



# Chapter 11

Groundwater and geology



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# Chapter 11 Groundwater and geology

## 11.1 Overview

This chapter addresses the potential environmental impacts of the Narrabri Gas Project on groundwater values within the assessment area. It considers potential changes in the quantity and quality of groundwater sources, potential disturbance to the structural integrity of aquifers and aquitards, and potential impacts on existing bore owners and groundwater dependent systems.

Specifically, the groundwater assessment considers the potential impacts of the project in relation to proposed extraction of 37.5 gigalitres of water over the 25-year assessment period from target coal seams in the Gunnedah Basin. There are no known existing third-party uses of the water for beneficial purposes in these coal seams, which typically have salinity around one third that of seawater. Produced water management, including treatment and beneficial reuse options, is considered in Chapter 7.

Supporting technical studies for this chapter include the project Groundwater Impact Assessment (Appendix F), Groundwater Dependent Ecosystems Impact Assessment Report (Appendix B to Appendix F), Subsidence Assessment (Appendix G to Appendix F) and the Water Monitoring Plan (Appendix G3).

The groundwater assessment has been undertaken to address the Secretary of the NSW Department of Planning and Environment's environmental assessment requirements (Secretary's requirements) for the Narrabri Gas Project, the requirements of the 'water trigger' under the Commonwealth *Environment Protection and Biodiversity Act 1999* (EPBC Act) in relation to coal seam gas and large mining development, the 'minimal impact considerations' established in the NSW Aquifer Interference Policy and the Independent Expert Scientific Committee's (IESC's) checklist of information requirements for modelling groundwater impacts of coal seam gas extraction.

As such, the Groundwater Impact Assessment for the project follows a rigorous procedure and utilises the best available hydrogeological data and water information available at the time of preparing the EIS. The predictions of potential impacts on groundwater sources and their dependent systems in the Groundwater Impact Assessment are based on the results of a groundwater model developed for the project.

The project's Water Monitoring Plan is designed to provide data for management strategies and mitigation measures as they relate to the project's water use and the potential effects of the project on other water users. The Water Monitoring Plan is focused on water assets and receptors, and aims to provide early detection of changes in water resource condition that may have adverse impacts.

It is proposed that hydrogeological data gathered as part of future field operations and groundwater monitoring program will be used to periodically review the impacts predicted in the groundwater assessment and, if necessary, update the modelling. In this way, the Groundwater Impact Assessment and the Water Monitoring Plan are complimentary and have been prepared together to address uncertainty in the modelling predictions, supporting ongoing monitoring of impacts to groundwater over the life of the project.

Overall, the Groundwater Impact Assessment concludes that the residual significance of potential impacts from the Narrabri Gas Project on groundwater are low. Specifically, the groundwater assessment shows that:

- depressurisation in the target coal seams at depth within the Gunnedah Basin would occur rapidly but vertical transmission of depressurisation into shallow overlying water sources in the Surat Basin and Namoi Alluvium would be attenuated in magnitude and delayed in time by thick aquitard sequences located above the target coal seams

- maximum predicted change in groundwater pressure in high-value groundwater sources due to the project is less than 0.5 metres, including less than 0.5 metres drawdown of groundwater pressure in the immediately overlying Pilliga Sandstone aquifer of the Surat Basin, and less than 0.5 metres decline of water table elevation in the Namoi Alluvium aquifer near the northern fringe of the project area
- potential impacts on groundwater in the Pilliga Sandstone and Namoi Alluvium from the project are expected to be indiscernible in relation to the existing variations in the groundwater pressures and storage volumes that occur in response to existing uses and replenishment, with the expectation that these changes would not be perceptible to existing bore owners
- no significant impacts on existing groundwater users or groundwater dependent ecosystems within the assessment area are predicted, including Hardy's Spring and Eather Spring, which are listed as high-priority springs under the Aquifer Interference Policy (refer to Section 11.7) and by the NSW Government's *State of the Catchments 2010 Namoi Region Groundwater* (DECCW 2010c)
- potential for impacts on shallow groundwater sources by poorer quality water in the deeper coal seams is assessed to be negligible because the direction of groundwater flow induced by the project would be downward toward the depressurised coal seams
- potential impacts to water related assets and infrastructure from subsidence caused by depressurisation and compaction of the target coal seams are assessed to be negligible
- no significant risks to groundwater from drill holes and installation of coal seam gas wells and groundwater monitoring bores have been identified
- fault zones would be unlikely to act as conduits for preferential groundwater or gas flows between deep and shallow groundwater sources due to lack of faulting that extends from the Surat Basin into the underlying Gunnedah Basin
- proposed beneficial reuse of treated produced water for crop irrigation on a suitable soil type is likely to have similar impacts as the existing irrigated farms within the assessment area, with the potential benefit of additional local recharge to groundwater in the irrigated area
- managed releases of treated produced water to Bohena Creek when flow in the creek is greater than, or equal to, 100 megalitres per day is not expected to adversely impact the River Flow Objectives and Water Quality Objectives of the Namoi Catchment area.

## 11.2 Regulatory context

The project would operate within an extensive regulatory framework for managing groundwater and surface water and associated environmental values. Both the Commonwealth Government and the NSW Government have set limits on how much water can be taken from groundwater sources and under what conditions. These long-term annual extraction limits define the average amount of water that can be taken each year on a sustainable basis.

The following sections describe and compare the amount of water that would be extracted from target coal seams for the project against the groundwater extraction limits established in relevant Commonwealth and NSW water plans. Brief overviews of the governing legislation, policies and regulations are also provided.

### 11.2.1 Project Water extraction in the Gunnedah-Oxley Basin

The project seeks approval to extract 37.5 gigalitres of water over 25 years from target coal seams in the Gunnedah Basin, which is equivalent in volume to an average rate of extraction of 1.5 gigalitres per year over the 25-year assessment period. Within the context of the groundwater extraction limits defined for water sources that are present in the assessment area, this average annual value (1.5 gigalitres per year) represents:

- 1.3 per cent of the maximum sustainable diversion limit of 114.5 gigalitres per year identified for the Gunnedah-Oxley Basin by the Commonwealth in its Murray Darling Basin Plan
- 0.7 per cent of the maximum sustainable diversion limit (LTAAEL) of 205.6 gigalitres per year currently identified in the Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Source (note: this limit will be replaced by the MDBA limit in July 2019)
- 6.5 per cent of groundwater in the Gunnedah-Oxley Basin that is currently made available to the market (23.1 gigalitres each year)
- 0.4 per cent of the average annual recharge to the Gunnedah-Oxley Basin estimated by the New South Wales Department of Primary Industries – Water (NSW DPI Water) (414.6 gigalitres per year)
- 0.2 per cent of the average annual recharge to the Gunnedah-Oxley Basin identified by the MDBA (624.7 gigalitres per year).

Water extracted as part of the project will only be permitted if there is a water access license in place, and in accordance with the same rules that apply to other activities that extracts water from a regulated water source in NSW.

### 11.2.2 Commonwealth

The groundwater assessment has been undertaken in accordance with relevant Commonwealth environmental and planning legislation, policies, plans and approvals, which are described below.

## Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the principle Commonwealth environmental legislation providing a legal framework to protect and manage listed Matters of National Environmental Significance (MNES). The EPBC Act establishes a process for environmental assessment and approval of proposed actions that have, or are likely to have, a significant impact on MNES. Nine MNES are protected under the EPBC Act, three of which are relevant to this project and have been determined as controlling provisions by the Department of the Environment:

- listed threatened species and communities
- a water resource in relation to coal seam gas development and large coal mining development
- Commonwealth land.

Relevant to this chapter is the assessment of the impact to a water resource, known as the 'water trigger'. The Groundwater Impact Assessment has been prepared to address the EPBC Act policy statement *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments-Impacts on Water Resources* (Commonwealth Government 2013b) which states that:

An action is likely to have a significant impact on a water resource if there is a real or not remote chance or possibility that it will directly or indirectly result in a change to:

- the hydrology of a water resource, and
- the water quality of a water resource,

that is of sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring.

An assessment of the project against the 'water trigger' of the EPBC Act is provided in Section 11.6.

## Water Act 2007

The *Water Act 2007* (Water Act) regulates the management of the water resources of the Murray Darling Basin and establishes an independent Murray Darling Basin Authority (MDBA) with the functions and enforcement powers needed to ensure that the water resources are managed in an integrated and sustainable way. A key function of the Murray Darling Basin Authority includes the preparation of a Basin Plan.

The Murray Darling Basin Plan (the Basin Plan) is guided by the Water Act, which specifies the measures the Basin Plan must contain. An important feature of the Basin Plan is the recommendation that the health of the Basin can be improved by setting a long-term environmentally sustainable level of water take from its rivers of 10,873 gigalitres per year and a volume of 3,324 gigalitres per year for groundwater.

### Water resource plans

Under the Basin Plan, the Commonwealth and State Governments are required to cooperate in the development of water resource plans that incorporate the Basin Plan requirements. Water resource plans set out arrangements to share water for consumptive use. They also establish rules to meet environmental and water quality objectives that take into account potential and emerging risks to water resources. The project would operate within the arrangements for water use and sharing under the plans, and would need to meet the requirements for relevant State water approvals, licensing and management.

The Basin Plan sets the limits on water that can be taken from the Murray Darling Basin, known as long-term average sustainable diversion limits, and provides transitional arrangements to support their implementation. The sustainable diversion limits specify the amounts of water that can be made available for consumptive purposes (including drinking water, and industrial and agricultural uses) while ensuring that there is enough water left in the basin to achieve healthy rivers and groundwater systems. The equivalent name used in the Water Act is the 'environmentally sustainable level of take'.



## Sustainable diversion limits for groundwater

Under the terms of the Water Act, the sustainable diversion limits identified by the Commonwealth will take effect on 1 July 2019, and will replace limits identified in the relevant State Government Water Sharing Plans.

There are a number of areas where it is proposed to decrease the sustainable diversion limits for groundwater relative to the current limits (Murray-Darling Basin Authority 2012). The Namoi region presently has the highest level of groundwater development in NSW and one of the highest levels of groundwater extraction within the Murray Darling Basin; estimated to be approximately 15.2 per cent of current total extraction from the Murray Darling Basin. Table 11-1 lists the current sustainable diversion limits for groundwater regions within the assessment area, as well as the proposed future reduction in the diversion limit within the Namoi Alluvium.

Table 11-1 Proposed groundwater sustainable diversion limits under the Water Act to take effect from 1 July 2019

| Region              | Area                                  | Sustainable diversion limits |                        |                           |
|---------------------|---------------------------------------|------------------------------|------------------------|---------------------------|
|                     |                                       | Current (GL/y)               | Proposed Reduction [%] | Proposed Reduction [GL/y] |
| Namoi               | Lower Namoi Alluvium                  | 86.9                         | 12.8                   | 11.1                      |
| Namoi               | Upper Namoi Alluvium                  | 122.1                        | 22.2                   | 27.1                      |
| NSW GAB             | Southern Recharge <sup>a</sup>        | 42.2                         | -                      | -                         |
| Eastern Porous Rock | Gunnedah-Oxley Basin MDB <sup>b</sup> | 114.5                        | -                      | -                         |

<sup>a</sup> NSW Department of Primary Industries 2015 / 16 NSW Water Register

<sup>b</sup> Murray Darling Basin Plan (2012)

Note: The *Water Act* excludes groundwater of the GAB from the definition of MDB resources - Schedule 1, MDBP.

## Gunnedah-Oxley Basin sustainable diversion limits

Different sustainable diversion limits for the Gunnedah-Oxley Basin currently exist in the NSW and Commonwealth water plans. In July 2019, the Long Term Average Annual Extraction Limits (LTAAEL) defined in NSW Water Sharing Plans will be replaced by the Commonwealth sustainable diversion limits. The current LTAAELs are based on an allowable percentage of the average annual rainfall recharge to groundwater sources. For the Gunnedah-Oxley Basin, the annual recharge rate is estimated to be:

- NSW DPI Water - 414.6 gigalitres per year
- Murray Darling Basin Authority – 624.7 gigalitres per year.

The sustainable diversion limits are:

- NSW Water Sharing Plan for Gunnedah-Oxley Basin – 205.6 gigalitres per year
- Commonwealth Basin Plan for Gunnedah-Oxley Basin – 114.5 gigalitres per year.

NSW DPI Water has also identified an extraction limit for deep groundwater sources for supplementary water access licenses (subcategory 'storage') which is currently set at 0.002 per cent of the total storage capacity. For the Gunnedah – Oxley Basin, a cumulative total of about 214 gigalitres during the life of the Water Sharing Plan is available, which is in addition to the annual sustainable diversion limits (MDBA 2014).

Both the Commonwealth and the NSW water plans protect a specified amount of groundwater for environmental purposes. Under the NSW Water Sharing Plan for the Gunnedah-Oxley Basin, the amount of groundwater set aside for maintaining environmental values is equal to:

- areas with high environmental values – 100 per cent of the long-term average annual rainfall recharge at the commencement of the plan
- areas without high environmental values – approximately 50 per cent of the long-term average annual rainfall recharge at the commencement of the plan
- 99.998 per cent of the long-term groundwater storage.

At present, the total volume of water access licenses for the Gunnedah-Oxley Basin that have been made available to the market is 23.1 gigalitres per year. This amount can only be increased if the NSW Government chooses to release more water through a controlled allocation under the NSW Water Management Act. The 23.1 gigalitres of water currently allowed to be extracted from the Gunnedah-Oxley Basin represents approximately 20 per cent of the maximum sustainable diversion limit of 114.5 gigalitres identified by the Commonwealth Government (refer to Chapter 7).

### *Review of the sustainable diversion limit for the Gunnedah-Oxley Basin*

A mechanism was included in the Basin Plan requiring a review of the long-term average sustainable diversion limits for the Eastern Porous Rock Water Resource Plan area, which includes the Gunnedah-Oxley Basin, to be undertaken within two years of the commencement of the Basin Plan. The stated purpose of the review was to consider all relevant information about the sustainable diversion limit resource unit, including modelling, State planning and policy arrangements and an evaluation of the appropriateness of precautionary factors associated with setting the sustainable diversion limits.

The review panel included members from the IESC, the (then) NSW Office of Water, CSIRO and the Murray Darling Basin Authority (MDBA). Findings were published by the Murray Darling Basin Authority in February 2014. The Panel noted that the (then) NSW Office of Water had provided advice to the MDBA on 6 August 2012 regarding a revision of the sustainable diversion limits for a number of resource units and Water Resource Plan areas, and specifically suggested a revised limit for the Eastern Porous Rock Water Resource Plan area of 146.6 gigalitres per year.

Based on its deliberation, the Panel recommended that:

‘The MDBA could consider varying the sustainable diversion limit to 146.6 GL as suggested by the (then) NSW Office of Water once assurances were made by NSW that they can demonstrate that the resource will be managed via State policies and plans in such a way that impacts are limited to acceptable levels. These assurances would need to be explicit and would include a review of the assets listed in Schedule 3 of the Water Sharing Plan (WSP), an agreement on the criteria that would be used to define acceptable impacts and monitoring, compliance, review and decision making processes.’

Based on this advice, the current MDBA maximum sustainable diversion limit of 114.5 gigalitres per year could be revised upward to 146.6 gigalitres per year if the NSW Government can meet the conditions specified in the recommendation. If this were the case, then the proposed average extraction of 1.5 GL per year of water from the target coal seams for the project would be approximately 1.3 per cent of the revised limit.

### 11.2.3 State

Additional to the Commonwealth requirements outlined in the preceding section, the groundwater assessment has been undertaken in accordance with the relevant NSW environmental and planning legislation, policies and plans. These requirements are described in the following sections.

#### Environmental Planning and Assessment Act 1979

The *Environmental Planning and Assessment Act 1979* (EP&A Act) is the principle legislation in NSW for the management, development and conservation of natural and artificial resources. Under the EP&A Act development consent is required for coal seam gas projects. Section 79C outlines the matters that must be considered when granting development consent, including environmental impacts on groundwater.

#### The Petroleum (Onshore) Act 1991

The *Petroleum (Onshore) Act 1991* (Petroleum Act) applies only to onshore exploration and production of oil and gas. It addresses issues relating to environmental protection and compensation, creates exploration and production titles, and allows for the following approvals to be granted:

- exploration licences
- assessment leases
- production leases
- special prospecting authorities.

#### Water Management Act 2000

The *Water Management Act 2000* (WM Act) dictates how surface water and groundwater resources are managed in NSW. Its main objective is to ensure the future and present supply of water sources at a state level, and protect, develop and restore water resources in the region. It controls the extraction of water, how water can be used, the construction of works such as dams and weirs and the carrying out of activities on or near water sources.

The primary mechanism that the WM Act provides for managing the State's water resources are Water Sharing Plans (WSP). The WM Act will generally apply to surface and groundwater sources in areas where a WSP is in place. In areas where there is no WSP the *Water Act 1912* applies. A number of WSPs apply to the project area. The WM Act requires new mining and petroleum exploration activities that take more than three megalitres per year from groundwater sources to hold a water access licence. WSPs relevant to the project area are described in the following sections.

An approval is required under the Act where aquifer interference activities include:

- the removal of water from a water source; or
- the movement of water from one part of an aquifer to another part of an aquifer; or
- the movement of water from one water source to another water source, such as:
  - from an aquifer to an adjacent aquifer; or
  - from an aquifer to a river/lake; or
  - from a river/lake to an aquifer.

If approval is obtained for the project, groundwater that is taken (extracted) during construction and operation of the project would only be permitted if a water access license is first obtained from the NSW Government. The project would be subject to the same rules that apply to other users of groundwater such as irrigators, water utilities and coal mines. The predicted quantity of produced water to be extracted by the project is 37.5 gigalitres over 25 years.

### Water sharing plans

NSW DPI Water is responsible for developing water sharing plans for rivers and groundwater systems across NSW. These water sharing plans define the rules for sharing water resources between consumptive users and the environment. The relevant plans that are in place in the general area of the project are summarised in Table 11-2.

Table 11-2 Groundwater source licenses

| Relevant Water Sharing Plan                                 | Groundwater Source                              | Long-Term Average Annual Extraction Limits (ML/y) <sup>a, c</sup> | Share component of Aquifer Access Licences (ML/y) <sup>b, c</sup> | Share component of Local Water Utility Access Licences (ML/y) <sup>a</sup> |
|---|---|---|---|--|
| Upper and Lower Namoi Groundwater Sources                   | Upper Namoi                                     | 122,100   | 109,804   | 6,280  |
|   | Lower Namoi                                     | 86,000  | 81,586  | 4,407  |
| NSW Great Artesian Basin Groundwater Sources                | Southern Recharge                               | 29,680  | 24,432  | 3,066  |
| NSW Murray-Darling Basin Porous Rock Groundwater Sources    | Gunnedah – Oxley Porous Rock Groundwater Source | 205,640   | 23,109  | 480  |
| NSW Murray-Darling Basin Fractured Rock Groundwater Sources | Lachlan Fold Belt Groundwater Source            | 875,652   | 68,507  | 2,371  |

<sup>a</sup> Excludes basic landholder rights

<sup>b</sup> Includes access licence categories: Aquifer, Aquifer (High Security), Aquifer (Town Water Supply) and Salinity and Water Table Management

<sup>c</sup> Assumes 1 ML per unit share

### Water access licenses

Relevant water licenses will be required to account for water taken under the project (refer to Table 11-3). The proponent has secured part of the required licences in the Gunnedah-Oxley Basin water source (600 megalitres) to facilitate its exploration activities. An analysis of the water licences available or issued for each water source from which water will be taken (including induced flows) as a result of the project has been undertaken (refer to Appendix F).

Each of the water sources for which licences are required for the project have a readily available market share component which is available to be transferred / purchased by the proponent under the terms of the relevant Water Sharing Plans and the *Water Management Act 2000*.

In the Gunnedah-Oxley Basin MDB Porous Rock Groundwater Source, the proponent requires around 3,650 units during the peak water production in around years 2 to 4. For the remaining period, the proponent requires around 1,500 units.

Table 11-3 Groundwater allocations

| Water Source                              | Predicted Peak Annual Water Take during operations (ML/y) | Predicted Peak Annual Induced flow (during and post operations) (ML/y) | Total Share Component Requirement for Project (Units/ML) | Share Component Currently held by Santos (Units/ML) | Total Number of Licences Issued                  | Total Share Components Issued                           | LTAAEL                    |
|---|---|--|--|---|--|---|---------------------------|
| Gunnedah – Oxley Basin                    | 3,650   | 0  | 3,650<br>(Peak years 2-4)<br>1,500<br>(Long term ave)    | 600   | 142 aquifer<br>3 local utility                   | 23,109 aquifer<br>480 local utility                     | 205,640 ML/yr             |
| Lower Namoi Groundwater Source (2 Zones)  | 0   | 1.0<br>(300 years after start of FDP)                                  | 1 <sup>a</sup>   | Nil   | 213 aquifer<br>3 local utility                   | 81,586 aquifer<br>4,407 local utility                   | 86,00 ML/yr               |
| Upper Namoi Groundwater Source (12 Zones) | 0   | 5.2<br>(250 years after start of FDP)                                  | 6 <sup>a</sup>   | Nil   | 562 aquifer<br>9 local utility                   | 109,804 aquifer<br>6,280 local utility                  | 122,100 ML/yr             |
| GAB Southern Recharge                     | 0   | 57<br>(190 years after start of FDP)                                   | 57 <sup>a</sup>  | 10  | 148 aquifer<br>9 local utility                   | 24,432 aquifer<br>3,066 local utility                   | 29,680 ML/yr              |
| GAB Surat                                 | 0   | 0.2<br>(950 years after start of FDP)                                  | 1 <sup>a</sup>   | Nil   | 51 aquifer<br>10 local utility<br>1 Aquifer (TW) | 5,502 aquifer<br>3,318 local utility<br>25 aquifer (TW) | 35,097 <sup>b</sup> ML/yr |

Source: 2016/17 NSW DPI Water – Water Register

<sup>a</sup> Assumes available water determination of 1

<sup>b</sup> As at 30 June 2014 as advised by DPI Water on 27 July 2016.

There are currently 23,109 aquifer units of share component issued for the Gunnedah-Oxley Basin water source (2016 / 17). Clause 32 of the Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011 provides that the Minister may grant an access licence where the right to apply for the licence has been acquired in accordance with an order made under section 65 of the Act. Section 65 of the WM Act authorises the Minister administering the Act to declare that the right to apply for an access licence for a specified water management area or water source. As Table 11-2 and Table 11-3 demonstrate, the amount of water made available to the market in the Gunnedah-Oxley Basin water source (23,109 megalitres) is significantly lower than the identified Long Term Annual Average Extraction Limit of 205,640 megalitres. There is sufficient water available to facilitate the making of a controlled allocation from the water source. For the peak water production period, it is anticipated that the proponent will utilise a combination of purchasing and leasing share components, which may include requesting the Minister make a controlled allocation of water.

For the remaining water sources, water licences may be required to cover induced water flows that occur over time. As Table 11-3 demonstrates, the maximum annual volumes from the relevant water sources are relatively small. Groundwater modelling for this EIS indicates that the maximum induced flow within the GAB Southern Recharge Water Source is 57 megalitres per year. By way of comparison, using the publically available data shown in Table 11-3, an individual licence in the GAB Southern Recharge Water Source takes on average around 160 megalitres a year. The groundwater assessment indicates that within each of the identified water sources, there is a readily available market from which to obtain licences where required.

In summary, the project will take a relatively small proportion of the available share components from the surrounding groundwater sources. The analysis of the water sources summarised in Table 11-3 demonstrates the ability to obtain the necessary water access licences on an open market to authorise the take of water by the project.

### *NSW Great Artesian Basin Groundwater Sources WSP*

The Great Artesian Basin WSP covers all water contained in the sandstone groundwater sources of the NSW portion of the Great Artesian Basin (GAB). The basin has been divided into five groundwater sources: the Eastern and Southern Recharge Groundwater Sources in the non-artesian eastern fringes of the basin, and the Surat, Warrego and Central Groundwater Sources in the artesian western part of the basin.

The project underlies the Southern Recharge Groundwater Source of the Great Artesian Basin (largely the Pilliga Sandstone). Similar-age rocks within the Oxley Basin are excluded from this Water Sharing Plan. Whilst the Permian strata that underlie the Great Artesian Basin, and from which the coal seam gas extraction is targeted, are excluded from the application of this WSP, the assessment must still consider the potential for indirect impacts.

### *NSW Murray-Darling Basin Porous Rock Groundwater Sources WSP*

The Porous Rock Groundwater WSP covers water-bearing strata within the Murray-Darling Basin not already included in other Water Sharing Plans, including the Gunnedah-Oxley Basin MDB, the Sydney Basin MDB, the Oaklands Basin and the Western Murray Porous Rock. In the context of this project, this WSP establishes the framework for licensing and allocation of groundwater resources within the Gunnedah-Oxley Basin groundwater source and sets limits on the long-term abstraction rates. The project would take a total of 37.5 gigalitres of water over the 25-year assessment period (at an average rate of 1.5 gigalitres per annum) from this deep groundwater source in accordance with the WSP.

The long term average groundwater extraction rate of the project (1.5 gigalitres a year) from the Gunnedah Oxley Basin is presented in Figure 11-1, and for comparison, the total water rights for other relevant water sharing plans are also presented.



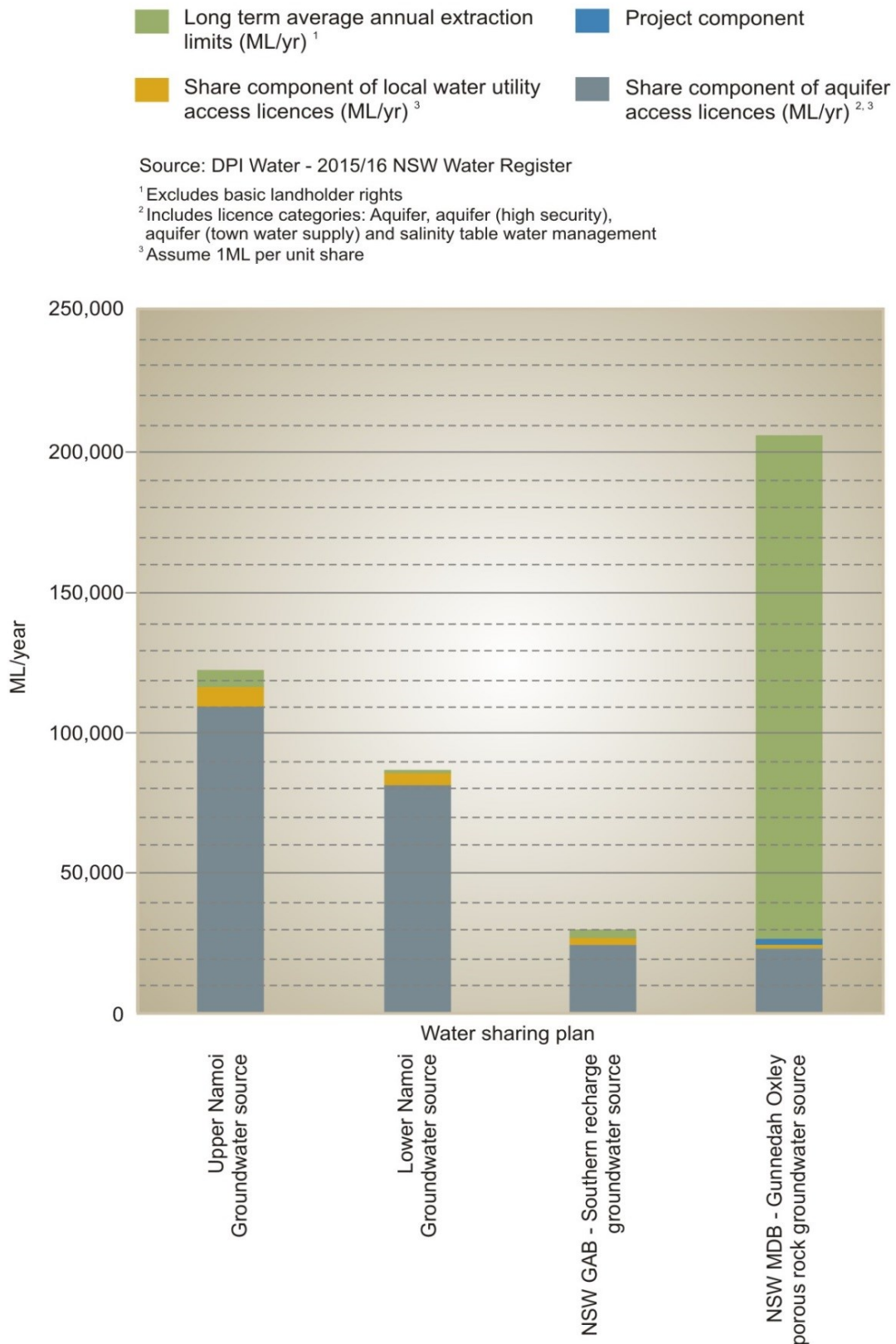


Figure 11-1 Project Average Long Term Assigned Groundwater rights in Groundwater Resources in the Project Area

### *NSW Murray-Darling Basin Fractured Rock Groundwater Sources WSP*

The Fractured Rock Groundwater WSP has designated water management areas in the fractured rock groundwater sources of the Murray-Darling Basin. These cover basalts, granites and fold belts in which groundwater flow occurs principally within fractures in the rock. Three water sources within this WSP fall within the Namoi catchment, which is at or beyond the limits of the model domain surrounding the project area. These water sources are associated with the fractured rocks of the New England Fold Belt MDB, Liverpool Ranges Basalt MDB and Warrumbungle Basalt.

### *Upper and Lower Namoi Groundwater Sources WSP*

The Upper and Lower Namoi groundwater sources WSP include all water contained in the unconsolidated alluvial groundwater sources associated with the Namoi River and its tributaries. These deposits are present at surface within the project area, generally towards the north and east. The current WSP aims to reduce the 'Available Water Determinations' for supplementary water access licences as well as reducing the extraction limit in response to the observed decline in groundwater levels in the Upper and Lower Namoi Alluvium.

### *NSW Great Artesian Basin Shallow Groundwater Sources WSP*

The Great Artesian Basin Shallow WSP covers groundwater resources associated with the alluvial formations and all other formations to a maximum depth of 60 metres below the surface of the ground that overlie the NSW GAB formations and are not included in other WSPs (within the boundaries of the NSW Upper and Lower Namoi Groundwater Sources WSP). The GAB Surat Shallow Groundwater Source extends across the north-western quarter of the project area. This WSP allows for granting of water access licences as part of a controlled allocation order made in relation to unassigned water in this water source.

### *Upper Namoi and Lower Namoi Regulated River Water Sources WSP*

The Namoi and Lower Namoi Regulated River WSP applies to two water sources. The Upper Namoi Regulated River Water Source includes the regulated river sections between Split Rock Dam and Keepit Dam. The Lower Namoi Regulated River Water Source includes the regulated river sections from downstream of Keepit Dam to the Barwon River. While not directly relevant to the project, this WSP would only apply if coal seam gas extraction or coal seam water management activities were found to have an impact on these surface water sources.

### *Namoi Unregulated and Alluvial Water Sources WSP*

The Namoi Unregulated and Alluvial Water Sources WSP incorporates twenty-three unregulated water sources upstream and downstream of Keepit Dam, as well as four alluvial groundwater sources to the east of the Namoi River catchment outside of the project area. This WSP regulates access to all unregulated surface waters.



## Aquifer Interference Policy

The purpose of the NSW Aquifer Interference Policy (AIP) is to explain the water licensing and approval processes and requirements for aquifer interference activities under the WM Act and other relevant legislative frameworks. The Policy has been developed to ensure equitable water sharing between various water users and proper licensing of water taken by aquifer interference activities such that the take is accounted for in the water budget and water sharing arrangements.

The AIP adopts the definition of an aquifer interference activity from the WM Act, which includes the following:

- the penetration of an aquifer
- the interference with water in an aquifer
- the obstruction of the flow of water in an aquifer
- the taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations
- the disposal of water taken from an aquifer (for example, as a consequence of mining or coal seam gas activities).

The AIP specifies that the volume of water taken from a water source(s) as a result of an activity needs to be predicted prior to project approval and that project approval will not be granted unless the Minister is satisfied that adequate arrangements are in force to ensure that no more than minimal harm will be done to a groundwater source or its dependent ecosystems.

An assessment of the project against the requirements of AIP is provided in Section 11.7.

## Strategic Regional Land Use Policy

The Strategic Regional Land Use Policy was introduced in 2012 with the aim of managing potential conflicts between land use activities, including activities associated with the development of coal seam gas resources and farming activities on high-quality agricultural land. The Policy has introduced a range of measures that affect the potential for development of coal seam gas resources, including:

- The Gateway Process, which introduces an additional level of assessment for coal seam gas activities that are proposed on biophysical strategic agricultural land (BSAL). The process requires a scientific assessment of the impacts of mining and coal seam gas production proposals on BSAL and its associated water resources, including an assessment of potential impacts on aquifers by the Minister for Primary Industries and the Commonwealth IESC.
- Coal Seam Gas Exclusion Zones, which have been defined around existing residential areas in all Local Government areas of the State.

## Strategic Regional Land Use Plan – New England North West

The *New England North West Strategic Regional Land Use Plan* (DPE 2012) covers part of the project area. The purpose of the plan is to provide a framework to support growth, protect the environment and respond to competing land uses, whilst preserving key regional values over the next 25 years.

The Plan introduces a gateway assessment process for resolving potential land use conflict between coal seam gas activities, including coal seam water management, and existing agricultural land. Under the gateway process, a panel of independent experts assesses coal seam gas development proposals on or within two kilometres of strategic agricultural land against criteria covering issues, such as soil and groundwater source impacts, impacts on critical industry clusters, and the overall public benefit of the proposal. If a proposal does not pass the gateway, it cannot proceed to the development application stage.

An Agricultural Impact Statement is required for all state significant mining and coal seam gas development applications that may impact agricultural resources, and for all exploration activity requiring approval under Part 5 of the *Environmental Planning and Assessment Act 1979*.

## Groundwater Policy Framework 1997

The main role of the Groundwater Policy Framework is to ensure that the groundwater resources of the state are appropriately maintained and the sustainability of groundwater resources and their support functions to ecosystems are given explicit consideration in resource management decision making. The Groundwater Policy Framework has been constructed with the aid of two NSW policies:

- Groundwater Quality Protection Policy 1998, which provides guidance on how to manage and protect groundwater quality against pollution.
- State Groundwater Dependent Ecosystems Policy 2002, which provides guidance on how to protect ecosystems that rely on groundwater, including their ecological processes and biodiversity.

## Policy for Managing Access to Buried Groundwater Sources

The Policy for Managing Access to Buried Groundwater Sources sets out a framework for how access to water will be managed in groundwater sources that are partly or fully buried. It outlines the limits to access water from storage in porous rock groundwater sources and also the licensing and approval requirements for the take of water from all contributing water sources.

Although not stated, this Policy appears to provide a general and strategic approach for access to groundwater, whilst specific water sharing details are contained within the NSW Water Sharing Plans discussed above.

## 11.3 Methodology

This section describes how the groundwater assessment has been undertaken and the methods that have been used to identify and assess potential impacts to groundwater values within the assessment area. In general, the groundwater assessment follows the broad methodology established for the project assessment as outlined in Chapter 10 – Approach to the impact assessment.

A combination of approaches has been used for the groundwater assessment:

- development of a regional groundwater flow model to predict potential impacts from depressurisation of the target coal seams (refer to Appendix F)
- calculations to predict the potential for subsidence (lowering on the land surface) due to subsurface depressurisation (refer to Appendix F)
- irrigation modelling to predict the potential impacts of reusing treated water for growing crops (refer to Appendix G2).

Further details are provided in the sections below.

### 11.3.1 Baseline data

Data and literature related to the environmental, geological, hydrological and hydrogeological conditions of the groundwater study area have been collected from a number of sources and analysed to establish the physical context for the project and water-related aspects of the project environment. Data that have been used for the groundwater assessment include:

- bore records, including groundwater levels and groundwater quality
- geological core hole and bore log data
- drill stem test measurements
- geophysical surveys
- geological and topographical mapping, including stratigraphic surfaces
- databases and literature pertaining to groundwater dependant ecosystems
- other field data and reports in the vicinity of the project and surrounds
- other supporting studies undertaken for the project.

The baseline monitoring for groundwater is compiled from hydrological records held by Santos and DPI Water, and includes:

- data from 50 monitoring bores with records of groundwater pressure
- data from 41 monitoring bores with records of groundwater quality.

Maps of the bore locations, and statistical summaries and graphs of the baseline data are presented in the Water Baseline Report (refer to Appendix G4).

## Data sources

Technical studies prepared to inform the EIS have relied on various data sets relating to the water environment and in some instances these data sets cover varying historical periods. It should be recognised that the majority of technical studies have used environmental data to investigate the impact of the proposed project on the environment, with the aim of informing semi-quantitative risk assessment and deriving conservative management and mitigation measures. Hence these appraisals are relatively independent of the passage of time and do not require to be continuously refreshed (updated with new data) to remain fully applicable.

Conversely the determination of actual impact of the proposed project, post-commencement, requires up-to-date data to enable an accurate assessment of environmental changes due to the project itself, but and due to natural environmental effects (climatic oscillations) and anthropogenic changes (induced climate change, irrigation and mining-induced effects) which will form the backdrop for the project.

As an example, 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 most 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. Whilst natural fluctuations of water levels may imply a different starting point from which these predicted impacts may be applied, the quantum of these impacts in time and space is relatively invariant. Hence the model predictions are applicable whether the project commenced last year, this year or at some other time in the future. Ongoing baseline monitoring provides the backdrop onto which these predicted impacts should be considered and management and mitigation measures applied to protect the environment and stakeholders.

## Environmental values

Environmental values within the groundwater assessment area, such as existing water supply bores, natural springs and groundwater dependent ecosystems have been identified through desktop assessment (refer to Section 11.4). Extensive fieldworks have also been conducted to provide baseline data for sensitive receptors identified in the desktop studies.

### 11.3.2 Regional groundwater modelling

The Groundwater Impact Assessment (refer to Appendix F) contains a detailed description of the regional groundwater model, including conceptualisation, model design and construction, and how the model has been used for predictive simulations. This section provides a summary of that information.

The groundwater modelling has been conducted based on the guiding principles and concepts established in the *Australian Groundwater Modelling Guidelines* (Barnett *et al.* 2012) and taking into account the recommendations of the IESC on Coal Seam Gas and Large Coal Mining Development in relation to modelling groundwater impacts of coal seam gas extraction (Commonwealth of Australia 2014).

The numerical groundwater model is assessed against the model confidence level criteria contained in the *Australian Groundwater Modelling Guidelines* (Barnett *et al.* 2012). On this basis, it is considered to be fit for purpose for predicting potential regional impacts on groundwater and surface water from the proposed water extraction from deep coal seams in the Gunnedah Basin. The numerical model is judged to have a confidence level of Class 1 to 2 based on the criteria established in the guidelines.

The groundwater model has also been independently reviewed by the CSIRO (refer to Appendix F of Appendix F).

## Conceptual model

The hydrogeological conceptual model is a statement and explanation of the key hydrological and geological processes that operate in the assessment area and which are relevant to the assessment of potential impacts from the project. The hydrogeological conceptual model therefore forms the basis for establishing the environmental values of groundwater and provides a platform for developing a numerical groundwater model. An important aspect of the conceptual model is the consideration of past, present and potential future states of groundwater within the context of the proposed project activities and other third-party activities that may contribute to cumulative impacts.

The hydrological conceptual model developed in the Groundwater Impact Assessment (Appendix F) is based on:

- the available baseline data (refer to Section 11.3.1)
- review of the existing environment and associated groundwater values (refer to Section 11.4)
- the objectives of the predictive groundwater modelling.

## Numerical model

A regional-scale numerical groundwater flow model of the Gunnedah-Oxley Basin and overlying parts of the Great Artesian Basin and Namoi Alluvium has been developed for the project based on the hydrogeological conceptual model outlined above. The groundwater model is used to predict the potential impacts on groundwater sources within the assessment area due to depressurisation of the target coal seams, which is simulated by extracting a prescribed volume of water from the coal seams.

A detailed description of the numerical model and predictive simulations conducted for the project is contained in the Groundwater Impact Assessment (Appendix F).

## Modelling programs

The model has been developed using MODFLOW-SURFACT™ (SURFACT) running under the Groundwater Vistas graphical user interface. Customised scripts were written in Python and ArcGIS™ to perform additional pre- and post-processing tasks. The geometry and layering of the SURFACT model is based on a geological model developed in Leapfrog Hydro with fourteen hydrostratigraphic layers.

## Model extent

The model boundary is designed to fully contain the anticipated impacts of the project on regional groundwater resources as well as other activities that may contribute to cumulative impacts. The total active area of the SURFACT model is 53,219 square kilometres (29,988 cells per model layer) with a minimum cell size of 1 square kilometre (smallest scale of predictions) and maximum cell size of 25 square kilometres.

## *Model calibration*

The model has been matched to average water table elevations in the Namoi Alluvium and average groundwater pressures in the Pilliga Sandstone aquifer of the Great Artesian Basin. As the deep groundwater sources are of poor quality and not utilised for water supply, there are no historical data in the deep strata hosting the target coal seams against which to match the model.

## *Hydrogeological properties*

The adopted values of hydrogeological properties for the rock and formation types represented by the groundwater model are based on a detailed review of the available information sources, including aquifer test data and field investigations, literature review, and review of values used in existing groundwater models.

## *Predictive capability*

The groundwater model has been designed for the purpose of assessing the potential impacts of water extraction from deep coal seams in the Gunnedah basin on the region's surface water and groundwater resources. Special attention has been paid to the following aspects of the model's design to ensure that its predictive capabilities are suitable for the purposes of the groundwater assessment:

- SURFACT was chosen as the preferred modelling program (refer above) because of its improved predictive capabilities compared to the standard MODFLOW 2005 code, including better capability for drying and re-wetting of discontinuous hydrostratigraphic units and more accurate tracking of the water table (Panday and Huyakorn 2008)
- considerable care has been taken to define regional model boundaries that do not influence the model's predictive capability within the project area; a detailed discussion of the model boundaries is provided in the Groundwater Impact Assessment
- special attention has been paid to vertical discretisation of aquitards above and below the target coal seams to improve the predictive accuracy of the model with respect to vertical transmission of depressurisation from the coal seams into overlying water sources (refer to Groundwater Impact Assessment)
- the approach adopted for representing the depressurisation of the target coal seams is faithful to the proposed volumes of water to be extracted from the seams, and thereby provides the predictive capability to track the contributions from all water sources to total water production over time; this is a key requirement of the Aquifer Interference Policy
- the model design allows recharge and discharge at the water table to change in response to changes in groundwater pressure induced by water extraction from the target coal seams, and thereby provides a predictive capability to simulate the recovery of groundwater pressure and storage after the project ceases; without this capability, pressure would be lost and would not recover.

The peer review of the model by CSIRO (refer below) concludes that the model '...can be considered state of art and is suited to assess the potential impacts of water extraction for coal seam gas depressurisation on the surface water and groundwater resources in the Gunnedah Basin district'.

## *Predictive simulations*

Predictive simulations have been conducted in the Groundwater Impact Assessment for three volumes of water production for the project over the 25-year assessment period: the Base Case simulated water production of 37.5 gigalitres; the Low Case of 35.5 gigalitres; and the High Case of 87.1 gigalitres. These simulations and the results are described in the Groundwater Impact Assessment (Appendix F). The Base Case is the estimate of water production being used as the basis for the project construction and design concept.

The modelled base case for the project simulates historical water production from coal seam gas pilots in the Gunnedah Basin and future extraction of 37.5 gigalitres of water from coal seams over the 25-year assessment period for the Narrabri Gas Project.

The simulated water production from the target coal seams includes:

- historical water production from the existing twelve gas pilots within the Gunnedah Basin, (approximately one gigalitre)
- future water production from Early Permian coal seam targets (35.6 gigalitres)
- future water production from Late Permian coal seam gas targets (1.89 gigalitres).

The base case predictive simulation spans a period of approximately 1,520 years, including 19 years of historical water production from coal seam gas pilots, 25 years of future water production from the project, and a recovery period of approximately 1,475 years after the project ceases.

## *Cumulative impacts*

The groundwater model has been used to assess the potential cumulative impacts from the Narrabri Coal Mine Stage 2 Longwall Project and the Narrabri Gas Project. Inflow to the Narrabri Coal Mine (represented as groundwater extraction) has been simulated as 22.6 gigalitres over 29 years based on the results of existing groundwater modelling of the mine (Aquaterra 2009).

Other existing and approved mines are not included in the modelling in this assessment because the potential for significant cumulative impacts from those operations and the project has been assessed to be minor based on the existing environmental assessments of those projects.

## *Model sensitivity*

A number of simulations have been performed with the groundwater model to investigate the sensitivity of the model results to changes in the assumptions and inputs to the modelling. These simulations and the results are described in the Groundwater Impact Assessment (Appendix F). As well as testing the sensitivity of the model results to variation in the assumed properties of the aquifers and aquitards, the sensitivity simulations include low and high case estimates of water production from the target coal seams. The low and high case simulations address uncertainty in the estimated volumes of produced water from the seams based on potential variation in the porosity of the coals (a measure of the spaces within the coal where water is stored).



## Peer review

A scientific peer review of the numerical model has been conducted by CSIRO Land and Water in accordance with the groundwater review principles outlined in the Australian Groundwater Modelling Guidelines (Barnett *et al.* 2012). Full details of the review are included as an appendix to the Groundwater Impact Assessment Technical Report (refer to Appendix F).

The review was based on an assessment of the draft model report and final model files followed by response to queries and a formal review of the final documentation. The CSIRO's key findings include:

- the model is fit for purpose and provides a justified assessment of changes in water balance, pressure head and water table levels
- the confidence level of the model is the highest which can be achieved at the modelled spatial and temporal scale
- vertical hydraulic conductivity is a key factor in the propagation of depressurisation and is supported by the findings of the faulting study which indicates that the target coal seams are effectively separated from the Pilliga Sandstone and are largely unaffected by faulting
- the model predictions of maximum amount of depressurisation, timing of maximum amount of depressurisation, time-series of exchanges fluxes between Water Sharing Plans are adequate for the prediction of impacts of the project.

The CSIRO review concluded that the regional groundwater model for the Gunnedah Basin could be considered 'state of the art' and was suited to assess potential impacts of water extraction for coal seam gas depressurisation on the surface water and groundwater resources in the Gunnedah Basin district.

### 11.3.3 Subsidence estimation

Estimates of the potential for subsidence to occur as a result of subsurface depressurisation from the project have been made using two predictive methods (refer to Appendix F):

- Linear Elastic Theory method (used previously in subsidence calculations for the Surat Basin, Queensland, such as Santos Coal Seam Gas Water Monitoring and Management Plan and accepted by the then Commonwealth Department of Sustainability, Environment, Water, Populations and Communities at the time of preparation)
- the Compaction at a Specific Location method (described in IESC, 2014).

Both methodologies estimate subsidence of the coal seam due to compaction from depressurisation. The difference between the two methodologies is the parameter used to describe the deformation of rock. The Linear Elastic Theory method uses Young's Modulus, an elastic property of the rock, to represent the rock type. The Compaction at a Specific Location method considers the ratio of axial compression to lateral strain using Poisson's Ratio with Young's Modulus used to calculate a coefficient of volume compressibility. Both calculations assume that ground conditions are uniform, compaction is one-dimensional, and linear elastic ground compaction.



### 11.3.4 Crop irrigation modelling

Details of the methodologies used to assess the potential impacts of growing irrigated crops with treated water from the project are contained in Appendix G2.

Detailed irrigation modelling using the HowLeaky program has provided estimates of recharge to the water table beneath the irrigated area, which in turn have been used to assess potential impacts of the irrigation concept on shallow groundwater sources.

The broad approach used to assess the potential impacts of irrigated cropping has included a combination of information surveys and water and salt balance modelling as listed below:

- review of available literature, maps and geographical information to identify cropping history and soil boundaries within the study area
- site visits and discussions with local agronomists, agri-businesses and farmers to identify suitable crop types for the assessment area
- preliminary irrigation modelling to assess land area requirements for various crop types and to estimate water storage requirements
- review of amended water quantity and quality characteristics (refer Chapter 7)
- review of quality and surface water quality and soil characteristics and (refer Chapters 12 and 14 respectively)
- salt balance estimation and assessment of potential soil limitations in accordance with *Environmental guidelines: Use of effluent by irrigation* (DEC 2004)
- further identification of cropping options based on soil assessment
- development of conceptual layout and design of irrigation infrastructure
- detailed irrigation modelling using the HowLeaky program to assess crop water consumption and water storage requirements
- development of operation, management and monitoring plans.

## 11.4 Existing environment

This section provides information about the existing environment of the project area that is relevant to the groundwater assessment; it includes overviews of:

- geology – providing the context for groundwater resources and the project gas resource
- hydrostratigraphy – how the geological layering relates to groundwater storage and flow
- groundwater – a description of the groundwater resources of the assessment area
- surface water – a description of the surface water resources and their connections with groundwater
- hydrogeological conceptualisation – a statement of understanding of the key hydrological processes operating within the assessment area that are relevant to the impact assessment, including the existing hydrological conditions and the potential future hydrological conditions with coal seam gas development
- environmental values – the importance of groundwater for environmental uses (e.g. groundwater dependent ecosystems and stygofauna).

More detailed descriptions of this information are contained in the Groundwater Impact Assessment (refer to Appendix F).

### 11.4.1 Geology

The project area is located within two sedimentary geological basins:

- Gunnedah Basin (Permo-Triassic Age) which contains the target coal seams for the project
- overlying Coonamble Embayment of the Surat Basin (Jurassic-Cretaceous Age).

The extents of the Gunnedah and Surat Basins within the assessment area, and the region over which they overlap can be seen in the map of surface geology in Figure 11-3.

The Gunnedah Basin covers an area of more than 15,000 square kilometres and forms the central part of the Sydney-Gunnedah-Bowen Basin system. The Gunnedah Basin contains up to 1,200 metres of marine and non-marine sediments that rest unconformably on basement rocks of Early Permian Age and older. The Permian Age sediments in the Sydney-Gunnedah-Bowen Basin system represent a major coal province in Eastern Australia.

Overlying the Gunnedah Basin is the Coonamble Embayment of the Surat Basin, which itself forms the western province of the Great Artesian Basin (GAB). The Coonamble Embayment contains mostly Jurassic Age clastic (made up of rock fragments) sedimentary strata and lower Cretaceous Age marine beds extending over the western part of the Gunnedah Basin.

Areas of higher and lower elevation of the basement rocks underlying the Gunnedah Basin form a number of sub-basins. The central Mullaley Sub-basin occupies the main part of the Gunnedah Basin and is further sub-divided into four troughs; from north to south they consist of the:

- Bellata Trough
- Bohena Trough
- Bando Trough
- Murrurundi Trough.

The project area is located within the Bohena Trough, which is described in more detail below.

### Geology of the project area

From land surface to the basement rocks, the local geology of the project area is characterised by:

- unconsolidated alluvial and colluvial surface deposits (superficial deposits)
- Surat Basin strata
- Gunnedah Basin strata of the Bohena Trough
- meta-volcanic basement rocks.

Figure 11-2 is a schematic of the project area geology (including the target coal seams) and the relevant water sharing plans for the project area.

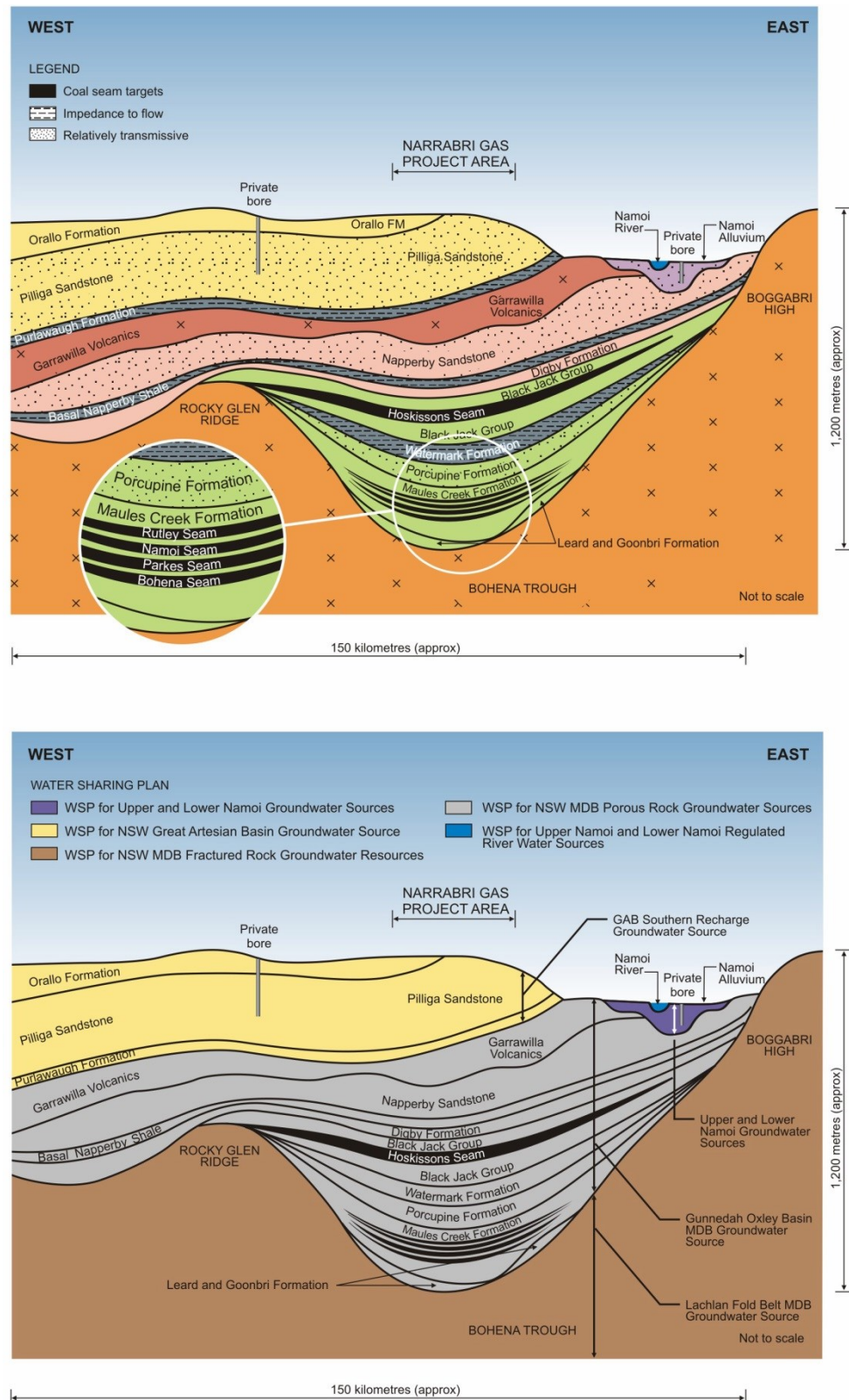


Figure 11-2 Schematic of geology of the project area showing target coal seams, and the applicable water sharing plans

The surface geology (refer to Figure 11-3) consists mainly of shallow superficial deposits underlain by the strata of the Surat and Gunnedah Basins, with areas where the basin strata outcrop directly at the surface. Brief descriptions of the characteristics of the stratigraphic units within the above sequences are contained in Figure 11-4 (Section 11.4.2).

The superficial deposits mainly contain unconsolidated strata of the Gunnedah and Narrabri formations (not formal stratigraphic names). The Gunnedah formation contains up to 115 metres of gravel and sand with minor clays. The overlying Narrabri formation consists of up to 70 metres of extensive clays with minor channel sands and gravels. The distributions of the Gunnedah and Narrabri formations is controlled by the existing major drainage patterns, with these sediments occupying the valley-fill bottom of the Namoi River and its tributaries. The combined thickness of the Narrabri and Gunnedah formations within the Gunnedah Basin is approximately 170 metres.

From shallow (youngest) to deep (oldest) the Surat Basin strata consist of the Orallo Formation (part of the Blythesdale Group), Pilliga Sandstone, Purlawaugh Formation and the Garawilla Volcanics at the base of the sequence. The Pilliga Sandstone contains gently dipping medium to coarse grained well sorted quartzose sandstones with conglomerates and minor thin siltstone and mudstone interbeds and coals extending up to 300 metres thick the south of the Coonamble Embayment. The Purlawaugh Formation generally consists of thinly interbedded carbonaceous claystone and siltstone with minor thin coal seams, and the Garawilla Volcanics mainly consist of volcanic flows and pyroclastic deposits infilling relic topographical lows, and are therefore discontinuous across the region.

The Gunnedah Basin strata include the Deriah Formation, Napperby Formation and Digby Formation, all of Triassic Age, which overlie the Black Jack Group (Late Permian Age), Millie Group (Middle Permian Age) and the Bellata Group (Early Permian Age) at the base of the sequence. The Napperby Formation ranges in thickness from 25 metres over the Rocky Glen Ridge to approximately 215 metres in the central east of the Mullaley Sub-basin. The Digby Formation is typically around 40 metres thick in the Bohena Trough and is divided into three subdivisions; basal conglomerate, overlain by a lithic sandstone unit, and topped by a quartzose sandstone unit.

The Black Jack Group is formed by the Brothers Sub-group at its base, which includes the Pamboola Formation and Arkarula/Brigalow Formation; the Coogal Sub-group, which includes the Hoskissons Coal, Benelebri Member and Clare Sandstone; and the Nea Sub-group at its top, which includes the Wallala Formation and Trinkey Formation. The maximum thickness of Black Jack Group within the Bohena Trough is approximately 185 metres, although the average thickness is likely to be around 140 metres. The Black Jack Group thins out against the eastern flank of the Rocky Glen Ridge and does not extend west of the Bohena Trough.

The Millie Group consists of the Porcupine Formation and overlying Watermark Formation. The thickest sequence of these formations is likely to be around 225 metres in the central part of the Bohena Trough.

The Bellata Group, containing the Lead Formation, Goonbri Formation and Maules Creek Formation is generally a sequence of alluvial, fluvial and colluvial deposits containing coal seams in the Maules Creek Formation, which include the primary target coal seams for the project. The Maules Creek Formation contains approximately 50 per cent lithic conglomerates and coarse sandstone, 40 per cent claystone, siltstone and fine to medium grained sandstone, and 10 per cent coals.

## Faults

An assessment of faulting within the study area has been undertaken, based on an examination of the available seismic lines to identify major faulting, including the fault types, their extents and probable ages (refer to Appendix F).

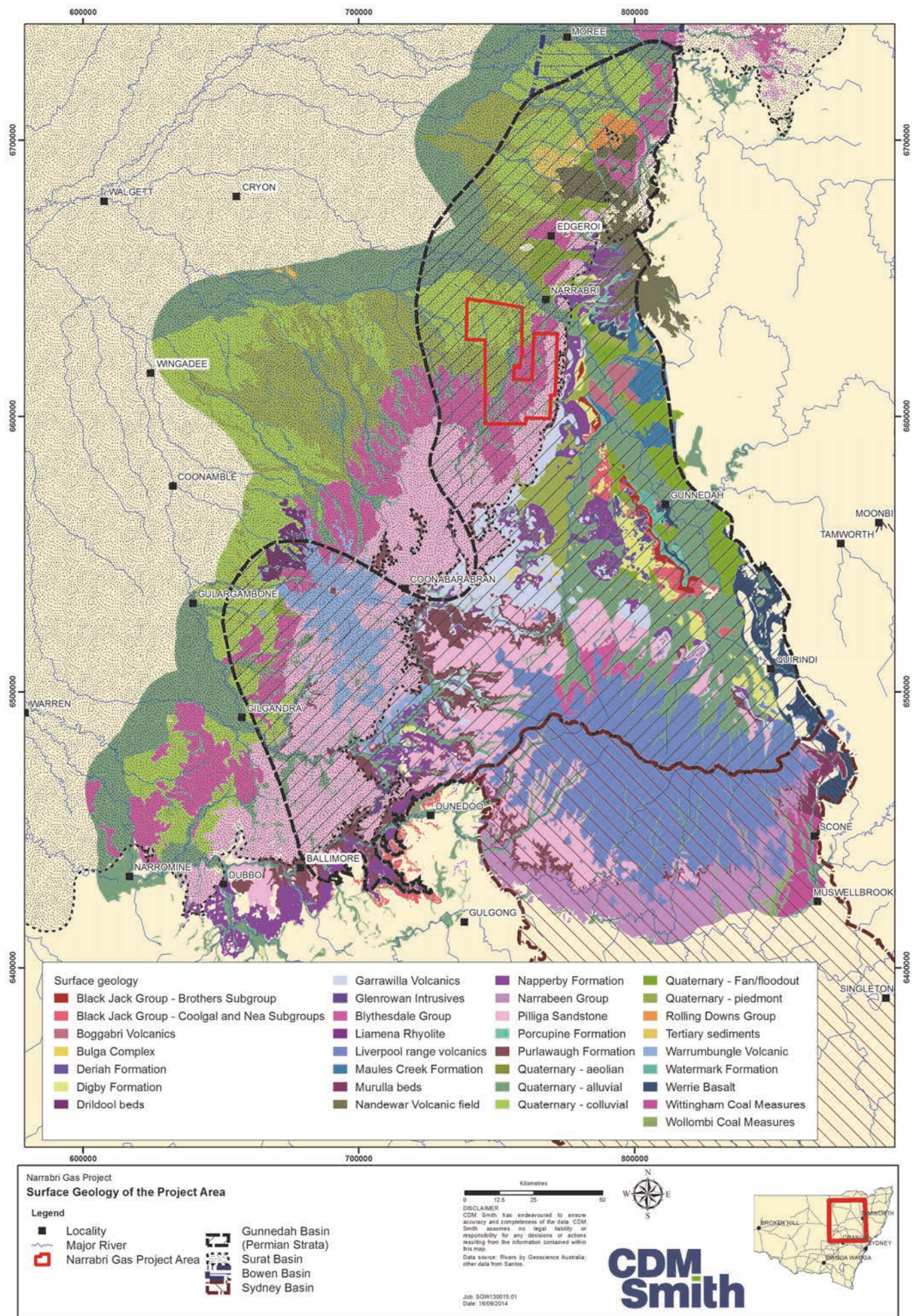
Four main phases of structural activity and faulting are identified:

- The Early Permian phase initiated the Gunnedah Basin as a discrete structural feature. In the project area, the Early Permian phase initiated the Bohena and Bellata troughs and their infill with the Boggabri Volcanics and the Leard, Goonbri and Maules Creek formations, including the Early Permian coals.
- The Middle Permian to Middle Triassic phase was marked by the development of the Gunnedah Basin as a foreland basin, and included east–west compression associated with subduction. In the project area, the compressional forces resulted in differential subsidence, compressional anticlines and basin inversion, and the formation of reverse and thrust faults. Anticlines are generally bounded at depth by high angle reverse faults, which rarely extend higher than the Late Triassic unconformity. Listric faults formed on the crests of some of the larger anticlines (such as at the property known as Wilga Park, within the project area).
- The Jurassic-Cretaceous phase featured the formation of the Surat Basin through intra-cratonic sag. Sediment deposition occurred in association with slow, relatively even and laterally extensive subsidence with little deformation. Within the project area, local structuring is characterised by drape over basement highs, subsidence caused by compaction above Permian and Triassic depocentres, and differential reactivation.
- The Tertiary phase was marked by intrusive and extrusive igneous activity, uplift of eastern NSW with tilting and erosion of the Surat Basin sequence, and gentle folding of Jurassic rocks with very minor fault reactivation.

The majority of the faults in the project area are found to be Permian to Triassic in age and mainly displace Permian Age and (to a lesser extent) Triassic Age strata, with the amount of displacement being less than 100 metres. From the seismic data, no evidence has been found of large post-Jurassic age faults that displace Jurassic Age strata and extend into underlying Triassic and Permian Age strata. Where it is present, surface faulting and displacement in the Jurassic Age strata is found to be minor.

A key conclusion of the faulting study is that strata located between the target coals seams and the overlying Surat Basin and superficial sediments are largely unaffected by faulting.





Narrabri Gas Project - Gas Field  
 Environmental Impact Statement

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Regional Surface Geology

Figure 11-3



## 11.4.2 Hydrostratigraphy

The term hydrostratigraphy describes how the layering of sedimentary geological deposits relates to groundwater storage and flow. Sedimentary sequences are rarely uniform in material type, texture and arrangement, and typically contain many strata with varying capacities to store and transmit water—both laterally within strata and vertically across strata. A common practice in hydrogeology is to divide or group geological layers into hydrostratigraphic units that share similar hydrogeological characteristics. These hydrostratigraphic units are generally used as the basis for developing conceptual and numerical groundwater models.

Figure 11-4 shows how the geological layers in the assessment area (refer to Section 11.4.1) have been grouped into hydrostratigraphic units based principally on their capacity to transmit water; this property of strata is known by hydrogeologists as ‘transmissivity’. For example, a hydrostratigraphic unit with large transmissivity can transmit more water than a unit with low transmissivity. The following classification of hydrostratigraphic units has been adopted for the groundwater assessment:

- significant transmissive units (STU)
- less significant transmissive units (LSTU)
- probable negligibly transmissive units (PNTU)
- negligibly transmissive units (NTU).

It can be seen from Figure 11-4 that the significant transmissive units (STUs) include the shallow alluvial Gunnedah and Cubaroo formations within the valley-fill of the Namoi River and its tributaries (Namoi Alluvium), the Pilliga Sandstone of the Great Artesian Basin (GAB), and coal seams within the Black Jack Group and Maules Creek Formation of the Gunnedah Basin. Less significant transmissive units (LSTUs) include the Garrawilla Volcanics at the base of the Surat Basin and the Clare Sandstone in the Gunnedah Basin, all of which exhibit less transmissivity or significance to groundwater flow than the STUs. Probable negligibly transmissive units (PNTUs) include much of the late Permian and late Triassic Age strata in the Gunnedah Basin. Negligibly transmissive units (NTUs) include the early and mid-Permian and early and mid-Triassic Age strata, which closely correlate with the most effective aquitards.

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

Further detail and rationale for this classification of hydrostratigraphic units is contained in the Groundwater Impact Assessment (refer to Appendix F).

| Province                 | Period/<br>Epoch | Division | Group                             | Sub-group         | Formation  | Lithology and hydrogeological classification   | Trans-<br>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<br>(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  |   |      |  |   |      |
|                          |                  | Late     |                                   |                   |  |  | STU  |   |      |  |   |      |
|                          | Jurassic         | Middle   |                                   |                   | Purlawaugh Fm  | Fine to medium grained sandstone thinly interbedded with siltstone, mudstone and thin coal seams   | NTU  |   |      |  |   |      |
|                          |                  | Early    | Garrawilla Volcanics              |                   |  |  |  | LSTU  |      |  |   |      |
|                          | Late             |          |                                   |                   |  | Dolerite, basalt, trachyte, tuff breccia   | LSTU   |   |      |  |   |      |
|                          | Gunnedah Basin   | Triassic | Middle                            |                   |  | Deriah Fm  | Sandstone  | PNTU  |      |  |   |      |
|                          |                  |          |                                   |                   | Napperby Fm  | Interbedded fine sandstone, claystone an siltstone   | PNTU   |   |      |  |   |      |
|                          |                  |          |                                   |                   |  | Basal Napperby Shale   | NTU  |   |      |  |   |      |
|                          |                  |          |                                   |                   | Digby Fm   | Quartzose sandstone (Ulinda Ss)  | NTU  |   |      |  |   |      |
|                          |                  |          |                                   |                   |  | Lithic sandstone   | NTU  |   |      |  |   |      |
|                          |                  |          |                                   |                   |  | Lithic conglomerate (Bomera Conglomerate)  | NTU  |   |      |  |   |      |
|                          |                  | Nea      |                                   | Trinkeby 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  |      |  |   |      |
|                          |                  |          |                                   |                   |  | 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 11-4 Hydrostratigraphic classification



## Hydraulic conductivity of aquitards

Direct measurements have been made of the hydraulic conductivity of rock samples from the assessment area. They include samples recovered from core holes in the Bando Trough from the Napperby and Digby Formations (Triassic Age), Porcupine Formation (Permian Age), Pilliga Sandstone and Purlawaugh Formation (Jurassic Age) and Orallo Formation (Cretaceous Age). Additional measurements have been made through Drill Stem Tests (DSTs) performed on selected coal seams, mainly within the Maules Creek Formation in the Bohena Trough. Further measurements have been derived from pumping tests conducted in groundwater monitoring bores installed within the vicinity of the project area. These measurements collectively have contributed toward the conceptualisation of the hydrogeology of the region, and informed the selection of parameter values for the numerical groundwater model.

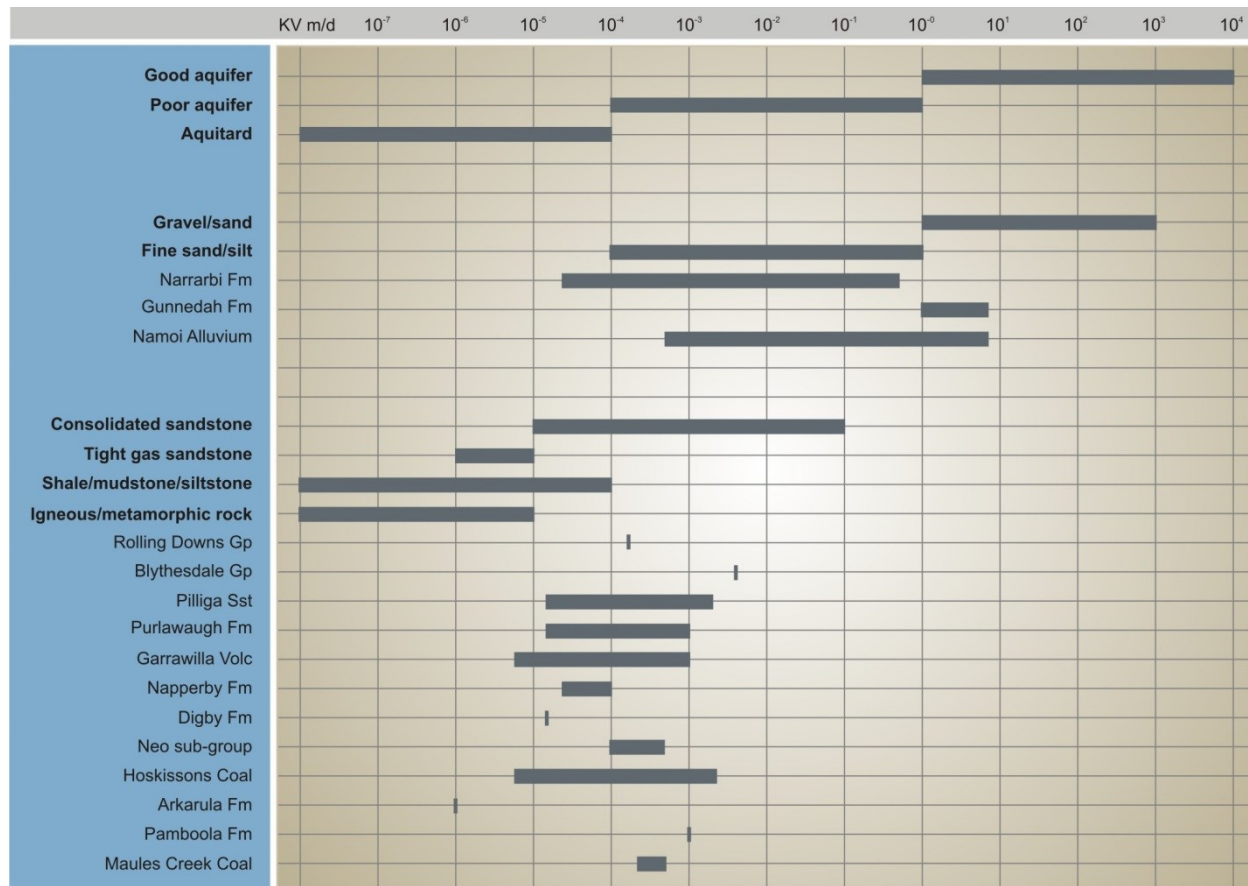
The water quality within hydrostratigraphic units can provide insight about movement and mixing of groundwater between the units, and contribute to the hydrogeological conceptualisation. Groundwater within the Permo-Triassic Age strata of the Bohena Trough is characteristically saline whilst groundwater qualities in the Namoi Alluvium and Pilliga Sandstone are typically much less saline, particularly at or near the outcrop of the Pilliga Sandstone. This difference in water quality of deep and shallow groundwater, when considered in conjunction with the characteristic hydraulic conductivities of the strata, the geological structure of the Bohena Trough and other evidence indicate that groundwater exchange between deep and shallow groundwater sources is likely to be very minimal.

Aquitards within the assessment area and beneath parts of the project area include some strata belonging to the Blythesdale Group, the Purlawaugh Formation, the basal Napperby Shale, parts of the Digby Formation, the Benelebri Member, the Watermark and Porcupine Formations and strata lying between the target coal seams of the Maules Creek Formation. Other aquitards are present in the geological sequence but when considered relative to the above-named strata, are less significant in impeding groundwater flow throughout the basin.

Directly to the east of the Pilliga Sandstone outcrop, the density of groundwater bores decreases sharply, correlating with the presence at surface of the typically low-permeability Permo-Triassic strata from which the extraction of economic quantities of water commonly is not possible. The highest density of bores in the region correlates very closely with the extent of the Namoi Alluvium, which, due to its relatively large hydraulic conductivity (Gunnedah and Cubbaroo formations) supports the largest individual water extractions. Good quality groundwater is easily extracted from these sediments and consequently, over-extraction during the twentieth century has led to a sharp decline in the alluvial water table.

In addition to, and in some cases in the absence of, reported field data, published literature values of hydraulic conductivity and calibrated values from existing groundwater models have been used to determine the likely range of values of hydraulic conductivity for use in the groundwater modelling. Published data on hydrogeological properties are not available for all formations present in the assessment area and the range of values available from field measurements typically represent a small number of measurements at a specific location; therefore, the results of such reviews should be carefully interpreted. For example, taken in isolation, the data shown in Figure 11-5 could indicate that the Pilliga Sandstone and Purlawaugh Formation have similar hydrogeological properties. In fact, it is known from existing utilisation of groundwater sources in the region that the Pilliga Sandstone is a major regional water supply aquifer and the Purlawaugh Formation is a relatively low to non-yielding formation that is not generally targeted for water supply. In this situation, it is reasonable to adopt values of hydrogeological properties for the Pilliga Sandstone that are characteristic of a water supply aquifer from within the range of existing estimates, and to adopt values of hydrogeological properties for the Purlawaugh Formation that are characteristic of a formation that does not yield usable water supplies from within the range of existing estimates.

A more detailed discussion of hydrogeological properties for strata within the assessment area is contained in the Groundwater Impact Assessment (Appendix F).



**Bold categories** are literature values (Bear 1972, Table 5.5.1; Freeze and Cherry 1979, Table 2.2; [http://petrowiki.org/Rock\\_type\\_influence\\_on\\_permeability](http://petrowiki.org/Rock_type_influence_on_permeability))

Figure 11-5 Vertical hydraulic conductivity from selected hydrogeological literature

## 11.4.3 Groundwater

### Groundwater resources

In the context of the Murray-Darling Basin Plan, the project lies within several groundwater resource plan areas including the New South Wales Great Artesian Basin Shallow (GW13), Namoi Alluvium (GW14), Eastern Porous Rock (GW16) from which the extraction of water for the project would occur, and the New England Fractured Rock groundwater resource (GW17).

Groundwater allocation, sharing and licencing within the assessment area is managed under six NSW Water Sharing Plans (WSPs), which define eight groundwater sources. Details of the WSPs groundwater sources are given in Section 11.2.3 (Table 11-2) and Figure 11-2, and include:

- shallow alluvial groundwater (Upper and Lower Namoi Groundwater Sources)
- shallow alluvial groundwater outside of the extent of the Namoi Alluvium (Great Artesian Basin Shallow Groundwater Sources)
- shallow groundwater within the Pilliga Sandstone (Great Artesian Basin Southern Recharge Groundwater Source)
- deeper groundwater within porous rocks of the Gunnedah Basin, including the Permian and Triassic Age strata in the Bohena Trough (Gunnedah-Oxley Basin Groundwater Source).

Shallow groundwater sources are generally of good quality and used for a diverse range of activities. Deeper groundwater in the Gunnedah Basin is less used due to its greater depth, inferior water quality, and the availability of more accessible shallower sources.

## Groundwater use

The Namoi catchment accounts for approximately 15 per cent all groundwater use in the Murray-Darling Basin and has the highest level of groundwater development in NSW (CSIRO 2007). There are over 18,000 groundwater bores in the Namoi catchment, which are licenced to extract 343,000 megalitres per year (Green *et al.* 2011). Of this entitlement, 95 per cent is used for irrigation and the remaining 5 per cent is used for industrial, stock and domestic water.

In general, groundwater resources in the assessment area are highly developed within the shallow alluvial sources occupying the valley-fill deposits of the main rivers and their major tributaries, and there is also a large number of abstractions from the Pilliga Sandstone. There is no known beneficial use of groundwater from the target coal seams in the Maules Creek Formation or from strata or coal seams of the Black Jack Group. Extraction of groundwater from bores represents the largest removal of groundwater from alluvial sources. Pumping from the Namoi Alluvium is estimated to be greater than 90 per cent of the total losses from the Lower Namoi alluvium (Merrick 2001) and greater than 85 per cent of the total losses from the Upper Namoi GMA zones (McNeilage 2006).

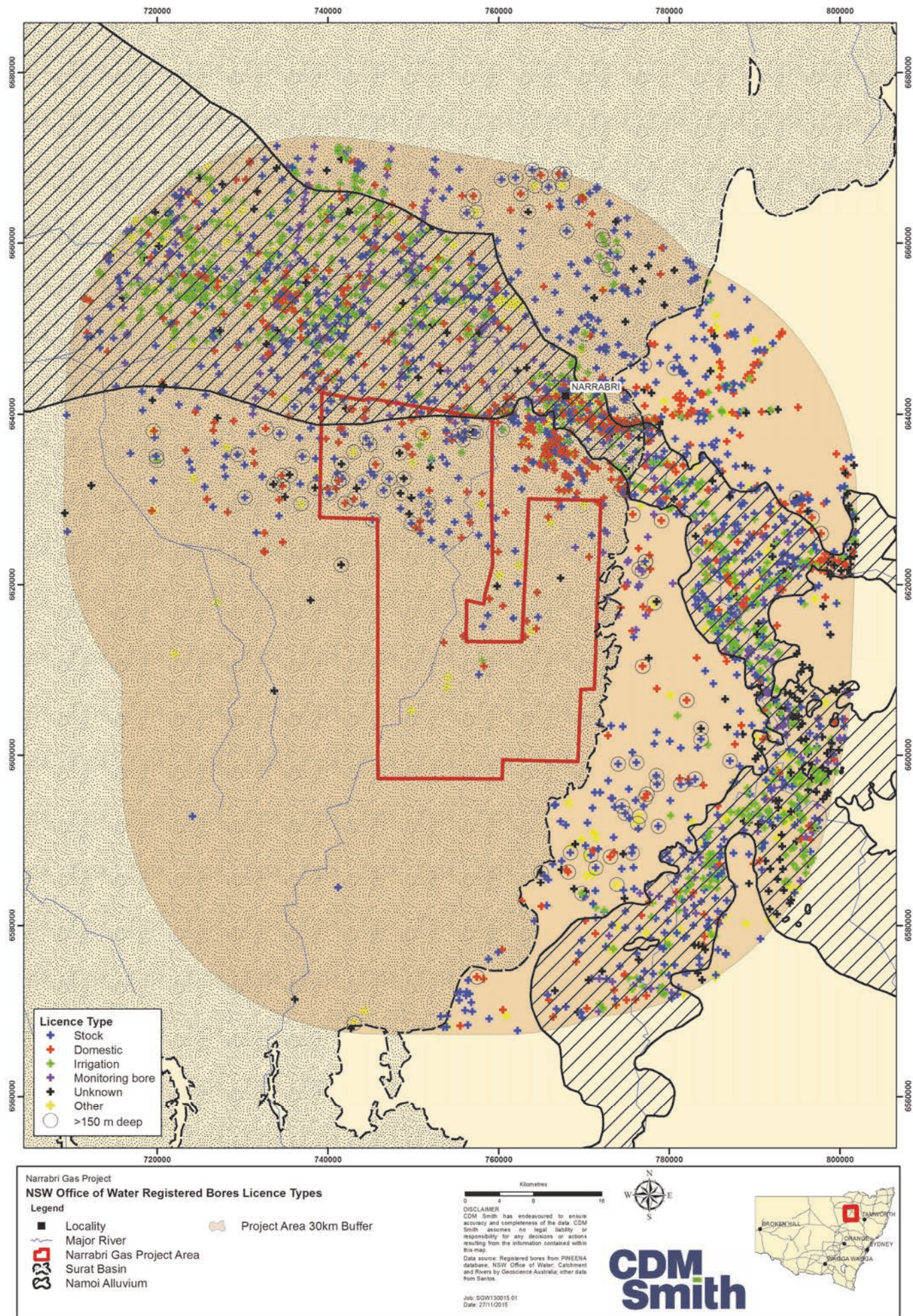
## Groundwater bores

Within the NSW Government's PINNEENA (v.4.1, October 2013) database, there are 4,682 registered bores within 30 kilometres of the boundary of the project area. The locations of bores and the licence types can be seen in Figure 11-6, which also shows the relatively small number of bores that are deeper than 150 metres. Review of the intended uses and target water sources for the bores has found that:

- most bores (around 97 per cent) are less than 150 metres deep and tap shallow groundwater sources within the Namoi Alluvium and the Pilliga Sandstone
- most of the bores deeper than 150 metres are within the Great Artesian Basin Groundwater Management Area, and are most likely screened within the Pilliga Sandstone, which is typically 150 to 300 metres thick in the project area
- bores to the south and south-east of the project area are 150 to 270 metres deep and possibly screened within the Garrawilla Volcanics
- approximately 15 bores appear to target groundwater sources east of the project area within the outcrop area of the Gunnedah Basin, situated between the southern recharge beds of the Pilliga Sandstone and the Namoi Alluvium.

Figure 11-7 shows a graphical summary of the types of groundwater bore licences located within 30 km of the boundary of the project area. Around one-third (33 per cent) of these bores are registered stock watering, 23 per cent each for domestic and irrigation uses, and seven per cent each for groundwater monitoring, 'other' and unknown uses.



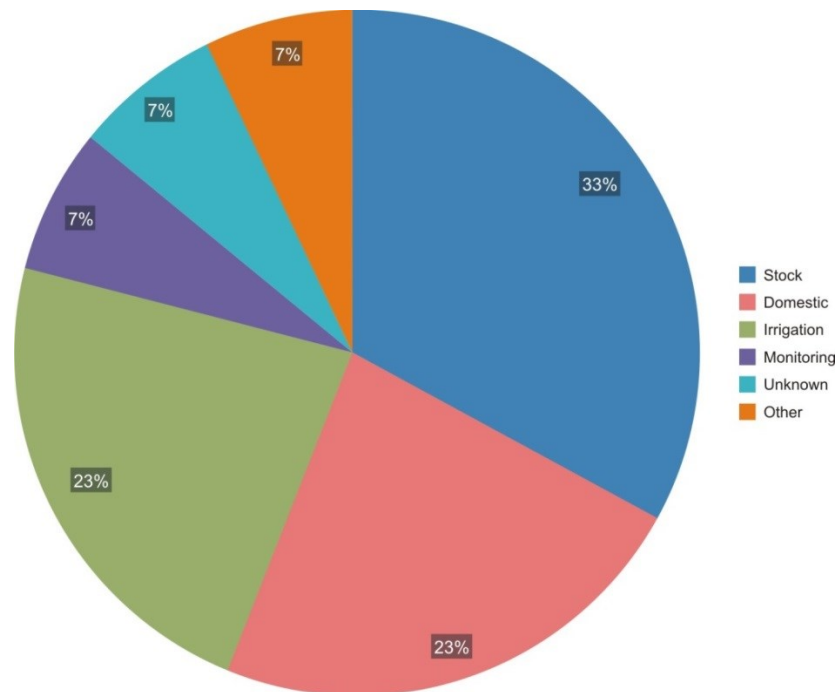


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Groundwater bore locations within  
 30km of the project area boundary **Figure 11-6**





Source: NSW DPI Water - PINNEENA (v.4.1) groundwater database

Figure 11-7 Groundwater bore licence types within 30 kilometres of the project area boundary

## Groundwater head and flows

The assessment area contains unconfined alluvial groundwater sources and variably unconfined and confined groundwater sources within the Great Artesian Basin (GAB) and Gunnedah-Oxley Basin. The shallow and deep groundwater sources are separated vertically by aquitards with potential for interaction largely limited to areas where the basin strata subcrop at the base of the alluvium.

Within the alluvial groundwater sources, the regional water table is topographically controlled and generally follows the fall of the land surface along the river and stream valleys. Measurements of water table elevation held within the NSW Government's PINNEENA (v.4.1) database are sparse outside of the alluvial areas of the Gwydir, Namoi, Castlereagh and Macquarie River alluvia. The direction of regional groundwater flow within the Upper Namoi Alluvium is generally northerly and follows the courses of the Mooki and Namoi Rivers and Coxs Creek. The alluvium narrows near the township of Narrabri before broadening into a substantial fluvial fan that forms the Lower Namoi Alluvium where the regional direction of shallow groundwater flow is north-westerly.

Within the Pilliga Sandstone aquifer of the GAB, artesian groundwater pressure (flowing bores) occur to the west of the recharge beds and project area. The direction of regional groundwater flow in the Pilliga Sandstone is generally northwest and consistent with the broader northwest flow direction within the Coonamble Embayment from the recharge beds of the Pilliga Sandstone toward the Bogan River Spring Group discharge area. Groundwater pressure in artesian bores where the Pilliga Sandstone subcrops beneath the Lower Namoi alluvium is above the elevation of the water table in the alluvium, which shows a hydraulic potential for upward leakage of groundwater into the alluvium from the underlying GAB aquifer.

Groundwater within the Coonamble Embayment is isolated from the Surat Basin to the north, which is also hydraulically disconnected from the Eromanga and Carpentaria Basins of the GAB.

## Groundwater balance of Namoi Alluvium

Previous groundwater modelling studies of the Lower Namoi Alluvium (Merrick 2001) and Upper Namoi Alluvium (McNeillage 2006) have provided estimates of the groundwater balances for these systems. Of particular interest to the groundwater assessment are the estimated annual inflows and outflows to the alluvium as they provide context for understanding the relative magnitude of expected water production from the project. The Lower and Upper Namoi groundwater models were also used by CSIRO for groundwater assessments of the Namoi Catchment as part of the *Murray-Darling Basin Sustainable Yields (MDBSY)* report (CSIRO 2007).

Summaries of the modelling results from these studies are presented in Table 11-4 and Table 11-5.

The rates of total inflow and outflow from the Namoi Alluvium (i.e. the total amounts of water entering and leaving the alluvium each year) were estimated to be around 135 to 172 gigalitres per year. Groundwater extraction by bores was the largest outflow and estimated to be 135 to 154 gigalitres per year. In comparison with these estimates from the modelling, extraction records held by NSW DPI Water show that annual extraction from the Namoi Alluvium has varied from around 150 to 300 gigalitres per year during the past 20 years (refer to Appendix F).

The project would require the extraction of approximately 37.5 gigalitres of groundwater from the Gunnedah-Oxley Basin Groundwater Source over 25 years, which is an average extraction rate of 1.5 gigalitres per year from deep groundwater sources that are hydrologically disconnected from the Namoi Alluvium. On the basis of this comparison, significant impacts on the water balance of the Namoi Alluvium from the project are not anticipated.

**Table 11-4** Water balance results from the Lower and Upper Namoi groundwater models

| Estimate  | Lower Namoi groundwater model 1980–1998 <sup>a</sup> |      | Upper Namoi groundwater model 1985–2001 <sup>b</sup> |      | Combined total rates |      |
|---|--|------|--|------|----------------------|------|
| Period of balance (years)   | 18.3   |      | 15   |      | 15 – 18.3            |      |
| Net inflow rate to model (gigalitres per year, and % of total inflow)     |  |      |  |      |                      |      |
| Rivers  | 41.3   | 57%  | 10.97  | 17%  | 52.27                | 38%  |
| Rainfall, irrigation and floods   | 21.1   | 29%  | 49.34  | 78%  | 70.44                | 52%  |
| Boundaries  | 1.8  | 3%   | 3.06   | 5%   | 4.86                 | 4%   |
| Artesian  | 7.9  | 11%  | n.a.   | 0%   | 7.9                  | 6%   |
| Total net inflow  | 72.1   | 100% | 63.37  | 100% | 135.47               | 100% |
| Net outflow rate from model (gigalitres per year, and % of total outflow) |  |      |  |      |                      |      |
| Rivers  | 1.6  | 2%   | 8.99   | 13%  | 10.59                | 7%   |
| Extraction  | 77.6   | 94%  | 57.53  | 86%  | 135.13               | 91%  |
| Boundaries  | 3.2  | 4%   | 0.36   | 1%   | 3.56                 | 2%   |
| Total net outflow   | 82.4   | 100% | 66.16  | 100% | 148.56               | 100% |
| Loss  | -10.3  |      | -3.45  |      | -13.75               |      |

<sup>a</sup> Adapted from Merrick (2001, Table 4.1)

<sup>b</sup> Adapted from McNeillage (2006, Table 6.1)

Note: Rounding errors may apply

Table 11-5 Water balance results from the Murray Darling Basin Sustainable Yield study using the Lower and Upper Namoi groundwater models

| Estimate  | Lower Namoi groundwater model Scenario A <sup>a</sup> |      | Upper Namoi groundwater model Scenario A <sup>a</sup> |      | Combined total rates |      |
|---|---|------|---|------|----------------------|------|
| Balance period (years)  | 111   |      | 111   |      | 111                  |      |
| Net inflow rate to model (gigalitres per year, and % of total inflow)     |   |      |   |      |                      |      |
| Rivers  | 32  | 40%  | 23.9  | 33%  | 55.9                 | 36%  |
| Rainfall, irrigation and floods   | 41  | 51%  | 45.1  | 62%  | 86.1                 | 56%  |
| Boundaries  | 8   | 10%  | 3.9   | 5%   | 11.9                 | 8%   |
| Total net inflow  | 81  | 100% | 72.9  | 100% | 153.9                | 100% |
| Net outflow rate from model (gigalitres per year, and % of total outflow) |   |      |   |      |                      |      |
| Rivers  | 6   | 6%   | 2.4   | 3%   | 8.4                  | 5%   |
| Extraction  | 83  | 85%  | 69.6  | 94%  | 152.6                | 89%  |
| Boundaries  | 9   | 9%   | 1.7   | 2%   | 10.7                 | 6%   |
| Total net outflow   | 98  | 100% | 73.7  | 100% | 171.7                | 100% |
| Loss  | -17   |      | -0.8  |      | -17.8                |      |

Source: CSIRO (2007)

<sup>a</sup> Historical climate and current development' scenario

Note: Rounding errors may apply

## Groundwater quality

Shallow groundwater sources within the assessment area are generally of good quality and used for a diverse range of activities. Deeper groundwater in the Gunnedah Basin is less used due to its greater depth, inferior water quality, and the availability of more accessible and better quality sources.

Water quality data from monitoring bores in the assessment area are available from the NSW Government's PINNEENA database, and additional water quality data for the project area have been collected as part of the ongoing baseline water monitoring (refer to Appendix G4 – Water Baseline Report). Based on this data, a summary of groundwater quality data for the assessment area is presented in Table 11-6.

Overall, the available data on groundwater quality show that:

Overall, the available data on groundwater quality show that:

- groundwater within alluvium is generally fresh (defined as less than 500 milligrams per litre (mg/L) total dissolved solids (TDS) to brackish (defined as 500 to 3,500 mg/L TDS) and has an alkaline pH (approximately 8)
- groundwater in the Pilliga Sandstone is fresh and has neutral pH (approximately 7)
- groundwater in Permo-Triassic strata of the Gunnedah-Oxley Basin tends to be brackish to saline (defined as 3,500 to 35,000 mg/L TDS) and has alkaline pH (approximately 9)
- groundwater within target coal seams is saline and has alkaline pH (approximately 8).

Table 11-7 contains a more detailed summary of water quality results from the target coal seams within the Maules Creek Formation. The seams generally have groundwater quality known as sodium-bicarbonate type because sodium and bicarbonate represent the most abundant positive and negative ions contributing to salinity.

More generally, the quality of water extracted from coal seams in the project area can be variable and is influenced by the local geology in the area of a coal seam gas well. Dependent on the local groundwater flow pathways towards an operating well, the quality of produced water may remain relatively consistent throughout the lifetime of the well or more commonly, it will change over time due to induced groundwater flow from bounding strata with differing water qualities.

Further details on groundwater quality and the chemistry results in the project area can be found in Appendix G4.

**Table 11-6 Regional groundwater quality**

| Hydrostratigraphic unit                         | Mean EC <sup>a</sup><br>( $\mu$ S/cm) | Equivalent TDS <sup>b</sup><br>(mg/L) | Mean pH |
|---|---------------------------------------|---------------------------------------|---------|
| Namoi Alluvium                                  | 697                                   | 446                                   | 7.9     |
| Bohena Creek Alluvium                           | 559                                   | 358                                   | 6.8     |
| GAB – Orallo Formation                          | 1,030                                 | 659                                   | 7.4     |
| GAB – Pilliga Sandstone                         | 402                                   | 257                                   | 6.2     |
| GOB – Digby, Napperby and Purlawaugh Formations | 4,785                                 | 3,062                                 | 9.2     |
| GOB - Black Jack Group                          | 14,158                                | 9,061                                 | 8.2     |
| GOB - Maules Creek Formation                    | 14,134                                | 9,046                                 | 7.9     |

<sup>a</sup> Electrical conductivity – a measure of water salinity

<sup>b</sup> Total dissolved solids – an alternative measure of water salinity

**Table 11-7 Groundwater quality of the Maules Creek Formation**

| Parameter              | Units      | No. of Samples | Minimum | Mean   | Maximum |
|------------------------|------------|----------------|---------|--------|---------|
| EC <sup>a</sup>        | $\mu$ S/cm | 227            | 4,980   | 14,134 | 21,700  |
| pH                     | log        | 227            | 6.2     | 7.9    | 9.3     |
| Bicarbonate alkalinity | mg/L       | 223            | 119     | 8,010  | 14,124  |
| Chloride               | mg/L       | 223            | 264     | 1,401  | 3,280   |
| Fluoride               | mg/L       | 52             | 3       | 5.7    | 10.8    |
| Calcium                | mg/L       | 192            | 1.8     | 18.4   | 162     |
| Magnesium              | mg/L       | 214            | 1       | 10.2   | 45      |
| Sodium                 | mg/L       | 233            | 1,200   | 4,147  | 7,360   |
| Potassium              | mg/L       | 233            | 107     | 107    | 773     |

<sup>a</sup> Electrical conductivity – a measure of water salinity



### 11.4.4 Surface water

The project area is located within the surface catchment of the Namoi River, which represents approximately 3.8 per cent of the area of the Murray-Darling Basin (MDB). The Namoi catchment is bounded to the east by the ridge of the Great Dividing Range, to the north by the Gwydir catchment, to the south by the Castlereagh, Macquarie and Hunter catchments and to the west by the Barwon-Darling catchment.

The boundary of the project area is predominately located within the Lower Namoi sub-catchment on gentle north and northwest valley-facing slopes. The flat open floodplain of the Namoi River is situated to the north and west of the project area, with steep to undulating and mostly vegetated land to the east and south. Mount Kaputar National Park is located approximately 50 kilometres to the northeast, and the Warrumbungle Ranges are approximately 112 kilometres to the south.

The Lower Namoi sub-catchment commences at Narrabri, which is considered to be the start of the true riverine zone of the Namoi catchment due to the increased frequency of lagoons, the low gradient of the channel and the development of several anabranches and effluent channels (NSW Office of Water 2011). The lower Namoi is regulated by two major weirs downstream of Narrabri; Mollee Weir and Gunidgera Weir.

Flow regimes in the rivers and major streams within the assessment area have been analysed using daily stream flow records held in the NSW Government's PINNEENA database. The following classification is based on the frequency at which daily flows exceed one megalitre per day:

- perennial – stream flow exceeds 1 megalitre per day more than 90 per cent of the time
- intermittent – stream flow exceeds 1 megalitre 10 to 90 per cent of the time
- ephemeral – stream flow exceeded 1 megalitre less than 10 per cent of the time.

The Namoi River is perennial, while the majority of the tributaries, including Bohena Creek are intermittent. In general, tributaries below Narrabri (e.g. Pian Creek and Baradine Creek) make minor or no contribution to flow in the Namoi River. A summary of stream flow statistics derived from the PINNEENA database is given in Table 11-8.

Table 11-8 Stream flow statistics

| Location                | Station Number | Median Flow (ML/d) | Average Flow (ML/d) | Contributing Catchment Area (km <sup>2</sup> ) |
|-------------------------|----------------|--------------------|---------------------|--|
| Namoi at Gunnedah       | 419001         | 520                | 1704                | 17,10  |
| Namoi at Narrabri       | 419002         | 1.7                | 787                 | 25,100   |
| Narrabri Ck at Narrabri | 419003         | 616                | 1550                | 25,120   |
| Namoi at North Cuerindi | 419005         | 150                | 566                 | 2,510  |
| Namoi D/S Keepit Dam    | 419007         | 101                | 738                 | 5,700  |
| Namoi River at Boggabri | 419012         | 325                | 1619                | 22,600   |
| Namoi River at Manilla  | 419022         | 205.0              | 794                 | 5,180  |
| Coxs Ck at Boggabri     | 419032         | 0                  | 199                 | 4,040  |
| Mooki at Caroona        | 419034         | 7.3                | 199                 | 2,540  |
| Namoi River at Mollee   | 419039         | 567                | 2021                | 28,200   |
| Pian Creek at Waminda   | 419049         | 3.7                | 238                 | Unknown  |

| Location                              | Station Number | Median Flow (ML/d) | Average Flow (ML/d) | Contributing Catchment Area (km <sup>2</sup> ) |
|---------------------------------------|----------------|--------------------|---------------------|--|
| Maules at Avoca East                  | 419051         | 8.2                | 51.5                | 663  |
| Cox Ck at Mullaley                    | 419052         | 0                  | 172                 | 2,370  |
| Namoi DS Gunidgera weir               | 419059         | 228                | 1324                | 28,500   |
| Gunidgera Ck DS Regulator             | 419061         | 125                | 319                 | Unknown  |
| Gunidgera-Pian cutting at Merah North | 419063         | 22.4               | 93.0                | Unknown  |
| Mooki at Rouvigne                     | 419084         | 0.3                | 353                 | 6,600  |
| Bohena Ck at Newell highway           | 419905         | 0                  | 127                 | 2,000 (estimated)                              |

## Surface water-groundwater connectivity

Interaction (exchange of water) between groundwater and surface water is commonly classified according to the direction of water movement across the stream bed:

- gaining stream – the river or stream gains water by groundwater flowing into the stream across the streambed; thus, the elevation of the water table adjacent to the stream is higher than the water level in the stream
- losing stream – the river or stream loses water by surface water flowing out of the stream across the stream bed; thus, the elevation of the water table adjacent to the stream is lower than the water level in the stream.

A stream can have gaining and losing conditions at different locations along its length, and these conditions can change in time from gaining to losing, or losing to gaining, due to changes in water table elevation and surface water level over time. A stream is considered to be 'connected' to groundwater if there is direct saturated contact with the water table, with both gaining and losing conditions possible. When an unsaturated zone is present between the stream bed and the underlying water table, the stream is considered to be 'disconnected', with only losing conditions possible.

Existing studies that were undertaken to assess the degree of connection between surface water and groundwater within the Namoi Catchment have showed that surface drainage lines located within the steeper upland regions, mainly in the eastern part of the catchment tend to be gaining streams, whereas surface drainage in low relief areas tend to be losing streams (Ivkovic 2006). The downstream reaches of the Namoi River between Wee Waa and Walgett was identified as disconnected and losing (CSIRO 2007). The CSIRO study found that the lower Namoi River had changed from a river that gained water from groundwater, prior to development of the groundwater resources in the alluvium, to a river that now loses considerable stream flow volumes to groundwater.

Whilst there is connectivity between the Namoi River and Namoi alluvium, there is no direct connection between the Namoi River and the GAB or Gunnedah Basin. Connection between the Namoi Alluvium and Pilliga Sandstone aquifer of the GAB occurs 10 to 15 kilometres northeast of the project area but both of these sources are hydrologically isolated from the target coal seam for the project by thick sequences of intervening aquitards (refer to Section 11.4.2).

### 11.4.5 Hydrogeological conceptualisation

On the basis of available groundwater and surface water information, the assessment area can be conceptualised as containing three connected hydrological systems with distinct spatial extents and dynamics. From smallest and most dynamic to largest and least dynamic they consist of:

- surface water sources – within rivers and streams, with hydrological response times of hours, days and weeks
- shallow alluvial groundwater sources – along river courses and streams with response times of weeks, months and years
- deep groundwater sources – within Jurassic to Permian Age hydrostratigraphic units, with hydrological response times of decades, centuries and possibly millennia.

The primary source of recharge water to the assessment area is from atmospheric precipitation, which imparts regional climate dynamics on surface water flows and groundwater levels. Daily variations of rainfall and evaporation that can be seen in rivers and streams are damped within the alluvial groundwater system, which typically exhibits seasonal and longer period dynamics in water table elevation and flow. The deep hydrostratigraphic units have much larger response times and follow multi-decadal dynamics and longer climate trends.

River and stream flows occur in response to rainfall and runoff, with connections to alluvial groundwater sources occurring by water exchanges across river and stream beds. Over annual time scales, the daily and seasonal exchanges between rivers and alluvium are damped by the slower response of the groundwater system caused by slow movement of groundwater compared to surface water, and the limited area of connection. On average, for a given section of stream there is either net loss of surface water to the alluvium (a losing stream) or there is net gain of groundwater draining into the river (gaining stream).

The direction of flow across the base of alluvial sediments containing groundwater is controlled by the difference in elevation between the water table in the alluvium and groundwater pressure in the underlying hydrostratigraphic units, with an expectation of complex flow patterns. Net inflow across the base of the alluvium is generally anticipated at the margins of the Namoi Alluvium due to topographical control of shallow groundwater flow toward valleys. Beneath central parts of the Namoi Alluvium, net outflow from the alluvium to deeper groundwater sources may occur where water table elevation in the alluvium is greater than groundwater pressures in the Gunnedah Basin to the west.

Counter balancing groundwater flow from the deep hydrostratigraphic units back to shallow aquifers occurs in lower lying areas within the western part of the assessment area, where artesian head occurs in the GAB and probably the Gunnedah Basin.

### Current state

The assessment area contains unconfined alluvial groundwater sources and variably confined and unconfined groundwater sources within the GAB and Gunnedah-Oxley Basin. The shallow and deep groundwater sources are separated vertically by aquitard systems, with some potential for interaction between deep and shallow sources where basin strata subcrop beneath the alluvium.

The regional water table within the alluvial system is topographically controlled and generally follows the fall of the land surface along the river and stream valleys. Recharge to the alluvium is from rainfall infiltration, irrigation and episodic flooding. Throughout most of the assessment area the river systems are losing streams, and therefore provide a net source of groundwater recharge. The entire Namoi River within the Lower Namoi Groundwater Management Area (GMA) and around two-thirds of the river within the Upper Namoi GMA zones was classified as a losing stream (CSIRO 2007). The remaining section of

river between the townships of Boggabri and Narrabri was classified as a gaining stream; however, it follows that a portion of the groundwater gained in this section of river is lost back to the alluvium further downstream where the river is losing.

Extraction from bores represents the largest removal of groundwater from alluvial sources. Pumping from the alluvium is estimated to be greater than 90 per cent of the total loss from the Lower Namoi (Merrick 2001) and greater than 85 per cent of the total loss from the Upper Namoi GMA zones (McNeillage 2006). The study by CSIRO (2007) found that the lower Namoi River has changed from a river that gained water from groundwater, prior to the development of groundwater resources, to a river that now loses considerable stream flow volumes to groundwater. Annual groundwater extraction is estimated to exceed total annual recharge in most years.

The inferred recharge area of the Permo-Triassic Age strata within the Gunnedah Basin is located along the eastern margin of the basin where the units are exposed at outcrops and where they subcrop younger shallow sediments. The recharge area corresponds broadly to the extent of the Upper Namoi alluvium, where there is potential for groundwater in the alluvium to leak downward into the basin strata in subcrop areas. Jurassic units within the GAB onlap the Gunnedah Basin from the west and it is expected that artesian pressures are present in the Permo-Triassic Age units where they underlie the GAB; particularly where the GAB has artesian pressure.

The regional distribution of groundwater pressure and associated groundwater flow patterns within the Gunnedah Basin are less well understood due to less measurements and lack of investigation and interest in these water sources. Where the Surat and Gunnedah Basins are both present, it is expected that the patterns of groundwater pressure and flow in the Gunnedah Basin will broadly reflect those within the GAB. A regional groundwater flow divide is expected within the Gunnedah Basin in the southeast of the assessment area, representing the divide between groundwater drainage northwest toward the GAB and groundwater drainage southeast toward the Sydney Basin. It is likely that the location of the divide corresponds broadly with the regional topographic divide defined by the Liverpool Ranges.

## Potential future state with coal seam gas development

Coal seam gas production is achieved by removing water to depressurise the target coal seams. The potential impact of water production during coal seam gas development depends on how much water is removed and the ultimate source for replacement of that water. It is possible to conceptualise four water balance adjustments that may occur to counter balance coal seam water production:

- a decrease in groundwater storage in the subsurface
- a decrease in groundwater discharge from the subsurface
- an increase in groundwater recharge to the subsurface
- a combination of the above, changing over time.

At the commencement of depressurisation of a coal seam the produced water must be derived from local storage in the seam. The zone of depressurisation that forms at an extraction location expands within the production seam and is slowly transmitted into the bounding and connected strata. Depressurisation does not mean that the strata are drained of water. Very locally, within a producing coal seam, the pore space becomes partly filled with gas, and this gas displaces the water that was previously stored. Strata that bound the coal seam remain fully saturated with water but the pressure in the water is lower than before gas production.

When the total water balance of the subsurface is considered, it follows that water production from coal seams can only induce a decrease in groundwater discharge or an increase in groundwater recharge when the zone of depressurisation reaches areas where water is lost or gained (e.g., at the water table or connected surface water features). Decline of groundwater pressure at a discharge area (sink) will reduce

the rate of discharge, whereas decline of groundwater pressure adjacent to a recharge area (source) will increase the rate of recharge. When either of these conditions occur, a portion of the produced water volume is effectively counter balanced by less discharge or more recharge, or a combination of both. After water production ceases, the subsurface remains depressurised but begins to gain storage from the induced changes in discharge and recharge. Full recovery of the basin takes a long time because, as the groundwater pressure recovers, the induced changes in discharge and recharge get smaller with time.

The implication of a long recovery time is that the volume of water extracted from the coal seams is also replaced over a long period of time. It follows that the induced changes in groundwater discharge and recharge at the surface must be much smaller than the rate of extraction at depth in the coal seams because the same volume of water is replaced over a much longer period of time.

## 11.4.6 Environmental values

### Potential groundwater dependent ecosystems

Assessment of the potential for groundwater dependent ecosystems (GDEs) to be present within the study area has been undertaken in accordance with the methods described in the *Australian groundwater-dependent ecosystem toolbox* (Richardson *et al.* 2011) and the NSW Department of Primary Industries (DPI) Water's *Risk assessment guidelines for groundwater dependent ecosystems* (Serov *et al.* 2012) (refer Appendix F). The methodologies recognise three broad types of GDEs defined by Eamus and Froend (2006) and adopted within the Namoi subregion bioregional assessment (Welsh *et al.* 2014):

- Type 1 GDEs - aquifers and stygofauna ecosystems referring to ecosystems that reside within the spaces of caves and aquifers.
- Type 2 GDEs - ecosystems dependent on the surface expression of groundwater, referring to ecosystems that are connected to groundwater that comes to the earth's surface, within wetlands, lakes, seeps, springs and river baseflow.
- Type 3 GDEs - ecosystems dependent on the sub surface presence of groundwater, referring to ecosystems associated with terrestrial vegetation utilising the water table below the natural surface.

Potential Type 2 and Type 3 GDEs are found to be present in the assessment area (Figure 11-8) whereas no Type 1 GDEs are identified from the stygofauna assessment (see following section). Potential Type 2 GDEs exist at nine sites and are assessed to have low ecological values due to the absence of protected or important wetland species, and heavily or moderately modified conditions. The source aquifers for all nine of these sites is determined to be either the Pilliga Sandstone or alluvium. Potential Type 3 GDEs are identified in riparian areas that support vegetation communities with potential dependence on subsurface expression of groundwater. Two vegetation communities identified as potential Type 3 GDEs in the assessment area are listed as endangered under the *NSW Threatened Species Conservation Act 1995* (TSC Act). Potential Type 3 GDEs are considered to source groundwater predominantly from the water table; however, they are also able to source soil water from rainfall recharge and surface flow events within alluvial settings.

Groundwater dependent ecosystems are protected through both State and Federal Government legislation. Within NSW, high priority sites are listed under Water Sharing Plans enacted through the *Water Management Act 2000*. These sites must be assessed in accordance with the Aquifer Interference Policy. Federally, GDEs associated with the GAB are defined as a threatened ecological community and represent a matter of national environmental significance.

All nine potential Type 2 GDEs identified through the risk assessment process were assessed to have low ecological value and as such do not meet the definition of being high priority GDEs requiring management.

The Minimal Impact Considerations for Aquifer Interference Activities in the NSW *Aquifer Interference Policy* set criteria for high priority GDEs. Specifically, the criteria state that:

Less than 0.2 metre cumulative variation in the groundwater pressure, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any:

- (i) high priority groundwater dependent ecosystem; or
- (ii) high priority culturally significant site;

listed in the schedule of the relevant water sharing plan.

While no high priority GDEs are identified in the relevant Water Sharing Plans, the *State of the Catchments 2010 Namoi Region Groundwater* (DECCW 2010c) identified two sites, Hardy's Spring and Eather Spring, as High Priority GDEs.

Thus, as a conservative measure, both springs have been treated as High Priority GDEs for the purposes of assessment against both the Aquifer Interference Policy and the State of the Catchments classification (DECCW 2010c).

None of the identified GDE sites exhibit characteristics of Matters of National Environmental Significance under the EPBC Act and are not considered to support species dependent on groundwater from the Great Artesian Basin. As such, the sites are not considered to represent a threatened ecological community under the EPBC Act.

## Stygofauna

Chapter 16 describes the assessment of stygofauna that has been undertaken for the project within the context of the proposed managed discharge of treated water to Bohena Creek and potential impacts on groundwater invertebrates. A brief summary of the findings from the study is given below.

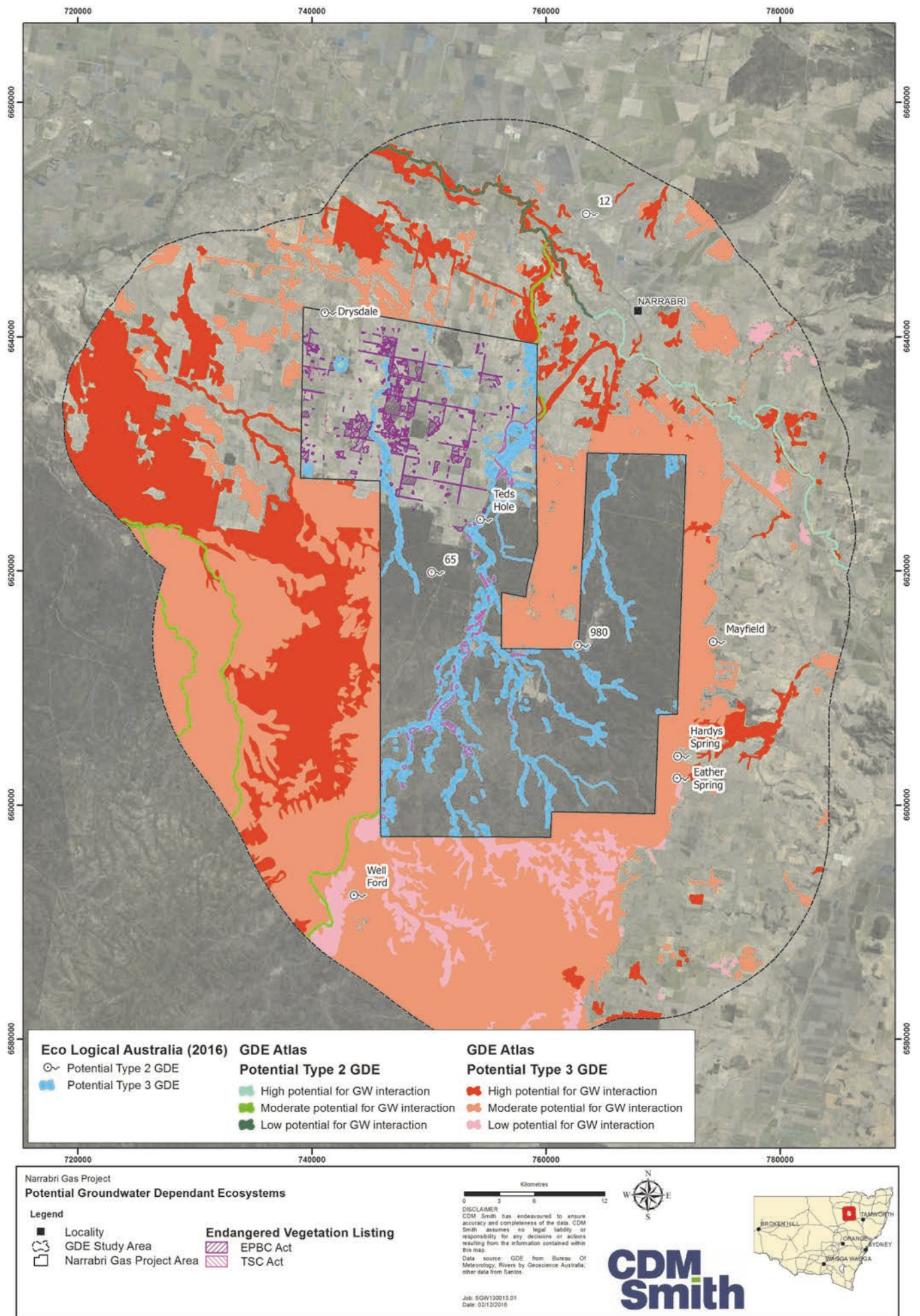
Nineteen samples collected from the following locations were found to contain no stygofauna:

- two monitoring bores in the colluvium at Leewood
- four production bores and three monitoring bores in the Bohena Creek alluvium
- five hand-dug pits in the Bohena Creek alluvium.

Although some of the bores sampled are probably too deep and isolated from sources of organic matter to support stygofauna, the water chemistry in the colluvium at Leewood and in the Bohena Creek alluvium was potentially suitable. Lack of stygofauna at these locations is thought to be related to the thinness (small saturated depth) of the aquifers and lack of permanent hydrological connection to a larger aquifer.

The target coal seams for the project are considered too deep, isolated from sources of organic matter and saline to support stygofauna.





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Figure 11-8

## 11.5 Impact assessment

The preceding sections of this chapter provide the context within which the project's potential impacts on groundwater can be assessed, including the regulatory requirements, the methods used to conduct the assessment, and the existing environmental values of the assessment area. This section identifies the potential impacts of the project on groundwater values and predicts how large or small they are likely to be. A risk-based evaluation of the environmental significance of the predicted impacts is provided in Section 11.10.

Project activities identified as having potential to cause an impact to the groundwater values in the assessment area include; installation of coal seam gas wells, extraction of water from the target coal seams for the project (generation of produced water), beneficial use of produced water for irrigation after it has been treated, and managed release of excess produced water to Bohena Creek after it has been treated.

These project activities have potential to cause the following impacts:

- subsurface depressurisation and drawdown at the water table from extraction of produced water
- groundwater flows between water sources induced by depressurisation
- aquifer interference through drilling and installation of coal seam gas wells and groundwater monitoring bores
- subsidence directly caused by the hydraulic depressurisation of coal seams
- changes to the recharge and discharge mechanisms of groundwater dependent ecosystems
- changes to the soil profile from irrigation and subsequent farming activities.

### 11.5.1 Predictions from the groundwater modelling

Predictive simulations have been conducted in the Groundwater Impact Assessment for three volumes of water production for the project over the 25-year assessment period:

- a base case simulated water production of 37.5 gigalitres
- a low case of 35.5 gigalitres
- a high case of 87.1 gigalitres.

The simulations and the results are described in the Groundwater Impact Assessment (Appendix F), and summarised below.

The Narrabri Gas Project is seeking approval for the extraction of up to 37.5 gigalitres of produced water over the 25-assessment period of the project—which is the base case.

The modelled base case for the project undertakes a simulation using historical water production from coal seam gas pilots in the Gunnedah Basin and future extraction of 37.5 gigalitres from coal seams over the 25-year assessment period for the Narrabri Gas Project as follows:

- historical water production from the existing twelve gas pilots within the Gunnedah Basin, (approximately one gigalitre)
- future water production from Early Permian coal seam targets (35.6 gigalitres)
- future water production from Late Permian coal seam gas targets (1.89 gigalitres).



Other simulations have been performed to investigate the sensitivity of the model results to changes in the assumptions of the model to assess potential cumulative impacts from the Narrabri Coal Mine. The full range of model simulations is presented in the Groundwater Impact Assessment (refer to Appendix F).

## Depressurisation and drawdown

Depressurisation of the target coal seams is achieved by pumping water from the seams. Initially, all of the extracted water comes from flow and local storage in the coal seam but as the zone of depressurisation slowly extends into the bounding formations, small flows are induced from outside of the coal seam. The groundwater modelling predicts that the initial depressurisation in the target coal seams for the project would be transmitted very slowly into the overlying and underlying strata that host the seams. Vertical transmission of depressurisation into shallower overlying water sources is predicted to be impeded (reduced in magnitude and delayed in time) by the thick sequences of intervening strata with low permeability.

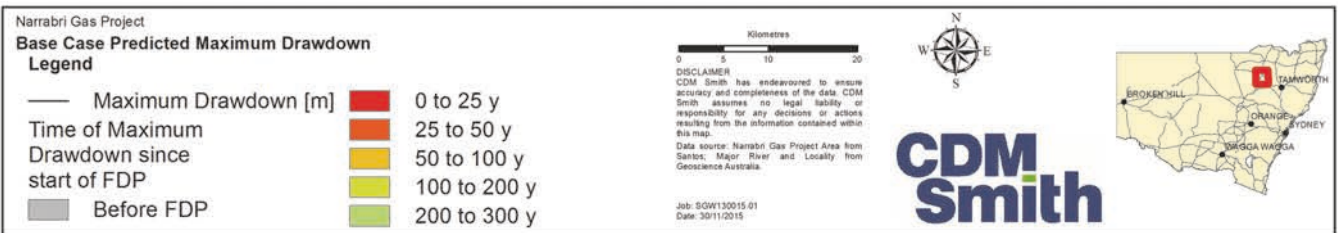
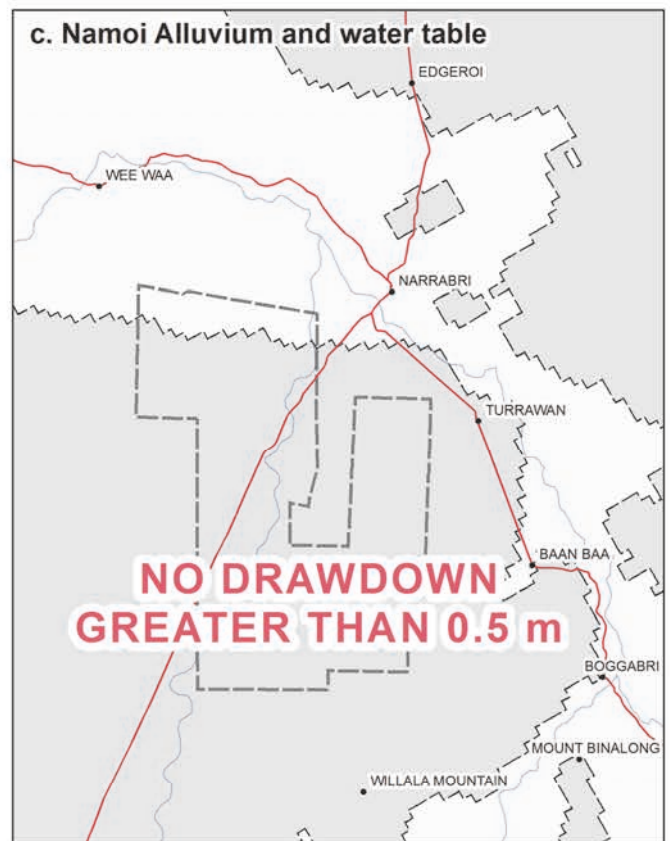
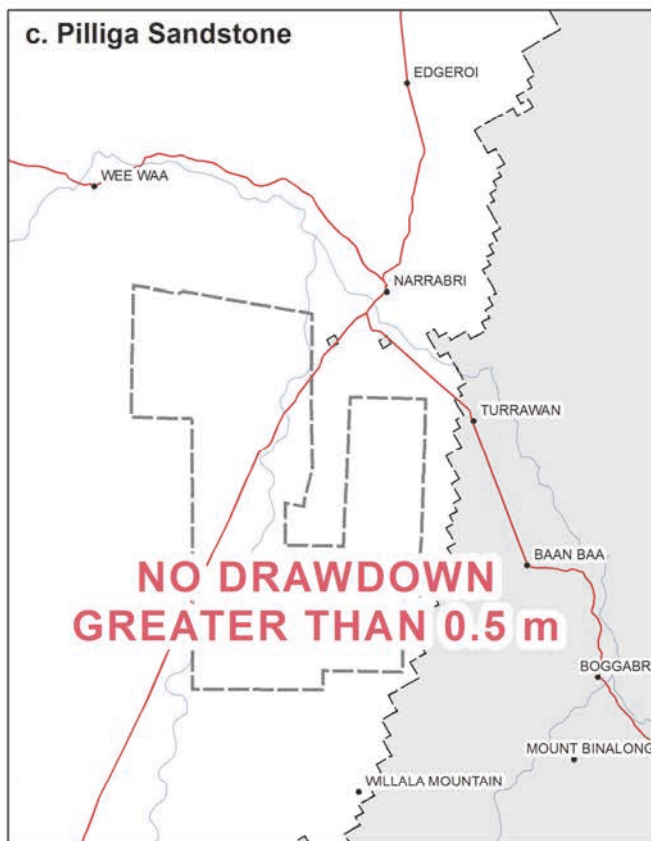
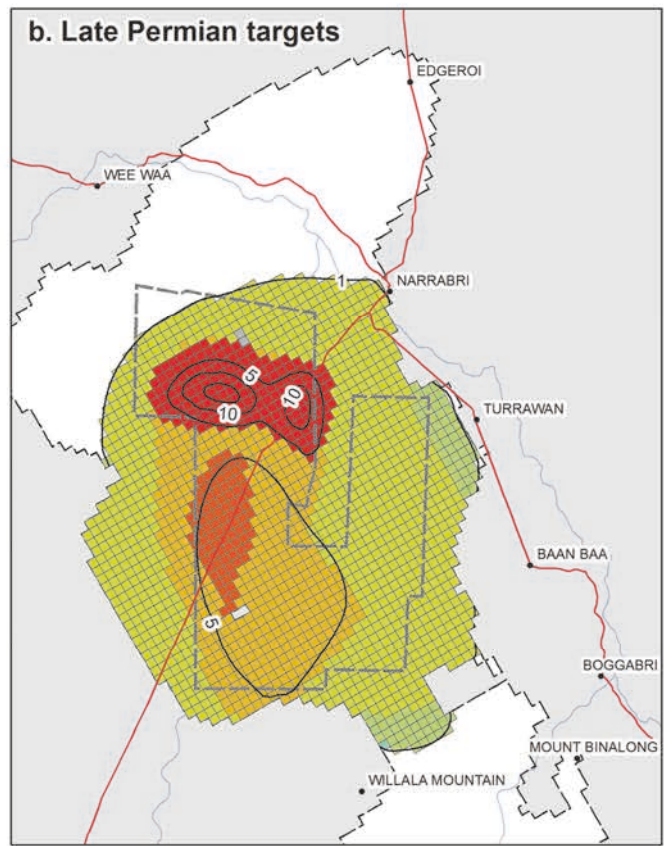
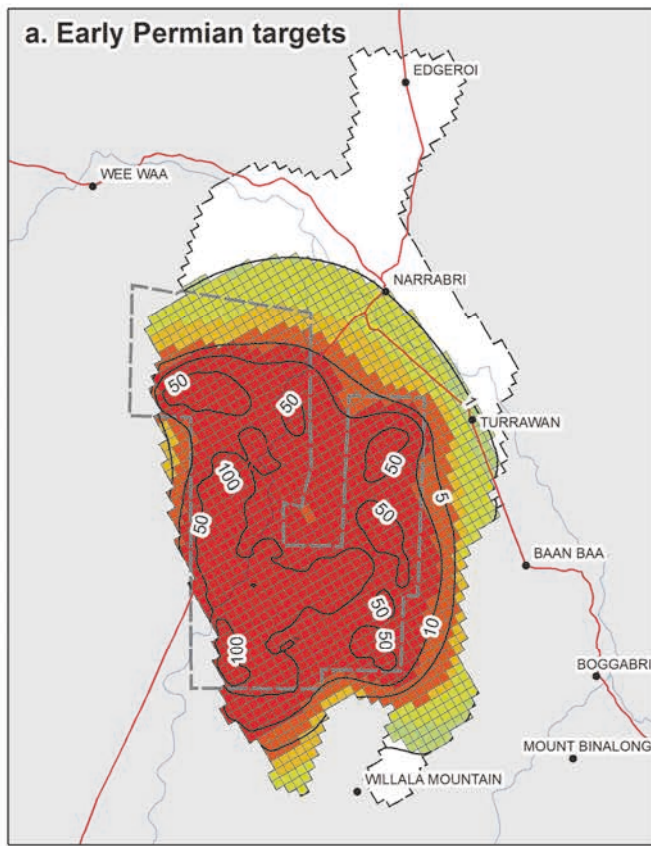
Maps of the maximum predicted changes in groundwater pressure (drawdown) due to extraction of 37.5 gigalitres of water from the target coal seams are shown in Figure 11-9. Table 11-9 also provides a summary of these results within the Early Permian and Late Permian coal seam targets, the Pilliga Sandstone aquifer of the GAB, and at the water table (the water table is a continuous surface within the varied rock types and sediments present at the surface across the assessment area). The term drawdown is used in a general sense to refer to a decrease in groundwater pressure relative to the value that exists prior to the start of water production. Where an aquifer is shallow and unconfined, drawdown represents a decrease in the elevation of the water table; whereas where an aquifer is deep or confined, drawdown represents a decrease in hydraulic head at that depth.

The maps in Figure 11-9 display the largest predicted values of drawdown in each of the model cells; however, it can be seen that these maximum values occur at different times in different locations. The maps do not show drawdown that is less than one metre. The colours on the maps show the times at which the maximum drawdowns occur relative to the start of the development. For example, in red coloured areas the maximum value of drawdown occurs within the assessed period (from 0 to 25 years). Outside of the project area, the maximum drawdowns occur much later because of the time it takes for depressurisation to be transmitted laterally beyond the well field. For example, in green coloured areas the time to reach maximum drawdown is predicted to be 200 to 300 years after the start of the project.

It can be seen that no drawdown greater than 0.5 metres is predicted within the Pilliga Sandstone and Namoi Alluvium, as well as elsewhere at the water table within the assessment area. Although the model does calculate values of maximum drawdown that are less than 0.5 metres, they are not reported in the groundwater assessment on the basis that this would claim unreasonable precision for a regional-scale model. It is sufficient to say that the predicted values of maximum drawdown in the shallow water sources are very small and occur many hundreds of years in the future.

**Table 11-9** Maximum drawdown within the assessment area for the Base Case

| Predictive modelling   | Purlawaugh Outcrop | Namoi Alluvium | Pilliga Sandstone | Late Permian targets            | Early Permian targets |
|--|--------------------|----------------|-------------------|---------------------------------|-----------------------|
| Largest drawdown [m]   | <0.5               | <0.5           | <0.5              | 16.4                            | 153                   |
| Time to reach maximum drawdown [from start of the development] | -                  | -              | -                 | Start of the development to 300 | 1 to 300              |



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Base case predicted  
 maximum drawdown

Figure 11-9

By way of comparison, the predicted impacts of the High Case simulated water production (87.1 gigalitres) are similar to the base case, but with larger drawdown and greater induced flow (refer to Table 11-10). The primary difference between the base case prediction and the high case predictions on beneficial water sources is a slight increase in drawdown in the Pilliga Sandstone from less than 0.5 metres for the base case, to 0.6 metres in the High Case.

Table 11-10 Maximum drawdown within the assessment area for the High Case

| Predictive modelling   | Purlawaugh Outcrop | Namoi Alluvium | Pilliga Sandstone | Late Permian targets            | Early Permian targets |
|--|--------------------|----------------|-------------------|---------------------------------|-----------------------|
| Largest drawdown [m]   | 1.1                | <0.5           | 0.6               | 32.3                            | 224                   |
| Time to reach maximum drawdown [from start of the development] | 350 - 550          | -              | 190 - 200         | Start of the development to 350 | 2 to 500              |

The Low Case predicted simulation impacts are less than the Base Case simulations.

Full details of the High Case and Low Case simulations and the results are described in the Groundwater Impact Assessment (Appendix F).

### *Drawdown in existing groundwater bores*

Potential impacts of depressurisation on the availability of groundwater in existing bores would depend on a number of factors:

- target aquifer and depth
- location relative to the project area
- potential decline of hydraulic head caused by depressurisation.

Potential drawdown and associated impacts on groundwater supply bores in the Namoi Alluvium are predicted to be negligible and not a risk. Similarly, for groundwater bores in the GAB, the groundwater modelling for the base case predicts that there would be no drawdown greater than 0.5 metres in the Pilliga Sandstone aquifer, with the largest predicted drawdown occurring approximately 325 years after the project ceases.

The groundwater modelling predicts large drawdowns within the target coal seams and their hosting strata, and more generally at depth within the Gunnedah-Oxley Basin Groundwater Source. Review of the NSW Government's PINNEENA (v4.1) database did not identify bores installed into these deeper formations for water supply (refer to Section 11.4.3). Because of the large depth from ground surface, generally poor water quality and lack of transmissive strata that can yield useable supplies, it is unlikely that these deeper formations have been targeted for groundwater supply bores.

## Induced flows between groundwater sources

Pressure differentials caused by depressurisation of the target coal seams have the potential to induce groundwater flows between water sources within the assessment area. Under the NSW *Aquifer Interference Policy* (refer to Section 11.2.3) taking of water from one groundwater source, and thereby inducing inflow to that source from another groundwater source constitutes 'aquifer interference' in both water sources. The groundwater model has been used to predict the potential impacts on flows between the following groundwater sources defined in NSW Water Sharing Plans (refer to Section 11.2.3):

- shallow groundwater within the Pilliga Sandstone aquifer (Southern Recharge Groundwater Source) and groundwater within the underlying strata of the Gunnedah Basin (Gunnedah-Oxley Basin Groundwater Source)
- shallow groundwater within the Namoi Alluvium (Upper and Lower Namoi Groundwater Sources) and
  - the underlying portion of the Pilliga Sandstone (Southern Recharge Groundwater Source)
  - the underlying portion of the Gunnedah Basin (Gunnedah-Oxley Basin Groundwater Source).

In general, it is predicted that the changes in flow rates between these water sources due to depressurisation of coal seams would be very small. Ultimately, 37.5 gigalitres of water extracted for the project must be replenished by downward flows from overlying water sources. Because the recovery of groundwater pressure in the coal seams is predicted to take around 1,500 years, it follows that the average flow rates induced by the water extraction are of order of magnitude ( $37.5/1,500 = 0.025$  gigalitres per year). Distributed over the project area of 950 square kilometres, this flow rate is equivalent to a very small distributed flux of less than 0.03 millimetres per year (i.e. 2.6 millimetres per 100 years)

Specifically, the groundwater modelling predicts:

- a maximum induced flow rate from the Southern Recharge Groundwater Source to Gunnedah-Oxley Basin Groundwater Source of approximately 0.06 gigalitres per year (equivalent to 1.8 litres per second) around 175 years after the project ceases
- a maximum induced flow rate from the Upper and Lower Namoi Groundwater Sources to the underlying strata of less than 0.01 gigalitres per year (equivalent to less than 0.32 litres per second).

Overall, the predicted impacts on existing flow rates between groundwater sources in the assessment area are considered to be negligible.

## Impacts to groundwater dependent ecosystems

The nine potential Type 2 groundwater dependent ecosystems (GDEs) identified within the assessment area have been assessed as having low ecological value and not subject to management (refer to Appendix F). Nevertheless, two of these GDE sites (Hardy's and Eather Springs) are listed as high-priority springs under the AIP (refer to Section 11.7) and by the NSW Government's *State of the Catchments 2010 Namoi Region Groundwater* (DECCW 2010c).

For significant impacts to occur to aquatic and terrestrial ecosystems, induced inter-formational recharge due to coal seam depressurisation must first propagate through thick stratigraphic sequences above the target coal seams that contain hydrostratigraphic units, which exhibit very low permeability. This would lead to a very low likelihood of impact to aquatic and terrestrial ecosystems.

Hardy's Spring and Eather Spring are understood to be sustained by rejection of rainfall recharge to the regolith surrounding the springs, which cannot enter the underlying strata of the GAB because the GAB aquifer is essentially full at those locations. In this situation, the spring flows are not expected to be sensitive to small changes in groundwater pressure in the Pilliga Sandstone aquifer of the GAB.



The groundwater modelling in the Groundwater Impact Assessment (refer to Appendix F) predicts no drawdown greater than 0.5 metres in the Pilliga Sandstone and alluvial aquifers, with the largest drawdown in Pilliga Sandstone occurring around 325 years after the project ceases. On basis of this assessment, the potential impacts of the project on groundwater dependent ecosystems within the assessment area are expected to be minor and a low risk.

### 11.5.2 Effects from subsidence

The potential for the project to cause subsidence at depth and at the land surface due to depressurisation of the target coal seams has been assessed in the Groundwater Impact Assessment (refer to Appendix F). The assessment considers:

- subsidence at depth due to compaction of the target coal seams and hydraulically connected strata
- subsidence at ground surface due to settlement of strata overlying the coal seams.

The general conclusion from the assessment is that the potential magnitude of subsidence due to the project is likely to be minor and not a concern, including the following results:

- the probable worst case range of subsidence at depth in the coal seams and hosting strata is 137 to 205 millimetres of vertical compaction
- the maximum predicted compaction at depth of 205 millimetres is likely to cause negligible subsidence at the land surface due to the large depth below ground surface of the target coal seams and the presence and thickness of structurally competent rock formations above the coal seams
- the predicted maximum tilt at ground surface due to the predicted subsidence is less than 0.08 millimetres per metre (less than 0.01 per cent).

In comparison to coal mining activities in the Gunnedah Basin, the predictions of subsidence at the land surface due to the project are orders of magnitude less than the values predicted for underground longwall mining; for example, land surface subsidence greater than two metres is anticipated at the nearby Narrabri Coal Mine (refer to Appendix F). Taking into account the above results, the potential impacts to water related assets and infrastructure from depressurisation of the target coal seams are considered to be negligible.

### 11.5.3 Changes to aquifer connectivity

#### Aquifer connectivity via wells

The development of coal seam gas resources involves drilling and installation of deep wells for exploration, production and monitoring. Coal seam gas wells can intersect multiple formations, which can include aquifers of varying yield and water quality. Penetration of multiple formations by wells creates a potential for interflows between the formations with the drill holes and wells providing a potential conduit for preferential vertical flow. Pressure differentials caused by depressurisation of the target coal seams have the potential to increase the rate of inter-aquifer flow in bore holes and wells should they exist.

The potential risks associated with induced flows between aquifers due to proposed and existing wells within the study area have been assessed for the following well types within the Gunnedah Basin:

- coal seam gas wells
- coal mine core holes
- groundwater bores.

Regardless of the type of well or bore there can be potential for inter-aquifer flow of groundwater or migration of gas if the casing construction in the bore hole is inadequate, or if the casing integrity is damaged. Further details of the risk assessment for aquifer connectivity via wells are contained in the Groundwater Impact Assessment (refer to Appendix F).

### Coal seam gas wells

In relation to coal seam gas wells that are constructed using industry best practices for drilling and well completion works:

- the potential for impacts on aquifers due to gas or water flow between formations are considered to be minor
- potential impacts of inter-aquifer flows during drilling (before the well is cased) can be reduced by ensuring appropriate drilling fluid or mud balance is maintained in the drill hole
- potential risk from inter-aquifer flows after wells are abandoned can be mitigated by proper decommissioning and integrity testing.

### Coal mine core holes

In relation to the potential for the project to enhance inter-aquifer flows in coal mine core holes due to pressure differentials caused by water extraction, the assessment has found that historical core samples for coal mining exploration were collected mainly from near-surface stratigraphic units and generally did not penetrate multiple aquifers. The assessment identified that many core holes were drilled as open holes in single geological formations.

Present-day core holes must be backfilled and sealed in accordance with the requirements of Part 5 of the *Coal Mines Regulation Act 1982*. As such, potential impacts of the project due to enhancement of inter-aquifer flows in core holes is considered to be minor.

### Groundwater bores

Modern construction standards for water bores require isolation of aquifers by casing and annular grouting. Nevertheless, many existing groundwater bores within the project area may not have been constructed to modern standards. The review of existing groundwater bores has found that while they commonly intersect multiple water-bearing zones to increase the bore yield, they were all completed in aquifers that are hundreds of metres shallower than the target coal seams for the project. On this basis, potential gas migration into groundwater bores is considered to be an unlikely impact of the project because existing groundwater bores are not completed in the target coal seams or the immediately overlying formations.

No significant impacts on inter-aquifer flow are anticipated as a result of new groundwater bores that would be installed as part of the Water Monitoring Plan. These bores would be installed in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC 2012) including both the mandatory requirements and adoption of the recommendations for good industry practice.

## Aquifer connectivity via geological faulting

Fault zones can influence the rates and directions of subsurface flows by either acting as obstructions (sealed faults) or conduits (open faults). Depressurisation of the target coal seams has the potential to enhance inter-aquifer flows through existing faulting in the Gunnedah Basin only if:

- open faults exist and extend vertically through multiple formations
- depressurisation would alter the existing pressure differentials cross the faults.

The main conclusion from the faulting study conducted for the Groundwater Impact Assessment (refer to Appendix F) is that the majority of faults in the Gunnedah Basin displace Permian Age and, to a lesser extent, Triassic Age strata. The typical amount of displacement in the Triassic Age strata is considerably less than 100 metres.

No evidence has been found of large post-Jurassic Age faults extending from the GAB and Namoi Alluvium into underlying strata of the Gunnedah-Oxley Basin. Where present, surface faulting and displacement in Jurassic Age strata is found to be minor.

Based on the faulting investigation and interpretation, it is concluded that individual fault zones within the project area would be unlikely to act as conduits for preferential groundwater flow or gas migration between groundwater sources as a result of depressurisation associated with the project.

### 11.5.4 Impacts from reuse of produced water

The project management plan for produced water (refer to Chapter 7) includes a six-stage treatment process to produce high-quality treated water, and the following reuse options for the treated water:

- crop irrigation and stock watering
- dust suppression, construction, drilling and firefighting (the latter as required)
- managed release to Bohen Creek under appropriate flow conditions.

The potential impacts to water sources of reusing treated water for the purposes summarised above are briefly considered below. Refer to Chapter 12 (Surface water quality) for additional information.

### Crop irrigation and stock watering

Crop irrigation schedules normally include a 'leaching fraction' which is an excess amount of irrigation water designed to percolate below the root zone of the crop and eventually to the underlying water table. The purpose of the leaching fraction is to prevent the accumulation of solutes and salinity in the root zone, which may damage the soil condition. This form of groundwater recharge is commonly referred to as deep drainage, and has potential to effect the water table elevation beneath irrigated areas.

An assessment of the potential impacts on groundwater sources in the assessment area due to reuse of treated produced water for crop irrigation has been undertaken utilising the HowLeaky program (refer to Section 11.3.4 and Appendix G2).

The results from the HowLeaky model are found to be consistent with irrigation experience in the project area. For example, a study of seven irrigated cotton farms on Vertosol soils in localities representative of the proposed irrigation area for the project (McGarry *et al.* 2006) found that average annual deep drainage was 48 millimetres per year, similar to the HowLeaky results for wheat-cotton rotation on Vertosol soil.

On the basis of this assessment, beneficial reuse of the treated water for crop irrigation on a suitable soil is likely to have the same impacts as existing irrigated farms, with the potential benefit of additional local recharge to groundwater in the irrigated area. Irrigation activities using the treated water are not expected to adversely impact on groundwater.

Table 7-2 in Chapter 7 compared the quality of treated water proposed for use in stock watering activities against ANZECC/ARMCANZ (2000) stock watering guidelines for beef cattle, sheep, pigs and horses. The comparison indicates that the treated water is suitable for the proposed activity of stock watering.

## Dust suppression, construction, drilling and firefighting

Relative water qualities are discussed in Chapter 12 (Surface water quality). In summary, the quality of treated water used for dust suppression is relatively consistent with the baseline water quality of the receiving catchments, with minor exceptions. The comparison is indicative only and assumes that treated water is directly introduced into Bohena Creek by comparing against baseline water quality. It does not consider environmental factors such as infiltration, and dilution effects from rainfall events and / or catchment runoff for example. It is therefore a conservative assessment.

The over-application of treated and / or amended water for dust suppression, construction activities, drilling and / or firefighting could potentially cause water quality impacts by adding salt, notwithstanding the low salinity of the treated water that would be used. This impact would be managed through routine procedures that would be integrated into the environmental management strategy for the project to ensure that the risk of over-application or use is minimised.

Mitigation measures would include:

- managing spraying to avoid ponding and runoff of water
- avoiding spraying during significant rainfall events
- adjusting application rates based on surface conditions and frequency of application
- routine visual inspections to check for ponding or runoff.

The application of these management and mitigation measures results in an assessed residual risk for dust suppression, construction, drilling and / or firefighting activities of low (refer to Chapter 12).

## Managed release to Bohena Creek

Managed release of treated water from the project to Bohena Creek is proposed only when the surface flow in the creek is equal to or greater than 100 megalitres per day at the Newell Highway gauging station. Under these conditions the releases of treated water have a minor impact on the volume of surface flow in the creek and a negligible impact on the underlying groundwater relative to effect of the existing creek flow.

Managed releases are not expected to adversely impact the River Flow Objectives and Water Quality Objectives of the Namoi Catchment area (refer also to Chapter 12 – Surface water quality).

### 11.5.5 Changes to groundwater quality

The following sections consider the potential for impacts of the project on groundwater quality due to:

- local changes to groundwater quality by drilling fluids



- mixing of groundwater sources of different water qualities caused by subsurface flows that are induced by depressurisation of the target coal seams.

## Impacts from drilling fluids

A chemical risk assessment was completed to assess the potential impacts on groundwater quality from drilling fluids (refer to Appendix T3 – Chemical risk assessment).

The assessment utilised a conservative groundwater modelling approach to assess the fate and transport of key chemical constituents in groundwater during drilling. The modelling indicates that under this highly conservative modelling scenario that potential exceedances of threshold water quality criteria within aquifer systems (the Alluvials and Pilliga Sandstone units) is confined to the immediate vicinity of the wells (less than 70 metres of the well). The greatest lateral extent of impacts was observed for organic constituents, which have the lowest criterion values.

In accordance with the Field Development Protocol, no project infrastructure will be located within 200 metres of an occupied residence on that property unless a written agreement is in place with the landholder. Therefore, the potential for impacts to water bores is considered to be very low.

The chemical risk assessment also 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 negligible. This is due to the limited mass of these chemicals in the produced water, the mass 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.

## Impacts from induced groundwater mixing

The potential for depressurisation of the target coal seams to induce changes in flows between groundwater sources is addressed above in Section 11.5.1. The results from the groundwater modelling show that the project would induce small changes of groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. The estimated order of magnitude of these changes in flow rates is 0.025 giganlitres per year, which is less than one litre per second.

Because the direction groundwater flow induced by the project would be downward toward the depressurised coal seams, the potential for mixing of shallow groundwater sources with poorer quality water in the deeper strata is considered to be negligible and not a risk.

There is potential for small improvements in water quality of the deep groundwater sources from downward flows from overlying water sources with better quality. The maximum potential impact on groundwater quality would be the eventual replacement of 37.5 giganlitres of low quality water extracted from the target coal seams by an equivalent volume of higher quality groundwater derived from the overlying sources. Overall, this potential change in water quality would occur very slowly and be imperceptible.

## Induced gas flows

The depth and poor water quality of groundwater in the Early and Late Permian coal seams of the project area and their hosting formations generally preclude alternative uses and it is understood that there are no known groundwater bores directly targeting the coal seams or bounding rock units within the project area. Therefore, the occurrence of induced gas flows into bores is considered unlikely.

## 11.6 Assessment against the ‘water trigger’

This section addresses the significance of potential impacts of the project on groundwater in relation to the ‘Significant Impact Guidelines’ for water resources under the EPBC Act (refer to Section 11.2.2). The guidelines set out six criteria for establishing whether an action will significantly impact a water resource. The following sections provide an overview of the key outcomes from the groundwater assessment that are relevant to each of these criteria. More detailed information about the potential impacts of the project on water sources within the assessment area is provided in Section 11.5.

### 11.6.1 Value of water resource

The Significant Impact Guidelines specify that the value of a water source should be taken in account when deciding if an impact is likely to be considered significant. Judgements regarding a water source’s value are subjective but generally depend on the utility of the water source to current and potential users, including producers, the community and the environment. As discussed in 11.3.1, existing groundwater use in the assessment area is focussed on the shallow groundwater sources of the Upper and Lower Namoi Alluvium and the Pilliga Sandstone aquifer of the GAB. These shallow sources are considered to have high value because they are generally good quality and widely used, including for stock watering, domestic uses and irrigation. In contrast, groundwater within the target coal seams for the project has limited utility for third party users due to its depth, inferior water quality (typically around one third the salinity of seawater) and lack of transmissive strata to yield viable supplies.

The numerical modelling conducted for the groundwater assessment shows that the high-valued groundwater sources in the Pilliga Sandstone and Namoi Alluvium would not be directly impacted by the project. Minor drawdowns of less than 0.5 metres may occur in these sources as indirect impacts of the project but the small magnitude of these impacts is unlikely to be considered as significant despite the high value of the water sources.

In relation to potential impacts of the project on low-value groundwater in the Gunnedah-Oxley Basin, the large intentional drawdown in the target coal seams is a prerequisite to producing gas, and that this would cause drawdowns in the bounding strata immediately above and below the coal seams. The groundwater modelling shows that vertical transmission of these impacts into overlying water sources would be impeded by thick sequences of intervening aquitards. The drawdowns that are predicted in the target coal seams and bounding strata are unlikely to be considered as significant impacts due to the low value of groundwater in the coal seams and, more generally, the low value of groundwater at depth within the Gunnedah-Oxley Groundwater Source.

Two high-priority-listed springs have been identified at locations immediately east of the project area. While the groundwater feeding these springs has high value, minor or negligible impacts from the project are predicted at these locations.

### 11.6.2 Changes to the hydrological characteristics of a water resource

The Significant Impact Guidelines define changes to the hydrological characteristics of a water source as changes in water quantity, changes in the integrity of hydrological and hydrogeological connections, and changes in the area or extent of a water resource. The potential for these impacts to occur has been assessed through the numerical modelling conducted for the groundwater assessment, as well as through assessments of drilling risks, associated inter-aquifer connectivity (refer to Appendix T3) and an assessment of subsidence potential and risk due to depressurisation (refer to Appendix F).

The groundwater modelling shows that negligible change in groundwater storage would occur within the Namoi Alluvium (less than 0.01 gigalitres per year maximum rate of storage change) and a correspondingly minor induced change in groundwater storage would occur in the Great Artesian Basin (less than 0.06 gigalitres per year maximum rate of storage change).

The predicted maximum rate of storage change in the Gunnedah-Oxley Basin Groundwater Source is 2.9 gigalitres per year around three years after the start of water production, which is equivalent to only 2.5 per cent of the maximum sustainable diversion limit of 114.5 gigalitres per year identified for the Gunnedah-Oxley Basin by the Commonwealth in its Murray Darling Basin Plan. The predicted maximum rate of storage change can be less than the rate of water production from the coal seams because it represents the difference between the rate that water is extracted from the seams and the rate at which water flows into the Gunnedah-Oxley Basin Groundwater Source from other groundwater sources due to the depressurisation. Therefore, there are insignificant expected changes to the hydrological characteristics of the Gunnedah-Oxley Basin Groundwater Source.

The risk assessment for aquifer connectivity via coal seam gas wells is discussed in Section 11.5.3 and in the Groundwater Impact Assessment (refer to Appendix F). In relation to coal seam gas wells that are constructed using industry best practices, it has been concluded that potential impacts to the integrity of aquitards and aquifers, and associated potential for migration of gas and water flows between formations are minor or negligible.

The potential for the project to cause subsurface compaction and damage to the integrity of aquitards and aquifers due to depressurisation of the coal seams has been considered in Section 11.5.2 and in the Groundwater Impact Assessment (refer to Appendix F). Potential subsidence from the project is estimated to be minor and would pose negligible risk to water related assets and infrastructure.

### 11.6.3 Changes to the water quality of a water resource

In relation to water quality, the Significant Impact Guidelines require consideration of potential change in the ability to achieve a relevant water quality objective, significant worsening of local water quality, or release of better quality water into an ecosystem that is adapted to a lower quality of water.

The assessment of potential impacts to the quality of groundwater sources within the assessment area concluded that there may be minor changes in water quality of deep groundwater due to induced recharge from overlying higher quality water sources; however, these changes would occur very slowly and most likely be imperceptible. The maximum potential impact on groundwater quality would be the eventual replacement of 37.5 gigalitres of low quality water extracted from the target coal seams by an equivalent volume of higher quality groundwater derived from overlying sources. Because recovery of pressure is achieved by downward movement of groundwater towards the area of largest depressurisation in the target coal seams there is no potential for low quality groundwater at depth in the Gunnedah Basin to contaminate higher-quality groundwater sources in the overlying Pilliga Sandstone and Namoi Alluvium.

## 11.6.4 Other considerations

### Cumulative impacts

The Significant Impact Guidelines specify that the assessment of potential impacts of the project must be considered within the context of impacts from other developments, whether past, present or reasonably foreseeable. The qualitative assessment of potential cumulative impacts from existing and approved mining operations within the assessment area found that cumulative impacts of the project are only expected to occur in association with the Narrabri Coal Mine Stage 2 Longwall Project, which has been included in the predictive groundwater modelling.

The main findings from the modelling are that the cumulative impacts of the Narrabri Coal Mine and Narrabri Gas Project are likely to be dominated by the effects of groundwater inflow to the Narrabri Mine, with very minor contributions to maximum cumulative drawdowns from the Narrabri Gas Project in the areas impacted by both activities. Cumulative impacts are not anticipated at the locations of other existing and approved mines because of their locations relative to the extent of predicted impacts on water sources from the project.

### Timing

The Significant Impact Guidelines require that the potential impacts of the project must be assessed over both short-term and long-term time scales that are relevant to the proposed activities. The timing of potential impacts to water sources from the project have been assessed using the groundwater model and a simulation period of approximately 1,520 years; including 19 years of historical water production, 25 years of proposed future water production, and a recovery period of approximately 1,475 years after water production ceases.

The modelling predicts that there will be a large time lag between the start of gas and water production and full recovery of groundwater pressure in the subsurface following cessation of the project. Transmission of depressurisation in the target coal seams to overlying water sources occurs very slowly due to the presence of thick intervening strata with low permeability. As a result, the short- to medium-term impacts of the project would generally be confined to the target coal seams, with less than 0.5 metres drawdown predicted in the water sources of the Pilliga Sandstone and Namoi Alluvium at a much later time. The predicted times to reach maximum drawdown at the water table vary between 200 and 700 years. Almost full recovery of subsurface pressure is predicted after 1,500 years.

Therefore, negligible impacts are anticipated considering the slow rate of recharge into the depressurised coal seams due to the geological characteristics including the low permeability of the overlying strata.

### Scale

In relation to the spatial scale of potential impacts on water sources from the project, the Significant Impact Guidelines stipulate that consideration should be given to local-scale, aquifer-scale and regional-scale effects. The groundwater assessment has found that regardless of the spatial extent of depressurisation, the target coal seams are confined vertically by overlying aquitards that limit the impacts in the high-valued water sources of the Pilliga Sandstone and Namoi Alluvium.

The potential spatial extent of impacts associated with the project have been assessed through the groundwater modelling, which predicts potential impacts on water sources over spatial scales varying from the minimum spatial resolution (model cell size) of one square kilometre up to the model area of 53,219 square kilometres.

For the simulations considered in this assessment, the predicted impacts do not extend to the boundaries of the model, thereby confirming that the model is large enough to predict the maximum extent of potential impacts from the project.

### 11.6.5 Conclusion of the assessment against the ‘water trigger’

Overall, the groundwater assessment shows that the project is unlikely to have a significant impact on water resources within the assessment area in relation to water availability, water quality and ecosystem functions supported by these values.

Specifically:

- the predicted impacts to the Gunnedah-Oxley Basin Groundwater Source in the project area are unlikely to be significant because:
  - water in the target coal seams has relatively low value, with no known third-party users extracting water from the coal seams or surrounding source rocks for beneficial purposes
  - the volume of water to be abstracted from the coal seams (average of 1.5 gigalitres per year) over the 95,000-hectare project area is approximately 1.3 per cent of the sustainable diversion limit of 114.5 gigalitres per year identified by the Commonwealth through the Murray Darling Basin Plan
- the predicted impacts to the Southern Recharge Groundwater Source and Surat Groundwater Source of the GAB are unlikely to be significant because:
  - no drawdown greater than 0.5 metres is predicted in the Pilliga Sandstone
  - only minor induced groundwater flow is predicted in the GAB
- the predicted impacts to the Upper and Lower Namoi Groundwater Sources are unlikely to be significant because:
  - no drawdown greater than 0.5 metres is predicted in the Namoi Alluvium
  - negligible induced change in groundwater storage is predicted in the Namoi Alluvium (less than 0.02 gigalitres per year maximum rate of storage change)
  - imperceptible induced groundwater flow is predicted in the Namoi Alluvium
- the groundwater modelling results indicate that perceptible changes in water quality of groundwater sources potentially impacted by the project are unlikely due to the small volume and slow rate of induced flow between water sources.

The Groundwater Impact Assessment shows that after depressurisation of the target coal seams has taken place, the characteristically low hydraulic conductivity of the hosting strata and overlying strata of the Gunnedah Basin acts to significantly impede groundwater replenishment in the coal seams, and limit related impacts on the overlying high-value groundwater sources. As such, there is unlikely to be significant impacts on users of the high quality groundwater sources or groundwater dependent ecosystems.

A summary of the assessment results against the ‘water trigger’ is provided as Table 11-11.

Table 11-11 Assessment against the 'water trigger'

| Criterion                                   | Impact on water resource   |
|---|--|
| Value of water resources                    | Impacts confined to low-value deep groundwater resources that are not utilised. No significant impact to shallow groundwater resources   |
| Changes to the hydrological characteristics | Negligible change to groundwater storage; negligible induced flow rates between sources  |
| Changes to water quality                    | No significant deterioration of water quality due to the project activities  |
| Cumulative impacts with other projects      | Cumulative impacts are dominated by the existing Narrabri North coal mine, with the cumulative contribution from the project distributed over very long timescales   |
| Timing of the impact                        | Timeframes for manifestation of impact from the project are very long; the extended time period combined with the relatively small amount of water taken from the coal seams diminishes the impact to high-value water sources                     |
| Scale of impact on water resources          | The groundwater assessment considers spatial scales varying from the minimum cell size of the groundwater model (one square kilometre) up to the model area of 53,219 square kilometres; predicted impacts do not extend beyond the model boundary |

## 11.7 Assessment against the NSW Aquifer Interference Policy

This section considers the significance of the project's potential impacts on groundwater in relation to the 'minimal impact considerations' established in the NSW Aquifer Interference Policy (refer to Section 11.2.3). Water sources and associated environmental values that have been addressed under the Aquifer Interference Policy (AIP) in this assessment include:

- directly affected groundwater in the target coal seams and hosting strata within the Gunnedah-Oxley Basin Groundwater Source, which fall within the AIP's definition of 'less productive groundwater sources' and 'porous rock'
- indirectly affected groundwater in the Upper and Lower Namoi Groundwater Sources, which fall within the AIP's definition of 'highly productive groundwater sources' and 'alluvial water sources'
- listed high-priority groundwater dependent ecosystems at Hardy's Spring and Eather Springs.



Minimal impact considerations defined in the AIP that apply to direct impacts on less productive groundwater sources and to indirect impacts on highly productive water sources are reproduced in Table 11-12 and Table 11-13, respectively. An assessment of the potential impacts of the project against each of the minimal impact considerations is given in the right-hand column of the tables. Further detailed assessment of the project's potential impacts in relation to the AIP is provided in Appendix F.

Table 11-12 Minimal impact consideration – Less productive water source

| Level 1 Minimal Impact Consideration   | Assessment  |
|--|---|
| Porous rock or fractured rock – Gunnedah-Oxley Basin Groundwater Source  |   |
| <p><b>Water table</b></p> <p>Less than or equal to a 10 per cent cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any:</p> <ul style="list-style-type: none"> <li>• high priority groundwater dependent ecosystem or</li> <li>• high priority culturally significant site</li> </ul> <p>listed in the schedule of the relevant water sharing plan.</p> <p>OR</p> <p>A maximum of a two metre water table decline cumulatively at any water supply work.</p> | <p><b>Level 1 – acceptable</b></p> <p>No high-priority GDEs associated with the Gunnedah-Oxley Basin Groundwater Source have been identified in the assessment area.</p> <p>No high priority culturally significant sites are present in the assessment area.</p> <p>Limited information on water supply works is available for the Gunnedah-Oxley Basin. The Clare Sandstone is the only recognised hydrostratigraphic unit with potentially significant transmissivity within the basin strata directly above the target coal seams; however, it is not generally utilised as a groundwater source due to its large depth below ground surface, unreliable water quality and the availability of alternate, shallower and better quality groundwater sources.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water table decline at GDEs, culturally significant sites and water supply work.</i></p> |
| <p><b>Water pressure</b></p> <p>A cumulative pressure head decline of not more than a two metre decline, at any water supply work.</p>   | <p><b>Level 1 – acceptable</b></p> <p>Limited information about water supply works is available for the Gunnedah-Oxley Basin. The Clare Sandstone is the only recognised hydrostratigraphic unit with potentially significant transmissivity within the basin strata directly above the target coal seams; however, it is not generally utilised as a groundwater source due to its large depth below ground surface, unreliable water quality and the availability of alternate, shallower and better quality groundwater sources.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water pressure decline at water supply works.</i></p>  |

| Level 1 Minimal Impact Consideration  | Assessment  |
|---|---|
| <p><b>Water quality</b></p> <p>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.</p> | <p><b>Level 1 – acceptable</b></p> <p>Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for contamination of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk. Potential improvements in water quality of the deep groundwater sources from downward flows are expected to be very slow and imperceptible.</p> <p>No change in the beneficial use category of the groundwater sources is predicted to occur.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water quality.</i></p> |

Table 11-13 Minimal impact considerations – Highly productive water source

| Level 1 Minimal Impact Consideration   | Assessment   |
|--|--|
| Alluvial aquifer – Upper and Lower Namoi Groundwater Sources   |  |
| <p><b>Water table</b></p> <p>Less than or equal to a 10 per cent cumulative variation in the water table, allowing for typical climatic post-water sharing plan variations, 40 metres from any:</p> <ul style="list-style-type: none"> <li>• high priority groundwater dependent ecosystem or</li> <li>• high priority culturally significant site</li> </ul> <p>listed in the schedule of the relevant water sharing plan.</p> <p>OR</p> <p>A maximum of a two metre water table decline cumulatively at any water supply work.</p>         | <p><b>Level 1 – acceptable</b></p> <p>No high-priority GDEs associated with the Upper and Lower Namoi Groundwater Sources have been identified in the assessment area.</p> <p>No high priority culturally significant sites are present in the project area.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water table decline at GDEs, culturally significant sites and water supply work.</i></p> |
| <p><b>Water pressure</b></p> <p>A cumulative pressure head decline of not more than 40 per cent of the post-water sharing plan pressure head above the base of the water source to a maximum of a two metre decline, at any water supply work.</p> <p>OR, for the Lower Murrumbidgee Deep Groundwater Source:</p> <p>A cumulative pressure head decline of not more than 40 per cent of the post-water sharing plan pressure head above the top of the relevant aquifer to a maximum of a three metre decline, at any water supply work.</p> | <p><b>Level 1 – acceptable</b></p> <p>No drawdown greater than 0.5 metres is predicted in the Namoi Alluvium, which contains the majority of water supply works.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water pressure decline at water supply works.</i></p>  |

| Level 1 Minimal Impact Consideration   | Assessment  |
|--|---|
| <p><b>Water quality</b></p> <p>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.</p> <p>No increase of more than one per cent activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.</p> <p>No mining activity to be below the natural ground surface within 200 metres laterally from the top of high bank or 100 metres vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a reliable water supply.</p> <p>Not more than 10 per cent cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 metres laterally from the top of high bank and 100 metres vertically beneath a highly connected surface water source that is defined as a reliable water supply.</p> | <p><b>Level 1 – acceptable</b></p> <p>Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for contamination of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk.</p> <p>No change in the beneficial use category of the groundwater sources is predicted to occur.</p> <p>No mining activity is included as part of the project.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water quality.</i></p> |
| Porous Rock – Great Artesian Basin Southern Recharge Groundwater Source  |   |
| <p><b>Water table</b></p> <p>Less than or equal to a 10 per cent cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any:</p> <ul style="list-style-type: none"> <li>• high priority groundwater dependent ecosystem or</li> <li>• high priority culturally significant site</li> </ul> <p>listed in the schedule of the relevant water sharing plan.</p> <p>OR</p> <p>A maximum of a two metre water table decline cumulatively at any water supply work.</p>   | <p><b>Level 1 – acceptable</b></p> <p>Two listed high-priority GDE springs (Hardy's and Eather Springs) have been identified immediately east of the project area in association with the Pilliga Sandstone aquifer. The groundwater modelling predicts maximum drawdown less than 0.5 metres in the Pilliga Sandstone at the locations of the springs.</p> <p>No high priority culturally significant sites are present in the project area.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water table decline at GDEs, culturally significant sites and water supply work.</i></p>   |

| Level 1 Minimal Impact Consideration   | Assessment   |
|--|--|
| <p><b>Water pressure</b></p> <p>Less than 0.2 metre cumulative variation in the groundwater pressure, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any:</p> <ul style="list-style-type: none"> <li>• high priority groundwater dependent ecosystem or</li> <li>• high priority culturally significant site</li> </ul> <p>listed in the schedule of the relevant water sharing plan.</p> <p>A cumulative pressure level decline of not more than 15 metres, allowing for typical climatic 'post-water sharing plan' variations.</p> <p>The cumulative pressure level decline of no more than 10 per cent of the 2008 pressure level above ground surface at the NSW State border, as agreed between NSW and Queensland.</p> | <p><b>Level 2</b></p> <p>Two listed high-priority GDE springs (Hardy's and Eather Springs) have been identified immediately east of the project area in association with the Pilliga Sandstone aquifer. The groundwater modelling predicts maximum drawdown less than 0.5 metres in the Pilliga Sandstone at the locations of the springs. Potential drawdown at the springs may meet the criteria of 0.2 metres; however, groundwater monitoring would be implemented at both sites.</p> <p>Hardy's Spring and Eather Spring are understood to be sustained by rejection of rainfall recharge to the regolith that cannot enter the GAB because it is full at those locations. In this situation, the spring flows are unlikely to be affected by relatively small changes in head in the Pilliga Sandstone.</p> <p>No high priority culturally significant sites are present in the project area.</p> <p>No impact on pressure levels would occur at the NSW State border as a result of the project.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water pressure decline at water supply works.</i></p> |
| <p><b>Water quality</b></p> <p>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.</p>  | <p><b>Level 1 – acceptable</b></p> <p>Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for contamination of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk. Potential changes in water quality of the Pilliga Sandstone due to downward flows from overlying sources are expected to be very slow and imperceptible.</p> <p>No change in the beneficial use category of the groundwater sources is predicted to occur.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water quality.</i></p>   |
| <b>Porous Rock – Great Artesian Basin Surat Groundwater Source</b>   |  |
| <p>Water table</p> <p>NOT APPLICABLE</p>   |  |
| <p><b>Water pressure</b></p> <p>Less than 0.2 metre cumulative variation in the groundwater pressure, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any:</p> <ul style="list-style-type: none"> <li>• high priority groundwater dependent ecosystem or</li> <li>• high priority culturally significant site</li> </ul>  | <p><b>Level 2</b></p> <p>No high-priority GDEs associated with the GAB Surat Shallow Groundwater Source have been identified in the assessment area.</p> <p>No high priority culturally significant sites are present in the project area.</p> <p>No impact on pressure levels would occur at the NSW State border as a result of the project.</p>   |

| Level 1 Minimal Impact Consideration   | Assessment   |
|--|--|
| <p>Listed in the schedule of the relevant water sharing plan.</p> <p>A cumulative pressure level decline of not more than 30 metres, allowing for typical climatic 'post-water sharing plan' variations.</p> <p>The cumulative pressure level decline of no more than 10 per cent of the 2008 pressure level above ground surface at the NSW State border, as agreed between NSW and Queensland.</p> | <p><i>The project is considered to be <b>acceptable</b> in regard to water table decline at GDEs, culturally significant sites and water pressure decline.</i></p>   |
| <p><b>Water quality</b></p> <p>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.</p>  | <p><b>Level 1 – acceptable</b></p> <p>Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for contamination of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk. Potential changes in water quality of the Pilliga Sandstone due to downward flows from overlying sources are expected to be very slow and imperceptible.</p> <p>No change in the beneficial use category of the groundwater sources is predicted to occur.</p> <p><i>The project is considered to be <b>acceptable</b> in regard to water quality.</i></p> |

## 11.8 IESC information requirements

An evaluation of the groundwater assessment against the most recent (October 2015) checklist of information requirements published by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development is presented in the Groundwater Impact Assessment (Appendix F). A reference to relevant sections of the Groundwater Impact Assessment is provided for each item of the checklist that applies to the Narrabri Gas Project.



## 11.9 Mitigation and management

Mitigation measures identified in the groundwater significance assessment include make good provisions that will be followed in the event of unanticipated impacts from the project. The make good provisions relate mainly to unanticipated drawdown or depressurisation of groundwater affecting the existing users, and are required under the *NSW Aquifer Interference Policy*.

In the event that an impact greater than the approved level of impact for the project is thought to have occurred at an existing water supply bore, the proponent will undertake an assessment of the bore to determine the extent to which the bore is impaired and the likelihood that the impairment has been caused by the activities of the project. If impairment of the bore is shown to be an impact of the project, the proponent will enter into a make good agreement with the bore owner for the purpose of ensuring access to reasonable quantity and quality of water supply (groundwater or otherwise) that is consistent with the authorised purpose of the bore.

The types of make good provisions that will be considered in the make good agreement will include:

- lowering the pump setting in the bore
- increasing the water column above the pump
- improving the pressure at the bore head, if the bore is artesian (e.g. new headworks and piping)
- changing the type of pump to suit the lower water level in the bore
- deepening the bore to allow it to draw groundwater from a deeper part of the aquifer
- bore reconditioning to improve hydraulic efficiency
- drilling a new bore
- other modification to the bore that will mitigate the impairment
- providing an alternate water supply
- providing compensation, which could be monetary, for impairment of the water supply.

Make good agreements will include a plan to monitor and undertake periodic assessments of the affected bore.

The proposed mitigation and management measures that would be undertaken to reduce the potential impacts of the project on groundwater resources within the assessment area are summarised below in Table 11-14.

Table 11-14 Mitigation and management measures

| Issue                           | Mitigation/management  |
|---------------------------------|--|
| Impacts on groundwater quality  | <ul style="list-style-type: none"> <li>• Drilling, completion and rehabilitation of wells in compliance with the <i>NSW Code of Practice for Coal Seam Gas Well Integrity</i>.</li> <li>• Compliance with NSW and / or Commonwealth policies relating to drilling fluids.</li> </ul>   |
| Impacts on groundwater quantity | <ul style="list-style-type: none"> <li>• Extraction (take) of groundwater in compliance with the <i>NSW Water Management Act, 2000</i>, specifically the procurement of sufficient Water Access Licence (WAL) allocations.</li> <li>• The Water Monitoring Plan (Appendix G3) will be implemented.</li> <li>• Groundwater monitoring bores will be installed in accordance with the <i>Minimum Construction Requirements for Water Bores in Australia</i>.</li> <li>• Implementation of make good protocols in accordance with the requirements of the <i>NSW Aquifer Interference Policy</i>.</li> <li>• Lined pits will be utilised during drilling. Drilling fluids and drill cuttings that are not appropriate for beneficial reuse will be removed after the completion of drilling.</li> </ul> |

## 11.10 Significance assessment

Potential impacts of the project have been identified and discussed in Section 11.5. This section considers the significance of those impacts based on the 'significance assessment' methodology outlined in Chapter 10.

A significance assessment is used when it is clear that an impact will occur and it is the sensitivity or vulnerability of the impacted value that determines if the impact is significant.

The results of the significance assessment conducted for groundwater assessment are summarised in Table 11-15. For each listed impact, the significance assessment considers:

- the pre-mitigated significance of the impact
- the mitigation measures that would be used to manage the impact; these measures would reduce the magnitude of the impact
- the residual significance of the impact after implementation of the mitigation measures.

Table 11-15 Environmental significance assessment

| Potential impacts  | Phase           | Pre-mitigated significance |           |              | Mitigation  | Residual significance |           |              |
|--|-----------------|----------------------------|-----------|--------------|---|-----------------------|-----------|--------------|
|  |                 | Sensitivity                | Magnitude | Significance |   | Sensitivity           | Magnitude | Significance |
| Decline in groundwater levels/pressure in existing bores and reduced supply to existing groundwater users  | Construction    | Moderate                   | Low       | Low          | The Water Monitoring Plan (Appendix G3) will be implemented.<br><br>Implementation of make good protocols in accordance with the <i>NSW Aquifer Interference Policy</i> .<br><br>Groundwater monitoring bores will be installed in accordance with the <i>Minimum Construction Requirements for Water Bores in Australia</i> .<br><br>Extraction (take) of groundwater in compliance with the <i>NSW Water Management Act 2000</i> , specifically the procurement of sufficient Water Access Licence (WAL) allocations. | Moderate              | Low       | Low          |
|  | Operation       |                            | Low       | Low          |   |                       | Low       | Low          |
|  | Decommissioning |                            | Low       | Low          |   |                       | Low       | Low          |
| Reduced groundwater levels/pressure at, and/or groundwater supply to, groundwater dependent ecosystems   | Construction    | Moderate                   | Low       | Low          | Groundwater monitoring bores will be installed in accordance with the <i>Minimum Construction Requirements for Water Bores in Australia</i> .<br><br>Extraction (take) of groundwater in compliance with the <i>NSW Water Management Act 2000</i> , specifically the procurement of sufficient Water Access Licence (WAL) allocations.  | Moderate              | Low       | Low          |
|  | Operation       |                            | Low       | Low          |   |                       | Low       | Low          |
|  | Decommissioning |                            | Low       | Low          |   |                       | Low       | Low          |
| Induced gas flow in existing groundwater supply bores  | Construction    | Moderate                   | Low       | Low          | Extraction (take) of groundwater in compliance with the <i>NSW Water Management Act 2000</i> , specifically the procurement of sufficient Water Access Licence (WAL) allocations.   | Moderate              | Low       | Low          |
|  | Operation       |                            | Low       | Low          |   |                       | Low       | Low          |
|  | Decommissioning |                            | Low       | Low          |   |                       | Low       | Low          |
| Decline in groundwater quality in bores and in quality of supply to groundwater users and groundwater dependent ecosystems due to depressurisation | Construction    | Moderate                   | Low       | Low          | Drilling, completion and rehabilitation of wells in compliance with the <i>NSW Code of Practice for Coal Seam Gas - Well Integrity</i> .<br><br>Lined pits will be utilised during drilling. Drilling fluids and drill cuttings that are not appropriate for beneficial reuse will be removed after the completion of drilling. Implementation of the Water Monitoring Plan.<br>Compliance with NSW and / or Commonwealth policies relating to drilling fluids.   | Moderate              | Low       | Low          |
|  | Operation       |                            | Low       | Low          |   |                       | Low       | Low          |
|  | Decommissioning |                            | Low       | Low          |   |                       | Low       | Low          |
| Induced aquifer connectivity that will impact on high quality water resources  | Construction    | Moderate                   | Low       | Low          | Drilling, completion and rehabilitation of wells in compliance with the <i>NSW Code of Practice for Coal Seam Gas - Well Integrity</i> .<br><br>Lined pits will be utilised during drilling. Drilling fluids and drill cuttings that are not appropriate for beneficial reuse will be removed after the completion of drilling. Implementation of the Water Monitoring Plan.<br>Compliance with NSW and / or Commonwealth policies relating to drilling fluids.   | Moderate              | Low       | Low          |
|  | Operation       |                            | Low       | Low          |   |                       | Low       | Low          |
|  | Decommissioning |                            | Low       | Low          |   |                       | Low       | Low          |

## 11.11 Monitoring

Strategies for implementing groundwater monitoring throughout the duration of the project have been identified based on the outcomes of the Groundwater Impact Assessment. Monitoring programs have been integrated into the project management plans and thereby provide the basis for measuring the effectiveness of the management strategies in those plans, and for review and update of management processes.

The project's Water Monitoring Plan (WMP) is contained in Appendix G3. This section provides a summary of the key monitoring commitments from the Plan that are relevant to groundwater. Groundwater monitoring in the WMP has been designed to measure and track the scale of potential impacts to groundwater sources that have been predicted by the groundwater modelling.

The numbers of existing and proposed additional monitoring locations within each of the ground sources within the assessment area is shown in Figure 11-10.

Table 11-16 is an overview of the proposed groundwater monitoring network. During operation of the project, the monitoring network would be equipped with either manual or automated logging equipment for measuring water level and electrical conductivity, with the choice being dependent on access to sites and the desired frequency of measurements. The locations and depths of monitoring bores have been designed to provide early detection of potential impacts from the project well in advance of potential impacts in high-value water sources in the Pilliga Sandstone of the GAB and the Namoi Alluvium.

Table 11-16 Groundwater monitoring network summary

| Stratigraphic Unit                         | Monitoring network status |         | Monitoring Details   |
|--|---------------------------|---------|--|
|  | Proposed additional       | Current |  |
| Bohena Creek colluvium                     | 0                         | 4       | <ul style="list-style-type: none"> <li>Automated level monitoring</li> </ul>   |
| Namoi Alluvium (Gunnedah and Narrabri Fms) | 1                         | 18      | <ul style="list-style-type: none"> <li>Potential monitoring bores already exist in the Namoi Alluvium but are not equipped with monitoring equipment.</li> </ul>   |
| Great Artesian Basin                       | 0                         | 26      | <ul style="list-style-type: none"> <li>To be undertaken in conjunction with NSW DPI Water by equipping additional existing bores with telemetered water level (or pressure) and electrical conductivity continuous monitoring</li> <li>Quarterly sampling for basic suite of water quality parameters and annual sampling for an enhanced suite of water quality parameters</li> </ul> |
| Gunnedah-Oxley Basin – Triassic            | 6                         | 7       | <ul style="list-style-type: none"> <li>Telemetered pressure monitoring</li> </ul>  |
| Gunnedah-Oxley Basin - Permian             | 0                         | 4       | <ul style="list-style-type: none"> <li>Telemetered pressure monitoring</li> <li>No formal water quality monitoring but water from coal seams would be tested as part of Produced Water Management Plan.</li> </ul>   |

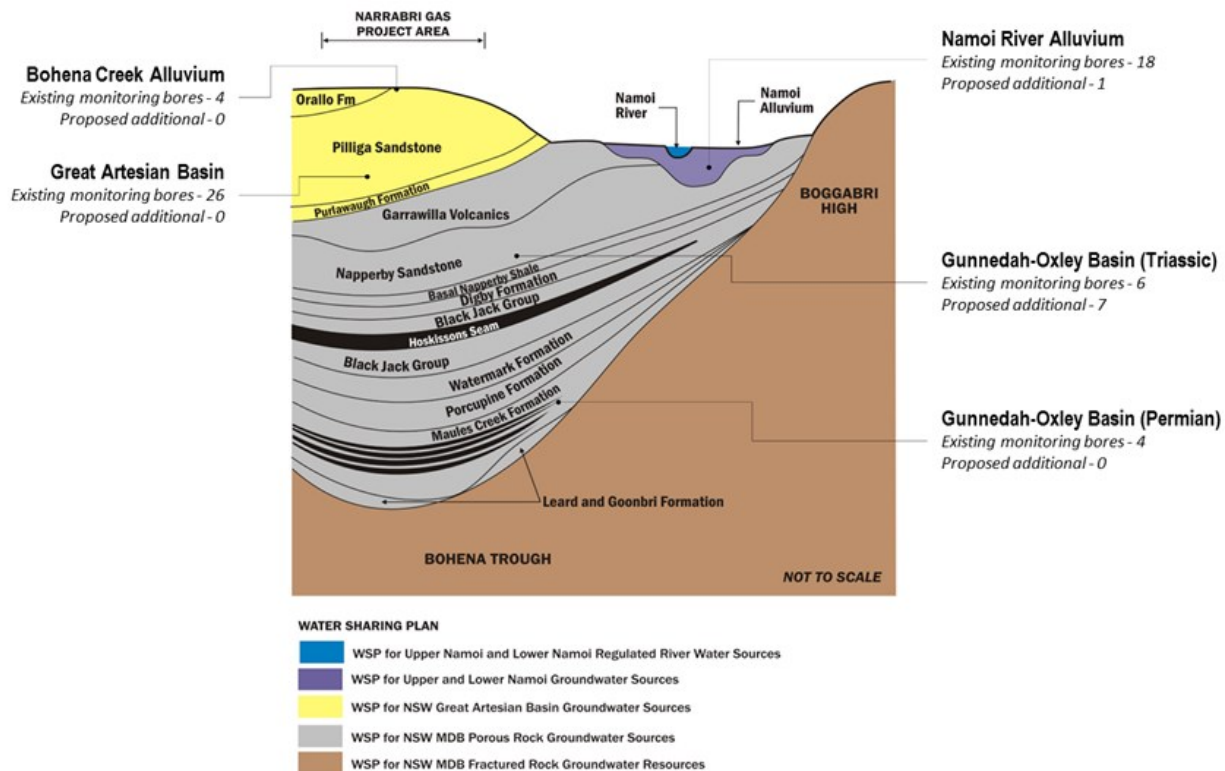


Figure 11-10 Existing and proposed additional water monitoring locations

## 11.12 Conclusions

Groundwater in the assessment area is extracted for private use and town water supply predominantly from the shallow groundwater sources of the Upper and Lower Namoi Alluvium and to a lesser extent from the Pilliga Sandstone aquifer of the GAB. Extraction of water to depressurise the target coal seams for the project would be conducted at much greater depth within strata of the Gunnedah Basin that are hydraulically remote from the shallow groundwater sources, and which have no known existing third-party uses.

Proposed water extraction from the target coal seams in the Bohena Trough would result in drawdown of hydraulic head and reduction of groundwater storage in the target coal seams and in the immediately overlying and underlying formations hosting the coal seams.

The principal mechanism for the eventual recovery of hydraulic head in the subsurface following cessation of water production would be decreased discharge and increased recharge at the water table, but at a much later time.

Large predicted time lags between the start of gas and water production and ultimate recovery of groundwater pressure within the subsurface reflect the long period of time required for predicted drawdown in the coal seams to be transmitted to the water table by means of vertical flow in overlying aquitards. The induced changes in groundwater discharge and recharge must be much smaller than the rate of extraction at depth in the coal seams because the same volume of water is replaced over a much longer period of time.



The groundwater modelling predicts that there is unlikely to be a discernible impact to shallow groundwater sources in the assessment area compared to natural variation in the pressures and storage volumes in these sources. In relation to induced change in water table elevation and groundwater pressure, the groundwater modelling predicts that:

- maximum drawdown of the water table in the Namoi Alluvium and elsewhere would be less than 0.5 metres
- maximum drawdown in the Pilliga Sandstone aquifer of the GAB would be less than 0.5 metres.

The predicted times to reach maximum drawdown at the water table vary between 200 and 700 years, with almost full recovery of groundwater storage predicted after 1,500 years.

Because the direction of groundwater flow induced by the project would be downward toward the depressurised coal seams, the potential for contamination of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk.

Potential impacts to water related assets and infrastructure from subsidence caused by depressurisation of the target coal seams are considered to be negligible.

Significant impacts on inter-aquifer flow or the integrity of aquifers and aquitards are not anticipated as a result of installation of coal seam gas wells or new groundwater bores for the proposed Water Monitoring Plan. No 'hazardous chemicals' have been identified in the make-up of drilling fluids that would make them a major concern for human health or ecological receptors. The risk assessment of five 'non-hazardous chemicals of potential concern' concludes that there would be a low risk of exposure to these chemicals in relation to construction of coal seam gas wells for the project.

Due to the lack of faulting extending from the GAB and Namoi Alluvium into the underlying strata of the Gunnedah-Oxley Basin within the project area, fault zones would be unlikely to act as conduits for preferential groundwater flow or gas migration between groundwater sources as a result of depressurisation associated with the project.

Beneficial reuse of treated produced water for crop irrigation on a suitable soil type is likely to have similar impacts as existing irrigated farms within the assessment area, with the potential benefit of additional local recharge to groundwater in the irrigated area.

Managed releases of treated produced water to Bohena Creek when the surface flow in the creek is greater than, or equal to, 100 megalitres per day at Newell Highway is not expected to adversely impact the River Flow Objectives and Water Quality Objectives of the Namoi Catchment area. Under these conditions, the releases are predicted to have a negligible impact on the underlying groundwater.

The residual significance of potential impacts after mitigation and management measures have been applied are listed in Table 11-17.

The assessment found that the residual significance of potential impacts from the Narrabri Gas Project on groundwater are expected to be low.

Table 11-17 Groundwater significance of residual impacts

| Potential impacts  | Residual significance |           |                 |
|--|-----------------------|-----------|-----------------|
|  | Construction          | Operation | Decommissioning |
| Decline in groundwater levels/pressure in existing bores and reduced supply to existing groundwater users  | Low                   | Low       | Low             |
| Reduced groundwater levels / pressure at, and / or groundwater supply to, groundwater dependent ecosystems   | Low                   | Low       | Low             |
| Induced gas flow in existing groundwater supply bores  | Low                   | Low       | Low             |
| Decline in groundwater quality in bores and in quality of supply to groundwater users and groundwater dependent ecosystems due to depressurisation | Low                   | Low       | Low             |
| Induced aquifer connectivity that will impact on high quality water resources  | Low                   | Low       | Low             |