10 GROUNDWATER

Chapter 10 provides a summary of findings from a detailed groundwater assessment study conducted for the Gas Field Component of the Queensland Curtis LNG (QCLNG) Project. The full report is provided in *Appendix 3.4*.

10.1 LOCATION

The Gas Field Component of the QCLNG Project lies in the Surat Basin within the eastern-most portions of the Great Artesian Basin (GAB) (refer *Figure 3.10.1*), one of the largest artesian groundwater basins in the world (NRW, 2005). It is also located primarily within the Condamine Balonne Water Management Area (surface water) and in or adjacent to the groundwater management areas of the Surat East, Eastern Downs, Surat North and Surat.

10.2 PROJECT ENVIRONMENTAL OBJECTIVES

The Project environmental objectives for groundwater resources are to:

- protect, as much as practicable, groundwater from contamination so as to preserve ecological health, public amenity and safety
- not extract groundwater resources to the detriment of other groundwater users and biodiversity dependent on groundwater supplies.

10.3 METHODOLOGY

The groundwater assessment study involved desktop studies, field investigations and modelling of potential groundwater impacts.

10.3.1 Desktop Studies

Desktop studies involved obtaining and interpreting available data from relevant sources. These data sources included QGC, Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) who have prepared previous studies for QGC, the former Environmental Protection Agency (EPA) (now the Department of Environment and Resource Management (DERM)) and the Water Entitlements Registration Database (WERD).

The data collected included information such as stratigraphy, bore casing, water levels and water quality in relation to both DERM and QGC's bores, outlined in *Figure 3.10.2*. The collated data was then used to prepare a model for assessing the potential impacts of Gas Field activities on groundwater resources.

10.3.2 Field Investigations

Field investigations were carried out to provide site-specific information on features which may directly or indirectly be impacted by the proposed operations. This part of the studies was aimed at determining aspects of the proposed works which would impact the environment and other groundwater users.

10.3.3 Modelling

A detailed conceptual groundwater model and an idealised numerical groundwater model of the region have been developed to estimate the magnitude of likely impacts on the environment and other groundwater users. The groundwater modelling domain is illustrated in *Figure 3.10.3*. The purpose of the modelling is to provide a visualisation of the groundwater flow and hydrogeological system.

Three main gas reserve development areas were nominated for the model:

- the Central Development Area (CDA)
- the South-East Development Area (SEDA)
- the North-West Development Area (NWDA).

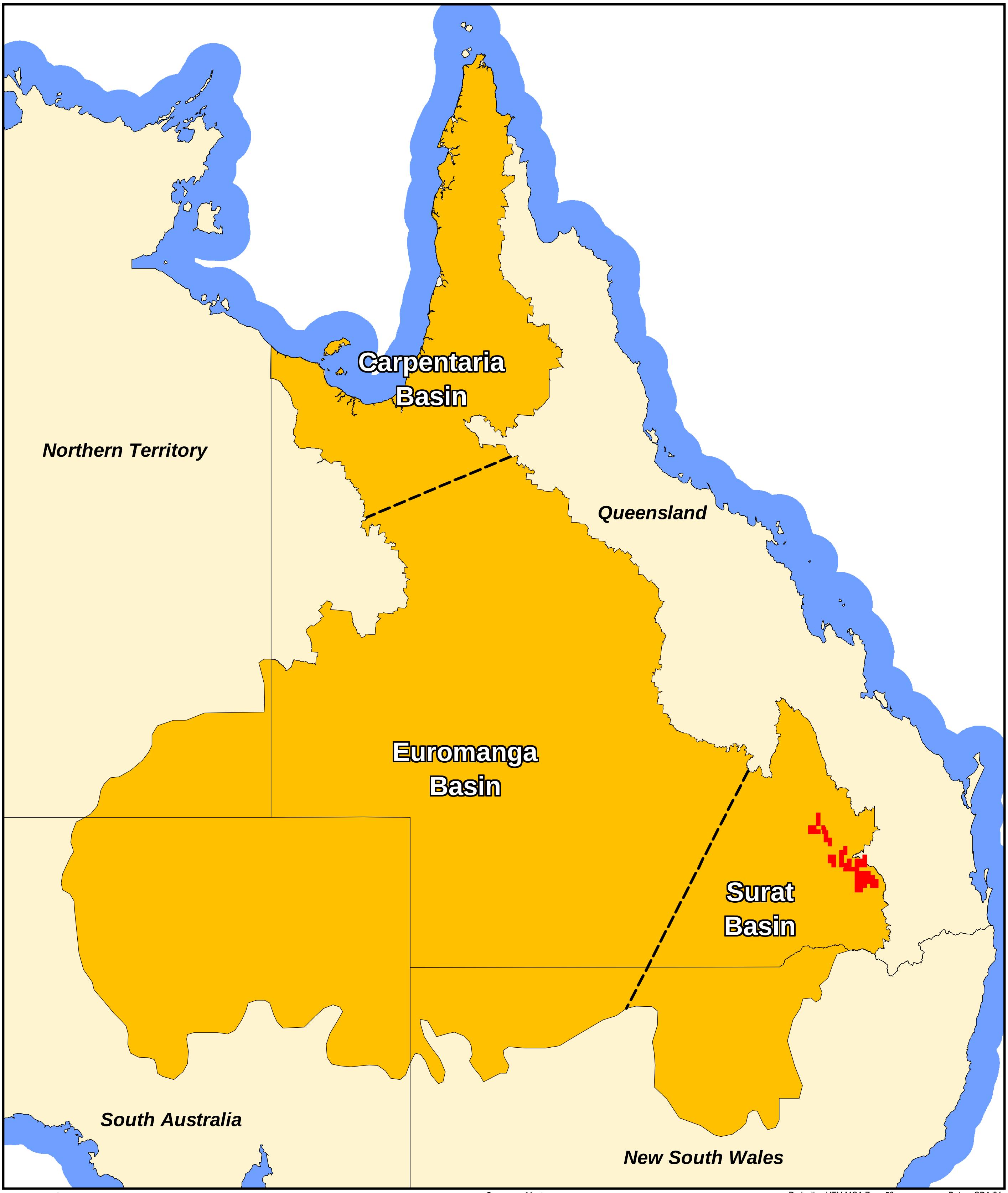
Based on the desktop studies, the geological formations underlying the Gas Field were grouped into six major hydrogeological units (refer *Section 10.4.4*). This was done to enable a model to be developed that would provide an uncomplicated and easily understood visual overview of the system that operates in the Gas Field area. The modelling is discussed in detail in *Appendix 3.4*.

The modelling was carried out on an idealised rectangular shaped production well field layout; conceptualised to represent an irregularly distributed array of tenements. This layout only approximates the actual situation in the field and does not take into account the existence of other (adjacent) coal seam gas (CSG) producers bordering on, or in close proximity to, the Gas Field.

10.4 EXISTING ENVIRONMENT

10.4.1 Environmental Values

The Queensland *Environment Protection Act 1994* (Qld) *(EP Act)* and *Environmental Protection (Water) Policy 1997* (Qld) *(EPP Water)*, are the principal state legislative controls concerning the water environment. Primarily aimed at surface water, *EPP Water* sets out environmental values that are required to be enhanced or protected.



Legend:

- Gas Fields - Authority to Prospect/ Petroleum Lease (application)
- Great Artesian Basin
- Artesian Sub-Basin

Source Note:
1:250,000 Topographic vector copyright Geoscience Australia
Artesian Basin data sourced from Natural Resources and Water

Projection UTM MGA Zone 56 Datum GDA 94

0 200 300 400
Kilometres

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QUEENSLAND CURTIS LNG
A BG Group business

Project	Queensland Curtis LNG Project	Title: **Great Artesian Basin and Sub Basins**
Client	QGC - A BG Group business	
Drawn: Mipela	Volume: 3 / Figure: 3.10.1	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.
Approved: CDP	File No: QC02-T-MA-00116	
Date: 10.06.09	Revision: A	

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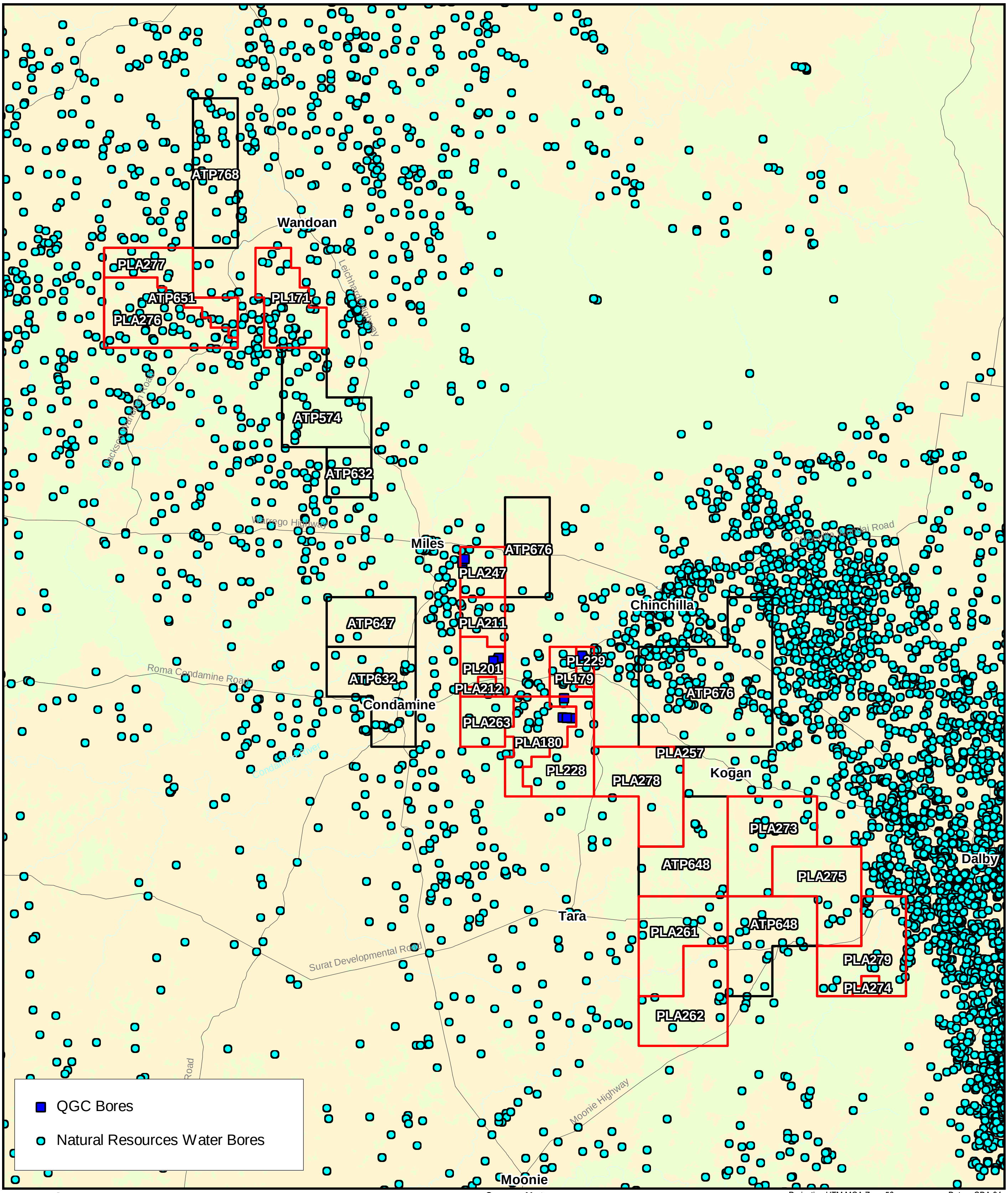

Legend:

Gas Fields - Petroleum Lease/Petroleum Lease Application

Gas Fields - Authority to Prospect

Source Note:

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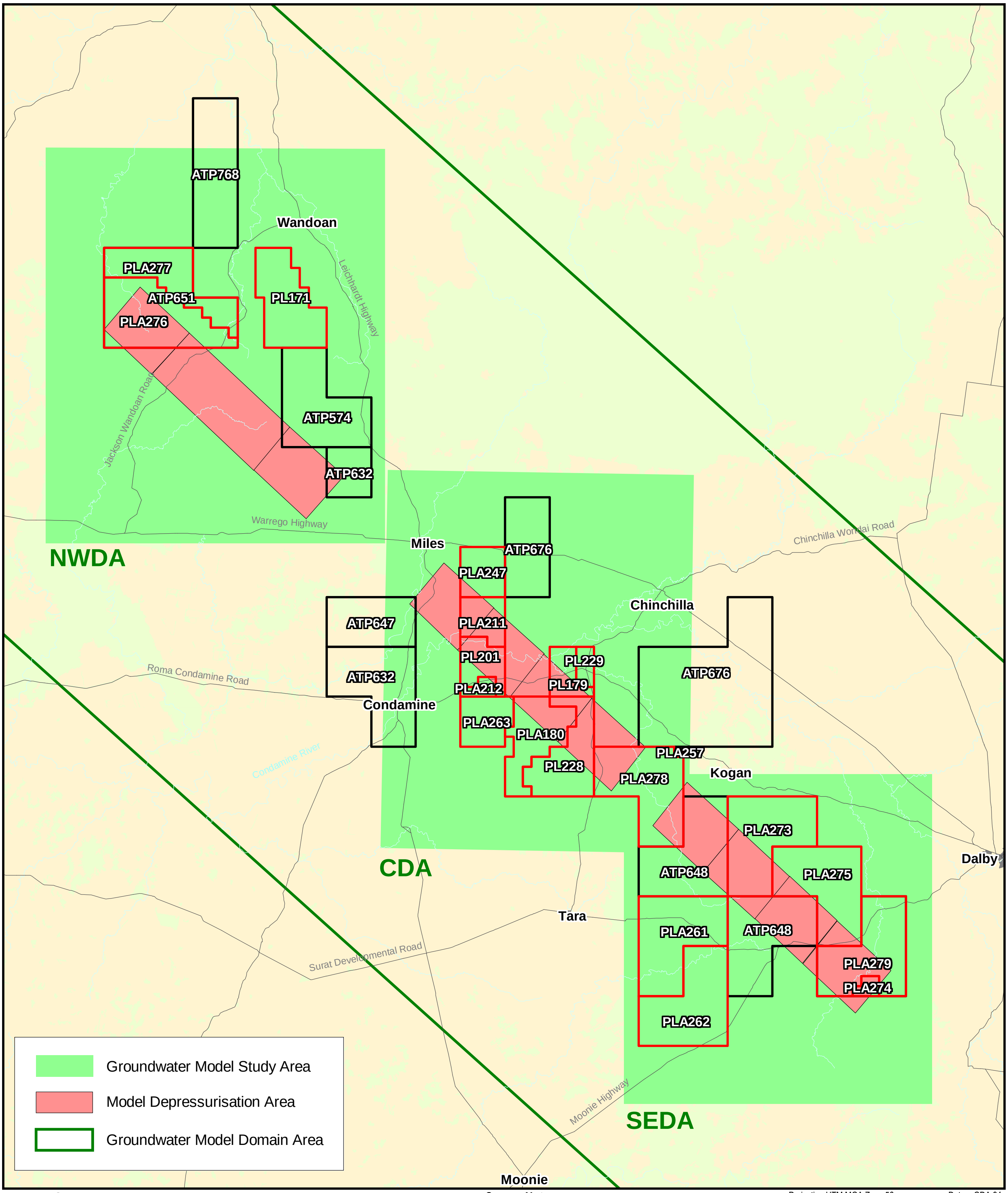
QUEENSLAND CURTIS LNG A BG Group business	Project **Queensland Curtis LNG Project**		Title **Groundwater Bores**
	Client **QGC - A BG Group business**		
ERM Environmental Resources Management Australia Pty Ltd	Drawn DB	**Volume** 3 **Figure** 3.10.2	Disclaimer: Maps and Figures contained in this Report may be based on Third Party Data, may not be to scale and are intended as Guides only. ERM does not warrant the accuracy of any such Maps and Figures.
	Approved CDiP	File No: QC02-T-MA-00117	
	Date 27.03.09	Revision A	



Legend:

Gas Fields - Petroleum Lease/Petroleum Lease Application

Gas Fields - Authority to Prospect

Source Note:
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Project	**Queensland Curtis LNG Project**		
Client	**QGC - A BG Group business**		
Drawn DB	**Volume** 3	**Figure** 3.10.3	
Approved CDiP	File No: QC02-T-MA-00118		
Date 10.06.09	Revision A		

Title **Groundwater Model Domain**

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Specific environmental values may be set for a given catchment and these are given in Schedule 1 of *EPP Water*. *EPP Water* does not list any relevant documents for the catchments potentially affected by the proposed Gas Field development and therefore there are no specified environmental values for the affected areas. Water quality objectives have therefore been determined using the *Queensland Water Quality Guidelines 2007* (QWQG), *Water Resource (Great Artesian Basin) Plan 2006, Great Artesian Basin Resource Operations Plan 2007*, *Water Resource (Condamine and Balonne) Plan 2004* and the *Condamine and Balonne Resource Operations Plan 2008.*

The environmental values considered pertinent to the Project area include:

- aquatic ecosystems, including groundwater dependent ecosystems (GDEs)
- drinking water uses
- industrial or agricultural uses:
  - irrigation – suitable supply for crops/pastures/parks/gardens and recreational areas
  - farm or domestic water supply (other than drinking water)
  - stock watering – suitable water supply to produce healthy livestock
  - other industrial uses (e.g. power generation and mining)
- cultural and spiritual values
- aquaculture
- scenic visual amenity
- recreational values.

In addition to the EP Act requirements, the *Petroleum and Gas (Production and Safety) Act 2004* (Qld) (*P&G Act*) requires petroleum tenure holders to develop a trigger threshold for aquifers in the area affected by the exercise of underground water rights for petroleum tenures. 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 *P&G Act* requires operators to develop trigger levels for the point at which groundwater impacts may result in the implementation of groundwater management plans. Based on the findings of the groundwater studies the following trigger levels are proposed:

- **Tier 1 Trigger Level:** An initial trigger value, defined as:
  - water level – 10 per cent reduction in the available drawdown, designed to provide an early warning of potential drawdown impacts before they occur
  - water quality – 10 per cent increase in physical or chemical parameter concentrations relative to statistically valid baseline values, designed to provide an early warning of potential water quality impacts before they occur

- **Tier 2 Trigger Level** – A final trigger value to be determined with the Chief Executive on a case by case basis, representing:
  - water level – the drawdown level at which some form of compensatory action is required for the affected bore owners (potential compensatory actions are discussed in *Section 10.6.2.3*)
  - water quality – the compliance criteria at which some form of compensatory or remedial action is required to mitigate the risks posed by the changes to water quality.

10.4.2 Regional Context

The Gas Field lies in the Surat Basin within the eastern-most portions of the Great Artesian Basin (GAB) (refer *Figure 3.10.1*). The GAB spans more than 1.7 million km^2, and underlies approximately one-fifth of the Australian continent. It extends 2,400 km from Cape York in the north to Dubbo in the south (NRW, 2006). At its widest, it is 1,800 km from the Darling Downs to west of Coober Pedy (NRW, 2006).

The GAB is made up of three main sub-basins (refer *Figure 3.10.1*):

- Carpentaria – in the north
- Euromanga – the largest
- Surat – in the south-east.

The existing natural environment within the study area has been, for the most part, moderately to severely modified by agricultural and pastoral activities.

10.4.3 Geology/Stratigraphy

The geology of the Gas Field area has been discussed in *Volume 3,Chapter 4*. This section considers the geology as it relates to groundwater.

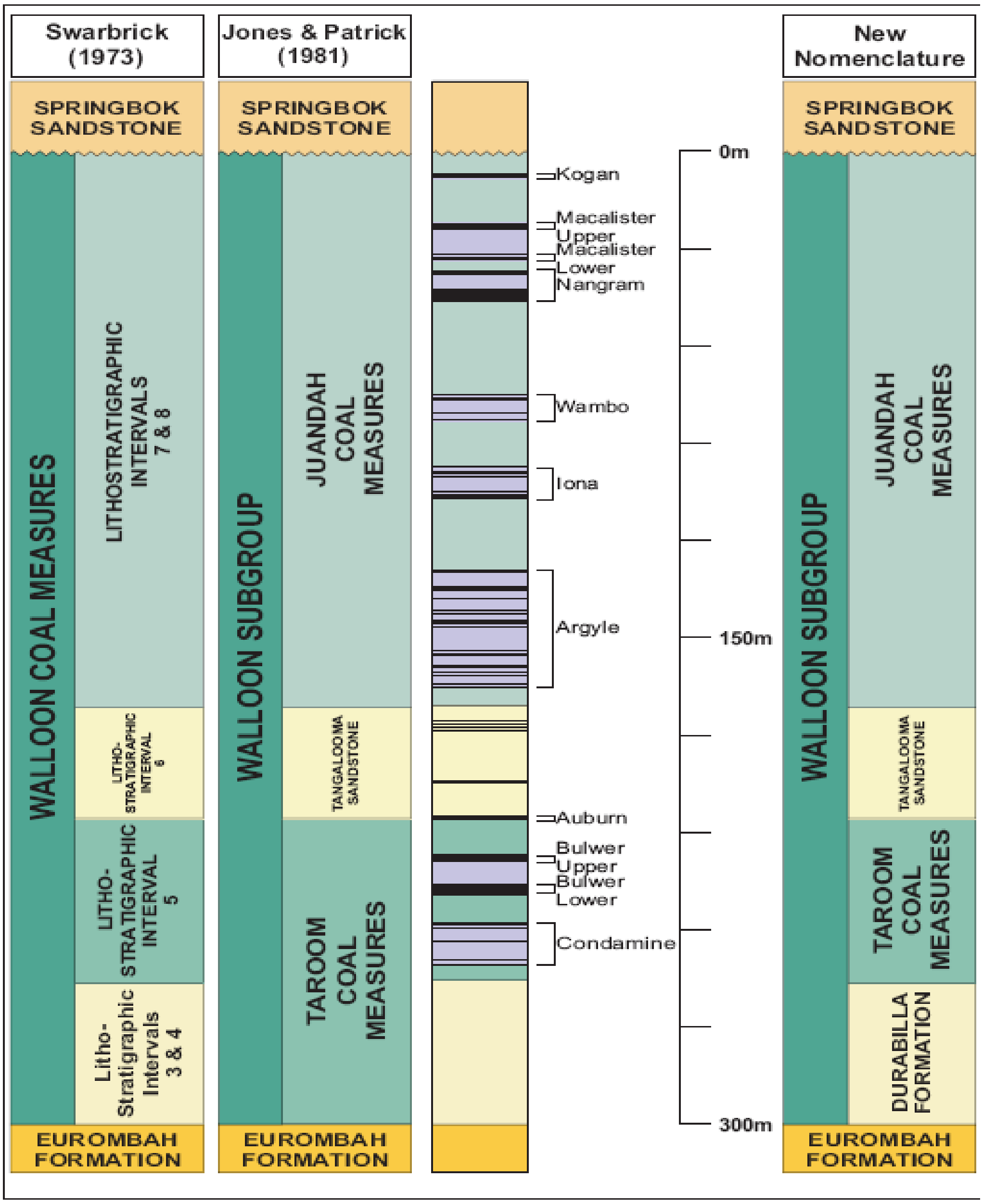
The Gas Field is located in the Surat Basin portion of the GAB which is dominated by fluvial quartzose sands. In the north-west region of the Gas Field the Surat Basin geological sequence overlays parts of the Bowen Basin sequence.

The Walloon Coal Measures (WCM) are the main gas bearing units within the Surat Basin, and are the target formation for the Gas Field operations. The thickness of the coal measures in the Gas Field ranges from 100 m to 460 m, at depths ranging from 170 m to 933 m below ground level. The coal seams are separated by a complex sequence of interbedded siltstones, mudstone and sandstones as described in *Figure 3.10.4*.

Regionally there is a slightly angular unconformable to disconformable contact between the Springbok Sandstone and the WCM. This could allow local increased hydraulic connectivity between the formations in areas where the basal porous and permeable sandstone unit of the Springbok Sandstone (when present) is in contact with the upper coal reservoir horizons of the WCM.

Faults are known to be present in the Surat Basin (refer *Volume 3 Chapter 4*). These faults have been interpreted by QGC as unlikely to extend through the full geological sequence. QGC's research to date, based on exploration work carried out, suggests that the three main basins of the GAB are not structurally linked.

Figure 3.10.4 Stratigraphy of the Walloon Coal Measures



Source: Scott S., Anderson B., Crosdale P., Dingwall J., Leblang G., Revised geology and coal seam gas characteristics of the Walloon Subgroup – Surat Basin, Queensland

10.4.4 Hydrogeology

The hydrogeological systems operating within the Surat Basin are numerous and complex and discussed in detail in *Appendix 3.4.*

Aquifers within the Gas Field comprise between 38 per cent and 52 per cent of the sequence with aquitard units comprising the remainder. Aquifers are geological formations from which groundwater can be extracted in useful quantities while aquitards contain much smaller quantities of water that are difficult to extract and generally impede groundwater flow.

The occurrence and spatial location (both vertically and horizontally) of aquitards and aquifers is a crucial aspect controlling the groundwater flow systems which operate within the portion of the Surat Basin stratigraphy in which the Gas Field lies.

The main aquifers of the Project area are (from the base of the sequence upward) the:

- Precipice Sandstone
- Hutton Sandstone
- Springbok Sandstone
- Gubberamunda Sandstone
- Mooga Sandstone.

Figure 3.10.5 provides an indicative representation of the stratigraphy of the Study Area.

To assist the assessment process and develop a meaningful model to assess the potential impacts, sedimentary rock-types have been grouped together to create six hydrogeological units or grouping units. These groupings do not necessarily refer to the depth of the aquifer, but rather a combination of the rocks genesis, its lithology and distinctness.

The six grouping units are:

1. Quaternary Alluvium
2. Shallow
3. Intermediate
4. Walloon
5. Hutton
6. Precipice.

The indicative hydrogeological parameters for the major aquifer and aquitard units in the study area are presented in *Table 3.10.1.* The data was sourced from numerous published datasets and is indicative of the general area and not specific to any individual location.

Figure 3.10.5 Stratigraphy of the Study Area

Litho-stratigraphy				Age (Million years before present)	Found in study area	Main Rock Types
Condamine Alluvium					✓	Unconsolidated sand, gravel and silt
Tertiary Sediments and Main Range Volcanics (East)						Unconsolidated sediments
Griman Creek Formation				Cretaceous (66 - 144)	✓	Sandstone, siltstone, mudstone conglomerate and coal
Surat Siltstone						Interbedded carbonaceous siltsone, mudstone and lithic sandstone
Wallumbilla Formation	Coreena Member				✓	Mudstone, siltstone, sandstone lenses with conglomerate and limestone
	Doncaster member				✓	
Bungil Formation	Minmi Member		Kumbarilla Beds		✓	Mudstone siltstone and lithic sandstone
	Nullawart Sandstone Member					
	Kingill Member					
Mooga Sandstone		Southlands Formation			✓	Fine to medium grained sandstone and shales
Orallo Sandstone				Jurassic (144 - 213)	✓	Sandstone carbonaceous siltstones mudstone coal
Gubberamunda Sandstone					✓	Medium and coarse quartz sandstone
Injune Creek Group	Westbourne Formation				✓	Shale, siltstone and fine grained sandstone
	Springbok Sandstone				✓	Sublabile, lithic sandstone with calcareous cement
	Walloon Coal Measures				✓	Shale, siltstone, labile argillaceous sandstone, coal, mudstone, limestone
		Eurombah Formation			✓	
Hutton / Marburg Sandstone					✓	Sandstone, siltstone, shale, conglomerate, coal, oolitic ironstone
Evergreen Formation		Boxvale Sandstone Member			✓	Sandstone, siltstone, shale, mudstone (carbonaceous with minor coal), oolitic limestone
Precipice / Helidon Sandstone					✓	Sandstone, pebbly sandstone, siltstone
Moolayember Formation		Wandoan Formation	Bowen Basin Sequences	Triassic (213 - 248)	✓	Predominantly sandstone, siltstone, shale and mudstone with coal measures
Clematis Sandstone					✓	
Rewan Formation					✓	

Source: Department of Natural Resources and Mines, Queensland, 2005, Hydrogeological Framework Report for the GAB WRP Area. Description and thickness from Parsons Brinckerhoff 2004, Coal Seam Gas, Water Management Study

Table 3.10.1 Aquifer Characteristics in the Study Area

Hydro-geological Unit	Aquifer Name	Hydraulic Conductivity, K	Transmissivity m^2/day, T [1]	Storage, S[1]	Porosity, ϕ	Yield
Quaternary Aquifers	Shallow Quaternary & Tertiary alluvium (incl. Condamine Alluvium)	Kx – $2.5x10^{-3}$ to $6x10^{-6}$ (average $1.8x10^{-4}$) m/day [2]	na		10 to 30%[3]	0.1 to 100L/s, median 1.3L/s [5]
Shallow Aquifers	Main Range Volcanics	0.5 to 50 m/day [6]	10 to 1000 [6]	na	na	0.01 to 30 L/s, median 1.7 L/s [5]
	Griman Creek Formation	na	na		10 to 30%[3]	3.5L/s [5]
	Wallumbilla Formation	na	50	$5x10^{-3}$	10 to 30%[3]	na
Intermediate Aquifers	Bungil Formation	na	50	$5x10^{-3}$	10 to 30%[3]	0.63 to 6.3 L/s [4]
	Mooga Sandstone	na	50	$5x10^{-3}$	10 to 30%[3]	0.2 to 8 L/s median 1.3L/s [4]
	Orallo Formation		50	$5x10^{-3}$	10 to 30%[3]	0.08 to 2.28 L/s median 1.2L/s [4]
	Gubberamunda Sandstone	Kx - 0.43 to 0.043 m/day [2]	50	$5x10^{-3}$	10 to 30%[3]	1.01 to 22 L/s, median of 4.6L/s [3]
	Kumbarilla Beds	na	na	na	na	0.03 L/s to 10 L/s, median at 0.8 L/s [4]
Walloon Unit	Westbourne Formation	na	150	$5x10^{-3}$	10 to 30%[3]	na
	Springbok Sandstone	na	150	$5x10^{-4}$	10 to 30%[3]	na
	Walloon Coal Measures	Kx - 1.4 m/day [7] (median for coal beds) and 10^{-1} to 10^{-4} m/day for aquitard layers	50	$5x10^{-4}$	<1% [8] for coal seams, and 10-30% for others	0.03 L/s to 19 L/s, median at 1.1 L/s [4]
Hutton Unit	Hutton Sandstone	Kx – 0.1 m/day [9]	150	$5x10^{-4}$	18-26%[10]	0.1 L/s to 600 L/s, median at 1.5 L/s [4]
	Evergreen Formation	Kz - 10^{-1} to 10^{-4} m/day [3]	150	$5x10^{-4}$	na	0.6 to 6.5 L/s , median 0.6 L/s [4]
Precipice Unit	Precipice Sandstone	0.1 to 10 m/day [10]	150	$5x10^{-4}$	18-20%[10]	0.1 to 30 L/s , median 3.8 L/s [4]

na: data not available for the purpose of the report
1: Great Artesian Basin Resource Operation Plan, February 2007
2: QGC, Kenya Pond Groundwater Investigation Report, September 2007
3: Habermehl M.A, 2002, Hydrogeology, Hydrogeochemistry and isotope Hydrology of the Great Artesian basin, Bureau of Rural Sciences
4: NRW database
5: Great Artesian Basin Resource Operation Plan, February 2007
6: Australian Government Department of the Environment and Water Resources - Groundwater Management Unit: Unincorporated Area - Clarence Moreton
7: Previous Groundwater Impact Study data
8: QGS; R.A. Freeze, J.A Cherry, 1979, Groundwater
9: Suggested by AGE.
10: Provided through previous work in Surat Basin;
11: R.A. Freeze, J.A Cherry, 1979, Groundwater

10.4.4.1 *Quaternary Alluvium Unit*

This unit comprises the most recent Quaternary and Tertiary unconfined alluvium aquifers with the most prevalent of these being the Condamine River Alluvium. The Condamine River Alluvium is a highly developed deposit which is currently being exploited for its water, with a high density of extraction bores on the Condamine River flood plain. Groundwater flow is generally north to north-west, is good quality and suitable for most purposes. However, the aquifer system is under stress with the resource over-allocated and over-abstracted (Australian Water Resources, 2005).

10.4.4.2 *Shallow Unit*

In the western region of the study area, the shallow unit is comprised of the most recent Quaternary and Tertiary unconfined aquifers and the underlying upper cretaceous aquifers of GAB, primarily the Wallumbilla Formation, where present. The Wallumbilla Formation is considered a confining unit elsewhere in the GAB. This unit is nonexistent in the north and eastern sections of the study area.

To the east of the Condamine River, the shallow unit comprises the basalts and associated rocks of the late Tertiary age Main Range Volcanics (MRV). The MRV are mainly located on the western escarpment of the Great Dividing Range and typically overlie the deeper hydrogeological units unconformably. They are commonly fractured with vesicular and weathered zones, and, depending on their location, may act as unconfined, semi-confined and confined systems. The MRV can yield around 0 to 30 litres per second (L/s), and can be of reasonable water quality with flows being generally in an east-south-east direction.

10.4.4.3 *Intermediate Unit*

This unit includes the major artesian sandstone aquifers above the Walloon Coal Measures with the exception of the Springbok Sandstone. The Intermediate Unit aquifers are confined to unconfined in the study area and include the Mooga and Gubberamunda Sandstones, both reasonably important aquifers in the area south and south-west of the Gas Field.

Water levels in this unit are around 280 m to 300 m Australian Height Datum (AHD) within the CDA, with salinity levels between 3,000 to 6,000 µS/cm. Groundwater flow tends to be from east to west, down dip. However, a low hydraulic gradient exists among a high density grouping of Intermediate bores in the northern part of the study area, west of Miles. Artesian bores of the Mooga and Gubberamunda Sandstones are located to the south of both the CDA and SEDA.

10.4.4.4 *Walloon Unit*

This unit includes the entire thickness of the Walloon Coal Measures (WCM) and importantly includes the following stratigraphic layers:

- coal seams comprising 10 to 16 per cent of the full thickness of the WCM including up to 40 to 45 individual coal seams of varying thicknesses.

These are the layers which are targeted for their coal seam gas (CSG) resource. The coal seams have a hydraulic conductivity of the order of 1.4 m/day (median for coal beds) and a porosity of approximately 0.2 per cent. As such they permit groundwater flow and are moderate aquifers, constrained only by their low storage capacity (water filled pore space voids, largely occurring as a consequence of the density of a network of structural micro-fracture, referred to as cleats).

- interbedded aquitard layers comprising shales, siltstones, mudstones and rare limestones dominate the WCM, and hence it is considered an aquitard (AGE 2007, unpublished). Aquifer beds, in the form of argillaceous sandstones, are also present in the WCM.

- the Springbok Formation, a unit including aquifer beds, is also included in this group. The Springbok Formation lies unconformably over the WCM and frequently occurs in small channel/valley structures eroded into the uppermost WCM layers, including the coal seams. This unconformable contact frequently places aquifer beds within the Springbok in direct hydraulic connection with the aquifer beds within the upper portion of the WCM sequence

The Springbok aquifer has the potential to make local contributions to water flows derived from the upper WCM beds (refer *Appendix 3.4*), inferring local hydraulic connection between the two units. This is important for assessing impacts on the Springbok aquifer when CSG extraction operations depressurise the WCM (refer to *Section 10.5.2*). Recharge to the Springbok occurs in the north and eastern sections of the Surat Basin. Although few measurements of electrical conductivity values are available in the Springbok formation; available values are similar to those observed within the WCM.

Groundwater elevations in this unit are between 290 m to 310 m AHD across the tenements, with groundwater flowing from the higher elevations in the east to the west following the dip of the sedimentary beds. There is a large variance of salinity levels across the area, ranging between 3,000 and 24,000 µS/cm. The water is generally not used for human or livestock consumption.

10.4.4.5 Hutton Unit

This unit is predominantly formed from the Hutton Sandstone, which is the second major Jurassic aged artesian aquifer in the GAB. The Hutton Sandstone can yield up to 50 L/s of good quality water, with recharge areas in the north and east of the Surat Basin margins. Typical hydraulic conductivities are up to 0.7 m/day. Groundwater flows are towards the west-south-west and groundwater elevations in this unit vary between 260 m and 300 m AHD.

The Marburg Sandstone is hydrogeologically equivalent to the Hutton Sandstone within the eastern region of the Gas Field. The groundwater is generally of reasonable quality.

The Evergreen Formation, which underlies the Hutton Sandstone (grouped here with the Hutton), is considered a major confining bed within the Surat Basin (NRW, 2005) and is significantly less conductive than the neighbouring Hutton Sandstone and Precipice Sandstones.

10.4.4.6 Precipice Unit

This unit typically forms the basal Jurassic artesian aquifer in the Surat Basin. Recharge to the Precipice Sandstone occurs from outcrops to the east of the study area. Water level and water quality data for the Precipice Unit were limited to the central part of the study area. Typical hydraulic conductivities are around 0.1 to 10 m/day and yields range between 0.1 and 30 L/s. Groundwater elevations for the unit are approximately 200 m AHD in the northern part of the study area. Based on available data, the groundwater in this unit has a salinity generally less than 6,000 µS/cm.

10.4.5 Water Levels and Water Quality

Water level and water quality data was obtained primarily from the former Department of Natural Resources and Water (now DERM) database. QGC's data was also utilised which predominantly covered the Walloon Coal Measures. To complement these two databases, data for the upper and intermediate aquifers was extracted from environmental monitoring and investigation reports.

QGC's data, which is based on the reservoir pressures measured before well testing or production commenced, was used to calculate the total water pressure in the Walloon Unit. It was assumed that the water pressure in the Walloon formation, prior to testing and CSG extraction, corresponded to QGC's water pressure data at the start of pumping in each well.

The consequences of this assumption, particularly with respect to the impact assessment modelling, were not considered significant, since there were other input parameters for which only ranges or generic values were available. Hence the predictive outcomes were not considered likely to be discernibly affected.

The analytes selected for the groundwater water quality assessment were pH, electrical conductivity (EC) and major ions. Available water quality information for each bore was identified and assessed. The water chemistry data were also linked to the aquifer/s that each well intersected.

10.4.6 Water Use

Water use within the study area is widespread with the main uses being stock watering, irrigation and domestic consumption. The region has become reliant on groundwater for economic growth, particularly in years where rainfall and surface flows are low. Primary use in the Condamine River Alluvium in the eastern margins of the study area is for irrigation.

In 2004/05 160 GL per year of groundwater was extracted from the Condamine and Balonne region of the Surat Basin; 97 per cent of the extraction occurring in the Upper Condamine catchment (CSIRO, 2008).

On average groundwater accounts for 18 per cent of all water diversions, while in dry years it accounts for as much as 61 per cent of water used (CSIRO, 2008).

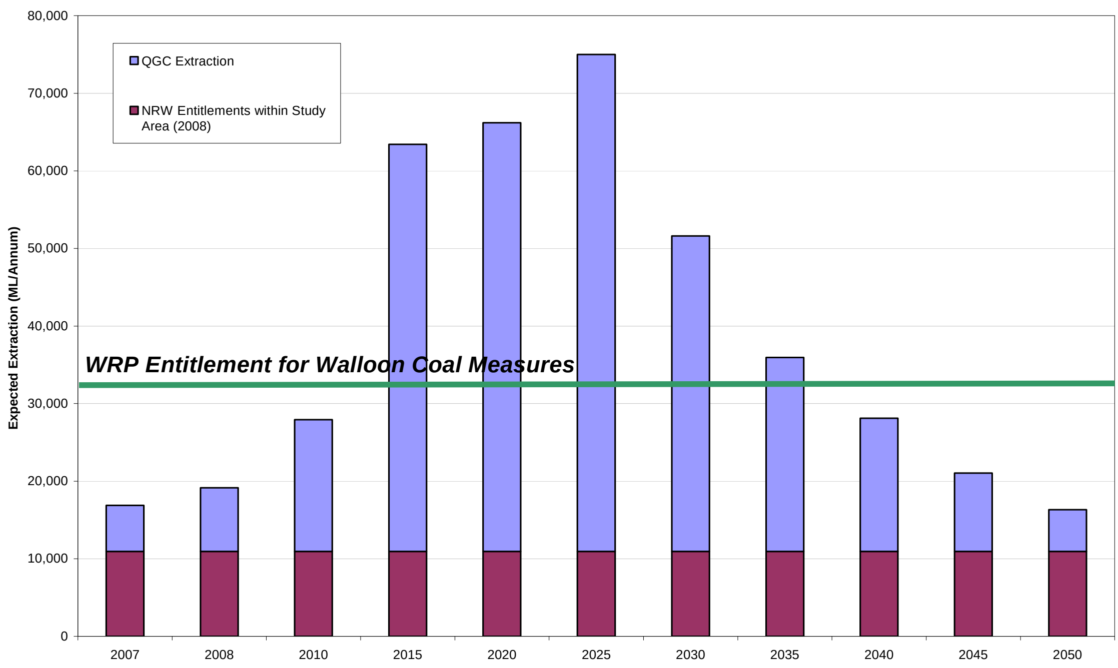
It is recognised that demands for water in the region may increase over time. Historic trends in water levels in the various units were analysed during the assessment (refer *Appendix 3.4*) and it was found that in some units bore levels have remained constant while in others, such as the Walloon and the Condamine, water table levels have changed over time.

Where there has been an increase in the amount of water extracted from an aquifer there has typically been an overall decline in water elevations in the same aquifers. Increased extraction and decreases in the water table have occurred where intensive agriculture and irrigation occur.

Analysis of QGC water production data indicates that:

- CSG water production will increase
- the Water Resource Plan (WRP) Entitlement for the Walloon Coal Measures set by the Queensland Government is not inclusive of Associated Water production under the P&G Act. Associated Water production is projected to exceed the government allocation for water extraction from the groundwater management units that contain the Walloon Coal Measures and is likely to continue to increase over the next 20 years (refer *Figure 3.10.6*).

Figure 3.10.6 Extraction of Water from the Walloon Coal Measure



10.5 POTENTIAL IMPACTS

Potential impacts to the groundwater system and its related environmental values, and in particular neighbouring users and the ecosystem, have been identified and assessed.

Consideration has been given to impacts associated with drilling and well installation, coal seam depressurisation, gas gathering systems, water storage, surface infrastructure and Associated Water management. Each activity was reviewed to determine the key risks, potential impacts and the potential to impact on environmental values.

10.5.1 *Drilling and Well Installation*

Drilling activities associated with Gas Field development have the potential to impact on the aquifers in the region through:

- intersecting multiple water bearing zones and creating artificial connectivity between the aquifers, with subsequent loss of pressure and cross contamination
- contamination through a loss of containment of drilling fluids.

The most common causes of such impacts include inadequate design, construction and wellhead completion of the wells, inappropriate drilling techniques and inappropriate abandonment methods.

Drawdown and cross-contamination can affect the availability and quality of the water. Depressurisation through the creation of artificial connectivity was considered to be negligible when compared with the level of depressurisation from the overall CSG production technique described in *Section 10.5.2*.

The risk of inter-aquifer flows arising from bore design or poor bore construction techniques was considered very low. Also, localised contamination of groundwater from a release of drilling fluids is considered low, based on subsequent pumping from the bore.

10.5.2 *Coal Seam Depressurisation*

As described in *Volume 2 Chapter 7* the extraction of CSG requires the lowering of the water pressure within the formation to allow gas to flow. The amount of dewatering typically required to achieve the optimal reservoir pressures within the coal seams results in the development of steep hydraulic gradients between the CSG target formation (i.e. Walloon Coal Measure) and adjacent water-bearing formations (i.e. Springbok and Hutton) which may induce seepage of groundwater between the formations.

The potential impacts of depressurisation were assessed through the development of a regional conceptual groundwater model, supplemented by the development and application of an idealised numerical groundwater model of the region. The model was used to estimate the order of magnitude of drawdown in aquifers in the region, arising from the CSG operations.

With respect to QGC's operations in the Gas Field, the modelling results indicated that extraction of groundwater for the purpose of CSG recovery from the Walloon Coal Measures (WCM) could induce inter-formational transfer of groundwater from the basal sandstone unit of Springbok Sandstone as it can be in local hydraulic contact with the uppermost coal reservoir of the WCM due to the unconformable contact between these two formations. This effect could potentially result in water level drawdown in this aquifer (in the order of between 10 m and 85 m). The effects were expected to be greatest in the CDA and least in the NDWA (in the order of between 0 m and 2 m).

Only limited inter-aquifer transfer from the Precipice and Hutton formations is predicted. The model found that a maximum simulated drawdown of between 0 m and 8 m could occur in the Hutton formation and between 0 m and 6 m in the Precipice formation. The effects were expected to be greatest in the SEDA for the Hutton and Precipice formations.

Impacts in the various formations could exceed the nominated Trigger Levels (refer *Section 10.4.1*) within the Gas Field. Bores into the Springbok Sandstone will also be monitored outside of the Gas Field to determine if CSG activities are the potential cause of water level changes in these areas. A monitoring program will be developed, including access to off-tenement properties. The monitoring program will consider the cause of any changes in bore levels, especially where there are other demands on an aquifer, including other producers of CSG overlying the Springbok bores.

The modelling predicted that inter-formational and inter-aquifer flows were likely to be low but could still affect available drawdown. The model also predicted that for a production life of 40 years, it would take from cessation to 75 years post-production for recovery to commence in the various aquifers. Recovery after pumping ceases is predicted to be slowest to commence (i.e. 75 years) in the Springbok Sandstone within the NWDA. More rapid recovery (i.e. immediate commencement) in the Springbok Sandstone is predicted for the CDA. Recovery in the Hutton Sandstone is predicted to take from 15 years to commence (in the SEDA) to 50 years (in the CDA). In the Precipice Sandstone it will take from 25 years (in the SEDA) to 60 years (in the CDA) to commence.

Modelling also predicted that QGC's CSG activities were unlikely to affect groundwater contributions to baseflow and springs, suggesting that the inter-aquifer transfer of groundwater was not predicted to extend to the shallow water table aquifers in these areas.

Groundwater modelling predictions indicate that groundwater aquifer depressurisation resulting from inter-formational flow does not measurably impact the shallow groundwater systems within the Project area (either due to distance from the CSG wellfields and/or degree of impact where potentially impacted aquifer (e.g. the Springbok Sandstone) outcrop/subcrop at locations where GDEs typically reside). It is recommended that precautionary monitoring and management of the key aquifers namely, the Springbok Sandstone, Precipice Sandstone and Hutton Formation aquifers, and Gubberamunda Sandstone be undertaken. In the unlikely event that WMP monitoring results indicate that the aquifers monitored are being unduly impacted by CSG extraction activities, further targeted assessment of those aquifers and their likelihood of causing adverse impact to the shallow aquifer systems which support GDEs will be required.

A reduction or loss of spring flow or baseflow contribution to rivers and creeks, as a result of CSG activities, could potentially affect the aquatic ecology of surface water ecosystems. However, for this to eventuate, inter-aquifer leakage associated with coal seam depressurisation would have to propagate through a thick stratigraphic sequence of overburden formations above the coal seams to affect the shallow 'water table' aquifers. The numerical modelling undertaken for these groundwater systems suggest that the effects of inter-aquifer leakage are likely to be limited to the first significant aquifer overlying the depressurised coal measures, and the shallow groundwater resources are unlikely to be affected. As such, it is predicted that there will be no measurable reduction or loss of baseflow contribution to rivers or creeks as a result of the Project operations.

It should be noted that the modelling results are subject to limitations based on data availability and assumptions adopted for the model construction as described in *Section 10.3.3*, and are therefore considered to be preliminary estimates. The presence of other (adjacent) CSG producers bordering on, or in close proximity to, QGC's Gas Field Component can be expected to affect the situation as overlapping drawdown affects are additive.

Impacts to existing bores will depend on their location in relation to the CSG activities. A monitoring program is proposed (refer *Section 10.6*) within the tenements as well as at a small number of bores outside of the Gas Field into the Springbok, Gubberamunda and Mooga Sandstones.

The reduction in pressure has also been assessed in relation to the potential to cause subsidence of the land at the surface (refer to *Appendix 3.4*). At this stage there is insufficient data to accurately determine the potential impacts although elastic settlement of the coal seams is predicted ranging from 30 mm to 300 mm depending upon the depth of the coal. A monitoring program is proposed to determine the potential affects of the dewatering on land subsidence.

It has been estimated that there will be a low potential to impact water levels in the local unconfined aquifers and underlying "Intermediate" aquifers. Nevertheless, close monitoring of this hydrogeological domain is proposed to develop an understanding of the relationship between rainfall, runoff and recharge to the aquifer and hence separate the potential impacts of other phenomenon (e.g. future drought) from those associated with the Gas Field operations.

The potential for water quality changes to any of the aquifers as a result of Gas Field activities is considered low. In contrast to intensive groundwater extraction from good quality aquifers, which is typical of most human consumptive use, the CSG operations will extract water from the lowest quality formations in the hydrostratigraphic sequence. Hence, the potential for degradation of groundwater quality in adjacent good quality aquifers as a result of aquifer depressurisation is negligible compared to typical intensive groundwater use scenarios. Other users are therefore unlikely to be impacted by changes in aquifer water quality (refer to *Appendix 3.4*).

Owing to the generally low to insignificant impacts expected on the water table aquifers in the study area, any measurable impact on the baseflow to the local river systems and in particular the Condamine River is unlikely to occur.

10.5.3 Associated Water Management

Associated Water management is addressed in detail in *Volume 3 Chapter 11*. Shallow aquifer contamination could potentially occur without adequate management of the Associated Water.

Associated Water will, potentially, be transferred through a network of water gathering pipelines to storage ponds (for the purpose of balancing water flows), water treatment facilities and beneficial uses. Water treatment facilities will produce saline brine, which may be stored in ponds.

The principal risk associated with the gathering systems and water treatment facilities, relevant to groundwater resources, is an uncontrolled release of Associated Water or saline brine to the environment. This could result from a leak or break in the pipelines or facilities, or leakage from drains and separators in the pipeline network.

An uncontrolled release of Associated Water or saline brine could potentially impact shallow groundwater quality, depending on the size and location of the release, the nature of the soils, and the relative quality of the Associated Water compared to shallow groundwater quality. Related environmental impacts could include surface water contamination, soil contamination, vegetation loss and soil erosion.

Water storage structures include ponds used for the management of Associated Water. The risk to the shallow groundwater system from leakage or over-topping of the ponds can be managed via a combination of appropriate design, engineering, monitoring and careful water management.

10.5.4 Surface Infrastructure

Surface infrastructure with the potential to impact groundwater includes the compressor stations (i.e. Field Compression Stations and Central Processing Plants), accommodation camp effluent systems and irrigation of water from sewage treatment. Releases from this infrastructure have the potential to contaminate soils and/or shallow groundwater aquifers.

10.6 MITIGATION MEASURES

Mitigation measures for groundwater fall into two categories:

- management practices to avoid creating contamination issues
- monitoring programs to determine the actual effect of coal seam depressurisation.

10.6.1 Mitigation and Management Practices to Avoid Contamination

Mitigation and Management practices to avoid contamination have been set out in the Draft EMP (*Volume 9*) and will include:

- well completions to be consistent with good industry practice as set out in the *Minimum Construction Requirements for Water Bores in Australia Ed. 2, Revised Sept 2003* (Land and Water Biodiversity Committee, 2003)
- storage and management of hazardous substances in accordance with AS 1940
- design and management of water storage ponds to prevent saline water contamination of groundwater resources, including:
  - design by suitably qualified engineers to withstand a one in 100 year 72 hour rainfall event plus 10% allowance for climate change
  - shallow groundwater monitoring piezometers
  - geophysical surveys of embankments and surrounds
  - monitoring to detect shallow lateral seepage and deeper infiltration to groundwater aquifers
  - maintaining embankment walls free of trees and shrubs capable of threatening wall integrity
  - regular inspections for integrity and appropriate freeboard levels
- annual structural and hydraulic integrity inspections of high hazard water storage ponds by a suitably qualified engineer
- minimising the size of sumps at well sites (e.g. less than 0.5 ML where practicable) and decommissioning within 14 days of well completion
- beneficial use of Associated Water appropriately managed so as not to lead to soil and water contamination (refer *Volume 3, Chapter 11*)
- appropriate procedures to transfer associated water to ponds, with staff trained in the relevant procedures
- sediment and erosion control measures established appropriate to each site
- any water released to land will be determined to be suitable in accordance with appropriate impact assessment, monitoring and risk management plans
- appropriate decommissioning plan for Associated Water infrastructure to be approved by senior QGC environmental management prior to undertaking of decommissioning (refer to *Volume 2, Chapter 15*)
- when decommissioning, all liquids will be removed from ponds either by evaporation or active removal so that they no longer contain flowable substances
- hyper-saline waters may be transferred to a significantly smaller, appropriately lined pond to reduce the footprint of saline residue
- residue within ponds will be encapsulated in situ using clay caps and capillary break layers topped with suitable growth medium
- ponds will be decommissioned to stable landforms.

10.6.2 Monitoring Program to Assess Impact of Depressurisation

Monitoring enables the evaluation of changes to water quality and quantity in the vicinity of Gas Field operations and evaluation of their potential to impact environmental values. While monitoring does not prevent impacts to groundwater resources occurring, it does provide a mechanism for early identification of potential impacts so that, if warranted, contingency actions can be implemented in a timely manner.

QGC currently gathers groundwater data from across the Gas Field. The proposed monitoring program based on the findings of the groundwater modelling will build on the current data to ensure interpretation can include a variety of shallow, intermediate and deep monitoring locations. The monitoring program will be used to establish baseline conditions for the Gas Field and, as a minimum, will include:

- a description of the drivers for the water monitoring program, including relevant legislation, current environmental authorities for the Project, and current and emerging policy with respect to water and CSG operations
- a risk analysis methodology for identifying areas of differing risk arising from the operations. For each risk area, a risk management approach will be developed
- a description of the underlying principles by which the specifics of the plan shall have been developed
- the details of a monitoring plan for the present operations and known future operations
- timing for regular reviews of the plan.

The monitoring results will be used:

- to guide ongoing operations and decommissioning design
- as an early warning system to identify potential impacts
- to improve CSG water management by utilising the data produced from the monitoring program.

A bore inventory has recently been completed which included inspection of 253 existing bores within the potential impact area of CSG activities (Golder, 2009c). The objective of the groundwater bore inventory was to identify privately owned bores within existing and proposed CSG extraction activity areas. The bore inventory has found very few monitoring locations for the Springbok Sandstone, Hutton Sandstone and Precipice Units that are ideally located with respect to monitoring water pressure impacts potentially associated with CSG water extraction.

However, there are a few bores near the Gas Field that are completed in the Springbok, Gubberamunda and Mooga Sandstones that could be used to monitor for potential pressure changes within these aquifer units.

Based on the groundwater modelling predictions, the water monitoring plan will consider monitoring areas within the Gas Field as well as a small number of bores outside of the tenements in the Springbok, Gubberamunda and Mooga Sandstones.

10.6.2.1 Data Management

Data collected from the monitoring program will be integrated with the CSG production datasets to enable the creation of one relational database designed for the storage and retrieval of water and environmental data.

10.6.2.2 Further Groundwater Modelling

As the Project progresses, with further well development and greater data gathering, the groundwater model will be reviewed to provide a less idealised representation of the regional hydrogeology, the impacts of other users and the CSG operations. It has been recommended that at between two and five years of data should be collected before attempting to update the model (refer *Appendix 3.4*). The model will provide support to the monitoring program enabling potential problem areas and issues to be identified and taken into account in the field development work.

10.6.2.3 Mitigation Measures

In the event that monitoring results indicate that a bore owner has been unduly impacted by QGC's CSG operations, either in terms of a significantly reduced bore yield, or a degradation of water quality such that it is unsuitable for its intended use, the following actions may be taken in consultation with the bore owner and regulatory authorities:

- re-setting the pump at a deeper level within the bore to access further available water column
- deepening the bore to provide access to an aquifer of suitable quality and yield that is less impacted by CSG operations
- installing a replacement bore, if the condition of the original bore is such that reconditioning and/or deepening of the bore is not possible, or if an alternative location on a bore owner's property is less affected by CSG operations
- provision of bulk water of suitable quality to the bore owner to compensate for loss of yield in their water supply bore (this may be treated associated water)
- Provision of monetary compensation to the bore owner equivalent to the loss incurred due to the diminished bore yield or water quality (eg. loss of agricultural productivity).

10.7 CONCLUSION

Based on the conceptual groundwater model, the proposed development and operation of the Gas Field Component of the Queensland Curtis LNG (QCLNG) Project is expected to have a minor-to-moderate impact on neighbouring users and a negligible impact on ecosystems. This is reinforced by aquifer connectivity limitations and there being no identified groundwater dependent ecosystems within the Gas Field.

Based on current data, predicted drawdown effects are expected to exceed nominated trigger levels within the Gas Field and, for the Springbok Sandstones, potentially outside of the Gas Field. Changes have been proposed to current data collection processes to provide better data to enable more accurate modelling and the ability to implement appropriate mitigation measures if required.

The risk of inter-aquifer flows arising from bore design or poor bore construction techniques are considered extremely unlikely.

There is low potential for impacts on water levels in local unconfined aquifers and underlying Intermediate aquifers. Water quality changes are not considered likely.

Owing to the negligible-to-minor impacts expected on the water table aquifers in the study area, a significant impact on the baseflow to the local river systems and in particular the Condamine River is unlikely.

Management strategies to ensure that other groundwater users are not disadvantaged have been proposed.

A summary of the impacts associated with this chapter is provided in *Figure 3.10.2.*

Table 3.10.2 Summary of Impacts for Groundwater

Impact assessment criteria	Assessment outcome
Impact assessment	Negative
Impact type	Direct
Impact duration	Long term
Impact extent	Local
Impact likelihood	High

Overall assessment of impact significance: minor.