6.6 Groundwater

This section discusses the results of the study of shallow groundwater (< 100 m) for the CSG activities from the technical report in Appendix P1. A further hydrogeological study included the assessment of the deep groundwater resources associated with the CSG development. Details of the study are in Appendix P2.

A review of the geological units mapped to outcrop within the GSG fields and the registered bores within these units was conducted. Based on bore depths and groundwater level data the shallow groundwater resources, comprising weathered and fractured rock aquifers, were identified to occur to a depth of ~ 100 m. The study aimed at characterising the groundwater resources within 100 m from surface. The deep groundwater resources, associated with the coal seam aquifers, were defined to occur at depths where there is sufficient hydrostatic pressure to prevent desorption of CSG from the coal. The deep groundwater resources also included the overlying and underlying aquifers along with the coal seam aquifers. Aquifers considered during the deep groundwater study were those assumed to be affected owing to their potential for vertical leakage.

6.6.1 Groundwater (shallow aquifers)

6.6.1.1 Introduction

The groundwater study assessed the reasonable foreseeable development (RFD) area including:

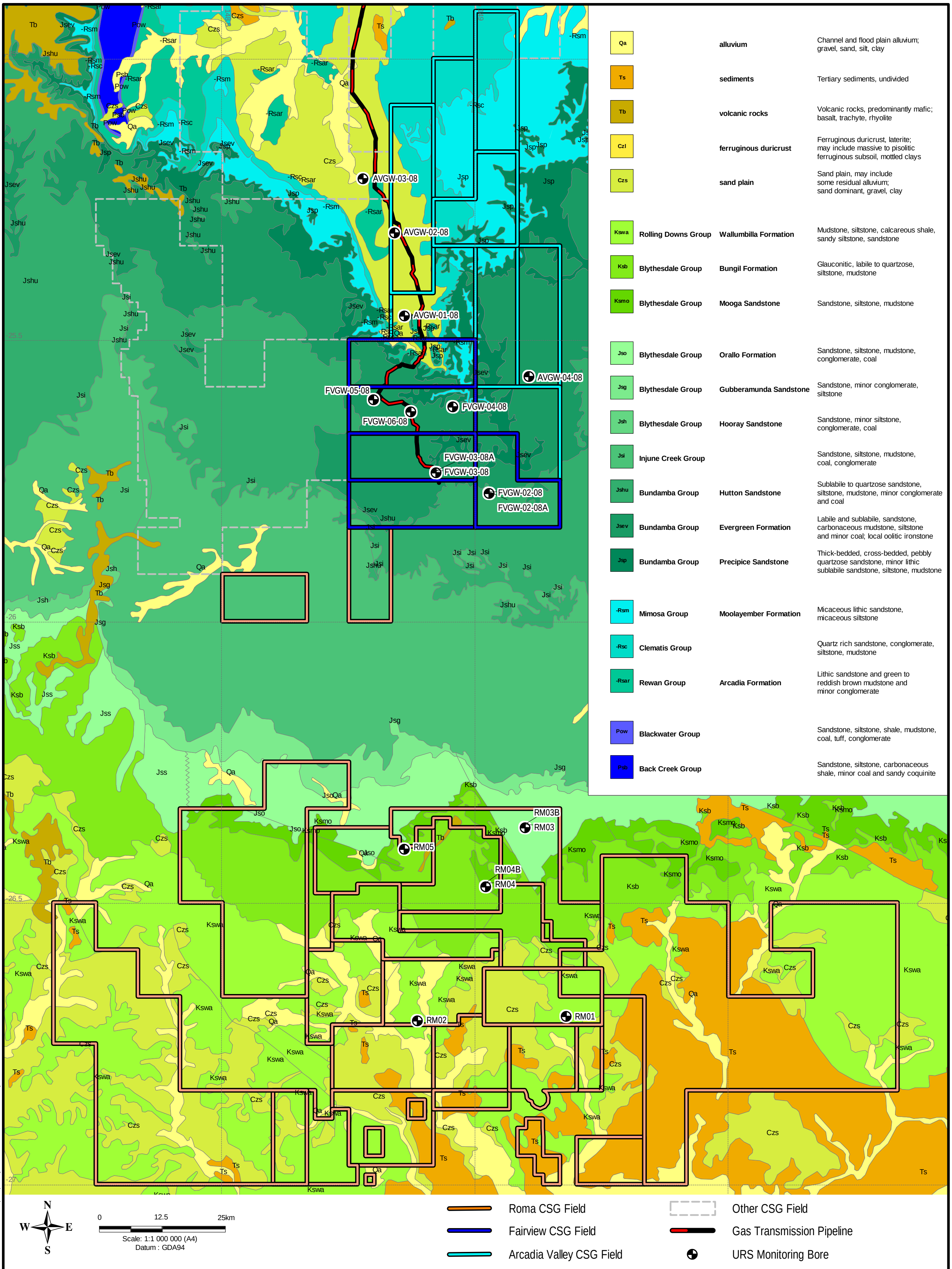
- The Roma field in the Surat Basin, within the upper reaches of the Murray-Darling catchment; and
- The Fairview and Arcadia Valley fields, within the Bowen Basin located within the Fitzroy catchment.

Note that Comet Ridge was not included in this assessment. In order to extract the CSG, target coal seams will be depressurised by dewatering, which causes methane desorption from the coal seam. The proposed dewatering, management of the associated water and operating the CSG infrastructure can potentially impact on the shallow groundwater resources within the project area. This groundwater is typically utilised for stock watering purposes.

6.6.1.2 Methodology

The shallow groundwater assessment was based on a desk top review of available geological and hydrogeological information and additional data compiled during field programs conducted between June and October 2008. The review and evaluation of data allowed for the compilation of the baseline groundwater descriptions and assessment of possible impacts. The environmental values of the water were then assessed according to the values identified in the Environmental Protection (Water) Policy (EPP Water 2008).

As the CSG fields cover a large area containing a significant amount of bores, as registered on the DNRW database, only a limited number of bores were required to verify the shallow groundwater characterisation. The bores were also drilled to allow for the construction of long term monitoring points within the CSG fields. Drilling targets were identified for monitoring bores within the shallow groundwater resources across the CSG fields. The targets were based on a review of DNRW data, geology, hydrology, and existing and proposed CSG infrastructure. The necessary approvals were obtained and 18 boreholes were drilled at 14 locations in order to obtain site-specific hydrogeological data. Figure 6.6.1 shows the 14 borehole locations. Note that two bores were drilled at locations FVGW-02-08A, FVGW-03-08A, RM03B and RM04B. Aquifer assessments were conducted to determine aquifer parameters, including hydraulic conductivity, transmissivity, and storage. Accurate groundwater level data was recorded.



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Client	Project	Title
URS	GLADSTONE LNG PROJECT ENVIRONMENTAL IMPACT STATEMENT	**INSTALLED MONITORING WELLS AND GEOLOGICAL REGIME CSG FIELD**

Drawn: RG/CA | Approved: JB | Date: 28-01-2009

Job No: **4262 6220** | File No: 42626220-g-863.wor

Figure: **6.6.1** | Rev:A | **A4**

Groundwater samples were collected and stabilised / preserved on site prior to being delivered to an accredited analytical laboratory for analysis. The resultant hydrochemical data assisted with the baseline assessment of the hydrogeology.

The proposed CSG operations, processes, and infrastructure were evaluated and potential impacts to the shallow groundwater were identified. The significance of these impacts, based on their consequence and likelihood, was compiled. A risk assessment methodology was adopted to assist in evaluating the potential impacts and compiling mitigation measures, where suitable.

A long-term groundwater monitoring program was developed to allow for the evaluation of possible impacts of the CSG operations and activities on the shallow groundwater. A site assessment protocol has been compiled as part of the Environmental Management Plan (EMP). Using the protocols developed under this EIS for Phase 2 (post EIS) processes, consideration will be given to site specific groundwater investigations as part of the site specific development of the CSG fields.

6.6.1.3 Regulatory Framework

The relevant groundwater resource legislation identified with regards to the proposed CSG fields of the GLNG Project includes:

- *Petroleum and Gas (Production and Safety) Act 2004, (Qld);*
- *Petroleum Act 1923, (Qld);*
- *Water Act 2000, (Qld);*
- *Water Supply (Safety and Reliability) Act 2008, (Qld);*
- *Water Resource (Great Artesian Basin) Plan 2006, (Qld);*
- *Water Resource (Fitzroy Basin) Plan 1999;*
- *Environmental Protection Act 1994, (Qld); and*
- *The Environmental Protection (Water) Policy 1997 (Qld) (EPP (Water)).*[1]

Petroleum and Gas (Production and Safety) Act 2004 (Qld)

The *Petroleum and Gas (Production and Safety) Act 2004* (Qld) (P&G Act) allows the holder of a petroleum tenure to take, interfere with and use an unlimited amount of underground water (referred to as 'associated water') that arises during the course of, or results from, activities that are authorised activities under the terms of the petroleum tenure.

Petroleum Act 1923

The *Petroleum Act 1923* (Qld) (Petroleum Act) regulates petroleum and natural gas in Queensland in relation to certain petroleum tenements granted prior to 2004. The Petroleum Act deals with authorities to prospect and leases, and provides for the ownership and pipelines and equipment.

Water Act 2000 (Qld)

The Water Act 2000 (Qld) (Water Act) provides a framework for the sustainable management of water and related resources. It regulates the taking, use and allocation of water through (among other things) water resource plans and resource operations plans. It sets out permitting and licensing requirements for taking or interfering with water and other resources. Development approval under the IP Act is also

[1] Note that at the time of technical report preparation (December 2008) the EPP Water policy was still in force. However, on 1 January 2009 the Environmental Protection Act 1994 Environmental Protection (Water) Amendment Policy (No.1) 2008 came into effect. The Amendment allowed for the identification of additional environmental values, with respect to water. The shallow groundwater resources have been evaluated according to the updated criteria.

required in respect of certain Water Act activities (including operational works and removing quarry material from a watercourse).Where water used for, or during, surface water activities is not associated water under the P&G (PS) Act, or is not water necessarily produced as a result of the carrying out authorised activities under the Petroleum Act a water licence, which regulates the taking or interfering with water from a watercourse or overland flowwater, will be required for those activities. A water licence is also required to authorise the access to/supply of treated or untreated associated water to any third party, other than for domestic or stock watering purposes.

Water Supply (Safety and Reliability) Act 2008 (Qld)

The *Water Supply (Safety and Reliability) Act 2008* (Qld) (WS (S&R) Act) aims to provide for the safety and reliability of water supply in Queensland. It provides for water service provider registration and sets out service provider obligations. It also determines what dams are referrable dams for which a failure impact assessment will be required. A failure impact assessment must be accepted by the DNRW before the construction of any referrable dam occurs.

Registration as a water service provider will also be required. A further ramification of the Water Act is that if the petroleum tenure holder is granted a water licence, it may not charge for the on-supply of water unless it is also registered as a water service provider.

Water Resource (Great Artesian Basin) Plan 2006

The Water Resource (Great Artesian Basin) Plan 2006 (GAB WRP) defines the availability of water in the plan area and provides a framework for sustainably managing and taking that water. The plan also identifies priorities and mechanisms for dealing with future water requirements.

The Great Artesian Basin Resource Operations Plan 2006 (GAB ROP) implements the objectives and outcomes specified in the GAB WRP.

Water Resource (Fitzroy Basin) Plan 1999

The Water Resource (Fitzroy Basin) Plan 1999 (Fitzroy Basin WRP) provides a framework for sustainably managing water, and the taking of water within the plan area. The Plan also provides a framework for establishing water allocations and the regulation of the taking of overland flow water.

The Fitzroy Basin Resource Operations Plan 2006 (Fitzroy Basin ROP) provides guidance on the allocation and management of water to implement the objectives set out in the Fitzroy Basin WRP.

Environmental Protection Act 1994

The *Environmental Protection Act 1994* (Qld) (EP Act) aims to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (being ecologically sustainable development).

Environmental Protection (Water) Policy 1997 (Qld)

The *Environmental Protection (Water) Policy 1997* (Qld) (EPP (Water)) aims to achieve the object of the EP Act in relation to Queensland waters by providing a framework for identifying environmental values, stating water quality guidelines and objectives to enhance or protect the environmental values, making consistent and equitable decisions about Queensland waters that promote their efficient use and best practice environmental management and providing for community consultation and education. Legislative amendments to the EPP Water that took effect on 1 January 2009 were considered during preparation of this EIS.

6.6.1.4 Existing Environmental Values

The environmental values of the shallow groundwater have been assessed according to the values identified in the EPP (Water). The environmental values to be enhanced or protected are:

- Biological integrity of a pristine or modified aquatic ecosystem;
- Suitability for primary, secondary, and visual recreational use;
- Suitability for minimal treatment before supply as drinking water;
- Suitability for use in agriculture;
- Suitability for use in aquacultural use;
- Suitability for producing aquatic food for human consumption;
- Suitability for industrial use; and
- Cultural and spiritual values of the water.

The review of available data allowed for an initial assessment of the groundwater resources for each geological unit, which outcrops within the CSG fields. This allowed for the identification of four environmental values of relevance to the shallow groundwater regime within the CSG fields. These include domestic use, biological integrity (maintaining the water quality so the plants and animals living in the waterway can survive), suitability for primary industry (livestock drinking water) use, and suitability for primary industry (irrigation) use.

Groundwater is recognised as being utilised for domestic and stock watering purposes from shallow groundwater resources. Small scale irrigation using groundwater is also recognised to occur from the various shallow aquifers within the large study area. Groundwater has also been assessed against the ANZECC guidelines, which included:

- The trigger levels for freshwater ecosystems - 95 % protection level of species;
- The short-term trigger values (STV) and long-term trigger values (LTV) in irrigation water; and
- The livestock drinking water guidelines.

Groundwater hydrochemical data has also been compared to the Australian Water Quality Guidelines (AWQG, 2004) for suitability for domestic use.

ToR Descriptions

Descriptions of the shallow groundwater resources were compiled based on the requirements detailed in the ToR. The descriptions and conceptualisation including groundwater characteristics, geology and hydrogeology, aquifer parameters, groundwater levels, flow, and recharge were compiled, where practicable. Aspects regarding sustainability and vulnerability were included to assist in evaluating environmental values and potential impacts.

A summary of the groundwater resources for each surficial geological outcrop is as follows (additional details are provided in the EIS Appendix P1).

Alluvium

Alluvium deposits are recognised adjacent to the main drainage lines within the CSG fields. The alluvium comprises clays, silt, sand, and gravel. The alluvium is of limited thickness (average depth 11 m) and thin (~ 4 m) saturated thickness. The alluvium has restricted effective storage and constrained interconnectivity, which reduces the sustainability of yields from this unit. The majority of these aquifers are unconfined and are vulnerable due the shallow groundwater levels (< 7 metres below ground level (mbgl)).

The alluvium aquifers receive recharge from both rainfall and stream flow during the wet seasons. The coarse grained material, sand and gravel, within the alluvium deposits provide increased storage capacity within the unit. This groundwater forms baseflow to the surface water courses once the flows in the rivers and streams decline. As the creeks within the CSG fields are non-perennial the effective storage in the alluvium is recognised to be limited, i.e. there is insufficient groundwater held within the alluvium to provide baseflow through out the entire dry season. Alterations to the alluvium aquifers, in terms of removal or diversion, will therefore have limited impact on the surface water flow patterns.

The hydrochemical results indicate variable groundwater quality, which is alkaline and sodium-chloride dominant. The groundwater associated with the alluvium is not potable and has limited suitability for use, only stock watering.

Although the alluvium aquifers are identified as limited and containing poor quality groundwater a level of protection is required for the shallow often permeable units as these aquifers can act as preferential flow paths for possible surface contaminants off site and impact on downstream users, surface water resources, and sensitive ecosystems (such as permanent pools).

Based on the non-perennial creeks within the CSG fields the shallow groundwater – surface water interaction is limited to the alluvium aquifers on site.

Wallumbilla Formation

A limited number of bores have been drilled in the Wallumbilla Formation sediments, which comprise mudstone and siltstone. This indicates limited groundwater use and potential.

No yield or static water level data has been captured on the DNRW database. Borehole depths are shallow; averaging ~ 40 m. Limited rainfall recharge is envisaged due to the low permeable nature of the Wallumbilla Formation sediments. The low permeability reduces the vulnerability of groundwater associated with this formation.

The groundwater is sodium-chloride dominant and variable across the CSG fields. Groundwater is predominantly fresh but records indicate areas of brackish water within this unit.

The unit is considered to comprise mainly aquitards with discrete minor aquifers associated with zones of alteration. The sustainability of these aquifers is considered low due to poor recharge and storage.

Bungil Formation

The Bungil Formation sandstone has good groundwater supply potential and is well utilised. Bore yields range between 0.2 and 6.3 L/s. The average yield is moderate, 1.7 L/s, indicating groundwater is not limited to discrete zones of secondary permeability.

The average borehole depth is 149 m and the average static water level is 48 mbgl. Limited groundwater level and elevation data indicates groundwater level variation is governed by confining conditions. Groundwater level data records indicate groundwater levels at 5 mbgl and 90 mbgl at elevations of 350 m AHD. This indicates discontinuous confining conditions within the Bungil Formation.

The groundwater is brackish and sodium-chloride dominant, but can be utilised for irrigation and live stock watering purposes.

Mooga Sandstone

The Mooga Sandstone unit is extensively utilised across the CSG fields, providing moderate borehole yields and has limited effective storage. The DNRW records indicate the majority of the boreholes within the Mooga Sandstone have intersected the sandstone at depth. The data was edited to only assess the borehole records for bores which intersected the sandstone unit at depths not greater than 100 m, i.e. in order to assess shallow groundwater resources associated with the Mooga Sandstone. The resultant records indicate that the boreholes drilled into the Mooga Sandstone at outcrop or close to surface have an average borehole depth of 63 m and have an average yield of 1.19 L/s.

The groundwater level data shows a poor correlation between groundwater levels and elevation, indicating that groundwater is likely to be confined or indicates possible impacts of dewatering or abstraction within the sandstone unit resulting in deeper groundwater levels at lower elevations.

The groundwater quality is sodium-chloride dominant with elevated electrical conductivity and sulfate concentrations. The groundwater is suitable for limited irrigation and stock watering purposes.

The high groundwater utilisation, rapid response to recharge and variable hydrochemistry indicates the Mooga Sandstone aquifer is vulnerable to possible groundwater contamination or dewatering.

Oralio Formation

Orallo Formation sandstone provides high yielding bores. This sandstone formation has the highest recorded yield (14.3 L/s) and highest average yield (4.6 L/s) of all of the units assessed in the Roma CSG field. The high yielding boreholes within this formation indicate the presence of secondary permeability which can act as preferential flow paths for groundwater.

The boreholes are on average 135 m deep, and the static water levels are relatively deep, averaging 40 mbgl. Groundwater level data indicates limited seasonal and long term fluctuations (± 1 m) in response to wet and dry seasons. The limited response may be as a result of overlying aquitards (low permeable units), which provide confining conditions and reduce direct recharge. Confined aquifer storage and large aquifer extent also reduces the influence of recharge or through flow on the groundwater levels and is recognised as typical of confined aquifers associated with the GAB units.

The groundwater is sodium-chloride dominant and contains areas of brine groundwater quality and records of elevated iron and fluoride concentrations. The groundwater is not suitable for drinking but can be utilised for live stock watering purposes and possible discharge into fresh water resources.

Birkhead Formation (Walloons Coal Measures)

The Birkhead Formation (Walloons Coal Measures), which comprises sandstone and coal, has enhanced groundwater potential within discrete zones of alteration. Few bores exist within the gas field tenements, with the majority located to the east of the Fairview and Arcadia Valley CSG fields. Based on an assessment of 141 borehole records the Birkhead Formation is recognised to have a low to moderate average borehole yield of 1.1 L/s. The groundwater potential is enhanced through secondary processes as yields range from 0.1 L/s to 12.6 L/s within this unit.

Groundwater level data indicates that the groundwater levels correlate well with the surface elevation. Groundwater level data indicates artesian conditions occur within this unit as groundwater level records show water levels above surface in several database entries. Groundwater is, however, considered to mimic topography and drain towards the main creeks in the CSG fields.

The long term groundwater level data is stable with limited seasonal fluctuations. These boreholes must penetrate aquifers which are confined from above and below by low permeable units, have large lateral extent, and large volume of water held in storage. These factors limit the groundwater level response to seasonal climatic changes.

Groundwater quality is variable as records indicate fresh, brackish, and brine groundwater quality based on Total Dissolved Solids (TDS) results. Groundwater can be utilised for irrigation and livestock watering purposes and may be suitable for discharge into fresh water.

Hutton Sandstone

The Hutton Sandstone forms one of the major Great Artesian Basin (GAB) aquifers within the CSG fields due to its physical characteristics, thickness (120 to 180 m) and transmissivity, which results in significant groundwater bearing potential.

Aquifer parameters include high transmissivity (100 to 150 m^2/day) and storage (5 x 10^{-4}). This results in bores with sustainable yields which range from 1.5 to 12 L/s.

Limited groundwater quality data indicates that the TDS values for the Hutton Sandstone average ~ 590 mg/L (fresh water) and pH values range from 7.7 to 11.3. The groundwater is sodium, chloride and bicarbonate (Na, Cl-HCO_3) type. The average concentration of sodium is 910 mg/L, ranging from 500 to 1,100 mg/L. Chloride concentrations range from 90 to 850 mg/L.

Long term groundwater level monitoring within the Hutton Sandstone indicates only slight fluctuations in groundwater levels during the dry and wet seasons. The limited groundwater level response to seasonal climatic changes indicates large lateral (aquifer) extent and large volume of water held in storage.

This good groundwater potential, high current abstraction, and fresh groundwater quality within the Hutton Sandstone aquifer indicates the need to protect this aquifer.

Boxvale Sandstone

The quartzose Boxvale Sandstone is a subunit of the Evergreen Formation and is of limited thickness and thus reduced groundwater potential when compared to the thicker sandstone units within the CSG fields.

The DNRW records indicate that the average borehole yield is moderate, 2 L/s, and the groundwater levels are relatively deep, averaging 65 mbgl.

The groundwater is sodium-chloride dominant with a large variation in pH conditions. Elevated sulfate, iron, and low pH have been recorded in the groundwater associated with the Boxvale Sandstone. This may be as a result of the coal within this unit.

The deep groundwater reduces the groundwater vulnerability. Groundwater can be utilised for irrigation and stock watering purposes but is not suitable for discharge to surface waterways.

Evergreen Formation

The shallow boreholes (< 100 m deep) constructed in the Evergreen Formation (excluding the Boxvale Sandstone) are low yielding (0.3 L/s average yield) and indicate limited groundwater resource potential when compared to the other units within the CSG fields.

Available groundwater level data indicates a linear relationship between groundwater levels and topography, which indicates that groundwater flow mimics topography. The average depth to groundwater is 22 m resulting in moderate vulnerability of the groundwater to possible surface contaminants.

Groundwater is of good quality with median results indicating that it is suitable for a wide range of uses. Elevated concentrations of iron have been recorded in some groundwater samples collected from this unit. Low sulfate concentrations are associated with the Evergreen Formation.

Precipice Sandstone

The Precipice Sandstone is another major GAB aquifer within the CSG fields. DNRW records reveal a large number of deep boreholes have been drilled to intersect this aquifer at depth. The drilling information indicates good groundwater potential throughout the highly transmissive aquifer unit. The average borehole yield for the shallow boreholes (< 100 m) is relatively high, 4.9 L/s.

Groundwater level measurements range from 0.5 to 54 m below surface and are 28 mbgl on average. No records of artesian conditions were recorded in the shallow boreholes.

Groundwater quality data for the shallow groundwater resources associated with the Precipice Sandstone indicate it is sodium-bicarbonate type water. The groundwater is suitable for a wide range of uses.

Moolayember Formation

The Moolayember Formation, comprising mudstone and siltstone, has low permeability and is regarded as a confining layer between the Precipice Sandstone and Clematis Sandstone aquifers. The average borehole yield is low, 0.9 L/s, and yields range between 0.01 and 4.5 L/s. This indicates discrete zones of secondary processes can enhance the groundwater potential associated with this formation. Low sustainable abstraction is envisaged for the majority of the boreholes constructed within this unit.

Groundwater levels are on average 20 m below surface, ranging between 8.5 and 51.8 mbgl, depending on topography. Available long term groundwater level data indicates only minor fluctuations to groundwater levels over time indicating limited recharge.

The hydrochemistry data indicates that the groundwater associated with the Moolayember Formation is sodium-chloride-bicarbonate type. Elevated manganese and low pH has been recorded from several boreholes within this unit. Long term groundwater quality monitoring has been conducted. The results indicate natural fluctuations in chloride and sodium concentrations with time; while the remaining major anion and cation concentrations are relatively stable with time.

Alterations in groundwater levels and concentrations due to the proposed CSG operations will be difficult to identify unless marked changes are recorded.

Clematis Sandstone

The medium grained quartz-rich sandstone of the Clematis Sandstone is a major aquifer unit. The associated groundwater resources are confined in places and artesian conditions occur. The average depth to groundwater level is only 1 m. There is a poor linear relationship between topography and groundwater levels due to the artesian conditions.

Borehole yield records indicate that the Clematis Sandstone intersected at shallow depths have moderate yields with an average of 3.65 L/s. The yield data does indicate the incidence of high yielding boreholes, ± 25 L/s, within this unit.

Long term groundwater quality data indicates that the hydrochemistry within the unit remains stable over time, indicating only minor fluctuations in concentrations. The groundwater type is typically sodium-bicarbonate dominant. The ambient groundwater quality data indicates records of elevated dissolved metals in some boreholes. The groundwater quality indicates that it is not suitable for long term irrigation use.

Rewan Formation

The Rewan Formation comprises sandstone and siltstone, which has moderate groundwater potential. The DNRW records indicate high groundwater use within this unit, comprising shallow boreholes (average depth is 61 m) with moderate yields (average yield of 2.2 L/s).

The aquifers are unconfined within the shallow outcrop areas and the groundwater levels are relatively deep, ± 36 mbgl on average. The groundwater levels are recognised to mimic topography.

Groundwater quality is variable across this unit; however, it is recognised to be generally of poor quality with elevated salinity levels. The groundwater is sodium-chloride dominant, with elevated potassium and sulfate. The deep groundwater and poor quality reduces the groundwater vulnerability and need for protection of this resource.

Section 3.4 of the ToR refers to the Surface Waterways and Groundwater, and includes non-riverine wetlands. The surface water descriptions, including the wetlands, are presented in the EIS Appendix O1.

The review of available data allowed for an initial assessment of the shallow groundwater resources associated with the geological outcrops within the CSG fields study area. The available information allowed for the evaluation of the shallow groundwater resource environment values. These include:

Biological Integrity of a Pristine or Modified Aquatic Ecosystem

Shallow groundwater quality associated with the majority of the aquifers identified within the CSG fields has dissolved metals concentrations, which exceed the ANZECC guideline trigger levels for freshwater ecosystems. Discharge of this water can potentially impact on the biological integrity of the fresh water resources within the CSG fields. No dewatering of the shallow groundwater resources will occur during the development of CSG. The discharge of shallow groundwater will, therefore, not occur during the GLNG Project.

Existing groundwater dependent ecosystems need to be identified on site and monitored to ensure CSG operations and activities do not impact on these sensitive landscapes.

Suitability for Recreational Use

This category of environmental values is not considered relevant in relation to groundwater.

Suitability for Minimal Treatment before Supply as Drinking Water

Available hydrochemical data from the DNRW database regarding the geological units mapped to outcrop in the CSG fields indicate that the groundwater quality is variable. Aquifers including GAB aquifers are recognised as having areas which contain brackish to brine groundwater quality. This groundwater would require complex and expensive treatment, such as reverse osmosis (RO), to achieve drinking water quality to satisfy the Australian Drinking Water Guidelines 2004.

Issues of salinity and the ease of obtaining a rainwater tank supply are factors which preclude the potential for usage of the groundwater as a drinking water source.

Suitability for Use in Agriculture, Aquaculture, Aquatic Food for Human Consumption

The large number of registered bores in the area indicates that irrigation and stock watering quality water is obtainable. Compared to the ANZECC (2000) guidelines, groundwater present within the bores indicates that the majority of the groundwater is suitable for livestock watering.

The water quality data suggests that the salinity is within or above the range proposed for irrigation of crops. The groundwater appears to have some potential use in terms of irrigation, depending on crop type, soil type and irrigation regime.

Several of the GAB aquifers are recognised to have good quality groundwater, which could be utilised for aquaculture and the production of aquatic food for human consumption.

Suitability for Industrial Use

The groundwater quality is generally suitable for a large number of industrial processes including cooling water, process water, utility water, and wash water. As industrial processes require particular water quality, specific hydrochemical data will be required to evaluate suitability for use.

Industrial users generally have the capital required to drill and equip bores and if necessary appropriately treat the water before use. However, industrial users tend to require large volumes of water which would be unsustainable for the majority of shallow groundwater resources in the area.

Cultural and Spiritual Values

Based on the work completed, no specific groundwater resources of cultural or spiritual values were recognised. Artesian conditions may allow for permanent water pools or springs. As these pools and springs are to be protected then any inherent cultural and spiritual values will also be protected.

6.6.1.5 Potential Impacts and Mitigation Measures

Potential Impacts

An impact assessment allowed for the identification of potential impacts associated with the proposed development of the CSG fields. Potential impacts resulting from the proposed CSG depressurisation/dewatering, the envisaged CSG associated water management, and the required CSG infrastructure were identified and considered. Potential impacts during decommissioning, associated with associated water infrastructure, have been considered as these may result in disturbed areas.

The identification and evaluation of impacts have been compiled to include considerations compiled in the ToR, which include:

- Potential regional impacts of groundwater extraction, which is considered in the deep groundwater study (Appendix P2 of the EIS);
- Potential impacts of the project on flow and quality of groundwater, which include the impacts of CSG depressurisation and resultant induced flow which could impact on the shallow groundwater resources and users;
- Potential impacts of managing associated water, which include artificial recharge to the shallow groundwater resources;
- Risk of uncontrolled releases, where associated water ponds fail have been evaluated;
- Chemical and physical properties of any waste water; impacts associated with water treatment waste storage and possible discharge have been considered; and
- An assessment of the potential to contaminant shallow groundwater was conducted and evaluated.

The potential impacts have been compiled in the risk assessment section of the technical report and summarised for the EIS section.

The impact of deep dewatering is induced flow from overlying and underlying aquifers into the coal seams. The impact can occur in areas of increased interconnectivity between the coal seams and the adjacent aquifers. The dewatering of the coal seams is predicted (deep groundwater model) to have limited impact on the shallow groundwater.

The impacts associated with the management of CSG associated water will depend on the volumes of water to be stored and managed on the surface. The associated water management options available may include discharge into surface water resources, deep well injection into suitable underlying formations, and treatment (refer to Appendix Q). The identified potential impacts related with the CSG associated water on the shallow groundwater resources include poor quality artificial recharge from CSG associated water containment, artificial recharge impacts on groundwater flow patterns, impacts of treated water waste, discharge impacts on alluvium aquifers, and irrigation (deep drainage) return water. Based on the need to contain associated water on the surface during the CSG operations, the impacts of artificial recharge, which can potentially alter the nature of the shallow groundwater resources, will require mitigation measures to limit or negate the potential impacts.

Ancillary infrastructure associated with the CSG fields development includes development and appraisal wells, CSG in-field pipeline networks and field compressor stations, workers accommodation, work shops, maintenance and lay down yards. This infrastructure could potentially impact on the shallow groundwater regime. The possible impacts are associated with loss of recharge, storage of chemicals, fuels and oils, waste generation and storage, and sanitation. The limited reduction in recharge and the containment and management processes to be adopted will require monitoring to ensure the CSG field infrastructure is not impacting negatively on the shallow groundwater environment.

During decommissioning once the dewatering has ceased the associated water ponds could either be utilised by landholders or the decommissioning and rehabilitation of the ponds to pre-CSG operational conditions. As the ponds are to be designed and constructed using a composite liner it is envisaged that the required rehabilitation will allow the disturbed areas to be restored to pre-CSG condition.

Mitigation Measures

Impacts of dewatering associated with CSG development could occur. The deep groundwater abstraction study (Appendix P2) provides an indication of the extent of dewatering within the coal seam aquifers as well as predictions regarding possible induced flow from adjacent units. It is proposed that appraisal boreholes drilled to the coal seams, not used for CSG operations, be modified to allow for the monitoring of groundwater levels within the coal seams. These boreholes can, if feasible, be equipped with piezometers to allow for the monitoring of additional aquifers within the CSG fields.

An evaluation of geology has been conducted to allow for the identification of areas where the coal seams are potentially in close contact with GAB aquifers, as these areas have increased potential for inter-aquifer flow. Monitoring boreholes or existing bores within these areas are required to allow for the monitoring of groundwater levels as well as hydrochemistry. The evaluation of groundwater quality will allow for an assessment of hydrochemical trends over time to determine whether groundwater quality in the coal seams is being altered through the induced flow from surrounding aquifers.

Santos is currently completing a regional bore census of groundwater users (including non-registered bores) to allow for potential monitoring of neighbouring bores, which could potentially be impacted by dewatering operations (as identified in the groundwater model simulations, EIS Appendix P2). DNRW data indicates that long term groundwater level data within the various units do not vary significantly over time in response to recharge or extended dry periods (where not affected by abstraction). This data is required prior to CSG dewatering to allow for baseline conditions to be accurately determined and allow for comparisons to evaluate possible dewatering impacts. It is proposed that site specific groundwater level data is obtained prior to the CSG dewatering commencing. The information from the census will aid in mitigation by increased monitoring, verifying the groundwater model, increasing the accuracy of the groundwater model, determining focused mitigation measures and enhancing the effectiveness of the mitigation.

Background groundwater level monitoring is proposed in order to assess natural responses to varying climate conditions.

The potential impacts of dewatering include lowering of groundwater levels and possible reduction in bore yields. It is therefore proposed that for subartesian aquifers selected bores are monitored using automated groundwater level monitors. The groundwater levels are to be monitored in shallow (< 100 m), moderate (± 200 m), and deep (coal seam) bores to assess groundwater level responses. The aquifers to be monitored are those identified as being impacted through induced flow, which include the Precipice Sandstone, Hutton Sandstone, and the coal seam aquifers, depending on the CSG field. The groundwater level data must be accurate, reliable, and should provide weekly groundwater level information. Records of rainfall, hydrochemistry, and water abstraction are required on a regular basis to facilitate the compilation of a groundwater balance of the study area. This information can be utilised to recalibrate the deep groundwater models to allow for more accurate predictions and simulations of dewatering over time.

Trigger levels, regarding declines in groundwater levels, are required to assess and manage the impacts of dewatering. Suggested trigger levels, regarding declines in available drawdown within bores, will be used to assess and manage the impacts of dewatering. Groundwater level variations are to be monitored. Should available drawdown (the column of water above the pump inlet) vary by 10 % then this will act as an early warning trigger. If the early warning trigger assessment indicates that dewatering is conclusively found to be the cause of the groundwater level impact then a water replacement plan will be considered to make good the loss of water. This plan will allow for the sourcing and replacement of the same quantity and quality of water lost to the affected groundwater user. Should the available drawdown in a bore decrease by 25 % then the water replacement plan / measure will be implemented. Compensation provisions are allowed according to the P&G Act and will be considered when implementing any water replacement plans. Sources of water will be identified depending on the location of the impacted supplies and could include treated associated water.

This mitigation measure, to reduce the negative impact of loss of groundwater supplies, requires the compilation of accurate information to be obtained during the regional bore census and pre-CSG operations monitoring.

The design and construction of the CSG wells is considered satisfactory to ensure that no interaction between aquifers via the wells. Well integrity monitoring will be conducted if necessary on each well to ensure construction according to design.

All exploration wells within the CSG fields, historic and proposed, will be backfilled (if not modified as monitoring piezometers) to prevent them acting as direct conduits between aquifers. The backfilling, to ensure an effective seal, could comprise cement with 5 % bentonite.

Water management within the large CSG field area will be required for the large number of envisaged production wells, which will result in the reticulation and storage of large volumes of associated water on the surface. The storage of water, either prior to treatment or the resultant brine after treatment, can potentially seep, leak, or spill (over the spillways) and cause alterations to the groundwater flow patterns and hydrochemistry. The ponds have been designed and will be constructed to limit this risk.

Geophysical surveys, comprising magnetic and electromagnetic techniques, could be employed during pond site selections, to ensure that the ponds are not located on underlying geological structures, which can act as preferential flow paths.

In order to reduce the potential for artificial recharge the correct design and sizing of the associated water containment facilities is ensured. The dams are correctly sized (to prevent overflow and adhere to regulations) and will be constructed to include a low permeability liner. This will reduce spillage and infiltration risks. The size calculations include for rainfall events based on a minimum of the 1:1,000 year flood events.

The design and water management should allow for sufficient free board to ensure dam safety and limited overtopping risks.

It is suggested that down gradient secondary containment facilities, such as toe dams, be included in the design of the brine storage facilities, if utilised.

Groundwater level and quality monitoring is required adjacent to the proposed associated water storage facilities to ensure the effectiveness of designs, maintenance, and management. Monitoring includes:

- Existing boreholes should be used, up and down gradient of the storage facilities where practicable, or else new monitoring boreholes must be constructed.
- One ± 60 m deep borehole located 50 m up gradient of each water storage facility is suggested, to provide shallow ambient groundwater data.
- Two ± 60 m deep boreholes, located at 5 and 15 m, down gradient of each water storage facility, based on geophysical survey, i.e. scientifically sited to intersect potential preferential flow paths.
- Automated monitoring of groundwater levels and rainfall data at each facility. Monitoring should begin prior to the start of construction.
- Groundwater quality monitoring, comprising major anions and cations, selected dissolved metals, and CSG water indicators. It is proposed that groundwater sampling is conducted quarterly at first and then reduced to bi-annually with time.
- All existing boreholes located within the dam footprints must be backfilled using a cement – bentonite slurry so as to prevent direct migration of potentially poor quality water into the aquifers.

In order to enhance or protect the identified shallow groundwater environmental values Santos will ensure all correct dam and CSG production well design and construction to protect groundwater resources.

Management (of water volumes in the ponds) and maintenance of the ponds and reticulation pipelines is required to minimise the volumes of water than can be “lost” to the groundwater. This should commence at the start of operations and continue for the life of the project.

The use of treated associated water will require groundwater monitoring programs (both groundwater levels and quality) to be developed to assist in determining the impacts of the treated water use on the shallow groundwater. The monitoring could include shallow (± 20 to 60 m) boreholes within the alluvium aquifers and within irrigated lands. Alterations to groundwater levels, groundwater flow patterns, and hydrochemistry need to be monitored to evaluate the possible impact of artificial recharge, which are deemed limited at this point.

Groundwater monitoring in shallow boreholes constructed in the same geological units located away from the storage facilities is proposed across the site. This will allow for the assessment of natural salinity changes. This should be done to aid in assessing the potential impacts of the storage facilities. Natural changes in salinity can for example occur due to:

- Exposure of impermeable rock intersected in the monitoring holes, which leads to the leaching of salts into the groundwater;
- The change in groundwater levels (possibly due to removal of vegetation), such that the groundwater rises into salt accumulation zones within the unsaturated zone;
- Prolonged periods of drought leading to deterioration in groundwater quality, and
- Anthropogenic influences from land use such as irrigation.

Recharge changes due to changes in land use from infrastructure within the CSG fields is envisaged to be limited due to the relatively small area compared to the entire CSG field area. Monitoring conducted to evaluate dewatering will also allow for an assessment of reduced recharge to the shallow groundwater resources.

Minor hydrocarbons may be present within the associated water and oils can potentially be present in other waste water streams. Such water will require treatment prior to any reuse on site (e.g. possible irrigation water). To reduce the probability of uncontained oil releases entering the water system, the following recommendations are made:

- Contain all oil storage facilities within a bunded area;
- Site records regarding clean up of spills and accurate volumes of fuel / oil are kept in the IMS system; and
- Maintain accurate records of oil volumes, purchased, used, disposed, and recycled.

The mitigation measures should be included in the design phase and regular (bi-annual) groundwater sampling for light non-aqueous phase liquids (LNAPL) should be conducted during CSG operations, adjacent to the bunded areas.

The conveyance and storage of hazardous chemicals and effluents should be through or in suitably sealed infrastructure, including tiles and coatings, concrete channels, trenches, and sumps. All chemicals are to be stored in above ground storage tanks located within suitable secondary containment (bunded) areas. Due to the threat to human health and the environment, it is proposed that all sealed infrastructures be inspected annually by a qualified person (e.g. civil engineer). Recommendations with respect to repair procedures must be compiled and conducted by a recognised specialist. The sealing and suitable material selection is to be conducted during the design phase.

The management of waste, domestic and industrial, stored in industry standard facilities will require the use of licensed contractors. Bi-annual audits of disposal facilities, disposal permits, and working conditions ought to be conducted to ensure adherence to the regulations.

During decommissioning it is proposed that associated water storage facilities are either utilised by landholders or rehabilitated (refer to Section 6.16 of the EIS for further details on water storage facility decommissioning and rehabilitation measures).

Water Supply Usage and Waste Water Disposal

The impacts associated with water supply usage and waste water disposal are detailed in Appendix Q.

The impacts on shallow groundwater are considered as follows:

- No shallow groundwater will be used for water supply during the project;
- The impacts of pond failure on the shallow groundwater have been considered;
- The potential impacts of poor quality associated water or brine (waste from treated associated water) on the shallow groundwater has been considered;
- The need or otherwise for licensing any dams has no relevance to the shallow groundwater; and
- The engineering design standards have been considered when evaluating the potential impacts on the shallow groundwater resources.

Cumulative Impacts

Section 1 identifies other CSG development projects planned for the surrounding region. Some of these projects are up to 100 km from the GLNG Project CSG field areas and some may be within the GLNG Project future development (FD) area. There is limited information available as to the planned development of those projects or the quantity and timing of the development of the wells or associated infrastructure; however, a qualitative assessment can be made of the possible cumulative impacts.

Santos will develop the CSG fields in accordance with the EIS. There will be no other development by other petroleum producers in the tenements described in the CSG fields. Infrastructure impacts will not exceed those stated in the project description.

It is however, possible that other companies may develop CSG facilities within the CSG fields FD area as part of their planned CSG development projects in addition to the existing CSG domestic supply facilities. This will mean that there will be more CSG development in the FD area than the Santos project. As an area is developed, the number of wells will increase, but the spacing of wells will not intensify.

Current CSG projects, such as the Spring Gully CSG project, are recognised adjacent to the proposed CSG fields. The deep groundwater modelling included the current CSG activities at Spring Gully to ensure representative predictions regarding the impacts of CSG depressurisation. The cumulative impacts of increased dewatering volumes, to produce CSG, were considered.

Possible cumulative impacts associated with additional CSG development projects will be an increased area of influence (dewatering extent) and increased induced flows, thus, the possible impacts on the groundwater resources will occur more rapidly and over a larger area. The impacts are associated with increased dewatering, increased contaminant sources, and larger disturbed areas.

It is expected that the other CSG field development projects would include some or all of the proposed mitigation measures in relation to groundwater impacts described in this section. By utilising these mitigation measures, it is anticipated that there will be a minimal cumulative impact on the surrounding environment.

In addition to the proposed mitigation measures to reduce cumulative impacts CSG producers will need to provide continued groundwater monitoring of the Surat and Bowen Basins, which will allow for the update of the deep groundwater prediction model (increasing the accuracy of the model), further assessment of the groundwater impacts and allow for the apportioning of responsibility to the CSG operators within the Surat and Bowen Basins. This will require the sharing of information and the development of working group(s) amongst the various projects to allow for the identification of impacts and the development of optimum mitigation measures for all CSG operators in the Surat and Bowen Basins.

Table 6.6.1 provides a summary of potential groundwater (shallow) impacts and mitigations measures for the CSG fields.

Table 6.6.1 Potential Groundwater (shallow) Impacts and Mitigation Measures

Aspect	Potential Impact	Mitigation Measures	Objective
Construction			
Loss of shallow groundwater recharge	The clearing of land for wells, plant, etc. and the alteration of topography can impact on rainfall recharge to the shallow groundwater regime.	• Minimise disturbed area.	To ensure minimum reduction of recharge to shallow groundwater resources.
Altered hydrogeology due to interflow in CSG exploration holes	Drilling can connect aquifers separated by aquitards; this could cause alterations in hydrochemistry.	• Identify bores and ensure effectiveness of backfilling.	Reduce interconnection between aquifers and aquitards within the underlying units.
Altered hydrochemistry	Spills or leaks of construction vehicle oils and fuels on surface can alter the shallow groundwater quality and impact on neighbouring users.	• Ensure bunded areas, oil traps, spill response, groundwater monitoring.	Prevent hydrocarbon contamination of groundwater and soil, and plume migration off site.
Operation			
Altered hydrogeology due to induced flow	Dewatering of coal seams can induce flow from surrounding units, potentially causing dewatering and reduction in shallow groundwater levels.	• Geological assessment, monitor hydrochemistry, determine potential for GAB dewatering and implement water replacement plan.	Reduce dewatering impacts on overlying and underlying aquifers.
Altered hydrogeology due to interflow in CSG wells	Drilling can connect aquifers separated by aquitards; this can allow for changes in hydrochemistry and increased dewatering impacts.	• Construct production wells to prevent interconnection, well integrity checks to ensure seals.	Prevent alteration to GAB aquifers through interflow.
Loss of shallow groundwater resources	Dewatering of groundwater resources can potentially impact on current users.	• Low probability, implement monitoring of neighbouring bores within shallow groundwater. Monitoring groundwater levels and identify natural fluctuations. • Identify local groundwater use and Groundwater Dependent Ecosystems (GDE) associated with shallow groundwater.	Identify possible impacts of deep dewatering on shallow groundwater.
Alteration of shallow groundwater quality	Artificial recharge with associated water can alter the hydrochemistry of the shallow groundwater.	• Correct dam design and size, monitoring up and down gradient, install toe dams, minimise water volumes, backfill	Prevent spills and leaks which can alter hydrochemistry.

Aspect	Potential Impact	Mitigation Measures	Objective
	Brine material generated during treatment stored on site can impact on the shallow groundwater.	bores.	
	Spills or leaks of potential contaminants on surface can possibly alter the shallow groundwater quality and impact on neighbouring users.	• All fuel, oil and chemicals storage facilities to be bunded. • All industrial waste storage tanks to be bunded. • Bunds to be inspected regularly for evidence of leakage. • Spills to be reported and immediately contained. • Contaminated soil to be removed and remediated. • Contaminated water (e.g. stormwater in bund) to be treated. • All vehicles, plant and equipment to be checked regularly for integrity of fuel tanks. • Monitoring and maintenance programs to be undertaken as required. • Refuelling to occur in bunded areas away from watercourses (> 50 m). • Spill cleanup kits in accordance with Australian Standards (AS1940 and AS3780) to be located in convenient locations and all work vehicles. • Refuelling to occur in bunded areas. • Develop and implement a water quality monitoring program, including telemetry and event based grab water samples, to further refine mitigation measures.	
	The storage or disposal of waste generated during the CSG operations and activities can potentially impact on the groundwater.	• Refer to above.	
	Sanitation systems associated with the accommodation and plants on site can potentially impact on the shallow groundwater.	• Correct waste management and disposal using licensed waste firm.	Reduce contamination threat potential.
Altered groundwater flow	Seepage or spills from the associated water containment infrastructure can cause	• Correct pond design and size, lined base, monitoring.	Prevent alterations to groundwater resources,

Aspect	Potential Impact	Mitigation Measures	Objective
patterns	increases in the shallow groundwater level (mounding), which will allow for flow away from the containment ponds.		quality and quantity.
Treated water	Increased recharge to the alluvium aquifers will occur if treated water is discharged into the adjacent creeks, this could result in erosion and a reduction of alluvium material and impact post closure on the alluvium aquifer resources.	• Determine suitable discharge methodology to prevent scouring. • Monitor hydrochemistry and receiving water bodies.	Reduce potential for loss of alluvium material.
	The treatment of CSG water will allow for additional irrigation water which allows for additional recharge and the mobilisation of nutrients into the shallow groundwater.	• Monitor background water quality and water levels, determine salinity of soils and ensure groundwater levels do not rise into possible salt accumulation zones.	Assess possible impacts of increased return flow due to irrigation.
Decommissioning			
Salinity impacts on groundwater	Disturbed pond footprints can act as sources of salinity to shallow groundwater.	• Correct design, continue dam use, composite linings will be utilised in the ponds, rehabilitation.	Reduce long term impacts on groundwater quality.

6.6.2 Groundwater (Deep Aquifer Modelling)

6.6.2.1 Introduction

Santos' future CSG field development program will involve the removal of methane gas from the coal seams after it has been desorbed from the coal by a reduction in the surrounding water pressure. This pressure reduction is achieved by extracting groundwater from wells in the area, through the reduction in hydrostatic head. The drawdown of groundwater heads within CSG aquifers is a necessary process and an unavoidable impact associated with the depressurisation of the target coal seam.

Matrixplus Consulting developed groundwater flow models capable of simulating existing conditions and predicting the potential groundwater impacts of CSG production. The groundwater assessment of the CSG fields allowed for the characterisation of the existing deep groundwater environment and the assessment of potential groundwater related impacts caused by CSG extraction from the deep aquifers.

6.6.2.2 Methodology

The study included an assessment of the baseline groundwater environment through the use of available geological and hydrogeological data, including the DNRW database. A review of previous groundwater modelling assessments for the Fairview CSG field was conducted. Conceptual models were prepared for the hydrogeology within the RFD area. The model constructed for Fairview and Arcadia Valley CSG fields also included the effects of the neighbouring Spring Gully CSG field.

A review of the relevant groundwater legislation was conducted with regards to CSG extraction. It was concluded that impacts on groundwater resources associated with the CSG field development program must be mitigated through compliance with legislative requirements to ensure environmental due diligence is occurring.

Potential impacts due to the drawdown of groundwater heads in the coal seam aquifers were identified. These potential impacts included drawdown of groundwater head levels within CSG aquifers, drawdown of groundwater head levels within overlying and underlying aquifers, reduction of landholder and town water supply bore yields located in the study area, reduction in spring flow and baseflow of streams, and subsidence of the land surface overlying the CSG fields.

In order to test the likely impact of significant depressurisation of coal measures within RFD area, conceptual and mathematical models of groundwater flow were developed. Conceptual models for both areas were developed by considering geologic frameworks, hydrologic frameworks, current groundwater users for all fields, and hypothetical future rates of use.

In the case of Roma, an analytical model was considered suitable, largely due to the scarcity of the CSG field data and the comparatively simple geologic geometry. Owing to the comparatively greater complexity of the geometry of the Arcadia Valley and Fairview CSG fields and the greater availability of field data, a numerical model of groundwater flow was constructed based on the MODFLOW groundwater flow simulation program.

A sensitivity analyses was completed and dewatering simulations were undertaken using the groundwater models.

6.6.2.3 Regulatory Framework

An outline of the groundwater regulatory framework is provided in Section 6.6.1.3 and Appendix P1.

6.6.2.4 Existing Environmental Values

The environmental values considered by the modelling of the deep aquifers have been assessed according to the values identified in the EPP Water 2008. A brief description of aquifer values is given below. For specific discussions refer to Appendix P2.

In the Fairview CSG field groundwater is utilised for domestic consumption, irrigation use, and stock watering purposes and is derived predominately from the Hutton and Precipice Sandstone aquifers. Some groundwater is derived from the Clematis Sandstone in the Arcadia Valley CSG field. Groundwater also discharges to perennial surface water bodies such as streams and mound springs from these aquifers. Potential impacts of groundwater abstraction for CSG activities on these aquifers were considered. Modelling predictions indicate that only groundwater resources related to the Precipice Sandstone could be impacted in the Arcadia and Fairview CSG fields.

In the Roma CSG field groundwater is used for domestic consumption and stock watering purposes and is derived predominantly from the Mooga and Gubberamunda Sandstone aquifers. The Mooga and Gubberamunda Sandstone aquifers provide the only current source of groundwater supply for urban purposes for Roma and towns in the surrounding area. As a result of the current demands on the Mooga and Gubberamunda Sandstone aquifers, it is anticipated that additional future supplies will be required to be drawn from the deeper Hutton Sandstone. The Hutton Sandstone underlies the Walloon Coal Measures and is relatively undeveloped in the Roma area due to its depth. Whilst the current entitlements and use are very small for the Hutton Sandstone proximal to the Roma field, future extraction needs to be monitored as this aquifer extends beyond the Roma field and it is often used in these locations along with the Hutton Sandstone. Model predictions indicate possible depressurisation within the Hutton Sandstone aquifers due to dewatering of the Roma CSG coal seam aquifers.

Other environmental values associated with the quality of groundwater and its discharge to the surface is discussed in the previous sub-section on groundwater (shallow aquifers).

6.6.2.5 Potential Impacts and Mitigation Measures

The deep aquifer modelling study was conducted to assess the impacts of groundwater abstraction within the coal seams underlying Santos' CSG fields. The modelling allowed for the simulation of groundwater abstraction during the CSG field operations. The drawdown of groundwater heads within CSG aquifers is a necessary process and an unavoidable impact associated with the depressurisation of the target coal seams. Potential impacts as predicted by the models include:

- To enable desorption of the gas from the coal, pressure in the coal seam must be lowered. The amount of pressure reduction required is dependent both on the elevation of the coal seam, the ambient coal seam water pressure and the properties of the coal, but can be up to around 6,000 KPa (equivalent to 600 m of water "head").
- This does not infer that the water table at this location will drop by the corresponding amount. The drop in water pressure in overlying and underlying aquifers is a function of the amount of induced pressure drop in the coal seam, the permeability of the intervening rock layers, the thickness of the rock layers and time. For GLNG, estimates have been made of the potential impacts on neighbouring aquifers. Based on the presently available data, the impacts will be generally low. Santos is implementing an intensive water monitoring program to enable forecast of pressure drops in aquifers long in advance of such pressure drops causing an observable impact.
- In the Arcadia Valley and Fairview CSG fields (which were modelled in conjunction with the neighbouring Spring Gully CSG field) the radius of influence within the coal seam aquifer is expected to spread outside the perimeter of the CSG fields.
- Groundwater drawdowns in the coal seam aquifers within the Arcadia Valley and Fairview CSG fields are expected to result in inter-aquifer transfer with the overlying Precipice Sandstone. Groundwater head loss within the Precipice Sandstone could range up to a maximum of 15 m at the end of 2013 and up to a maximum of 65 m at the end of 2028 (these predictions include the effect of the Spring Gully CSG field) No impact on the other aquifers, Hutton and Clematis Sandstone, are predicted in the Arcadia and Fairview CSG fields.
- It is anticipated that four existing bores which are drilled into the Precipice Sandstone aquifer may be impacted by the groundwater drawdowns in the coal seam aquifer within the Arcadia Valley and Fairview CSG fields. One bore (DNRW record 14988) is located inside the CSG fields and the other 3 (DNRW bore records 16091, 14838, and 16785) are situated outside the CSG fields. It is

anticipated that these bores will be impacted by a maximum 7 to 25 m drawdown in groundwater level by 2028 depending on their locations within the area of influence.

- In the Roma CSG field, the radius of influence of drawdown within the coal seam aquifer is expected to be confined to an area proximal to the CSG fields.
- Groundwater drawdowns within the Roma CSG field are expected to result in minor inter-aquifer transfer with the underlying Hutton Sandstone. Groundwater head loss within the Hutton Sandstone is predicted to decline by approximately 3 m at the edge of the CSG fields and by lesser values further out from the CSG fields No impact on the Mooga and Gubberamunda Sandstone aquifers within the Roma CSG field are predicted.
- No landholder bores are expected to be impacted as a result of groundwater withdrawal from the Roma CSG field.
- No town water supply bores are likely to be impacted as a result of groundwater withdrawal from the Roma CSG field or from the Fairview and Arcadia Valley CSG fields.
- Drawdown of groundwater heads within the Precipice Sandstone as a result of extraction at Arcadia Valley and Fairview CSG fields is not expected to significantly alter the baseflow contributions to the perennial portion of the Dawson River and groundwater discharge volumes to springs located in the vicinity.
- Groundwater drawdown and associated inter-aquifer transfer is unlikely to have an adverse impact on the water quality of the CSG coal seam aquifers and the deep aquifers surrounding the CSG fields.

Cumulative Impacts

Refer to Section 6.6.1.5.

Table 6.6.2 provides a summary of potential groundwater (deep) impacts and mitigation measures for the CSG fields.

Table 6.6.2 Potential Groundwater (Deep) Impacts and Mitigation Measures

Aspect	Potential Impact	Mitigation Measures	Objective
Operation			
Dewatering of coal seam aquifers	Drawdown of groundwater head levels within CSG aquifers.	• Monitor any groundwater users within the coal seam aquifers, determine trigger levels and implement water replacement plans.	Reduce the impact of dewatering on any groundwater users with bores screened in affected aquifers.
	Drawdown of groundwater head levels within overlying and underlying aquifers.	• Monitor groundwater levels in selected GAB units, optimum injection to reduce drawdown extent, quarterly water level measurements, biannual hydrochemical monitoring.	Reduce the extent of dewatering within the GAB aquifers.
	Reduction of landholder bore yields within and surrounding CSG fields (due to lower groundwater heads) where the landholder extracts groundwater from impacted aquifers.	• Conduct water level measurements biannually, undertake bore census within 30 km radius of the CSG field boundaries, submit annual comparison of monitored water level data to predicted water levels, determine trigger levels and implement water supply restoration measures as necessary. These measures include: – Lower pump inlet in affected bore – Drill new bore outside zone of influence – Provide alternative supplies – Compare to trigger values and if required implement water replacement plan and possible compensation	Reduce the impact of dewatering on surrounding groundwater users.
	Alteration of groundwater quality due to induced flow.	• Develop and implement a program to monitor aquifer quality bi-annually.	Verify no deterioration in groundwater quality due to induced flow.
	Reduction in spring flow and baseflow of streams by reducing the groundwater discharge to those features.	• Develop and implement a program to monitor surface water flows.	Verify predicted limited reduction in baseflow due to dewatering.

Aspect	Potential Impact	Mitigation Measures	Objective
	Subsidence of the land surface overlying the CSG field.	• Develop and implement a program to monitor possible land subsidence subject to further geological investigation undertaken as part of the future field development programs.	Verify land subsidence does not occur due to coal seam dewatering.
Storage of associated water	Contamination of shallow aquifers and surface waters surrounding CSG water storage facilities via leakage of associated water storages.	• Refer to shallow groundwater mitigations.	Reduce artificial recharge and potential contamination of shallow groundwater.
Decommissioning			
Groundwater rebound within the coal seams	Continued dewatering of GAB aquifers after pumping ceases due to induced flow into dewatered coal seam aquifers, long term alteration of flow patterns.	• Model predictions of groundwater rebound and final extent of drawdown cones to be done in future based on monitoring data, implement aquifer injection to reduce head loss.	Duration and extent of dewatering needs to be determined to accurately predict all impacts and develop suitable mitigation measures.

6.6.2.6 Summary of Findings

A desktop review and field assessment of the shallow (near surface) formations indicate that there are both non-aquifers and minor shallow groundwater aquifers developed within the CSG fields. The majority of shallow formations have negligible permeability and are generally regarded as not containing groundwater in exploitable quantities. Groundwater quality renders the aquifers unusable or of limited suitability for use. However, groundwater flow is recognised to occur within the non-aquifers, although imperceptible, and can allow the migration of contaminants from persistent pollutants. Records indicate that groundwater potential has been enhanced along areas of secondary processes, such as faulting, fracturing, etc., which has allowed for the development of discrete minor shallow aquifers within the CSG fields. The shallow aquifer extent is envisaged to be limited and groundwater quality is variable. Although these aquifers seldom produce large quantities of water, they are important for local stock watering supplies. Based on the aquifer types present and the variable salinity, an evaluation of the aquifer vulnerability indicates that limited to low levels of groundwater protection are required for these aquifers.

Santos' CSG operations will involve the removal of methane from the coal seams after it has been desorbed from the coal by a reduction in the surrounding water pressure. This pressure reduction is achieved by extracting groundwater from wells in the area, thereby reducing the hydrostatic head of the groundwater system. The drawdown of groundwater heads within CSG aquifers is a necessary process and an unavoidable impact associated with the depressurisation of the target coal seam.

Groundwater flow models capable of simulating existing conditions and predicting the potential groundwater impacts of CSG production were developed. The groundwater assessment of the CSG fields allowed for the characterisation of the existing deep groundwater environment and the assessment of potential groundwater related impacts caused by CSG extraction from the deep aquifers. Modelling outputs included predicted drawdowns within the coal seam aquifers and adjacent aquifers due to induced flow. Affected aquifers and zones of influence were determined allowing for risk assessments, which were compiled to evaluate potential impacts associated with the proposed CSG field expansion and associated infrastructure on the groundwater resources. The risk assessment aimed at providing information regarding the management of recognised impacts and allowing for the optimum management to mitigate the impacts.

A summary of mitigation measures around shallow/deep groundwater included continued monitoring and surveys of the groundwater within the CSG fields and surrounding 30 km of the CSG fields. It is recommended that Santos submit an annual comparison of monitored water level data to predicted water levels, determine trigger levels and implement water supply restoration measures as necessary. These measures include:

- Lower pump inlet in affected bore;
- Drill new bore outside zone of influence;
- Provide alternative supplies; and
- Compare to trigger values and if required implement water replacement plan and possible compensation.

Further monitoring of water quality and quantity will need to be developed for irrigation and treated water release to streams which have the potential to recharge shallow/deep aquifers.

Also to reduce the possibility of interconnection of aquifers well construction will have to ensure the integrity of the seals between aquifer.

Injection of water into aquifers which have been subjected to loss of head due to coal seam depressurisation will be selectively implemented to reduce the area of influence of the CSG production on aquifer drawdown.