Australia Pacific LNG Project

Volume 2: Gas Fields

Chapter 10: Ground Water

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10.1 Introduction

10.1.1 Purpose

The proposed development of the Walloons gas fields in south central Queensland, including site preparation, construction, operation, decommissioning and rehabilitation, has the potential to affect the groundwater environment within and beyond the proposed gas fields area.

The purpose of this groundwater assessment is to describe the potential effects of the proposed gas fields development on groundwater and identify suitable management and mitigation measures to avoid or minimise these potential impacts.

Australia Pacific LNG has developed a set of 12 sustainability principles (Volume 1 Chapter 3) which will be applied during all phases of the proposed gas fields' development. The purpose of these sustainability principles is to guide decision making to provide appropriate management of potential impacts on the groundwater environment. Sustainability principles specifically relevant to groundwater include:

- Minimising adverse environmental impacts and enhancing environmental benefits associated with Australia Pacific LNG's activities, products or services; conserving, protecting, and enhancing where the opportunity exists, the biodiversity values and water resources in its operational areas
- Identifying, assessing, managing, monitoring and reviewing risks to Australia Pacific LNG's workforce, its property, the environment and the communities affected by its activities
- Working cooperatively with communities, governments and other stakeholders to achieve positive social and environmental outcomes, seeking partnership approaches where appropriate.

These sustainability principles provide the framework within which potential groundwater impacts are assessed and adaptive management and mitigation strategies identified. Consistent with these principles, the groundwater assessment is based on a combination of modelling, monitoring and management measures that will continue to be refined as additional data becomes available.

10.1.2 Scope of work

To fulfil the environmental impact statement (EIS) terms of reference for the Australia Pacific LNG Project (the Project) and support the Project's sustainability principles, the following key groundwater-related matters have been evaluated:

- Environmental values of the aquifer systems
- Nature and hydrology of the aquifer systems
- Information concerning existing groundwater supply facilities
- Potential of the proposed gas fields to affect regional-scale groundwater levels, physical and chemical quality and storage capability in aquifer systems during project operations and post-operations
- Potential groundwater-related impacts and risks associated with the proposed gas fields

- Potential cumulative groundwater-related impacts caused by the gas field operations in combination with other existing or planned coal seam gas (CSG) developments in the region
- Groundwater management options to monitor for change, assess collected information and mitigate (if necessary) the development related impacts.

The geographical area identified during the impact assessment process for the groundwater assessment (hereafter referred to as the study area) is situated in the Surat Basin, Queensland and stretches across an area of approximately 300km, located about 150km west of Brisbane. More specifically, the area extends from latitude 25° to 29° and from longitude 147° to 152° and encompasses approximately 173,000km^2.

This chapter provides a summary of the groundwater assessments conducted for the gas fields element of the Australia Pacific LNG project. The full report is provided in Volume 5 Attachment 21.

10.1.3 Legislative framework

The legislative framework relating to the management of groundwater production, its storage and disposal in association with the gas fields element of the Project is outlined below.

Environmental Protection Act, Queensland

Policies and regulations associated with the *Environmental Protection Act 1994* include the Environmental Protection Regulation 2008, the Environmental Protection (Waste Management) Policy 2000 and the Environmental Protection (Waste Management) Regulation 2000. This legislation is also supported by the former Environmental Protection Agency's 2007 Operational Policy titled 'Management of water produced in association with petroleum activities (associated water)'. This policy has been augmented by the Queensland Government's 2009 Blueprint for Queensland's LNG Industry.

Petroleum and Gas (Production and Safety) Act

The *Petroleum and Gas (Production and Safety) Act 2004* (PAG Act) governs groundwater management in relation to the proposed gas fields' development. According to the Act, the petroleum tenure holder may take or interfere with groundwater to the extent that it is necessary and unavoidable (with no volumetric limit) during the course of an activity authorised under the petroleum tenure such as drilling petroleum wells. The PAG Act imposes obligations on each petroleum tenure holder and importantly, the 'make good' obligation stipulated in Part 9 Sections 244 to 280 indicates that, if the petroleum activity unduly affects an existing water bore, the tenure holder must implement measures to restore a supply of water to the owner of the bore, or compensate the owner for being unduly affected.

The holder of the tenure must also provide an underground water impact report of its activities. To prepare such a report, the Act requires fixing 'trigger' thresholds for aquifers in the area affected by the exercise of underground water rights associated with a petroleum tenure. The trigger value is defined as 'the water level drop in the aquifers that the chief executive considers would be a level that causes a significant reduction in the maximum pumping rate or flow rate of the existing Water Act bores in the area affected by the exercise of the underground water rights'. The time period over which the pumping is conducted is not stipulated in the Act.

In the event that the associated water is utilised for purposes other than domestic and stock watering, or activities authorised by the petroleum tenure or the PAG Act, the operator must acquire a water licence or water permit in accordance with the *Water Act 2000*.

Water Act

The Queensland *Water Act 2000* vests the use and control of all the State's water to the Queensland Government. According to Section 206(4), a petroleum tenure holder may apply for a water licence to take water or interfere with the flow of water, if such water is produced as a result of testing or commercial production activities for which a right is not conferred under the PAG Act. The requirements for a water licence application by a petroleum tenure holder are outlined in Sections 206 and 206A. If a water licence is granted to a petroleum tenure holder, there may be a requirement under Section 214 (2)(e) 'to carry out and report on a stated monitoring program'.

Water Resource (Great Artesian Basin) Plan

The Water Resources (Great Artesian Basin) Plan 2006 is the primary legislation for groundwater management of the Great Artesian Basin (GAB) in Queensland. Water licences for associated water under the PAG Act are excluded from the allocation and management of water in the plan area. The Project is within the Eastern Downs, Surat East, Surat and Surat North management areas.

Great Artesian Basin Resource Operations Plan

The Great Artesian Basin Resource Operations Plan 2007 implements the Water Resource (Great Artesian Basin) Plan 2006. Twenty-five 'groundwater management areas' and associated 'groundwater management units' are identified in the plan. A groundwater management unit corresponds to a formation or to a group of formations. For each unit a specified upper annual allocation of water is identified. Specifically, the Surat Basin is divided into seven groundwater management areas and 26 groundwater management units. The plan also stipulates that for new licence applications, a minimum separation distance from existing licenced bores be maintained to ensure a drawdown of no more than 5m.

Water Resource (Condamine and Balonne) Plan, and Condamine and Balonne Resource Operations Plan

Water Resource (Condamine and Balonne) Plan 2004, and Condamine and Balonne Resource Operations Plan 2008 regulate the taking of water from all surface bodies and may pertain to associated water in instances where it is stored in dams or other reservoirs within the Plan area.

Moratorium Notice Condamine Catchment Underground Water Area

A moratorium on new extraction of groundwater in the Condamine Catchment Underground Water Area was issued on 10 July 2008. The moratorium affects groundwater contained in the Main Range Volcanics (Basalt) Aquifer System, excluding water in this aquifer system that is captured by the Toowoomba Moratorium Notice; the Condamine River and Tributaries Alluvium Aquifer System and the Tertiary Chinchilla Sands Aquifer System. The moratorium notice does not apply to the taking of water for a project of State significance or Regional significance pursuant to the *State Development and Public Works Organisation Act 1971*.

Water Supply (Safety and Reliability) Act

The purpose of the *Water Supply (Safety and Reliability) Act 2008* is to provide for the safety and reliability of water supply. The Act refers to manufactured water which is defined as water, including desalinated or recycled water or any substance resulting from the production of desalinated or recycled water, from any source.

Environmental Protection (Water) Policy, Queensland

The Environmental Protection (Water) Policy 2009 aims to support the *Environmental Protection Act 1994* with a range of water management guidelines. Section 6 of this policy describes the environmental values of waters to be enhanced or protected under the policy, and Section 7 outlines the indicators and water quality guidelines for environmental values.

Blueprint for Queensland's LNG Industry, Queensland Government

In accordance with the Queensland Government's Blueprint for Queensland's LNG Industry policy document released in September 2009, all CSG operators are responsible for the treatment and disposal of their CSG production water (or associated water). Notably, evaporation ponds are to be discontinued as a primary means for disposing of associated water. Furthermore, unless producers use reinjection of associated water or have arrangements for an environmentally-acceptable beneficial use, the untreated associated water must be treated and managed in accordance with standards defined by the Department of Environment and Resources Management (DERM). The Blueprint document also states that the Government is committed to developing a regional groundwater monitoring regime to assist in evaluating potential impacts on groundwater resources as a consequence of CSG developments in the region.

10.2 Methodology

The groundwater assessment for the proposed gas fields adopted a staged approach, and can be broadly outlined as follows:

- Collation and review of data and information sources
- Development of a regional scale conceptual hydrogeological model
- Execution of a field program including collection of groundwater samples and instrumentation of monitoring bores for water level assessment
- Development of a regional scale numerical groundwater model
- Impact assessment, risk evaluation and identification of management and mitigation measures.

A description of each of these key components is provided below.

10.2.1 Data and information sources

The groundwater assessment relies primarily on pre-existing and available data and information sources. Key references utilised to interpret the regional scale geology and hydrogeology of the study area include:

- A Summary of the Hydrogeology of the Southern Eromanga and Surat Basins of the Great Artesian Basin (Hennig 2005)
- The Surat and Bowen Basins South-East Queensland (Department of Mines and Energy 1997)
- The Geology of Surat Basin in Queensland (Exon 1976)
- The Great Artesian Basin, Australia (Habermehl 1980)
- Groundwater Recharge in the Great Artesian Basin Intake Beds (Bureau of Rural Sciences and Queensland Department of Natural Resources and Mines (BRS and NRM) 2003)

To inform definition of the existing environment and environmental values, borehole and licenced water allocation data was acquired from the following five primary sources:

- DERM groundwater bore database, supplied on 7 January 2009
- Borehole logs, drill stem test results and geophysical logs for petroleum exploration bores and CSG wells, provided by Origin Energy
- The database associated with wire-line logs for selected water bores in the Great Artesian Basin (GABLOG: Habermehl 2001)
- Groundwater licence data from the DERM water entitlements register database, which included licences as of 18 June 2009
- The location, formation, and estimated use for stock and domestic bores as compiled by DERM during the formulation of the GAB water resource plan.

It is acknowledged that the data accessed from each source contains both unverified and unvalidated data records. Any apparent or obvious data inaccuracies or inconsistencies identified during the assessment process were removed. It is recognised that bore data tends to be clustered within current and previous petroleum development areas, with large gaps in data between these areas. While due care has been taken while making assumptions to fill these gaps, particularly in the compilation of geological layers for the numerical model, it is recognised that these assumptions may affect the results of the assessment. However, the data used is considered suitable for this regional-scale assessment.

10.2.2 Regional scale conceptual hydrogeological model

For the purposes of generating a regional scale conceptual hydrogeological model, the regional geology was simplified into 12 hydrogeologically similar units (represented by major aquifers and aquitards). This was achieved by combining vertically-adjacent units with similar geological characteristics. These units are referred to as 'hydrostratigraphic units' and collectively represent a simplification of the conceptual regional geological model.

Key information for each hydrostratigraphic unit was initially compiled and included depths to the top of each unit obtained from available bore data (Australia Pacific LNG interpretations in the first instance) combined with the elevation of the ground surface where each unit outcrops. In instances where poor bore data coverage existed, the model was supplemented with digitised data from published sources. In turn, the bore data was contoured to generate surfaces representing the top of each hydrostratigraphic unit, thereby creating a three dimensional digital model of the study area within the Surat Basin.

It is noted that several assumptions were made with regards to areas where there was poor data coverage, and thus the geological model may be inconsistent with other interpretations, particularly in areas outside of the gas fields tenements. Details of the assumptions can be found in Volume 5 Attachment 21. This consistent set of hydrostratigraphic unit surfaces has been adopted for the following components of the groundwater assessment:

- Numerical groundwater flow model development
- Development of a water level and water chemistry database.

Groundwater level and groundwater chemistry data was acquired from the Queensland groundwater bore database. Only data that could be assigned to a particular hydrostratigraphic unit was utilised in the study and, for the purposes of mapping water levels, only the most recent data from each bore

was used. A total of 4,933 water levels, 11,232 chemistry records and over 12,000 data points pertaining to geology were incorporated during completion of this hydrogeological assessment.

Groundwater usage data was obtained from the DERM water entitlements registration database, which includes licences as of 18 June 2009. Stock and domestic bore data was obtained from background studies used for the development of the water resource plans (DERM 2004). Each licence was specific to a geological formation or management unit under the Water Resource (Condamine and Balonne) Plan 2004 or Water Resource (Great Artesian Basin) Plan 2006, respectively. Each licence acquired from these data sources was allocated to an established hydrostratigraphic unit corresponding to the formation or interval accesses. These units are summarised in Table 10.1.

Table 10.1 Water resource plan operation units and associated hydrostratigraphic units

Management unit	Aquifers	Assigned hydrostratigraphic unit
Condamine River Alluvium		Cainozoic Units
Condamine Tributary Alluvium		
Main Range Volcanics		
Surat 2	Wyandra Sandstone Member	Bungil/Mooga/Orallo Grouping
	Bungil Formation	
	Minmi Member	
	Nullawart Sandstone Member	
	Kingill Member	
Surat 3	Mooga Sandstone	
Surat East 1	Kumbarilla Beds	Gubberamunda Sandstone
Surat 4	Orallo Formation	
	Gubberamunda Sandstone	
Surat 5	Westbourne Formation	Springbok Sandstone
	Springbok Sandstone	
	Birkhead Formation	
	Walloon Coal Measures	
	Eurombah Formation	
Surat East 2	Walloon Coal Measures	Walloon Coal Measures
Eastern Downs 1	Walloon Coal Measures	
Surat 6	Hutton Sandstone	Hutton Sandstone
	Evergreen Formation	
	Boxvale Sandstone Member	
Surat East 3	Hutton Sandstone	

Management unit	Aquifers	Assigned hydrostratigraphic unit
	Evergreen Formation	
Eastern Downs 2	Marburg Sandstone	
Eastern Downs 3	Helidon Sandstone	Precipice Sandstone
Surat East 4	Precipice Formation	

Most of the licences have more than one associated extraction bore. In such cases, the first bore in the list was adopted and it is assumed that the entire allocation applies. Bore location details provided in water entitlements register database have been adopted for this assessment. Location information for stock and domestic bores was provided with the entitlement data.

10.2.3 Groundwater monitoring program

Fieldwork activities were completed to support a baseline monitoring program focussing initially on the current Talinga development area, which is proposed for expansion early in the Project's development. This program was conducted during June 2009. The scope of the fieldwork included:

- Locating nominated well bores and obtaining spatial co-ordinates
- Measurement of standing water levels in well bores accessed
- Completion of well bore surveys (downhole video and natural gamma readings) to confirm or determine construction details and qualitatively assess lithology
- Collection of water samples for field measurement and/or laboratory analysis of physical and chemical parameters
- Instrumentation of appropriate well bores with automated water level monitoring devices.

The following data was collected from the initial groundwater monitoring program:

- Seventeen individual water level readings
- Laboratory analyses of groundwater samples from 10 bores
- Ongoing water level readings, set at 12-hour intervals, in 10 bores.

Ongoing groundwater monitoring is planned and results will be incorporated on a continual basis to update knowledge of the region and effects from CSG operations. Australia Pacific LNG intends to expand this monitoring program in advance of development in accordance with future development approvals and activity. Further details of the groundwater monitoring program are provided in Volume 5 Attachment 21.

10.2.4 Numerical groundwater model

Australia Pacific LNG has developed a framework for comprehensive assessment of the potential cumulative effects of groundwater withdrawal for CSG production within the Surat Basin. This has involved the construction of a regional-scale numerical groundwater model that has incorporated known geological complexities and hydraulic interactions considered necessary to project the groundwater level response to activities of this nature.

Groundwater modelling has commenced, with the development of a calibrated numerical finite element groundwater flow model (FEFLOW). Initial simulations have been conducted throughout the period of CSG development for:

- The project case, representing the gas fields element of the Australia Pacific LNG Project only
- The cumulative case, representing all known and potential CSG activities in the region plus an approved underground coal gasification pilot project and groundwater extraction from an existing power station.

For clarification, the cumulative case has been considered, as required under the terms of reference (December 2009), to:

- Provide an assessment of potential effects from CSG development and other activities
- Assist in the development of a robust regional monitoring system by identifying key areas to establish monitoring infrastructure
- Provide the necessary data from the monitoring infrastructure to verify model results and/or better constrain the model results.

The extent of the groundwater model domain, which also constitutes the study area, is illustrated in Figure 10.1.

10.2.5 Impact assessment and identification of management and mitigation strategies

On the basis of the conceptual hydrogeological model, baseline groundwater monitoring and the initial numerical modelling undertaken to date, potential impacts on the groundwater system are assessed with regards to activities associated with the proposed gas fields. Subsequent groundwater monitoring and refinements of the numerical model will help further assess and manage any potential effects associated with CSG development within the Surat Basin, in Queensland.

The activities associated with the proposed gas fields development that have the potential to impact upon the local and regional scale groundwater resources are evaluated according to the following categories:

- CSG and associated water production (Section 10.4.1)
- CSG associated water management practices (Section 10.4.2)
- Construction and operation of CSG infrastructure, and the installation and extraction from water supply bores in non-CSG production aquifers (Section 10.4.3).

Potential impacts have been evaluated from a hydrogeological perspective, according to the risk evaluation framework described in Volume 1 Chapter 4. The assignment of risk levels provides a basis for identifying areas or issues requiring further review or the implementation of appropriate management and mitigation measures (Section 10.5).

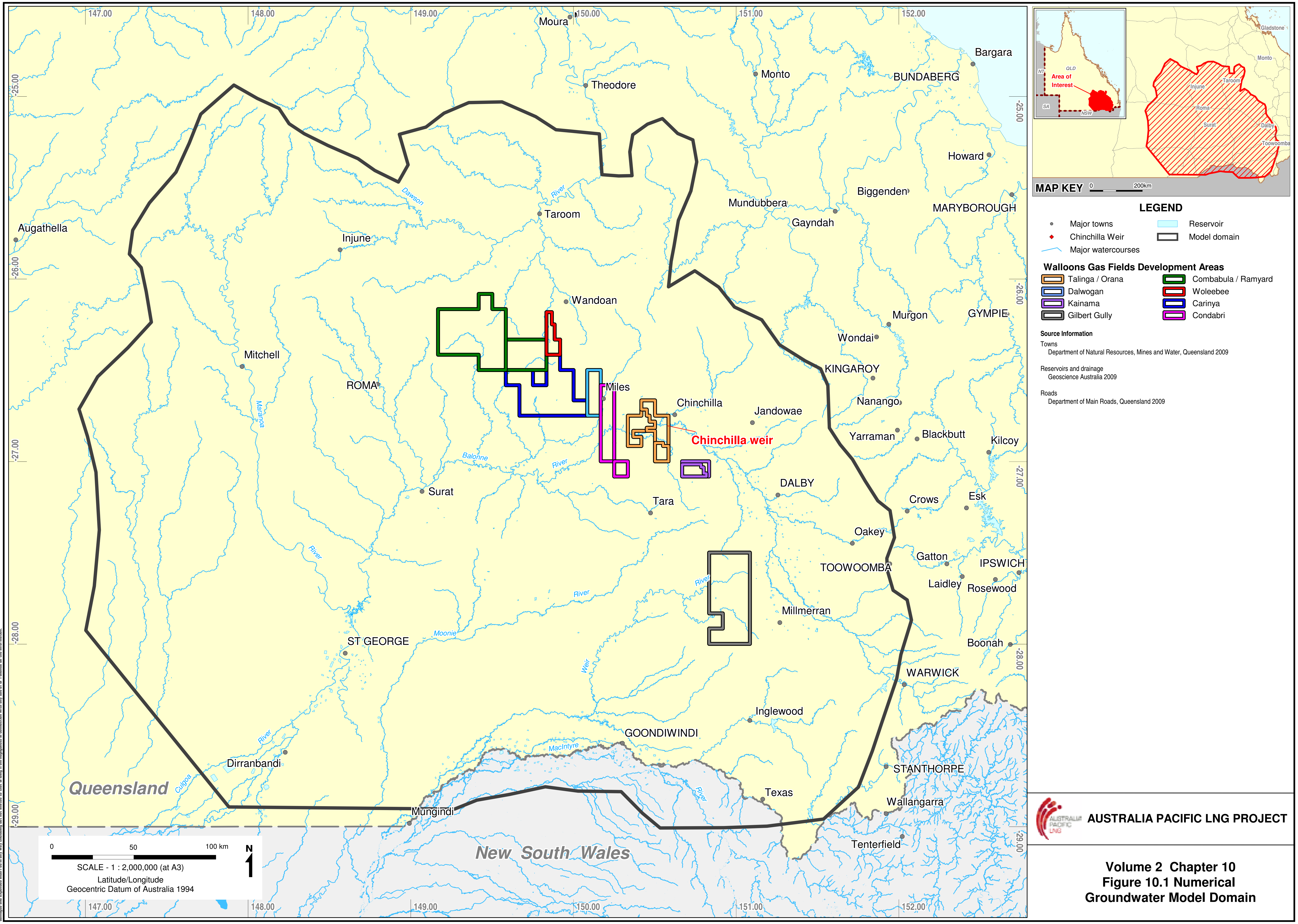

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Figure 10.1 Numerical Groundwater Model Domain

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10.3 Existing environment

10.3.1 Regional setting

Geological and hydrogeological setting

The Surat Basin is an elongate basin with a thickness of sediments reaching up to approximately 2,500m. While the Surat Basin is geologically bound by the Kumbarilla Ridge in the east and the Nebine Ridge in the west, it is hydrogeologically connected to the Clarence-Morton and Eromanga Basins (to the east and west, respectively), and is one of the major basins comprising the GAB. The southern extent of the Bowen Basin underlies the Surat Basin.

The Surat Basin is characterised by a series of layered formations deposited during a sequence of sea level changes between the Jurassic and Cretaceous time periods. The sandstone-dominated units in the Surat Basin form regional aquifers. In turn, the typically finer-grained marine sequences represented by siltstone and mudstone form regionally extensive, low permeability aquitards. Many of these units extend across the Nebine Ridge into the Eromanga Basin. A detailed description of the geology is provided in Volume 5 Attachment 21.

Twelve distinct hydrostratigraphic units have been defined for this study. These hydrostratigraphic units and their constituent geological units are provided in Table 10.2.

Table 10.2 Hydrostratigraphic units defined for the study area

Age	Hydrostratigraphic unit	Geological units	Aquifer / confining unit
Cainozoic	Cainozoic units	Alluvium	Aquifer (watertable)
		Colluvium	
		Chinchilla Sand	
		Main Range Volcanics	
Cretaceous	Rolling Downs Group	Griman Creek Formation	Confining unit
		Surat Siltstone	
		Wallumbilla Formation	
	Bungil/Mooga/Orallo Grouping	Bungil Formation	Aquifer
		Mooga Sandstone	
Jurassic		Orallo Formation	
	Gubberamunda Sandstone	Gubberamunda Sandstone	Aquifer
		Kumbarilla Beds	
		Hooray Sandstone	
		Southlands Formation	
	Westbourne Formation	Westbourne Formation	Confining unit

Age	Hydrostratigraphic unit	Geological units	Aquifer / confining unit
	Springbok Sandstone	Springbok Sandstone	Aquifer
		Pilliga Sandstone	
	Walloon Coal Measures	Upper Walloons Formation*	Confining unit
		Macalister Coal Seams	Aquifer (coal seams)/ confining unit (siltstone, mudstone)
		Juandah Sandstone	Confining unit
		Lower Juandah Coal Seams	Aquifer (coal seams)/ confining unit (siltstone, mudstone)
		Tangalooma Sandstone	Aquifer
		Taroom Coal Seams	Aquifer (coal seams)/ confining unit (siltstone, mudstone)
	Eurombah Formation	Eurombah Formation	Confining unit
	Hutton Sandstone	Hutton Sandstone	Aquifer
		Marburg Sandstone	
	Evergreen Formation	Upper Evergreen Shale	Confining unit
		Lower Evergreen Shale	
		Basal Evergreen Sandstone	
		Boxvale Sandstone	
	Precipice Sandstone	Precipice Sandstone	Aquifer
Triassic	Model Base	Bowen Basin Sequence and Basement	Confining unit

* The Upper Walloons Formation is defined as the interval between the bottom of the Springbok Sandstone and the top of the Macalister Coal Seam.

The hydrostratigraphic units were deposited as broadly flat-lying formations, but uplift and erosion along the eastern and northern margins of the basin has resulted in a south-westerly tilt and exposure of most units along the northern and eastern boundary of the basin. These subcropping and outcropping areas represent the intake beds, or recharge area, for the Surat Basin.

Erosion of the less resistant formations, including the Walloon Coal Measures, followed by relatively recent deposition of alluvial sediments by the Condamine River (and its tributaries) and volcanic activity depositing basalt rocks, has resulted in the 'Cainozoic Units' directly overlying the subcrop areas, putting these more recent deposits in direct connection with the main aquifers of the GAB. The distribution of hydrostratigraphic units occurring at ground surface is illustrated in Figure 10.2, while Figure 10.3 provides an interpretive cross-section through the study area.

A schematic diagram of Australia Pacific LNG's CSG production in relation to the geological setting is illustrated in Figure 10.4.

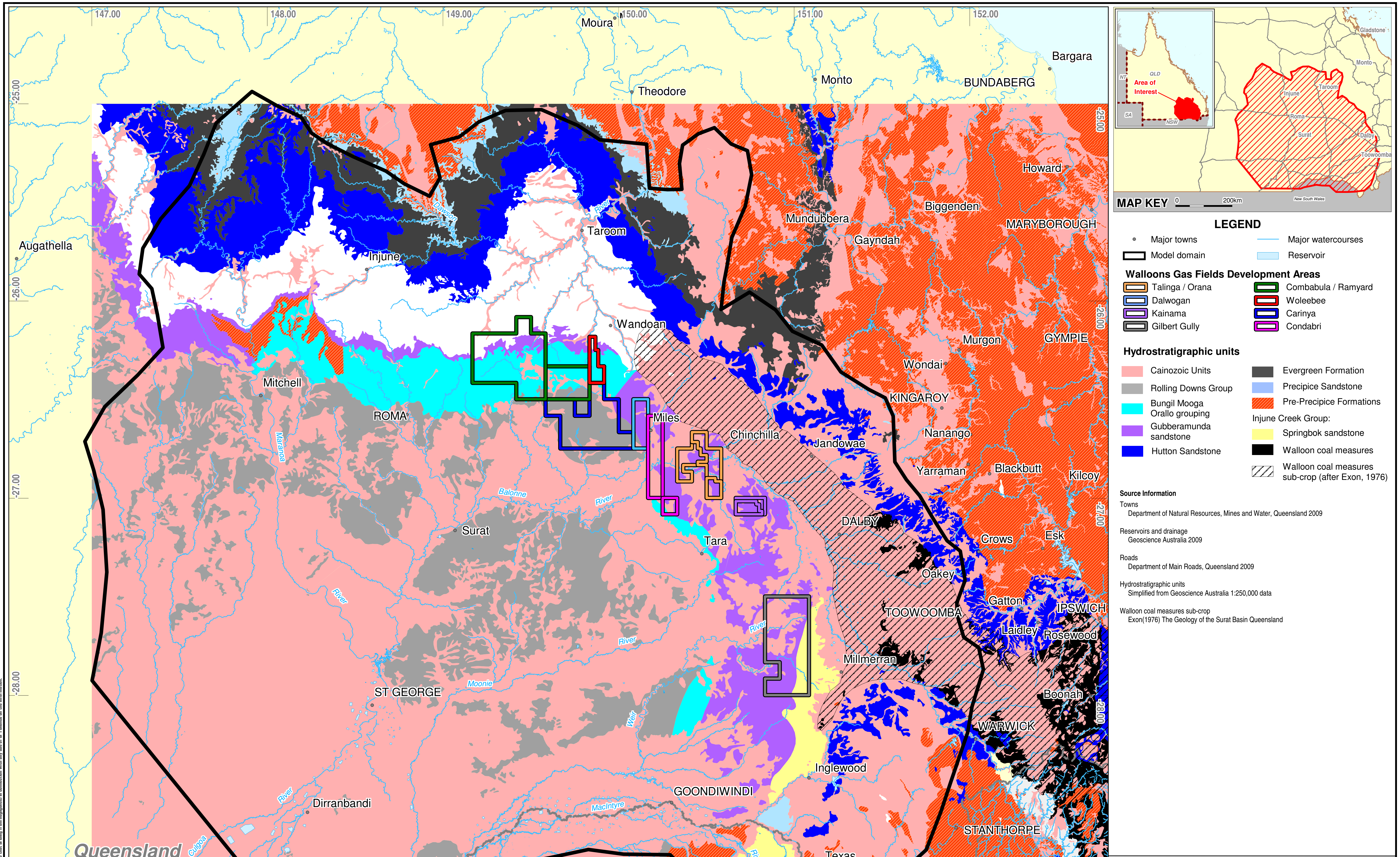

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Figure 10.2 Hydrostratigraphic unit outcrop

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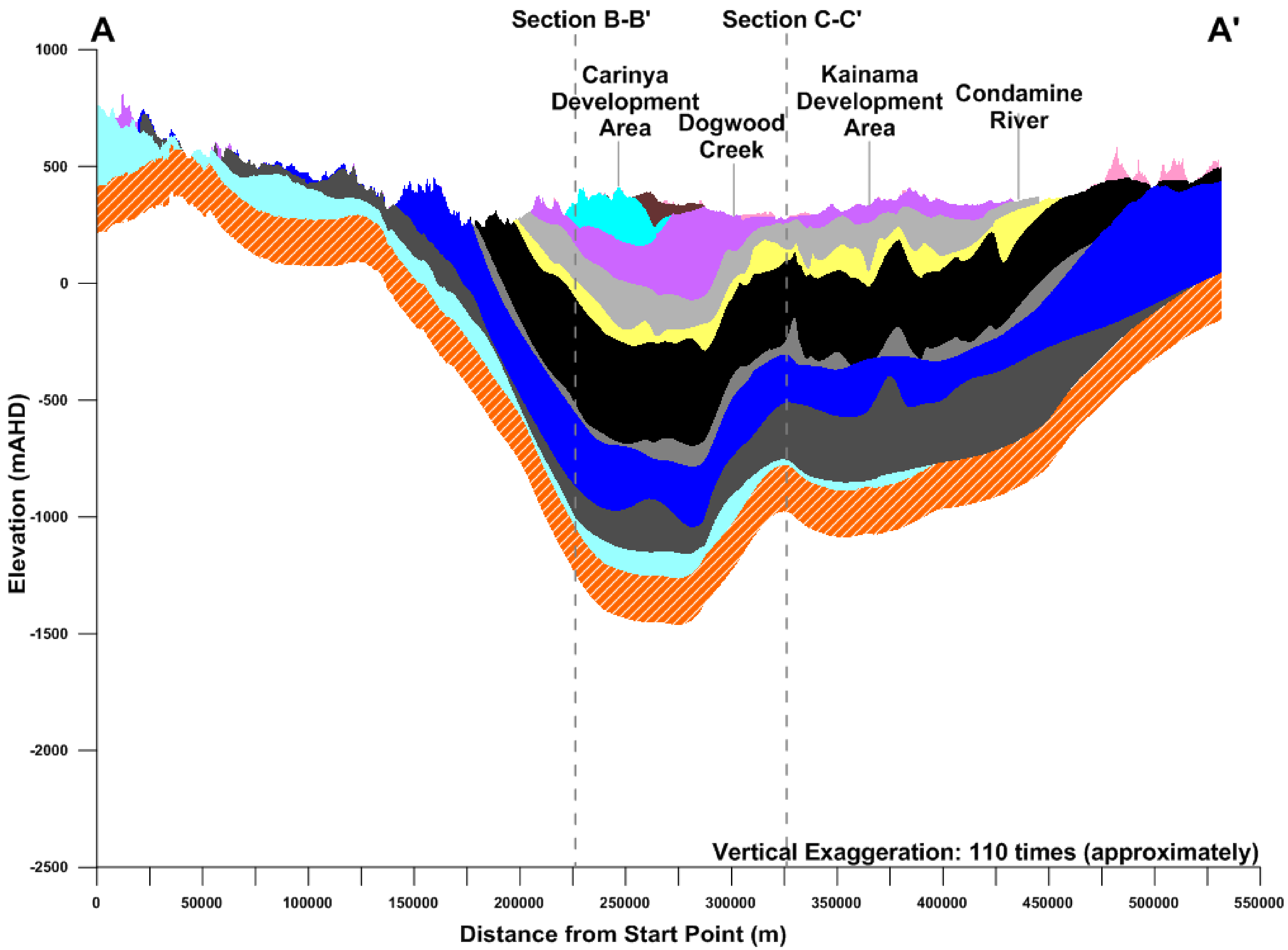

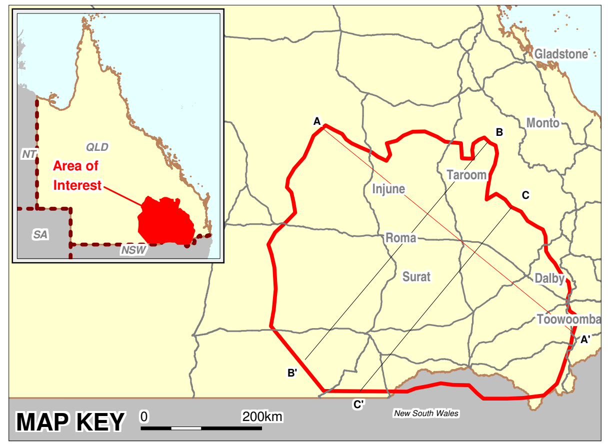

LEGEND

- Major towns
- Major roads
- Model domain

Hydrostratigraphic units

- Cainozoic Units
- Rolling Downs Group
- Bungil Mooga Orallo grouping
- Gubberamunda Sandstone
- Westbourne Formation
- Springbok Sandstone
- Walloon Coal Measures
- Eurombah Formation
- Hutton Sandstone
- Evergreen Formation
- Precipice Sandstone
- Pre-Precipice Formations

Source Information

Cross-section
Created by WorleyParsons based upon Origin Energy and Department of Environment and Resource Management bore data

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Figure 10.3 Hydrostratigraphic cross - section A-A'

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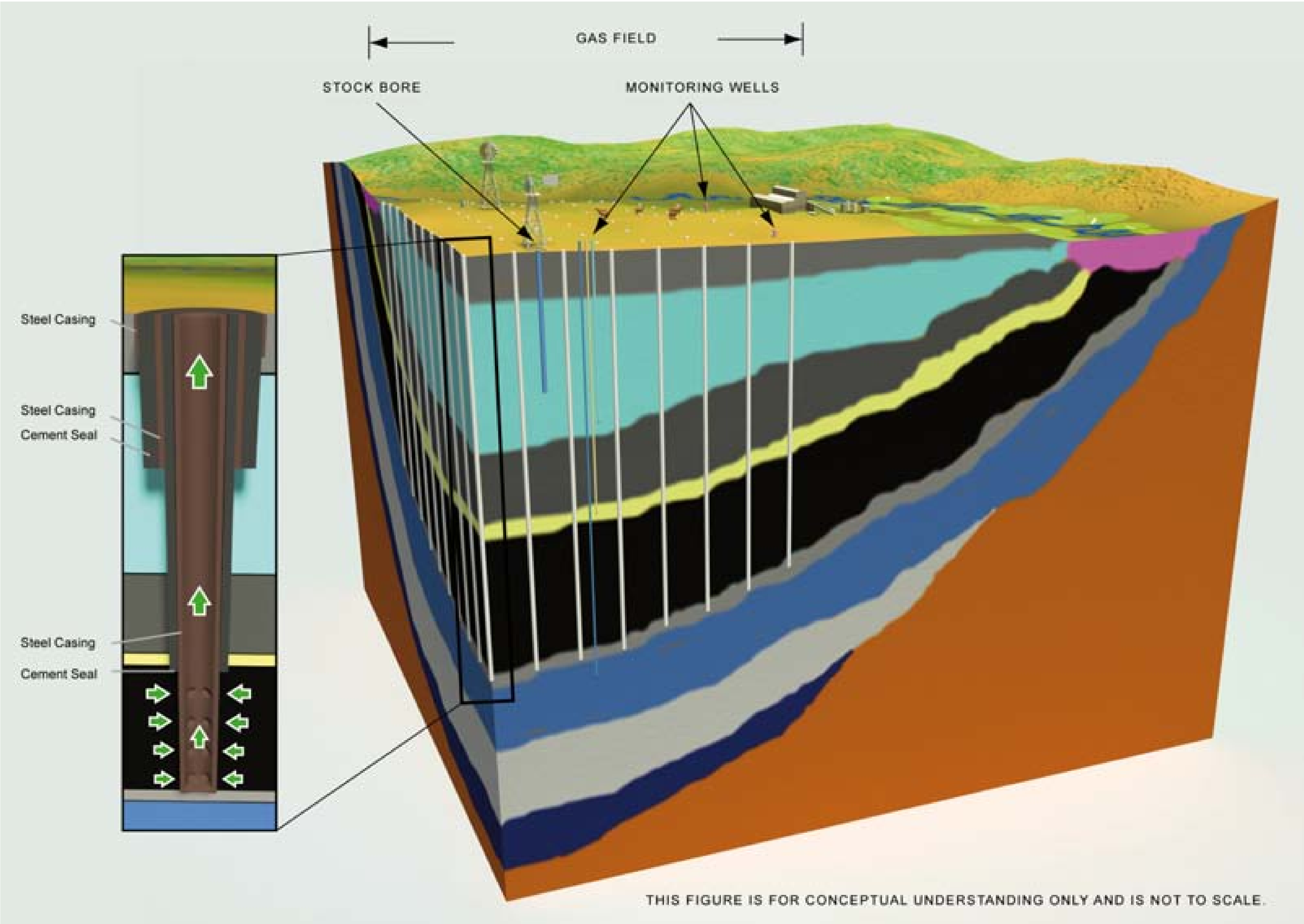

LEGEND

- Cainozoic Units
- Rolling Downs Group
- Bungil Mooga Orallo grouping and Gubberamunda Sandstone
- Westbourne Formation
- Springbok Sandstone
- Gas and associated water movement
- Walloon Coal Measures
- Eurombah Formation
- Hutton Sandstone
- Evergreen Formation
- Precipice Sandstone
- Pre-Precipice Formations

Source Information

Schematic diagram
WorleyParsons 2010

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Figure 10.4 Schematic diagram of Australia Pacific LNG's CSG production in relation to the geological setting.

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Climatic conditions

The climate of the study area is sub-tropical with warm, wetter summer months and cooler, drier winter months. Rainfall is approximately 25% to 35% of the evaporation that occurs. The region is categorised as semi-arid. The Surat Basin is subject to varying climatic conditions which extend over a decadal time-scale. One such phenomenon is the Interdecadal Pacific Oscillation (IPO). Positive phases of the IPO tend to result in extended periods of below average rainfall, with the inverse effect occurring during negative phases. The IPO data is currently, and has been, indicating a negative phase since approximately the mid-1980s, which corresponds to generally wetter conditions in the north-eastern part of Australia.

Climate change assessment work, completed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2007) in the vicinity of the proposed gas fields, projects the following changes to occur between now and 2070:

- A change in average annual temperature of approximately +1.3 to +4.4°C
- Variation in average annual precipitation from approximately -3.5% to +17%
- A change in average annual potential evaporation of approximately +6% to +16%.

Regional flow patterns

Water levels in most Cainozoic Units are shown to respond directly to rainfall recharge and heavy groundwater extraction. This, combined with extended periods of below average rainfall, has resulted in declining water levels over time. Such a trend is noted to some extent in the deeper Gubberamunda Sandstone and Walloon Coal Measures in areas where the units occur close to the surface. Lack of data for other aquifer units limits the assessment of water level trends in those intervals.

Based on available data, the regional lateral groundwater flow direction is to the south-west, and is generally a subdued reflection of the regional topography and basin structure. Locally, shallow groundwater flow may be towards surface water features, where these intersect subcropping or outcropping units. In the case of the Cainozoic Units, groundwater flow will be influenced by the presence of the Condamine River valley.

With respect to flow rates, the average lateral groundwater flow velocities are estimated to range from 0.35m per year up to 5m per year.

Monitoring bore hydrographs for several units and groundwater elevation maps for the Cainozoic Units and the Gubberamunda Sandstone are provided in Volume 5 Attachment 21, Section 5.4.2.

Inter-aquifer flow

It is expected that vertical hydraulic gradients vary across the study area and between units. Habermehl (1980, 2002) suggests that vertical movement between the aquifers is limited by the low vertical hydraulic conductivities of the confining beds (usually two or more orders of magnitude lower than the horizontal values). Despite the low hydraulic conductivities, the inter-aquifer leakage is estimated to constitute a significant portion of the water balance of the GAB (Habermehl 2002).

Geological features such as faults may also provide a pathway for groundwater movement between aquifers, specifically where faults connect aquifers (Hennig 2005), assuming that they are open and provide a pathway for fluid movement.

Groundwater quality

With respect to regional groundwater quality, most aquifer units beneath the CSG gas fields contain groundwater originating from rainfall received in the area over the last 25,000 years (BRS and NRM 2003), and are marginally alkaline with median salinities below 1,500mg/L total dissolved solids. The dominant water type is Na-HCO_3-Cl or a close variant. The Walloon Coal Measures tend to contain groundwater of higher salinity, with total dissolved solids values averaging approximately 4,000mg/L.

A detailed discussion of groundwater quality within the Surat Basin is provided in Volume 5 Attachment 21, Appendix B.

Recharge and discharge processes

Recharge to the groundwater regime predominantly occurs through infiltration of rainfall at intake beds exposed in outcrops or subcrops within the elevated northern and eastern margins of the Surat Basin (BRS and NRM 2003). Infiltration of rainfall may occur directly into the outcropping sandstone aquifers, through contributions from losing reaches of creeks or rivers, or by percolation through unconsolidated sediments which overlie the aquifers as localised recharge (BRS and NRM 2003; Habermehl 2002). The regional extent of the intake beds (or outcrop areas) for each hydrostratigraphic unit is shown in Figure 10.2.

In the BRS and NRM (2003) study, recharge processes to Queensland's GAB intake beds were differentiated according to the mechanisms of localised recharge, preferred pathway flow and diffuse recharge. In general, preferred pathway flow (represented mainly by bedding plane partings and thin porous bands) was determined to be the dominant recharge process.

Localised recharge zones are limited in size, being restricted to the areas where alluvium has been deposited, unless the weathered surface of the sandstone has been eroded by a stream and the aquifer is in hydraulic connection with ponded water. Although the area of influence of diffuse rainfall recharge was determined to be substantial (i.e. virtually the entire Queensland GAB intake beds), the rates are estimated to be an order of magnitude lower than the preferred pathway or localised recharge mechanisms. The ranges of recharge rates for each process evaluated are reported as follows:

- Diffuse rainfall: 0.03mm/year to 2.4mm/year
- Preferred pathway flow: 0.5mm/year to 28.2mm/year
- River leakage (i.e. localised recharge): up to 30mm/year.

Discharge from the confined aquifers in the Surat Basin occurs by way of outflow from spring complexes, subsurface outflow into neighbouring basins, baseflow to rivers and as artificial discharge by means of free artesian flow or controlled flow from water bores accessing these aquifers. Diffuse discharge from the artesian aquifers through the confining beds towards the ground surface is known to occur in the outer reaches of the basin where the confining beds are relatively thin, groundwater levels are high and the water table is shallow.

Groundwater-surface water interactions

The study area is principally located in the Condamine-Balonne River Catchment. Groundwater and surface water connectivity relationships in the catchment area have been assessed in numerous studies (e.g. CSIRO 2008; AGE 2005; Huxley 1982; Lane 1979). The studies indicate that the Condamine River is variably connected to the watertable aquifer, with rates of interaction contingent

on a range of factors including groundwater extraction, surface water storages in the Chinchilla Weir, river bed and aquifer permeability, geomorphology and climatic conditions.

Tributaries of the Condamine-Balonne River system in and around the study area are ephemeral in character. During rainfall events, flow in the creeks and streams partially recharges the underlying alluvial deposits. Groundwater in these deposits constitutes baseflow to the surface water courses once flow in the creeks and streams diminish, and only when the elevation of the groundwater surface is greater than the base of the streambed. The ephemeral nature of these tributaries implies that the effective storage within alluvial deposits is limited and insufficient to supply baseflow over the entire dry season. It is also recognised there are various river reaches in the study area that potentially receive baseflow from the outcropping aquifer systems of the GAB.

Spring complexes and groundwater dependent ecosystems

Springs and areas of seepage are abundant in the marginal regions of the GAB, particularly in the southern, south-western and northern areas. Most springs are concentrated in groups and are distributed over relatively small areas (Great Artesian Basin Consultative Council (GABCC) 1998). Many springs occurring in the GAB are recognised as having unique cultural and ecological values. 'Groundwater dependant ecosystems' are commonly associated with springs and are classified as ecosystems which have their species composition and their natural ecological processes determined by, and reliant on, groundwater (Australia and New Zealand Environmental and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) 2000).

'Recharge' springs[1] with high conservation value exist approximately 25km north and northeast of the Roma township[2]. These springs are located within outcropping areas of the Gubberamunda Sandstone (Department of Natural Resources (DNR) 2005). Numerous high value recharge and discharge spring complexes, associated with the Hutton Sandstone and Precipice Sandstone units, also occur in proximity to the Taroom and Injune townships, outside the Project's development areas (DNR 2005). The discharge spring complexes located near the Taroom township are supplied by artesian flow from the Precipice Sandstone, rising to the surface through joints and fractures in that unit. These complexes are known locally as 'boggomosses' (GABCC 1998), and provide a wetland habitat in an area that experiences prolonged drought conditions. A total of 203 vascular plant taxa have been identified in the boggomosses (GABCC 1998).

The location of known springs in proximity to the study area (DERM 2010) are shown in Figure 10.5, and are discussed in more detail in Volume 5 Attachment 21.

[1] A spring where water is absorbed into sandstone sediments that outcrop on the margins of the Great Artesian Basin and discharge water locally after relatively short residence times.

[2] The DERM wetlands mapping database indicates that one 'recharge' spring complex occurs in the western corner of Australia Pacific LNG's Pine Hills development area.

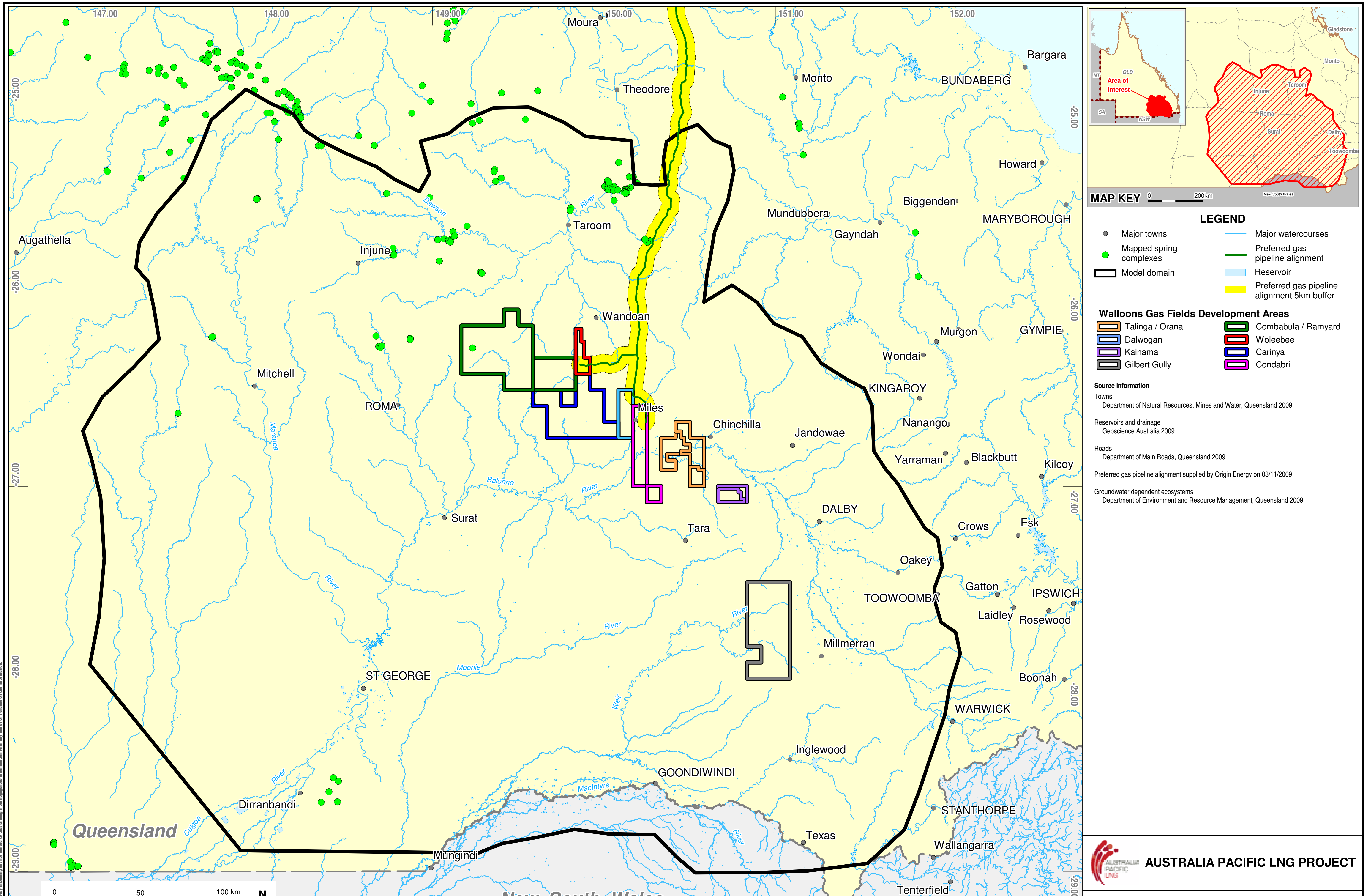

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Figure 10.5 Great Artesian Basin spring complexes in proximity to the study area (DERM wetland mapping database)

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10.3.2 Groundwater usage

A search of the DERM water entitlement register database returned a total of 877 groundwater extraction licences within the vicinity of the proposed gas fields. As only the first bore associated with the licence is represented in the figure, it is emphasised that additional licenced bores do exist in the study area; however, the general bore distribution pattern is expected to remain similar.

Licenced allocations for the study area equate to approximately 125,000ML/a and over 1,700 associated works (water bores) exist. The majority of the bores, both in terms of licenced volume and number of licences, are permitted to extract groundwater from the relatively shallow Cainozoic Units (inclusive of the Condamine River Alluvium, the alluvium of tributaries to the Condamine River, and the Main Range Volcanics) which reside above the GAB aquifers. Approximately 99,500ML/a (80%) of licences in the vicinity of the proposed gas fields are associated with the Cainozoic Units. Most of these bores are located in and around the town of Dalby, in the eastern part of the study area. Within the vicinity of the Project's gas fields, the majority of the licenced groundwater use is for agricultural purposes, with irrigation representing about 33% of allocations and 10% for intensive stock use. The remaining allocations are for industrial use (26%), commercial use (17%), town water supply (10%) and other unidentified uses (4%). This distribution of licence groundwater allocations is represented graphically in Figure 10.6.

It is important to note that the numbers cited above do not include volumes of water used for livestock watering and domestic purposes, as these particular uses do not require a licence. Stock and domestic use constitutes the greatest amount of groundwater taking from the GAB aquifers in the Surat Basin, both in terms of estimated volumes (currently estimated at approximately 81,500ML/a compared with licenced allocations of approximately 25,000ML/a) and number of bores (approximately 6,480 bores - DNR 2005). The largest number of stock and domestic bores access water from the Hutton Sandstone hydrostratigraphic unit (30%) which includes the Marburg Sandstone, whereas in terms of volumes extracted, the greatest taking is from the Gubberamunda Sandstone (30%). Approximately 27% of bores access the Walloon Coal Measures. The distribution of bores and estimated usage for each aquifer unit are provided in Figure 10.7 and Figure 10.8. The locations of the licences are illustrated in Figure 10.9, while locations of the stock and domestic bores are shown in Figure 10.10.

There is currently a moratorium on applications for new licences in the Condamine River Catchment, specifically relating to the alluvium of the Condamine River and its tributaries, the Main Range Volcanics and the Chinchilla Sands (DNRW 2008).

Australia Pacific LNG will participate in studies into the long term sustainable water supply options and will support programs for water conservation within the region.

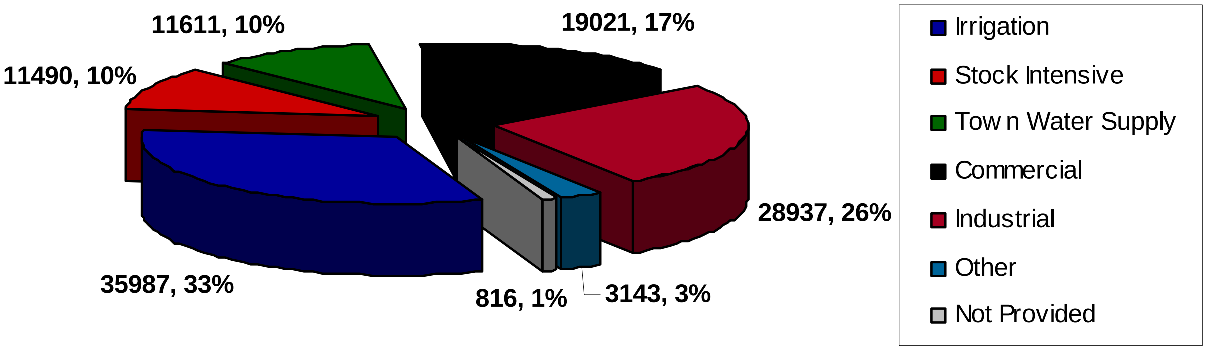

Figure 10.6 Distribution (ML/a and percentage of total) of licenced volume by use in the vicinity of the Project's gas fields

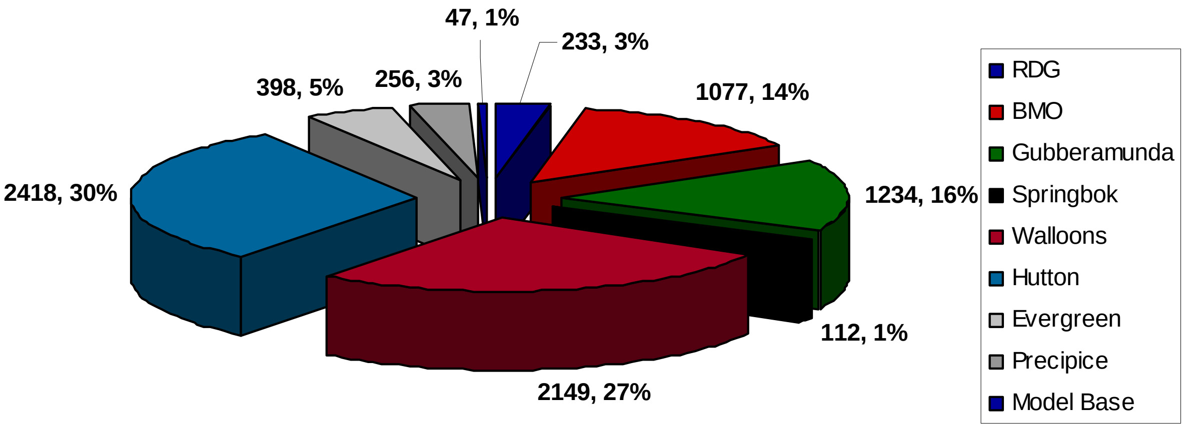

Figure 10.7 Distribution (number and percentage of total) of stock and domestic bores by hydrostratigraphic unit in the Surat Basin

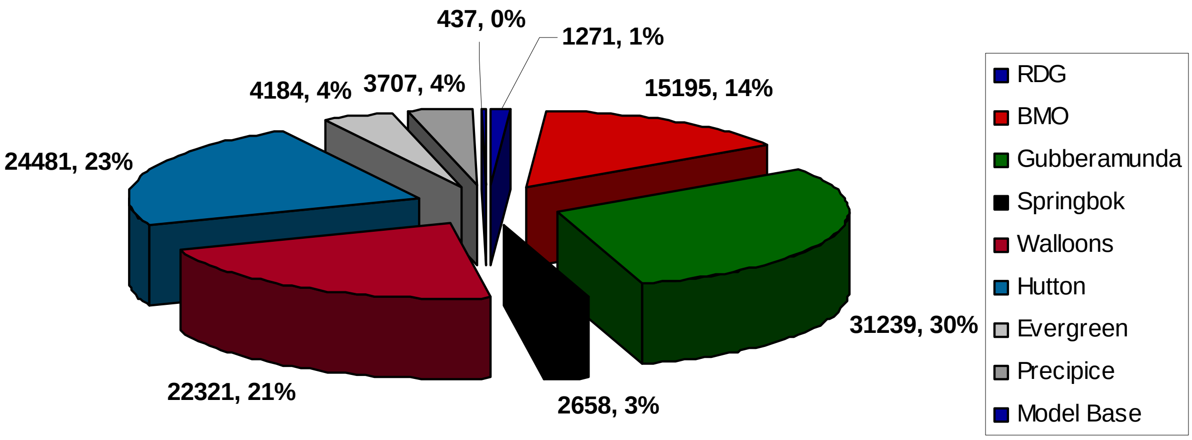

Figure 10.8 Distribution (ML/a and percentage of total) of estimated groundwater use by stock and domestic bores for each hydrostratigraphic unit in the Surat Basin

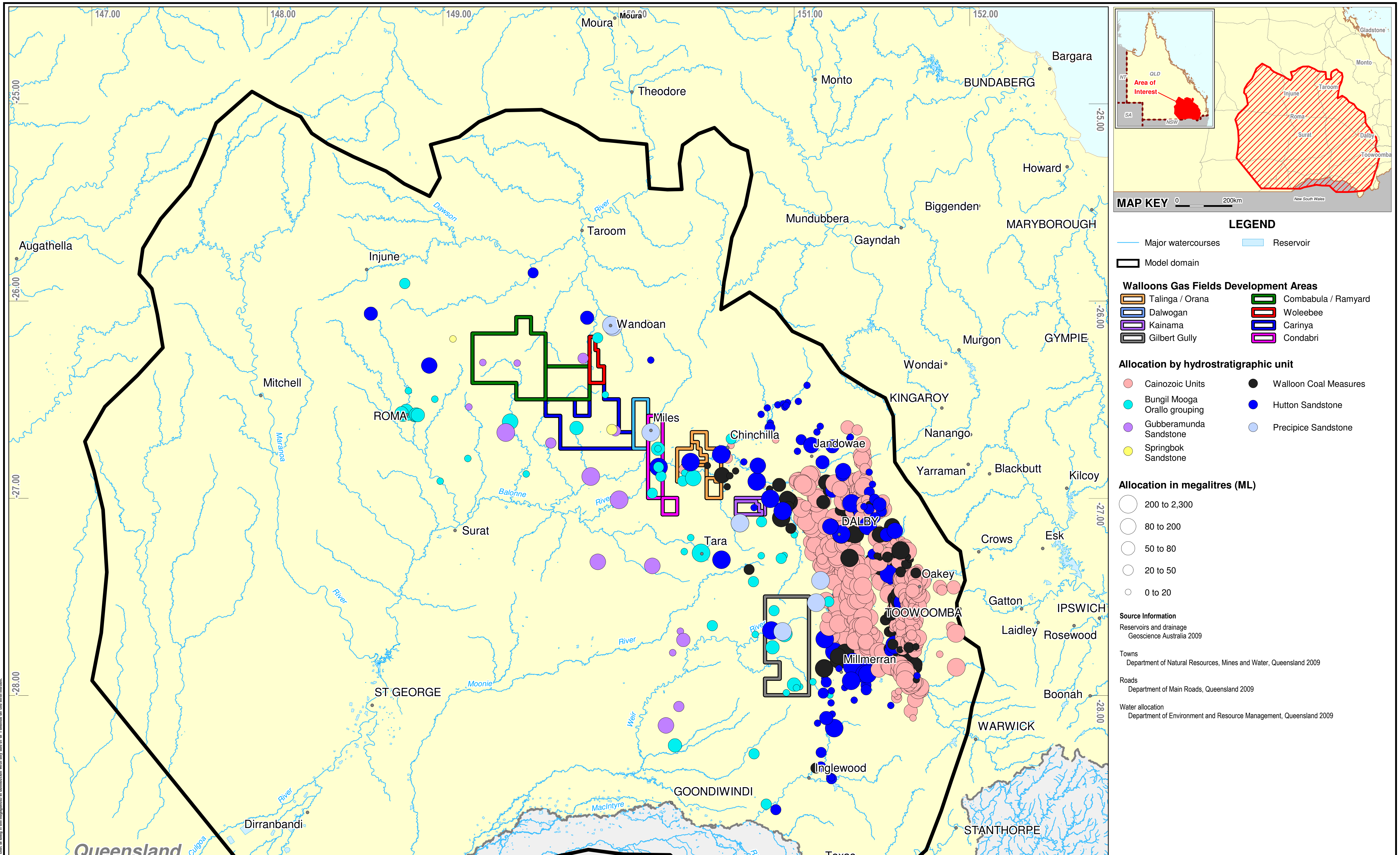

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Figure 10.9 DERM licenced allocations in the gas fields' study area

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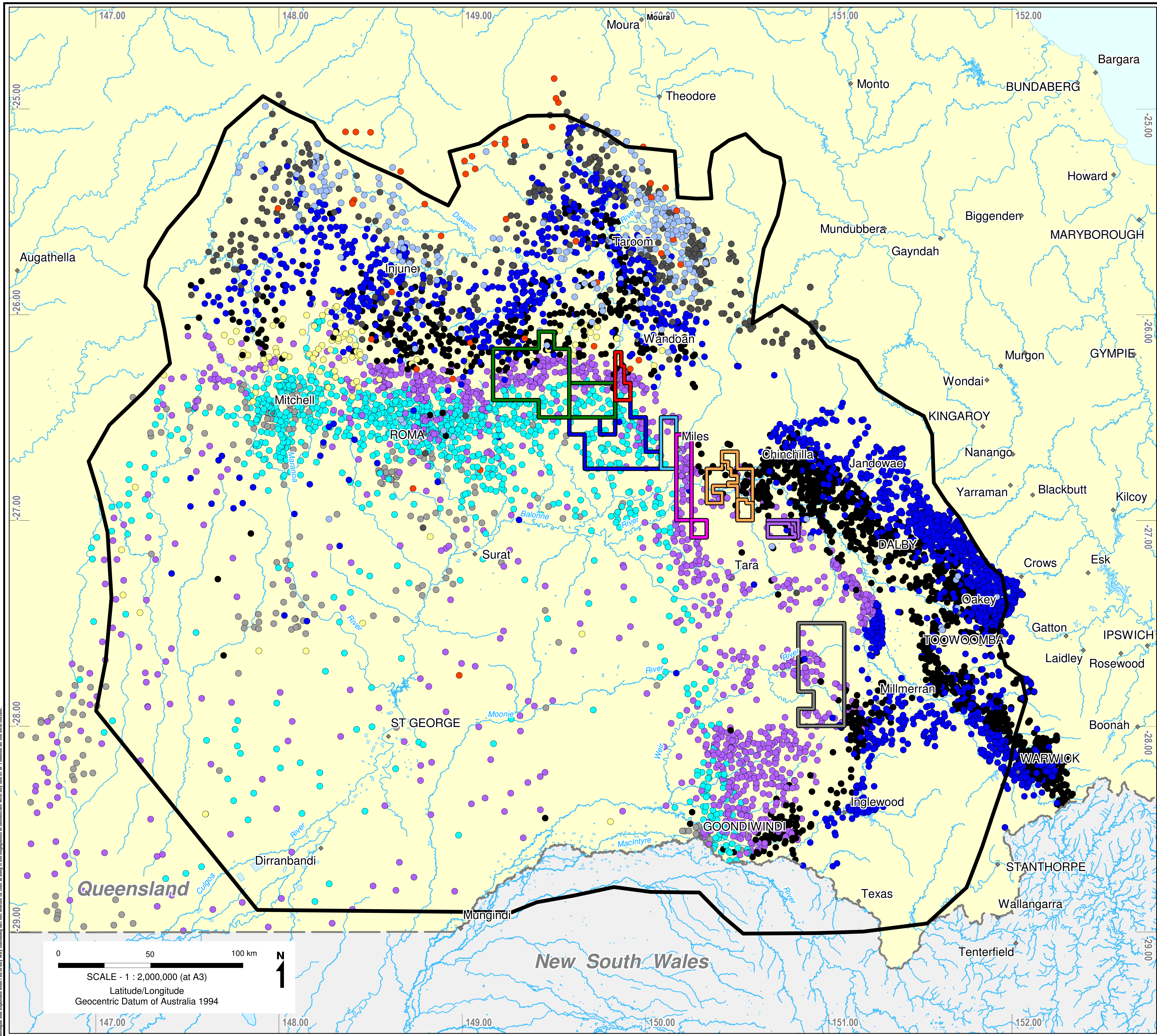

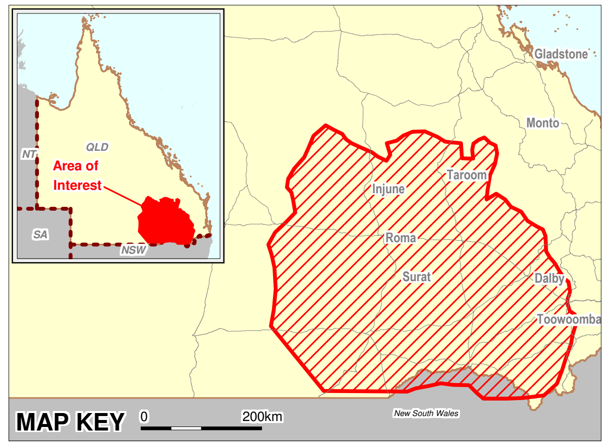

LEGEND

- Major watercourse
- Reservoir
- Model domain

Walloons Gas Fields Development Areas

- Talinga / Orana
- Combabula / Ramyard
- Dalwogan
- Woleebee
- Kainama
- Carinya
- Gilbert Gully
- Condabri

Stock and domestic bores

- Rolling Downs Group
- Walloon Coal Measures
- Bungil Mooga Orallo grouping
- Eurombah Formation
- Gubberamunda Sandstone
- Hutton Sandstone
- Westbourne Formation
- Evergreen Formation
- Springbok Sandstone
- Precipice Sandstone
- Pre-Precipice Formations

Source Information

Reservoirs and drainage
Geoscience Australia 2009

Towns
Department of Natural Resources, Mines and Water, Queensland 2009

Roads
Department of Main Roads, Queensland 2009

Stock and domestic bore locations within the Great Artesian Basin
Department of Environment and Resource Management, Queensland 2009

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Figure 10.10 Stock and domestic bores in the Surat Basin, Queensland

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10.3.3 Environmental values

The environmental values of groundwater within the study area have been assessed in accordance with the Environmental Protection (Water) Policy 2009 (EPP 2009). As stipulated in this policy document, the following environmental values are to be enhanced or protected:

- Biological integrity of an unmodified, highly-valued or modified aquatic ecosystem
- Suitability for primary, secondary and visual recreational use
- Suitability for supply as drinking water
- Suitability for agriculture use
- Suitability for aquaculture use
- Suitability for producing aquatic food for human consumption
- Suitability for industrial use
- Cultural and spiritual values of the water.

10.4 Potential impacts

10.4.1 CSG and associated water production

The process of associated water production from the coal seams in the Walloon Coal Measures will lower water levels in that interval, altering vertical hydraulic gradients, thereby creating a potential for water movement to the production zone from overlying and underlying units through intervening aquitards. The magnitude of water transfer, and the resulting effects to groundwater levels, is governed by the pressure differential between the units (i.e. hydraulic gradient) and the ability of the intervening aquitards to transmit groundwater, which is a function of the unit's vertical permeability and thickness.

The initial numerical groundwater modelling provides projections of the groundwater level response in the Walloon Coal Measures and overlying and underlying aquifers as a consequence of associated water production from the Project's gas fields (the project case) and all other existing and proposed CSG developments in the Surat Basin (the cumulative case). The proposed expansion of the Darling Downs Power Station groundwater supply and the projected groundwater production in association with the proposed Linc Energy underground coal gasification operation have also been considered in the cumulative case model.

It is important to note that some of the initial model parameters are considered conservative. Further refinement of the numerical model is expected to project reduced groundwater level drawdowns.

Further details on the outcomes of groundwater impact assessment are provided in Volume 5 Attachment 21.

Potential implications for groundwater levels (project case)

The projected groundwater level response to associated water production from the gas fields (the project case) is presented in Figure 10.11 (Taroom Coal Seam); Figure 10.12 (Springbok Sandstone); Figure 10.13 (BMO Grouping and Gubberamunda Sandstone); Figure 10.14 (Watertable aquifer);

Figure 10.15 (Hutton Sandstone) and Figure 10.16 (Precipice Sandstone), and described in the following sections.

The figures illustrate the projected extent of groundwater drawdown in key hydrostratigraphic units from the Australia Pacific LNG Project activities at model year 2049. Model year 2049 was chosen to illustrate projected drawdown as it generally represents the time of maximum magnitude of effect in these units.

As documented in the accompanying explanatory notes of the Great Artesian Basin Resource Operation Plan (2007), a 5m groundwater drawdown has been adopted for evaluating the criteria for the protection of existing groundwater entitlements. The same criteria has been applied here to evaluate potential effects to existing registered water bores.

Coal seams of the Walloon Coal Measures

In the model, associated water production by the Project's gas fields in the target coal seams is assumed to be representative of a progressive lowering of water levels to approximately 35m above the Macalister Coal Seams. The groundwater level drawdown projections generally demonstrate consistency with the elevation of this unit and are most significant in areas where the unit occurs at its lowest elevation, for example, beneath the Carinya development area.

During the CSG operational period, the projected radial extent of groundwater level drawdown in the coal seam units is limited to the development areas and nearby proximities, and within 50km of the development area boundaries. Post-production, during the groundwater level recovery phase, the radial extent of the drawdown is projected to broaden to less than 100km beyond the development area boundaries.

Major aquifer units overlying the Walloon Coal Measures

The Springbok Sandstone is projected to experience the highest groundwater level drawdown outside the Walloon Coal Measures. On average, the groundwater level drawdown is projected to be less than 15m across the CSG development areas and their proximities. Localised areas are projected to experience greater drawdown during associated water production, being generally concentrated in areas where both the coal seam elevations are comparatively deep and the Upper Walloons unit aquitard (separating the Springbok Sandstone and target coal seams) is inferred to be thin. These localised areas of elevated drawdown are projected to occur in the Gilbert Gully, Ramyard, Carinya, Condabri South and Condabri Central development areas.

The BMO Grouping and Gubberamunda Sandstone are projected to experience comparatively less drawdown (on average below 3m), but in a localised area may approach between 5m and 8m. This localised effect, which is projected to occur in the Carinya development area and to the south, generally corresponds to a comparatively larger drawdown effect in the underlying Springbok Sandstone aquifer.

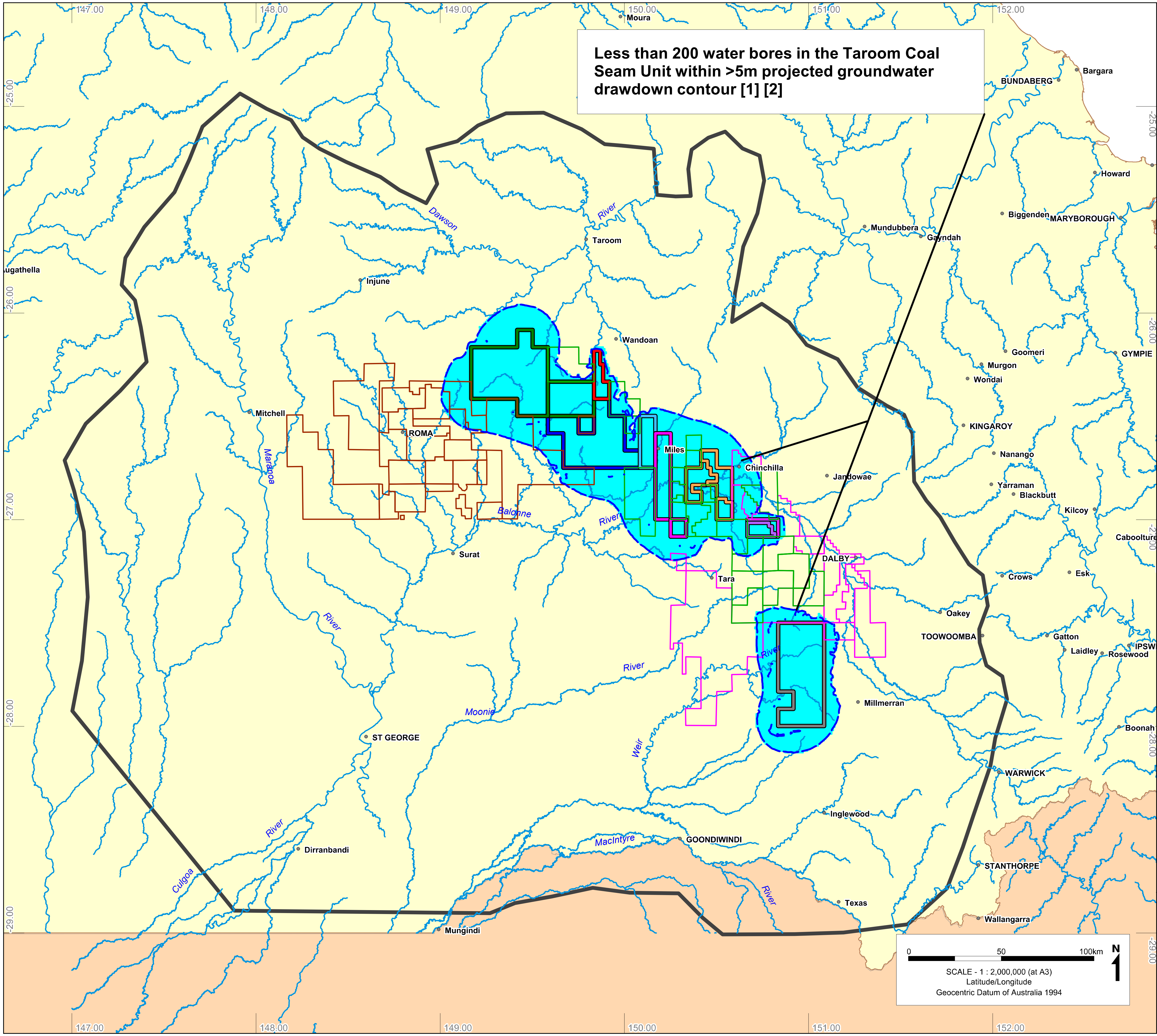
Similarly, the watertable interval is projected to experience a comparatively low level of groundwater drawdown, generally less than 2m. According to the initial numerical model results, very isolated groundwater drawdowns between 5m and 7m are projected to occur east of Condabri Central and in Condabri South. These isolated areas correspond to a projected groundwater level drawdown in the deeper Gubberamunda Sandstone aquifer, and are representative of a localised zone where the Rolling Downs aquitard (separating the Cainozoic Units and the underlying Gubberamunda Sandstone) is inferred to be thin or absent.

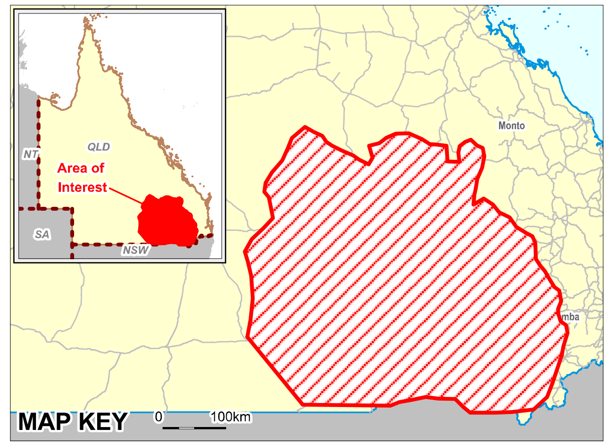
During associated water production, the radial extent of the groundwater level drawdown within these overlying aquifers is projected to be concentrated within close proximity to the development area boundaries. Post-production, during the groundwater level recovery phase, the radial extent of the groundwater level drawdown is projected to expand.

Major aquifer units underlying the Walloon Coal Measures

The Hutton Sandstone is projected to experience very limited groundwater level drawdown of less than 2m, on average. During associated water production, the radial extent of the groundwater level drawdown is projected to be concentrated around the development areas. Post-production, during the groundwater level recovery phase, the radial extent of the groundwater level drawdown is projected to broaden beyond the development area boundaries.

Negligible upwards leakage of groundwater from the Precipice Sandstone aquifer, to the Hutton Sandstone unit, is projected to occur due to the presence of the intervening and low permeability Evergreen Formation aquitard.





LEGEND

- Major towns
- Major watercourses

Walloons Gas Fields Development Areas

- Talinga / Orana
- Dalwogan
- Kainama
- Gilbert Gully
- Combabula / Ramyard
- Woleebee
- Carinya
- Condabri

Groundwater Level Drawdown

- Projected 5m groundwater drawdown contour at model year 2049 (best estimate project case scenario)
- Projected area of groundwater drawdown > 5m at model year 2049 (best estimate project case scenario)
- Santos leases
- Arrow leases
- QGC leases
- Model domain

Source Information

Water bores
[1]Derived from the DERM Groundwater database and Great Artesian Basin water resource stock and domestic register

Projected 5m Drawdown
[2]The Great Artesian Basin Resource Operation Plan (2007) adopts a 5m groundwater drawdown for evaluating the criteria for the protection of existing groundwater entitlements.
The same criteria has been applied in the impact assessment to evaluate potential effects to existing registered groundwater bores.

Mining Resources
Department of Mines and Energy, MERLIN Mining Tenures system and Database (MTDB) 2009

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Figure 10.11 Project case projected groundwater level drawdown in the Taroom Coal Seam unit at model year 2049

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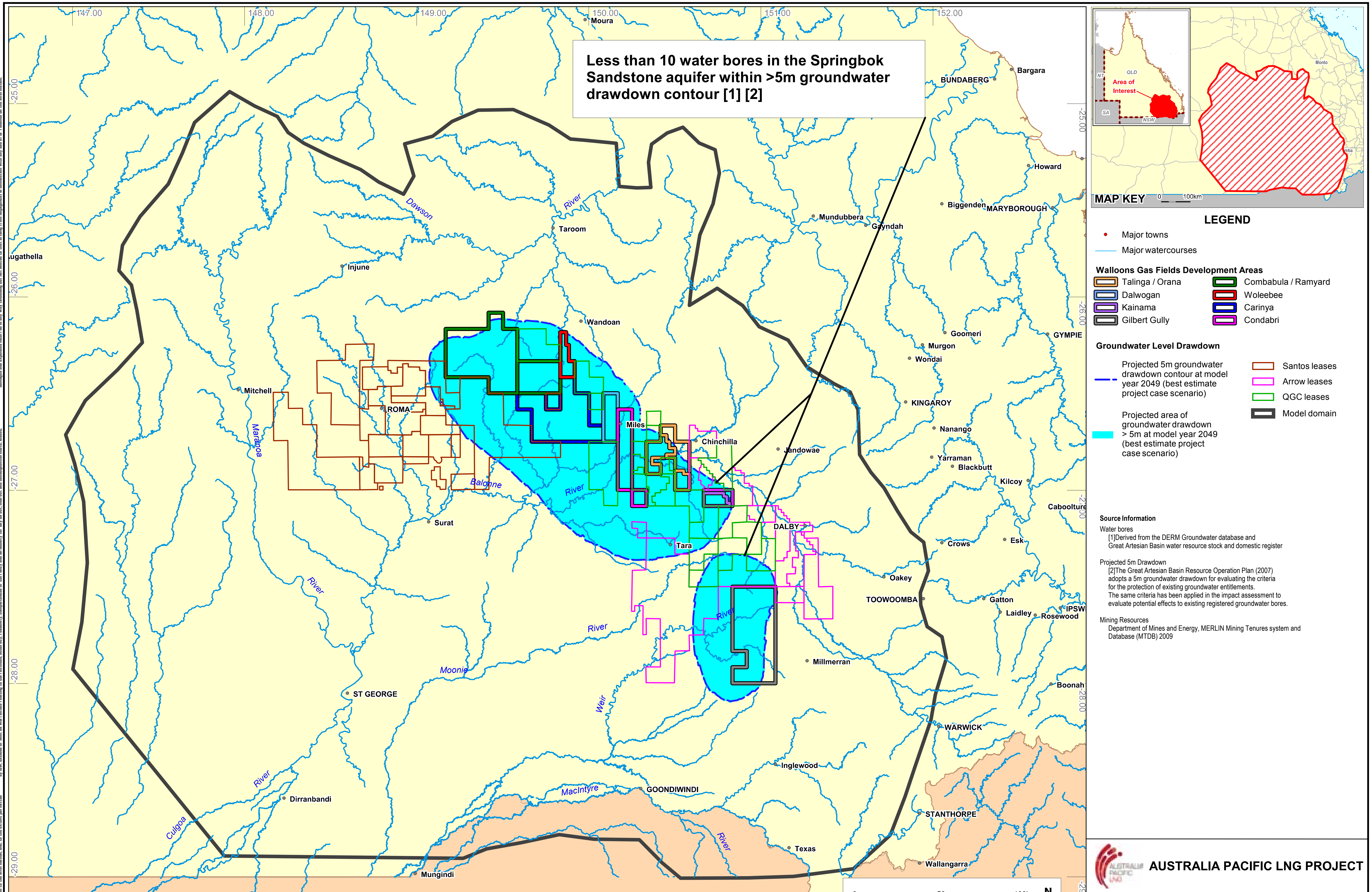

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Figure 10.12 Project case projected groundwater level drawdown in the Springbok Sandstone aquifer at model year 2049

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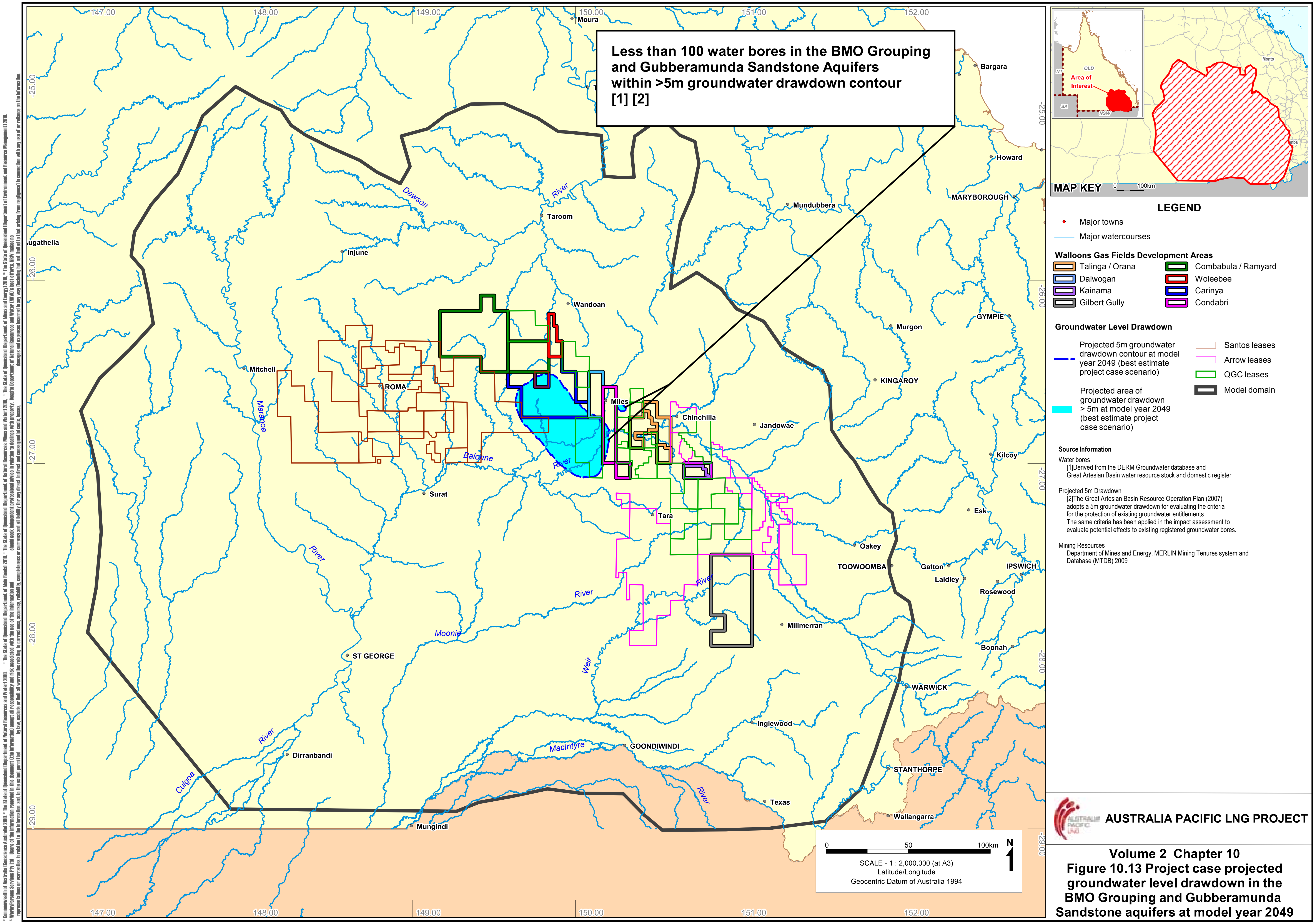

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Figure 10.13 Project case projected groundwater level drawdown in the BMO Grouping and Gubberamunda Sandstone aquifers at model year 2049

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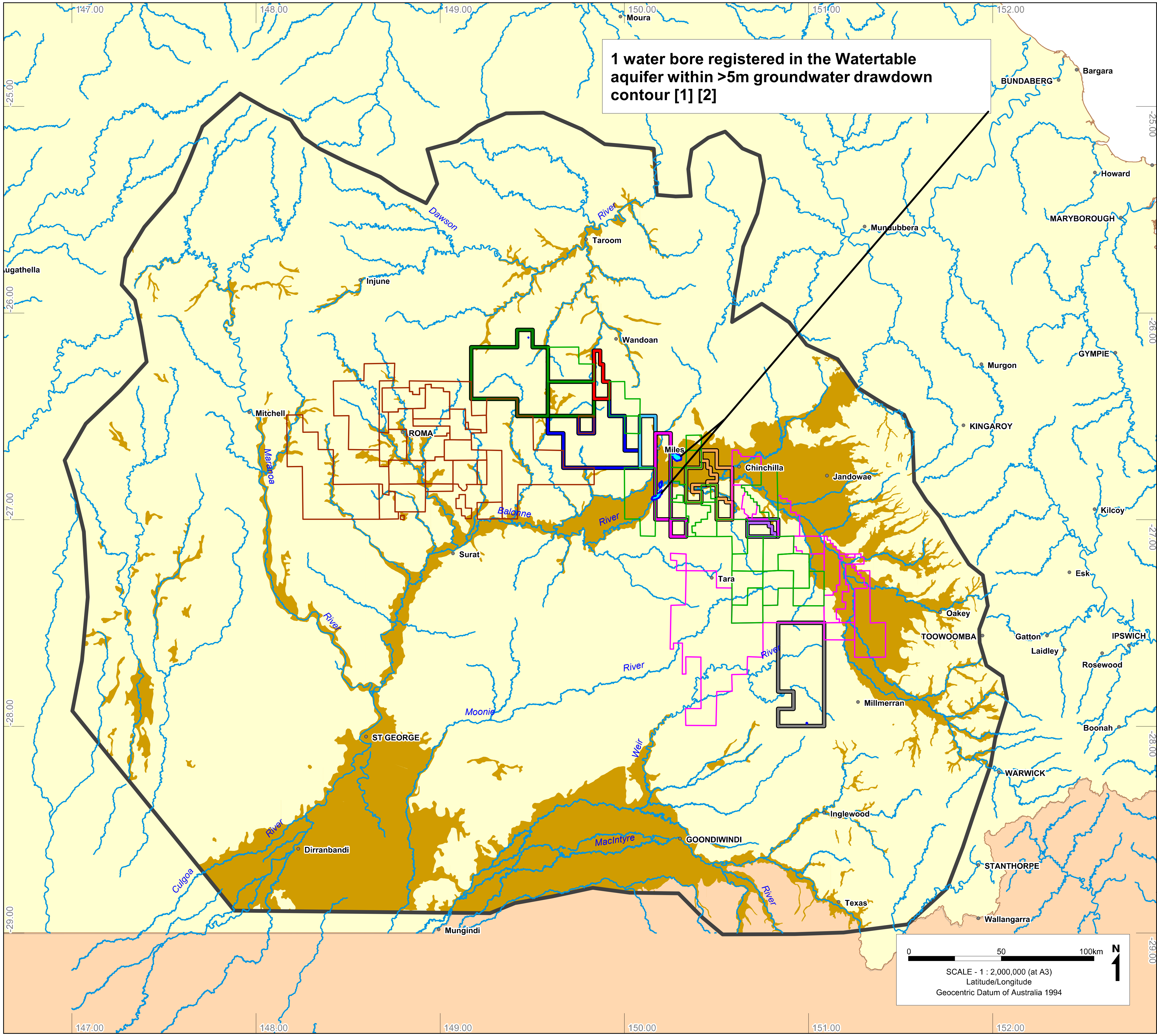

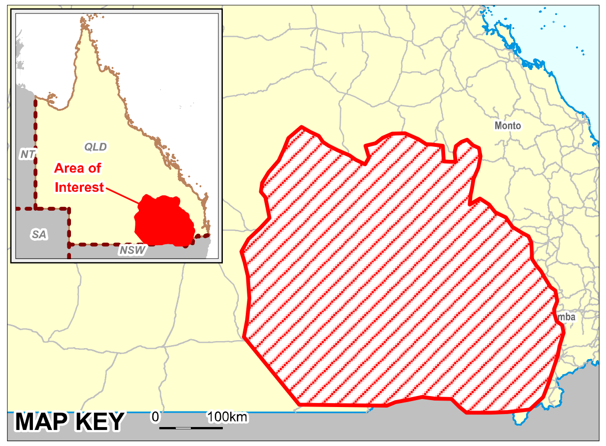

LEGEND

- Major towns
- Major watercourses

Walloons Gas Fields Development Areas

- Talinga / Orana
- Dalwogan
- Kainama
- Gilbert Gully
- Combabula / Ramyard
- Woleebee
- Carinya
- Condabri

Groundwater Level Drawdown

- Projected 5m groundwater drawdown contour at model year 2049 (best estimate project case scenario)
- Projected area of groundwater drawdown > 5m at model year 2049 (best estimate project case scenario)
- Santos leases
- Arrow leases
- Extent of Alluvium within the model domain
- Model domain
- QGC leases

Source Information

Water bores
[1]Derived from the DERM Groundwater database and Great Artesian Basin water resource stock and domestic register

Projected 5m Drawdown
[2]The Great Artesian Basin Resource Operation Plan (2007) adopts a 5m groundwater drawdown for evaluating the criteria for the protection of existing groundwater entitlements. The same criteria has been applied in the impact assessment to evaluate potential effects to existing registered groundwater bores.

Extent of Alluvium
The Commonwealth of Australia, Geoscience Australia. 2007. Surface geology of Australia 1:1,000,000 scale, Queensland - 2nd edition [Digital Dataset].

Mining Resources
Department of Mines and Energy, MERLIN Mining Tenures system and Database (MTDB) 2009

0 50 100km

SCALE - 1 : 2,000,000 (at A3)
Latitude/Longitude
Geocentric Datum of Australia 1994

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Figure 10.14 Project case projected groundwater level drawdown in the Watertable interval at model year 2049

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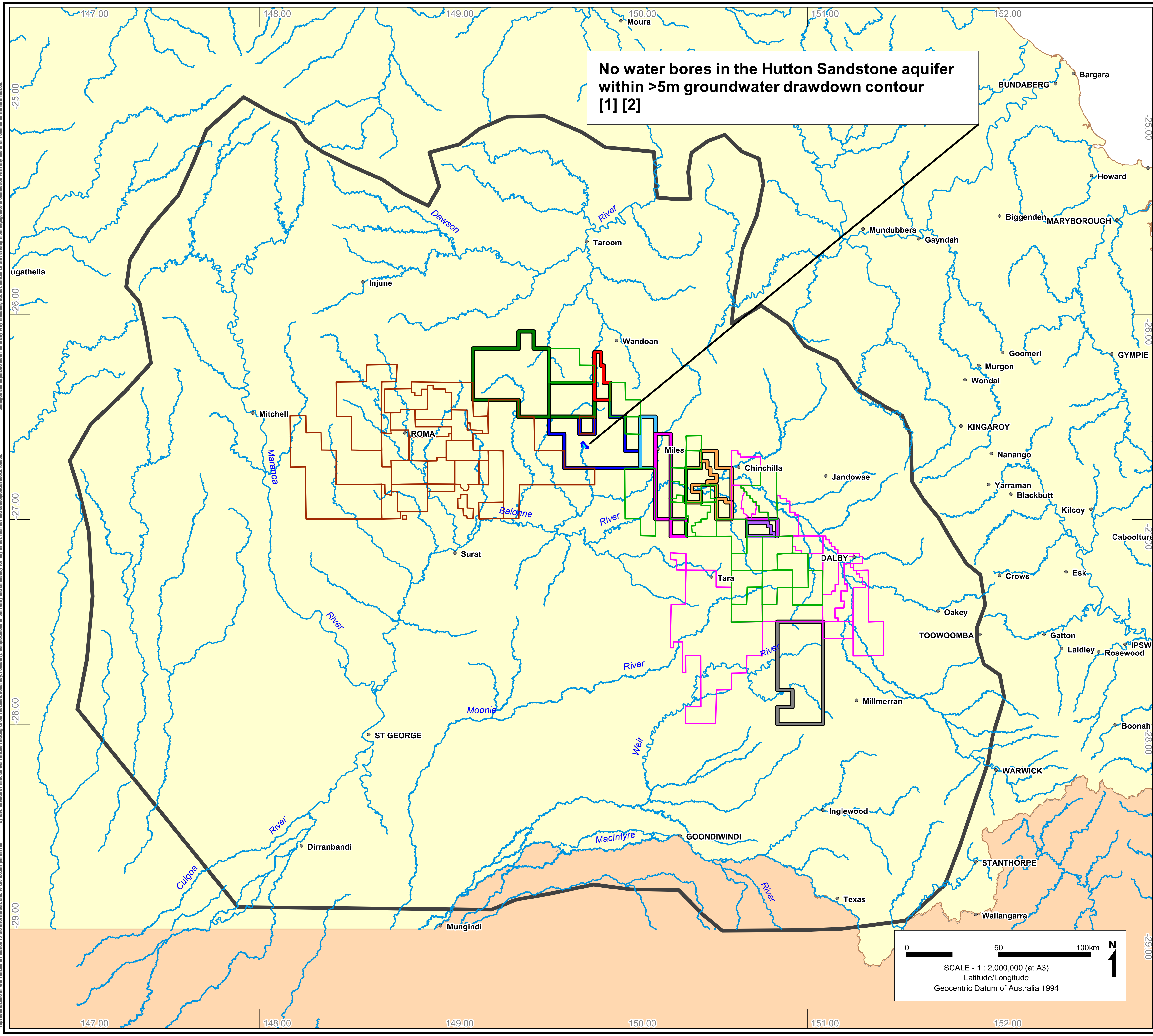

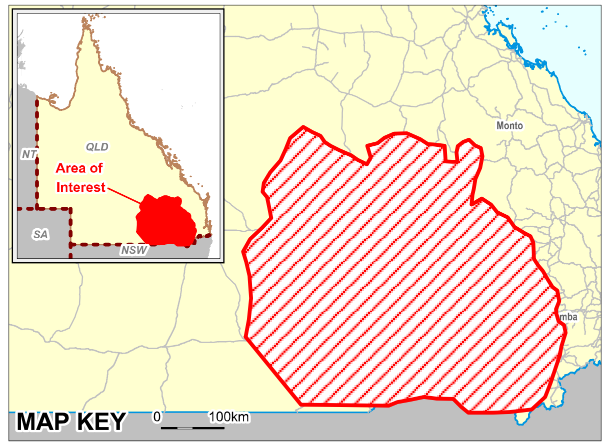

LEGEND

- Major towns
- Major watercourses

Walloons Gas Fields Development Areas

- Talinga / Orana
- Dalwogan
- Kainama
- Gilbert Gully
- Combabula / Ramyard
- Woleebee
- Carinya
- Condabri

Groundwater Level Drawdown

- Projected 5m groundwater drawdown contour at model year 2049 (best estimate project case scenario)
- Projected area of groundwater drawdown > 5m at model year 2049 (best estimate project case scenario)
- Santos leases
- Arrow leases
- QGC leases
- Model domain

Source Information

Water bores
[1]Derived from the DERM Groundwater database and Great Artesian Basin water resource stock and domestic register

Projected 5m Drawdown
[2]The Great Artesian Basin Resource Operation Plan (2007) adopts a 5m groundwater drawdown for evaluating the criteria for the protection of existing groundwater entitlements. The same criteria has been applied in the impact assessment to evaluate potential effects to existing registered groundwater bores.

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Department of Mines and Energy, MERLIN Mining Tenures system and Database (MTDB) 2009

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Figure 10.15 Project case projected groundwater level drawdown in the Hutton Sandstone aquifer at model year 2049

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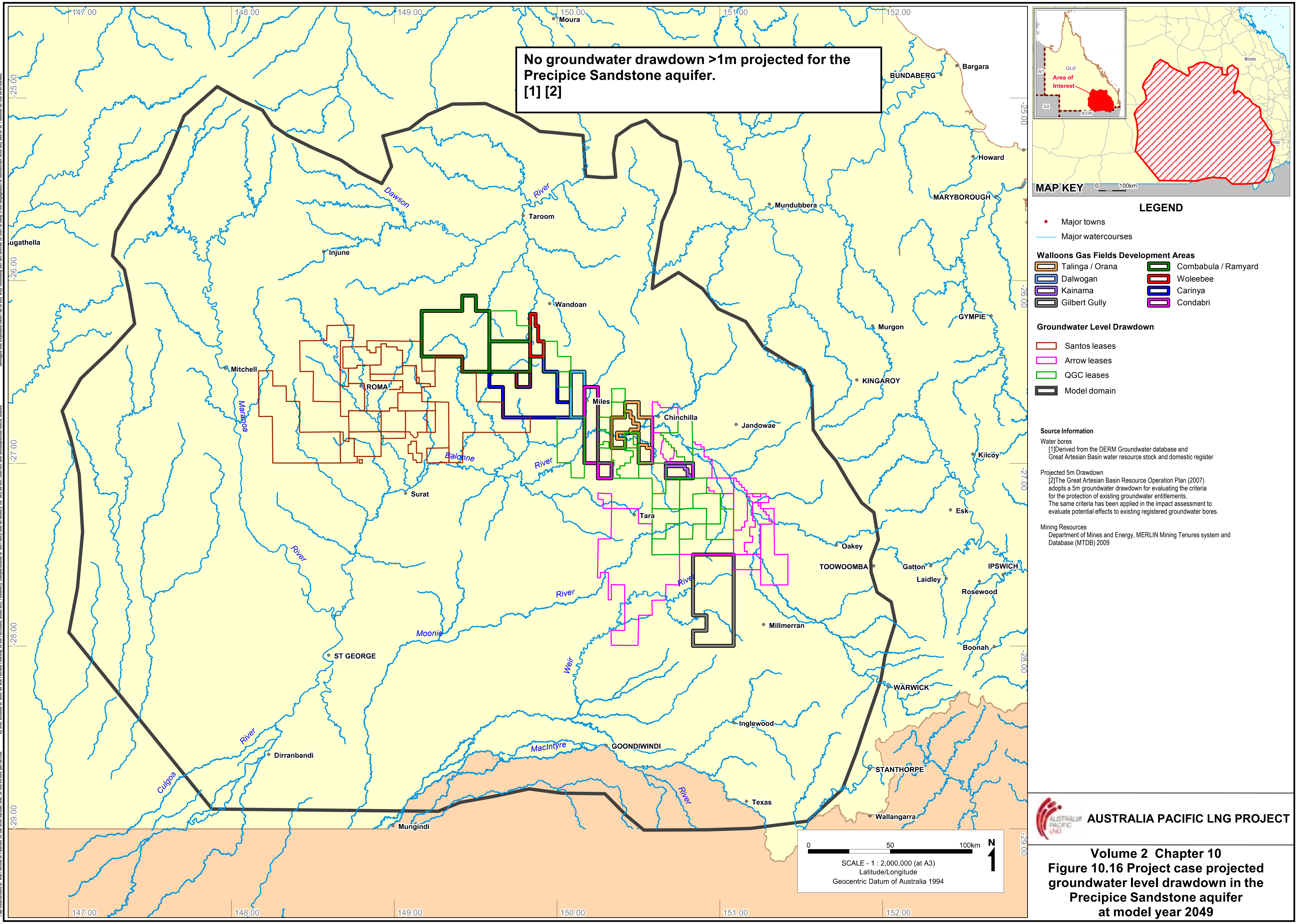

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Figure 10.16 Project case projected groundwater level drawdown in the Precipice Sandstone aquifer at model year 2049

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Potential implications for groundwater levels (cumulative case)

In general, the projected extent of groundwater level drawdown in the Walloon Coal Measures and overlying and underlying units in the cumulative case model (relative to the project case) is expected to expand due to the associated water production by all CSG operators. The projected magnitude of the groundwater drawdown in each unit is, however, anticipated to be of the same order as indicated for the project case.

Coal seams of the Walloon Coal Measures

The groundwater level drawdown projections generally demonstrate consistency with the elevation of this unit and are most significant in areas where the unit occurs at its lowest elevation, such as 50km west of Gilbert Gully (North), 10km west of Condabri South and 10km, 40km and 100km south-west of the Carinya development area.

During the combined CSG activities in the region, the radial extent of groundwater level drawdown in the coal seam units is projected to be limited to the cumulative development areas and nearby proximities, within 50km of the area boundaries. Post-production, during the groundwater level recovery phase, the radial extent of the drawdown is projected to broaden to less than 100km beyond the cumulative development area boundaries.

Major aquifer units overlying the Walloon Coal Measures

The Springbok Sandstone is projected to experience the highest cumulative groundwater level drawdown outside the Walloon Coal Measures. On average, the groundwater level drawdown is projected to be approximately 15m across the cumulative CSG development areas and their proximities. Localised areas are projected to experience greater drawdown during associated water production, being generally concentrated in areas where both the coal seam elevations are comparatively deep and the Upper Walloons unit aquitard (separating the Springbok Sandstone and target coal seams) is inferred to be thin. These localised areas of elevated drawdown are projected to occur in proximity to the Gilbert Gully, Ramyard, Carinya, Condabri South and Condabri Central development areas, between the Gilbert Gully and Kainama development areas and 100km southwest of the Pine Hills development area.

The BMO Grouping and Gubberamunda Sandstone are projected to experience comparatively less drawdown (on average below 3m) but in localised areas may approach 10m. These localised effects generally correspond to larger drawdown effects in the Springbok Sandstone aquifer, and in some instances occur in areas where the intervening aquitard (i.e. Westbourne Formation) is inferred to be thin. These localised areas of elevated drawdown are generally projected to occur in the Carinya development area and to the south, 100km southwest of the Pine Hills development area and north and northwest of the Gilbert Gully development area.

Similarly, the watertable interval is projected to experience a comparatively low magnitude of groundwater drawdown, generally less than 2m. According to the initial numerical model results, localised areas of the watertable interval are projected to experience greater drawdowns in the following areas:

- East of Condabri Central and in Condabri South
- North and northwest of the Gilbert Gully development area

These isolated areas correspond to the projected groundwater level drawdown in the deeper Gubberamunda Sandstone aquifer, and are representative of localised zones where the Rolling Downs aquitard (separating the Cainozoic Units and the underlying Gubberamunda Sandstone) is inferred to be thin or absent.

During associated water production, the radial extent of the groundwater level drawdown within these overlying aquifers is projected to be concentrated within close proximity to the cumulative development area boundaries. Post-production, during the groundwater level recovery phase, the radial extent of the groundwater level drawdown is projected to expand.

Major aquifer units underlying the Walloon Coal Measures

The Hutton Sandstone is projected to experience groundwater level drawdown, particularly in areas where both the coal seam elevations are comparatively deep and the overlying aquitards (i.e. Taroom mudstones and Eurombah Formation) are believed to be thin. Groundwater level drawdowns are generally expected to be less than 10m.

Minimal upwards leakage of groundwater from the Precipice Sandstone aquifer is anticipated due to the presence of the intervening Hutton Sandstone aquifer and confining properties of the Evergreen Formation aquitard. Areas at higher risk of drawdown correspond to those regions with concentrated effects from depressurisation in the overlying Hutton Sandstone and/or thinning of the overlying Evergreen Formation aquitard.

During the associated water production, the radial extent of the groundwater level drawdown within the Hutton Sandstone and Precipice Sandstone aquifers is projected to be concentrated around the development areas. Post-production, during the groundwater level recovery phase, the radial extent of the groundwater level drawdown is projected to broaden beyond the cumulative development area boundaries.

Potential implications for groundwater storage

Associated water production from the project's gas fields (the project case) and all other existing and proposed CSG developments in the Surat Basin (the cumulative case), will change groundwater storage within the Walloon Coal Measures. The initial projections of the numerical groundwater model indicate a level of inter-aquifer leakage may occur as a consequence of the pressure differential created between the coal seams and the overlying and underlying units.

Hence, while associated water production will primarily affect groundwater storage in the Walloon Coal Measures, storage in overlying and underlying aquifers potentially may also be affected through a reduction in hydrostatic pressure as water moves towards the low pressure area created in the Walloon Coal Measures. Notably, groundwater released from these overlying and underlying confined aquifers is almost exclusively from storage (i.e. aquifer compression and water expansion).

Furthermore, the intervening aquitard layers (separating the coal measures from adjacent aquifer formations) will ultimately restrict the potential for significant inter-aquifer leakage and, subsequently, the level to which groundwater storage in these overlying and underlying aquifer units is affected.

Potential implications for groundwater quality

The production of associated water from the Walloons Coal Measures, in both the project case and cumulative case, is not expected to have a detrimental effect on the groundwater quality (including salinity) in the region. The pressure differential created by the associated water production has the potential to move water from overlying and underlying aquifers towards the coal seams through

intervening aquitards. While the poorer quality groundwater in the Walloon Coal Measures is extracted during the CSG process, the effect will be to intercept fresher groundwater from adjacent formations.

Given the quality of groundwater in the non-coal bearing aquifers is broadly similar, any groundwater transfers induced by associated production are unlikely to compromise the regional quality of groundwater aquifers outside of the coal measures.

Potential impacts to existing Water Act bores

Depressurisation from associated water production may potentially affect water levels and water availability in existing bores licenced under the *Water Act (2000)*. These effects extend to other stock and domestic bores, which are authorised under the Act but not licenced.

Initial groundwater modelling of the project case indicates that a number of bores in the BMO Grouping, Gubberamunda Sandstone and Springbok Sandstone aquifers may incur greater than 5m drawdown as a consequence of associated water production from the Project’s gas fields. Those bores extracting water from the Walloon Coal Measures (licenced and stock and domestic), particularly those immediately to the east of the Orana development area and south-east of the Gilbert Gully development area (where the coal measures are at shallow depths), have the greatest potential to be affected. The bores accessing groundwater from the Hutton Sandstone and Precipice Sandstone aquifers are not expected to experience drawdowns greater than 5m as a consequence of associated water production.

With respect to the initial cumulative case model projections, a larger number of water bores may potentially be affected due to the comparatively larger drawdown footprint associated with cumulative development in the region. It is possible that drawdown impacts may affect bores in the Cainozoic Units, particularly in the high usage area between Dalby and Millmerran. The Condamine River Alluvial aquifer beneath this area is currently under heavy use in support of irrigation activities, which has reduced groundwater levels substantially in some of the Cainozoic aquifers. It is anticipated that the drawdown levels associated with CSG activities will not significantly add to the currently already observed drawdown levels in water supply bores accessing the Condamine Alluvium.

Potential impacts to streamflow

According to the initial project case model projections, the potential drawdown effects to the watertable aquifer is expected to be of limited extent, and is projected to occur immediately downstream of the Chinchilla Weir (Figure 10.1). Drawdown of the watertable aquifer could potentially alter groundwater – surface water interaction rates between the Condamine River and underlying aquifers in this localised area. However, operation of the weir itself is likely to override any potential changes to the groundwater–surface water relationship at this location.

Additional localised occurrences of drawdown in the watertable aquifer upstream of the Chinchilla Weir are projected in the initial cumulative case model. Such drawdowns may alter the groundwater – surface water interaction rates between the Condamine River and underlying aquifers in these localised areas. However, on the basis of the limited extent of the projected drawdown such affects are expected to be minimal.

The initial project case and cumulative case numerical model projects a minor effect to shallow groundwater levels in other localised regions across the study area. These localised areas largely occur in proximity to ephemeral streams and creeks which only receive limited baseflow following rainfall events. Shallow groundwater level drawdown in these localised areas is not expected to have a significant effect to the baseflow occurring in these ephemeral systems.

On the basis of the initial project case and cumulative case numerical model projections, there is considered to be a low potential that various river reaches in the study area potentially receiving baseflow from the outcropping aquifer systems of the Great Artesian Basin (as identified by AGE 2005), will be affected.

Potential impacts to mound springs and Groundwater Dependent Ecosystems (GDEs)

During the project case and cumulative case scenarios, drawdown in GAB aquifers is expected to be limited to areas within, or just beyond, the boundaries of the proposed CSG tenements. According to the DERM wetlands mapping database (Figure 10.5) and other sources of publically available information (DNR 2005), no 'discharge' spring complexes are documented to occur in proximity to the CSG tenements. It is noted that a 'recharge' spring complex may be present in the western corner of the Project's Pine Hills development area. As this is a recharge spring, it is not expected to be affected by any groundwater level drawdown that may occur in this area.

For a period of time post-production (during the groundwater level recovery phase), the drawdown cones in the affected GAB aquifers, whilst reducing in magnitude, are projected to broaden beyond the boundaries of the CSG development areas. According to the initial project case and cumulative case projections, there is a low risk that groundwater levels (and potentially the rate of vertical groundwater movement) will be affected (post-CSG operation) in proximity to the high-value discharge spring complexes and their associated groundwater dependant ecosystems east of the Injune township.

Other spring complexes and accompanying GDEs known to exist within the study area are not expected to be at risk.

The initial project case and cumulative case model projections also indicate that groundwater levels within the shallow Cainozoic Units may be affected, in localised areas, by groundwater level drawdown from CSG development. Given the local climatic conditions and drainage characteristics of these areas, surface water runoff and infiltrated rainfall are likely to represent the primary source of water flux required to satisfy ecosystem requirements. As the level of groundwater dependency of ecosystems in these areas is likely to be low, species dependent on groundwater in the shallow watertable aquifers associated with drainage lines are considered to be at very low risk of impact.

Potential implications for gas migration

Gases, including methane, are present in the subsurface in one or more of the following conditions:

- Adsorbed to the matrix material
- Dissolved phase or
- Free phase.

The gas phase is directly related to pressure and temperature conditions in the subsurface and is also influenced by the porewater salinity and the presence of other gases. In the undisturbed coal seams, methane is predominantly in the adsorbed phase. Depressurisation of the coal seams by pumping groundwater and reducing the hydraulic head allows the adsorbed gases in coal seams to desorb and migrate to the CSG production well. Extraction of the gas occurs almost exclusively in the free phase.

The primary driving forces of a free gas are pressure and buoyancy. That is, gas moves from high pressure areas to low pressure areas, and it will tend to rise in the water column due to buoyancy effects. The majority of free and dissolved gas in the zone affected by CSG depressurisation (i.e. the cone of depression) will move towards the production wells. However, at some distance from the edge

of the gas field, where the effects of depressurisation are less, the force of the buoyancy will dominate. The gas released in this area of influence will have the potential to move in an up-dip direction away from the production zone. These gases might eventually make their way to shallower intervals and potentially discharge to the surface, either through wellbores or via natural geological pathways to surface seeps. Gas may also accumulate in overlying aquifers where there is an established pathway between the coal seams and the overlying aquifer.

Investigations conducted in the Raton Basin and the San Juan Basin in the USA have demonstrated that methane occurring in domestic water wells is often natural in origin and not linked to migration from the CSG intervals (Viellenave et al. 2002). The baseline monitoring program conducted in support of this application identified dissolved methane concentrations in waterbores completed in the Gubberamunda Sandstone at concentrations similar to those measured in the CSG wells completed in the Walloon Coal Measures. However, the source of methane in the Gubberamunda Sandstone is unknown.

Gas migration, seepage and venting are natural phenomena where coal beds are close to the surface. All seeps vary in spatial and temporal expression depending on a wide range of natural environmental factors (e.g. barometric pressure; decreased recharge due to drought - Viellenave et al. 2002). Additionally, human-made conduits have been linked to the conveyance of gas to overlying aquifers and surface environments (Chafin 1994). This includes improperly constructed bores or poorly sealed well annuli, or inappropriately abandoned bores. CSG production wells are designed to produce free-phase gas safely to the surface; however, standard water bores generally are not.

The build-up of gas in a non-CSG well bore constitutes a potential health and safety risk. Pumped water bores pose a greater risk as the pressure reduction in the well may result in dissolved phase gas transitioning to the free phase. Significant gas release in operating water bores may also result in pump cavitation and subsequent pump damage or failure (Fisher 2001). Section 10.5 discusses how these impacts will be managed and mitigated. It should be noted that not only water bores accessing the Walloon Coal Measures pose a risk. Bores accessing overlying aquifers with sufficient dissolved gas concentrations do as well.

Although there are approximately 2,100 water bores in the Walloon Coal Measures, they are mostly located where the unit is shallow and distal to the Australia Pacific LNG tenements. The overall risk is predominantly limited to those water bores that are completed within the Walloons within the development areas.

Potential for aquifer compaction and land subsidence

The risk of land subsidence associated with the extraction of water and natural gas from consolidated underground reservoirs such as the Walloons Coal Measures is minimal. While subsidence due to groundwater extraction is known to occur in unconsolidated sediments (and primarily in highly compressible clays), its occurrence in consolidated formations is far less common. Groundwater in the GAB is stored in consolidated, confined, porous sandstone aquifers with limited compressibility.

There is a risk of some subsurface compaction associated with those regions where the coal seams reside at greater depth, and are therefore subject to greater drawdowns during CSG development .

However, all or part of this compaction is unlikely to be expressed at the surface (as land subsidence) as the overlying consolidated and competent rock formations will serve to attenuate any downward movement caused by compaction of the coal seams. Therefore, on the basis of the initial assessment, the potential risk of land subsidence as a consequence of associated water production in the project case and cumulative case is considered low.

10.4.2 CSG associated water management

As part of the associated water management options being considered for the gas fields element of the Australia Pacific LNG Project, the following potential implications for groundwater resources in the study area have been identified:

- Potential for the uncontrolled discharge of associated water from the feed ponds, or waste water from the brine storage ponds and associated pipe work and infrastructure at a magnitude that would cause an impact to shallow groundwater resources
- Potential impacts to shallow groundwater flow and quality conditions from the short-term discharge of treated water to regulated and unregulated watercourses
- Potential impacts to groundwater flow and quality conditions from the injection of blended treated and untreated associated water to aquifers within the Surat Basin
- Potential impacts to groundwater flow and quality conditions from the injection of brine concentrate into isolated geological formations.

Potential for uncontrolled discharge of water from storage ponds and associated pipework and infrastructure

From a hydrogeological perspective, the primary risk associated with the proposed feed and brine storage ponds is the uncontrolled discharge of water or waste water to the environment by way of:

- Vertical seepage or other losses through the base of the storage ponds to the underlying unconfined (watertable) aquifers
- Overtopping of the embankment during, or following, heavy rainfall events and subsequent seepage to underlying unconfined (watertable) aquifers or discharge to surface watercourses.

Any uncontrolled seepage from the feed and brine storage ponds has the potential to affect the quality of shallow groundwater and alter groundwater flow patterns by way of localised mounding of the uppermost groundwater surface. Such risks will be managed through appropriate engineering design, construction, monitoring and maintenance of the feed and brine storage ponds.

In particular, storage ponds will be lined, constructed and maintained to conform to Queensland Government guidelines. Furthermore, monitoring will be conducted at strategic locations around the perimeter of these containment structures to detect any seepage and therefore trigger intervention with the appropriate mitigation measures, if necessary.

Potential implications of short-term treated water discharge to the surface watercourses

Discharging high quality treated water to the Condamine River has the potential to temporarily alter the groundwater – surface water relationship between the river and the subsurface. Any changes to river and aquifer connectivity will be temporary and localised at the site of discharge. The minor and temporary increase in the Condamine River flow rates during such discharge events may marginally reduce the river's baseflow (i.e. groundwater discharge) component or marginally increase leakage through the riverbed at a local scale. In turn, a marginal rise in local groundwater levels adjacent to the river system may temporarily occur. Such changes are not expected to have any significant implications for groundwater quality or flow patterns in the near-surface alluvial aquifers.

Discharging treated water to unregulated ephemeral watercourses will have short-term implications for the local groundwater resource. During a discharge event to an ephemeral stream or creek, the

underlying alluvial deposits will receive a level of recharge. Following cessation of discharge, the recharged groundwater may partially constitute baseflow to the ephemeral stream or creek for a short period. Any affects to the groundwater system, upon discharge to an ephemeral watercourse, are likely to be localised and temporary to the groundwater environment.

Use of treated water for agricultural uses will ultimately be dependent on the demand for the water, with higher demands projected for the drier seasons of autumn and winter. Such use is not expected to cause major detrimental impacts to the shallow groundwater system. In particular, the use of high quality treated water for irrigation purposes, in place of lower quality surface water or groundwater resources, will ultimately contribute to a level of localised dilution of the shallow groundwater resources and a reduction in the potential for soil salinisation. Furthermore, using this readily available and good quality water resource will alleviate the demand placed on heavily utilised surface water and groundwater resources.

Potential implications of associated water injection

The injection of raw or treated production water into selected aquifer systems of the Surat Basin is one beneficial use strategy being considered within the Project's adaptive associated water management plan. This option may provide a solution which, if feasible, would allow CSG production to proceed with minimal operational risks while maintaining a sustainable water balance within the GAB and minimising the project’s ecological and social footprint on the land surface.

To facilitate such an approach, a range of criteria identified with the regulatory agencies (including those concerning injection pressures and source water quality) would need to be adhered to in order to protect the integrity of the natural groundwater system and accompanying receptors.

An aquifer injection feasibility assessment has commenced and, if deemed feasible, is likely to be followed by an initial field investigation and pilot injection trials to test deliverability and chemical compatibility of the injected water and receiving aquifer(s). The outcomes of feasibility studies and any pilot trials will enable an assessment of the viability and potential effects of this management strategy.

Potential implications of brine concentrate injection

A waste brine is generated during the treatment of associated water by reverse osmosis. Australia Pacific LNG is considering the strategy of injecting brine concentrate into suitably isolated and deep geological formations.

Preferred locations identified in the pre-feasibility phase would aim to fulfil the following criteria to minimise potential environmental risks and impacts:

- A geological horizon that is suitably isolated from potential oil and gas reservoirs and groundwater development activities
- A hydrogeological horizon with no agricultural, economic or cultural value
- Lithology that has sufficient capacity to accommodate the required disposal rates of brine concentrate
- An interval that demonstrates geologic containment.

Any brine injection system will require a comprehensive study (potentially including exploratory drilling and pilot injection trials) to evaluate the efficiencies and operational risks of a prospective system. This will include an assessment of potential environmental impacts in accordance with the proposed injection management plan.

10.4.3 CSG infrastructure activities

Potential impacts to groundwater resources which could arise from the construction and operation of CSG infrastructure include:

- The loss of recharge due to surface alterations
- Water quality impacts as a consequence of operational leaks or spills
- Inter-aquifer leakage or water level changes due to poorly constructed wellbores
- Localised water level drawdown due to groundwater extractions for construction and operational activities.

Groundwater recharge has the potential to decline if the permeability of large areas of ground surface is affected by way of compaction or creation of hardstand surfaces. Relative to the overall scale of the gas fields, the area of land that will be affected is small, and in most cases, rainfall runoff will be re-directed to surrounding drains. Therefore, any reduction in recharge to the shallow aquifers is expected to be negligible.

Pipeline leaks, sewage system leaks, storage pond leaks and chemical (including fuel) spills have the potential to impact on groundwater quality at a local scale. Lined ponds will be designed and constructed to prevent leakage, pipelines will be pressure tested (hydrostatic testing) prior to commissioning, and operational areas will be properly bunded.

It is considered a low risk that leakage from pipelines and ponds will impact on shallow groundwater at a magnitude that would cause significant harm. Operational items such as refuelling, chemical storage and waste transfer (including septic tank) will be managed through the Project's environmental management plans.

A schematic diagram of the current Australia Pacific LNG CSG production well design is provided in Figure 10.4, while a detailed description of the well construction staging is provided in Volume 5 Attachment 21. As this figure demonstrates, the design affords an effective seal to all overlying aquifers through the use of pressure cemented (i.e. from the bottom up) seals around the casing, particularly to the upper units which are double-cased.

Australia Pacific LNG's CSG production well design exceeds the Minimum Construction Requirements for Waterbores in Australia (Land and Water Biodiversity Committee (LWBC) 2003) and the Minimum standards for the construction and reconditioning of water bores that intersect the sediments of artesian basins in Queensland (NRM 2004). Only water-based drilling fluids are used in the drilling process, reducing the potential for groundwater quality impacts.

In areas where the aquitard overlying the coal is thin or non-existent, a portion of the upper coal measures may be sacrificed during well construction where practicable, thus minimising the potential for drawdown effects to overlying aquifers. The benefits of this practice, related to reduced drawdown, have not been incorporated in the modelling and model results presented in this section.

Given these construction and mitigation measures, the CSG production approach being proposed by Australia Pacific LNG is unlikely to result in groundwater drawdown effects or water quality issues to local water bores through the CSG production wells themselves. As a result, the potential adverse effects to groundwater from CSG well construction are likely to be minimal.

It is likely that groundwater will be used for construction activities in some locations. These activities will be of relatively short duration and only needed prior to the availability of associated water (either

treated or untreated depending on water quality). Over the life of the Project, the primary source of water will be produced water treated to a level appropriate for the intended use.

In the latter stages of development and during operation, Australia Pacific LNG intends to be largely self-sufficient for water use. Any associated impacts will therefore be localised in extent. Water bores that are drilled for the supply of construction water have been, and will be, designed and installed in accordance with the construction standards identified previously. Drilling and installation of such wells will be supervised by an appropriately licenced water bore driller.

10.5 Monitoring, management and mitigation

Although monitoring will not reduce the potential impacts associated with the Project, the information acquired from the monitoring program will be used to inform management decisions to limit potential impacts. Australia Pacific LNG is committed to implementing a performance monitoring and management system to measure operational groundwater levels and groundwater quality during CSG development and operation.

Monitoring will be conducted through the development and implementation of a program meeting objectives agreed to with DERM, and consistent with the sustainability principles of adaptive management. Adaptive management, also known as adaptive resource management, is a structured, iterative process of optimal decision-making with a focus on reducing uncertainty through improved knowledge. In this way, decision-making simultaneously maximises one or more resource objectives and gathers information needed to improve future management (Holling 1978). Therefore, by using adaptive management, as new groundwater quality and quantity information is generated, models and understanding can be updated and water management approaches and decisions adapted accordingly.

The adaptive management and performance assessment approach is illustrated in Figure 10.17. This forms the basis for the groundwater monitoring, management and mitigation strategy for the Project. Notably, the performance assessment system connects the regional groundwater outcomes with indicators and management actions, consistent with Queensland government commitments (Department of Employment, Economic Development and Innovation 2009). Australia Pacific LNG will develop its own monitoring program and collaborate with the Government to develop a regional monitoring program as follows:

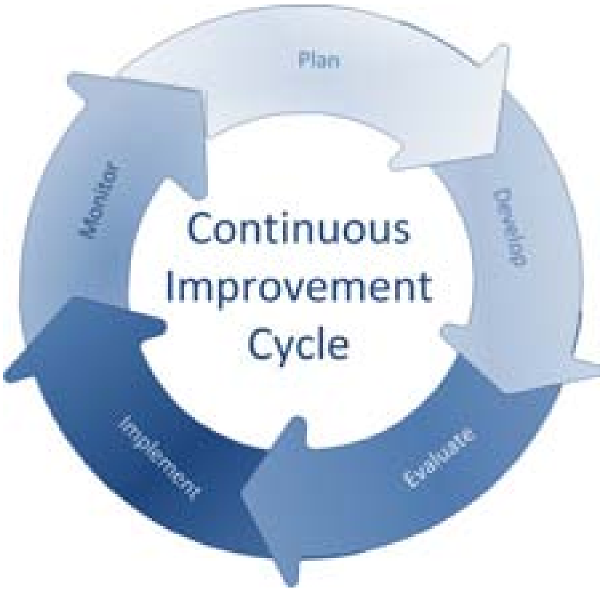
1. Continuously increase understanding

- Ongoing collection of hydrogeological data to continuously improve understanding of the regional groundwater system
- Building a comprehensive database of groundwater-related information
- Engaging and collaborating with stakeholders on associated water production effects, management strategies, monitoring and community expectations

2. Sustainable management approach

- Adopting holistic water management techniques, considering environmental, social, safety and financial consequences throughout and beyond the life of the Project
- Implementing design and management controls to minimise the potential for impacts to occur
- Investigating the feasibility of injection of associated water
- Operating responsibly to manage the water resources under Australia Pacific LNG's control

- Consulting with community stakeholders, government authorities and shareholders and considering external views in decision making



3. **Monitoring and performance evaluation**
   - Establishing an adaptive groundwater monitoring framework promoting active response to regulatory change and stakeholder engagement
   - Adopting adaptive and continuous improvement management practices to plan, develop, evaluate, implement and monitor potential impacts associated with associated water withdrawal
   - Managing operations to respond in a positive manner to negative monitoring data through appropriate design and mitigation measures.

Figure 10.17 Adaptive management and continuous improvement process

A comprehensive discussion of the groundwater monitoring, management and mitigation strategy proposed by Australia Pacific LNG is provided in Volume 5 Attachment 21.

10.5.1 Monitoring

Objectives

If groundwater quality impacts occur around infrastructure during construction or operations, these impacts will be localised and detectable by established monitoring systems. Additionally, the relatively slow groundwater flow rates (5m per year or less) and attenuation capacity of the natural groundwater system will allow sufficient time for appropriate action to be taken, where needed. The objectives of the local-scale monitoring around project infrastructure (local monitoring) are:

- An appropriately located and designed monitoring network to address spatial and temporal needs
- Development of a high-quality dataset of background conditions against which potential impacts can be assessed
- Timely identification and mitigation of potential impacts from local-scale activities
- Application of a flexible and adaptive approach to ongoing monitoring and management of water resources to minimise impacts in accordance with the project's sustainability principles.

In contrast, possible groundwater impacts from associated water production require more of a regional-scale approach. The objectives of the regional groundwater monitoring program (regional monitoring) are to:

- Provide good regional coverage and establish baseline groundwater conditions
- Gain further understanding of aquifer interactions and how the groundwater system is connected to surface environments

- Verify and refine understanding of the regional hydrogeology
- Gain a better understanding of natural variability in the regional aquifers
- Provide information to better understand natural groundwater recharge and discharge in the region
- Identify long-term water level trends and potential cumulative effects from current and future CSG development
- Detect any potential groundwater quality effects from CSG development
- Identify higher risk areas that may require monitoring or additional monitoring
- Provide information to differentiate effects between operating gas fields and other sources of groundwater variability
- Generate data against which projections made through groundwater modelling can be verified
- Gather high quality data to develop target and threshold values for key indicator parameters within each major aquifer in the development areas (using an adaptive management process)
- Liaise with, and where possible, involve the community in the groundwater monitoring program
- Interpret and communicate the results of the monitoring efforts to stakeholders.

Locations and timing

Initial groundwater modelling was completed to identify areas with the highest potential risk from CSG development, taking into account the intrinsic vulnerability of the aquifer under assessment as well as nearby receptors. Figure 10.18 shows the locations of an indicative monitoring network. It is noted that the number of proposed locations and their actual locations may change after further refinement of the model.

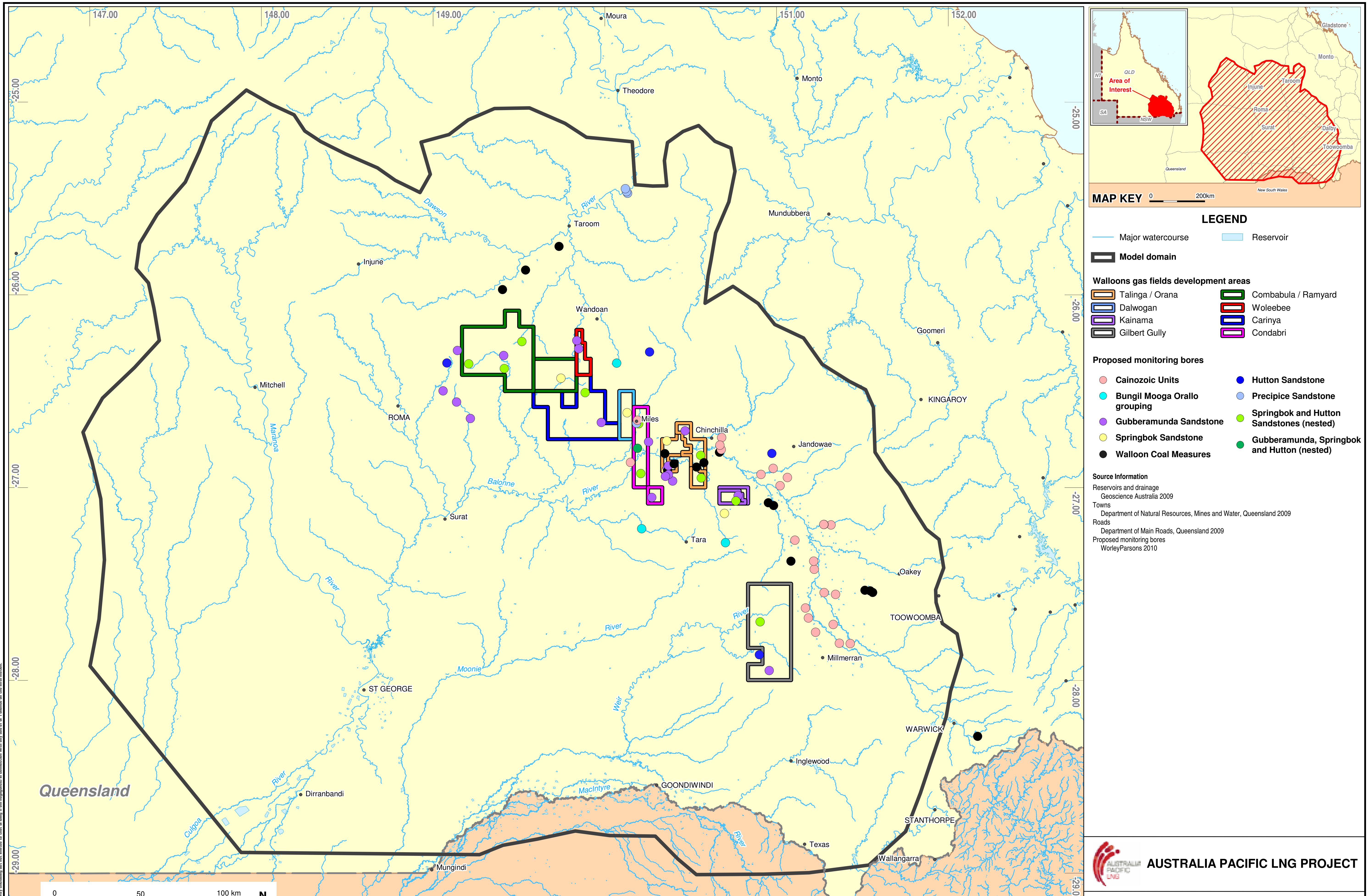


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Figure 10.18 Indicative monitoring locations

Proposed groundwater monitoring initially focuses on the Springbok and Hutton Sandstone aquifers, as these units are the ones with the greatest potential to be affected by earliest depressurisation in the Walloon Coal Measures. It is recognised that this may be reviewed following interpretation of monitoring and future modelling results.

The intention, as part of the adaptive management process described above, is that if significant effects associated with CSG development are observed, that overlying or underlying aquifers would then be monitored or existing monitoring would be intensified. Some baseline monitoring of the shallower intervals has been conducted to date, and further baseline assessment is intended for the Springbok, Hutton, Gubberamunda Sandstones and BMO Group as necessary. As existing bores in the Precipice Sandstone are identified, these too may be included in the initial regional network (if deemed appropriate).

It is further noted that monitoring may be implemented concentrically outward from the gas fields. That is, if a significant effect is observed in close proximity to the gas fields, then monitoring locations at some distance (either horizontally in the same aquifer, or vertically in a different aquifer) may be incorporated into the network, hence the actual number of monitoring bores may be different from the number identified in Figure 10.18. It should also be noted that the monitoring locations incorporate indicative regional monitoring locations which will be developed in collaboration with other CSG proponents and government, in accordance with the Government's Blueprint for the LNG Industry. Indicative monitoring locations include existing and new bores.

Where possible, existing bores will be used and any new monitoring bores will be drilled and constructed on existing drill pads (where practicable) to minimise impacts associated with land disturbance and drilling activities. The added benefit of co-location with production infrastructure is the potential for connection to production monitoring systems, allowing real-time automatic data downloads of water level information through existing production monitoring systems. Monitoring will be brought on-line in advance of development (where practicable) to allow the establishment of baseline conditions. Timing and locations of proposed monitoring in a particular development area will also take into account Australia Pacific LNG's current development schedule as well as developments proposed by other operators.

With reference to local monitoring, this will be conducted in the immediate vicinity of infrastructure activities, with actual locations identified upon finalisation of their design. Identifying specific locations for local monitoring locations will take into account site-specific hydrogeology, particularly an understanding of anticipated groundwater flow directions, preferential pathways for groundwater movement and potential receptors of impacts (essentially a risk-based approach). The existence of local wellbore infrastructure, which could potentially provide longer term background data, will also be assessed for possible incorporation into the monitoring network. Monitoring bores will be installed prior to, or approximately with, construction activities to facilitate baseline monitoring prior to commissioning of CSG production activities.

Indicators

Indicators are used to measure the cause and effect relationship between human activities on the environment and the environmental response to those activities.

The primary indicator for groundwater quantity will be any change to a groundwater level in a defined aquifer at an established monitoring location. Secondary indicators will be variations in groundwater flow to rivers or springs (as assessed by water level changes or modelled results). Dedicated monitoring bores will be instrumented with permanent automated water level/pressure monitoring

devices, which will record water levels at agreed intervals. Data from the loggers will be downloaded on a regular basis and uploaded into a central database. Manual water level measurements will be collected at the time of download to confirm the quality of the data.

Water quality indicators will be selected based on the natural hydrochemical conditions of the aquifer and potential chemical compounds associated with CSG development. The groundwater will initially be sampled and analysed to provide a baseline condition. Water quality sampling will be conducted using methods appropriate for the analytes being monitored and the bores being sampled. Sampling methodologies will be in accordance with established protocols including the Water Quality Sampling Manual (Environmental Protection Agency 1999).

Data analysis and monitoring bore trigger development

Once sufficient data is collected, targets will be developed based on statistical analysis which considers natural variability and trend identification. Statistical control charting can be utilised for each selected indicator parameter measured at a given monitoring well. This method honours natural data variability and allows tracking of any changes to quality and quantity conditions. Control charting is commonly used to determine whether or not an observed value, within a given set of data, is significantly different from historical values (Gibbons 1994). The overall goal of control charting and trend analysis is to detect situations that may be heading in a direction and at a rate that is unacceptable. An upper control limit (UCL) is calculated for each parameter measured at a well where a large number of data points exist. Similarly, a lower control limit (LCL) is calculated to determine the lower bounds on the temporal data set. A data point that exceeds either control limit is an indication that something may be occurring outside the range of natural variability or understanding.

An example of the style of proposed data charting and comparison to established control limits is provided as Figure 10.19. In this figure, the action level and initiation of a follow-up response is indicated at the point where a measurement falls outside the natural range of variability and/or past an established trigger value. The approach uses a green, yellow and red condition to establish the level of action required. Thus, changing from a green condition to yellow condition is defined as exceeding an established trigger level indicating the need for further investigation. Subsequently, if conditions move from yellow to red, more stringent controls and/or mitigation may be necessary.

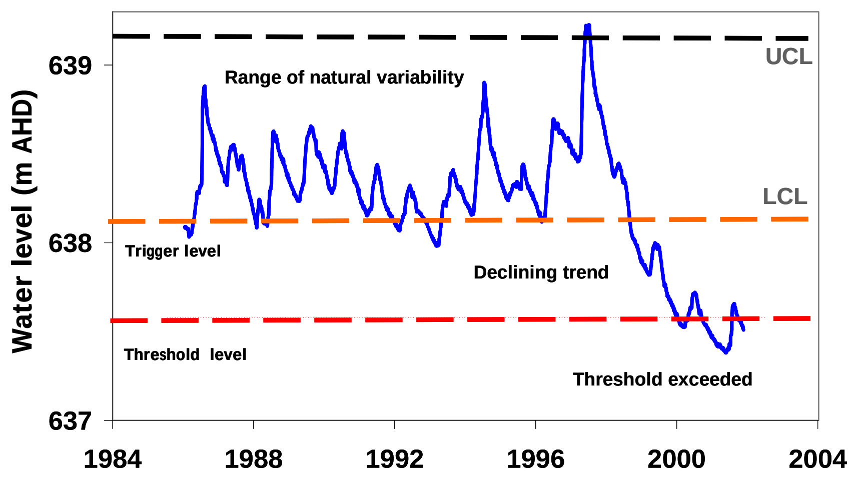

Figure 10.19 An example of statistical charting for followup response

Reporting monitoring results

All monitoring results will be verified and entered into a single database. There will be ongoing review of the data, and reporting to the appropriate regulator will be completed on an annual basis. At a minimum, these reviews will provide comment on:

- Changes to the proposed monitoring network from the previous report (e.g. new monitoring bores brought online)
- Most recent and historical monitoring results, trends, and any changes in trends compared to interim or adopted triggers and thresholds
- Comparisons between monitoring results and model projections
- Histories and management of complaints lodged by private water bore owners
- The proposed response plan for investigation of events or conditions outside the established control conditions.

The monitoring report will be submitted to the approving agency in accordance with the requirements of the PAG Act. Australia Pacific LNG will work with government to develop a publically-accessible database which will contain easily interpreted groundwater level and quality monitoring data.

Investigation and response process

Monitoring data collected during routine field programs will be reviewed against established targets. A response process will be implemented where monitoring data:

- Deviates from established baseline conditions or range of natural variability
- Levels exceed statistical control limits or
- A significant trend is identified.

Where an indicator is detected outside established targets, Australia Pacific LNG will initiate a phased investigative response incorporating:

- Verification
- Evaluation
- Management and/or mitigation.

This assessment will be reviewed and reported as required to the regulating agencies.

10.5.2 Mitigation and management

Most of the potential groundwater-related impacts associated with the Australia Pacific LNG project will be managed or mitigated through appropriate well design, construction and management practices. However, some residual risk remains and mitigation measures are proposed to address these risks.

Minimising drawdown effects through appropriate production well construction

Drawdown effects to overlying and underlying aquifers are strongly controlled by the thickness and permeability of the intervening aquitard layers between the coal measures and the Springbok Sandstone and Hutton Sandstone. The Springbok Sandstone unconformably overlies the Walloon

Coal Measures, and in places erosion of the upper Walloon Coal Measures has resulted in the Springbok being in direct connection with the coal seams. Thinner accumulations of aquitard material, or lack of it, will lead to greater drawdown effects.

Some of the effects can be mitigated by effectively increasing the distance, and aquitard thickness, between the uppermost coal seam and the Springbok Sandstone. This can be achieved by sacrificing the uppermost coals (where practicable) by sealing them off from the productive part of the CSG well.

Australia Pacific LNG employs this design in the majority of production wells where connection is identified. This control measure will continue to be employed (where practicable) where the aquitards are thin or non-existent.

Mitigating impacts to existing water bores

Trigger thresholds are yet to be developed in accordance with the PAG Act for the aquifers in the Surat Basin. However, preliminary triggers are being discussed with DERM.

As there is little existing precedence with regards to a blanket rule for assessing impacts, Australia Pacific LNG will continue to consult with government to develop appropriate trigger thresholds. The use of trigger thresholds applies to water level changes in groundwater extraction bores only and are not applicable to monitoring bores where a trend analysis approach is proposed.

Exceedance of the ultimately-adopted investigation trigger will initiate follow-up investigation into the cause of the drawdown to gain a full understanding of Australia Pacific LNG's contribution. This will be achieved through monitoring and assessment of the data in relation to natural variability of conditions and groundwater extraction rates and volumes of the bore in question. In the event that a downward trend in water levels is detected outside the range of natural variability, and the downward trend continues, management measures will be implemented to reverse or stabilise the trend, and/or the loss of water supply would be mitigated by the 'make good' provision.

If the result of the investigation confirms that declining water levels are the result of Australia Pacific LNG's activities, and if the make good provision is required, Australia Pacific LNG will make good the water supply to the impacted water bore in compliance with the PAG Act. Where appropriate, such actions may include:

- Lowering of the owner's pump to increase the available drawdown
- Deepening the bore within the same aquifer, if the current construction allows
- Installing a replacement bore at a location less affected by the CSG operations or into a different aquifer
- Injection of treated water (of similar quality to the native groundwater)
- Monetary compensation for the increased cost of pumping, or for the effects of impaired capacity
- Provision of an alternative water source.

It is noted that with respect to these actions to 'make good' the water supply in an impacted bore, a CSG industry-wide response may be required. In this regard, Australia Pacific LNG is committed to collaborating with the Queensland Government and other CSG operators and stakeholders in the region to develop an approach to regional-scale groundwater monitoring and cumulative effects assessment (using groundwater modelling), along with an agreed process to assessing and apportioning the 'make good' responsibility.

Mitigating risks associated with gas migration

Australia Pacific LNG production wells will be constructed in accordance with industry standards, with the goal of maintaining hydraulic isolation between discrete water-bearing formations, and will therefore inherently mitigate the risk of gas migration into overlying aquifers and/or releases at surface. In addition, the integrity of the wellhead and casing will be monitored as part of normal operations.

A good understanding of natural and existing occurrences of dissolved and free phase gas, prior to the onset of CSG development, is important for future management of potential issues. Although risks associated with gas migration are considered low, further assessment will be carried out.

Future activities

Data obtained from regional monitoring efforts will be compared to model projections as part of a verification process. Significant deviation from measured versus simulated drawdown values will provoke further investigation using information and data acquired during the period. Consideration will be given to refining the monitoring network if significant gaps are noted.

A large volume of data has been utilised in this study, and it is anticipated that a much larger dataset will be accumulated as a result of collaboration with government on monitoring. Australia Pacific LNG will work with the Queensland Government to develop a publically-accessible database which will contain easily interpreted groundwater level and quality monitoring data.

10.6 Conclusions

10.6.1 Assessment outcomes

On the basis of the studies conducted to date, the outcomes of the groundwater assessment are summarised in Table 10.3. The table lists the environmental values within the study area and the sustainability principles inherent to this project as they relate to the groundwater environment. Accompanying the identification of potential impacts, appropriate management and mitigation strategies are described. In addition to the management and mitigation measures described in Table 10.3, the implementation of a comprehensive groundwater monitoring program has commenced. The purpose of the monitoring program is primarily to monitor changes in groundwater levels which may result from CSG development activities. If an observed water level change is confirmed to be due to Australia Pacific LNG’s project's activities, any required management and mitigation measures will be implemented to address the potential impact.

A residual risk level following the proposed treatment (management or mitigation) approach for the potential impacts has also been provided in the table.

Table 10.3 Summary of environmental values, sustainability principles, potential impacts and mitigation measures

Environmental values	Sustainability principles	Potential impacts	Possible causes	Potential mitigation measures	Residual risk level [1]
Biological integrity of an unmodified, highly-valued or modified aquatic ecosystem Suitability for primary, secondary and visual recreational use Suitability for minimal treatment before supply of drinking water Suitability for agriculture use Suitability for aquaculture use Suitability for industrial use Cultural and spiritual values of the water Suitability for producing aquatic food for human consumption	Minimising adverse environmental impacts and enhancing environmental benefits associated with Australia Pacific LNG's activities, products or services; conserving, protecting, and enhancing where the opportunity exists, the biodiversity values and water resources in its operational areas Identifying, assessing, managing, monitoring and reviewing risks to Australia Pacific LNG's workforce, its property, the environment and the communities affected by its activities Working cooperatively with communities, governments and other	**Activity: CSG and associated water production**			
		Loss or reduction of groundwater supply to bore owners.	Associated water production in coal seams potentially resulting in drawdown effects in landholder bores.	Employ CSG production well construction that minimises impact to overlying and underlying units. Comply with PAG Act 'make good' provisions. Injection (if proven feasible) of water to selected aquifers to reverse potential negative effects to groundwater storage.	Medium (Low after 'make good')
		Reduction of baseflow and/or increase in stream losses and implications for river ecology, particularly during low flow.	Associated water production from coal seams and risk of depressurising near-surface aquifers and confined aquifers adjacent to surface water systems.	Early intervention (if required) to mitigate localised impacts.	Low
		Reduction of flows to springs and Groundwater Dependent Ecosystems to an extent that the integrity, health and habitat of these ecosystems is affected.	Associated water production from the coal seams and potential to depressurise confined aquifers providing flows to springs and accompanying Groundwater Dependent Ecosystems.	Early intervention (if required) to mitigate localised impacts	Low

Environmental values	Sustainability principles	Potential impacts	Possible causes	Potential mitigation measures	Residual risk level [1]
	stakeholders to achieve positive social and environmental outcomes, seeking partnership approaches where appropriate.	Regional scale groundwater-induced salinity and implications for the beneficial use of the groundwater resources.	Associated water production of the coal seams and potential to induce groundwater laterally or from overlying/underling of aquifers of poorer salinity.	Australia Pacific LNG CSG production well design minimises potential for inter-aquifer leakage and pressure transmittal through pressure cementing of annuli and sacrificing of higher risk coal seams.	Low
		Gas migration to overlying aquifers and/or ground surface and potential for health and safety risks.	Potential migration of gas away from the CSG fields, via wellbores and through geological pathways.	Further identification of existing water bores at risk of gas migration. Plug and abandonment of inappropriately constructed wellbores where practicable. Installation of hydraulic barriers (e.g. extraction wells).	Low
		Artificial connection between aquifers via CSG wells resulting in increased drawdown and water quality changes.	Potential transmittal of pressure reduction directly from the Walloon Coal Measures to overlying and/or underlying aquifers due to improperly constructed CSG wells.	Australia Pacific LNG CSG production well design minimises potential for inter-aquifer leakage and pressure transmittal through pressure cementing of annuli and sacrificing of higher risk coal seams.	Low
		Artificial connection between aquifers via old wells resulting in increased drawdown and water quality changes.	Potential for improper well construction (or abandonment) or casing failure possibly resulting in connection between discrete aquifer units.	Further investigation to be undertaken to identify potential pathways.	Low

Environmental values	Sustainability principles	Potential impacts	Possible causes	Potential mitigation measures	Residual risk level [1]
		Aquifer compaction and differential land subsidence.	Production of associated water from coal seams	Not currently required	Low
		Activity: Associated CSG water management practices			
		Significant harm due to uncontrolled discharge of water to shallow groundwater.	Vertical seepage of water and/or wastewater through the base of the containment ponds to underlying aquifers and/or overtopping of the embankment and subsequent seepage to underlying aquifers.	Appropriate engineering design, construction and operation of the storage ponds.	Low
		Disturbance of the groundwater – surface water connectivity relationship.	Short-term transfer of treated water to surface water courses .	No controls required.	Low
		Adverse pressure and water quality changes.	Injection of treated or blended associated water or brine and potential to affect the receiving hydrogeological regime.	Injection management plan.	Low

Environmental values	Sustainability principles	Potential impacts	Possible causes	Potential mitigation measures	Residual risk level [1]
		Activity: Construction and operation of CSG infrastructure and the installation and extraction from water supply bores in non-CSG production aquifers			
		Shallow and localised groundwater quality impacts.	Potential for leakage of pipeline infrastructure and other gas and water transfer infrastructure due to poor design, installation, operation and/or maintenance practices.	Appropriate site selection. Appropriate infrastructure design and integrity management. Infrastructure integrity monitoring.	Low
			Potential for chemical spillage or wastes due to inappropriate handling, storage, or disposal of chemicals, fuels and/or associated waste materials.	Suitable guidance in environmental management plans for waste and chemical management will be implemented.	Low
		Localised groundwater level drawdown.	Groundwater extraction for exploration, construction and operations.	Comply with PAG Act 'make good' provisions.	Low

10.6.2 Commitments

Australia Pacific LNG makes the following ongoing commitments as part of its groundwater mitigation and management strategy:

- Continue to assess impacts from associated water extractions over the life of the Project
- Collaborate with the Queensland Government in support of its Blueprint for Queensland's LNG Industry (2009), and other CSG operators in the region, to develop an agreed approach to regional groundwater monitoring and cumulative effects assessment
- Work with government to develop a publically-accessible database which will contain easily interpreted groundwater level and quality monitoring data
- Manage and implement appropriate (early intervention) strategies to minimise adverse impacts as a consequence of proposed CSG activities
- Comply with the 'make good' provisions where required under the *Petroleum and Gas (Production and Safety) Act 2004* and consult with stakeholders on strategies to 'make good'
- Involve community groups in the implementation of the ongoing groundwater monitoring program
- As part of the ongoing groundwater monitoring program, conduct further evaluations of the potential for gas migration during CSG production and, where necessary, develop appropriate monitoring and control measures to mitigate any residual risks
- Employ CSG well and infrastructure designs and construction methods, in accordance with relevant legislation and standards agreed in consultation with government, which minimise the potential for impacts to the local and regional groundwater regime
- Actively investigate alternative water management strategies including aquifer injection
- Participate in studies into the long-term sustainable water supply options for the region and support programs for water conservation within the region.

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