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QGC - A BG GROUP BUSINESS

Groundwater Study - Northwest Development Area

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REPORT

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EXECUTIVE SUMMARY

The Project

QGC – A BG Group business (QGC) is proposing to expand its Coal Seam Gas (CSG) field in the Chinchilla area of southern Queensland. The extended CSG field is divided into three development areas: the North West Development Area (NWDA); the Central Development Area (CDA); and the South East Development Area (SEDA).

The CSG field reserve is located in the Jurassic Walloon Coal Measures of the Surat Basin, which lies within the eastern-most portions of the Great Artesian Basin (GAB). The associated water extracted during CSG production can be high volume and low quality, which presents environmental risks and requires careful management.

The extraction of CSG associated water will have an impact on the groundwater levels in the Walloon Coal Measures, and the Hutton, Precipice, Gubberamunda and Springbok Sandstone aquifers. Little or no impact will occur in the shallow aquifer system. Surface water flow such as base flow to the rivers and to wetland areas will not be affected by the dewatering of the Walloon Coal Measures.

The Project was declared a significant Project in July 2008, under the *State Development Public Works Organisation Act 1971 Qld* (SDPWO Act) (Section 26). An Environmental Impact Statement (EIS) is required, as part of the significant Project declaration. To assist in the development of the EIS, Golder Associates Pty Ltd (Golder) was commissioned by QGC to examine the effects of the *CSG Field* component of the Project on surface water and groundwater resources (Golder 2009a and b).

Subsequent to the submission of the draft EIS, QGC acquired additional tenements within the boundaries of their North-West Development Area (NWDA). This document provides an assessment of the groundwater conditions focussing on the NWDA tenements only. It is a stand alone document; however, is based on and references the Project-wide study (087633050 016 R Rev2, Golder 2009a).

The Existing Environment

The Project lies in the Surat Basin which falls within the eastern-most portions of the Great Artesian Basin (GAB), one of the largest artesian groundwater basins in the world. It is also located in or adjacent to three of the 25 GAB groundwater management areas' in Queensland: Surat East, Surat North and Surat. Certain management and monitoring requirements follow from the Projects location within these management areas.

The NWDA is located largely within those portions of the low undulating planes of the Condamine and Balonne River catchment which are present in the north western portion of the Project Area. Most of the existing natural environment consists of areas that have been moderately modified by agricultural and pastoral activities; however, a number of state forests are also located throughout the southern regions of the NWDA.

The climate of the Project Area is subtropical with dry winters. Precipitation is irregular but intense at times, and flooding occasionally occurs. Predictions indicate that climate change may cause a 30% increase in precipitation intensity in peak tropical cyclone precipitation and increase existing average runoff by 10%.

In the Surat Basin the stratigraphic sequence is dominated by Cretaceous and Jurassic age sedimentary formations comprised of fluvial quartzose sandstones, siltstones, mudstones and lutites, and which include numerous coal seams. The latter a particularly well developed in the Walloon Coal Measures (WMC) sequence, which are the target resource for the proposed QGC CSG operation on the Project Area, including the NWDA. Overlying these bedrock sequences, it is typical to encounter an irregular veneer unconsolidated alluvial sediments of Recent, Quaternary and Tertiary ages.

Two primary hydrogeological systems exist in the Project Area. The upper, shallow, unconfined aquifer system contains surficial sediments, Quaternary unconsolidated alluvial sediments, and some Tertiary formations. Beneath this lies the Surat Basin aquifer system comprising Cretaceous and Jurassic sandstone aquifers including the Bungil, Mooga, Gubberamunda, Springbok, Hutton and Precipice Sandstones.

The groundwater regimes in the NWDA are characterised by groundwater pressures (or levels) in most aquifers (including the Gubberamunda, WMC and the Hutton) ranging between 180 m and 300 m AHD within the tenements areas. The direction of groundwater flow is generally down dip towards the south and south-west. Low groundwater gradients exist between adjacent aquifers, with a typical downward direction of groundwater flow. Groundwater quality ranges from fresh to brackish. The WCM coal seams contain moderate to high salinity groundwater.

Many of the aquifers are already over abstracted or approaching sustainable abstraction levels.

Three key structural features exist in the NWDA. The Leichhardt-Burunga Fault is a fault structure which separates the NWDA from the eastern half of the Project Area; the Mimosa Syncline is a broad and open extensive synclinal fold structure affecting the western portion of the NWDA; and the Wallumbilla Fault, fault structure, which together with the Arcadia Anticline marking the western boundary of the NWDA. These structures are inferred to partially or complete hydraulically isolate the NWDA from the surrounding portions of the Surat and Bowen Basins.

Environment Values

The Environmental Values associated with the groundwater in the Project Area include:

- Primary, secondary and visual recreation amenity of surface water bodies within the Project Area;
- Anthropogenic groundwater uses such as drinking water supply, and uses such as irrigation of crops and pastures, and farm or domestic water supply for stock watering
- Industrial water, many industrial water applications, applicable in the NWDA, are relatively sensitive to the reliability of supply, and may also have a limited tolerance range for variations in water quality;
- Aquatic ecosystems including the intrinsic groundwater environment and stygofauna, and where the groundwater interacts with the surface water such as supply of base flow to rivers, streams, wetlands, and springs;
- Other uses include irrigation of recreational areas such as parks and gardens, aquaculture, and cultural and spiritual values.

Within the NWDA groundwater is mostly used for irrigation and stock watering. Irrigation water demand is predicted to increase over time. Increasing industrial uses for the water are groundwater sources.

Potential Impacts

CSG associated water abstraction in the NWDA has the potential to affect a number of environmental values through:

Potential impacts to the groundwater system, related environmental values, neighbouring users, and the ecosystem have been examined. The assessments have involved the development of a regional conceptual groundwater model, supplemented by the development and application of an idealised numerical groundwater model of the region. The predictive model was then used to estimate, at ‘order of magnitude’ level of accuracy, the potential drawdowns which the aquifers in the region might experience, arising from the QGC CSG operations.

General Comments on Predicted Impacts

Groundwater drawdown impacts, within the 5 key aquifer units identified as vulnerable (the Precipice, Hutton, Springbok and Gubberamunda sandstone and the WCM), can be summarised as follows (with specific comments for each development area following):

- The magnitude of drawdown decreases with distance from the CSG wellfield boundaries;
- The magnitude of drawdown decreases gradually after cessation of the CSG groundwater pumping. Note: water levels will continue to decline in adjacent affected aquifers for a considerable period of time follow cessation of pumping due to delayed leakage;
- Drawdown is greatest beneath the depressurisation area (idealised representation of the CSG wellfield areas, i.e. the area bounded by the tenement boundaries);
- The modelled potential maximum parameter set (high end hydraulic conductivity, storage and lowest K_v/K_h ratio simulations) is typically associated with the maximum predicted drawdown and the modelled potential minimum parameter dataset is associated with the minimum predicted drawdown;;

Predicted Aquifer Impacts

WCM

- Estimated drawdown in the WCM was as defined by the final model depressurisation pressure head (approximately 70m above the top of the WCM), which at the extraction area boundary equates to the maximum specified drawdown to achieve optimal CSG desorption; and
- Recovery of the aquifer is predicted to commence immediately, but very gradually, after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years);

Springbok Aquifer

- Water level impacts are predicted to be greatest within the Springbok Sandstone aquifer largely because it has been modelled as being in good but patchy hydraulic contact with the WCM units - which are being depressurised for CSG recovery (i.e. no laterally extensive aquitard layer separates the Springbok Sandstone aquifer from the WCM unit);
- Specifically, drawdown in the Springbok Sandstone is predicted to range from less than 0.5 m to an expected maximum of approximately 2 m immediately outside of the depressurisation area boundary, i.e. the boundary of the tenements (for convenience this is defined in the model as 1.8km from the edge of the depressurisation zone);
- At a nominal distance of 10 km and 20 km from the depressurisation boundary, drawdown impacts are likely to reach a potential maximum of 0.4m and 0.1m, respectively;
- Recovery of the aquifer is predicted to commence 75 years after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years, being 40 years of operation plus 150 years of modelled recovery); and
- The predicted maximum drawdown in the Springbok Sandstone in the NWDA is less than the CDA and SEDA. This is because the NWDA is deeper (tighter fracture permeability) and is significantly less structurally affected than the other development areas.

Hutton and Precipice Aquifers

- The predicted maximum drawdown in the Hutton Sandstone and the Precipice Sandstone aquifers is insignificant, being predicted to be less than approximately 0.1m during the 190 years of CSG pumping and recovery;
- Recovery of the aquifer is not predicted to have started within the 190 years of modelling; and
- The magnitude of modelled maximum drawdown (and its recovery), at the levels predicted, are not considered discernable within the natural fluctuation of the deep groundwater systems operating in these aquifers.

Gubberamunda Aquifer

- The Gubberamunda aquifer is least affected by extraction of groundwater from the WCM, with predicted drawdowns being modelled as negligible (or not within the resolution of the model) – largely due to the large intervening thickness of aquitard layers.

Other conclusions reached include:

- The risk of inter-aquifer flows arising from bore design or poor bore construction techniques is very low.
- It has been estimated that there will be a low potential impact on water levels in the local unconfined aquifers and underlying “Intermediate” aquifers. Nevertheless, close monitoring of this hydrogeological domain is recommended so as to develop an understanding of the relationship between rainfall, runoff and recharge to the aquifer and hence separate the potential impacts of future drought from those associated with the CSG operations.
- Trigger levels have been established for each of the key hydrogeological units (aquifers) considered likely to be impacted. If groundwater levels/pressures were to reach these trigger levels, provisions might be activated (e.g. more intensive monitoring, detailed hydrogeological assessment, and if CSG extraction impacts are deemed to be the cause, to “*make good”* any affected groundwater supplies (if any exist within the impacted area).
- Water quality changes have been determined to be less likely in the aquifers described in this impact assessment (the groundwater quality regionally and between aquifers has been found to be sufficiently similar). If significant groundwater migration does occur due to inter-formational flow induced by CSG depressurisation of the WCM, significant changes in aquifer water quality within aquifers being used by neighbours is considered to have a low probability of occurrence.
- Owing to the generally low to insignificant impacts expected on the water table aquifers (shallow alluvial aquifers) in the Study Area, any measurable impact on the baseflow to the local river systems is unlikely to occur.

Cumulative impacts from Adjacent Projects

While the model provides a reasonable representation of aquifer behaviour in the NWDA region, it does not directly take into account the cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these activities are not currently known, and as such, have been treated here in a qualitative manner based on the inferred impacts presented by the proponents for each project.

- The proposed *Wandoan Coal Project* (WCP) is likely to draw down local water levels by between some 40m and 60m (within their tenement and common tenement areas held by QGC). Further, this dewatering effect will induce a limited halo of drawdown outside their tenement and, again, this will impact QGC tenure areas locally. Golder consider that this affect will be largely indistinguishable from the CSG extraction when considered in relation to the impacts of the key aquifers (where present);

- *UCG operations, such as those proposed by Cougar Energy* and potentially *Cockatoo Mining Limited,* target coal seams at deeper depth than the proposed WCP open pit depth, and may impact groundwater levels at common tenement boundaries. NOTE: UCG operations typically do not drawdown water levels within the target aquifer/s (in this case the Macalister Seam) to quite the same degree as required for CSG extraction (no specific information of these impacts is available at this time); and

- Again, only ongoing monitoring will provide concrete evidence of these hypotheses (refer to Section 9.5.1, and to the Groundwater Monitoring Plan, Golder, 2009d)

In summary, the predictive groundwater modelling suggests that there is a low to moderate risk to the local environment values (particularly neighbouring groundwater users and/or the ecosystems) likely to ensue from the development and future operation of the proposed QGC CSG wellfields in the NWDA.

Mitigation Measures and Monitoring

To manage the potential impacts of lowering groundwater tables on other users, trigger levels have been established for each of the principal hydrogeological units (aquifers). These act as early warning systems to activate management measures to reduce the likelihood of impacts happening. If trigger levels are reached, provisions that might be activated include: more intensive monitoring, detailed hydrogeological assessment, and providing alternative water supplies to replace the affected groundwater.

If other water users are demonstrated to be impacted by CSG operations, either in terms of a significantly reduced bore yield, or a degradation of water quality so that it was unsuitable for its intended use; actions would be considered in conjunction with the water user, bore owner and regulatory authorities. The actions that could be taken include one or more of the following:

- Re-set the pump at a deeper level within the bore to access further available water column;

- Deepen the bore to provide access to an aquifer of suitable quality and yield that is less impacted by CSG operations;

- Install 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;

- Provide bulk water of suitable quality to the bore owner to compensate for loss of yield in their water supply bore. This supply could include treated associated water; and

- Provide monetary compensation to the bore owner equivalent to the loss incurred due to the diminished bore yield or water quality such as the value of the loss of agricultural productivity.

Appropriate drilling and well installation techniques can prevent or reduce inter aquifer flow impacts.

Leakage or over-topping of the CSG water containment or evaporation ponds at surface could pose a risk to the water quality of the shallow groundwater system. The risks could be managed by a combination of monitoring and careful water management involving pond lining, seepage interception drains and groundwater monitoring. This is considered in more detail in the surface water report.

A robust monitoring plan (Golder 2009d) has been prepared and is to be implemented for the entire Project Area, including the NWDA. This will enable complete documentation of baseline conditions, to allow the changes to water levels in the aquifers or inter aquifer flow to be assessed and contingency actions to be implemented in a timely manner. The program includes monitoring of each of the primary aquifer zones; the Alluvial, Springbok Sandstone, Gubberamunda Sandstone, WCM, Precipice Sandstone, and Hutton Formation aquifers.

Ideally, once additional monitoring data is available from the GWMP program, the predictive groundwater model developed for this study should be updated or a higher resolution numerical groundwater model developed - using the new monitoring data and refined hydrogeological parameters, and adapted to ensure the model stays realistic. Inclusion of the impacts of other neighbouring CSG producers, coal mining operation and underground coal gasification operations (currently proposed for overlapping and/or adjacent tenements) should be carried out to quantify the cumulative impacts on the system. Such modelling is recommended to be undertaken in collaboration with the other CSG producers, miners and the regulators, Queensland Department of the Environment and Resource Management (DERM, previously the NRW and EPA).

(GWMP, Golder 2009c) and will be used as baseline data for the assessment of future monitoring and management needs. The results will also be presented as part of the *Underground Water Impact Report* [in preparation] and 2009 *Annual Return*, as required under the P&G Act.

In the event that monitoring results indicate that a bore owner has been ‘unduly impacted’ by CSG operations in the NWDA 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 “make good” actions will be considered in conjunction with the bore owner and regulatory authorities, in order of preference:

- 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; or
- providing 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).

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GLOSSARY

Item	Definition
1 barrel	1 barrel = 159 litres (approx.) = 42 U.S. Gallons = 35 Imperial Gallons (approx.)
Adsorption	The attraction and adhesion of ions from an aqueous solution to the surface of solids.
AHD	Australian Height Datum
Alluvial	Of, or pertaining to, material transported by water.
Alluvium	Sediments deposited by or in conjunction with running water in rivers, streams, or sheetwash and in alluvial fans.
Analytical model	A mathematical model that provides an exact or approximate solution of a differential equation (and the associated initial and boundary conditions) for subsurface water movement or transport.
Anisotropy	The conditions under which one or more of the hydraulic properties of an aquifer vary with direction. (See also isotropy).
Anticline	A fold that is convex upward or had such an attitude at some stage of development. In simple anticlines the beds are oppositely inclined, whereas in more complex types the limbs may dip in the same direction. Some anticlines are of such complicated form that no simple definition can be given. Anticlines may also be defined as folds with older rocks toward the centre of curvature, providing the structural history has not been unusually complex.
Aquiclude	A geologic formation which may contain water (sometimes in appreciable quantities), but is incapable of transmitting significant quantities under ordinary field conditions.
Aquifer	[A] a consolidated or unconsolidated geologic unit (material, stratum, or formation) or set of connected units that yields a significant quantity of water of suitable quality to wells or springs in economically usable amounts. Several types of aquifers are distinguished: *confined* (or artesian) - an *aquifer* overlain by a confining layer or *aquitard* (layer of low *permeability*) that restricts the upward movement of water. A confined aquifer does not have a water table. In a confined *aquifer* there is no *watertable* because the *aquitard* prevents water from rising (i.e. the *piezometric head* is above the *aquifer*). *leaky/semi-confined* – (i) an aquifer that receives recharge via cross-formational flow through confining layers. (ii) an *aquifer* overlain by a layer that partly restricts the upward movement of water. *perched* - a local, unconfined aquifer at a higher elevation than the regional unconfined aquifer. An unsaturated zone is present between the two unconfined aquifers. Or a sub-surface material containing *perched groundwater*, separated from a deeper *aquifer* by unsaturated materials. *unconfined* (or water-table) – (i) the upper surface of the aquifer is the water table. Water-table aquifers are directly overlain by an unsaturated zone of a surface water body. (ii) an *aquifer* containing water that is not under pressure; the upper boundary is the top of the *zone of saturation*. In an unconfined aquifer, the water level in a well is the same as the *watertable* outside the well. See also Aquitard, and Aquiclude.
	[B] (i) A layer of geologic material that contains water. (ii) A zone, stratum, or group of strata that can store and transmit water in sufficient quantities for a specific use.

Item	Definition
	[C] A geological formation comprising layers of rock, unconsolidated deposits or *regolith* that is capable of receiving, storing and transmitting significant quantities of water. The term is usually applied to saturated materials that currently contain water.
Aquifer system	Intercalated permeable and poorly permeable materials that comprise two or more permeable units separated by aquitards which impede vertical groundwater movement but do not affect the regional hydraulic continuity of the system.
Aquitard	A semi-pervious geologic formation which can store water but transmits water at a low rate compared to the aquifer.
Artesian aquifer	a confined aquifer in which the piezometric head sits above the ground surface so that the pressure causes water to flow freely from bores drilled into the aquifer.
Average annual recharge	Is the volume of water added to the groundwater source naturally, usually by infiltration from rainfall and river flows, and assessed on a long-term average basis. This recognises that the amount of recharge to a groundwater source can vary from year to year depending on climatic conditions.
Barrel (bbl)	The unit of volume measurement used for petroleum and its products (1 bbl = approximately 42 US gallons or 158.9873 (159L).
Base flow	Part of the discharge which enters a stream channel mainly from groundwater (but also from lakes and glaciers) during long periods when no precipitation (or snowmelt) occurs.
Basement	A general term for the solid rock that lies underneath the soil and other unconsolidated material. Also known as bedrock. When exposed at the surface it is referred to as outcrop.
Basin	A depression of large size in which sediments have accumulated.
BCF	Billion cubic feet (1 BCF = approximately 1.08 PJ).
Bedrock	a general term for the solid rock that lies underneath the soil and other unconsolidated material. Also referred to basement. When exposed at the surface it is referred to as rock outcrop.
bgl	Below Ground Level.
Boundary condition	specified conditions at the edges or surfaces of a groundwater system
Catchment	(a) Area of land that collects rainfall and contributes to surface water (streams, rivers, wetlands) or to groundwater. (b) The total area of land potentially contributing to water flowing through a particular point.
CDA	Central Development Area
Cleat	The vertical cleavage or fracture plane in coal seams. There are usually two cleat systems developed perpendicular to each other. The main set of joints along which coal breaks when mined. They provide the predominant pore space within the coal mass and can provide void space and a conduit plane for groundwater movement and storage.
Coal seam	A layer, vein, or deposit of coal.
Coal seam gas (CSG)	Natural gas (mostly methane) contained within coal.
Completed	Defines which aquifer the well screened is positioned opposite
Contour	an imaginary line on the surface of the earth connecting points of the same elevation (i.e. the same height above sea level).

Item	Definition
Dam	a barrier, embankment or excavated earth structure constructed primarily to impound water for storage. Dams are generally built in or near *drainage* lines. Dam walls can range from large concrete structures such as the Wellington Dam to the small earthen walls typical of many farm dams. ECe measurements on a saturation extract paste from soil samples
Darcy's law	The mathematical relationship that governs the rate of flow of groundwater or other fluids, through porous media: a) Generalization for three dimensions The rate of viscous flow of water in isotropic porous media is proportional to, and in the direction of, the hydraulic gradient. b) Generalization for other fluids The rate of viscous flow of homogeneous fluids through isotropic porous media is proportional to, and in the direction of, the driving force. While it was established under saturated flow conditions, Darcy's Law may be adjusted to account for unsaturated and multiphase flow.
DERM	Queensland Department of the Natural Resources and the Environment (formally NRW, Department of Natural Resources and Water, - the functions of the NRW were combined with the EPA in April 2009 to form DERM).
Discharge	Water that moves from a *groundwater* body to the ground surface (or into a surface water body such as a lake or the ocean). Discharge typically leaves *aquifers* directly through *seepage* (*active discharge*) or indirectly *through capillary rise* (*passive discharge*). The term is also used to describe the process of water movement from a body of *groundwater*.
Discharge area	Where significant amounts of *groundwater* come to the surface, either as liquid water or as vapour by *evaporation*.
Drawdown	The lowering of a *watertable* resulting from the removal of water from an *aquifer* or reduction in hydraulic pressure.
Drill stem test (DST)	The controlled flowing of the fluids from a reservoir so that estimates of the flow rate and fluid type can be made. It is usually conducted for a short time only. It can be run in open hole or through perforations in a cased hole.
Electrical Conductivity (EC)	A measure of the ability of a medium to conduct electricity. EC is used often as a surrogate measure of salinity levels in water or soil as the conductivity of a solution generally increases in proportion with its salt content.
Effective porosity	The porosity contributing to the flow of water or the interconnected porosity.
Effects	Effects include direct effects and indirect effects. Direct effects are caused by the action and occur at the same time and place. Indirect effects are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems. Effect and impacts as used in this report are synonymous. Effects includes ecological such as the effects on natural resources and on the components, structures and functioning of affected ecosystems, aesthetic, historic, cultural, economic, social or heath, whether direct, indirect, or cumulative. Effects may also include those resulting from actions which may have both beneficial and detrimental effects.

Item	Definition
Elevation	A general term for a topographic feature of any size that rises above the adjacent land or the surrounding ocean bottom; a place or station that is elevated. The vertical distance from a datum (usually mean sea level) to a point or object on the Earth's surface; especially the height of a ground point above the level of the sea. The term is used synonymously with altitude in referring to distance above sea level, but in modern surveying practice the term elevation is preferred to indicate heights on the Earth's surface, whereas altitude is used to indicate the heights of points in space above the Earth's surface.
EPA	Environment Protection Agency, now part of Department of the Environment and Resource Management (DERM)
Equipotential (f)	In hydrogeology, equipotential is usually a line connecting points of equal hydraulic potential or hydraulic head. In general, in mathematics, chemistry and physics equipotential or isopotential refers to a region in space where every point in it is at the same potential.
Evaporation	The conversion of a liquid into a vapour. In the *hydrological cycle*, evaporation involves heat from the sun transforming water (held in surface storages in soil) from a liquid into a gaseous state. This allows the water to move from water bodies or the soil and enter the atmosphere as water vapour.
Evaporation basin	A shallow excavated earth tank or natural pond that can be used to store water (usually *saline*) and allow it to evaporate. For this reason, evaporation basins can be used as a method of disposal of *groundwater* that has been extracted from sub-surface *aquifers* or *deep drains*.
Evapotranspiration	The transfer of soil water to the atmosphere from vegetated land through the combined processes of *evaporation* from soils and *transpiration* from plants.
Exploration well	A well drilled to determine whether hydrocarbons are present in a particular area or structure.
Extraction limit	Is the average yearly volume that can be extracted from a water source by all access licences.
Fault	(a) A fracture in the Earth’s crust along which the rocks on one side are displaced relative to those on the other. (b) a fracture which has experienced translation or movement of the fracture walls parallel to the plane of the fracture
Fault line	a fracture or fracture zone of the Earth’s crust with displacement along one side in respect to the other.
Fault trap	A hydrocarbon trap which relies on the termination of a reservoir against a seal due to fault displacement.
Field	A geographical area under which an oil or gas reservoir lies.
Flow model	A digital computer model that calculates a hydraulic head field for the modelling domain using numerical methods to arrive at an approximate solution to the differential equation of groundwater flow.
Flow rate	The amount of surface water or *groundwater* flowing past a given point or line over a defined period of time. Measured as volume, depth or area of water per unit time.

Item	Definition
Flow system	Local a flow system transporting groundwater in which discharge and recharge occur within a few kilometres of each other. Flows may be permanent or temporary and the water is typically transported down a hill-slope through an unconfined aquifer that is relatively thin (<20 m) and close to the surface.
Flow velocity	The speed at which surface water or *groundwater* flows. Measured as a distance per unit time (e.g. mm/hr, or m/day).
Fluvial, fluviatile	Having originated by deposition within riverine environments (see Alluvial). Referring to processes occurring in a river.
Formation	(a) A unit in stratigraphy defining a succession of rocks of the same type. (b) A body of rock strata that consists of a certain lithology or combination of lithologies.
Fracture	a sub-planar discontinuity in a rock or soil formed by mechanical stresses.
Fracture skin	A coating of the fracture surface and/or the altered zone beneath the fracture surface which has different hydrogeological properties than the unaltered rock or sediment.
Fractured rock aquifers	Rocks that are capable of receiving, storing and transmitting significant quantities of water due to the presence of numerous cracks, fissures or fractures in what would otherwise be an *impermeable* material.
Fresh water -	Water with a salinity < 1000 mg/l; drinkable or potable water is implied.
GDE	Groundwater Dependent Ecosystem.
Geological time scale	The subdivision of millions of years of geologic time into Eras, Periods and Epochs, allowing the interpretation of stratigraphic relationships between rocks.
Geology	The science relating to the history and development of the Earth’s crust.
Geomorphology	The science of describing and interpreting *landform* patterns and processes of landscape formation.
Gigajoule (GJ)	1,000,000,000 joules.
Gravel	In general, gravel refers to sedimentary grains having a particle size of between 2 and 4 mm. The term is applied to grains that are larger than coarse sand but finer than pebbles.
Gravel pack, filter pack	Graded sand or gravel placed in the annular space of a groundwater installation to protect the screens or slotted casing adjacent to selected aquifer horizons.
Groundwater (ground water)	Water stored below the ground surface that saturates (in available openings) the soil or rock and is at greater than atmospheric pressure and will therefore flow freely into a bore or well. This term is most commonly applied to permanent bodies of water found under the ground.
Groundwater flow	The movement of water through openings in sediment and rock that occurs in the zone of saturation. Lateral groundwater flow - movement of *groundwater* in a non-vertical direction. *Lateral groundwater flows* are usually, although not always, more or less parallel to the ground surface.
Groundwater model	A simplified conceptual or mathematical image of a groundwater system, describing the features essential to the purpose for which the model was developed and including various assumptions pertinent to the system. Mathematical groundwater models can include numerical and analytical models.

Item	**Definition**
Guideline value	The concentration or measure of a water quality characteristic that, based on present knowledge, either does not result in any significant risk to the health of the consumer (health-related guideline value), or is associated with good quality water (aesthetic guideline value).
Head (hydraulic head, static head)	The energy contained within a column of water resulting from elevation or pressure. The static head is the height at which the surface of a column of water could be supported against the action of atmospheric pressure.
Hydraulic conductivity	(a) A measure of the potential rate of flow of a fluid through soil or rock. As such, it takes into account the nature of the fluid, the degree of saturation and the *permeability* of the material the fluid passes through. The hydraulic conductivity of a material can be measured in either the saturated or unsaturated states. The unsaturated hydraulic conductivity will change as a material becomes wetter, but the saturated hydraulic conductivity of a material remains constant. Hydraulic conductivity is expressed in units of length per unit time, typically millimetres per hour (mm/hour) or metres per day (m/day). (b) A coefficient of proportionality describing the rate at which a fluid can move through the interconnected pore spaces in a porous medium. The density and viscosity of the fluid must be considered in determining conductivity. (c) The volume of fluid that flows through a unit area of porous medium for a unit hydraulic gradient normal to that area; (d) The rate of horizontal groundwater flow through a unit area (1 x 1) of an aquifer under a unit hydraulic gradient (δh / δl = 1). Hydraulic conductivities are reported as m/day [L/T]. Values commonly range between 0.02 and 40 m/day for unconsolidated sand aquifers, less than 0.5 m/day for sandstone, and below 0.0001 m/day for clays or shale (see Hydraulic Gradient).
Hydraulic gradient	(a) The slope of the water table or potentiometric surface. The hydraulic gradient is determined from the decline in groundwater level (δh) at two measuring points divided by the distance between them (δl). (b) The change in hydraulic head with direction.
Hydraulic head (h)	The elevation in a well in reference to a specific datum; the mechanical energy per unit weight of water [L].
Hydrocarbons	Naturally-occurring organic compounds containing only the elements hydrogen and carbon that may exist as solids, liquids or gases.
Hydrogeology	The study of *groundwater* movement through soil, sediment or rock under natural or induced conditions.
Hydrological cycle	The continuous circulation of water between the land, sea (or other water surface) and the atmosphere.
Hydrology	The study of water and water movement in relation to the land. Deals with the properties, laws, geographical distribution and movement of water on the land or under the Earth's surface.
Impermeable	Describes the nature of solid material that will not allow fluids to pass freely.
In situ	Latin description of a material that occurs in the position in which it was originally formed or deposited, literally "at the site".
Infiltration	The process whereby water enters the soil through its surface. The downward movement of water into the soil profile.
Isotropy	The condition in which the properties of a system or a parameter do not vary with direction.

Item	Definition
Joints	Fractures along which there has been little or no displacement parallel to the fracture surface.
Juvenile water	Water which has never before been part of the hydrologic cycle.
Leakage	a flux of fluid from or into an aquifer or reservoir. This commonly refers to cross-formational flow.
Leakance	The vertical permeability of a hydrostratigraphic unit divided by its thickness.
Licence	An authority to explore for or produce oil or gas in a particular area issued to a company by the governing state.
Lithology	The physical and mineralogical characteristics of a rock. The characteristics, including grain size, of the strata of the subsurface media.
Matrix flow	Water that passes through the interconnected pores in the *soil matrix* as opposed through macropores as preferential flow.
Mesozoic	An era of geologic time between approximately 230 and 65 million years ago and including the Triassic, Jurassic and Cretaceous Periods (see Era).
Metamorphic rock	Rock of any origin altered in mineralogical composition, chemical composition or structure by heat, pressure, or movement at depth in the Earth’s crust. Examples of metamorphic rocks include schist, gneiss and quartzite. Most have parallel bands of minerals evident.
Meteoric water	Water which is or has recently been a part of the atmospheric portion of the hydrologic cycle.
Migration	The movement of a fluid (water, gas or oil) from regions of higher to lower pressure.
Mining	In hydrogeology, this implies extraction of water from a groundwater system which is not currently receiving recharge.
Mudstone	Mudstone is the result of grains of clay having been deposited layer upon layer, compacted by the weight of overlying material and cemented together over millions of years to form a hard rock. They are similar to shales but lack the feature of a layered structure.
Nested monitoring wells	A groundwater installation comprising a single large diameter hole containing multiple piezometer casings screened at varying depths to intersect different aquifers or aquifer levels. The construction of nested wells requires the accurate placement of individual filter packs and bentonite seals to isolate each of the aquifers intersected.
NWDA	North west development area
Outcrop	(a) The part of a rock formation that appears at the surface of the ground. (b) A term used in connection with a vein or lode as an essential part of the definition of apex. It does not necessarily imply the visible presentation of the mineral on the surface of the earth, but includes those deposits that are so near to the surface as to be found easily by digging. (c) The part of a geologic formation or structure that appears at the surface of the earth; also, bedrock that is covered only by surficial deposits such as alluvium. (d) To appear exposed and visible at the earth’s surface; to crop out.
Overburden	Designates material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal--esp. those deposits that are mined from the surface by open cuts.
Palaeochannel	A river channel or drainage line incised into an ancient land surface that has been subsequently infilled by the deposition of younger sediments.

Item	Definition
Palaeozoic	an era of geologic time extending between around 600 and 230 million years ago and including the Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian Periods (see Era).
Perched aquifer (perched water table)	An aquifer in which infiltrating water remains separated from an underlying main body of groundwater, with an unsaturated zone existing between the two. Usually perching occurs due to the presence of an intermediate impermeable or low permeability layer. Where the perched aquifer is unconfined, a perched water table exists. See aquifer.
Period	a geologic timeframe smaller than Eras and subdivided into Epochs.
Permeability	A measure of the capacity of rock or stratum to allow water or other fluids such as oil to pass through it (i.e. the relative ease with which a porous medium can transmit a fluid). Typically measured in darcies or millidarcies.
Permian	A geological time period approximately 298 to 251 million years ago.
Petroleum	A generic name for hydrocarbons, including crude oil, natural gas liquids, natural gas and their products.
pH	a measure of the acidity or alkalinity of water. It is related to the free hydrogen ion concentration in solution pH = 7 is neutral; pH < 7 acidic; pH > 7 alkaline.
Phase	Sequenced operational areas to divide the progression of a mining activity, including coal seam gas ‘mining’.
Piezometer	A pressure measuring device (a tube or pipe, or other device), open to the atmosphere at the top and to water at the bottom, and sealed along its length, used to measure the hydraulic head in a geologic unit. This device typically is an instrument that measures fluid pressure at a given point rather than integrating pressures over a well. (b) a borehole cased and completed with a seal(s) adjacent to the slotted section to observe the *groundwater* pressure over the slotted interval rather than the elevation of the *watertable*.
Piezometric head	The elevation to which water will rise in a *piezometer* connected to a point in an *aquifer*. Differences in piezometric head determine the hydraulic *gradient* and therefore the direction of *groundwater* flow.
Piezometric surface	A surface of equal hydraulic heads or potentials, typically depicted by a map of *equipotentials* such as a map of water-table elevations. See potentiometric surface.
Piper diagram	A graphical means of displaying the ratios of the principal ionic constituents in water. (modified from Davis and DeWiest, 1966, and Freeze and Cherry, 1979). SMOW is standard mean ocean water.
PJ	Petajoule (one million gigajoules).
PL	Petroleum Lease.
Pleistocene	a epoch of geologic time between approximately 2 million and 10,000 years ago (see Epoch).
Pore water pressure	Pressure exerted by fluid in the void space of soil or rock. It is usually expressed with respect to atmospheric pressure so that positive pressures indicate that the porous medium is saturated and negative pressures indicate that it is unsaturated.

Item	Definition
Porosity (s or n)	The volume of the voids divided by the total volume of porous medium (the percentage of a rock or soil that is represented by open voids or spaces): *effective* - the interconnected porosity which contributes to groundwater flow. Often used synonymously with specific yield although the two terms are not synonymous. *fracture* - the porosity of the fractures; *intergranular* - the porosity between the grains of a sediment or sedimentary rock; primary - intergranular porosity formed during the deposition of the sediment or from vesicles in igneous rocks; *secondary* - porosity formed after the rock is lithified by either dissolution or fracturing.
Porous	Having porosity.
Potable	Drinkable. Potable waters can be consumed safely.
Potentiometric surface	a surface of equal hydraulic heads or potentials, typically depicted by a map of equipotentials such as a map of water-table elevations.
Precipitation	(a) Water condensing from the atmosphere and falling under gravity in drops or particles (e.g., snow, hail, sleet) to the land surface. (b) Formation of a solid from dissolved or suspended matter. (c) The transfer of water from the atmosphere to the land surface, predominantly as rainfall, but also includes dews, frosts, mists, snow, sleet, hail and fog.
Preferential flow (sediment or rock)	Rapid groundwater flow that occurs through any structure significantly more permeable than the bulk sediment or rock.
Preferential flow (soil)	Rapid soil water flow that occurs through *macropores* or any other structure significantly more permeable than the bulk soil.
Preferred pathway	A channel or pore in a soil layer that has low *permeability* through which water flows preferentially. Old tree root channels are preferred pathways in many clayey *subsoil*s in the South-West Agricultural Region.
Pressure (p)	Force per unit area [MLt -2L-2 or ML-1t-2 or Pa]: *abnormal* - any departure from hydrostatic pressure. This includes overpressures and underpressures. *excess or overpressure* (u) - fluid pressures above the hydrostatic pressure (ps). Also called geopressures, abnormal pressures, or excess pore-fluid pressures. *hydrostatic* (ps) - the pressure equal to that which is (or would be) induced by the weight of the overlying column of water, ps = rwgh , where h is the height of water above the point in question. *lithostatic pressure* (s) - the pressure equal to that which is (or would be) induced by the weight of the overlying column of materials of bulk density rb , s = rbgH , where H is the height of the materials (rock and water) above the point in question.
Production bore	A bore from which abstraction of groundwater may take place, either through pumping or artesian flow.
Project Area	The term "Project Area" refers to those areas of land contained with QGC tenements (refer to Figures 1 and 3).
Pump-out Test (Pumping Test, Test Pumping)	A test conducted in a production bore or other installation using a pump to abstract groundwater. May be used to estimate the hydraulic characteristics of the aquifer or bore. Commonly involves the use of a production bore in association with observation bores.
Radius of influence	Radial distance to points where hydraulic head is noticeably affected by a pumping well.

Item	Definition
Recharge	The water that moves into a groundwater body and therefore replenishes or increases sub-surface storage. Recharge typically enters an aquifer by rainfall infiltrating the soil surface and then percolating through the zone of aeration (unsaturated soil). Recharge can also come via irrigation, the leakage of surface water storage or leakage from other aquifers. Recharge rate is expressed in units of depth per unit time (e.g. mm/year).
Recharge	The process by which water enters the groundwater system or, more precisely, enters the phreatic zone.
Recharge area	An area of land from which a significant amount of *groundwater* recharge occurs. In the agricultural areas most of the cleared land that is not discharging *groundwater* contributes some *recharge*.
Recovery	The rate at which the water level in a pumped bore rises once abstraction has ceased.
Relative permeability	The ability of a porous medium to allow flow of a fluid when other fluid phases are present, relative to its ability to allow flow of that fluid when no other fluid phases are present.
Relief	Difference in elevation between the highest mountaintop, ridge, or hill and the lowest valley within a permit area.
Representative sample	A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.
Residual drawdown	The difference between the original standing water level measured prior to pumping, and the depth to groundwater at a given instant during the recovery period following the cessation of pumping.
Retention basin	A basin (either natural or constructed) used to hold *run-off* or stream flow and thus reduce *peak flows* and the risk of *flooding*. Some of the water may be stored permanently in the basin, while the remainder is released at a controlled rate.
Reverse osmosis (RO)	The flow of fluid through a membrane from the high salinity to the low salinity side of the membrane typically caused by exerting very high fluid pressures on the high salinity side.
Risk assessment	The overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences (adapted from AS/NZS 43601999).
Risk management	The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.
Runoff	(a) That portion of the rainfall that is not absorbed by the deep strata, is used by vegetation or lost by evaporation, or that may find its way into streams as surface flow. (b) Water flowing downslope over the ground surface, also known as overland flow. *Precipitation* that does not *infiltrate* into the soil and is not stored in depressions becomes run-off.
Safe yield	The volume of water that can be annually withdrawn from an aquifer (or groundwater basin or system) without 1) exceeding average annual recharge; 2) violating water rights; 3) creating uneconomic conditions for water use; or 4) creating undesirable side effects, such as subsidence or saline water intrusion.
Saline (water)	a term used to describe water that has high *salinity* levels (in excess of 5,000 mg/L) which limit its suitability for many uses.

Item	Definition
Salinity	An accumulation of soluble salts in the soil *root zone*, at levels where plant growth or land use is adversely affected. Also used to indicate the amounts of various types of salt present in soil or water. (see Total Dissolved Solids).
Sand	Sedimentary mineral grains deposited by wind or water action having a particle size of between 1/16 and 2 mm diameter. The grains are made up of predominantly quartz and can include other minerals such as feldspars, mica, glauconite and iron oxides.
Sandstone	A sedimentary rock composed predominantly of consolidated sand-sized grains (typically between 1/16 and 2 mm), usually quartz, with some cement.
Saturated zone	The part of a body of soil or rock in which the voids and spaces are filled with water.
Screen, slotted section	A section of casing, usually steel or PVC, with apertures or slots cut into the tubing to allow groundwater to flow through. Screen usually refers to machined sections with openings that can be sized appropriate to the aquifer matrix and filter pack grading.
Seal	A largely impermeable rock (usually claystone or shale) that retards the passage of fluids (including water, gas or oil).
SEDA	South east development area
Sediment	a) Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the Earth's surface either above or below sea level.
	b) Solid material, whether mineral or organic, which has been moved from its position of origin and redeposited.
Sedimentary rock	Any rock that has formed from the consolidation of sediment.
Seep	Point at where *seepage* occurs.
Seepage	Occurs where the *watertable* intersects the ground surface and water flows out. This is *active discharge* and is driven by the hydraulic *gradient*.
Seismic survey	A technique for determining the detailed structure of the rocks underlying a particular area by passing acoustic shock waves into the strata and detecting and measuring the reflected signals.
Shale	A fine-grained *sedimentary rock* comprised of clays and other finely sized mineral particles.
Share component	Of the water access licence is the volume share of water made available in a water source. It is similar to the entitlement volume on previous water licences under the *Water Act 1912*. The amount of water a licence holder is allocated in any year as a result of an available water determination is based on their share component.
Silt	Silts are sedimentary grains having a particle size of between 0.002 to 0.05 mm diameter. It is almost always deposited by water action and usually comprises finely divided particles of quartz, carbonate dust, carbon and iron pyrite minerals. Silt transmits and absorbs water but does not become sticky and is therefore considered to be non-plastic.
Siltstone	A *sedimentary rock* comprised of *silt*-size particles cemented together. They are the result of grains of silt particles having been deposited layer upon layer, compacted by the weight of overlying material and cemented together over millions of years to form a hard rock.

Item	Definition
Sorption	The general process by which solutes, ions, and colloids become attached (sorbed) to solid matter in a porous medium. Sorption includes absorption and adsorption.
Specific storage (Ss)	The amount of water absorbed, released or expelled from storage in a unit volume (i.e. 1 x 1 x 1) of aquifer under a unit change in hydraulic head (i.e. δh = ± 1).
Specific yield (Sy)	The quantity of groundwater that will drain under gravity from a unit volume (i.e. 1 x 1 x 1) of an unconfined aquifer. A unit decline in hydraulic head under unconfined conditions results in both a reduction in pressure and in the saturated thickness of the aquifer. Because of this, the storativity of an unconfined aquifer is related to the specific yield (Sy), the thickness of the saturated zone (h) and the specific storage (Ss) according to the equation S = Sy + h Ss. The product of specific storage and saturated thickness (i.e. h Ss) is generally considerably less than the value of the specific yield. Hence, for almost all unconfined aquifers, the storativity is considered to be equivalent to the specific yield (see Storage Coefficient, Specific Storage).
Standing water level (static water level, SWL)	The depth to groundwater measured at any given time when pumping or recovery is not occurring.
Storage coefficient (Storativity; S)	The volume of groundwater that is expelled from or absorbed into storage under a unit change (i.e. δh = ± 1) in hydraulic head over a unit area (i.e. 1 x 1) of the aquifer. The storativity of a confined aquifer is related to the specific storage (Ss) and saturated thickness (b), by the equation S = b Ss (see Specific Storage).
Stratigraphy	The study of stratified rocks, especially their age, correlation and character.
Structure	Deformed sedimentary rocks, where the resultant bed configuration is such as to form a trap for migrating water gas and/or hydrocarbons.
Study Area	The term “Study Area” refers to that area of land from which the entire data set considered by the assessment was gathered in describing the existing environment, environmental values and potential impacts (refer to Figures 1 and 3).
Stygofauna	stygofauna are very small animals and microbes that live below the Earth’s surface in groundwater and caves. They comprise crustaceans of many types as well as other groups such as fish, worms, snails, arachnids, mites and insects.
Subsidence	(a) The vertical movement of the surface, although small-scale horizontal movements may be present. This sinking or settlement of the land surface can be caused by a number of processes, including production of fluids, solution, compaction, or cooling of magmatic bodies. (b) Lowering of the ground surface resulting from removal of hydrostatic pore space pressure (through buoyancy) or collapse of underground mine voids.
Surface drainage	Systems that are designed to intercept and remove excess surface water. Surface drainage works include *spoon drains* and *W-drains*.
Surface flow	A term used to describe the movement of water across the ground surface as *run-off* or stream flow.

Item	Definition
Sustainable yield	Is the volume that can be extracted by all water users in a groundwater source without causing unacceptable impacts (i.e. without detrimentally affecting existing supplies or flows to dependent environments). The average annual recharge minus the portion reserved for the environment determines the sustainable yield.
Tertiary	A period of geologic time between approximately 65 and 2 million years ago (see Period).
Texture (soil)	Proportion of gravel, sand, *silt* and clay in a soil. Heavy texture implies a higher proportion of smaller particles such as clay, while lighter texture involves more larger particles such as sand.
Theis equation	The equation for radial transient flow to a well in an idealized confined aquifer.
Thiem equation	The equation for radial steady flow to a well in an idealized confined aquifer.
Throws	Distance of movement along a fault plane.
Tortuosity (T or t)	Actual length of a groundwater flow path (La) divided by the straight line distance between the ends of the flow path (L). There are several variations in the exact formula used in calculating this ratio in the literature. They are t =(La L)2 , t = La L, or their reciprocals.
Total dissolved solids (TDS)	An expression of the total soluble mineral content of water determined by either measuring the residue on evaporation or the sum of analysed chemical constituents. Usually quoted in milligrams per litre (mg/L) or the equivalent parts per million (ppm), TDS may also be approximated from electrical conductivity (EC) measurements using the conversion EC (µS/cm) x 0.68 = TDS (mg/L) (see Electrical Conductivity).
Transmissivity (T)	The rate of horizontal groundwater flow through the full saturated thickness (b) of an aquifer across a unit width (i.e. an area of b x 1) (i.e. through a 1 metre wide slice across the entire depth of an *aquifer*) under a unit hydraulic gradient ($\delta h / \delta l = 1$). Transmissivity may be quoted as m^3/day/m [$L^3/T/L$], but is more commonly expressed as m^2/day [L^2/T]. It provides a better comparison of the possible yield of an *aquifer* than saturated *hydraulic conductivity* because it takes into account the saturated thickness of an *aquifer*. Transmissivity is related to the hydraulic conductivity of the aquifer by the equation $T=Kb$.
Triassic	A period of geologic time extending from 230 to 180 million years ago (see Period).
Unconfined aquifer (water table aquifer)	An aquifer in which the surface of the saturated zone is at atmospheric pressure. See aquifer.
Unconformity	A surface between successive strata representing a missing interval in the geologic record of time, produced either by an interruption in deposition or by the erosion of depositionally continuous strata followed by renewed deposition. An unconformity is a type of discontinuity.
Unsaturated zone	The part of a body of soil or rock separating the land surface and the water table.
Water balance	The relationship between input, storage and output within a hydrological system. If the amount of water entering the system is the same as the amount leaving, then storage remains constant and the system can be considered to be in equilibrium. Where input exceeds output, the water balance becomes altered and the amount of water stored in the system

Item	Definition
	increases. Conversely, the balance can be altered as storage decreases in response to output exceeding input.
Watertable	(a) The upper surface of a body of *groundwater* occurring in an *unconfined aquifer*. At the watertable, pore water pressure equals the atmospheric pressure. (b) The surface of a body of groundwater within an unconfined aquifer at which the pressure is atmospheric.
Well	a shallow work that is larger in diameter than a bore, but usually no greater than 1.5 m wide. Commonly, wells are less than 20 m deep and may be partially lined with concrete cylinders.
Well screen	A portion of a well casing that is perforated or slotted to allow water to flow through it. The screen and associated filter packing (sand) act as a filtering device to permit the flow of liquid or air but prevents the passage of sediments or backfill particles.
Well yield	The discharge of well at (nearly) steady flow [L^3t-1].
Wetland	Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes 1. At least periodically, the land supports predominantly hydrophytes; 2. The substrate is predominantly undrained hydric soils; and 3. The substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year.

1.0 INTRODUCTION

QGC - A BG Group business (QGC) is proposing to develop a Liquefied Natural Gas (LNG) export facility at Gladstone in Central Queensland (herein referred to as the Project). The facility will produce three to four million tonnes per annum (Mtpa) of LNG, with the potential for future expansion to twelve Mtpa. The Project involves the following key components:

- Development of Coal Seam Gas (CSG) fields centred on Chinchilla, Miles, Moonie, Kogan, Wallumbilla and Dalby in the Surat Basin. This, "Supplemental Groundwater Study, Northern Tenements" report, focuses on the latter areas;
- Construction of pipelines for gas transmission to Gladstone; and
- Development of an LNG liquefaction and export facility at the port at Gladstone.

The Project was declared a significant Project in July 2008, under the *State Development Public Works Organisation Act 1971 Qld* (SDPWO Act) (Section 26). An Environmental Impact Statement (EIS) is required, as part of the significant Project declaration. To assist in the development of the EIS, Golder Associates Pty Ltd (Golder) was commissioned by QGC to examine the effects of the *CSG Field* component of the Project on groundwater and surface water resources (Golder 2009a and b).

Subsequent to the submission of the draft EIS, QGC acquired additional tenements within the boundaries of their North-West Development Area (NWDA). This document provides an assessment of the groundwater conditions focussing on the NWDA tenements only (Figure 1). Although it is a stand alone document, it is based on and routinely references the Project-wide groundwater assessment report "QGC Groundwater Study Surat Basin, Queensland" (087633050 016 R Rev2, Golder 2009a).

For the purposes of this report the following definitions are used:

- the term "Project Area" refers to those areas of land contained within QGC tenements located within the area referred to as the North-West Development Area (NWDA), as shown in Figures 1 and 3. The NWDA and its associated Study Area form a *subset* of the areas consider by Golder report 087633050 016 R Rev2 (June 2009);
- the term "Study Area" refers to that area of land from which the entire data set considered by the NWDA assessment was gathered in describing the existing environment, environmental values and potential impacts (Figure 1); and
- The entire QGC operational area, of which the NWDA is a subset, it referred to as the QGC *Surat Basin Operations Area* (Figure 3).

This Supplemental EIS study also considers the effects which might arise from the other mining and gas production activities which are proposed for overlapping or adjacent tenement (Figure 1) to QGC tenement in the NWDA, namely,:

- The Wandoan Coal Project, a proposed open-cut coal mine located west of the Wandoan township, north of PL171 and through ATP768; and
- Tenement proposed for coal 'mining' by underground coal gasification (UCG) methods.

1.1 Project Background

Coal seam gas is a combination of natural gases, predominantly comprising methane gas. In its natural condition it is found adsorbed within underground coal beds where it exists in a near-liquid state, lining the inside of pore space openings within the coal matrix. Methane also occurs, to a much lesser extent, as a free gas in the groundwater within open pore space, fractures and cleats in the coal and it can occur in the dissolved state (saturated) within the groundwater.

The procedure for recovering this gas involves drilling a series of extraction wells into targeted coal layers (seams) and pumping out groundwater (referred to as ‘associated water’) to lower the coal reservoir pressure in order to release the methane gas from the coal (reversing the adsorption reaction by causing the methane to de-sorb from the coal matrix).

CSG recovery is therefore closely linked to groundwater extraction to achieve the optimum hydraulic head pressure conditions which facilitate the release of gas from the coal beds. The groundwater and gas extraction process consists of constructing a deep production well into the coal beds, then placing a groundwater extraction pump in the well, typically above the coal seam, and initiating groundwater extraction to lower the water level in the production well and, consequentially, the head pressure in the aquifer. The adsorption reaction which fixes the CSG to the coal is reversed as a result. Groundwater pumping continues until the gas flows freely (decreasing the water pressure in the coal seam(s) liberates the gas). As the gas moves into the gaseous phase, it migrates, under the induced pressure gradients, to the production well, where it is pumped to the surface for capture and processing.

Often, no groundwater pumping is required once the gas begins to flow as the velocity of the gas acts as a lifting mechanism for the groundwater and the pump may be removed. When the gas flow rate falls, and the groundwater can no longer be extracted by the gas lifting effect, a pump is set back into the well to continue the water extraction until the CSG has been exhausted to an economic level.

The Walloon Coal Measures (WCM) contain the main gas bearing coal beds within the Surat Basin CSG fields. Pumping of groundwater from the WCM during pilot CSG activities has successfully lowered the reservoir pressure, and has produced good quantities of CSG.

The WCM are considered to be in poor hydrogeological connection to overlying and underlying aquifers because the siltstone and mudstones that separate the sandstone and coal seam aquifers are low permeability rocks, i.e. they impede groundwater flow, but do not prevent groundwater flow to or from adjacent aquifers. The risk that depressurisation of the coal aquifer could potentially lead to long term depressurisation and dewatering of adjacent aquifer units, thus potentially impacting nearby groundwater users, has been recognized. This report considers these aspects of the groundwater system which operates in the study area.

1.2 QCLNG Project Description

The Queensland Curtis LNG (QCLNG) Project export facility at Gladstone will allow QGC to commercialise their Surat Basin CSG resources and export the processed gas, in the form of LNG, to overseas markets. The Project will involve the construction of a 380 km gas transmission pipeline from the QGC CSG fields to the LNG facility in Gladstone, and construction of the LNG facility.

To supply the LNG facility, QGC will need to significantly increase output from its petroleum tenures in the Surat basin. This will involve a major expansion of well development, in-field compression stations, processing plants, associated water management, land access and ancillary infrastructure. The CSG gasfield component of the Project will comprise developing:

- up to a total of 6000 production wells for two LNG trains;
- associated surface equipment; gas and water gathering systems; and gas processing and compression infrastructure; and
- management, storage and beneficial use of CSG water.

Upstream facilities will include:

- production well sites, gas and associated water gathering infrastructure;
- field compression and processing facilities;
- support infrastructure;

- access tracks; and
- CSG water disposal infrastructure that will comprise one or more of the following:
  - evaporation ponds;
  - water treatment plants and/or injection wellfield/s; and
  - associated water reticulation systems.

At this stage of Project planning, the CSG wells in the NWDA will be nominally located approximately 750 metres (m) apart to optimise production. Each gas production well site will require a firm and level area of approximately 100 m by 100 m size (approximately 1 hectare) for the drilling rig and associated plant. Site selection will be based primarily on the geological analysis completed as part of the exploration works currently underway in the NWDA. The Wandoan Coal Project, the proposed open-cut coal mine located west of the Wandoan township and possible UCG operations on tenement located to the south-west of Wandoan (Figure 1), will also govern the number and distribution of CSG wells to be sited through the NWDA.

A network of pipelines will link the NWDA CSG wells to the main gas pipeline infrastructure corridor. This pipeline network has a planned minimum design life of 40 years. The pipelines will be monitored remotely through a central control room, as well as by field inspection.

1.3 Project Setting and Context

1.3.1 Local Setting

The NWDA lies approximately 400 km west of Brisbane (Figure 1), within the Surat Basin, a sub-basin of the Great Artesian Basin (GAB). The Surat Basin is approximately 280,000 sq km in area and is located in the southeast corner of the GAB. The GAB underlies the majority of inland Queensland and inland northern New South Wales. The Surat Basin contains significant geological resources including coal, coal seam gas, oil, natural gas, water and bentonite.

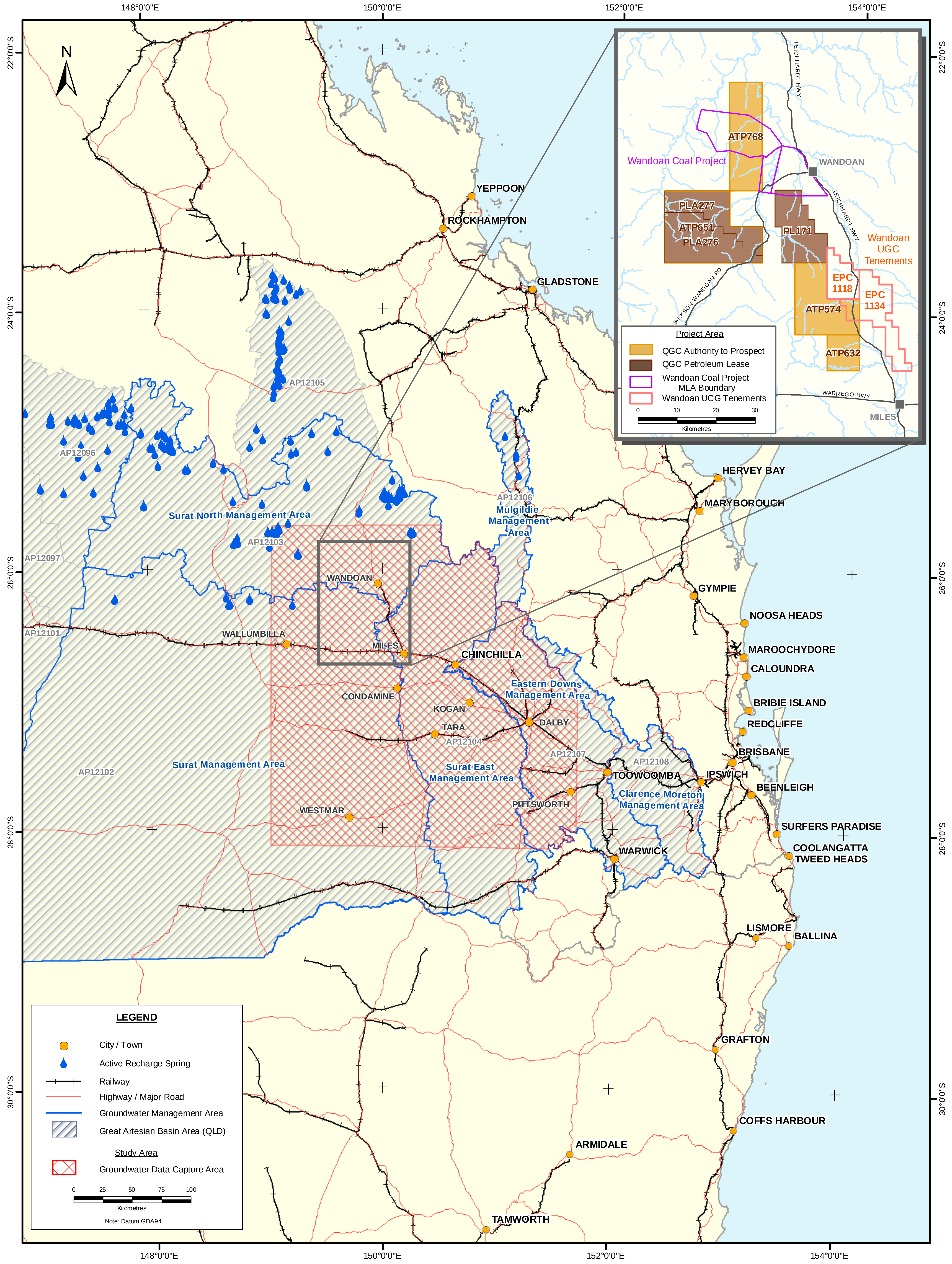
The major towns near the proposed NWDA of operation include Miles, Condamine, Wallumbilla and Wandoan. The major rivers running through the area include the Condamine, Balonne and Dawson Rivers. The area is serviced by major roads, railways, and many gas pipelines, including one that transfers gas from Roma to Brisbane.

The region has become reliant on groundwater for economic growth, particularly in years where rainfall and surface flows are low. In 2004/2005, a total of 160 gigalitres (GL) of groundwater was extracted from the Condamine and Balonne region of the Surat Basin, of which 97% of the extraction occurred in the Upper Condamine River catchment (CSIRO, 2008). On average groundwater accounts for 18% of all water diversions, while in dry years it accounts for as much as 61% of water used (CSIRO, 2008).

Significant agricultural production occurs in the area above the eastern part of the Surat Basin due to the presence of fertile clay soils and adequate rainfall. Grazing and dry land cropping dominates the land area above the western part of the Surat Basin, where the climate becomes drier. Agriculture in the western portion of the Surat Basin is supported by irrigation. Over 112,000 hectares of irrigated crops were grown in 2000 and 63% of the irrigated crop was cotton (CSIRO 2008). Surface water is the main source of irrigation water. Approximately 55% of surface water in the WMA is diverted to agricultural purposes (CSIRO 2008).

The region is managed by three local government areas:

- Western Downs Regional Council;
- Roma Regional Council; and
- Banana Shire Council.



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SCALE	1:3,000,000		PROJECT No 097626104_001	FIGURE No 1	REV No 2 A3

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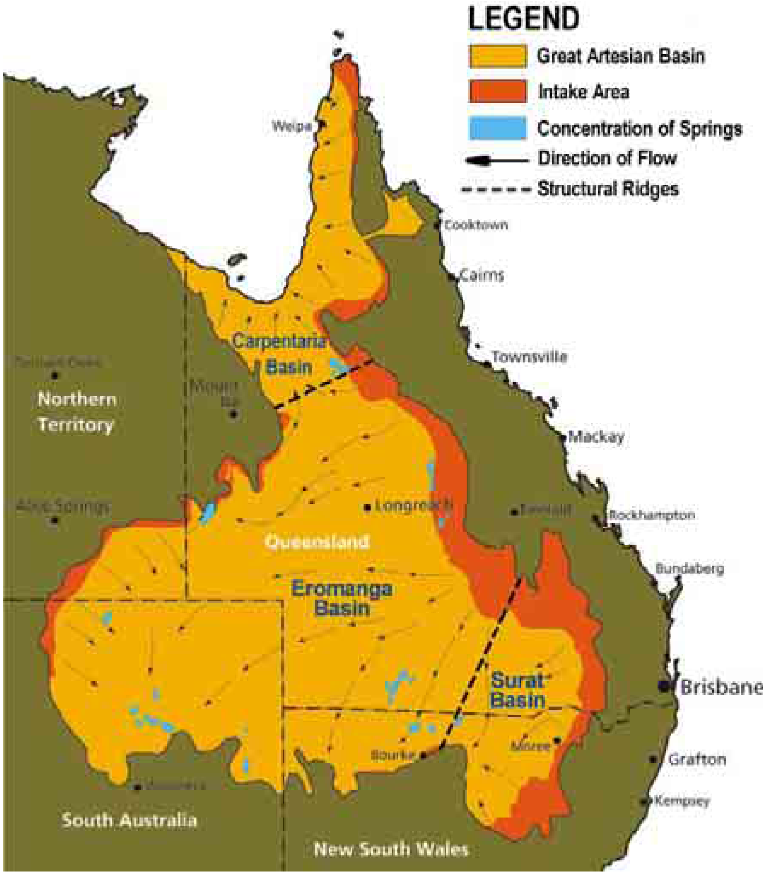
1.3.2 Hydrogeological Context

The Surat Basin lies within the GAB, one of the largest artesian groundwater basins in the world (DNRW[1], 2006, now DERM). Figure 2 illustrates the geographic extent of the GAB and the location of the Surat Basin within it.

The GAB spans over 1.7 million square kilometres (m^2) and underlies approximately one-fifth of the Australian continent. It extends 2,400 kilometres (km) from Cape York in the north to Dubbo in the south (DERM, 2006). At its widest extent, it is 1,800 km from the Darling Downs to west of Coober Pedy (DERM, 2006).

The GAB is made up of three main sub basins (Figure 2):

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



Source: The Great Artesian Basin; DERM 2006

Figure 2: Extent of Great Artesian Basin

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[1] NRW: Department of Natural Resources and Water. Note the functions of the NRW has recently (April 2009) been combined with the EPA, and is now know as the Department of the Environment and Resource Management (DERM).

The GAB is showing signs that its groundwater resources are being overexploited (NRW, 2006). It is estimated that, excluding the Carpentaria sub- Basin, 1,040 megalitres (ML) of water enter the aquifers of the GAB in Queensland each day (DERM, 2006). Together with the volume of recharge from the other Australian States, water discharged as surface springs and a natural equilibrium of inflow to outflow was maintained. Total outflow from the GAB reportedly reached a peak of over 2,000 megalitres per day (ML/d) in 1915 (DERM, 2006). Since then, artesian pressure and flow rates have declined, while the number of bores has increased. Many water bores initially flowed at rates of over 10 ML/d (DERM, 2006). Recent flow rates are now between 0.01 ML/d and 6 ML/d (DERM, 2006) and the current total outflow from the GAB is about 1,500 ML/d (DERM, 2006). About one-third of all artesian bores which flowed when they were drilled, have now ceased to flow and require pumps to bring the water to the surface (DERM, 2006).

To address the unsustainable use of water in the GAB, the Commonwealth and State governments have established the Great Artesian Basin Sustainability Initiative (GABSI). The GABSI is part of a collaborative 15 year *Strategic Management Plan* used by Queensland, New South Wales, South Australia and the Northern Territory to achieve sustainability of the GAB and its resources. In Queensland, the GAB is administered under the *Water Resource (Great Artesian Basin) Plan 2006* (GABWRP) and the *Great Artesian Basin Resource Operations Plan 2007* (GABROP). They divide the Queensland component of the GAB into 25 Groundwater Management Areas (GMAs) and 93 Groundwater Management Units (GMUs).

The NWDA is contained within three of GMAs, including:

- Surat East (GMA 21);
- Surat North (GMA 20); and
- Surat (GMA 19).

Table 1 provides a breakdown of the GMUs within the three GMAs considered in this study.

Table 1: Groundwater Management Areas and Units in the Surat Basin

Groundwater Management Area	Groundwater Management Unit	
Surat	Surat 1 Surat 2 Surat 3 Surat 4	Surat 5 Surat 6 Surat 7 Surat 8
Surat East	Surat East 1 Surat East 2 Surat East 3	Surat East 4 Surat East 5
Surat North	Surat North 1 Surat North 2	Surat North 3 Surat North 4

Source: Water Resource (Great Artesian Basin) Plan 2006

In Queensland, surface water is administered in terms of catchments and Water Management Areas (WMAs). The bulk of the Surat Basin is contained within three WMAs, namely:

- Condamine and Balonne;
- Border Rivers; and
- Moonie.

To the north east, the Surat Basin also overlaps with the Clarence and Moreton Catchments.

The Project and Study Areas are primarily contained within the Condamine and Balonne WMA. Surface water in this WMA is administered through the *Water Resource (Condamine and Balonne) Plan 2004* (CBWRP) and the *Condamine and Balonne Resource Operations Plan 2008* (CBROP). There are also small sections of the Study Area draining into the Moonie and Fitzroy catchments. The Condamine and Balonne catchment, together with the Moonie catchment, form part of the Murray Darling Basin; however, the Moonie catchment does not affect the NWDA.

1.4 Scope of Work

Golder was commissioned to provide information to support preparation of the groundwater impacts component of the Supplementary EIS with regard to those areas in the vicinity of NWDA tenements and which are additional to those presented in the original Project-wide groundwater assessment. The scope of works for this report is presented in Appendix A.

The aim of this report is to:

- identify the potential impacts of associated water extraction in the *additional* tenements on groundwater levels and quality (including but not limited to those which might affect the Wandoan Coal Project and the UCG projects);
- describe the environmental values associated with groundwater environments in the NWDA; and
- identify methods to mitigate undue impacts on groundwater to acceptable levels, should they occur.

1.5 Definition of the Study and Model Area

Figure 3 presents the location of the NWDA petroleum leases, the study area, and the full extent of the groundwater model domain for the NWDA. The associated petroleum leases held by QGC considered in the preparation of the groundwater model and the groundwater impact assessment are presented in Table 2.

Table 2: Petroleum Tenements Included in the Study Area[1]

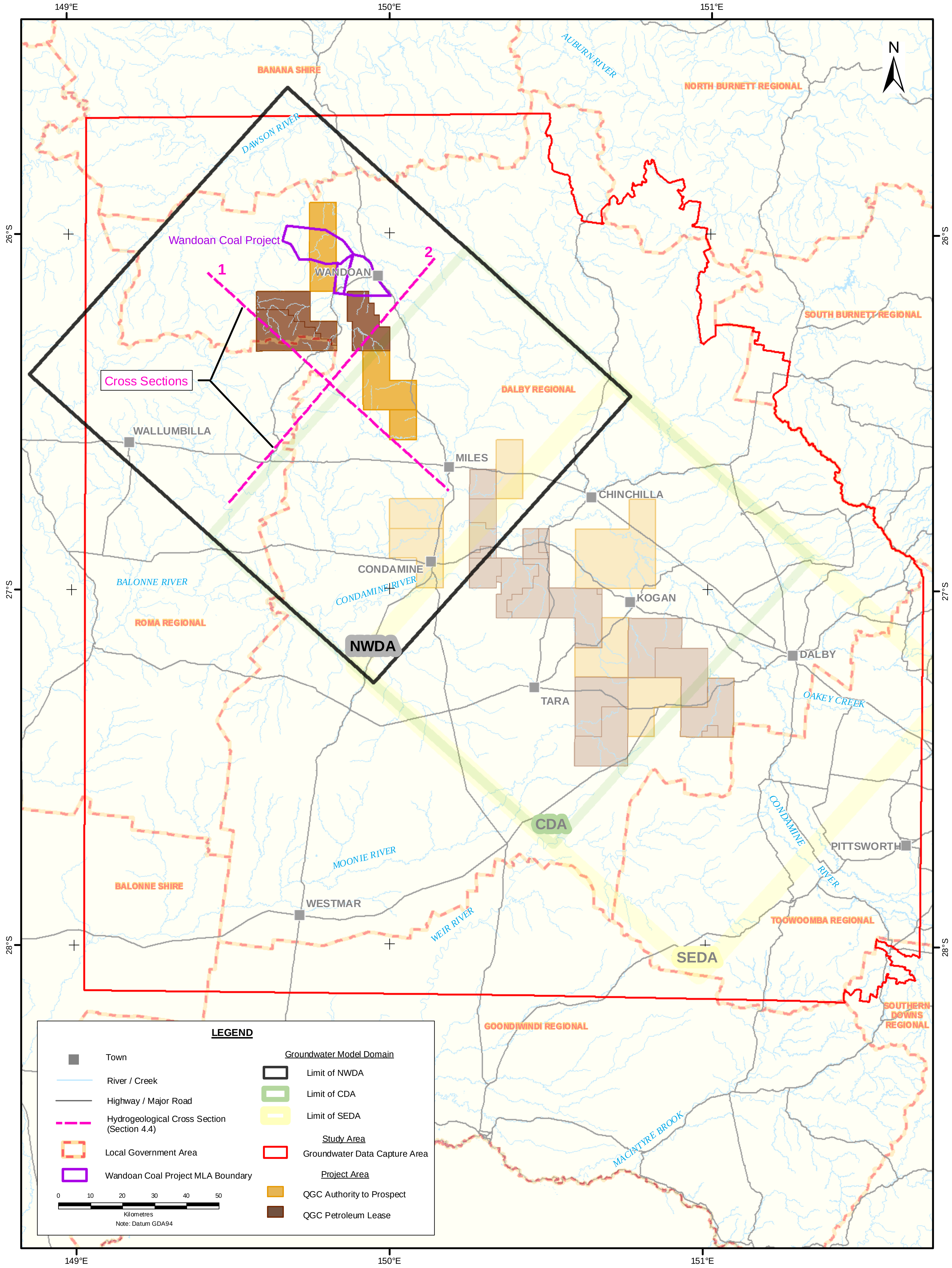
NWDA[1]
ATP574
ATP 651 (PL276 and PL277)
ATP 632[2]
ATP 768
PL 171

1. ATP for Authority to Prospect, PL for Petroleum Lease, and PLA for Petroleum Lease Application,

2. ATP632 is partially located in both CDA and NWDA

The prediction of groundwater impacts for the proposed CSG depressurisation and gas extraction activities in the NWDA was performed using computer-based predictive modelling methods carried out at an indicative level of resolution (Section 5.4). To better represent the additional tenements, the existing model domain was moved northward relative to its location originally assessed as part of the original Project-wide groundwater assessment (087633050 016 R Rev2; Golder 2009a). The modelling domain was designed to extend beyond the predicted area of impacts likely to be associated with the CSG operations.

The NWDA and predictive model area were selected to guide the assessment and documentation of the existing environment conditions where potential impacts by the proposed QGC activities might reasonably be anticipated. The model does not directly account for impacts which might result from neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these activities are not currently known, and as such, have been treated here in a qualitative manner.



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SCALE	1:1,100,000	PROJECT No	097626104_001
FIGURE No	3	REV No	2
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2.0 LEGISLATIVE FRAMEWORK

Legislation and regulation requires petroleum tenure holders to manage the associated water generated through CSG development activities in an environmentally sustainable manner. A more detailed review of the key legislation and planning policies which apply to the CSG industry and the management of groundwater is presented in the original Project-wide groundwater assessment (Golder 2009a).

Table 3 presents a summary of the main elements for the use of water by the petroleum industry in Queensland.

Table 3: Summary of Legislative Requirements for Water Monitoring (Regulatory Texts)

Legislation/Section	Driver	Key Points as they Apply to the QGC Operations
Great Artesian Basin Resource Operations Plan 2006	Defines the maximum amount of water that can sustainably be extracted from the recognised aquifers within each groundwater management area. Requires monitoring for all licensed bores	QGC groundwater CSG bores are not licensed for water extraction with DERM as they are covered by the P&G Act.
Water Resource (*Condamine and Balonne*) Plan 2004	Defines the regulatory requirements and amount of water for the use of surface water in the Condamine and Balonne defined area.	Non applicable. QGC does not extract water from the Condamine River. QGC CSG bores are not licensed for water extraction with DERM as they are covered by the P&G Act.
Water Resource (Fitzroy Basin) Plan 1999	Defines the regulatory requirements and water allocations governing the use of surface water in the Dawson River. Groundwater in the Fitzroy basin area is managed through declared sub artesian areas.	Non applicable. QGC does not extract water from the Dawson River. QGC groundwater CSG bores are not licensed for water extraction with DERM as they are covered by the P&G Act.
Petroleum and Gas (Production and Safety) Act 2004	Provides all rights of water extraction to a petroleum activity. Requires a water impact report to be prepared and a “trigger value” to be estimated.	Water monitoring is required for assessing the impact of pumping on groundwater and potential impact to other groundwater users. “Trigger values” must be defined.
Water Act 2000, Queensland	A water licence is required to take water and provide it to any use other than domestic and stock watering. When a water licence is required, there may be a requirement under Section 214 (e) to carry out and report on a monitoring program. If water is to be provided to others as part of the activities, they are required to be registered as a Water Service Provider	Limited application to QGC. CSG operations under the authority of the P&G Act. QGC proposes to utilise a limited water service provider for those activities covered by that requirement.
Environmental Protection Act 1994, Queensland	Section 98 can be imposed on a petroleum activity and cause the activity to prepare environmental report and, implement water management plans. The EPA can also cease, put on hold or limit the petroleum activities.	Conditions are issued through Environmental Authorities.

Legislation/Section	**Driver**	**Key Points as they Apply to the QGC Operations**
Environmental Protection (Water) Policy, 1997, Queensland	Section 26 relates to the monitoring of the release of waste water on land or into water. Release either accidental or planned are controlled by the EPA	Contamination must be minimised or prevented and any release, or potential release, will be monitored against site baseline conditions. An EA is required for all ponds.
Queensland Coal Seam Gas Water Management Policy, October 2008	A policy developed to provide direction for treatment and disposal of the coal seam gas water.	QGC will be responsible for the treatment and disposal of the associated water.
Management of Water Produced in Association with Petroleum Activities (associated water), December 2007	To promote the beneficial use of associated water from petroleum activities in Queensland, including the promotion of beneficial use, and reinjection.	The management options chosen by QGC must comply with the conditions of the General Notice, and they must have appropriate facilities at the site where the water is to be used. If QGC wishes to use associated water for purposes other than domestic or stock purposes (such as irrigations), the holder must obtain a water licence under the *Water Act 2000*.
Water Supply (Safety and Reliability) Act 2008	This act provides a regulatory framework for providing recycled water and drinking water quality, primarily for health. It governs who must apply for registration as a service provider.	If QGC reuses the groundwater for beneficial use, this act outlines the requirements as a service provider.
National Water Initiative	A shared commitment by governments to increase the efficiency of Australia's water use, leading to greater certainty for investment and productivity, for rural and urban communities, and for the environment.	The NWI should be applied equally to all water users to avoid any adverse impacts to water quantity and quality that may affect other water users and the environment.
Water Fluoridation Act 2008	This act sets out the requirements for adding fluoride to relevant public potable water supplies.	If QGC is to provide treated associated water for drinking water supplies, they must consider fluoridation.

3.0 STUDY METHODS

The original Project-wide groundwater assessment involved the following investigation methods:

- obtaining, preparing and interpreting available data – in order to provide, as complete as possible, a background to the study area and the compliance requirement for the proposed CSG operations;
- conducting field investigations – to provide site specific information on features which directly or indirectly impact the proposed operations, and to highlight those aspects of the proposed works which will cause impacts on the environment and other groundwater users; and
- developing a computer-based numerical groundwater model – to permit an estimate of the magnitude of the likely impact on the environment and other groundwater users.

The details of these data collection and assessment studies are outlined in Section 3.0 of the original study. New data acquired for the purpose of this report was assessed using the same methodology. The data attributes selected for assessment were those considered pertinent for the development of a thorough understanding of the *existing environment and environmental values,* and the *potential impacts* of these which might arise from the proposed CSG operations.

With regard to the proposed Wandoan Coal Project and the UCG projects within the NWDA, information was obtained as follows:

- The Wandoan Coal Project, data obtained from the published project EIS: “Wandoan Coal Project - Integrated Environmental Impact Statement” (December 2008) and “Wandoan Coal Project Preliminary Groundwater Assessment (November 2008); and
- UCG project – internet based search of UCG tenements and general information of UCG methods.

3.1 Data Collation and Review

The first stage involved assessing the bores and wells located within the broader Study Area (Figure 1). Utilising the geological, hydrogeological and groundwater level and quality information available for each bore[2] or well, a conceptual groundwater model of the study area was developed.

Data were received in many different formats and in some instances the accuracy of the data was questionable. Considerable effort was invested in importing the data into a central database and validating them. Data quality was thoroughly checked, and data were excluded from further analysis if found to be of poor quality. Typically, poor quality information was attributed to contradictory information, lack of units for measurements, or the absence of key hydraulic parameters for some formations.

All coordinates were converted to Geographic Datum GDA94 (latitude & longitude). Corrections and/or conversions were made when required. All elevations in the report are provided in metres, in relation to the Australian Height Datum (m AHD).

Most of the DERM registered bores do not have ground elevation information. Thus, for consistency, all bores were allocated a ground elevation by means of a digital elevation model (DEM) grid with coverage of the entire study area. The DEM is considered to be a complete dataset of known accuracy, whereas the source of the elevations within the DERM database is questionable or not provided. The elevation data for the two data sets was cross-checked for consistency. This method was considered appropriate due to the generally flat terrain of the area and the lack of precise topography data for the study area.

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[2] . In this report, the term ‘well’ refers to infrastructure used to extract CSG and associated water from the subsurface. A ‘bore’ refers to the structure that is used to extract groundwater for domestic, stock, irrigation, industrial or commercial purposes. Although wells and bores are defined differently; they are similar engineering structures.

3.1.1 Geology and Stratigraphy

The study area is located within the Surat Basin The literature extensively documents the regional and local geological settings of this portion of the Great Artesian Basin (GAB) and its easternmost sub-basin, the Surat Basin.

QGC geologists and engineers were consulted to confirm and identify site specific geological and hydrogeological characteristics and irregularities in the local geology of the study area.

Stratigraphy was interpreted by compiling stratigraphic data from the DERM groundwater database and QGC exploration data. The stratigraphic information, made available by QGC, focused on the stratigraphy of the Walloon Coal Measures (WCM) and the adjoining formations. Using this data compliment, geological and general data management principles were applied to develop stratigraphic unit surfaces using ArcGIS 3D Analyst software. From the three dimensional interpreted surface maps, multiple cross sections were established along a north-east to south-west axis (dip axis) and along a north west to south east axis (strike axis).

3.1.2 Water Levels and Water Quality

Water level and water quality data was obtained primarily from the DERM database. QGC data was also utilised and it predominantly covered the WCM. To compliment those two databases, data for the upper and intermediate aquifers was extracted from environmental monitoring and investigation reports.

QGC does not routinely measure water levels at bore completion; however, QGC provided the reservoir pressures measured in the WCM before well testing or production. These pressures were converted to hydraulic heads and assumed to represent the static hydraulic condition of the WCM formation concerned. The consequence of this assumption, particularly with respect to the impact assessment modelling, is not considered significant, since there are other input parameters for which only ranges or generic values are available, and hence the predictive outcomes would not be discernibly affected.

Water level data from the DERM database was extracted, referenced and quality checked:

- ‘water level’ table (where the majority of the data was obtained from);
- ‘aquifer’ table; and
- ‘strata log’ table.

Duplicate information was removed from the dataset.

Water levels were assigned to particular aquifer/s that each well/bore targeted, by relating the bore opening details (screen interval) to the stratigraphy and aquifer tables. In these two tables, the ‘bore construction’ and the ‘formation tops and bottoms’ information was used to determine the appropriate water level data.

Water quality data was extracted from various sources that included various DERM databases, Excel spreadsheets and reports (tables and text). 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 bore was open to (or screened in).

3.1.3 Metadata Management

Metadata is “data about data”. That is, metadata information comprises the following primary components of data:

- data available;
- amount of data;
- coverage of data;

- quality of data; and
- source of the data.

As part of the data quality checking process, each piece of bore or well data sourced from the DERM databases and from QGC was assigned a “data quality” *score* or rating for each of the criteria as presented in Table 4. In the table, ‘1’ is allocated to the better quality information, ‘2’ indicates partial information, and ‘3’ indicates no data available for bore stratigraphy, bore construction, water levels, bore chemistry and water quality.

Available data and their associated score are shown on Figures 4 through 7 as a means of showing the density and quality of the available data considered for this study. A summary of the data available within the NWDA is provided in Table 5.

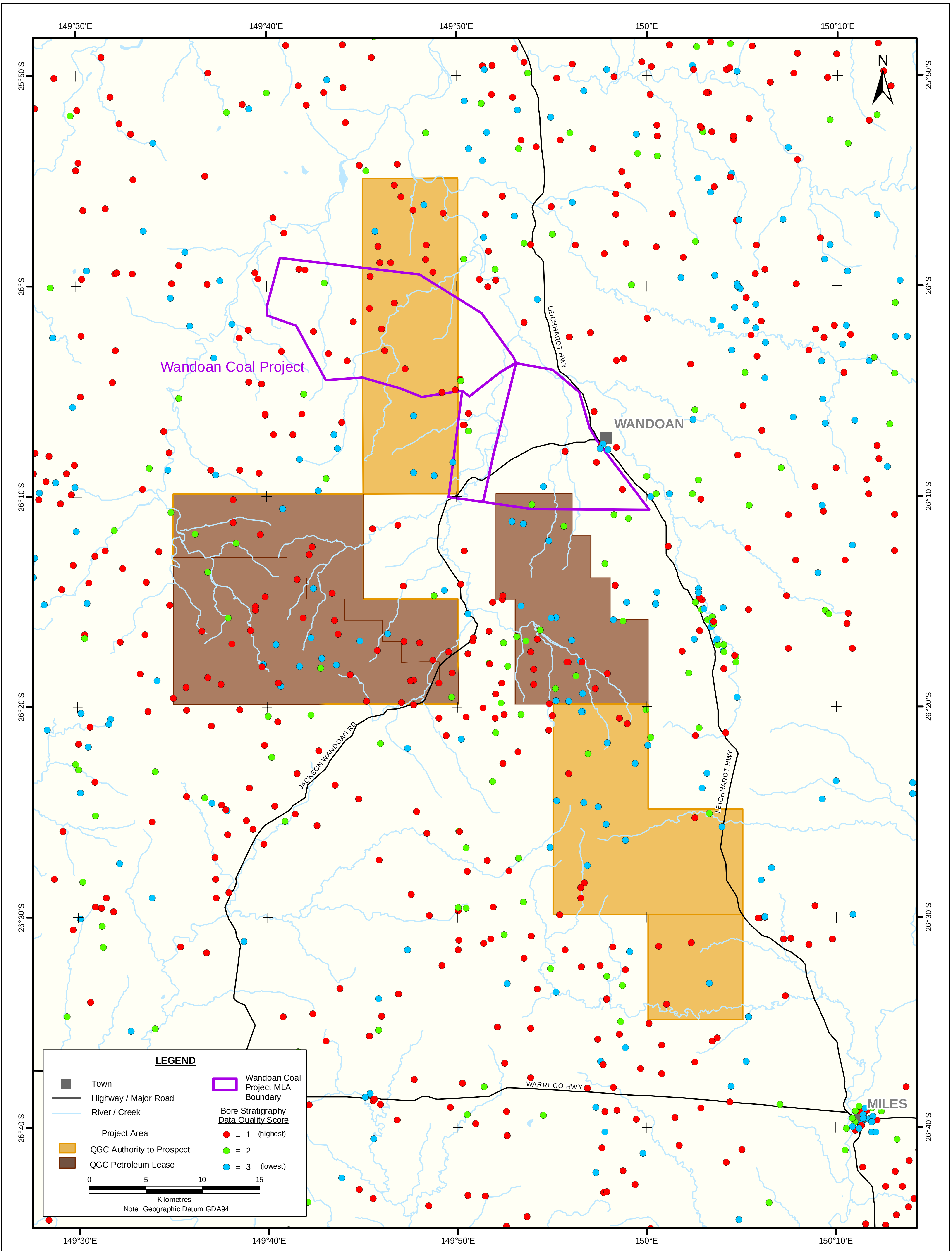
Table 4: Metadata Assessment Card

Information	Score	Criteria
Bore Stratigraphy	1	Good stratigraphy information
	2	Partial stratigraphy information available
	3	No information
Bore Construction	1	Good bore construction practices
	2	Bore construction practice in doubt
	3	No information / bad bore construction
Water Levels	1	Water level information and date of survey
	2	Water level but no date
	3	No data
Bore Chemistry	1	EC and pH measurements and date of sampling
	2	Partial information
	3	No data
Water Quality	1	Major ions chemistry available and date of sampling
	2	Partial information
	3	No data

Table 5: Metadata Summary in the NWDA

Score	Stratigraphy		Construction		Water Level		Chemistry	
1	315	62%	282	56%	325	64%	54	11%
2	4	1%	94	19%	7	1%	89	18%
3	188	37%	131	26%	175	35%	364	72%

Over half of the registered bores in the NWDA have good stratigraphy and construction information available (62% and 56% respectively) and approximately two-thirds of the bores have complete water level information (including a depth and date of measurement). Very few bores have a complete chemistry data set (11%).



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TITLE	LEVEL OF DATA RELIABILITY - BORE CONSTRUCTION DATA		
SCALE	1:300,000	PROJECT No	097626104_001
FIGURE No	4	REV No	2
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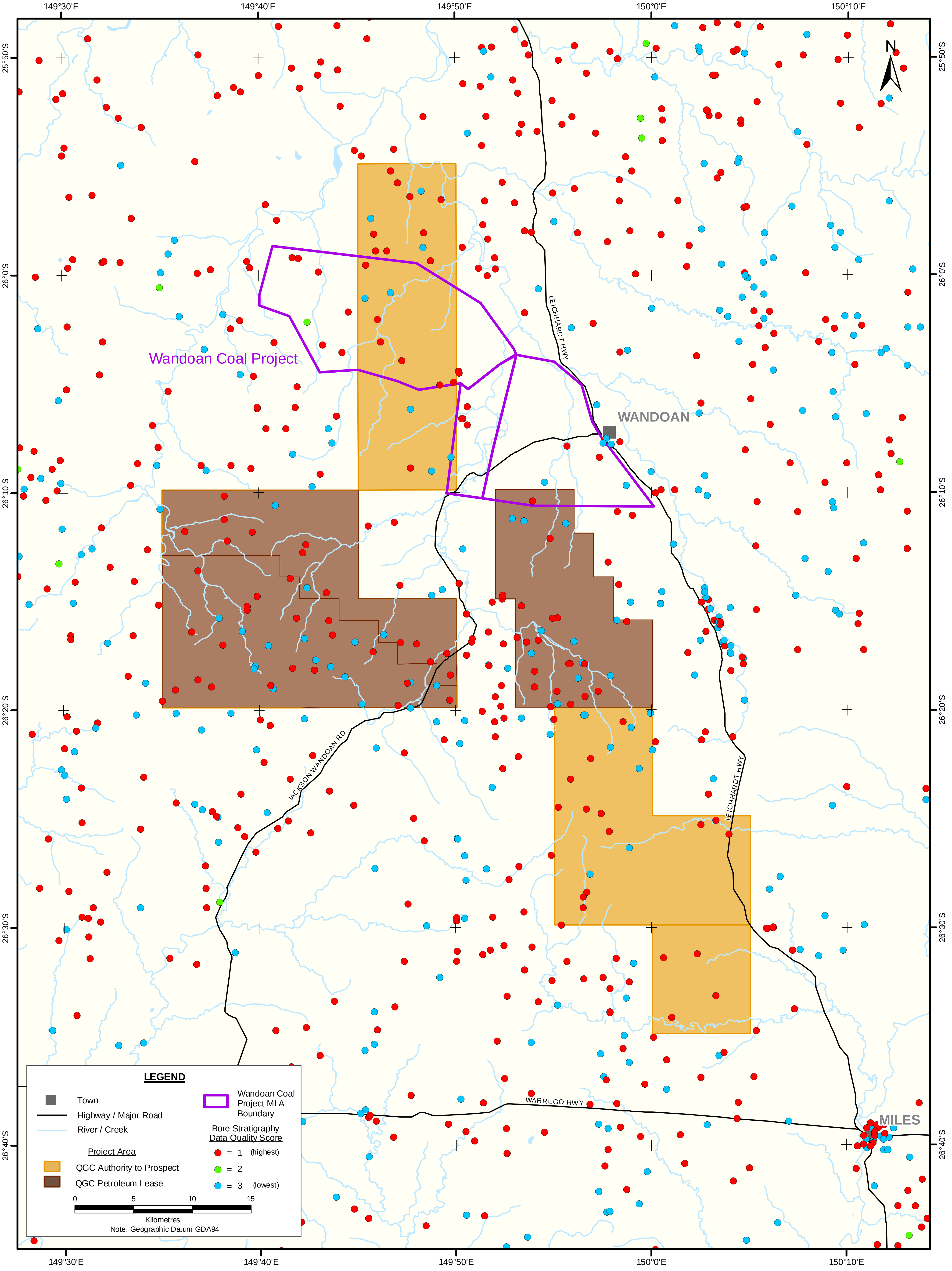

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TITLE

LEVEL OF DATA RELIABILITY -
BORE STRATIGRAPHY DATA

SCALE 1:300,000

PROJECT No 097626104_001

FIGURE No 5

REV No 2

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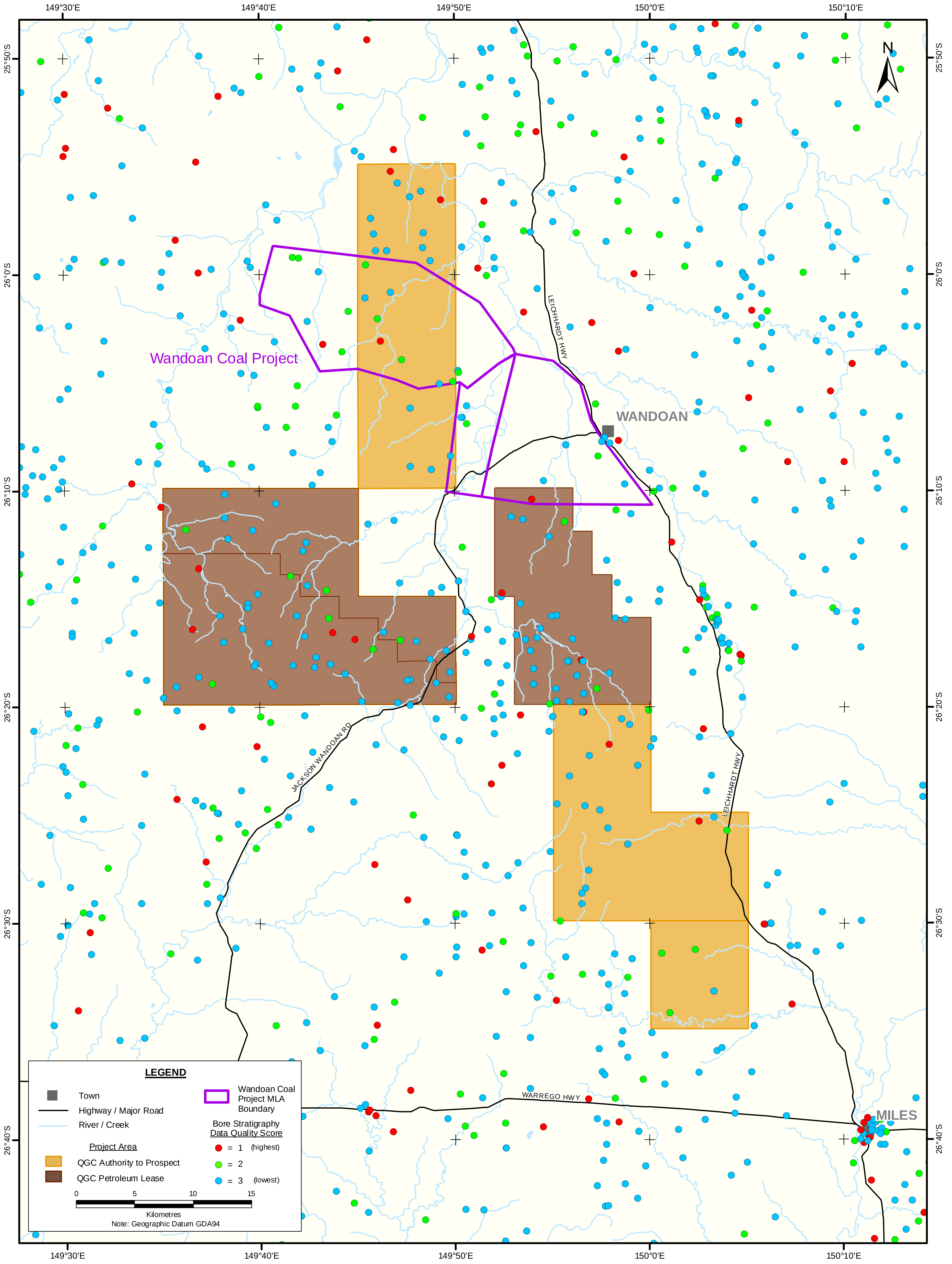

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LEVEL OF DATA RELIABILITY -
WATER QUALITY DATA

SCALE 1:300,000
PROJECT No 097626104_001
FIGURE No 6
REV No 2
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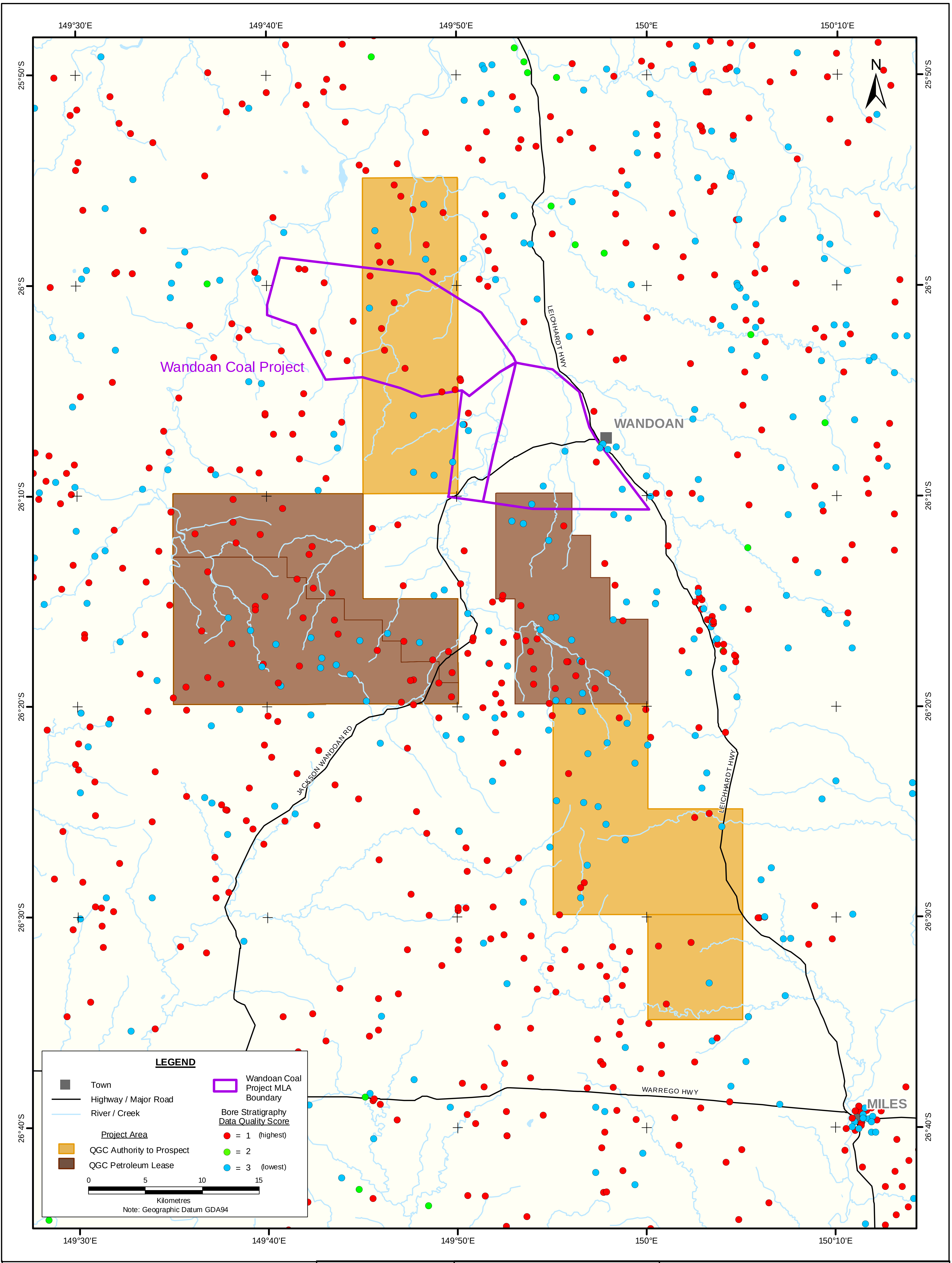

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3.2 Development of the Conceptual Groundwater Model

To formulate an understanding of the hydrogeology and the groundwater regime operating in the study area, a conceptual groundwater model (CGM) was developed for the original groundwater study report and revised for this supplementary EIS study where applicable.

A CGM is a simplified non-mathematical presentation of the hydrogeology of a region and may include descriptions of the various components of the subsurface groundwater environment, and/or an illustration of the conceptualisation in the form of a drawing.

The CGM provides real or inferred information about the nature and extent of geological layers and their hydraulic properties (together referred to as the hydrostratigraphy), including:

- aquifers, aquitards and aquicludes - their characteristics and interactions between each other;
- groundwater flow; and
- geological and man-made influences on the groundwater systems.

The purpose of the conceptual model is to provide a visualisation of the hydrogeological system. It may also be used to define the baseline groundwater conditions (the existing environment and environmental values) that can be used to assess potential future impacts. The CGM is largely based on available published information, and associated geological cross sections and contour maps, of the local interpreted stratigraphy. The sections and maps identify the locations, depth and thickness of each formation (in this case, the sedimentary layers) and areas of outcrop at the surface.

After completing the literature and data review, a CGM was developed for the Project study area. The geological formations were grouped into six major hydrogeological units (groupings of units), which are detailed in Section 4.4.3.

For each of the units, hydraulic head and salinity data (supplied by DERM and QGC) were compiled to create hydrogeological maps. As the units are considered to be largely continuous and connected across the entire Project Area (CDA, NWDA and SEDA), all three development areas are presented in the hydrogeological maps presented in this report. The maps represent the baseline hydrogeological system in the region prior to development of the proposed CSG fields, and indicate the areas with a higher probability of impact from QGC operations.

3.2.1 Groundwater Modelling and Impact Assessment

Having defined the baseline groundwater conditions, including the existing environment and environmental values, a method to assess the potential future impacts to these values was developed.

This involved the development of a numerical groundwater model to represent the NWDA CSG Project area. This model, a revised version of that presented in Golder report 087633050 016 (June 2009) and designed to be more representative of the new tenement areas included in the NWDA, has employed numerical mathematical techniques to simulate the behaviour of a groundwater system under proposed future CSG extraction operations.

The model has been employed in this study to provide predictions of the impact of extracting CSG and groundwater from the WCM on the existing environment values including other groundwater users in and around the NWDA (Appendix B).

Therefore, the modelling work sought to allow the:

- Development of an *idealised* regional groundwater model for the NWDA CSG resource area;
- Interpretation of both the conceptual groundwater model and the “order of magnitude” results of the numerical groundwater modelling to provide an estimation of the *relative* risk of groundwater impacts

arising from the proposed NWDA CSG operations, and for the post-production period of groundwater recovery (post-closure period);

- Development of recommendations for groundwater management and monitoring associated with the NWDA CSG operations as part of the Project-wide groundwater monitoring plan (GWMP, 2009); and
- Determination of preferred trigger levels, consistent with the definition provided in the *Petroleum and Gas Act 2004.*

The numerical groundwater model was developed using the MODFLOW modelling code in the PMWin software package. The model was developed to be conservative in its predictions; providing over-estimates of the potential drawdowns over the term of the CSG well field operations.

While the model provides an indicative representation of aquifer behaviour in the region under a CSG extraction regime, it does not include the cumulative influence expected from neighbouring CSG operators, the Wandoan Coal Project or possible UCG operations since the impact information for these activities is not know at this time.

A summary of the groundwater modelling methods employed and their results are presented in Section 5.4, with a full description of the methods used for the modelling provided in Appendix B.

The interpretation of the results and the arising recommendations are provided in Sections 8.0 and 10.0 and Appendix B.

4.0 DESCRIPTION OF THE EXISTING ENVIRONMENT

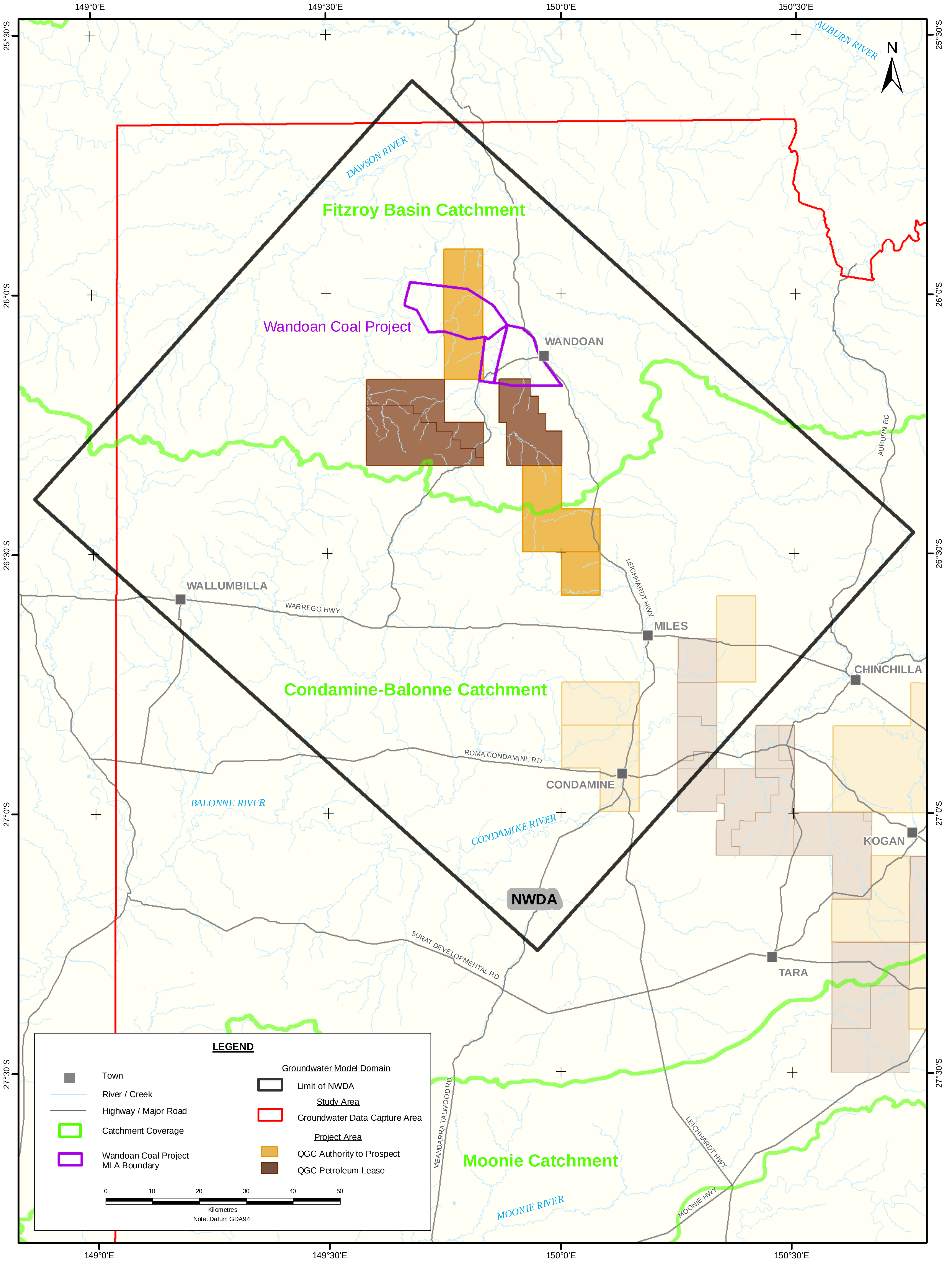
The existing environment, as it relates to groundwater, is described in this section, providing a baseline dataset of specific information from which future effects and potential impacts may be assessed, if required.

Within the NWDA, the existing natural environment mostly consists of areas that have been moderately modified by agricultural and pastoral activities. The areas of highest environmental value are limited to the less disturbed areas. Their attributes are described in the following sections.

4.1 Topography and Drainage

The northern portion of the NWDA is generally flat with elevations ranging from approximately 300 to 400 m AHD. A western section of the Great Dividing Range passes through the centre of the study area; however, the vertical variance is less than that seen in the Ranges to the east and south east of the study area. A number of state forests are located throughout the southern regions of the study area, the most significant of these being the Gurulmundi State forest.

The Condamine River, located within the Condamine and Balonne catchment, flows through the very southern portion of the NWDA. In the north, tributaries of the Dawson River (within the Fitzroy River catchment), flow in a northerly direction beyond the limits of the study area. Figure 8 indicates the locations of the rivers in proximity to the QGC tenements.



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DRAWN BQ
DATE 11-12-09
CHECKED RKH *
DATE 11-12-09

TITLE
SURFACE WATER DRAINAGE AND MAJOR CATCHMENTS

SCALE 1:750,000
PROJECT No 097626104_001
FIGURE No 8
REV No 2
A3

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Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

4.2 Climate

The climate around the NWDA is sub tropical with a dry winter season. Figure 9 presents the mean monthly rainfall and evaporation data for the Miles Post Office weather station. The yearly climate pattern is illustrated in Figure 9. The histogram represents the mean rainfall and the curve represents the mean temperature.

The dry season occurs during winter, from April to September. December and January are the hottest months. The average annual rainfall is 610mm. Rainfall is received throughout the year; however more rainfall is expected in the summer months from November to February. Evaporation ranges from 7.8mm per day in summer (January) to 2.2mm per day in winter.

Table 6: Mean Climate Characteristics for the Project Area

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall in mm													
	95.2	75	58.6	36.6	39.1	39.6	37.6	29.3	30.8	54	66	88.6	650.2
Evaporation in mm/day													
	7.8	6.7	5.9	4.6	3.1	2.2	2.4	3.4	5.1	6.4	7.5	8.2	5.3
Temperature in °C													
Maximum	33.2	32.3	30.8	27.5	23.2	19.8	19.3	21.4	25.1	28.6	31.2	32.9	27.1
Minimum	19.5	19.3	17	12.4	7.9	5.0	3.6	4.9	8.5	13.1	16.3	18.4	12.2
Average	26.4	25.8	23.9	20.0	15.6	12.4	11.5	13.2	16.8	20.9	23.8	25.7	19.7

Source: Averaged climate statistics derived from climatic data for the Miles Post Office weather station, data from the Bureau of Meteorology website (www.bom.gov.au)

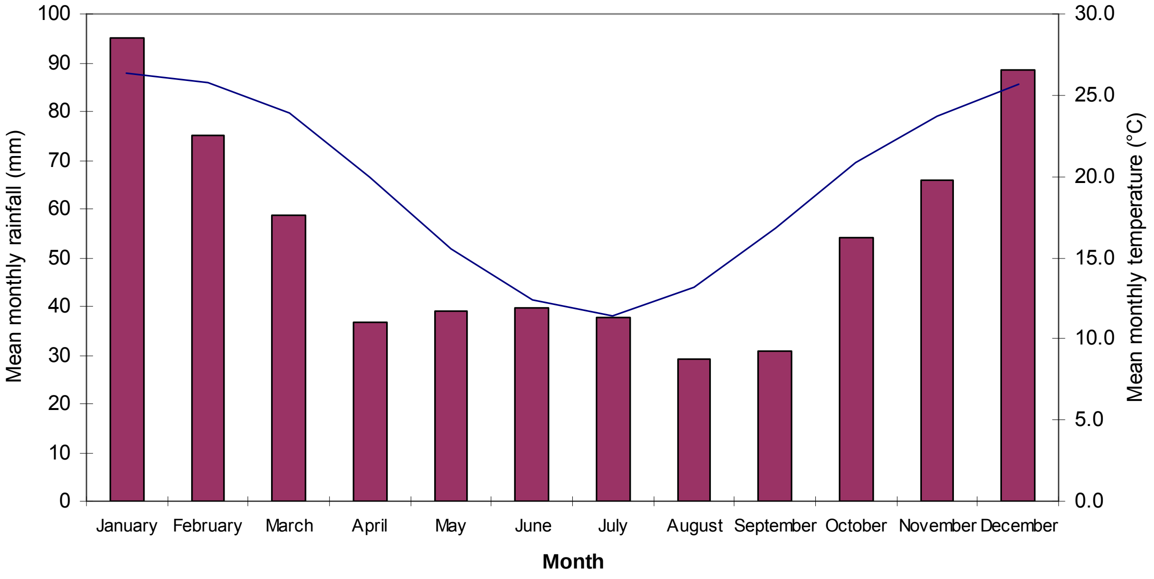


Figure 9: Mean Climate BOM Statistics for Miles Post Office Weather Station

Source: Averaged climate statistics derived from BOM climatic data for the Miles Post Office weather station.

4.3 Geology

The QCLNG Project is located within the eastern reaches of the GAB. An overview of the regional and local geology underlying the NWDA are provided below and set the scene for the development of the CGM (Section 5.3) and the numerical model for groundwater impact assessment (Section 5.4).

4.3.1 Regional Geology of the GAB and Surat Basin

The GAB is a sedimentary basin that underlies about a fifth of Australia, extending under parts of Queensland, New South Wales, South Australia and the Northern Territory. It comprises a multi-layered sedimentary system comprising units deposited under widely varying depositional environments (Great Artesian Basin Consultative Council, 1998). Figure 10 shows a schematic cross section through the GAB.

The GAB is divided into three sedimentary basins: the Eromanga Basin, the Surat Basin and the Carpentaria Basin. These sub-basins were separated by ridges in the basement rock formations until the early Jurassic period. At that time, deposits covered the whole of the GAB in continuous layers. The QCLNG Project lies within the Surat Basin.

In the Surat Basin the stratigraphic sequence is dominated by sedimentary formations comprised of fluvial quartzose sands. The Surat Basin stratigraphy overlies parts of the Bowen Basin sequences in the Project Area.

4.3.2 Geology in the NWDA Study Area

The geology (and hydrogeology) of the Surat Basin has been thoroughly described in the literature. The following narrative provides a brief summary of the geology in the NWDA, which was largely derived from PB (2004) and AGE (2007), as well as Quarantotto (1989), ANRA (2005) and Scott *et al*. (2005).

4.3.2.1 Surficial Geology

The surface geology in the study area primarily corresponds to Tertiary sediments (Figure 11). The Tertiary sediments predominantly include unconsolidated alluvial sediments (sand, gravel and silts) associated with the major drainage systems as infill alluvium. The Condamine River, lying to the south and south-east of the Project Area, is an example of unconsolidated alluvial sediments in the region.

These surficial geological units (layers) do not have a consistent geological dip and attitude, and generally conform with the paleo-topography in which they were deposited, that is, they are confined to the valleys and drainages which pre-date their deposition.

4.3.2.2 Surat Basin Stratigraphy

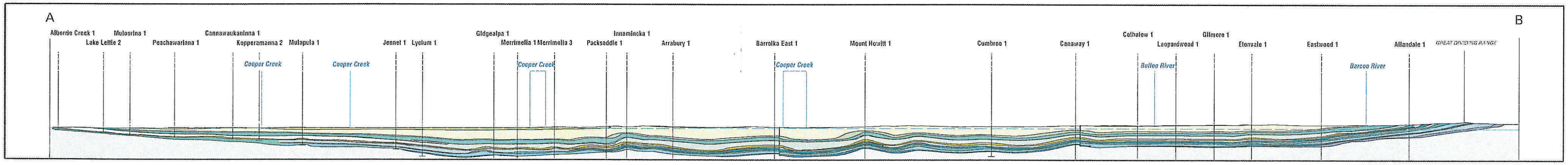
Figure 12 presents the dominant Jurassic-Cretaceous stratigraphy, primarily composed of fluvial quartzose sandstones, underlying the NWDA tenements.

The lower-most layer of the Surat Basin geological sequence is the Precipice Sandstone, which unconformably overlies the Triassic sediments of the Bowen Basin (The Moolayember Formation, Clematis Sandstone and Rewan Formation).

The Precipice Sandstone outcrops within the north-eastern part of the Project Area, as well as to the north and northeast of the Project Area. The younger Surat Basin formations (namely, the Kumbarilla Beds and Injune Creek Group) outcrop progressively south-west through Miles-Chinchilla-Kogan (Bureau of Mineral Resources, Geology and Geophysics Surficial Geology, 1967).

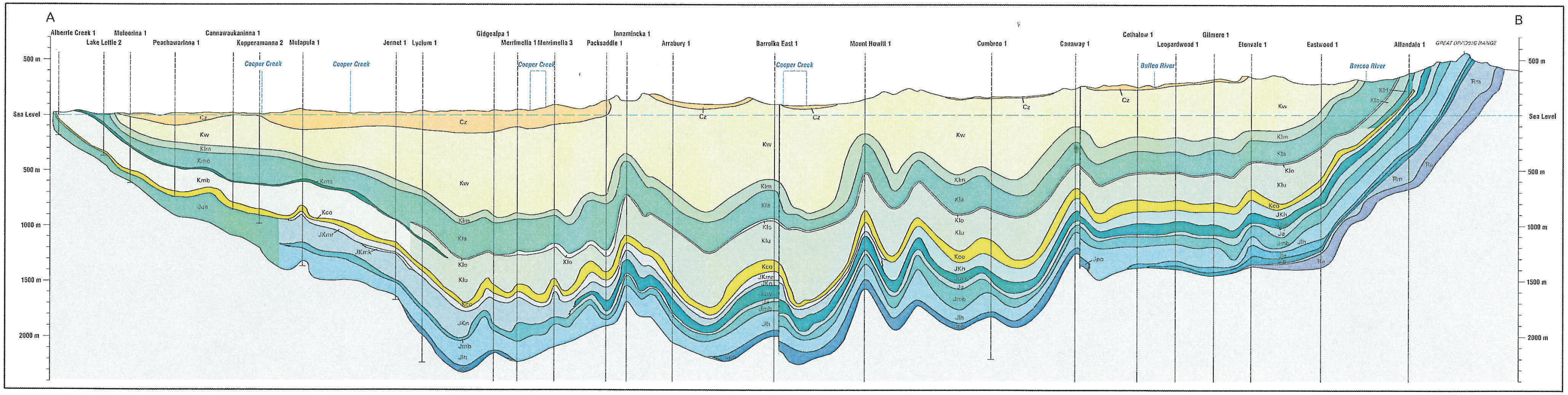
The geological units (layers) generally dip in a south to south-western direction in the study area, and therefore, the depth to each layer will vary from location to location (refer to Section 4.3.2.3 for a detailed discussion of the structural aspects of the Surat Basin stratigraphy).

Vertical Exaggeration Profile (x 10.0)



GREAT ARTESIAN BASIN CROSS SECTION

Vertical Exaggeration Profile (x 87.5)



Cz	Cainozoic (Section only) (Quaternary and Tertiary units)
Ja	Adori Sandstone
Jgw	Garraway beds
Ji	Injune Creek Group
JKb	Helby beds
JKg	Gilbert River Formation
JKh	Hooray Sandstone
JKk	Kumbarilla beds
JKmk	McKinlay Member
JKmr	Murta Formation
JKn	Namur Sandstone
JKr	Ronlow beds
JKs	Southlands Formation
Jlb	Boxvale Sandstone Member
Jle	Evergreen Formation
Jlh	Hutton Sandstone
Jlp	Precipice Sandstone
Jmb	Birkhead Formation
Jp	Pilliga Sandstone
Jpo	Poolowanna Formation
Jpu	Purlawaugh Formation
Js	Springbok Sandstone
Jua	Algebuckina Sandstone
Jue	Eulo Queen Group
Jug	Gubberamunda Sandstone
Juo	Orallo Formation
Juw	Westbourne Formation
Jw	Walloon Coal Measures
Kco	Cadna-owie Formation
Kla	Allaru Mudstone
Klc	Coreena Member
Kld	Doncaster Member
Klgc	Griman Creek Formation
Klm	Mackunda Formation
Klms	Mooga Sandstone
Kln	Normanton Formation
Klo	Toolebuc Formation
Klr	Rolling Downs Group
Kls	Surat Siltstone
Klu	Wallumbilla Formation
Kly	Bungil Formation
Kmb	Bulldog Shale
Kmc	Coorikiana Sandstone
Kmo	Oodnadatta Formation
Kw	Winton Formation
Re	Clematis Sandstone
Rlw	Warang Sandstone
Rm	Moolayember Formation

after:-
Habermehl, M.A. & Lau, J.E., 1997 - Hydrogeology of the Great Artesian Basin, Australia (Map at scale 1 : 2 500 000)
Australian Geological Survey Organisation, Canberra
[Cross Section A-B]

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CLIENT QGC - A BG Group business
PROJECT QGC - LNG EIS Groundwater Study
DRAWN BQ DATE 11-12-09
CHECKED RKH* DATE 11-12-09
TITLE REGIONAL GEOLOGY CROSS SECTION
SCALE Not To Scale
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FIGURE No 10
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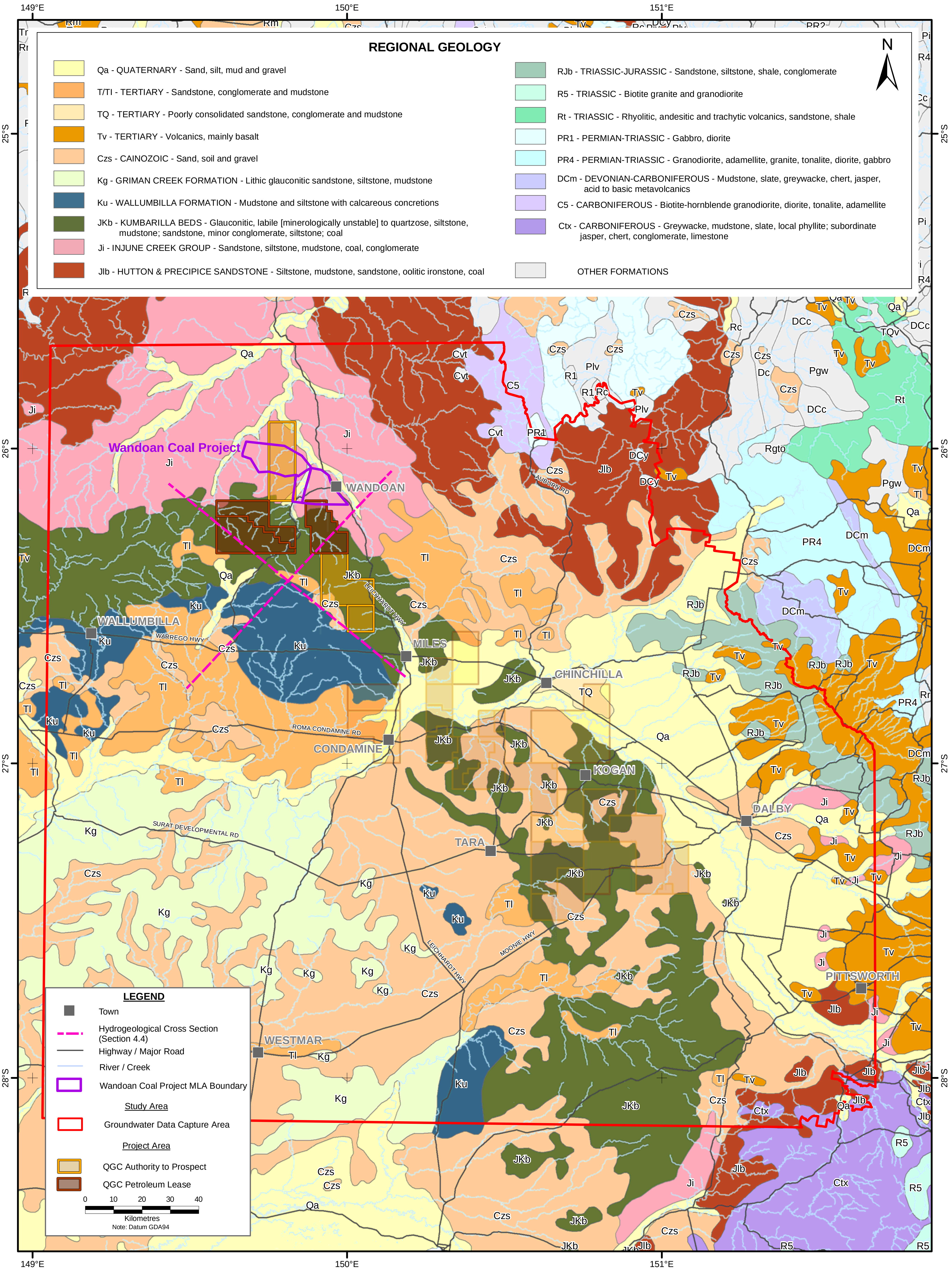

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CLIENT QGC - A BG Group business		PROJECT QGC - LNG EIS Groundwater Study	
DRAWN DK/BQ	DATE 11-12-09	TITLE SURFACE GEOLOGY IN THE STUDY AREA	
CHECKED RKH *	DATE 11-12-09		
SCALE 1:1,250,000		PROJECT No 097626104_001	FIGURE No 11 · REV No 2 · A3

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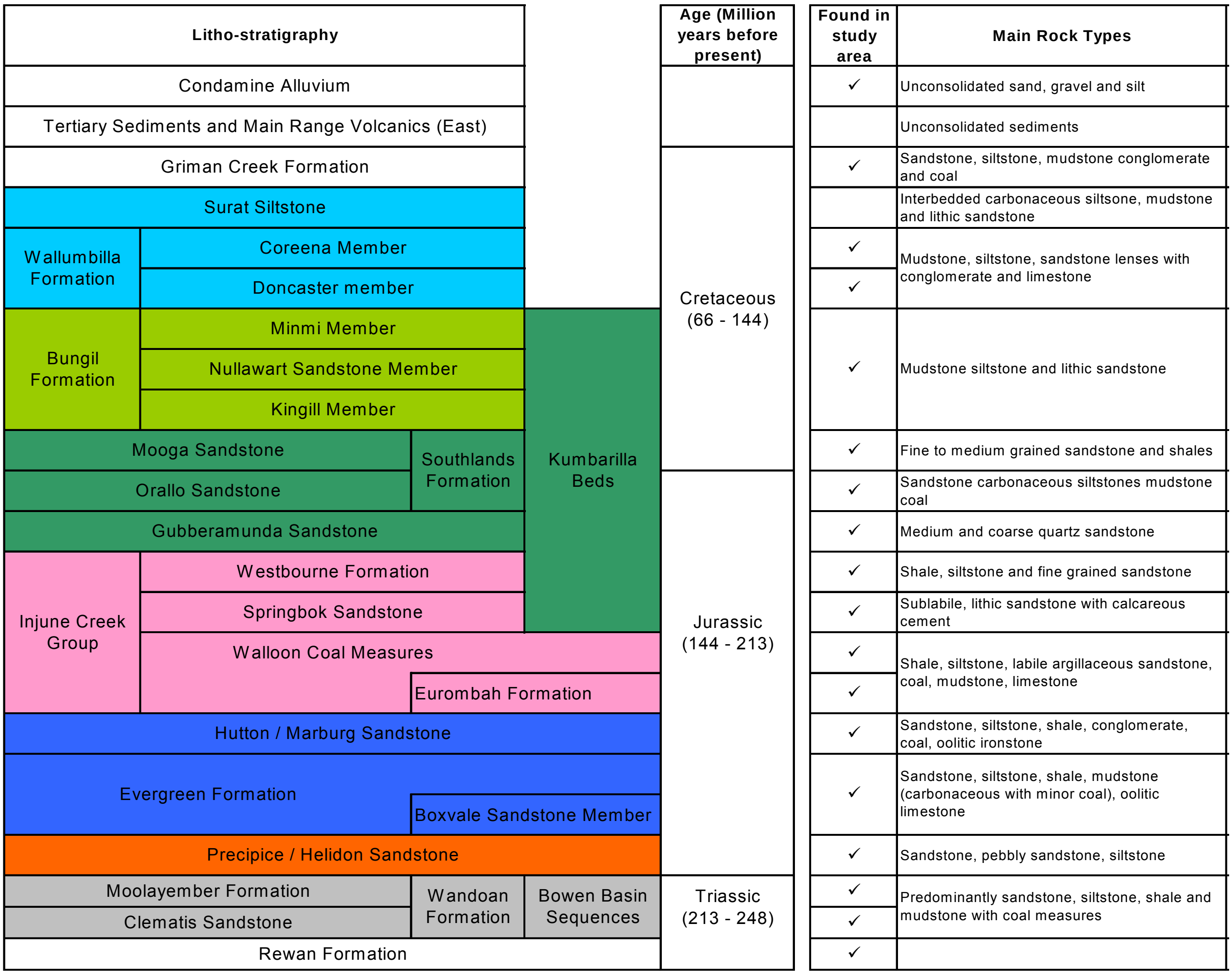


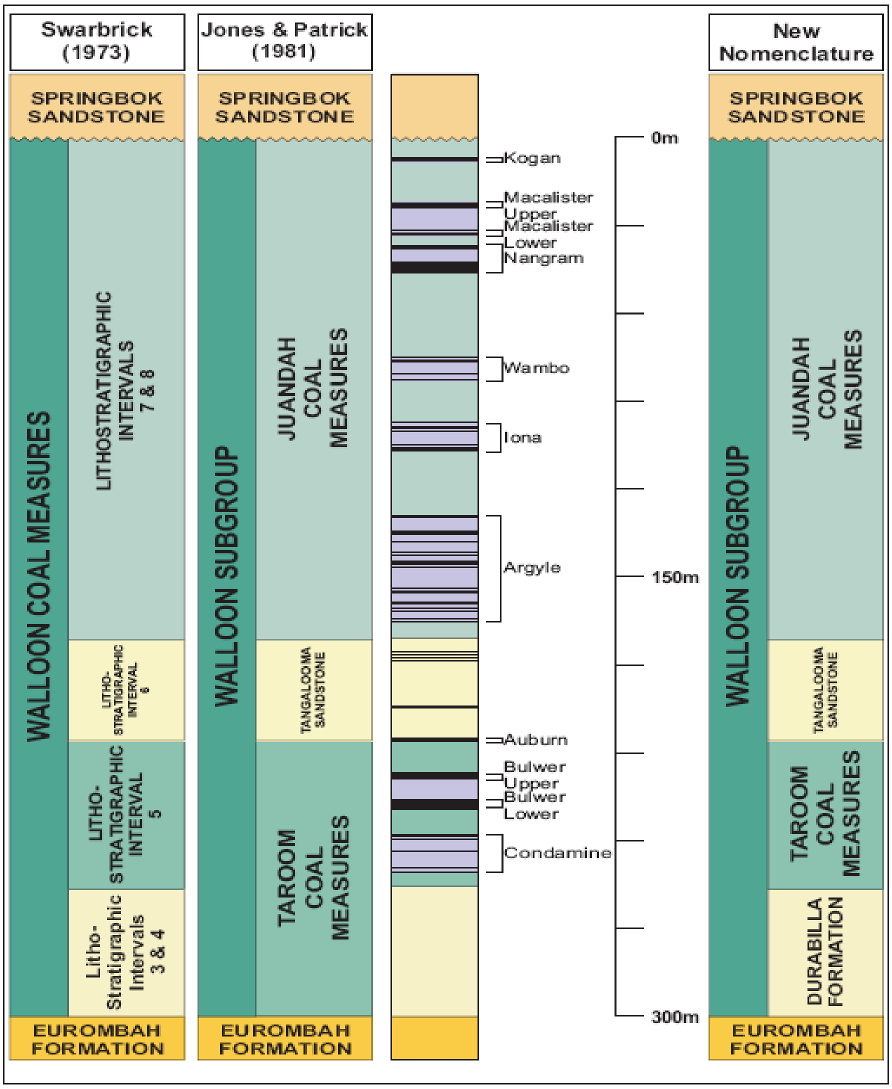
Litho-stratigraphy				Age (Million years before present)	Found in study area	Main Rock Types
Condamine Alluvium					✓	Unconsolidated sand, gravel and silt
Tertiary Sediments and Main Range Volcanics (East)						Unconsolidated sediments
Griman Creek Formation				Cretaceous (66 - 144)	✓	Sandstone, siltstone, 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 from Parsons Brinckerhoff 2004, Coal Seam Gas, Water Management Study

Figure 12: Stratigraphy in the Study Area.

The WCM are the main CSG bearing units within the Surat Basin, and are the target formation for CSG operations within the NWDA, and the broader Project Area.

The approximate thickness of the WCM stratigraphy is 260 m at depths averaging 560 m AHD (approximately 210 m below ground level) in the central portion of the NWDA decreasing to less than 60 m in the northern portion of the area. The individual coal seams are separated by a complex sequence of interbedded siltstones, mudstone and sandstones through the WCM. The detailed stratigraphic sequence within the WCM is presented in Figure 13. Of particular note is that there is an unconformable contact between the Springbok Sandstone and the WCM, similar to the unconformity between the Precipice and the upper Bowen Basin Formations. These unconformable contacts can bring higher permeability layers within each formation into direct contact with one another.



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

Figure 13: Detailed Stratigraphy of the Walloon Coal Measures

4.3.2.3 Structural Geological Controls

The Surat Basin stratigraphy is affected by a number of faults and folds (Figure 14). These structures are variously interpreted as fully or partially penetrating through the full geological sequence described above.

The underlying Bowen Basin basement is block-faulted; however, the faulting and folding that is recognized in the older subsurface strata is either absent or attenuated in the outcropping Jurassic-Cretaceous sediments.

The key structural features are summarised in Table 7 and presented in Figure 14.

Table 7: Key Structural Features in the NWDA

Structural Element	Description
Leichhardt-Burunga Fault	A fault structure that separates the NWDA from the eastern half of the Project Area. It is considered to be an extension of the Goondiwindi - Moonie Fault located further south-east. The throw on this fault is to the east, but the amount of displacement is not accurately known.
Mimosa Syncline	A broad open and extensive synclinal fold structure affecting the western portion of the NWDA. It is not believed to have resulted in significant faulting and fracturing of the Surat Basin stratigraphy.
Wallumbilla Fault	A fault structure, which together with the Arcadia Anticline marks the western boundary of the NWDA.

Other smaller faults have been inferred (by QGC geologists) below the WCM with throws of up to 50 metres. These faults were interpreted as being unlikely to extend through the full geological sequence.

In summary, the NWDA appears to be structurally separated from the CDA and SEDA production areas by these fault/s, fold/s or monocline/s features, as alluded to in Figure 14. It supports the hypothesis that the CSG presence and availability within the different development areas are somewhat structurally (QGC and AGE, 2007), and potentially hydrogeologically, isolated from each other to some, as yet unknown, degree.

4.4 Hydrogeological Setting

4.4.1 Great Artesian Basin Setting

As noted earlier, the Surat Basin is a sub-basin of the GAB, one of the largest artesian groundwater basins in the world. The Surat Basin, together with the Bowen Basin, comprise the eastern-most sub-basins within the GAB, and are considered structurally separate sedimentary depositional centres. They are, however, stratigraphically and hydraulically interconnected to varying degrees (DME, 1997).

The Surat basin is a multi-layered mainly confined hydrogeological system consisting of alternating layers of water-bearing (permeable) sandstones and non-water-bearing (impermeable) siltstones and mudstones. The sandstone units store and transmit groundwater and are defined as aquifers. These rocks are sufficiently permeable to conduct groundwater and to yield economically significant quantities of groundwater to water bores and springs.

The siltstone and mudstones within these systems are low permeability rocks (commonly termed impermeable) that do not qualify as aquifers. They hinder, but do not totally prevent, groundwater flow or leakage between aquifers, and thus they are considered to be aquitards. The formations are laterally continuous and hydraulically connected across the NWDA.

The GAB aquifers are recharged by infiltration (rainfall directly and indirectly), and leakage from streams into outcropping sandstone formations, mainly on the eastern and north-eastern margins of the GAB along the western slopes of the Great Dividing Range. Regional groundwater flow is from the topographically higher recharge areas around the basin margins towards the lowest parts of the basin in the southwest. The NWDA is, therefore, located over outcrop regions of the water-bearing formations in the Surat Basin, which are considered to be the part of the recharge areas of the GAB.

4.4.2 Local Hydrogeological Setting

As presented in Section 1.3.1, the NWDA lies across portions of the following GMAs:

- Surat East (GMA 21);
- Surat North (GMA 20); and
- Surat (GMA 19).

The geological formations present within the GMAs are sub-divided into stratigraphical GMUs based on the variation of hydraulic parameters and behaviours of the different aquifer systems. These subdivisions are presented in Table 1 and Figure 3.

It is evident from the data obtained for this study, that the hydrogeological systems operating within the Surat Basin are numerous and complex, both in their vertical heterogeneity and their areal variability. To make sense of the systems, and to make a reasonable assessment of the likely impact of groundwater extraction as part of the proposed CSG operations, it has been necessary to identify and group specific hydrostratigraphic units and rock-types (primarily based on the aquifers) into three primary hydrostratigraphic zones. These, in turn can be readily subdivided into six groupings or hydrogeological sub-units (Section 4.4.3).

From this process, a sensible hydrogeological and groundwater flow model (Sections 5.3 and 5.4) can be developed to provide an uncomplicated and visually comprehendible overview of the system operating in the NWDA. These groupings do not necessarily refer to the depth of the aquifer, but rather a combination of the rocks genesis, its lithology, uniformity and distinctness. The regional outcrop and subcrop areas of most of the formations occur on the northern margin of the Project Area. These grouping are illustrated in Figure 12 and, where appropriate, described in the text which follows the table.

Table 8: Primary Hydrostratigraphic Zones Identified in the NWDA

Hydrogeological Units and Sub-units			**Formation Name**
A	**1**	Quaternary Alluvium Units	Shallow Quaternary & Tertiary alluvium
B	**2**	Shallow Unit	Wallumbilla Formation / Surat Sandstone
	3	Intermediate Unit	Bungil Formation (Nallumwurt) (aquifer)
			Mooga Sandstone (aquifer)
			Orallo Formation
			Gubberamunda Sandstone (aquifer)
			Kumbarilla Beds
	4	Walloon Unit	Westbourne Formation (aquitard)
			Springbok Sandstone
			Walloon Coal Measures (aquifers and aquitards)
	5	Hutton Sandstone Unit	Hutton Sandstone (aquifers) Evergreen Formation (aquitard)
	6	Precipice Sandstone Unit	Precipice Sandstone (aquifers)
C	Bowen Basin sequences		

Note: The interpretation of aquifer occurrence is based on DERM groundwater database information.

The stratigraphic units which comprise this hydrostratigraphy are also detailed in Figure 12, which focuses on the dominant Jurassic-Cretaceous stratigraphy underlying the NWDA.

4.4.3 Hydrostratigraphy

The following characteristics of the hydrostratigraphic zones identified in Table 8 are considered of note:

- **Quaternary Alluvium Unit:** This unit comprises the most recent Quaternary and Tertiary unconfined alluvium aquifers. This unit is not continuous across the Study Area. Groundwater is typically good quality and suitable for most purposes.

- **Shallow Unit**: In the NWDA, the Shallow Unit comprises Quaternary and Tertiary unconfined aquifers and the underlying Upper Cretaceous aquifers of the GAB, primarily the Wallumbilla Formation, where present. The Wallumbilla Formation is considered a confining unit elsewhere in the GAB. This unit is non-existent in the north and eastern sections of the study area.

- **Intermediate Unit**: The Intermediate Unit includes the major artesian sandstone aquifers above the WCM 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 that outcrop through the QGC leases in the NWDA.

- **Walloon Unit**: This unit includes the entire thickness of the WCM and includes, importantly:

    - *Coal seams* comprise 10 to 16% of the full thickness of the WCM and include up to 40 to 45 individual coal seams of varying thicknesses. These are the layers which are targeted for their CSG resource. The coal seams have a hydraulic conductivity of the order of 1.4m/day (median for coal beds, from available DERM and QGC information) and a porosity of approximately 1.2%. As such they permit groundwater flow and are considered poor to 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-fractures, referred to as 'cleats').

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

    - The *Springbok Formation*, the topmost layer in the Walloon Unit, includes a number of aquifer beds. DERM data suggest this unit ranges in thickness from 40m to 120m. 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. From local knowledge, the Springbok aquifer is known to be locally contributing to water flows derived from the upper WCM beds, confirming local hydraulic connection between the two units (this has important consequences when CSG extraction operations depressurise the WCM and have the potential to impact the Springbok, as discussed in the following sections of this report). Recharge to the Springbok occurs in the north and eastern sections of the Surat Basin. Although few measurements of electrical conductivity are available in the Springbok formation, the available data are similar to those observed within the WCM.

- **Hutton Sandstone Unit:** This unit consists predominantly of the Hutton Sandstone, which is the second major Jurassic aged artesian aquifer in the GAB. DERM data suggest this unit ranges in thickness from 120m to 380m. Generally, the Hutton Sandstone yields up to 50 L/s of good quality water, with recharge areas in the north and east of the Surat Basin margins. Typical hydraulic conductivity is up to 0.7 m/day. The Evergreen Formation, which underlies the Hutton Sandstone (grouped here with the Hutton), is considered a major confining bed within the Surat Basin (GABCC, 1998) and is significantly less hydraulically conductive than the neighbouring Hutton Sandstone and Precipice Sandstones (Golder 2009a). Both the Hutton Sandstone and Evergreen Formation outcrop in the northern portion of the NWDA.

- **Precipice Formation Unit**: This unit typically forms the basal Jurassic artesian aquifer in the Surat Basin. DERM data suggest this unit ranges in thickness from 40m to 100m, while seismic survey data indicates a thickness of 20m to 150m. Recharge to the Precipice Sandstone occurs from outcrop to the north of the NWDA. Typical hydraulic conductivities range from 0.1 to 10 m/day and yields range between 0.1 and 30 L/s.

The sandstone sequences contain low permeability sediments, which cause the hydraulic conductivity to be highly variable within the stratigraphic sequence. The most conductive strata are typically associated with high energy stream sediments deposited at the base of each of the major aquifer units.

Of key hydrogeological importance, is the presence of an unconformable contact between the Springbok Sandstone and the WCM and between the Precipice and the lower Bowen Basin Formations (Figure 12).

4.4.3.1 Identification of Key Aquifers

From the key hydrostratigraphic units identified in Table 8. The major Surat Basin aquifers within the NWDA, assessed in terms of groundwater development, include:

- The Precipice Sandstone aquifer;
- The Hutton Sandstone aquifer;
- The Springbok Sandstone aquifer;
- The Gubberamunda Sandstone aquifer; and
- The Mooga Sandstone aquifer.

These aquifers have significant water bearing/yielding capacities because of their physical characteristics that include thickness, porosity, hydraulic conductivity and storativity, as well as, water quality. They are considered key environmental values for the Project. It should be noted that the Mooga and Gubberamunda Sandstones outcrop across the central region of the NWDA and are thus not present through the northern reaches of the study area.

There are also minor aquifers, which typically yield less water than the major aquifers. The coal seams within the WCM are examples of minor aquifers. These seams are not high yielding aquifers, or of the best water quality (Golder 2009a), but they are used by a number of farmers and landowners in the Project Area, and for industrial and domestic activities. They have also become further utilised by the broader CSG industry in the region.

The hydrogeological parameters (primarily, thickness, porosity, hydraulic conductivity and storativity, and typical water yield) for the major Surat Basin aquifer and aquitard units are presented in the original Project-wide groundwater assessment (Golder 2009a). The highly varied geological processes that were involved in the creation of these GAB sedimentary units have given rise to laterally and vertically heterogeneous hydrogeological systems within the local and regional groundwater systems.

4.4.4 Structural Implication for Hydrogeology in the NWDA

As noted in Section 4.3.2.3, a number of dominant structural features overprint the hydrostratigraphy described previously in the Project Area.

The location of these structural features is illustrated in Figure 14.

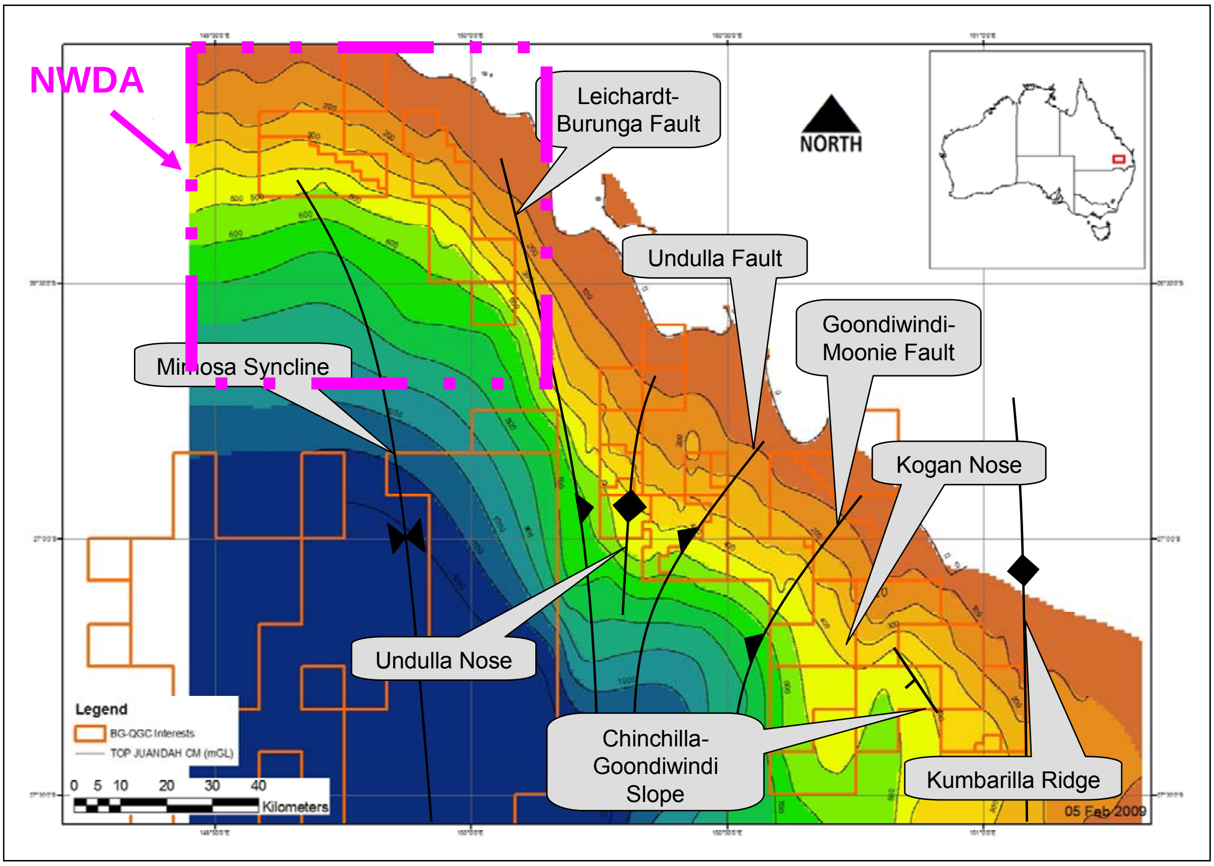


Figure 14: Major Structural Features Affecting the Project Area

These structural features include a number of folds (anticlinal and synclinal features), faults and fracture zones and are known or are inferred to have important ramifications in regard to hydrogeological behaviour and groundwater flow in the NWDA. These include:

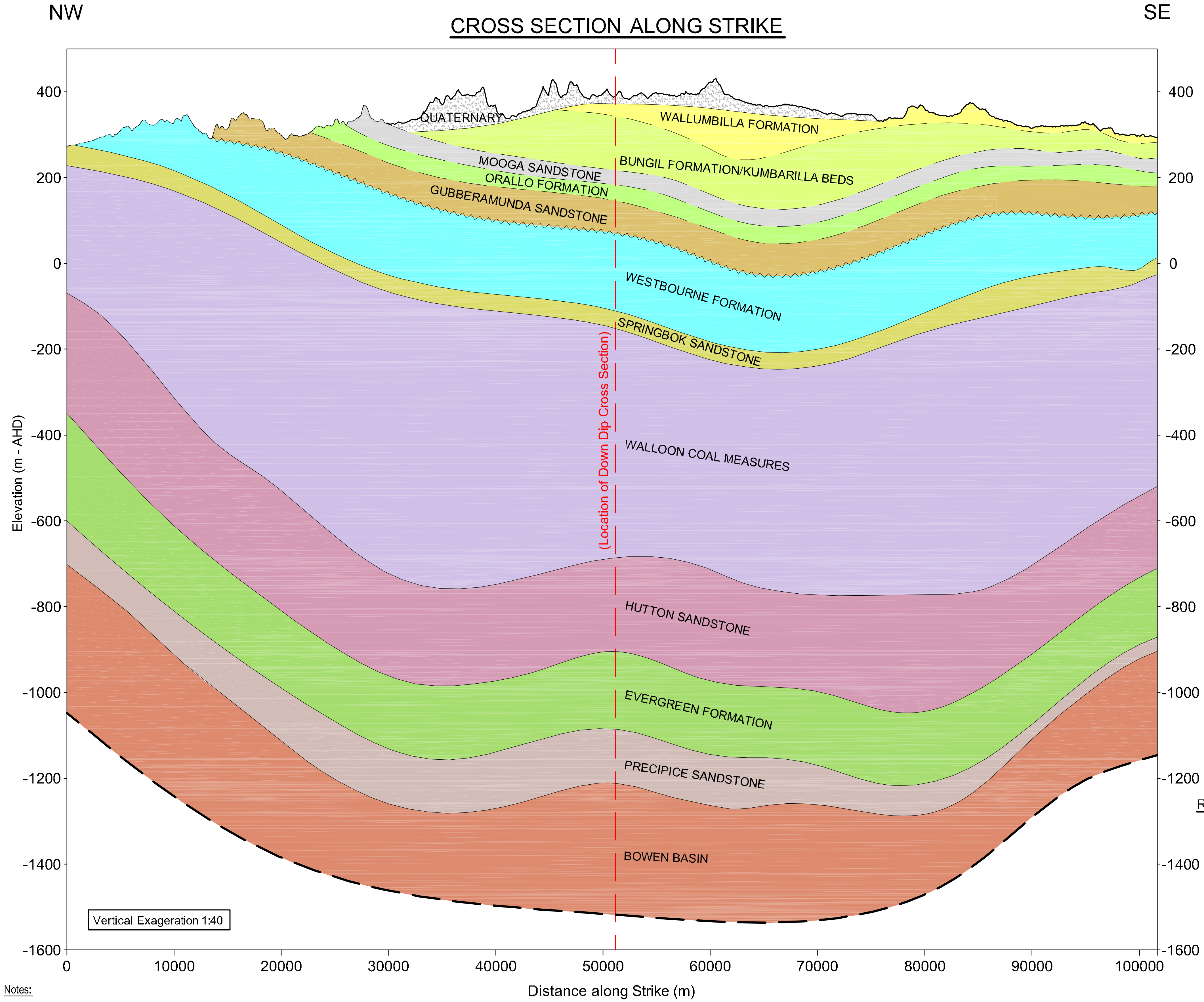
- *Leichhardt-Burunga Fault*: A fault structure (separates the NWDA and the CDA) It is considered to be an extension of the Goondiwindi - Moonie Fault to the south-east. Similarly, the dislocation along this fault lineament is inferred to be sufficient to reduce hydraulic connection between the NWDA and the CDA areas, partially hydraulically isolating the latter from the former.
- *Mimosa Syncline*: A broad open and extensive synclinal fold structure affecting the western portion of the NWDA. It is not believed to cause significant faulting and fracturing of the Surat Basin stratigraphy, and is inferred to be largely the caused of low groundwater yields noted from the hydrostratigraphy of the NWDA (low density fracturing being the primary reason for this phenomenon).
- *Wallumbilla Fault*: A fault structure which, together with the Arcadia Anticline, marks the western edge of the NWDA. Again, the dislocation along this fault is inferred to be sufficient to reduce hydraulic connection between the NWDA and the Surat-Bowen Basin systems to the west, and is inferred to present a low-flow boundary. As such it is considered here as being the western edge of the NWDA compartment.

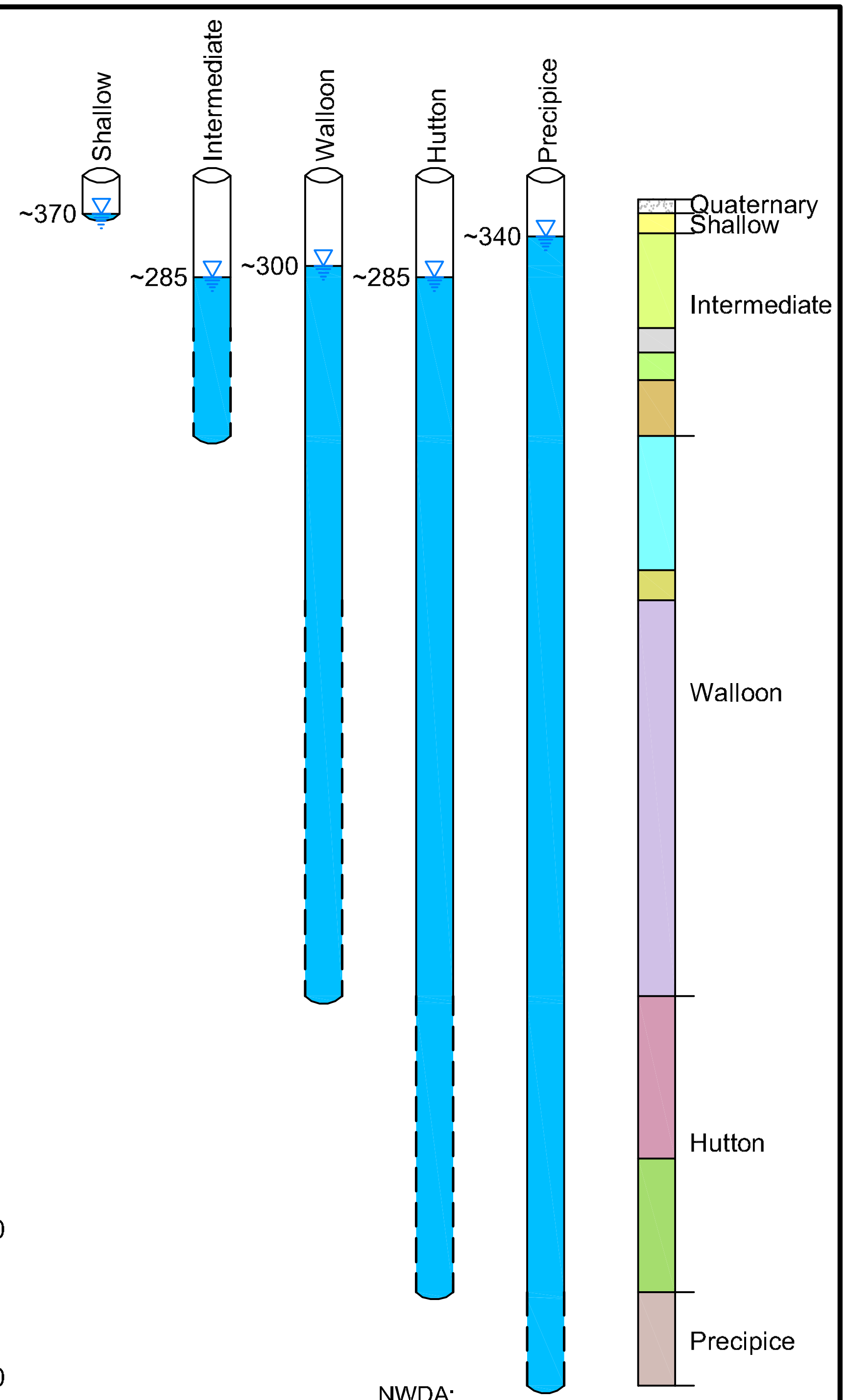
From this summary of the key structural features present within the NWDA it is apparent it is structurally separated from the other two compartments to its southeast, being partially to largely hydraulically isolated from the others. On this basis, restricted groundwater flow between the three development areas has been inferred, and has been used to define the numerical groundwater modelling domains (boundaries for the model). By virtue of these structural overprints, the hydrogeology within the NWDA compartment is considered unique, being characterised by distinctive hydraulic properties (hydraulic conductivity, storativity and porosity), hydraulic connectivity and depth features, even though the hydrostratigraphy is largely similar.

4.4.5 Hydrogeological Cross Sections

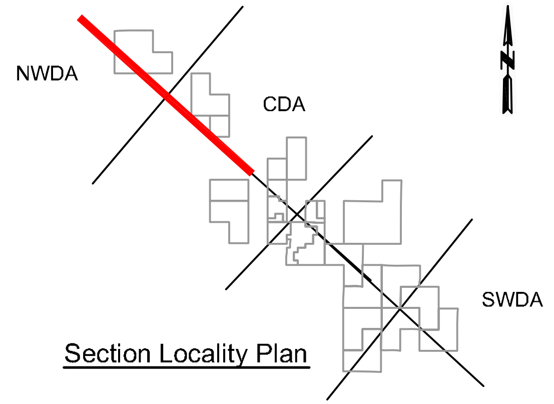
As a means of graphically presenting the hydrostratigraphy described above, interpreted hydrogeological cross sections have been prepared for the NWDA (Figures 15 and 16). Both the along strike and down dip representations are presented. The locations of the cross sections are illustrated on Figure 3.

CROSS SECTION ALONG STRIKE





NWDA:
Representitive piezometric levels in indictive bores in the main groundwater units



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1:400,000 H 8000 4000 0 8000 16000m

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DRAWN	GPG	DATE	20/11/08
CHECKED	*SRH	DATE	20/11/08
TITLE	HYDROGEOLOGICAL SECTION NORTHWEST ALONG STRIKE - NWDA		
SCALE	1:10,000 V, 1:400,000 H	PROJECT No	097626104-001
FIGURE No	15	REV No	1
A3			

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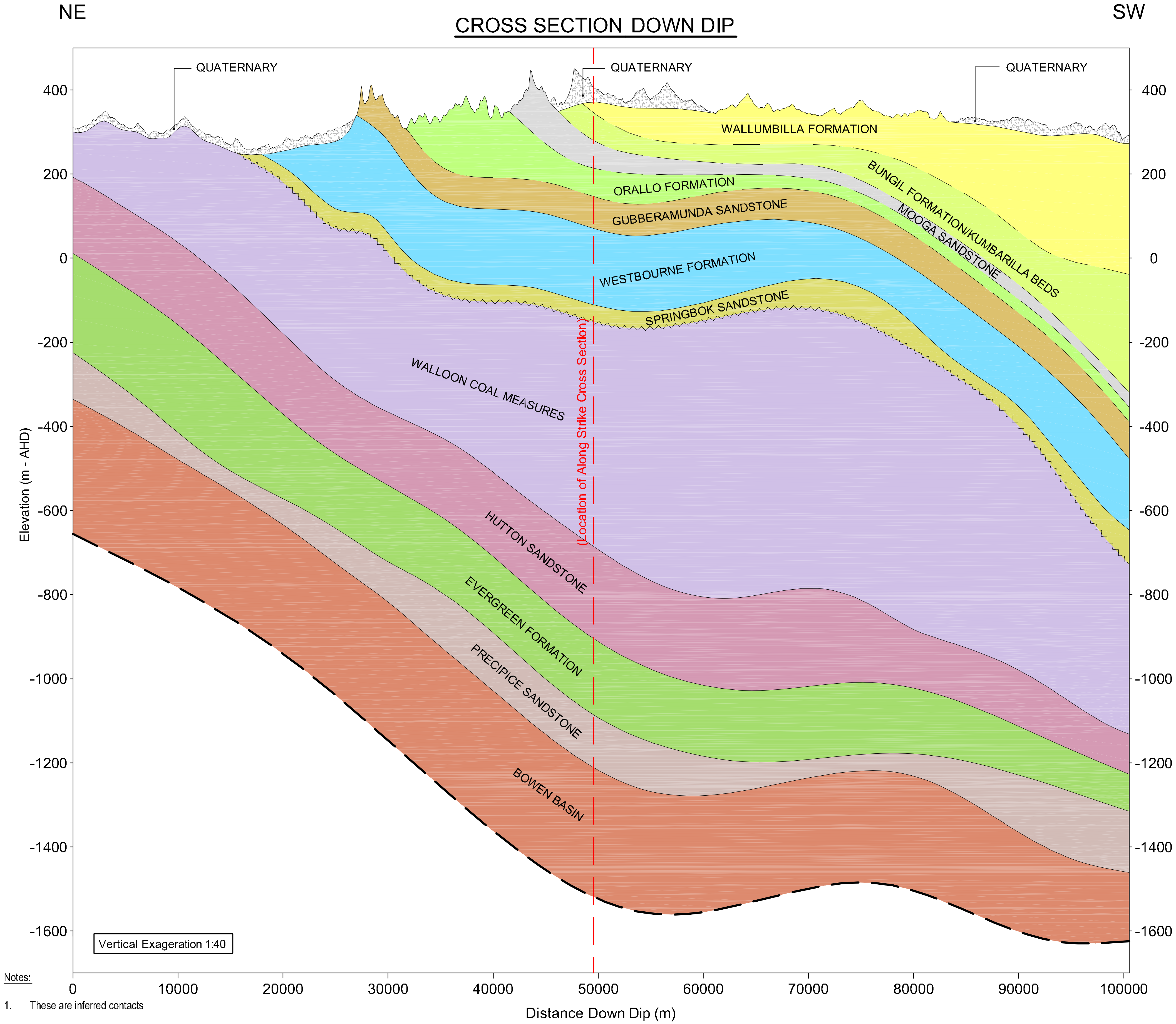
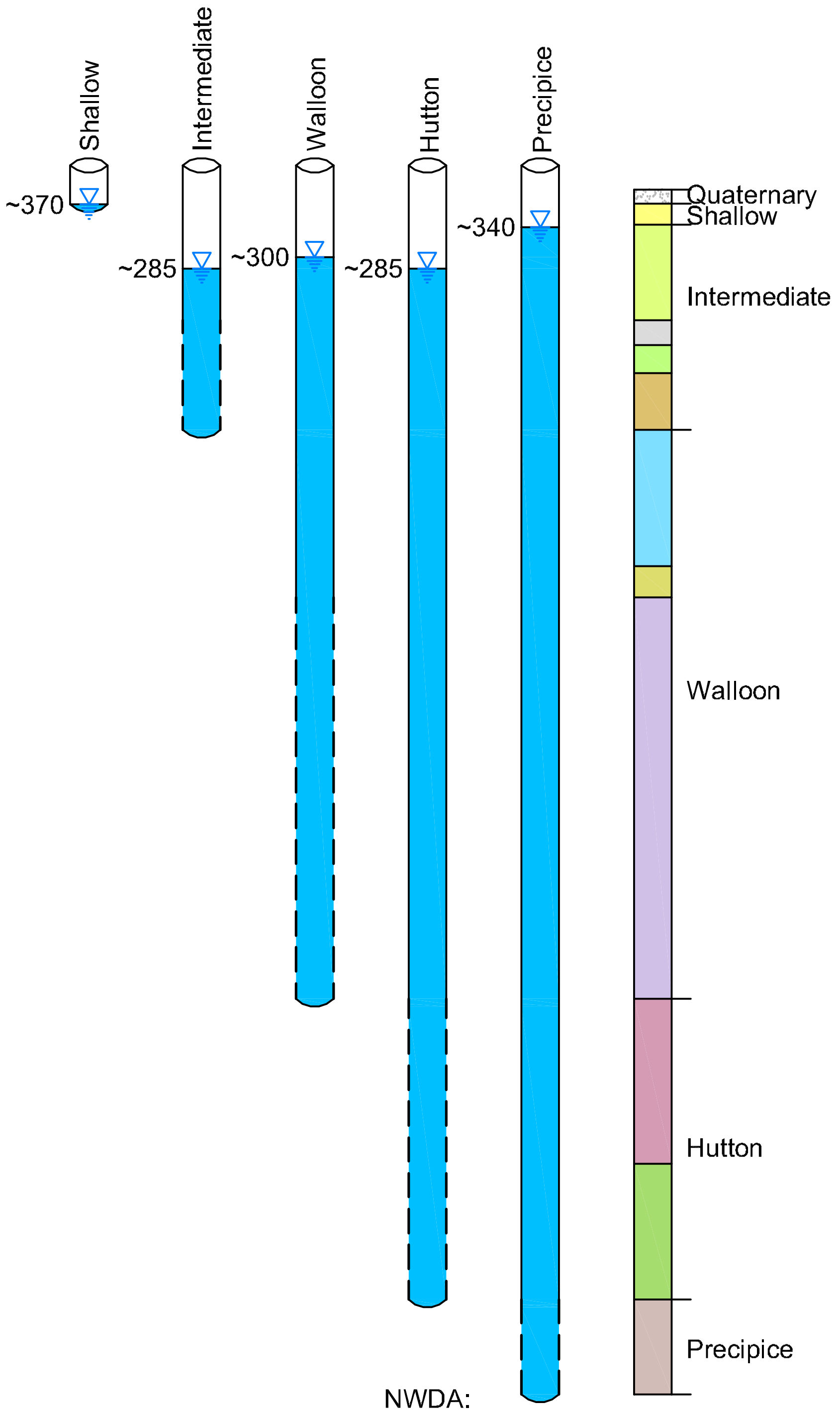
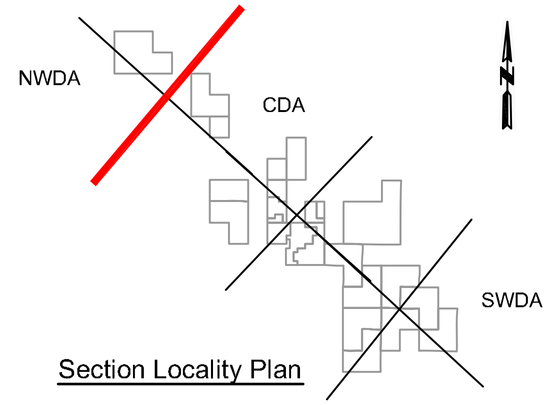
CROSS SECTION DOWN DIP





NWDA:
Representitive piezometric levels in the main groundwater units



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1:10,000 V 200 100 0 200 400m

1:400,000 H 8000 4000 0 8000 16000m

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CLIENT	QGC - A BG Group business	PROJECT	QGC LNG EIS WATER STUDIES
DRAWN GPG	DATE 20/11/08	TITLE	HYDROGEOLOGICAL SECTION NORTHWEST DOWN DIP - NWDA
CHECKED *SRH	DATE 20/11/08		
SCALE	1:10,000 V, 1:400,000 H	PROJECT No 097626104-001	FIGURE No 16 · REV No 1 · A3

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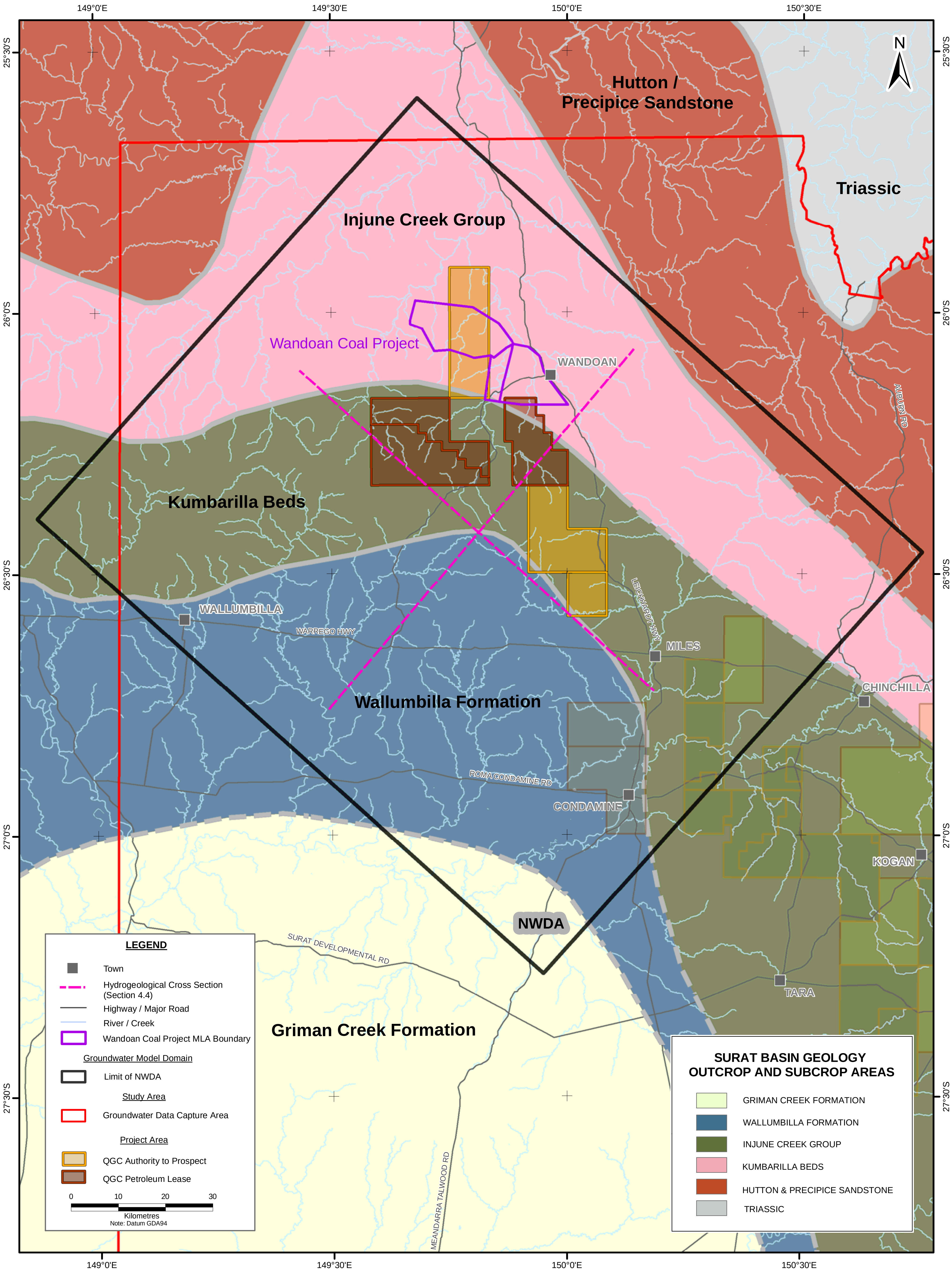
4.4.6 Recharge and Discharge

Most recharge for the GAB aquifers (including the Intermediate, Walloon, Hutton and Precipice Sandstone Units) occurs on the eastern and north-eastern margins of the GAB, and its sub-basin, the Surat Basin, including the area encompassed by the NWDA. The intake beds are located along the western slope of the Great Dividing Range where the sandstone aquifers outcrop or are buried by permeable sediments (i.e., alluvium). The intake beds comprise a layered sequence of sandstone aquifers and interbedded mudstone aquitards that dip to the west and south west. Sporadic recharge occurs in the arid western part of the GAB. The GAB groundwater flow models, GABSIM and GABHYD, developed by the Bureau of Rural Sciences, indicate that approximately 1% of the current rain falling over the intake beds is incorporated into the aquifers as recharge (Great Artesian Basin Strategic Management Plan, September 2000).

Artesian springs are often connected to a major fault in the basin and are classified as either recharge or discharge springs (EPA, 2006). Most recharge springs occur where a sandstone aquifer is at the surface (such as in the eastern margins of the GAB), allowing water to be absorbed and discharged again locally in a relatively short period of time (i.e. the spring flow comprises recharge rejection or recently infiltrated water). *As such they are typically situated within the recharge zones of the eastern margin of the GAB according to Habermehl and Lau (1997). This zone coincides with those areas where the sediments that comprise the water-bearing aquifers of the GAB outcrop or is buried by permeable sediments*. There are a few recharge springs located approximately 40 km from the northern boundary of the study area (Figure 1). *Discharge springs are those emanating from deeper GAB aquifers under artesian pressure, other than the recharge springs;* however, no discharge springs have been reported within the Project Area.

Discharge of the GAB also occurs from controlled and uncontrolled flowing artesian bores that pump water from the different aquifers (DERM database indicates that historically, artesian bores did exist in the study area, but their current status in not clear). Natural discharge may occur from water flowing vertically to the upper aquifers at the GAB margins and at springs. The main discharge in the NWDA is from pumping activities.

The primary recharge zones (outcrop and subcrop) of the Intermediate unit (Kumbarilla Beds) occur as a band across the central portion of the NWDA study area (Figure 17). Recharge zones of the Walloon (Injune Creek Group), Hutton, and Precipice Sandstone Units are located north-northeast of the tenements. Recharge to the Shallow Unit can be expected to occur from surface water infiltration and leakage from creek beds. No discharge zones, including Artesian springs, are believed to be present within the NWDA and the broader Project Area.



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PROJECT QGC - LNG EIS Groundwater Study

TITLE

GENERALISED SUBCROP ZONES
IN THE STUDY AREA

PROJECT No 097626104_001 FIGURE No 17 REV No 2 A3

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4.5 Hydrogeological Mapping of Units

The following section provides a description of potentiometric and electrical conductivity distribution within the individual units, prior to the development of CSG activities (pre 2001). A hydrogeological map for each unit is presented on Figure 18 to Figure 21. Contours were generated using the water levels and electrical conductivity data available from both the DERM groundwater database and from QGC. The data was contoured using computer programming methods (Surfer® and ArcGIS®) with plots of equipotential bands defining inferred regions of similar value. Where anomalous areas were detected some discretionary data exclusions were required to produce a sensible and realistic result. Hydrogeological maps of the entire QGC Project Area (including the NWDA, CDA and SEDA) are illustrated to present the connectivity and spatial variability across the region.

Potentiometric contours for the aquifer water levels are presented in terms of the Australian Height Datum (AHD), as adopted by the National Mapping Council of Australia. Electrical conductivity (EC) values are expressed in micro-siemens per centimetre (μS/cm) with areas of equal or similar EC value plotted as isocontrol contours. EC is used as a major indicator of groundwater salinity. In the figures, the contoured areas are colour shaded to show regions of higher versus lower values of water level or EC (i.e., green shading represents good quality (low EC) groundwater and red/pink shading represents poorer quality water).

The data available from the Precipice Sandstone is limited across the unit, thus potentiometric contours are not presented (Figure 22).

It should be noted that data used in the generation of the contour maps were measured from bores at different times and locations, and with various uses. Since some of the bores from which the measurements were taken are used for water supply, the reported groundwater elevations could potentially represent pumped rather than ambient (natural) conditions.

Routine monitoring data is available for very few bores. For many bores, water levels and EC have been measured only once; yet the timeframe to collect the data used to create the plots was over many decades. Therefore the plots do not represent conditions at a single point in time. They provide only general representation of the conditions within the local hydrostratigraphy prior to commencement of CSG activities (except NWDA where CSG extraction has not yet commenced).

4.5.1 Shallow GAB Aquifers

Figure 18 presents the potentiometric surfaces of the Shallow GAB aquifers. Limited data are available for the Shallow GAB aquifers. Groundwater flow through this unit appears to be generally down dip. Direct recharge from the overlying Quaternary and Tertiary deposits is considered to be possible.

Groundwater quality in the shallow groundwater unit is generally fresh.

4.5.2 The Intermediate Aquifers

Groundwater flow through the intermediate aquifers (Mooga to the Gubberamunda Sandstones) tends to be from east to west, down dip; however, a low hydraulic gradient exists among a high density grouping of bores located west of Miles (Figure 19). Based on the data available, salinity generally varies between 3,000 to 6,000 µS/cm across the unit.

4.5.3 The Walloon Coal Measures (Walloon Unit)

Figure 20 presents the potentiometric surface of the WCM Unit prior to major CSG operations in the area. Groundwater elevations vary between 180 to 350 metres AHD across the NWDA, with groundwater flowing from the higher elevations in the east towards 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 18,000 µS/cm within the NWDA. Higher salinities are observed to the east, near the town of Chinchilla. Water from the WCM is generally not used for human and livestock consumption. The Wandoan Coal Project EIS reports values as high as 26,000 µS/cm within the Kogan Seam, with EC values typically between 8,000 to 18,000 µS/cm for the deeper seams (locally of 50 to 100 m depth) of the Macalister and Wambo seams

4.5.4 The Hutton Sandstone Aquifer

Based on available data, the direction of groundwater flow through the Hutton Sandstone Unit is inferred to be towards the west-southwest (down dip). Recharge to the Hutton likely occurs to the north of the NWDA where the aquifer outcrops. The distribution of piezometric levels varies between 180 and 300 metres AHD.

The salinity of the groundwater in the Hutton Sandstone is generally fresh through the NWDA (Figure 22). As with the Walloon Unit, there appears to be a zone of relatively high salinity water east of the NWDA (based on contour plots presented in Figure 20 and Figure 21 and which are based on a small number of bores showing above average salinity water present there). Previous studies (Section 4.4.4) have suggested a likely hydraulic connection between the WCM and the underlying Hutton Sandstone in the area of the CDA and that there may be a mixing process between the formations (AGE 2007; PB 2004).

4.5.5 The Precipice Sandstone Aquifer

Water level and water quality data for the Precipice Sandstone Unit were generally limited to the northeast of part of the study area where the top of the aquifer is present at relatively shallower depths. Given the scarcity of regional water level data for this aquifer within the Project Area, the hydrogeological map (Figure 22) provides numerical data only (not contoured). Groundwater elevations for the unit are approximately 200 metres AHD.

Salinity in this unit in the NWDA is, on average, less than 2,500 µS/cm. From the small amount of data available for the Precipice Sandstone Aquifer, the highest EC reported in 3,840 µS/cm.

4.5.6 Inter-formational and Inter-aquifer Flows

Groundwater movement within the Surat Basin sequence is dominated by sub-horizontal flow which is largely controlled by the shallow dipping nature of the layered sequence, their hydrogeological parameters (primarily hydraulic conductivity) and structural overprints. Groundwater is inferred to flow, under the prevailing hydraulic heads, along the plane of the layers, parallel with their bedding and contacts. This translates to water flow down-gradient (effectively down the dip of the formations) toward the centre of the Surat Basin.

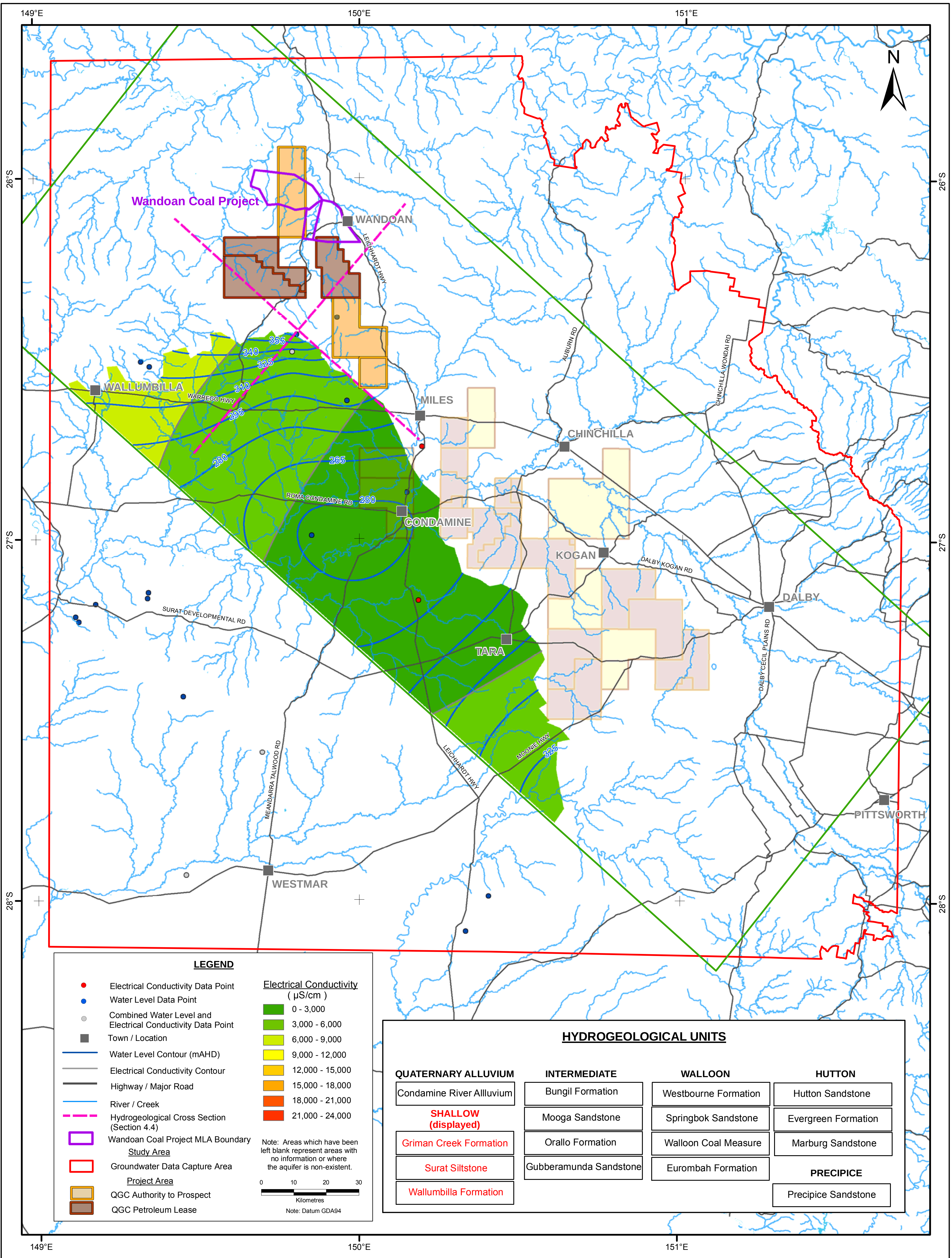
Limited groundwater flow will likely take place perpendicular to the bedding plane, i.e. in the vertical direction. That is, cross- or inter-formational flow (from bed-to-bed, layer-to-layer and unit-to-unit, in a vertical direction) is restricted by the natural bedding plane alignment of the sedimentary particles parallel to the bedding plane. In this way, limited flow is anticipated between the various units in the sedimentary sequence (as reflected in the high ration vertical conductivity to horizontal conductivity values (Kv / Kh).

It is noted that, within the GAB, inter-aquifer flows occur naturally where there is direct aquifer connectivity and where favourable hydrogeological conditions exist. This situation frequently occurs at the margins of the GAB or locally in association with existing faults or unconformable contacts. Inter-aquifer flow can be enhanced or changed as a consequence of groundwater abstraction.

The average water pressures in the study area are classified as ‘subartesian’ (non-flowing bores). The DERM database does indicate that historically some artesian wells existed in the area, although their current status as artesian is not clear. The natural hydraulic head gradient between the Hutton Sandstone, Walloon and Intermediate Units is consistent across the study area. The Hutton has an average hydraulic head of 220 m AHD across most of the Project Area. The Intermediate Unit has a head of about 350 m AHD and the hydraulic heads vary between 180 and 350 metres AHD in the WCM Unit. The direction of groundwater flow between the intermediate unit aquifers and Quaternary formations is inferred to be downwards (recharge to deeper aquifers) in the NWDA (Golder 2009a).

The hydraulic head (piezometric levels) in the Hutton Sandstone and WCM are similar. Shallow hydraulic gradients typify the NWDA where the surface terrain is subdued (unlike the steeper gradients associated with the eastern ranges to the east of the NWDA). However, based on the available data, a component of downward vertical flow has been inferred between the WCM Unit (largely an aquitard unit with interbedded coal seam aquifers) and the Hutton Sandstone Unit (an aquifer). The similarity in the salinity characteristics between these formations suggests a potential connection in some areas between the formations. The movement of water between these two formations has the potential to be reversed and/or amplified from the CSG production.

The undulations observed in the piezometric head surface and water quality for selected units plotted in Figure 18 to Figure 21 suggest that a hydraulic connection via favourable hydrogeological conditions (e.g. coincident areas of higher hydraulic conductivity in adjacent layers associated with the unconformable contacts) does occur, to varying degrees, across the NWDA Project Area .



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DATE 11-12-09
TITLE
HYDROGEOLOGICAL MAP
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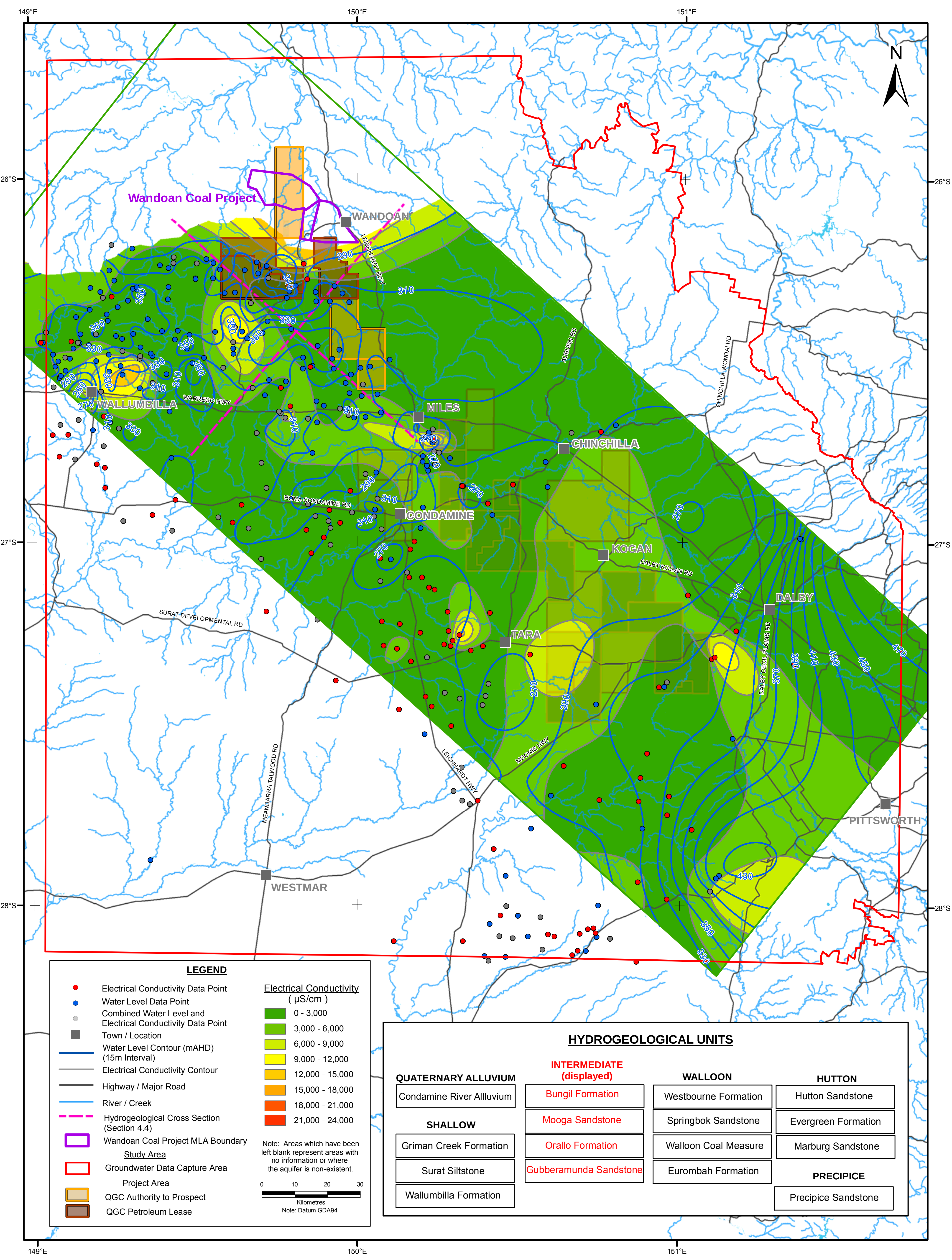

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PROJECT
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TITLE
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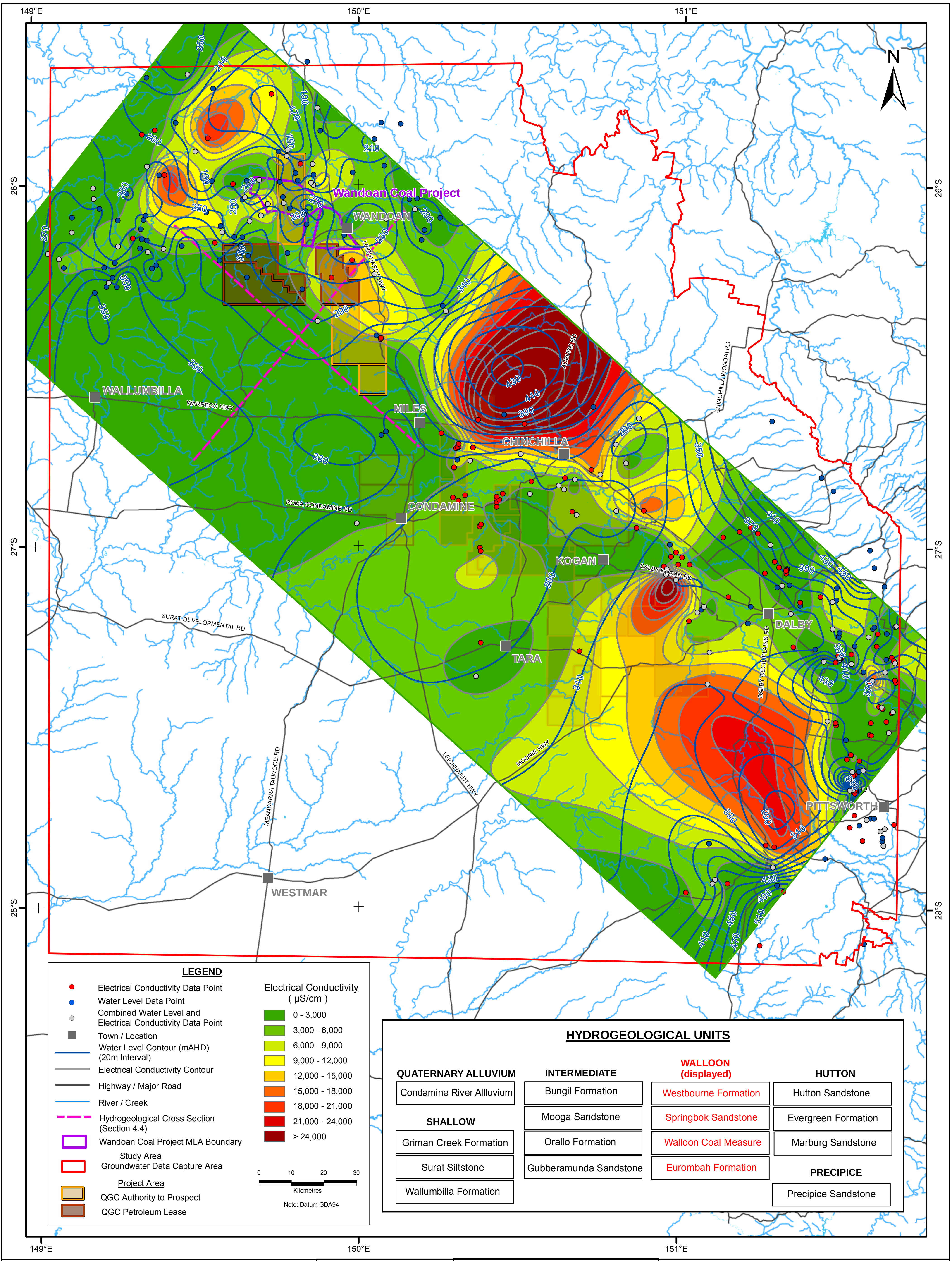

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HYDROGEOLOGICAL MAP WALLOON UNIT

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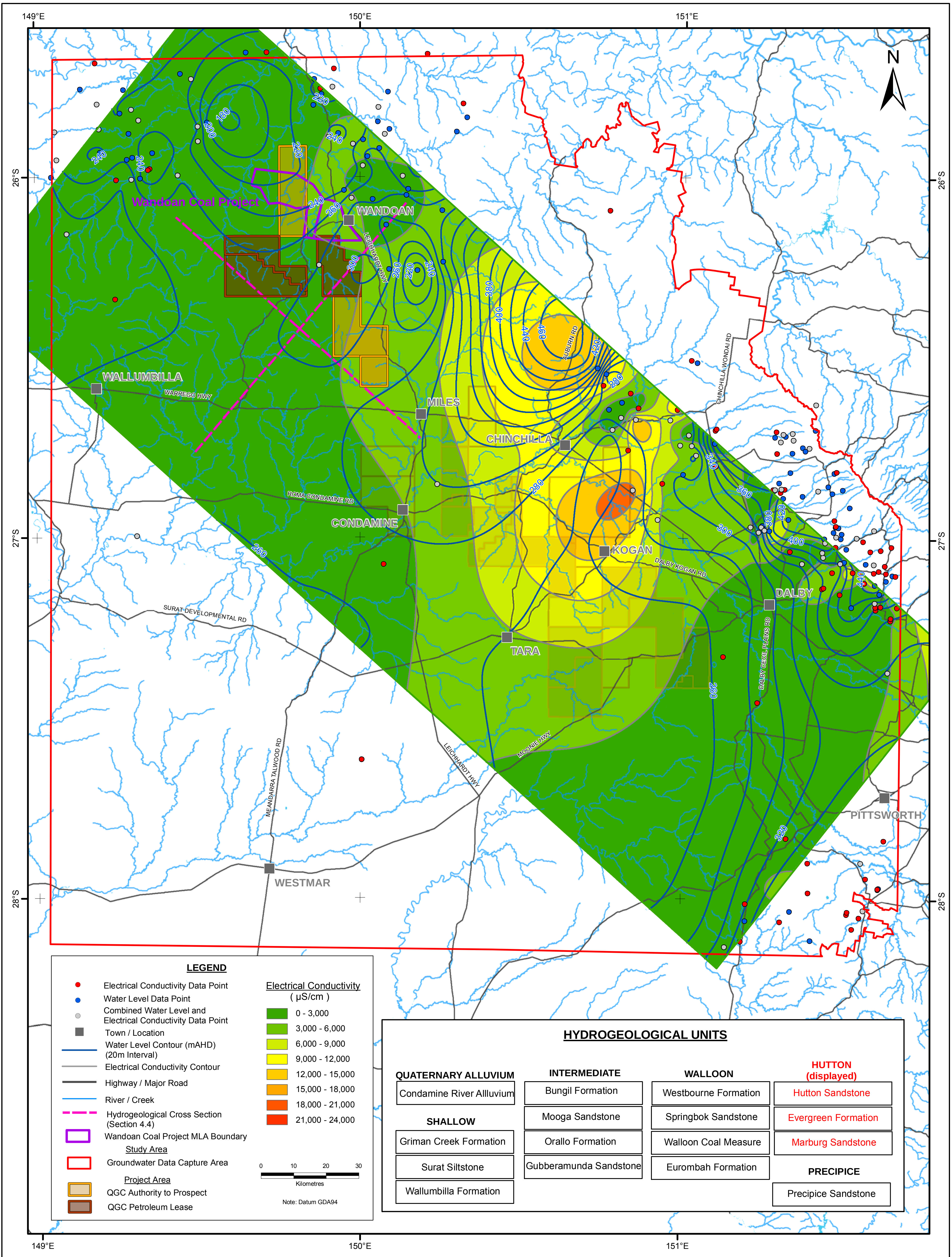

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DRAWN: DK/BQ
DATE: 11-12-09
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DATE: 11-12-09
TITLE: HYDROGEOLOGICAL MAP HUTTON UNIT
SCALE: 1:1,050,000
PROJECT No: 097626104_001
FIGURE No: 21
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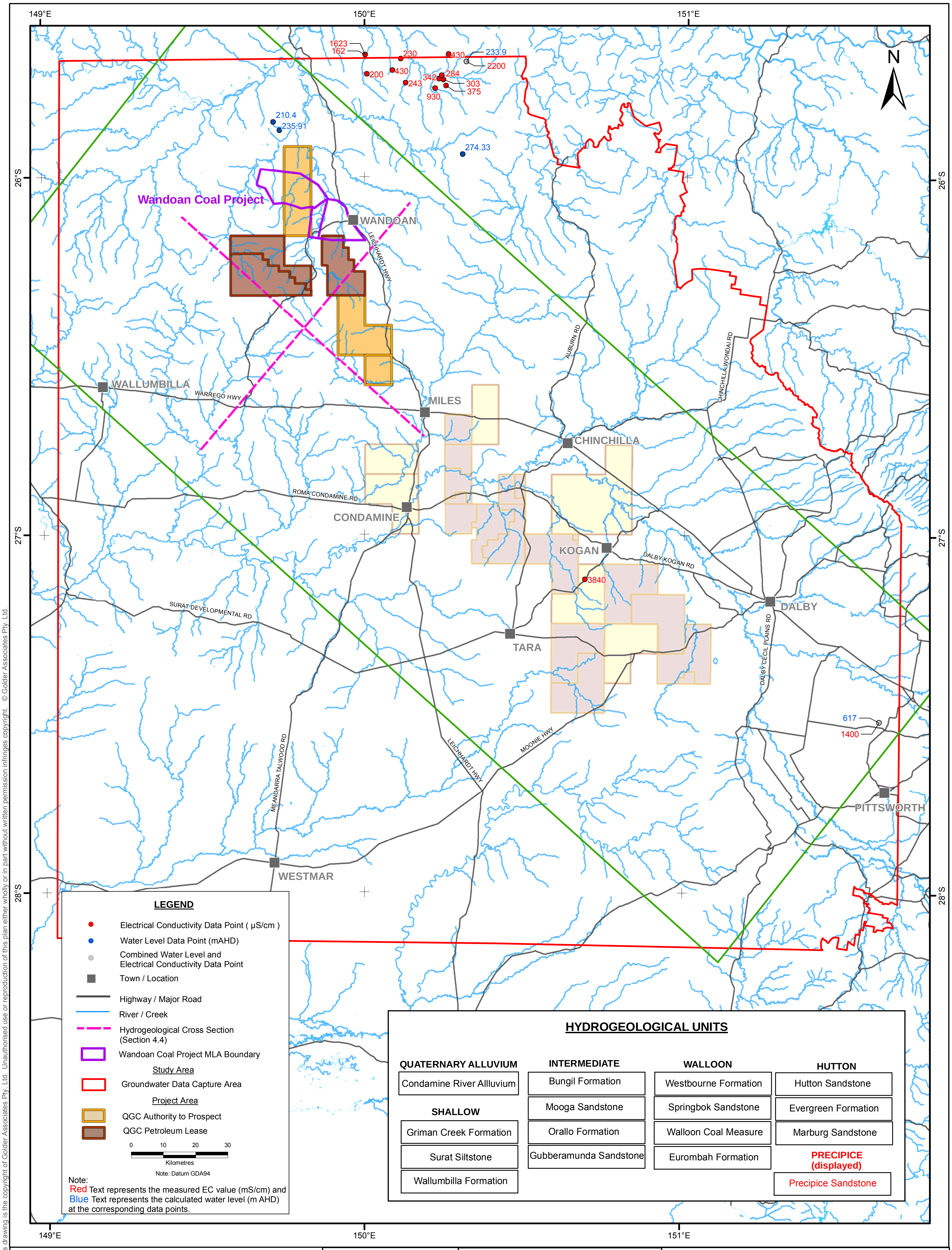
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



Note:
Red Text represents the measured EC value (mS/cm) and Blue Text represents the calculated water level (m AHD) at the corresponding data points.

QUATERNARY ALLUVIUM	INTERMEDIATE	WALLOON	HUTTON
Condamine River Allluvium	Bungil Formation	Westbourne Formation	Hutton Sandstone
SHALLOW	Mooga Sandstone	Springbok Sandstone	Evergreen Formation
Griman Creek Formation	Orallo Formation	Walloon Coal Measure	Marburg Sandstone
Surat Siltstone	Gubberamunda Sandstone	Eurombah Formation	PRECIPICE (displayed)
Wallumbilla Formation			Precipice Sandstone

Note:
1. Base map data copyright Mapinfo Australia Pty Ltd.
2. This map has been prepared using NRW groundwater database & QGC information.
3. Authority To Prospect & Petroleum Leases data supplied by QGC Limited, files received dated 17-09-2009.
4. Wandoan Coal Project - Mining Lease Application (MLA) Boundary is based on or contains data provided by the State of Queensland (Department of Employment, Economic Development and Innovation) [2009].

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DRAWN	DK/BQ	DATE	11-12-09
CHECKED	RKH *	DATE	11-12-09
TITLE	**HYDROGEOLOGICAL MAP** **PRECIPICE UNIT**		
SCALE	1:1,050,000	PROJECT No	097626104_001
FIGURE No	22	REV No	2
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File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\097626104_GW\097626104_001_R_F0022_Rev2_PrecipiceHydroMap_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

4.6 Groundwater Quality

Groundwater quality from aquifers in the NWDA was assessed by analysing available sampling results. Appendix C presents the complete groundwater quality assessment.

Groundwater quality from aquifers in the NWDA was assessed by analysing available sampling results. A total of 144 groundwater samples from the DERM database and 18 samples from CSG production wells were assessed using the standard hydrogeochemical analyses including Piper and Scatter plots and statistical analysis.

Groundwater pH ranged from 5.5 to 12 in the NWDA, with the majority of data between 7 and 9. Dominant major ions in the majority of groundwater samples include sodium, chloride and bicarbonates, with lower proportion of calcium, magnesium and sulphates. Identified water types and data grouping are presented in (Figure 23). The majority of groundwater data fall in the range between sodium-bicarbonate and sodium-chlorite water types with an exception of few samples from Hutton Sandstone Unit and Intermediate Unit (Orallo Formation). The most common groundwater types were sodium-bicarbonate-chloride and sodium-chloride.

Approximately 25 % of the DERM database groundwater samples can be classified as fresh with calculated TDS values less than 1,000 mg/L. The majority of the DERM groundwater samples were slightly brackish (52%) with TDS concentration in the range from 1,000 to 3,000 mg/L. Brackish groundwater, with TDS concentrations between 3,000 mg/L and 10,000 mg/L, and saline groundwater, with TDS concentrations greater than 10,000 mg/L, were less common and contributed to 17% and 6%, respectively. Groundwater from the CSG wells was classified as brackish.

The groundwater salinity increases in order Precipice Formation < Hutton Formation < Intermediate Unit < Walloon Unit < CSG Wells.

Groundwater quality variations throughout the NWDA are due to the heterogeneity in sediment depositional environments, sediment composition, groundwater residence time, and depth and direction of groundwater flow. During groundwater movement along the flowpath from recharge to discharge areas a variety of chemical reactions take place. These reactions vary spatially and temporally depending on the nature of the recharge water composition, geological formation and residence time.

Comparison of groundwater quality with regulatory guidelines indicates that:

- Approximately 86% of the analysed groundwater samples in the NRW database and 100% groundwater samples from the GSG wells would not be suitable for use as potable water;
- Groundwater from some locations in the Precipice and Hutton Sandstones with low salinity and sodium concentrations, appears to be suitable for irrigation purposes. Most CSG water would pose a very high salinity and sodicity hazard; and
- The majority of groundwater in the NWDA is suitable for livestock watering. Up to 74% of the groundwater samples would be suitable for watering of beef cattle.
- The majority of groundwater in the NWDA is suitable for livestock watering. Up to 74% of the groundwater samples would be suitable for watering of beef cattle.

A Piper plot of the available groundwater quality data is presented in Figure 23; Section 1.1.3 of Appendix C provides further details in relation to this plot.

A full description of the groundwater quality in the individual hydrogeological units across the entire QGC Project Area is presented in the original Project-wide groundwater assessment (Golder 2009a).

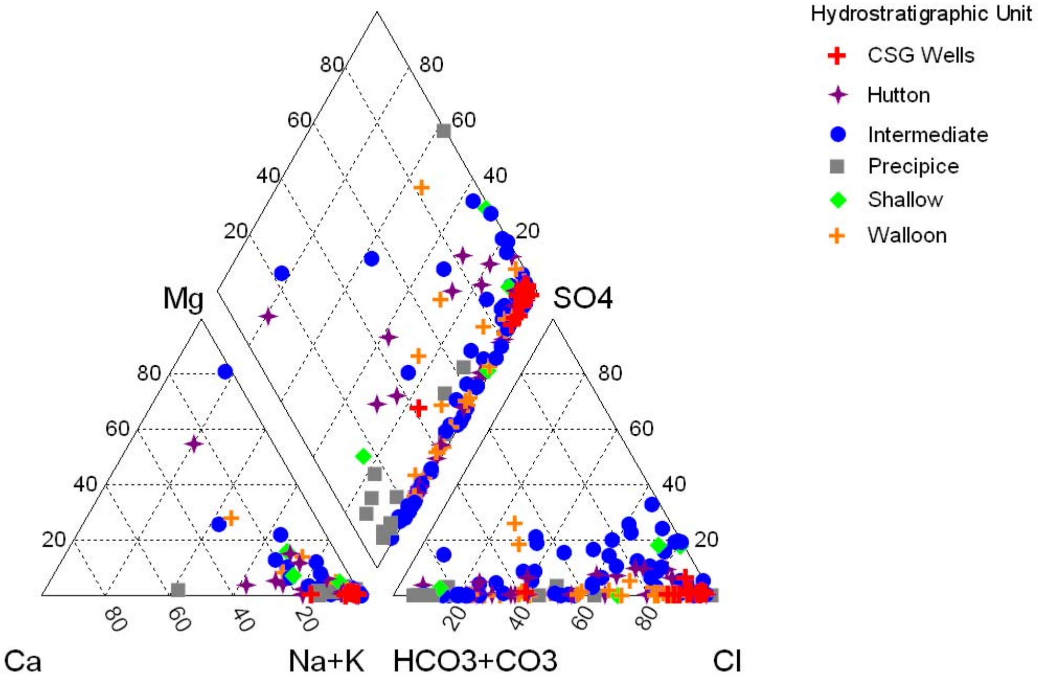


Figure 23: Piper Plot of All Groundwater Samples in the NWDA

4.7 Water Use

The majority of the NWDA is contained within the areal boundaries of the following GMAs: Surat GMA 19, GMA 20 (Surat North) and GMA 21 (Surat East) (refer to Figure 1 and Figure 3). Existing uses for groundwater throughout the NWDA vary proportionally across the three groundwater management areas. Figure 24 illustrates groundwater use (by percentage), excluding CSG extraction. The main uses for groundwater are stock and domestic. Other uses include town water supply, irrigation and aquaculture. It is likely that demands for water for these uses will also increase over time. Many of the GMUs are already over-committed or are approaching their maximum abstraction levels, as identified in the GAB WRP (2006).

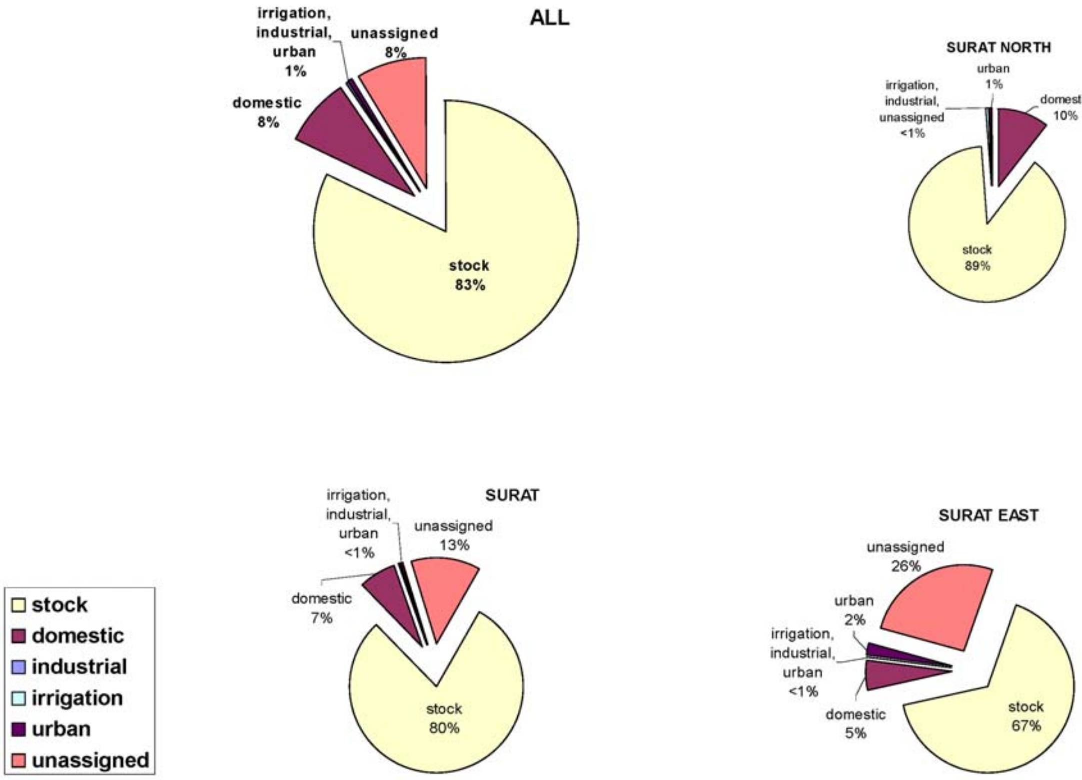


Figure 24: Groundwater use in the Study Area

4.7.1 Water Allocation and Entitlement

Information on the number, location and entitlements was extracted from the Queensland DERM Water Entitlements Registration Database (WERD) which can be summarised in the following list and associated references:

- A summary of the number of registered and licensed groundwater bores across the NWDA is provided in Table 9, divided by the targeted aquifers exploited.
- Entitlements are minimal, less than 9,000 ML of groundwater per annum.
- The number of bores registered in WERD is less than the total number of water bores in the Project Area. Many bores have been removed from WERD following changes in licensing policies or they have not been registered. For example, many bores are drilled and used for stock and domestic purposes, and although the water level, water quality or yield data for these bores have been considered in the preparation of this report (where both available and of suitable quality), they do not appear in WERD.

- Table 9 does not consider unlicensed bores, for which the licence is not currently active, or bores which could not be related to aquifers due to incomplete data. WERD is also limited to officially metered water use information.
- Small groundwater users (most of them using water for stock and domestic) are only issued with a water licence. These users often do not have flow meters installed and information on the quantity used from the aquifers they target is not available. Entitlements are only provided to significant groundwater users (generally >5 ML/year).
- An important aquifer unit targeted for its groundwater resource in the Surat and Surat East GMAs is the Intermediate Unit, with extraction primarily within the Bungil Formation, Mooga and Gubberamunda Sandstones.
- In the Surat North GMA, the Hutton Sandstone unit is the most developed aquifer, with extraction also from the Birkhead Formation and other undifferentiated formations of the Injune Creek Group (to which the WCM are associated).
- The Hutton Sandstone and Precipice Sandstone Units are more intensely used to the north-east of QGC's NWDA tenement areas where the depth to the units decreases as they approach the regional subcrop/outcrop zones.

Table 9: Aquifer Usage in the QGC Surat Basin - NWDA

GMA	Management Units[1]	Geological Member	Hydrogeological Unit[2]	Licensed Users[3]	Registered Bores[3]	Licensed Bores with Entitlement[4]	Entitlements (ML/yr)
Surat	-	Quaternary	Shallow	1	2	0	
		Griman Creek		-	-	-	
	Surat 1	Surat Siltstone		-	-	-	
		Coreena Member		1	2	0	
		Doncaster Member		4	4	0	
		Wallumbilla Formation		1	1	0	
	Surat 2	Bungil Formation	Intermediate	39	39	1	50
		Minmi Member		0	0	0	
		Nullawart Sandstone Member		-	-	-	
		Kingill Member		-	-	-	
	Surat 3	Mooga Sandstone		61	61	5	718
	Surat 4	Orallo Formation		12	12	1	383
		Gubberamunda Sandstone		32	33	6	1,765
	Surat 5	Westbourne Formation	Walloon	-	-	-	-
		Springbok Sandstone		-	-	-	-
		Birkhead Formation		-	-	-	-
		Walloon Coal Measures		3	3	0	-
		Eurombah Formation		2	2	0	-
		Undifferentiated		15	16	1	395
	Surat 6	Hutton Sandstone	Hutton	2	2	0	-
		Evergreen Formation		-	-	-	-
		Boxvale Sandstone Member		-	-	-	-
	Surat 7	Precipice Sandstone	Precipice	-	-	-	-
	Surat 8	Moolayember Formation	-	-	-	-	-
		Clematis Sandstone		-	-	-	-
		Rewan Formation		-	-	-	-

GMA	Management Units[1]	Geological Member	Hydrogeological Unit[2]	Licensed Users[3]	Registered Bores[3]	Licensed Bores with Entitlement[4]	Entitlements (ML/yr)
Surat North	-	Quaternary	Shallow	-	-	-	-
		Bungil Formation	Intermediate	-	-	-	-
		Gubberamunda Sandstone		2	2	0	-
	Surat North 1	Westbourne Formation	Walloon	-	-	-	-
		Springbok Sandstone		1	1	0	-
		Walloon Coal Measures		3	3		570
		Eurombah Formation		14	14		290
		Undifferentiated		59	59	4	1,470
	Surat North 2	Hutton Sandstone	Hutton	68	68	4	1,762
		Evergreen Formation		6	6	2	680
	Surat North 3	Precipice Sandstone	Precipice	23	23	2	865
	Surat North 4	Moolayember Formation	-	1	1	0	-
		Clematis Sandstone		2	2	0	-
Surat East	-	Condamine River Alluvium	Shallow Quaternary Alluvium	-	-	-	-
		Quaternary	Shallow	-	-	-	-
		Main Range Volcanics		-	-	-	-
		Doncaster Member		-	-	-	-
		Wallumbilla Formation		-	-	-	-
	Surat East 1	Mooga to Springbok Sandstone / Kumbarilla Beds	Intermediate	17	20	2	777
	Surat East 2	Walloon Coal Measures	Walloon	3	3	3	-
	Surat East 3	Hutton Sandstone	Hutton	4	4		-
		Evergreen Formation		1	1	0	-
	Surat East 4	Precipice Sandstone	Precipice	-	-	-	-
	Surat East 5	Moolayember Formation	-	-	-	-	-
		Clematis Sandstone		-	-	-	-

1. Management Units as outlined in the *Hydrogeological Framework Report (Hydrogeological Framework Report for the Great Artesian Basin Water Resource Plan Area, Queensland Department of Natural Resources and Mines, 2005)* for the GAB WRP Area. Shallow Aquifers are not identified as part of management units in this document.

2. As defined in Section 4.4 of this report.

3. Includes issued licences and those under amendment, renewal, transfer and variation

4. Entitlements are not issued to bores that extract less than or equal to approximately 5 ML/year.

4.7.2 Estimate CSG Water Extraction

Water from the Walloon Unit is not typically used by farmers or other water users in the NWDA area because of its depth, poor water quality and generally low yield. Significant extraction from the WCM has commenced with the development of CSG exploration in the CDA and SEDA. The total number of wells pumping from the WCM Unit is expected to increase significantly over the next 20 years in the NWDA.

Using initial production forecasts provided by QGC, it is estimated a combined total of 30,000 ML will be extracted in 2013. The predicted extraction volumes for QGC's proposed Surat Basin NWDA wellfields over the next 20 years are provided in Figure 25. The figure also presents the volume of unallocated water for the relevant GMAs, defined as the 'General Reserve' in the *Water Resource (Great Artesian Basin) Plan 2006* (Subdivision 2 and Schedule 5). Water entitlements for CSG activities are not subject to the terms of the *Water Act 2000*, and the general reserve volumes are presented for reference only.

It should be noted that the following applies for the individual GMAs:

- *Surat GMA 19*: the remaining allocation of the reserve under the WRP is limited to two GMUs – 3000 ML from Surat 6 (Hutton Sandstone and Evergreen Formation) and 2000 ML from Surat 7 (Precipice Sandstone).
- *Surat North GMA 20*: the remaining allocation of the reserve under the WRP is limited to two GMUs – 100 ML each from Surat North 2 (Hutton Sandstone and Evergreen Formation) and Surat North 3 (Precipice Sandstone).
- *Surat East GMA 21*: the remaining allocation of the reserve under the WRP is limited to two GMUs – 1000 ML each from Surat East 3 (Hutton Sandstone and Evergreen Formation) and Surat East 4 (Precipice Sandstone).
- No reserves are assigned to the GMAs to which the Walloon Coal Measures apply (Surat 6, Surat East 2 and Surat North 1).

Based on this forecast, the quantity of water extracted by QGC in the NWDA will exceed the general reserve for the Surat GMA 19 between 2015 and 2030, between 2015 and 2035 for the Surat East GMA 21, and exceed the general reserve for the Surat North GMA 20 for almost the entire extent of CSG operations (Figure 25).

The significance of these exceedances is that they are likely to be considered by DERM to create a potential for adverse groundwater impacts on the WCM unit and its adjacent aquifers. The comparison also assumes that any additional extraction will be associated with CSG activities, and does not account for granting of additional entitlements for other purposes from the general reserve. Consideration of potential impacts of pumping for CSG extraction is presented in Sections 7.0 (risk based impact assessment).

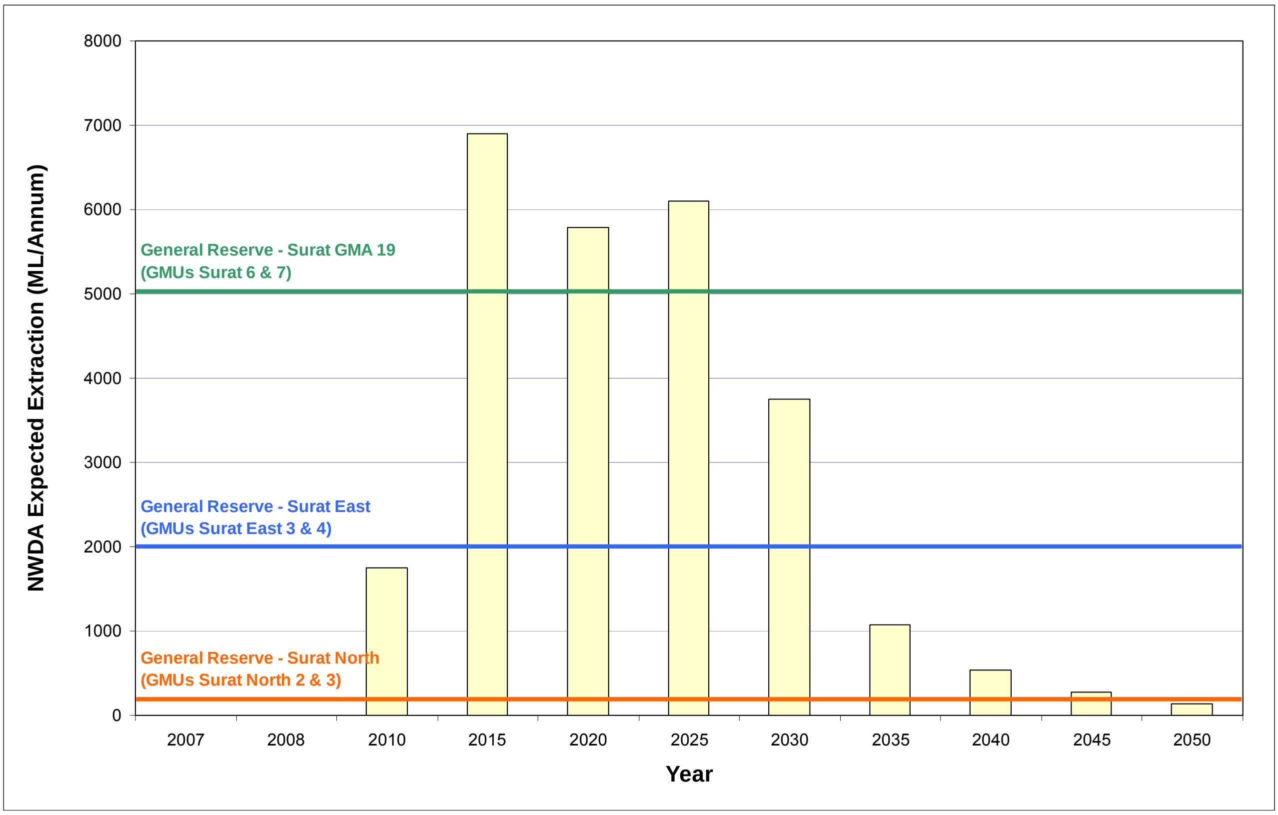


Figure 25: Extraction of Water from the Walloon Coal Measures in the NWDA

The estimated production forecast presented in Figure 25 was used in the calibration of the numerical groundwater model described in Section 5.4.

5.0 GROUNDWATER SYSTEM CHARACTERISATION: *EXISTING AND FUTURE*

5.1 Purpose of Groundwater System Characterisation

Having described the existing environment in the preceding section, this section consolidates the information gathered by bringing it together into a *conceptual model of the groundwater system,* which presents a concise and representative picture of the hydrogeological conditions within the Project Area.

The conceptualisation will then form the basis for defining a *current* or baseline groundwater environment conditions. This provides a presentation of the existing environment and environmental values, as a means of assessing the potential future impacts to these values. As such, it will be used as the basis of assessing how the system may change into the *future* as the proposed QGC CSG extraction operations proceeds.

5.2 Introduction

The process of undertaking the conceptualisation of the groundwater systems for the three development areas (CDA, SEDA and NWDA; Golder 2009b) involved a two step process:

- Development of a *Conceptual Groundwater Model* (CGM), describing the existing conditions; and then,
- Development of *computer-based numerical groundwater models* in the three representative CSG development areas to simulate the behaviour of the groundwater system to the CSG recovery operations in each development area into the future.

A CGM is a simplified *non-mathematical* presentation of the hydrogeology of a region and typically includes descriptions of the various components of the subsurface groundwater environment, and an illustration of the conceptualisation in the form of a drawing. The CGM's prime purpose is to provide a summary visualisation of the groundwater flow and hydrogeological system.

The numerical model for the NWDA is based on the CGM applicable to the entire Surat Basin study area (Golder, 2009b) and provide the ability to predict the groundwater systems responses to CSG extraction in that area.

While the model provides a representation of aquifer behaviour in the NWDA region, it does not directly detailed account for cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these activities are not currently known, and as such, have been treated here in a qualitative manner (Section 5.4 and Appendix B).

5.3 Conceptual Groundwater Model (CGM)

To better understand and describe the groundwater regime operating in the NWDA, a CGM has been developed for this study. This CGM is itself based on that presented for the Project-wide groundwater sturdy (Golder, 2009b).

The CGM is used here to bring together the available baseline groundwater conditions information (the existing environment and environmental values, as presented in the preceding sections of this report) that can be used to assess potential future impacts. It has been largely based on available published information, and associated geological cross sections and contours maps, of the local interpreted stratigraphy. The sections and maps identify the locations, depth and thickness of each formation (in this case, the sedimentary layers) and areas of outcrop at the surface.

The CGM for the NWDA also provides a summary of information about the nature and extent of geological layers comprising the subsurface of:

- aquifers, aquitards and aquicludes - their characteristics and interactions between each other;
- groundwater flow – both regionally and locally, and in the plain of the bedding and inter-formation flow;

- geological and man-made influences on the groundwater systems – including structural affects and those resulting from groundwater extraction; and
- water quality.

The hydrogeological cross sections, previously presented in Figure 15 and Figure 16 were used to generate the CGM, since they present the geological characteristics of the regional stratigraphic column and hydrogeology in vertical profile. These figures also provide a perspective on the water level (estimated hydraulic heads) for the six hydrogeological units selected, both in strike and dip sections, and illustrate the structural (folding) patterns observed in the Project Area geology

The CGM is presented in a tabular form in Table 10 and as a graphic representation in Figure 26.

Table 10: NWDA Conceptual Groundwater Model – Surat Basin Bedrock Hydrogeological System

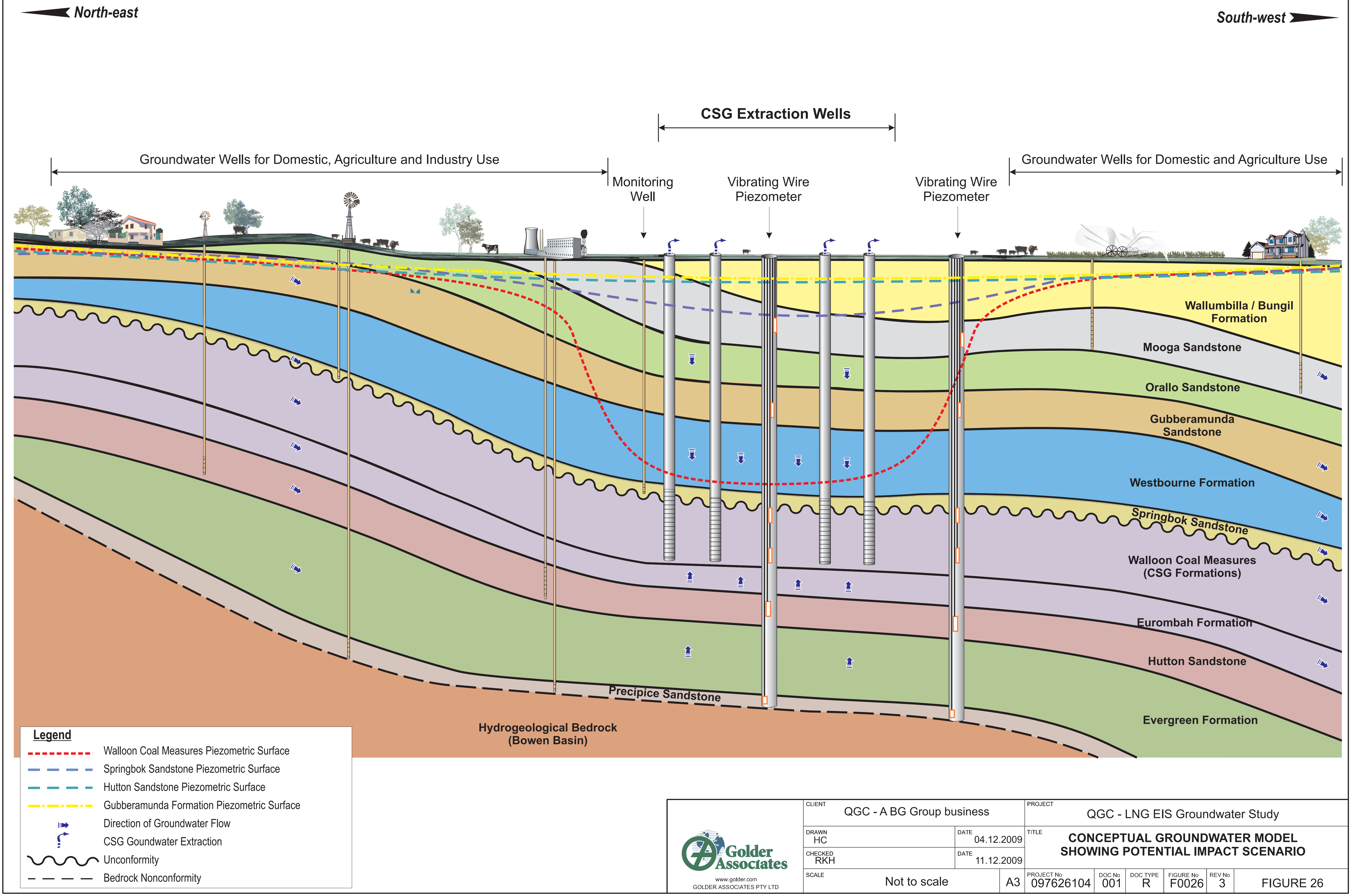
Component	**Description**
Geological System	The Surat Basin geology, present within the NWDA, comprises a multi-layered sedimentary sequence of beds, bands and units comprising combinations of sandstones, mudstones, siltstones, coal seams and volcanics (with rare limestones) rock-types. Five groupings of stratigraphies are distinguished: Shallow Unit, Intermediate Unit, Walloon Unit, Hutton Sandstone Unit and Precipice Sandstone Unit. The Surat Basin sedimentary sequence was deposited on Bowen Basin stratigraphy and is unconformably overlain by a sequence of younger alluvial sediments. Although the thicknesses of the Surat Basin sedimentary formations are relatively uniform through their profiles, the lateral variability within the layers (or sedimentary units) is moderate to significant across the Study Area. The biggest variability occurring within the Shallow and Intermediate Unit and the lower beds within the WCM. A highly variable but thin veneer of recent and Quaternary age alluvium is present over much of the Study Area. These sediments typically comprise sandy soils and valley infill deposits along the historic and active drainage lines.
Structural Setting	The Surat Basin stratigraphy in the NWDA (and more broadly within the Study Area) is a layered sequence, with a slight dip of between 1° and 2° degrees to the south to south-west. The Surat Basin stratigraphy is variably *faulted* and *fractured* through the entire sequence. The fault structures are generally north-south orientated dislocations of the stratigraphy (perpendicular to the basin edge), as is illustrated in Figure 14. The Surat Basin sequence is also variably but gently folded in a series of alternating anticlines and synclines. These fold structures are ubiquitous through the Project Area and are present as low open structures. Major fault and fold zones include: The Kumbarilla Ridge, the Chinchilla-Goondiwindi Fault, the Leichhardt-Burunga Fault, the Mimosa Syncline and the Wallumbilla Fault. The Shallow Unit is not well developed in the NWDA. The Intermediate and Walloon Units outcrop (or subcrop) in the north eastern part of the Project Area. The Hutton Sandstone outcrops in the far north east part of the Project Area.

Hydrogeological Setting: Aquifers	A number of aquifer layers are distinguished within the Surat Basin stratigraphy: They are primarily sandstone units (but including the coal seams) which yield sufficient economic quantities of groundwater, of suitable quality, for use as potable, stock, irrigation and industrial water supplies. The primary aquifer units present within the Project Area include: the Precipice Sandstone aquifer, the Hutton Sandstone aquifer, Springbok Sandstone aquifer, Gubberamunda Sandstone aquifer and the Mooga Sandstone aquifer. The coal seams in the WCM are regarded as aquifer units in this report (even though their yields are moderate to low). The aquifer beds are typically confined over most of the Project Area, except where they outcrop or sub-crop in the north eastern part of the study area. Importantly fracturing of the WCM within the Mimosa Syncline and the Leichhardt-Burunga Fault may result in enhanced permeability and storage capacity of coal measures in the NWDA. The Springbok Formation lies unconformably over the WCM, frequently occurring in small channel/valley structures eroded into the uppermost WCM layers. This may facilitate spatially variable hydraulic connection between the Springbok and WCM aquifer units. The Surat Basin stratigraphy is considered hydrogeologically distinct from the underlying Bowen Basin stratigraphy (some hydraulic connection id inferred). The surficial or shallow aquifers (primarily the Quaternary alluvium), in the NWDA are limited in occurrence and where present are typically unconfined to semi-confined, depending on depth of burial of a particular aquifer. They are heavily developed for their water resources to the southeast of the NWDA (e.g. the Condamine Alluvial Aquifer).
Hydrogeological Setting: Aquitards	The Surat Basin aquifers are “sandwiched” between a multilayered sequence of low permeability aquitard layers (siltstone, mudstone and lutite) which dominate the hydrostratigraphy and which limit flow of groundwater along their aerial extent, as well as, between the layers (restricting inter-formational connectivity) of the “sandwich”.
Hydrogeological parameters	Hydraulic Conductivity values reported range from 0.4 to 50m/day for the major aquifer sandstones to 1.4 m/day for coal seams, and 10^{-1} to 10^{-4} m/day for aquitard layers. Vertical to horizontal hydraulic conductivity ratios (Kv/Kh) for the units which comprise the sequence range from extremes of 1:50 for the least bedded or laminated rock-types to 1:10,000 for the most bedded and laminated rock-types, with 1:100 to 1:1000 being the typical values reported (from literature and Appendix B). Storativity values 10^{-3} to 10^{-4} apply for the majority of the sequence. Porosity values of 0.1 - 0.2% for the coal seams (average 1.2%), and 10 - 30% for the other members of the sequence.

Recharge	Rainfall recharge occurs directly and indirectly to the various aquifer (and aquitard) layers where they outcrop and/or sub-crop beneath the Quaternary and recent alluvial beds. Infiltration to the various members of the Surat Basin hydrostratigraphy occurs directly from rainfall incident to the outcrop or via temporary storage in the overlying alluvial beds. Inter-formational flow also provides a component of recharge to the various units within the Surat Basin sequence Site specific recharge values are not known for the area, but are typically approximately 1% of rainfall for the GAB (on a basin-wide basis).
Groundwater Levels and Piezometric Heads	Groundwater cross sections through the NWDA illustrate the distribution of piezometric head surfaces for the confined Surat Basin stratigraphy (aquifers) where data was available. There are subtle differences in the heads across the area largely reflecting hydrogeological parameter differences (laterally and vertical) in the various aquifer units and the effects of groundwater use (depletion of resource). Groundwater cross sections are presented in Figure 15 and Figure 16. The contoured piezometric surfaces generally reflect the groundwater flow gradients described as follows: *Shallow Aquifers*: water elevations in the alluvium mimic topography with flow direction normal to topographical contours. *WCM*: varies between 180 to 350 metres AHD. *Hutton Sandstone Aquifer*: varies between 180 and 300 metres AHD. *Precipice Sandstone Aquifer*: water elevations of approximately 200 metres AHD in the northern part of the Study Area (limited data available).
Groundwater Flow	*Horizontal Flow*: Groundwater flow is largely controlled by the shallow dipping nature of the layered sequence, their hydrogeological parameters (primarily hydraulic conductivity) and structural overprints, and is largely parallel (to sub-parallel) to the bedding. Groundwater is inferred to flow, under the prevailing hydraulic heads, along the plane of the stratigraphic layers, parallel with their bedding and contacts. This translates to water flow down-gradient (effectively down the dip of the formations) toward the centre of the Surat Basin and, further into the GAB. *Vertical Flow*: Limited groundwater flow will likely take place perpendicular to the bedding plane, i.e. in the vertical direction. Cross or inter-formational flow (from bed-to-bed, layer-to-layer and unit-to-unit) is restricted by the natural bedding plane alignment of the sedimentary particles parallel to the bedding plane. In this way, limited flow is anticipated between the various units in the sedimentary sequence (as reflected in the high Kv/Kh ratios; Appendix D) under typical (baseline) hydraulic gradient. This is inferred to change if excessive artificial hydraulic heads are applied to the system. Exceptions to this general condition are inferred to occur where the stratigraphy is affected by the structural features discussed previously, i.e. the fault and fold zones, where vertical dislocations provide vertical or Subvertical conduits, which in term enhance vertical hydraulic conductivity and therefore connectivity. Intra-formational flow of groundwater is considered to be a consequence of these overprinted structural features.
Groundwater Quality	*Shallow Aquifers:* Groundwater quality in all of the shallow flow units is generally fresh. *Intermediate Aquifers*: salinity levels between 3,000 to 6,000 µS/cm. *Walloon Coal Measures:* salinity levels across the NWDA typically range between 3,000 and 18,000 µS/cm (water is generally not used for human and livestock

	consumption, but industrial use is possible). *Hutton Sandstone Aquifer*: salinity levels across the NWDA generally range between 2,000 and 9,000 µS/cm. *Precipice Sandstone Aquifer:* Salinity in this unit is generally less than 3,500 µS/cm.
Environmental Values (Refer Section **6.2**)	The key groundwater uses and environmental values identified within the NWDA are as follows: ■ primary industry 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). ■ drinking water uses ■ other industrial uses ■ recreation uses (level of protection based on contact, either direct (swimming), or indirect (boating)) ■ cultural and spiritual values. ■ stygofauna ecosystems. These are discussed in detail in Section 6.2 and Section 7.0.

The CGM and its key hydrogeological components have been used to provide a basis for evaluating the existing environment and its environmental values (EV), and then, for assessing potential impacts which might be reasonably expected on those EVs in the NWDA. This analysis is presented in the sections which follow (Section **6.0**).



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TITLE
CONCEPTUAL GROUNDWATER MODEL
SHOWING POTENTIAL IMPACT SCENARIO

PROJECT No	DOC No	DOC TYPE	FIGURE No	REV No	
097626104	001	R	F0026	3	FIGURE 26

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5.4 Numerical Model – Groundwater Impact Prediction

Introduction

Following the conceptualisation of the groundwater system (Section 5.3) a predictive groundwater flow model was developed. The assessment presented herein has included the construction of an updated[3] and revised computer based numerical groundwater model to better represent any geological conditions in the new tenement distribution in the NWDA CSG field. As such, it follows the methodology presented in the Project-wide groundwater study, Golder 2009b, but has revised the model parameters and location to better represent the NWDA tenement distribution (model centre was moved northward to accommodate the additional tenement, Figure 1).

A full description of the model is provided in Appendix B, with a summary provided in the text which follows.

Background

The model employs numerical mathematical techniques to simulate the behaviour of a groundwater system under proposed future CSG extraction operations. The primary purpose for this component of the assessment has been to provide estimates (predictions) of the impact of extracting CSG and groundwater from the Walloon Coal Measures on the existing groundwater condition and its associated environmental values, and particularly the impacts that might be anticipated on other groundwater users (Appendix B).

Therefore, the modelling work sought to allow the:

- Development of an *idealised* regional groundwater model for each CSG development area – a tabular shape depressurisation zone is used to present the irregular tenement shapes (Figure 1 and 3);
- Interpretation of both the CGM and the "*order of magnitude*" results of the numerical groundwater modelling to lead to estimation of the *relative* risks of groundwater impacts arising from the current and proposed CSG operations, and for the post-production period of groundwater recovery, as an envelope of possible outcomes;
- Development of recommendations for groundwater management and monitoring associated with the QGC CSG operations to accommodate the unknowns and uncertainties of the model; and
- Determination of the trigger levels, defined in the *Petroleum and Gas Act 2004,* to permit early warning of possible impacts, which, in turn, permit pre-emptive mitigation actions.

5.4.1 Numerical Modelling – Concept, Goal and Setup

The numerical groundwater model were developed using the modular finite-difference ground-water flow model (MODFLOW) computer code. MODFLOW was developed by the U.S. Geological Survey (USGS) and is a computer program for simulating common features in ground-water systems. MODFLOW is designed to simulate aquifer systems in which (a) saturated-flow conditions exist, (b) Darcy's Law applies, (c) the density of ground water is constant, and (d) the principal directions of horizontal hydraulic conductivity do not vary within the system. For this study, the MODFLOW model has been applied as a three-dimensional flow model.

MODFLOW uses specific hydrogeological input to construct and solve equations of *ground-water flow* in the aquifer system. The ground-water flow equation is solved using the finite-difference approximation. The flow region is subdivided into blocks in which the medium properties are assumed to be uniform (a process known as discretisation). In plan view the blocks are made from a grid of mutually perpendicular lines that may be variably spaced. The vertical dimension of the blocks (the z dimension) are defined to represent the stratigraphic layering of the modelled sequence of aquifers and aquitards. Model layers can have varying thickness. A flow equation is written for each block, referred to as a 'cell' (cubes or tabular blocks). The x and

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[3] Updated from that provided in *"QGC Groundwater Study Surat Basin, Queensland" (087633050 016 R Rev2, June 2009)*

y dimensions of the blocks or cells are sized to permit adequate resolution for the calculation process, being representative of topographic, geological and/or structural feature. The solution from the model consists of hydraulic head (ground-water level) at every cell in the aquifer system at intervals called time steps.

MODFLOW has become the de-facto standard method for simulating groundwater flow systems.

For this study, a graphical pre- and post-processor to the MODFLOW computer code, the PMWin software package, was employed to manage the inputs and outputs most efficiently. The model was developed to be conservative in its predictions; providing over-estimates of the potential drawdowns over the term of the CSG extraction operations.

5.4.1.1 Model Layout

As noted earlier, the NWDA is considered geographically and geologically distinct, being delineated by inferred and actual structural breaks, from the CDA, located its immediate SE. Interference effects from the other development areas (CDA and SEDA) were not considered in this assessment for the reasons described earlier (Sections 4.4.4 and 5.3), namely the structural and inferred hydraulic compartmentalisation (inferred hydraulic separation and isolation from the other development areas to the SE). Also, interference effects from the operations of *other CSG operators* adjacent to the three development areas were not consider in this assessment. Figure 27 presents the location of the NWDA groundwater model domain (with reference to petroleum leases, the Project Area and the Study Area). The NWDA domain encompasses an approximately centrally located and tabular shaped area, defined for the purposes of this modelling as an *idealised representation* of the zone of depressurisation for the development area. That is to say, the tabular zone presented in Figure 27 is conceptually representative of the tenement areas and is used as the effective zone over which groundwater pressures are lowered to achieve CSG extraction.

To accommodate the additional tenement (Figure 1) recently acquired by QGC as part of the NWDA operations, the location of the modelling domain was amended[4]. The centrally-located depressurisation zone was moved further 10km NE to be more representative of the currently arrangement of CSG tenements. That is, it was placed over the centre-line of the tenement distribution such that it provided a better representation of the likely CSG gas-field in the NWDA.

However the zone of influence from the depressurization process could be defined to extend beyond an area within which groundwater impacts would reasonably be expected for the operation of a CSG field of this size and nature.

The model was amended from existing site specific data provided by QGC and general data obtained from the literature and DERM sources.

While the model provides a representation of aquifer behaviour in the NWDA region, it does not directly take into account for cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these proposed activities are not currently known, and as such, have been treated here in a qualitative manner based on the inferred impacts presented by the proponents for each project:

- The Wandoan Coal Project – proposes 15 pits within the currently defined tenement (Figure 1) with the maximum depth of open pit mining anticipated to be approximately 80 mbgl. With current pre-mining water levels measured at between 22.5 and 41.1 mbgl, mining is inferred to penetrate some 38.9 m and 57.5 m into the water table (PB, 2008). The estimated groundwater impacts from groundwater extraction and mine dewatering, and associated mitigation measures, are described as follows (Xstrata, 2008):
    - “The potential effect of mining on coal seam groundwater users was determined to be limited to approximately 20 bores outside of the MLA areas. Deep bores (>600 m) extracting water from the

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[4] Amended from that originally presented in *“QGC Groundwater Study Surat Basin, Queensland” (087633050 016 R Rev2, June 2009)*

GAB were deemed not to be impacted to due to significant depth of separation and presence of impermeable strata between the mine operations and these aquifers.”

- “The results of the groundwater impact analysis show that the impacts of drawing additional water for construction from the GAB Precipice Sandstone aquifer are relatively small and temporary on water users and environmental values.”
- “The Project is expected to have negligible impacts on users and environmental values of groundwater from the Great Artesian Basin and sub-artesian bores.”
- “Groundwater impacts are expected to be confined to the Walloon Coal Measures (in particular the Juandah Coal Measures) and other overlying aquifers. Any exception to this would likely be the result of geological structures (e.g. faults) that have not yet been identified on the geological models.”

- UCG Tenement in the Wandoan area – Cougar Energy and Cockatoo Coal hold tenement adjacent to the QGC tenement in the vicinity of the NWDA (Figure 1). The UCG proposed ‘mining’ area targets the Macalister Coal Seam between 150 m and 300 m depth. Groundwater drawdown and water quality impacts may potentially affect groundwater up to 300 m depth within and adjacent to their defined tenement areas. In particular, the depressurisation of groundwater piezometric levels arising from these UCG operations may therefore impact upon the QGC tenement up to similar levels of magnitude to those likely arising from QGC activities in the area.

5.4.1.2 *Representation of the Hydrostratigraphy*

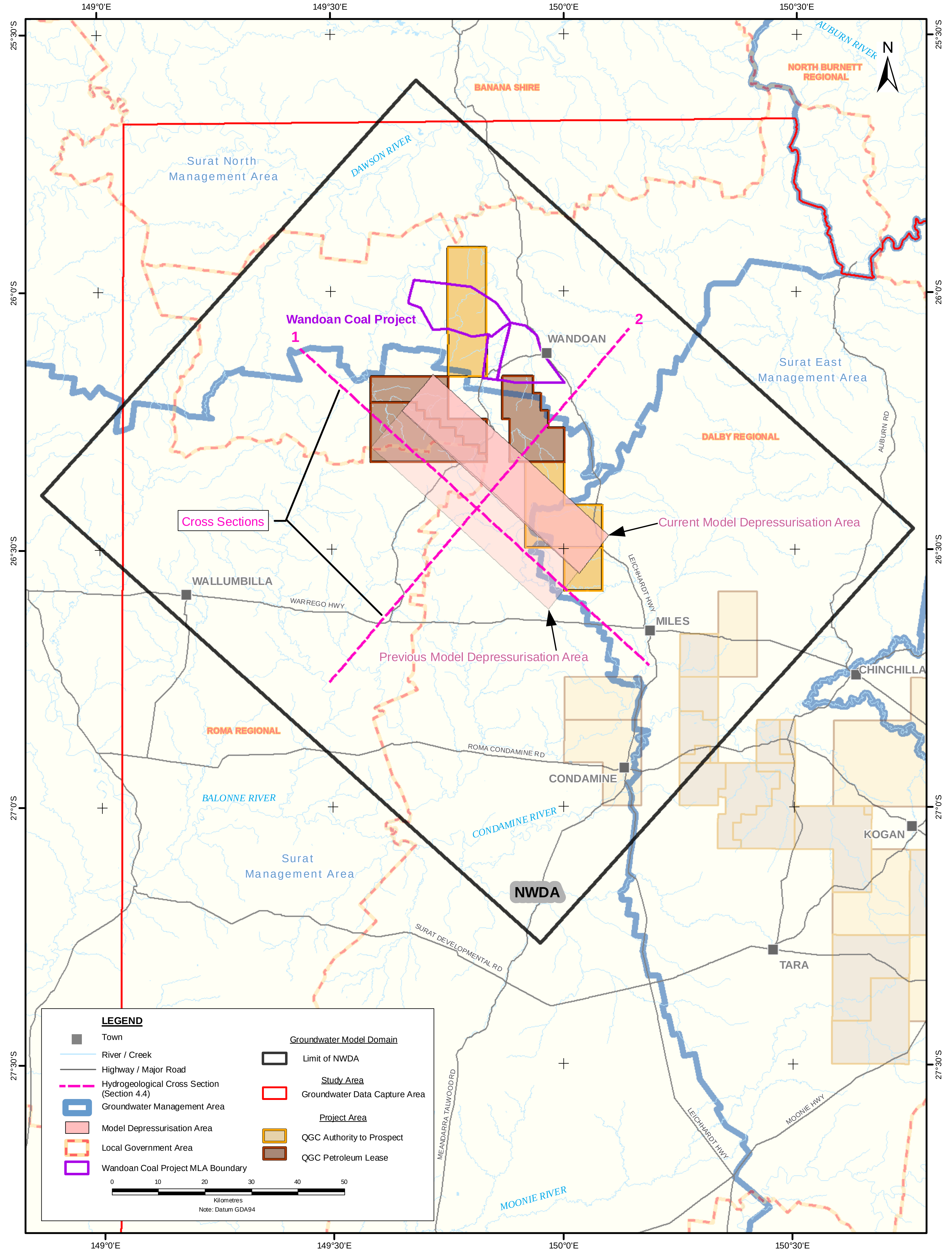
The hydrostratigraphy was developed based on the CGM compilation and development area specific data obtained from QGC and DERM sources, as described in Sections 4.0 and 5.3.

The Surat Basin hydrostratigraphy was simplified to comprise 18 groups or layers for the purposes of NWDA model.

5.4.1.3 *Model Hydrogeological Parameters*

The initial input hydrogeological parameters, including hydraulic conductivity (K), transmissivity (T), porosity (ϕ) and storage (S), and which form the basis upon which the model conceptualisation was prepared, were obtained from the following sources:

- available literature;
- communication with QGC;
- QGC’s third party reviewers, AGE; and
- information provided by DERM (the authority responsible for managing the Great Artesian Basin, previously the DERM).



Note:
1. Base map data copyright Mapinfo Australia Pty Ltd.
2. Authority To Prospect & Petroleum Leases data supplied by QGC Limited, files received dated 17-09-2009.
3. Wandoan Coal Project - Mining Lease Application (MLA) Boundary is based on or contains data provided by the State of Queensland (Department of Employment, Economic Development and Innovation) [2009].

The State of Queensland gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws.

Golder Associates

CLIENT: QGC - A BG Group business
PROJECT: QGC - LNG EIS Groundwater Study
DRAWN: BQ
DATE: 11-12-09
CHECKED: RKH *
DATE: 11-12-09
TITLE: GROUNDWATER MODEL AREAS
SCALE: 1:750,000
PROJECT No: 097626104_001
FIGURE No: 27
REV No: 2
A3

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\097626104_GW\097626104_001_R_F0027_Rev2_GWmodelAreas_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

5.4.1.4 *Inclusion of Structural Geology and Boundaries*

The key structural features present within the NWDA Project Area support the hypothesis that the NWDA is treated as a hydrogeologically separate domain (from the CDA and SEDA compartments[5]), being considered to be largely hydraulically isolated from the adjacent hydrogeological compartments. Restricted groundwater flow between the adjacent compartments is thus implied. The NWDA model is therefore defined a standalone numerical groundwater modelling domain, separate from the CDA and SEDA.

5.4.1.5 *Model Construction and Modelled Processes*

The NWDA model was conceptualised as a rectangular strip running parallel to the regional strike of the geology. The model comprised a discretised mesh of rectangular cells representing the CSG production area of 250 m by 250 m in dimension, increasing in width *beyond* the CSG field with an expansion factor of 1.5 towards the edges of the model. The boundary dimensions of the model were 144 km long (NW-SE direction) by 120 km wide (NE-SW direction), sufficiently large to provide model stability and appropriately resolved outcomes. Within this rectangle, the NWDA CSG production field was conceptually represented by a central rectangle of 50 km by 10 km (of smaller cell size), each area approximating the likely extent of the CSG development area (where CSG production wells will be located) and representing the *depressurisation area*, which is the representative area where groundwater will be extracted for the purpose of recovering the CSG.

Thus, the depressurisation area, the idealised representation of QGC NWDA production area (tenements/lease, current and proposed), of the model was considered as one single area with time-varying-specified-heads used to simulate the proposed pumping schedule for CSG extraction in the NWDA. Constant head boundary conditions were applied around the external borders of the modelled CSG production fields (i.e. the water levels were held at a constant elevation, and, as such, they permit groundwater flow into the model *ad infinitum* for the duration of the modelled period). The starting piezometric heads were defined by the assigned constant head boundary (CHB) for NWDA modelled development area.

The proposed *depressurisation schedules* for NWDA CSG extraction were provided by QGC. These were translated into head or water level changes imposed on the defined existing piezometric heads (within the defined depressurisation area) for the localised Walloon Coal Measure (WCM) ‘aquifer’ layers. The depressurisation pumping was simplistically simulated by having the modelled piezometric heads ‘dragged’ down in the central area of each model, the depressurisation area, according to the proposed QGC depressurisation timeframes. This was the method of simulating the CSG groundwater extraction sequencing.

For this modelling assessment, rainfall recharge was not taken into account at this low level of model resolution.

5.4.1.6 *Model Simulation Methodology*

Once the NWDA model construction was complete, the model was run through an initial series of iterative simulations which are performed to achieve as close an approximation of the existing conditions as is possible. This process of matching the model output to existing (observed) conditions is referred to as model calibration.

Typically the groundwater model calibration process involves trying to match observed historical groundwater level (or piezometric head) data using measured or estimated groundwater extraction (pumping data). Model hydraulic parameters values for variables such as hydraulic conductivity and storativity are adjusted (within the range expected for the conditions being examined) until a close match between observed and modelled output has been achieved.

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[5] Refer to Golder 2009a

Due to the absence of suitable monitoring data in the development areas, the traditional calibration process could not be used

The approach of ‘model calibration’ adopted for this numerical modelling for the NWDA study was to:

- Use a time-dependant schedule of groundwater head decline in the WCM (depressurisation schedules for CSG extraction) as input variables. Note: due to the *large* number of proposed extraction wells modelling using individual wells, the well extraction was not considered to be a realistic modelling approach;
- Estimate groundwater extraction quantities with time required to achieve the depressurisation schedule;
- Compare the numerically derived groundwater extraction estimates with the QGC estimates for the NWDA CSG field. Note: the QGC estimates are based on observed historical extraction data but have been used for predictive purposes in a non-numerical way;
- Where necessary, adjust the numerical model input parameters (within realistic ranges) so that reasonable matches with QGC predictions could be achieved (Note: QGC predictions were achieved using standard reservoir engineering methodologies for the calculation of required gas and groundwater production rates from the reservoir materials concerned); and
- Use the resultant models to predict groundwater head (water level) changes in the various modelled aquifers.

Since this does not constitute model calibration in the strict sense of the term, it will be referred to here as *model matching*, and will refer to a mechanism whereby model output was matched (as closely as possible) to the proposed groundwater extraction estimates (calculated by QGC reservoir engineers).

Basis of Model Matching – QGC Groundwater Extraction Estimates

Estimates of groundwater extraction (associated water production) provided by QGC for the NWDA field was used to frame two simulation scenarios: a modelled *potential minimum parameter* set; and a modelled *potential maximum parameter* set.

The model outcomes were validated against estimates of associated water production rate and scheduling provided by QGC (John Bailey, QGC, email 19 February 2009[6]). The methodology used is described in detail in the original groundwater assessment study report (Golder, 2009b) and Appendix B.

The Model Matching Process – Adjustment of the Numerical Model Input Parameters

The depressurisation schedule estimates (extraction rates, inclusive of the *±50% accuracy provision defined by QGC*) were used to match the model’s output with the extraction estimates. This was done by generating a range of model scenarios (generated by varying input parameters of hydraulic conductivity, Kv/Kh ratios and storativity values) that produced outputs of associated water volumes that bounded (bracketed or enveloped) the QGC predicted associated water production figures. That is, the process of model matching has required a range of model input parameters (considered realistic for the hydrostratigraphy) to be used to estimate a range of groundwater piezometric head drawdowns that can be used to assess potential impacts. Iterative methods were used to carry out the model matching process of the three models, i.e. until the modelled simulations reasonably matched the QGC predicted extraction rates (within the depressurisation schedule).

The model matching iterations varied hydraulic parameters within realistic ranges (determined as being the realistic minimum and maximum for each of the aquifer and aquitard units) based on the available limited published and site specific data. Ratios of vertical hydraulic conductivity versus horizontal hydraulic conductivity (refer to as Kv / Kh ratios) of between 1:10 and 1:1000, considered appropriate for various

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[6] Applies to the entire QGC Surat Basin Operations (i.e., the NWDA, CDA and SEDA)

layers in the model, with 1:500 and 1:1000 considered most particular to the coal and finer grained (mudstones and siltstones) members of the hydrostratigraphy (i.e. the aquitards) for this modelling study.

Groundwater extraction rates were then calculated by the model for the 40 years of wellfield operations (defined by QGC), followed by 150 years of recovery (non-pumping). The consideration that 150 years was sufficient to provide an indication of how the groundwater system would recover after the CSG extraction operations were completed was nominal and is only considered a crude approximation of the recovery phase. Progressive wellfield monitoring of this process will be the only way to show how recovery progresses. Ongoing iterations of the model or its replacement will be required to verify recovery progress.

5.4.1.7 Model Simulations for Drawdown Prediction

Having matched the NWDA model output to estimated production rates in the fashion described above, a series of forward-looking model simulation runs were carried out. The drawdown in the various aquifer and aquitards of concern (i.e., those currently considered, or may in the future be considered to be, important local groundwater producers) were simulated:

- First for the *potential minimum parameter* data set (the lower bound of the calibration envelope); and
- Second, for a modelled *potential maximum parameter* data set (the upper bound of the calibration envelope).

The *drawdown versus time* and *drawdown versus distance* were modelled for 5 key aquifer units (deemed potentially at risk of impact) present within the Project Area, namely, the Precipice, Hutton, Springbok and Gubberamunda sandstone aquifers, and the WCM (refer to the text and figures in Appendix B).

5.4.2 Drawdown Prediction Results

The simulations provided a range of estimates of drawdown with time and distance away from the edge of the idealised CSG area (the tenements).

NOTE: The predictions of groundwater impacts provided in this revised model configuration (incorporating the additional tenement area) is *not meaningfully different* from that presented in the original groundwater assessment study report (Golder, 2009b). This is largely as a result of the close similarity of the general model parameters between the two models, their approximate nature (due to the lack of site specific data) and the low level of resolution of the model. That is, there are only very minor differences in the model input parameters of thickness and depth, and, to a much lesser degree, hydraulic conductivity and aquifer storage between the original and the revised depressurisation area locations (being only 10 km distance apart).

With this in mind, the simulation results are summarised below (refer to Appendix B for detailed discussion and Figures B2 to B5):

General Comments

Groundwater drawdown impacts, within the 5 key aquifer units identified as vulnerable (the Precipice, Hutton, Springbok and Gubberamunda sandstone and the WCM), can be summarised as follows (with specific comments for each development area following):

- The magnitude of drawdown decreases with distance from the CSG wellfield boundaries;
- The magnitude of drawdown decreases gradually after cessation of the CSG groundwater pumping. Note: water levels will continue to decline in adjacent affected aquifers for a considerable period of time follow cessation of pumping due to delayed leakage;
- Drawdown is greatest beneath the depressurisation area (idealised representation of the CSG wellfield areas, i.e. the area bounded by the tenement boundaries);

- The modelled potential maximum parameter set (high end hydraulic conductivity, storage and lowest K_v/K_h ratio simulations) is typically associated with the maximum predicted drawdown and the modelled potential minimum parameter dataset is associated with the minimum predicted drawdown;

Predicted Aquifer Impacts

WCM

- Estimated drawdown in the WCM was as defined by the final model depressurisation pressure head (approximately 70m above the top of the WCM), which at the extraction area boundary equates to the maximum specified drawdown to achieve optimal CSG desorption;

- Recovery of the aquifer is predicted to commence immediately, but very gradually, after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years);

Springbok Aquifer

- Water level impacts are predicted to be greatest within the Springbok Sandstone aquifer largely because it has been modelled as being in good but patchy hydraulic contact with the WCM units - which are being depressurised for CSG recovery (i.e. no laterally extensive aquitard layer separates the Springbok Sandstone aquifer from the WCM unit);

- Specifically, drawdown in the Springbok Sandstone (Figure B-3, Appendix B) is predicted to range from less than 0.5 m to an expected maximum of approximately 2 m immediately outside of the depressurisation area boundary, i.e. the boundary of the tenements (for convenience this is defined in the model as 1.8km from the edge of the depressurisation zone);

- At a nominal distance of 10 km and 20 km from the depressurisation boundary, drawdown impacts are likely to reach a potential maximum of 0.4m and 0.1m, respectively;

- Recovery of the aquifer is predicted to commence 75 years after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years, being 40 years of operation plus 150 years of modelled recovery);

- The predicted maximum drawdown in the Springbok Sandstone in the NWDA is less than the CDA and SEDA. This is because the NWDA is deeper (tighter fracture permeability) and is significantly less structurally affected than the other development areas (Section 4.4.4);

Hutton and Precipice Aquifers

- The predicted maximum drawdown in the Hutton Sandstone and the Precipice Sandstone aquifers is insignificant, being predicted to be less than approximately 0.1m during the 190 years of CSG pumping and recovery (Figure B-3, Appendix B).

- Recovery of the aquifer is not predicted to have started within the 190 years of modelling;

- The magnitude of modelled maximum drawdown (and its recovery), at the levels predicted, are not considered discernable within the natural fluctuation of the deep groundwater systems operating in these aquifers;

Gubberamunda Aquifer

- The Gubberamunda aquifer is least affected by extraction of groundwater from the WCM, with predicted drawdowns being modelled as negligible (or not within the resolution of the model) – largely due to the large intervening thickness of aquitard layers.

The predicted drawdowns for the Springbok Sandstone, Hutton Sandstone and Precipice Sandstone are presented in Figures B-3 and B-4 (Appendix B).

5.4.3 Model Limitations

The limitations of the model are:

- The model provides a simplified representation of actual conditions, with homogeneous isotropic conditions within the model layers, and assumptions related to the applied constant head boundaries;
- The lack of a significant data-set of site specific model input parameters, i.e. hydraulic conductivity (vertical and horizontal), K_v/K_h ratios, transmissivity and storativity values, means that the model outcomes are approximate and are able to provide *indicative level estimates* of groundwater head declines arising from CSG and groundwater extraction. They are considered suitable to provide the basis for developing guidance level decision-making tools for deciding precautionary management and monitoring practices. These water management guidance's are discussed further in Section 8.2.3;
- The models have not been formally calibrated due to the absence of appropriate long-term groundwater level monitoring data, and the absence of quantitative information on the amount of rainfall recharge occurring to areas where significant aquifers outcrop at ground surface;
- The model applies average (bulk) hydraulic parameters for the layers, however in reality, there is likely to be variability in hydraulic parameters within the model domain;
- The potential influence of residual drawdown from previous activities is uncertain because the NWDA has been modelled independently of the other two development areas (CDA and SEDA). The basis for this is the structural separation provided by key fault and fold zones in the area to the SE of the NWDA, and inferred in the CGM to provide a measure of hydraulic isolation, however this assumption has not been tested in practice. Only ongoing monitoring will provide concrete evidence of these hypotheses;
- While the model provides a reasonable representation of aquifer behaviour in the NWDA region, it does not directly take into account the cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these activities are not currently known, and as such, have been treated here in a qualitative manner based on the inferred impacts presented by the proponents for each project.
    - The proposed Wandoan Coal Project (WCP) is likely to draw down local water levels by between some 40m and 60m (within their tenement and common tenement areas held by QGC). Further, this dewatering effect will induce a limited halo of drawdown outside their tenement and, again, this will impact QGC tenure areas locally. Golder considers that this effect will be largely indistinguishable from the CSG extraction when considered in relation to the impacts of the key aquifers (where present);
    - UCG operations target coal seams at a deeper depth than the proposed WCP open pit depth, and may impact groundwater levels at common tenement boundaries. NOTE: UCG operations typically do not drawdown water levels within the target aquifer/s (in this case the Macalister Seam) to quite the same degree as required for CSG extraction (no specific information of these impacts is available at this time); and
    - Again, only ongoing monitoring will provide concrete evidence of these hypotheses (refer to the Groundwater Monitoring Plan, Golder, 2009d)
- The sophistication of model predictions is necessarily limited because the extent of information available on the hydraulic properties of the various hydrogeological units is limited.

6.0 INDENTIFICATION OF APPLICABLE ENVIRONMENTAL VALUES

6.1 Introduction

The GAB, and by association, the Surat Basin, supports a wide range of ecosystems (natural and human influenced) and a wide variety of flora and fauna. The extraction and use of the groundwater in the basin can impact, both directly and indirectly, upon ecosystems that are partially or wholly sustained by groundwater.

With this overarching consideration in mind, it is noted that specific regulatory frameworks provide guidance to, and requirements for, assessing and managing these impacts. The Environmental Protection (Water) Policy (2007) identifies *environmental values* (EV) for watercourses, and, *by association* (through hydraulic connection, where it might exist), groundwater where an impact is likely to give rise to collateral impacts to water courses.

Further, the EVs of a surface water or groundwater resource are defined as “those qualities of the waterway that make it suitable to support particular aquatic ecosystems or human use” (EPP 2007). The EPP 2007 provides guidelines on determining the EVs that should be considered for a particular Project site or area, which follow the framework set out in *Appendix H* of the *Queensland Water Quality Guidelines 2006* (QWQG 2006).

The original Project-wide groundwater assessment detailed the EVs relevant to the Project (refer to Section 6.0 of Golder 2009b) – reference to this document is recommended. The following presents an overview of environmental values relevant to the NWDA.

6.2 Environmental Values in the NWDA

6.2.1 Primary Industry

The primary use of groundwater in the NWDA is for stock and domestic purposes, and some irrigation. Of the primary industry EVs identified in the guidelines, the following are considered to be most relevant to the Project Area:

- farm or domestic water supply – suitability for domestic farm water supply for purposes other than drinking water (for example, water used for laundry and produce preparation);
- stock watering – suitability of water supply for the production of healthy livestock; and
- irrigation – suitability of water supply for crops, pastures, parks, gardens and recreational areas.

Groundwater supply for the primary industry uses, listed above, accounts for over 90% of licensed groundwater allocations across the NWDA (Section 4.7). Many of these licensed allocations are assigned to the Intermediate Unit (the Bungil Formation, Mooga and Gubberamunda Sandstones), and the Hutton Sandstone in the north and other undifferentiated formations of the Injune Creek Group to which the WCM are associated. These are the aquifers that modelling results suggest will be most affected by coal seam depressurisation (refer to Section 5.4.2). As such, the EVs associated with primary industry are considered to represent the principle issue of concern with regards to CSG depressurisation operations.

6.2.2 Drinking water

Groundwater is a common drinking water source for many inland areas of Australia, especially where aquifers of good quality and yield are present at reasonably shallow depths. Western Downs Regional Council reports that a number of towns in the region are supplied with treated bore water (Western Downs Regional Council, 2009). These include: Miles, Dulacca and Wandoan.

Although municipal water supply only accounts for less than 1% of the licensed groundwater allocation across NWDA, protection of drinking water supplies is a highly sensitive issue for the affected communities, particularly where no alternative drinking water source is readily available, and is therefore considered to be an important EV for the groundwater resources in the Project Area.

6.2.3 Industrial Uses

According to groundwater allocation information from DERM, industrial uses account for less than 1% of the licensed groundwater entitlements in the NWDA. While this represents a minor proportion of the human consumptive uses of groundwater in the development areas, many industrial water applications are relatively sensitive to the reliability of supply, and may also have a limited tolerance range for variations in water quality. As such, industrial use has been considered amongst the relevant EVs for the groundwater resources of the NWDA area, with the recognition that it comprises a minor component of the overall licensed allocation. The Wandoan Coal Project proposes to use one or more groundwater sources located within and beyond the NWDA tenement areas, including, the potential use of associated water from CSG operations either to the west or south of the NWDA. UCG operations, by their operational nature consume groundwater and can be considered as industrial users.

6.2.4 Recreation and Aesthetics

The EVs associated with recreation and aesthetics are traditionally more applicable to surface water bodies than groundwater resources. Where surface water and shallow groundwater are hydraulically connected there is a potential for impacts to shallow groundwater resources to result in indirect impacts to surface water EVs. With respect to the CSG operations in the NWDA Project Area, the most relevant scenario affecting these EVs would be contamination of shallow groundwater (in the limited alluvial aquifers present in the river drainage alignments) from some aspect of CSG activities (primarily from the surface infrastructure, storage and treatment systems, and gathering systems), which in turn, might impact surface water quality and affects the recreational or aesthetic amenity of the surface water body.

On this basis, the following EVs have therefore not been ruled out as irrelevant, but would apply to only a very specific set of circumstances:

- primary recreation – health of humans during recreation which involves direct contact and a high probability of water being swallowed, for example, swimming, and water skiing;
- secondary recreation – health of humans during recreation which involves indirect contact and a low probability of water being swallowed, for example, wading, boating, and fishing; and
- visual recreation – amenity of waterways for recreation which does not involve any contact with water, for example, walking and picnicking beside a waterway.

6.2.5 Cultural and Spiritual Values

This EV category includes indigenous and non-indigenous cultural heritage issues, for example:

- custodial, spiritual, cultural and traditional heritage, hunting, gathering and ritual responsibilities;
- symbols, landmarks and icons (such as waterways, turtles and frogs); and
- lifestyles (such as agriculture and fishing).

These are issues that are more relevant to surface water bodies than groundwater resources, except for the circumstances previously described regarding the connection of surface water and shallow groundwater. Given the descriptions of this EV category, it is considered unlikely that the groundwater resources themselves would have significant cultural or spiritual value; hence this EV is not considered to be relevant to the groundwater resources within the NWDA.

Further details of the environmental values described in this section are provided in the QWQG 2006 and the EPP 2007.

6.2.6 Aquatic Ecosystems

This EV category comprises two inter-related aspects:

- The intrinsic value of aquatic ecosystems, habitat and wildlife in waterways and riparian areas – for example, biodiversity, ecological interactions, plants, animals, key species, (such as fresh water fish and crustacean, turtles and platypus) and their habitat, food and drinking water; and
- Waterways which include perennial and intermittent surface waters, ground waters, tidal and non-tidal waters, lakes, storages, reservoirs, dams, wetlands, swamps, marshes, lagoons, canals, natural and artificial channels and the bed and banks of waterways.

Whilst aquatic ecosystems are traditionally associated with surface water bodies rather than groundwater systems, any surface water body with a hydraulic connection to shallow groundwater would be potentially susceptible to impacts to shallow groundwater (either water quality degradation, or lowering of the water table). This EV is considered to have only limited relevance to the NWDA, since the creeks and rivers present within this area are not perennial in their behaviour and, as such, potential impacts felt within the groundwater systems which may be connected surface water bodies, are considered unlikely to measurably impact those surface water systems.

Groundwater dependent ecosystems (GDEs), typically associated with surface drainage features or shallow groundwater resources related to aquifer recharge and discharge zones, fall within this EV category.

7.0 POTENTIAL IMPACTS

7.1 Introduction

The original Project-wide groundwater assessment (Golder 2009b) presented a discussion of the Project related risks, the drivers for impact governing monitoring and management activities, an the potential for impact to the relevant environmental values (EV) associated with the groundwater resources and their extraction as part of CSG recovery infrastructure within the Project Area. This section presents a summarised assessment of potential impacts to the EVs *as they apply to* the NWDA. The original Project-wide groundwater assessment should be referred to for a full presentation or potential impacts due to CSG activities.

The EVs associated with a groundwater resource have been defined as comprising primary industry, drinking water, other industrial uses, recreation uses, cultural and spiritual values and aquatic systems (Section 6.2). A detailed assessment of each of the key CSG related activities likely to impact these EVs is presented below.

7.1.1 Drilling and Well Installation Activities

QGC operations within the NWDA involve drilling of exploration boreholes and completion of selected boreholes as either CSG production wells or monitoring bores. With the exception of shallow groundwater monitoring bores around infrastructure, exploration and well installation boreholes related to CSG operations will intersect multiple water bearing zones of varying yield and quality, including the potential to encounter formations under artesian pressure.

Associated Risk Issues

The primary risks associated with drilling and well installation include:

- creating an artificial connection between water-bearing formations that bypasses aquitards;
- loss of drilling fluid into the formation; and
- management of artesian flows, if encountered.

The factors that traditionally contribute to these risks include inadequate design, construction and well head completion techniques for the wells, inappropriate drilling technique and/or drilling fluid selection, and inappropriate abandonment methods.

Anecdotal information, collected during the bore inventory (Golder 2009c) suggests the historical drilling activities (not by QGC) for groundwater and, oil and gas exploration may have permitted such cross-formational leakage to occur through inappropriately constructed or inadequately abandoned boreholes and wells.

Discussion of Potential Impacts

The potential impacts associated with improper drilling, well installation or borehole abandonment include depressurisation and/or cross-contamination of groundwater resources through leakage within the borehole, groundwater quality impacts resulting from loss of drilling fluid to the formation, and cross-contamination or depressurisation of water-bearing formations through inadequate control of flowing artesian conditions. In addition to groundwater impacts, mismanagement of flowing artesian conditions can result in erosion and surface water impacts from uncontrolled overland flow of artesian water into surface water courses. While the likelihood of encountering flowing artesian well conditions within the NWDA are low, should these circumstance occur appropriate management will be required.

Environmental Values Potentially Affected

The EVs at risk from potential impacts related to inappropriate drilling, well installation and abandonment include:

- Human consumptive uses, such as groundwater supply for drinking water or stock watering, which could be effected either through degradation of groundwater quality to a condition that is unsuitable for current uses, or depressurisation of water supply aquifers through inter-borehole leakage. Migration of saline water through leaky boreholes is a commonly sited impact from poor well completion or borehole abandonment techniques. These circumstance is considered unlikely, if the management measures described in Section 8.0 are applied; and

- Aquatic ecosystems, which could be affected by degradation of aquifers, particularly those shallow aquifers that contribute baseflow to surface water features, or induced vertical leakage of water table aquifers resulting in reduced baseflow contributions to aquatic ecosystems. This circumstance is considered unlikely, since these conditions are rarely encountered in the NWDA.

It is noted that the risk of aquifer depressurisation due to borehole leakage between aquifers is expected to be minor relative to similar effects resulting from depressurisation of coal seams during CSG extraction. Degradation of groundwater quality is considered to be a significant risk associated with improper drilling, well installation and abandonment techniques.

7.1.2 Extraction Activities - Coal Seam Depressurisation

As described in Section 1.1, groundwater is extracted from a CSG reservoir (coal seam or coal measures) to facilitate desorption of the gases (predominantly methane) adsorbed to the coal. Typically the amount of dewatering required to achieve the optimal reservoir pressures within the coal seams is significant, and results in the development of steep hydraulic gradients between the CSG target formation and adjacent water-bearing formations.

NOTE: Depressurisation of the coal seams will also be locally enhanced as the effects of dewatering operations at the proposed Wandoan Coal project propagates away from the mine and by the UCG operation proposed for the areas to the east of the NWDA tenement

Along with management of the associated water generated, coal seam depressurisation represents the greatest risk to groundwater resources in the vicinity of the CSG operations.

Associated Risk Issues

The primary risk associated with coal seam depressurisation is induced leakage of groundwater from adjacent (laterally and, importantly, vertically) water-bearing formations into the CSG production formation, which is also referred to as inter-formational or inter-aquifer transfer, as a result of the steep hydraulic gradients that are generated.

Environmental Values Potentially Affected

Loss of available drawdown in existing bores in the NWDA

Inter-aquifer transfer related to coal seam depressurisation may result in a measurable reduction in the available water column for bores screened within the affected aquifers; significantly in the Springbok Sandstone, and to a lesser extent the Hutton and Precipice Sandstone in the vicinity of QGC CSG extraction bore wellfields (Section 5.4.2).

The relative impact to surrounding bore owners will depend on the location of their production bores relative to the CSG well fields and the associated cone of depression in the affected aquifer. The modelling results (Appendix B) predict that depressurisation effects within the Springbok Sandstone would extend approximately 1.8 km from the edge of the depressurisation zone of the CSG fields. Due to the relatively high hydraulic connectedness of this aquifer to the WCM units, water supply bores completed within these aquifer formations in the NWDA CSG may face a risk from loss of available drawdown (Section 5.4).

The potential influence of coal seam depressurisation on water supply aquifers in the NWDA is presented conceptually on Figure B-4 (Appendix B). Appendix B presents the modelled drawdown results of the groundwater modelling performed for these fields with the relative magnitude and radial extent of drawdown for the depressurised coal seams and proximal major aquifer formations are presented diagrammatically.

The Wandoan Coal Project (WCP) is proposed to cut into the WCM just north of PL171 and through ATP768. Dewatering operations of this project will target the upper coal seams of the WCM, to the Lower Juandah Coals (Xstrata Coal, 2008). Preliminary estimates presented in the proponents EIS predict that based on shallow mining (80m) and poor aquifer parameters, dewatering during coal mining operations would result in a possible reduction in shallow groundwater levels within a ~ 2 km zone from the centre of the pits. Therefore, the proposed WCP is likely to draw down local water levels by between some 40m and 60m (within their tenement and common tenement areas held by QGC) with a drawdown cone extending as much a 2km from the pit boundaries. Typically, mining activities will occur where the coal seams are less than 100m deep whereas CSG operations will typically target the WCM at depths greater than 300m. However, where both the depressurisation zone of influence from QGC CSG extraction activities and the zone of influence from the Wandoan Coal Project dewatering operations intersect, their impacts will be a superimposed (sum of the individual drawdown). This will impact QGC tenure areas with regard to CSG production where locally shallow CSG resources are to be extracted. However, Golder consider that this affect will be largely indistinguishable from the CSG extraction when considered in relation to the impacts of the key aquifers (where present adjacent and beneath the WCM).

Cougar Energy Limited and Cockatoo Coal Limited hold tenements adjacent to the QGC tenement in the vicinity of the NWDA (Figure 1). These proposed UCG operations target coal seams at deeper depth (Macalister Coal Seam between 150m and 300m depth) than the proposed WCP open pit depth, and may impact groundwater levels at common tenement boundaries with the QGC tenure. UCG operations typically do not drawdown water levels within the target aquifer/s to quite the same extent as required for CSG extraction. However, groundwater drawdown and water quality impacts may potentially affect groundwater up to 300 m depth within and adjacent to their defined tenement areas. In particular, the depressurisation of groundwater piezometric levels arising from these UCG operations may potentially affect QGC tenement with impacts up to similar levels of magnitude to those likely arising from QGC activities in the area (however no specific information of these impacts is available from the proponents at this time).

Therefore water supply bores within and in close proximity to the CSG operations and located in the combined zone of influence (discussed above), will need to be monitored as CSG production develops, such that potential losses resulting from a reduced water column in the bores can be identified early and impacts appropriately mitigated, if warranted. Increased monitoring will be required in the combined zone of influence to ensure that it will be possible to determine the level of impact from the individual operators. Further discussion of potential monitoring and management options for affected bore owners is provided in Section 8.0.

Loss of Artesian Flow

The potential for reduction or loss of artesian pressure is a slight variation on the loss of available drawdown discussed above. It is possible that inter-aquifer transfer, particularly from the Springbok Sandstone, could result in a reduction of pressure for bore owners with bores completed in the portions of the Springbok Sandstone (and to a lesser extent, Precipice and Hutton Formations) in the NWDA, resulting in a potential reduction or loss of natural artesian flow (where present).

Subsidence

The removal of groundwater from the fractures and interconnecting pore spaces in a ‘hard’ rock does not normally result in perceptible settlement or ground subsidence, particularly if the stress change due to dewatering is not great compared with the stiffness of the rock mass. The depth of the coal seams can range from near surface in the far north to approximately 700 m in the southern portion of the NWDA. Elastic settlement of a series of coal seams is likely to occur. Given the assumed extent of depressurisation of the WCM coal seams, elastic settlement will likely progress to the surface and result in surface subsidence.

As an indication of the amount of surface subsidence that could occur, an estimation of the elastic response of the dewatered coal seams is based on the following assumptions:

- the dewatering assumptions indicated previously (WCM depressurisation to approximately 100KPa or approximately 70 m above the top of the WCM unit);

- a rock mass modulus of 2 GPa;
- a total thickness of coal seams of approximately 20 m to 70 m; and
- an average depth to the coal seams of 300 m to 400 m, and up to a maximum coal depth as indicated above.

Based on these assumptions, the calculated subsidence is 30 mm to 100 mm for the average depths to coal and 200 mm to 300 mm for the maximum depths. The impact this amount of subsidence may have on the overlying rock formations has not been assessed. It is not known whether the subsidence will result in additional fracturing or opening of existing fractures in the overlying shallower strata, and thus increase the rock mass permeability. If fracturing was induced in aquitards, then there is a risk of increased leakage occurring between aquifers. Given the calculated subsidence (above), it is considered that the risk of subsidence is low. However, it is suggested that the assessed subsidence and associated impacts be the subject of further study.

It is considered that monitoring be carried out, particularly during dewatering of the coal seams, to validate: design assumptions; subsidence predictions; and the assessed risk. A monitoring program should include survey of the ground surface and measurement of water pressure in aquifers in the coal overburden in the NWDA.

Water Quality Changes

In general, groundwater quality becomes more saline within aquifer formations with distance from the recharge zone, as increased residence time and water-rock interactions result in dissolution of soluble minerals within the aquifer matrix. Induced leakage of groundwater from aquifers in close stratigraphic succession to depressurised coal seams can potentially result in induced horizontal flow of lower quality groundwater from within the affected aquifer. It can also promote leakage of more saline water from aquitard units. The net result is a steady decline in groundwater quality over time, which is a process that has been observed in many areas of intensive groundwater extraction.

In contrast to intensive groundwater extraction from good quality aquifers, which is typical of most human consumptive groundwater uses, CSG operations extract water from the lowest quality formations in the hydrostratigraphic sequence. Hence, the potential for degradation of groundwater quality in adjacent good quality aquifers due to associated water extraction is negligible compared to the typical intensive groundwater use scenario.

Reduction in Recharge

As previously mentioned, the NWDA is located over intake beds of a number of GAB aquifers. As such, any induced leakage of groundwater from water supply aquifers during CSG operations directly impacts the recharge to that formation, and hence may affect the sustainability of licensed allocations in the affected formations further from the recharge zone. For the reasons presented in Section 5.0, and previously in this section, the likelihood of this occurring is considered negligible.

Loss of Baseflow (Including Non-Mound Springs)

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.

7.1.3 Gathering Systems

Gathering systems comprise the pipelines and associated infrastructure used to transport associated water from CSG production bores. Depending on the specific associated water management approach, the water may be transmitted to surface storage (ponds and dams), treatment plants, injection wells, surface discharge location remote from the production site, or provided directly to alternative end uses.

Associated Risk Issues

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

Discussion of Potential Impacts

An uncontrolled release of associated water from a gathering system could potentially impact shallow groundwater quality, depending on the size and location of the release, the nature of the soils, the presence of an aquifer (or not), and the relative quality of the associated water compared to shallow groundwater quality. Related environmental impacts could include surface water contamination, soil contamination, and soil erosion.

Environmental Values Potentially Affected

The EVs that would potentially be affected by an uncontrolled release from an associated water gathering system are generally those that are associated with shallow groundwater systems (and surface water systems). Potential contamination of a groundwater resource for municipal supply or primary industry uses would be the primary concern for this scenario. It is likely that an uncontrolled release from a gathering system would be relatively limited in areal extent, and as such any resulting impact to shallow groundwater should be localised. Aquatic ecosystems could also potentially be affected, although in this scenario it is likely that greater impact would occur from direct overland runoff of associated water into a surface water body rather than via infiltration into shallow groundwater and subsequent discharge of a contaminant plume into a surface water body.

7.1.4 Water Storage and Associated Infrastructure

Water storage structures (ponds and dams) are currently integral components of the CSG infrastructure supporting extraction activities. The principle use of ponds and dams is for temporary or permanent management of associated water generated during CSG production.

Other uses include storage of treated effluent from the sewage treatment ponds servicing field camps, potential storage of permeate and brine from reverse osmosis (RO) water treatment facilities, and storage of oily water associated with compressor stations.

Associated Risk Issues

The primary risk issue for water storage would be an uncontrolled discharge to the environment, either through vertical seepage through the base of unlined dams or ponds, or an overtopping of the embankment during heavy rainfall. This could cause seepage into the groundwater aquifers and discharge to surface water courses where they are close to the storage or release.

Discussion of Potential Impacts

An uncontrolled discharge from a CSG pond or dam, where present, may have a reasonable chance of impacting shallow groundwater quality if shallow aquifers are present at that specific location, and could potentially affect soil salinity and structure depending on the quality of the released water. Related impacts not directly relevant to groundwater might include erosion, overland flow of released water into surface water bodies, vegetation mortality, and even flood and property damage, depending on the nature of the release.

Environmental Values Potentially Affected

The groundwater-related EVs most likely to be affected by an uncontrolled release of poor quality water from a storage structure include human consumptive uses such as drinking water supply, and supply to primary industries and other industrial uses. Whilst municipal water supply bores often target deeper aquifer formations for security purposes, domestic water supply bores tend to preferentially access shallow groundwater resources to reduce the costs of well installation.

In the event of an impact to shallow groundwater that contributes to spring flow or baseflow, the aquatic ecosystem, and potentially the recreational and aesthetic amenity, associated with the receiving surface water body may be indirectly affected by impacts to shallow groundwater quality.

7.1.5 Project-Related Surface Infrastructure

The groundwater risks from surface infrastructure in the NWDA, and potential causes associated with surface infrastructure, were separated into three categories: processing facilities, camp services, irrigation and stock water.

The CSG processing plants generally consist of inlet separation, gas compression and dehydration units. Wastewater streams generated include oily washdown water, cooling tower water, and glycol-affected water from tri-ethylene-glycol (TEG) units used to remove water vapour from the gas stream. Cooling tower water and condensate from the inlet separator are relatively clean and low TDS, and are discharged to grade. Oily washdown water is currently managed in mostly lined evaporation ponds, but treatment using “reed beds” and off-site disposal are being evaluated for future operations. Glycol-contaminated water is directed to underground storage tanks and is trucked off-site to a licensed disposal facility. Bulk fuel and chemical storage associated with these sites can also act as point sources of contamination in the event of an uncontrolled release to the environment.

The risks associated with camp services involve contaminant release caused by effluent release from the waste, grey-water and sewage infrastructure from showers, toilet blocks and kitchen facilities (and including sewage treatment plant).

The risks associated with irrigation pertain to water quality which can be variable due to variable CSG water quality; water quantity which may vary due to CSG production schedules; treatment processes which could have inappropriate dosing and leachate rates where the application of leachate quality may be exceeded for the soil/geology.

Treated associated water may be provided to surrounding land managers, mainly for stock water, although the water quality may not be suitable for all uses. The water may have trace elements or total dissolved solids (TDS) which are too high for all uses.

Associated Risk Issues

The risks to groundwater from surface infrastructure are limited to potential contamination of shallow groundwater resources by the various waste streams, generated by the support infrastructure. The potential risk to groundwater quality would be commensurate with the volume and quality of any uncontrolled release to the environment will depend on whether shallow aquifers are present at the surface infrastructure sites.

Discussion of Potential Impacts

The primary groundwater-related impact associated with a waste stream release would be potential contamination of shallow groundwater resources, if present. Related impacts would also include soil contamination, and potential surface water contamination, depending on the location and nature of the uncontrolled release.

Environmental Values Potentially Affected

Whilst there is the potential for waste water releases to impact shallow groundwater quality, the supporting Project infrastructure is generally located away from the environmental values within the CSG fields.

Where this is not the case (or is unavoidable), those environmental values which may be affected by the surface infrastructure include primary industry activities, drinking water and industrial uses.

The primary industries that could be affected are irrigation, farm and domestic water supply and stock water. If additional treatment is required, or the treatment system is unable to handle the volume of water, a suitable water supply may not be available.

7.1.6 Associated Water Management (Water Reuse and Disposal Schemes)

The Queensland government has recently released a new policy regarding the preferred management options for associated water in 2008 in which injection, as well as, beneficial reuse schemes are preferred in favour of the traditional use of evaporation ponds. To comply with this policy, QGC is investigating associated water injection and reuse options for associated water management within the Project Area.

Associated water management options that are currently used, or that are being evaluated for future use, include (but are not limited to) discharge to grade (both treated and untreated), construction, dust suppression, grey water uses at processing plants, stock watering, irrigation, municipal and industrial supply (treated and untreated), and injection, singularly or in combination (as is appropriate to the water quality and quantity).

Associated Risk Issues

The primary risk associated with injection, reuse and/or disposal of associated water is the potential for water quality changes of the target aquifer groundwater. A change in the volume and quality of water provided for municipal supply and industrial reuse applications is also possible.

Discussion of Potential Impacts

The potential impacts related to associated water reuse and disposal in the NWDA, where applicable, include:

- contamination of shallow groundwater;
- erosion and sediment transport from discharge to grade locations, where they are permitted;
- changes to water quality in the deeper GAB groundwater supply aquifers from associated water injection;
- impacts to soil structure from irrigating with sodium-rich associated water; and
- impacts to municipal supply or industrial applications resulting from inconsistent water supply or variable quality.

Environmental Values Potentially Affected

Given the broad range of associated water management activities and related potential impacts, the potentially affected environmental values include the full range of natural and human consumptive uses. There is also a potential for human consumptive uses to be affected if water supply aquifers are impacted, either through infiltration of associated water to shallow groundwater resources, or leakage from injection wells.

Aquatic ecosystems associated with creeks and rivers present through the NWDA may be affected through discharge to grade operations, if permitted.

8.0 MONITORING, MANAGEMENT AND MITIGATION STRATEGY

8.1 Introduction

QGC is committed to understanding, managing and mitigating the potential impacts of their operations on local and regional groundwater and surface water resources. To achieve this, QGC are committed to implementing a comprehensive and socially responsible water management program. This program will comply with all of the legislative requirements and QGCs risk management objectives.

As part of this programs process, QGC will monitor and manage the impacts on the hydrological cycle and associated EVs arising from the extraction of CSG.

On this basis, this section will consider each of these processes as they apply to QGC CSG extraction operations, under the following headings:

- Monitoring.
- Impact management and mitigation.

8.2 Monitoring

The only realistic defence against potential impacts to groundwater resources associated with coal seam depressurisation is a robust monitoring program to evaluate changes to water quality and quantity in the vicinity of CSG operations, and effects on relevant environmental values. Whilst this approach does not mitigate against impacts to groundwater resources occurring as a result of CSG operations, it does provide a mechanism for early identification of potential impacts, so that contingency actions, if warranted, can be implemented in a timely manner.

QGC have recently developed and submitted a groundwater monitoring plan to DERM (Golder 2009d). The groundwater monitoring plan (GWMP) provides the proposed monitoring programs and the monitoring strategy behind the plan, incorporating the following major components:

- the regulatory requirements (general CSG regulation and QGC Environmental Authorities);
- the result of the risk analysis with higher frequency monitoring recommended for higher risks activities/locations;
- trigger levels; and
- an operational optimisation approach (incorporating QGC existing groundwater monitoring).

The monitoring of groundwater is covered by three monitoring programs:

- a regional groundwater monitoring program addressing all the shallow, intermediate and deep groundwater aquifers, including all the GAB aquifers;
- a shallow groundwater monitoring program addressing the subsurface and shallow unconfined aquifers around QGC infrastructure and operations; and
- a monitoring plan specific to the pilot groundwater injection schemes, currently being developed by QGC.

Details as to the technical aspects of the groundwater monitoring programs (the monitoring locations, the frequency of monitoring and the parameters monitored), reporting agenda, and analytical suites can be referred to in the GWMP (Golder 2009d).

8.2.1 Baseline Conditions

Baseline or existing conditions (groundwater conditions existing prior to the initiation of CSG extraction activities) need to be established for pertinent key indicators of potential impacts. These will provide the basis for future comparisons to be made and mitigation measures to be determined.

As part of the process of assembling information for the development of the EIS and the assessment of the effects of the CSG field activities on groundwater and surface water resources, QGC commissioned a "Groundwater Bore Inventory" (Golder, 2009c) to provide baseline information for future monitoring and management of their Surat Basin proposed operation.

The objective of the Groundwater Bore Inventory (GBI) was to identify a number of privately owned bores within a 10km radius of QGC's Surat Basin CSG Operations. It was expected that gaining knowledge of the origin, quality and depth of groundwater within each bore would give a clear "snap shot" of the groundwater conditions at this time.

A total of 321 bores selected to be assessed for the entire Surat Basin Operations (includes the NWDA), of which 104 were successfully located within the NWDA. A second round of monitoring (water level and water quality data) was completed on a subset of these bores (44 bores sampled) in October/November 2009. The results were incorporated to aid in the development of the GWMP and will be used as baseline data for the assessment of future monitoring and management needs. The results will also be presented as part of the Underground Water Impact Report [in preparation] and 2009 Annual Return, as required under the P&G Act.

8.2.2 Monitoring Trigger Levels

Having established the baseline conditions, monitoring is required to provide measurements of key parameters likely to readily and unambiguously demonstrate that an impact to the groundwater systems is not occurring, is beginning to occur, or has already occurred. The measurements would be assessed by comparing there magnitude with the baselines conditions for the selected parameters.

The parameters considered for routine measurement as part of the required GWMP are:

- water level or piezometric head; and
- water quality.

The following sections describe the most appropriate and reasonable trigger levels (defined as the difference between the measured values and that determined previously to be the pre-existing or baseline level) which should apply to each parameter, which, if approached, equalled or exceeded would trigger appropriate management and potentially mitigation.

8.2.2.1 Water Levels Trigger Levels

The *P&G Act 2004*, Part 9, Division 3, Subdivision 1 (Sections 252 to 255), requires petroleum tenure holders to develop a "trigger threshold" for aquifers in the area affected by the exercise of underground water rights for a petroleum tenure. The trigger threshold 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 trigger threshold to be developed at which groundwater impact might result in the need for groundwater management plans to be implemented by the CSG operators.

In accordance with guidance recently provided by DERM (in a meeting on October 12, 2009 with the APEAA water managers), the following trigger thresholds are *proposed*[7] for aquifers potentially affected by CSG activities for consideration by the *Chief Executive*:

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[7] The trigger thresholds presented here are proposed and are for the consideration by the *Chief Executive*. Further discussions with DERM are anticipated.

- **Surficial Alluvial Aquifers:** the lesser of a 2 m decline in water level, or a 10% reduction of the available water column; and
- **Consolidated Aquifers (including sandstone and all other non-alluvial aquifers):** the lesser of a 5 m decline in water level, or a 10% reduction of the available water column.

In the event that a trigger threshold is exceeded, the following response actions are recommended:

- Identify specific bores affected.
- Establish the factors contributing to the decrease in water levels (eg. CSG activities, non-CSG groundwater extraction, sustained below average rainfall, etc).
- Repeat measurement to confirm extent of drawdown and available water column.
- Establish whether the trigger level exceedance has resulted in impairment of the affected bore's function such that it is unfit for its intended purpose.
- If CSG activities are determined to be a significant contributing factor to the impairment of bore function, then the CSG operator and the bore owner/operator would negotiate to establish a suitable course of action.

It is important that observations and results from the monitoring program be assessed immediately after collection against the assigned trigger thresholds to evaluate the level of risk and initiate a control measure or further monitoring actions.

For this approach to be successful, baseline water levels need to be established for all aquifers, and in all areas of the Project (NWDA, CDA, and SEDA) to provide a reference for assessing future water level changes. The baseline data will QGC assess the scale of natural water level fluctuations in the aquifers, as well as any additional stresses on the aquifers (such as over use impacts from existing groundwater users or drought). The trigger levels would be considered following each routine monitoring event in the GWMP.

8.2.2.2 Groundwater Quality

Water Quality

The principal legislative drivers in Queensland for the maintenance of groundwater quality are the Environmental Protection Act 1994, which is administered by DERM, and the relevant supporting guidelines (i.e. Queensland Water Quality Guidelines). Conditions related to maintenance of water quality for petroleum tenure holders are typically incorporated into Environmental Authorities for the petroleum-related activities within those tenures. Compliance criteria are less ambiguous for water quality than for water levels, as there are specific published guideline values that can be referenced. However, adoption of a tiered approach to evaluating potential water quality impacts provides a mechanism for addressing the potential impacts before they reach regulatory thresholds.

Until specific water quality trigger thresholds are provided by the administering authority, the following approach to assessing potential impacts to water quality is proposed:

- **Tier 1 trigger level:** A conservative initial trigger value, defined as a 10% increase in physical or chemical parameter concentrations relative to background values (considering possible seasonal influences and natural spatial variability), and designed to provide an early warning of potential water quality impacts before they occur.
- **Tier 2 trigger level:** A final trigger value representing the threshold at which some form of management action is required to mitigate the risks posed by the changes to water quality.

A summary of the proposed trigger levels and associated actions is presented in Table 11. This approach to water quality assessment provides advanced warning of potential water quality issues so that appropriate site-specific triggers for remedial or other options can be evaluated. These may include reference to published guideline values or the development of site-specific assessment criteria for key water quality parameters (relevant to the specific environmental values, such as ecological, human health or licensed water uses).

The development of site-specific assessment criteria is encouraged in the ANZECC 2000 (October 2000) guidelines, which include a detailed framework for deriving site-specific criteria based on the values being protected.

Table 11: Trigger Values for Water Quality Assessment

Trigger Level	Value	Actions Triggered
Tier 1	10% change in concentration of physical or chemical parameters relative to background conditions	■ Identify specific bores affected ■ Assess all potential contributing factors to the change in water quality (e.g. CSG activities, non-CSG groundwater extraction, sustained below average rainfall, etc) ■ Resample and reanalyse to confirm extent of change to water quality – include revised analytical suite if warranted ■ Evaluate potential site-specific environmental values at risk from changes to water quality ■ Develop an appropriate Tier 2 trigger level on the basis of the assessment, beyond which the water quality would be unfit for its intended purpose (likely to be direct reference to published water quality guidelines, but may include derivation of site-specific guidelines for key parameters) ■ Report to QGC management ■ Report to Regulators
Tier 2	To be determined as Tier 1 action	Evaluate and implement the appropriate management option(s) for the affected bore owners.

Mitigation Recommendations

In the event that a trigger threshold (either water level or water quality) is exceeded, the following response actions would be undertaken:

- Identify the specific registered bores affected.
- Establish the primary and secondary contributing factors (eg. CSG activities, non-CSG groundwater extraction, sustained below average rainfall, etc).
- Repeat measurements to confirm extent of drawdown and available water column, or resample to confirm whether the quality has changed relative to background conditions.
- Establish whether the trigger level exceedance has resulted in impairment of the affected bore's function such that it is unfit for its intended purpose (unduly impacted).
- If CSG activities are determined to be the principal or a significant contributing factor to the impairment of bore function, then the CSG operator and the bore owner/operator would negotiate to establish a suitable course of action.

8.2.3 Application of Trigger Values

8.2.3.1 Induced Drawdown Predicted

This study has highlighted the potential affects of induced groundwater drawdown from CSG extraction operations in the NWDA as the key Project groundwater impact as it has the potential to affect the existing environmental values.

The predictive groundwater modelling (Appendix B) has provided a groundwater drawdown estimate in various key modelled aquifers arising from CSG extraction within each the NWDA area over a proposed 40 years of operation (and 150 additional years of recovery). The largest induced drawdown impacts are likely to occur within the Springbok Sandstone aquifer where maximum drawdowns at the tenement boundaries of up to 2 m were predicted. This is largely because this aquifer is potentially in partial or direct hydraulic connection with the WCM. Where it is not, the intervening aquitard beds are not very thick and they may not provide a substantial hydraulic barrier to vertical flow.

Specifically, these groundwater impacts were calculated estimates of drawdown measured over time from the start of CSG production and with distance from the edge of the idealised CSG extraction areas. They show how CSG operations might affect the current groundwater levels (or piezometric head) within relevant aquifer units above and below the WCM. The estimates indicate what the reduction in head might be reduced by, and at what distance from the CSG areas this reduction might apply. The drawdowns are considered to be those estimated impacts largely arising from inter-formational groundwater flow induced by the depressurisation of the WCM for the duration of operational CSG extraction within each modelled aquifer in the development areas.

The groundwater impact modelling provides estimates of the minimum and maximum areas over which EVs may be affected and the duration of the potential affects. On the basis of these spatial and temporal definitions, appropriate monitoring and water management may be more confidently defined. The requirements for monitoring, its location and density, its design, frequency and duration can be determined.

These drawdown estimates can be used to:

- define the EVs which may be impacted, the area over which they are potentially affected and the duration of any impact;
- define the need for monitoring and the basis for a GWMP to provide forewarning of the above;
- select monitoring locations within *and* surrounding the CSG extraction areas for purpose built designing and installing appropriate monitoring installations;
- select the aquifer layers for targeted monitoring of water level (piezometric head) and/or water quality; and
- define a pool of existing bores (domestic, industrial, stock or irrigation) from which an appropriate number might be selected for ongoing monitoring.

Since the estimates of drawdown are largely based on regional hydrogeological data gathered during the study, specific data on the WCM provided by QGC and the literature, their basis is limited by the current status of knowledge. The estimates are considered indicative only, but are a reasonable starting point from which to initiate responsible management of the EVs potentially impacted and to develop an appropriate monitoring plan (refer to Section 8.3.6 and Golder 2009d).

8.3 Groundwater Management and Mitigation

Project risks will be managed using a combination of preventative measures to reduce the likelihood of the key risks occurring, implementation of a robust monitoring program (the GWMP) to facilitate early identification of the onset and development of impacts, and make good options to assist those affected by CSG operations as required.

8.3.1 Summary of Impacts Requiring Management

Sections 5.0 and 7.0 have provided detail regarding the potential impacts resulting from groundwater extraction and depressurisation of GAB aquifers associated with CSG activity in the NWDA. The GWMP and the original Project-wide groundwater assessment present a monitoring strategy to provide early warning of pending adverse impacts. This section describes the management and mitigation measures available should pending or actual adverse impacts be detected.

Of the impacts presented, the following are identified as posing *key risks* to the Project and, as such, are those which may require monitoring, management and mitigation as part of the Project's water management strategy:

- reduced access to groundwater entitlements;
- reduced discharge to groundwater dependent ecosystems; and
- aquifer compaction and land subsidence

Each of these risks has previously been presented in detail. However, for convenience, they have been summarised in the following sections. Following this discussion, the management of associated water will be considered.

8.3.2 Groundwater Extraction Impacts and Their Mitigation

Groundwater extraction associated with CSG activity has the potential to result in depressurisation of GAB aquifers over wide areas (refer to Section 5.4). Depressurisation could potentially impact the intensively utilised groundwater resources or accelerate existing impacts. The following sections outline the risks associated with aquifer depressurisation and stresses that mitigation options be considered as part of the Project's water management strategy.

8.3.2.1 Reduced Access to Groundwater Entitlements

Effect

While the WCM have previously been characterised as having limited potential for vertical hydraulic connectivity with overlying and underlying formations (PB, 2004); the uncomformable contact between the WCM and the overlying Springbok Formation suggests the potential for a reasonably interconnected system. The impact of large-scale depressurisation has been numerically modelled (Section 5.4 and Appendix B), which has shown that depressurisation may enhance vertical connectivity of multiple layered aquifer zones. This may provide preferential pathways for inter-formation groundwater flow (potential up welling of deep, saline groundwater into previously good quality aquifers during depressurisation of the formations).

Consequence

The potential consequence of this inter-formation flow phenomenon is the loss of available groundwater resources (and associated entitlements) for existing users and other EVs from key aquifers, which may pose a risk to the Project. This requires monitoring, management and mitigation.

Mitigation

In the event that monitoring results indicate that a bore owner has been 'unduly impacted' by CSG operations, either in terms of a significantly reduced bore yield, or a degradation of water quality so that it is unsuitable for its intended use; the following "make good" actions will be considered in conjunction with the bore owner and regulatory authorities, in order of preference:

- 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; and
- providing 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).

8.3.2.2 Reduced Discharge to Groundwater Dependent Ecosystems

Effect

Groundwater dependent ecosystems (GDEs) are typically associated with surface drainage features or shallow groundwater resources related to aquifer recharge and discharge zones. Although the modelling indicates that it is unlikely to occur, depressurisation of GAB aquifers within the NWDA could potentially reduce the availability of groundwater for the GDEs through reduced contribution to river/creek flows, lowering of water levels in wetlands or reduced discharge to baseflow.

Consequence

Groundwater modelling predictions (Section 5.4 and Appendix B) indicate that groundwater aquifer depressurisation resulting from inter-formational flow (described above) 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).

Mitigation

The GWMP 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.

If a cause-and-effect relationship is established, either in terms of a significantly reduced recharge or a degradation of water quality to the potentially impacted GDEs, remedial measures would need to be considered (for example, supplementation of recharge water).

8.3.2.3 Aquifer Compaction and Land Subsidence

Effect

As discussed in Section 7.0, the reduction in hydrostatic pressure within an aquifer formation from significant depressurisation (or dewatering) can result in irreversible compaction of the formation.

Consequence

This could result in a permanent reduction in the capacity of the formation to store and transmit water. In some cases differential subsidence can results in vertical rock fracturing which can enhance inter-formational groundwater flow, and so can cause the degradation of water quality in otherwise high quality water aquifers. Additionally, compaction of multiple aquifer zones can collectively contribute to surficial land settlement. The magnitude and extent of the surficial land subsidence (also referred to as land settlement) depends on the extent of compaction in the underlying aquifers. Differential land settlement can contribute to geotechnical problems for surface infrastructure, and in severe cases it can interfere with surface drainage patterns.

Based on the assumed extent of depressurisation of the WCM in the NWDA, elastic settlement will likely progress to the surface and result in surface subsidence. The magnitude of the settlement has been estimated at 30 mm to 100 mm for the average depths to coal and 200 mm to 300 mm for the maximum depths (Section 7.0).

Mitigation

Monitoring and continual assessment of evidence of subsidence are recommended. Make-good options would need to be assessed on a case-by-case basis, and would be dependant on the magnitude of any potential impact and the likely consequences. Such mitigation measures could include simple rectification works through to injection strategies to manage or minimise (reduce) depressurisation and, consequential subsidence effects.

8.3.3 Management of Associated Water

The Queensland Government's released the water management policy framework for the CSG industry in 2008, providing direction to producers to achieve environmentally sustainable outcomes and encourage greater beneficial use of CSG produced water. The key implications of the CSG policy framework for the Project are as follows:

- use of evaporation ponds to manage associated water is to be phased out over the next three years, along with remediation of existing evaporation ponds to render the land suitable for alternative future uses;
- injection of associated water is promoted as the *preferred management option;*
- if injection is not possible (technically or environmentally), beneficial reuse of associated water is promoted as the next preferred management option. This option may require treatment to achieve appropriate water quality standards for various end uses;
- CSG producers are to be responsible for treating and disposal of produced water; and
- aggregation of surplus associated water will be considered as a last option where no feasible alternative management option exists.

Currently, QGC is assessing the suitability of selected formations for placement of the associated water by injection. QGC is currently designing and planning the trial and pilot injection programs with the intention of progressing development of a long-term program of associated water injection.

Underground injection of associated water is a common management strategy in other CSG production areas (primarily in North America), and has been identified as a desirable approach under the new Queensland Government CSG water management policy. The WCM targeted for CSG production in the Surat Basin occur between productive and highly utilised water supply aquifers of the GAB. The alluvial aquifers overlying the bedrock formations are generally high quality and utilised for agriculture, domestic and municipal water supply.

Before this method implemented, a program of injection testing trials will be undertaken to better characterise the receiving capability of the selected formations, particularly, aquifer units within the Precipice Sandstone (currently considered the preferred target aquifer). The depth of the Precipice Sandstone implies a lower risk of leakage to frequently utilised, good quality aquifers such as the Gubberamunda and Mooga Sandstones.

The programs targets 'favourable' units within the Precipice Sandstone based on:

- continuity across the region;
- water quality that is similar to AW;
- favourable aquifer characteristics (hydraulic conductivity and storage coefficient); and
- relatively few existing groundwater users of the aquifer in the proposed test area.

During these tests, the response of neighbouring aquifers will be monitored to provide the basis of the final design of the most efficient injection wells and, ultimately, the injection wellfield/s.

In general, a good understanding of the hydraulic properties of potential receiving formations is required, both for the design of injection trials, and for predictive numerical modelling of how the aquifer system will respond to injection over the life of the program. Critical information includes:

- development of a robust geological model for the NWDA, including the prospective injection locations, that includes the areal extent, thickness, and depth of aquifer units and confining layers, along with any relevant structures that influence groundwater flow;
- hydrogeological properties of target injection formations and all surrounding formations, including: porosity, permeability, transmissivity, hydraulic conductivity, flow direction and velocity; and
- water quality of the receiving aquifer and the injected water.

Injection of water into underground formations is less efficient than the extraction of water. Therefore, multiple wells may be required to manage the CSG water produced. To determine the design and nature of a reinjecting field it is necessary to know the hydrogeology of the selected receiving aquifer system. Considerable exploration and field testing will be required to first locate an appropriate aquifer(s) and to design suitable injection well fields.

Depleted gas wells that are sufficiently remote, where they will not interfere with the current production area, may be considered for injection points; but it is likely that installation of specially constructed injection wells would also be required to address the volumes of water requiring management. These issues will be further developed with the results of studies, currently underway.

8.3.4 Management and Mitigation of Other Groundwater-related Risks

Section 7.0 has highlighted the potential impacts of CSG extraction activities to the groundwater regime and associated EVs, and the Project risks they pose in the proposed NWDA operations. These will be managed using a combination of industry best-standard preventative measures to reduce the likelihood of the other key risks occurring, implementation of a robust monitoring program to facilitate early identification of the onset and development of impacts, and make good options to assist those affected by CSG operations as required. Two priority risks identified (pertinent to groundwater impacts) requiring appropriate preventative measures to reduce the likelihood of occurrence include:

- **Well Design and Construction**: Appropriate drilling and well installation techniques have been adopted, which include casing and pressure cementing of non-target formations to prevent inter-aquifer leakage through the boreholes and well annulus. Poor drilling and well construction technique is a commonly identified source of pressure loss and water quality degradation in layered aquifer systems; and
- **Water Storage Facilities**: Numerous safety measures have been, and will continue to be, adopted for construction of water storage structures (ponds and dams) to significantly reduce the odds of uncontrolled releases of poor quality water to the environment. Measures include (but are not limited to) appropriate siting, fully lined bases, seepage interception drains, and perimeter groundwater monitoring programs.

9.0 SUMMARY

QGC – A BG Group business (QGC), proposes to develop a Liquefied Natural Gas (LNG) export facility at Gladstone in Central Queensland ("the Project"). Phase 1 of the Project consists of the construction a facility to produce three to four million tonnes per annum (Mtpa) of LNG, with the potential for future expansion to twelve Mtpa. The Project consists of the following key components:

- Development of Coal Seam Gas (CSG) fields centred on Chinchilla, Miles, Moonie, Kogan, Wallumbilla and Dalby in the Surat Basin, encompassing the NWDA, CDA and SEDA). This, "Supplemental Groundwater Study, Northern Tenements" report, focuses on the latter areas;
- Construction of pipelines for gas transmission to Gladstone; and
- Development of an LNG liquefaction and export facility at the port at Gladstone..

The Project was declared a significant Project in July 2008, under the *State Development Public Works Organisation Act 1971 Qld* (SDPWO Act) (Section 26). An Environmental Impact Statement (EIS) is required, as part of the significant Project declaration. To assist in the development of the EIS, Golder Associates Pty Ltd (Golder) was commissioned by QGC to examine the effects of the *CSG Field* component of the Project on groundwater and surface water resources (Golder 2009a and b).

Subsequent to the submission of the draft EIS, QGC acquired additional tenements within the boundaries of their North-West Development Area (NWDA). This document provides an assessment of the groundwater conditions focussing on the NWDA tenements only (Figure 1). Although it is a stand alone document, it is based on and routinely references the Project-wide groundwater assessment report "QGC Groundwater Study Surat Basin, Queensland" (087633050 016 R Rev2, Golder 2009b).

9.1 Context

The Project lies in the Surat Basin which is within the eastern-most portions of the Great Artesian Basin (GAB), one of the largest artesian groundwater basins in the world. It is also located in or adjacent to the following 'Groundwater Management Areas': Surat East, Surat North and Surat. Certain management and monitoring requirements follow from the Projects location within these management areas.

This report is concerned with the obligations to these administrative instruments, and other pertinent State and Federal legislation. Impacts upon the identified Environmental Values (EVs) through the proposed CSG production have been assessed and management and monitoring recommendations provided.

On this basis, the aim of this report was to:

- identify the potential impacts of associated water extraction in the NWDA on groundwater levels and quality;
- describe the environmental values associated with groundwater environments in the NWDA; and
- identify the methods to mitigate impacts on groundwater to acceptable levels.

9.2 Data Assessment and Impact Prediction

Broadly, the groundwater assessment study has involved the following investigation methods:

- incorporate data reviewed as part of the original Project-wide groundwater assessment, including the definition of the pertinent environmental values; and
- develop a detailed conceptual groundwater model for the NWDA, followed by predictive numerical groundwater modelling, to obtain an estimate of the magnitude of the likely impact on the local environment values, and in particular, other groundwater users.

The modelling was the crucial process to evaluate the effect of the Project on environmental values. The prediction of groundwater impacts for the proposed CSG depressurisation and gas extraction activities in the NWDA was developed using predictive modelling methods. The indicative-level computer-based numerical modelling methods were performed within a groundwater model domain area defined adequately represent the NWDA. The model domain was designed to extend beyond the predicted area of groundwater impact likely to be associated with the operation of the NWDA CSG field.

9.3 The Existing Environment and Environment Values

To describe the groundwater conditions operating in the NWDA Project Area, a conceptual groundwater model (CGM) has been developed, which is based on the CGM presented in the original Project-wide assessment (Golder, 2009b).

The CGM provides a summary of information about the nature and extent of geological layers comprising the subsurface of:

- aquifers, aquitards and aquicludes - their characteristics and interactions between each other;
- groundwater flow – both regionally and locally, and in the plain of the bedding and inter-formation flow;
- geological and man-made influences on the groundwater systems – including structural affects and those resulting from groundwater extraction; and
- water quality.

On this basis, the groundwater conditions present in the NWDA have been distinguished into six hydrogeological units:

- **Quaternary Alluvium:** This unit comprises the most recent Quaternary and Tertiary unconfined alluvium aquifers. The alluvials occur as a thin veneer of unconsolidated sediments and host useful aquifers, and, hence are a resource for various water supply uses.

- **The Shallow Unit**: In the NWDA, the shallow unit is comprised of the most recent Quaternary and Tertiary unconfined aquifers and the underlying Upper Cretaceous aquifers of the GAB, primarily the Wallumbilla Formation, where present. The Wallumbilla Formation is considered a confining unit elsewhere in the GAB.

- **The Intermediate Unit**: This unit includes major sandstone aquifers units which lie above the Walloon Coal Measures (with the exception of the Springbok Sandstone). The intermediate aquifers are confined to unconfined and subartesian in the Project Area and include the Mooga and Gubberamunda Sandstones - which outcrop across QGC's NWDA tenements and are both reasonably important aquifers in the NWDA.

- **The Walloon Unit**: This unit includes the whole thickness of the Walloon Coal Measures (WCM) and includes the Springbok Formation. 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. Recharge to the Springbok occurs in the North and East sections of the Surat Basin, including portions of the NWDA. From local knowledge, the Springbok aquifer is known to be locally contributing to water flows derived from the upper WCM beds. Although few measurements of electrical conductivity values are available in the Springbok formation, available values are similar to those observed within the WCM. Although the WCM are considered to be an aquitard sequence, the coal seams within this formation are considered to be aquifers and are able to transmit water more readily than the interburden layers (AGE 2007)

- **Hutton Sandstone:** This unit comprises the Hutton Sandstone, which is the second major Jurassic aged aquifer in the GAB. The recharge area of the Hutton Sandstone lies within the north and east margins of the Surat Basin (north and north-west of the NWDA). The aquifer is subartesian in the Project Area.

- **Precipice Sandstone**: This unit typically forms the basal Jurassic artesian aquifer in the Surat Basin. Recharge to the Precipice Sandstone occurs from outcrop to the north of the study area (north and north-west of the NWDA).

Analysis of the DERM groundwater database in combination with the data provided by QGC has indicated that across the Project Area:

- Groundwater pressures (levels) in the Intermediate to Hutton Sandstone Units generally range between 180 m and 300 m AHD within the tenements areas. Groundwater flow is typically down the geological dip or the geological layers. Low groundwater gradients exist between adjacent aquifers, with a typical downward direction of groundwater flow;
- Groundwater quality is typically fresh to brackish. Generally, the WCM is of equal or higher salinity than other formations. Previous studies have referred to a likely hydraulic connection between the Walloon Coal Measures and the underlying Hutton Sandstone, in the area of QGC's CDA tenements situated to the east of the NWDA, inferring that there may be mixing processes occurring between the formations (AGE 2007, PB 2004), which may, potentially, also affect the NWDA aquifer systems.

9.4 Water Use

Water use within the NWDA is widespread, and is occurring from almost all aquifers. Primarily, the water is used for stock and domestic purposes. It is likely that demand for water for these uses will increase over time. Many of the groundwater management units are already over abstracted or approaching sustainable abstraction levels.

Analysis of water production data provided by QGC indicates that:

- CSG water production requirements are rising rapidly
- CSG water production exceeds the remaining allocation in the general reserve from the groundwater management units that contain the Walloon Coal Measures. Production is set to increase over the next 20 years.

9.5 Environmental Values and Potential Impacts on the Environmental Values

There is a wide range of uses for water in the Study Area and multiple environmental values to the Project.

Potential impacts to the groundwater system, related environmental values, neighbouring users, and the ecosystem have been examined. The assessments have involved the development of a regional conceptual groundwater model, supplemented by the development and application of an idealised numerical groundwater model of the region. The predictive model was then used to estimate, at 'order of magnitude' level of accuracy, the potential drawdowns which the aquifers in the region might experience, arising from the QGC CSG operations.

Accommodating the additional tenements, PL171 and ATP768, into the predictive modelling does not significantly change the magnitude of predicted impacts within the NWDA due to QGC CSG operations, as is summarised in the following test:

General Comments on Predicted Impacts

Groundwater drawdown impacts, within the 5 key aquifer units identified as vulnerable (the Precipice, Hutton, Springbok and Gubberamunda sandstone and the WCM), can be summarised as follows (with specific comments for each development area following):

- Drawdown declines with distance from the CSG wellfield boundaries;
- Drawdown declines gradually after cessation of the CSG groundwater pumping;

- Drawdown is greatest beneath the depressurisation area (idealised representation of the CSG wellfield areas, i.e. the area bounded by the tenement boundaries);

- The modelled potential maximum parameter set (high end hydraulic conductivity, storage and lowest K_v/K_h ratio simulations) is typically associated with the maximum predicted drawdown and the modelled potential minimum parameter dataset is associated with the minimum predicted drawdown;

Predicted Aquifer Impacts

WCM

- Estimated drawdown in the WCM was as defined by the final model depressurisation pressure head (approximately 70m above the top of the WCM), which at the extraction area boundary equates to the maximum specified drawdown to achieve optimal CSG desorption;

- Recovery of the aquifer is predicted to commence immediately, but very gradually, after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years);

Springbok Aquifer

- Water level impacts are predicted to be greatest within the Springbok Sandstone aquifer largely because it has been modelled as being in good but patchy hydraulic contact with the WCM units - which are being depressurised for CSG recovery (i.e. no laterally extensive aquitard layer separates the Springbok Sandstone aquifer from the WCM unit);

- Specifically, drawdown in the Springbok Sandstone (Figure B-3, Appendix B) is predicted to range from less than 0.5 m to an expected maximum of approximately 2 m immediately outside of the depressurisation area boundary, i.e. the boundary of the tenements (for convenience this is defined in the model as 1.8km from the edge of the depressurisation zone);

- At a nominal distance of 10 km and 20 km from the depressurisation boundary, drawdown impacts are likely to reach a potential maximum of 0.4m and 0.1m, respectively;

- Recovery of the aquifer is predicted to commence 75 years after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years, being 40 years of operation plus 150 years of modelled recovery);

- The predicted maximum drawdown in the Springbok Sandstone in the NWDA is less than the CDA and SEDA. This is because the NWDA is deeper (tighter fracture permeability) and is significantly less structurally affected than the other development areas (Section 4.4.4);

Hutton and Precipice Aquifers

- The predicted maximum drawdown in the Hutton Sandstone and the Precipice Sandstone aquifers is insignificant, being predicted to be less than approximately 0.1m during the 190 years of CSG pumping and recovery (Figure B-3, Appendix B).

- Recovery of the aquifer is not predicted to have started within the 190 years of modelling;

- The magnitude of modelled maximum drawdown (and its recovery), at the levels predicted, are not considered discernable within the natural fluctuation of the deep groundwater systems operating in these aquifers;

Gubberamunda Aquifer

- The Gubberamunda aquifer is least affected by extraction of groundwater from the WCM, with predicted drawdowns being modelled as negligible (or not within the resolution of the model) – largely due to the large intervening thickness of aquitard layers.

The predicted drawdowns for the Springbok Sandstone, Hutton Sandstone and Precipice Sandstone are presented in Figures B-3 and B-4 (Appendix B).;

Other conclusions reached include:

- The risk of inter-aquifer flows arising from bore design or poor bore construction techniques is very low.
- It has been estimated that there will be a low potential impact on water levels in the local unconfined aquifers and underlying "Intermediate" aquifers. Nevertheless, close monitoring of this hydrogeological domain is recommended so as to develop an understanding of the relationship between rainfall, runoff and recharge to the aquifer and hence separate the potential impacts of future drought from those associated with the CSG operations.
- Trigger levels have been established for each of the key hydrogeological units (aquifers) considered likely to be impacted. If groundwater levels/pressures were to reach these trigger levels, provisions might be activated (e.g. more intensive monitoring, detailed hydrogeological assessment, and if CSG extraction impacts are deemed to be the cause, to "*make good*" any affected groundwater supplies (if any exist within the impacted area).
- Water quality changes have been determined to be less likely in the aquifers described in this impact assessment (the groundwater quality regionally and between aquifers has been found to be sufficiently similar). If significant groundwater migration does occur due to inter-formational flow induced by CSG depressurisation of the WCM, significant changes in aquifer water quality within aquifers being used by neighbours is considered to have a low probability of occurrence.
- Owing to the generally low to insignificant impacts expected on the water table aquifers (shallow alluvial aquifers) in the Study Area, any measurable impact on the baseflow to the local river systems is unlikely to occur.

Cumulative Impacts from Adjacent Projects

While the model provides a reasonable representation of aquifer behaviour in the NWDA region, it does not directly take into account the cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these activities are not currently known, and as such, have been treated here in a qualitative manner based on the inferred impacts presented by the proponents for each project.

- The proposed *Wandoan Coal Project* (WCP) is likely to draw down local water levels by between some 40m and 60m (within their tenement and common tenement areas held by QGC). Further, this dewatering effect will induce a limited halo of drawdown outside their tenement and, again, this will impact QGC tenure areas locally. Golder consider that this affect will be largely indistinguishable from the CSG extraction when considered in relation to the impacts of the key aquifers (where present);
- *UCG operations, such as those proposed by Cougar Energy* and potentially *Cockatoo Mining Limited,* target coal seams at deeper depth than the proposed WCP open pit depth, and may impact groundwater levels at common tenement boundaries. NOTE: UCG operations typically do not drawdown water levels within the target aquifer/s (in this case the Macalister Seam) to quite the same degree as required for CSG extraction (no specific information of these impacts is available at this time); and
- Again, only ongoing monitoring will provide concrete evidence of these hypotheses (refer to Section 9.5.1, and to the Groundwater Monitoring Plan, Golder, 2009d)

In summary, the predictive groundwater modelling suggests that there is a low to moderate risk to the local environment values (particularly neighbouring groundwater users and/or the ecosystems) likely to ensue from the development and future operation of the proposed QGC CSG wellfields in the NWDA.

9.5.1 Monitoring and Mitigation

Sections 5.0 and 7.0 provided detail regarding the potential impacts resulting from groundwater extraction and depressurisation of GAB aquifers associated with the proposed NWDA CSG activities. Of the impacts presented, the following are identified as posing *key risks* to the Project and, as such, are those which may require monitoring, management and mitigation as part of the Project's water management strategy:

- reduced access to groundwater entitlements;
- reduced discharge to groundwater dependent ecosystems;
- aquifer compaction and land subsidence; and
- the management of associated water (including injection, treatment, beneficial use and disposal).

All other risks will be managed using a combination of industry best-standard preventative measures (compliant with the pertinent legislative framework described in the original Project-wide groundwater assessment (Golder 2009b)) to reduce the likelihood of the other key risks occurring, implementation of a robust monitoring program to facilitate early identification of the onset and development of impacts, and make good options to assist those affected by the proposed CSG operations in the NWDA, as required.

The only realistic defence against potential impacts to groundwater resources associated with coal seam depressurisation is a robust monitoring program to evaluate changes to water quality and quantity in the vicinity of NWDA CSG operations and relevant environmental values. Whilst this approach does not mitigate against impacts to groundwater resources occurring as a result of CSG operations, it does provide a mechanism for early identification of potential impacts, such that contingency actions, if warranted, can be implemented in a timely manner.

QGC have recently developed and submitted a groundwater monitoring plan to DERM (Golder 2009d). The monitoring programs should be implemented as soon as possible, so as to establish baseline conditions for the region. A second round of monitoring was completed on a subset of the bores visited as part of the original bore inventory (Golder 2009c). The results were incorporated to aid in the development of the groundwater monitoring plan (GWMP, Golder 2009c) and will be used as baseline data for the assessment of future monitoring and management needs. The results will also be presented as part of the *Underground Water Impact Report* [in preparation] and 2009 *Annual Return*, as required under the P&G Act.

In the event that monitoring results indicate that a bore owner has been 'unduly impacted' by CSG operations in the NWDA 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 "make good" actions will be considered in conjunction with the bore owner and regulatory authorities, in order of preference:

- 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; or
- providing 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).

10.0 RECOMMENDATIONS

10.1 Data Management

Although considerable effort was invested in validating the data supplied by the client or other external sources (i.e. DERM), in some instances the reliability of the data provided was still questionable. Golder recommends a systematic control on source data quality and consistency, which would address certain data-constraints on the interpretations presented in this report.

This groundwater monitoring plan (Golder 2009d) highlights the need for a data management system to be put in place. Data collected from the monitoring program(s), should be integrated with the CSG production datasets and preferably stored in one relational database designed for the storage and retrieval of water and environmental data. Microsoft EXCEL spreadsheet data management is not recommended for this purpose. It is expected that managing, updating the database and answering requests would be a full time role. There is a need to nominate a staff member to be the coordinator of the database/data management tool.

10.2 Groundwater Monitoring Plan

QGC have recently developed and submitted a groundwater monitoring plan to DERM (Golder 2009d). The monitoring of groundwater is covered by three monitoring programs:

- a regional groundwater monitoring program addressing all the shallow, intermediate and deep groundwater aquifers, including all the GAB aquifers;
- a shallow groundwater monitoring program addressing the subsurface and shallow unconfined aquifers around QGC infrastructure and operations; and
- a monitoring plan specific to the pilot groundwater injection schemes, currently being developed by QGC.

The monitoring strategy incorporates the following major components:

- the regulatory requirements (general CSG regulation and QGC Environmental Authorities);
- the result of the risk analysis with higher frequency monitoring recommended for higher risks activities/locations;
- the information from the bore inventory;
- trigger levels, as defined in Golder (2009b); and
- an operational optimisation approach (incorporating QGC existing groundwater monitoring).

Details as to the technical aspects of the groundwater monitoring programs (the monitoring locations, the frequency of monitoring and the parameters monitored), reporting agenda, and analytical suites can be referred to in the GWMP (Golder 2009d). The programs should be implemented as soon as possible so as to collect and regularly provide opportunity to review data on the groundwater system and the interaction of the climate, groundwater users and CSG operations with the groundwater system.

10.3 Further Groundwater Modelling

It is not recommended that any further groundwater modelling be performed *until* a substantially improved groundwater database is available to assist in refining and calibrating the model.

Potentially after between two and five years when quality data has been collected, the groundwater models developed for this study, and the related *“QGC Groundwater Study Surat Basin, Queensland” (087633050 016 R Rev2, June 2009b),* should be updated and adapted to provide a more realistic representation of the regional hydrogeology. At this time, there should be a far greater understanding of the likely water production rates for current and proposed wellfield developments.

An updated groundwater model would potentially prove useful in developing long term water monitoring and management plans for the future CSG operations. Since the modelling study carried out for this report did not incorporate the impacts of other neighbouring CSG producers, future modelling efforts must include their impacts, as well as, refined inputs of hydrogeological parameters, recharge and surface water interaction.

Idealistically, it would be preferred that any future modelling effort be rather done as an industry-wide effort, and in collaboration with the regulators (DERM and EPA).

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Report Signature Page

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APPENDIX A

Scope of Works

QGC
A BG Group business

Groundwater Impact Assessment Study for Supplementary Environmental Impact Statement

Scope of Work for External Consultancy Services

QCLNG-BB00-ENV-WSC-00006

Rev 0

August 2009

Uncontrolled when printed

QCLNG PROJECT

DOCUMENT INFORMATION SHEET

TITLE: **Scope of Work for External Consultant Services**

PURPOSE AND SCOPE:

To provide a scope of work for use by external contractors to prepare an environmental impact assessment for the Supplementary Environmental Impact Statement.

DOCUMENT VERIFICATION

Responsible:

Signature:	**Position:** Project EIS Coordinator
Name: Richard Oldham	**Date:** : 17-08-2009

Accountable:

Signature:	**Position:** Manager – Environmental Approvals
Name: **Margaret Harris**	**Date:** 25 08 · 09

Consulted:

Enter name/position of those who have reviewed the document

Steve Fox	John Grounds
David Ord	Murray Brims
Paul Wright	John Baker

Informed

All

Endorsed:

Signature	**Position:** President, Upstream Projects
Name: **John Stubbs**	**Date:** 25-8-09

RACIE Terms

R	**Responsible:**	the person who actually produces the document
A	**Accountable:**	the person who has to answer for the success or failure of the quality and timeliness of the document
C	**Consulted:**	those who must be consulted before the document is published
I	**Informed:**	those who must be informed after the document is published
E	**Endorsed:**	the person who must approve the document before publication

Revision Record

Issue	Date	Reason for Issue	Responsible	Accountable
A	17/08/09	Issue for Squad Check	Richard Oldham	Margaret Harris
0	24/08/09	Issued for use	Richard Oldham	Margaret Harris

Table of Contents

1.0 INTRODUCTION

QGC - a BG Group Business (referred to as "the Proponent"), is proposing to develop an integrated Liquefied Natural Gas (LNG) project in Queensland, Australia, hereafter referred to as the QCLNG Project. The QCLNG Project involves the extraction of coal seam gas (CSG) from deep coal beds in the Surat Basin in South East Queensland from which liquefied natural gas (LNG) will be produced for export from a port in Gladstone. In extracting CSG substantial quantities of associated water must also be extracted.

QGC has initiated the environmental impact assessment procedures of the Queensland State Development and Public Works Organisation (SDPWO) Act 1971 for the development of gas fields in the Surat Basin, the construction of a 380km gas transmission pipeline (and other associated pipelines) and the construction of a Liquefied Natural Gas (LNG) plant and export terminal near Gladstone.

The Gas Field component of QCLNG covers the extraction of gas from QGC's petroleum tenures in the Surat Basin, to provide gas for the LNG plant. Over the minimum 20-year life of the Project, this development will comprise:

- approximately 6000 wells for 2 LNG trains;
- well surface equipment;
- gas and water gathering systems;
- gas processing and compression infrastructure; and
- water treatment and beneficial use of associated water.

The Project has been declared a "significant project", for which an Environmental Impact Statement (EIS) will be required. The draft EIS will be submitted in August 2009 and will be available for public comment for approximately 6 to 8 weeks. The Proponent will respond to all submissions on the draft EIS through the preparation of a Supplementary EIS.

This Scope of Work is for the activities required to:

- review any changes to the project description as presented in the draft EIS and
    - identify the environmental values that may be impacted by air emissions from the construction and operation of the Gas Fields;
    - quantify the potential environmental impacts on the environmental values;
    - provide mitigation measures to minimise impacts on environmental values; and
- respond to queries raised during the public consultation period.

1.1 Scope of Document

To provide a scope of work for use by an external consultant for the provision of specialist services to assist and advise QGC in the preparation of a Supplementary EIS for the QCLNG Project.

1.2 Document Revisions and Approval

This document has been prepared by the Project EIS Coordinator and shall be reviewed and endorsed in accordance with the Project RACIE Matrix.

This document bears a revision status identifier which will change with each revision. All revisions to this document (after approval and distribution) will be subject to review and endorsement by the same functions as the original.

1.3 Distribution and Intended Audience

This document is intended for QCLNG Upstream Project Team members as well as other QCLNG Project stakeholders and contractors. The document will be made available on the project portal. This document will be updated during subsequent project lifecycle stages and changes communicated to the project team as applicable utilising the Management of Change Procedure.

1.4 Definitions

In this document, the following definitions apply:

Term	Meaning
ADDITIONAL TENEMENTS	QGC's petroleum tenements not included in the Previous Report
COMPANY	BG Group or a wholly owned subsidiary company or other client organisation
CONTRACTOR	The person, firm or company undertaking to supply services, plant, or equipment to which this document applies
SHALL	A mandatory term - no dispensation is permitted without written approval using the formal dispensation procedure
GROUP TECHNICAL AUTHORITY	The manager or principal discipline engineer responsible for producing and maintaining a given Standard / Guideline Review and either approve or reject Dispensation Requests made against BG Standards by Asset / Project
PREVIOUS REPORT	**June 2009** **COAL SEAM GAS FIELD COMPONENT FOR ENVIRONMENTAL IMPACT STATEMENT** **QGC Groundwater Study Surat Basin, Queensland** **Report Number:** 087633050 016 R Rev2 Prepared by Golder Associates
PROPONENT	QGC – A BG Group Business
GAS FIELDS	Those petroleum tenements owned by QGC that form part of the QCLNG Project

1.5 Acronyms and Abbreviations

In this document, the following acronyms and abbreviations apply:

Acronym/Abbreviation	Meaning

Acronym/Abbreviation	Meaning
AS	Australian Standard
AUS$	Australian Dollar
BG	British Gas
CPP	Central Processing Plant
CSG	Coal seam gas
DERM	Department of Environment and Resource Management
FCS	Field Compressor Station
LNG	Liquefied Natural Gas
QCLNG	Queensland Curtis LNG Project
Qld	Queensland
SDPWO Act	State Development and Public Works Organisation Act 1971
TOR	Terms of Reference
WTP	Water Treatment Plant

1.6 Referenced / Associated Documents

Ref.	Document Number	Title/Description
	BGA-BGA-GEN-GL-0002	Reference List of Codes and Standards

1.7 Responsibilities

Without limitation, the codes and standards listed in 1.6 (Referenced / Associated Documents) shall apply.

The contractor shall advise QGC if there are any other relevant International, National, State and/or local Regulations, Acts, Practices and Legislation that should form the criteria for the Project. The most current version of these documents shall be applicable.

All subsequent deviations from these Regulations, Acts, Industry Practices and Legislation shall be submitted, in writing, to the nominated QGC representative in accordance with the Management of Change Procedure. The deviation/s shall be assessed by the relevant QGC representative/s and if approved, the contractor will be notified in writing and the relevant documentation will be amended to reflect the change.

The contractor shall recommend any additional applicable Codes and Standards that should form part of the criteria for the Project.

The contractor shall advise QGC if there are any other relevant Best Practices currently known to them that should form part of the criteria for the Project.

1.8 Order of Precedence

Australian Standards shall be applied as the first priority.

Should an Australian Standard be unavailable the contractor shall apply one of the approved standards listed within the Reference List of Codes and Standards document number BGA-BGA-GEN-GL-0002.

Any deviation from the BG Reference List of Codes and Standards shall be submitted, in writing, to the nominated QGC representative in accordance with the Management of Change Procedure. The deviation/s shall be assessed by the relevant QGC representative/s and if approved, the contractor will be notified in writing and the relevant documentation will be amended to reflect the change.

2.0 PURPOSE

The purpose of this Scope of Work is to define the activities required to be carried out by an external consultant to assist QGC in preparing the Supplementary EIS for the QCLNG Project. Information presented by the consultant will inform the Supplementary EIS and hence regulatory approvals and environmental conditions for the QCLNG Project.

The project petroleum tenements included in the groundwater impact assessment for the Gas Fields, as presented in the Previous Report, have been expanded. The Proponent expects that the inclusion of additional tenements will require additional environmental impact studies to be conducted in response to public submissions. The Proponent has decided to conduct additional environmental impact assessments prior to the end of the submission period and may require responses to meet the issues raised in the public submission period.

3.0 OBJECTIVES

The objective of this Scope of Work is to understand the impacts of associated water extraction on environmental values associated with groundwater in the vicinity of tenements additional to those in the Previous Report, and means to mitigate impacts.

The objectives of the activities defined in this Scope of Work include:

1) Definition of work activities for use in the establishment of activity timeframes, a work schedule and a cost estimate for budget purposes.
2) Preparation of a report on the impacts of associated water extraction in Additional Tenements on groundwater levels and quality that have not been impact assessed in the Previous Report.
3) Preparation of a report that identifies methods (that have not been identified in the Previous Report) to mitigate impacts on groundwater to acceptable levels.
4) Provide technical responses in relation to matters raised in public submissions during draft EIS consultation.

4.0 IMPLEMENTATION STRATEGY

The consultant is required to provide a technical report that utilises the information from the Previous Report to identify the environment values of Additional Tenements, the potential impacts of the project on those values and the recommended management measures to minimise adverse impacts.

The report shall draw on the Previous Report, but focus on providing information about the impacts of groundwater extraction in Additional Tenements. The report should include, as a minimum:

- Executive summary, set out in two parts:

  - Environmental values of the Additional Tenements; and
  - Potential impacts and mitigation measures.
- Description of standard methodology used;
- Summary of the desktop studies undertaken;
- Description of the hydrogeology of the Additional Tenements;
- Environmental values of the area;
- Potential impacts of the proposal on the environmental values being studied;
- Interpretation of the groundwater impact assessment in relation to Gas Field development activities including impacts on shallow aquifers, other aquifers utilised by third parties and groundwater dependent ecosystems;
- Mitigation measures to minimise adverse impacts;
- Environmental protection objectives for enhancing or protecting each environmental value, including proposed indicators to be monitored;
- Potential groundwater monitoring parameters, points and frequency recommendations;
- Additional supporting information in appendices and in electronic form (e.g. results of database searches);
- Cumulative impacts from other potential sources of impacts on groundwater in the vicinity of the tenements being assessed (e.g. Wandoan Coal Mine);
- Technical Responses to public submissions during consultation; and
- Identify any additional regulatory approvals, related to groundwater, that may be required.

5.0 SCOPE OF WORK

Proposals are sought to carry out studies to assess the impacts on groundwater from extraction of associated water in the Additional Tenements. These tenements include ATP 768 and PL171 and any other tenements to be advised by the Proponent. Annex B includes a figure of the tenements to be assessed and should be compared to the tenements assessed in the Previous Report to determine the Additional Tenements. Impacts on groundwater in tenements addressed in the Previous Report should not be considered in this proposal, except from a cumulative perspective.

This section sets out the requirements for the studies to support the environmental assessment. The studies will be required to address the ToR (refer Annex A) and the following requirements.

- The groundwater impact assessment will include an evaluation of impacts in the vicinity of the Additional Tenements,

- The assessment will identify potential impacts to groundwater levels and quality in shallow aquifers, other aquifers utilised by third parties and groundwater dependent ecosystems in the vicinity of the Additional Tenements.

- The consultant will provide a qualitative assessment based on desktop studies and information and modelling utilised for the Previous Report;

- The consultant should provide feedback, where necessary, regarding areas that would be constrained with respect to locating CSG wells and hence extracting associated water.

- The assessment will consider potential impacts on groundwater levels and quality from other major mining projects in the vicinity of the Additional Tenements, such as the Wandoan Coal Project (http://www.dip.qld.gov.au/projects/mining-and-mineral-processing/coal/wandoan-coal-project.html)

- The consultant shall propose a monitoring programme for the Additional Tenements to detect impacts on groundwater levels and quality from QGC's extraction of associated water.

5.1 Proposal

The proposal should comply with the Terms of Reference for the Project, with an extract of the section applicable to groundwater as Annex A, and be based on the work as set out in this section. The work is to be undertaken on a time and expense basis with an upper cost estimate.

The proposal shall contain the following information as a minimum:

1. Tasks that in your professional opinion you believe are required to address the topic in sufficient detail to meet the anticipated level of assessment under a SDPWO Act EIS.

2. Names and resumes (no more than 1 page each) of proposed personnel, if not supplied previously.

3. Hourly and day rates (excluding GST) for all staff to be involved in the work.

4. Schedule illustrating how the work will be undertaken to enable completion of the draft report by 25 September 2009 and final report by 16 October 2009.

5. Breakdown of the tasks/hours/personnel/costs for:

   Desktop studies
   Fieldwork (should not be required but a day rate for fieldwork should be presented)
   Report Writing
   Project Management
   Quality Control
   Administration Tasks (e.g. printing, binding).

6. Timing and availability.

7. Clear definition and format (in as much detail as possible) of the information required to commence and complete the defined scope of work.

5.2 Scheduling of Services

It is anticipated that desktop work and qualitative impact assessment can be undertaken in August and September 2009.

The Draft technical report to support the Supplementary EIS is to be submitted by 25 September 2009.

The Final technical report to support the Supplementary EIS is to be submitted by 16 October 2009.

Reports are to be provided as:

- 1 soft copy of each draft;
- 1 soft copy of each final report; and
- 1 hard copy of the final report.

A soft copy version in Microsoft Word of the draft and final report shall be provided to assist in the preparation of the Supplementary EIS. A full portable data file (pdf) version of the final report is also required. Digital files of all illustrations, maps and/or diagrams shall also be provided.

5.3 GIS

Consultants are advised that the Project will populate a single GIS data base. Accordingly consultants will be supplied with mapping and digital data to assist their studies as required. Consultants will be required to provide all spatial data (layers and maps) in MapInfo Professional (version 8.5 or higher) format with metadata supplied for each table (if available) as per the Australian New Zealand Land Information Council (ANZLIC) Core Metadata Elements Version 2 (http://www.anzlic.org.au/asdi/metaelem.htm) to enable a standard set of maps to be produced for the documentation. For each layer supplied the following information shall be provided (number of fields, number of data records, field number, field name, type, width and description) along with definitions for any codes in the attributes. The datum/projection for all data is Latitude/Longitude (GDA94).

The purchase of any special data required for the studies shall be purchased/licensed by QGC and made available to the consultant for use in this assignment.

5.4 Project Management

The proponent requires fortnightly reporting against:

- Activities completed in the fortnight;
- Activities for the next fortnight;
- Progress against schedule;
- Any key issues, such as anticipated delays, problems, issues highlighted and any mitigation measures provided to deal with said issues; and
- Budget utilised (percentage).

The report should be approximately one page and be in dot point format. If additional information is required, the proponent will contact the consultant to clarify.

The consultant should nominate a point of contact for the project;

If fieldwork were found to be required the consultant would also be required to comply with

- all QGC Health, Safety and Security Requirements;
- All QGC land access requirements. At no time is private property to be entered without owner awareness and prior consent.

5.5 Invoices

Invoices are to be issued to QGC on a monthly basis, based on work completed. Receipts are to be attached to support all claims for disbursements.

5.6 Information to be supplied by Proponent

Where relevant, the following documentation will be supplied to the consultant. This information is to be used for the preparation of the specialist studies for this project, and not for any other project.

- Terms of Reference;
- Area and tenement maps;
- Aerial photography (where required to assist with investigations and report preparation);
- Existing groundwater modelling reports for the tenements (where not already held by the consultant).

Annex A – Extract from the ToR

3.4 Water resources

3.4.1 Surface waterways and groundwater

Description of environmental values

The section of the EIS should provide a description of the existing environment for water resources that may be affected by the project in the context of environmental values as defined in such documents as the EP Act 1994, ANZECC/ARMCANZ (2000) National Water Quality Management Strategy Paper 4:, Australian Water Quality Guidelines for Fresh and Marine Waters and the Queensland DERM (2006) Queensland Water Quality Guidelines (March 2006).

This section should also encompass non-riverine (palustrine and lacustrine) wetlands, utilising the DERM's Queensland Wetlands Programme maps for the location and classification of both riverine and non-riverine wetlands. This can be accessed at Wetland*Info* www.epa.qld.gov.au/wetlandinfo.

An indication should be provided of the quality and quantity of water resources in the vicinity of the project area. This section should describe:
- existing surface and groundwater in terms of physical, chemical and biological characteristics;
- existing surface drainage patterns, ephemeral water systems, permanent and episodic wetlands, overland flows, history of flooding including extent, levels and frequency and present water uses;
- environmental values of the surface waterways of the affected area in terms of:
  - values identified in the EPP (Water)
  - physical integrity, fluvial processes and morphology of watercourses, including riparian zone vegetation and form
  - hydrology of waterways and groundwater, in particular the interconnectiveness of surface water and aquifers to adjoining features
  - existing and other potential (where details have been provided to QGC by the DIP or are otherwise published) surface and groundwater users and holders of Quarry Material Allocation Notices in the Project area
  - any Water Resource Plans and Resource Operations Plans relevant to the affected catchments.

The likely impact of the project on local and regional groundwater sources should be assessed. This section should provide a description of groundwater resources in the area in terms of:
- geology/stratigraphy
- Water Resource Plans and Resource Operation Plans relevant to the affected catchments
- aquifer type - such as confined, unconfined
- depth to and thickness of the aquifers
- process for assessing and monitoring impacts on alluvial aquifers to qualify water levels and salt concentrations
- depth to water level and seasonal changes in levels, if possible
- groundwater flow directions (defined from water level contours)
- interaction with surface water to the greatest extent possible using existing information
- possible sources of recharge
- vulnerability to pollution.

The environmental values of the groundwater of the affected areas should be described in terms of:
- values identified in the EPP (Water)
- sustainability, including both quality and quantity
- physical integrity, fluvial processes and morphology of groundwater resources.

Potential impacts and mitigation methods

This section should assess potential impacts of the project on water resource environmental values identified in the previous section. It should also define and describe the objectives and practical measures for protecting or enhancing water resource environmental values, to describe how nominated quantitative standards and indicators may be achieved, and how the achievement of the objectives will be monitored, assessed and managed.

Matters to be addressed should include:
- the potential impacts of managing associated water, particularly from current and future proposed activities including – beneficial uses of treated or untreated water, discharge to grade with or without treatment, direct injection and injection of brine from RO plants
- the potential impacts the proposed project may have on the flow and the quality of surface and ground waters from all phases of the project, with particular reference to their suitability for the current and potential downstream uses and discharge licences
- potential regional impacts of groundwater extraction should be assessed, document and monitored
- potential impacts on springs and base flows as a result of lower potentiometric heads in the target coal seams and adjacent aquifers
- the potential impacts of surface water flow on existing infrastructure, with reference to the EPP (Water) and the *Water Act 2000*
- chemical and physical properties of any waste water including stormwater at the point of discharge into natural surface waters, including the potential effects of effluent to flora and fauna
- potential impacts (e.g. salt distribution) on other relevant downstream creeks, if it is proposed to discharge water to the creek system
- risk and potential spread of pest and disease in aquatic and riparian areas associated with discharge into the creek system (e.g. aquatic weeds, feral fish species and parthenium in stream bed/banks)
- the results of a risk assessment for uncontrolled releases to water due to system or catastrophic failure, implications of such releases for human health and natural ecosystems, and list strategies to prevent, minimise and contain impacts
- an assessment of the potential to contaminate groundwater resources and measures to prevent, mitigate and remediate such contamination
- details of any watercourse crossings and rehabilitation methods.

In relation to water supply, usage and wastewater disposal, the EIS should assess:
- anticipated flows of water to and from the project areas
- the effects of predictable climatic extremes (droughts, floods) upon the structural integrity of containment walls where dams, weirs or ponds are proposed
- quality of water contained in dams
- the need or otherwise for licensing any dams (including referable dams) or other works/activities, under the *Water Act 2000*
- The engineering design standards required for containment structures to ensure that they are fit for purpose and achieve best practice in design, construction, operation and decommissioning.

The impact assessment should define the extent of the area within which groundwater resources are likely to be affected by the proposed operations and the significance of the proposal to groundwater depletion or recharge, and propose management options available to monitor and mitigate these effects. The response of the groundwater resource to the progression and finally cessation of the proposal should be described.

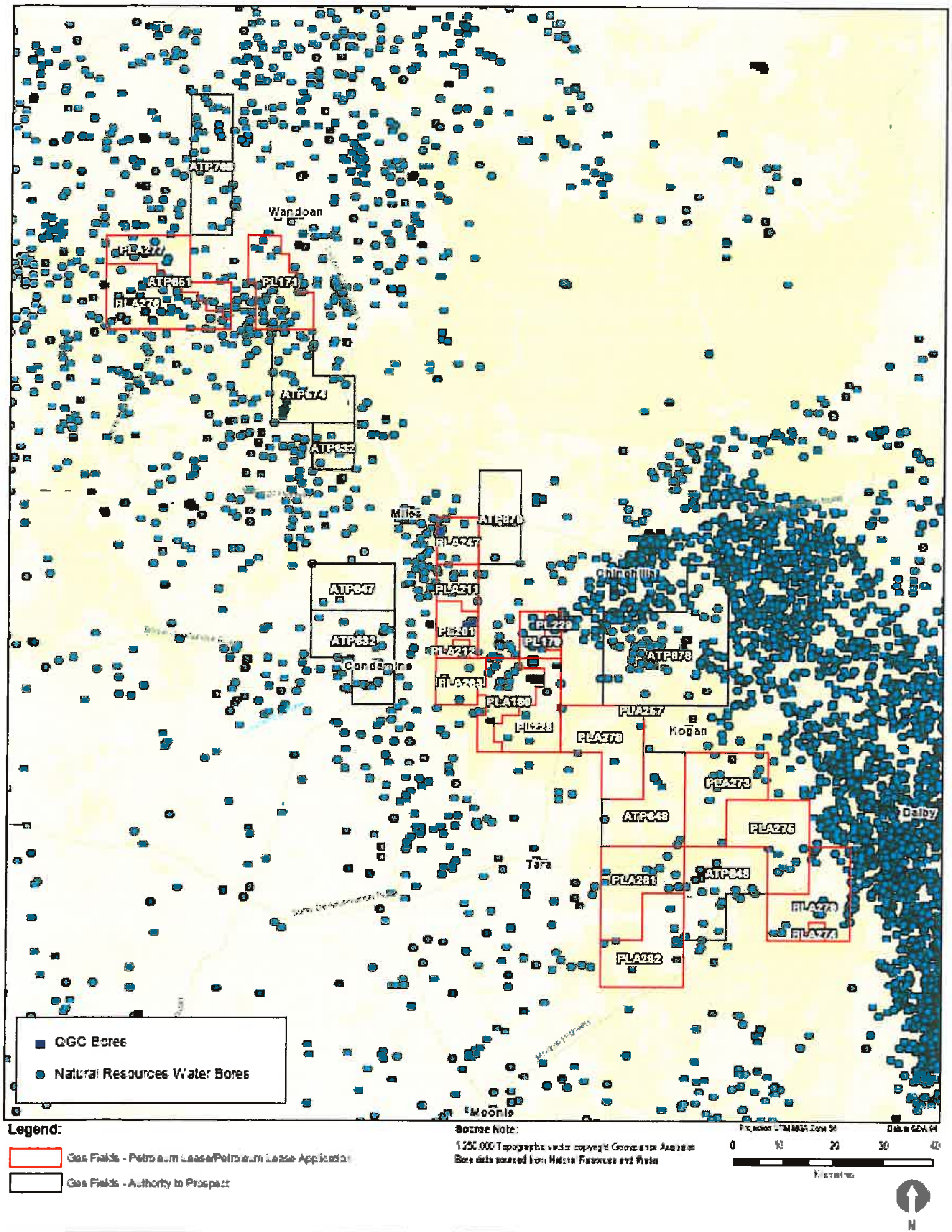
An assessment should be undertaken of the impact of the proposal on the local ground water regime caused by the altered porosity and permeability of any land disturbance.

An assessment of the potential to contaminate groundwater resources and measures to prevent, mitigate and remediate such contamination should be discussed.

The ANZECC/ARMCANZ (2000) National Water Quality Management Strategy Paper 4: Australian Water Quality Guidelines for Fresh and Marine Waters and the Queensland DERM (2006) Queensland Water Quality Guidelines (March 2006) may be used as a reference data for evaluating the effects of various levels of contamination, where no local data is available.

Management strategies should be adequately detailed to demonstrate best practice management and that environmental values of receiving waters will be maintained to nominated water quality objectives. Monitoring programs, which will assess the effectiveness of management strategies for protecting water quality during the construction, operation and decommissioning of the project, should be described. GPS referenced site should be established in the CSG fields to measure the quality of potentially impacted surface water and groundwater resources. In the case of groundwater systems, the target aquifer as well as adjacent aquifers will need to be monitored.

Annex B – Tenements Map



QUEENSLAND CURTIS LNG
A BG Group business

ERM
Environmental Resources Management Australia Pty Ltd

Project Queensland Curtis LNG Project

Client QGC - A BG Group business

Title **Groundwater Bores**

Drawn DB
Volume 3
Figure 3.10.2
Approved CDP
File No. Q202-T-MA-00117
Date 27.03.09
Revision A

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ERM does not warrant the accuracy of any such Maps and Figures

APPENDIX B

Groundwater Modelling

1.0 INTRODUCTION

Queensland Gas Company (QGC) plans to increase its coal seam gas (CSG) fields in the Surat Basin, 200 kilometres west of Brisbane, Queensland. The project involves a major expansion of their CSG production wellfield (up to 6,000 production wells are proposed). Golder Associates Pty Ltd (Golder) was commissioned by QGC to examine the effects of this CSG field expansion on the groundwater environment. As part of this impact assessment was to develop a conceptual groundwater from which a numerical hydrogeological model was built. The purpose of the model was primarily to provide indicative level predictions of groundwater impacts which might be a consequence of groundwater extraction required for CSG production.

The predictive modelling work formed part of the ‘Groundwater Assessment Study’ of QGC’s Chinchilla activities (Golder, June 2009). For this study, the model study covered three distinct CSG gasfield development areas, namely:

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

The groundwater impact assessment on the 3 development arising for CSG-groundwater extraction was conducted by using a three *separate* numerical flow models. Indicative impact affects were calculated for a range of likely input parameters, with the results presented for each of the separate models. The methodology employed for the modelling produced a range of potential drawdown effects, expected as drawdown versus time and drawdown versus distance from the model boundaries.

However, QGC has acquired additional tenements (ATP 768 and PL171) within the NWDA. These tenements are additional resources for QGC’s Liquefied Natural Gas Project (QCLNG Project) were not considered in the previous modelling study for the NWDA, therefore the model for the NWDA was re-visited to consider these additional tenements.

The aim of this report is to:

- provide updated input into the risk management strategy being developed for the proposed CSG operations in NWDA
- update groundwater impact predictions for the proposed CSG operations, considering the additional tenements in the NWDA.

1.1 Study Area

The study area encompasses the current QGC development areas in NWDA, and the proposed CSG development areas in the Surat Basin. It is located on the Darling Downs of Queensland, in an area centred on the towns of Wandoan, Miles, Chinchilla, Wallumbilla and Condamine.

1.2 Project objectives

The objectives of the modelling program were to:

- Develop an *idealised* regional groundwater model for each of the development areas, including the NWDA;
- Interpret the conceptual model and the “order of magnitude” results from the numerical groundwater modelling; and to use those results to estimate the *relative* risks of groundwater impacts arising from the current and proposed CSG operations, and for the post-production period of groundwater recovery;
- Present predictions of expected groundwater drawdown and groundwater extraction volumes associated with proposed CSG operations by QGC; and

- Develop recommendations for groundwater management and monitoring associated with the QGC CSG operations.

2.0 MODEL DESCRIPTION

The study area (NWDA) is outlined in the main report (Figure 1). The NWDA is considered geologically and hydrogeologically distinct from the other two development areas (CDA and SEDA), being delineated by inferred and actual structural breaks. The NWDA area was modelled separately and independently from the CDA and SEDA. Therefore, interference effects from the other development areas was not considered in the previous modelling study (Golder 2009b) and were also not considered in this study.

The model was constructed from site specific data provided by QGC and from data obtained from DERM. Where site specific information was not available; published sources of information were utilised. The geological and conceptual groundwater model (CGM), updated as required, formed the basis of the numerical model presented in this report.

MODFLOW was selected as the groundwater model for use in this modelling project. MODFLOW, developed by the United States Geological Survey (USGS), is recognised as an industry standard groundwater flow simulator. The MODFLOW model of the NWDA was processed using Processing MODFLOW for Windows (PMWIN), Version 5.3.0, by Chiang and Kinzelbach. The MODFLOW variant selected within PMWIN was “MODFLOW 96 + INTERFACE TO MT3D96 AND LATER”. The main criteria for selecting MODFLOW as the model software is presented in the previous model report (Golder, 2008).

3.0 AQUIFER CHARACTERISTICS IN THE STUDY AREA

The aquifer characteristics of the study area (hydraulic conductivity, transmissivity, storage, porosity and estimated yield) are presented in Table 1. These characteristics were developed from available literature and are the same as that presented in the previous model report.

Table 1: Aquifer Characteristics in the Study Area

Hydrogeological Unit	Aquifer Name	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day) (1)	Storage(1)	Porosity	Yield (L/s)
Quaternary Aquifers	Shallow Quaternary & Tertiary alluvium (Including the Condamine Alluvium)	Kh - 2.5x10^{-3} to 6x10^{-6} (average 1.8x10^{-4}) (2)	-	-	10 to 30%(3)	0.1 to 100L/s, median 1.3L/s (5)
Shallow Unit	Main Range Volcanics	0.5 to 50 (6)	10 to 1000 (6)	-	-	0.01 to 30 L/s, median 1.7 L/s (5)
	Griman Creek Formation	-	-	-	10 to 30%(3)	3.5L/s (5)
	Wallumbilla Formation	-	50	5x10^{-3}	10 to 30%(3)	
Intermediate Unit	Bungil Formation	-	50	5x10^{-3}	10 to 30%(3)	0.63 to 6.3 L/s (4)
	Mooga Sandstone	-	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	Kh - 0.43 to 0.043 (2)	50	5x10^{-3}	10 to 30%(3)	1.01 to 22 L/s, median of 4.6L/s (3)
	Kumbarilla Beds	-	-	-	-	0.03 L/s to 10 L/s, median at 0.8 L/s (4)
Walloon Unit	Westbourne Formation	-	150	5x10^{-3}	10 to 30%(3)	
	Springbok Sandstone	-	150	5x10^{-4}	10 to 30%(3)	
	Walloon Coal Measures	Kh - 1.4 (7) (median for coal beds)	50	5x10^{-4}	<1% (8)	0.03 L/s to 19 L/s, median at 1.1 L/s (4)
Hutton Unit	Hutton Sandstone	Kh – 0.1 (9)	150	5x10^{-4}	18-26%(10)	0.1 L/s to 600 L/s, median at 1.5 L/s (4)

Hydrogeological Unit	Aquifer Name	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day) (1)	Storage(1)	Porosity	Yield (L/s)
	Evergreen Formation	Kv - 10^{-1} to 10^{-4} (3)	150	$5x10^{-4}$	-	0.6 to 6.5 L/s , median 0.6 L/s (4)
Precipice Unit	Precipice Sandstone	0.1 to 10 (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
Kh hydraulic conductivity in the horizontal (x) direction (or Kx)
Kv hydraulic conductivity in the vertical (z) direction (or Kz)

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: R.A. Freeze, J.A Cherry, 1979, Groundwater
9. Suggested by AGE
10: Provided through previous work in the Surat Basin

4.0 MODEL SETUP

A detailed description of the construction of the model is presented in the previous modelling report (Golder, 2008). The changes to the model to allow consideration of the two additional tenements are documented here.

4.1 Model Domain

To accommodate the additional tenement (Figure 1) recently acquired by QGC as part of the NWDA operations, the location of the modelling scheme was amended[1]. The centrally-located depressurisation zone was moved further 10km NE to be more representative of the currently arrangement of CSG tenements. That is, it was placed over the centre-line of the tenement distribution such that it provided a better representation of the likely CSG gas-field in the NWDA. The model domain of the previously model of the NWDA was however retained.

The previous and updated depressurisation area, together with the model domain, is presented in Figure B-1.

4.2 Model Structure

The model consists 18 layers, with 272 columns and 234 rows. The model dimensions were 144 km long (NW-SE direction) by 120 km wide (NE-SW direction). Within this rectangle, the CSG well field was represented by a central rectangle of 50 km by 10 km, referred to as the depressurisation area, being larger than the likely extent of the CSG development area. The model structure was adjusted as required to account for the change in the location of the depressurisation area.

Layers were assigned in accordance with known aquifer or aquitard units, and their elevations were calculated according to the CGM presented in the main report. The thicknesses of each of these layers were assumed to be constant throughout the model, which is a simplification. The adopted model elevations and adopted model aquifer parameter are discussed in the next section. Layers in the model dip in a southwest direction.

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[1] Amended from that originally presented in *“QGC Groundwater Study Surat Basin, Queensland” (087633050 016 R Rev2, June 2009)*

The model domain comprises the Intermediate, Walloon, Hutton and Precipice aquifer units. The shallow, unconfined aquifers at ground surface are represented by the uppermost layer. This typically represents the Quaternary or Shallow GAB aquifers, where present in the area of the CSG well field development. An impermeable basement was assumed to exist below the Precipice Formation, which is a conservative assumption. Layer 10 and 12 in the model represent the target coal seam members from where CSG extraction will occur.

4.3 Model Parameters

4.3.1 Model Layer Elevations

QGC has recently conducted a series of Drill Stem Tests (DST) in the NWDA. This provided an opportunity to validate the top and bottom elevations of the coal seam measures in the model at the new location of the depressurisation area. Table 2 presents a summary of the results from the DST program and calculated centre of seam. The sub-group referred to as “Lower Juandah” is represented as Layer 10 in the model and sub-group “Taroom” is represented as Layer 12 in the model.

From Table 2, the average tested elevation of the Lower Juandah and Taroom is -202 mAHD and -425 mAHD respectively. The model elevation for the top of Layer 10 (Lower Juandah), at the new location of the depressurisation area, was -218 mAHD and the model elevation of the bottom of Layer 12 (Taroom) was -408 mAHD respectively, therefore the model elevations already in the model were used.

Table 2: Summary of DST Conducted by QGC on Selected Bores

Well	Seam	Coal Subgroup	From (m)	To (m)	Centre of Seam (m)	Surface (mAHD)	Centre of Seam (mAHD)	Av. Centre of Seam (mAHD)	Model Layer
Cam	Argyle	Lower Juandah	553.0	560.3	556.7	322.4	-234.3	-202	Layer 10
Connor	Iona	Lower Juandah	549.0	559.1	554.1	330.5	-223.6		Layer 10
Kathleen	Argyle	Lower Juandah	496.4	521.7	509.1	321.6	-187.4		Layer 10
Mamdal	Iona	Lower Juandah	439.0	455.9	447.4	310.3	-137.2		Layer 10
Mamdal	Argyle	Lower Juandah	457.0	473.9	465.4	310.3	-155.2		Layer 10
Mamdal	Argyle	Lower Juandah	563.0	576.0	569.5	310.2	-259.3		Layer 10
Mamdal	Wambo	Lower Juandah	479.0	488.0	483.5	310.2	-173.3		Layer 10
Ogle Creek	Iona/Argyle	Lower Juandah	518.0	556.0	537.0	330.1	-206.9		Layer 10
Ross	Argyle	Lower Juandah	546.0	556.8	551.4	344.9	-206.5		Layer 10
Woleebee Creek	Lower Mac, Nangram & Wambo	Lower Juandah	490.1	590.8	540.5	381.3	-159.2		Layer 10
Woleebee Creek	Iona/Argyle	Lower Juandah	595.1	668.8	632.0	381.3	-250.7		Layer 10
Woleebee Creek	Argyle	Lower Juandah	604.0	617.6	610.8	367.3	-243.5		Layer 10
Woleebee Creek	Wambo	Lower Juandah	554.0	566.6	560.3	367.3	-193.0		Layer 10
Cam	Condamine	Taroom	721.0	730.8	725.9	322.4	-403.6	-425	Layer 12
Connor	Condamine	Taroom	745.0	756.3	750.7	330.5	-420.2		Layer 12
Kathleen	Bulwer	Taroom	657.9	678.0	668.0	321.6	-346.3		Layer 12
Mamdal	Condamine	Taroom	775.0	785.0	780.0	310.2	-469.8		Layer 12
Ross	Condamine	Taroom	766.0	780.0	773.0	344.9	-428.1		Layer 12
Woleebee Creek	Condamine	Taroom	840.0	856.1	848.0	367.3	-480.7		Layer 12

Table 3 presents the modelled elevations in the depressurisation area of the NWDA and the adopted layer thicknesses, together with the hydrostratigraphic group name, aquifer type (aquifer or aquitard) as well as the respective model layer.

Table 3: Layer Elevations and Thicknesses of NWDA

Layer Number	Description	Modelled Unit	Top	Bot	*Thickness*
1	Aquifer	Unconfined Shallow / Intermediate Unit	350	310	*40*
2	Aquifer	Intermediate Unit	310	270	*40*
3	Aquifer	Intermediate Unit	270	230	*40*
4	Aquifer	Intermediate Unit	230	190	*40*
5	Aquitard	Confining unit	190	150	*40*
6	Aquifer	Intermediate Unit	150	75	*75*
7	Aquitard	Westbourne Formation	75	-105	*180*
8	Aquifer	Springbok	-105	-208	*103*
9	Aquitard	Confining unit	-208	-218	*10*
10	Aquifer	Upper representative Coal Seam	-218	-228	*10*
11	Aquitard	Confining unit	-228	-408	*180*
12	Aquifer	Lower representative Coal Seam	-408	-418	*10*
13	Aquitard	Confining unit	-418	-468	*50*
14	Aquifer	Hutton Sandstone	-468	-543	*75*
15	Aquifer	Hutton Sandstone	-543	-618	*75*
16	Aquifer	Hutton Sandstone	-618	-693	*75*
17	Aquitard	Evergreen Formation	-693	-863	*170*
18	Aquifer	Precipice Formation	-863	-924	*61*

Note: Top is Top Elevation (mAHD); Bot is Bottom Elevation (mAHD). It is noted that Top and Bottom elevations are with respect to the depressurisation area.

Coal seam gas is typically extracted from a number of coal seams in the upper Walloon Coal Measures (WCM), however, gas is also extracted from a few deeper seams, located below the Tangalooma Sandstone within the WCM. The upper WCM coal seams are represented by Layer 10 within the model and the lower seams (Taroom Coal Measures) are represented by Layer 12. The aquitard above the coal seams (Layer 9) represents a thin layer of mudstone, siltstone and coal, as CSG wells are typically screened below the Kogan coal seam. The bottom aquitard (Layer 13) is about 10 times thicker than the upper aquitard and separates the Taroom Coal Measures (Lower Seam) from the Eurombah Formation and the Durambilla Formation. Layer 11 is assumed to be an aquitard between the extraction zones. That aquitard represents mudstones, shales and sandstones (i.e. Tangalooma Sandstone) within the study area.

4.3.2 Model Aquifer Parameters

As discussed in the previous modelling report (Golder, 2008), there is only preliminary information available at this stage for formal model calibration therefore it was not attempted. The water production schedule provided by QGC, for the 30 year intended production period, was, however, derived from performance of currently installed and producing wells (producing for approximately 2+ years). This provided an opportunity to develop a potential maximum and minimum model parameter set that bounded the QGC's expected "associated water" extraction volumes. There is considerable uncertainty, however, in the production schedule provided by QGC (±50%, as discussed in Golder (2008)), therefore the range of model aquifer parameters (considered realistic for the hydrostratigraphy) were developed in light of that uncertainty. At this stage, there has not been a revision to these parameter sets, therefore the potential maximum and minimum parameter sets, for the NWDA, from the previous model study were retained. Further details of the development of the model is provided in the previous modelling report.

Table 5 presents the modelled potential maximum and potential minimum aquifer parameter datasets used in the updated model for the NWDA.

4.4 Model Boundary Conditions

As presented in the previous model report, the model is defined as a “bathtub” with constant head boundary conditions around the outside, allocated to the topographically appropriate layers since the model stratigraphy is sloped to match the regional dip of 1.3% to the southwest. The depressurisation area, the idealised representation of QGC’s production area, was again considered as a single area with Time-Varying-Specified-Head boundary conditions used to simulate the proposed dewatering schedule, as per the previous model approach. The production schedule applied to the depressurisation area is presented in Figure B-2 and was the same as that presented in the previous modelling report.

Table 4 presents a summary of the depressurisation adopted in this modelling exercise. Dewatering of the development areas assumed 50% depressurisation will occur within the first four to seven years of production with residual depressurisation of the WCM to a target of between 150 psi (~100 m above the top of the WCM aquifer) and 50 psi (~35 m above the top of the WCM aquifer) from Year 7 to Year 40 (the end of well field production life). At the end of the well field production life, the model was allowed to recovery for the next 150 years.

Table 4: Generalised Depressurisation Schedule

Modelled Years	Stress Periods	Remarks
0 to 40	17	Depressurisation pumping of lower & upper coal seam groups (simulating groundwater pumping from Walloons aquifers from CSG well field)
40 to 190	18	Depressurisation pumping terminates, CSG extraction complete, and aquifer recovery begins.

5.0 MODEL RESULTS

5.1 Predicted Drawdown

The model was run for the potential maximum and potential minimum parameter datasets for the NWDA. The predicted drawdown envelope for the Springbok, Hutton and Precipice Sandstones are presented in Figure B-3.

For the NWDA, (Figure B-3), the modelled potential maximum parameter set is associated with the maximum predicted drawdown and the modelled potential minimum parameter dataset is associated with the minimum predicted drawdown. For the modelled potential maximum parameter dataset, drawdown in the Springbok Sandstone is predicted to reach about 2 m at a distance of 1.8km from the edge of the depressurisation zone. Recovery of the aquifer is predicted to commence 75 years after pumping terminates (115 years). Figure B-3 indicates that the predicted maximum drawdown in the Hutton Sandstone and the Precipice Sandstone is insignificant. These results are consistent with the previous predicted drawdown for the NWDA.

The predicted drawdown for the Springbok Sandstone is presented in Figure B-4. The drawdown is from the centre of the depressurisation area, in a southeast direction, for Years 10, 25 and 40.

Figure B-4 indicates that the modelled maximum drawdown within the Springbok Sandstone could vary between less than 0.5 m and approximately 2 m, near the centre of the depressurisation area. Drawdown continuously decreases away from the centre of the depressurisation area. The predicted drawdown is consistent with the model results presented in the previous model report (Golder, 2008).

5.2 Predicted Water Budget

The model simulated extraction rates for the Upper (Layer 10) and Lower (Layer 12) Coal Seams for the NWDA is presented in Figure B-5. The expected extraction rate supplied by QGC, referred to in Section 4.4

as water production schedule, for the NWDA development area is also presented in Figure B-5 for comparison.

From Figure B-5, the extraction rate is predicted to rapidly increase during the first 4 to 7 years, and then gradually decline to the end of the simulation for the NWDA as per the model results presented in the previous model study. These predicted extraction rates generally match the water production schedule provided by QGC.

The predicted groundwater extractions from the WCM (Layers 10 and 12) is presented in Table 6, with the equivalent expected extraction rate provided by QGC.

The predicted gradient-induced transfer of groundwater from the Springbok (Layer 8), Hutton Sandstone (Layer 14) and Precipice Sandstone (Layer 18) are presented in Table 7 for *Year 40* (nominally).

5.3 Cumulative impacts

While the model provides a representation of aquifer behaviour in the NWDA region, it does not directly take into account for cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these proposed activities are not currently known, and as such, have been treated here in a qualitative manner based on the inferred impacts presented by the proponents for each project:

- The Wandoan Coal Project – proposes 15 pits within the currently defines tenement (Figure 1) with the maximum depth of open pit mining anticipated to be approximately 80 mbgl. With current pre-mining water levels measured at between 22.5 and 41.1 mbgl, mining is inferred to penetrate some 38.9 m and 57.5 m into the water table (PB, 2008). Groundwater impacts from groundwater extraction and mine dewatering, and associated mitigation measures, are described as follows (Xstrata, 2008):
  - “The potential effect of mining on coal seam groundwater users was determined to be limited to approximately 20 bores outside of the MLA areas. Deep bores (>600 m) extracting water from the GAB were deemed not to be impacted to due to significant depth of separation and presence of impermeable strata between the mine operations and these aquifers.”
  - “The results of the groundwater impact analysis show that the impacts of drawing additional water for construction from the GAB Precipice Sandstone aquifer are relatively small and temporary on water users and environmental values.”
  - “The Project is expected to have negligible impacts on users and environmental values of groundwater from the Great Artesian Basin and sub-artesian bores.”
  - “Groundwater impacts are expected to be confined to the Walloon Coal Measures (in particular the Juandah Coal Measures) and other overlying aquifers. Any exception to this would likely be the result of geological structures (e.g. faults) that have not yet been identified on the geological models.”

UCG Tenement in the Wandoan area – Cougar Energy and Cockatoo Coal hold tenement adjacent to QGC tenement in the vicinity of the NWDA (Figure 1). The UCG proposed ‘mining’ area targets the Macalister Coal Seam between 150 m and 300 m depth. UCG operations typically do not drawdown water levels within the target aquifer/s to quite the same extent as required for CSG extraction. However, groundwater drawdown and water quality impacts may potentially affect groundwater up to 300 m depth within and adjacent to their defined tenement areas. In particular, the depressurisation of groundwater piezometric levels arising from these UCG operations may potentially affect QGC tenement with impacts up to similar levels of magnitude to those likely arising from QGC activities in the area (however no specific information of these impacts is available from the proponents at this time).

Table 5: Model Hydraulic Parameters- Modelled Potential Maximum and Minimum Parameter Sets for NWDA

Layer Number	Description	Modelled Unit	Modelled Potential Maximum Parameter Set				Modelled Potential Minimum Parameter Set			
			Kh (m/day)	Kv (m/day)	Kh/Kv	Storativity (S)	Kh (m/day)	Kv (m/day)	Kh/Kv	Storativity (S)
1	Aquifer	Intermediate Unit	3.60E-02	7.20E-03	5	1.00E-03	3.60E-03	7.20E-04	5	5.00E-04
2	Aquifer	Intermediate Unit	3.60E-02	7.20E-03	5	5.00E-03	3.60E-03	7.20E-04	5	5.00E-04
3	Aquifer	Intermediate Unit	3.60E-02	7.20E-03	5	5.00E-03	3.60E-03	7.20E-04	5	5.00E-04
4	Aquifer	Intermediate Unit	3.60E-02	7.20E-03	5	5.00E-03	3.60E-03	7.20E-04	5	5.00E-04
5	Aquitard	Confining unit	3.60E-03	7.20E-03	<1	5.00E-03	3.60E-04	7.20E-05	5	5.00E-04
6	Aquifer	Intermediate Unit	3.60E-01	7.20E-03	50	5.00E-03	3.60E-02	7.20E-04	50	5.00E-05
7	Aquitard	Westbourne Formation	1.00E-03	2.00E-05	50	5.00E-04	1.00E-04	2.00E-06	50	5.00E-05
8	Aquifer	Springbok	1.25E+00	2.50E-02	50	5.00E-04	1.25E+00	2.50E-02	50	5.00E-05
9	Aquitard	Confining unit	7.57E-05	1.15E-07	500	5.00E-04	2.50E-05	5.00E-08	500	5.00E-05
10	Aquifer	Upper Representative Coal Seam	4.12E-02	1.37E-02	3	5.00E-04	1.40E-03	4.67E-04	3	5.00E-05
11	Aquitard	Confining unit	1.15E-04	3.03E-07	380	5.00E-04	5.00E-05	1.00E-07	500	5.00E-05
12	Aquifer	Lower Representative Coal Seam	4.12E-02	1.37E-02	3	5.00E-04	1.40E-03	4.67E-04	3	5.00E-05
13	Aquitard	Confining unit	7.57E-05	1.15E-07	500	5.00E-04	2.50E-05	5.00E-08	500	5.00E-05
14	Aquifer	Hutton Sandstone	1.00E-01	1.40E-02	7	5.00E-04	1.00E-02	1.43E-03	7	5.00E-05
15	Aquifer	Hutton Sandstone	1.00E-01	1.40E-02	7	5.00E-04	1.00E-02	1.43E-03	7	5.00E-05
16	Aquifer	Hutton Sandstone	1.00E-01	1.40E-02	7	5.00E-04	1.00E-02	1.43E-03	7	5.00E-05
17	Aquitard	Evergreen Formation	1.00E-02	2.00E-04	50	5.00E-04	1.00E-04	2.00E-06	1000	5.00E-05
18	Aquifer	Precipice Formation	3.80E+00	1.01E-01	38	5.00E-04	1.00E-01	2.63E-03	38	5.00E-05

Table 6: Predicted Groundwater Extraction Rate at *Year 40* for NWDA

Extraction Rate - Modelled Potential Maximum Parameter Set (ML/day)	Extraction Rate - Modelled Potential Minimum Parameter Set (ML/day)	QGC Expected Extraction Rate (ML/day)
WCM*	WCM*	WCM*
17.7	4.2	0.5

where WCM is Walloon Coal Measures, SPG is Springbok, HS is Hutton Sandstone and PS is Precipice Sandstone;

* Note that WCM is the aquifer being pumped.

Table 7: Predicted rate of groundwater transfer from Springbok Formation, Hutton Sandstone and Precipice Sandstone at *Year 40* for NWDA

Modelled Area	Volumetric Transfer - Modelled Potential Maximum Parameter Set (ML/day)[a]			Volumetric Transfer - Modelled Potential Minimum Parameter Set (ML/day)[a]		
	SPG	HS[b]	PS	SPG	HS[b]	PS
NWDA	2.9	<0.1	<0.1	0.3	<0.1	<0.1

where SPG is Springbok, HS is Hutton Sandstone and PS is Precipice Sandstone.

[a] The transfer rates reported for SPG, HS and PS reflect internal movement of water out of these aquifers;

[b] The volumetric transfer rate reported for HS is from Layer 14 only and represents transfer from Hutton Sandstone upward.

6.0 MODEL LIMITATIONS

The limitations of the model are:

The limitations of the model are:

- The model provides a simplified representation of actual conditions, with homogeneous isotropic conditions within the model layers, and assumptions related to the applied constant head boundaries;
- The lack of a significant data-set of site specific model input parameters, i.e. hydraulic conductivity (vertical and horizontal), K_v/K_h ratios, transmissivity and storativity values, means that the model outcomes are approximate and are able to provide *indicative level estimates* of groundwater head declines arising from CSG and groundwater extraction. They are considered suitable to provide the basis for developing guidance level decision-making tools for deciding precautionary management and monitoring practices. These water management guidance's are discussed further in Section 8.2.3;
- The models have not been formally calibrated due to the absence of appropriate long-term groundwater level monitoring data, and the absence of quantitative information on the amount of rainfall recharge occurring to areas where significant aquifers outcrop at ground surface;
- The model applies average (bulk) hydraulic parameters for the layers, however in reality, there is likely to be variability in hydraulic parameters within the model domain;
- The potential influence of residual drawdown from previous activities is uncertain because the NWDA has been modelled independently of the other two development areas (CDA and SEDA). The basis for this is the the structural separation provided by key fault and fold zones in the area to the SE of the NWDA, and inferred in the CGM to provide a measure of hydraulic isolation, has not been tested in practice. Only ongoing monitoring will provide concrete evidence of these hypotheses;
- While the model provides a reasonable representation of aquifer behaviour in the NWDA region, it does not directly take into account the cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The

exact details of these activities are not currently known, and as such, have been treated here in a qualitative manner based on the inferred impacts presented by the proponents for each project.

  - The proposed Wandoan Coal Project (WCP) is likely to draw down local water levels by between some 40m and 60m (within their tenement and common tenement areas held by QGC). Further, this dewatering effect will induce a limited halo of drawdown outside their tenement and, again, this will impact QGC tenure areas locally. Golder consider that this affect will be largely indistinguishable from the CSG extraction when considered in relation to the impacts of the key aquifers (where present);
  - UCG operations target coal seams at deeper depth than the proposed WCP open pit depth, and may impact groundwater levels at common tenement boundaries. NOTE: UCG operations typically do not drawdown water levels within the target aquifer/s (in this case the Macalister Seam) to quite the same degree as required for CSG extraction (no specific information of these impacts is available at this time); and
  - Again, only ongoing monitoring will provide concrete evidence of these hypotheses (refer to the Groundwater Monitoring Plan, Golder, 2009d)

- The sophistication of model predictions is necessarily limited because the extent of information available on the hydraulic properties of the various hydrogeological units is limited at this stage.

7.0 SUMMARY

In summary, the simulations provided a range of estimates of drawdown with time and distance away from the edge of the idealised CSG area (the tenements):

General Comments

Groundwater drawdown impacts, within the 5 key aquifer units identified as vulnerable (the Precipice, Hutton, Springbok and Gubberamunda sandstone and the WCM), can be summarised as follows (with specific comments for each development area following):

- Drawdown declines with distance from the CSG wellfield boundaries;
- Drawdown declines gradually after cessation of the CSG groundwater pumping;
- Drawdown is greatest beneath the depressurisation area (idealised representation of the CSG wellfield areas, i.e. the area bounded by the tenement boundaries);
- The modelled potential maximum parameter set (high end hydraulic conductivity, storage and lowest K_v/K_h ratio simulations) is typically associated with the maximum predicted drawdown and the modelled potential minimum parameter dataset is associated with the minimum predicted drawdown;

Predicted Aquifer Impacts

WCM

- Estimated drawdown in the WCM was as defined by the final model depressurisation pressure head (approximately 70m above the top of the WCM), which at the extraction area boundary equates to the maximum specified drawdown to achieve optimal CSG desorption;
- Recovery of the aquifer is predicted to commence immediately, but very gradually, after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years);

Springbok Aquifer

- Water level impacts are predicted to be greatest within the Springbok Sandstone aquifer largely because it has been modelled as being in good but patchy hydraulic contact with the WCM units - which are being depressurised for CSG recovery (i.e. no laterally extensive aquitard layer separates the Springbok Sandstone aquifer from the WCM unit);
- Specifically, drawdown in the Springbok Sandstone (Figure B-3, Appendix B) is predicted to range from less than 0.5 m to an expected maximum of approximately 2 m immediately outside of the depressurisation area boundary, i.e. the boundary of the tenements (for convenience this is defined in the model as 1.8km from the edge of the depressurisation zone);
- At a nominal distance of 10 km and 20 km from the depressurisation boundary, drawdown impacts are likely to reach a potential maximum of 0.4m and 0.1m, respectively;
- Recovery of the aquifer is predicted to commence 75 years after groundwater extraction terminates – complete recovery is not predicted to be achieved within the modelled timeframes (190 years, being 40 years of operation plus 150 years of modelled recovery);
- The predicted maximum drawdown in the Springbok Sandstone in the NWDA is less than the CDA and SEDA. This is because the NWDA is deeper (tighter fracture permeability) and is significantly less structurally affected than the other development areas (Section **Error! Reference source not found.** in the main report);

Hutton and Precipice Aquifers

- The predicted maximum drawdown in the Hutton Sandstone and the Precipice Sandstone aquifers is insignificant, being predicted to be less than approximately 0.1m during the 190 years of CSG pumping and recovery (Figure B-3, Appendix B).
- Recovery of the aquifer is not predicted to have started within the 190 years of modelling;
- The magnitude of modelled maximum drawdown (and its recovery), at the levels predicted, are not considered discernable within the natural fluctuation of the deep groundwater systems operating in these aquifers;

Gubberamunda Aquifer

- The Gubberamunda aquifer is least affected by extraction of groundwater from the WCM, with predicted drawdowns being modelled as negligible (or not within the resolution of the model) – largely due to the large intervening thickness of aquitard layers.

The predicted drawdowns for the Springbok Sandstone, Hutton Sandstone and Precipice Sandstone are presented in Figures B-3 and B-4 (Appendix B).

8.0 CONCLUSIONS

The groundwater flow model for the NWDA has been updated to account for additional tenements recently acquired by QGC in that area. The update consisted change of the location of the modelled depressurisation area and, accordingly, adjustment of the upper and lower layer elevations within the depressurisation area.

Groundwater flow and drawdown predictions considering the change in location of the depressurisation area does not lead to a change in the model predictions from the previous modelling study because there is not a change in modelled thickness of WCM and non-WCM layers. The updated location of the depressurisation area was reviewed with respect to it’s proximity to model external boundary and was found to be still satisfactory.

NOTE: The predictions of groundwater impacts provided in this revised model configuration (incorporating the additional tenement area) is *not meaningfully different* from that presented in the original groundwater assessment study report (Golder, 2009b). This is largely as a result of the close similarity of the general model parameters between the two models (i.e. there is not a change in modelled thickness of WCM and non-WCM layers), their approximate nature (due to the lack of site specific data) and the low level of resolution of the model. That is, there are only very minor differences in the model input parameters of thickness and depth, and, to a much lesser degree, hydraulic conductivity and aquifer storage between the original and the revised depressurisation area locations (being only 10 km distance apart).

9.0 RECOMMENDATIONS

The following consequences and recommendations are provided:

- The current model is appropriately simple and it can be improved by increasing the density of the dataset upon which it is based. The simplicity of the current model is due to the lack of, and quality of, available data.

- The current model has not been calibrated for regional steady state or transient state simulations. The model could be calibrated for rainfall recharge if historical groundwater level data were available. The model could also be extended to the northeast, to include the area where the sandstone aquifers outcrop at ground surface and where potential rainfall recharge may occur into the deeper aquifers.

- Establishing a long-term groundwater monitoring program for selected bores from different aquifers is important. Installing automated data loggers for groundwater level monitoring in selected bores is strongly recommended. This data could be incorporated into future modelling activities.

- Conducting a routine program of drill stem testing on units other then the WCM to estimate hydraulic parameters for pertinent aquifer and aquitard layers in the Surat Basin sequence remains an important recommendation. This data would provide a solid foundation for increasing the confidence in model predictions.

- It is not recommended that any further groundwater modelling be performed *until* a substantially improved groundwater database is available to assist in refining and calibrating the model. Potentially after between two and five years when quality data has been collected, the groundwater models developed for this study, and the related *“QGC Groundwater Study Surat Basin, Queensland” (087633050 016 R Rev2, June 2009),* should be updated and adapted to provide a more realistic representation of the regional hydrogeology. At this time, there should be a far greater understanding of the likely water production rates for current and proposed wellfield developments. An updated groundwater model would potentially prove useful in developing long term water monitoring and management plans for the future CSG operations. Since the modelling study carried out for this report did not incorporate the impacts of other neighbouring CSG producers, future modelling efforts must include their impacts, as well as, refined inputs of hydrogeological parameters, recharge and surface water interaction. Idealistically, it would be preferred that any future modelling effort be rather done as an industry-wide effort, and in collaboration with the regulators (DERM and EPA).

10.0 REFERENCES

Golder, 2009. “QGC Groundwater Study Surat Basin, Queensland” (Reference No. 087633050 016 R Rev2, June 2009)

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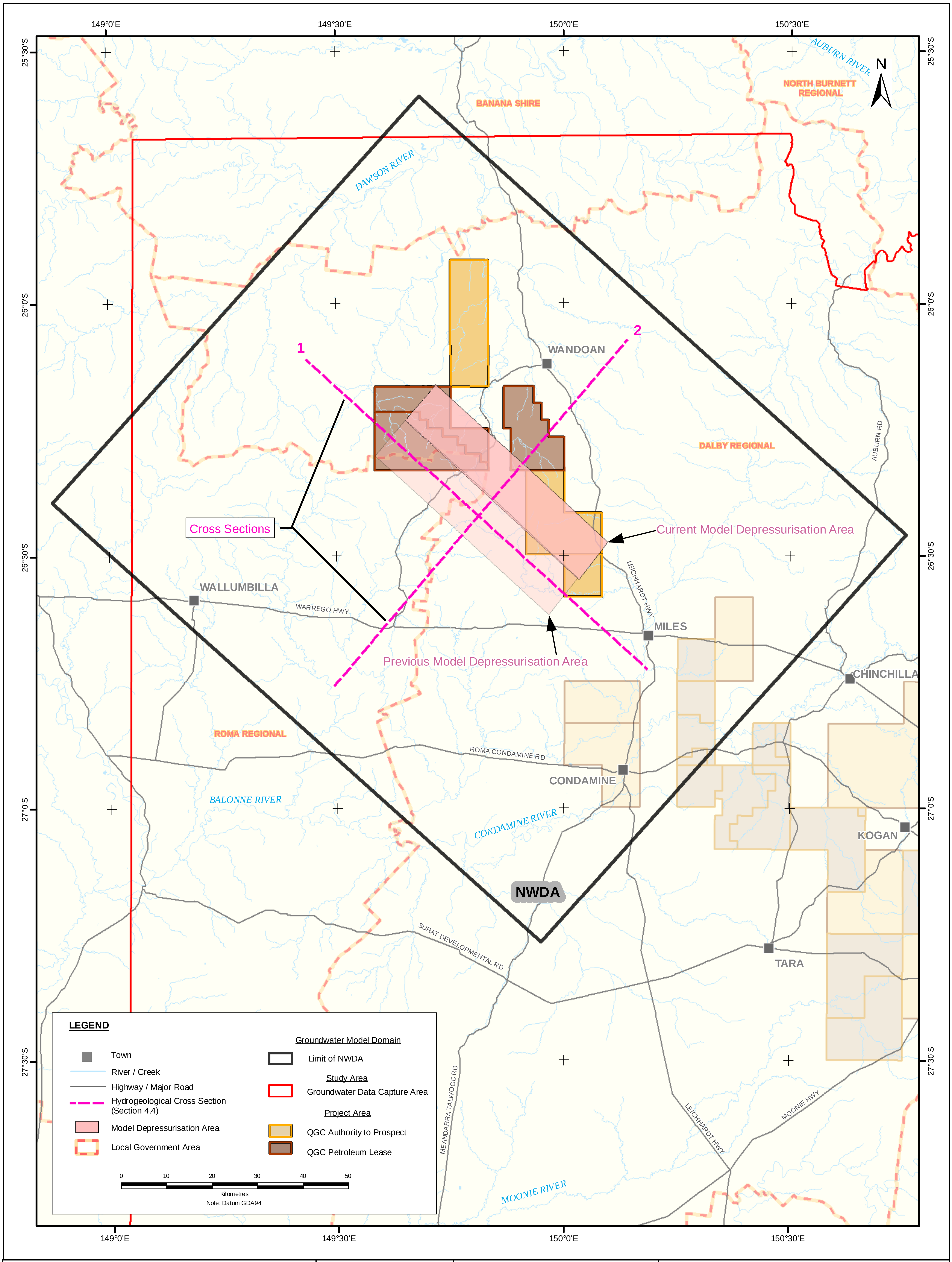

Note:
1. Base map data copyright Mapinfo Australia Pty Ltd.
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Golder Associates

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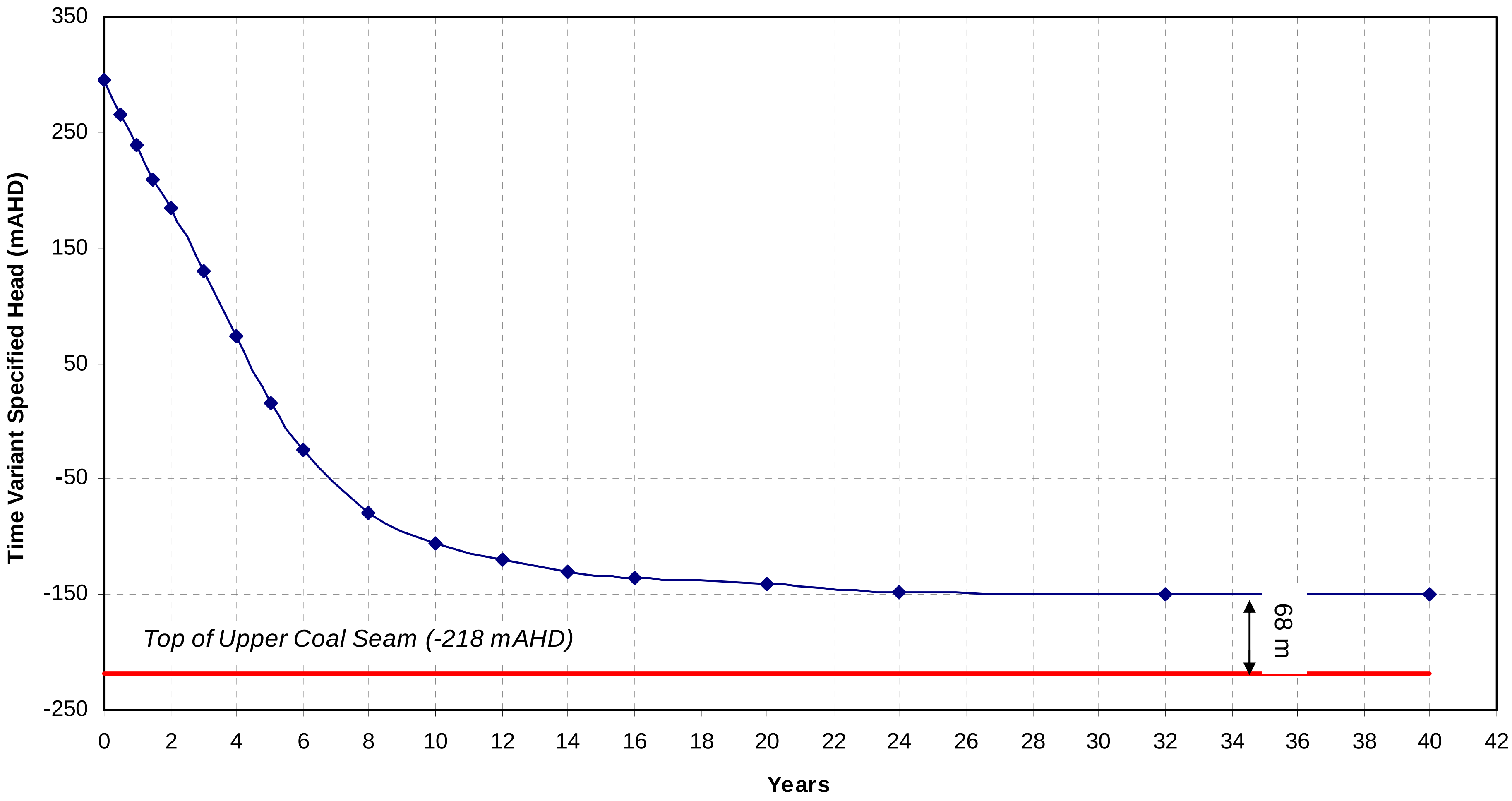
CHECKED	SH *	DATE	11-12-09
SCALE	1:750,000		

TITLE
MODEL DOMAIN - NORTH WEST DEVELOPMENT AREA (NWDA)

PROJECT No	FIGURE No	REV No	
097626104_001	B-1	2	A3

Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



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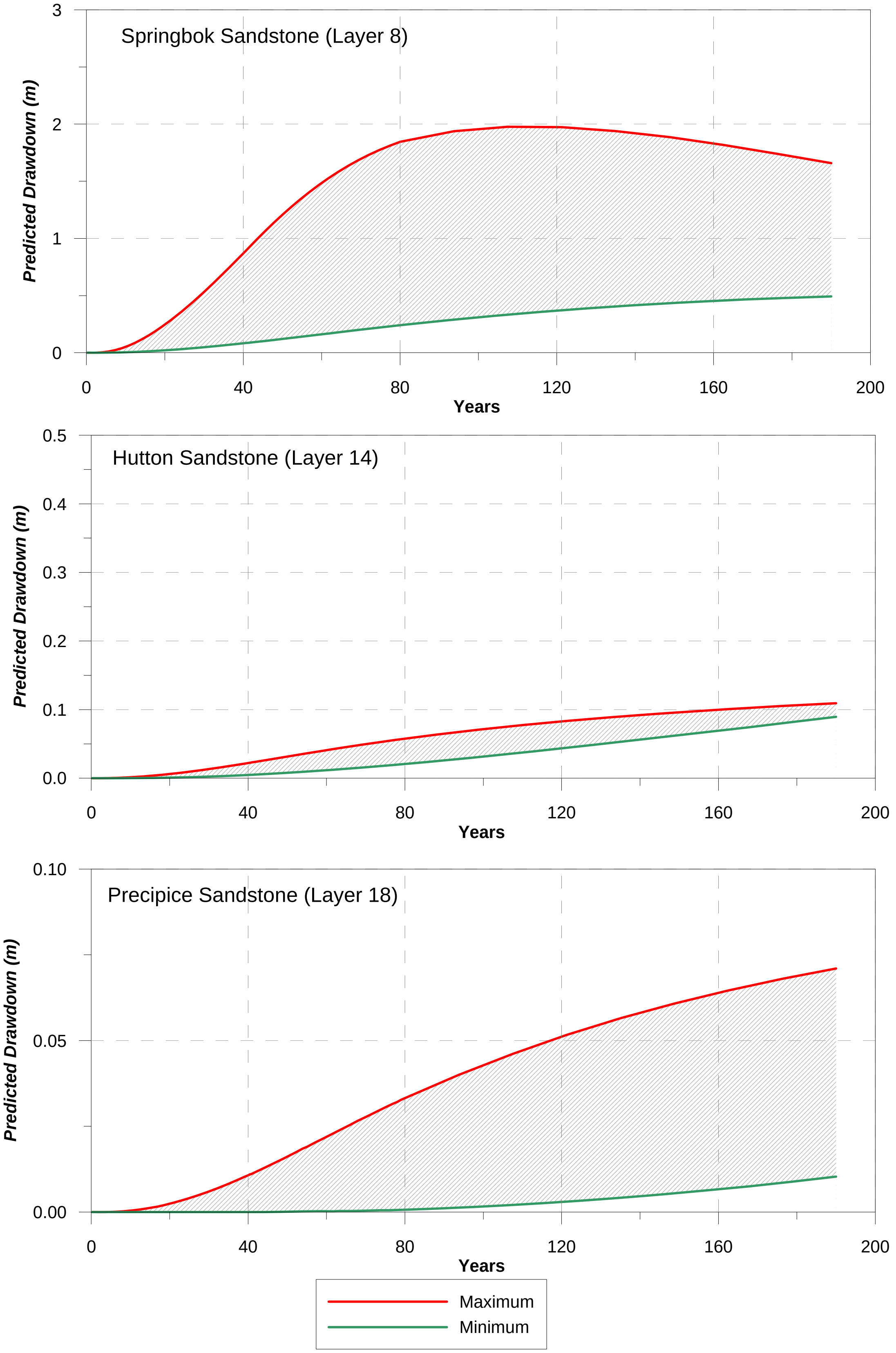
PROJECT	QGC – LNG EIS Groundwater Study				
TITLE	**DEPRESSURISATION SCHEDULE** **NWDA**				
PROJECT No	097626104_001	FIGURE No	**B-2**	REV No	2

A4



Golder Associates

CLIENT
QGC – A BG Group business

PROJECT
QGC – LNG EIS Groundwater Study

DRAWN
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DATE
Oct 2009

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Oct 2009

TITLE
TIME VS DRAWDOWN AT 1.8KM FROM EDGE OF NWDA (SPRINGBOK, HUTTON AND PRECIPICE SANDSTONE)

SCALE
NA

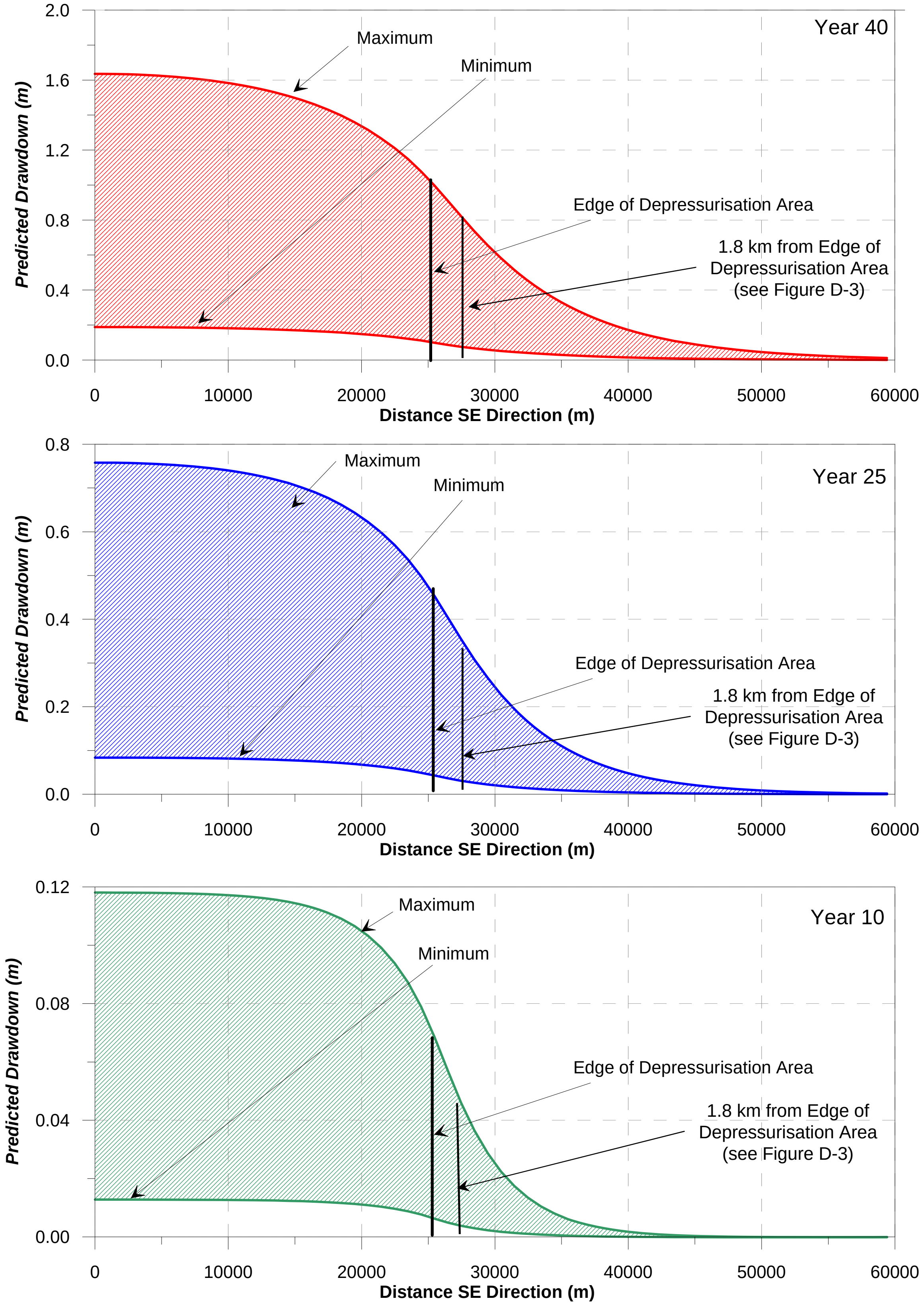
PROJECT No
097626104_001

FIGURE No
B-3

REV No
2

A4

Note: 'Maximum' refers to results of model simulation considering maximum potential parameter dataset and 'Minimum' refers to results of model simulation considering minimum potential parameter dataset.



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CLIENT	QGC – A BG Group business	PROJECT	QGC – LNG EIS Groundwater Study
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CHECKED	RKH	DATE	Oct 2009
SCALE	NA		

TITLE
DRAWDOWN VS DISTANCE FROM CENTRE OF NWDA (SPRINGBOK SANDSTONE)

PROJECT No	FIGURE No	REV No	
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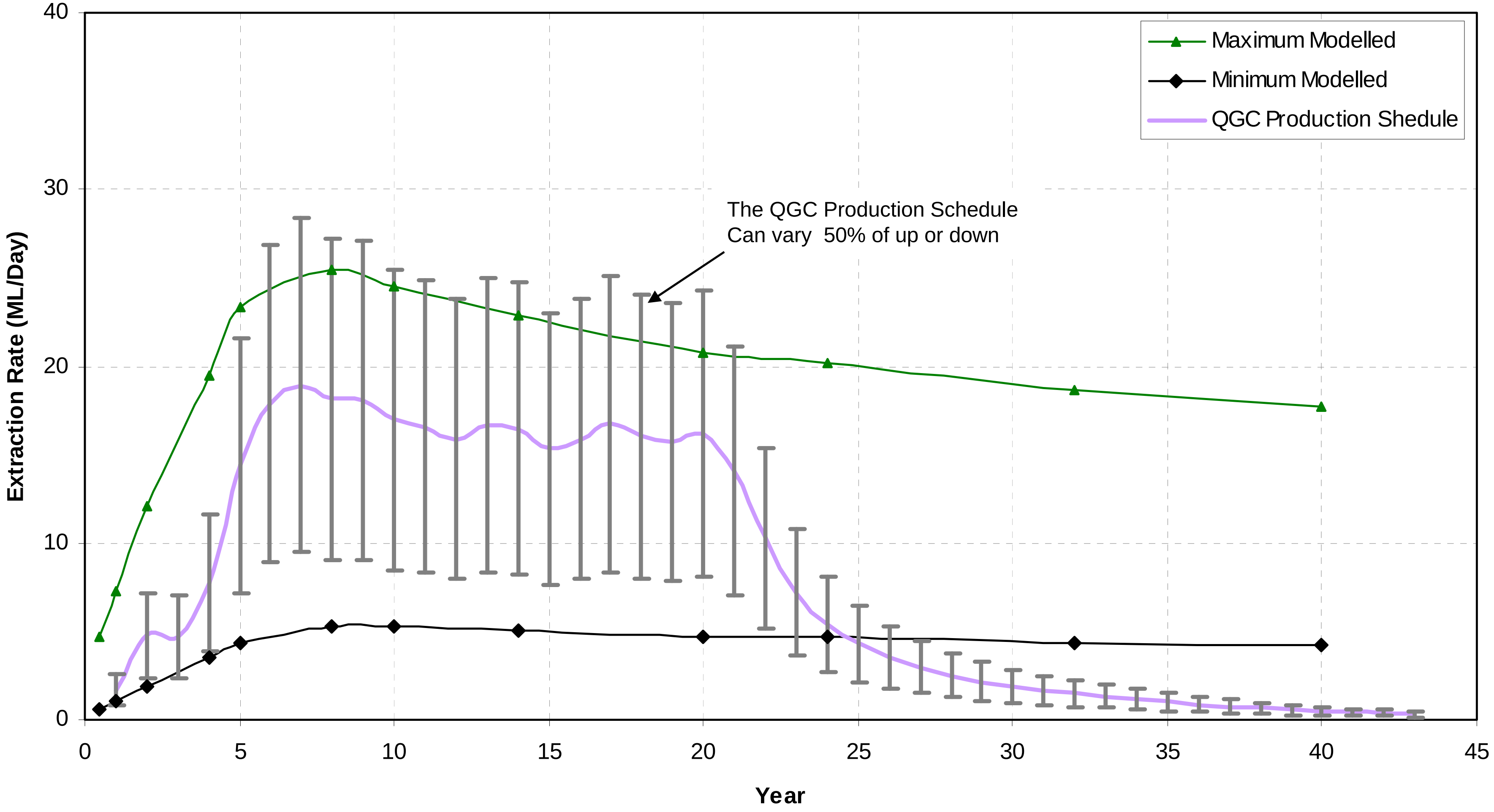
Note: 'Maximum' refers to results of model simulation considering maximum potential parameter dataset and 'Minimum' refers to results of model simulation considering minimum potential parameter dataset.



CLIENT QGC – A BG Group business		PROJECT QGC – LNG EIS Groundwater Study	
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CHECKED RKH	DATE Oct 2009		
SCALE Not to scale		PROJECT No 097626104_001	FIGURE No **B-5** REV No 2 **A4**

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APPENDIX C

Groundwater Quality Assessment

1.0 INTRODUCTION

Groundwater quality from the DERM bores in the NWDA was assessed based on identified major hydrostratigraphic units. Available chemical data from coal seam gas (CSG) production wells were also included in this assessment. A total of 144 groundwater samples from the DERM database and 18 samples from CSG production wells were assessed using the standard hydrogeochemical analyses including Piper and Scatter plots and statistical analysis. Location of DERM and CSG wells is shown in Figure 1.

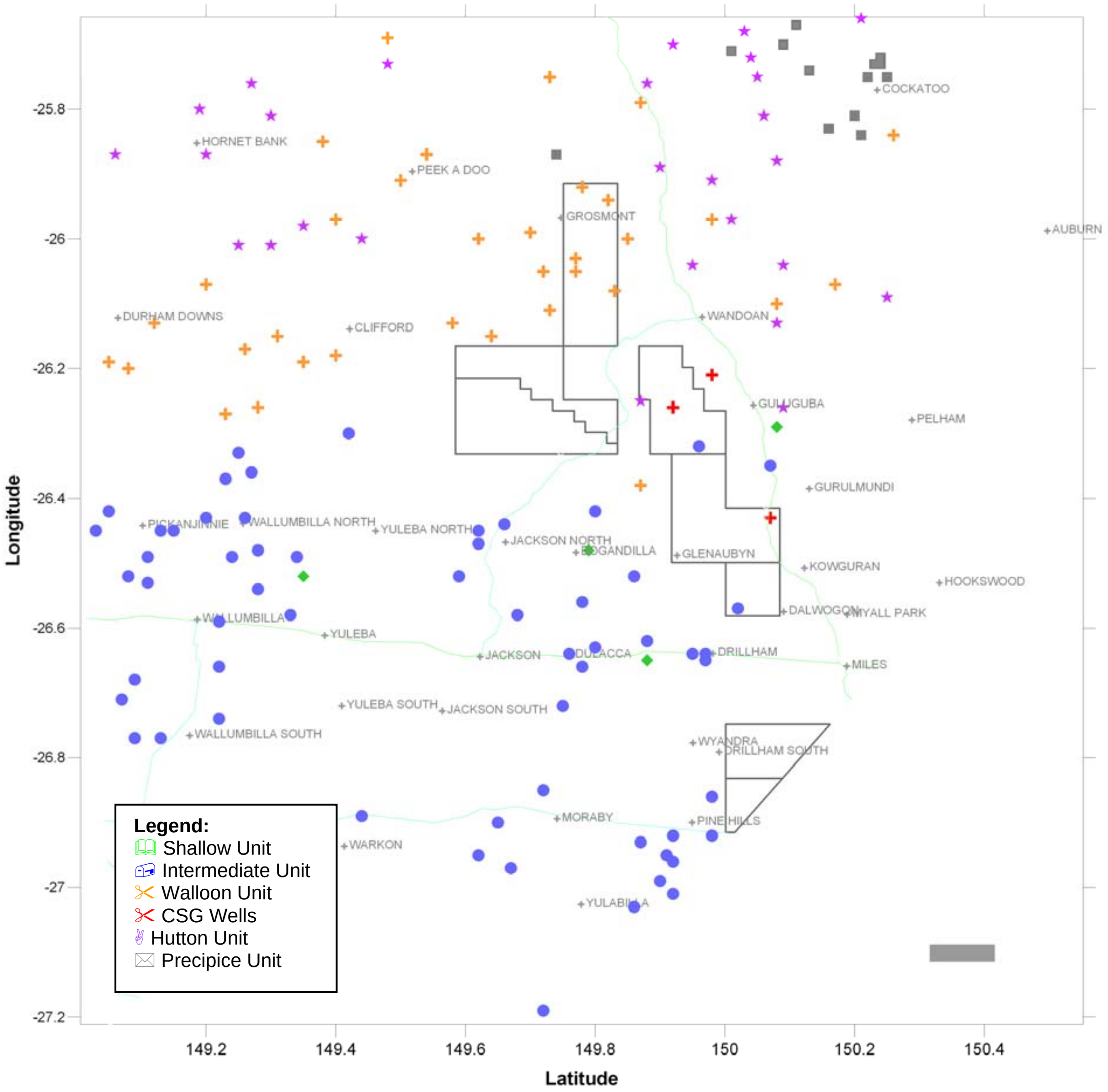

Figure 1: Distribution of Groundwater Samples in the NWDA (scale bar represents 10 km)

1.1 Methodology

1.1.1 Data Quality Assessment

The chemistry data available in the DERM database has been collected over a period of 30 years, with the majority of data sampled between 1980 and 1999. The quality of available data cannot be verified; however, data reliability and accuracy for major ions can be estimated from the ion balance, since positive and negative charges in the water should be equal. Ion balance error (IBE) is calculated as follows:

$$IBE(\%) = \frac{\sum Cations + \sum Anions}{\sum Cations - \sum Anions} \times 100$$

where cations and anions are expressed in meq/L. A milliequivalent (meq) is a measurement of the molar concentration of the ion divided (normalized) by the ionic charge of the ion. Approximately 99% of analytical data from the DERM database had ion balances within the ± 10 % range, indicating that the major ion analyses were of good quality.

1.1.2 Water Quality Description

Groundwater quality assessment included the analyses of pH, total dissolved solids (TDS) and major ion chemistry. Groundwater classification in terms of pH is presented in Table 1.

Table 1: Groundwater pH

Range	Description
pH < 5	Acid
pH 5 - 7	Slightly Acid
pH 7	Neutral
pH 7 - 9	Slightly Alkaline
pH >9	Alkaline

TDS and Electrical Conductivity (EC) are measures of the dissolved salt content of water. TDS is reported as concentration (in mg/L) and can be measured by evaporating a known volume of water and weighing the residual solids; or calculated by summing the major dissolved ions.

A range of salinity classifications (based on TDS concentration) have been published in literature. Classifications are generally based on application (irrigation or livestock watering) and do not define the full range of TDS found in natural waters (e.g. seawater or brines). The water salinity classification adopted for this study is presented in Table 2, as adopted from Fetter (1994) and divide further brackish water into slightly brackish and brackish (USDA, 2007).

Table 2: Groundwater salinity classification based on TDS concentration

Salinity Classes (modified from Fetter, 1994)	
Water type	TDS (mg/L)
Fresh	less than 1,000
Slightly brackish	1,000 to 3,000
Brackish	3,000 to 10,000
Saline	10,000 to 100,000
Brine	more than 100,000

Electrical conductivity (EC) measures the charge carrying ability (i.e. conductance) of liquid and is reported in microSiemens per centimetre (µS/cm) at 25°C. The more dissolved salt in the water, the stronger the current flow and the higher the EC. Measurements of EC can be used to give an estimate of TDS. For the studied area, EC can be converted to TDS using the following relationship:

TDS (mg/L) = EC (µS/cm at 25°C) x 0.534

1.1.3 Major Ion Chemistry

AQUACHEM software (Waterloo Hydrogeologic Inc, 2003) was used for graphical interpretations of the groundwater quality data as follows:

1.1.3.1 Piper Diagram

Cation and anion concentrations for each groundwater sample are converted to meq/L and plotted as percentages of their respective totals in two triangles of the Piper diagram (Figure 2). The cation and anion relative percentages in each triangle are then projected into a quadrilateral polygon that describes the water type. The Piper diagram therefore is a convenient tool to show different groundwater types.

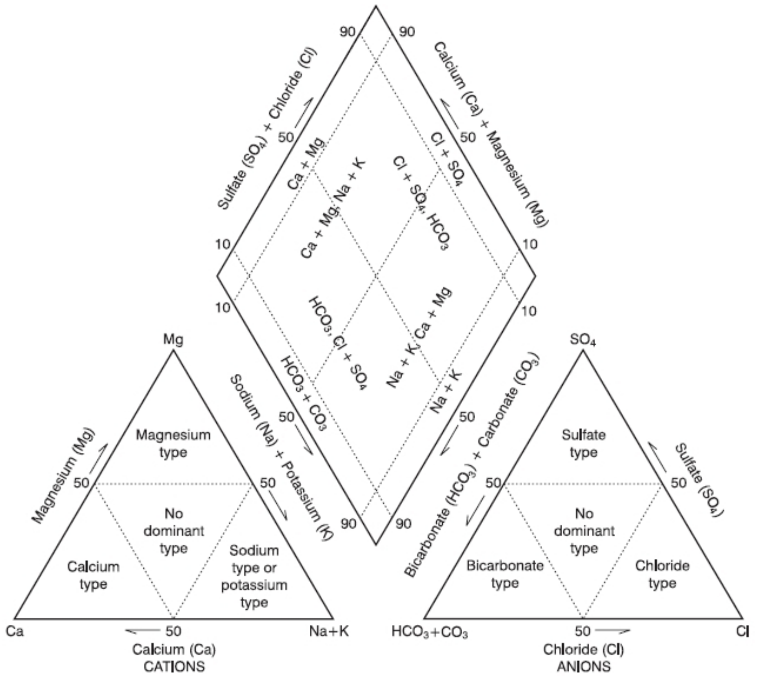

Figure 2: Classification of Hydrochemical Facies Using the Piper Plot

1.1.3.2 Scatter Diagram

X-Y scatter plots are the simplest way of the interpretation of geochemical data. In this assessment scatter plots of Conductivity vs TDS were used. The scatter diagrams include additional horizontal lines referring to TDS concentration boundaries as follows:

- green line (TDS 1,000 mg/L) represents the boundary fresh and slightly brackish waters;
- red line (TDS 3,000 mg/L) is the boundary between slightly brackish and brackish waters; and
- blue line (TDS 10,000 mg/L) represents boundary between brackish and saline waters.

1.1.3.3 Wilcox Diagram

The Wilcox plot is also known as the U.S. Department of Agriculture diagram (AQUACHEM, 2003). A Wilcox plot is used to determine the suitability of water for irrigation purposes. The Wilcox plot is a simple semi-log scatter plot of Sodium Hazard (SAR) on the Y-axis vs. Salinity Hazard (Conductivity) on the X-axis. The salinity and sodium hazard classes are in detail described in Table 10 and Table 11 (Section 3.1.2).

2.0 GROUNDWATER QUALITY WITHIN THE STUDY AREA

2.1.1 Shallow Unit

Groundwater in this unit has limited amount of data including two samples from the Quaternary Alluvium aquifers and two samples from the Shallow Unit representing the Doncaster and Wallumbilla Formations.

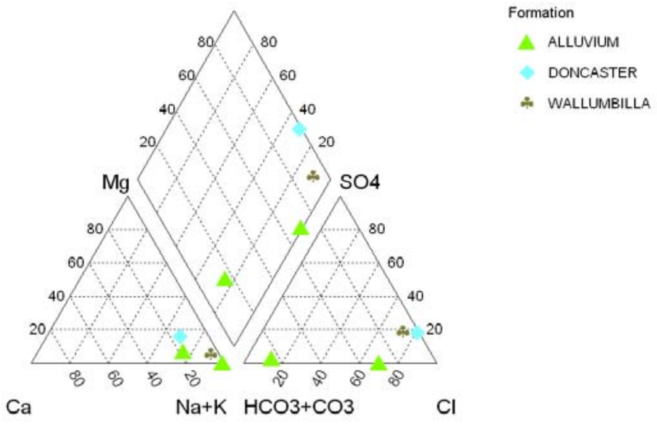

Figure 3: Piper Plot for Shallow Unit

The relative ionic composition of ground-water samples plotted on a trilinear diagram in Figure 3 indicate occurrence of sodium-bicarbonate and sodium-bicarbonate-chloride waters. Based on calculated TDS concentrations, groundwater salinity in the Shallow Unit ranged from fresh to brackish.

2.1.2 Intermediate Unit

The Intermediate Unit is represented by the Bugil Formation, Gubberamunda Sandstone, Mooga Sandstone, Orallo and Southlands Formation. The majority of groundwater samples were collected from the Mooga (39), Gubberamunda (12) and Bungil (9) Formations. Only four groundwater samples were available for Orallo and one sample for the Southland Formations.

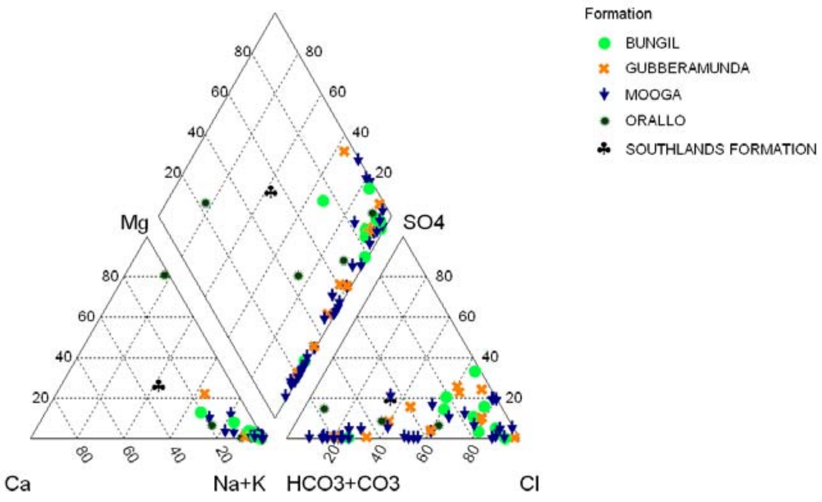

Figure 4: Piper Diagram for Intermediate Unit

Groundwater in the Intermediate Unit is generally dominated by a range of water types between sodium-chloride and sodium-bicarbonate waters (Figure 4). Groundwater from the Gubberamunda and Bungil Formations represent several water types dominated by sodium, bicarbonate and chloride. The majority of groundwater samples from the Bungil Formation are sodium-chloride type. One sample from the Orallo Formation is magnesium-bicarbonate type and sample from the Southland Formation is sodium-magnesium-calcium-carbonate type. Groundwater in the intermediate aquifer is mostly slightly brackish (72%) and brackish (22%). Only four samples (6%) could be classified as fresh groundwater with TDS concentrations below 1000 mg/L (Figure 5).

Groundwater chemical composition is summarised Table 3. The pH of groundwater in the Intermediate Unit ranged from slightly acidic to alkaline with the majority of values from 7 to 9. Sodium concentrations fall in the range from 41 mg/L to 4,290 mg/L (862 mg/L average), calcium from 1 mg/L to 688 mg/L, magnesium from below detection up to 502 mg/L. Bicarbonate concentrations ranged from below detection to 1,200 mg/L (426 mg/L average) and carbonates from below detection to 486 mg/L. Chloride concentrations in 90% of samples varied from 67 mg/L to 1,936 mg/L. Sulphate concentrations in the majority of samples did not exceed 525 mg/L.

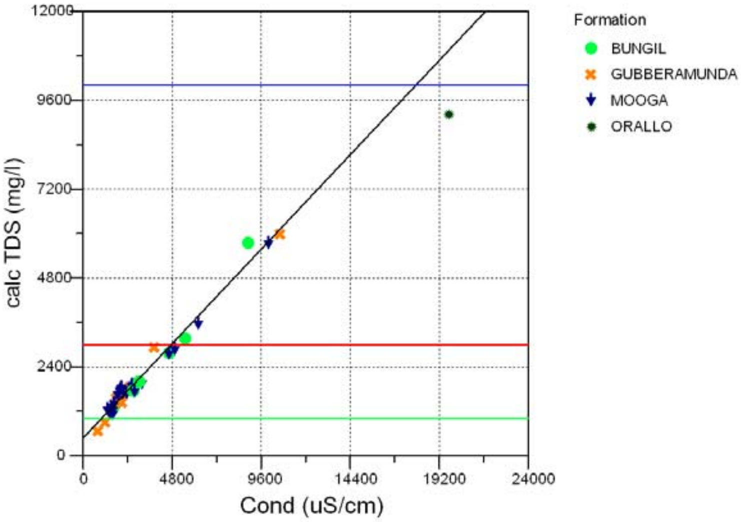

Figure 5: TDS vs EC for groundwater from Intermediate Unit

Table 3: Summary of Groundwater Quality in Intermediate Unit

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	# Samples
pH	-	5.6	9.9	7.23	-	-	-	55
Conductivity	µS/cm	775	19700	3295	1465	2050	5860	45
calc TDS	mg/L	227	13292	2621	1074	1743	5161	65
Ca	mg/L	1	688	58	2	8	121	63
Mg	mg/L	<LOR	502	23.2	<LOR	2	63	64
Na	mg/L	41	4290	862	348	540	1725	65
Cl	mg/L	52	7631	986	119.5	452	2075	65
HCO_3	mg/L	<LOR	1200	426	<LOR	389	935	65
CO_3	mg/L	<LOR	486	78.9	1.41	26.2	249	61
SO_4	mg/L	<LOR	2198	201.1	<LOR	31.5	525	62

Note: 10 -10th percentile, Q50-median, Q10-90th percentile; LOR – limit of reporting

2.1.3 Walloon Unit

The aquifers within the Walloon Unit include Birkhead (12 samples), Eurombah (4 samples), Injune Creek (17 samples) and the Walloon Coal Measures (1 sample). Piper diagram showing data grouping is presented on Figure 6. The majority of groundwater samples from the Birkhead beds are sodium-chloride type waters and from the Eurombah beds are sodium-bicarbonate-chlorite type waters. Groundwater from the Injune Creek Formation is dominated by a range of water types between sodium-chloride to sodium-bicarbonate-chloride types. One sample from this Formation is sodium-magnesium-calcium-chloride type. Groundwater sample from Walloon Coal Measures represents sodium-chloride-bicarbonate type.

The pH of groundwater from the Walloon Unit ranged from 5.5 to 9.2 with an average of 7.0.The lowest pH was observed in groundwater from the Birkhead beds and the highest pH in the Injune Creek Formation. Water salinity varied from fresh to saline with calculated dissolved solids ranging from 346 mg/L to 10,447 mg/L (Table 4). The scatter plot of TDS concentration and EC presented on Figure 7 indicates that groundwater from the Eurombah Formation is fresh. Groundwater from the Injune Creek Formation is mostly slightly brackish. The saline groundwater was observed in the Birkhead Formation.

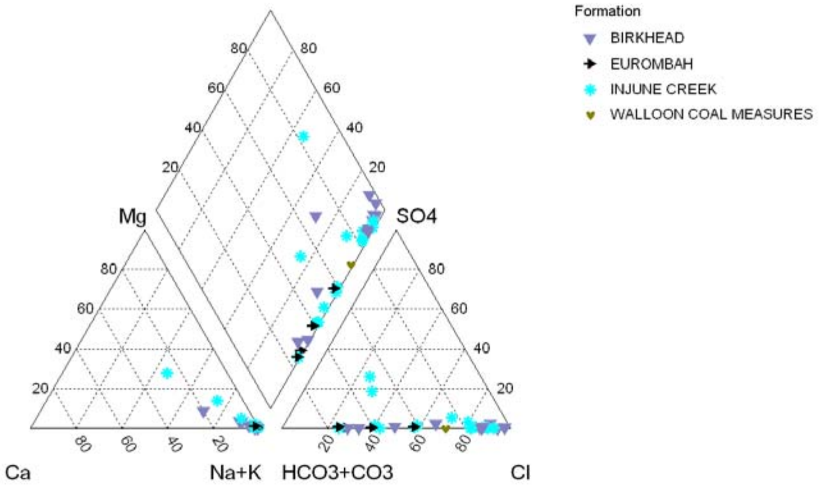

Figure 6: Piper diagram of the Walloon Unit

A summary of groundwater chemical composition is presented in Table 4. The majority of groundwater samples appear to have calcium concentrations below 57 mg/L and magnesium concentrations below 18 mg/L. The majority of data appear to have sodium concentrations ranging from 585 mg/L to 2,089 mg/L. Bicarbonate concentrations ranged from below detection to 928 mg/L and carbonates from below detection to 343 mg/L. Chloride concentrations varied from 43 mg/L to 6,030 mg/L with 90% of data not exceeding 3,141 mg/L. Sulphate concentrations appear to be generally low with 90% data lower than 41 mg/L.

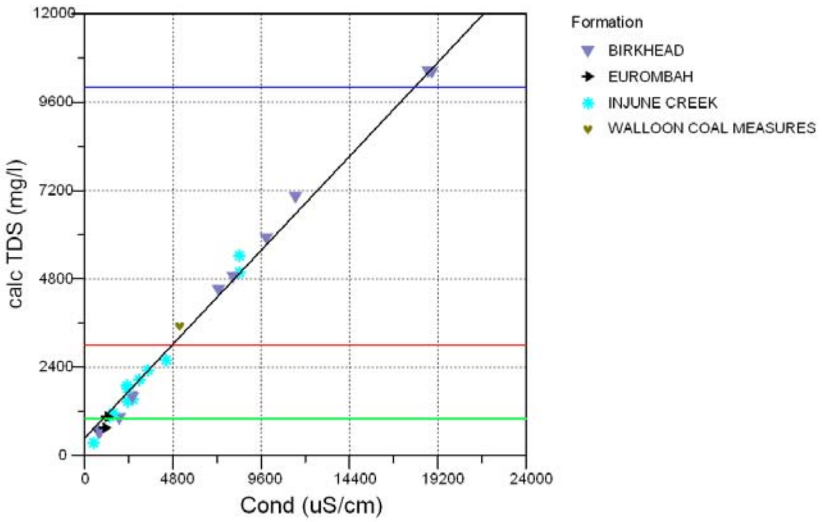

Figure 7: Scatter Plot of Conductivity vs TDS in Groundwater from Walloon Unit (excluding production wells)

Table 4: Summary of Groundwater Quality in the Walloon Unit

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	# Samples
pH	-	5.5	9.2	7	-	-		32
Conductivity	µS/cm	475	18900	4759	848	2550	10220	28
calc TDS	Mg/L	346	10447	2926	558	1811	5715	34
Ca	mg/L	1	250	28	2	8	57	34
Mg	mg/L	<LOR	83	10	<LOR	2	18	34
Na	mg/L	81	3970	1042	193	585	2089	34
Cl	mg/L	43	6030	1380	113	620	3141	34
HCO3	mg/L	<LOR	928	408	<LOR	350	822	34
CO3	mg/L	<LOR	343	42	0.24	10.15	130	33
SO4	mg/L	<LOR	124	13	<LOR	1.8	41	33

Note: Q10 -10th percentile, Q50-median, Q10- 90th percentile; LOR – limit of reporting

2.1.4 Hutton and Precipice Units

Major aquifers within the Hutton and Precipice Units include Hutton Sandstone (27 samples), Evergreen Formation (1 sample) and Precipice Sandstone (13 samples). Major ion composition indicates that groundwater from the Hutton Formation appears to have a range of water types between sodium-chloride and sodium-bicarbonate types. The majority of groundwater from the Precipice Formation is sodium-bicarbonate type (Figure 8).

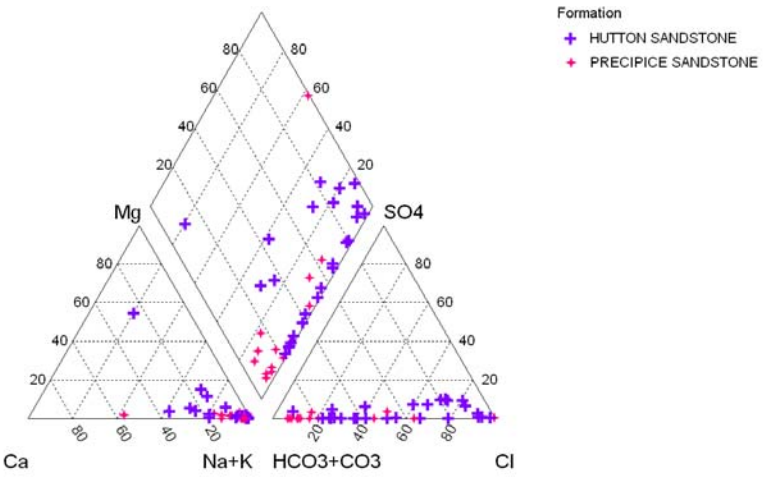

Figure 8: Piper diagram of Hutton and Precipice Formations

TDS concentrations in Figure 9 indicate that groundwater from the Hutton, Evergreen, and Precipice Formations is mostly fresh to slightly brackish. The range of major ion concentrations in groundwater from the Hutton Formation is summarised in Table 5 and from the Precipice Formation in Table 6.

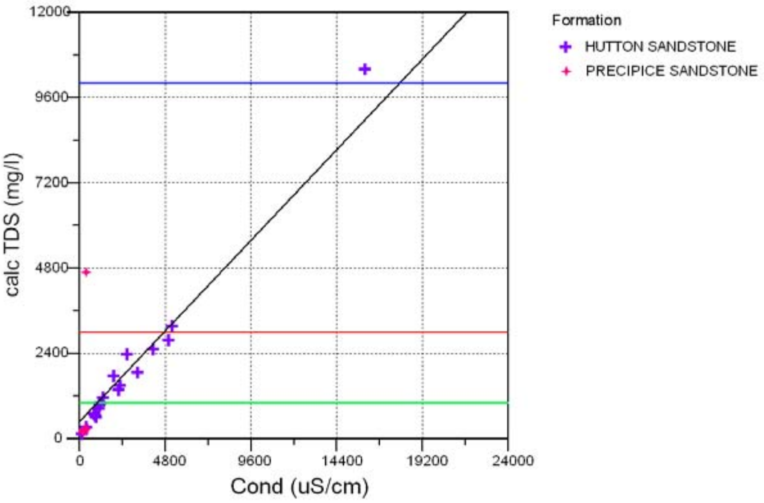

Figure 9: TDS and Conductivity of Hutton and Precipice Formations

Sodium concentrations in the Hutton sandstone aquifer varied between 24 mg/L and 3,450 mg/L (Table 5). Calcium concentrations were generally below 154 mg/L and magnesium below 25 mg/L. Bicarbonate concentrations ranged from below detection to 1,350 mg/L and carbonates from below detection to 583 mg/L. Chloride concentrations in the majority of samples did not exceed 1,366 mg/L and sulphate concentrations 147 mg/L.

Table 5: Summary of Groundwater Quality in Hutton and Evergreen Formations

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	# Samples
pH	-	6.6	9.4	7.35				26
Conductivity	µS/cm	167	16000	2598	250	1173	5000	20
calc TDS	Mg/L	111.2	10394	1777	298.5	1154	2843	28
Ca	mg/L	2	285	46	2	6	154	28
Mg	mg/L	0	120	11	<LOR	1	25	28
Na	mg/L	24	3450	574	39.8	364	926	28
Cl	mg/L	12	6300	735	24	290	1366	28
HCO3	mg/L	<LOR	1350	296	<LOR	205	572	28
CO3	mg/L	<LOR	583	81	0.55	8.3	220	25
SO4	mg/L	<LOR	193	43	<LOR	9.7	147	26

Note: Q10 -10th percentile, Q50-median, Q10- 90th percentile; LOR – limit of reporting

Sodium concentrations in the Precipice Sandstone aquifer varied between 24 mg/L and 3450 mg/L with 90% of data not exceeding 855 mg/L (Table 6). Calcium concentrations were generally below 104 mg/L and magnesium below 9 mg/L. Bicarbonate concentrations ranged from below detection to 3,103 mg/L and carbonates from below detection to 184 mg/L. Chloride concentrations in the majority of samples did not exceed 214 mg/L and sulphate concentrations 9 mg/L. Sulphate concentrations in the Precipice Formation appear to be the lowest from all NWDA aquifers.

Table 6: Summary of Groundwater Quality in Precipice Formation

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	# Samples
pH	-	6.7	8.8	7.37				13
Conductivity	µS/cm	200	930	371	180	293	480	9
calc TDS	Mg/L	159	11730	1561	173	280	3519	13
Ca	mg/L	1.0	2332	195	1	2.5	104	13
Mg	mg/L	<LOR	43	4.7	<LOR	0.5	9	13
Na	mg/L	42	2003	333	46	70	855	13
Cl	mg/L	8.0	7313	628	8	18	214	13
HCO3	mg/L	<LOR	3103	360	<LOR	132	405	13
CO3	mg/L	0.1	182	37	0.12	6	98	12
SO4	mg/L	<LOR	19	2.62	<LOR	<LOR	9	13

Note: Q10 -10th percentile, Q50-median, Q10- 90th percentile; LOR – limit of reporting

2.1.5 CSG Production Wells

The CSG production wells in the NWDA included the Lawton, Pinelands and Trafalga wells. The Piper diagram showing data grouping is presented in Figure 10. The majority of groundwater from production wells represents sodium-chloride types.

Scatter plot of calculated TDS concentrations and observed EC presented in Figure 11 indicate that groundwater from production wells is mostly brackish. Groundwater salinity in production wells increased in the order of Pinelands < Lawton < Trafalgar.

A summary of groundwater chemical composition is presented in Table 7. The pH of groundwater from the production wells ranged from 7.6 to 12.The highest pH was observed at Pinelands Well#3. Conductivity varied from 6,700 µS/cm to 20,000 µS/cm with an average of 12,589 µS/cm. Sodium concentrations ranged from 1,500 mg/L to 4,000 mg/L and calcium ranged from 12 mg/L to 240 mg/L. Magnesium concentrations appear to be much lower and did not exceed 20 mg/L. Chloride concentrations ranged from 1,500 mg/L to 5,700 mg/L. Bicarbonate concentrations were in the range from 5 mg/L to 645 mg/L. The majority of data had sulphate concentrations below 100 mg/L.

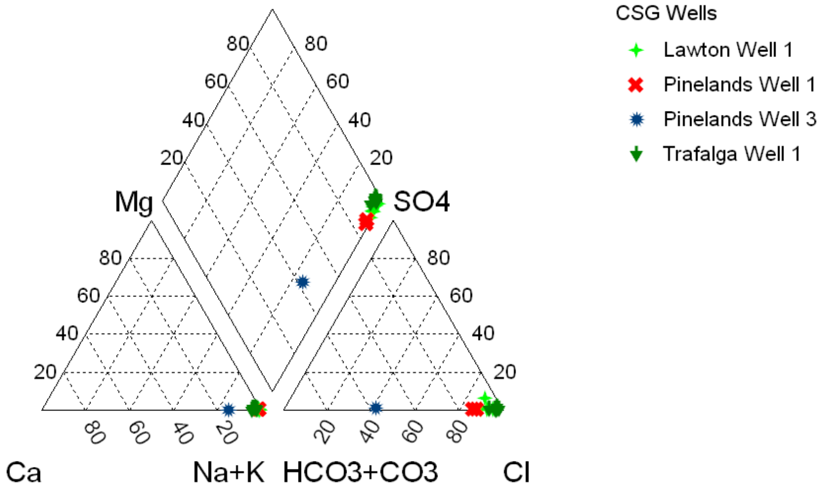

Figure 10: Piper diagram of CSG Production Wells

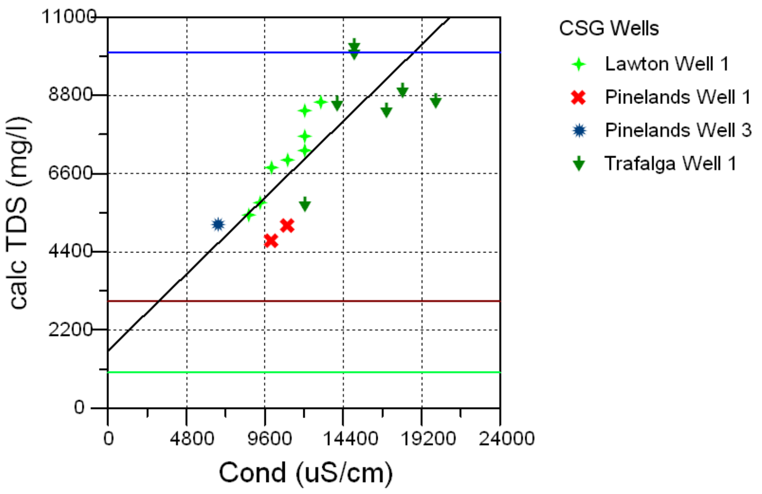

Figure 11: TDS and Conductivity of CSG Production Wells

Table 7: Summary of Groundwater Quality in CSG Production Wells

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	# Samples
pH	-	7.6	12	7.89				18
Conductivity	µS/cm	6700	20000	12589	8220	12000	17200	18
calc TDS	Mg/L	4698	10177	7338	5050	7241	9121	18
Ca	mg/L	12	240	62	12.8	47	108	18

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	# Samples
Mg	mg/L	2	20	10	2	9	18	18
Na	mg/L	1500	4000	2728	1580	2600	3500	18
Cl	mg/L	1500	5700	4017	2220	4200	5440	18
HCO3	mg/L	5	645	319	5.8	332	545	18
CO3	mg/L	1	1793	125	1	9	92	18
SO4	mg/L	10	350	65	18	50	100	18

Note: Q10 -10th percentile, Q50-median, Q10- 90th percentile; LOR – limit of reporting

2.2 Discussion of Water Quality Results

2.2.1 Spatial and Vertical Trends

Figure 12 compares TDS concentrations and Figure 13 observed conductivity in groundwater from all hydrostratigraphic units in the NWDA. Approximately 25 % of the groundwater samples from the DERM database can be classified as fresh with calculated TDS values less than 1,000 mg/L. The majority of the DERM groundwater samples were slightly brackish (52%) with TDS concentration ranging from 1,000 to 3,000 mg/L. Brackish and saline groundwater were less common and contributed to 17% and 6%, respectively. Groundwater from the CSG wells was classified as brackish. The groundwater salinity increased in order Precipice Formation < Hutton Formation < Intermediated Unit < Walloon Unit < CSG Wells.

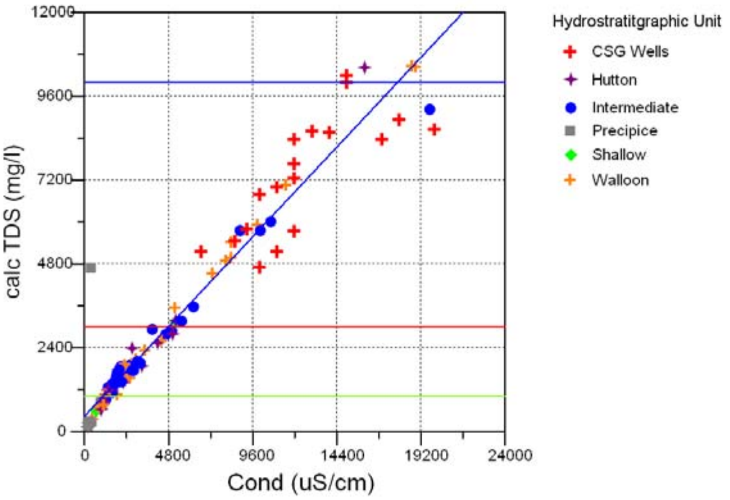

Figure 12: Comparison of Groundwater Salinity in the Project Area

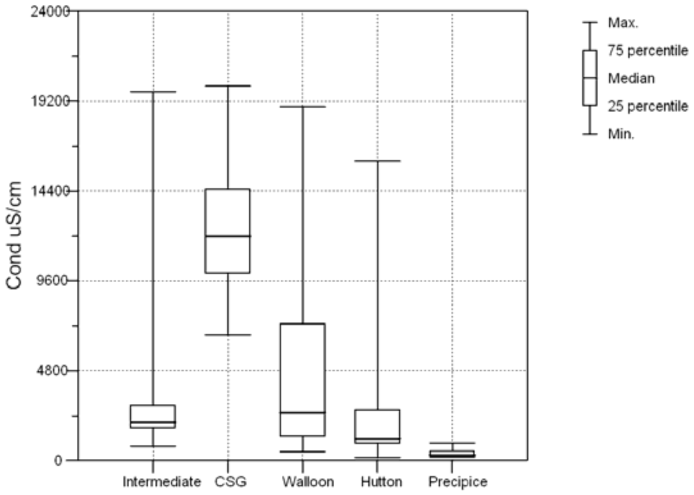

Figure 13: Comparison of Groundwater Conductivity for the Major Units/Formations in the Project Area

Identified water types and data grouping are presented in Figure 14. Dominant major ions in the majority of groundwater samples include sodium, chloride and bicarbonates, with lower proportion of calcium, magnesium and sulphates. The black line in Figure 14 represents conservative (non-reactive) mixing of fresh water and sea water. The position of the markers away from the conservative mixing line is an indication of geochemical reactions, which is discussed in the section below.

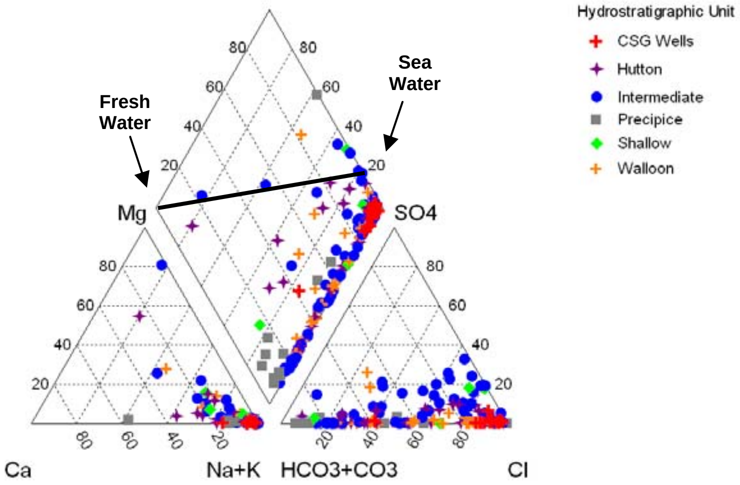

Figure 14: Piper Diagram of All Groundwater Samples in the Project Area

2.2.2 Geochemical processes

During groundwater movement along the flowpath from recharge to discharge areas a variety of chemical reactions take place. These reactions vary spatially and temporally depending on the nature of the recharge water composition, geological formation and residence time.

High sodium concentrations are generally attributed to the dissolution of sodium bearing minerals (sodium plagioclases, halite) and ion exchange with clays or shales of marine origin. Compared to conservative chloride, which does not participate in chemical reactions, concentrations of sulphate in groundwater may be affected by redox reactions and precipitation/dissolution of common sulphate (gypsum and anhydrite) and sulphide minerals (pyrite). Bicarbonates originate from the dissolution of carbonates and reduction processes involving organic matter. The overall groundwater chemical composition is evolving by increasing sodium, chloride and bicarbonate content and depletion of calcium, magnesium and sulphate along the flowpath (Taulis and Milke, 2007).

Coal bed methane generally exists in areas where the dominant chemistry of water, in the coal seam, is sodium and bicarbonate (Van Voast, 2003). Geochemical processes, inherent to methane occurrence, which modify groundwater composition to sodium-bicarbonate type include:

- Anaerobic methane oxidation, utilising sulphate as an electron acceptor, which produces bicarbonates; and
- Depletion of calcium and magnesium through precipitation (principally as carbonates and the bicarbonate concentration increases) and/or ion exchange reactions.

Similarities in the chemical composition of CSG production water in various parts of the world indicate that the same water type can be expected within CSG beds regardless of the formation lithology, or age. In basins where coal is in stratigraphic association with marine or marine-transitional beds, chloride and sodium are the substantial components of the production water (Van Voast, 2003).

In summary, groundwater quality variations observed throughout the Project Area can be attributed to the heterogeneity in sediment depositional environment and composition, groundwater residence time, and depth and direction of groundwater flow. A conceptual chemical model, accounting for observed water-quality include the dissolution and precipitation of minerals, cation exchange reactions with clay and redox processes involving organic matter, sulphate and carbon dioxide.

3.0 COMPARISON OF GROUNDWATER QUALITY TO REGULATORY GUIDELINES

3.1.1 Public Supplies and Domestic Use

The Australian drinking water guidelines (ADWG, 2004) established drinking water regulations for public supplies of drinking water. The regulations specify:

- A health-related guideline value is the concentration that does not result in any significant risk to the health of the consumer over a lifetime of consumption; and
- An aesthetic guideline is the concentration associated with acceptability of water, based on appearance, taste and odour.

The assessment criteria for public supplies and domestic use are presented in Table 8.

Sodium, chloride and pH appear to have the highest percentage of exceedances within the Project Area. More than 86% of samples from the DERM database and 100% of the CSG samples exceed the sodium drinking water standard. Approximately 75% of DERM samples exceeded 1,000 mg/L TDS, and 100% of CSG samples. The pH standard was exceeded in 26% of DERM samples and 77% of CSG wells, with majority of groundwater being slightly alkaline and alkaline rather than acidic.

Table 8: Comparison of groundwater quality with standards for drinking water (ADWG, 2004)

Analyte	Drinking water standard (mg/L; except of pH)	DERM database	CSG production wells
		No of samples (% of total) exceeded standard***	No of samples (% of total) exceeded standard***
pH	6.5 - 8.5	34 out of 129 (26%)	4 out of 18 (77%)
Chloride	250**	79 out of 144 (55%)	18 out of 18 (100%)
Sodium	180**	124 out of 144 (86%)	18 out of 18 (100%)
Sulphate	250** 500*	13 out of 138 (9%) 8 out of 138 (6%)	0 0
TDS	< 500 – good quality 500-1,000 – acceptable based on taste >1,000 – excessive scaling, corrosion, unsatisfactory taste	15 out of 144 (10%) 21 out of 144 (15%) 108 out of 144 (75%)	0 0 18 out of 18 (100%)

* - health value, ** aesthetic value; *** values corresponding to the specified TDS range

Total hardness is a commonly used measure to characterize the suitability of water for public-supply and domestic use. Total hardness was calculated from the chemical composition and refers to the sum of calcium and magnesium (expressed in mg/L of $CaCO_3$). Total hardness can be characterized into four classes (Table 9; ADWG, 2004). Approximately 59% of DERM samples represent soft groundwater, 21% moderately hard, and approximately 9% of groundwater would cause scaling. The majority of groundwater sampled from CSG wells would be classified as moderately hard (50%) and hard (33%).

Table 9: Groundwater Hardness

Total Hardness as CaCO3 (mg/L)	Hardness Classes	Percent of Samples (DERM database)	Percent of Samples (CSG Wells)
<60	Soft, but possibly corrosive	59 (83 out of 141)	11 (2 out of 18)
60-200	Good quality (moderately hard)	21 (30 out of 141)	50 (9 out of 18)
200-500	Increasing scaling problem (hard)	11 (15 out of 141)	33 (6 out of 18)
>500	Severe scaling (very hard)	9 (13 out of 141)	6 (1 out of 18)

3.1.2 Agricultural Use

Agricultural use of groundwater includes irrigation and livestock watering. Irrigating with water that has a high content of dissolved salts and excess sodium can adversely impact the soil structure or adversely affect plant growth. This can depend on the amount of salt present in the water, the soil type being irrigated, the climate and the specific plant species and the growth stage.

The irrigation water quality classification system is based on two characteristics:

- salinity hazard; and
- sodium (alkali) hazard of the water.

Both salinity hazard and sodium hazard, are each divided to four classes using the specific conductance of water and sodium absorption ratio (SAR). The SAR indicates the tendency of sodium to replace calcium and magnesium in soil and is calculated as follows:

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \times 100$$

The characteristics of the salinity and sodium hazard classes are presented in Table 10 and Table 11, respectively. Salinity hazard and sodium hazard are combined into a single plot to evaluate the suitability of water for irrigation (Figure 15). Approximately 40% of groundwater samples from the DERM database and 100% of CSG wells produced SAR values above 32 and had conductivities greater than 5,000 µS/cm. These samples were not included in the Wilcox salinity/sodicity hazard plot (Figure 15).

Table 10: Salinity Hazard Classes

Salinity Hazard Class	Electrical Conductivity (µS/cm)	Characteristics
C1 – Low	0-250	Can be used for irrigation on most soil with minimal likelihood that soil salinity will develop
C2 – Medium	251-750	Can be used for irrigation if a moderate amount of drainage occurs
C3 – High	751-2250	Not suitable for use on soil with restricted drainage; some soils with adequate drainage may require special management control for salinity
C4 – Very High	> 2250	Not suitable for irrigation under normal conditions

Table 11: Sodium Hazard Classes

Sodium Hazard Class	Sodium Adsorption Ratio (SAR)	Characteristics
S1 – Low	0-10	Suitable for irrigation on most soil with minimal danger of harmful levels of exchangeable sodium
S2 – Medium	10-18	Appreciable sodium hazard in fine textured soil having high cation exchange capacity
S3 – High	18-26	Produces harmful levels of exchangeable sodium in most soils
S4 – Very High	>26	Unsatisfactory for irrigation purposes

Figure 15 suggests that groundwater collected from bores completed in a variety of formations within the Project Area plot within a wide range of both sodium and salinity hazard classes. With increasing conductivity, the sodium content and subsequently SAR index increases. Groundwater from the Precipice and Hutton Sandstone predominantly plots in the area with the lowest sodium hazard (S1) and as salinity hazard (C1-C3) and would be suitable for irrigation.

Groundwater from the CSG production wells had both SAR and conductivity higher than those plotted in the Wilcox diagram (Figure 15). This water would not be suitable for irrigation without prior treatment.

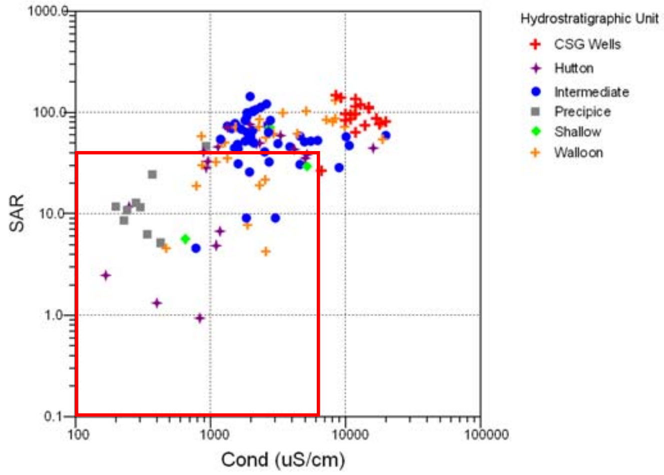

Figure 15: Scatter plot of SAR vs Conductivity Showing the Data Range Plotted in Wilcox Diagram

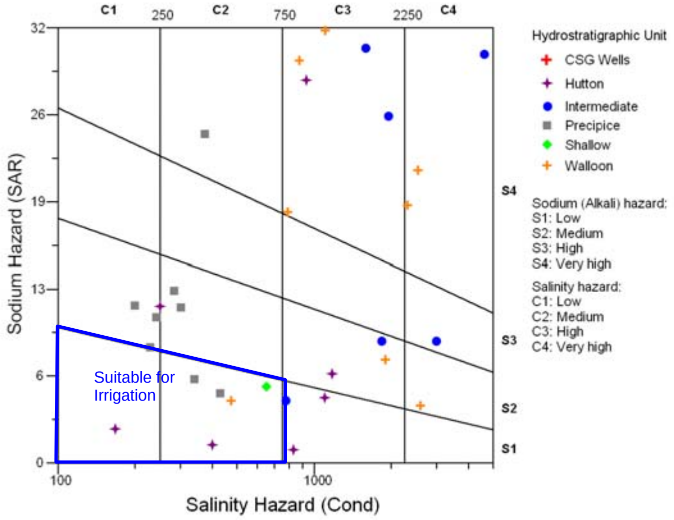

Figure 16: Wilcox Plot Showing Salinity and Sodicity Hazard Classes

Groundwater suitability of livestock watering is assessed on the basis of TDS concentrations and the concentration of specific ions, particularly calcium and sulphate. The trigger values for both calcium and sulphate are 1,000 mg/L. Sulphate concentrations above 1,000 mg/L were observed in only four samples in the Intermediate Unit including the Bungil, Gubberamunda, Mooga Formations and Shallow Unit (Doncaster Formation). Calcium concentrations exceeding 1,000 mg/L were observed only in one sample from the Precipice Sandstone. Concentrations of both of these ions did not exceed 350 mg/L in the CSG wells.

Recommended TDS concentrations in drinking water for livestock watering are given in Table 12. Up to 62% of groundwater samples would be suitable for watering of dairy cattle (TDS <2,500 mg/L) and 74% of groundwater samples would be suitable for watering of beef cattle (TDS < 4,000 mg/L). Groundwater exceeding 13,000 mg/L of TDS was observed only in two samples from Alluvium (1 sample) and the Mooga Formation (1 sample).

Table 12: Tolerances of Livestock to TDS in Drinking Water (ANZECC & ARMCANZ, 2000)

Livestock	TDS (mg/L)		
	No adverse effect on animals	Stock should adapt without loss of production	Stock may tolerate these levels for short periods if introduced gradually
Beef cattle	< 4,000	4,000-5,000	5,000 – 10,000
Dairy cattle	< 2,500	2,500 – 4,000	4,000 – 7,000
Sheep	< 5,000	5,000 – 10,000	10,000 – 13,000
Horses	< 4,000	4,000 – 6,000	6,000 – 7,000
Pigs	< 4,000	4,000 – 6,000	6,000 – 8,000
Poultry	< 2,000	2,000 – 3,000	3,000 – 4,000

4.0 CONCLUSIONS

The geochemical assessment of groundwater quality was based on a detailed analysis of major groundwater management units, as well as, major aquifers present in the Project Area. Golder’s conclusions include:

- Groundwater quality variations throughout the Project Area are due to the heterogeneity in sediment depositional environments, sediment composition, groundwater residence time, and depth and direction of groundwater flow;
- The most common groundwater type is sodium-bicarbonate-chloride and sodium-chloride;
- Groundwater salinity varies from fresh to brackish with the majority of groundwater being slightly brackish. Saline groundwater (TDS > 10,000 mg/L) was observed in bores completed in the Doncaster, Birkhead, Mooga, Gubberamunda, Hutton and Precipice Formations;
- Comparison with regulatory guidelines indicates that approximately 86% of the analysed groundwater samples in the DERM database and 100% groundwater samples from the GSG wells would not be suitable for use as potable water;
- Groundwater from some locations in the Precipice and Hutton Sandstones with low salinity and sodium concentrations, appear to be suitable water for irrigation purposes. Most CSG water would pose a very high salinity and sodicity hazard; and
- The majority of groundwater in the Project Area is suitable for livestock watering. Up to 74% of the groundwater samples would be suitable for watering of beef cattle.

5.0 REFERENCES

ADWG, 2004. Australian Drinking Water Guideline, National Health and Medical Research Council (NHMRC) and Natural Resource Management Ministerial Council (NRMMC)

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APPENDIX D

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