarbon spills would be mitigated through both design and operational level mitigation methods. Potential construction, operational and decommissioning impacts would be comprehensively and routinely managed using an environmental management strategy that incorporates materials handling and refuelling protocols, and staff inductions. Further, bunding would be incorporated at hydrocarbon and chemical storage facilities to Australian Standards to contain potential chemical spills or leaks”* (Page 12-29 of Santos, 2017).

Details of the protocols mentioned in the NGP EIS have not been provided. The NGP EIS also mentions the development of various management plans relevant to the project, including:

- Trigger Action Response Plan;
- Produced Water Management Plan;
- Pollution Incident Response Management Plan;

- Irrigation Management Plan; and
- Dam Safety Emergency Plan.

These plans have not been sighted by the WEP. Some have already been developed for exploration activity and others would be developed should project approval be granted. They form an important part of the strategy for mitigating the risks associated with potential spills and leaks, and so it is recommended by the WEP that these plans should be prepared in consultation with the NSW Environment Protection Authority (EPA) or other relevant agencies, prior to commencement of the construction.

Such plans should contain a description of the procedures to be followed to avoid spills and leaks, to detect them should they occur, as well as the corrective and remedial actions that must be adopted if an unforeseen spill or leak should occur.

Recommendation 22

The WEP recommends to Government that all Management Plans relating to the mitigation of risks associated with potential surface spills and leaks be prepared in consultation with the EPA and other relevant agencies as appropriate, prior to construction.

In Table 12-6 of the NGP EIS, the residual impacts on the surface water quality resulting from spills and leaks are indicated as being “Low” in all three stages of the project, viz., during construction, operation and decommissioning. This assessment is considered to be reasonable, provided the appropriate management plans are put in place and adhered to. The issue of adherence to these plans and compliance with the relevant legislation, other statutory requirements and relevant conditions of approval need to be regulated and monitored by the appropriate government agencies.

6.2.1 Likelihood of liquid leakages and spills from process plant

Concern over the possibility of leaks and spills from the produced water processing plant was a feature of many of the responses to the NGP EIS. As previously noted, such concerns are commonplace with regard to plants processing chemicals and, less frequently, to water treatment and sewerage plants. At the NGP the potential consequence of a leak or spill is contamination of the local environment including soil, surface water and groundwater. Because there is an exchange between surface water and groundwater, there is a remote possibility if the spill is sufficiently large that underlying shallow aquifers may become contaminated. The Management Plans should include plant design and operational measures to ensure that the possibility of a spill being this large is negligible.

Possible routes to spillage have been discussed in the NGP EIS, Chapter 14.

The greatest risk is overtopping or failure of a storage dam. This aspect is discussed in the NGP EIS and further expanded on in the response to submissions (Santos 2018a and b). It is also covered in Chapter 4 of this report.

At the WEP site visit, Santos indicated how leaks from vessels and within-plant and cross-site transmission lines would be detected and contained by constant monitoring and sectional shutdown capabilities that would minimise the volume lost.

6.2.2 Likely intensity and contaminant concentrations

The environmental severity of a spill depends on the volume and concentration of contaminants. Concentrate from the reverse osmosis plant will contain species at over three times the concentration found in produced water. Still higher concentrations will be experienced in streams in the salt concentrator and salt crystalliser sections of the plant. Storage ponds and transfer lines will reflect these concentrations.

Previous spills at the NGP site have been discussed in a number of references cited (Khan and Kordek, 2014; Responses, 2017). The history extends over earlier operations at the site by Eastern Star Gas Ltd and more recent spillages at NGP and Santos operations in Queensland. In absolute terms these have been small spills (as judged by the EPA) with, in the case of the Pilliga site, some die-back of inundated forest land. A US EPA study (Khan and Kordek, 2014; Doctors for the Environment, 2017) gives details of 151 spills at CSG sites in the USA with spill volumes of 1.3 to 3.8 ML. 13% of these spills reached surface water.

Also of concern (National Toxics Network, 2017) has been the failure of the geotechnical lining of a previous storage dam associated with the Eastern Star Gas Ltd operations at Narrabri that allowed produced water to escape to groundwater, thus contaminating a number of nearby bores. This has been attributed to faulty construction of the dam. Santos subsequently rebuilt this storage facility to an appropriately high standard.

The proponent has reported a history of 4.5 years of spill free operation of the Leewood plant (Santos, 2018). There has been no history of surface spillages contaminating waters in the GAB.

6.3.3 Preventative measures in process plant design

Steps can be taken at the front-end engineering design (FEED) stage of the produced water treatment plant design to incorporate fail-safe features including the containment of spills. Examples include detection of transfer line failures by pressure drop, automated isolation of sections of plant and holding vessel bunding.

Recommendation 23

The WEP recommends to Santos that at the FEED stage of plant design, fail-safe measures be included to minimise the risk of leakages and spills and to ensure the containment or rapid and effective treatment of these.

It was noted previously in this chapter that the possibility of spillages of various substances, including liquid hydrocarbons, spent drilling fluids, produced water, stored chemicals, and retentate from the reverse osmosis process used to treat the produced water, was raised by a number of parties. Appendix S of the NGP EIS considers certain

spills, both less than and greater than 100 L in total volume of spill. These risks have been rated by Santos as “low” or “very low” risk (see Table 12-6 of Santos, 2017).

Accordingly, the WEP asked the following questions of Santos (under the heading Question 19 – Spillages, see Appendix C).

- A) To what extent has the [concept of a] maximum allowable spillage been used as a design parameter in developing vessel and piping design?
- B) What will be the maximum spillage for each potential spill liquid in the front-end engineering design (FEED) of the NGP?
- C) What minimum spillage of each potential spill liquid is the threshold of a “significant spill”?
- D) What provision will be made for detection, sectional shut down, and safe isolation of offending plant or transfer lines in the event of a spill?
- E) What steps will be taken to handle a spill to prevent it from contaminating groundwater?

In the opinion of the WEP, overall, the initial Santos response to these questions (see Appendix C) addressed the issue of the potential for spillages in very broad terms, rather than addressing some of the specifics that were requested. The WEP then posed a more focused follow-up question, requesting Santos to indicate what would be the maximum spillage of each potential spill liquid assumed in the front-end engineering design (FEED) of the NGP. In addition, Santos was asked what minimum spillage of each particular spill liquid was regarded by Santos as the threshold of a “*significant spill*”.

In its subsequent response, Santos provided a Table indicating that where appropriate and possible, the potential maximum spill volumes for each of the main potential spill liquids of the NGP (Table 4 in Santos 2019), or quantitative information from which such volumes might be inferred. This Table also presented commentary on the likelihood of spills of these magnitudes occurring and the measures to be put in place to monitor whether they do occur and some of the measures to be employed to control any such spills should they occur.

Santos also suggested: “*No threshold ‘significant spill volumes for [sic] have been set for the project’*”, but did suggest that “*a spill would be assessed to be significant if it threatens ‘material harm to the environment’ as defined in section 147 of the Protection of the Environment Operations Act 1997 (POE Act)*”.

It should also be noted that a national assessment of chemicals associated with CSG extraction in Australia was commissioned by the Department of the Environment and Energy and prepared in collaboration with the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (DoEE, 2017). This assessment also included consideration of the risks of spills of some of these chemicals during CSG operations.

In particular, a results table was provided, and 113 chemicals used in drilling and hydraulic fracturing for CSG in Australia between 2010 and 2012 were identified. Not all of these chemicals were used at any one CSG site. The results table shows whether the chemical is a potential risk to workers, the public or the environment, specifically in the absence of all the usual precautions and legal requirements for handling chemicals. The principal risks appear to be associated with road transport of the chemical.

The stringent protective measures imposed by state and territory and Commonwealth governments for industry are also described in detail. It is important and, indeed, reassuring to note that these regulatory measures significantly reduce the likelihood of potential harm to humans and the environment, provided they are followed and enforced.

Key Observation 17

The WEP considers that the current regulatory requirements in Australia by state and federal governments for handling chemicals that may be used in the NGP, provide reassurance that the likelihood of potential harm to humans and the environment is low if these regulations are followed and enforced.

6.4 Subsurface contamination

Several potential sources of contamination of the surface soils and the various groundwater aquifers involved in the NGP have been identified in the NGP EIS and in submissions from stakeholders. These include the following:

- loss of drilling fluids into the geological formations penetrated by the gas wells;
- methane migration and leakage through the geological formations via the well bores; and
- reservoir cross-contamination due to the movement of salts through the groundwater, particularly along wellbores.

6.4.1 Loss of drilling fluids

Loss of drilling fluid, either into the geological formations penetrated by the drilling, or as surface spills, present potential contamination hazards and consequently should be avoided. The proponent has recognized these potential hazards. According to the NGP EIS: “*Losses of drilling fluid into the soil profile is [sic] very unlikely due to the drilling methodology and engineering and operational controls that would be implemented. Drilling would comply with the Code of Practice for Coal Seam Gas: Well Integrity (DTIRIS 2012) which sets out the design, construction and maintenance requirements for gas wells to ensure the safe and environmentally sound production of gas.*” (Page 14-17 of Santos, 2017).

Furthermore, proper management of drilling fluids returned to the surface in a well-designed recirculation process should reduce any risk of surface spillage of these

drilling fluids. Such practices are well-established and considered standard industry practice.

Key Observation 18

The WEP agrees that adherence to the Code of Practice for Coal Seam Gas: Well Integrity would mitigate the risk of drilling fluids escaping into the soil (and rock) profile.

6.4.2 Methane migration

It was suggested by a number of stakeholders that the baseline data collected to date for the NGP may be inadequate or incomplete. This includes data relating to water quality in the various aquifers, groundwater-dependent ecosystems (GDEs) fauna and stygofauna, the methane content of surface and groundwater, and the background methane content in the atmosphere close to ground level. It is generally considered important to collect such baseline data, and to capture baseline readings accurately so that any future changes can be detected, and their causes identified.

As a particular example of baseline data that is lacking, there is little or no documentation in the original NGP EIS of existing occurrences of methane in domestic or agricultural bores or in natural waterways. Given the extent to which there has been controversy in Queensland regarding whether some methane leakages are “natural” or the result of nearby CSG production, this seems to be a significant omission for the NGP. Whilst monitoring of fugitive emissions will be dealt with by EPA regulation, this will not necessarily be done for natural occurrences, which are essentially geological and biological phenomena. As discussed previously in Chapter 2, and stated explicitly in Recommendation 3, as a minimum, it would seem appropriate that Santos document such occurrences before the NGP is approved and moves to its operational phase.

Accordingly, the WEP asked the following questions of Santos (see Appendix C).

- A: What baseline data exists regarding the presence of methane in the various aquifers that will be penetrated during the drilling for CSG in the NGP?
- B: What protocols were used in the collection of data relating to the presence of methane in surface and groundwater and in the atmosphere, and what sampling methods were used to collect this data?
- C: If there is little or no data available on natural occurrences of methane, how would Santos address this information gap before the NGP is underway?

The WEP has noted the Santos response to these questions (see Appendix C) and is of the opinion that the response is adequate and satisfactory. In particular, it includes summary information about the levels of methane that have been monitored in dedicated monitoring bores, augmented by sampling of local landholder bores and DPI monitoring bores. It also provides commentary on the sampling techniques and protocols adopted to collect these data, as requested. It is noted that the revised Baseline Water Report now contains the recently collected data.

Of particular relevance is the advice in the Santos response:

“In general, methane is observed at low and varying levels in all formations above the target formations, though the majority of groundwater samples from across the monitoring network do not record any hydrocarbons above the level of reporting.”

and

“In all recorded cases of methane in groundwater outside the coal measures, including in the alluvium aquifers, concentrations are below 10 ppm. It should be noted that successful ignition of gas in water can only be achieved when concentrations are in excess of 50,000 ppm.” [i.e., when methane exists as a separate gas phase].”

Key Observation 19

The WEP considers pre CSG-activity baseline data will be helpful when assessing the levels of methane detected in groundwater at any time in the future. It considers that the risk of methane leakage into groundwater is low provided the regulations are strictly adhered to.

6.4.3 Reservoir cross-contamination

The migration of salts dissolved in the groundwater by either advection or diffusion, especially along wellbores, has been identified by some stakeholders as a possible source of groundwater contamination, particularly the valuable groundwater resource contained in the upper alluvial and GAB aquifers.

In Appendix F of the NGP EIS it is noted: *“Permo-triassic Age strata within the upper GOB contain groundwater that tends to be brackish to saline with a TDS [Total Dissolved Salts] range of around 500 to 6000 mg/L. Groundwater within the Black Jack Group and Maules Creek Formation that host the target coal seams is typically saline, with TDS values around two orders of magnitude larger than in the shallow alluvial groundwater sources and Pilliga Sandstone.”* (Page 5-42 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017).

These significant differences in groundwater quality between the upper and lower aquifers have been the result of the different geological and hydrological histories of the relevant geological formations. Furthermore, these differences have probably been maintained over geological time, presumably due to the presence of aquitard layers separating the different aquifers, thereby preventing significant migration of salts between the different groundwater bodies by either advection or diffusion or osmosis.

Nevertheless, preferential pathways for the migration of dissolved salts could occur. For example, the Groundwater Impact Assessment (GIA) presented in Appendix F of the NGP EIS considers the risks associated with changes in water quality of the various aquifers and suggest these may be caused by *“induced flows of groundwater and hydrocarbons via pathways within geological faulting and via compromised well integrity.”* (Page 7-1 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017).

The WEP agrees that these are the most likely pathways, and if this type of salt migration were to occur, it would have the potential to affect locally the quality of some groundwater in the GAB and the Upper Alluvium.

However, it should also be noted that any such contamination would be very localised and dilution effects would be effective in reducing the overall impact of the salt migration. Because the target coal seam is depressurized to release gas, the expected migration of salts would be downwards.

In a recent and related study by Sreekanth et al. (2018), particle tracking analyses were conducted in order to make an assessment of the water quality risks posed by the CSG wells. *“Specifically, the particle tracking analysis was undertaken to do a screening analysis to quantify the likelihood of ... contaminant particles flowing along the groundwater flow direction and travelling to different risk receptors including GAB bores, springs or GDEs in the CSG development areas”*. In particular, Sreekanth et al. simulated the travel paths of contaminant particles released from 409 presumed CSG well locations within the Narrabri Gas Project area. The migration, by advection, of such contaminants was predicted to be very slow, which supports the argument presented previously for the impacts being highly localised.

As an illustration of this particular point, consider Figure 6.1 below (reproduced from Figure 10 of Sreekanth et al. (2018)). The predicted migration pathways shown in this figure correspond to a time 3,000 years into the future. They were obtained assuming that accidental damage is equally likely for any of the presumed CSG wells in the NGP. The simulation of the particle travel paths was undertaken considering the water extraction proposed for the NGP CSG development.

It may be observed from the map shown in Figure 6.1 that contaminant particles do not travel very far from the CSG wells in 3000 years. The maximum travel distance for particles released from any CSG well location in the GAB aquifer is predicted to be 6.7 km over the next 3000 years.

These results presented by Sreekanth et al. indicate specifically that the risk of contamination, resulting from CSG well bore de-bonding, to farmers' bores and other risk receptors beyond the project area can be ruled out with high confidence. However, these results can also be interpreted more broadly to infer that the migration of groundwater with high salt content is also likely to be very slow and thus should remain highly localised.

The assessment presented in Appendix F of the NGP EIS considered the potential risks associated with all known well types, viz., historical coal exploration core holes, conventional gas wells, existing water supply bores, and existing and proposed CSG wells. While this assessment considered in some detail well bores of various types as potential pathways for the migration of dissolved salts, it addressed geological faults and fault zones as preferential pathways only briefly. The important issue of these potential pathways is discussed further below.

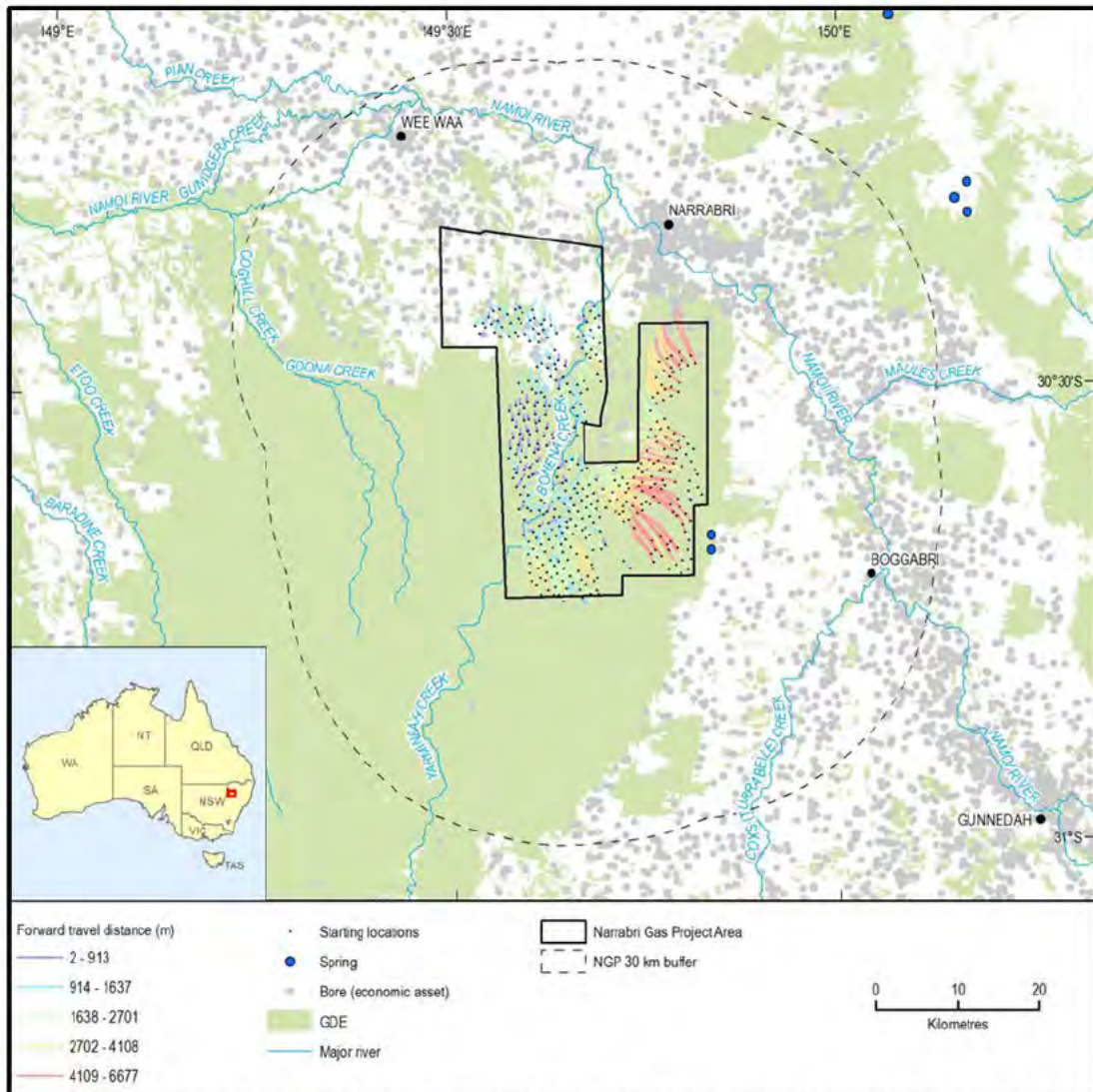


Figure 6.1 Forward particle tracking analysis over 3000 years from CSG wells to risk receptors (after Sreekanth et al. 2018)

6.4.4 CSG wells

The extraction of CSG in the Gunnedah Basin involves drilling and installation of deep wells for exploration, production and monitoring purposes. These wells may intersect multiple geological formations (Figure 2-2), including water-bearing rock units containing groundwater of varying quality. The penetration of multiple formations by wells creates a potential for groundwater flows between the formations, with the drill holes and wells possibly providing preferential pathways for vertical flow.

Possible leakage pathways in CSG wells, particularly abandoned wells, include flow along material interfaces and through degraded cement and corroded casings as shown in Figure 6.2 (after Nordbotten et al. 2005).

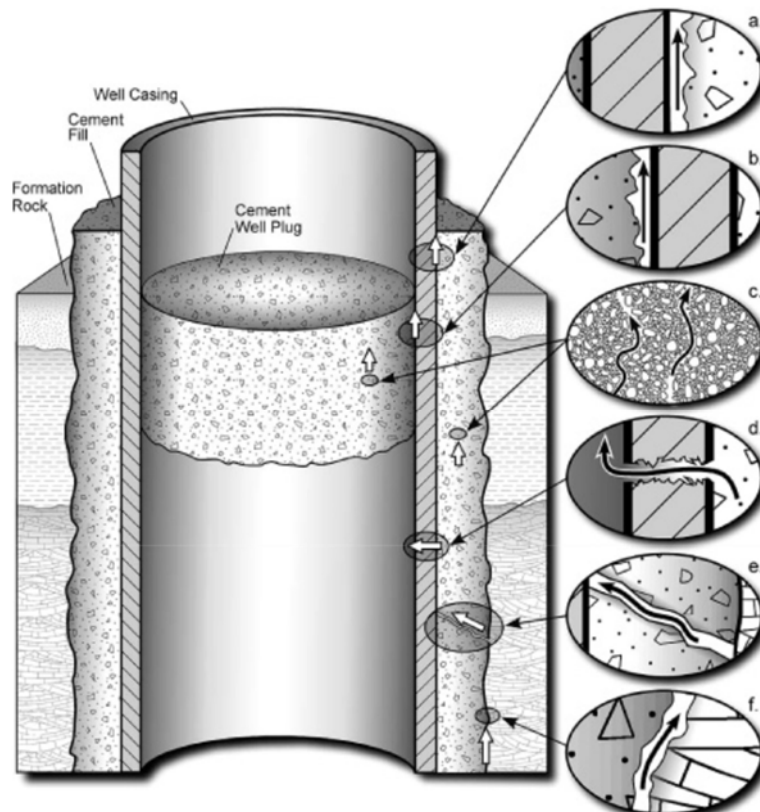


Figure 6.2. Potential pathways for leakage along an abandoned well, including flow along the material interfaces (a, b, f) and through well cements and casings (c, d, e) (After Nordbotten et al. (2005))

In the NGP EIS, Santos has addressed the hazard, likelihood and potential consequences of CSG wells acting as preferential pathways and has suggested that consequences will be mitigated to an acceptable level through various actions. These are listed primarily as the development of individual Well Integrity Plans for each CSG well; plans that presumably will be designed to reduce risk to the environment and beneficial groundwater uses and will employ industry best practices for drilling and well completion works.

According to the NGP EIS, geological mapping and seismic investigation will be conducted prior to selecting well locations. The purpose of such investigations should include, but not necessarily be limited to the identification of significant geological structures that may provide preferred pathways for groundwater migration. It is recommended by the WEP that such investigations should be a requirement before construction commences.

The NGP EIS also states that petroleum industry standards and guidelines for drilling and well completion and the selection of appropriate casings and completion materials will be adopted for all wells. Indeed, the NSW guidelines for well integrity should be strictly adhered to and their application be monitored closely and enforced.

The NGP EIS also states: *“Risks of inter-formational flows following the abandonment of coal seam gas wells are mitigated by cement plugging of the wells at strategic depths and conducting tests to check the integrity of the cement bond.”* (Page 7-5 of

the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017).

According to the NSW Code of Practice for Coal Seam Gas - Well Integrity: *“The titleholder must ensure that an abandoned well is sealed by filling the near-vertical section from total depth to top with cement or other sealing program as approved by the department. There is to be no open annulus to the surface”* (Section 4.9.4, Page 5-42 of NSW, 2012).

It is noted that the NSW code of practice appears to be silent on the issue of sealing horizontal wells and so this issue is discussed subsequently in this chapter. Nevertheless, the mandatory requirement for sealing vertical and near vertical wells should ensure that the entire length of such wells will be plugged with a suitable cement from the bottom of the vertical or near-vertical section of the well, normally located in the target coal seam or a short distance above it, to the ground surface. This Code of Practice also specifies the type and strength of the plug cement and under what conditions it shall be placed.

If such measures are carried out and enforced, then the WEP agrees that properly constructed CSG wells are *“likely to pose a very low risk for gas or water migration between formations due to unlikely occurrence of leakage and minor consequence [if such leakage occurs].”*

Recommendation 24

The WEP recommends to Government and Santos that the NSW best practice guidelines for well integrity be strictly adhered to and this should be a condition of approval of the project and should be monitored by the Regulator.

Recommendation 25

Consistent with Recommendation 6, the WEP recommends to Government and Santos, that mapping and seismic investigation be conducted prior to selecting well locations, in order to identify any significant geological structures before drilling takes place, and that this should be a condition of approval, which should be monitored by the Regulator.

6.4.5 Conventional gas wells

The NGP EIS also addressed the issue of the risk of flows between different hydrogeological units via conventional gas wells, which may act as connecting conduits between vertically stacked geological formations. The NGP EIS reported that a review of approximately 71 wells, for which records were available, indicated that the majority of these wells were adequately plugged or cemented, thus reducing or even eliminating the potential for migration of gas and water to other formations. These records have not been provided, nor have their locations been provided, so an independent check of this assertion has not been possible.

As stated in the NGP EIS: “A small number of former conventional gas wells were identified where the potential risk of interformational flow was likely to be greater than negligible risk. The need for further investigation and rehabilitation will be assessed through the groundwater monitoring program, which will detect in advance if significant impacts from the project activities are expected at these locations in the future.”

“If found to be posing a risk of inter-formation gas or fluid migration, conventional gas wells may be entered, cement plugged and abandoned to industry standards.” (Page 7-6 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017).

The NGP EIS does not identify what is meant by “significant impacts from the project activities”. These should be enumerated by Santos. It was also not clear to the WEP how the “need for further investigation and rehabilitation [would be] assessed through the groundwater monitoring program”. It is recommended that these details should be provided to the satisfaction of the relevant government authority.

Recommendation 26

The WEP recommends to Government that the Regulator ensure the relevant monitoring plan, to be developed by Santos prior to construction of gas wells, is sufficient to detect any failure of the identified conventional gas wells.

6.4.6 Coal mine core holes

According to the assessment described in the NGP EIS, core samples obtained originally for coal mining exploration were collected mainly from near-surface stratigraphic units and they generally did not penetrate multiple aquifers. “The assessment identified that many core holes were drilled as open holes in single geological formations. Santos is in the process of locating historical coal mine core holes to manage potential risks at these locations.”

“Present-day core holes must be backfilled and sealed in accordance with the requirements of Part 5 of the Coal Mines Regulation Act 1982, and therefore they are considered to pose a negligible risk.”

“The risk of induced flows within coal mine core holes that materially affects the quantity or quality of groundwater sources in the GIA study area is assessed to be very low.” (Page 7-6 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of the Santos EIS).

The WEP agrees that these conclusions are reasonable.

Key Observation 20

The WEP agrees the risk of induced flows within coal mine core holes that materially affects the quantity or quality of groundwater sources in the GIA study area, is very low.

6.4.7 Groundwater bores

The NGP EIS states: “*completion guidelines for groundwater bores did not exist prior to 1997, with some groundwater bores drilled as open holes and others completed with cast iron or mild steel casings.*” (Page 7-6 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017). Furthermore, “*all bores were found to be completed in aquifers that are considerably shallower than the target coal seams for coal seam gas production, with bores commonly intersecting multiple water-bearing zones to increase the bore yield. Significant degradation of bore casings may have occurred in bores more than 70-years old. Santos is conducting a survey of landholder groundwater bores to monitor water levels and manage potential impacts on groundwater head in these bores should they occur.*”

“*For groundwater bores greater than 150 m deep, there is generally insufficient information available to identify which groundwater sources they tap, although they are most likely to be screened within locally permeable layers within the upper part of the Permo-Triassic strata sequence. By comparison, the coal seams to be targeted for gas production are considerably deeper, with the primary Early-Permian target seams being located approximately 850 m to 1000 m deep within the Maules Creek Formation, and the secondary Late-Permian target seams being located 600 m to 700 m deep within the Black Jack Group.*” (Page 7-6 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of Santos, 2017).

According to the NGP EIS: “*Gas migration into groundwater bores is considered to be a low risk because the bores are not completed in the target coal seams or the immediately overlying formations.*” The WEP considered this assessment to be reasonable.

Key Observation 21

The WEP considers the risk of gas migration into groundwater bores is low.

6.4.8 Wellbore leakage

In the NGP EIS, Santos has considered the possibility of wellbores (of all types) providing conduits for the leakage of groundwater from various deep sources to the upper aquifers and the ground surface. Leakage rates estimated by Santos, presumably leakage of formation fluids, indicate that “*greater than 5 bores per km² intersecting the Late Permian coal seam targets, or greater than 30 bores per km² intersecting the Early Permian coal seam targets would need to fully fail before flow in the bores accounted for greater than 10% of the pre-existing vertical flux.*” (Page 7-7 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of the NGP EIS).

These particular estimates have not been independently checked, as the detailed assumptions on which the underlying calculations are based have not been provided in the NGP EIS. However, it is possible to do at least an independent order of magnitude check on the leakage rates that might be expected should a single wellbore

fully fail, so that it acts like an unobstructed smooth walled pipe connecting the target coal seam (containing highly saline water) to the ground surface.

Simple example calculations of this type have been presented in Appendix E. For any reasonable estimates of the input parameters to this calculation it can be concluded that any upward leakage rates would be very small. For example, in the case shown in Appendix E, where it was assumed a 10 mm diameter hole extended from the Early Permian coal seam to the ground surface and where the head in the formation fluid at the level of the coal seam was 10 meters above ground surface level, the calculated leakage rate is typically about 0.74 ML/year.

This calculated value is less than about 0.05% of the (revised) upward flow rates of 1.6 GL/year estimated in the NGP EIS to be occurring internally into the Lower Namoi Alluvium from the GAB in the so-called “steady state” condition (see Figure 6.18 of Section 6.6 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of the NGP EIS and the Santos response to Question 5A posed by the WEP – see Appendix C1 of this report).

Of course, leakage that involved upward flow of formation fluids through a wellbore would require the condition where the head at depth in the formation exceeded the head at the ground surface. During most of the life of the CSG operations, and for a very long period after the project is completed (typically at least 1,500 years according to the NGP EIS), the hydraulic gradient will be such that downward flow of groundwater is much more likely than upward flow through a failed wellbore.

On the basis of these approximate calculations it is reasonable to infer that, overall, the risk of induced and enhanced aquifer connectivity via groundwater and CSG production bores is likely to be very low.

Key Observation 22

The WEP considers the risk of induced and enhanced aquifer connectivity via CSG production bores, is very low.

This conclusion supports the assertion and conclusions provided in the NGP EIS regarding the low risk of bores of various types providing a pathway for the leakage of saline groundwater from deep aquifers to the upper aquifers and the ground surface.

6.4.9 Faulting pathways

Geological faulting in the Gunnedah Basin has the potential to enhance the hydraulic connectivity between rock layers if there are major fault zones that extend through multiple formations that could channel the flow of groundwater, particularly in the vertical direction. The issue of faulting and its potential implications for the NGP are discussed at length in Chapter 2, so detailed discussion of them is not repeated here. However, it is worthwhile reiterating the views of the WEP, as set out in Recommendation 6, viz., there is no evidence of any major geological structures that would adversely impact on CSG production, but further work is required, as the project proceeds, to provide a more detailed assessment of the faulting at a resolution that

meets modern petroleum industry standards and of whether the exclusion of faulting from groundwater modelling remains justified.

6.5 Well drilling

A number of potential hazards related to drilling wellbores for the NGP have been identified by Santos and by various stakeholders. Those that pose risks to the quality of surface and ground water, as well as to the operations in general, include the following:

- The possibility of encountering conventional gas;
- The possibility of well blowouts; and
- Inadequate well integrity.

The first two of these hazards are considered in this section, while the third is considered in a subsequent section.

6.5.1 Conventional gas

Conventional gas occurs in the GOB and as pointed out in Chapter 2, some of the wells that detected and accessed this conventional gas lie in or near the NGP area. For example the Coonarah conventional gas well is located in the northwest section of the NGP, east of Yarrie Lake. Unlike most CSG operations, when drilling for and extracting conventional gas, special precautions are required to mitigate the risk of well blowout due to overpressure.

Accordingly, the WEP asked the following questions (identified as Question 3 - Conventional Gas) of Santos (see Appendix C).

- A) Other than the Coonarah Gas Field, has any other conventional gas been detected in the NGP tenement?
- B) Are the operating procedures that will be adopted by Santos to drill wells and produce CSG sufficiently robust to deal adequately and safely with conventional gas if it were to be encountered in any of the Santos wells?

The Santos response stated: *“Historical conventional hydrocarbon shows are primarily associated with the Early Triassic Digby Formation and Middle Porcupine sandstone”,* and included the following additional information.

“A total of 19 conventional petroleum wells have been drilled throughout PEL 238 (and associated tenure) from 1963 - Present”

“Excluding the Coonarah Gas Field, only two of these wells, Wilga Park (1985) and Bohena 2 (1998), have flowed gas at significant rates from conventional reservoirs. In addition, a number of minor hydrocarbon indications ... have been noted in offset wells including local conventional and coal seam gas wells, coal and water bores. To date all conventional gas accumulations, outside the Coonarah Gas Field, are of insufficient size to be produced commercially”.

The WEP considered the Santos response to question 3A (listed above) as reasonable.

In response to question 3B, enquiring about the adequacy of operating procedures if conventional gas was encountered, Santos responded in the affirmative, asserting that the proposed CSG well design and construction will be in accordance with the NSW Government's Code of Practice for Coal Seam Gas Well Integrity. Further, Santos indicated: *"company requirements ensure that the well operates safely within design criteria (casing and wellhead design and pressure ratings, etc.). During drilling operations, stringent systems and operating procedures are implemented to monitor and manage any unforeseen pressures or situations and implement corrective actions to resolve or isolate safely as required"*.

The WEP considers the Santos response to question 3B and the additional comments relating to well design, to be acceptable.

6.5.2 Well blowout

In oil and gas well drilling a blowout is the uncontrolled release of crude oil or natural gas from the well after pressure control systems have failed. Blowout is also a potential risk, which arises largely from the possibility of encountering conventional gas at relatively high pressures during a CSG drilling operation.

In modern wellbores the fluid pressures are controlled by balancing the hydrostatic pressure provided by the column of drilling mud in the wellbore. The aim is to create the condition where the pressure gradient with depth in the drilling mud is equal to or slightly greater than the pressure gradient in the fluids present in the pores of the rock formation that is being penetrated by the well, to prevent the formation fluids escaping up the borehole. Conversely, if the mud pressure is too high relative to the pressure in the formation fluids, there will be a possibility of formation damage, which, for example, can have an adverse impact on permeability and gas production.

If the required balance is not achieved, and the mud pressure is too low, then the formation fluids, i.e., oil, gas and/or water, can begin to flow into the wellbore and up the annular space between the outside of the drill string and the wall of the open hole or the inside of the well casing. This is commonly called a "kick".

In modern drilling operations, mechanical barriers such as blowout preventers can be closed to isolate the well while the hydrostatic balance is regained by circulating fluids in the well.

In the GAB and GOB, which will be penetrated by the CSG wells of the NGP, it is highly unlikely that groundwater pressures will exist that are far above hydrostatic pressure (10-11 MPa/km of vertical wellbore), even though they may be artesian, i.e., groundwater can be extracted at the surface without requiring pumping. Hydrostatic or near hydrostatic pressure is considered the "normal" situation in those regions of the GAB and GOB that will be penetrated by wells of the NGP. Evidence supporting this position has been provided in Figure 4 of Santos (2019), which indicates groundwater versus depth in the Maules Creek and Black Jack formations. This likelihood of near-hydrostatic conditions is in contrast to the condition of "overpressure", which refers to groundwater pressures substantially greater than the pressure from a static column of water.

Thus, in contrast to some other oil and gas operations, where pressures in the formation fluids may be far above hydrostatic pressure, it should not be necessary to

take exceptional measures to guard against a gas blowout in CSG operations of the NGP. Standard well designs and safety measures should be sufficient to address the small risk of a blowout. The NGP EIS indicates that Santos will adopt the NSW Code of Practice for Coal Seam Gas, and this code sets out strict mandatory requirements that are designed to prevent a blowout.

Given that the likelihood of encountering conventional gas is relatively low, and assuming that the NSW Code of Practice for Coal Seam Gas will be strictly followed by Santos for the NGP, the WEP considers that the risk of a blow-out to be very low and any residual risk would be manageable by the company given its long history of successfully producing conventional gas in the Cooper Basin, for example.

Key Observation 23

The WEP considers the risk of well blow-out is very low.

6.6 Well integrity

The construction of gas exploration and production wells normally includes drilling the borehole through the various groundwater aquifers and aquitards, the installation of one or more levels of casing (normally steel tubing) and cementing the well casing into place using specialized cement types, prior to advancing into the deeper coal seams. A schematic illustration of a typical CSG well, with its various types of casing and well cement is provided in Figure 6.3.

This figure indicates the usual arrangement of surface casing, secondary casing and production casing, as well as the annular regions of cement that normally surround each level of casing. Note that in many CSG operations the production casing and its surrounding cement might only penetrate into the top of the coal seam. An important characteristic of this type of well is the existence of multiple barriers against the movement of fluid and gas from inside the well to the surrounding rock (or soil) mass.

An informative discussion on well integrity in the context of unconventional gas recovery is presented in Chapter 5 of the report of the Northern Territory Scientific Enquiry into Hydraulic Fracturing (NT, 2018). Much of its description of well integrity for shale gas extraction is directly applicable to the extraction of CSG. In particular, the report states:

“Well integrity is crucial for the safe operation of a well and to ensure that aquifers are not contaminated. The International Standards Organization (ISO) defines well integrity as follows: ‘Well integrity refers to maintaining full control of fluids (or gases) within a well at all times by employing and maintaining one or more well barriers to prevent unintended fluid movement between formations with different pressure regimes or loss of containment to the environment.’” (ISO, 2017).

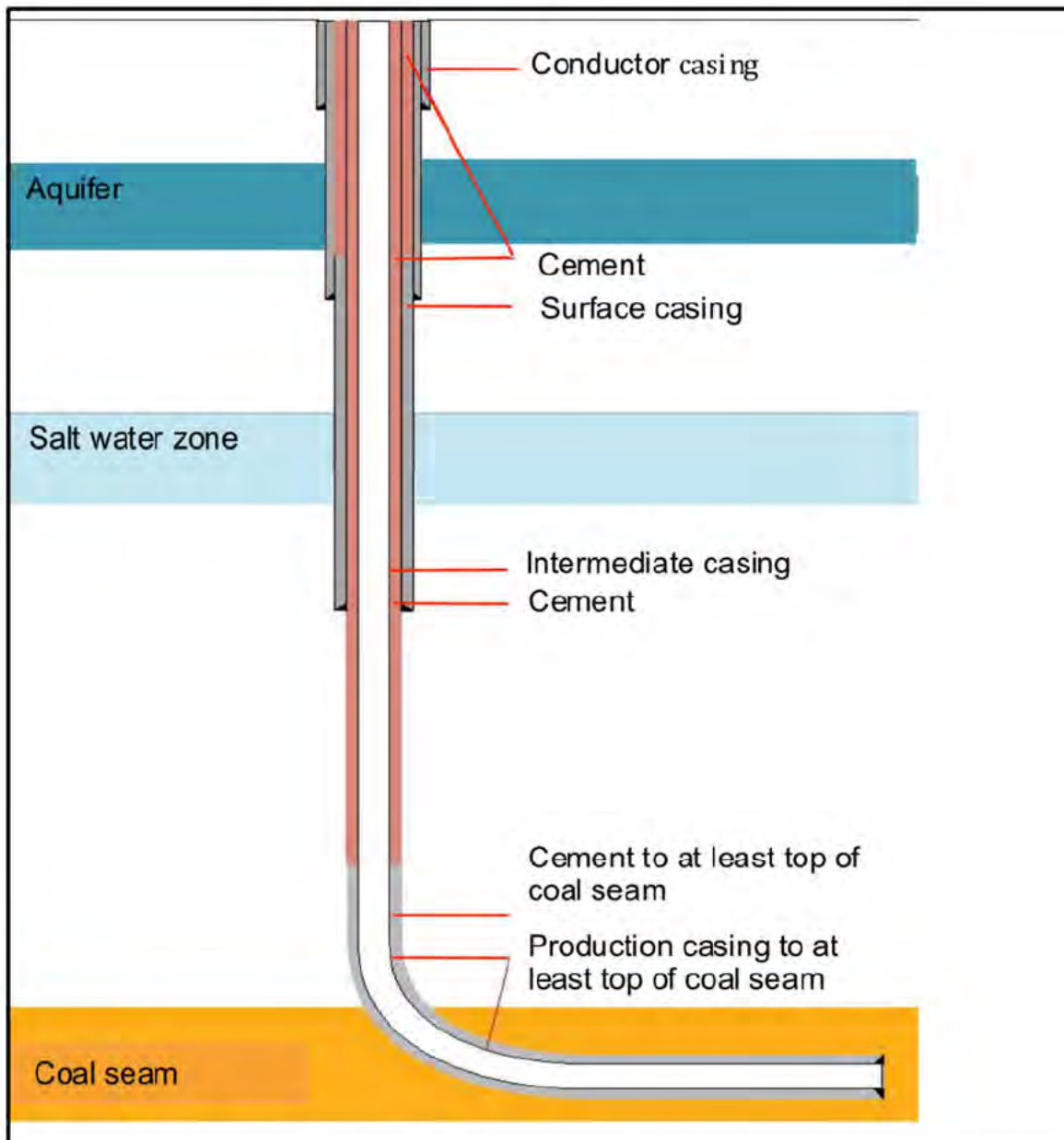


Figure 6.3 Schematic illustration of the stages of casing for a horizontal well in a CSG (or shale gas) operation (adapted from Royal Society, 2012)

Figure 6.4 shows a schematic illustration of the (at least) two-barrier system that needs to be maintained throughout the life cycle of a CSG well. As indicated in the Northern Territory report, there are two types of failure associated with gas wells:

- well integrity failure: in which all barriers have failed, and a pathway exists for fluid to flow into or out of the well. In a dual-barrier design, both barriers must fail for a well integrity failure to occur; and
- well barrier failure: in which one barrier has failed but this does not result in a loss of fluids to, or from, the environment as long as the second barrier remains intact.

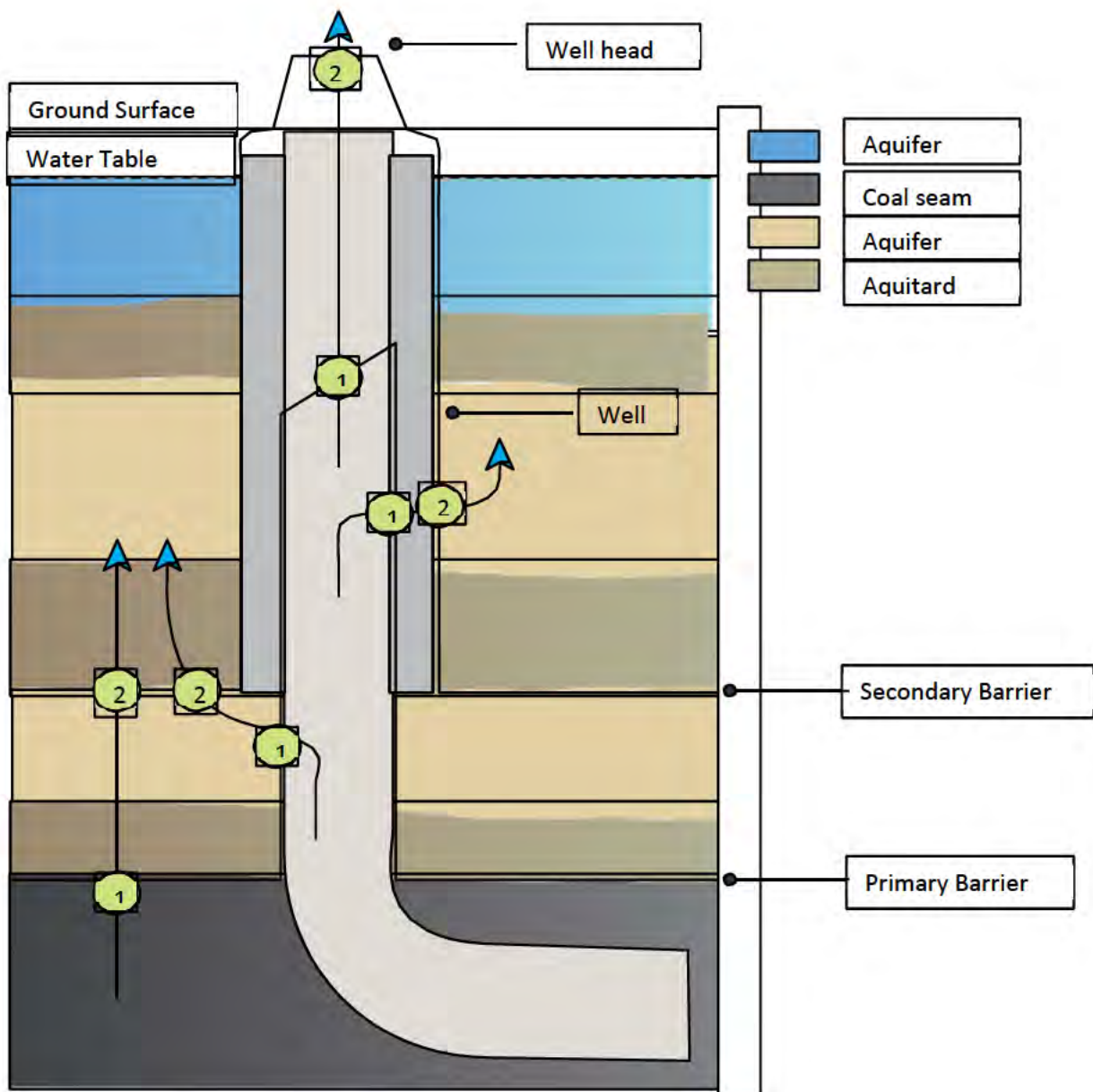


Figure 6.4: Schematic illustration of the two-barrier system and potential leakage pathways (adapted from NT, 2017)

The Northern Territory report also lists possible mechanisms of failure and describes them at some length. These include well failure during drilling and prior to casing; failure of the casing; and failure of the cement. The relevant detail is not repeated here but it is worth noting the summary of potential well failure mechanisms presented in this report:

“Historically, the highest instance of well barrier integrity failure appears to be related to insufficient or poor-quality cementing coverage to seal aquifers and/or hydrocarbon-bearing formations. In older wells, this is likely due to lack of information on non-reservoir hydrocarbon bearing geological layers and the weak regulatory regime under which the wells were constructed. The other common well barrier integrity failure mechanism is associated with the degradation of the cement sheath and the cement bonds to the casing and rock formations. This failure mechanism can be exacerbated if the well is subjected to cyclic pressures, such as those experienced during hydraulic fracturing. There is also a growing body of research conducted on cement durability

related to CO₂ storage that is relevant because CO₂ is considered more corrosive than methane gas. This research has indicated that even after 1,000 years, only a small fraction of the total available length of the cement seals will have been degraded. Well barrier integrity failure can also occur through corrosion of the well's metal casing. If a well barrier failure is observed, or suspected to have developed, technologies, tools and mitigation measures are available to conduct remediation operations".

To put the issue of well integrity and the loss of well integrity into perspective, CSIRO has noted that many studies of well integrity do not make the distinction between failures of individual barriers and well integrity failures. This is critically important because a distinction between a full integrity failure (i.e., the failure of multiple barriers) is required in order to provide a pathway for any contamination of the environment.

Based on data sets, largely from the USA, CSIRO found that the rate of well integrity failures that have the potential to cause environmental contamination is in the order of 0.1%, with several studies finding no well integrity failures. Meanwhile, the rate for a single well barrier failure was in the order of 1–10% (CSIRO, 2017). Once again it is worth noting that failure of a single barrier does not necessarily (and does not usually) constitute a significant failure.

New South Wales drilling regulations address the important issue of groundwater protection, including specifying mandatory requirements for the provision of surface casing, which must be set at an appropriate depth. In particular: *"The surface casing should also be set deep enough that in the event of a kick, while drilling the next hole section, the casing should be able to contain the flow without fracturing the shoe"* (Page 14 of NSW, 2012) and *"Minimum surface casing setting depth should be sufficient to meet isolation requirements of beneficial aquifers and provide an acceptable kick tolerance for the next hole section to be drilled. The kick tolerance criteria shall be selected by the operator and will be dependent upon knowledge of the local pore pressure and fracture gradient profiles, and of the likely kick conditions in the well"* (Page 15 of NSW, 2012).

The WEP notes that in CSG operations in Queensland, the Santos procedures (approved by the Queensland regulators) have included extensive testing programs, and operational and systems monitoring to ensure well integrity. As part of these procedures, if a loss of integrity is identified in a well, immediate measures must be employed to decommission the well, or rectify the situation (QLD, 2015). The WEP believes that adoption of similarly stringent well drilling and operating procedures for the NGP should be a condition of project approval.

Recommendation 27

The WEP recommends to Government that if a loss of well integrity is identified in a well, immediate measures must be employed by Santos to decommission the well, or to restore well integrity.

The NSW Guidelines for Well Integrity state as a mandatory requirement: *"Oil-based muds must not be used for CSG drilling in NSW"* (Page 20 of NSW, 2012). However, the NSW Guidelines are silent on the question of whether synthetic-based muds can be used. Synthetic-based drilling fluids are a relatively new class of drilling muds that

have found application for deep-water offshore drilling and deviated hole drilling. They were originally developed to provide an environmentally superior alternative to oil-based drilling fluids.

In a synthetic-based drilling mud, the continuous liquid phase is a well-characterised synthetic organic compound. Brine is usually dispersed in the synthetic phase to form an emulsion. It is notable that the use of synthetic-based drilling muds has been prohibited in some Queensland CSG operations, e.g., see page 96 of the Queensland Co-ordinator General's evaluation report of Santos GLNG Gas Field Development project (QLD, 2015).

Key Observation 24

The WEP notes the prohibition of synthetic-based drilling muds in some Queensland CSG operations and suggests the matter of their use in NSW needs to be considered by the appropriate regulatory authority.

In addition, any drilling activities must not result in the hydraulic connection of the target gas producing formation and another aquifer. The internal and external mechanical integrity of the well system should be ensured at all times, such that there is: (a) no significant leakage in the casing, tubing, or packer; and (b) there is no significant fluid movement into another aquifer through vertical channels adjacent to the well bore hole. Practices and procedures should be in place to detect, as soon as practicable, any loss of well integrity.

The susceptibility of the well casing materials and cements to corrosion and chemical attack should also be considered in the design of all well bores. In particular, the possibility of acid attack of these materials due to either carbon dioxide that is likely to be present in places, in the extracted gas and groundwater or the possible presence of sulphate-reducing bacteria in the groundwater that can cause anaerobic corrosion of iron and steel must also be considered. Evidence of the latter may be available from inspection and sampling of existing groundwater bores in the region. However, as also noted in Chapter 2 and in Appendix F of the NGP EIS, there is a very low presence of sulphate in the target aquifers, and the inference is made that sulphate-reducing bacteria, if present, will have little sulphate to reduce. The WEP believes this is a reasonable inference.

The process of aqueous CO₂ corrosion and the corrosion rate on steels are well known. CO₂ in combination with water creates an acidic environment that may cause corrosion of steel products in wellheads and casing and well completion strings. It may also "attack" well cement by causing chemical reactions with the cement components. In general, corrosion can be mitigated or controlled by either selecting materials that are resistant to the service environment or by the use of chemical inhibition. This area of corrosion mitigation in wellbores is now well advanced, particularly due to recent activities aimed at injecting and storing CO₂ into sedimentary basins. Further details on the recent advances in this area are provided in IEGHG (2018).

It is also noted that specialized cements can now be engineered for use in casing lining as well as in well plugs in areas in which the groundwater is high in carbon

dioxide (Benge, 2009). Given that there is evidence of high-CO₂ groundwater in the GOB, the use of specialized cements, suitable for use in such environments, is recommended for the NGP wells that encounter high levels of CO₂.

As noted in the Queensland Code of Practice for the construction and abandonment of CSG wells and associated bores in Queensland (QLD, 2017), special precautions are required in areas where the groundwater is corrosive. This Code states:

“Some groundwater is corrosive to mild steel which is widely used for casing, particularly groundwater with a high concentration of dissolved CO₂. In such environments, casing life can be very short, and use of inert casing material such as PVC-U, fiberglass (FRP and FRE) or stainless steel is the primary method of ensuring long bore life. These must be designed to meet the minimum casing design requirements.”

According to this Code, where a bore is located in a formation containing potentially corrosive groundwater, i.e., with a high carbon dioxide content, the use of inert materials for production casing and inner lining casing is mandatory. The WEP agrees that such measures should also be mandatory in NSW, and in particular they should be mandatory for the NGP.

The NSW Code of Practice for Coal Seam Gas is not quite as specific as the Queensland Code, but does state (Section 4.2.2): *“Casing, casing connections, wellheads, and valves used in a CSG well must be designed to withstand the loads and pressures that may act on them throughout the entire well life cycle. This includes casing running and cementing, any treatment pressures, production pressures, any potential corrosive conditions, and other factors pertinent to local experience and operational conditions [Underlining added].”*

Recommendation 28

If potentially corrosive groundwater is encountered in the NGP, then inert materials should be used by Santos for production casing and inner lining casing, as required by the Queensland Code of Practice. Cements resistant to attack by groundwater with a high CO₂ content should also be used by Santos in corrosive formations.

It was also noted by the WEP, as defined in *the NSW Code of Practice for Coal Seam Gas* (NSW, 2012), the NSW DPI Water may order remediation works or the plugging and abandonment of a well if the beneficial use category of a water source is compromised. This option provides additional comfort that a lack of well integrity should not pose a major hazard, at least during the development and operational phases of the NGP.

Finally, it is worthwhile reiterating the CSIRO finding as quoted in the Northern Territory Scientific Inquiry into Hydraulic Fracturing:

“The likelihood of a well integrity failure (that is, where all barriers fail), which is required for an actual release of fluids to the environment, is very low, typically less than 0.1%.”

6.7 Well completion

In the oil and gas industry, “completion” is the process of making a well ready for the production of oil or gas after well drilling has essentially finished. This principally involves preparing the bottom section of the wellbore to the required specifications, running in the production tubing and any associated down hole tools, as well as possibly perforating and stimulating the formation (or coal seam), as required. Sometimes, the process of running in and cementing casing is also included.

Santos has not applied for approval to use hydraulic fracturing, or fracking, to stimulate the formation to assist the production of CSG in the NGP.

According to the NSW Code of Practice for Coal Seam Gas, well completion reports, inclusive of the Plug and Abandonment Report (see below), are mandated. Indeed, this code of practice states: *“Accurate information on drilling, completion, workover and well abandonment must be recorded. Titleholders must ensure that these records are maintained in an accessible way for the periods specified in legislation or, if no such retention periods are specified, for 5 years following the abandonment of a well”* (see Section 3, page 5 of NSW, 2012).

It is also noted that a mandatory requirement of the NSW Code of Practice is as follows: *“To verify casing integrity during the well construction process, casing must be pressure tested prior to drilling out for the next hole section (in the case of surface or intermediate casing), and prior to completion operations commencing (in the case of production casing). The test pressure must be greater than the anticipated formation pressure possible at the surface, but must not exceed 60% of the burst pressure rating of the casing with the safety factor applied [underlining added]”* (see Section 4, page 15 of NSW, 2012).

Furthermore, the NSW code of practice also states: *“Horizontal wells that are drilled within a coal seam should have the production casing just inside the coal seam. The coal seam may be left open or lined with suitable (not steel) slotted casing to ensure open hole well stability.”*

Key Observation 25

Provided Santos follows the best practice code provisions, the risk of leakage from a completed well will be low. The WEP is also of the view that in the unlikely event of leakage occurring, industry best practice would ensure the leak was quickly controlled and any impact remediated.

6.8 Plug and abandonment

When gas production from a well ceases, or becomes impractical or uneconomical, the well needs to be sealed and the associated surface equipment removed. This is a process known in the industry as “plug and abandonment”. The purpose of the process of plug and abandonment is generally as follows:

- To isolate and protect all groundwater zones;

- To isolate and protect all “commercial” producing horizons for future development, if relevant;
- To prevent leaks from or into the well; and
- To remove surface equipment and cut and plug pipe below ground level.

Indeed, Section 4.9.4 of the NSW Code of Practice for Coal Seam Gas states:

“The outcomes of well abandonment are to:

- *maintain isolation of beneficial aquifers within the well from each other and hydrocarbon zones;*
- *maintain isolation of hydrocarbon zones within the well from each other, from aquifers, water bearing zones or from zones of different pressure;*
- *minimize risk to possible future coal mining;*
- *isolate the surface casing or production casing from open hole;*
- *place a surface cement plug in the top of the casing; and*
- *recover /remove the wellhead.”*

Sealing of a well is usually achieved by installing a cement plug. In some oil and gas operations, other mechanical seals may also be used. In NSW, the Code of Practice for Coal Seam Gas requires the vertical or near vertical section of the CSG well to be completely filled with a cement plug, from the bottom of the vertical section to the ground surface. Section 4.9.2(f) of the code of practice states: *“The titleholder must ensure that an abandoned well is sealed by filling from total depth to top with cement of at least 24 hour laboratory strength of at least 500 psi (3.5 MPa). In near-vertical open hole sections of the well, cement is to be placed in plugs of not more than 200 m lengths”*

However, the NSW Code of Practice appears to be silent on the issue of sealing horizontal wells. A history of well plugging practices and regulations in the USA, including horizontal wells, is presented in Technology Subgroup (2011).

Plugging horizontal wells with conventional plugging systems that use cement can be done successfully in many instances, but there is a risk of channelling or mud contamination of the cement from gas or other fluids that can create a pathway for fluids to migrate out of the zones being plugged. As noted in Technology Subgroup (2011) *“The horizontal [well] orientations introduce different gravitational effects compared with vertical wells. In a typical vertical well, where there is a large column of cement, some migration of the solids downward or the water upward does not cause a significant change in the cement properties. In a horizontal well, the solids migrating to the bottom of the section and the water migrating to the top can provide areas of the well that do not have a complete seal. If the water in the cement separates from the mixture before the cement is set, it can migrate to the top of the wellbore and form a channel along the top of the wellbore which can allow migration of formation fluids. If the solids in the cement mixture settle to the bottom of the cement before the cement can harden, the solids can cause the cement to not set up correctly and the weakened*

area along the bottom of the wellbore can fail under pressure during stimulation activities (Salehi and Paiaman, 2009)."

With advances in well drilling technology and the types of wells being drilled and completed, it has been suggested that cementing technology has improved to the extent that it can now allow for cementing of horizontal wells, as well as other specialty applications. It is also suggested that the same cement technologies can be used in the plugging of abandoned wells (Technology Subgroup, 2011).

It is the view of the WEP that consideration needs to be given to the question of whether plugging only the vertical section of a well with cement is sufficient for the gas wells of the NGP or whether the inclined and horizontal sections of these wells within the coal seams, should also be sealed with cement. If the latter is deemed to be required, then the latest available and proven cementing technologies should be adopted.

Recommendation 29

The WEP recommends that Santos be required to demonstrate prior to construction of gas wells, to the satisfaction of the relevant government authority, that wells with inclined and horizontal sections can be adequately sealed during plug and abandonment.

6.9 Conclusions

This chapter has addressed some of the potential water-related contamination issues that may arise during the life of the NGP, i.e., in the development and operational and decommissioning phases of the project. Some of the associated hazards and risks, as identified by Santos in the NGP EIS, as well as by stakeholders and by members of the WEP, have been described, as have their mitigation strategies and measures.

A number of recommendations have been made that relate to the management of the risk of contamination of surface water and groundwater, during the life of the project and beyond. If correct procedures are followed (and the WEP expects that they will be), the risk of trans-aquifer contamination from drilling procedures is considered by the WEP to be minimal, in keeping with the claim made in the Santos NGP EIS.

6.10 References

- Benge, G. (2009) Improving wellbore seal integrity in CO₂ injection wells, *Energy Procedia* 1, pp. 3523–3529. [doi:10.1016/j.egypro.2009.02.145](https://doi.org/10.1016/j.egypro.2009.02.145)
- CSIRO (2017) Report into the shale gas well life cycle and well integrity. Report for the Scientific Inquiry into hydraulic fracturing in the Northern Territory. Commonwealth Scientific and Industrial Research Organisation. <https://publications.csiro.au/rpr/download?pid=csiro:EP179028&dsid=DS2>
- Doctors (2017) Submission from Doctors for Environment in response to NGP EIS, 2017.
- Dusseault, M. et al. (2014) Discussion Paper: Energy Well Integrity - Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process. <https://www.cbu.ca/wp-content/uploads/2015/10/hfstudy-energy-well-integrity.pdf>
- IEAGHG (2018) Well Engineering and Injection Regularity in CO₂ Storage Wells, IEAGHG Technical Report 2018/08, November 2018, International Energy Agency Green House Gas R&D Programme.
- ISO (2017) Petroleum and natural gas industries - Well integrity - Part 1: Life cycle governance. International Standards Organisation ISO 16530-1. <https://www.iso.org/standard/63192.html>.
- Khan S. and Kordek G. (2014) *Coal Seam Gas: Produced Water and Solids*, UNSW 2014.
- Mallants D., Bekele E., Schmid W., Miotlinski K. and Bristow K. (2017), Literature review: Identification of potential pathways to shallow groundwater of fluids associated with hydraulic fracturing, Project report prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra. <http://www.environment.gov.au/system/files/resources/e2512ded-4b0f-4281-bcb5-5952c790b1bb/files/technical-report-number-06-lit-rev-identification-potential-pathways.pdf>
- National Toxics Network (2017) Response of National Toxics Network to NGP EIS, 2017.
- Nordbotten J.M., Celia M.A., Bachu S. and Dahle H.K. (2005) Semianalytical solution for CO₂ leakage through an abandoned well. *Environmental Science and Technology*, 39:602-11.
- NSW (2012) NSW Code of Practice for Coal Seam Gas – Well Integrity. 2012. ISBN: 978 1 74256 328 2. https://www.resourcesandenergy.nsw.gov.au/data/assets/pdf_file/0006/516174/Code-of-Practice-for-Coal-Seam-Gas-Well-Integrity.PDF
- NSW (2014) Final Report of the Independent Review of Coal Seam Gas Activities in NSW, September 2014. Office of the Chief Scientist of NSW. <http://www.chiefscientist.nsw.gov.au/reports/coal-seam-gas-review>
- NT (2018) Scientific Inquiry into Hydraulic Fracturing in the Northern Territory. <https://frackinginquiry.nt.gov.au/inquiry-reports/final-report>
- Patterson LA, Konschnik KC, Wiseman H, Fargione J et al. (2017) Unconventional oil and gas spills: risks, mitigation priorities, and state reporting requirements. *Environmental Science and Technology* 51, 2563–2573.
- Perry, R.H., Green, D.W. (1997) *Perry's Chemical Engineers' Handbook* 7th edition. McGraw-Hill Professional
- Pratt W (1998) – Gunnedah Coalfield (North) Regional Geology 1:100,000 First Edition. Geological Survey of New South Wales. Sydney
- QLD (2015) Santos GLNG Gas Field Development Project. Queensland Coordinator-General's evaluation report on the environmental impact statement, December 2015. <https://www.statedevelopment.qld.gov.au/resources/project/santos-glng/santos-glng-report-on-final-eis.pdf>
- QLD (2017) Code of Practice for the construction and abandonment of coal seam gas wells and associated bores in Queensland. https://www.dnrm.qld.gov.au/data/assets/pdf_file/0011/119666/code-of-practice-csg-wells-and-bores.pdf

Radke B M, Ferguson J, Cresswell R G, Ransley T R and Habermehl M A (2000) – Hydrochemistry and Implies Hydrodynamics of the Cadna-owie – Hooray aquifer. Great Artesian Basin Bureau of Rural Sciences. Canberra.

Royal Society (2012) Shale gas extraction in the UK: a review of hydraulic fracturing http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf

Santos (2017) Narrabri Gas Project – Environmental Impact Statement, Submitted to the NSW Government under Section 78A(8A) of the Environmental Planning and Assessment Act 1979. http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=6456/

Santos (2018) *Response to Submissions*, Santos, 2018

Santos (2019) *Response to WEP Follow Up Questions*, 2019

Sreekanth J., Gladish D., Gonzalez D. Pagendam D, Pickett T., Cui T. (2018) CSG-induced groundwater impacts in the Pilliga region: prediction uncertainty, data-worth and optimal monitoring strategies. GISERA – W8 CSIRO Land And Water, CSIRO Data61. <https://gisera.csiro.au/wp-content/uploads/2018/06/Water-8-Final-Report.pdf>

Tadros N. V. Z. (1993) – The Gunnedah Basin. New South Wales. Reference No Geological Survey NSW. Memoir Geology 12.

7. MONITORING, MANAGEMENT AND REGULATION

This chapter considers issues related to monitoring of the NGP, its management and some of the regulatory requirements for the project and their compliance. The specific topics covered in this chapter include risks associated with the following:

- monitoring networks;
- management plans and incident response provisions; and
- regulation compliance.

A general discussion on the topic of managing environmental and human health risks from CSG activities is provided in a report of the NSW Chief Scientist and Engineer (O’Kane, 2014a), which focuses on the identification and management of a wide range of risks associated with CSG activities in relation to the environment and human health. This report also comments on the characteristics of the regulatory framework required to manage such risks effectively. This framework is detailed in a companion report prepared as part of the Chief Scientist and Engineer’s Review dealing specifically with regulatory compliance (O’Kane, 2014b).

7.1 Monitoring networks

The need for monitoring the performance of certain aspects of the NGP is self-evident. For example, monitoring of the operational phase of the project is required to detect possible spills and leaks of various fluids, seepage from storage dams, leakage of methane and other gases, either as so-called fugitive emissions or due to the failure of engineering systems and components. Monitoring the quality of the water drawn from the coal seam at various stages of its processing and release is also required.

Early detection of problems and issues of concern will allow effective controls and remediation measures to be activated in a timely manner. This will lessen the potential contamination of the environment should an unforeseen spill or leak occur.

Careful consideration must also be given to the monitoring techniques to be employed and the sampling protocols that will be used. In general, the NGP EIS provides little detail of these important measures and protocols. Careful consideration also needs to be given to the level of reporting of any monitoring stations that are deemed mandatory.

7.1.1 Groundwater monitoring

The issue of coal seam water quality is discussed in Appendix F of the NGP EIS. In particular, it is noted in the report prepared by CDM Smith (Page 5-42 of the Groundwater Impact Assessment report prepared by CDM Smith in Appendix F of the NGP EIS) that “*Observed variation of water quality over time is a likely consequence of induced groundwater flow from stratigraphically adjacent or structurally juxtaposed hydrostratigraphic units of differing water qualities.*”

This being the case, raises the question of whether changes in the geochemistry of groundwater samples extracted at various depths might be used during and after the operational phase of the project as a reliable means of detecting whether significant

salt migration between aquifers is taking place and including such detection in TARPs? For example, could significant changes in the content of either lithium or barium or other chemical species in the GAB be used as a reliable indicator of the migration of dissolved salts from the GOB to the GAB?

It is recommended that the proponent should consider whether changes in groundwater chemistry over time could be used as a reliable means of detecting the migration of groundwater and dissolved salts from the lower aquifers to the GAB. Furthermore, if such movement should be detected, what response action (if any) should be triggered? What would be the significance of such migration of dissolved salts?

Recommendation 30

The WEP recommends that Santos investigate whether changes in groundwater chemistry over time could be used as a reliable means of detecting the migration of groundwater and dissolved salts from the lower aquifers to the GAB

7.1.2 Released water

It is proposed by Santos in its NGP EIS that produced water will be treated using the reverse osmosis process. This aspect of the project, and the salts that will be produced, have been dealt with in some detail in chapters 4 and 5 of this report. Of concern here is the water that will be released, after treatment, either into Bohena Creek during periods when it is flowing, or onto farming land as irrigation water, as proposed in the NGP EIS.

Clearly, there will be a need to monitor the content of this released water to ensure it meets acceptable standards. Conductivity monitoring will be useful in this regard and the relevant irrigation standards should at least be met. It is the view of the WEP that the sampling protocols to be used for these released waters requires further clarification before project approval, and Santos should be required to provide this information to the satisfaction of the appropriate government authority.

Recommendation 31

The WEP recommends to Government that issues of sampling protocol and frequency of sampling, be addressed to the satisfaction of the appropriate government authority.

7.1.3 Boreholes

Monitoring of boreholes used for gas production will assist in the detection of fugitive emissions of methane and in the possible leakage of saline groundwater or drilling fluids via vertical flow pathways resulting from, for example, inadequate cementing of borehole casing.

This monitoring should be capable of detecting the leakage of methane, drilling fluids and saline groundwater along and adjacent to the borehole, at the surface and preferably also at depth beneath the ground surface.

Monitoring of this nature, for each of the proposed 850 production gas wells and 425 well pads is unrealistic from both a practical and economic perspective. It is suggested that monitoring of well pads constructed during the early stages, e.g., the first 2 to 5 years, of the production phase of the NGP should be mandatory. If and only when it can be demonstrated that such leaks are minimal or non-existent, this provision for monitoring can be relaxed for subsequent well pads. The decision on whether to continue or to cease such monitoring during the operation period should be at the discretion of the relevant government authority.

Should monitoring of wells be extended beyond plug and abandonment? Under current NSW legislation, once a well is plugged and abandoned and certified by the Regulator as being satisfactorily abandoned, the area is remediated and handed back to the landowner or the State. There is no ongoing requirement for monitoring the decommissioned well. Nevertheless, the risk of wells leaking or failing in the future needs to be considered. The WEP believes that an agreed plan should be developed by Santos and the Regulator for monitoring plugged and abandoned wells once the project is completed.

Recommendation 32

The WEP recommends that prior to construction, a plan be developed by Santos in consultation with the Regulator, to detect and monitor any leakage of methane, drilling fluids and saline groundwater, at the surface and at depth. This plan should cover the operational phase of the project as well as the long term, beyond the end of the project. It should include any measures for restoring well integrity, should they become necessary.

7.1.4 Fugitive emissions

Issues relating to the composition of gas produced by the NGP are addressed in Chapter 2. The processes used to extract and distribute both coal and natural gas (including CSG) are subject to fugitive emissions of methane (CH₄) and sometimes carbon dioxide (CO₂). Fugitive emissions from coal mining are due to seam gas being released during and after mining, whereas in the oil and gas industry they comprise the gas lost from production, processing, transport and distribution facilities, either from venting (or in some cases flaring) or from leaks in pipes, valves and other equipment. In CSG operations the sources of fugitive emissions may include the following:

- the wells themselves and associated surface pipe work and processing equipment, and
- gas escaping during the stages of exploration drilling and well construction.

The possibility of fugitive emissions from the NGP is an important issue and requires consideration by Santos and the relevant government authorities. However,

consideration of fugitive emissions and their detection and monitoring is beyond the terms of reference of the WEP, so no further discussion of the matter is provided here.

7.1.5 Other monitoring

As indicated in previous chapters, the extraction of CSG requires substantial lowering of groundwater pressure in the coal seam. At any point below the ground surface, the weight of overlying strata is supported partly by water pressure and partly by the fabric of the rock mass. Any reduction in water pressure therefore results in an increased proportion of the load being carried by the rock mass, potentially leading to some compression of the rock. The combined compression over the thickness of rock strata affected by reduced water pressure can result in measurable subsidence at the ground surface.

The issue of ground subsidence was considered in some detail in Chapter 2 and it was concluded that the risk of significant or even measurable ground subsidence was very low, largely because of the relatively incompressible nature of the rock strata overlying the coal seam. However, as stated in Recommendation 5, it would be prudent to consider establishing an accurate topographic baseline survey in the Narrabri region via interferometric synthetic aperture radar (INSAR) with periodic re-runs, to monitor any subsidence associated with large-scale irrigation or CSG extraction. This technique has been applied successfully on CSG projects in Queensland in the Surat Basin. It would also be useful to consider what levels of observed subsidence might trigger the implementation of appropriate mitigation strategies.

Consideration should also be given to microseismic monitoring of the proposed CSG operations and this is discussed in Chapter 2.

Microseismic events can either have a natural origin (e.g., tectonic or volcanic events) or they can be induced by industry-related operations. Anthropogenic seismicity has been observed for operations close to oil and gas reservoirs, mines, water reservoirs, and geothermal systems. In oil and gas applications, microseismic events have been used to map the distribution of fractures inside hydrocarbon reservoirs, in order to find areas characterized by higher permeability and enhance production.

Traditional microseismic mapping usually determines the location and magnitude of the microseismic event. When microseismicity is observed over time, patterns of seismicity related to production activities may be identified. Advanced microseismic analysis can reveal how the rock is responding to mining or oil and gas production activities, leading to increased efficiency and optimized operations.

In particular, microseismic monitoring is often adopted for oil and gas operations that employ hydraulic fracturing, principally to gain information about the location and extent of the induced fractures. Although no fracking is proposed for the NGP, there may be merit in conducting seismic monitoring of the NGP to assist in the optimisation of gas production and to observe and record any significant effects of the proposed dewatering and gas extraction processes.

7.2 Management plans and incident response provisions

As mentioned in Chapter 6, the NGP EIS refers to the development of various management plans relevant to the NGP. These include:

- Trigger Action Response Plan;
- Water Monitoring Plan;
- Produced Water Management Plan;
- Pollution Incident Response Management Plan;
- Irrigation Management Plan;
- Dam Safety Emergency Plan;
- Operations Emergency Response Plan; and
- Bushfire Management Plan.

Some plans have already been developed and approved for exploration activity and others will be developed should project approval be granted. The WEP considers that these plans should contain a description of the procedures to be followed to avoid spills and leaks and thus avoid the risk of contaminating surface and groundwater sources. Importantly, they should also contain descriptions of how such events could be detected should they occur, as well as the corrective and remedial actions that must be adopted if an unforeseen spill or leak should occur, i.e., the incident response provisions should be clearly identified and detailed. In this regard, the WEP reiterates the importance of its Recommendation 23.

During discussions with some stakeholders, the question arose of whether some of these management plans should be developed before approval is granted for CSG production or whether they could be adaptive, i.e., further developed and refined after approval of the project, as additional information about the project and the sub-surface conditions becomes available? Some stakeholders were opposed to this concept of adaptive planning. However, the WEP formed the view that for projects of this nature some measure of adaptivity in the planning process was appropriate.

Adaptive planning and adaptive management are commonplace in many areas of engineering, especially when dealing with natural systems and especially in activities like CSG operations, where uncertainty about ground conditions is simply a 'fact of life'. The possibility, indeed the necessity, of gathering data and accumulating knowledge as the project proceeds, and then routinely reviewing and possibly modifying predictive models and production techniques in light of that knowledge, is established practice in a number of areas of engineering. It is often regarded as 'best practice' engineering.

Key Observation 26

The WEP strongly supports the use of "adaptive planning" and "adaptive management" in the NGP.

7.3 Regulation compliance

Regular monitoring of the NGP will be required in order to ensure compliance by the project operator with the various conditions imposed by the NSW government. In particular, the WEP suggests that compliance monitoring should include at least the following:

- Methane leakage from production and exploration wells;
- Groundwater quality and head;
- Well planning records; and
- Well integrity.

The WEP noted and endorses the Chief Scientist and Engineer's Recommendation 7 that in part states: *"that [Government] establish a single independent regulator. The regulator will require high levels of scientific and engineering expertise, including geological and geotechnical ability, environmental and water knowledge and information, and ICT capability including data, monitoring and modelling expertise; and will be required to consult – and publish details of its consultations – with other arms of Government and external agencies, as necessary. The regulator will also require appropriate compliance monitoring and enforcement capability"* (See page 13 of NSW, 2014).

The WEP notes that some of these compliance monitoring tasks will be conducted by the NSW EPA. Most if not all stakeholders concede that transparent compliance monitoring is essential for this project. The manner by which the EPA will lead this aspect is set out in EPA (2016). Key to the approach is the coordination of the various agencies involved. The proposal set out in the MOU to implement the EPA compliance policy provides clear guidelines on roles and responsibilities.

The WEP understands from agency and gas producer meetings that there were some initial problems with functional boundaries and with human resourcing, as would be expected in such a high profile activity. However, the WEP understands from agency meetings that these have now been resolved. In particular, during its review, the WEP questioned the resourcing required and the resources to be made available to carry out these tasks. It was provided with information that allowed the WEP to have confidence that resourcing of these tasks by the EPA is currently adequate and should remain so for the foreseeable future.

On the basis of the level of professional and management expertise available as well as field activity to be carried out, the WEP has confidence that compliance with any conditions of approval will be adequate and timely. However, a publicly available annual report for the first 5 years of the project, at least, is warranted.

Key Observation 27

The WEP has confidence that resourcing of the regulatory tasks to be conducted by the NSW EPA in relation to the proposed NGP is currently adequate and should remain so for the foreseeable future.

7.4 References

- DoEE (2017) National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia – Overview. <http://www.environment.gov.au/water/coal-and-coal-seam-gas/publications/overview-assessment>
- NSW (2012) NSW Code of Practice for Coal Seam Gas – Well Integrity. 2012. ISBN: 978 1 74256 328 2. https://www.resourcesandenergy.nsw.gov.au/_data/assets/pdf_file/0006/516174/Code-of-Practice-for-Coal-Seam-Gas-Well-Integrity.PDF
- NSW (2014) Final Report of the Independent Review of Coal Seam Gas Activities in NSW, September 2014. Office of the Chief Scientist and Engineer of NSW. http://www.chiefscientist.nsw.gov.au/_data/assets/pdf_file/0005/56912/140930-CSG-Final-Report.pdf
- O’Kane (2014a) Independent Review of Coal Seam Gas Activities in NSW - Managing environmental and human health risks from CSG activities, September 2014. Office of the Chief Scientist and Engineer of NSW. http://www.chiefscientist.nsw.gov.au/_data/assets/pdf_file/0006/56922/140930-Final-Managing-Environmental-and-Human-Health-Risks.pdf
- O’Kane (2014b) Independent Review of Coal Seam Gas Activities in NSW - Study of regulatory compliance systems and processes for coal seam gas, September 2014. Office of the Chief Scientist and Engineer of NSW. http://www.chiefscientist.nsw.gov.au/_data/assets/pdf_file/0006/56913/140930-Final-Compliance-Report.pdf
- Technology Subgroup (2011) “Plugging and Abandoning Oil and Gas Wells”, Working Document, Paper #2-25, of the NPC North American Resource Development Study Made Available September 15, 2011. https://www.npc.org/Prudent_Development-Topic_Papers/2-25_Well_Plugging_and_Abandonment_Paper.pdf
- Salehi, R. and Paiaman, A. (2009) A Novel Cement Slurry Design Applicable to Horizontal Well Conditions. Petroleum & Coal 51, No. 4: 270-72. http://www.vurup.sk/pc/vol51_2009/issue4/pdf/pc_4_2009_mirzaei_045.pdf
- Santos (2017) Narrabri Gas Project – Environmental Impact Statement, Submitted to the NSW Government under Section 78A (8A) of the Environmental Planning and Assessment Act 1979. http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=6456/

8. CONCLUSIONS, RECOMMENDATIONS AND KEY OBSERVATIONS

The main conclusion reached by the WEP is that it did not identify any land or water issues that would constitute a major barrier to the NGP going forward.

The WEP has identified some questions and concerns arising from a current lack of information, or uncertainty regarding an interpretation or a model. If the NGP is to proceed, these will need to be addressed through ongoing monitoring, improved understanding, adaptive management and a robust regulatory regime that is vigorously and effectively enforced.

If the NGP proceeds, then as is the case with all resource projects, a great deal of new information will be acquired and a far greater understanding of the subsurface reached. This will in turn provide the basis for a far better understanding of the Namoi region and its mineral, energy and water resources and how best to manage them.

Below are a number of WEP observations and recommendations that warrant consideration by the Department in taking forward recommendations to Government on the future of the NGP.

Summary table of recommendations

Number	Recommendation
1	The WEP recommends to Government that when the Narrabri region is next mapped, consideration should be given by the Geological Survey of NSW to remapping and renaming the time-discordant Pilliga Sandstone east of the GAB, to better reflect its setting, age and lithological properties and to eliminate current confusion regarding its distribution and its significance to GAB recharge.
2	The WEP recommends Santos makes comprehensive data on the composition of CSG available to Government on a regular basis because of its implications to subsurface equipment and processes and related regulations.
3	The WEP recommends that Santos enhances its documentation of natural leaks and accumulations of methane in wells, at the surface and in water bodies in and around the area of the NGP, prior to commencement of any large-scale gas production. This will provide a comprehensive baseline against which environmental changes might be assessed. It also recommends that this information be made publicly available.
4	The WEP recommends that as a wider range of subsurface samples becomes available, Santos obtains additional reliable data on geological heterogeneity and on rock properties such as permeability, especially for the Gunnedah and Surat Basins. This additional information should be used in future modelling and be made publicly available.
5	The WEP considers that the risk of subsidence associated with the NGP is low to very low. However, consideration could be given by Government and Santos, to establishing an accurate topographic baseline survey in the Narrabri region via interferometric synthetic

Number	Recommendation
	aperture radar (INSAR) with periodic re-runs, to monitor any subsidence associated with large scale irrigation or CSG extraction.
6	<p>Although the WEP does not believe there is evidence of any major geological structures that would adversely impact on CSG production, it recommends that if the project proceeds and as new information emerges, Santos:</p> <ul style="list-style-type: none"> • undertakes a more detailed structural assessment at a resolution that meets modern petroleum industry standards; • undertakes an assessment of neotectonics and the stress field in the NGP and adjacent areas; • assesses the impact of excluding faulting from groundwater modelling (supporting the recommendation of the IESC); and • makes new structural information publicly available.
7	The WEP recommends to Santos that the impact on GAB pressure levels from the GABSI rehabilitated bore and water saving measures (that are monitored by the NSW Government groundwater network), should be included in all future modelling and the results made publicly available.
8	<p>The WEP recommends that should the NGP proceed, Santos:</p> <ul style="list-style-type: none"> • develop a transient groundwater flow model with no less than the steady state model layers, based on the monitoring network to be agreed with the relevant regulator, including other sources of data that are available in the model domain. • present a report on the transient model for public comment within 3 years of commencing the project if approved. • updates and presents the transient model every 3 years thereafter, for the life of the project unless otherwise advised.
9	The WEP recommends to Santos that the GAB heads predicted by the EIS model should be used from hereon in the LNA groundwater flow model to provide an improved estimate of the impact of leakage from the GAB to the Lower Namoi Groundwater Source.
10	The WEP recommends that if the project is approved and prior to construction, Santos specifies the level of entitlement required from the LNA and assesses the potential impact of that entitlement on access of existing users and groundwater trading under a range of climatic conditions.
11	The WEP recommends that Santos develops a groundwater monitoring plan (to be applied once the phasing in of the production well sites is decided). It should include what government-conducted monitoring might be required outside the CSG production area.
12	The WEP recommends to Santos and to Government that prior to construction, the groundwater modelling be migrated from the current MODFLOW-SURFACT software to a more flexible package, such as MODFLOW-USG or a similar unstructured grid type software.
13	The WEP recommends that Santos conducts regular analyses of production and treated water and makes the results of these analyses publicly available. Analyses should include chemicals of potential concern.
14	The WEP recommends to Government that the proposed Produced Water Management Plan should provide further information to the EPA

Number	Recommendation
	on the adequacy of the Leewood storage ponds to cope with any process plant outages and extreme weather events. In addition, Santos should clarify what operational steps would be taken in the event that a storage facility exceeds its safe operating level. The preparation of the Plan should be undertaken in consultation with the EPA prior to commencement of production.
15	The WEP recommends that prior to the commencement of irrigation using produced and treated water, a study be undertaken by an agricultural expert to determine the appropriate process settings for process water amendment, and the preferred soil types to be irrigated, so as to preserve the agricultural integrity of the irrigated land.
16	The WEP recommends to Santos that a full analysis be undertaken of representative produced water and its ranges and means, as this would allow a mass balance to be established across the reverse osmosis and salt recovery units.
17	The WEP recommends that Santos, provides current information on Leewood Plant operations, that gives a clear basis for an estimate of likely salt production, recognising that this may change as more wells are commissioned.
18	The WEP recommends to Santos that the likely composition of lesser components in the recovered salt be more closely studied prior to Front End Engineering Design (FEED), as it may impact on its attractiveness for beneficial use of the salt and operation of the salt recovery circuit.
19	The WEP recommends to Government and to Santos, recognising the recovered salt from the NGP is primarily sodium carbonate, further consideration by Santos be given to options for its beneficial use and that this be ongoing.
20	The WEP recommends that prior to construction, Santos provides the regulator with any data available on chemicals of potential concern (COPCs) including their likely concentration in the recovered salt and that such data be provided on an ongoing basis if the project proceeds.
21	The WEP recommends that Santos, provides to the EPA formal statements from licensed waste disposal operators, that they have available the necessary storage facilities for salt or are willing to develop them.
22	The WEP recommends to Government that all Management Plans relating to the mitigation of risks associated with potential surface spills and leaks be prepared in consultation with the EPA and other relevant agencies as appropriate, prior to construction
23	The WEP recommends to Santos that at the FEED stage of plant design, fail-safe measures be included to minimise the risk of leakages and spills and to ensure their containment or rapid and effective treatment.
24	The WEP recommends to Government and Santos that the NSW best practice guidelines for well integrity should be strictly adhered to and this should be a condition of approval of the project and should be monitored by the Regulator.
25	Consistent with Recommendation 6, the WEP recommends to Government and Santos, that mapping and seismic investigation be conducted prior to selecting well locations, in order to identify any

Number	Recommendation
	significant geological structures, and that this should be a condition of approval, which should be monitored by the Regulator.
26	The WEP recommends to Government that the Regulator ensure the relevant monitoring plan, to be developed by Santos prior to construction of gas wells, is sufficient to detect failure of any identified conventional gas wells.
27	The WEP recommends to Government that if loss of well integrity is identified, immediate measures must be employed by Santos to decommission the well, or restore well integrity.
28	If potentially corrosive groundwater is encountered in the NGP, then inert materials should be used by Santos for production casing and inner lining casing, as required by the Queensland Code of Practice. Cements resistant to attack by groundwater with a high CO ₂ content should also be used by Santos in corrosive formations.
29	The WEP recommends that Santos be required to demonstrate prior to construction of gas wells, to the satisfaction of the relevant government authority, that wells with inclined and horizontal sections can be adequately sealed during plug and abandonment.
30	The WEP recommends that Santos investigate whether changes in groundwater chemistry over time could be used as a reliable means of detecting the migration of groundwater and dissolved salts from the lower aquifers to the GAB.
31	The WEP recommends to Government that issues of sampling protocol and frequency of sampling, be addressed to the satisfaction of the appropriate government authority.
32	The WEP recommends that prior to construction, a plan be developed by Santos, in consultation with the Regulator, to detect and monitor any leakage of methane, drilling fluids and saline groundwater, at the surface and at depth. This plan should cover the operational phase of the project as well as the long term, (beyond the end of the project). It should include any measures for restoring well integrity, should they become necessary.

Summary table of key observations

Number	Key Observation
1	The volume of water that provides the recharge in the NPG area to be developed by Santos is relatively small compared to that of the dominant area of recharge in NSW to the south along the eastern flank of the Coonamble Embayment of the GAB.
2	Based on the evidence presented in the EIS and the depth from which the CSG will be produced, provided the wells are completed to industry best practice, the WEP considers the risk of migration of methane into overlying aquifers is low to very low.
3	Based on the evidence presented in the EIS, the WEP considers it unlikely that faulting constitutes a major risk to the NGP or is likely to have a major impact on groundwater flow.
4	The WEP considers, in the absence of any deep reinjection of produced water, the probability of induced seismic activity associated with the production of CSG in the NGP area, is very low and the risk of a damaging seismic event associated with CSG production to be extremely low.
5	Hydraulic parameters (such as hydraulic conductivity) used in the EIS groundwater flow model are based on literature values. Subsequent laboratory analysis and upscaling of the regional model provides confidence in the parameter selection for the GOB and GAB layers used in the NGP EIS model.
6	The WEP notes that the steady state model was found by CSIRO to be a suitable platform on which to make decisions for the purposes of the EIS but prior to construction, the model-improved prediction will be required.
7	The NGP EIS steady state groundwater model predicts a very small volumetric impact on flows between the GAB and the LNA. However, these flows are different to those published for the Lower Namoi Groundwater Source, which may indicate some uncertainty in the NGP predictions.
8	For the LNA, the drawdown triggers in the local management rules are currently being approached by the existing users at the end of the pumping season in each water year. This may restrict future access to the groundwater.
9	There is currently a high level of entitlement and use in both the surface and shallower groundwater systems. The water entitlement that Santos is seeking for the Lower Groundwater Source whilst not large compared to current water usage, is likely to be significant in relation to historic trading patterns.
10	Adherence to the minimal impact considerations of the Aquifer Interference Policy in the NGP region will ensure that high value GDEs will be protected from any unacceptable cumulative impacts associated with CSG production or other groundwater-based activities in the region.
11	On the basis of operating experience on a pilot-scale unit at the NGP and at large-scale in Queensland, the WEP believes Santos has the capacity to commission the design and operate a successful process

Number	Key Observation
	for the treatment of CSG-produced water, such as is likely to be experienced at the NGP.
12	Existing storage ponds at Leewood appear to be appropriately constructed. Adherence to the NSW Codes of Practice and close attention at the FEED stage to the requirement for environmentally safe operations, should ensure that any risks associated with storage of produced, treated and concentrated produced water are met.
13	The proposed process for recovering salt from reverse osmosis concentrate, represents state-of-art technology and should function effectively when allied with sound equipment purchase and competent operation.
14	Essentially all the bicarbonate present in the produced water is converted to carbonate in the salt concentration and crystallisation sections of the treatment plant.
15	Information provided in the NGP EIS suggests the salt product will meet the requirements to be treated as a general solid waste and to be categorised as “non trackable”.
16	In lieu of a proposal to make beneficial use of the salt product, the proposal in the NGP EIS to transfer salt to a licensed disposal site capable of long-term storage of leachable solids, is considered acceptable.
17	The WEP considers that the current regulatory requirements in Australia by state and federal governments for handling chemicals likely to be used in the NGP, provide reassurance that the likelihood of potential harm to humans and the environment, is low if these regulations are followed and enforced.
18	The WEP agrees that adherence to the Code of Practice for Coal Seam Gas: Well Integrity would mitigate the risk of drilling fluids escaping into the soil (and rock) profile.
19	The WEP considers pre-CSG activity baseline data will be helpful when assessing the levels of methane in groundwater at any time in the future. It considers that the risk of methane leakage into groundwater is low provided the regulations are strictly adhered to.
20	The WEP agrees the risk of induced flows within coal mine core holes that materially affect the quantity or quality of groundwater sources in the GIA study area, is very low.
21	The WEP considers the risk of gas migration into groundwater bores is low.
22	The WEP considers the risk of induced and enhanced aquifer connectivity via groundwater and CSG production bores is very low.
23	The WEP considers the risk of well blow-out is very low.
24	The WEP notes the prohibition of synthetic-based drilling muds in some Queensland CSG operations and suggests the matter of their use in NSW needs to be considered by the appropriate regulatory authority.
25	Provided Santos follows the mandatory code provisions, the risk of leakage from a completed well will be low. The WEP is also of the view that in the unlikely event of leakage occurring, industry best practice would ensure the leak was quickly controlled and any impact remediated.

Number	Key Observation
26	The WEP strongly supports the use of “adaptive planning” and adaptive management in the NGP.
27	The WEP has confidence that resourcing of the regulatory tasks to be conducted by the NSW EPA in relation to the proposed NGP, is currently adequate and should remain so for the foreseeable future.

APPENDIX A – EXPERT PANEL

Professor Peter J Cook CBE FTSE (Chair of the Expert Panel)

Peter Cook is a geologist, and an expert in sedimentary basin resources and subsurface environments and processes. He is a Professorial Fellow in Earth Sciences at the University of Melbourne, CO2CRC Distinguished Scientist and an international Consultant. He has been an adviser to industry and governments in Australia, UK, USA, Canada, Portugal, Greece, Germany and Finland.

Peter is the author of more than 100 publications. He has occupied a number of senior executive positions including: Associate Director of the Bureau of Mineral Resources (with responsibility for sedimentary basins and groundwater), Executive Director of the British Geological Survey (BGS), Director of the Australian Petroleum Cooperative Research Centre and Chief Executive of the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC). He chaired the Australian Council of Learned Academies (ACOLA) Review of Unconventional Gas and the 2015 International Conference and Workshop on Shale Gas.

Peter holds the degrees of BSc (Hons), MSc, PhD and DSc and has held academic positions in the UK, Australia, France and the USA. He has received many Awards and Honours, including the CBE (UK), the Order of Merit (France), the Greenman Award (IEAGHG), the John Coke Medal (Geological Society of London), the Leopold von Buch Medal (Germany), the Lewis G Weeks Gold Medal (Australian Petroleum Exploration Association), and the Centennial Medal (Australia). He is a Fellow of the Academy of Technological Sciences and Engineering and a Life Member of the Geological Society of Australia.

Professor John Phillip Carter AM, FAA, FTSE, FRSN, FIEAust, FAIB

John Carter is a geotechnical engineer with more than 40 years of experience in teaching, research and consulting in civil and geotechnical engineering. He is currently Emeritus Professor and formerly Pro Vice-Chancellor and Dean of Engineering at the University of Newcastle, NSW. He is also a former Director of Advanced Geomechanics Pty Ltd (now Fugro AG Pty Ltd), a geotechnical consultancy based in Perth, Western Australia. He is a graduate of the Australian Institute of Company Directors and a former Director of the Newcastle Port Corporation.

John is the author of more than 400 technical articles in peer-reviewed journals and international conferences. He has experience as an expert witness in legal cases in Queensland, New South Wales and Victoria. He has also been an advisor and consultant to government, industry and engineering firms, most recently as a lead investigator of the Opal Tower incident at Homebush, NSW and the Mascot Towers incident in NSW. In 2019 he was appointed as a Commissioner for the Commission of Inquiry into the Paradise Dam in Queensland.

John holds the degrees of BE (Hons 1), PhD and DEng, all from the University of Sydney. He is a Fellow of the Australian Academy of Science, the Australian Academy of Technology and Engineering, the Royal Society of NSW, the EU Academy of Sciences, Engineers Australia and the Australian Institute of Building.

In January 2006 he was appointed as a Member of the Order of Australia (AM) for his contributions to civil engineering through research into soil and rock mechanics and as an adviser to industry.

Professor Chris Fell AM FTSE Hon FIEAust CPEng FIChemE FAICD

Chris Fell is a chemical engineer by training with degrees from UNSW (BSc [Chem. Eng.]) and Cambridge University (PhD). He is a former Head of School of Chemical Engineering, Dean of Engineering and Deputy Vice-Chancellor of the University of New South Wales.

Chris' expertise lies in water treatment, separation technology, the environment and the handling of chemicals. He led a Commonwealth Special Research Centre and was co-inventor of the Memtec technology that developed low pressure membrane microfiltration for the reclamation and recycle of water, now a major international enterprise with over 50,000 major facilities established worldwide from a base in Windsor, NSW. He established the first-round CRC for Waste Management and Pollution Control and was its inaugural Chairman.

He is a former member of the Prime-Minister's Science, Engineering and Innovation Council and current consultant to government on environmental matters, including writing a review of the treatment of production water from coal seam gas recovery for the NSW Chief Scientist and a review of the safety of urban water in the Sydney catchment.

Elected as a Fellow of the Australian Academy for Technology and Engineering in 1988, he was awarded the Chemeca Medal for contributions to Australian chemical engineering in that year and made a Member of the Order of Australia in 2003. Chris was selected by the NSW Government as a Commissioner of the NSW Independent Planning Commission in August 2018.

Mr R Michael Williams PSM

Michael holds an MSc from UNSW. He was employed by the NSW government primarily as a hydrogeologist for 43 years in groundwater investigation, development, policy and management in Australia and overseas. He was Principal Hydrogeologist for over a decade, retiring as Director, Groundwater Management, in 2013.

More recently he developed and implemented the NSW Water Sharing Plans within NSW and federal legislation, negotiating the diversion limits and associated rules with water users, cultural, environmental and industry groups and a number of government departments. Since leaving government service, Michael has served on several independent expert panels in Australia, including 'Mining in the Catchment in NSW'.

APPENDIX B – CONSULTATION UNDERTAKEN BY THE WEP

Meeting Date	Purpose of Meeting
7 August 2017 (Narrabri)	Site visit
7 August 2017 (Narrabri)	Landowners
8 August 2017 (Narrabri)	Namoi Water
8 August 2017 (Narrabri)	People for the Plains/ Northwest Alliance Representatives
8 August 2017 (Narrabri)	Narrabri Community Consultative Committee Meeting, including representatives from: <ul style="list-style-type: none"> • EPA • Narrabri Council • Lower Namoi Cotton Growers Assoc • North West Local Land Services • Country Women’s Association • People for the Plains • Narrabri Chamber of Commerce • Narrabri Local Aboriginal Land Council • NSW Famers • Namoi Water
23 May 2017 (Sydney)	NSW Government agencies: <ul style="list-style-type: none"> • DPI Water • EPA • DRG
11 July 17 (Sydney)	Santos water experts
25 August 2017 (Sydney)	Artesian Borewater Users Association Great Artesian Basin Protection Group Wilderness Society Lock the Gate Alliance Environmental Defenders Office (EDO) Experts engaged by North West Alliance/EDO: <ul style="list-style-type: none"> • Matthew Currell • Andrea Broughton • Kevin Hayley
30 August 2018 (Sydney)	GISERA presentation of findings

APPENDIX C – WEP QUESTIONS TO SANTOS

(See Attachments C1-C4)

C1 – WEP QUESTIONS TO SANTOS

C2 – SANTOS RESPONSE TO WEP QUESTIONS

C3 – WEP RESIDUAL QUESTIONS TO SANTOS

C4 – SANTOS RESIDUAL RESPONSES

APPENDIX D – TREATED AND AMENDED WATER QUALITY

Table D1: Treated and Amended Water compared with bore and stream flows

Parameter	Treated Water Leewood ^a	Amended Water Leewood ^a	Amended Water NGP EIS ^b	Leewood Bore Water ^c	Bohena Creek ^d (Range)	Namoi River ^e (Range)
pH	7.9	7.1	7.7	n/a	7.1 (5.6 – 8.1)	7.8 (5.7 – 9.3)
Conductivity μ S/cm	n/a	107	985	237	216 (103–447)	397 (128-921)
TDS mg/L	56	71	640	145	192 (85-586)	248 (81-486)
Sodium (Na ⁺) mg/L	17	18	140	19	27 (9-47)	33 (7-120)
Chloride (Cl ⁻) mg/L	10	19	83	36.5	38 (16-102)	32 (6-86)
Bicarbonate (HCO ₃ ⁻) as CaCO ₃ mg/L	n/a	n/a	139	n/a	41	n/a
Bicarbonate (HCO ₃ ⁻) Calculated mg/L	n/a	n/a	169	n/a	50	n/a
Carbonate (CO ₃ ⁻) mg/L	n/a	n/a	< 0.01	n/a	n/a	n/a
Total Alkalinity (as CaCO ₃)	34	28		n/a	n/a	n/a
Ammonia (as N)	0.25	0.24	0.005		n/a	n/a
Potassium (K ⁺) mg/L	< 1	< 1	1	20	3.5 (2-9)	4.6 (2-11)
Calcium (Ca ⁺⁺) mg/L	< 1	6	40	3.3	7 (2-21)	29 (3-54)
Barium (Ba ⁺⁺) mg/L	< 0.001	<0.001	< 0.001	0.33	0.05 (0.02-0.18)	0.03 (0.001-0.058)
Magnesium (Mg ⁺⁺) mg/L	< 1	< 1	< 0.027	n/a	n/a	n/a
Sulphate (SO ₄ ⁻) mg/L	< 1	< 1	156	n/a	(1 – 45)	(1 – 47)
Nitrate (NO ₃ ⁻) mg/L	0.04	0.06	n/a	n/a	n/a	n/a
Total Nitrogen mg/L	0.3	0.3	n/a	n/a	n/a	n/a
Boron (B) mg/L	0.11	0.09	0.12	< 0.05	0.05 (0.05)	0.056 (0.05-0.44)
Fluoride (F ⁻) mg/L	< 0.1	< 0.1	0.15	< 0.1	0.1 (0.1)	0.2 (0.1-0.5)
Silica (Si) mg/L	< 0.1	< 0.1	0.532	n/a	15	n/a
Manganese (Mn) mg/L	<0.001	< 0.001	< 0.001	0.29	0.34 (0.004-2.63)	0.04 (0.001-0.68)
Strontium (Sr) mg/L	n/a	n/a	0.01	n/a	0.11 (0.03-0.3)	0.15 (0.001-0.573)
Iron (Fe) mg/L	<0.05	<0.05	< 0.001	n/a	5.3	n/a
SAR	29	3.7	xxx	n/a	1.63 (0.71-3.0)	1.18 (0.6-3.77)

Parameter	Treated Water Leewood ^a	Amended Water Leewood ^a	Amended Water NGP EIS ^b	Leewood Bore Water ^c	Bohena Creek ^d (Range)	Namoi River ^e (Range)
Aluminium (Al) mg/L	< 0.01	< 0.01	< 0.001	n/a	n/a	n/a
Ammonia (as N) mh/L	0.25	0.24	0.005	n/a	15	n/a
Arsenic (As) mg/L	< 0.001	< 0.001	n/a	n/a	n/a	n/a
Uranium (U) mg/L	< 0.001	< 0.001	< 0.0028	n/a	ND	n/a
Lead (Pb) m g/L	< 0.001	< 0.001	n/a	n/a	n/a	n/a
Mercury (Hg) mg/L	< 0.00001	< 0.0001	< 0.001	n/a	ND	n/a
Molybdenum (Mb) mg/L	< 0.001	< 0.001	n/a	n/a	n/a	n/a
Cadmium (Cd) mg/L	< 0.0001	< 0.0001	n/a	n/a	ND	n/a
Cobalt (Co) mg/L	< 0.001	< 0.001	n/a	n/a	n/a	n/a
Nickel (Ni) mg/L	< 0.001	< 0.001	n/a	n/a	n/a	n/a
Chromium (Cr) mg/L	< 0.001	< 0.001	n/a	n/a	n/a	n/a
Copper (Cu) mg/L	< 0.001	< 0.001	n/a	n/a	0.0011	n/a
Zinc (Zn) mg/L	< 0.005	< 0.005	n/a	n/a	0.0035	n/a
Selenium (Se) mg/L	< 0.01	< 0.01	n/a	n/a	< 0.01	n/a

Notes:

- a Treated water Baseline Water Report, Table 7.1, RTS (Santos, 2018a)
- b Amended water Baseline Water Report, Table 7.1 RTS (Santos, 2018a)
- c NGP EIS Table 12.3 - Leewood bore water - average taken
- d NGP EIS Table 12.2 and 12.3 - Bohena Creek Baseline - mean + (range)
- e NGP EIS Table 12.1 Baseline water quality data for the Namoi River – mean + (range)
- n/a Not available
- ND Not detected
- < Indicates limit of resolution of analytic method applied

Table D2: Composition of Amended Water Compared with ANZECC Guidelines

Parameter	Amended Water	ANZECC Guidelines for Irrigation Water – Short Term ¹	ANZECC Guidelines for Irrigation Water – Long Term ¹
pH	7.1	6.0 - 8.5	6.0 – 8.5
Conductivity μ S/cm	107	Lucerne 2,700	Lucerne 2,700
TDS mg/L	71	Lucerne 1,273 - 3,015	Same
Sodium (Na ⁺) mg/L	18	Lucerne 330 - 460	Same
Chloride (Cl ⁻) mg/L	19	Lucerne 350 - 700	Same
Boron mg/L	0.09	0.5 - 15	0.5
Fluoride mg/L	< 0.1	2	1
Ammonia (as N) mg/L	0.24	25 - 125	
Uranium (U) mg/L	< 0.001	1	0.1
Mercury (Hg) mg/L	< 0.0001	0.002	0.002
Cadmium (Cd) mg/L	< 0.0001	0.05	0.1
Copper (Cu) mg/L	< 0.001	5	2
Zinc (Zn) mg/L	<0.005	5	2
Selenium (Se) mg/L	<0.01	0.05	0.2

Note 1: Short-term period is 20 years, Long-term period is 100 years

APPENDIX E – POTENTIAL LEAKAGE VIA WELLBORES

This Appendix provides an estimate of the possible rate of leakage of saline formation fluid up an existing wellbore should that wellbore completely fail, i.e., should a contiguous opening form along its entire length. In other words, what would be the flow rate from a deep aquifer if an existing wellbore were to act as if it were a straight circular pipe providing an unobstructed conduit for the flow of groundwater from deep below the surface to the ground surface?

In order to perform this calculation a number of key assumptions must be made. These relate to the type of pipe flow that is assumed and its governing equation, and also to the numerical values of the parameters that should be used as inputs to that equation. Very conservative assumptions have been selected here, which should result in the leakage rate being substantially overestimated.

For simplicity it is first assumed that turbulent flow will occur in a circular pipe (wellbore) so that the Darcy-Weisbach equation (page 6-16, Perry and Green, 1997) will govern the flow of fluid in the pipe. This equation may be written as:

$$\left(\frac{\Delta P}{\rho}\right) = 2f_D v^2 \left(\frac{L}{D}\right)$$

where ΔP is the pressure difference between the two ends of the pipe,

ρ is the mass density of the fluid flowing in the pipe,

f_D is a dimensionless friction factor that characterises the roughness of the internal surface of the pipe,

v is mean velocity of the flow in the pipe,

L is the length of pipe, and

D is the internal pipe diameter.

This flow equation can be simply rearranged to provide the average velocity of flow in the pipe as

$$v = \sqrt{\left\{ \frac{\left(\frac{\Delta P}{\rho}\right) \left(\frac{D}{L}\right)}{2f_D} \right\}}$$

In turn, this average velocity may be multiplied by the cross-sectional area of the interior of the pipe, A , to provide the expected flow rate, Q , i.e.,

$$Q = Av = \pi \left(\frac{D^2}{4}\right) \sqrt{\left\{ \frac{\left(\frac{\Delta P}{\rho}\right) \left(\frac{D}{L}\right)}{2f_D} \right\}} = \pi \sqrt{\left\{ \frac{\left(\frac{\Delta P}{\rho}\right) \left(\frac{D^5}{L}\right)}{32f_D} \right\}}$$

The assumption of turbulent flow can always be checked by estimating the value of Reynolds number, R_e , defined in this case of pipe flow as

$$R_e = \frac{\rho v D}{\mu}$$

where μ is the dynamic viscosity of the flowing fluid. Turbulent flow sets in when the Reynolds number of the flow exceeds about 2,100. If the Reynolds number is less than about 2,100, then the flow is more likely to be laminar rather than turbulent. If the flow is laminar, then the flow rate may be calculated from the Hagen-Poiseuille equation (page 6-10, Perry and Green, 1997), i.e.,

$$Q = \left(\frac{\Delta P}{L}\right) \frac{D^4}{128\mu}$$

Example Calculation

It is reasonable to assume that the fluid in the pipe (wellbore) has a dynamic viscosity similar to that of water at about 40 °C, i.e., approximately 0.65×10^{-3} Ns/m². Its mass density is assumed to be that of water, viz., 1,000 kg/m³.

For the purpose of illustration, it is also assumed initially that the effective internal diameter of the pipe is approximately 0.1 m (100 mm). This is of the same order as the internal diameter of typical production casing used in CSG operations, and this is considered to be an extreme (and highly unlikely) case, thus providing a worst-case scenario. Also for the purpose of illustration, it is assumed that the value of the friction factor is approximately that of a modestly rough steel pipe, i.e., $f_D \approx 0.007$.

It is also necessary to assume the effective length of the pipe, equivalent to the depth from which the water flows upward, as well as the pressure difference that is driving the flow in the pipe. A typical depth to the Early Permian coal seams of 800 m is assumed here. What is less certain is the pressure difference along the pipe that would drive the flow upward. However, for purposes of illustration it is assumed in the first instance that this difference is the equivalent of a head difference between the water in the coal seam and the ground surface of 10 m say, i.e., $\Delta P = 100$ kPa or 10^5 N/m². For this extreme case it is possible to estimate the average velocity of flow and the flow rate in the pipe as follows:

$$v = \sqrt{\left\{ \frac{\left(\frac{10^5}{10^3}\right) \left(\frac{0.1}{800}\right)}{2 \times 0.007} \right\}} \approx 0.94 \text{ m/s}$$

$$Q \approx v \left(\frac{\pi D^2}{4}\right) \approx 0.0074 \text{ m}^3/\text{s} \approx 0.23 \text{ GL/year}$$

Sensitivity

The sensitivity of the calculated leakage rate to the values of some of the key (and likely to be most uncertain) input parameters for this equation, viz., the head difference along the pipe and the effective pipe diameter, is illustrated in the following table.

Head difference (m)	Pressure difference ΔP (kPa)	Diameter D (m)	Leakage rate Q (varies)	Average velocity v (m/s)	Reynolds number (-)	Flow type (-)
10	100	0.1	0.23 GL/year	0.945	~145,000	Turbulent
1	10	0.1	0.07 GL/year	0.300	~46,000	Turbulent
10	100	0.01	0.74 ML/year	0.300	~4,500	Turbulent
1	10	0.01	0.15 ML/year	0.060	~920	Laminar

The high sensitivity of the calculated leakage rate to the internal pipe diameter is most evident from these figures. For example, reducing the effective pipe diameter by an order of magnitude reduces the calculated leakage rate by approximately three orders of magnitude.

Important Observations

As previously noted, these calculations are likely to be very conservative because they represent ‘worst case’ situations, thus generally providing an over-estimate of the upward leakage rate through a failed wellbore. One reason for this assertion is the uncertainty in assigning an effective pipe diameter to a failed well bore. It is highly unlikely that in the longer term, when the well has been plugged with cement and abandoned, that a uniform circular opening roughly equivalent to the internal diameter of the initial production casing would be applicable in practice. But this is exactly the worst-case condition assumed in some of the calculations presented above.

Any restrictions in the ‘pipe’ cross-section would substantially reduce the flow, as demonstrated by the calculations presented here. In addition, it is likely that discharge would not be from the top of the wellbore at atmospheric pressure, but rather it might be at or near the top of the wellbore into an already filled aquifer. In this case, any substantial flow would develop a backpressure, lessening the head change along the length of the pipe and therefore reducing the leakage flow.

However, perhaps the most important and convincing reason for making this assertion of extreme conservatism in these calculations, is the assumption of a higher head at depth in the coal seam compared to the ground surface level, driving the leakage flow upwards. During most of the life of the CSG operations, and for a very long period after the project is completed (typically at least 1,500 years according to the NGP EIS), the hydraulic gradient will be such that downward flow of groundwater is much more likely than any upward flow through a failed wellbore.

Appendix C – WEP Questions to Santos

C1 – WEP Questions to Santos

C2 – Santos Response to WEP Questions

C3 – WEP Residual Questions to Santos

C4 – Santos Residual Responses

**QUESTIONS FOR SANTOS
FROM THE WATER EXPERT PANEL
(WEP)**

QUESTION 1 - PRODUCED WATER ESTIMATES

Context

Resource and reserve values for the Namoi Gas Project (NGP) do not fall within the ambit of the WEP, but the closely related issue of produced water does. The level of confidence in gas production for the NGP should provide an indication of the level of confidence that can be expected in volumes of produced water. Given that Santos have operated their appraisal wells for several years, it presumably has a great deal of data on permeability, heterogeneity, pump tests and water production for the coal measure strata, and perhaps for other strata. However, little of this data is provided in the EIS.

Questions

- A) From the abstraction rates obtained from its pilot wells, what level of confidence does Santos have in its predictions of the volumes of water produced over the life of the Project and for the anticipated variation in volume over time?
- B) What is the basis for its level of confidence?
- C) Will Santos provide more data from the appraisal wells, so that the WEP can consider the impact of those numbers on the groundwater models?
- D) Will Santos provide more details on its reservoir modelling results and specifically those results which have informed the predictions of produced water volumes?

QUESTION 2 - GAS COMPOSITION

Context

There is very little information provided in the EIS on the composition of produced gas, but presumably a great deal of compositional information has been acquired over the past few years from the appraisal wells. It is well known that some parts of the Gunnedah Basin are high in carbon dioxide and therefore it is not unreasonable to expect some wells in the NGP area will be high in carbon dioxide. This has implications to the economics of the NGP, to well completions and well integrity and to greenhouse gas emissions. It is claimed by some Special Interest Groups (SIGs) that other gases such as hydrogen sulphide are present in some wells. If hydrogen sulphide or carbon dioxide is present, this will have implications for process design, well cement, water processing and health and safety.

Questions

- A) Will Santos provide detailed analyses of the of the gas composition in the NGP area?
- B) What information is available on the areal distribution of gas contaminants such as carbon dioxide, hydrogen sulphide and other significant trace gases and on variations in their concentration?
- C) What strategy does Santos have for dealing with gas contaminants?

QUESTION 3 - CONVENTIONAL GAS

Context

Conventional gas has been found previously in the Gunnedah-Oxley Basin (GOB). In particular, some of the wells that detected and accessed this conventional gas lie in or near the NGP area, for example the Coonarah conventional gas well located in the northwest section of the NGP, east of Yarrie Lake. Unlike coal seam gas, when drilling for and extracting conventional gas, special precautions are required to mitigate the risk of well blowout due to overpressure.

Questions

- A) Other than the Coonarah Gas Field has any other conventional gas been detected in the NGP tenement?
- B) Are the operating procedures that will be adopted by Santos to drill wells and produce Coal Seam Gas (CSG), sufficiently robust to deal adequately and safely with conventional gas if it were to be encountered in any of the Santos wells?

QUESTION 4 - GROUNDWATER MODEL AND CONCEPTUALISATION

Context

SURFACT was the model code selected by Santos for the NGP and this choice together with the modelling process, was accepted both by the CSIRO and IESC reviews.

The model was conceptualised as a series of aquifer and aquitard layers whose parameters were derived from literature values. The measured parameters and those calculated from field testing referred to in the EIS were apparently not used. Since the EIS was developed, the WEP was advised in the field that Santos has continued field testing which apparently has provided additional information if not data.

While the above approach may be suitable for the GOB units, it is a questionable approach for the overlying Great Artesian Basin (GAB) and the alluvial units, where there is considerably more information available. This is discussed further in the context of Question 5.

Questions

- A) Why did Santos use generic aquifer parameters from the literature, rather than aquifer parameter data available for each of the major groundwater sources (GAB and the Namoi alluvials)?
- B) What additional field data has been collected that could be used to support the model parameters adopted and for sensitivity testing (see also Question 6)?

QUESTION 5 – GROUNDWATER FLUX AND WATER BALANCE

Context

The EIS defines the steady state condition referred to in the report and outlines how the impacts are quantified.

“the Groundwater Impact Assessment derives a steady state condition for groundwater as the starting point for model prediction. The steady state condition of groundwater was derived from an analysis of DPI Water data to reveal those years with the most prevalent spatial data array, considered to be representative of the study area. The model was then used to make predictions of the impact of the project activities (primarily the extraction of groundwater to depressurise the target coal seams) on the groundwater environment. The model quantified impact to groundwater pressures and levels.”

The resultant steady state water balance is given in Appendix F (Figure A6.18). The predictive capacity of the model is difficult to assess, given the lack of flux information, except for comparison with the modelled water balances for Upper Namoi Alluvium (UNA) and Lower Namoi Alluvium (LNA) water sources. These groundwater flow models are used for water resource management and underpin the water sharing plans for each water source. Both have distributed parameters and time series for all input and output parameters based on over 30 years of measured data.

The upward leakage from the GAB to the LNA was first identified by Calf (1978) using water chemistry and stable isotopes. It was quantified using this data and the hydraulics of the GAB and alluvium. Since that time the signal was lost due to the decreased utility of tritium and the groundwater mixing associated with the increased rates of groundwater extraction. Identification of the area of leakage was supported by pre Tertiary strata samples from the government monitoring bores.

When the water source GAB interchange volumes are compared with those from the models for UNA and the LNA water sources given in in the EIS (Table A5.9) the volumes are considerably different.

- LNA leakage from the artesian aquifer is estimated at 7.9 GL/year by the water sharing plan model compared to 1.1 GL/year in the EIS model. However, this is for observed dynamic heads. For the fixed head (akin to the average heads approach modelled in the EIS) Merrick (2001) estimated a flux of 10.3 GL/year.
- The UNA model assumes no leakage between the basement rocks and the alluvium; also the area of contact between the alluvium and the GAB sediments is so limited that there is little scope for leakage between these two formations. Despite this, the EIS model has leakage of 7.46 GL/year from the GAB and 1.11 GL year from the basement rocks.

The WEP is concerned that that the EIS model may have poor predictive capacity in relation to the impact of production of the surrounding impacted water sources. The IESC indicated that the use of daughter models in areas of interest could be developed.

Questions

- A) Would Santos please explain the modelled differences in flux interchange for the GAB to LNA and UNA?
- B) Assuming the water balance fluxes remain, what would be the impact of incorporating the existing water management models to upgrade the existing EIS model?

QUESTION 6 - GROUNDWATER MODEL - CONNECTIVITY

Context

If the connectivity between units is controlled by unit heterogeneity the current conceptualisation may restrict the predictive capacity of the timing and flux. The pilot production field testing may have provided some guidance of this matter particularly if there is monitoring close to the production zone.

Several SIGs have suggested increased monitoring in a range of areas. While the WEP agrees that regional baseline monitoring is important, impacts of sufficient magnitude to be detectable may not occur for some considerable time. Monitoring in the areas where impacts are predicted to occur soon after production occurs, are critical. They assist in proving the conceptual groundwater model and allow management responses to be developed in a timely manner.

Questions

- A) Have any impacts arising from pilot well production been detected by Santos monitoring?
- B) Has any data collected from the operation and monitoring of the pilot wells been used to determine the impact of production on aquifers and aquitards and/or to estimate aquifer or aquitard parameters?
- C) If the answer to B is no, then why not?

QUESTION 7 - FAULTING

Context

Faulting can have a very significant impact on groundwater, whether by providing a pathway for upward leakage of saline groundwater or gas, or in the case of sealing faults, disruption of flow through compartmentalization of stratigraphic intervals. In the EIS, including in the groundwater modelling, it seems that any fault with a displacement of less than 100m is ignored. But the geological cross sections provided in the EIS are very small scale and so lacking in detail that it is impossible for the reader to make an assessment of whether this approach is valid. Further, there appears to have been no attempt to assess the possibility of neotectonics affecting the shallow aquifers, nor are any seismic profiles provided that would offer the opportunity to assess faulting in the deeper sediments. In all, the information providing on faulting and tectonic (including neotectonic) processes in the EIS is considered sparse by the WEP and also, it would seem, by a number of other individuals and organisations.

Questions

- A) What additional information, such as magnitude and distribution, is available on faulting within the project area?
- B) using such information, can a better assessment of the potential impact of faulting, including on groundwater flow, be provided?
- C) If adequate information on faulting is not available, what additional steps does Santos propose to take to address any data deficiencies?

QUESTION 8 - WATER TAKE AND DRAWDOWN PREDICTIONS

Context

The current NSW legislation and policies require water entitlements to be held to cover the predicted maximum annual water take from each of the water sources prior to commencement of a project.

Given the current level of uncertainty in the distribution and level of drawdown levels, Santos may be required to obtain additional entitlement from the UNA, LNA, GAB above that predicted, and perhaps even drawing on surface water sources for impacts that may be heavily lagged. Additional information and data has the potential to significantly lessen the current uncertainty.

Questions

- A) What additional information and data does Santos hold, including data collected since the EIS was published, that could be used to improve confidence in the drawdown and water-take predictions, particularly those in the GAB, UNA and LNA?

QUESTION 9 - WATER ENTITLEMENTS

Context

Each of water sources from which Santos will have to gain an entitlement, has different levels of development and management characteristics. The Gunnedah Oxley Basin (GOB) Water Source has a Sustainable Diversion Limit (SDL) of 114.5 GL/year. There is significant unassigned water which is available to the proponent that can be activated by application to government.

The GAB is effectively fully allocated so that Santos would need to go to the market to obtain entitlement. However the two impacted zones appear to have quite different management rules:-

- Southern Recharge Groundwater Source is the primary impact area, with an SDL of 25 GL/year based on estimates of direct rainfall recharge.
- Surat Groundwater Source had an SDL of 15.1 GL/year but this is based on the sustainable pressure estimate. The SDL will decrease over time through measured water savings that result from restored artesian pressures due to capping of bores and improved water use efficiency activities.

The SDL for the LNA is 88.3 GL/year and for the UNA 123.4 GL/year respectively. Both of these systems are fully allocated so any volumetric impact from the proposed development may have a material impact on the community.

The surface water plans are not addressed although the surface water is a recharge source and may be impacted.

The property rights are held as entitlement that are subject to annual announced allocation which may reduce the value of the entitlement to something less than 1. They are tradable although their activation to use is subject to impact rules. The groundwater is managed by the rules set out in each plan so that adverse impacts can be avoided or at least recognised.

The WEP notes the anticipated high level of entitlement and use in both the surface and shallower groundwater systems and also that the impacts which the EIS describes as insignificant, may in fact be volumetrically large. It further notes that detailed information is now available for the historic water use and trading patterns provide by Aither (2017). The entitlement that Santos is seeking is large in comparison to the historic trades.

Questions

- A) How does Santos propose to manage the impact of annual announced allocation on their operations?
- B) How does Santos propose to manage the impact of drawdown rules that are in the LNA management plan on their operation?
- C) How will proposed Santos water management actions impact on access of the existing entitlement holders?

QUESTION 10 - PROCESS WATER BALANCE

Context

Santos proposes a total of 900 ML for the storage of production water and reverse osmosis concentrate and 200 ML for the storage of treated water. Treated and amended water will be used for irrigation of 500 ha of lucerne and other on-site outlets. During periods of prolonged inclement weather, treated water may be discharged into Bohena Creek when the creek is flowing at 100 ML/day or more. Storage and treatment plant operations must be managed so that involuntary discharge of untreated production water or reverse osmosis concentrate will not occur, especially when production flows are greatest, i.e., in the first 2-4 years of operation. Weather records in the EIS show a maximum monthly precipitation in excess of 900 mm. Were this to occur over a period when the water flow in Bohena Creek does not consistently exceed 100 ML/day, or rainfall records be exceeded, involuntary release of contaminants could occur. The possibility of prolonged reverse osmosis plant outage at a critical time cannot be ruled out.

Questions

- A) Will Santos provide evidence from its process water model that would give the WEP confidence that the proposed storage and its mode of operation is sufficient to ensure that an involuntary release of contaminated water will not occur in the first 2-4 years of operation?
- B) What effect will extended downtime of the reverse osmosis unit have on the process water balance?
- C) What experience has Santos had in its operating experience in Queensland of extended outages of reverse osmosis plant?

QUESTION 11 - USE OF TREATED AMENDED WATER FOR IRRIGATION

Context

The EIS quotes electrical conductivity figures as a basis for the suitability of treated amended water for irrigation. The principal anion in the treated water before amendment is bicarbonate, rather than the more usual chloride. Specification for the maximum level of bicarbonate in irrigation water does not appear in the ANZECC guidelines for irrigation water.

Questions

- A) What are the implications of the water to be used for irrigation (given that it contains significant levels of bicarbonate) in terms of its impact on Sodium Adsorption Ratio (SAR) and Residual Soil Carbonate (RSC)?
- B) Has Santos any experience in the successful use of water of this type for irrigation in its other operations?

QUESTION 12 - BOHENA CREEK ISSUES

Context

In the EIS proposal, treated water will flow to Bohena Creek intermittently and be significantly diluted by rain-induced flow. A comparison of treated production water with Bohena Creek Baseline values shows that treated water is significantly higher in boron than baseline water. The converse is true for calcium. It is understood that estimates of the quality of treated water are based on a Hydranautics model of the reverse osmosis process. Other membrane manufacturers may be able to give better outcomes.

Questions

- A) Do the Hydranautics model predictions correspond with practice in other Santos production water treatment operations?
- B) Would it be possible to match treated water concentrations (if possible by amendment) to closely mirror Bohena Creek baseline concentrations and to thus allow the discharge of treated water to Bohena Creek without having to rely on significant dilution during rain events?

QUESTION 13 - PRODUCED WATER COMPOSITION

Context

The flow of and concentrations of various components in the produced water stream will set the agenda for detailed plant design in the front-end engineering design (FEED) stage. While there is reasonable agreement between reported figures in the EIS and previously reported data for produced water from PEL 238 in:

http://www.santos.com/library/PEL238_PAL2_and_PPL3_Produced_Water_Management_Plan.pdf 2014 – Web site since removed) the earlier information provided greater detail of trace species present. Depending on where these report in the treatment process, they may cause problems. A fuller analysis is highly desirable, with potential ranges and limits to detection being provided.

Questions

- A) Will Santos provide a more detailed analysis of species present in raw production water, indicating potential ranges and limits to detection? This information should also include any organics present and potentially troubling species such as radionucleides.

QUESTION 14 - SALT

Context

Throughout the EIS, the term “salt” is widely used to describe the inorganic species present in the production water and its concentrate. An analysis of the flowsheet shows that the “salt” contains approximately six times as much sodium bicarbonate as sodium chloride. This has implications for the use of treated water and also for the possible beneficial recovery of a solid product from the salt recovery process. It also has implications for the ultimate storage of the salt if a beneficial process cannot be developed. Sodium carbonate, which can be derived from sodium bicarbonate, is an article of international commerce and has, until recently been produced in Australia by the Solvay process.

Questions

- A) What prospects does Santos see for the beneficial use of the salt product from the salt recovery process?
- B) Will the fact that the “salt” recovered is primarily sodium bicarbonate have an impact on the hazardous nature of the “salt” in terms of its storage and transportation?
- C) Has an analysis been conducted on the nature of other species that might report to the salt product?

QUESTION 15 - WELL INTEGRITY

Context

Maintaining the integrity of a well during all phases of the project, i.e., the pilot phase, the operational phase, and the post-production phase - after the well has been plugged and abandoned, is a critical requirement of all coal seam gas projects, including the NGP. Well integrity is especially important in the case of the NGP, where the exploration, pilot and production wells must pass through aquifers in the upper alluvial layers, the Great Artesian Basin and the Gunnedah-Oxley basin. The groundwater present in some of these artesian reservoirs is critically important for agriculture and domestic consumption. The leakage of substances such as methane from a well into any of these aquifers, or the mixing of groundwater from one aquifer to another via a compromised well bore should be avoided.

In addition, the composition of the produced gas has not been detailed.

The proponent has indicated in the EIS that it will adopt the NSW Code of Practice for well integrity. It is therefore assumed that all mandatory requirements of this Code will be implemented. However, to date, the proponent has not provided details on its approach to the optional measures in the Code nor the expected chemical composition of the produced gas in the NGP.

Questions

- A) Given that it has indicated in the EIS that it will adopt the NSW Code of Practice for Well Completion, which of the “Best Practice” provisions will be adopted by Santos for the NGP?
- B) Information is requested on the range of gas compositions for the wells it has constructed and operated to date for the NGP, and on how this composition has been reflected in the well completions to date and how it will be in the future, particularly, though not exclusively, in terms of the steel or type of cement used in their construction
- C) Detailed information is requested on the well completions that will be adopted to minimise the chance of contamination of aquifers as a result of well failure?

- D) Santos is asked to provide details of any well failures or any cases of compromised well integrity in the wells it has constructed and operated to date in the Surat Basin?

QUESTION 16 - MONITORING

Context

There are currently 58 groundwater monitoring locations in the vicinity of the NGP, almost all of which are in the shallow aquifers. A further eight monitoring bores are proposed. Little information is provided in the EIS on the location of monitoring bores (other than the publicly monitored bores), nor on the hydrogeological interval that is or will be monitored. While there is some information provided, there is little information on the parameters that will be monitored, and the information that is provided suggests that the proposed extent of monitoring of the chemical composition of the ground waters and of hydrogeological data such as hydraulic head is likely to be inadequate to detect anything other than very large impacts. Additionally it likely to be inadequate for validating model predictions. The publicly available Santos site/water portal has approximately 36 monitoring sites shown with only two of those providing hydraulic head data, chemical data is limited and there are few time series.

In all, whilst no doubt Santos has given the issue of monitoring significant attention, this is not reflected in the EIS or in other sources of information. Nor is there evidence that consideration has been given to more comprehensive monitoring, how monitoring can be used to validate models or detect impacts such as pollution of aquifers. Further, has consideration been given to monitoring to detect excessive drawdown or the role that monitoring might have in remediation. In all, the monitoring scheme currently proposed, seems inadequate. In the previous question the need was highlighted for an adequate monitoring network and this then leads to issues relating to the need for baseline data against which to measure impact. The EIS does not provide confidence that sufficient attention has been paid to the need to establish an adequate base line nor what Santos might regard as an 'adequate baseline'.

Questions

- A) Santos is asked to provide a more comprehensive proposal for extending the baseline dataset and adequately monitoring the impact of the NGP, within and surrounding the project.
- B) As an extension of its response to (A), Santos is asked to indicate its future intentions regarding the number of monitoring bores, their location, the hydrogeological intervals that will be monitored and the parameters that will be monitored.
- C) How will Santos use the information it will collect (as outlined in B, to demonstrate that the NPG has not adversely impacted on groundwater, surface water, Groundwater Dependant Ecosystems (GDE)s, natural seeps and springs etcetera?
- D) What sampling protocols does Santos intend to adopt, including for water quality?

QUESTION 17 - DOCUMENTATION OF METHANE OCCURRENCES

Context

As indicated previously, there is some question that the baseline data collected to date for the NGP may be inadequate or incomplete. This includes data relating to water quality in the various aquifers,

GDE fauna, stygofauna, the methane content of surface and groundwater, and the background methane content in the atmosphere close to ground level. It is generally considered important to collect such baseline data, and to capture baseline readings accurately so that any future changes can be detected and their causes identified. As a particular example, there is little or no documentation in the EIS of existing occurrences of methane in domestic or agricultural bores or in natural waterways. Given the extent to which there has been controversy in Queensland regarding whether some methane leakage are “natural” or the result of nearby CSG production, this seems to be a significant omission for the NGP. Whilst monitoring of fugitive emissions will be dealt with by EPA regulation, this will not necessarily be done for natural occurrences, which are essentially a geological phenomenon. As a minimum, it would seem that Santos needs to document such occurrences before the NGP is underway.

Questions

- A) What baseline data exists regarding the presence of methane in the various aquifers that will be penetrated during the drilling for CSG in the NGP?
- B) What protocols were used in the collection of data relating to the presence of methane in surface and groundwater and in the atmosphere, and what sampling methods were used to collect this data?
- C) If there is little or no data available on natural occurrences of methane, how would Santos address this information gap before the NGP is underway?

QUESTION 18 - GREAT ARTESIAN BASIN

Context

GAB aquifers have an iconic and economic importance both locally and nationally. Since 1999 significant coordinated government and landholder investment in bore rehabilitation and groundwater water savings have been made. The outcrop of the Pilliga Sandstone forms a recharge area for the GAB and this is reflected in the Water Sharing Plans used to guide entitlement and management actions in the basin. However, the importance of the recharge in the NGP area (in terms of volume and potential for contamination) is more contentious, with many stakeholders regarding this area as a very significant in terms of recharge, whereas Santos believes the area is not a major recharge area. While the GAB is not the target for coal seam gas production, it is predicted in the EIS that it will be impacted.

Questions

- A) What evidence is there to support the Santos view that Pilliga Sandstone recharge in the NGP area is not significant?

QUESTION 19 SPILLAGES

Context

The possibility of spillages of various substances, including liquid hydrocarbons, spent drilling fluids, produced water and retentate from the reverse osmosis process used to treat the produced water, has been raised by a number of parties. Appendix S of the EIS considers certain spills, both less than and greater than 100L. These risks have been rated by Santos as “low” or “very low” risks.

Questions

- A) To what extent has the maximum allowable spillage been used as a design parameter in developing vessel and piping design?
- B) What will be the maximum spillage for each potential spill liquid in the front-end engineering design (FEED) of the NGP?
- C) What minimum spillage of each potential spill liquid is the threshold of a “significant spill”?
- D) What provision will be made for detection, sectional shut down, and safe isolation of offending plant or transfer lines in the event of a spill?
- E) What steps will be taken to handle a spill to prevent it from contaminating groundwater?

QUESTION 20 - BREAK-DOWN OF SODIUM BICARBONATE IN THE SALT RECOVERY PROCESS

Context

Sodium bicarbonate breaks down at 80°C to form sodium carbonate, releasing carbon dioxide. This would affect the amount of “salt” produced as well as the release of carbon dioxide from the produced water treatment process. It is indicated in the EIS that when the “salt” was heated to 180°C it decomposed, but little information is provided on the salt recovery step in the salt crystalliser.

Questions

- A) Has a detailed analysis been done on the effect of temperature in the salt crystalliser and the possibility of the formation of sodium carbonate from sodium bicarbonate?
- B) Is the carbon dioxide released during this process taken into account in the greenhouse gas assessment of the overall process?

QUESTION 21 - HOSKISSONS SEAM

Context

Santos has indicated that some gas will be extracted from the Hoskissons coal seam and that this might represent typically 5% of the total gas extracted over the life of the project. This coal seam, which rises to around 300 m below ground level, is much closer to the GAB than the lower coal seams, from which it is proposed to extract the majority of the gas. This then raises the question of whether extraction of gas from the Hoskisson Seam will have a greater impact because of its proximity to the GAB

Questions

- A) What will be the impact of gas production from the Hoskissons Seam on the GAB and other shallower aquifers in terms of drawdown and flux?
- B) What would be the impact(s) on the GAB and shallower aquifers if pumping from the Hoskissons seam was shut down during production?



Santos Ltd
ABN 80 007 550 923
Santos Centre
GPO Box 1010
Brisbane Queensland 4001
Telephone: 61 7 3838 3000
Direct: 61 7 3838 3861
www.santos.com

24 April 2018

Mr Mike Young
Director Resource Assessments
NSW Department of Planning and Environment
GPO Box 39
Sydney NSW 2001

Dear Mr Young

Thank you for the opportunity to provide a response to the Land and Water Expert Panel's questions in relation to the Narrabri Gas Project. Attached is the responses that have been prepared in consultation with the relevant technical consultants for the project.

Santos would be happy to meet with the Land and Water Expert Panel to discuss the responses or provide further information as considered necessary.

Yours sincerely,

A handwritten signature in black ink, appearing to read 'Neale House', is positioned above the typed name.

Neale House
Manager, Environment and Water
Santos Limited

Att. 1

QUESTION 1 - PRODUCED WATER ESTIMATES

Context

Resource and reserve values for the Namoi Gas Project (NGP) do not fall within the ambit of the WEP, but the closely related issue of produced water does. The level of confidence in gas production for the NGP should provide an indication of the level of confidence that can be expected in volumes of produced water. Given that Santos have operated their appraisal wells for several years, it presumably has a great deal of data on permeability, heterogeneity, pump tests and water production for the coal measure strata, and perhaps for other strata. However, little of this data is provided in the EIS.

Questions

- A) ***From the abstraction rates obtained from its pilot wells, what level of confidence does Santos have in its predictions of the volumes of water produced over the life of the Project and for the anticipated variation in volume over time?***

Data from the historical cumulative water production in thirty-seven appraisal wells from seven coal seam gas pilots in Early-Permian targets provide some guidance and constraint on production profiles for the extraction of produced water. This information has been used in the groundwater modelling, such that the model mimics optimised water extraction. The Base Case is designed to emulate the optimal production profile based on the data from the appraisal wells. The High Case represents a production curve that is significantly larger than the appraisal wells (i.e. no appraisal well to date has produced more than half the production simulated by the High Case scenario).

On this basis, the modelling for the EIS may be considered conservative in that it assumes more production than anticipated based on experience from existing appraisal wells.

This conservative approach is also consistent with industry experience to date regarding water production. For example, the Queensland Office of Groundwater Impact Assessment reported in 2016, in relation to the Surat Cumulative Management Area (covering CSG development in the Surat and southern Bowen Basin), that "the coal seams being developed are producing less water than was expected when the industry commenced".

Regardless, the proponent is committed to producing a maximum volume of 37.5 GL of produced water over the life of the project and will be seeking allocation licences to cover this extraction.

The Office of Groundwater Impact Assessment, Department of Natural Resources and Mines (2016). *Underground Water Impact Report for the Surat Cumulative Management Area* at p. xiii

- B) ***What is the basis for its level of confidence?***

As stated in the response to Part A of this question, data from thirty-seven appraisal wells have guided estimates of water production based on optimised gas production.

Predictions from the groundwater modelling inform the quantity of water entitlements that the proponent must hold or acquire within the potentially affected groundwater sources. If these entitlements are acquired for the project in accordance with the water sharing rules, then the predicted drawdowns simulated by the model are less relevant because they do not account for transfer of entitlements (trades) that will be required in heavily or fully allocated sources (e.g. the Great Artesian Basin and Lower Namoi Alluvium).

Acquisition of entitlements under the water sharing rules is designed to ensure that unacceptable drawdowns do not occur in the groundwater sources covered under the associated water sharing plans.

Furthermore, water production is continuously monitored during gas development, while the groundwater monitoring network is designed to continuously assess production impacts. This allows

the Proponent to ensure that the Project remains within the requested approval to extract a cumulative volume of up to 37.5GL over the life of the Project.

Notwithstanding this, a more recent groundwater modelling exercise of the project by GISERA (Sreekanth et al. 2017) considered probabilistic results based on 500 realisations of various model parameters, generating a range of water production volumes between 4.4 gegalitres and 107 gegalitres (compared to the EIS Base Case of 37.5 gegalitres). 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 EIS and also included estimates of water flux increases between the coal measures and the Pilliga Sandstone aquifer and the Pilliga Sandstone aquifer and the alluvium.

The GISERA modelling did, however, assume water extraction from coal seams in the ratio of 50 per cent from Late Permian (shallowest) coal seams and 50 per cent from Early Permian (deepest) coal seams. This modelling differs from the field development plan for which approval is sought under the EIS, which is based on water extraction from coal seams in the ratio of five per cent from Late Permian (shallowest) coal seams and 95 per cent from Early Permian (deepest) coal seams. Thus, the GISERA modelling extracted more water than is proposed from coal seams located closer to the Great Artesian Basin, and thereby over-estimated potential impacts on the Great Artesian Basin.

Previously, SWS (2012) carried out numerical groundwater modelling to assess potential impacts from a range of coal seam gas and coal mine scenarios in the Namoi region. Critically, despite invoking "extensive and widespread mining and coal seam gas" (Scenario 3), including an expanded Narrabri Gas Field and gas production from the Bando Trough near Gunnedah, the long-term predicted maximum impacts on groundwater levels associated with gas production in the Narrabri area remained below the minimal impact trigger as defined by the NSW Aquifer Interference Policy. The modelled coal seam gas groundwater extractions in SWS (2012) were comparable to the Base Case profiles modelled for the EIS, but multiplied across multiple gas fields.

The lack of significant modelled potential impacts in drawdown from recent numerical groundwater models, under different modelling frameworks, optimisation and analyses provides good confidence that modelling flux, as was undertaken for the EIS, does not underestimate drawdown impacts away from the point of abstraction.

Further, the existing sensitivity and uncertainty assessment in the Groundwater Impact Assessment of the EIS has tested model parameters that result in groundwater pressure drawdowns in the Great Artesian Basin and at the water table. The results are discussed in Section 6.10 of the Groundwater Impact Assessment and a summary of results for all simulations is presented in Section 6.11 of the Groundwater Impact Assessment (EIS Appendix F). All determined drawdowns would be considered minimal impact under the NSW Aquifer Interference Policy and would occur over 150 years in the future.

Sreekanth J., Cui T., Pickett T. and Barrett D. (2017). *Uncertainty analysis of CSG-induced GAB flux and water balance changes in the Narrabri Gas Project area*. CSIRO, Australia.

SWS (2012). *Namoi Catchment Water Study Independent Expert Phase 3 Reference Manual*. Prepared by Schlumberger Water Services (Australia) Pty Ltd for the Department of Trade and Investment, Regional Infrastructure and Services, NSW.

C) *Will Santos provide more data from the appraisal wells, so that the WEP can consider the impact of those numbers on the groundwater models?*

Data from appraisal wells does not provide information that can help inform groundwater models and is not proposed to be provided.

Appraisal wells are not designed, operated nor monitored in ways analogous to aquifer pumping tests and hence existing data acquired from operation of the Proponent's appraisal wells in general does

not support analysis of hydrogeological properties of sealing strata above and below target coal seams. Instead appraisal wells are operated to achieve rapid desorption of methane from the coals and limit well bore instability and coal fine production.

Thus, constraints mitigating against the use of pilot well data to assess pressure decline in adjacent groundwater units include: that pressure monitoring occurs only in-seam; water extraction rates are variable by design and can have multiple draw points; flow is two-phase when gas is produced, and appraisal wells can have relatively complex in-seam alignments and inter-connections compared to water bores.

D) *Will Santos provide more details on its reservoir modelling results and specifically those results which have informed the predictions of produced water volumes?*

The Proponent does not propose to release further information regarding the project reservoir modelling due to commercial sensitivity. Notwithstanding this, the historical water-production data discussed in the response to Part A of this question demonstrate the level of confidence in the estimates of modelled project water production.

The Response to Submissions includes an update to the Water Baseline Report that includes additional ground water monitoring data collected up to mid 2017.

QUESTION 2 - GAS COMPOSITION

Context

There is very little information provided in the EIS on the composition of produced gas, but presumably a great deal of compositional information has been acquired over the past few years from the appraisal wells. It is well known that some parts of the Gunnedah Basin are high in carbon dioxide and therefore it is not unreasonable to expect some wells in the NGP area will be high in carbon dioxide. This has implications to the economics of the NGP, to well completions and well integrity and to greenhouse gas emissions. It is claimed by some Special Interest Groups (SIGs) that other gases such as hydrogen sulphide are present in some wells. If hydrogen sulphide or carbon dioxide is present, this will have implications for process design, well cement, water processing and health and safety.

Questions

A) *Will Santos provide detailed analyses of the of the gas composition in the NGP area?*

Detailed spatial analysis of gas in coal measures in the Gunnedah Basin sequences is commercial-in-confidence. A number of analyses of gas concentrations, particularly methane, in groundwaters, are reported in summary form in the revised Water Baseline Report.

Multiple isotopic analyses on water and gas from coal seams have been undertaken at 29 separate locations (including data from non-NGP gas exploration and production wells) across the NGP and local surrounds. Analyses include stable carbon, hydrogen and oxygen isotope analyses as well as measurements on hydrocarbon and CO₂ gas concentrations. Please refer to the response to Question 17 for further information on methane in other formations.

B) *What information is available on the areal distribution of gas contaminants such as carbon dioxide, hydrogen sulphide and other significant trace gases and on variations in their concentration?*

It should be noted that gas from coal seams differs from conventional (or traditional) oil and gas in that it is almost entirely comprised of methane (CH₄), carbon dioxide (CO₂), nitrogen (N₂) and water vapour (H₂O(g)). There are also very small traces of ethane (C₂H₆). Gas from coal seams does not contain reduced sulfide species (such as hydrogen sulfide and mercaptans) or liquid hydrocarbons that have to be removed during processing.

The Proponent holds considerable data on gas composition across the region. This data is commercially sensitive, and will be used to define the field development program. Gas composition data gained during well drilling is submitted to the NSW Government and becomes available on the NSW Government's Geological Survey of NSW DIGs website after a set period of time. As with most resources, the composition of the gas varies significantly across different coal seams as well as laterally across the project area.

Trace gases are also analysed in groundwater samples from the Santos' water monitoring network. Methane results are reported in the Water Baseline Report. Other gases are not reported as they do not generally occur at levels above limits of laboratory reporting (LOR). For example, analyses for hydrogen sulphide in Santos' 41 water quality monitoring bores across the region only realised a single instance that recorded just above limits of detection (i.e. >0.1 mg/L), recorded at 0.2 mg/L from a shallow bore in the Bohena Creek Alluvium.

Field gas analyses have been carried out across a selection of monitoring sites on different dates. Only a single landholder bore, extracting water from the Orallo Formation, contained 7 mg/m³ CO₂ and 1 mg/m³ H₂S when sampled in 2013. The salinity of this bore was 1365 µS/cm and hence the bore is not designated for beneficial use.

This analysis is consistent with the findings of a report prepared for the Office of the New South Wales Chief Scientist and Engineer (Cook, 2013), that found natural gas from coal seams is "in most cases...of pipeline quality and requires minimal treatment".

Cook P.J. (2013). Life Cycle of Coal Seam Gas Projects: Technologies and Potential Impacts. Report for the NSW Office of the Chief Scientist and Engineer. 85 pp.

C) *What strategy does Santos have for dealing with gas contaminants?*

Please refer to response above regarding the composition of gas from coal seams being almost entirely comprised of methane (CH₄), carbon dioxide (CO₂), nitrogen (N₂) and water vapour (H₂O(g)) with very small traces of ethane (C₂H₆).

The Proponent has considerable expertise and experience in handling gas fields with variable gas content and composition, and will fine-tune the field development program to reflect the local conditions. If areas of high contaminant level are encountered that the Proponent determines to be unsuitable, strategies will be put in place to manage and/or avoid these areas, which may include avoidance, filtering or blending.

QUESTION 3 - CONVENTIONAL GAS

Context

Conventional gas has been found previously in the Gunnedah-Oxley Basin (GOB). In particular, some of the wells that detected and accessed this conventional gas lie in or near the NGP area, for example the Coonarah conventional gas well located in the northwest section of the NGP, east of Yarrie Lake. Unlike coal seam gas, when drilling for and extracting conventional gas, special precautions are required to mitigate the risk of well blowout due to overpressure.

Questions

- A) ***Other than the Coonarah Gas Field has any other conventional gas been detected in the NGP tenement?***

Historical conventional hydrocarbon shows are primarily associated with the Early Triassic Digby Formation and Middle Permian Porcupine sandstone, formally referred to as the Maules Creek sandstone. Prior to 1995, conventional hydrocarbons were the primary exploration objective throughout the region. A total of 19 conventional petroleum wells have been drilled throughout PEL 238 (and associated tenures) from 1963-Present.

Excluding the Coonarah Gas Field, only two of these wells, Wilga Park 1 (1985) and Bohena 2 (1998), have flowed gas at significant rates from conventional reservoirs. In addition, a number of minor hydrocarbon indications (including fluorescence, gas shows, gas flows, and kicks) have been noted in offset wells including local conventional and coal seam gas wells, coal and water bores. To date all conventional gas accumulations, outside the Coonarah Gas Field, are of insufficient size to be produced commercially.

- B) ***Are the operating procedures that will be adopted by Santos to drill wells and produce Coal Seam Gas (CSG), sufficiently robust to deal adequately and safely with conventional gas if it were to be encountered in any of the Santos wells?***

Yes. Well design and construction is in accordance with the NSW Government's Code of Practice for Coal Seam Gas Well Integrity. In addition to these, company requirements ensure the well operates safely within design criteria (casing and wellhead design and pressure ratings, etc.). During drilling operations, stringent systems and operating procedures are implemented to monitor for and manage any unforeseen pressures or situations and implement corrective actions to resolve or isolate safely as required.

All gas wells are treated the same in terms of safety systems and precautions. Prior to drilling commencing on any well the sub-surface team (Geologists) would select the well location within the development area and outline the formation pressures that could potentially be encountered on a well-by-well basis. Data from existing wells are reviewed and considered as part of the development of a well's design.

QUESTION 4 - GROUNDWATER MODEL AND CONCEPTUALISATION

Context

SURFACT was the model code selected by Santos for the NGP and this choice together with the modelling process, was accepted both by the CSIRO and IESC reviews.

The model was conceptualised as a series of aquifer and aquitard layers whose parameters were derived from literature values. The measured parameters and those calculated from field testing referred to in the EIS were apparently not used. Since the EIS was developed, the WEP was advised in the field that Santos has continued field testing which apparently has provided additional information if not data.

While the above approach may be suitable for the GOB units, it is a questionable approach for the overlying Great Artesian Basin (GAB) and the alluvial units, where there is considerably more information available. This is discussed further in the context of Question 5.

Questions

- A) ***Why did Santos use generic aquifer parameters from the literature, rather than aquifer parameter data available for each of the major groundwater sources (GAB and the Namoi alluvials)?***

It should be noted that the modelling did not use "generic aquifer parameters from the literature". Rather, 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 provides 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. Specifically, information and literature review supporting the hydrogeological conceptualisation and parameterisation for the EIS groundwater modelling includes the following:

- Review of stratigraphy and conceptual hydrogeology from previous work (GIA Section 5)
 - modelling of the Lower Namoi alluvium (Merrick 1999, 2000, 2001) and Upper Namoi alluvium (McNeilage 2006)
 - modelling of the Lower Gwydir alluvium (Bilge 2002) and Lower Macquarie alluvium (Bilge 2007)
 - investigation and modelling of the Great Artesian Basin (Radke et al. 2000; Welsh 2000, 2006)
 - regional-scale modelling of the Gunnedah-Oxley Basin, GAB and alluvial groundwater sources for the Namoi Catchment Water Study (SWS 2011, 2012)
 - review of groundwater modelling of the GAB (Smith and Welsh 2011)
- Development of the EIS geological model (GIA Section 6.4.2)
 - surface geology mapping (outcrop map)
 - 315 proponent drilling logs defining formation tops within the Gunnedah Basin and 25 additional drilling logs from the NSW Department of Primary Industries' DIGS Database
 - digital stratigraphic surfaces from the Lower Namoi alluvium groundwater model (Merrick 2001) and Upper Namoi alluvium groundwater model (McNeilage 2006)
 - digital basement stratigraphic surface from the Gunnedah Bowen Study SEEBASE study (SRK 2010)
- Hydrogeological properties (GIA Section 5.3 and Appendix C)
 - ten existing groundwater modelling studies within the model extents (summarised in GIA Table 5-3 and Figure 5-4)
 - comparison to literature estimates for rock and aquifer properties (e.g. GIA Figure 5-4)
- Hydraulic head and groundwater flow patterns
 - Review of data from 3,728 monitoring bores within the NSW Government's PINNEENA database (GIA Section 5.4.1 and 5.4.4)
 - Assessment of Santos drill-stem pressure measurements in 62 holes (GIA Section 5.4.2).

Specific parameterisation of the numerical model was undertaken with separate consideration of the GAB and alluvial aquifers:

1 - GAB

A review of groundwater modelling of the GAB (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 GAB and Gunnedah-Oxley Basin for the Namoi Catchment Water Study (SWS 2012) adopted uniform hydrogeological properties in the GAB of this area. More recent groundwater modelling, specifically considering the NGP 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 GAB 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 GIA describes a limited number of very localised (falling head) measurements of hydraulic conductivity in GAB 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 GAB.

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 GIA, therefore, are values adopted specifically for groundwater modelling studies and do not constitute measurements or field-based estimates of these parameters.

References

- Bilge H. 2002. Lower Gwydir Valley groundwater model. NSW Department of Land and Water Conservation.**
- Bilge H. 2007. Lower Macquarie groundwater flow model (Draft). NSW Department of Water and Energy.**
- McNeilage C. 2006. Upper Namoi groundwater flow model: Groundwater Management Area 004; zones 2, 3, 4, 5 11 and 12 (Draft). NSW Department of Natural Resources.**
- Merrick N.P. 1999. Lower Namoi groundwater budgets: simulations 1980-1994. Prepared by Insearch Limited, University of Technology, Sydney to Department of Land and Water Conservation.**
- Merrick N.P. 2000. Lower Namoi groundwater flow model: hydrographic verification 1980-1994 and conceptualisation scenarios. Prepared for Department of Land and Water Conservation by Insearch Limited, University of Technology, Sydney.**
- Merrick N.P. 2001. Lower Namoi groundwater flow model: calibration 1980-1998. Prepared for Department of Land and Water Conservation by Insearch Limited, University of Technology, Sydney.**
- Radke B.M., Ferguson J., Cresswell R.G., Ransley T.R. and Habermehl M.A. 2000. Hydrochemistry and implied hydrodynamics of the Cadna-owie – Hooray aquifer, Great Artesian Basin. Bureau of Rural Sciences, Canberra.**
- Smith AJ and Welsh WD 2011. Review of groundwater models and modelling methodologies for the Great Artesian Basin. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.**
- Sreekanth J, Cui T, Pickett T and Barrett D 2017. Uncertainty analysis of CSG-induced GAB flux and water balance changes in the Narrabri Gas Project area. CSIRO, Australia.**
- SKR 2010. Gunnedah Bowen Study. SRK Consulting; <http://www.resourcesandenergy.nsw.gov.au/miners-and-explorers/geoscience-information/gis-data-packages/petroleum-and-geothermaldata-packages/data/gunnedah-bowen-seebasetm-and-structural-gis-project>**
- SWS. 2011. Namoi Catchment Water Study Independent Expert Phase 2 Report. Prepared by Schlumberger Water Services (Australia) Pty Ltd for the Department of Trade and Investment, Regional Infrastructure and Services, NSW.**
- SWS 2012. Namoi Catchment Water Study Independent Expert Phase 3 Reference Manual. Prepared by Schlumberger Water Services (Australia) Pty Ltd for the Department of Trade and Investment, Regional Infrastructure and Services, NSW.**
- Welsh W.D. 2000. GABFLOW: A steady state groundwater flow model of the Great Artesian Basin. Bureau of Rural Sciences, Canberra.**
- Welsh W.D. 2006. Great Artesian Basin transient groundwater model. Bureau of Rural Sciences, Canberra.**

2 - Namoi alluvium

The scale of the EIS groundwater modelling is such that the Namoi alluvium is represented with a single model layer. It is impracticable in this model to directly adopt spatial distributions of hydrogeological properties from the multi-layered Upper Namoi and Lower Namoi aquifers as has been done for more local-scale models. Specifically:

- i) The Upper Namoi groundwater model (McNeilage, 2006) and Lower Namoi groundwater model (Merrick, 2001) used two and three layers, respectively, to represent the Narrabri, Gunnedah and Cubaroo formations within the alluvium.
- ii) Other differentiating factors between the alluvial groundwater models and the EIS groundwater model include the relative sizes of model cells and the extent of coverage of the alluvium by each model due to different model boundaries.

In this circumstance, therefore, order-of-magnitude values of hydrogeological properties, informed by the existing estimates, is considered the only practicable choice for assigning hydrogeological properties in the single layer representing the alluvium in the EIS groundwater model.

References

Merrick NP 2001. Lower Namoi groundwater flow model: calibration 1980-1998. Prepared for Department of Land and Water Conservation by Insearch Limited, University of Technology, Sydney.

McNeilage C 2006. Upper Namoi groundwater flow model: Groundwater Management Area 004; zones 2, 3, 4, 5 11 and 12 (Draft). NSW Department of Natural Resources.

B) *What additional field data has been collected that could be used to support the model parameters adopted and for sensitivity testing (see also Question 6)?*

The numerical groundwater model has been revisited twice since the original model was developed in 2014. This was undertaken as improved appreciation of the gas field's water and gas productivity from pilot well investigations allowed refinement of the expected water production curves and consequent definition of the Base Case used in the current model version. At each reassessment, additional data collected from the baseline monitoring network was re-evaluated against the data used in the numerical model and calibration statistics were revised in response to the additional field data. Inclusion of the updated field data in the calibration process did not result in any changes to the parameterisation of any of the groundwater units and the only significant change to groundwater fluxes were directly as a result of the updated production curves.

No pilot well data was used in any of these calibrations. As discussed in response 1, data from appraisal wells does not provide any additional information that can inform model parameterisation or constraint. Appraisal wells are not designed, operated nor monitored in ways analogous to aquifer pumping tests and hence existing data acquired from operation of the Proponent's appraisal wells in general does not support analysis of hydrogeological properties of sealing strata above and below target coal seams.

QUESTION 5 – GROUNDWATER FLUX AND WATER BALANCE

Context

The EIS defines the steady state condition referred to in the report and outlines how the impacts are quantified.

“the Groundwater Impact Assessment derives a steady state condition for groundwater as the starting point for model prediction. The steady state condition of groundwater was derived from an analysis of DPI Water data to reveal those years with the most prevalent spatial data array, considered to be representative of the study area. The model was then used to make predictions of the impact of the project activities (primarily the extraction of groundwater to depressurise the target coal seams) on the groundwater environment. The model quantified impact to groundwater pressures and levels.”

The resultant steady state water balance is given in Appendix F (Figure A6.18). The predictive capacity of the model is difficult to assess, given the lack of flux information, except for comparison with the modelled water balances for Upper Namoi Alluvium (UNA) and Lower Namoi Alluvium (LNA) water sources. These groundwater flow models are used for water resource management and underpin the water sharing plans for each water source. Both have distributed parameters and time series for all input and output parameters based on over 30 years of measured data.

The upward leakage from the GAB to the LNA was first identified by Calf (1978) using water chemistry and stable isotopes. It was quantified using this data and the hydraulics of the GAB and alluvium. Since that time the signal was lost due to the decreased utility of tritium and the groundwater mixing associated with the increased rates of groundwater extraction. Identification of the area of leakage was supported by pre-Tertiary strata samples from the government monitoring bores.

When the water source GAB interchange volumes are compared with those from the models for UNA and the LNA water sources given in in the EIS (Table A5.9) the volumes are considerably different.

- LNA leakage from the artesian aquifer is estimated at 7.9 GL/year by the water sharing plan model compared to 1.1 GL/year in the EIS model. However, this is for observed dynamic heads. For the fixed head (akin to the average heads approach modelled in the EIS) Merrick (2001) estimated a flux of 10.3 GL/year.
- The UNA model assumes no leakage between the basement rocks and the alluvium; also the area of contact between the alluvium and the GAB sediments is so limited that there is little scope for leakage between these two formations. Despite this, the EIS model has leakage of 7.46 GL/year from the GAB and 1.11 GL year from the basement rocks.

The WEP is concerned that that the EIS model may have poor predictive capacity in relation to the impact of production of the surrounding impacted water sources. The IESC indicated that the use of daughter models in areas of interest could be developed.

Questions

A) *Would Santos please explain the modelled differences in flux interchange for the GAB to LNA and UNA?*

As stated above, the EIS model only considers the Namoi Alluvium as a single layer and hence does not treat the LNA and UNA separately. However, investigation into the spatial variability of the LNA and UNA and consideration of the separate consequences of leakage between the alluvium and the underlying GAB has been undertaken. These investigations and comparison to others' work is summarised below:

Part 1 - GAB to LNA

Several previous estimates of artesian leakage between the GAB and LNA are reported in the hydrogeological literature, predominantly for the area of alluvium located between Narrabri and Wee Waa. Aquitards that elsewhere separate the GAB and LNA are largely absent in this area, which creates a stronger vertical connection between the GAB and LNA groundwater sources. The EIS groundwater modelling represents this area of enhanced connection through the absence of aquitards and computes vertical leakage between the GAB and LNA that is broadly consistent with the existing estimates reported in the literature (Please note that there is a flux accounting error in Figure 6-18 of the GIA that is corrected in this response, see Table 1 below).

Calf's 1978 finding was qualitative and inferred there was artesian recharge of the alluvium based on geochemical evidence. Subsequent estimates of the rate of artesian leakage in Williams (1985), Merrick et al. (1986) and Merrick (2001) were all modelling based. The recent geochemical findings by Iverach et al. (in press) based on chloride concentration are also qualitative regarding the leakage rate between the GAB and LNA. No direct measurements of artesian leakage rates were reported in these studies. On this basis, the existing modelling-derived estimates can be considered as benchmarks rather than as calibration targets. A tabulated summary of leakage estimates is presented in Table 1 and each estimate is briefly discussed below.

Table 1 Estimates of artesian leakage from GAB to LNA

Estimate	Rate, ML/d	Area, km ²	Rate, mm/y	Comment
Calf (1978)	Not calculated	N.A.	Not calculated	Qualitative regarding leakage rate
Williams (1985)	2 - 10	79	9 - 46	Estimate provided to the study by Merrick
Merrick (1986)	10.1	62.5	59	Area based on 10 cells × 625-ha per cells
Merrick (2001)	20 - 25	143.75	51 - 63	Area based on 23 cells × 625-ha per cells
Merrick (2001)	0.2 - 0.35 per cell	6.25 one cell	12 - 24 per cell	Based on the statement "the inflows generally reduce from east to west (from about 3.5 ML/d per cell to 0.2 ML/d per cell"
Iverach et al. (in press)	Not calculated	N.A.	Not calculated	Qualitative regarding leakage rate
EIS modelling - GAB direct	4.5 net	1153 total	-67 - +93 per cell	WSP reporting area 29 and adjacent alluvium (Narrabri to Wee Waa); consisting of 8.5 ML/d artesian recharge and 4 ML/d artesian discharge
EIS modelling - GAB via aquitards	3.6 net	5461 total	-0.26 - +0.78 per cell	WSP reporting area 29 (Wee Waa to Walgett)

Calf (1978)

Based on environmental isotope data from groundwater sampling, it was concluded in this study that these data "...may indicate that part of the deeper water in the Namoi Valley aquifers originated from leakage of water from the Great Artesian Basin, underlying the Namoi Valley." The study was conducted in an area of the LNA located predominantly between Narrabri and Wee Waa (Figure 1). The results and conclusions of the study were qualitative regarding the leakage rate.

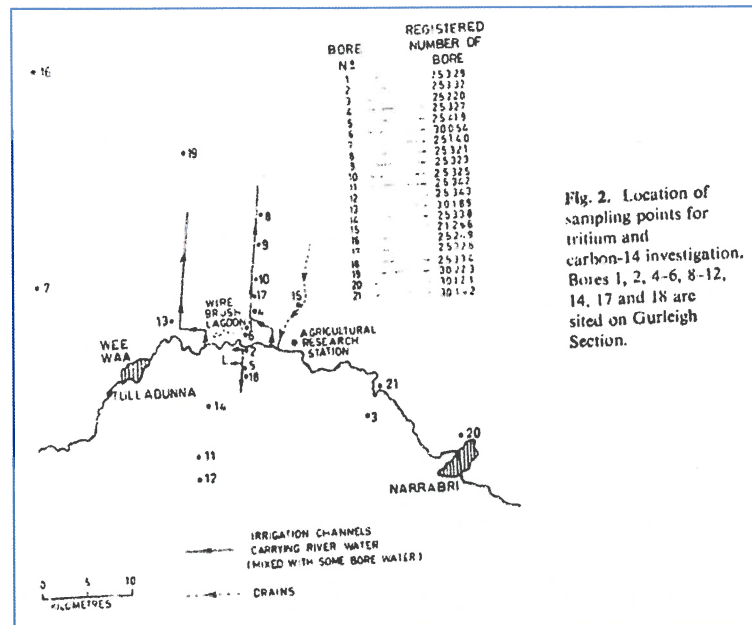


Figure 1 Map of groundwater sampling locations in Calf (1978)

Fig. 2. Location of sampling points for tritium and carbon-14 investigation. Bores 1, 2, 4-6, 8-12, 14, 17 and 18 are sited on Gulleigh Section.

Williams (1985)

This work used an estimate of net artesian recharge provided to the author by Merrick as pers. comm. The estimate of 2 to 10 ML/d artesian leakage into the LNA applied to an area of approximately 79 km² and was based on a "...quasi-three-dimensional model for recharge of the alluvium by losses from the underlying Cretaceous sandstone aquifers."

The estimate of leakage reported within the study (Figure 2) is equivalent to an average artesian recharge depth of 9 to 46 mm/y.

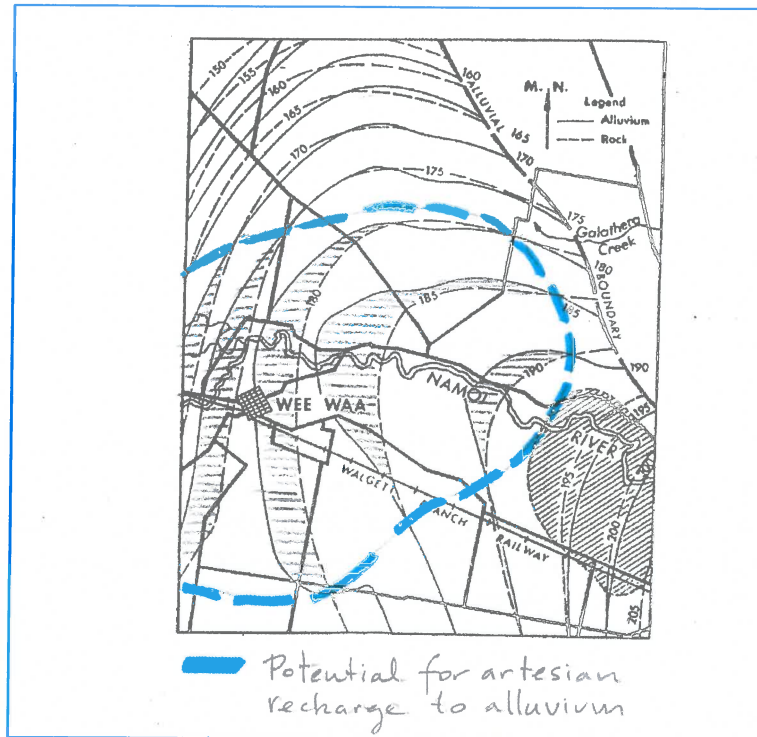


Figure 2 Area of potential artesian recharge in Williams (1985)

Merrick et al. (1986)

A two-layer groundwater model of the LNA was developed using a uniform grid with 2.5 × 2.5 km (6.25 km²) cell size. It was stated that "On the basis of radiocarbon dating (Calf, 1978), piezometric heads and bore logs, artesian leakage was attributed to 10 cells in the south-eastern part of the study area." (Figure 3). Artesian leakage of 10.1 ML/d was applied over an area of 62.5 km², equivalent to an average artesian recharge depth of 59 mm/y.

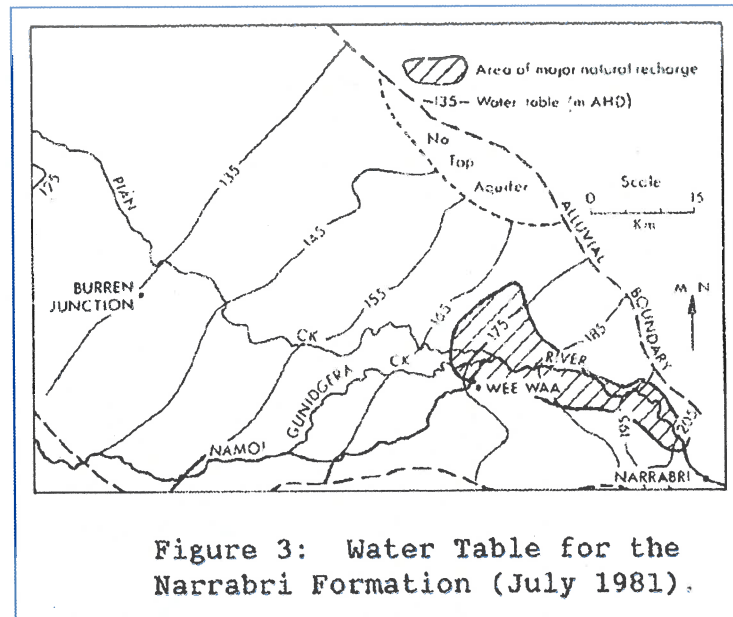


Figure 3 Study area of Merrick et al. (1986)

Merrick (2001)

This updated groundwater model for the LNA introduced a head dependent boundary condition to represent artesian recharge from the GAB. A uniform model grid with 2.5×2.5 km (6.25 km^2) cell size was used (Figure 4). Artesian boundary conditions were assigned in 23 cells, equivalent to an area of artesian recharge of 143.75 km^2 . The artesian leakage rate was estimated to be 20 to 25 ML/d over this area, equivalent to an average artesian recharge depth of 51 to 63 mm/y.

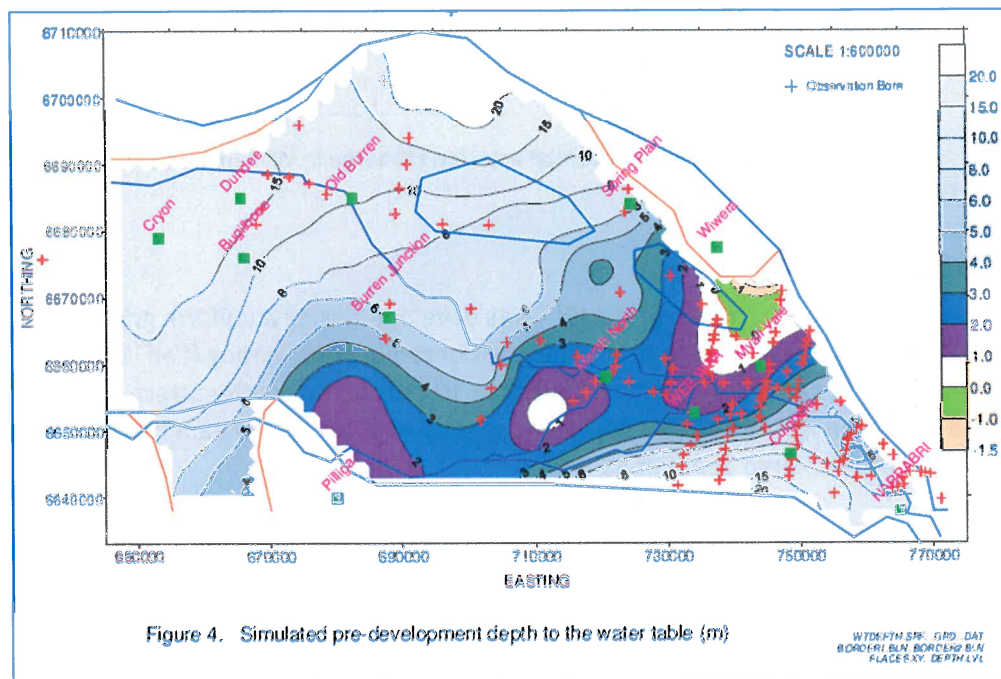


Figure 4 Groundwater model area of Merrick (2001)

Iverach et al. (in press)

This study estimated the proportions of GAB groundwater contributing to samples of alluvial groundwater collected in the LNA in the region between Narrabri and Wee Waa. Chloride was used as the tracer. Estimated GAB contributions to the alluvial groundwater samples were between 0% and 70%. The estimates cannot be directly compared to existing estimates of artesian recharge to the LNA (e.g., Merrick 1986, 2001) as they are point samples collected over a large area of potential mixing and do not take into consideration any inputs from irrigation waters drawn directly from the GAB. Alluvial groundwater samples showing 0% contribution from GAB groundwater indicate either no significant

vertical flux between the groundwater sources at those locations due to local barriers, or the direction of vertical leakage is from the alluvium to the GAB.

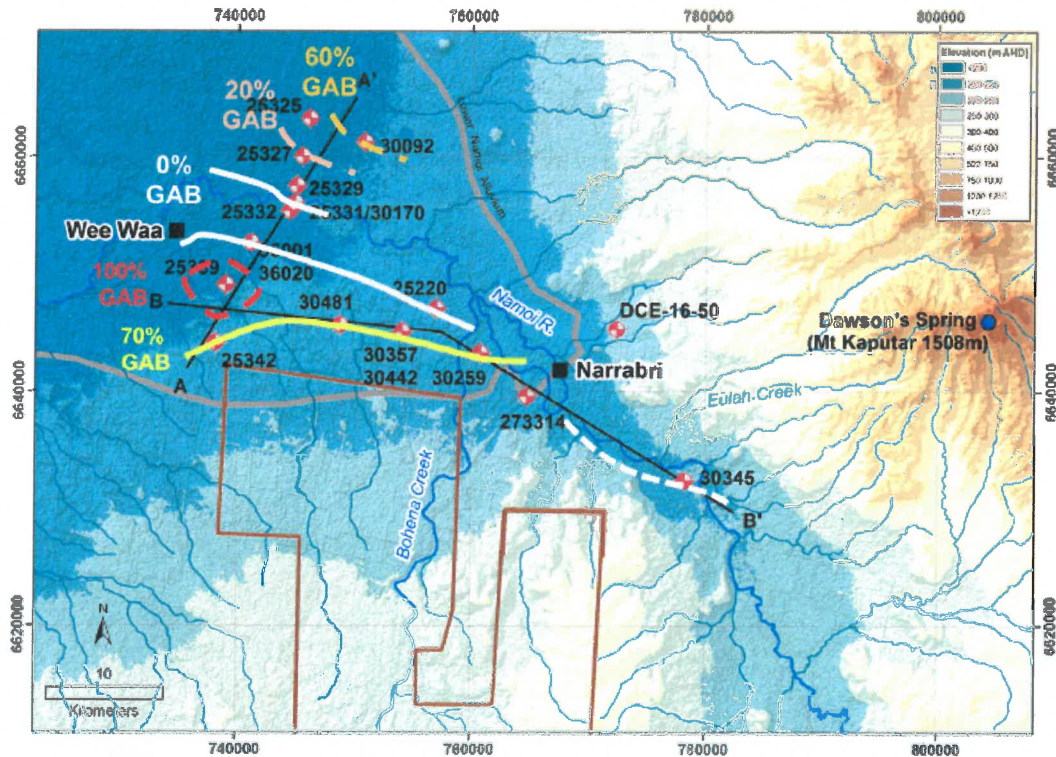


Figure 5 Approximate percentages of GAB contribution to the LNA (Iverach et al., in press)

Narrabri Gas Project groundwater modelling

The groundwater modelling for the Narrabri Gas Project EIS incorporates enhanced vertical connection between the GAB and LNA in the area between Narrabri and Wee Waa where the Pilliga Sandstone directly underlies the LNA (Figure 6). A map of steady-state leakage between the GAB and LNA from the modelling is shown in Figure 7 and the simulated steady-state water balance (corrected from that issued with the EIS) is reproduced in Figure 8.

Figure 7 was not presented in the EIS, whilst Figure 8 differs from the version (Figure 6-18) published in the EIS with respect to the groundwater flux of 1.6 GL/y (4.5 ML/d), now shown by the additional arrow extending from the Pilliga Sandstone to the LNA. The original figure contains an accounting error, whereby this flux to the LNA was included in the flux component from the Pilliga Sandstone to the UNA.

The map of steady-state leakage in Figure 7 shows areas of both recharge and discharge from the LNA, with overall net recharge. The direction of leakage is controlled by the vertical head difference between the Pilliga Sandstone and LNA, such that contours with negative values indicates head in the alluvium is less than head in the Pilliga Sandstone. This provides conditions with potential for recharge. Simulated values of head difference vary from around -35 m near the northwest extent of the alluvium to ± 5 m in the region between Narrabri and Wee Waa. It should be noted that enhanced vertical connection acts to reduce vertical head gradients.

The modelled net rate of recharge for WSP reporting area 29 (Narrabri to Wee Waa) and adjacent alluvium (outside of area 29) is 4.5 ML/d, consisting of 8.5 ML/d vertical leakage from the GAB to LNA and 4 ML/d vertical leakage from the LNA to GAB. The associated leakage rates in model cells vary between -67 mm/y (leakage out) and +93 mm/y (leakage in). These rates of leakage are broadly consistent, though on the low side, compared to the estimates from other studies.

Outside the area of direct connection between Pilliga Sandstone and LNA, the EIS modelling simulates net recharge of 3.6 ML/d through the Rolling Downs Group aquitards over a large area of 5,461 km² (WSP reporting area 17). This is equivalent to an average recharge depth of 0.24 mm/y.

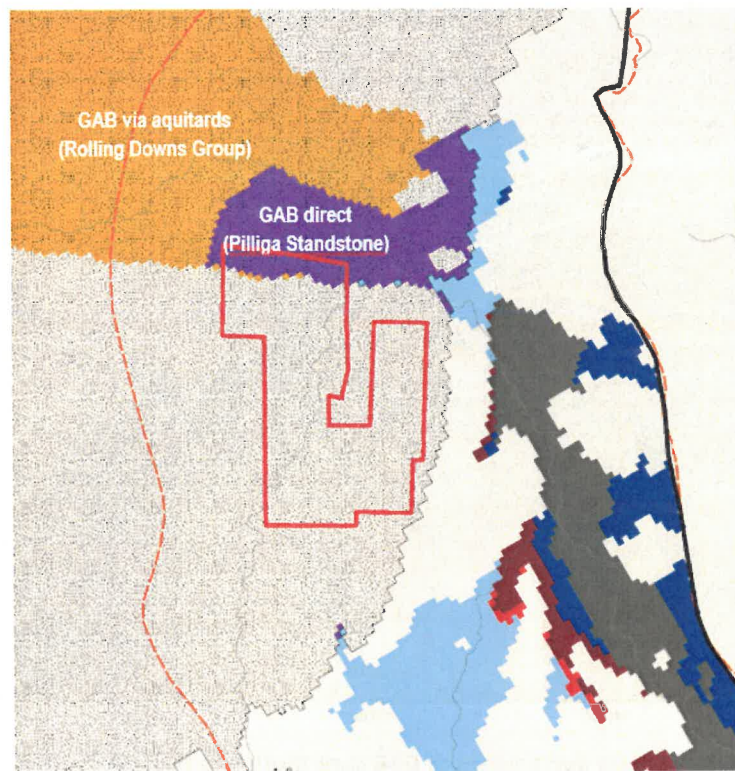


Figure 6 EIS groundwater modelling – LNA sub-crop units

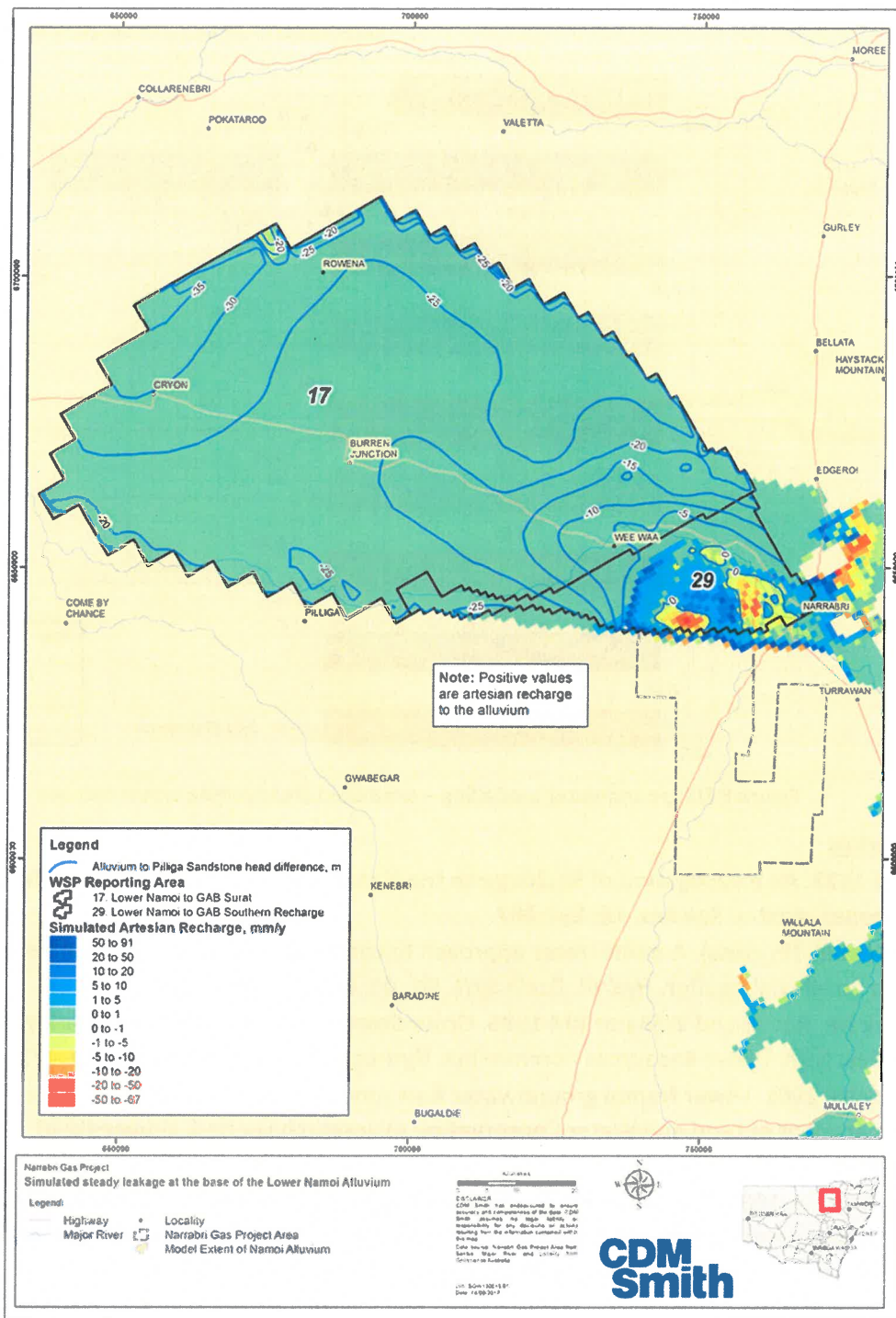


Figure 7 EIS groundwater modelling - simulated steady leakage at base of LNA

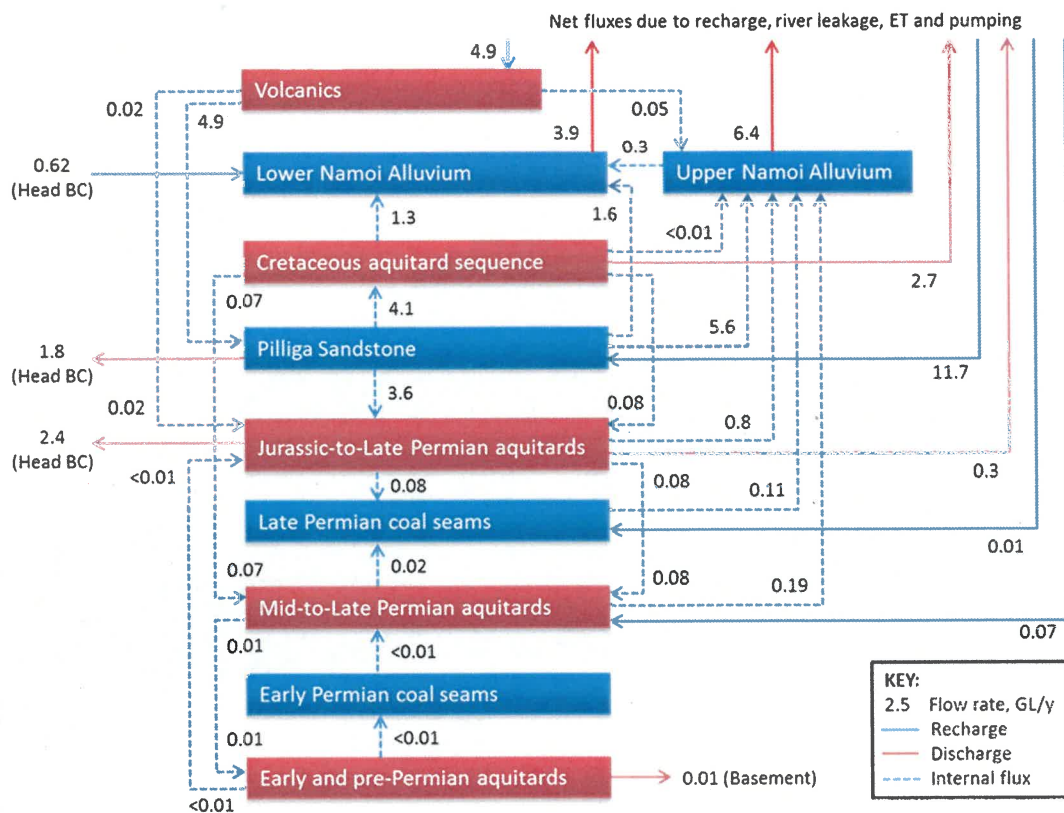


Figure 8 EIS groundwater modelling – simulated steady-state water balance

References

- Calf GE 1978. An Investigation of Recharge to the Namoi Valley Aquifers Using Environmental Isotopes. *Aust. J. Soil Res.* 16: 197-207.
- Iverach et al. (in press). A multi-tracer approach to constraining artesian 1 groundwater discharge into an alluvial aquifer. *Hydrol. Earth Syst. Sci.* doi.org/10.5194/hess-2017-327.
- Merrick NP, Ros JB and Williams RM 1986. Groundwater in the Lower Namoi Valley, New South Wales. NSW Water Resources Commission, Hydrogeological Section, pp. 461-471.
- Merrick NP 2001. Lower Namoi groundwater flow model: calibration 1980-1998. Prepared for Department of Land and Water Conservation by Insearch Limited, University of Technology, Sydney.
- Williams R. M. 1985. The Cainozoic Geology, Hydrogeology and Hydrochemistry of the Unconsolidated Sediments Associated with the Namoi River in the Lower Namoi Valley, N.S.W. Centre for Natural Resources, Hydrogeology Unit, September, CNR 97.093.

Part 2 - GAB to UNA

There are differences in reported vertical leakage between the GAB and UNA leakage as represented in the Upper Namoi groundwater model of McNeilage (2006) and the EIS groundwater model which can be explained by:

- the different extent of the Upper Namoi alluvium covered by each model
- the assumption of zero artesian leakage in the Upper Namoi groundwater model.

Specifically, the Upper Namoi groundwater model covers Zones 2, 3, 4, 5, 11 and 12 within GMA 004. In contrast, the EIS groundwater model includes all the Upper Namoi alluvium, inclusive of the area where Pilliga Sandstone (Oxley Basin) forms a sub-crop to the alluvium, which is outside the geographic extent of the Upper Namoi groundwater model. The EIS steady-state model computes a value of artesian recharge from the Oxley Basin to the Upper Namoi alluvium of approximately 15 ML/d (5.6 GL/y) in the sub-crop area.

The Proponent is not aware of any other estimates of this flux as a basis for comparison. Elsewhere, the EIS model computes minor (non-zero) vertical leakage from the Gunnedah Basin to the Upper Namoi Alluvium, which is consistent with, but not identical to, the assumption of zero artesian leakage implemented by the Upper Namoi groundwater model (McNeilage, 2006).

A) *Assuming the water balance fluxes remain, what would be the impact of incorporating the existing water management models to upgrade the existing EIS model?*

If the EIS model were adjusted to match a larger estimate of average (steady-state) artesian recharge from the GAB to the LNA in the region between Narrabri and Wee Waa, as suggested by previous studies, then it is expected that the predicted impact of the project on absolute flux would be similar in magnitude as the simulated water extraction from the coal seams in the Gunnedah Basin is a fixed volume. It should be noted, however, that the impact would not be identical and the amount of variation from the current estimate would depend on how the EIS model were adjusted. Predicted impacts on drawdown in the LNA resulting from adjustment of the EIS model would be expected to be similar and likely smaller as the change in vertical flux induced by water extraction (a fixed volume in the modelling) would be smaller relative to the adjusted pre-development vertical flux and thus represent a smaller relative perturbation of the pre-existing condition.

It should be noted, on the basis that GAB and LNA groundwater entitlements are acquired for the Project in accordance with the water sharing rules that, regardless of the initial flux estimates, there would be no difference to drawdown impacts in the groundwater sources relative to any drawdown that would occur without project development.

QUESTION 6 - GROUNDWATER MODEL - CONNECTIVITY

Context

If the connectivity between units is controlled by unit heterogeneity the current conceptualisation may restrict the predictive capacity of the timing and flux. The pilot production field testing may have provided some guidance of this matter particularly if there is monitoring close to the production zone.

Several SIGs have suggested increased monitoring in a range of areas. While the WEP agrees that regional baseline monitoring is important, impacts of sufficient magnitude to be detectable may not occur for some considerable time. Monitoring in the areas where impacts are predicted to occur soon after production occurs, are critical. They assist in proving the conceptual groundwater model and allow management responses to be developed in a timely manner.

Questions

A) *Have any impacts arising from pilot well production been detected by Santos monitoring?*

No impacts have been detected to date.

At the location of the former Bibblewindi 9-Spot pilot, ongoing monitoring of groundwater pressure is undertaken in the Porcupine Formation, which immediately overlies the Early Permian coal measures. All other water pressure data acquired associated with the Proponent's appraisal wells consist of in-seam pressure records only.

The former Bibblewindi 9-Spot pilot targeted Early Permian coal seams and ceased operation in 2012. Groundwater pressure monitoring in the overlying Porcupine Formation (Bore Bibblewindi 6) subsequently commenced in 2015. There is no period of overlap between the in-seam pressure monitoring during pilot operation and subsequent pressure monitoring in the Porcupine Formation. Water production at nearby pilots, Bibblewindi West and Bibblewindi East, however, is currently ongoing. The updated Water Baseline Report (provided as part of the Response to Submissions report) includes a further 15 months' worth of pressure data from Bibblewindi 6 monitoring, subsequent to that reported for the EIS.

To date, pressure monitoring in well Bibblewindi 6 has not indicated any definitive impact by historical water production from the former Bibblewindi 9-Spot pilot, nor from ongoing water production from Bibblewindi West and Bibblewindi East pilots. Ongoing monitoring at the site will continue to be assessed.

- B) ***Has any data collected from the operation and monitoring of the pilot wells been used to determine the impact of production on aquifers and aquitards and/or to estimate aquifer or aquitard parameters?***

Data acquired from the Proponent's historical pilots do not support this type of analysis. Please refer to the response to Question 1, Part C for an explanation of why this is the case. The use of longer-term actual water-production data from producing wells, combined with longer-term pressure monitoring in overlying strata, could be used for future refinement to the model.

- C) ***If the answer to B is no, then why not?***

Please refer to the response to Part B of this question above.

QUESTION 7 - FAULTING

Context

Faulting can have a very significant impact on groundwater, whether by providing a pathway for upward leakage of saline groundwater or gas, or in the case of sealing faults, disruption of flow through compartmentalization of stratigraphic intervals. In the EIS, including in the groundwater modelling, it seems that any fault with a displacement of less than 100m is ignored. But the geological cross sections provided in the EIS are very small scale and so lacking in detail that it is impossible for the reader to make an assessment of whether this approach is valid. Further, there appears to have been no attempt to assess the possibility of neotectonics affecting the shallow aquifers, nor are any seismic profiles provided that would offer the opportunity to assess faulting in the deeper sediments. In all, the information providing on faulting and tectonic (including neotectonic) processes in the EIS is considered sparse by the WEP and also, it would seem, by a number of other individuals and organisations.

Questions

- A) ***What additional information, such as magnitude and distribution, is available on faulting within the project area?***

Detailed seismic studies indicate that faulting within the NGP development area is small scale and sparse. Most structures are only identifiable on single seismic lines, with associated fault throws of 5-40m, compared to 50-100m of hydrostratigraphic formation thickness. That is, faults do not break the key aquitard layers. There is also no evidence that deep faults extend up through the overlying formations.

It is acknowledged that some larger structures are evident on the flanks of the basin (e.g. to the west of Dewhurst 9) and/or are associated with Triassic intrusive activity (e.g. on the Coonarah and Brigalow Park anticlines). These structures, however, generally do not extend into the overlying Jurassic strata, which remains largely unstructured. Most faulting within the project area is considered to be compressional and is believed to be associated with closure of the Bowen-Gunnedah-Sydney basinal system during the Middle Triassic.

These conclusions are drawn from interpretation of thousands of kilometres of 2D seismic lines of various vintage that have been acquired across the Narrabri region since the early 1960's. Some of the early seismic data is of variable quality and has been reprocessed to enhance overall image quality. These lines currently form a broad 2-4 km seismic grid across the main NGP development area. Key seismic horizons (including the Base Jurassic, and Triassic unconformities, the Hoskisson's and Bohena Seam and Basement) have been interpreted across the Bohena Trough, with structure maps generated

for each horizon. Faults have been mapped on each seismic line and incorporated into detailed structural mapping.

It is noted that most other studies of the area have generated inferred fault maps based on features derived from several sources, including magnetic and gravity data, with no indication as to the age or amount of displacement of the inferred faulting (e.g. Welsh, et al., 2014), with few verification studies using detailed seismics.

References

Welsh W, Hodgkinson J, Strand J, Northey J, Aryal S, O'Grady A, Slatter E, Herron N, Pinetown K, Carey H, Yates G, Raisbeck-Brown N and Lewis S (2014) Context statement for the Namoi subregion. Product 1.1 from the Northern Inland Catchments Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

- B) ***Using such information, can a better assessment of the potential impact of faulting, including on groundwater flow, be provided?***

Multiple lines of evidence indicate most known faulting within the project area is of small scale and does not extend into the overlying formations. Potential impacts to groundwater flow due to faulting is therefore considered to be highly unlikely. There is no evidence to contradict this view.

- C) ***If adequate information on faulting is not available, what additional steps does Santos propose to take to address any data deficiencies?***

Data obtained through drilling further exploration and appraisal wells would be used to further refine the structural information for the project area. Pressure monitoring of key reservoir and aquifer zones will also be undertaken throughout project life, to monitor the impact of production activities. Where necessary, the acquisition of further seismic data may be considered for the NGP.

QUESTION 8 - WATER TAKE AND DRAWDOWN PREDICTIONS

Context

The current NSW legislation and policies require water entitlements to be held to cover the predicted maximum annual water take from each of the water sources prior to commencement of a project.

Given the current level of uncertainty in the distribution and level of drawdown levels, Santos may be required to obtain additional entitlement from the UNA, LNA, GAB above that predicted, and perhaps even drawing on surface water sources for impacts that may be heavily lagged. Additional information and data has the potential to significantly lessen the current uncertainty.

Questions

- A) ***What additional information and data does Santos hold, including data collected since the EIS was published, that could be used to improve confidence in the drawdown and water take predictions, particularly those in the GAB, UNA and LNA?***

Please refer to the responses to:

- Question 1 – regarding produced water volumes from the Proponent's pilot operations.
- Question 4, Part B – regarding groundwater pressure data.
- Question 6, Part B – regarding potential local-scale analysis of hydrogeological properties.

QUESTION 9 - WATER ENTITLEMENTS

Context

Each of water sources from which Santos will have to gain an entitlement, has different levels of development and management characteristics. The Gunnedah Oxley Basin (GOB) Water Source has a Sustainable Diversion Limit (SDL) of 114.5 GL/year. There is significant unassigned water which is available to the proponent that can be activated by application to government.

The GAB is effectively fully allocated so that Santos would need to go to the market to obtain entitlement. However, the two impacted zones appear to have quite different management rules:

- Southern Recharge Groundwater Source is the primary impact area, with an SDL of 25 GL/year based on estimates of direct rainfall recharge.
- Surat Groundwater Source had an SDL of 15.1 GL/year but this is based on the sustainable pressure estimate. The SDL will decrease over time through measured water savings that result from restored artesian pressures due to capping of bores and improved water use efficiency activities.

The SDL for the LNA is 88.3 GL/year and for the UNA 123.4 GL/year respectively. Both of these systems are fully allocated so any volumetric impact from the proposed development may have a material impact on the community.

The surface water plans are not addressed although the surface water is a recharge source and may be impacted.

The property rights are held as entitlement that are subject to annual announced allocation which may reduce the value of the entitlement to something less than 1. They are tradable although their activation to use is subject to impact rules. The groundwater is managed by the rules set out in each plan so that adverse impacts can be avoided or at least recognised.

The WEP notes the anticipated high level of entitlement and use in both the surface and shallower groundwater systems and also that the impacts which the EIS describes as insignificant, may in fact be volumetrically large. It further notes that detailed information is now available for the historic water use and trading patterns provided by Aither (2017). The entitlement that Santos is seeking is large in comparison to the historic trades.

Questions

A) ***How does Santos propose to manage the impact of annual announced allocation on their operations?***

All water extracted for the project will be taken under an access licence issued by the NSW Department of Primary Industries, just as is the case for other water users including irrigators, industrial users, other resource developments and those drawing under licence for stock and domestic use.

Assuming this question asks whether the Proponent will be prepared to modify their annual water take, and (by implication) potentially impact gas production, if its extraction share under the annual announced allocation is less than the predicted peak extraction rate, then the answer is yes. As any required water licences will be determined based on peak projected water demand, in most years predicted take will be sufficiently below any reduction imposed through allocation reductions that this will not be an issue.

The EIS (Appendix F) presents the net flux (take) to each groundwater source. The table below, reports the maximum take from the base of each source, directly comparable to the definition of water take in the water sharing plans. The table also provides the Long term Average Annual Extraction Limits (ML/y)(as per EIS, as at 30 June 2014 as advised by DPI Water July 2016).

Peak induced flows (maximum take) for the EIS Base Case

Groundwater source	EIS Base Case (37.5 GL) Peak flux change at source base		Long term Average Annual Extraction Limits (As per EIS, advised by DPI Water July 2016) ML/y
	ML/y	Time (years after start of FDP, to nearest model time step)	
Gunnedah-Oxley Basin	3,553	3	205,640
GAB Southern Recharge	57.3	190 - 200	29,680
GAB Surat	0.16	950 – 1,000	35,097
NSW GAB Surat Shallow	<0.16	>1,000	143,335
Lower Namoi Alluvium	4.19	250 – 300	86,000
Upper Namoi Alluvium (UNA)	1.00	250 – 300	122,100
UNA Zone 2	0.16	550 – 600	
UNA Zone 5	0.90	250 - 300	

B) How does Santos propose to manage the impact of drawdown rules that are in the LNA management plan on their operation?

Currently modelled potential peak flux (maximum take) from the Lower Namoi Alluvium is predicted to occur in excess of 250 years in the future and may constitute 4.19 ML/y. This should be considered in light of the current long-term average annual extraction limit of 86,000 ML/y (see Table above in response to Question 9A) i.e. it represents less than 0.005% of the LTAAEL. This does not constitute a material or measureable impact to the LNA.

The sentinel location of the monitoring bores together with the defined thresholds, response triggers and management actions set out in Section 3.7 of the Water Monitoring Plan would ensure that any unexpected potential impact is identified early and management actions implemented, including in consultation with agencies.

C) How will proposed Santos water management actions impact on access of the existing entitlement holders?

Current predictive modelling indicates that the Proponent will have no impact on existing entitlement holders. If it becomes apparent through modelling and monitoring reviews that any Proponent water management actions are having an impact, the Proponent will enter into a “make good” arrangement with that licence holder.

QUESTION 10 - PROCESS WATER BALANCE

Context

Santos proposes a total of 900 ML for the storage of production water and reverse osmosis concentrate and 200 ML for the storage of treated water. Treated and amended water will be used for irrigation of 500 ha of lucerne and other on-site outlets. During periods of prolonged inclement weather, treated water may be discharged into Bohena Creek when the creek is flowing at 100 ML/day or more. Storage and treatment plant operations must be managed so that involuntary discharge of untreated production water or reverse osmosis concentrate will not occur, especially when production flows are greatest, i.e., in the first 2-4 years

of operation. Weather records in the EIS show a maximum monthly precipitation in excess of 900 mm. Were this to occur over a period when the water flow in Bohena Creek does not consistently exceed 100 ML/day, or rainfall records be exceeded, involuntary release of contaminants could occur. The possibility of prolonged reverse osmosis plant outage at a critical time cannot be ruled out.

Questions

- A) ***Will Santos provide evidence from its process water model that would give the WEP confidence that the proposed storage and its mode of operation is sufficient to ensure that an involuntary release of contaminated water will not occur in the first 2-4 years of operation?***

Firstly, please note that the value of 900mm of precipitation stated above actually represents the annual maximum, not monthly. Also note that maximum historic monthly rainfall was 330mm (Feb 1928).

The proponent has operated water treatment facilities as part of its activities across a wide range of operating environments and fields and, as such, has considerable experience in effectively managing produced water volumes and operating water storages. Most notably in relation to coal seam gas operations, there are currently around 18 water storage facilities with maximum operating volume larger than 150ML (the approximate volume of each cell in the Leewood Water Management Facility) operating for the Santos GLNG project in Queensland.

The approach to water management ensures there will be adequate storage capacity in the system. This includes, in the highly unlikely scenario that ponds are approaching levels that would result in an overtopping event, controls on water production that can be exercised to limit or suspend water production. That said, the management procedures (as outlined below) mean that this scenario is not likely, as the pond design and operational management practices include capacity for storage of extreme rainfall events.

The produced water storage at Leewood includes the use of the existing two storage ponds (four cells) with a total storage volume of approximately 600ML and the construction and operation of a further pond (2 cells) with approximate volumes of 150ML per cell, providing a total storage volume at Leewood of approximately 900ML.

Consistent with the existing ponds at Leewood, the new pond would be designed, constructed and operated to meet best practice standards. Details of the operational requirements of the existing ponds is set out below to demonstrate the comprehensive approach taken to the design, construction and operational management of the ponds to ensure the produced water is stored appropriately. This approach would continue for the production project.

Once the brine concentrator and salt crystalliser stages of the Leewood plant are in operation, produced water and the brine by-product would generally undergo continuous processing through all stages of the treatment system to produce the treated water and salt product. As such, the Leewood ponds would predominantly be used to store produced water (prior to treatment) and treated water (if required) and are unlikely to store significant quantities of brine.

The facility meets the requirements of the NSW Government's Code of Practice *Produced Water Management, Storage and Transfer* (NSW Dept. of Industry). The current ponds include primary and secondary lining, leak detection and collection and an engineered spillway. In addition, the NSW Dam Safety Committee reviewed the design of the ponds and confirmed construction was to specification.

Monitoring of storage levels is undertaken with the use of pressure sensors that continuously measure and record storage depth, volume and surface area based on hydrostatic pressure. These automated meters are submersed in the pond to a depth as close to the base of the pond as reasonably practicable, and are used in conjunction with surveyed data to determine the water level of the pond. Telemetry is used to allow for remote real-time monitoring of the pond levels and this is used to monitor storage capacity in conjunction with other parameters, such as upstream pilot or well-head water production data.

Field operators are required to record the pond level and volume on a daily basis. Other operating markers/indicators may also be used in conjunction with the pressure sensor monitoring, such as volume and maximum operating level (MOL) indicator markers on storage facility walls. The level sensors system used in the existing ponds undergoes regular assessment and, when necessary, recalibration occurs six monthly in order to ensure the accuracy of readings.

A Dam Safety Emergency Plan has been provided to the NSW Dam Safety Committee in accordance with the requirements of the *Dams Safety Act 1978*. The plan provides emergency response procedures for the management of the Leewood ponds in the event of an imminent or actual uncontrolled release from the ponds.

Importantly, in respect of capacity to store in the event of sustained rainfall, the Leewood ponds have, consistent with the Produced Water Code of Practice:

- a spillway capacity designed to pass 0.01% Annual Exceedance Probability (AEP) flows;
- spillway level located above the 1 in 100 year ARI flood level;
- an environmental containment freeboard (the volume between the maximum operating level (MOL) and full supply level (FSL/spillway level) capable to contain inflow from a rainfall event up to and including 1:100 AEP 72 hour duration;
- pond level and collection sump monitoring;
- an implemented regular inspection and monitoring program.

The Leewood ponds operate under Trigger Action Response Plans (TARPs), approved by the (now) Division of Resources and Geoscience under the *Petroleum (Onshore) Act 1991*.

TARPs are developed to identify, assess and respond to abnormal conditions and are implemented to manage risk to operations, personnel and the environment. Two TARP documents have been developed to address the requirements of the Produced Water Code of Practice:

- Produced water storage pond level TARP – provides the actions to be taken if defined pond management levels are reached.
- Leewood pond leakage management TARP – provides actions to be taken if defined leakage rates are reached.

In addition to the trigger points and associated actions to be undertaken, these documents also detail the delegation of responsibility at each trigger points and contact details for both internal and external notification requirements.

Thus, in summary, the Leewood ponds are designed and operated to ensure that there is sufficient storage capacity to contain produced water in extreme rainfall events, in accordance with the relevant Codes of Practice and guidelines. In addition, pond levels are monitored and field operations can be managed to control the volume of produced water if this is necessary. As an experienced oil and gas operator, the proponent has considerable expertise in managing water balances and storage and management infrastructure, to ensure the water is appropriately managed.

B) *What effect will extended downtime of the reverse osmosis unit have on the process water balance?*

It is expected that produced water volumes will peak at around 10 megalitres per day at around years two to four, gradually declining over the life of the project. The long term average would be around four megalitres per day.

It is general practice to include allowance in the design capacity of treatment plants for down time for cleaning and maintenance (e.g. membrane replacement) periods. For example, if it is determined that 10 ML/day processing capacity is required and experience shows that downtime for cleaning/maintenance is around 10%, then the design capacity of the water treatment plant would be $10 \text{ ML/day} / 90\% = 11.1 \text{ ML/day}$. This approach ensures that over a given period the design flowrate may be maintained even after outages are taken into account.

Industry experience has been that the selection of water treatment plant capacity tends to be very conservative, i.e. the required capacity is overestimated resulting in an excess of installed capacity.

The modular approach to be taken for the Leewood central water treatment plant will allow a maximum design capacity of 14 megalitres per day to be installed during the produced water peak, which will provide more than sufficient capacity, based on the likely volumes and downtime allowances.

The water treatment plant would employ a "train-based" design. To provide an example of the design considerations, a plant with a design capacity of 14 ML/day may consist of 3 x 4.66 ML/day trains. Maintenance would be undertaken on the trains sequentially so that at any given time only one train would be offline as part of a planned maintenance. Using a train-based design means that it is most unlikely that there would be no water treatment capacity available.

Additional engineering considerations that are utilised to maximise availability is the inclusion of duty/standby or N + 1 design for critical pieces of the plant that are most likely required to be off-line for maintenance. So, for example, if it was determined that three pumps are needed to supply the feed water to the water treatment plant, four pumps may be installed. Hence, at any given time, the design feed flowrate to the facility could be supplied even if one pump was off line.

As discussed for the produced water management in the previous response, there is significant storage capacity available in the Leewood ponds to ensure produced water can be safely stored in the unlikely situation of a complete plant outage. If water levels should approach maximum storage capacity, production could also be reduced, or halted, until the treatment process can recommence.

C) *What experience has Santos had in its operating experience in Queensland of extended outages of reverse osmosis plant?*

Consistent with the proposed approach as discussed above, the proponent's Queensland operations have employed redundancies; a programmed approach to operational maintenance and availability of key spares. A modular approach to the water treatment design has been employed to allow the ongoing treatment of water during maintenance activities.

The Queensland operations have realised >95% availability for reverse osmosis plants utilised to treat produced water. The main scheduled maintenance activities include: control system calibration (control valves, flow meters, water quality analysers etc); pump / motor / gearbox servicing and critical function testing. These occur at varying frequencies (typically 3, 6 and 12 months) and the typical duration the RO plant is required to be off line for these activities is less than 8 hours, with some activities completed online.

QUESTION 11 - USE OF TREATED AMENDED WATER FOR IRRIGATION

Context

The EIS quotes electrical conductivity figures as a basis for the suitability of treated amended water for irrigation. The principal anion in the treated water before amendment is bicarbonate, rather than the more usual chloride. Specification for the maximum level of bicarbonate in irrigation water does not appear in the ANZECC guidelines for irrigation water.

Questions

A) *What are the implications of the water to be used for irrigation (given that it contains significant levels of bicarbonate) in terms of its impact on Sodium Adsorption Ratio (SAR) and Residual Soil Carbonate (RSC)?*

Modelled results presented in the EIS were based on theoretical concentrations for an un-tested plant. Analytical results from the commissioned RO plant indicate much lower concentrations of carbonate

and sodium have been achieved. These are reported in the revised Water Baseline Report provided with the Response to Submissions report.

Levels of bicarbonate are expected to be very low (~30 ppm HCO₃ – based on demonstrated performance and existing water quality data from the Leewood treatment facility), hence any produced carbonate will also be low. (Note, this is based on commissioned concentrations of 34 ppm alkalinity, not the expected – modelled – value of 139 ppm used in the EIS, and assumes bicarbonate breakdown to carbonate will be minimal as temperatures in the RO plant are unlikely to reach decomposition temperatures of 80°C.

The addition of carbonate and bicarbonate to the local sodosols and vertosols will act to improve local soil structure and the bio-availability of nutrients in the soil.

B) *Has Santos any experience in the successful use of water of this type for irrigation in its other operations?*

The proponent has extensive experience in the use of treated water for irrigation in its Queensland GLNG project operations. Irrigation activities are carried out on ten properties across the Roma, Fairview and Scotia fields, including on a number of private landholders' properties. Over 1,700 hectares are under irrigation, utilising a range of irrigation methods such as pivot and above and below ground drip irrigation, for a broad selection of crop types from Chinchilla White gums, Leucaena and Rhodes grass to cereal and grain crops. The irrigation operations are undertaken in accordance with the requirements of Beneficial Use Agreements, which provide standards for water quality and general monitoring and operating conditions.

Some general information on how the beneficial use of CSG water framework in Queensland operates is set out below. There is further detail on the Queensland Government's website here:

<https://www.ehp.qld.gov.au/management/non-mining/csg-water.html>

The Queensland Gas Fields Commission is the independent statutory body formed to manage and improve sustainable coexistence between rural landholders, regional communities and the onshore gas industry in Queensland, Australia. The Gas Field Commission's Technical Communication states:

Where properly managed and treated, CSG water can be reused in a range of different ways including irrigation. The Coal Seam Gas (CSG) Water Management Policy 2012 sets out the Queensland Government's framework for the management of CSG water. The objective of the policy is:

"To encourage the beneficial use of CSG water in a way that protects the environment and maximises its productive use as a valuable resource".

QUESTION 12 - BOHENA CREEK ISSUES

Context

In the EIS proposal, treated water will flow to Bohena Creek intermittently and be significantly diluted by rain-induced flow. A comparison of treated production water with Bohena Creek Baseline values shows that treated water is significantly higher in boron than baseline water. The converse is true for calcium. It is understood that estimates of the quality of treated water are based on a Hydranautics model of the reverse osmosis process. Other membrane manufacturers may be able to give better outcomes.

Questions

A) *Do the Hydranautics model predictions correspond with practice in other Santos production water treatment operations?*

The Hydranautics modelling was predicated on theoretical concentrations for produced water following treatment through a typical RO plant and represented conservative (i.e. high-level expectations) analyte concentrations. Actual analyses of treated water from the modular OsmoFlo

configuration of the commissioned RO plant reveal significantly better performance has generally been achieved. Boron concentrations of 0.1 mg/L are an order of magnitude below ANZECC guidelines (for any potential beneficial use receptor) and below the ANZECC/ARMCANZ default water quality guideline trigger value of 0.37 mg/L for NSW lowland rivers. Other analytes (e.g. mercury, aluminium) do not present at levels above laboratory limits of reporting and are below all guideline values.

- B) ***Would it be possible to match treated water concentrations (if possible by amendment) to closely mirror Bohena Creek baseline concentrations and to thus allow the discharge of treated water to Bohena Creek without having to rely on significant dilution during rain events?***

Bohena Creek is an ephemeral creek and can only be sampled during flow events to provide baseline characterisation of the natural levels of all constituents. Currently, treated water concentrations are less than Bohena Creek baseline levels for all constituents except boron (reported at 0.1 mg/L, compared to below LOR (<0.05 mg/L) for the Bohena Creek samples), and all are below ANZECC/ARMCANZ guidelines. Consequently, any discharge of treated (not amended) waters would be slightly fresher than the creek waters. The managed release into the flowing creek through the diffuser ensures that water quality targets are met.

Ecotoxicology assessment of the potential impacts of the managed release have been undertaken and findings included in the EIS (Appendix G1). The study found no potentially detrimental impacts would occur from the managed release to the creek during the managed release scenario flow event of >100ML/day.

QUESTION 13 - PRODUCED WATER COMPOSITION

Context

The flow of and concentrations of various components in the produced water stream will set the agenda for detailed plant design in the front-end engineering design (FEED) stage. While there is reasonable agreement between reported figures in the EIS and previously reported data for produced water from PEL 238 in: (http://www.santos.com/library/PEL238_PAL2_and_PPL3_Produced_Water_Management_Plan.pdf 2014 – Web site since removed) the earlier information provided greater detail of trace species present. Depending on where these report in the treatment process, they may cause problems. A fuller analysis is highly desirable, with potential ranges and limits to detection being provided.

Questions

- A) ***Will Santos provide a more detailed analysis of species present in raw production water, indicating potential ranges and limits to detection? This information should also include any organics present and potentially troubling species such as radionuclides.***

Analyses of raw production water (sampled from storage ponds) are provided in the revised Water Baseline Report provided with the Response to Submissions. Analyses are reported from samples taken from the storage ponds as well as at the RO plant intake (and hence a blend of the ponds).

Only a limited number of the total catalogue of analytes analysed recorded concentrations greater than the limit of reporting. Whilst salinities ranged up to 40,000 TDS, the mean and 84th percentile (1 standard deviation above the mean) were 16,000 and 20,000 ppm, respectively. Only barium (maximum level of 14.5 mg/L, mean 3.35 mg/L), fluoride (11.8 mg/L; 7.6 mg/L), nickel (0.79 mg/L; 0.17), arsenic (1 mg/L; 0.1), cadmium (0.14 mg/L; 0.02) and molybdenum (0.073 mg/L; 0.02) report values that would be significant if the produced water to be used directly for stock or domestic purposes which is not proposed. Organics (as total organic carbon) are present in concentrations up to 2870 mg/L. Numerous species of bacteria, protozoa and cyanobacteria are recorded as the ponds are open and used by local wildlife. No radionuclides were recorded above the limit of reporting (e.g. <0.001 mg/L for uranium). No hydrocarbons heavier than methane were detected in over 400 analyses since the ponds were commissioned in September 2014.

QUESTION 14 - SALT

Context

Throughout the EIS, the term “salt” is widely used to describe the inorganic species present in the production water and its concentrate. An analysis of the flowsheet shows that the “salt” contains approximately six times as much sodium bicarbonate as sodium chloride. This has implications for the use of treated water and also for the possible beneficial recovery of a solid product from the salt recovery process. It also has implications for the ultimate storage of the salt if a beneficial process cannot be developed. Sodium carbonate, which can be derived from sodium bicarbonate, is an article of international commerce and has, until recently been produced in Australia by the Solvay process.

Questions

A) ***What prospects does Santos see for the beneficial use of the salt product from the salt recovery process?***

The produced salt has high sodium bicarbonate / carbonate content with a high neutralising potential for the product. There is a range of industrial applications for sodium carbonate and sodium bicarbonate and currently no known domestic production of these products following the closure of Penrice Soda’s Osbourne facility in South Australia. Additionally, the value of sodium bicarbonate / carbonate products is relatively high in comparison with that of common sodium chloride. On this basis, opportunities for the beneficial reuse of the salt product are being investigated. If a commercially viable market were found for the sodium bicarbonate then the proponent may consider making a further approval application for that process if one is required.

B) ***Will the fact that the “salt” recovered is primarily sodium bicarbonate have an impact on the hazardous nature of the “salt” in terms of its storage and transportation?***

The composition of the mixed solid salt product has been forecast based on water quality analysis of both the produced water generated through the exploration and appraisal activities and the brine produced by the Leewood Water and Brine Treatment Plant.

Testing was undertaken in accordance with the EPA’s Waste Classification Guidelines, based on the chemical contaminants known or likely to be present in the produced water.

The results are summarised in the revised Water Baseline Report provided with the Response to Submissions and show that the solid salt waste product would be classified as general solid waste, with contaminant levels significantly below the relevant Contaminant Threshold (CT1) values for general solid waste. Thus, when crystallised, the salt will meet the general solid waste classification in accordance with the EPA’s Waste Classification Guidelines.

General solid waste is the lowest (least risk) level of waste under the guidelines.

There are no hazards associated with the storage and transfer of waste above that of storing and transporting other general solid waste.

Waste transporters and receivers are licensed to transport and receive waste based on the level of waste classification. The EPA’s waste licensing framework applies to monitor and regulate the transport and disposal of regulated waste.

C) ***Has an analysis been conducted on the nature of other species that might report to the salt product?***

As per the response above, laboratory analysis has been conducted on a solution of the salt from brine produced through the reverse osmosis plant. The salt was produced by boiling off the water to obtain a dry salt material, consistent with the process for brine concentration and thermal crystallisation proposed for the project. Chemical analysis of this brine is reported in the updated Water Baseline Report.

QUESTION 15 - WELL INTEGRITY

Context

Maintaining the integrity of a well during all phases of the project, i.e., the pilot phase, the operational phase, and the post-production phase - after the well has been plugged and abandoned, is a critical requirement of all coal seam gas projects, including the NGP. Well integrity is especially important in the case of the NGP, where the exploration, pilot and production wells must pass through aquifers in the upper alluvial layers, the Great Artesian Basin and the Gunnedah-Oxley basin. The groundwater present in some of these artesian reservoirs is critically important for agriculture and domestic consumption. The leakage of substances such as methane from a well into any of these aquifers, or the mixing of groundwater from one aquifer to another via a compromised well bore should be avoided.

In addition, the composition of the produced gas has not been detailed

The proponent has indicated in the EIS that it will adopt the NSW Code of Practice for well integrity. It is therefore assumed that all mandatory requirements of this Code will be implemented. However, to date, the proponent has not provided details on its approach to the optional measures in the Code nor the expected chemical composition of the produced gas in the NGP

Questions

A) ***Given that it has indicated in the EIS that it will adopt the NSW Code of Practice for Well Completion, which of the "Best Practice" provisions will be adopted by Santos for the NGP?***

All mandatory requirements outlined in the *NSW Code of Practice for CSG Wells* will be adopted. This includes all requirements relating to: well design; casing; cementing; wellheads; drilling fluids; evaluation, logging, testing and coring; well monitoring and maintenance; well suspension and well abandonment.

In general, Santos will also adopt all of the good industry practices outlined in the Code of Practice, with local site and well conditions and operations dictating the final set of measures that will be implemented. For example, some of the 'good industry practices' that would be implemented include:

- Well design
 - Offset well information should be reviewed to assist in the design process for new wells.
 - Identify beneficial aquifers and ensure that these zones are cased off to ensure their long term protection. Formation horizons or zones from which water bores produce should be noted during the offset well review and used to assist the placement of surface and/or production casing.
- Casing
 - For casing run in CSG wells, pipe body and connections should have verifiable properties (i.e. in terms of burst, collapse and tensile strengths). Note that casing manufactured to API specifications by definition must meet strict requirements for compression, tension, collapse and burst resistance, as well as quality and consistency.
 - When making up a casing connection it is important to apply the recommended torque. Too much torque may over-stress the connection and result in failure of the connection. Too little torque may result in leaks at the connection.
- Cementing
 - Proper wellbore preparation, hole cleaning and conditioning prior to the cement job. Once casing has been run to landing depth, CSG operators should circulate a minimum of one hole volume immediately prior to commencing cementing procedures.

B) ***Information is requested on the range of gas compositions for the wells it has constructed and operated to date for the NGP, and on how this composition has been reflected in the well completions to date and how it will be in the future, particularly, though not exclusively, in terms of the steel or type of cement used in their construction.***

To date there are no known gas constituents (e.g. H₂S) which give rise to longevity concerns. Please refer to previous responses in relation to gas composition (Question 2).

Gas composition varies across the field. The proposed well design and installation process has taken into account the range of gas compositions that may be encountered within the project area.

A 'basis of well design' will be completed for each well type. This process takes into account well parameters of pressure, temperature and fluid properties (water and gas composition) to inform material selection (such as casing and cement) and the approach for the safe installation and operation of the well for its designated design life.

The fluid properties (water and gas composition) are monitored and analysed through an Integrity Management Program (IMP) utilising a variety of information sources such as corrosion coupons, tubing / vessel and pipeline inspections, caliper logs, etc.

The IMP, in conjunction with the basis of well design, are used to ensure that learnings are fed back into future well designs. Therefore, if the fluid properties change to levels outside the NGP standard well design then the material selection will be reviewed for suitability and/or control measures implemented to maintain well-bore barrier integrity.

C) *Detailed information is requested on the well completions that will be adopted to minimise the chance of contamination of aquifers as a result of well failure.*

The wells will be constructed adopting the *NSW Code of Practice for CSG wells*. Chapter 6 of the EIS (page 6-54) provides details on the process for well installation. The process includes:

- The surface hole will be drilled to isolate aquifers and prior to interception of any hydrocarbon zones. Surface casing will then be run into the hole and cemented with cement returns back to surface to isolate aquifers.
- The production hole will then be drilled to the required depth. Production casing will then be run into the hole and cemented with cement returns (as a minimum requirement as per the CoP) back inside the previous casing string of the surface casing.
- These two cemented casing strings help minimise any chance of aquifer contamination from production casing well failure.

D) *Santos is asked to provide details of any well failures or any cases of compromised well integrity in the wells it has constructed and operated to date in the Surat Basin.*

Santos has not had any loss of well control in any of Santos' Surat Basin Wells. In accordance with the *Queensland Code of Practice for CSG Well head emissions, detection and reporting* (Version 2, June 2011), Santos provides a report to the Queensland Government on an annual basis that summarises results from its leak detection and reporting program.

QUESTION 16 - MONITORING

Context

There are currently 58 **Santos** groundwater monitoring locations in the vicinity of the NGP, almost all of which are in the shallow aquifers. A further eight monitoring bores are proposed. Little information is provided in the EIS on the location of monitoring bores (other than the publicly monitored bores), nor on the hydrogeological interval that is or will be monitored. While there is some information provided, there is little information on the parameters that will be monitored, and the information that is provided suggests that the proposed extent of monitoring of the chemical composition of the ground waters and of hydrogeological data such as hydraulic head is likely to be inadequate to detect anything other than very large impacts. Additionally, it likely to be inadequate for validating model predictions. The publicly available Santos site/water portal has approximately 36 monitoring sites shown with only two of those providing hydraulic head data, chemical data is limited and there are few time series.

In all, whilst no doubt Santos has given the issue of monitoring significant attention, this is not reflected in the EIS or in other sources of information. Nor is there evidence that consideration has been given to more comprehensive monitoring, how monitoring can be used to validate models or detect impacts such as pollution of aquifers. Further, has consideration been given to monitoring to detect excessive drawdown or the role that monitoring might have in remediation. In all, the monitoring scheme currently proposed, seems inadequate. In the previous question the need was highlighted for an adequate monitoring network and this then leads to issues relating to the need for baseline data against which to measure impact. The EIS does not provide confidence that sufficient attention has been paid to the need to establish an adequate base line nor what Santos might regard as an 'adequate baseline'.

Questions

A) Santos is asked to provide a more comprehensive proposal for extending the baseline dataset and adequately monitoring the impact of the NGP, within and surrounding the project.

The updated Water Baseline Report included with the Response to Submissions provides further data for the monitoring wells since the preparation of the EIS. The Water Monitoring Plan will be finalised in consultation with DPI Water.

It is noted that the above context considers only the Santos-constructed bores. In addition, there are also over 150 additional landholder and DPI bores that are also sampled as part of the monitoring network.

The Water Monitoring Plan is focussed on early detection of a specific and measurable change that can be reasonably attributed to project activities. The key principle of the Water Monitoring Plan is that monitoring activities are designed to inform an understanding of whether or not the project is contributing to changes in water quantity or quality within water assets, particularly the high valued groundwater sources in the GAB and alluvial aquifers.

This includes four monitoring bores in the Bohena Creek Alluvium, 18 wells in the Namoi Alluvium with one more proposed, and 26 wells in the GAB. The Water Monitoring Plan sets out the monitoring locations, monitoring target and form of measurement as well as response triggers and management actions in the event that a response trigger identification of

The approach utilises leading resource condition indicators for early warning of potential changes to water resource condition arising from the project. Sentinel monitoring locations are nominated at intermediate depths within the Gunnedah-Oxley Basin (seven existing wells with another six proposed in the Triassic and four existing in the Permian) to detect unexpected change in subsurface condition prior to potential impacts on receptors within shallow high-valued groundwater sources.

B) As an extension of its response to (A), Santos is asked to indicate its future intentions regarding the number of monitoring bores, their location, the hydrogeological intervals that will be monitored and the parameters that will be monitored.

As set out above, the Water Monitoring Plan included with the EIS provides details of the monitoring locations, including proposed locations for additional monitoring.

Appendix B of the Water Monitoring Plan sets out lithological units, screened intervals and water sharing plan for all of the proponent's existing groundwater monitoring bores.

The Proponent's proposed water monitoring network includes sentinel monitoring bores that are strategically located both within deeper formations close to target coal seams and centralised around the first phase of production. The monitoring plan includes trigger values for early warning and threshold actions for impacts to local receptors.

All monitoring data is compiled into a reporting framework, such that sufficiency of monitoring will be regularly assessed to allow identification of any additional monitoring requirements. The Water Monitoring Plan will be finalised in consultation with DPI Water.

- C) ***How will Santos use the information it will collect (as outlined in B, to demonstrate that the NPG has not adversely impacted on groundwater, surface water, Groundwater Dependant Ecosystems (GDE)s, natural seeps and springs etcetera?***

The primary indicator initially will be compliance with modelling results as there are no expected impacts for many years (up to 190 years for potential impacts to the GAB groundwater sources). Modelling will be supported by local responses to water levels within the NPG and on-going monitoring between the NPG and any receptors, including identified GDEs. In addition to water monitoring, remote sensing and comparison to expected climatic responses will be incorporated into the monitoring framework.

- D) ***What sampling protocols does Santos intend to adopt, including for water quality?***

The Proponent will sample in accord with the Geoscience Australia National Sampling Guidelines and the State sampling procedures.

QUESTION 17 - DOCUMENTATION OF METHANE OCCURRENCES

Context

As indicated previously, there is some question that the baseline data collected to date for the NPG may be inadequate or incomplete. This includes data relating to water quality in the various aquifers, GDE fauna, stygofauna, the methane content of surface and groundwater, and the background methane content in the atmosphere close to ground level. It is generally considered important to collect such baseline data, and to capture baseline readings accurately so that any future changes can be detected and their causes identified. As a particular example, there is little or no documentation in the EIS of existing occurrences of methane in domestic or agricultural bores or in natural waterways. Given the extent to which there has been controversy in Queensland regarding whether some methane leakage are “natural” or the result of nearby CSG production, this seems to be a significant omission for the NPG. Whilst monitoring of fugitive emissions will be dealt with by EPA regulation, this will not necessarily be done for natural occurrences, which are essentially a geological phenomenon. As a minimum, it would seem that Santos needs to document such occurrences before the NPG is underway.

Questions

- A) ***What baseline data exists regarding the presence of methane in the various aquifers that will be penetrated during the drilling for CSG in the NPG?***

The majority of gas data 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 (WBR) provided with the Response to Submissions. A total of 41 groundwater bores across multiple formations have been sampled in the area.

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

Alluvium groundwaters with elevated methane (up to 6 mg/L) occur along the Namoi River, north-east of the NPG. The source of this gas has not been determined to date. Alluvium- and colluvium-sourced groundwaters above and adjacent to gas exploration sites, however, show negligible to below background CH₄ levels, indicating that gas is not escaping to the surface related to these development activities.

In all recorded cases of methane in groundwater outside the coal measures, including in the alluvium aquifers, concentrations are below 10 ppm. It should be noted that successful ignition of gas in water can only be achieved when concentrations are in excess of 50,000 ppm.

- B) ***What protocols were used in the collection of data relating to the presence of methane in surface and groundwater and in the atmosphere, and what sampling methods were used to collect this data?***

The proponent has developed a series of standard operating procedures (SOPs) for all aspects of sampling across the NGP. Results of analyses conducted for dissolved methane in collected produced water samples are included in the updated Water Baseline Report included with the Response to Submissions. Sampling is carried out using different procedures for water table bores, deep confined bores, artesian bores and production bores (including pilot wells). In all cases, sampling is carried out to minimise potential cross-contamination and exposure to the atmosphere and analyses are undertaken at NATA-accredited laboratories that are well-versed in analysing samples from oil and gas fields.

Gas sampling has been undertaken by GISERA (<https://gisera.csiro.au/research/greenhouse-gas-and-air-quality/>) and other academics and this data has been variously reported in the academic and white literature. Notably, no emissions were detected from recent analysis at 32 mobile sites across the NGP (Ong, et al., 2017), though earlier surveys did record slightly elevated levels at some wells (up to 10 ppm), though the same wells recorded no elevated levels on other occasions (Day, et al., 2016).

References

Day, S., Tibbett, A., Sestak, S., Knight, C., Marvig, P., McGarry, S., Weir, S., White, S., Armand, S., van Holst, J., Fry, R., Dell'Amico, M., Halliburton, B., Azzi, M. (2016). Methane and Volatile Organic Compound Emissions in New South Wales. CSIRO, Australia

Ong, C., Day, S., Halliburton, B., Marvig, P., White, S. (2017). Regional methane emissions in NSW CSG basins. CSIRO, Australia

- C) ***If there is little or no data available on natural occurrences of methane, how would Santos address this information gap before the NGP is underway?***

There is no data gap, just a paucity of long-term data, hence little information on temporal variability. This will be reconciled during the ongoing monitoring program under the Water Monitoring Plan.

QUESTION 18 - GREAT ARTESIAN BASIN

Context

GAB aquifers have an iconic and economic importance both locally and nationally. Since 1999 significant coordinated government and landholder investment in bore rehabilitation and groundwater water savings have been made. The outcrop of the Pilliga Sandstone forms a recharge area for the GAB and this is reflected in the Water Sharing Plans used to guide entitlement and management actions in the basin. However, the importance of the recharge in the NGP area (in terms of volume and potential for contamination) is more contentious, with many stakeholders regarding this area as a very significant in terms of recharge, whereas Santos believes the area is not a major recharge area. While the GAB is not the target for coal seam gas production, it is predicted in the EIS that it will be impacted.

Questions

- A) ***What evidence is there to support the Santos view that Pilliga Sandstone recharge in the NGP area is not significant?***

BRS and Geoscience Australia studies on the recharge beds of the southern GAB determined that the area immediately in the vicinity of the NGP constitutes a low recharge area as the Pilliga Sandstone outcrop is limited and rainfall is relatively low for the region. Primary recharge to this region occurs via the Warrumbungles, to the south of the NGP, where higher rainfall and greater outcrop area exists (Figure 9).

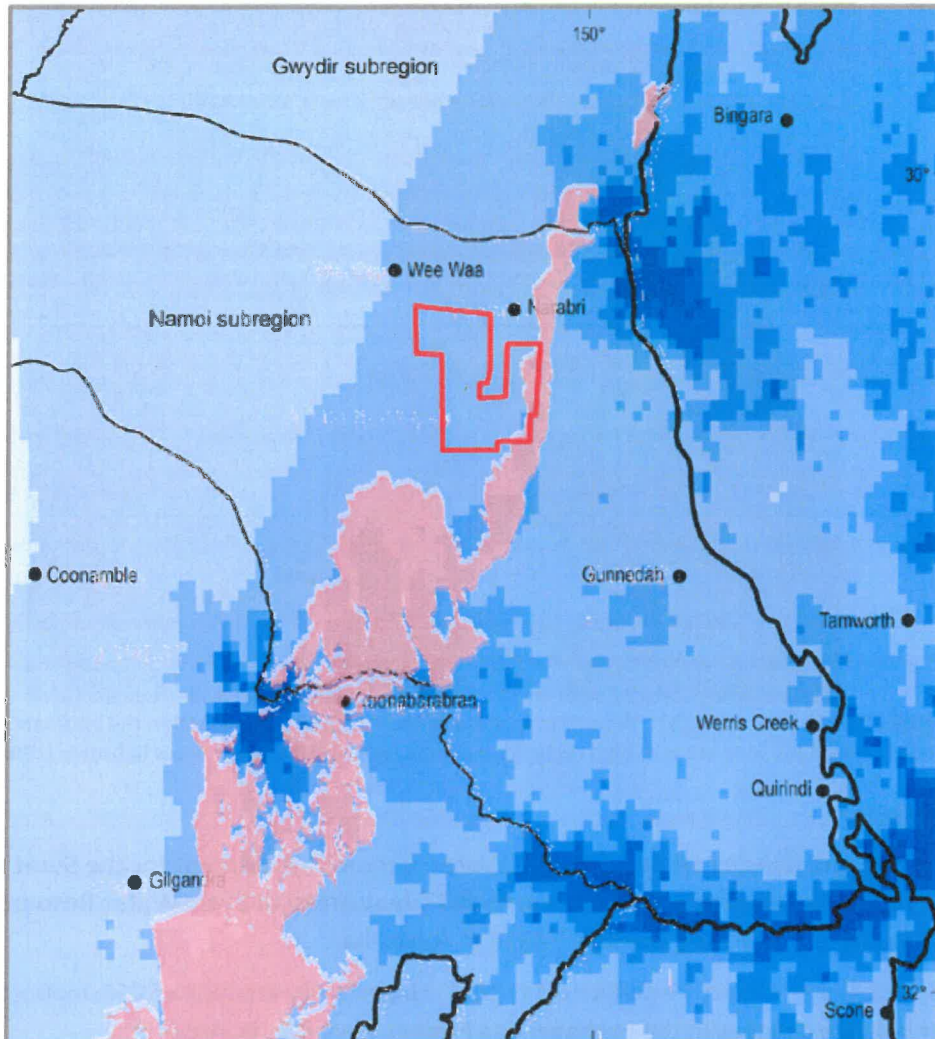


Figure 9 Rainfall (blue gradient) and Pilliga Sandstone outcrop (pink shading) in the Narrabri-Gunnedah region

Indirect recharge does occur via the overlying colluvium (soils and weathered materials overlying the Pilliga Sandstone) in the area, though this is impeded and reduced due to poor transmissivity soils and high evaporation rates during the wettest months (summer). A recent modelling exercise by GISERA (Sreekanth, et al. 2017) re-designated the entire region as a recharge zone, but differentiated between low and high recharge areas (Figure 10), based on the recharge assessments carried out by GA and CSIRO for the GABWRA project (Smerdon and Ransley, 2012). The Project is clearly defined within a low recharge zone (<5 mm/year) of the Southern Recharge Area of the GAB.

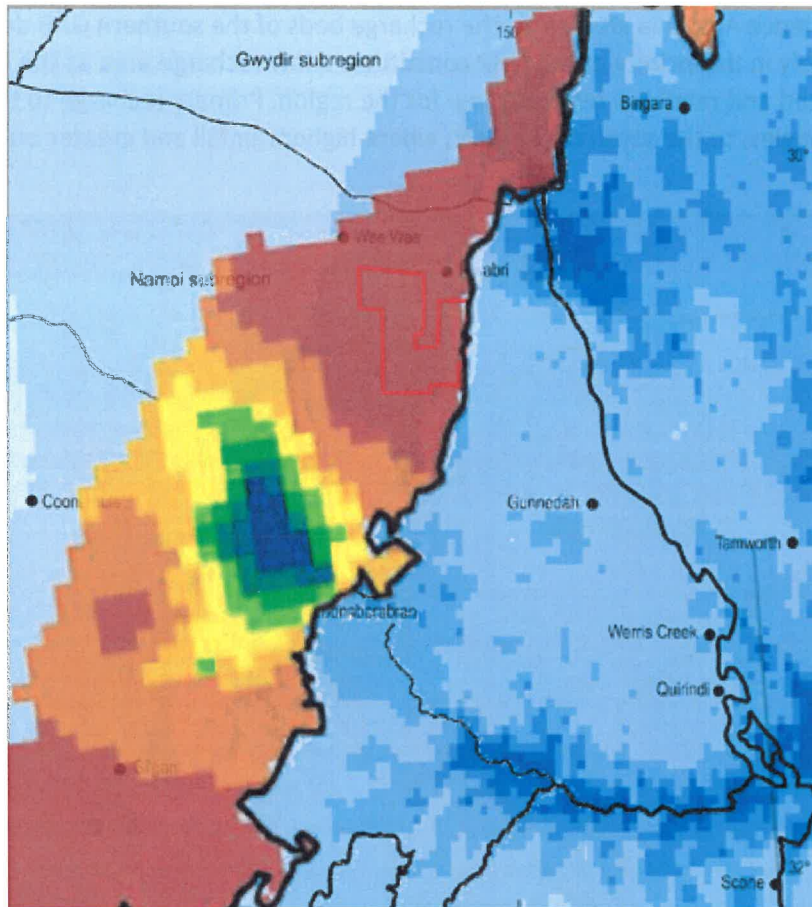


Figure 10 Modelled recharge to the sub-crop areas of the Pilliga Sandstone within the Southern Recharge Zone for the GAB. Blue areas of high recharge (>40 mm/year) grade to low areas in brown (<5mm/year).

References:

Smerdon BD and Ransley TR (*eds.*) (2012) Water resource assessment for the Surat region. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Sreekanth J, Cui T, Pickett T and Barrett D 2017. Uncertainty analysis of CSG-induced GAB flux and water balance changes in the Narrabri Gas Project area. CSIRO, Australia.

QUESTION 19 SPILLAGES

Context

The possibility of spillages of various substances, including liquid hydrocarbons, spent drilling fluids, produced water and retentate from the reverse osmosis process used to treat the produced water, has been raised by a number of parties. Appendix S of the EIS considers certain spills, both less than and greater than 100L. These risks have been rated by Santos as “low” or “very low” risks.

Questions

- A) ***To what extent has the maximum allowable spillage been used as a design parameter in developing vessel and piping design?***

Consistent with the findings of the Chief Scientist’s report that the risks associated with coal seam gas are no greater than that associated with other extractive industries, the potential for impacts related to spills have been assessed as very low to low.

The risk of accidental spills of fuel, drilling additives, produced water, chemicals and cement affecting surface water (Chapter 12), groundwater (Chapter 11), soils (Chapter 14) and sensitive receivers (Chapter 25) are assessed in each of the relevant chapters of the EIS Mitigation measures to prevent and minimise the potential impact are also identified.

As demonstration of the low risk, the proponent has operated the Narrabri field, including the construction and operation of the Leewood Water Treatment Plant without a single reportable incident in over 4.5 years.

In addition, and importantly, the EPA has designated the Narrabri operations as a Level 1 risk (being the lowest level of risk) since commencement of the Narrabri operations risk assessment framework in 2015. This designation is based on: the operations being conducted at the site; the risk of a pollution incident, and the performance of the licensee (Santos).

Vessel and piping design has not been undertaken for the project at this stage. This will be part of the design work to be undertaken if project approval is received. That said, as an experienced oil and gas operator for over 40 years, the design and operation of water and gas system infrastructure is core business for the proponent. In addition to the application of all relevant Australian Standards, the company has extensive internal engineering standards that are applied by qualified and experienced engineers. The prevention and minimisation of spills is a key design parameter.

In accordance with the Australian Pipeline Industry Association (APIA) Code of Practice for Upstream Polyethylene Gathering Networks in the CSG Industry, the design of pipelines would implement integrity controls to mitigate risk by selecting a combination of physical and procedural controls for both integrity and external interference.

B) *What will be the maximum spillage for each potential spill liquid in the front-end engineering design (FEED) of the NGP?*

Please see responses above and further information in responses below. Detailed design has not been undertaken at this stage of the project.

C) *What minimum spillage of each potential spill liquid is the threshold of a "significant spill"?*

The proponent undertakes HAZOP reviews of all infrastructure prior to its operation. This process involves a multi-disciplinary team undertaking a structured risk assessment process to identify, assess and classify significant risks and develop appropriate mitigation and management measures to eliminate or minimise the risks. These measures are then integrated into Work Methods or standard operational procedures. Environment and safety professionals are key participants involved in this process and assist to ensure environmental risks are identified, assessed and mitigated.

As with most risks, the significance of a spill will depend on a number of factors, such as the volume and nature of the material spilt, the location of the spill and the sensitivity of the receiving environment.

D) *What provision will be made for detection, sectional shut down, and safe isolation of offending plant or transfer lines in the event of a spill?*

All facilities including gas and water gathering lines would be designed to the relevant Australian Standards and protocols, including the Australian Pipeline Industry Association (APIA) Code of Practice for Upstream Polyethylene Gathering Networks in the CSG Industry.

Isolation principles would be based on risk assessment protocols and systems would have valves and isolation facilities to enable regular operations and maintenance activities and limit exposure in the event of a uncontrolled release.

There is continuous pressure monitoring of produced water pipelines for any 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 that would minimise the potential for spills or leaks to occur. Bunding, drip trays and other preventative measures would be utilised as necessary and spill kits would be in place as appropriate.

In summary there are a significant number of design controls and operational management procedures to minimise the risk of leaks or spills occurring.

E) *What steps will be taken to handle a spill to prevent it from contaminating groundwater?*

See above response regarding measures for spill monitoring and response.

In the unlikely event a spill or leak did occur, risk to groundwater is negligible. 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 (see detailed description of Leewood pond design and operations in response 10A, above). 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 a number of shallow monitoring bores installed adjacent to the ponds as part of the monitoring network.

There is a low risk of bores being affected as these generally take from sources over 50 metres below perched or shallow water bodies that could be (though unlikely) impacted by a spill. In addition the presence of relatively impermeable geological units, in addition to perched water bodies having very low transmissivity, further minimises the risk.

The chemical risk assessment (Appendix T3) undertaken for the EIS concluded that the potential for releases of chemicals to groundwater as a result of the storage and conveyance of produced water, brine and treated water is considered to be negligible. This is due to the limited mass of these chemicals in the produced water, the loss mechanisms (biotic and abiotic decay) and the design, engineering and monitoring of operations in pipelines and Ponds. Refer to Appendix T3 for additional information.

QUESTION 20 - BREAK-DOWN OF SODIUM BICARBONATE IN THE SALT RECOVERY PROCESS

Context

Sodium bicarbonate breaks down at 80°C to form sodium carbonate, releasing carbon dioxide. This would affect the amount of "salt" produced as well as the release of carbon dioxide from the produced water treatment process. It is indicated in the EIS that when the "salt" was heated to 180°C it decomposed, but little information is provided on the salt recovery step in the salt crystalliser.

Questions

A) *Has a detailed analysis been done on the effect of temperature in the salt crystalliser and the possibility of the formation of sodium carbonate from sodium bicarbonate?*

The proponent is aware that the bicarbonate will decompose to carbonate in the brine concentrator and crystalliser. We are also aware that sodium carbonate salts can form hydrates (sodium carbonate monohydrate $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$, sodium carbonate heptahydrate $\text{Na}_2\text{CO}_3 \cdot 7\text{H}_2\text{O}$, and sodium carbonate decahydrate $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$) depending on the conditions at which the crystal is precipitated. This will form part of the detailed design considerations. Post crystallisation treatment will be considered

to produce an anhydrous salt should this be necessary / economically beneficial. In order to manage CO₂ production in the brine concentrator / crystalliser it is intended to purge vapour from the vessels.

Maximising the amount of decomposition of the bicarbonate prior to introducing the liquid to the brine concentrator / crystalliser is a likely objective of this process and would occur by holding the feed water at specific elevated temperatures in a holding tank, prior to its introduction to the brine concentrator.

B) *Is the carbon dioxide released during this process taken into account in the greenhouse gas assessment of the overall process?*

The greenhouse gas assessment considered the emissions from water processing. The *de minimis* principle is applicable to these emissions as they are of limited magnitude relative to overall project emissions.

QUESTION 21 - HOSKISSONS SEAM

Context

Santos has indicated that some gas will be extracted from the Hoskissons coal seam and that this might represent typically 5% of the total gas extracted over the life of the project. This coal seam, which rises to around 300 m below ground level, is much closer to the GAB than the lower coal seams, from which it is proposed to extract the majority of the gas. This then raises the question of whether extraction of gas from the Hoskissons Seam will have a greater impact because of its proximity to the GAB

Questions

A) *What will be the impact of gas production from the Hoskissons Seam on the GAB and other shallower aquifers in terms of drawdown and flux?*

Potential impacts of proposed water extraction from the Hoskissons Coal (Late Permian coal seam targets) are already considered in the published EIS. The Base, High and Low Case modelling simulations all have five percent of total water extraction from the Hoskissons Coal. Table 6-10 in the Groundwater Impact Assessment in the EIS shows that the indicative field development plan in the EIS includes 60 well sets in Hoskissons Coal within water extraction areas 11 and 13 (two of 16 water extraction areas). Thus, the Base Case simulation includes water extraction of 35.6 GL from Maules Creek Formation (Early Permian) coals seams and 1.89 GL from Hoskissons Coal.

B) *What would be the impact(s) on the GAB and shallower aquifers if pumping from the Hoskissons seam was shut down during production?*

Cessation of water extraction from Late Permian coal seams during field development would result in less local impact on overlying groundwater sources. This effect would be negligible at project scale as the action would only have a potential to reduce overall water extraction by a maximum of 5 percent and more likely only a few percent.

Water Expert Panel - Follow-up questions for Santos

QUESTION 2 – GAS COMPOSITION

Previously, the WEP has asked for more information about gas composition. Santos has declined to provide further information on the grounds that “detailed spatial information of gas..... is commercial-in-confidence”. The WEP recognises the commercial issues and for that reason does not seek detailed spatial or compositional information. However, to address this issue, Santos should indicate the range of CO₂ concentrations in the region of the NGP and/or provide an average value and an indication of variability in CO₂ concentration, so that the WEP can comment on the potential impact of CO₂ on cements, equipment, well completions or monitoring or long-term liability, as appropriate. In addition, Santos should provide details of their planned procedures for cements, equipment, well completions or monitoring or long-term liability in the area of the NGP

The WEP requests that Santos provide further information on gas composition and its variability and further details on procedures used for design and construction to account for the CO₂ concentration range to be extracted.

QUESTION 7 - FAULTING

Previously, the WEP has posed questions to Santos regarding faulting because of possible implications to transmissivity and groundwater flow. Santos has indicated it does not believe there is any issue with faulting, based on its examination of many kilometres of seismic profiles. It would be useful if Santos would provide some examples of interpreted high quality seismic lines to illustrate why they are so confident that there is no potential for fault-related issues to occur in the area of the NGP.

The WEP requests that Santos provide further information that would better illustrate the nature and extent of faulting in the vicinity of NGP.

QUESTION 10 - PROCESS WATER BALANCE

Santos has provided a comprehensive response that draws on the *Produced Water Code of Practice* and gives appropriate *Trigger Action Response Points* and a description of how the storage facilities will be instrumented and operated. It is indicated that, based on Queensland experience, the expected percentage downtime of the reverse osmosis plant will be 5%. WEP will acknowledge that the 900 mm figure given in the original question is yearly rainfall. Table 4.2.2 of Appendix G1 of the EIS gives 406.9 mm as the maximum monthly rainfall recorded (not 330 mm as in the Santos response to the WEP). To assist the WEP in assessing the impact of such an event, it would be helpful to have available an estimate of the surface areas of the present and proposed produced water storage ponds.

The WEP requests that Santos provide details on the approximate surface areas of the current 4 x 150 ML and the proposed 2 x 150 ML production water storage ponds on the Leewood site in the full and 50% full conditions.

QUESTION 11 - USE OF TREATED WATER

The Santos response to this question has drawn on a revised Water Baseline Report that gives in Table 7.1 amended figures for treated and amended water based on operation of the Leewood production water treatment plant. The quality of both treated and amended water is significantly better than in the target figures provided in the EIS and the treated and amended water meets drinking water and environmental standards for irrigation with COPCs under control or not detectable. For the purposes of conducting a mass balance around the reverse osmosis plant and the salt recovery section and comparing this with figures given in the EIS, it would be useful to know the percentage water recovery in the reverse osmosis plant now that it is operating.

The WEP requests that Santos provide (i) the percentage water recovery attained in the Leewood reverse osmosis plant now that it is in operation; (ii) the total dissolved solids in the RO plant brine in Table 7.1; and (iii) the concentration profile of the feed stream to the reverse osmosis plant for which the brine profile is provided, noting that Table 6.1 provides only minimum and maximum figures and means.

What was the analysis of the feed stream to the RO plant for which the analysis of treated water is given? Can it be taken as represented by the mean values in the Leewood ponds?

QUESTION 13 - PRODUCED WATER COMPOSITION

Concentration Profile

In the revised Water Baseline Report, Santos has provided a detailed analysis of Leewood pond chemistry and this gives a guide to production water composition. Maximums, minimums and means are given as well as the 16th and 84th percentiles. This information is informative. It would be helpful to have a complete concentration profile for one representative sample, so that internal consistency of the measurements can be checked.

The WEP requests that Santos provide a complete concentration profile for one representative sample of produced water.

Discrepancy – EC/ TDS

The EIS gives **14,000 $\mu\Omega/cm$** and comments that it is one-third that of seawater.

The RTS gives for Leewood Ponds (presumably primarily production water and feed to the RO plant) provides the following summary:

Minimum: 4,223, Maximum: 28,399 **Average 22,613 $\mu\Omega/cm$** (Average is 62% higher than in EIS)

The Digby and Napperby aquifers in GOB (presumably feeders to the production water) are 6,714 to 10,773 and 3,126 to 7,488 $\mu\Omega/cm$ respectively i.e. much lower.

Total Dissolved Solids (TDS) reported paints a different picture:

The EIS gives **23,800** mg/L for TDS.

The RTS gives: Minimum - 2,749, Maximum - 24,371 **Average 14,669** mg/L for TDS. This is counter to the reported conductivities as a higher TDS would be expected to give a higher conductivity. There could be a pH –bicarbonate/carbonate split at work, but Santos should explain why there is this discrepancy. This has bearing on the effectiveness of the RO unit and the amount of “salt” produced.

The WEP requests that Santos provide further advice as to why the field-measured electrical conductivities for production water in the Santos RTS (specifically the updated Water Baseline Report) are so much higher than in the EIS.

QUESTION 14 - SALT

The information provided in the revised Water Baseline Report (Table 6.1), principally the analysis of Leewood RO brine, enables an estimate to be made of the composition of the salt product. What is lacking in Table 6.1 is an analysis of bicarbonate as CaCO₃ and carbonate as CaCO₃ so that the ratio of bicarbonate to carbonate can be followed through the salt recovery process. This transition is pH as well as temperature dependent.

The WEP requests that Santos provide for the Leewood WTP plant RO brine, the bicarbonate as CaCO₃ and carbonate as CaCO₃ as has been provided for the analysis of samples reported in table 7.1 of the updated Water Baseline Report.

QUESTION 16 - MONITORING

It appears that some text may be missing in the Santos response to question 16A. In the copy the WEP received, the fourth paragraph of this response ends abruptly with the words “ *in the event that a response trigger identification of*”. It would be helpful to the WEP to view the entire response to this question.

The WEP requests that Santos please provide their entire response to Question 16.

QUESTION 19 - SPILLAGES

Overall, the Santos response to question 19 addresses the issue of the potential for spillages in very broad terms, rather than addressing some of the specifics that were being sought by the WEP. Santos points out “*the risks associated with coal seam gas are no greater than that associated with other extractive industries*”, a view consistent with one expressed by the Chief Scientist. Further, Santos indicated that they have assessed the potential for impacts related to spills as very low, to low. They also mentioned their record as an experienced oil and gas operator for over 40 years and in particular their recent operation of the Narrabri field “*without a single reportable incident in over 4.5 years*”. None of these particular views, as expressed by Santos, is disputed by the WEP. Indeed, they are reassuring.

However, the WEP was seeking a more quantitative response to questions 19A, 19B and 19C, rather than the qualitative response provided. As stated by Santos, it is a fact that *“vessel and piping design has not been undertaken for the project at this stage”* and *“This will be part of the design work undertaken if project approval is received”*. This is understood and accepted by the WEP as normal practice. But given Santos’ more than 40 years experience as an oil and gas operator, it is assumed that there would be information available from existing operations, such as their CSG operations in Queensland. It would be helpful, therefore, for the WEP to have a more specific response, if only in terms of indicative figures at this pre-design stage.

The WEP requests that Santos indicate what would be the likely maximum spillage of each potential spill liquid in the front-end engineering design (FEED) of the NGP. Additionally, what minimum spillage of each particular spill liquid is the threshold of a “significant spill”.

Attachment 1 – Response to WEP follow up questions

QUESTION 2 - GAS COMPOSITION

Follow-up question

Previously, the WEP (Water Expert Panel) has asked for more information about gas composition. Santos has declined to provide further information on the grounds that “detailed spatial information of gas is commercial in confidence. The WEP recognises the commercial issues and for that reason does not seek detailed spatial or compositional information. However, to address the issue, Santos should indicate the range of CO₂ concentrations in the region of the NGP and/or provide an average value and an indication of variability in CO₂ concentration, so that the WEP can comment on the potential impact of CO₂ on cements, equipment, well completions or monitoring or long-term liability, as appropriate. In addition, Santos should provide details for their planned procedures for cements, equipment, well completions or monitoring or long-term liability in the area of the NGP.

The WEP requests that Santos provides further information on gas composition and its variability and further details on procedures used for design and construction to account for the CO₂ concentration range to be extracted.

Response

Santos will design, construct, operate and, plug and decommission wells in accordance with the *Code of practice for CSG well integrity* (NSW Government 2012) and industry best practice to ensure their integrity throughout the life of the development and into perpetuity (once decommissioned). The *Code of practice for CSG well integrity*, stipulates mandatory practices for well design and construction to ensure Coal Seam Gas activities are environmentally safe and groundwater resources are protected.

Aquifer(s) for agriculture and community are generally within a few hundred metres of surface and to migrate risk of impact to groundwater resources, the surface casing for the well will be set so as to provide a secondary barrier to reservoir fluids. This forms the basis of a robust multiple barrier well construction physiology of casing and cement sheath as outlined in the mandatory requirements under the *Code of practice for CSG well integrity* (NSW Government 2012).

While the CO₂ concentration can be variable across the Narrabri Gas Project area, it is understood by Santos what impact this will have on the well design. This understanding allows Santos to analyse, and if required build in additional control measures to the engineering design and operating procedures throughout the life of the development and into perpetuity.

Santos has an engineering team dedicated to asset integrity including a well integrity engineer independent of, but working closely with the drilling and completion team. This enables independent oversight of well designs to ensure well integrity standards are maintained and built into engineering practices.

Santos utilises a highly skilled workforce to monitor and maintain the well population through wellbore annuli pressure surveillance and fluid testing. Mechanisms that impact asset integrity are well understood inside Santos’ operations and the Well Integrity team is in communication with other operators and external sources to ensure that Santos is at the forefront of best practices in surveillance and well design to migrate the risk(s).

Attachment 1 – Response to WEP follow up questions

QUESTION 7 - FAULTING

Follow-up question

Previously, the WEP has posed questions to Santos regarding faulting because of possible implications to transmissivity and groundwater flow. Santos has indicated it does not believe there is any issue with faulting, based on its examination of many kilometres of seismic profiles. It would be useful if Santos would provide some examples of interpreted high quality seismic lines to illustrate why they are so confident that there is no potential for fault-related issues to occur in the area of the NGP.

The WEP requests that Santos provides further information that would better illustrate the nature and extent of faulting in the vicinity of NGP.

Response

Figure 1 provides the high resolution image of a seismic line (EB08-06) acquired in the project area, with key seismic horizons interpreted. In the image both the Gunnedah and Surat Basin strata show a relatively simple structure in the Dewhurst area of the Bohena Trough, where the project is proposed.

Figures 2 and 3 below show basic structure maps for the top Maules Creek formation and Base Jurassic interpreted horizons respectively. No faults have been interpreted to affect the overlying Cretaceous and Jurassic strata (Surat Basin) which contains the main aquifer zones. The maps also identify the location of the seismic line that is shown in Figure 1.

Furthermore, reservoir pressure data indicates that the early Permian (Maules Creek formation) and overlying late Permian (Black Jack Group) and younger strata have different pressure gradients and are therefore isolated from one another. Reservoir pressure has been calculated for successful formation tests and is plotted against subsurface depth in Figure 4 below. Two separate pressure trends are apparent in this data for the Late Permian Black Jack Group and Early Permian Maules Creek Formation respectively. The two trends are separated by an average of approximately 50psi. The data indicates that the Black Jack coals are normally pressured for their depth, and the deeper Maules Creek coals are over-pressured by an average of 50psi. This is consistent with field observations suggesting that initial Early Permian pilot wells were artesian, flowing water to surface unaided.

W Seismic Line Example (EB08-06) – Dewhurst Area, PEL 238 E

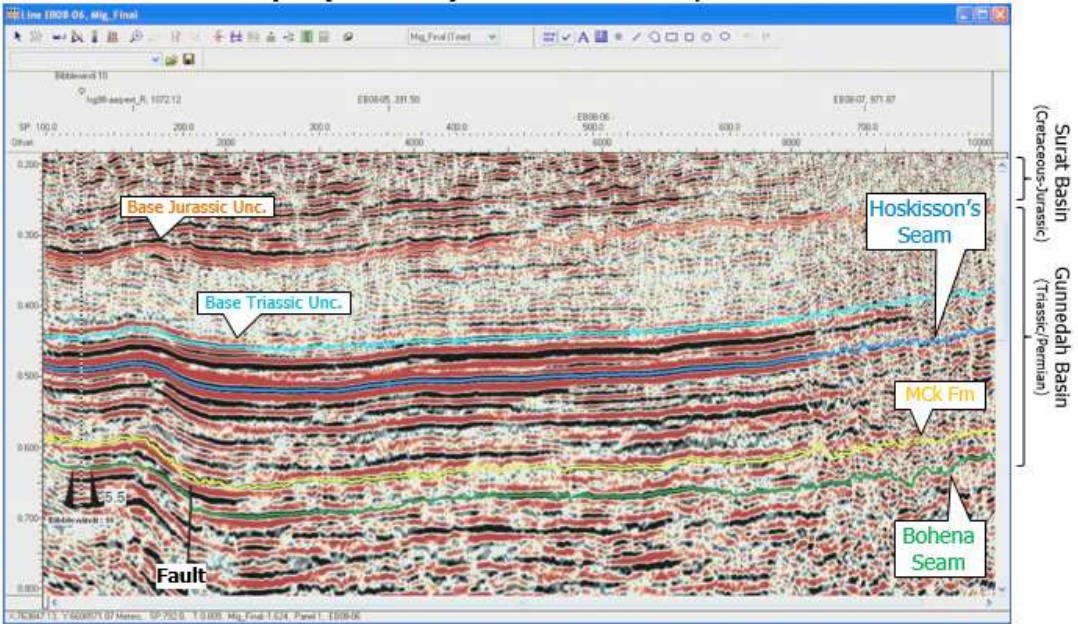


Figure 1 Seismic line example

Attachment 1 – Response to WEP follow up questions

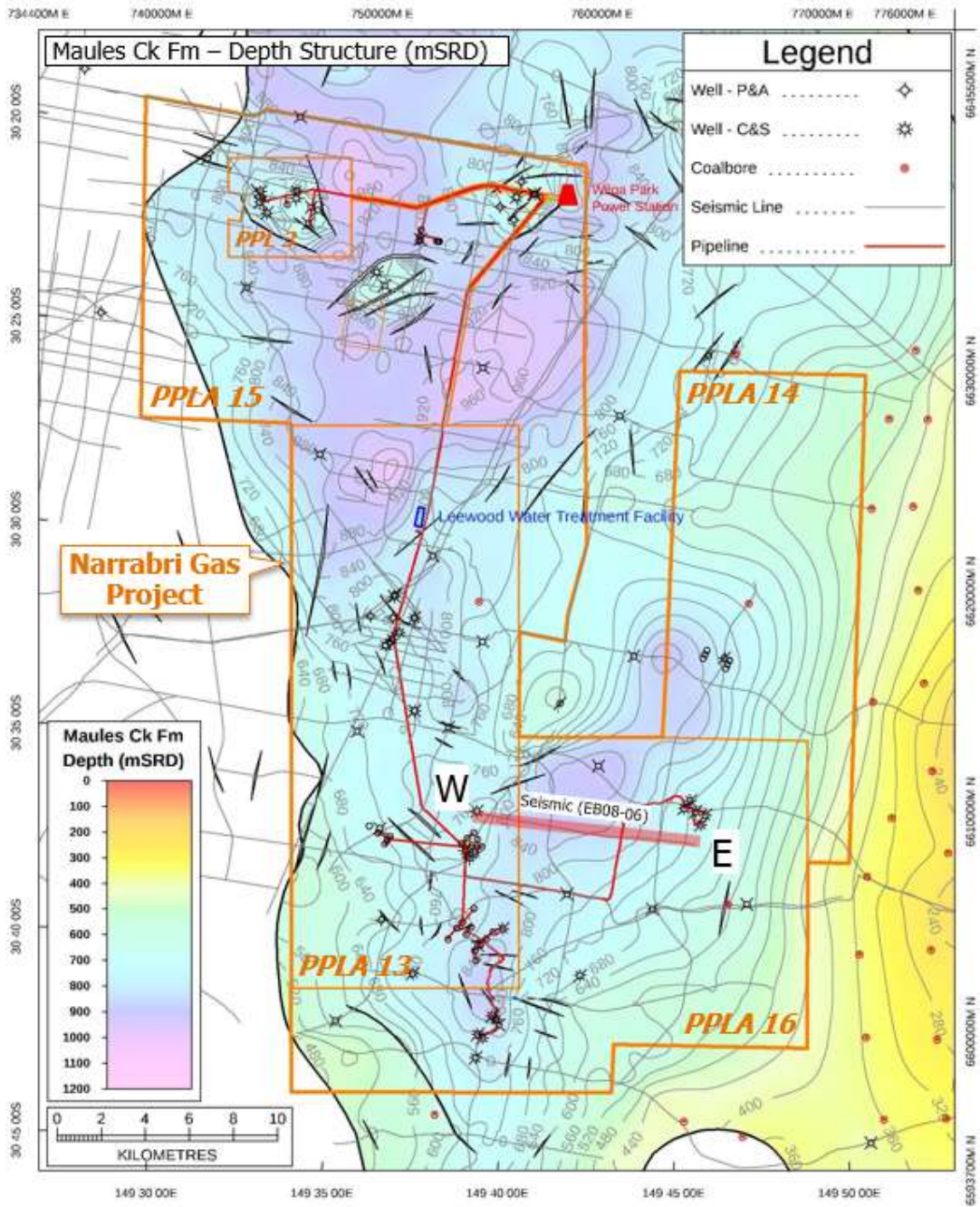


Figure 2 Depth structure map (Maules Creek Formation)

Attachment 1 – Response to WEP follow up questions

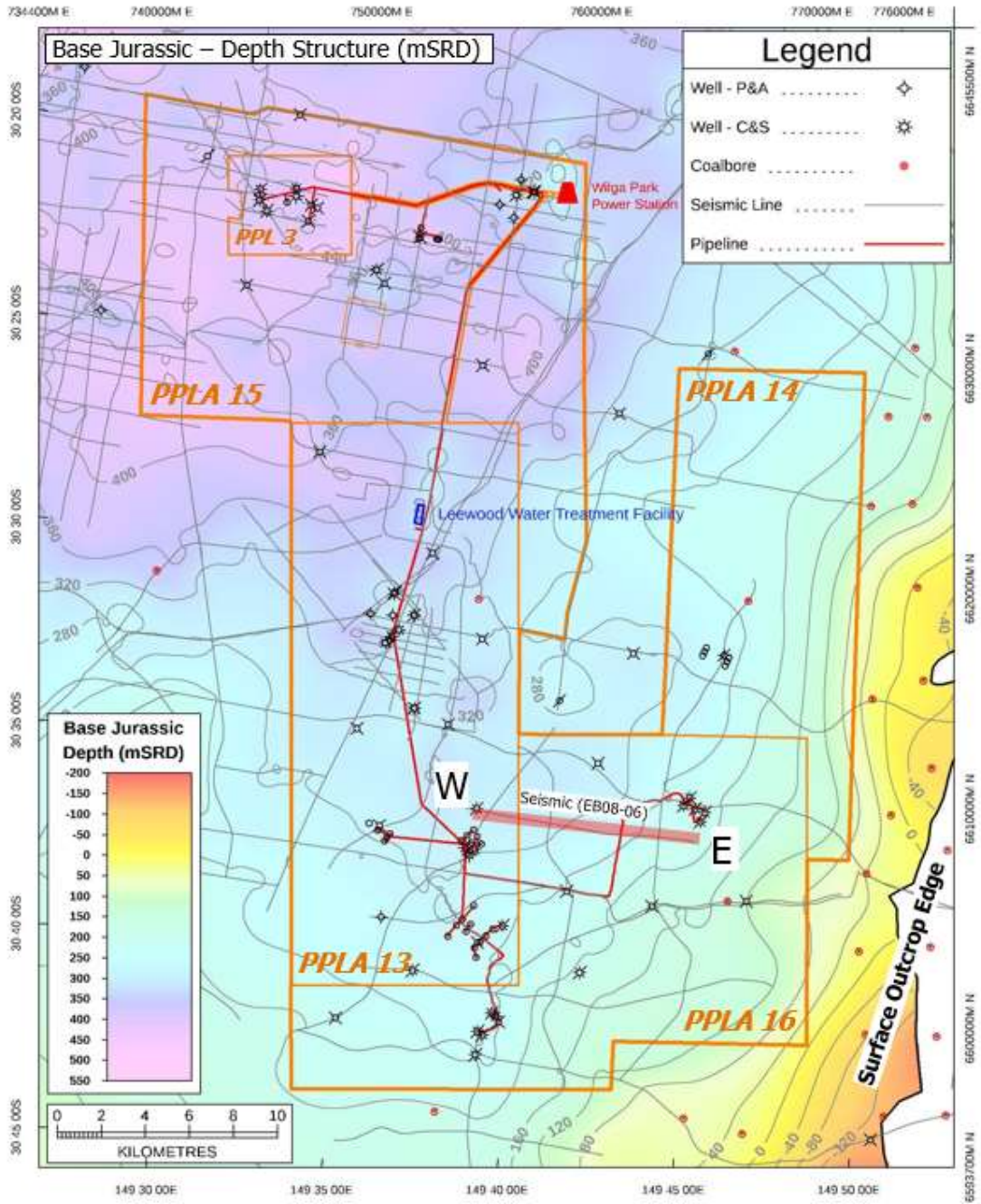


Figure 3 Depth structure map (Base Jurassic Formation)

Attachment 1 – Response to WEP follow up questions

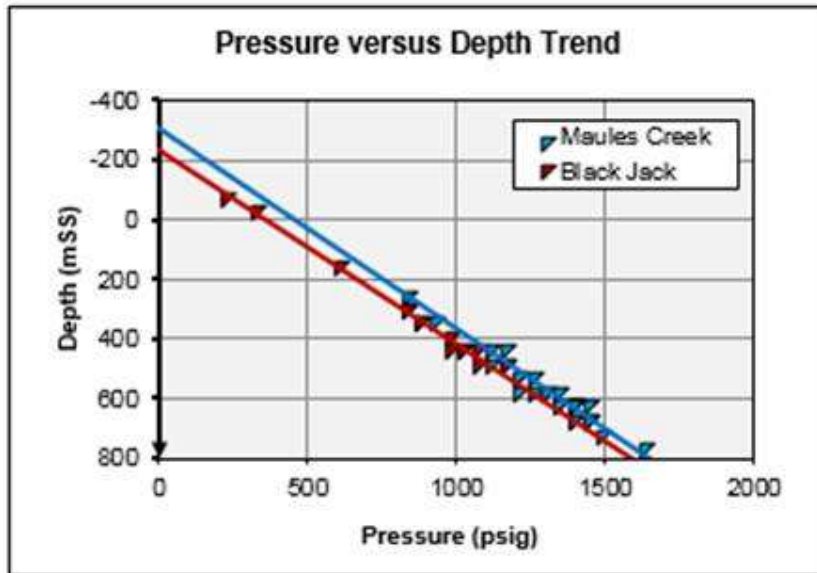


Figure 4 Pressure vs depth trend

QUESTION 10 - PROCESS WATER BALANCE

Follow-up question

Santos has provided a comprehensive response that draws on the *Produced Water Code of Practice* and gives appropriate Trigger Action Response Points and a description of how the storage facilities will be instrumented and operated. It is indicated that, based on Queensland experience, the expected percentage downtime of the reverse osmosis plant will be 5%. WEP will acknowledge that the 900 mm figure given in the original question is yearly rainfall. Table 4.2.2 of Appendix G1 of the EIS gives 406.9 mm as the maximum monthly rainfall recorded (not 330 mm as in the Santos response to the WEP). To assist the WEP in assessing the impact of such an event, it would be helpful to have available an estimate of the surface areas of the present and proposed produced water storage ponds.

The WEP requests that Santos provide details on the approximate surface areas of the current 4 x 150 ML and the proposed 2 x 150 ML production water storage ponds on the Leewood site in the full and 50% full conditions.

Response

Santos acknowledges the variation in the reported monthly maximum rainfall at weather stations in that region. Over the 308 months of data examined from the Rosewood weather station (BoM site #53103), rainfall exceeded 330mm in only one month. Further, monthly data is not the appropriate metric when considering pond design as monthly potential evaporation exceeds the 95th percentile for rainfall (Table 1) for most months (Figure 5) and exceeds mean rainfall for all months.

Table 1 Rainfall statistics for the NGP area (Rosewood: BoM stations #53103)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	83.9	64.1	41.5	25.1	47.8	51.2	48.4	30.5	45.8	47.6	76.3	87.2	671
Lowest	2.8	18.2	0	0	0	0	0	0	0	0	0	5.2	386.5
5 th %ile	5.6	21.4	0.7	0.4	0	5.9	4.3	0.6	0	5	5.4	14.7	411.1

Attachment 1 – Response to WEP follow up questions

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
10 th %ile	11.2	25.3	4.8	1.3	0.3	18.3	6	3	0	10.5	10.3	16	459.3
Median	68.7	51.3	27.3	16.8	38.2	34.9	31.2	25.2	31.2	44	64.8	68.7	646.1
90 th %ile	158.5	127.7	82.9	58.6	118.2	93.9	98.3	67.2	92.7	85	157.4	163.8	933.5
95 th %ile	215.8	141.2	119.9	78.6	131.4	134.7	129.9	91.7	107.6	89.1	194.7	226.9	971.2
Highest	329.2	199.3	191.8	99.6	175.8	232.2	201.6	109	176.9	95.4	230	406.9	992.8

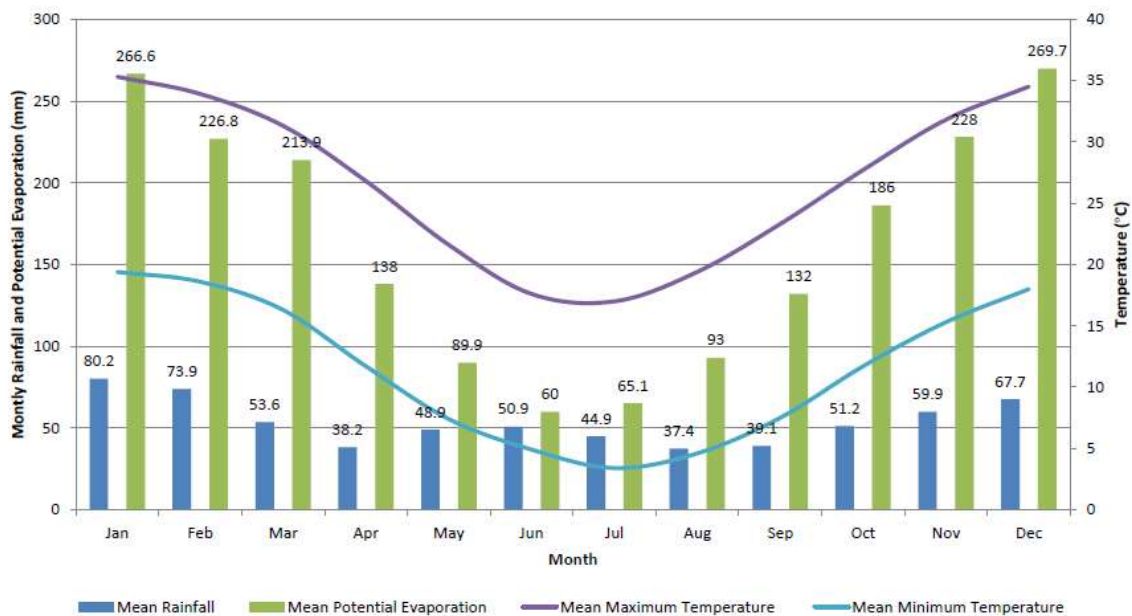


Figure 5 Long-term average climate conditions near the NGP (Rosewood: BoM station #53103)

The water balance model that informed the design of the ponds considered major rainfall events and the likely peak produced water production rates from wells that will feed into the ponds. The ponds are designed with an Environmental Containment Freeboard (ECF) sufficient to provide storage for a 48 hour, 1:20,000 Average Recurrence Interval (ARI) event, equivalent to 650 mm over 48 hours, or three 48-hour, 1:100 year ARI events. Thus, if ponds were at the Maximum Operating Water Level immediately prior to a 48-hour 650 mm rainfall event, levels will still be below the spillway following that event. This ECF significantly exceeds the requirements of the NSW Dam Safety Committee guidance. Only one 48-hour period across the 10,841 days of recorded rainfall at the Rosewood weather station has exceeded even 240 mm (maximum daily = 196 mm).

The previous response to the WEP described the role of the NSW Dam Safety Committee. The response also described sensors that continuously measure and record storage depth, and real-time monitoring by operators using Telemetry. In addition, the response confirmed that Leewood Ponds are operated in accordance with the Trigger Action Response Plan.

Attachment 1 – Response to WEP follow up questions

The as-built design drawings for the Leewood Ponds are provided at Appendix I. The dimensions of each cell are detailed in the drawings. Brine Ponds 1 and 2 in the drawings are now referred to as Cells 1 and 2, respectively and Produced Water Ponds 1 and 2 are now Cells 3 and 4, respectively. Cell 1 currently holds the bulk of the legacy waters (that had been treated previously through a brackish-water reverse osmosis plant by the previous operator, Eastern Star Gas) from the Bibblewindi Ponds; Cells 2 and 3 hold predominantly produced water from pilot wells (as well as some brine, treated water and washwater from the Leewood Water Treatment Plant (WTP)) and Cell 4 has been receiving output brine from the WTP.

Sampling points for analyses reported in the Baseline Report (and in Table 2, below) are indicated in Figure 6. There are two sampling locations for the Treated Water one before and one after amendment with calcium chloride.

Attachment 1 – Response to WEP follow up questions

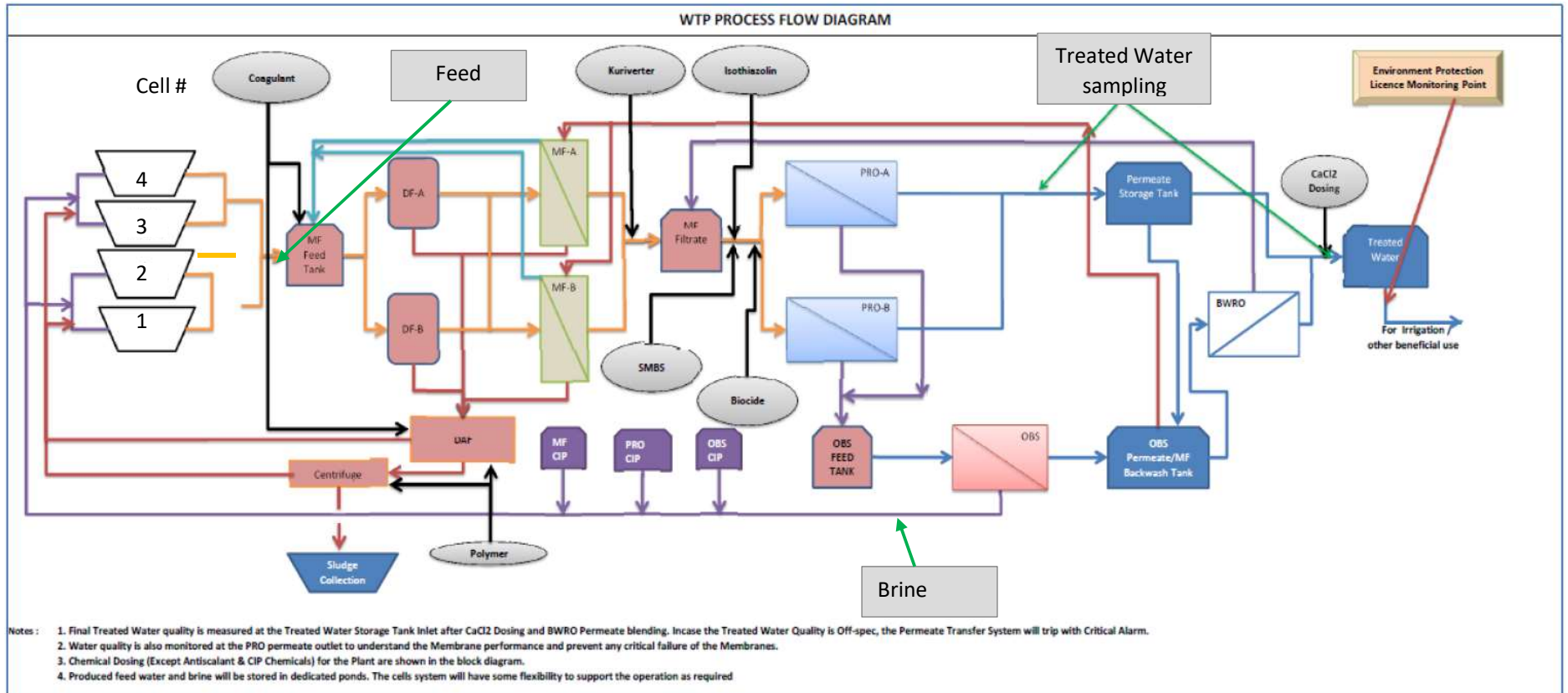


Figure 6 Schematic of process flow and sampling points for the Leewood Water Treatment Plant

Attachment 1 – Response to WEP follow up questions

QUESTION 11 - USE OF TREATED AMENDED WATER FOR IRRIGATION

Follow-up questions

The Santos response to this question has drawn on a revised Water Baseline Report that gives in Table 7.1 amended figures for treated and amended water based on operation of the Leewood production water treatment plant. The quality of both treated and amended water is significantly better than in the target figures provided in the EIS and the treated and amended water meets drinking water and environmental standards for irrigation with COPCs (contaminants of potential concern) under control or not detectable. For the purposes of conducting a mass balance around the reverse osmosis (RO) plant and the salt recovery section and comparing this with figures given in the EIS, it would be useful to know the percentage water recovery in the RO plant now that it is operating.

The WEP requests that Santos provide (i) the percentage water recovery attained in the Leewood RO plant now that it is in operation; (ii) the total dissolved solids in the RO plant brine in Table 7.1; and (iii) the concentration profile of the feed stream to the RO plant for which the brine profile is provided, noting that Table 6.1 provides only minimum and maximum figures and means.

What was the analysis of the feed stream to the RO plant for which the analysis of treated water is given? Can it be taken as represented by the mean values in the Leewood Ponds?

Response

Data collected by the WTP contractors, Osmoflo, during the operation of the WTP 2017/2018 indicates full accountability of all water entering the system (0.02% long-term variance between the volume into and volume out of the plant). During this period, an average 70% of the feed volume was recovered as Treated Water. However undertaking mass balances on a daily basis does not yield reliable results due to the nature of the operation of the WTP, which considers storage capacities within the WTP (Figure 7), return chemistry, irrigation requirements and feed blended from different cells.

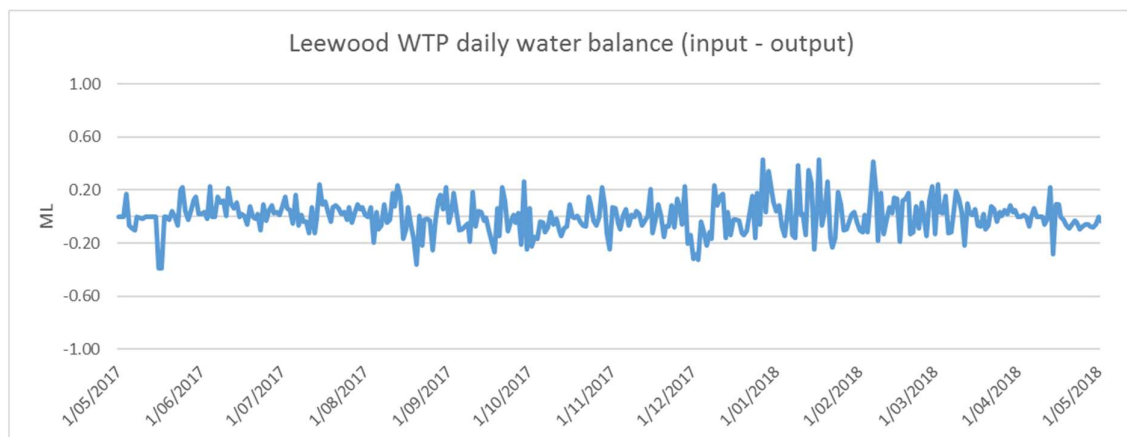


Figure 7 Daily water balance for the Leewood Water Treatment Plant

TDS for the brine produced from the WTP (sampled 08/09/2017) was determined as 122,000 mg/L (from the sum of analysed ion concentrations). TDS is variably reported in datasheets as TDS (calc) (which refers to estimation of TDS from electrical conductivity measurements and is assessed at $0.65 \times \text{EC}$ in $\mu\text{S}/\text{cm}$) and/or as TDS @ 180°C (the mass remaining after drying at 180°C). The latter provides a

Attachment 1 – Response to WEP follow up questions

closer approximation to actual TDS, but does not consider losses from bicarbonate decomposition due to the high bicarbonate concentration in the brine.

Feed to the WTP plant consisted of blends from the storage ponds (cells 2 and 3, as well as higher salinity legacy water from cell 1). Inputs to the Feed, and therefore Feed sampling, constituted variable quantities from each cell. While final brine from the WTP has been directed primarily to cell 4, during the commissioning and operation of the plant varying quantities of brine, washwater and treated water were also directed back to cells 2 and 3.

As part of their plant operation, Osmoflo sampled simultaneous input Feed, output Brine and output Treated waters between September 2017 and February 2018, and the analytical sheets for these data are provided at Appendix II. The analyses for samples taken on 13th February, 2018 are reproduced in Table 2 and are indicative of all samples analysed.

Mass balance indicates a rejection of >95% of salt through the WTP. Concentration to the brine indicates around 70% recovery of water to the Treated Water stream, as determined from major ion comparisons. This is consistent with Osmoflo records of the measured volumes of Treated Water as a proportion of the Feed.

Table 2 Reported chemistry of water treatment plant samples for 13 February 2018¹

	WTP Feed (Raw Feed)	Treated and Amended water	WTP brine
Parameter (mg/L unless otherwise indicated)	13/02/2008	13/02/2018	13/02/2018
pH (pH units)	9.62	8.28	9.41
Electrical conductivity (lab) ($\mu\text{S}/\text{cm}$)	36300	133	81600
Total dissolved solids	29300	69	88600
Carbonate alkalinity as CaCO_3	15800	<1	33400
Bicarbonate alkalinity as CaCO_3	7320	31	33600
Alkalinity (total as CaCO_3)	23100	31	67000
Calcium (filtered)	16	5	27
Magnesium (filtered)	13	<1	34
Sodium (filtered)	11800	24	38600
Sodium Adsorption Ratio	531	3	1160
Chloride	3180	21	8710
Sulfate	<10	<1	42
Fluoride	15.1	0.4	58.5
Silica (SiO_2)	0.09	1.88	6.23
Aluminium	<0.1	<0.01	n/a
Potassium (filtered)	250	<1	758
Chromium (VI)	<0.01	<0.001	n/a

Attachment 1 – Response to WEP follow up questions

	WTP Feed (Raw Feed)	Treated and Amended water	WTP brine
Parameter (mg/L unless otherwise indicated)	13/02/2008	13/02/2018	13/02/2018
Manganese	0.02	<0.001	n/a
Iron	<0.1	<0.05	n/a
Boron	1.74	0.07	5.22
Cobalt	<0.001	<0.001	n/a
Nickel	<0.001	<0.001	n/a
Copper	<0.001	<0.001	n/a
Zinc	<0.005	<0.001	n/a
Arsenic	<0.001	<0.001	n/a
Selenium	<0.01	<0.01	n/a
Molybdenum	<0.001	<0.001	n/a
Cadmium	<0.0001	<0.0001	n/a
Barium	5.55	0.005	12.6
Mercury	<0.0001	<0.0001	n/a
Lead	<0.01	<0.001	n/a
Uranium	<0.001	<0.001	n/a
Ammonia (as N)	<0.1	0.02	<0.1
Nitrate (as N)	<0.1	<0.1	<0.1
Total N	4.8	<0.1	n/a
Total phosphorous	0.66	<0.01	n/a

¹ALS Certificate of Analysis # ES1804784

QUESTION 13 - PRODUCED WATER COMPOSITION

Follow-up question

Concentration Profile

In the revised Water Baseline Report, Santos has provided a detailed analysis of Leewood Pond chemistry and this gives a guide to production water composition. Maximums, minimums and means are given as well as the 16th and 84th percentiles. This information is informative. It would be helpful to have a complete concentration profile for one representative sample, so that internal consistency of the measurements can be checked.

The WEP requests that Santos provide a complete concentration profile for one representative sample of produced water.

Discrepancy – EC/ TDS

Attachment 1 – Response to WEP follow up questions

The EIS gives 14,000 $\mu\Omega/\text{cm}$ and comments that it is one-third that of seawater.

The RTS gives for Leewood Ponds (presumably primarily production water and feed to the RO plant) provides the following summary:

Minimum: 4,223, Maximum: 28,399 Average 22,613 $\mu\Omega/\text{cm}$ (Average is 62% higher than in EIS)

The Digby and Napperby aquifers in GOB (presumably feeders to the production water) are 6,714 to 10,773 and 3,126 to 7,488 $\mu\Omega/\text{cm}$ respectively i.e. much lower.

Total Dissolved Solids (TDS) reported paints a different picture:

The EIS gives 23,800 mg/L for TDS.

The RTS gives: Minimum - 2,749, Maximum - 24,371 Average 14,669 mg/L for TDS. This is counter to the reported conductivities as a higher TDS would be expected to give a higher conductivity. There could be a pH –bicarbonate/carbonate split at work, but Santos should explain why there is this discrepancy. This has bearing on the effectiveness of the RO unit and the amount of “salt” produced.

The WEP requests that Santos provide further advice as to why the field-measured electrical conductivities for production water in the Santos RTS (specifically the updated Water Baseline Report) are so much higher than in the EIS.

Response

Just as WTP Feed water chemistry is not representative of the chemistry in a particular cell, so the chemistry in a cell also does not give a true representation of produced water chemistry at the well head. This is especially so considering the period of pond use, over 30 months, before the WTP was granted approval for use. Prior to WTP commissioning each cell received waters from various sources, including legacy (higher salinity) water from the Bibblewindi Ponds, produced water from various pilot wells, rainfall and re-distribution between ponds. Further, as evaporation exceeds the 95th percentile rainfall in most months (Table 1) the open ponds also undergo evaporation at rates indicated in Figure 5. Since the WTP commenced operation in 2017 the cells also received brine, washwater returns and treated water from the WTP.

It is anticipated that the pond chemistry and Feed water will become more representative (over time) of produced water at the well head(s) after production commences and currently stored water is treated.

The EIS values for EC and TDS are derived from produced water samples from pilot wells targeting the Maules Creek and Black Jack seams. Conductivities (not resistivities as indicated above, i.e. Ω not Ω) of produced water (over 200 samples at the well head) from these formations were recorded at about 14.1 mS/cm for both seams and this was rounded to 14,000 $\mu\text{S}/\text{cm}$ in the EIS. Measured TDS (from evaporation at 180°C of over 80 samples collected at the well head) are a mean value of 11,700 mg/L. The WEP’s reference to 23,800 mg/L appears to be taken from the Review of Environmental Factors for the Leewood WTP and relates to the 90th percentile value for produced water at that time. This value is not used in the EIS.

The values for the Baseline Report, reported in the RTS differ to those reported in the EIS in two important aspects:

1. The Water Baseline Report in the RTS, Table 6-1, reports on samples from the Leewood Ponds, which, as reported above, received water from multiple sources. Thus, Table 6-1 reports on Leewood Pond chemistry, not produced water chemistry at the well head.

Attachment 1 – Response to WEP follow up questions

2. The reported values in the Water Baseline Report represent the average of all samples taken from cells 2 and 3 only (cell 1 contains mostly higher salinity – typically 50 mS/cm – legacy water transferred from the Bibblewindi Ponds and; Cell 4 had been used for produced water intermittently and for some periods contained primarily rainfall) and it is not possible to back-calculate the relative proportions of the multiple sources to these cells, except to acknowledge that the bulk of water will be produced water. The analyses also do not attempt to correct for evaporation, changes to pond volumes, nor changes in temperature. Baseline values as reported therefore constitute statistical means across the entire database for a given parameter. Thus, TDS is the mean TDS for all samples under consideration and EC is the mean EC across those same samples. EC and TDS should be correlated, but the exact values may not be directly related. Indeed, whilst most TDS values were calculated (as $0.65 \times \text{EC}$), some TDS values were estimated from evaporation at 180°C (for samples where EC was not recorded), which will slightly skew the EC:TDS correlation. Notwithstanding, the average EC and average TDS reported in the Water Baseline Report provided with the RTS are consistent ($\text{TDS} = 0.648 \times \text{EC}$) with recorded data. Therefore the carbonate and bicarbonate concentrations are unduly affecting the results.

We also note that the Digby and Napperby Aquifers lie above the targeted coal seams and are equipped with monitoring bores only. No water will be produced directly from these formations and the values reported in the Water Baseline Report are not relevant to the assessment of produced water chemistry.

QUESTION 14 - SALT

Follow-up question

The information provided in the revised Water Baseline Report (Table 6.1), principally the analysis of Leewood RO brine, enables an estimate to be made of the composition of the salt product. What is lacking in Table 6.1 is an analysis of bicarbonate as CaCO_3 and carbonate as CaCO_3 so that the ratio of bicarbonate to carbonate can be followed through the salt recovery process. This transition is pH as well as temperature dependent.

The WEP requests that Santos provides for the Leewood WTP plant RO brine, the bicarbonate as CaCO_3 and carbonate as CaCO_3 as has been provided for the analysis of samples reported in table 7.1 of the updated Water Baseline Report.

Response

Bicarbonate and carbonate values are reported in Table 2, above, for samples taken on 13 February, 2018. These allow direct comparison of Feed water to Treated water and brine produced on the same day. Appendix III provides an update of Table 7-1 in the Water Baseline Report and includes compositions of samples taken on the dates of WTP brine sampling. The relative proportions of major ions in these samples are indicative of the broader range of samples taken during operation of the WTP.

However, as explained above, the feed water chemistry during the operation of the WTP 2017/2018 is not consistent with the chemistry of produced water at the well head and is therefore not consistent with the produced water that will be treated during production. In particular, approximately two-thirds of the cell 1 water, higher salinity legacy water transferred from the decommissioned Bibblewindi Ponds, has been treated through the WTP.

Attachment 1 – Response to WEP follow up questions

To validate the estimated production of dry salt waste during production, all of the baseline data at the well head has again been reviewed and analysed (Table 3). From this data, and given the bicarbonate decomposition will be 100% (acknowledging the elevated operating temperature in the proposed brine concentration and crystallisation plant, together with post crystallisation drying at an elevated temperature) and with produced water processed at an average of 4.1 ML/day (or 1.5 GL/year), we derive approximately (and slightly less than) the estimated 47.5 tonnes/day of dry salt waste assessed in the EIS.

Table 3 Mean (n>150) well-head and post-bicarbonate decomposition carbonate speciation concentrations

Analyte	Raw Data from Lab Analysis		Bicarbonate & Carbonate Converted to Respective Ionic Concentrations		Post-Bicarbonate Decomposition	
	Unit	Mean		Mean	Analyte	Mean
Carbonate as CaCO ₃	mg/L	487.8	Carbonate as CO ₃ ²⁻	293	Carbonate as CO ₃ ²⁻	5,404
Bicarbonate as CaCO ₃	mg/L	8,518.5	Bicarbonate as HCO ₃ ⁻	10,393	Bicarbonate as HCO ₃ ⁻	0
			Total alkalinity by \sum Ions	10,685	Total recorded TDS by \sum Ions	11,475

QUESTION 16 - MONITORING

Follow-up question

It appears that some text may be missing in the Santos response to question 16A. In the copy the WEP received, the fourth paragraph of this response ends abruptly with the words “... *in the event that a response trigger identification of*”. It would be helpful to the WEP to view the entire response to this question.

The WEP requests that Santos please provide their entire response to Question 16.

Response

This was a typographical error. The revised response is provided below:

The Water Monitoring Plan sets out the monitoring locations, monitoring target and form of measurement, as well as response triggers and management actions in the event that an unexpected impact is detected.

QUESTION 19 SPILLAGES

Follow-up question

Overall, the Santos response to question 19 addresses the issue of the potential for spillages in very broad terms, rather than addressing some of the specifics that were being sought by the WEP. Santos points out “*the risks associated with coal seam gas are no greater than that associated with other extractive industries*”, a view consistent with one expressed by the Chief Scientist. Further, Santos indicated that they have assessed the potential for impacts related to spills as very low to low. They

Attachment 1 – Response to WEP follow up questions

also mentioned their record as an experienced oil and gas operator for over 40 years and in particular their recent operation of the Narrabri field “without a single reportable incident in over 4.5 years”. None of these particular views, as expressed by Santos, is disputed by the WEP. Indeed, they are reassuring.

However, the WEP was seeking a more quantitative response to questions 19A, 19B and 19C, rather than the qualitative response provided. As stated by Santos, it is a fact that “vessel and piping design has not been undertaken for the project at this stage” and “This will be part of the design work undertaken if project approval is received”. This is understood and accepted by the WEP as normal practice. But given Santos’ more than 40 years experience as an oil and gas operator, it is assumed that there would be information available from existing operations, such as their CSG operations in Queensland. It would be helpful, therefore, for the WEP to have a more specific response, if only in terms of indicative figures at this pre-design stage.

The WEP requests that Santos indicate what would be the likely maximum spillage of each potential spill liquid in the front-end engineering design (FEED) of the NGP. Additionally, what minimum spillage of each particular spill liquid is the threshold of a “significant spill”.

Response

Table 4 discusses the potential maximum spill volumes for each of the main potential spill liquids of the NGP.

Table 4 Maximum potential spill volumes for NGP

Potential spill liquid	Maximum potential spill volume
Produced water and brine	<p>The largest volumes of produced water and brine would be contained at the Leewood and Bibblewindi water management facilities, in 150 ML capacity pond cells. Catastrophic failure or overtopping of a pond wall would need to occur for significant quantities of water or brine to be released from these facilities. The Hazard and Risk Assessment (Appendix S of the EIS) assessed the likelihood of this occurring as very low on the basis that the ponds are designed in accordance with Australian National Committee on Large Dams (ANCOLD) and NSW Dam Safety Committee guidelines. The ponds must also meet the mandatory standards for produced water storage from the NSW Government’s <i>Exploration Code of Practice: Produced Water Management, Storage and Transfer</i> (‘the Code’) (DPE 2015), which include:</p> <ul style="list-style-type: none"> • operation in accordance with a Produced Water Management Plan that meets specific requirements outlined in the Code • maintaining an environmental containment freeboard capable of containing inflow from events up to and including a 1 in 100 year Annual Exceedance probability (AEP) 72 hour rainfall event • a location and design which is structurally stable in all events up to and including the probable maximum flood. <p>Extensive monitoring of the ponds will be carried out in accordance with the Produced Water Management Plan. This will include continuous monitoring of water levels and inflows, and quarterly monitoring of embankment, pond crest and hydraulic structure integrity.</p> <p>The next largest potential spill source of produced water (after the ponds) would be the Bibblewindi to Leewood pipeline corridor. When full, each pipeline would contain 0.823 ML of liquid. The loss of all fluids from a pipeline would require major mechanical failure. This is considered improbable as the pipelines are not under high pressure, and will be designed and constructed to Australian Standards including the APIA Code of Practice for Upstream Polyethylene Gathering Networks in the CSG Industry. Fluid loss from the pipelines, would trigger low pressure alarms and shut down pumps, limiting the extent of impact in the unlikely event of a release.</p>
Drilling fluid and additives	<p>Drilling fluids at the well site would be held in 0.08 ML (500 bbl oil equivalent) sized tanks. Up to three tanks may be required on site per well while it is being drilled.</p> <p>Drilling fluid additives may be stored at the Narrabri Operations Centre, the Bibblewindi and Leewood facilities, and/or, in smaller quantities, at the well site during drilling. Table 4-3 of the Hazard and Risk</p>

Attachment 1 – Response to WEP follow up questions

	<p>Assessment (Appendix S of the EIS) identifies the drilling fluid additives classified as dangerous goods (DG) and indicates that the maximum quantities of DG liquids to be stored on site would be 1200 L of Glutaraldehyde and 70 L of Methanol.</p> <p>The chemicals to be used in drilling are commonly used across many industries and products (refer to Table 6-9, Chapter 6 of the EIS). All chemicals would be stored and handled in accordance with relevant Australian Standards, including AS 1940-2004 <i>The storage and handling of flammable and combustible liquids</i>.</p>
Other chemicals, fuels and oils	<p>Chemicals required in water treatment and gas compression processes, fuels, and oils would be stored at the Leewood and Bibblewindi facilities. Tables 4-4 and 4-6 of the Hazard and Risk Assessment (Appendix S of the EIS) identifies the anticipated maximum quantities of dangerous goods, other than drilling additives, to be stored at these facilities.</p> <p>Chapter 6 of the EIS identifies that Leewood would include a 100,000 L bunded diesel storage tank.</p> <p>Vessels containing chemicals and fuels would be stored within bunded areas with the capacity to hold 110% of the vessel volume in accordance with <i>Australian Standard 1940-2004 The storage and handling of flammable and combustible liquids</i>.</p>
Sewage	<p>Sewage would be managed using packaged wastewater plants at Leewood, Bibblewindi and Westport worker's accommodation. These plants use aerobic processes to treat the raw sewage, generating a treated effluent that can be released to land and a residual sludge that is stored prior to collection and disposal to an appropriate facility. Leewood would have the largest wastewater plant servicing up to 400 people during peak construction period. The size of holding tanks would depend on the model of treatment plant selected and particular design flow rates. However, these would be contained within bunded hardstand areas and subject to relevant local and/or state government requirements.</p>

No threshold 'significant spill' volumes for have been set for the project.

Generally, a spill would be assessed to be significant if it threatens 'material harm to the environment', as defined in section 147 of the *Protection of the Environment Operations Act 1997* (POEO Act):

a. Harm to the environment is material if:

i. It involves actual or potential harm to the health or safety of human beings or to ecosystems that is not trivial, or

ii. It results in actual or potential loss or property damage of an amount, or amounts in aggregate, exceeding \$10,000 (or such other amount as is prescribed by the regulations), and

b. Loss includes the reasonable costs and expenses that would be incurred in taking all reasonable and practicable measures to prevent, mitigate or make good harm to the environment.

Under section 148 of the POEO Act, Santos has a duty to notify all relevant authorities of incidents causing or threatening material harm to the environment.

Attachment 1 – Response to WEP follow up questions

Appendix I As built design drawings for Leewood Ponds

Attachment 1 – Response to WEP follow up questions

Appendix II Leewood Water Treatment Plant same day analyses

Appendix III Updated Table 7.1 from Appendix D of the Response to Submissions

Parameter	Australian Drinking Water Guidelines (NHMRC 2011)	ANZECC / ARMCANZ (2000) Irrigation Guidelines (Short Term < 20 years)	ANZECC / ARMCANZ (2000) Stock watering	Treated water ^{a,c}	Amended water ^{b,c}	Treated water ^c	Amended water ^{c,d}	RO brine ^{c,e}
				Target values		Leewood WBTP (3 samples)	Leewood WBTP (16 samples)	Leewood WBTP (6 samples)
All values mg/L unless stated								
pH (pH units)	6.5 – 8.5	6.0 -9.0	Not referenced	7.1	7.1	7.9	pH (Field) – 7.4 pH (Lab) – 7.2	8.5 (Lab)
Electrical conductivity (laboratory) (µS/cm)	Not referenced	Crop specific – Lucerne (2,700 in loamy soils)	Not referenced	357	566	n/a	90.1	85,267
Total dissolved solids	Health: Not referenced Aesthetic as follows: <600 Good quality 600-900 Fair quality 900-1,200 Poor quality >1,200 Unacceptable	Crop specific – Lucerne (1,273 – 3,015)	No adverse effects to: Beef cattle, pigs and horses 4,000 Sheep 5,000	232	368	51 (at 180°C)	99 (Field) 54.2 (at 180°C)	86,700 (calc.)

Attachment 1 – Response to WEP follow up questions

Parameter	Australian Drinking Water Guidelines (NHMRC 2011)	ANZECC / ARMCANZ (2000) Irrigation Guidelines (Short Term < 20 years)	ANZECC / ARMCANZ (2000) Stock watering	Treated water ^{a,c}	Amended water ^{b,c}	Treated water ^c	Amended water ^{c,d}	RO brine ^{c,e}
				Target values		Leewood WBTP (3 samples)	Leewood WBTP (16 samples)	Leewood WBTP (6 samples)
Sodium Adsorption Ratio	Not referenced	<1 Excellent 1-2 Good 2-4 Fair 4-8 Poor 8-15 Very poor >15 Unacceptable	Not referenced	130	3.3	7	1.6	1020
Sodium (filtered)	Health: Not referenced Aesthetic: 180	Crop specific – Lucerne (230 - 460)	Not referenced	77	77	13.2	11.17	36,350
Magnesium (filtered)	Not referenced	Not referenced	Not referenced	<0.01	<0.01	<1	<1	43.2
Aluminium	Health: Not referenced Aesthetics: 2	20	5	<0.001	<0.001	0.04, <0.005	<0.01, <0.005	<0.05
Silica (SiO ₂) (µg/L)	900	Not referenced	Not referenced	23	0.15	<0.1	<0.1	135
Potassium (filtered)	Not referenced	Not referenced	Not referenced	0.8	0.8	<1	<1	651
Calcium (filtered)	Health: Not referenced Aesthetic as follows: <60 Soft	Not referenced	1,000	0.01	40.01	<1	3.8	24

Attachment 1 – Response to WEP follow up questions

Parameter	Australian Drinking Water Guidelines (NHMRC 2011)	ANZECC / ARMCANZ (2000) Irrigation Guidelines (Short Term < 20 years)	ANZECC / ARMCANZ (2000) Stock watering	Treated water ^{a,c}	Amended water ^{b,c}	Treated water ^c	Amended water ^{c,d}	RO brine ^{e,e}
				Target values		Leewood WBTP (3 samples)	Leewood WBTP (16 samples)	Leewood WBTP (6 samples)
	60-200 Good quality >200 Increased scaling							
Chromium (III+VI)	0.05	1 (Cr ^{VI})	1	<0.001	<0.001	<0.001 (Cr ^{VI})	<0.001 (Cr ^{VI})	0.01
Manganese	0.5	10	Not sufficiently toxic	<0.001	<0.001	<0.001	0.001	0.014
Iron	<1	10	Not sufficiently toxic	<0.001	<0.001	<0.05, <0.002	<0.05, <0.002	0.27
Boron	4	Crop specific 0.5 (sensitive) to 15 (very tolerant)	5	0.12	0.12	0.1	0.072	3.38
Cobalt	Not referenced	0.1	1	<0.001	<0.001	<0.001	<0.001	<0.005
Nickel	0.02	2	1	<0.001	<0.001	<0.001	<0.001	<0.005
Copper	2	5	0.4 (sheep) 1 (cattle) 5 (pigs)	<0.001	<0.001	<0.001	<0.001	<0.005
Zinc	Health: Not referenced Aesthetic: 3	5	20	<0.001	<0.001	<0.005, <0.001	<0.005, <0.001	<0.025

Attachment 1 – Response to WEP follow up questions

Parameter	Australian Drinking Water Guidelines (NHMRC 2011)	ANZECC / ARMCANZ (2000) Irrigation Guidelines (Short Term < 20 years)	ANZECC / ARMCANZ (2000) Stock watering	Treated water ^{a,c}	Amended water ^{b,c}	Treated water ^c	Amended water ^{c,d}	RO brine ^{c,e}
				Target values		Leewood WBTP (3 samples)	Leewood WBTP (16 samples)	Leewood WBTP (6 samples)
Arsenic	0.01	2	0.5 – 5	<0.001	<0.001	<0.001	<0.001	0.018
Selenium	0.01	0.05	0.02	<0.001	<0.001	<0.01, <0.0002	<0.01, <0.0002	<0.05
Molybdenum	0.05	0.05	0.15	<0.001	<0.001	<0.001	<0.001	0.006
Cadmium	0.002	0.05	0.01	<0.001	<0.001	<0.0001	<0.0001	0.001
Barium	2	Not referenced	Not referenced	<0.001	<0.001	<0.001	0.002	12.6
Mercury	0.001	0.002	0.002	0.0000067	<0.001	<0.00004, <0.0001	<0.00004, <0.0001	<0.0005
Lead	0.017	5	0.1	<0.001	<0.001	<0.001	<0.001	<0.005
Uranium	0.017	0.1	0.2	<0.0028	<0.0028	<0.001	<0.001	<0.005
Alkalinity (total as CaCO ₃)	Not referenced	Not referenced	Not referenced	139	139	31.7	22.6	73,500
Ammonia (as N)	Health: Not referenced Aesthetic: 0.5	Crop specific as N (25 – 125)	Not referenced	0.005	0.005	0.24	0.19	3.3
Nitrate (as N)	50	Crop specific as N (25 – 125)	400	0.005	0.005	0.04	0.25	0.54
Total N	Not referenced	25 - 125	Not referenced	0.005	0.005	0.23	0.42	n/a
Sulfate	500	Not referenced	1,000	0.003	95.9	<1	1	356

Attachment 1 – Response to WEP follow up questions

Parameter	Australian Drinking Water Guidelines (NHMRC 2011)	ANZECC / ARMCANZ (2000) Irrigation Guidelines (Short Term < 20 years)	ANZECC / ARMCANZ (2000) Stock watering	Treated water ^{a,c}	Amended water ^{b,c}	Treated water ^c	Amended water ^{c,d}	RO brine ^{c,e}
				Target values		Leewood WBTP (3 samples)	Leewood WBTP (16 samples)	Leewood WBTP (6 samples)
Chloride	Health: Not referenced Aesthetics: 250	Crop specific – Lucerne (350 – 700)	Not referenced	15	15	7.3	14.211	9232
Fluoride	1.5	2	Not referenced	0.08	0.08	<0.01, <0.1	0.182	48
Total phosphorous	Not referenced	Crop specific – (0.8 – 12)	Not referenced	0.01	0.01	<0.01	0.02	n/a

n/a not analysed

^a theoretical composition based on manufacturers specifications

^b calculated composition based on theoretical treated water and amendment with 1 mol gypsum

^c all values reported as maximum recorded values, except pH reported as average; multiple values reflect different laboratory limits on reporting (LOR)

^d treated water amended with calcium chloride

^e laboratory limits raised due to high salinity

^f single sample reported 0.04 mg/L

From: peter.cook@pinct.com.au
To: Steve O'Donoghue
Subject: Request for further advice - Narrabri Gas - Post Production - Decommissioning Risks
Date: Friday, 5 June 2020 7:38:06 PM

Mr Steven O'Donoghue,
Director Resources Assessment
NSW Department of Planning Industry and Environment

Dear Mr O'Donoghue,

Thank you for your email of 2 June in which you request that the Water Expert Panel provide supplementary advice via a letter on the post production / decommissioning risks associated with long term well integrity related to the Narrabri Gas Project.

I have consulted with the members of the WEP on the issue and the Panel is pleased to provide the following advice.

POST PRODUCTION/DECOMMISSIONING RISKS ASSOCIATED WITH LONG TERM WELL INTEGRITY

A number of stakeholders expressed concern about well integrity and suggested that the integrity of every well drilled by Santos should remain assured in perpetuity. This may not be exactly how they expressed these concerns, but nevertheless it was how the WEP interpreted their various comments.

Clearly, there is no engineering activity, including drilling, completing and abandoning a well, that can be absolutely guaranteed to remain effective in perpetuity. The high standards required for the completion of wells, does provide confidence that they will be effective for many decades if not centuries. But as pointed out eloquently by one landowner, with a century-long connection to his land, the average life of a CSG project is short compared to his family connection to the land. And of course, the connection of indigenous groups extends far beyond that.

The risks associated with abandoned wells have recently been described in the Northern Territory Report of the Scientific Inquiry Into Hydraulic Fracturing (NT, 2018, page 53):

"In common with operating wells, leakage or failure of decommissioned wells could occur by poorly cemented or deteriorating casing/hole annuli, faults in the interface between cement and the formation rock and casing failure. Additionally, for decommissioned wells, the interface between cement plugs and casing has been identified as a preferential pathway for gas/fluid flow. Migration of gas/fluid can also occur through fractures, channels, and the pore space in the cement sheath. In the latter case, gas/fluid flow will only occur when the cement sheath is degraded or did not form properly during the cementing process..."

The WEP believes that similar arguments can be mounted for CSG operations and supports the view of the NT Inquiry (NT 2018, page 54) that:

"The combination of small cross-sectional areas, long vertical lengths of flow pathways and low driving pressure differentials means that overall, there is a low likelihood of substantial vertical movement of fluids post decommissioning."

These conditions apply generally to the proposed NGP. In Appendix E of the WEP Report (WEP 2020) example calculations are given to illustrate the typical rate and quantities of leakage that might occur in a worst-case scenario. The overall leakage is very small and it should be noted that the conditions required to produce such upward leakage, such as the existence of an upward hydraulic gradient are highly unlikely to occur at the Narrabri site.

The Council of Australian Governments' (COAG) Standing Council on Energy and Resources (SCER) National Harmonised Framework (NHF 2013, page 30) requires that "Decommissioning and well abandonment must ensure the environmentally sound and safe isolation of the well for the long term" and the NSW Code of Practice for CSG Wells (NSW 2012) is consistent with this. The NSW Code is intended to apply to all CSG wells drilled in NSW but as pointed out in the O'Kane Review (O'Kane 2014a,b,c), it is only formally applied to a title at the time of licence issue or renewal, or at an activity approval on a Petroleum Exploration Licence (PEL).

In the case of the NGP area (O'Donoghue, pers comm), there are 2 State Significant Development planning approvals that cover construction and operation of exploration and appraisal wells – the Dewhurst and Bibblewindi pilot expansions. These approvals cover the more recent appraisal wells but include conditions that require design, construction, maintenance and abandonment in accordance with the Code of Practice for Well Integrity. The following conditions are included in both approvals for the construction and operation of petroleum wells:

"The Applicant must ensure that all petroleum wells:

- must be designed, constructed, maintained, and abandoned in accordance with the Code of Practice for Coal Seam Gas - Well Integrity (DTRIS 2012)*
- ensure hydraulic isolation between the Upper Namoi and Lower Namoi alluvium and the Great Artesian Basin Southern Recharge during drilling activities*
- have all casing fully cemented from casing shoe to surface, leaving no open annuluses*
- have a blow-out prevention device on the well head secured to the steel casing, and*
- are sealed with cement from the total depth to 1.5metres below the surface when exploration is completed and the well is no longer required*

in order to protect the integrity of any underground aquifers, prevent gas escape and maintain groundwater quality."

Under current NSW legislation, once a well is plugged and abandoned and certified by the Regulator as being satisfactorily abandoned, the area is remediated and handed back to the landowner or the State. There is no ongoing requirement for monitoring the abandoned well. As O'Kane (2014c, page 5) points out "Despite the abundance of information and research on petroleum well integrity (including design and cements), very little data exists about the long-term (100 -1000 years) durability of abandoned petroleum wells." There is no evidence that the vast majority of plugged and abandoned oil and gas wells have an adverse impact on the environment.

Nonetheless, the potential does exist in a few instances for well failure to adversely impact on groundwater quality or flow. Problems with well integrity may occur due to the breakdown over time of the materials forming the well casing, cement or final well plug. These problems may manifest as the leakage of methane and/or saline groundwater from the target coal seams into and along the plugged well, with the potential to contaminate overlying aquifers. But it would be quite impractical to put the onus on a Project or Government to monitor all plugged and abandoned wells indefinitely.

Therefore, the primary strategy must be to ensure that the wells are plugged and abandoned using the best available technology and to the satisfaction of the Regulator. The NSW regulations (NSW 2012, page 13) provide the basis for doing just this and are designed to guarantee the safe and environmentally sound production of CSG by:

- "preventing any interconnection between hydrocarbon-bearing formations and aquifers;*
- ensuring that gas is contained within the well and associated pipework and equipment without leakage;*
- ensuring zonal isolation between different aquifers and water bearing zones is achieved; and*
- not introducing substances that may cause environmental harm."*

Bearing these regulations in mind, it could be deemed that the long-term risk of failure is so small, that the only strategy necessary, is to have a robust plan in place for dealing promptly and effectively with the rare case of failure as soon as it happens. The problem with such a strategy is that, as pointed out earlier, little is known about long-term durability of abandoned wells. Additionally, such an approach may not imbue sufficient confidence in some stakeholders, if it is perceived that there is no certainty that well failure was recognised.

What strategy might then provide landowners and other stakeholders with a greater degree of certainty that if well integrity problems do occur long after abandonment, the problems will be recognised in a timely manner and remediation measures taken?

The strategy cannot be to monitor every well for evermore. If a system is to be put in place, it needs to be graded temporally and perhaps spatially, so that as the risk of well failure is progressively quantified, the extent of monitoring can be adjusted to reflect that risk (an example of adaptive management.) This will require some practical means of assessing the likely performance of wells over time. One possible option might be for the Regulator to monitor a representative selection of wells for say 5-10 years after abandonment. At the end of that time a small number of sentinel wells could be selected for monitoring over a further 10-20 years. Provided no failures are encountered during that time and the risk of well failure is better understood, then monitoring could reasonably be terminated at that point.

As noted by Dusseault (2014, page 212) "Most jurisdictions have 'orphan well funds, provided by a levy on production, that are used to fix wells for which an owner cannot be found' It is the opinion of the WEP that similar plans should be developed for ensuring long term on-going well integrity. If leakage is detected, then a plan for rectifying leaking wells will be required. It is the view of the WEP that establishing a legacy fund should be considered, as a mechanism to meet future costs that may be incurred in carrying out necessary rectification works. The WEP considered that this is a policy issue that merits the attention and consideration of the relevant NSW government authorities.

According to the NSW Chief Scientist and Engineer: "Land is a key issue and one that strikes an emotional chord due to the strong affinity Australians have with their land and its central role in the livelihood of rural communities. There is a perceived lack of support for rights of landowners in terms of access to their land. Lack of consultation, inadequate compensation, property value decreases, and potential legacy issues are also cited as major issues by landowners as are the negative impacts on amenity and a lack of adequate benefits for their neighbours and their communities" (NSW 2014, page 7). Furthermore: "Legacy issues, including better understanding of inappropriately abandoned wells, need attention" (NSW 2014, page 10).

Accordingly, the Chief Scientist and Engineer made a recommendation in her report :

"Recommendation 15 - That Government develop a plan to manage legacy matters associated with CSG. This would need to cover abandoned wells, past incomplete compliance checking, and the collection of data that was not yet supplied as required under licences and regulations. There will also need to be a formal mechanism to transition existing projects to any new regulatory system" (NSW 2014, page 15). The WEP endorses this recommendation of the Chief Scientist and Engineer, particularly in regard to abandoned wells.

In conclusion, the WEP recommends to Government that it develops policies and procedures to monitor and inspect abandoned CSG wells, beyond the life of the NGP, for the purpose of detecting leakage of methane or saline groundwater, and the rectification of leaking wells should that be deemed necessary. Furthermore, the WEP suggests government should consider the establishment of a legacy fund to cover the costs of rectification work that may be required in the future.

If you require further advice on this matter or clarification of any of the points raised, then do not hesitate to contact me.

Relevant references are provided below.

Peter Cook
Professor Peter J Cook CBE FTSE
Chair, Water Assessment Panel

References

- Dusseault (2014) Chapter 7 Well Integrity - Report of the Nova Scotia Independent Panel on Hydraulic Fracturing.
<https://energy.novascotia.ca/sites/default/files/Report%20of%20the%20Nova%20Scotia%20Independent%20Panel%20on%20Hydraulic%20Fracturing.pdf>
- NHF (2013) The National Harmonised Regulatory Framework for Natural Gas from Coal Seams.
<http://www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/National%20Harmonised%20Regulatory%20Framework%20for%20Natural%20Gas%20from%20Coal%20Seams%2028May%202013%29.pdf>
- NSW (2012) NSW Code of Practice for Coal Seam Gas – Well Integrity.
https://www.resourcesandenergy.nsw.gov.au/_data/assets/pdf_file/0006/516174/Code-of-Practice-for-Coal-Seam-Gas-Well-Integrity.PDF
- NSW (2014) Final Report of the Independent Review of Coal Seam Gas Activities in NSW, September 2014. Office of the Chief Scientist and Engineer of NSW.
http://www.chiefscientist.nsw.gov.au/_data/assets/pdf_file/0005/56912/140930-CSG-Final-Report.pdf
- NT (2018) Scientific Inquiry into Hydraulic Fracturing in the Northern Territory.
<https://facingscientist.nsw.gov.au/inquiry-reports/final-report>
- O'Kane (2014a) Independent Review of Coal Seam Gas Activities in NSW - Managing environmental and human health risks from CSG activities, September 2014. Office of the Chief Scientist and Engineer of NSW.
http://www.chiefscientist.nsw.gov.au/_data/assets/pdf_file/0005/56922/140930-Final-Managing-Environmental-and-Human-Health-Risks.pdf
- O'Kane (2014b) Independent Review of Coal Seam Gas Activities in NSW - Study of regulatory compliance systems and processes for coal seam gas, September 2014. Office of the Chief Scientist and Engineer of NSW.
http://www.chiefscientist.nsw.gov.au/_data/assets/pdf_file/0005/56913/140930-Final-Compliance-Report.pdf
- O'Kane (2014c) Independent Review of Coal Seam Gas Activities in NSW Information paper: Abandoned wells. Office of the Chief Scientist and Engineer 17p.
https://www.chiefscientist.nsw.gov.au/_data/assets/pdf_file/0009/56925/141002-Final-Abandoned-Well-report.pdf
- WEP (2020) Report of the Narrabri Gas Project.

Appendix H: Expert Advice

Advice received from independent experts engaged by the Department is listed in the table below. The advice may be viewed on the Department's website at <https://www.planningportal.nsw.gov.au/major-projects/project/10716> under 'Recommendation'.

Hazards	<ul style="list-style-type: none">• H1-A – Hazards and Risks Expert Advice
Economics	<ul style="list-style-type: none">• H2-A – Economics Expert Advice• H2-B – Economics Expert Advice Appendix
Aboriginal Heritage	<ul style="list-style-type: none">• H3-A – Aboriginal Heritage Expert Advice
Social Impact	<ul style="list-style-type: none">• H4-A – Social Impact Expert Advice• H4-B – Social Impact Expert Advice Appendix

Appendix I: Conditions

See the Department's website at <https://www.planningportal.nsw.gov.au/major-projects/project/10716>