14. GROUNDWATER

This chapter provides a summary of the groundwater values within the project development area and an assessment of the potential for these values to be affected by direct and indirect impacts associated with the construction, operations and decommissioning phases of the project. For the detailed findings of the project's groundwater impacts, see Appendix G, Groundwater Impact Assessment Report. Environmental protection objectives have been developed, and the mitigation, monitoring and management measures to achieve these objectives have been identified. The residual impact assessment assumes that the proposed mitigation, monitoring and management measures have been applied.

Chapter 15, Surface Water, details the assessment of impacts on surface water hydrological and geomorphic systems and surface water quality associated with waterways; and Chapter 12, Geology, Landform and Soils, provides additional details of potential impacts on soils and surface geological and landform features, together with a strategy for the management of contaminated land (including soils and groundwater).

14.1 Legislative Context

The following legislation, policy and plans are relevant to identifying values and avoiding, mitigating and managing impacts on groundwater during construction, operation and decommissioning of the project.

Environment Protection and Biodiversity Conservation Act 1999 **(Cwlth) (EPBC Act).** The EPBC Act provides for the protection of matters of national environmental significance, including groundwater-dependent ecosystems and groundwater springs. Any action with potential significant impacts on these groundwater systems must be referred to the Minister for Sustainability, Environment, Water, Population and Communities, and may require approval under this act.

Environmental Protection Act 1994 **(Qld) (EP Act).** The objective of the EP Act is to protect Queensland's environment by promoting ecologically sustainable development. The Environmental Protection Regulation 2008 provides a mechanism to enforce the EP Act and allows for an assessment of the risk that an environmentally relevant activity poses to environmentally sensitive areas.

Petroleum and Gas (Production and Safety) Act 2004 **(Qld) (P&G Act).** The *Petroleum Act 1923* is the original act regulating the petroleum industry and was not repealed by the P&G Act. The two pieces of legislation govern groundwater management in relation to proposed gas field developments. Under the P&G Act, the petroleum tenure holder may take or interfere with groundwater to the extent that it is necessary and unavoidable during the course of an activity authorised under the petroleum tenure. The P&G Act defines underground water taken or interfered with from petroleum wells as associated water (also called coal seam gas water). There are no limits placed on the volume of groundwater that can be taken; however, the P&G Act limits where and in what way the water can be beneficially used. Groundwater monitoring requirements and make-good obligations related to groundwater supply impacts on third-party bores and natural springs are included in the *Water Act 2000* (Qld).

Water Act 2000 **(Qld).** This act provides the framework to deliver sustainable water planning, allocation management and operation of water authorities to ensure the improved security of water resources. It also regulates impacts on groundwater caused by the exercise of underground water rights by petroleum tenure holders. Specifically, it sets out the monitoring and reporting requirements, groundwater drawdown trigger thresholds, and associated make-good obligations to be met by the tenure holder in the event that groundwater supply to a third-party water bore or a natural spring is found to be impaired due to the extraction of coal seam gas water. The act also defines the roles and responsibilities of the Queensland Water Commission (QWC) in relation to cumulative impacts on groundwater resources (third-party bores and springs) due to multiple coal seam gas proponents operating in the Surat Basin. The expansion of coal seam gas operations in Queensland has resulted in the declaration of the Surat Cumulative Management Area.

***Water Supply (Safety and Reliability) Act 2008* (Qld).** This act aims to provide for the safety and reliability of water supply in Queensland. It sets out the process for applying to be a water service provider where the owner of any water supply infrastructure intends for a change to be made. Water service providers must submit and maintain several management plans, and the act also sets out the obligations in relation to the potential to impact on drinking-water supplies and the requirement for recycled-water management plans. Arrow may be required to operate under the requirements of this act when providing water commercially.

***Sustainable Planning Act 2009*.** The purpose of the Sustainable Planning Act is to achieve ecological sustainability by managing the process by which development takes place, including ensuring the process is accountable, effective and efficient and delivers sustainable outcomes. It also aims to manage the effects of development on society and the environment, including managing the use of premises, and to continue the coordination and integration of planning at the local, regional and state levels. The act also regulates the development of infrastructure and provides details of the Development Approval/Operational Works approval process for construction of infrastructure that is ‘off lease’. This relates specifically to Arrow’s coal seam water management strategy and the delivery of suitably treated coal seam gas water to beneficial users.

Water Resource (Great Artesian Basin) Plan 2006 (Qld). This plan comes under the Water Act and is the primary regulation for groundwater management of the Great Artesian Basin (GAB) in Queensland. Coal seam gas water (called associated water under the P&G Act) is excluded from the allocation and management of water in the plan area. Twenty-five groundwater management areas are identified in the plan. The project development area is within the Eastern Downs, Surat East, Surat and Surat North groundwater management areas.

Great Artesian Basin Resource Operations Plan 2007 (Qld) (DNRW, 2007b). This plan implements the Water Resource (Great Artesian Basin) Plan 2006 (Qld). Within each groundwater management area, associated groundwater management units are identified in the plan. A groundwater management unit corresponds to a geologic formation or to a group of geologic formations. For each groundwater management unit, a specified upper annual allocation of water is identified. The plan also stipulates that, for new licence applications, a minimum separation distance from existing licensed bores be maintained to ensure a drawdown of no more than 5 m. Coal seam gas water is excluded from the allocation and management of water in the plan area.

Queensland Coal Seam Gas Water Management Policy 2010 (Qld) (DERM, 2010a). This policy aims to ensure that salt produced through the generation of coal seam gas water does not adversely impact the environment and to maximise the opportunities for beneficial reuse of the water. Under the policy, producers of coal seam gas water are required to meet appropriate treatment standards prior to disposal or supply of coal seam gas water to third parties. In addition, evaporation dams are to be discontinued as a primary means for coal seam gas water disposal, and all new coal seam gas water aggregation and storage dams must be fully lined to standards defined by the Department of Environment and Resource Management (DERM). The policy also requires the preparation of a coal seam gas water management plan and provides options for management and disposal of saline effluent and solid salt wastes.

Environmental Protection (Water) Policy 2009 (EPP (Water)). This policy is under the EP Act and aims to achieve Queensland's objectives relating to waters. The EPP (Water) also governs the discharge of wastewater to land, surface water, and groundwater; and it aims to protect designated environmental values. The EPP (Water) sets water quality objectives to provide guidance to protect environmental values. The values for groundwater are closely related to those of surface and aquatic ecology resources, which are detailed in Chapter 15, Surface Water, and Chapter 16, Aquatic Ecology, of this EIS.

Guide to the Proposed Basin Plan: Technical Background (Murray–Darling Basin Authority, 2010) (MDBA, 2010). The pending Murray–Darling Basin Plan is proposed to operate under the Commonwealth *Water Act 2007* and requires the Murray–Darling Basin Authority to determine the volume of water required to maintain and restore environmental assets within the Murray-Darling system. At present, a guide to the proposed basin plan has been released. The proposed plan will set out environmental water requirements and volumes of water that can be taken for consumptive uses (sustainable diversion limits). The plan refers to groundwater assets in the project development area, specifically the Condamine-Balonne and Border River regions shallow aquifers; however, GAB aquifers, including the Walloon Coal Measures, are not legislated under the plan.

14.2 Assessment Methods

The groundwater assessment comprised a desktop study and a numerical model to gain an understanding of and describe the existing environment. These were followed by an impact assessment. The methods used in the three assessments are summarised below.

14.2.1 Desktop Study

The project commenced with a desktop study of available geological and hydrogeological information together with reviews of previous and related studies for the study area, which includes the project development area, as well as the surrounding Surat Basin and Clarence-Moreton Basin, as defined by the groundwater modelling extent (Figure 14.1). The groundwater modelling extent covers a representative section of the Surat Basin and is limited to the east by the New England Fold Belt and to the north by the Bowen Basin. The southern and western boundaries are defined by the likely extent of potential impacts within the key groundwater systems and with consideration of the extent of basin formations.

The desktop study involved a detailed literature review and searches of the following government and non-government databases and other sources:

- Water bores registered with DERM (database extracted on 6 October 2009) (DERM, 2009c).
- The Queensland water entitlements registration database (database extracted on 17 February 2010) (DERM, 2010e).
- Geological maps and stratigraphic information obtained from DERM.
- Geological maps and stratigraphic information for the project development area provided by Arrow.

Queensland groundwater bores are registered on the DERM database, with the license information consigned to the water entitlements registration database. The information extracted from the DERM and Queensland water entitlements registration databases is considered to provide a representative regional understanding of stratigraphy, bore casing depths, groundwater levels, groundwater quality and groundwater use across the project development area. This information was collated in an in-house relational database that allowed the available information to be assessed and interpreted. The relational database in conjunction with the literature review provided a foundation to establish baseline groundwater conditions across the project development area, including basin stratigraphy, aquifer properties, groundwater depths and groundwater chemistry.

The desktop study has assessed the data contained within the DERM and Queensland water entitlements registration databases. It is recognised that the data in these government databases is incomplete. The bores contained in the government databases are limited to those that are licensed. The number of data points regarding groundwater levels, quality and stratigraphy from the different bores is highly variable, ranging from representative to inadequate. Certain inaccuracies are expected; and, where data appears to be anomalous, it has been excluded from the dataset and from any subsequent interpretation or discussion. However, the available data is considered sufficient to allow an initial-level assessment of the baseline hydrogeological characteristics of aquifers within the project development area.

14.2.2 Numerical Groundwater Model

A detailed conceptual and regional numerical groundwater model of the study area was developed by Schlumberger Water Services (Australia) Pty Ltd to predict potential impacts on the environment and other groundwater users. The groundwater model was developed to the requirements specified by and under the guidance of Coffey Environments. The completed modelling and results were subsequently peer reviewed by Coffey Environments and a suitably qualified third party, Dr Lloyd Townley of NTEC Environmental Technology.

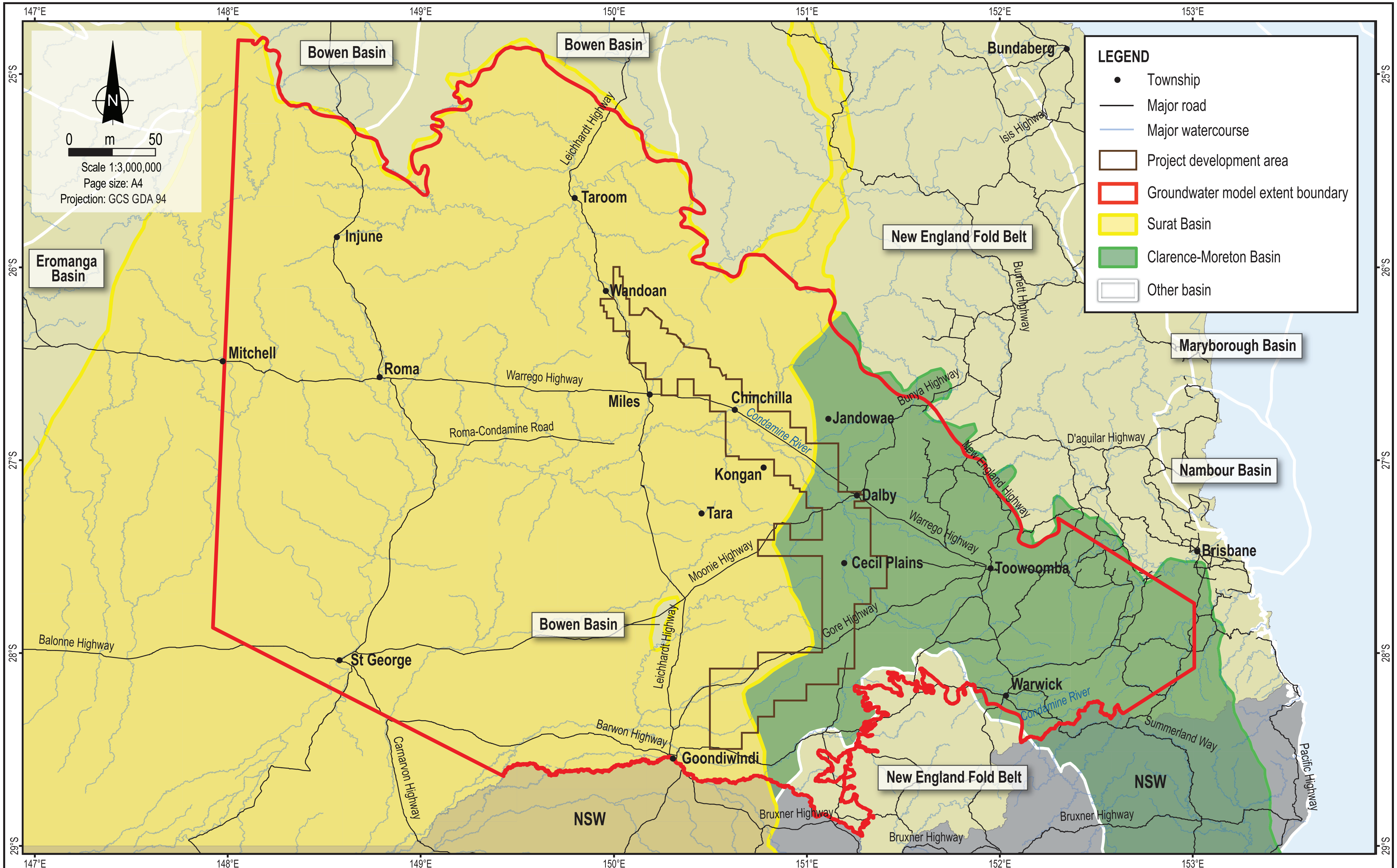
For the purposes of the EIS, the prediction of groundwater level changes that will occur in response to the extraction of groundwater from the coal seams within the Walloon Coal Measures is the key model output. The model design allows the prediction of changes in groundwater levels in aquifers deeper and shallower than the Walloon Coal Measures.

The groundwater modelling extent is illustrated in Figure 14.1. The full modelling report and results are discussed in Appendix G, Groundwater Impact Assessment Report.

The numerical groundwater model was developed using MODFLOW-2000 software (Harbaugh et al., 2000) and involved several stages as detailed below.

Model Inputs

Various model inputs were defined and used to develop the groundwater model. For key geological formations within the eastern area of the Surat Basin and the northern and western areas of the Clarence-Moreton Basin, hydrogeological parameters were defined using available published literature. Available literature included information from journal articles, government agencies and various proponents operating in the area, including power supply, mining and coal seam gas companies. The parameters included (but were not limited to) the permeability and specific storage of the geological formation. The permeability of a geological formation is a measure of its ability to transmit fluids, while specific storage describes the capacity of an aquifer



Source:
Place names, roads and watercourses from GEODATA250k.
Basins from Geoscience Australia.
Groundwater modelling domain from Schlumberger.

coffey environments

Date: 13.12.2011
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File Name: 7040_04_F14.01_GIS_GL

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Surat Gas Project

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Groundwater modelling extent and study area

Figure No: 14.1

to release groundwater in response to a decline in pressure (hydraulic head). In some cases, groundwater pumping parameters and recharge rates were available. The information available from these sources varied and is provided in more detail in Appendix G, Groundwater Impact Assessment Report.

Existing groundwater levels were also used as a model input to provide details on the condition of groundwater levels prior to the commencement of the Surat Gas Project. In some cases, the information also showed historical groundwater variations across the study area as a result of past and current extraction activities. A summary of data used to characterise the groundwater and geological conditions prior to the commencement of the Surat Gas Project is provided in Table 14.1.

Table 14.1 Groundwater level and geological data points used to inform the numerical model

Formation Name		Number of Groundwater Level Data Points	Number of Geological Points (Top of Formation)
Condamine Alluvium		128	452
Lower Cretaceous sequence[1]		Not included	1,420
Kumbarilla Beds[2]		94	Not applicable
Individual datasets available for the component units of the Kumbarilla Beds	Mooga Sandstone	269	1,351
	Orallo Formation	Too few to use	1,359
	Gubberamunda Sandstone	199	1,775
	Westbourne Formation	11	1,648
	Springbok Sandstone	213	1,638
Walloon Coal Measures		120	2,279
Hutton Sandstone/Marburg Subgroup		491	2,344
Evergreen Formation		11	2,108
Precipice Sandstone		92	1,655

[1] The Lower Cretaceous sequence represents a series of units to the west of the project development area (Griman Creek Formation, Surat Siltstone, Coreena Member, Doncaster Member and the Bungil Formation). For the purposes of the numerical model, these units were combined.

[2] This represents data assigned to the Kumbarilla Beds and not assigned to a component unit of this group.

The groundwater model was also based on an approximate development sequence, with defined development regions across the project development area. Information about each development region included an approximation of the number of production wells likely to be installed, the likely volumes of coal seam gas and coal seam gas water to be removed, and an estimate of the likely timing of development. This information constitutes Arrow's conceptual design.

Geological Model

The numerical groundwater model was based on a regional-scale geological model of the stratigraphy of the study area. This model forms the physical basis for the numerical model in that it shows the lateral and vertical extent of the geological units present within the study area.

Model Development and Calibration

The groundwater model was developed and calibrated so that model outputs reflected actual observed groundwater conditions. The results of the groundwater model calibration are presented in Appendix G, Groundwater Impact Assessment Report.

Model Sensitivity Analysis

Using the calibrated parameters and the starting baseline conditions, the model was used to simulate different coal seam gas and water extraction rates. The sensitivity of the model outputs to changes in the key hydrogeological parameters (e.g., permeability) was also assessed.

Predictive Groundwater Extraction Scenarios

For the purposes of the numerical groundwater model, predicted coal seam gas water extraction rates used to define Arrow's conceptual design were used to simulate groundwater drawdown over a 30-year project production life span and 20 years of recovery after cessation of gas extraction activities. In addition, some predicted future extraction rates by third parties were included to develop three modelling scenarios. Details of the scenarios are displayed in Table 14.2.

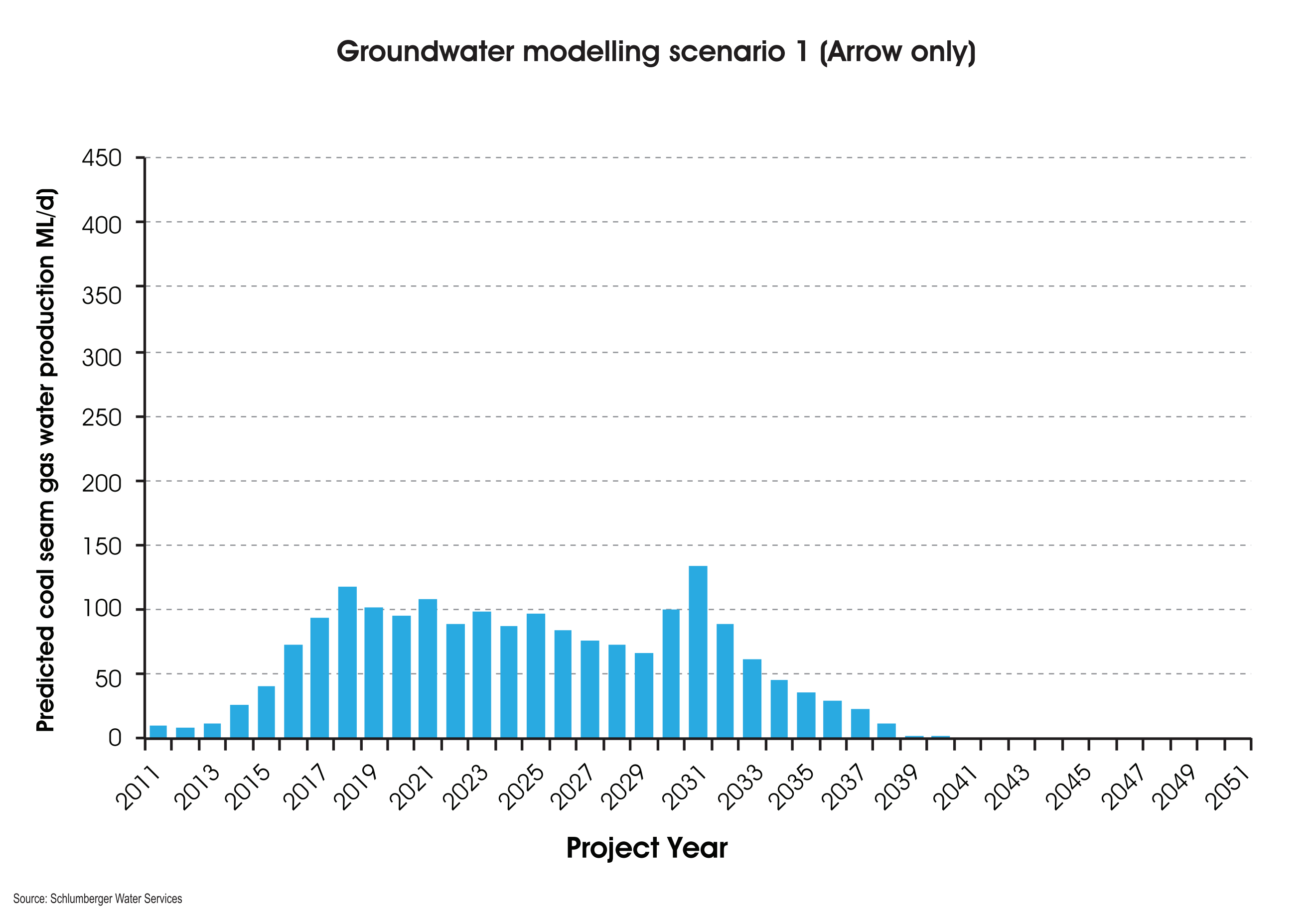
Table 14.2 Details of groundwater modelling scenarios

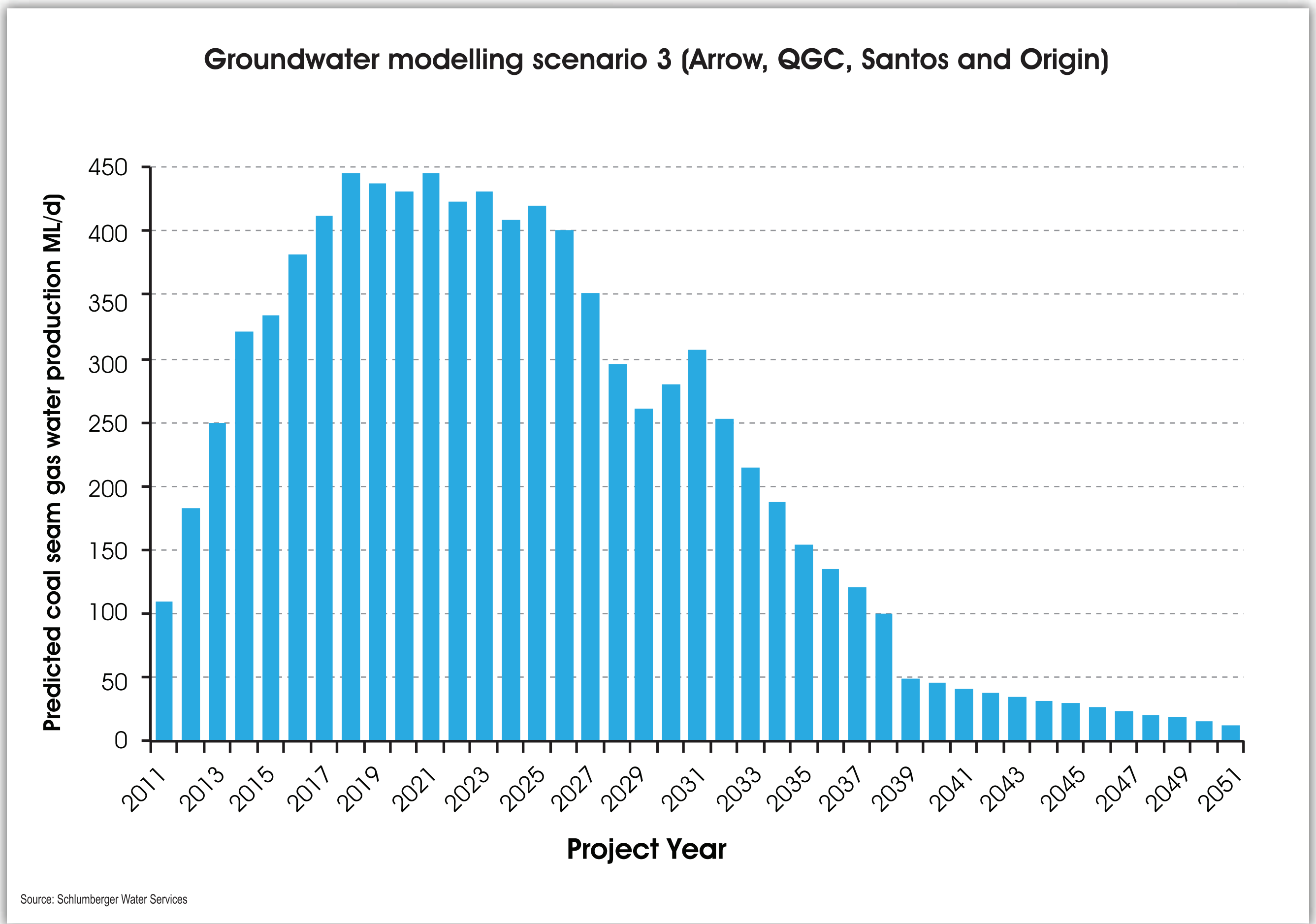
Modelling Scenario	Objective	Arrow Activities Included	Third-party Activities Included
Scenario 1 Arrow-only conceptual design	Simulate the potential unmitigated impacts on the groundwater system resulting from Arrow operations alone.	Predicted extraction from coal seam gas wells at Arrow's conceptual design case production rates.	No third-party predicted extraction data included in this modelling scenario.
Scenario 2 Combined base case	Simulate the potential unmitigated impacts on the groundwater system resulting from a combination of Arrow operations and other coal seam gas proponents that had made a final investment decision prior to 31 January 2011.	Predicted extraction from coal seam gas wells at Arrow's conceptual design case production rates.	Predicted third-party extraction data included for the following proponents: • QGC. • Santos.
Scenario 3 Cumulative case	Simulate the potential unmitigated impacts on the groundwater system resulting from all coal seam gas operations in the Surat Basin, regardless of their final investment decision status.	Predicted extraction from coal seam gas wells at Arrow's conceptual design case production rates.	Predicted third-party extraction data included for the following proponents: • QGC. • Santos. • Origin Energy.

The results of modelling scenario 1 are discussed in this chapter, while the results of scenario 3 are presented and discussed in Chapter 28, Cumulative Impacts. Additional details on the results of the scenario 2 modelling can be found in Appendix G, Groundwater Impact Assessment Report. The predicted groundwater extraction data used to generate scenarios 1 and 3 is presented in Figure 14.2.

14.2.3 Impact Assessment Method

The potential impacts of the project on groundwater were assessed using the significance assessment method defined in Chapter 7, Impact Assessment Method. This assessment method was adopted on the basis that it considers the sensitivity of groundwater systems in their current state and that it provides a sound basis for determining the severity of potential impacts on the groundwater values.





coffey environments	Job No: 7040	Arrow Energy	arrow energy go further	Total predicted coal seam gas water extraction - modelling scenarios 1 and 3	Figure No: 14.2
	File Name: 7040_04_F14.02_GL	Surat Gas Project			

Sensitivity of the Environmental Value

The sensitivity of an environmental value is determined by its susceptibility or vulnerability to threatening processes. Applying the representative attributes that define sensitivity enables the sensitivity of an environmental value to be ranked as very high, high, moderate, low or very low. Table 14.3 below describes the sensitivity ranking criteria. The criteria are based on the following attributes of groundwater systems:

- Conservation status elements of the groundwater system as defined by statutory and regulatory authorities. This is related to the suitability of the water to support:
  - Biological values.
  - Consumptive and productive values.
  - Human interaction values, such as cultural and spiritual importance.
- Rarity of occurrence, abundance or distribution of the groundwater system or aquifer type and availability of equivalent or representative alternatives locally and regionally.
- Resilience to change as a function of intrinsic properties of the groundwater system, such as permeability and porosity.
- The dynamics of the existing environment. This is related to hydrogeological processes, such as recharge and discharge mechanisms, acting upon the groundwater system.
- The rehabilitation potential of the groundwater system at the completion of project activities.

Table 14.3 Criteria for sensitivity of groundwater values

Sensitivity Criteria	Very Low Sensitivity	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Very High Sensitivity
Conservation status - biological values	Within the potential impact area of the project, groundwater does not support ecosystems.	Within the potential impact area of the project, groundwater can discharge to surface features and its intrinsic properties support highly disturbed ecosystems.	Within the potential impact area of the project, groundwater can discharge to surface features and its intrinsic properties support slightly to moderately disturbed ecosystems.	Within the potential impact area of the project, groundwater has the potential to discharge to surface features and its intrinsic properties may support pristine ecosystems.	Within the potential impact area of the project, groundwater discharges to surface features and its identified intrinsic properties support pristine ecosystems of national environmental significance.
Conservation status - consumptive and productive values	Within the majority of the potential impact area of the project, groundwater quality is unsuitable for any practical use.	Within the majority of the potential impact area of the project, groundwater quality is suitable for industrial use or aquaculture.	Within the majority of the potential impact area of the project, groundwater quality is suitable for production of aquatic food for human consumption or stock watering.	Within the majority of the potential impact area of the project, groundwater quality is suitable for agricultural use.	Within the majority of the potential impact area of the project, groundwater quality is suitable for potable supply.
Conservation status – human interaction values	Intrinsic properties of groundwater do not support areas of spiritual or cultural significance within the potential impact area of the project.	Intrinsic properties of groundwater support isolated areas of spiritual or cultural significance within the potential impact area of the project.	Intrinsic properties of groundwater support numerous areas of spiritual and cultural significance within the potential impact area of the project.	Intrinsic properties of groundwater support areas of spiritual or cultural significance within the potential impact area of the project that are listed on the National Heritage Register.	Intrinsic properties of groundwater support areas of spiritual or cultural significance within the potential impact area of the project that are inscribed on the World Heritage List.
Rarity	Attributes of the groundwater system are commonly found and widely distributed.	Attributes of the groundwater system are common on a local, regional and national basis and therefore have local equivalents.	Attributes of the groundwater system are locally unique but have regional equivalents.	Attributes of the groundwater system are locally unique but have few regional equivalents.	Attributes of the groundwater system are unique. There are no regional equivalents.

Table 14.3 Criteria for sensitivity of groundwater values (cont'd)

Sensitivity Criteria	Very Low Sensitivity	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Very High Sensitivity
Resilience to change	Intrinsic properties of the groundwater system are completely resilient to change (as a result of depressurisation, for example).	Intrinsic properties of the groundwater system are highly resilient to change (as a result of depressurisation, for example).	Intrinsic properties of the groundwater system are moderately resilient to change (as a result of depressurisation, for example) and the overall function of the groundwater system is relatively unchanged.	Intrinsic properties of the groundwater system are slightly resilient to change (as a result of depressurisation, for example) and the overall function of the groundwater system could be temporarily altered.	Intrinsic properties of the groundwater system are rigid to change (as a result of depressurisation, for example) and the overall function of the groundwater system could be permanently altered.
Dynamics of the system	Groundwater systems have high recharge rates and short recovery periods.	Groundwater systems have moderate recharge rates and medium-term recovery periods.	Groundwater systems have low recharge rates and longer recovery periods.	Groundwater systems have very low recharge rates and very long recovery periods.	Groundwater systems are isolated from recharge processes and pressure reduction would be permanent.
Rehabilitation potential	Rehabilitation can be successfully achieved in all cases.	Rehabilitation can be successfully achieved in the majority of cases.	Rehabilitation is likely to be slow or only partially successful.	Rehabilitation potential is limited or successful only in the minority of cases.	Rehabilitation potential is extremely limited if impact on the value cannot be avoided.

Magnitude of Impact

The magnitude of an impact on an environmental value is an assessment of the geographical extent, duration and severity of the impact. Applying suitable criteria enables the magnitude of an impact to be ranked as very high, high, moderate, low or very low as shown in Table 14.4.

Table 14.4 Criteria for magnitude

Magnitude	Description
Very high	Irreversible or persistent high-severity project impacts on environmental values are likely, with no recovery from such impacts in the foreseeable future. Impacts extend across regional areas. Where impact is on an aquifer: • The impact occurs across aquifers regionally. • Groundwater discharge features and users are affected at a regional scale or in multiple locations.
High	Moderate-severity impacts on environmental values are likely to persist over time, or high-severity impacts are likely to have a short duration only, with rapid recovery when the impacting activity is completed. Impact extends across regional areas. Where impact is on an aquifer: • The impact occurs across aquifers. • Groundwater discharge features and users are affected.
Moderate	Low-severity impacts on environmental values are likely to persist over time, or moderate-severity impacts are likely to have a short duration only, with rapid recovery when the impacting activity is completed. Impact extends beyond the area of activity or footprint. Where impact is on an aquifer: • The impact may occur across aquifers. • Groundwater discharge features and users may be affected.
Low	Low-severity impacts on environmental values are likely to be for short durations, with rapid recovery when the impacting activity is completed. Impact may extend beyond the area of activity or footprint but is localised. Where impact is on an aquifer: • The impact is restricted to within that aquifer only. • Other aquifers or groundwater discharge features and users are not affected.
Very low	Low-severity and short-term impacts are restricted to within the area of activity or footprint. No medium-term or long-term project impacts are likely on environmental values.

Significance of Potential Impacts

The significance of the potential impacts on the groundwater values was determined in consideration of the sensitivity of the value and the magnitude of the potential impact. The significance assessment matrix below (Table 14.5) shows how, using the criteria above, the significance of an impact on the groundwater values was determined.

Table 14.5 Significance assessment matrix

	Sensitivity of the Environmental Value				
Magnitude of Impact	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	**Very High**	**Very High**	High	High	Moderate
High	**Very High**	High	High	Moderate	Low
Moderate	High	High	Moderate	Moderate	Low
Low	High	Moderate	Moderate	Low	**Very Low**
Very Low	Moderate	Low	Low	**Very Low**	**Very Low**

The classifications for determining the significance of an impact are as follows:

- **Very High.** An impact occurs that causes high-severity, long-term and widespread harm to an aquifer or groundwater environmental value that is irreplaceable because of its uniqueness, restricted occurrence, sensitive uses or supply to pristine surface features. The impact is largely irreversible, and no mitigation, monitoring or management measures have been proven to ameliorate the impact. The system has extremely limited rehabilitation potential when the impact cannot be avoided.
- **High.** An impact occurs that causes high-severity, moderate- to long-term and regional harm to an aquifer or groundwater environmental value that is locally unique with few regional equivalents and potentially supports sensitive uses or pristine surface features. The impact temporarily alters the system; and the system has limited rehabilitation potential, with recovery occurring over a very long time period.
- **Moderate.** An impact occurs that causes moderate-severity, short- to medium-term harm to an aquifer or groundwater environmental value that is locally unique with several regional equivalents and supports a range of uses or slightly to moderately disturbed surface features. The impact temporarily alters the system; however, the system can be partially rehabilitated, with recovery occurring over a medium to long time period.
- **Low.** An aquifer or groundwater environmental value is of local importance only and impacts will be short term, not affecting the long-term viability of the system. A range of mitigation and management measures are known to restore the system or reverse the process of degradation.
- **Very Low.** An impact occurs to an aquifer or groundwater environmental value that is of limited importance on a local or regional basis. The impact is largely reversible, with degradation controlled by a range of standard mitigation and management measures that have been proven to be extremely effective.

14.3 Existing Environment and Environmental, Social and Cultural Values

This section describes the general characteristics of the groundwater environment and identifies the characteristics of the different groundwater systems present within the project development area and the broader study area. The environmental, social and cultural values of the existing groundwater environment are also described.

14.3.1 Regional Geology

The properties and distribution of groundwater systems within the study area are a reflection of the geological evolution of the region. The project development area covers the eastern margin of the Surat Basin and the western margin of the Clarence-Moreton Basin. The majority of the formations across these basins are sedimentary, with some limited outcrops of igneous rocks towards the eastern boundary of the study area (the Main Range Volcanics). The geological formations of the project development area are relatively continuous across the boundary between these two basins. For practicality, the description and characterisation of geology and groundwater systems within the project development area are consistent with Surat Basin terminology.

Geological nomenclature has evolved over time, and variations in terminology are common in publications and reports. The Walloon Coal Measures is a term synonymous with the Walloon Sub Group and the Walloons. In addition, while some geological formations are not physically located within the project development area, they are often included for context and to address potential impacts that may extend beyond the project development area. Given the position of the project development area on the boundary between two basins and its orientation along the eastern extent of the Surat Basin, formations can become thin and are not necessarily included in published mapping.

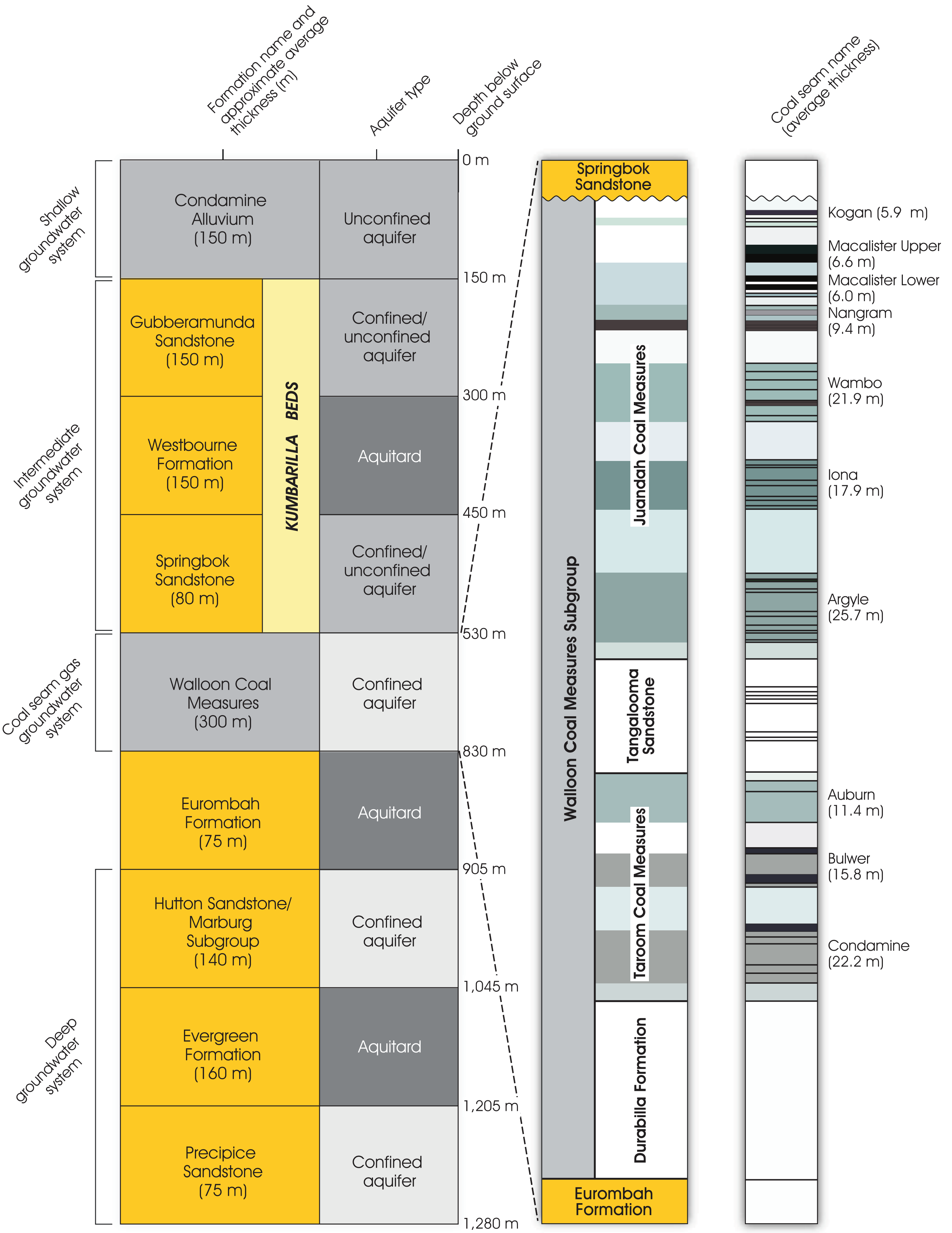
Sedimentation into the Surat Basin commenced approximately 200 million years ago, resulting in a sedimentary sequence with a maximum thickness of around 2,500 m. The geological sequence contains a series of interbedded groundwater-bearing formations (aquifers) and low-permeability, generally fine-grained formations (aquitards). Major aquifer formations (the Mooga Sandstone is excluded due to its limited extent within the project development area) present within the project development area can be grouped into groundwater systems with similar characteristics, as presented in Figure 14.3. The relationships between these units are also shown on the geological cross-section in Figure 14.4.

14.3.2 Regional Hydrogeology

Each aquifer is characterised by a set of intrinsic hydrogeological parameters, such as porosity, hydraulic conductivity and specific storage. These parameters control how the aquifers behave in the subsurface environment.

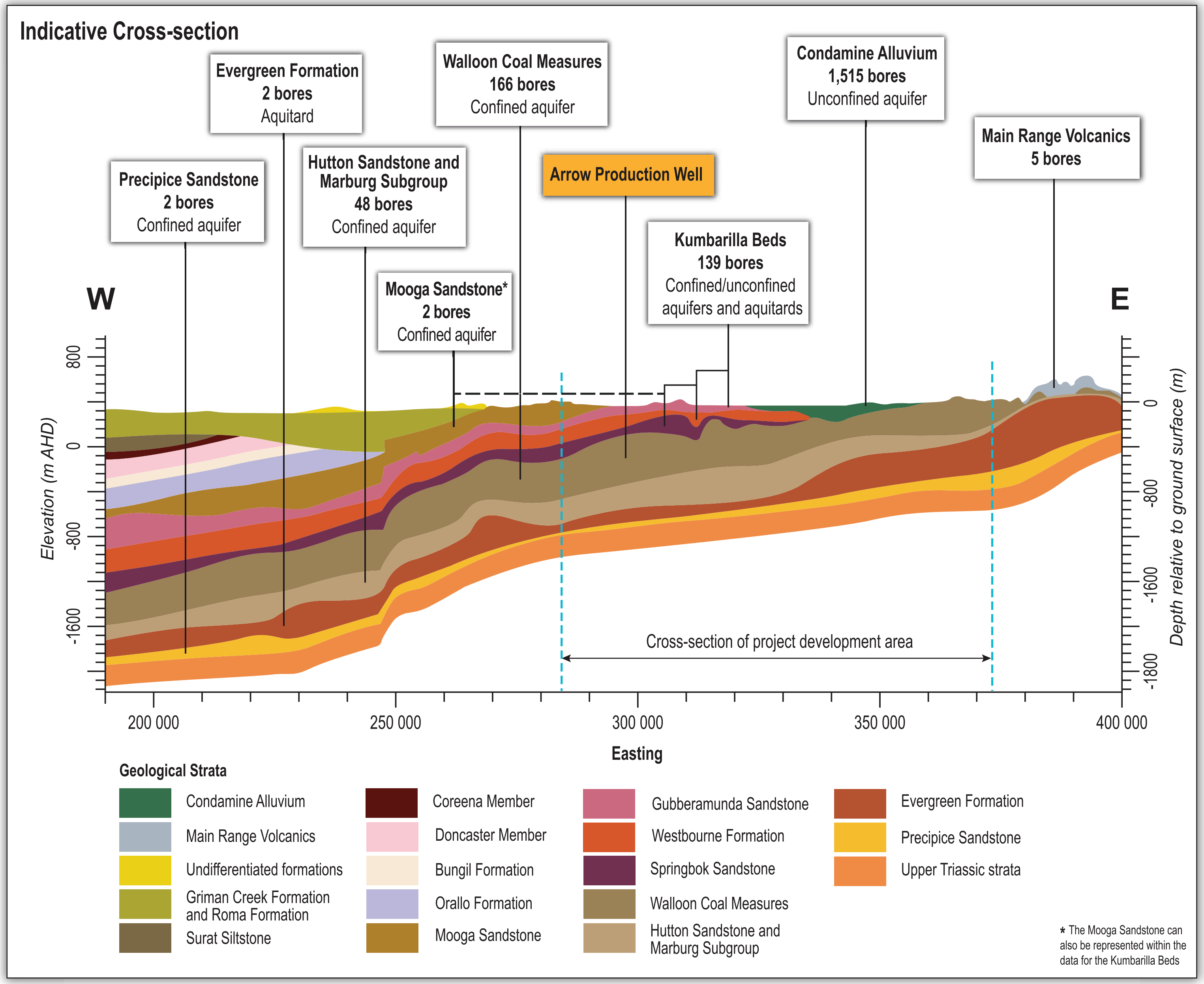
Groundwater movement in the major confined aquifers of the Surat Basin is predominantly horizontal. The lower permeability units between these aquifers (aquitards) restrict vertical interconnection between the groundwater systems; however, vertical inter-aquifer flow may occur in areas where the aquitards are thinner or eroded. In addition, if significant groundwater pressure differences occur across different formations, then inter-aquifer groundwater flow can occur.

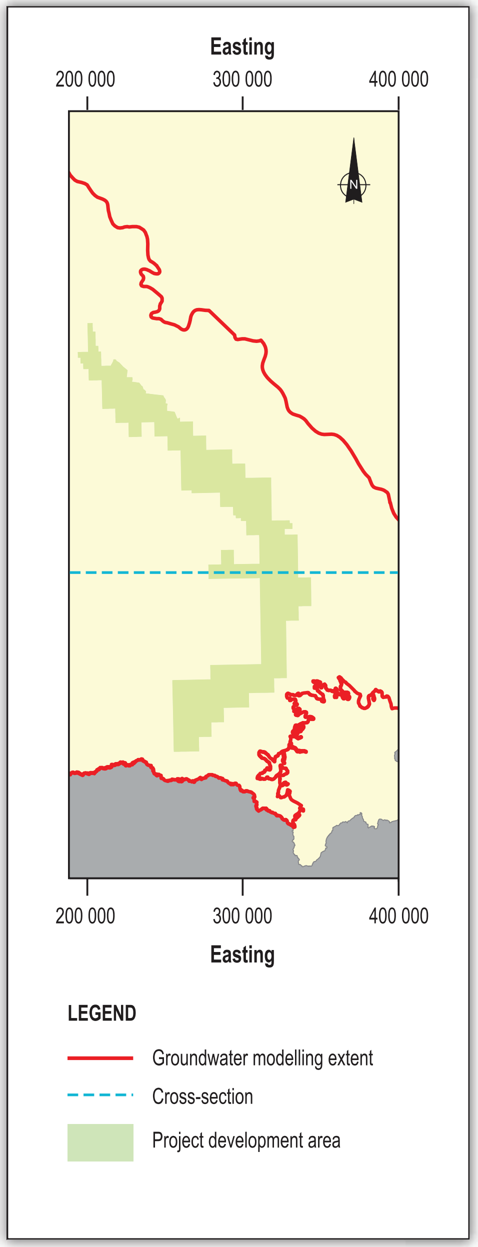
The project development area is located on the eastern margin of the GAB (Figure 14.5), which is Australia's largest contiguous groundwater resource. The GAB is made up of a multilayered confined aquifer system and is up to 3,000 m thick. Sandstone aquifers that make up the GAB are exposed at the surface along its eastern margin, in areas of relatively high rainfall, forming a recharge area that extends in a continuous arc from south and east of Goondiwindi to the top of Cape York Peninsula (see Figure 14.5). Average basin-wide recharge across the GAB is estimated to range between 5 and 10 mm/a (Herczeg et al., 1991). In Queensland, the formations that are exposed along this eastern recharge zone and that are also found within the project development area include the Gubberamunda Sandstone, Hutton Sandstone and Precipice



Source: Data form Arrow Energy
Scott et al (2004)

coffey environments	Job No: 7040 File Name: 7040_04_F14.03_GL	Arrow Energy Surat Gas Project	arrow energy go further	Stratigraphy and groundwater systems present within the project development area	Figure No: 14.3





Source:
Data from Schlumberger

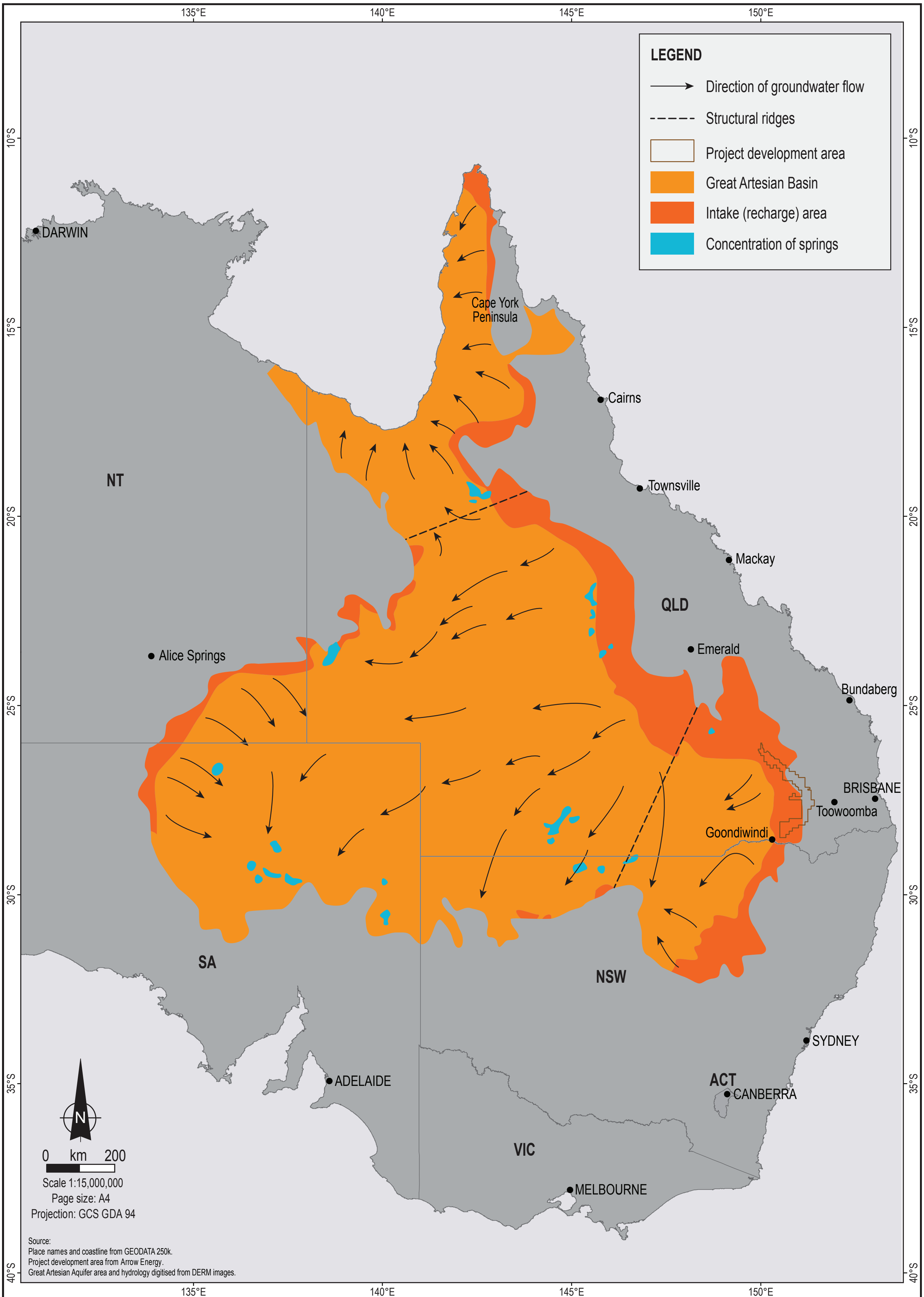
coffey environments

Job No: 7040	Arrow Energy
File Name: 7040_04_F14.04_GL	Surat Gas Project

arrow energy go further

Groundwater resources accessed by registered bores within the project development area

Figure No: 14.4



coffey environments	Date: 02.12.2011 MXD: 7040AC_04_GIS106_v1_2 File Name: 7040_04_F14.05_GIS_GL	Arrow Energy Surat Gas Project	arrow energy go further	Great Artesian Basin hydrology	Figure No: 14.5

Sandstone. From the recharge zone, subsurface groundwater flow within the GAB is generally towards the southern, southwestern, western and northern margins of the GAB. In some areas, natural groundwater discharge occurs via flowing artesian springs. According to the Water Resources (Great Artesian Basin) Plan 2006, the GAB aquifers that are present within the project development area include:

- Kumbarilla Beds:
  - Mooga Sandstone. This formation is generally of limited extent in the eastern section of the Surat Basin (Exon, 1968).
  - Gubberamunda Sandstone.
  - Springbok Sandstone.
- Walloon Coal Measures.
- Hutton Sandstone/Marburg Subgroup.
- Precipice Sandstone.

A typical range of recharge for the Surat Basin is reported to be between 0 and 3 mm/a (Kellett et al., 2003); and higher rates of up to 10 mm/a are reported in localised areas, such as the Main Range Volcanics, which provide an element of seepage to the underlying Walloon Coal Measures and Hutton Sandstone/Marburg Subgroup (see Figure 14.4).

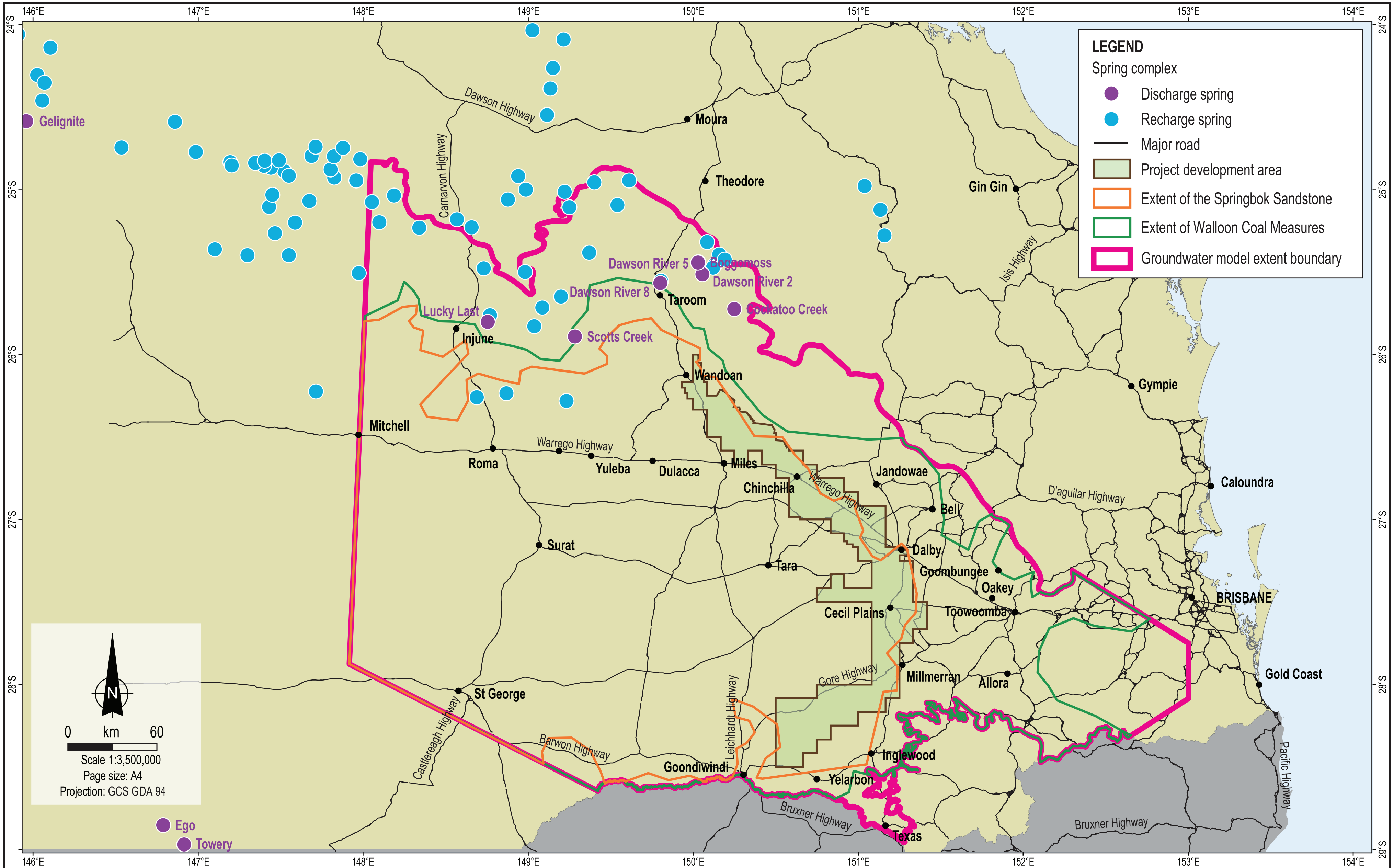
A shallow unconfined aquifer that does not form part of the GAB is the Condamine Alluvium. In this aquifer, the watertables are generally below streambed levels, and baseflow from the aquifer to watercourses is limited. Mechanisms for recharge and discharge of the Condamine Alluvium aquifer indicate that significant aquifer recharge occurs via rainfall, irrigation runoff and leakage from river beds, with little flow from aquifers to watercourses (Barnett & Muller, 2008; Hillier, 2010). The Condamine Alluvium is recharged at a rate estimated to range from 0 to 25 mm/a (Huxley, 1982; Hansen, 1999; Barnett & Muller, 2008).

14.3.3 Groundwater-dependent Ecosystems

Groundwater-dependent ecosystems rely on groundwater for survival and can potentially include but are not limited to wetlands, vegetation, springs, river baseflows (where groundwater flows from aquifers to watercourses) and cave ecosystems. Within the groundwater study area, springs and limited areas of groundwater flow to watercourses are known to occur.

Groundwater-dependent ecosystems can be present within natural springs located in groundwater recharge zones (recharge springs) and in discharge zones (discharge springs). Recharge and discharge springs can contain endemic faunal communities that are therefore groundwater-dependent.

Recharge springs generally occur along the margins of the GAB, where rates of water inflow (from rainfall and surface runoff) are greater than water infiltration into the subsurface. This causes water to seep out at the surface from exposed sandstone formations. Recharge springs are commonly an ephemeral feature in a local aquifer and not necessarily connected to regional groundwater systems. Recharge springs are therefore not considered to be susceptible to groundwater drawdown; and, while there are several recharge springs mapped within the groundwater model extent (Figure 14.6), they are not specifically referred to within the impact assessment.



Source:
Place names and roads from GEODATA250k.
Groundwater model extent, Walloon Coal Measures and Springbok Sandstone extents boundaries from Schlumberger.
Project development area from Arrow Energy.
Location, physical and biological attributes of Great Artesian Basin spring complexes, R.J. Fensham, R.J. Fairfax, T. Gotch, D. Niejalke, November 2005, Queensland Herbarium, Environmental Protection Agency

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Date: 01.12.2011
MXD: 7040AC_04_GIS108_v1_4
File Name: 7040_04_F14.06_GIS_GL

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Approximate location of known groundwater springs within the groundwater model extent

Figure No: 14.6

Discharge springs can occur in a number of settings but generally result when groundwater-bearing formations approach the ground surface or where groundwater flows to the surface through faults in the overlying formations. Discharge springs fed from aquifers of the GAB (also known as mound springs) are common, especially in the southern and western margins of the GAB and also where structural controls, such as faults, have provided pathways for artesian groundwater to reach the surface. While discharge springs are not known within the project development area, they are mapped within the groundwater model extent, as shown on Figure 14.6 (Fensham et al., 2005).

The identified discharge springs are located between 50 and 300 km north and northwest of Wandoan, the northernmost extent of the project development area. The Injune Creek Group and the Evergreen Formation are identified as the potential sources of groundwater supporting these springs (Fensham et al, 2005). The Injune Creek Group contains the Westbourne Formation, Springbok Sandstone, the Walloon Coal Measures and the Eurombah Formation. Of these formations, the Springbok Sandstone and the Walloon Coal Measures are considered regional aquifers, with the Westbourne and Eurombah Formations mapped as aquitards and therefore considered less likely to act as a groundwater source to these discharge springs. Similarly, the Evergreen Formation is not generally identified as an aquifer across the region.

The mapped extents of the Springbok Sandstone and Walloon Coal Measures are shown on Figure 14.6, illustrating that the known discharge springs are located either outside the mapped extent of these potential source aquifers or very near to the mapped boundary. The specific aquifers that serve as a groundwater source for the identified discharge springs are therefore unclear, and the identification and ground truthing of priority springs forms part of the responsibilities of the QWC.

Ecosystems of the Condamine River are considered to be groundwater-dependent in areas where the Condamine Alluvium aquifer discharges to the Condamine River. While this process is interpreted to be limited (Barnett & Muller, 2008; Hillier, 2010), it is an important interaction between groundwater and surface water within the project development area.

Significant surface waterbodies within the project development area, such as Lake Broadwater, are not known to be groundwater-dependent. Lake Broadwater is situated at the edge of the broad valley of the Condamine River and is connected to surface watercourses, specifically Wilkie Creek via the Broadwater Overflow, and also the Condamine River, when in flood.

14.3.4 Groundwater Use

Extraction of groundwater in the Surat Basin has occurred since before the 1900s, resulting in a large-scale decline in groundwater levels within key aquifer units. The majority of once artesian (free-flowing) bores have ceased to flow due to pressure decline. However, the recent government initiative of capping freely flowing artesian bores (typically located at significant distances from the project development area) has restored some of this pressure decline within certain areas. In addition, analysis of records and hydrographs shows that the watertable within the Condamine Alluvium has also been trending downwards over the past 40 years due to groundwater extraction exceeding recharge (Hillier, 2010).

The GAB aquifers are stratified, containing groundwater ranging from potable to brackish to saline quality, often varying widely within a given formation. The spatial variability of water quality means that the suitability of groundwater for a given purpose, including drinking purposes, will be, in many cases, location-specific.

A significant portion of the non-potable groundwater in the region is suitable for (and used for) irrigation and stock watering purposes. In some cases, such as are typical of the coal seam gas groundwater system, the high sodium adsorption ratios rather than salinity limit irrigation uses due to potential soil structural impacts.

Aquaculture and the production of aquatic food for human consumption are viable uses for brackish and saline waters, although the water quality parameters for these uses are often highly process-specific. Aquaculture uses have not been identified within the project development area but are feasible, given that there are bores registered for this use within the project development area.

The groundwater quality present within the project development area is generally suitable for a large number of industrial processes, including cooling water, process water, utility water and wash water. As industrial processes require particular water quality, specific hydrochemical data is normally required to evaluate suitability for a specific industrial use.

Based on information from the DERM database, Figure 14.7 displays the distribution of registered bores across the project development area, and the left-hand side of Figure 14.8 shows the number of registered bores within each groundwater system. The majority of registered bores within the project development area access groundwater within the Condamine Alluvium, as shown in Figure 14.4.

Based on the information extracted from the Queensland water entitlements registration database, the approximate general breakdown of groundwater use across the project development area is presented in the right-hand side of Figure 14.8. Note that where the bore use category information was insufficient to allow clear identification of groundwater use, the data has not been included.

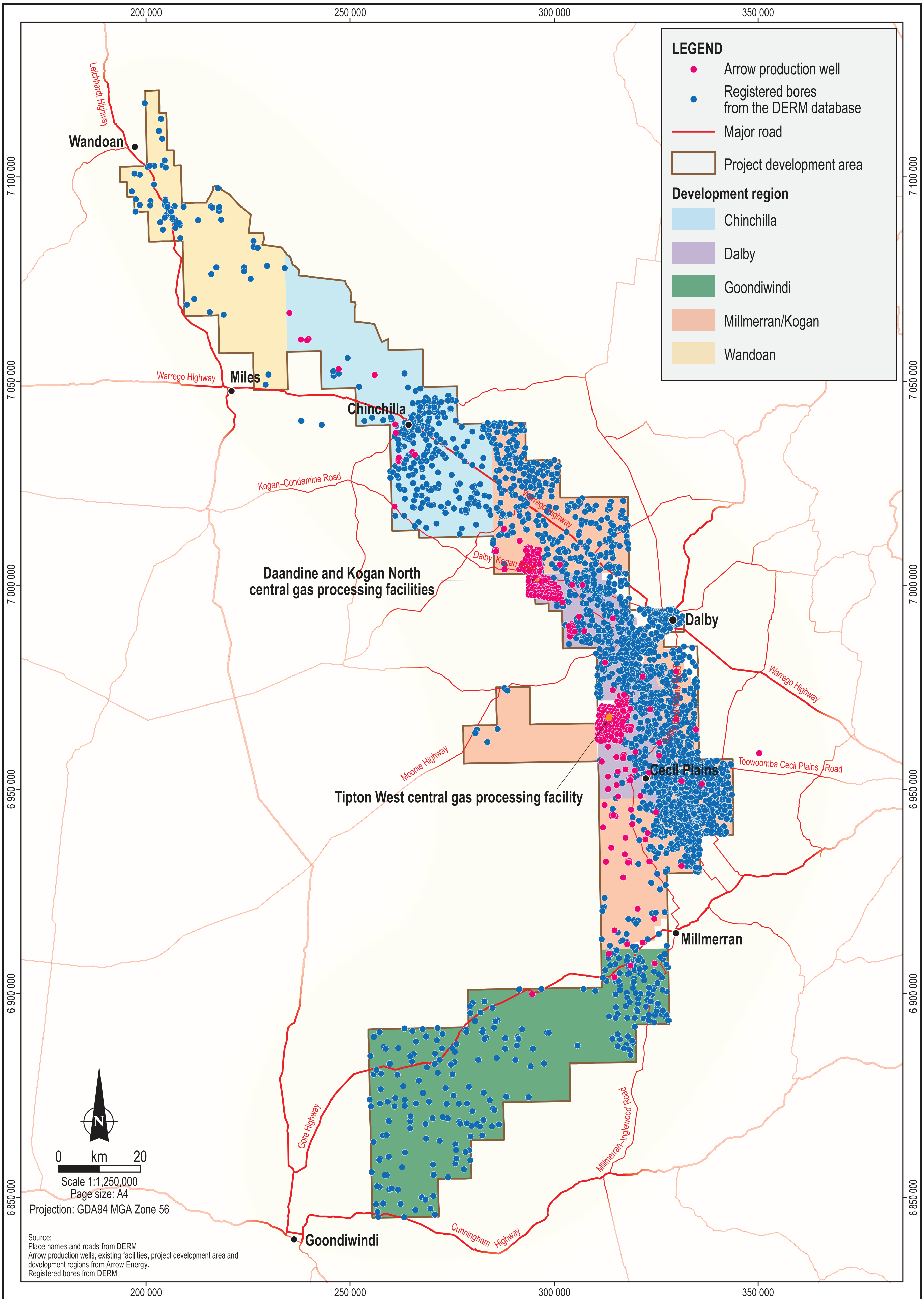
Available groundwater monitoring data (primarily sourced from the DERM database) indicates that groundwater level changes have occurred in the Walloon Coal Measures and adjacent strata from approximately 1995, which marks the approximate initiation of mining projects and coal seam gas projects in the area. This date was therefore used to define two datasets, a pre-1995 group and a post-1995 group. Each dataset is described briefly below for each groundwater system and is considered representative of the groundwater level conditions in the project development area. The variability in the baseline groundwater level data across the project development area is a function of historical extraction activities.

The documented ‘nominal entitlement’ of the licensed groundwater bores within the project development area is 331,545 ML/a and may be a significant underestimate. Only 51% of licenses had a nominal entitlement referenced. One hundred and ninety-one bores either are not metered or have not had any groundwater usage data incorporated into the Queensland water entitlements registration database.

14.3.5 Groundwater Systems

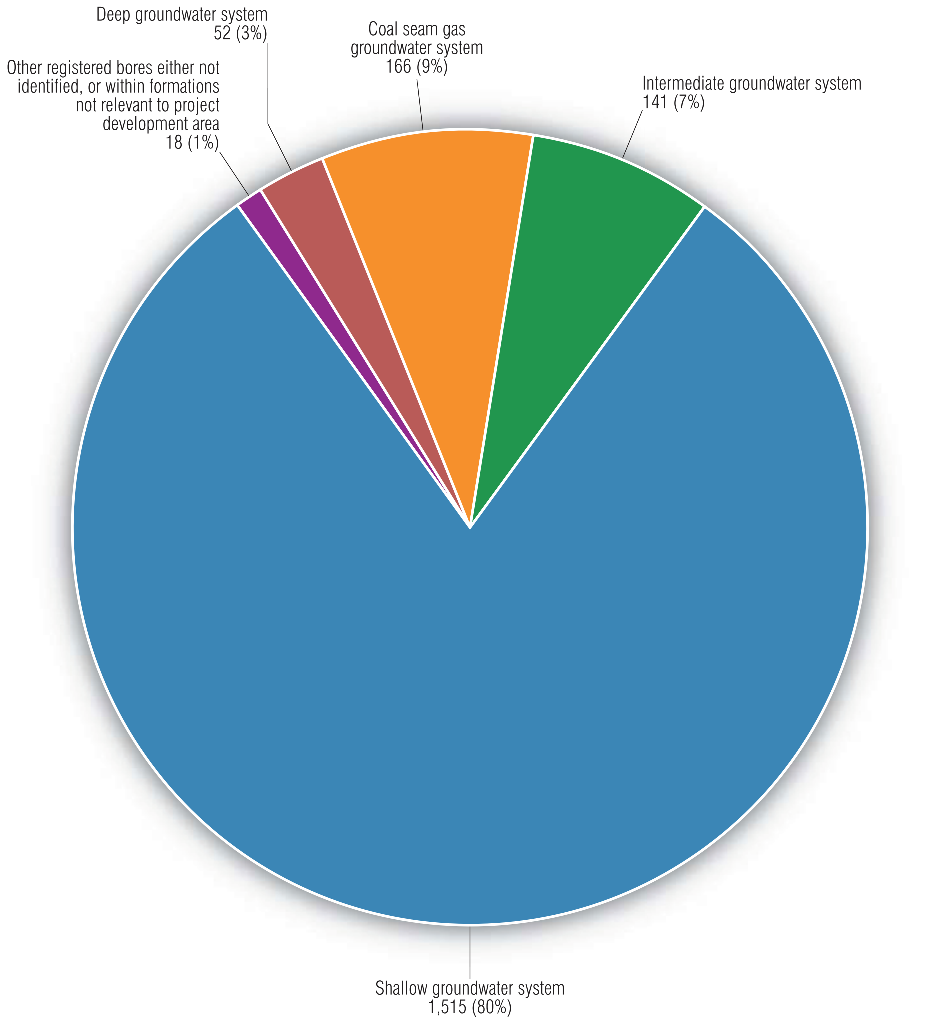
There are broadly similar geological, hydrological and water chemistry characteristics within each groundwater system in the project development area, and the environmental values to be protected are categorised under these defined systems.

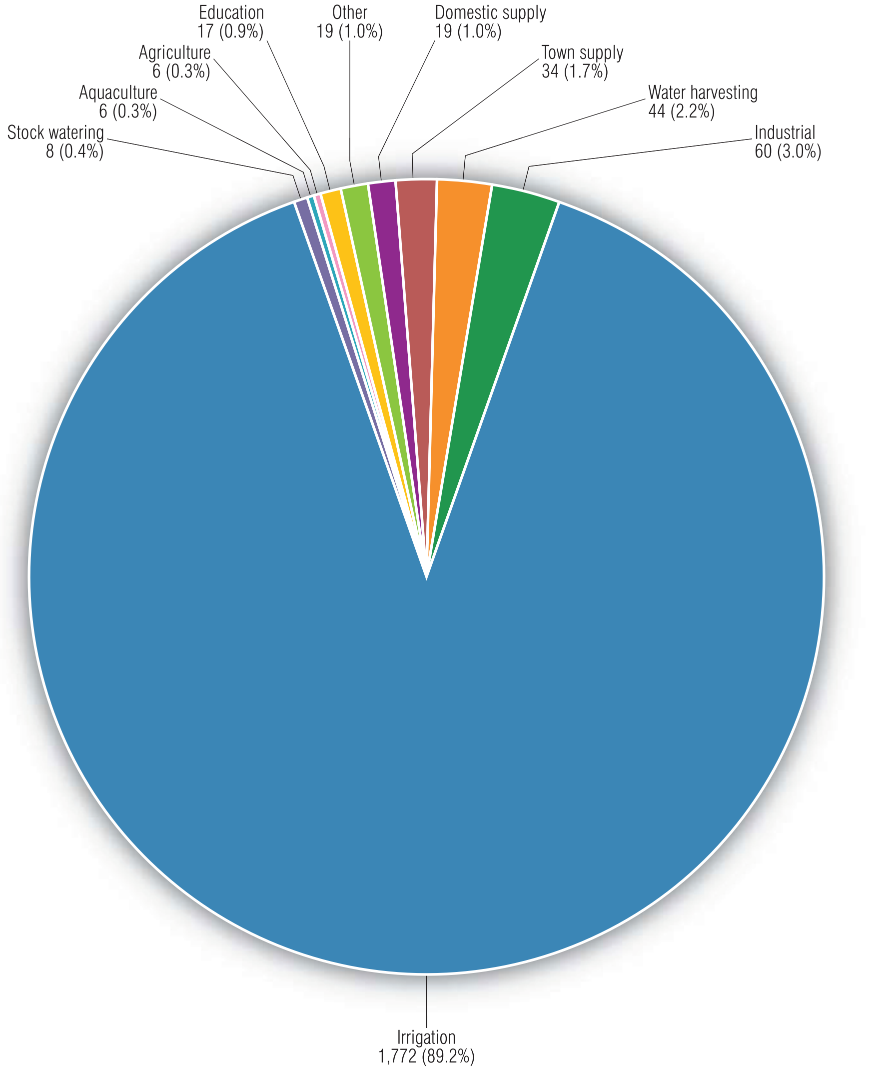
Additional details on the depth to water levels and associated groundwater flow directions as defined from water-level contour maps are provided in Appendix G, Groundwater Impact Assessment Report.



coffey environments	Date: 13.12.2011 MXD: 7040AC_04_GIS193_v1_2 File Name: 7040_04_F193_GIS_HU	Arrow Energy Surat Gas Project	arrow energy go further	Approximate location of registered water bores and Arrow production wells within the project development area

Figure No: 14.7





Source:
DERM registered bores database (data extracted October 2009).
Queensland water entitlements registration database (data extracted February 2010).

coffey environments	Job No: 7040	Arrow Energy	arrow energy go further	Distribution of licensed groundwater bores (left) and uses (right) within the project development area
	File Name: 7040_04_F14.08_JO	Surat Gas Project		Figure No: 14.8

Shallow Groundwater System

The shallow groundwater system is contained within unconfined aquifers, also known as watertable aquifers, where groundwater levels rise when recharge occurs (e.g., via rainfall infiltration or irrigation seepage) and fall when discharge occurs (e.g., via natural springs or pumping). Groundwater is found extensively across the project development area in these unconfined aquifers, with the Condamine Alluvium forming the main unconfined resource aquifer.

The Condamine Alluvium overlies the sediments that form the Surat Basin and is predominantly associated with the Condamine River valley. The Condamine Alluvium is up to 150 m thick and comprises unconsolidated clay, silt, sand and gravel deposited through processes associated with the Condamine River and its tributaries. In places, it is interpreted that the Condamine Alluvium is incised into the Walloon Coal Measures (Hillier, 2010). Deposition of a 'hydraulic separation layer' (comprising clay and other low-permeability material) at the base of the Condamine Alluvium may restrict the movement of water between the Condamine Alluvium and Walloon Coal Measures. Current conceptual modelling implies that groundwater movement between the Walloon Coal Measures and overlying aquifers is low where these confining layers are present.

These confining layers may be absent beneath some parts of the Condamine Alluvium where the alluvium is incised into the Walloon Coal Measures and the 'hydraulic separation layer' is not present.

Shallow aquifers in the project development area recharge predominantly from surface drainage, in particular from the main branch of the Condamine River (Huxley, 1982; SKM, 1999). However, recharge of the Condamine Alluvium aquifer can be inhibited by the presence of surficial cracking clay soils (see Chapter 12, Geology, Landform and Soils) that swell when wet and reduce the volumes of infiltration to the watertable below. In addition to recharge via surface infiltration, there can be areas of more focused recharge associated with leakage through stream beds and seepage from underlying bedrock.

The quality of the groundwater within the shallow groundwater system is generally variable and is influenced by surface recharge processes and interactions with deeper groundwater systems. The groundwater is slightly alkaline (average pH of 7.9) and ranges from fresh to very saline. Metal concentrations in the shallow groundwater system also vary, with elevated concentrations of iron and manganese limiting potable use of the water. The variability of the groundwater quality in this system allows a wide variety of uses but can also have limited uses in localised areas. The system is also more prone to modification due to the infiltration of pollutants, nutrients and agricultural chemicals, such as fertilisers, herbicides and pesticides, into the shallow subsurface profile due to land development, settlement and urbanisation.

No specific sites of cultural and spiritual importance related to this groundwater system were identified within the project development area. However, where baseflow discharge to the Condamine River occurs, the Condamine Alluvium aquifer may indirectly support cultural values associated with the Condamine River.

Groundwater in the Condamine Alluvium generally flows to the northwest, and available data indicates that groundwater elevations have declined from 1995 onwards. This decline is likely to relate to historical extraction of groundwater for irrigation, combined with long-term low recharge rates due to low rainfall. The estimated overall decline ranges from a few centimetres to 10 m.

Intermediate Groundwater System

Groundwater within the intermediate groundwater system is contained within the Mooga, Gubberamunda and Springbok Sandstones. The sandstone aquifers of the intermediate groundwater system are confined aquifers, where groundwater is contained under pressure.

The Mooga Sandstone has a limited extent and is mapped within the western extent of the project development area only. It is more prevalent in the western parts of the Surat Basin and is included in the impact assessment because it is located to the west of Arrow activities and may be impacted by coal seam gas activities.

The Gubberamunda Sandstone is medium to coarse grained, with minor components of siltstone and conglomerate, forming a permeable freshwater aquifer varying in thickness from less than 100 m to greater than 200 m in the central areas of the Surat Basin.

The Springbok Sandstone is an aquifer that can produce substantial quantities of groundwater from highly permeable beds, particularly specific coarse-grained units that are informally called the 'Proud Sandstone'. It predominantly contains sandstone beds with some siltstone, mudstone and thin coal seams. This aquifer can often be gas charged due to leakage of coal seam gas from the underlying Walloon Coal Measures.

There is limited discrete groundwater quality data available for the Mooga, Gubberamunda and Springbok Sandstones; however, data is available for the Kumbarilla Beds, a formation that includes these units. For discussion and comparison purposes, data available for the Kumbarilla Beds is used to characterise the quality of the intermediate groundwater system. The available data indicates that groundwater within this system has variable quality, likely to reflect chemical evolution and mineral dissolution within the aquifer units (Herczeg et al., 1991). The groundwater is slightly alkaline (average pH of 8.2) and ranges from fresh to moderately saline. The variability of the groundwater quality in this system allows a wide variety of uses.

No specific sites of cultural and spiritual importance related to this groundwater system were identified within the project development area. However, these areas may be present within the broader study area.

Discrete groundwater elevation data for the aquifers within the intermediate groundwater system is limited; however, the data available for the Kumbarilla Beds indicates relatively uniform groundwater elevations prior to 1995 and a groundwater flow direction predominantly to the southwest. Limited discrete data for the Gubberamunda Sandstone indicates an overall groundwater flow direction from north to south. Groundwater elevation data available for the Springbok Sandstone shows a general flow direction from northwest to southeast. The dataset available for 1995 to 2009 shows relatively little change in the groundwater elevations over time; however, based on limited data, groundwater elevations have generally declined in the Springbok Sandstone since 1995.

Coal Seam Gas Groundwater System

Groundwater within this system is contained within confined aquifers of the Walloon Coal Measures. Within the project development area, the Walloon Coal Measures range in thickness from 100 to 500 m and are formally subdivided into the following formations:

- Juandah Coal Measures
- Tangalooma Sandstone.
- Taroom Coal Measures.
- Durabilla Formation.

The Juandah and Taroom Coal Measures consist of coal seams separated by a complex sequence of interbedded siltstones, mudstones and sandstones. The coal tends to occur as discontinuous thin stringers that can have limited lateral extent. Within the project development area, the Tangalooma Sandstone is very discontinuous and consists of individual sand lenses rather than a consistent sheet, and therefore mapping is limited. The Durabilla Formation is predominantly interbedded mudstone, siltstone and sandstone. In places, this formation is described in conjunction with the Eurombah Formation, forming an aquitard between the Walloon Coal Measures and the underlying Hutton Sandstone/Marburg Subgroup (see Figure 14.3).

Groundwater quality information available for the Walloon Coal Measures indicates variable groundwater quality. It is interpreted that this variability is related to chemical evolution and mineral dissolution within the aquifer, together with the assorted rock types within this formation (Herczeg et al., 1991). Groundwater within the Walloon Coal Measures is generally slightly alkaline (average pH of 8.1) and saline. Individual measurements for total dissolved solids, however, range widely from fresh to very saline, with some concentrations approaching seawater salinity. This wide range indicates a corresponding wide range of uses, with limited uses in localised areas.

No specific sites of cultural and spiritual importance related to this groundwater system were identified within the project development area. However, these areas may be present within the broader study area.

Groundwater levels available for the Walloon Coal Measures show a dominant flow direction to the west, with a secondary flow direction to the east. More extensive data in the Dalby and Millmerran areas is available for the Walloon Coal Measures. These datasets show a variety of responses, with some bores having little variation in groundwater elevations since 1995 and others having more significant reductions. In particular, a monitoring bore installed in the Daandine area (an existing Arrow gas field located approximately 30 km northwest of Dalby) provides data from 2005 to 2007, reflecting the effects of initial Arrow coal seam gas activities. Groundwater levels recorded in this bore show a drawdown in the Walloon Coal Measures of nearly 30 m, with the rate of drawdown increasing from 2.5 m/a between 2005 and 2006 to 12.5 m/a between 2006 and 2007.

Deep Groundwater System

The deep groundwater system contains confined aquifers characterised as porous, permeable medium- to coarse-grained quartzose sandstones that generate significant groundwater resources in the study area. Within the project development area, the deep groundwater system contains the Hutton Sandstone/Marburg Subgroup and the Precipice Sandstone, separated by the Evergreen Formation, which acts as an aquitard. The Hutton Sandstone/Marburg Subgroup is commonly 120 to 180 m thick and consists of fine- to medium-grained sandstone with some mudstone and siltstone. In the Surat Basin, the Hutton Sandstone grades into the Marburg Subgroup where it transitions into the Clarence-Moreton Basin.

The Precipice Sandstone is generally coarse grained at the base, with a finer-grained upper section. It can vary in thickness from 50 m to over 100 m and is an aquifer that can produce significant quantities of high-quality groundwater.

Based on limited data, groundwater quality within the Hutton Sandstone is variable but is generally fresh to brackish and alkaline (average pH of 8.4). A larger dataset is available for the Marburg Subgroup, which also indicates fresh to moderately saline and alkaline (average pH of 7.8) groundwater with overall variable quality, interpreted to reflect chemical evolution and mineral dissolution within the aquifers (Herczeg et al., 1991). The aquifers that make up the deep groundwater system within the project development area form part of the GAB. The groundwater quality characteristics available for these aquifers are similar to the overall GAB groundwater quality, and the variability is related to chemical processes that occur as the groundwater migrates away from recharge areas.

No specific sites of cultural and spiritual importance related to this groundwater system were identified within the project development area. However, aquifers in the deep groundwater system have historical cultural significance as artesian groundwater resources. Groundwater from the deep system can also support spiritually important springs, especially in more regional GAB discharge areas outside the project development area.

Groundwater from this system is of moderate to high biological importance due to higher water quality than other groundwater systems. Aquifers in the deep groundwater system have the potential to naturally discharge to surface features. They are of high biological importance due to the identified connection between them and mound springs in more regional GAB groundwater discharge areas.

Groundwater elevation data available for the Hutton Sandstone shows flow directions from north to south and northwest to northeast. Groundwater flow within the Precipice Sandstone generally originates from exposed recharge areas in the northeast, and subsequent groundwater flow is towards the Dawson River catchment to the southwest. Limited groundwater elevation data is available for the period after 1995, and four bores within the Hutton Sandstone and Marburg Subgroup do not show any significant reduction in groundwater elevations. In summary, the variability in the available baseline groundwater-level data reflects general groundwater variability across the project development area.

14.3.6 Environmental, Social and Cultural Values

Each groundwater system identified within the project development area has a variety of characteristics that define the sustainability of the groundwater resource in terms of quantity and quality. The combination of characteristics that define a groundwater system allow the groundwater to be relied upon in a number of ways, including:

- Support to biological areas.
- Consumptive or productive uses.
- Support to areas of cultural and spiritual importance.

Biological Areas and Ecological Value of Groundwater

Groundwater systems can support biological areas either directly or indirectly. For example, where an aquifer discharges to a spring system (e.g., a discharge spring), then the groundwater system may be directly supporting an ecosystem. Where an aquifer discharges to a wetland, lake or stream, support may be indirect. The ability of groundwater systems to maintain the biological integrity of such ecosystems depends on the ecological value of the groundwater.

The EPP (Water) defines the biological integrity of receiving ecosystems as follows:

- Pristine or modified aquatic ecosystems that are effectively unmodified or highly valued (for waters of high ecological value).

- Aquatic ecosystems that are affected adversely to a relatively small but measurable degree by human activity (for slightly to moderately disturbed waters).

- Aquatic ecosystems that are measurably degraded and of lower ecological value than waters mentioned above (for highly disturbed waters).

For the purpose of assessing the ecological value of groundwater and its ability to maintain the integrity of the receiving biological area, the following aspects are considered:

- The chemistry of the groundwater system in relation to potential receiving environments.
- The ability of the groundwater system to discharge to ecosystems within lakes, wetlands, watercourses and springs.
- The level of isolation of the groundwater system from potentially impacting human processes.

Consumptive and Productive Value of Groundwater

Groundwater systems can support a variety of consumptive and productive uses. As defined in the EPP (Water), groundwater systems can be further characterised as displaying attributes that support the following uses:

- Drinking water with minimal treatment.
- Agriculture.
- Aquaculture and production of aquatic food for human consumption.
- Industrial uses.

Cultural and Spiritual Value of Groundwater

The characteristics of groundwater systems that support areas of cultural and spiritual importance would relate to physical features where groundwater interaction can occur, such as wells and springs with Indigenous and non-Indigenous anthropological, archaeological, historic, sacred or scientific significance. (Other details of human cultural and spiritual values within the project development area are contained in Chapter 23, Indigenous Cultural Heritage, and Chapter 24, Non-Indigenous Cultural Heritage.)

Summary of Groundwater Environmental Values

The characteristics of each groundwater system determine the groundwater environmental values, as described above. How a groundwater system responds to disturbance is controlled by a combination of the intrinsic characteristics of the groundwater system (e.g., groundwater quality, porosity and permeability) and the hydrogeologic processes acting on the groundwater system (e.g., recharge and discharge mechanisms). Table 14.6 summarises the groundwater values relating to each groundwater system, and Table 14.7 summarises the sensitivity of the groundwater value relating to each existing system.

As there are several aspects of a groundwater system that determine its sensitivity, the following assumptions and constraints have been applied to arrive at an overall sensitivity rating for each system:

- The sensitivity criteria are assessed based on the potential impact area of the project, which can extend beyond the boundary of the project development area.
- The overall sensitivity rankings incorporate a variety of characteristics that respond in different ways.
- Biological values are assessed with consideration of typical groundwater quality potentially available to support ecosystems, as well as the physical likelihood of supporting ecosystems (i.e., the ability of the groundwater system to discharge to surface features).

Table 14.6 Summary of groundwater values

Ground-water System	Ecological Value	Biological Integrity Able to be Maintained	Potential Consumptive and Productive Uses	Cultural and Spiritual Values
Shallow	The system is more prone to modification due to the infiltration of pollutants, nutrients, and agricultural chemicals, such as fertilisers, herbicides and pesticides, into the shallow subsurface profile due to land development, settlement, and urbanisation. There are physical connections between this groundwater system and such surface features as the Condamine River.	Where physical connection between this groundwater system and surface features occurs, the groundwater quality is predominantly able to maintain slightly to moderately disturbed ecological systems.	Groundwater from this system has generally low to moderate total dissolved solids concentrations (average of approximately 1,300 mg/L), allowing a wide range of beneficial uses; however, it is predominantly suitable for agricultural use within the project development area.	No specific sites are identified within the project development area; however, where baseflow discharge to the Condamine River occurs, the Condamine Alluvium aquifer may indirectly support cultural values associated with the Condamine River.
Intermediate	The ecological value of the intermediate groundwater system increases with depth, as this generally reflects increased isolation from potentially impacting human processes. There are no known areas of physical connection between this groundwater system and surface features within the project development area; however, they may exist within the groundwater model extent.	If a physical connection between this groundwater system and surface features exists, the groundwater quality is predominantly able to maintain effectively undisturbed ecological systems and some slightly to moderately disturbed ecological systems.	Based on variable total dissolved solids concentrations (average of approximately 1,400 mg/L), groundwater from this system has a range of uses; however, it is predominantly suitable for agricultural use within the project development area.	No specific sites are identified within the project development area.
Coal seam gas	Groundwater from this system is generally considered to be of lower ecological value due to higher salinity and high sodium absorption ratios. There are no known areas of physical connection between this groundwater system and surface features within the project development area; however, they may exist within the groundwater model extent.	If a physical connection between this groundwater system and surface features exists, the generally poor groundwater chemistry and salinity would likely fail to support ecological systems.	The aquifers within the coal seam gas groundwater system are generally considered to be of lower quality due to higher salinity (average total dissolved solids values of approximately 4,600 mg/L) and high sodium absorption ratios. The groundwater is generally suitable for stock watering and production of aquatic food for human consumption.	No specific sites are identified within the project development area.

Table 14.6 Summary of groundwater values (cont'd)

Ground-water System	Ecological Value	Biological Integrity Able to be Maintained	Potential Consumptive and Productive Uses	Cultural and Spiritual Values
Deep	The deep groundwater system is generally considered to be of high ecological value due to lower salinity and isolation from potentially impacting human processes. There no known areas of physical connection between this groundwater system and surface features within the project development area; however, they may exist within the groundwater model extent.	If a physical connection between this groundwater system and surface features exists, groundwater quality from this system is predominantly able to maintain effectively undisturbed ecological systems and some slightly to moderately disturbed ecological systems.	Lower total dissolved solids concentrations allow a wide range of uses; however groundwater from this system is predominantly suitable for agricultural uses within the project development area.	No specific sites are identified within the project development area; however, aquifers in the deep groundwater system have historical cultural significance as artesian supply.

Table 14.7 Sensitivity of the value of each groundwater system

Existing Environment/ Groundwater System	Intrinsic Characteristics and Hydrogeological Processes Contributing to the Value	Sensitivity of the Value
Shallow groundwater system	• The Condamine Alluvium aquifer discharges to the Condamine River in some reaches, indirectly supporting biological values. • Groundwater from this system is a supply generally suitable for agricultural uses. • Where baseflow discharge to the Condamine River occurs, the Condamine Alluvium aquifer may indirectly support cultural values associated with the Condamine River. • The Condamine Alluvium aquifer is associated with the Condamine River valley. Although shallow aquifers are generally common, there are few regional equivalents, and the aquifer is locally unique. • The shallow groundwater system is dynamic, with several recharge mechanisms, producing a resilient system and enabling regular and rapid groundwater level recovery, compared with confined systems. • The Condamine Alluvium directly overlies the Walloon Coal Measures in some parts of the project development area. Groundwater flow between these two units is possible. • Historical overextraction by groundwater users and overallocation of the groundwater resource has led to modification of the system. • Rehabilitation can be achieved when impacts are removed.	Moderate
Intermediate groundwater system	• Groundwater from this system is of moderate biological importance due to generally better water quality than that of coal seam gas formations. • There are no known areas of physical connection between this groundwater system and surface features within the project development area; however, they may exist within the groundwater model extent. • The aquifers in the intermediate groundwater system are not known to support specific areas of cultural or spiritual significance. • The aquifers in this groundwater system provide a supply generally suitable for agricultural uses. • The intermediate groundwater system forms a regional aquifer system across the GAB, and equivalent aquifers are common in many areas. • The intermediate groundwater system is more dynamic than deeper groundwater systems, with multiple recharge mechanisms producing a moderately resilient system that can recovery over the medium term. • Rehabilitation can be achieved when impacts are removed.	Moderate

Table 14.7 Sensitivity of the value of each groundwater system (cont'd)

Existing Environment/ Groundwater System	Intrinsic Characteristics and Hydrogeological Processes Contributing to the Value	Sensitivity of the Value
Coal seam gas groundwater system	• Groundwater from this system is of low biological importance due to generally poorer water quality than other groundwater systems. • There are no known areas of physical connection between this groundwater system and surface features within the project development area; however, they may exist within the groundwater model extent. • The aquifers in the coal seam gas groundwater system are not known to support areas of cultural or spiritual significance. • The aquifers in the coal seam gas groundwater system provide a brackish to saline supply generally suitable for industrial uses or stock watering. • The coal seam gas groundwater system is a regional aquifer system across the GAB, and equivalent aquifers are common in many areas. • The coal seam gas groundwater system is less dynamic than other shallower systems, with limited recharge mechanisms. The aquifers within the coal seam gas groundwater system are recharged through rainfall only where outcropping and through inter-aquifer leakage and can recover from groundwater drawdown slowly. • Rehabilitation can be achieved when impacts are removed.	Low
Deep groundwater system	• Groundwater from this system is of moderate to high biological importance due to higher water quality than other groundwater systems. Aquifers in the deep groundwater system have the potential to naturally discharge to surface features. They are of high biological importance due to the identified connection between them and mound springs in more regional GAB groundwater discharge areas. • There are no known areas of physical connection between this groundwater system and surface features within the project development area; however, they may exist within the groundwater model extent. • The aquifers in the deep groundwater system have historical cultural significance as artesian supply. • The aquifers in this groundwater system provide a supply generally suitable for agricultural uses. • The deep groundwater system is a locally unique aquifer system; however, equivalent regional aquifers are common across the GAB. • The physical aspects of the aquifers within the deep groundwater system provide some resilience to depressurisation impacts. • The deep groundwater system is less dynamic than other shallower systems, with limited recharge mechanisms and lower resilience. The aquifers within the deep groundwater system are recharged through rainfall in distal areas where formations outcrop and through inter-aquifer leakage and can have long recovery periods. • Rehabilitation can be achieved when impacts are removed.	High

- Discharge springs or areas of known cultural or spiritual importance are potentially within the area that may be affected by drawdown of groundwater. Accordingly, a number of specific springs located north and west of the project development area (see Figure 14.6) (and within the extent of the numerical groundwater model) have conservatively been included in the impact assessment, despite their location outside the mapped extent of the potential groundwater source aquifers (the Springbok Sandstone and the Walloon Coal Measures). The specific aquifers that serve as a groundwater source for the identified discharge springs are unclear, and the impact assessment below is based on known information.
- Consumptive and productive uses consider the general groundwater quality available.
- Although specific cultural and spiritual sites have not been identified that will be impacted by the project, it is feasible that isolated occurrences might exist and therefore have been considered in the impact assessment, in particular:
  - Groundwater baseflow to the Condamine River has been considered to support cultural values of the river.
  - Aquifers in the deep groundwater system have historical cultural significance as artesian supply.
- The context for the resilience of groundwater systems is with respect to drawdown recovery sensitivity, whereby high sensitivity equates to longer expected recovery times when coal seam gas water extraction ceases, while low sensitivity equates to shorter expected recovery times.
- Rehabilitation potential is considered with respect to impacts from depressurisation.

14.4 Issues and Potential Impacts

The significance of potential impacts on the groundwater values has been assessed using the sensitivity of the value and the magnitude of the potential impact (as described in Chapter 7, Impact Assessment Method).

Coal seam gas water will be extracted from the Walloon Coal Measures, so direct impacts on the groundwater levels in this aquifer cannot be avoided. In addition to direct impacts on the Walloon Coal Measures from depressurisation, there are potential indirect impacts on surrounding groundwater systems as a result of coal seam gas water extraction.

Other than coal seam gas water extraction, other activities conducted by Arrow that have the potential to affect groundwater include drilling, storage of saline water, and storage of chemicals and fuels. Potential impacts on the groundwater values from associated project activities include:

- Reduced flows to groundwater-dependent ecosystems and areas of cultural and spiritual importance fed by groundwater from the Walloon Coal Measures and adjacent aquifers.
- Reduced groundwater supply to existing or future groundwater users accessing groundwater from the Walloon Coal Measures and adjacent aquifers.
- Diminished groundwater quality, caused by:
  - Surface activities related to the storage of chemicals and fuels and the storage, treatment and transfer of coal seam gas water.

- – Subsurface activities related to aquifer depressurisation, drilling of production wells and monitoring bores, and the installation of buried infrastructure.

- Diminished rainwater infiltration, reduced aquifer recharge and altered groundwater flow patterns.
- Land subsidence affecting surface water flow regimes and landforms.

Activities with the potential to cause these adverse impacts on groundwater values during the life of the project are described in the following sections; and Table 14.9 lists the potential impacts; causes; significance of impacts; proposed mitigation, monitoring and management measures; and significance of the residual impact.

14.4.1 Coal Seam Gas Water Extraction: Direct Impacts

The extraction of coal seam gas will result in depressurisation of the Walloon Coal Measures, which will lower aquifer pressures, potentially resulting in the following direct impacts:

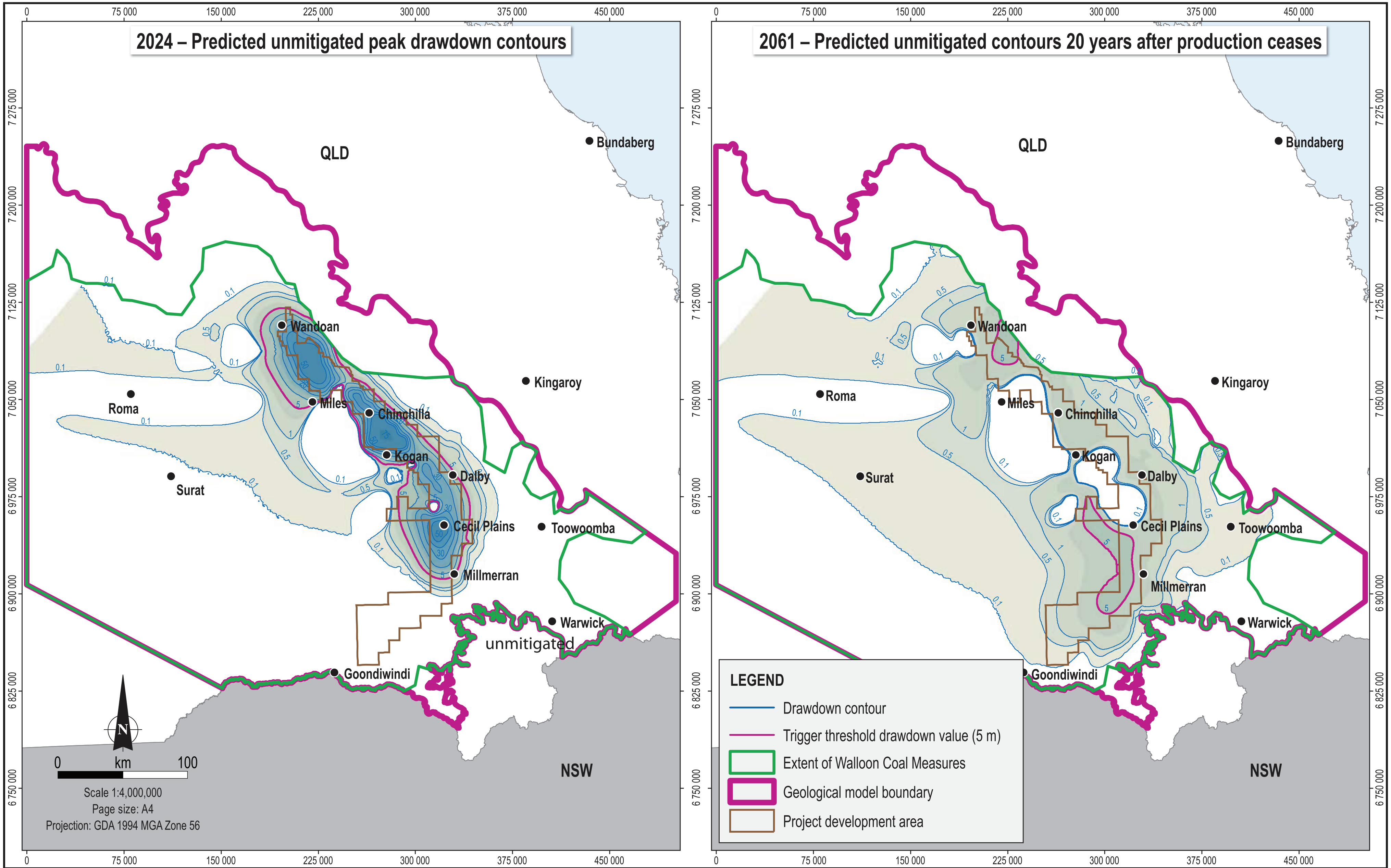
- Reduced groundwater flow to groundwater-dependent ecosystems or areas of cultural and spiritual importance fed by the Walloon Coal Measures.
- Reduced groundwater supply to existing or future groundwater users accessing groundwater from the Walloon Coal Measures.

The results of the numerical groundwater model predict the unmitigated direct groundwater drawdown in the Walloon Coal Measures as a result of coal seam gas extraction by Arrow-only (modelling scenario 1) as follows:

- Drawdown is predicted to be greatest in the Juandah Coal Measures, peaking in 2024 in excess of 75 m (Figure 14.9).
- In 2024, drawdown is predominantly limited to within the project development area, and predicted drawdown reduces to less than 5 m approximately 10 km from the project development area.
- Maximum predicted drawdown in the Taroom Coal Measures and the Tangalooma Sandstone is estimated to range from 50 to 75 m in 2024.
- By 2061, significant groundwater recovery is predicted due to recharge areas along the east boundary of the model extent, with residual drawdown predicted to be less than 10 m across the Juandah and Taroom Coal Measures and the Tangalooma Sandstone.
- Maximum predicted groundwater drawdown can vary across the five development regions as a function of the modelled thickness of the units within the Walloon Coal Measures and the predicted coal seam gas extraction rates.

14.4.2 Coal Seam Gas Water Extraction: Indirect Impacts

The extraction of coal seam gas results in depressurisation of the aquifers in the Walloon Coal Measures and has the potential to impact indirectly upon other groundwater systems present within the project development area.



Source:
Place names from DERM.
Project development area from Arrow Energy.
Extent of Waloon Coal Measures, geological model boundary and drawdown contours from Schlumberger.

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MXT: 7040AC_04_GIS168_v1_4
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Predicted unmitigated groundwater drawdown contours in the Juandah Coal Measures (modelling scenario 1: Arrow-only)

Figure No: 14.9

Subsequent indirect depressurisation of adjacent aquifers has the potential to cause aquifer interflow and groundwater drawdown, resulting in the following indirect impacts:

- Diminished groundwater quality in aquifers above and below the Walloon Coal Measures. This relates to groundwater mixing as drawdown in the Walloon Coal Measures aquifers induces flow across deeper and shallower aquifers, especially the Springbok and Hutton sandstones.
- Reduced groundwater flow to groundwater-dependent ecosystems or areas of cultural and spiritual importance fed by the adjacent aquifers.
- Reduced groundwater supply to existing or future groundwater users accessing groundwater from the adjacent aquifers.
- Land subsidence and changes to surface water flow regimes and landforms.

The results of the numerical groundwater model can be used to predict the indirect groundwater drawdown in the aquifers above and below the Walloon Coal Measures as a result of coal seam gas extraction by Arrow (modelling scenario 1).

The results of the Arrow-only scenario modelling are summarised in Table 14.8 below:

Table 14.8 Summary of predicted unmitigated indirect groundwater drawdown in shallow, intermediate and deep groundwater systems

Groundwater System and Aquifer	Predicted Maximum Groundwater Drawdown	Comments
Shallow groundwater system Condamine Alluvium (Figure 14.10)	Greater than 0.1 to less than 1 m	Greatest drawdown is predicted within the Dalby development region, along the western extent of the Condamine Alluvium. Average drawdown across the project development area is less than 1 m. Peak drawdown is predicted in 2059, indicating a lag between gas extraction activities across the entire project development area and corresponding drawdown in the shallow Condamine Alluvium. Recovery is predicted to be slower than drawdown, with groundwater levels not returning to initial levels by 2061. Additional model outputs (Appendix G, Groundwater Impact Assessment Report) show that groundwater levels also do not recover to initial levels by 2071, which is maximum temporal extent of the model.
Intermediate groundwater system Kumbarilla Beds (Figure 14.11)	30 m	Maximum drawdown is predicted in 2029. Greater drawdown, up to 20 to 30 m, is predicted along the eastern boundary of the Kumbarilla Beds. Average drawdown over the majority of the project development area is predicted to range from 2.5 to 5 m. By 2061, drawdown along the eastern extent of the Kumbarilla Beds has recovered to approximately 5 m; however, drawdown contours extend across the southern portion of the project development area. This is primarily due to the late onset of coal seam gas water extraction from the Goondiwindi development region.

Table 14.8 Summary of predicted indirect groundwater drawdown in shallow, intermediate and deep groundwater systems (cont'd)

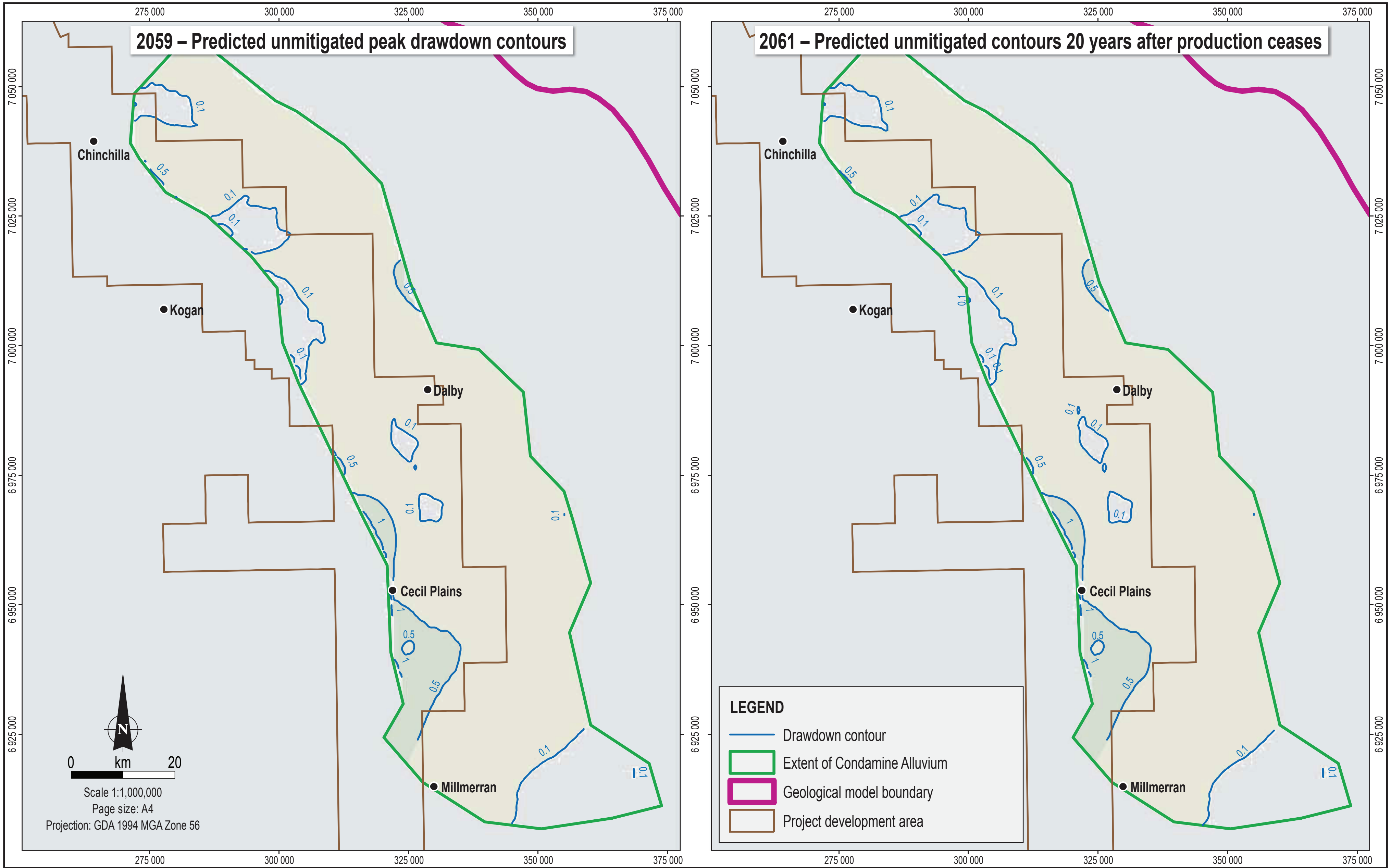
Groundwater System and Aquifer	Predicted Maximum Groundwater Drawdown	Comments
Deep groundwater system Hutton Sandstone/ Marburg Subgroup (Figure 14.12)	20 to 30 m	Maximum drawdown is predicted in the Goondiwindi development region in 2035.[1] In all other development regions, peak drawdown is predicted in 2027, with the greatest drawdown observed in the Wandoan development region. Across the majority of the project development area, an average drawdown of 10 to 20 m is predicted. During 2027, drawdown up to 0.5 m extends approximately 25 km west and 5 km east of the project development area. By 2061, predicted drawdown has reduced to an average of 5 m across the project development area, and drawdown up to 0.5 m expands to the west, approximately 60 km from the project development area.
Deep groundwater system Precipice Sandstone (Figure 14.13)	10 to 15 m	Maximum predicted drawdown of 10 to 15 m is modelled in 2042 within the Dalby development region. At this time, the average drawdown across the majority of the project development area is predicted to range from 1 to 5 m. By 2061, predicted drawdown has reduced in the vicinity of the Dalby development region; however, the contours across the remainder of the project development area indicate slow recovery rates.

[1] The Goondiwindi development region begins extraction of coal seam gas water later than all other development regions, creating a peak in the production curve that is reflected in the outcomes of the predictive modelling.

14.4.3 Surface Activities

Surface activities that can impact groundwater values include:

- Leaks and spills of chemicals, fuels and oils stored at the surface in association with production facilities may result in contamination of the intersected aquifers.
- Discharges of liquid domestic wastes and effluent to land have the potential to contaminate groundwater systems.
- Reduced rainwater infiltration and subsequent reductions in aquifer recharge from the surface due to the following:
  - Construction of impervious surface coverings associated with production facilities.
  - Land disturbance activities resulting in reduced porosity and permeability of surface profiles.



Source:
Place names from DERM.
Project development area from Arrow Energy.
Extent of Condamine Alluvium, geological model boundary and drawdown contours from Schlumberger.

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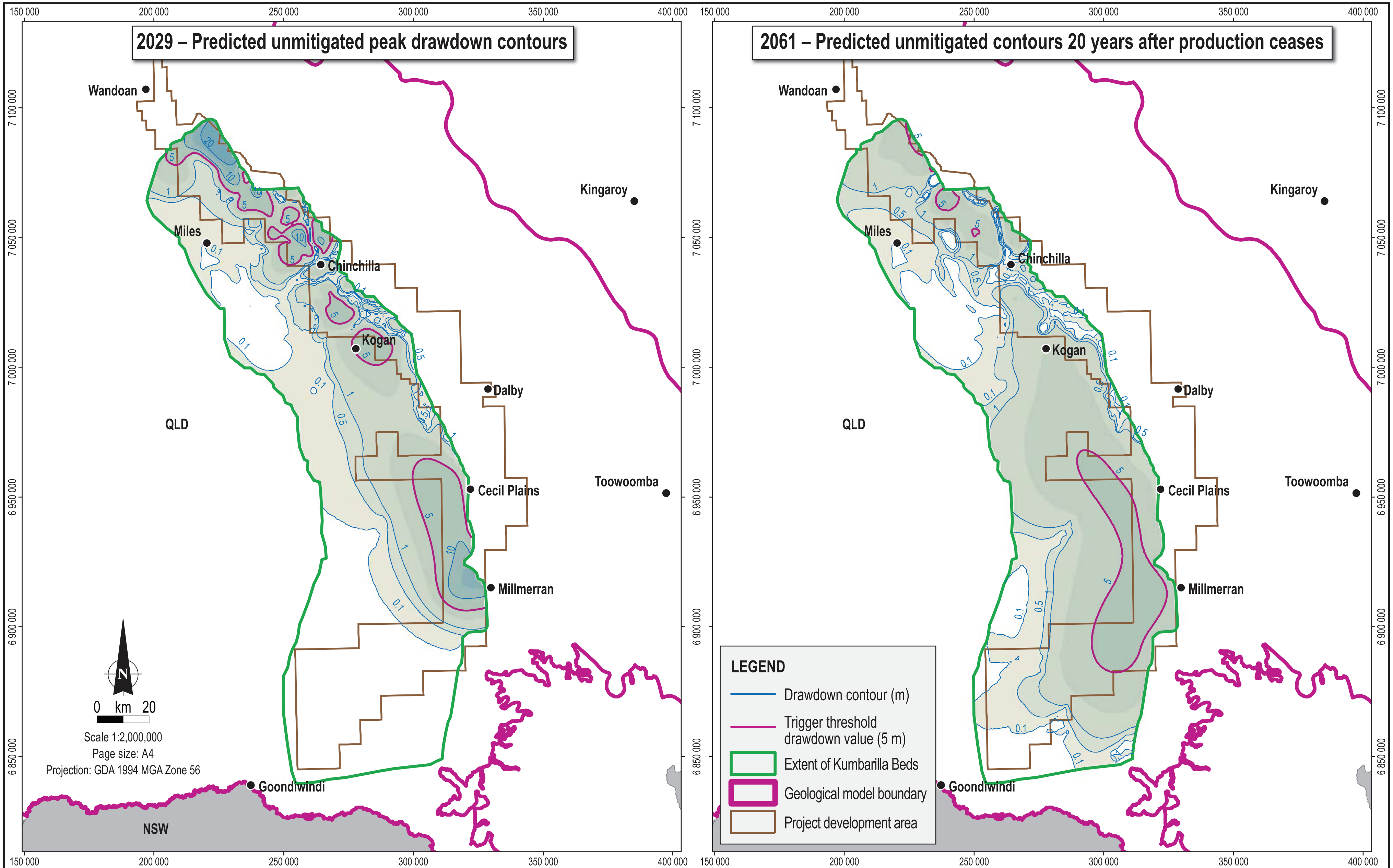
Predicted unmitigated groundwater drawdown contours in the Condamine Alluvium (modelling scenario 1 : Arrow-only)

Figure No: 14.10



Source:
Place names from DERM.
Project development area from Arrow Energy.
Extent of Kumbarilla Beds, geological model boundary and drawdown contours from Schlumberger.

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MXT: 7040AC_04_GIS167_v1_2
File Name: 7008_04_F14.11_GIS_FT

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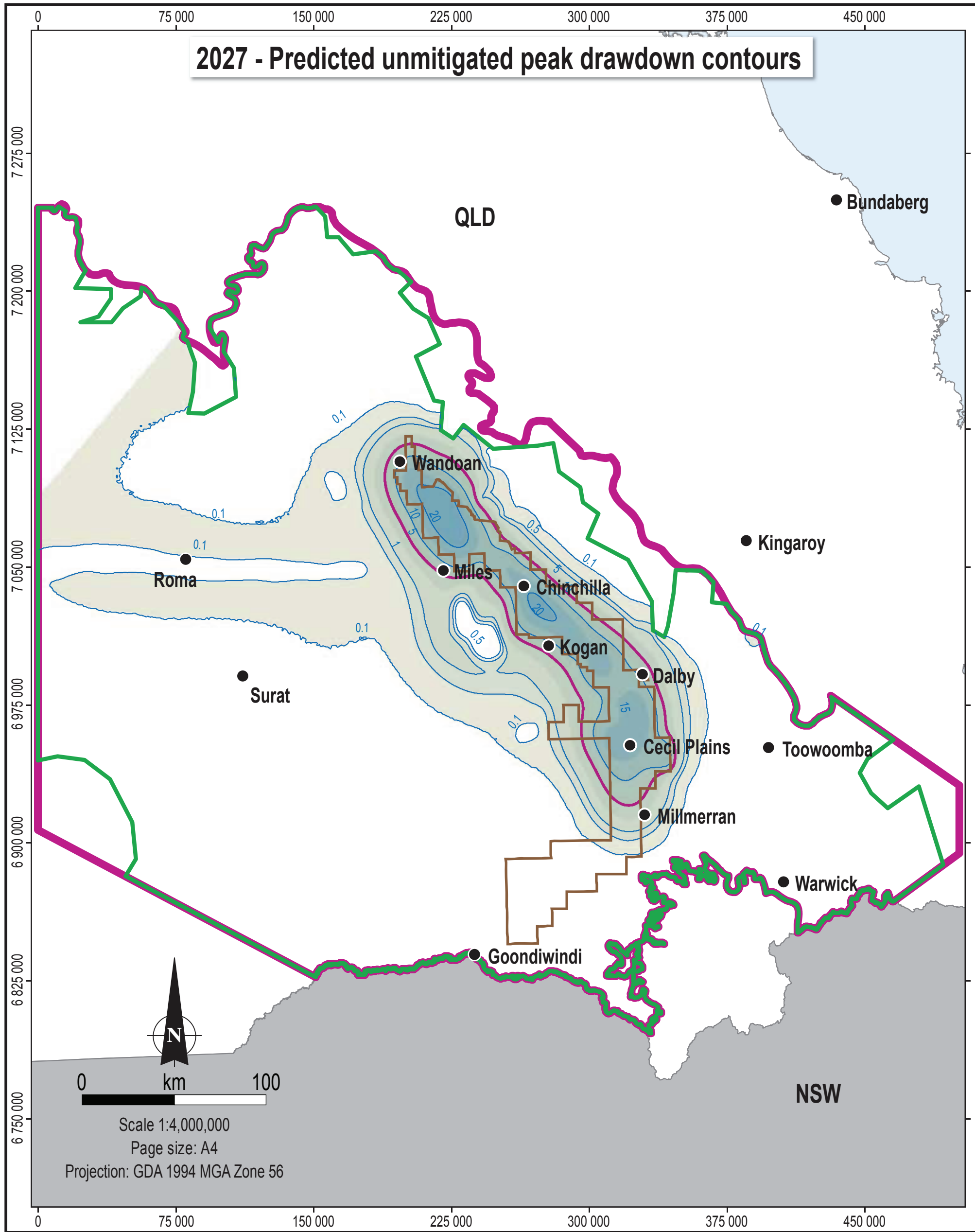
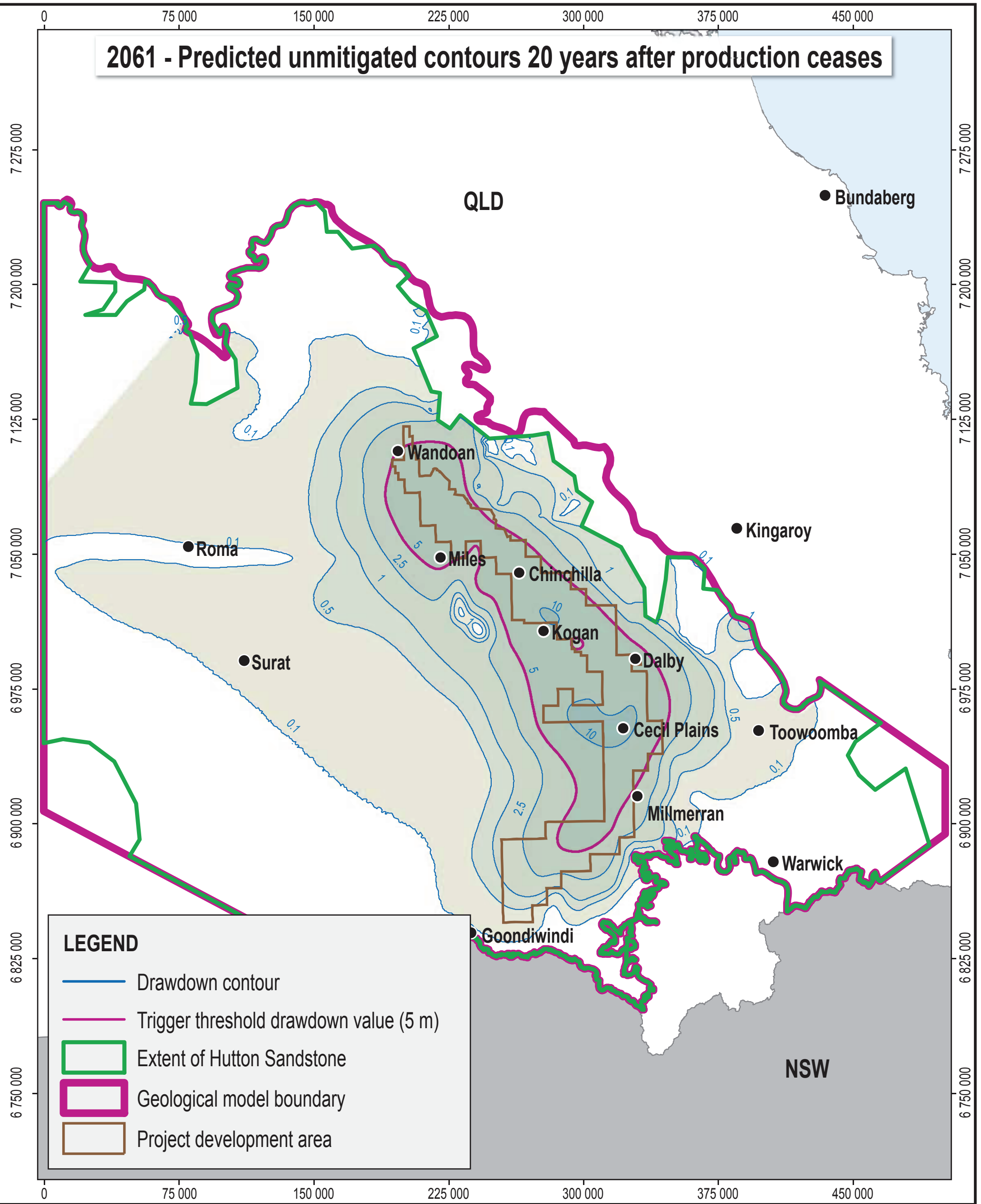
Predicted unmitigated groundwater drawdown contours in the Kumbarilla Beds (modelling scenario 1: Arrow-only)

Figure No: **14.11**





Source:
Place names from DERM.
Project development area from Arrow Energy.
Extent of Hutton Sandstone, geological model boundary and drawdown contours from Schlumberger.

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Date: 12.12.2011
MXT: 7040AC_04_GIS169_v1_3
File Name: 7008_04_F14.12_GIS_FT

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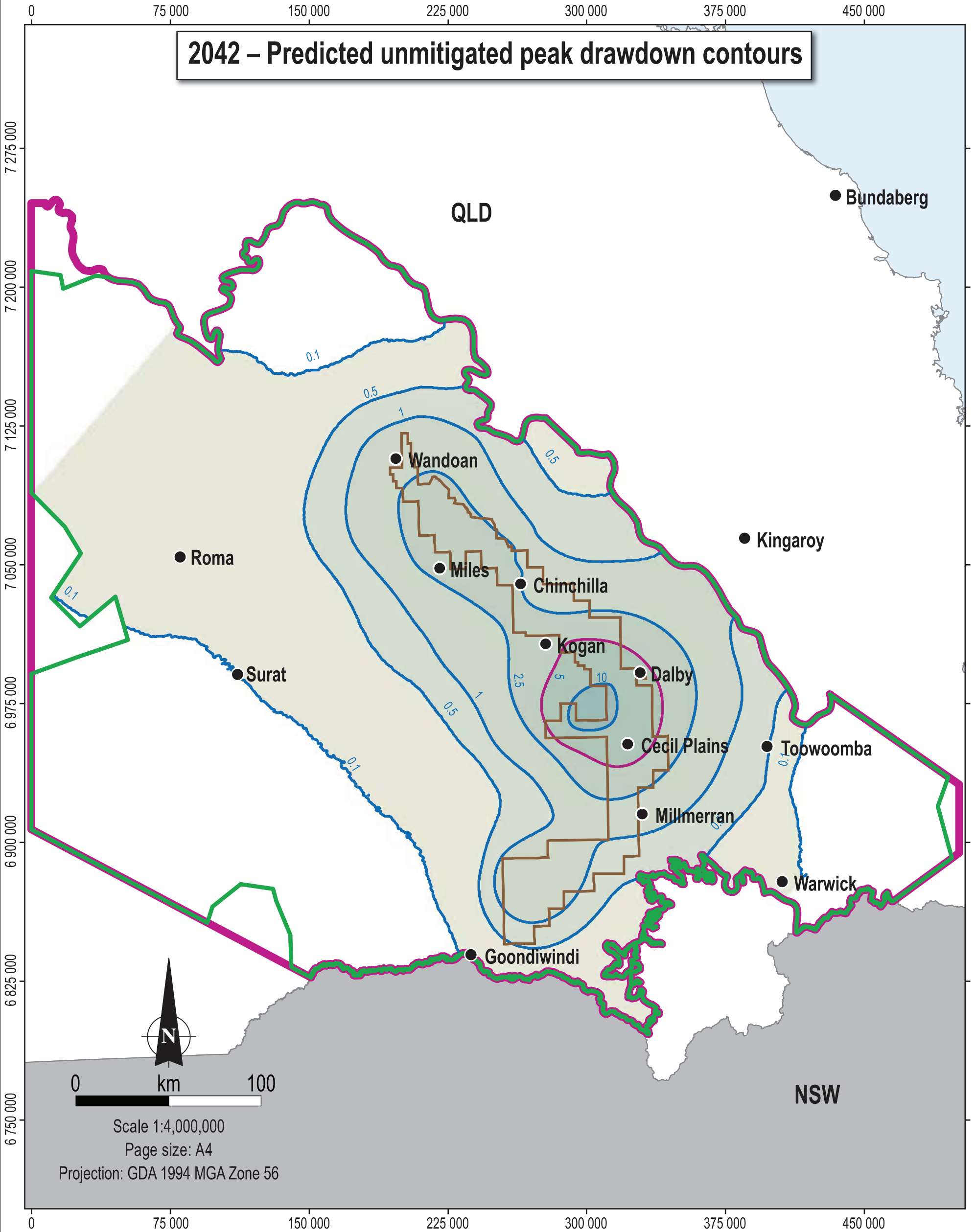
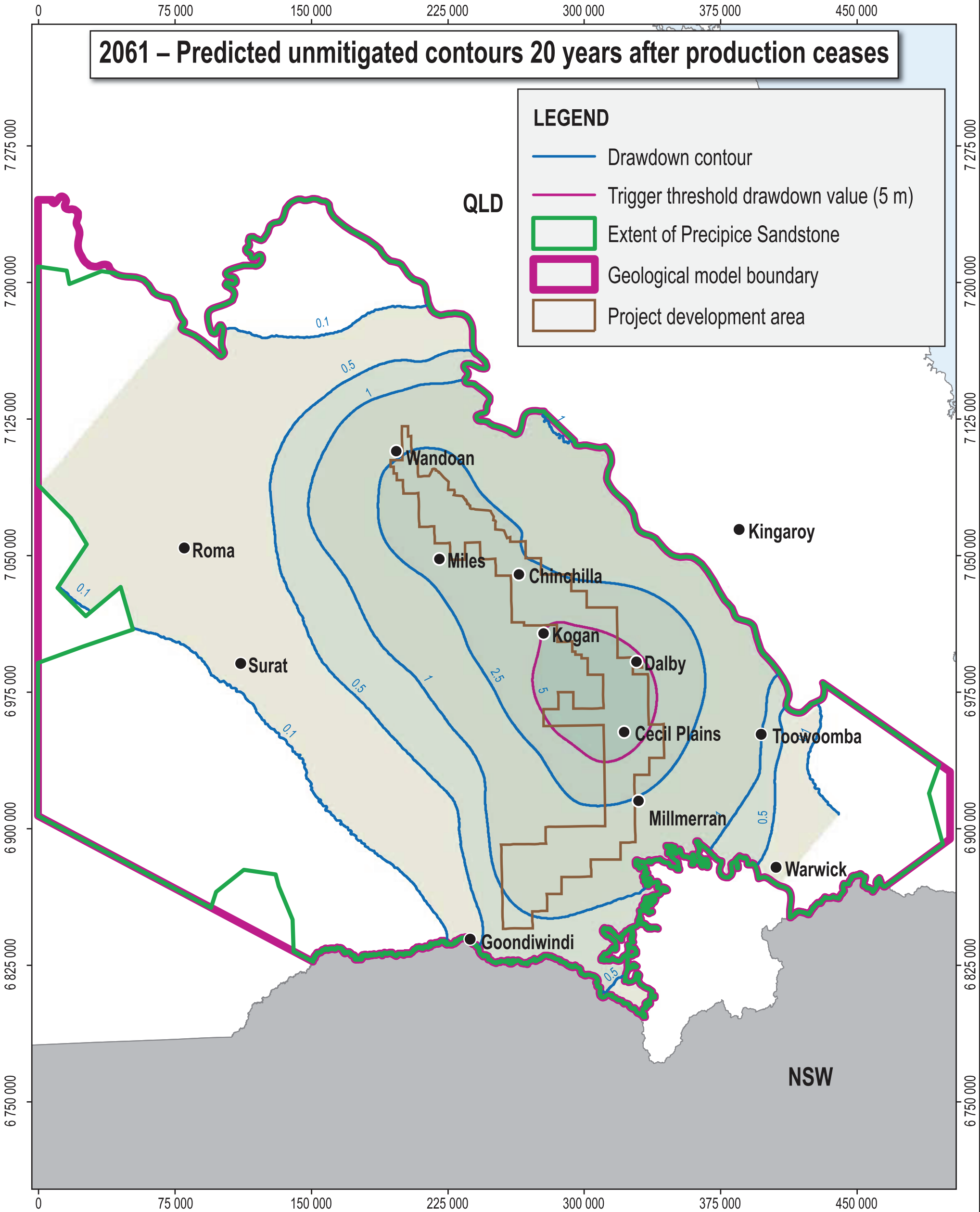
Predicted unmitigated groundwater drawdown contours in the Hutton Sandstone (modelling scenario 1: Arrow-only)

Figure No: 14.12





Source:
Place names from DERM.
Project development area from Arrow Energy.
Extent of Precipice Sandstone, geological model boundary and drawdown contours from Schlumberger.

coffey environments

Date: 12.12.2011
MXT: 7040AC_04_GIS170_v1_3
File Name: 7008_04_F14.13_GIS_FT

Arrow Energy

Surat Gas Project

Predicted unmitigated groundwater drawdown contours in the Precipice Sandstone (modelling scenario 1: Arrow-only)

Figure No: 14.13

14.4.4 Coal Seam Gas Water Storage, Treatment and Transfer

Activities related to the storage, treatment and transfer of coal seam gas water and its by-products have the potential to impact on groundwater values as listed below:

- Seepage or leaks of coal seam gas water and its by-products from storage facilities (e.g., dam failure) have the potential to contaminate the shallow groundwater system.
- Coal seam gas water discharged to streams has the potential to infiltrate the subsurface profile and contaminate the shallow groundwater system.
- Seepage or leaks of coal seam gas water and its by-products from storage facilities (e.g., dam failure) have the potential to alter the shallow groundwater flow direction and associated recharge or discharge patterns.

14.4.5 Other Subsurface Activities

Other activities conducted in the subsurface profile have the potential to impact on groundwater values as listed below:

- Incomplete or incorrect well installation may result in interconnection of aquifers and consequential cross-contamination.
- Use of lubricants and drilling fluids during the drilling process has the potential to contaminate aquifers.
- Leaks and spills at the wellhead during drilling may drain and infiltrate into the borehole leading to contamination of the intersected aquifers.
- Leaks and spills from subsurface infrastructure, e.g., gathering lines, could result in contamination of the intersected aquifers.

14.5 Environmental Protection Objectives

The environmental protection objectives for groundwater are to:

- To minimise impacts due to altered groundwater levels.
- To minimise impacts on groundwater quality.

14.6 Mitigation, Monitoring and Management Measures

Potential impacts on groundwater systems in the project development area will be managed through a hierarchy of mitigation, monitoring and management options that form the basis for an adaptive management framework. The hierarchy of groundwater mitigation, monitoring and management options is linked to Arrow's coal seam gas water management strategy (Attachment 9, Coal Seam Gas Water Management Strategy), specifically substitution of groundwater allocations and injection.

The management of potential impacts to groundwater that are related to land contamination as a result of disturbance of existing contaminated land or the potential to cause land contamination through project activities is discussed in Chapter 12, Geology, Landform and Soils.

14.6.1 Adaptive Management Framework

The adaptive management framework is structured to allow management decisions to be made based on an increased knowledge base developed over time. Key aspects of the adaptive management framework are detailed below:

- The framework allows protection and management of groundwater values and resources into the future.
- The framework is based on the collection of local and regional monitoring data that informs and calibrates numerical models, identifying areas of increased risk and subsequently enforcing the implementation of change where required over time.
- Legislative amendments and refined industry-practice environmental management and technologies can be implemented over time and as required.

14.6.2 Role of the Queensland Water Commission

The Queensland Government has established a 'cumulative management area' for the Surat and Southern Bowen Basin areas, including the alluvium of the Condamine River (the Surat Cumulative Management Area). Recent changes to the Water Act enable a cumulative management area to be declared if an area contains two or more petroleum tenures (including tenures on which coal seam gas activities operate) and where there may be cumulative impacts on groundwater resulting from water extraction by the tenure holders. Within the Surat Cumulative Management Area, the QWC is responsible for relevant activities like groundwater impact monitoring, modelling, and preparation of cumulative underground water impact reports. The contents of the underground water impact reports are described by the Water Act, and the reports are prepared to describe, make predictions and manage the impacts on groundwater resources caused by extraction of underground water by petroleum tenure holders. The reports will also establish responsibilities for tenure holders within the Surat Cumulative Management Area and put measures in place to respond to impacts on underground water.

The underground water impact reports will be used to:

- Establish make-good obligations for the petroleum tenure holder.
- Define a monitoring program for impacts on aquifers.
- Establish obligations to monitor potential impacts on springs.
- Impose a strategy to mitigate impacts on potentially affected springs.

The QWC also has the responsibility for management of cumulative impacts from coal seam gas operations on springs. The QWC has prepared terms of reference for assessment of identified priority springs and will prepare a Springs Impact Management Strategy. The outcomes of this strategy will enable Arrow to refine their mitigation, monitoring and management measures to minimise impacts to groundwater-dependent ecosystems associated with springs.

The requirements of the underground water impact reports will form the basis for Arrow's mitigation, monitoring and management activities. Arrow will also implement the following hierarchy of mitigation, monitoring and management measures throughout the life of the project as part of their groundwater adaptive management framework.

14.6.3 Design and Planning

The following mitigation, monitoring and management measures have been developed to address the potential impacts on groundwater values during the design and planning phase of the project:

- Consider local biological, groundwater and surface water conditions when identifying sites for coal seam gas water dams and brine dams. [C124]
- Consider local groundwater conditions when identifying sites for the installation of buried infrastructure (e.g., gathering lines). [C125]

- Arrow will enforce a no hydraulic fracturing (fraccing) policy in the project development area. [C079]
- Develop and continually maintain the coal seam gas water management strategy throughout the project life to optimise the investigation and implementation of the potential coal seam gas water management options in alignment with the overall project development. [C201]
- Maintain water balance models for long-term planning and management of coal seam gas water. Review and update modelling in alignment with the production-forecasting schedule. [C204]
- Avoid development on contaminated land through the completion of appropriate register searches and desktop investigations (i.e., avoid land or the contaminated portion of a parcel of land that is listed on the Contaminated Land Register or the Environmental Management Register, where practicable). [C049]
- Conduct physical investigations on selected parcels of land to influence facility siting decisions on a localised scale (i.e., target the portion of land that is not contaminated by understanding the extent of contamination). [C050]
- Inspect and observe site locations for the presence of contamination prior to commencement of intrusive activities. [C019]
- Avoid unnecessary impervious surface coverings and minimise land footprint and vegetation clearing when designing facilities. [C126]
- Apply appropriate international, Australian and industry standards and codes of practice for the design and installation of infrastructure associated with the storage of hazardous materials (such as chemicals, fuels and lubricants). [C048]
- Apply appropriate international, Australian and industry standards and codes of practice for the handling of hazardous materials (such as chemicals, fuels and lubricants). [C035]
- Continue an investigative program that will help quantify the connectivity between the Condamine Alluvium and the Walloon Coal Measures. The program will involve:
  - Monitoring the effects of groundwater extraction in the Walloon Coal Measures on the Condamine Alluvium to estimate horizontal and vertical hydraulic conductivity between the alluvium and the Walloon Coal Measures.
  - An investigative drilling program that will provide greater definition of the interface between the two units and will evaluate the geological and hydrogeological properties of the material at the interface of the units.
  - Groundwater chemistry studies to characterise mixing and migration between the units.
  - Groundwater modelling, utilising the connectivity data obtained through investigative components of the program, to understand important processes in the system and predict potential impacts. [C128]
- Continue a program of aquifer testing in dedicated groundwater monitoring bores to increase the predictability of aquifer properties and groundwater movement. [C129]
- Collect relevant geological and hydrogeological data from existing and future production wells, monitoring bores and registered third-party bores (where possible) together with information collated collaboratively with other proponents and regulatory authorities. [C130]

- Prepare a baseline assessment plan to establish benchmark data in registered third-party bores (where possible) prior to the commencement of Arrow extraction activities in accordance with the Water Act, including the preparation and implementation of a groundwater monitoring and investigation strategy. [C120]
- Undertake bore assessments of third-party bores (where possible) in accordance with the Water Act, including:
  - Having the Queensland Water Commission for the Surat Cumulative Management Area identify bores requiring assessment.
  - Developing make-good agreements that include the outcome of bore assessments and implementation of make-good measures in the event that impaired capacity occurs. [C127]
- Update and calibrate the geological model and the numerical groundwater model with relevant data on an ongoing basis, including:
  - Aquifer thicknesses and interfaces between formations.
  - Aquifer properties, e.g., porosity, permeability.
  - The location of sensitive areas, e.g., groundwater discharge springs.
  - Observed responses in monitoring bores that reflect aquifer behaviour during coal seam gas extraction. [C131]
- Utilise the updated geological and numerical groundwater models to:
  - Make ongoing predictions regarding changes to groundwater levels and groundwater quality as the project develops.
  - Improve confidence in the understanding of the sensitivity and resilience of the aquifers within the identified groundwater systems. [C132]
- Install an appropriate regional groundwater monitoring network (that satisfies Arrow's obligations as described in the underground water impact reports) to:
  - Establish baseline groundwater level and groundwater quality conditions.
  - Assess natural variation (i.e., seasonal variations) in groundwater levels.
  - Monitor groundwater levels during the operations phase.
  - Monitor groundwater quality during the operations phase.
  - Establish suitable datum levels for each aquifer system.
  - Target sensitive areas where more frequent monitoring and investigation is required (e.g., groundwater-dependent ecosystems).
  - Monitor groundwater drawdown as a result of coal seam gas extraction.
  - Monitor impacts in accordance with the Water Act and regulations.
  - Provide an 'early warning system' that identifies areas potentially impacted by project activities to allow early intervention. [C524]

- Verify the preferred water management strategy by modelling the effectiveness of substitution and injection (where conducted) in offsetting depressurisation impacts in aquifers. [C134]
- Perform groundwater modelling simulations to predict impacts on groundwater resources in overlying and underlying aquifers. This information will subsequently be used to evaluate the suitability of these resources for use in make-good measures. [C133]

Research into the potential for regional land subsidence across the project development area was based on a review of relevant projects internationally. Land subsidence is generally associated with the depressurisation of unconsolidated formations. In the case of the Walloon Coal Measures and other GAB formations within the project development area, all aquifers are consolidated (i.e., lithified); and so it is considered unlikely that coal seam gas extraction activities in this geological setting and over a large area will result in land subsidence at the surface. Therefore, this issue is not considered further in the impact assessment.

However, Arrow will address the potential for surface deformation through participation by Arrow in a collaborative study with other proponents using historical and baseline data from the Advanced Land Observation Satellite covering a time-lapse period from January 2007 until January 2011. This will allow a detailed analysis of the region and will enable the analysis of the evolution of measured surface deformation in space and time. The assessment will correlate and calibrate data deliverables (calibrated global map and vector files for measurement points) from the Advanced Land Observation Satellite to show the mean deformation rate, identify areas of large-scale deformation and compare patterns with other information (e.g., geology, basin structure, extraction wells and injection data). [C136]

14.6.4 Construction

The following mitigation, monitoring and management measures have been developed to address the potential impacts on groundwater values during the construction phase of the project:

- Avoid disturbance of contaminated soil and groundwater when it is identified or observed during intrusive works. [C064]
- Manage contaminated soil or groundwater that cannot be avoided through physical investigation; manage quantification of the type, severity and extent of contamination; and remediate or manage in accordance with the Queensland Government's Draft Guidelines for the Assessment and Management of Contaminated Land (DE, 1998). [C065]
- Construct all coal seam gas production infrastructure in accordance with the standards described in the P&G Act and regulations to that act. [C137]
- Construct all monitoring bores in accordance with the minimum construction requirements for water bores in Australia (LWBC & NMBSC, 2003) and the minimum standards for the construction and reconditioning of water bores that intersect the sediments of artesian basins in Queensland (DERM, 2004a). [C138]
- Select drilling fluids to minimise potential groundwater impacts. Do not use oil-based drilling fluids. [C139]
- Ensure well drilling is monitored by a suitably qualified geologist to ensure aquifers are accurately identified for correct well construction. [C140]
- Develop the construction, design and monitoring requirements for new dams (either raw water, treated water or brine dams) and determine the hazard category of the dam in accordance

with the requirements of the most recent version of Manual for Assessing Hazard Categories and Hydraulic Performance of Dams (DERM, 2011a). Construct the dams under the supervision of a suitably qualified and experienced person, in accordance with the relevant DERM schedule of conditions relating to dam design, construction, inspection and mandatory reporting requirements. [C141]

- Install groundwater monitoring bores near dams as a leak detection measure:
  - The number of monitoring bores and their location will take into account site-specific hydrogeology, preferential pathways and potential receptors of impacts.
  - Monitoring bores installed near dams will have groundwater levels and relevant water quality parameters monitored on a routine basis.
  - The number of monitoring bores and associated monitoring frequencies will be increased and further investigation will be triggered where impacts are identified. [C504]

14.6.5 Operations

The following mitigation, monitoring and management measures have been developed to address the potential impacts on groundwater values during the operations phase of the project:

- Manage potential impacts to identified spring complexes by:
  - Supporting the identification of specific aquifers that serve as a groundwater source for discharge springs.
  - Assessing springs that are predicted to be subject to unacceptable impacts through the source aquifer.
  - Developing monitoring and mitigation strategies to avoid or minimise unacceptable impacts. [C142]
- Implement a well integrity management system during commissioning and operation of production wells. [C143]
- Minimise impacts of groundwater depressurisation on sensitive areas (e.g., groundwater-dependent ecosystems). [C144]
- Develop a procedure for investigating the impaired capacity of third-party bores. The investigation will be comprise (but not be limited to) the following phased investigation response:
  - Verify groundwater levels in the nominated bores and investigate groundwater levels and groundwater quality in compliance monitoring bores against established trigger thresholds.
  - Request bore information and groundwater data from affected parties.
  - Review and assess data.
  - Advise bore owners in writing of findings. [C145]
- If impaired capacity is confirmed (bore can no longer produce quality or quantity of groundwater for the authorised purpose, and the impact is due to coal seam gas activities), implement make-good measures in accordance with the Water Act. [C146]

- Include where possible, make-good measures such as substitution of groundwater allocations of equal or better quality to maintain user supply, deepening of bores, modification of pumps, or supply of groundwater from an alternative source. [C147]
- Consider injection of coal seam gas water or brine of a suitable quality (if proven technically feasible) into shallow or deep aquifers to offset depressurisation impacts in aquifers. [C135]
- Connect wastewater and sewerage systems to sewers where locally present. Alternatively, install wastewater treatment or reuse systems in accordance with AS/NZS 1547:2000, On-site Domestic Wastewater Management (Standards Australia, 2000); DERM guideline for managing sewerage infrastructure to reduce overflows and environmental impacts (DERM, 2010f); and Queensland water recycling guidelines (DERM, 2005). [C148]
- Store and manage all waste materials (domestic and industrial) in accordance with industry regulations and DERM conditions. Use licensed waste management contractors. Conduct audits of disposal facilities, disposal permits and onsite operations to ensure adherence to regulations. [C149]
- Store onsite materials in suitable containment systems constructed to industry standards and Australian standards (AS 1940-2004, The Storage and Handling of Flammable and Combustible Liquids (Standards Australia, 2004a), and AS 3780, The Storage and Handling of Corrosive Substances (Standards Australia, 2008b) at a minimum). Maintain quality control and quality assurance procedures to monitor volumes and quantities. Bund aboveground storage areas to contain spills. [C102]
- Develop and implement emergency response and spill response procedures to minimise any impacts that could occur as a result of releases of hazardous materials or any loss of containment of storage equipment. [C036]
- Incorporate into an emergency response plan or water management plan procedures for the controlled discharge of coal seam gas water under emergency conditions. Procedures will include water balance modelling, weather monitoring and forecasting, stream flow data, notification and reporting. [C069]
- Carry out corrective actions immediately upon the identification of any contamination of soil or groundwater that has occurred as a result of project activities. [C038]

14.6.6 Decommissioning

The following mitigation, monitoring and management measures have been developed to address the potential impacts on groundwater values during the decommissioning phase of the project:

- Decommission or repair all production wells and monitoring bores, either at the end of their operating life span or in the event of a failed integrity test in accordance with the minimum construction requirements for water bores in Australia (LWBC & NMBSC, 2003) and the P&G Act and regulations to that act. Should production wells be converted into monitoring bores, do so in accordance with relevant regulations. [C150]
- Excavate any saline material during rehabilitation of coal seam water dams or brine dams and select an appropriate option for management for the material (e.g., treat for reuse, or dispose of in a registered landfill). [C073]
- Implement a decommissioning and rehabilitation plan in accordance with the dam design plan. [C074]

Methods of disposal and management of waste materials during the decommissioning phase of the project are addressed in Chapter 26, Waste Management.

14.7 Residual Impacts

The mitigation, monitoring and management measures outlined above will avoid adverse impacts on or reduce the severity of the magnitude of potential impacts on groundwater values. The significance of any residual impacts associated with project activities are described below.

14.7.1 Reduced Flows to Groundwater-Dependent Ecosystems and Areas of Cultural and Spiritual Importance

Reduced flows to groundwater-dependent ecosystems and areas of cultural and spiritual importance are related to direct coal seam gas water extraction from the Walloon Coal Measures and subsequent induced groundwater drawdown in adjacent aquifers. The numerical model predicts the degree of groundwater drawdown in these aquifers. The likelihood and potential for groundwater systems in the project development area to have physical connection with surface features or to be of cultural and spiritual importance varies across the systems and can be influenced by several factors, such as depth and structural controls (e.g., faults). In some instances, information on the potential for and mechanisms of connection between different groundwater systems and these features is scarce. Mitigation, monitoring and management measures will be implemented to minimise impacts from coal seam gas water extraction on groundwater flows to these surface features.

The Condamine Alluvium (shallow groundwater system) has physical connection with the Condamine River in some places. Based on the predicted groundwater drawdown within this unit (approximately 1 m under the Arrow-only modelling scenario) and with implementation of mitigation, monitoring and management measures, the magnitude of residual impacts on surface features supported by groundwater from the Condamine Alluvium will be **very low** resulting in a residual impact significance of **low**.

The intermediate and coal seam gas groundwater systems are not known to have areas of physical connection with surface features within the project development area. These areas, however, may exist within the groundwater model extent. The magnitude of residual impacts on any surface features supported by groundwater from the intermediate groundwater system will be **very low** with implementation of mitigation, monitoring and management measures resulting in a residual impact significance of **low**. The magnitude of residual impacts on any surface features supported by groundwater from the coal seam gas groundwater system will be **very low** with implementation of mitigation, monitoring and management measures resulting in a residual impact significance of **very low**.

The deep groundwater system has historical cultural significance as an artesian groundwater supply resource. The groundwater drawdown is predicted to range from 10 m to 30 m due to indirect impacts of coal seam gas water extraction from the Walloon Coal Measures under the Arrow-only modelling scenario (scenario 1). The magnitude of residual impacts on any surface features supported by groundwater from the deep groundwater system will be **very low** to **low** with implementation of mitigation, monitoring and management measures resulting in a residual impact significance of **low** to **moderate**.

14.7.2 Reduced Groundwater Supply to Existing or Future Groundwater Users

Reduced supplies to existing or future groundwater users are related to direct coal seam gas water extraction from the Walloon Coal Measures and subsequent indirect groundwater drawdown in surrounding aquifers. The numerical model predicts the degree of groundwater drawdown in these units. Application of Arrow's coal seam gas water management strategy (including the substitution strategy and make-good measures), Arrow's adaptive management framework and the hierarchy of mitigation, monitoring and management measures will result in a **very low** magnitude of impact for the shallow and intermediate groundwater systems, a **low** residual magnitude of impact for the coal seam gas groundwater system, and a **very low** to **low** residual magnitude of impact for the deep groundwater system. This results in a residual impact significance of **low** for the shallow, intermediate and coal seam gas groundwater systems and of **low** to **moderate** for the deep groundwater system.

14.7.3 Diminished Groundwater Quality

A decline in groundwater quality could result from a number of activities, such as:

- Aquifer interflow and groundwater mixing in aquifers above and below the Walloon Coal Measures caused by direct coal seam gas water extraction from the Walloon Coal Measures.
- Surface activities, such as leaks and spills of fuels, chemicals, solid and liquid wastes, and coal seam gas water stored and treated at the surface.
- Subsurface activities, such as drilling and installation of gathering lines and the installation of any underground storage containers and tanks.

Some project activities have the potential to directly impact groundwater values in the subsurface (e.g., disturbance to aquifers via vertical drilling) while other activities are restricted to the surface. Therefore, the magnitude of potential impacts is related to the depth of the groundwater system; and residual magnitude and impact significance ranking vary across aquifer systems, as presented in Table 14.9.

Surface leaks and spills of fuels, chemicals, and solid or liquid wastes stored and treated at the surface have the potential to diminish groundwater quality in the shallow, intermediate and coal seam gas groundwater systems. Key mitigation and management measures include implementation of standard design and construction methods for dams and surface storage areas for fuels, chemicals and waste streams. The magnitude of potential impacts will reduce to **very low** (intermediate and coal seam gas groundwater systems) to **low** (shallow groundwater system) and the significance of residual impacts will be **very low** for the coal seam gas groundwater system, **low** for the intermediate groundwater system, and **moderate** for the shallow groundwater system.

Surface processes associated with the treatment and storage of coal seam gas water and associated by-products (e.g., brine) have the potential to diminish groundwater quality in the shallow groundwater system. Key mitigation, monitoring and management measures to minimise potential impacts on groundwater quality include implementation of standard design and construction methods for dams and appropriate shallow groundwater monitoring programs to detect seepage of contaminants from storage dams. The magnitude of potential impacts will reduce to **very low** and the significance of residual impacts will be **low** for the shallow groundwater system.

In general, the magnitude of indirect residual impacts related to diminished groundwater quality as a result of aquifer interflow and groundwater mixing caused by coal seam gas water extraction from the Walloon Coal Measures will be **low**, resulting in a residual impact significance of **moderate** for the shallow, intermediate and deep groundwater systems.

Subsurface activities, such as drilling and installation of gathering lines and underground storage containers and tanks, have the potential to diminish groundwater quality in all groundwater systems. Key mitigation and management measures include appropriate infrastructure placement and the implementation of standard construction methods for wells, gathering lines and storage containers by suitably qualified personnel. The magnitude of potential impacts will reduce to **very low** and the significance of residual impacts will be **very low** for the coal seam gas groundwater system and **low** for the shallow, intermediate and deep groundwater systems.

14.7.4 Reduced Aquifer Recharge and Altered Groundwater Flow Patterns

The installation of impervious surface coverings associated with integrated production facilities has the potential to reduce rainwater infiltration and subsequent groundwater recharge rates from the surface to the underlying shallow, intermediate and coal seam gas groundwater systems. Given the project footprint areas in relation to the overall project development area and the intended minimisation of impervious surface coverings and land disturbance activities, the magnitude of potential impacts will reduce to **very low** and the significance of residual impacts will be **very low** for the coal seam gas groundwater system and **low** for the shallow and intermediate groundwater systems.

Seepage or leaks of coal seam gas water and its by-products from storage facilities have the potential to alter the local groundwater flow direction and associated recharge and discharge patterns of the shallow groundwater system. Implementation of standard design and construction methods for dams and appropriate shallow groundwater monitoring programs to detect seepage of water from storage dams will reduce the magnitude of potential impacts to **very low** and the significance of residual impacts to **low** for the shallow groundwater system.

14.7.5 Summary of Residual Impacts

Table 14.9 summarises the potential impacts prior to mitigation, along with proposed mitigation, monitoring and management measures and the subsequent residual impacts assuming implementation of the proposed measures.

Table 14.9 Summary of groundwater impact assessment

Cause of Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation, Monitoring and Management Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Coal Seam Gas Water Extraction from the Walloon Coal Measures Causing Reduced Flows to Groundwater-dependent Ecosystems and Areas of Cultural and Spiritual Importance							
Coal Seam Gas Water Extraction: Direct Impacts: • Pressure reduction in the Walloon Coal Measures and subsequent reduced groundwater flows to groundwater-dependent ecosystems or areas of cultural and spiritual importance fed by the Walloon Coal Measures.	Shallow groundwater system	Moderate	Very low to low	Low to moderate	**Design and Planning:** • Apply the adaptive management framework and hierarchy of general mitigation, monitoring and management measures. • Consider local biological, groundwater and surface water conditions when identifying sites for infrastructure. • Prepare a baseline assessment plan prior to the commencement of the project. • Install an appropriate regional groundwater monitoring network.	Very low	Low
	Intermediate groundwater system	Moderate	Low	Moderate		Very low	Low
	Coal seam gas groundwater system	Low	Moderate	Moderate		Very low	Very low
Coal Seam Gas Water Extraction: Indirect Impacts: • Subsequent indirect depressurisation of adjacent aquifers causing reduced groundwater flow to groundwater-dependent ecosystems or areas of cultural and spiritual importance fed by the adjacent aquifers.	Deep groundwater system	High	Low to high	Moderate to high	**Construction:** • Construct all coal seam gas production wells and monitoring bores in accordance with appropriate standards. **Operations:** • Minimise impacts of groundwater depressurisation on sensitive areas (e.g., groundwater-dependent ecosystems). • Manage potential impacts to identified spring complexes by: – Supporting the identification of specific aquifers that serve as a groundwater source for discharge springs.	Very low to low	Low to moderate

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation, Monitoring and Management Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Coal Seam Gas Water Extraction from the Walloon Coal Measures Causing Reduced Flows to Groundwater-dependent Ecosystems and Areas of Cultural and Spiritual Importance (cont'd)							
Coal Seam Gas Water Extraction: Indirect Impacts: • Subsequent indirect depressurisation of adjacent aquifers causing reduced groundwater flow to groundwater-dependent ecosystems or areas of cultural and spiritual importance fed by the adjacent aquifers. (cont'd)					– Assessing springs that are predicted to be subject to unacceptable impacts through the source aquifer. – Developing mitigation, monitoring and management strategies to avoid or minimise unacceptable impacts. **Decommissioning:** • Decommission or repair all coal seam gas production wells and monitoring bores in accordance with appropriate standards.		
Coal Seam Gas Water Extraction from the Walloon Coal Measures Causing Reduced Flows to Groundwater Supply to Existing or Future Groundwater Users							
Coal Seam Gas Water Extraction: Direct Impacts: • Pressure reduction in the Walloon Coal Measures and subsequent reduced groundwater flows to existing and future users accessing groundwater from the Walloon Coal Measures.	Shallow groundwater system	Moderate	Very low to low	Low to moderate	**Design and Planning:** • Apply the adaptive management framework and hierarchy of general mitigation, monitoring and management measures. • Prepare a baseline assessment plan prior to the commencement of the project. • Undertake bore assessment s of third-party bores (where possible) in accordance with the Water Act 2000.	Very low	Low
	Intermediate groundwater system	Moderate	Low	Moderate		Very low	Low

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation, Monitoring and Management Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Coal Seam Gas Water Extraction from the Walloon Coal Measures Causing Reduced Flows to Groundwater Supply to Existing or Future Groundwater Users (cont'd)							
Coal Seam Gas Water Extraction: Indirect Impacts: • Subsequent indirect depressurisation of adjacent aquifers causing reduced flow to existing and future users of groundwater from adjacent aquifers.	Coal seam gas groundwater system	Low	Very high	High	• Install an appropriate regional groundwater monitoring network. • Continue an investigative program that will help quantify the connectivity between the Condamine Alluvium and the Walloon Coal Measures. • Continue a program of aquifer testing in dedicated groundwater monitoring bores to increase the predictability of aquifer properties and groundwater movement.	Low	Low
					• Perform groundwater modelling simulations to predict impacts on groundwater resources in overlying and underlying aquifers. • Verify the preferred water management strategy by modelling the effectiveness of substitution and injection in offsetting depressurisation impacts in aquifers. **Construction:** • Construct all coal seam gas production wells and monitoring bores in accordance with appropriate standards.	Low	Low

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation, Monitoring and Management Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Coal Seam Gas Water Extraction from the Walloon Coal Measures Causing Reduced Flows to Groundwater Supply to Existing or Future Groundwater Users (cont'd)							
Coal Seam Gas Water Extraction: **Indirect Impacts:** • Subsequent indirect depressurisation of adjacent aquifers causing reduced flow to existing and future users of groundwater from adjacent aquifers. (cont'd)	Deep groundwater system	High	Low to high	Moderate to high	**Operations:** • Develop a procedure for investigating the impaired capacity of third-party bores and implement appropriate make-good measures where necessary. • Prepare groundwater monitoring reports in accordance with relevant legislative requirements. **Decommissioning:** • Decommission or repair all coal seam gas production wells and monitoring bores in accordance with appropriate standards.	Very low to low	Low to moderate
Surface Activities Causing Diminished Groundwater Quality							
• Leaks and spills of chemicals, fuels and oils stored at the surface in association with production facilities, resulting in contamination of the intersected aquifers. • Discharges of liquid domestic wastes and effluent to land have the potential to contaminate groundwater systems.	Shallow groundwater system	Moderate	Moderate	Moderate	**Design and Planning:** • Consider local biological, groundwater and surface water conditions when identifying sites for infrastructure. • Apply appropriate standards and codes of practice for the design and installation of infrastructure associated with the storage of hazardous materials. **Construction:** • Connect wastewater and sewerage systems to sewers where locally present, or appropriately treat wastes onsite.	Low	Moderate
	Intermediate groundwater system	Moderate	Low	Moderate		Very low	Low
	Coal seam gas groundwater system	Low	Low	Low		Very low	Very low

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation, Monitoring and Management Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Surface Activities Causing Diminished Groundwater Quality (cont'd)							
	Deep groundwater system	Not applicable. The deep groundwater system is excluded based on depth and isolation from these surface processes.			**Operations:** • Store and manage all waste materials (domestic and industrial) in accordance with industry regulations and DERM conditions. • Use licensed waste management contractors. Conduct audits of disposal facilities, disposal permits and onsite operations to ensure adherence to regulations. • Store onsite materials in suitable containment systems constructed to industry standards and Australian standards. • Maintain quality control/quality assurance procedures to monitor volumes and quantities of stored materials. • Develop and implement emergency response and spill response procedures. **Decommissioning:** • Disposal and management of waste streams during decommissioning will be in accordance with relevant waste management practices.	Not applicable. The deep groundwater system is excluded based on depth and isolation from these surface processes.	

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation, Monitoring and Management Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Surface Activities Associated with Storage, Treatment and Transfer of Coal Seam Gas Water Causing Diminished Groundwater Quality							
• Seepage or leaks of untreated coal seam gas water and brine from storage facilities have the potential to contaminate the groundwater systems. • Coal seam gas water discharged to streams has the potential to infiltrate the subsurface profile and contaminate the groundwater systems.	Shallow groundwater system	Moderate	Moderate	Moderate	**Design and Planning:** • Consider local biological, groundwater and surface water conditions when identifying sites for infrastructure. • Design new dams in accordance with appropriate standards. **Construction:** • Construct new dams in accordance with appropriate standards. • Install groundwater monitoring bores near dams as a leak detection measure: – The number of monitoring bores and their location will take into account site-specific conditions. **Operations:** • Monitor bores near dams as a leak detection measure: – Monitoring bores installed near dams will have groundwater levels and relevant parameters monitored on a routine basis in accordance with the dam operating plan. – The number of monitoring bores and associated monitoring frequencies will be increased and further investigation triggered where impacts are identified. **Decommissioning:** • Excavate any saline material during rehabilitation of coal seam water dams or brine dams and dispose of in a registered landfill. • Implement a decommissioning and rehabilitation plan in accordance with the dam design plan.	Very low	Low
	Intermediate groundwater system	Not applicable. The intermediate, coal seam gas and deep groundwater systems are excluded based on depth and isolation from these surface processes.				Not applicable. The intermediate, coal seam gas and deep groundwater systems are excluded based on depth and isolation from these surface processes.	
	Coal seam gas groundwater system						
	Deep groundwater system						

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts (Shading) and Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Other Subsurface Activities Causing Diminished Groundwater Quality - Depressurisation							
Coal Seam Gas Water Extraction: Indirect Impacts: • Aquifer interflow and groundwater mixing in aquifers above and below the Walloon Coal Measures caused by coal seam gas water extraction from the Walloon Coal Measures.	Shallow groundwater system	Moderate	High	High	**Design and Planning:** • Apply the adaptive management framework and hierarchy of general mitigation, monitoring and management measures. • Prepare a baseline assessment plan prior to the commencement of the project. • Undertake bore assessment s of third-party bores (where possible) in accordance with the Water Act 2000. • Install an appropriate regional groundwater monitoring network. • Continue an investigative program that will help quantify the connectivity between the Condamine Alluvium and the Walloon Coal Measures. • Continue a program of aquifer testing in dedicated groundwater monitoring bores to increase predictability of aquifer properties and groundwater movement. • Perform groundwater modelling simulations to predict impacts on groundwater resources in overlying and underlying aquifers. **Construction:** • Construct all coal seam gas production wells and monitoring bores in accordance with appropriate standards.	Low	Moderate
	Intermediate groundwater system	Moderate	High	High		Low	Moderate
	Coal seam gas groundwater system	Low	Very High	High		Low	Low

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts (Shading) and Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Other Subsurface Activities Causing Diminished Groundwater Quality – Depressurisation (cont'd)							
Coal Seam Gas Water Extraction: Indirect Impacts: • Aquifer interflow and groundwater mixing in aquifers above and below the Walloon Coal Measures caused by coal seam gas water extraction from the Walloon Coal Measures. (cont'd)	Deep groundwater system	High	High	High	**Operations:** • Prepare groundwater monitoring reports in accordance with relevant legislative requirements. **Decommissioning:** • Decommission all coal seam gas production wells and monitoring bores in accordance with appropriate standards.	Low	Moderate
Other Subsurface Activities Causing Diminished Groundwater Quality							
• Incomplete or incorrect well installation results in interconnection of aquifers and consequential cross-contamination. • Use of lubricants and drilling fluids during the drilling process has the potential to contaminate aquifers. • Leaks and spills at the wellhead drain and infiltrate into the borehole leading to contamination of the intersected aquifers.	Shallow groundwater system	Moderate	Low to high	Moderate	**Design and Planning:** • Consider local groundwater conditions when identifying sites for the installation of underground infrastructure (e.g., gathering lines). • Implement well integrity management system. **Construction:** • Construct all coal seam gas production wells and monitoring bores in accordance with appropriate standards. • Select drilling fluids to minimise potential groundwater impacts. Do not use oil-based drilling fluids. • Ensure well drilling is monitored by a suitably qualified geologist to ensure aquifers are accurately identified for the purposes of correct well construction. **Operations:** • Develop and implement emergency response and spill response procedures.	Very low	Low
	Intermediate groundwater system	Moderate	Very Low to high	Low		Very low	Low
	Coal seam gas groundwater system	Low	Very low to low	Very low to low		Very low	Very low

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts (Shading) and Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Other Subsurface Activities Causing Diminished Groundwater Quality (cont'd)							
• Leaks and spills from subsurface infrastructure, e.g., gathering lines, results in contamination of the intersected aquifers.	Deep groundwater system	High	Very low to high	Low	**Decommissioning:** • Decommission all coal seam gas production wells and monitoring bores in accordance with appropriate standards. • Should production wells be converted into monitoring bores, do so in accordance with relevant regulations.	Very low	Low
Reduced Groundwater Recharge and Altered Groundwater Flow Directions							
• Reduced rainwater infiltration and subsequent reductions in aquifer recharge from the surface due to the construction of impervious surface coverings and land disturbance activities resulting in reduced porosity and permeability of surface profiles.	Shallow groundwater system	Moderate	Low	Moderate	**Design and Planning:** • Consider local biological, groundwater and surface water conditions when identifying sites for infrastructure. • Avoid unnecessary impervious surface coverings, minimise land footprint, and vegetation clearing when designing facilities. • Design new dams in accordance with appropriate standards. **Construction:** • Construct new dams in accordance with appropriate standards. • Install groundwater monitoring bores near dams as a leak detection measure: – The number of monitoring bores and their location will take into account site-specific conditions.	Very low	Low
	Intermediate groundwater system	Moderate	Very low	Low		Very low	Low
	Coal seam gas groundwater system	Low	Very low	Very low		Very low	Very low

Table 14.9 Summary of groundwater impact assessment (cont'd)

Cause of Potential Impacts (Shading) and Potential Impacts	Existing Environment	Values Sensitivity	Premitigated Impact		Summary of Mitigation Measures	Residual Impact	
			Magnitude	Significance		Magnitude	Significance
Reduced Groundwater Recharge and Altered Groundwater Flow Directions (cont'd)							
• Seepage or leaks of coal seam gas water and its by-products from storage facilities have the potential to alter the groundwater flow direction and associated recharge and discharge patterns in the shallow groundwater system only.	Deep groundwater system	Not applicable The deep groundwater system is excluded based on depth and isolation from these surface processes.			**Operations:** • Monitor bores near dams as a leak detection measure: – Monitoring bores installed near dams will have groundwater levels and relevant parameters monitored on a routine basis in accordance with the dam operating plan. – The number of monitoring bores and associated monitoring frequencies will be increased and further investigation triggered where impacts are identified. **Decommissioning:** • Implement a decommissioning and rehabilitation plan in accordance with the dam design plan.	Not applicable The deep groundwater system is excluded based on depth and isolation from these surface processes.	

14.8 Inspection and Monitoring

The objective of the groundwater monitoring and inspection program is to minimise impacts on groundwater levels and quality. The groundwater monitoring and inspection program is an intrinsic part of the adaptive management framework detailed in Section 14.6 and involves several aspects associated with site-specific controls for project infrastructure, as well as more regional monitoring of groundwater levels and groundwater quality associated with Arrow's activities. There is also the requirement to contribute to cumulative models and monitoring programs.

Groundwater-related monitoring and inspection programs will focus on:

- Project infrastructure.
- Regional groundwater monitoring.
- Contaminated land monitoring requirements.
- Cumulative monitoring requirements.

Through the application of the groundwater monitoring and inspection program, Arrow will:

- Ensure methods used to monitor groundwater levels and quality, together with monitoring frequencies and parameters are in accordance with approved regulatory standards. [C521]
- Prepare groundwater monitoring reports in accordance with the P&G Act, EP Act and Water Act. [C510]
- Develop a structured database to host groundwater data from the project (i.e., groundwater levels and groundwater quality). [C522]

More specific information on the inspection and monitoring programs is provided below.

14.8.1 Project Infrastructure

A groundwater monitoring program will be implemented in areas near any infrastructure with the potential to impact on underlying groundwater resources. This monitoring program will be developed so that it provides the following information:

- Identification of background groundwater quality.
- Details on the locations of monitoring points, parameters to be measured, frequency of monitoring, and monitoring methodology.
- Identification of trigger values, or the process for developing trigger values, for the measured parameters.
- Assessment of the level of impact on underlying groundwater in the event of contamination from the monitored infrastructure.
- Details on additional hydrogeological investigations (e.g. aquifer testing and groundwater flow mapping) to assess the extent and significance of potential contamination.

Monitoring and inspection programs related to project infrastructure are detailed below:

- Any issues related to well integrity will be identified through the implementation of a well-integrity management system during commissioning and operation of production wells.

- Routine inspection and monitoring of bores installed near dams will be conducted as a leak detection measure (see [C504]). General details of groundwater monitoring in the vicinity of dams includes the following:
  – Site-specific conditions related to geology and hydrogeology will be taken into consideration when designing and installing the groundwater monitoring bore network around dams.
  – Monitoring of groundwater levels and selected water quality parameters, including (but not limited to) electrical conductivity, pH, total dissolved solids, major cations and major anions, will be conducted on a routine basis and in accordance with the dam operating plan.
  – The number of monitoring bores and associated monitoring frequencies will be increased and further investigation will be triggered where impacts are identified.

14.8.2 Regional Groundwater Monitoring Program

As the field development sequence becomes better defined and additional data is collected, this information will be used to inform an adaptive management process for groundwater. As gas field development continues and groundwater monitoring programs commence, the additional information about the behaviour of regional groundwater will be used to update and calibrate the numerical model. This will allow mitigation, monitoring and management measures to be applied to site conditions.

The regional groundwater monitoring program aims to:

- Satisfy Arrow’s obligations as described in the underground water impact reports (as per [C524]).
- Establish baseline groundwater conditions prior to the commencement of Arrow depressurisation activities.
- Provide a configuration of monitoring bores that allows identification of drawdown across the project development area and within key aquifers.
- Understand basin-specific aquifer interactions further and verify the understanding of regional hydrogeology.
- Identify long-term groundwater level trends and potential cumulative effects from current and future coal seam gas development.
- Provide information to differentiate between the effects of operating gas fields and the effects of other sources of groundwater variability (e.g., seasonal variations).
- Develop an ‘early warning system’ that identifies areas potentially impacted by project activities and allows early intervention.
- Develop a mechanism for continuous improvement of the model features (recharge and discharge areas, natural variations, aquifer interconnectivity, impacts on groundwater-dependent ecosystems, long-term trend data and other surface features) as more field development data becomes more available.
- Share information with regulatory authorities.

Groundwater monitoring reports will be prepared in accordance with the P&G Act, EP Act and Water Act. At a minimum, the reports will provide comment on:

- Changes to the monitoring network from the previous report (i.e., any new or damaged monitoring bores).
- Most recent and historical monitoring results, trends, and any changes to trends compared to adopted trigger levels.
- Comparison of actual groundwater levels with projected modelled groundwater levels.
- The current projections of the extent of water level impacts on the coal seam gas system aquifers and adjacent aquifers. This will include maps of the areas where water levels are expected to be affected, in the upcoming period, by more than the trigger threshold values.
- Any complaints lodged by bore owners.

14.8.3 Contaminated Land

The strategy for addressing land contamination is presented in Chapter 12, Geology, Landform and Soils. Any inspection or monitoring of related groundwater contamination will be conducted in accordance with the Queensland Government's Guidelines for the Assessment and Management of Contaminated Land 1998 (DE, 1998).

Arrow will be required to provide chemical monitoring of contaminated soils and groundwater in relevant monitoring bores. [C515]

14.8.4 Cumulative Impacts

The project development area is within the Surat Cumulative Management Area as defined by DERM. Within a cumulative management area, the QWC will be responsible for relevant activities including the following:

- Proposal of monitoring program requirements.
- Groundwater impact monitoring and modelling.
- Preparation of cumulative impact reports.

Arrow is required to comply with inspection and monitoring requirements developed by the Queensland Water Commission in relation to groundwater drawdown and springs. [C525]

Arrow will liaise with the QWC throughout the life of the project and will be required to communicate relevant data relating to groundwater to enable predictive models and required monitoring programs to be updated over time.