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COAL SEAM GAS FIELD COMPONENT FOR ENVIRONMENTAL IMPACT STATEMENT

QGC Groundwater Study Surat Basin, Queensland

Submitted to:
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REPORT

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Executive Summary

The Project

Queensland Gas Company (QGC), a wholly owned subsidiary of the BG Group plc, 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; the Central Development Area; and the South East Development Area.

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 and the Condamine River Alluvium. 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.

Initial estimations indicate that dewatering would cause negligible subsidence of the existing land surface.

The investigation involved the collection, compilation, interrogation and interpretation of bore databases including those of the NRW, QGC, EPA, AGE, and WERD; a literature study; field investigations including a bore inventory; and the development of conceptual and numerical groundwater models. Data collected was within and beyond the tenements, referred to as the study area, to describe and document the existing environmental condition and values. Potential impacts of groundwater dewatering on environmental values are recorded and possible mitigation measures noted. A water monitoring plan was developed.

Legislation and regulatory requirements

The primary legislative requirements that will guide the management and development of groundwater components for the Project are the Queensland Coal Seam Gas Water Management Policy 2008, the *Water Act 2000,* the *Environmental Protection Act 1994,* the *Environmental Protection (Water) Policy 1997*, *Petroleum Act 1923*, *Petroleum and Gas (Production and Safety) Act 2004,* and the *Water Resource (Great Artesian Basin) Plan 2006* and Great Artesian Basin Resource Operations Plan 2007.

The Existing Environment

The Project is located largely within the Condamine and Balonne River catchment. The Condamine and Balonne Rivers catchment, and the Moonie River catchment, are upper catchments of the Murray Darling Basin. Part of the development area is also located within the Fitzroy catchment that contains a number of smaller streams including Horse Creek, Wandoan Creek and Woleebee Creek.

Diverse landforms, from steep mountainous terrain near the Great Dividing Range to extensive floodplains of the Condamine River occur. The region is essentially flat with low relief hills scattered throughout the floodplains of the Moonie River. The majority of the floodplains and lowland areas have been cleared of native vegetation

The climate of the Project area is sub tropical with dry winters. Precipitation is irregular but intense, and flooding regularly 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%.

The CSG field reserves are contained in the Walloon Coal Measures of the Surat Basin a sub-basin of the Great Artesian Basin (GAB). The three CSG development areas are separated by geological structures such as faults or folds. The Project area covers four of the 25 GAB groundwater management areas; the Surat East, Eastern Downs, Surat North and Surat areas.

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 Project Area are characterised by groundwater pressures (or levels) in most aquifers (including the Gubberamunda, Walloon Coal Measures and the Hutton) ranging between 260 m and 300 m AHD within the tenements areas.   The direction of groundwater flow is generally down dip. Low groundwater gradients exist between adjacent aquifers, with a typical downward direction of groundwater flow. Groundwater quality ranges from fresh to brackish. The WCM contain the highest salinity water.

The water table levels in the Alluvium have been declining for decades. The decline is considered to be due to abstraction from the Alluvium mainly for irrigation purposes.

Many of the aquifers are already over abstracted or approaching sustainable abstraction levels. CSG water production now exceeds the allocation from the groundwater management units containing the Walloon Coal Measures.

Environment values

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

- 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
- Groundwater levels in the hydrogeological systems of the GAB and Surat Basin including artesian water flows
- Anthropogenic groundwater uses such as drinking water supply, and uses such as irrigation of crops and pastures; farm or domestic water supply for stock watering.
- Other uses include irrigation of recreational areas such as parks and gardens, aquaculture, and cultural and spiritual values, scenic visual and amenity areas.

Within the Project area groundwater is mostly used for irrigation. Irrigation water demand is predicted to increase over time.

Potential Impacts

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

- Lowering water levels in adjacent aquifers, depleting supplies to other water users and reducing artesian flows, and impacting surface water base flows, wetlands and aquatic systems
- Increasing inter-aquifer transfer of groundwater as the coal measures are depressurised..
- Increasing potential impacts of the associated water at surface unless strict management controls are imposed. This aspect is dealt with in detail in the surface water report produced by Golder Associates.

The drawdown of water table levels for each aquifer in each of the development areas were estimated to an 'order of magnitude' value using conceptual and numerical groundwater models. The levels were estimated based on 40 years of CSG production, followed by a nominal 150 years of recovery after extraction has ceased.

Groundwater drawdown impacts, within the aquifer units can be summarised as follows:

- decline with distance from the CSG wellfield boundaries
- decline gradual after cessation of the CSG groundwater pumping
- greatest beneath the depressurisation area (idealised representation of the CSG wellfield, namely within the QGC tenement boundaries)
- are greatest within the Springbok Sandstone aquifer largely because it is in direct hydraulic contact with the WCM units which are being pumped for CSG recovery
- the Gubberamunda Aquifer is least affected by extraction of groundwater from the WCM (drawdowns are negligible or not within the resolution of the model);
- the Hutton and Precipice are drawn down to a minor to moderate extent as a result of the CSG groundwater extraction;

Specific to each of the three development areas, the following conclusions regarding groundwater drawdown impacts can be reached:

Central Development Area (CDA)

- Drawdown in the Springbok Sandstone is predicted to range from approximately 5 m to an expected maximum of 55 m at 1.8 km from the edge of the depressurisation area (i.e. boundary of the tenements). Recovery of the aquifer is predicted to commence immediately after groundwater extraction terminates.
- The predicted drawdown in the Hutton Sandstone ranges from less than 0.5 m to an expected maximum of 2.5 m. Recovery of the Hutton Sandstone is predicted to commence about 50 years after groundwater extraction terminates.
- The predicted drawdown in the Precipice Sandstone ranges from less than 0.2 m to an expected maximum of 1.8 m. Recovery of the Precipice Sandstone is predicted to commence at about 60 years after groundwater extraction terminates.
- The maximum predicted drawdown occurs in the Walloon Coal Measures seams and the Springbok Sandstone aquifers.
- Throughout the simulation, the predicted aquifer drawdown in the Intermediate Unit (Mooga, Oralla, and Gubberamunda Sandstone) was minimal.
- The modelled drawdown within the Springbok Sandstone, *near the centre of the depressurisation area*, is expected to range between 10 m and 85 m (within and beneath the tenement boundaries). The drawdown also decreases continuously away from the centre of the depressurisation area.

South East Development Area (SEDA)

- Drawdown in the Springbok Sandstone aquifer is predicted to range from less than 2 m to an expected maximum of 23 m at 1.8 km from the edge of the depressurisation area (i.e. boundary of the tenements). Recovery of the aquifer is predicted to commence 5 years after groundwater extraction terminates.
- The model predicts that drawdown in the Hutton Sandstone may range from less than 2 m to an expected maximum of about 8 m. Recovery of the Hutton Sandstone is predicted to commence about 15 years after groundwater extraction terminates.
- The modelled drawdown in the Precipice Sandstone ranges from less than 0.5 m to an expected maximum of 6 m. Recovery of the Precipice Sandstone is predicted to begin at about 25 years after groundwater extraction terminates.
- The predicted maximum drawdown in the Springbok Sandstone in the SEDA is less than the CDA.
- The modelled drawdown in the Springbok Sandstone is expected to range from less than 2 m to 36 m, near the centre of the depressurisation area after 40 years of groundwater extraction. Again, drawdown continuously decreases away from the centre of the depressurisation area.

North West Development Area (NWDA)

- Drawdown in the Springbok Sandstone is predicted to range between less than 0.5 m up to an expected maximum of 2 m at 1.8 km from the edge of the depressurisation area (i.e. boundary of the tenements). Recovery of the Springbok Sandstone aquifer is predicted to commence 75 years after groundwater extraction terminates.
- The predicted maximum drawdown in the Gubberamunda, Hutton Sandstone and the Precipice Sandstone is insignificant.
- The predicted maximum drawdown in the Springbok Sandstone in the NWDA is less than the CDA and SEDA.
- The modelled drawdown within the Springbok Sandstone is expected to range between less than 0.5 m and approximately 2 m, near the centre of the depressurisation area. Drawdown, again, continuously decreases away from the centre of the depressurisation area.

Water Quality Impacts

Inter-formational flow induced by CSG depressurisation is unlikely to cause significant groundwater quality changes regionally within an aquifer or between aquifers. Although the aquifer water quality may vary within an aquifer, this variation is too small to cause significant changes if inter-aquifer flow occurs. Other users of the water are therefore unlikely to be impacted.

Incorrect bore design and poor bore construction techniques would have the potential to increase the risk of inter-aquifer flows, pressure loss and water quality degradation.

Mitigation Measures

To manage initial the 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 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-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
- providing 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.
- providing 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 program should be implemented for each of the three development areas. This would 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 should include monitoring of each of the primary aquifer zones; the Alluvial, Springbok Sandstone, Gubberamunda Sandstone, WCM, Precipice Sandstone, and Hutton Formation aquifers.

Once additional monitoring data is available for a period (e.g. 2 to 3 years), the groundwater model developed for this study should be updated with new monitoring data and refined hydrogeological parameters, and adapted to ensure the model stays realistic. Inclusion of the impacts of other neighbouring CSG producers should be done to quantify the cumulative impacts on the system. Such modelling is recommended to be undertaken in collaboration with the other CSG producers and the regulators, Department of the Environment and Resource Management (ERM, previously the NRW and EPA).

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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. [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).

Item	Definition
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).
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.
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.
EC	An abbreviation for electrical conductivity, 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. Three types of electrical conductivity measurements are made on soils: ECa measurements are taken in the field using an electromagnetic induction meter. EC15 measurements on a solution obtained by mixing one part soil with five parts distilled water.
Effective porosity	The porosity contributing to the flow of water or the interconnected porosity.

Item	Definition
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.
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.
ERM	Department of the Environment and Resource Management (ERM, previously the NRW and EPA)
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.
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).

Item	Definition
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.
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.

Item	Definition
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.
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.

Item	Definition
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.
NRW	Queensland Department of the Natural Resources and the Environment (NRW now part on ERM)
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.
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.

Item	Definition
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.
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.
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.

Item	Definition
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.
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. $\delta h = \pm 1$).
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. $\delta h = \pm 1$) 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

Item	Definition
	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.
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 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.

Item	Definition
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 wholly owned subsidiary of the BG group plc, is proposing to develop a Liquefied Natural Gas (LNG) export facility at Gladstone in Central Queensland. The facility will produce three to four million tonnes per annum (Mtpa) of LNG, with the potential for future expansion to 12 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;
- 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. This study has been prepared to support the EIS. 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.

The purpose of an EIS in Queensland is to:

- provide stakeholders with sufficient information to understand the type, nature, and extent of the proposed Project;
- identify, examine and assess direct, indirect and cumulative impacts on the natural, built and social environment;
- determine how adverse impacts can be avoided or mitigated so that any residual effects are acceptable; and
- ensure the Project is based on sound environmental protection and management criteria.

An EIS should provide this information in a form suitable for use by:

- affected persons;
- interested persons;
- relevant State Government agencies ; and
- the Australian Government Minister for the Environment, Heritage and the Arts.

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; and
- 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 (Figure 1).

1.1 This Report

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.

This report considers the groundwater component of the Project only. It recognises that groundwater is part of the larger hydrological cycle, which interlinks strongly with surface water. The effect of the CSG activities on surface water components of the Project is covered in a separate Golder report (Golder report 087633050 014 Rev1, 2009).

The report provides information on the Project Area under the following thread of logic:

- The Legislative and Regulatory Framework — Section 2
- Study Approach and Methods — Section 3
- Description of the Existing Environment and Identification of Existing Values — Sections 4 and 5
- Potential Impacts — Section 7
- Mitigation — Section 8
- Summary, Conclusion and Recommendations — Sections 9 and 10

1.2 Project Background

CSG is predominantly methane gas adsorbed in underground coal beds. The methane occurs 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 wells into targeted coal layers (seams) and pumping out groundwater (CSG 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).

Groundwater extraction for CSG is closely linked to gas pressure and groundwater gas extraction. The groundwater and gas extraction process consists of placing a pump in the production well, typically above the coal seam, and initiating groundwater extraction to lower the water level in the production well, and consequentially the piezometric head pressure in the aquifer.

Groundwater pumping continues until the gas flows freely (decreasing the water pressure in the coal seam(s) liberates the gas). Often, no 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 units within the Surat Basin. 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 which 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.

1.3 Project Description

The proposed LNG 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 CSG fields. 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 field component of the Project will comprise developing:

- up to a total of 6000 production wells;
- 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 re-injection wellfield/s; and
  - associated water reticulation systems.

Wells will be located approximately 750 metres (m) apart to optimise production. The well sites 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.

A network of pipelines will link the gas 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.

1.4 Project Setting and Context

1.4.1 Local Setting

The Study Area lies approximately 200 km west of Brisbane (Figure 1: Location Plan), within the Surat Basin, a sub-basin of the GAB. It 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 area of operation include Chinchilla, Miles, Moonie, Kogan, Wallumbilla and Dalby. The major rivers running through the area include the Condamine and Balonne, Moonie, and the Weir 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).

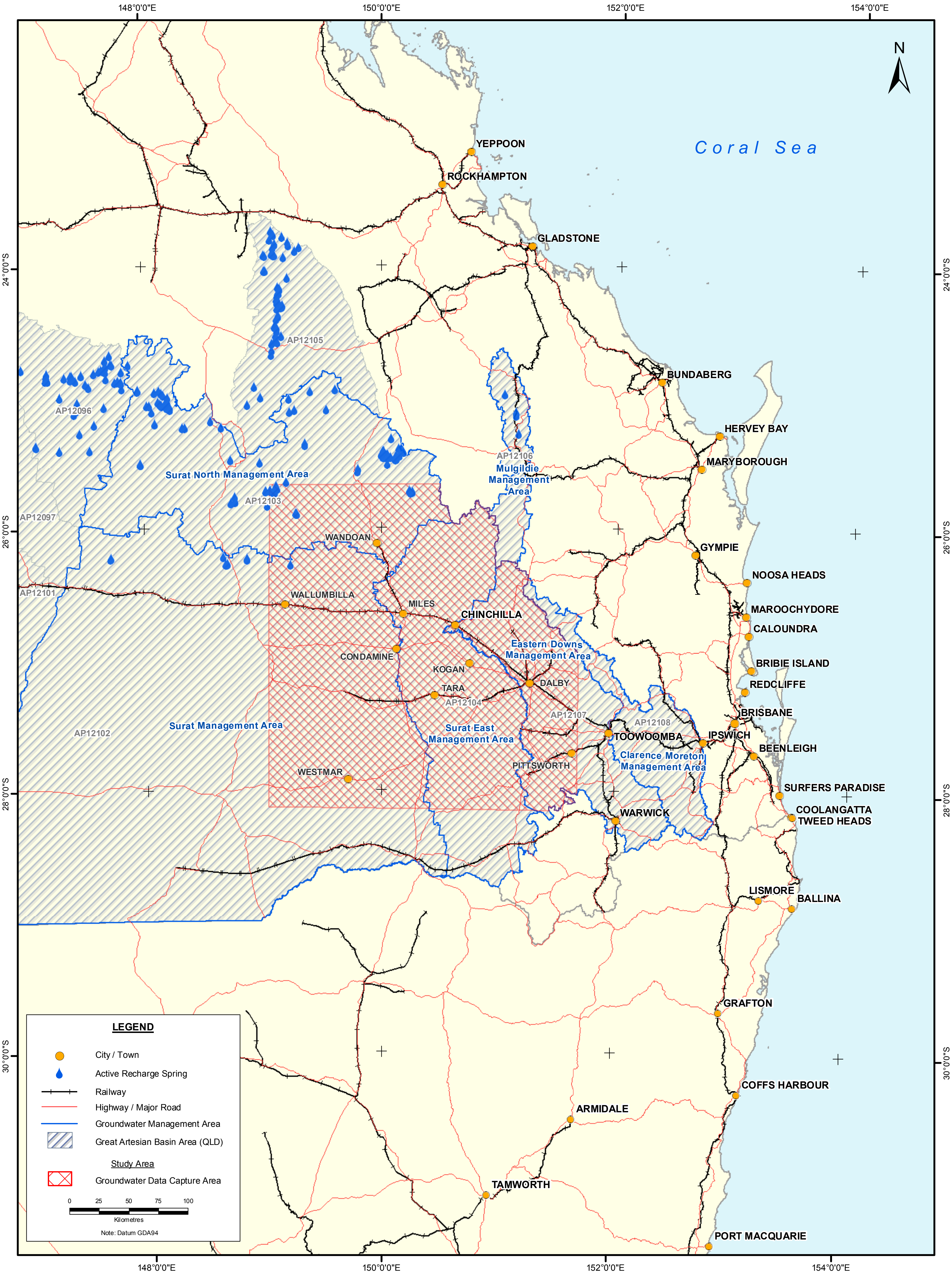
Significant agricultural production occurs in the area above the eastern part of the Surat Basin due to the presence of fertile cracking clay soils and adequate rainfall. Grazing and dry land cropping dominates the land area above the western part of the Surat Basin, where the climate becomes drier. 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).

Native woodland covers areas of the Surat Basin. Most of this native woodland is contained within protected State Forests and National Parks, including the Carnarvon National Park located in the northern part of the basin and north of QGC's tenements.

There are nationally significant wetlands located on the lower Balonne River system in New South Wales and on the Narran River. The Ramsar-listed Narran Lake Nature Reserve (which includes Back and Clear Lakes) is part of a large terminal wetland system.

Less than 5% of Queensland's total population lives in the GAB area (OESR, 2008). The region is managed by three local government areas:

- Toowoomba Regional Council;
- Dalby Regional Council; and
- Roma Regional Council.



Notes:
1. Base map data copyright Mapinfo Australia Pty Ltd
2. Artesian springs copyright by the State of Queensland (Environmental Protection Agency), 2008.

Golder Associates

CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN	PB/DK/BQ	DATE	03-06-09
CHECKED	RKH *	DATE	03-06-09
TITLE	LOCATION PLAN		
SCALE	1:3,000,000	PROJECT No	087633050_016
FIGURE No	1	REV No	2
A3			

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0001_Rev2_RegionalLocationMap_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

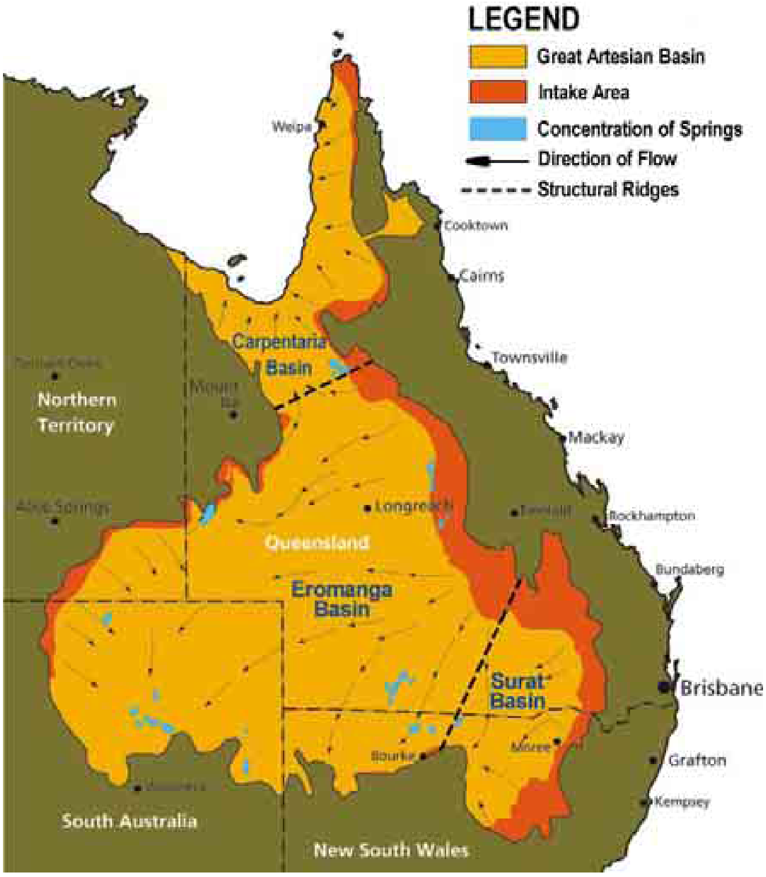
1.4.2 Hydrogeological Context

The Surat Basin lies within the Great Artesian Basin (GAB) - one of the largest artesian groundwater basins in the world (NRW[1], 2006, now the ERM). 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 (NRW, 2006). At its widest extent, it is 1,800 km from the Darling Downs to west of Coober Pedy (NRW, 2006).

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

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



Source: The Great Artesian Basin, NRW, 2006

Figure 2: Extent of Great Artesian Basin

[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 (ERM).

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 entered the aquifers of the GAB in Queensland each day (NRW, 2006). Together with the volume of recharge from the other States, water discharged as surface springs and a natural equilibrium of inflow to outflow was maintained. Total outflow from the GAB reached a peak of over 2,000 megalitres per day (ML/d) around 1915 (NRW, 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 (NRW, 2006). Recent flow rates are now between 0.01 ML/d and 6 ML/d (NRW, 2006) and the current total outflow from the GAB is about 1,500 ML/d (NRW, 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 (NRW, 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 Surat Basin (a Sub-Basin of the GAB) contains QGC's CSG resources. It is divided into 7 GMAs and 26 GMUs. The QGC CSG fields are located in, or adjacent to four of these GMAs, including:

- Surat East;
- Eastern Downs;
- Surat North; and
- Surat.

Table 1 provides a breakdown of the GMU's within the four GMA's 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
Eastern Downs	Eastern Downs 1 Eastern Downs 2 Eastern Downs 3
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 Balonne WMA. Surface water in this WMA is administered through the *Water Resource (Condamine and Balonne) Plan 2004* (CBWRP) and *Condamine and Balonne Resource Operations Plan 2008* (CBROP). There are also small sections of the Project 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. For a full description of the study area, refer to Section 1.7 below.

1.5 EIS Terms of Reference

The Terms of Reference (TOR) for the EIS identifies three main components of the Project:

- CSG field (the upstream component);
- Gas transmission pipeline; and
- LNG liquefaction and export facility.

The TOR identifies *three phases* of Project activities:

- Construction;
- Operation; and
- decommissioning and rehabilitation.

For each component and phase, the TOR requires that the EIS contains an explanation or description of the following:

- the need for the Project;
- costs and benefits of the Project;
- alternatives to the Project;
- the methodologies used to prepare the EIS;
- how pubic consultation will be managed and conducted;
- the relevant policies and legislation with which the Project must comply;
- the Project's consistency with existing land uses or long-term policy frameworks for the Project Area;
- a description of the local and regional context including:
  - natural, built and social environment;
  - State and National environmentally sensitive assets;
  - natural resources to be used by the project; and
  - built and social infrastructure required by the project.
- proposed waste management systems;
- identification and characterisation of direct, indirect and cumulative impacts on the local and regional natural, built and social environment; and
- proposed methods for avoiding, ameliorating, and managing impacts on the:
  - local and regional natural, built and social environment;
  - local and regional State and Nationally environmentally sensitive assets; and
  - resources used by the project.

In terms of the CSG fields, the TOR requires the EIS contain information about:

- local and regional water resources, particularly the Great Artesian Basin (GAB) and the Condamine River and its tributaries;
- local and regional aquatic and terrestrial ecosystems;
- the use of local and regional ground and surface water resources, particularly the GAB and the Condamine River and its tributaries;
- demand for raw and treated water for the various processes and the proposed and optional sources of water (bores, any surface storage such as dams and weirs, municipal water supply pipelines) for construction and operational aspects of the Project;
- estimated rates of supply from each source (average and maximum rates);
- identification and characterisation of daily, seasonal and/or peak operational requirements;
- total annual consumption;
- potable water demand and supply requirements for each phase, including existing town water supply to meet such requirements;
- storage and distribution of water on and off the CSG fields;
- the capability of the water network to provide for the necessary demand;
- any additional water supply infrastructure;
- current and projected raw and treated water consumption and storage;
- contingency plans for planned and non-planned supply failures;
- projected dates for increased raw and treated water supplies;
- the water balance;
- impacts of the project on ground and surface water resources;
- project hydrological and climatic risks;
- storage and treatment of saline water; and
- decommissioning of saline water and other waste storage facilities.

This report deals with the groundwater components of the TOR, as applicable to the CSG field development.

1.6 Scope of Work

Golder was commissioned to provide information to support preparation of the ground and surface water components of the Project's EIS Terms of Reference (Section 1.5). The scope for this report is presented in Appendix A.

For the purposes of this report, Golder was commissioned to conduct eight major tasks:

- describe the environmental values associated with groundwater environments in the Project Area;

- describe the quality, current yields and capacities, and other physical features of the ground and surface water resources in the Project Area;
- conduct a legislative review with respect to ground and surface water;
- review the climatic and hydrologic history of the project development area;
- assess the likelihood of flooding within the project development area and suggest mitigation measures where relevant;
- identify constraints to well development and operation, access track construction, water and gas gathering pipeline installation and other infrastructure;
- identify and assess likely impacts of the Project on:
  - groundwater and surface water resources and associated ecosystems;
  - bores and bore users within the area; and
  - any State or Nationally significant environmental assets.
- review and identify measures for management and mitigation of groundwater risks and impacts, including a brief assessment of re-injection of associated water; and
- complete a bore inventory of bores surrounding and within the tenements.

1.7 Definition of the Study Area

The area investigated in this study is approximately 260 km by 275 km in size and includes:

- the majority of the Surat Basin – which is the south eastern part of the GAB; and
- small parts of the Clarence - Moreton Basin – a sub-basin of the GAB. .

The investigation area is contained within the Surat, Surat North, Surat East, and Eastern Downs Groundwater Management Units (Qld Department of Natural Resources and Environment, 2005). It also extends beyond the predicted areas of likely water impacts associated with QGC's activities in Queensland.

QGC have defined three main gas reserve development areas for their CSG Operations (Figure 3):

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

The prediction of groundwater impacts for the proposed CSG depressurisation and gas extraction activities in each of these development areas was performed using computer-based modelling methods (Section 5). Three separate groundwater model domain areas were defined for each development area (i.e. three separate computer models). The modelling was designed to extend beyond the predicted area of impacts likely to be associated with the CSG operations.

The study area and the areas modelled were selected to guide the documentation of the existing environment conditions where potential impacts by the proposed QGC activities might reasonably be anticipated.

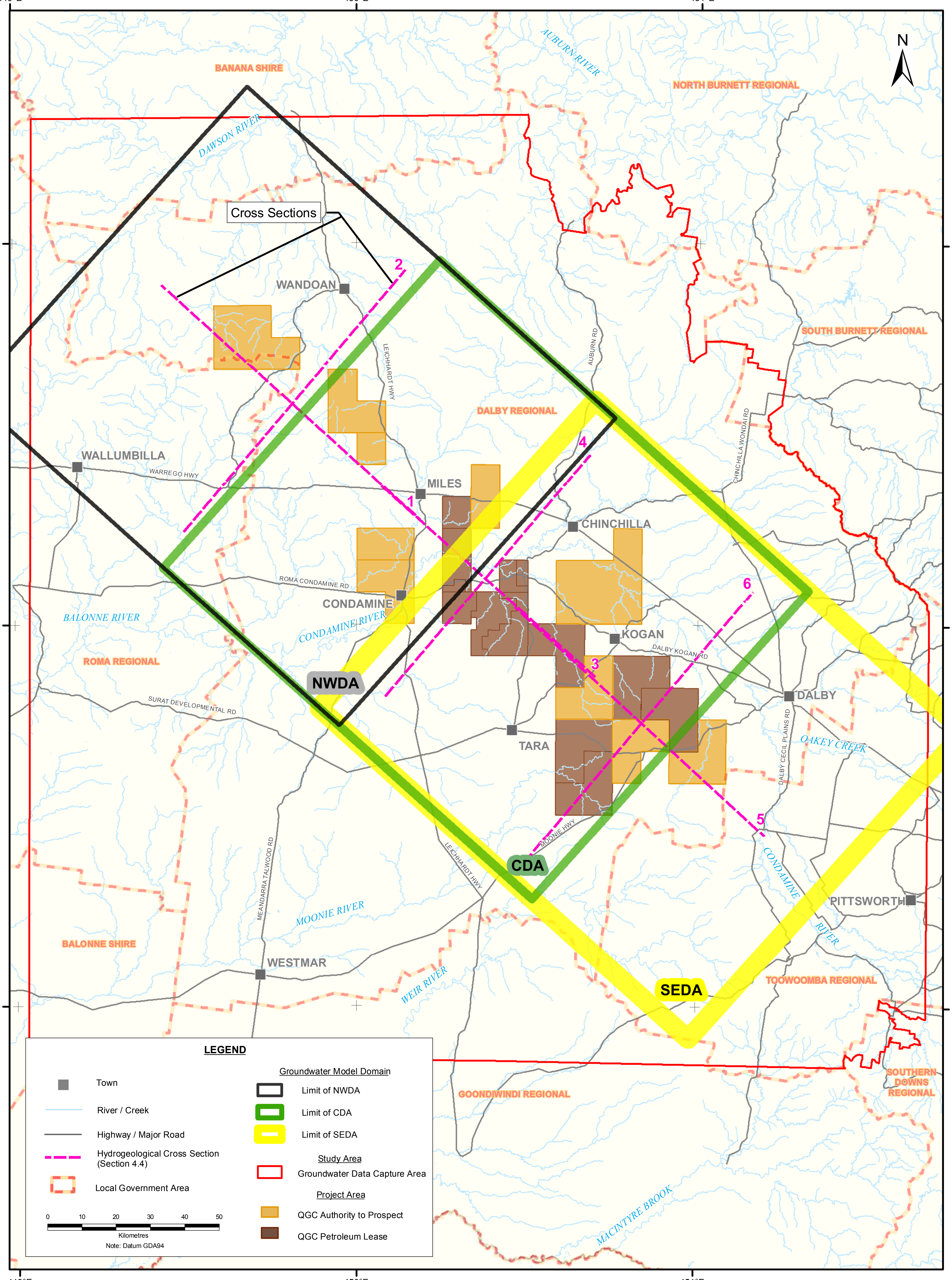
Figure 3 presents the location of the petroleum leases, the study area and the full extent of the groundwater model domains. It encompasses the location of the NWDA, CDA, and SEDA development areas (and the associated petroleum leases held by QGC) considered in the preparation of the groundwater models and the groundwater impact assessment.

QGC's petroleum leases within the Surat basin are listed in Table 2.

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

SEDA	CDA	NWDA
ATP 648	ATP 647	ATP574
PLA259	ATP 676	ATP 651
PLA261	PL179	ATP 632[3]
PLA262	PLA180	
PLA269	PL201	
PLA257[2]	PLA211	
	PLA212	
	PL228	
	PL229	
	PLA247	
	PLA263	

1. ATP for Authority to Prospect, PL for Petroleum Lease, and PLA for Petroleum Lease Application,
2. PLA257 is partially located in both CDA and SEDA
3. ATP632 is partially located in both CDA and NWDA



Notes:
1. Base map data copyright Mapinfo Australia Pty Ltd
2. Authority To Prospect & Petroleum Leases data supplied by Queensland Gas Company (QGC), dated 15-10-2008 and 23-10-2008.

Golder Associates

CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN	PB/DK/BQ	DATE	10-06-09
CHECKED	RKH *	DATE	10-06-09
TITLE	GROUNDWATER AND SURFACE WATER STUDY AREAS		
SCALE	1:1,050,000	PROJECT No	087633050_016
FIGURE No	3	REV No	2
A3			

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0003_Rev2_Study Area_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

1.8 Previous and Related Studies

Several regional studies of the hydrogeology of the GAB are available (Cox and Barron, 1998; GABCC, 2000, Habermehl, 2000; DNRM, 2005) which focus on describing the importance of the GAB as a water resource. Most studies focus on the geology and stratigraphy and define aquifers and recharge areas within the GAB. These studies were funded or authored by governments, and their purpose was to provide technical tools for the management of various parts of the GAB.

In recent years, the significant development of the CSG operations and the associated extraction of water from the Walloon Coal Measures (WCM) have raised concerns about the potential impacts of CSG extraction within the GAB (Parsons Brinckerhoff (PB), 2004). In 2004, the Qld Department of Natural Resources Mines and Energy (DNRM), now Department of Natural Resources and Water (NRW), funded a study to assess the potential impacts arising from CSG operations in the GAB (PB, 2004). This report provided an overview of potential impacts arising from CSG operations within the Surat area, including a brief summary of potential impacts to groundwater resources.

A list of the previous groundwater studies is provided in Table 3 which follows.

Table 3: List of Previous and Relevant Studies

Reference	Source	Content
Kellet, K.R. et al., 2003. Groundwater Recharge in the Great Artesian Basin Intake Beds, Queensland, Bureau of Rural Sciences, Queensland Government Natural Mines and Resources, Brisbane.	NRW	Report on groundwater recharge in the Great Artesian Basin (GAB) to quantify recharge rates for the development of Groundwater Management Plans and policies of groundwater within its sustainable yield throughout intake beds.
Cox, R. and Barron, A., 1998. Great Artesian Basin. Resource Study., The Great Artesian Basin Consultative Council.	NRW	Great Artesian Basin Resource Study describing the nature of the GAB, extraction of water from the GAB and the impacts of extraction, existing arrangements for groundwater management, and significant issues for groundwater management within the basin
Cox, R. and Barron, A., 1998. Great Artesian Basin. Resource Study Summary., The Great Artesian Basin Consultative Council.	NRW	Resource study summary for the GAB
Cox, R. and Barron, A., 1998. Great Artesian Basin. Strategic Management Plan, The Great Artesian Basin Consultative Council.	NRW	Strategic Management Plan for the GAB to maximise the benefits the community obtains from the use and existence of GAB water resources while minimising the adverse impacts associated with its use
Queensland Department of Natural Resources, 2005. Hydrogeological Framework Report for the Great Artesian Basin Water Resource Plan Area.	NRM	This Report provides an overview of the hydrogeology of the Basin and details: • The establishment of framework for the management of water; • The establishment of “Management Areas”; • The establishment of “Management Units”; • The estimation of current use, entitlements and demand; • The extent of groundwater dependant ecosystems; • The impact of past and current development and management responses; • The proposed management arrangements.
Bowman, A. and Davis, K., 2004. Coal seam gas (CSG) Water management study, Parsons Brinckerhoff.	NRM	Report identifying some issues and concerns relating to the potential groundwater impacts and water management options of the CSG industry.

Reference	Source	Content
Scott, S., Anderson, B., Crosdale, P., Dingwall, J. and Leblang, G., 2004. Revised geology and coal seam gas characteristics of the Walloon Subgroup - Surat Basin, Queensland, PESA Eastern Austalasian Basins Symposium II, Adelaide.	QGC	Article detailing the stratigraphy and gas characteristics of the Walloon Coal Measures
Department of Mines and Energy, 1997. The Surat and Bowen Basins South-East Queensland.	DME	Geological and resource information
Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) 2007, Report on Groundwater Assessment. Berwyndale and Argyle Gas Fields – Surat Basin. Prepared for Queensland Gas Company Pty Ltd. Brisbane, QLD, January 2007.	QGCI	Quantitative assessment of the groundwater volumes produced through the extraction of coal seam gas at QGC gas fields in the Surat Basin
The Australian Natural Resources Atlas, 2005, Australian Government Department of the Environment and Water Resources.	ANRA	Detailed reports and assessments based on data collected for the NLWRA 's 2000 Australian Water Resources Assessment, including water availability, allocation and use, management and development, and Australia's water quality
Quarantotto. P., 1989. Hydrogeology of the Surat Basin, Queensland, Queensland Government, Record 1989/26.	QGC	Summary of the quality, quantity and movement of groundwater within the Surat Basin.
Welsh. W. D., 2006. Great Artesian Basin transient groundwater model. Australian Government, Bureau of Rural Sciences.	BRS	This study describes the development of a time-varying numerical model for the prediction of effects on pressure heads of chance to bore discharge rates. Used for hydrogeological parameter sourcing for this studies numerical model.

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. This section aims to discuss the key Queensland and National legislation requirements in relation to the extraction of groundwater from deep aquifers, management of associated water, and the implications for the proposed Project.

2.1 Legislative Drivers

The relevant legislation assessed for this report includes:

- *Water Act 2000;*
- *Water Resource (Great Artesian Basin) Plan 2006* and Great Artesian Basin Resource Operations Plan 2007;
- *Petroleum Act 1923;*
- *Petroleum and Gas (Production and Safety) Act 2004;*
- *Queensland Coal Seam Gas Water Management Policy 2008;*
- *Water Supply (Safety and Reliability) Act 2008;*
- *Environmental Protection Act 1994;*
- *Environmental Protection (Water) Policy 1997;*
- *Management of Water Produced in Association with Petroleum Activities (associated water), December 2007;*
- *Water Resource (Condamine and Balonne) Plan 2004 and Condamine and Balonne Resource Operations Plan 2008;*
- *National Water Initiative;*
- *Water Resource (Moonie) Plan 2003;*
- *Water Resource (Fitzroy Basin) Plan 1999; and*
- *Water Fluoridation Act 2008.*

This chapter provides the main elements of the legislation or planning policy for managing groundwater in Queensland.

QGC activities in their Surat Basin tenements are also subject to the requirements of Environmental Authorities (EAs) delivered by the Queensland EPA. The specific requirements of EAs issued to QGC for the various activities conducted in their petroleum leases were assessed and incorporated into the Water Monitoring Plan (Golder, 2009 [Draft]).

Table 4 summarises the main elements of the legislation for the use of water by the petroleum industry in Queensland. Each element is discussed in the following sections.

2.2 Water Act 2000

The *Water Act 2000* vests the use and control of all water in Queensland in the state. The Act was developed to provide for the sustainable management of water and other resources and the establishment and operation of water authorities, and for other purposes.

The *Water Act 2000* states that a water licence is required in order to take water or interfere with the flow of water (Section 204) and to provide for any use other than domestic and stock watering (Section 206, 206A). The decision made regarding taking or interfering with the flow of water is to be in accordance with the relevant water resource plan (WRP). Thus, associated water, once it comes to the surface (and is not being used for stock or domestic purposes) will be managed by the Water Act and the appropriate WRP such as the *Water Resource (Condamine and Balonne) Plan 2004*. Water resource plans regulate taking water from all surface water bodies which includes rivers, lakes and runoff.

A water licence under the Water Act 2000 is subject to conditions. Under Section 214 (e) a water licensee is required to carry out and report on a stated monitoring program. No details on requirements of a monitoring program are provided in the Water Act.

A petroleum tenure holder may apply for a water licence only if the water is 'associated water' under the *Petroleum and Gas (Production and Safety) Act 2004* and the water is not being used, or proposed to be used, for an activity that, under the P&G Act, is an authorised activity for the tenure (Section185(5)). If a water licence is granted to a petroleum tenure holder, there may be a requirement under Section 214 (e) to carry out and report on a stated monitoring program.

The Water Act sets out the requirements for a transmission water licence, required by a relevant authority for a recycled water scheme (Section 212A).

2.3 Water Resource (Great Artesian Basin) Plan 2006

The *Water Resource (Great Artesian Basin) Plan 2006* is the key legislation for managing groundwater of the GAB in Queensland. It is designed to define the availability of water (either artesian, sub-artesian, or springs) in the GAB and provide a framework for sustainably managing water or the taking of water within the Basin. It also aims to identify priorities and mechanisms for dealing with future water requirements. Re-injection of water into aquifers is not currently defined in the plan.

The plan is concerned with allocating and managing groundwater for current users; storing water in aquifers for future generations; and protecting the flow of water to springs and baseflow to watercourses that support significant cultural and environmental values (Section 8). Water licenses for water associated with oil and gas extraction under the *Petroleum and Gas (Production and Safety) Act 2004* are excluded from the allocation and management of water in the plan area where the goal is not to increase the average volume of water taken (Section 10).

Section 12 of the plan states that a water license granted for taking water must be consistent with the criteria for the protection of the flow of water to springs and baseflow to watercourses stated in the resource operations plan (Section 2.4 of this report). The resource operations plan must contain criteria for the protection of the flow of water to springs and baseflow to watercourses (Section 31).

Recycled water (Section 18) may be considered as an alternative water source to using unallocated groundwater.

Under Section 30, Miscellaneous Provisions, the Plan provides the following note with regard to Water Licenses which have not had a maximum volumetric condition applied to them: "A water licence, in not stating a maximum volume of water that may be taken, is not inconsistent with this plan if the licence is only -

a) for stock or domestic purposes; or

b) to lower water levels to prevent water entering a mine; or

c) for associated water under the *Petroleum and Gas (Production and Safety) Act 2004*.

The Plan notes that "The chief executive must, during the period this plan is in force, amend the licence [one not stating the maximum volume], under Section 217 of the Act, to state a volumetric limit.

The Plan provides for an obligation for a measuring device to be used to measure the volume of water taken, unless the water is for stock or domestic purposes (Section 36). The monitoring requirements for this plan include:

- monitoring artesian water pressure and subartesian water levels;
- monitoring the flow of water to springs and baseflow to watercourses; and
- monitoring water use.

The monitoring requirements are to be achieved by monitoring programs administered by relevant State agencies; and if a water licence requires the holder of the license to carry out a monitoring program—the program must be carried out by the holder.

Schedule 2 sets out the management areas for the plan area. This project is within the Surat (19), Eastern Downs (24), Surat East (21) and Surat North (20) management areas as discussed in Section 1.4.2.

2.4 Great Artesian Basin Resource Operations Plan 2007

The Great Artesian Basin Resource Operation Plan 2007 identifies groundwater management areas and management units within each management area. A 'unit' corresponds to a formation or a group of formations[2]. For each unit a specified upper annual take (or allocation) of water has been allocated under the plan. From time to time, NRW may see fit to announce a reduced allocation, typically as a percentage of the full allocation although other rules may also be imposed.

There is currently a moratorium for granting of further groundwater licences within this region. The area comprises the area of the Condamine River Catchment excluding the area under the moratorium for the former Toowoomba City Local Government Area.

2.5 Petroleum and Gas (Production and Safety) Act 2004

The *Petroleum and Gas (Production and Safety) Act 2004* (P&G) considers the underground water taken or interfered with from a petroleum well to be called 'associated water' (Section 185). It requires the production of a water impact report, defines uses of associated water, monitoring requirements and 'trigger' values.

Under Section 185 of the P&G Act, a petroleum tenure holder may take or interfere with the groundwater *if* it is taken during the course of, or results from, the carrying out of an authorised activity. Otherwise the petroleum holder must not take or interfere with or use water as defined under the Water Act, unless it has been authorised under the Water Act. This water is referred to as "associated water".

2 These units should not be confused with the Groundwater Management Units defined by Australian Natural Resources Atlas, which define the areal boundaries for reasons such as protection of town water supplies and to enable legislative control of groundwater in response to various development pressures.

2.5.1 Associated Water Use

A petroleum tenure holder can use associated water for domestic or stock purposes on the land in the area of the tenure or land that joins land in the area of the tenure and is owned by the same person (Section 186). If the tenure holder wants to use associated water for another purpose, the holder must obtain a water licence under the *Water Act 2000*. The water extraction rights for or during petroleum purposes as defined in the P&G Act include:

- taking water when drilling a bore, however, the bore construction must comply to the regulation and be completed as a water supply bore;
- no limit to the volume of water that may be taken (Section 185 (3)); and
- the associated water can be used for the authorised mining activity or for domestic and stock purposes on the land covered by the tenure and adjoining land or by any land owned by the land owner (Section 186).

2.5.2 Monitoring Associated Water

Section 187 of the P&G Act, further identifies the requirements for water monitoring for associated water. Water monitoring is required for assessing compliance with the tenure. The following requirements are set out under this Act:

- gathering information about, or auditing an existing Water Act bore (termed a water monitoring activity). (An existing Water Act bore for a petroleum tenure is a water bore as defined under the Water Act if taking of or interference with water from the bore is authorised under the Water Act; it required a development approval under the *Integrated Planning Act 1997*; and the bore was in existence prior to the start of approved testing for petroleum production or the start of commercial production);
- gathering information for an underground water impact report, pre-closure report, monitoring report or review report;
- monitoring the effect of the exercise of the underground water rights for the tenure;
- constructing or plugging and abandoning a water observation bore; and
- carrying out restoration measures in relation to an existing Water Act bore for which the make good obligation applies.

A petroleum tenure holder may also apply for a water monitoring authority (Section 190), which may include land outside the tenure area to allow the holder to comply with the tenure requirements. This allows the authority holder to carry out any water monitoring activity, but not water transmission, treatment or sales activities, in the area of the authority (Section 194). For example, permitted activities include gathering information about, or auditing an existing Water Act bore.

2.5.3 Water Impacts and Impact Reporting

If the exercise of a petroleum tenure holder's underground water rights unduly affects an existing Water Act 2000 bore, then the tenure holder must (see Sections 250 to 251 of the P&G Act, and Sections 165B of the Petroleum Act) either take measures to restore the supply of water to the owner of the bore, or compensate the owner of the bore being unduly affected. These "make good obligations" provide for a continuation of the requirement to make good even if the bore was first unduly affected by the exercise of underground water rights after the term of the petroleum tenure expires.

The P&G Act provides for spatial consideration, namely, the impact could be on bores within the area of the petroleum tenure, or, the impact could be detected on bores outside of the area of the petroleum tenure. In either case, a bore is regarded as being "unduly affected" when either:

- the water level in the bore drops below a set *trigger threshold* for the relevant aquifer; or
- the bore is recognised as having "*impaired capacity*".

Section 247 of the P&G Act provides a definition of "impaired capacity" as follows: a bore is generally recognised as having "impaired capacity" in the following circumstances:

- In the case of a bore for domestic purposes: where the bore is no longer able to provide a reasonable supply of water for the domestic purpose required at the location; and
- In the case of a bore for stock purposes: where there is a material reduction in the number of stock able to be watered from the bore (having regard to the stock carrying capacity of the land serviced by the bore); or
- Under a water licence: where there is a material reduction in the pumping supply required to service the relevant enterprise or town water supply.

The holder of the tenure must provide a water impact report of its activities (Sections 252 to 257).

2.5.4 Trigger Values

Sections 252 to 255 of the P&G Act provide a process for the fixing of a trigger threshold for aquifers in the area affected by the exercise of underground water rights for a petroleum tenure. Under those provisions, the trigger level set by the chief executive of the Department must be a level the chief executive considers would cause a significant reduction in the maximum pumping rate or flow rate of the existing bores in the area.

That is, the legislation does not specify maximum drawdown of groundwater levels or water extraction limits. Instead, the P&G Act requires the fixing of a "trigger threshold" for aquifers in the area affected by the exercise of underground water rights for a petroleum tenure in order to prepare an underground impact report for the tenure. Section 253 states that "*The petroleum tenure holder may ask the chief executive what the trigger threshold is for the aquifers".* The trigger value is defined as "*the water level drop in the aquifers that the chief executive considers would be a level that causes a significant reduction in the maximum pumping rate or flow rate of the existing Water Act bores in the area affected by the exercise of the underground water rights."* (Section 254(1) of P&G Act). Hydraulic conductivity, geometry and water levels of the aquifers are defined as the criteria to be considered in the definition of the trigger value.

No time value over which the pumping is performed to create the associated impact is mentioned in the P&G Act. However, the length of time used to estimate the drawdown is critical to the establishment of a trigger value. The length of time for evaluation of triggers should also consider:

- the regime of the pumping (intermittent, continuous); and
- the total length of time over which the pumping will take place.

When the trigger value fails to incorporate the notion of time, its value becomes meaningless as it will not characterise the range of impacts of groundwater extraction on the aquifers.

2.6 Queensland Coal Seam Gas Water Management Policy 2008

The Queensland Government recently developed a water management policy framework for the CSG industry to address the potential environmental risks associated with the anticipated expansion of CSG activity in the major Queensland basins (October 2008). The expansion of CSG production in Queensland will result in a significant imbalance between the volume of produced CSG water and demand by potential users. The purpose of the new policy is 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;
- Re-injection of associated water is promoted as the *preferred management option;*
- If re-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 responsible for treating and disposal of produced water. Unless CSG producers have arrangements for injection and reuse of untreated CSG water, associated water must be treated to a standard defined by EPA before disposal (re-injection) or supply to other water users;
- Aggregation of surplus associated water will be considered as a last option where no feasible alternative management option exists. Details regarding aggregation and disposal of surplus water are still under development, but will likely require a significant financial commitment to be borne by the participating members of the CSG industry; and
- A CSG *Water Monitoring Plan* (WMP, in preparation) is to be incorporated in the Environmental Management Plan (EMP) required for Level 1 Environmental Authority (EA) applications.

A flowchart of the new management framework is presented Figure 4 below.

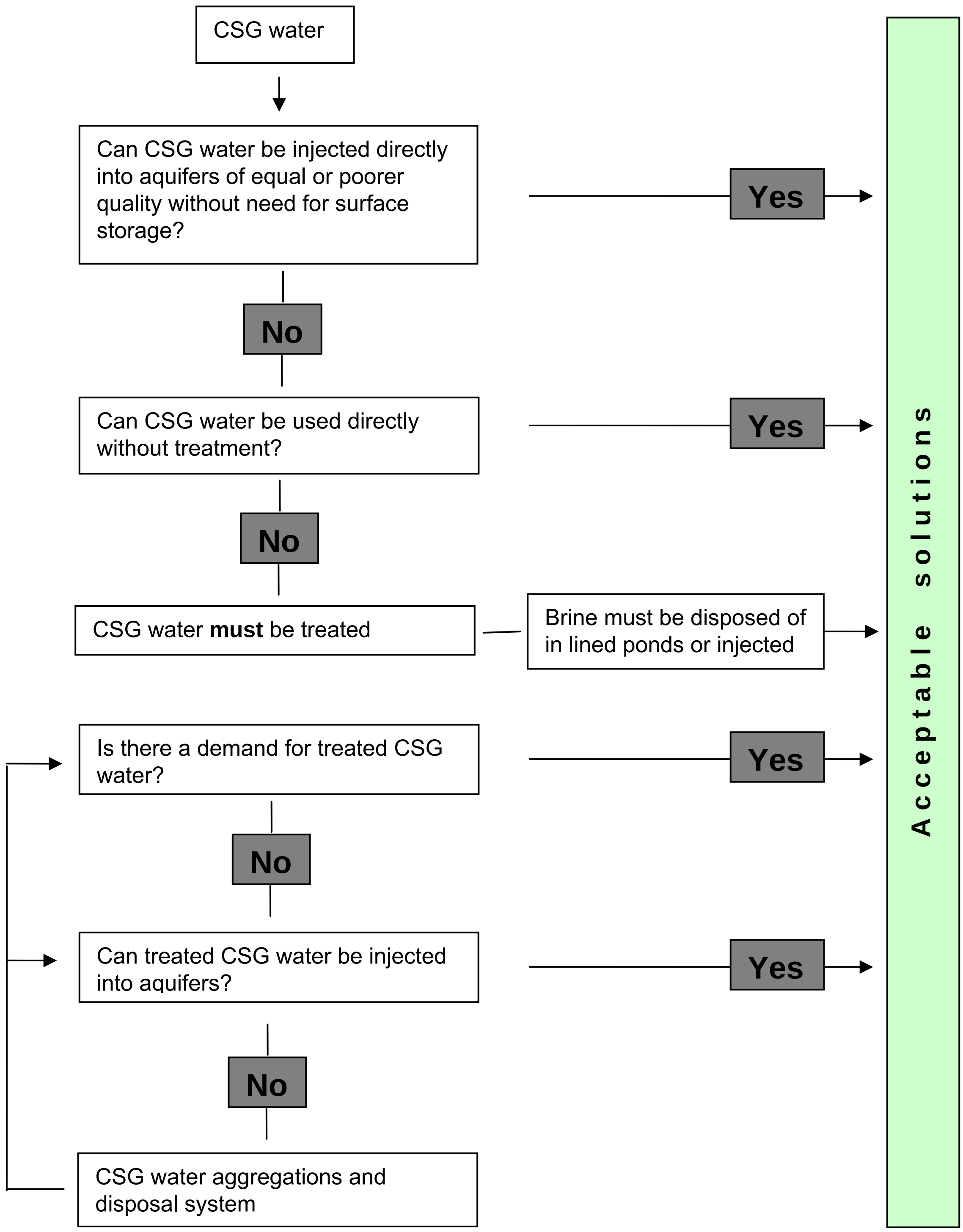


Figure 4: Queensland CSG Management Framework

2.7 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.

It defines recycled water as waste water and it defines manufactured water as water, including desalinated or recycled water or any substance resulting from the production of desalinated or recycled water.

The act also outlines who must apply for registration as a service provider and what the requirements are for a service provider. This Act may become important if the groundwater is to be reused for a beneficial use.

2.8 Environmental Protection Act 1994

Sections of the *Environmental Protection Act 1994* (EP Act) relevant to the project are:

- Section 7 of the *EPA Regulations – Regulated Wastes*, defines “saline effluent and residues” as “regulated waste” for the purposes of the *Environmental Protection Act 1994*;
- Section 9 of the EPA Regulations defines “regulated waste” to mean non-domestic waste mentioned in Schedule 7 (whether or not it is treated or immobilised), and includes:
  - for any element – any chemical compound containing the element; and
  - anything that has contained the waste.

  Under the *Environmental Protection Act 1994*, “regulated waste” is required to be contained. Hence the reason it needs to be contained in environmental ponds on the tenement.
- Sections 14 to 17 of the (EP Act) which defines environmental harm, environmental nuisance, material environmental harm and serious environmental harm. Environmental harm is any adverse effect, or potential adverse effect on an environmental value;
- Section 18 which classifies petroleum activities as environmentally relevant activities;
- Sections 77 and 78 outline what constitutes a petroleum activity. It includes:
  - activities required under a condition of an “Environmental Authority” (EA) – see below;
  - rehabilitating or remediating environmental harm caused, for example, by conveying petroleum resources.
- Section 98 may impose conditions on a petroleum activity (i.e. under an EA). Under the act the, Environmental Protection Agency (EPA) may:
  - ask the petroleum activities to prepare environmental reports and prepare and carry out environmental programs;
  - report on monitoring programs;
  - limit the petroleum activities holder to change, replace or operate any plant if the action can substantially increase the risk of environmental harm;
  - order the activity to cease or be put on hold.

  Conditions may be imposed and continue to apply after the EA has ceased.

Environmental Authorities (EA) are *a set of conditions with which a company must comply*. EAs are required under the *Environment Protection Act 1994* and the *Petroleum and Gas (Production and Safety) Act 2004*.

Petroleum activities are classified as either level 1 or level 2 environmentally relevant activities (ERAs). ERAs require a corresponding EA (petroleum activities) under the *Environment Protection Act 1994*.

- Level 2 activities are petroleum activities that have a low risk of environmental harm and they must comply with the standard environmental conditions; and
- Level 1 activities are prescribed in the schedule of the *Environment Protection Regulation 1998*. Level 1 ERAs require site specific environment management plans as part of the EA.

A number of the EAs have been issued to QGC. The main EA for the Project is number 150161.

A CSG Water Monitoring Plan (WMP) is to be incorporated in the Environmental Management Plan (EMP) required for Level 1 Environmental Authority (EA) applications.

2.9 Environmental Protection (Water) Policy 1997

This act has particular relevance to associated water use, either by on-site storage, beneficial use, treatment, discharge to surface water, and/or re-injection, as summarised below:.

The purpose of the *Environmental Protection (Water) Policy 1997* is to provide a framework for:

- identifying environmental values for Queensland waters;
- deciding and stating water quality guidelines and objectives to enhance or protect the environmental values;
- making consistent and equitable decisions about Queensland waters that promote efficient use of resources and best practice environmental management; and
- involving the community through consultation and education and promoting community responsibility.

The *Environmental Protection (Water) Policy* identifies environmental values for watercourses though no specific guidelines refer to the watercourses within the Project Area. Where no specific guidelines relate, the *Environmental Protection (Water) Policy* states that the following documents are to be used to identify the environmental values of the watercourse:

a) site specific documents

b) the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC 2000)

c) documents published by a recognised entity.

The main sections of the *Environmental Protection (Water) Policy* relevant to the Project relate to associated water[3] recycling, water releases on land, water releases to surface water and stormwater management. In each case the administrating authority must consider the existing quality of waters that may be affected, the cumulative effect of the release in question, the water quality objectives for waters affected and the maintenance of acceptable health risks.

3 NOTE: The *Environmental Protection (Water) Policy 1997 classifies CSG associated water as* "waste water"

Section 7 sets out the environmental values for waters. The waters for this project are not listed in Schedule 1 which sets out environmental values for those waters. Section 8 and 9 set out the indicators for environmental values.

The direct release of water to surface water and to groundwater is regulated under Sections 15 and 16. There is a management four step hierarchy that sets out how waste water release will be allowed. It establishes the requirements for waste water treatment; waste water recycling options; and disposal to groundwater. Where there will be a release of waste water or contaminants to water; Section 16 provides the management intent for high ecological value waters; slightly to moderately disturbed waters; and highly disturbed waters.

The release of water to surface water is only permitted after an assessment of the water quality and the impact of mixing the released water with the existing water quality. The Environmental Protection Agency (EPA) may control the releases. The release of water to groundwater is only permitted after an assessment of the impact on the environment and will only be allowed under certain aquifer conditions.

This Act has a monitoring component (S 26) relating to monitoring the release of waste water on land or into water. The administering authority would decide on the level of monitoring dependant on the activity, the risk of harm to environmental values, and the frequency needed.

Impact monitoring may also be required (S 27) if an administering authority is making an appropriate decision about an activity involving a release or potential release of waste water.

Section 21, which regulates the accidental release of water to the groundwater, requires that infiltration of release water to soil and groundwater is minimised or prevented and any release or potential release monitored against site baseline conditions.

2.10 Management of Water Produced in Association with Petroleum Activities (associated water), December 2007

The EPA released an operational policy to be used when determining management practices under the Environmental Protection Act 1994 for water produced in association with petroleum activities. The aim of the policy is to promote the beneficial use of associated water from petroleum activities in Queensland, in accordance with the principles set out in the EPA's Environmental Protection (Waste Management) Policy 2002. The policy objectives include the promotion where feasible, of beneficial use (reusing or recycling) or injection of water in preference to the usual disposal options, which have largely been evaporation ponds. The policy applies to all new applications for non-code compliant environmental authorities (petroleum activities).

To facilitate the beneficial use of associated water, the EPA has granted a general approval under Section 66F Environmental Protection (Waste Management) Regulation 2000 (Waste Regulation) for the use of associated water of certain types. If the associated water complies with the conditions outlined in the notice, it is not classified as a waste and can be reused in accordance with the conditions in the notice. The policy provides direction on the preferred methods of handling associated water, which can include treated options, non-treated options (direct use or reinjection). However, the chosen management option must comply with the conditions of the notice, otherwise an application must be submitted for a resource approval for beneficial use.

The conditions of the general approval include water quality criteria for the different types of water uses, limitations of the different water uses, maintenance and release obligations, and the responsibilities of both the producer and the user.

The producer of the water must only release the water to a user who has certified in writing that that user is going to use the resource for one or more of the following:

- irrigation;
- stock (drinking water) and domestic;
- aquaculture;
- drinking water;
- dust suppression; and
- landscaping and revegetation.

The user must have appropriate facilities at the site where the water is to be used. If the associated water is to be used for purposes other than domestic or stock purposes, the holder must obtain a water licence under the *Water Act 2000*. This policy provides significant potential benefits to CSG producers, however such producers need to ensure they comply not only with the terms of their environmental authorities and the policy, but also legislation that regulates water and water related infrastructure, such as the *Water Act 2000* and the *Integrated Planning Act 1997*.

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.

2.11 Water Resource (Condamine and Balonne) Plan 2004

The Water Resource (Condamine and Balonne) Plan 2004 defines the availability of water in the Condamine and Balonne catchments and regulates the taking of water from all surface water bodies that include rivers, lakes, runoff and overland flow. The Water Resource Plan (WRP) defines the regulatory requirements and the amount of surface water for use in the relevant plan area. The WRP may pertain to associated CSG where it will be stored in dams, or other reservoirs within the plan area (but does not provide specific allocations to CSG operations).

The plan identifies surface water monitoring requirements relative to the quantity and quality of the water, and its associated natural ecosystems.

The purpose of the WRP for the Condamine and Balonne is to:

- define the availability of water in the plan area;
- provide a framework for sustainably managing water and the taking of water;
- identify priorities and mechanisms for dealing with future water requirements;
- provide a framework for establishing water allocations;
- provide a framework for reversing, where practicable, degradation that has occurred in natural ecosystems, including, for example, stressed rivers; and
- regulate the taking of overland flow water.

The Water Resource (Moonie) Plan 2003 and the Water Resource (Fitzroy Basin) Plan 1999 also operate within the Project Area. They both have similar purposes to the Condamine and Balonne WRP.

2.11.1 Condamine and Balonne Resource Operations Plan 2008

This plan provides the method to implement the day to day management requirements contained in the *Water Resource (Condamine and Balonne) Plan 2004*. This plan applies to surface watercourses; lakes; springs connected to artesian water or subartesian water which is connected to artesian water; and overland flow. It deals with water supply schemes; water management areas and resource operations plan zones. It also manages the water licences allocated under the *Water Act*.

2.11.2 Water Resource (Fitzroy Basin) Plan 1999

The Water Resource (Fitzroy) Plan 1999 defines the availability of water in the plan area and regulates the taking of water from all surface water bodies (rivers, lakes) and runoffs. Groundwater in the Surat Basin is not managed under the Fitzroy Basin WRP, although there is an intention to include groundwater when the plan is reviewed. However, groundwater in the Fitzroy basin area is already managed through declared sub artesian areas. In these areas, a water license is required for all groundwater extraction, except for stock and domestic use. Groundwater is not managed outside the declared areas (i.e. no license required).

2.12 National Water Initiative (NWI)

The NWI represents a shared commitment by the Commonwealth and State Governments to:

- prepare water plans with provision for the environment;
- deal with over-allocated or stressed water systems;
- introduce registers of water rights and standards for water accounting;
- expand the trade in water;
- improve pricing for water storage and delivery; and
- meet and manage urban water demands.

The project will have an excess of water due to groundwater abstraction. It is therefore possible that it may be able to supply water to an over allocated or stressed water region.

2.13 Water Fluoridation Act 2008

This act sets out the requirements for adding fluoride to relevant public potable water supplies (potable- means water that is intended to be, or is likely to be, used for human consumption.) There are also exemptions to fluoridation outlined. This act may have relevance for beneficial use of associated water where it is likely to be used for human consumption.

2.14 Existing and Anticipated Environmental Authorities (EA)

Environmental Authorities (EA) are *a set of conditions with which a company must comply*. EAs are required under the *Environment Protection Act 1994* and the *Petroleum and Gas (Production and Safety) Act 2004*.

Petroleum activities are classified as either level 1 or level 2 environmentally relevant activities (ERAs). ERAs require a corresponding EA (petroleum activities) under the *Environment Protection Act 1994*.

- Level 2 activities are petroleum activities that have a low risk of environmental harm and they must comply with the standard environmental conditions; and
- Level 1 activities are prescribed in the schedule of the *Environment Protection Regulation 2008*. Level 1 ERAs require site specific environment management plans as part of the EA.

A number of the EAs have been issued to QGC. The main EA for the Project is number 150161.

A CSG Water Monitoring Plan (WMP) is to be incorporated in the Environmental Management Plan (EMP) required for Level 1 Environmental Authority (EA) applications.

2.15 Summary of Legislative Water Monitoring Requirements

As can be seen from the above discussion, the legislation applicable to QGC operations do not, in most cases, provide clear and unambiguous direction as to the location, frequency and parameters for monitoring. Instead they provide guidelines for Project owners to use to develop and manage their own monitoring programs.

Table 4 provides a practical distillation of the guidelines into recommendations for monitoring arising from the legislation.

Table 4: 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 NRW 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 NRW 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 NRW as they are covered by the P&G Act.

Legislation/Section	Driver	Key Points as they Apply to the QGC Operations
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.
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*.

Legislation/Section	Driver	Key Points as they Apply to the QGC Operations
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.

A further discussion of legislative drivers and the Project monitoring requirements is to be provided in the Water Monitoring Plan (Golder, 2009 [Draft]), along with a summary of the Environmental Authorities (EAs), delivered by the Queensland EPA to QGC for their activities in their Surat Basin tenements.

3.0 STUDY METHODS

The groundwater assessment study has 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 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 provided in the sections which follow. 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.

3.1 Sources of Data

Data used in the groundwater portion of the study were made available to Golder by:

QGC: A data request was distributed to QGC at the commencement of the project and is presented in Appendix B. The information is confidential and has not been reproduced directly in this report.

NRW: The Department of Natural Resources and Water (NRW) were the main source for supplying bore data. The data supplied by QGC for bores and wells was limited. No responsibility is taken by Golder for data interpreted by QGC and NRW.

Once the study area was defined, digital bore data was requested from NRW. This bore data included bore locations, groundwater levels, groundwater quality, aquifer thickness, depth to top of aquifer, and lithological logs. Abstraction and allocation data were obtained from the NRW Water Entitlements Registration Database (WERD).

AGE: Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) also provided some data and references.

Complementary documentation was sought from literature review and previous reports. A data request was distributed to QGC at the commencement of the Project and much of the information was made available to Golder. Much of the information received is commercial in confidence and has not been reproduced directly in this report, unless authorisation was provided

Table 5 below provides the list of the available data and it indicates where the data was obtained.

Table 5: List of Available Data

Data	Source	Comment
Bore names & locations	QGC	Data Available
	NRW	Extraction from Groundwater Database
Hydraulic conductivity and storativity of coal seam formations and other formations	QGC	Some estimates of the coal seam permeability available though discussions with QGC reservoir engineers
	Literature Review	Available estimates of hydraulic conductivity for majority of formations (refer to Section 4.4.3.2 and Appendix D)
	AGE	Hydraulic conductivity parameters for the Hutton, Evergreen and Precipice Formations
Water quality data	QGC	Data available as excel spreadsheets. Chemistry data for production wells in the Walloon Formation and surface pond sampling locations was supplied. Water quality for monitoring bores in the Westbourne, Mooga and Gubberamunda units was also available.
	NRW	Data extracted from NRW groundwater database
Interpreted geological sections	QGC	None available
Water levels	QGC	Initial reservoir pressures (prior to testing and production) available for some production wells
	NRW	Data available from groundwater database
Past and current and predicted water use	QGC	Available for selected wells
	NRW	Water use extracted from WERD
Well field estimates for future production and pressures	QGC	Production Forecast document available in excel spreadsheets.
Well completions information	QGC	Available for selected wells
	NRW	Information available in groundwater database
Purpose of well & status	QGC	Data available as excel spreadsheets
Status of well (abandoned, suspended, working, in production)	QGC	Available for selected wells
Property limits /ATP locations	QGC	GIS format – available for this study
Contour map of top/bottom of formations	QGC	Data not available for this study

3.2 Data Collation and Review

The first stage involved assessing the bores and wells located within the study area. Utilising each bore[4] or wells' hydrogeological information, a hydrogeological conceptual model of the study area was developed. 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.

Data were received in many different formats. In some instances, the accuracy of the data provided 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).

3.2.1 Geology and Stratigraphy

The study area is located within the Surat Basin, and a small part of the Clarence Moreton 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 NRW groundwater database and QGC data. The stratigraphic information, made available by QGC, focused on the stratigraphy of the Walloon Coal Measures and the adjoining formations. Using the data, 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).

3.2.2 Water Levels and Water Quality

Water level and water quality data was obtained primarily from the NRW database. QGC data was also utilised and it predominantly covered the Walloon Coal Measures. 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 Walloon Coal Measures (WCM) before well testing or production. These pressures were converted to hydraulic heads and assumed to represent the static condition of the formation. 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

4. 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.

only ranges or generic values are available, and hence the predictive outcomes would not be discernibly affected.

Water level data from the NRW 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 NRW 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 well was open to (screened in).

3.2.3 Bore Construction

Included in the Scope of Works is the requirement to … “review production well designs and assess the potential for groundwater, discharged in association with the CSG extraction process, to mix with shallow aquifers (based on design plans provided by the proponent).”

NRW requires a registered water bore driller to drill water bores. The main intention of this requirement is to minimise (assure against) adverse impacts to aquifer yield and quality from inter-aquifer leakage. Of note is that under the P&G Act, coal seam gas wells may be drilled by non-registered water drillers.

Where available, QGC CSG well construction details were assessed[5] to determine whether the CSG wells, as drilled and constructed by QGC, meet the objectives of the NRW requirements for licence well drillers to perform this work.

3.2.4 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.

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[5] Golder relied on details provided for a previous groundwater impact study (Golder 2007).

As part of the data quality checking process, each piece of bore or well data sourced from the NRW databases and from QGC was assigned a “data quality” *score* or rating for each of the criteria as presented in Table 6 (below). 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.

The data from QGC and NRW was compiled into one comprehensive “metadata table” and two sub-tables. The main metadata table identifies the data available for each well or bore and when available, provides general information for each. The secondary tables provide the water levels and water chemistry data. A summary of the metadata is presented in Table 7.

Available data and their associated score are shown on Figures 5 through 8 as a means of showing the density and quality of the available data considered for this study. The ‘cleaned’ and sorted metadata used in this study, as a result of the data quality checking, is provided on a CD as Appendix C. A summary of the data is provided in Table 8.

Table 6: 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 7: Metadata Summary

Metadata Table	Field	Description
Meta Data Summary Table	Bore Name	Unique name for each bore
	Pipe	Represents casing for NRW bores only. X=no pipe, A= Deepest, B=2nd Deepest, and so on
	Source	NRW, ELP or QGC
	Coordinates	Geographic Datum GDA94, latitude and longitude
	Elevation	In metre AHD
	Area	ATP name – when available
	ATP	ATP number – when available
	Date of drilling	Date of start of drilling
	Hole depth	Drilled depth (in metres)
	Interpreted stratigraphy	Score 1, 2 or 3 (refer to Table 6)
	Opening from/to	Depth of perforation, screen or opening
	Targeted geological unit	Name of targeted formation
	Construction details	Score 1, 2 or 3 (refer to Table 6)
	Water chemistry	Score 1, 2 or 3 (refer to Table 6)
	Water level	Score 1, 2 or 3 (refer to Table 6)
	Purpose	Investigation, core hole, CSG, monitoring well etc.
	Status	Abandoned, suspended, producing, monitoring well, etc.

Metadata Table	Field	Description
Water Levels (Refer to Figure 8)	Bore Name	Unique name for each bore
	Event date	in date format
	Depth to water	In m bgl
	Elevation of Water level	In m AHD
	Formation	Geological formation
	Aquifer group	Shallow Quaternary Alluvium, Shallow, Intermediate, Walloon, Hutton or Precipice
Water chemistry (Refer to Figure 7)	Bore Name	Unique name for each bore
	Event date	Date in date format
	Electrical Conductivity	Electrical conductivity (EC) at 25ºC, expressed in µS/cm
	pH	pH units (-)
	Major Ions	Concentration of major ions in mg/L: calcium, sodium, magnesium, potassium, sulphate, chloride, carbonates
	Formation	Geological formation
	Aquifer group	Shallow Quaternary Alluvium, Shallow, Intermediate, Walloon, Hutton or Precipice

Table 8: Metadata Summary in the Three Development Areas

NRW Bores in CDA

Score	Stratigraphy		Construction		Water Level		Chemistry	
1	255	57%	229	51%	237	53%	84	19%
2	6	1%	83	18%	8	2%	104	23%
3	188	42%	137	31%	204	45%	261	58%

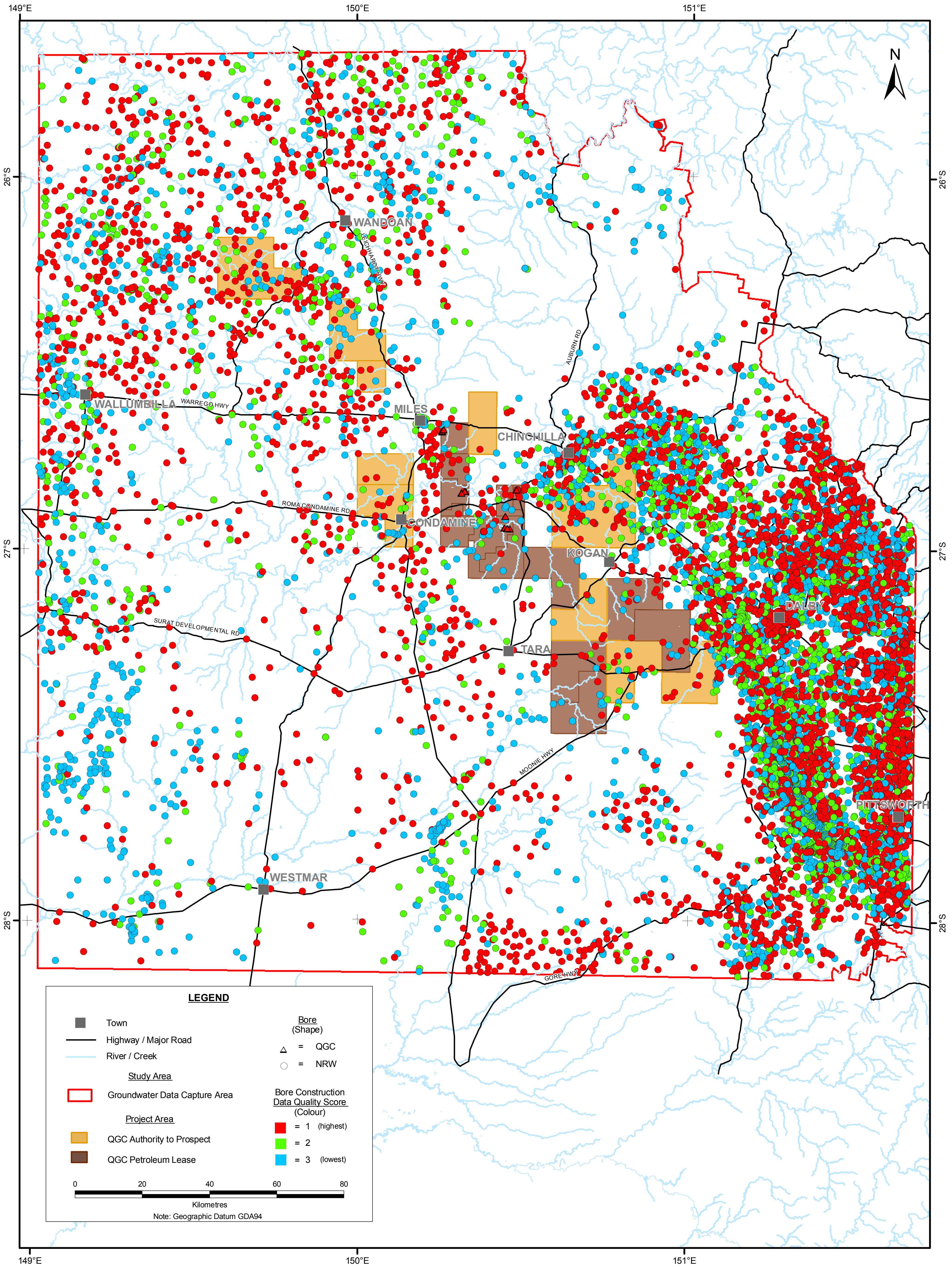
NRW Bores in SEDA

Score	Stratigraphy		Construction		Water Level		Chemistry	
1	215	56%	172	45%	131	34%	69	18%
2	7	2%	88	23%	0	0%	54	14%
3	162	42%	124	32%	253	66%	261	68%

NRW Bores in 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%

In general, half of the registered bores within the three development areas (CDA, NWDA and SEDA) have good stratigraphy and construction information available. Approximately half of the bores have complete water level information (measurement and date); however, only 34% of the bores in the SEDA have complete information. Very few bores (less than 20%) have complete chemistry data.

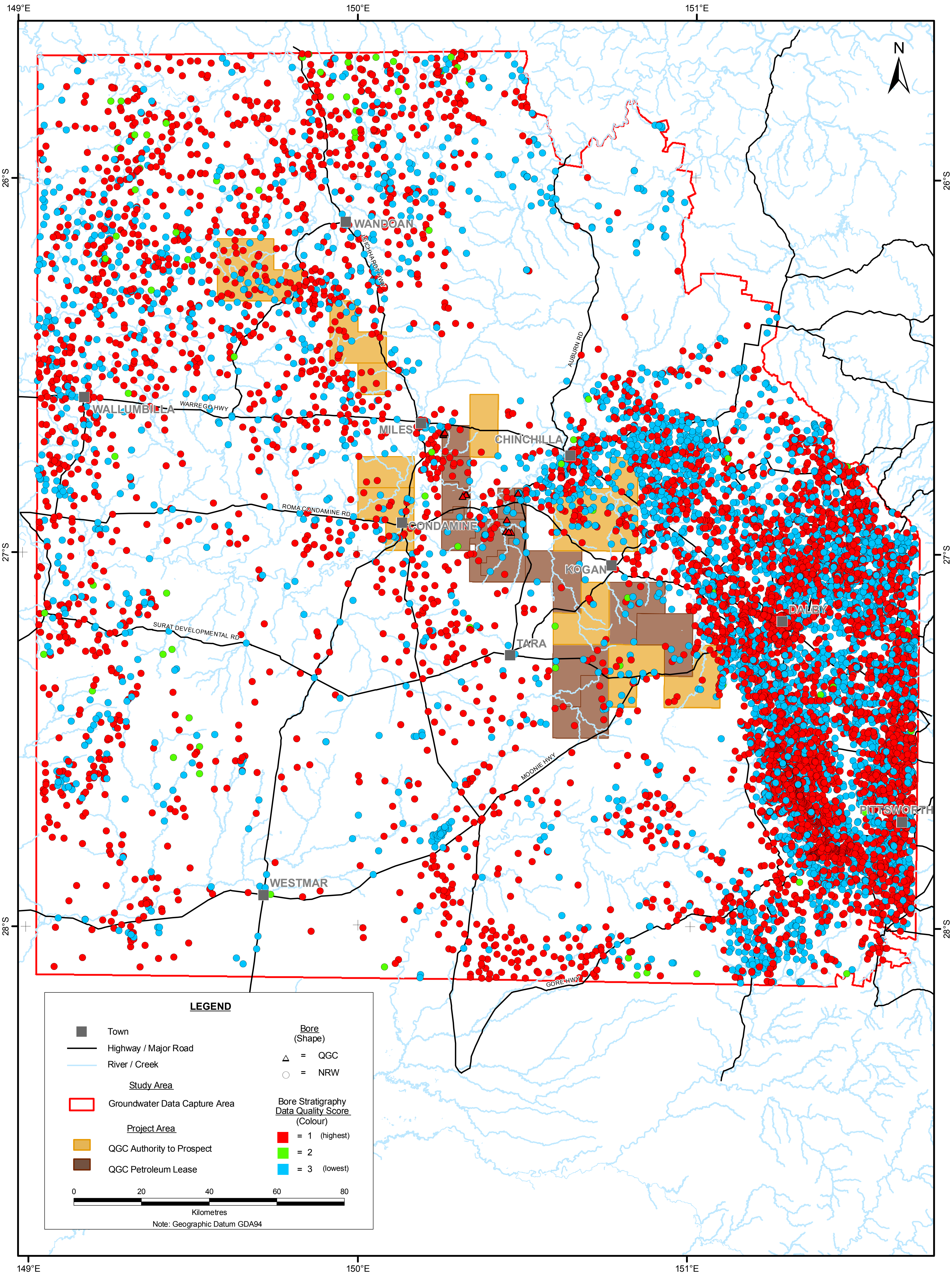


Notes:
1. Base map data copyright Mapinfo Australia Pty Ltd
2. Authority To Prospect & Petroleum Leases data supplied by Queensland Gas Company (QGC), files received dated 17-09-2008.
2. Borehole data copyright the State of Queensland (Natural Resources and Water) and Queensland Gas Company (QGC).

Golder Associates

CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN DK/BQ	DATE 04-06-09	TITLE	LEVEL OF DATA RELIABILITY - BORE CONSTRUCTION DATA
CHECKED RKH *	DATE 04-06-09		
SCALE	1:1,050,000	PROJECT No 087633050_016	FIGURE No 5 · REV No 1 · A3

File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0005_Rev1_DataReliability_BoreConstruction_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



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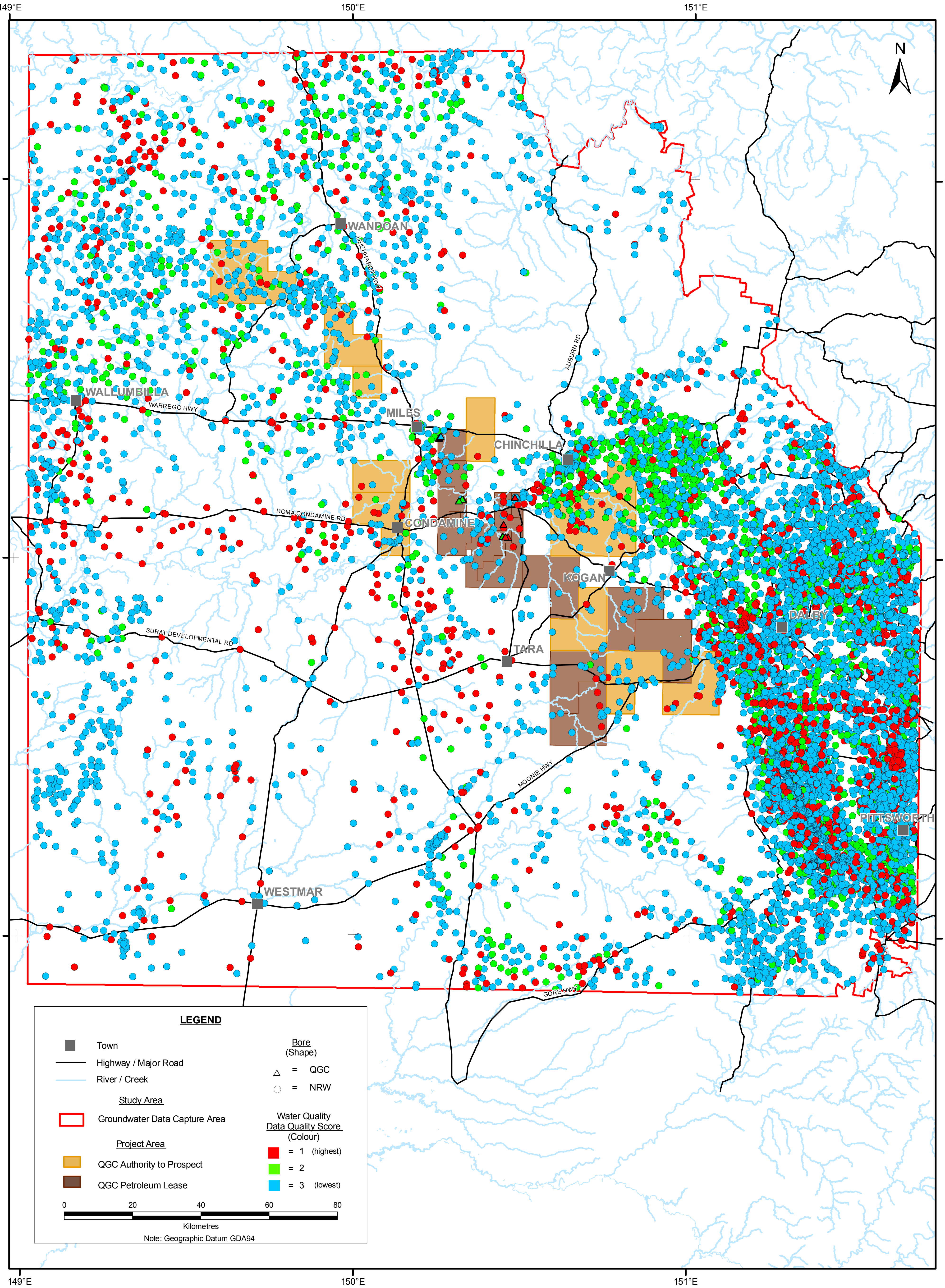
Golder Associates

CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN DK/BQ	DATE 04-06-09	TITLE	LEVEL OF DATA RELIABILITY - BORE STRATIGRAPHY DATA
CHECKED RKH *	DATE 04-06-09		
SCALE	1:1,050,000	PROJECT No 087633050_016	FIGURE No 6 · REV No 1 · A3

File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0006_Rev1_DataReliability_BoreStratigraphy_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



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DRAWN DK/BQ	DATE 04-06-09	TITLE LEVEL OF DATA RELIABILITY - WATER QUALITY DATA	
CHECKED RKH *	DATE 04-06-09		
SCALE 1:1,050,000		PROJECT No 087633050_016	FIGURE No 7 / REV No 1 / A3

File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0007_Rev1_DataReliability_WaterQuality_A3.mxd
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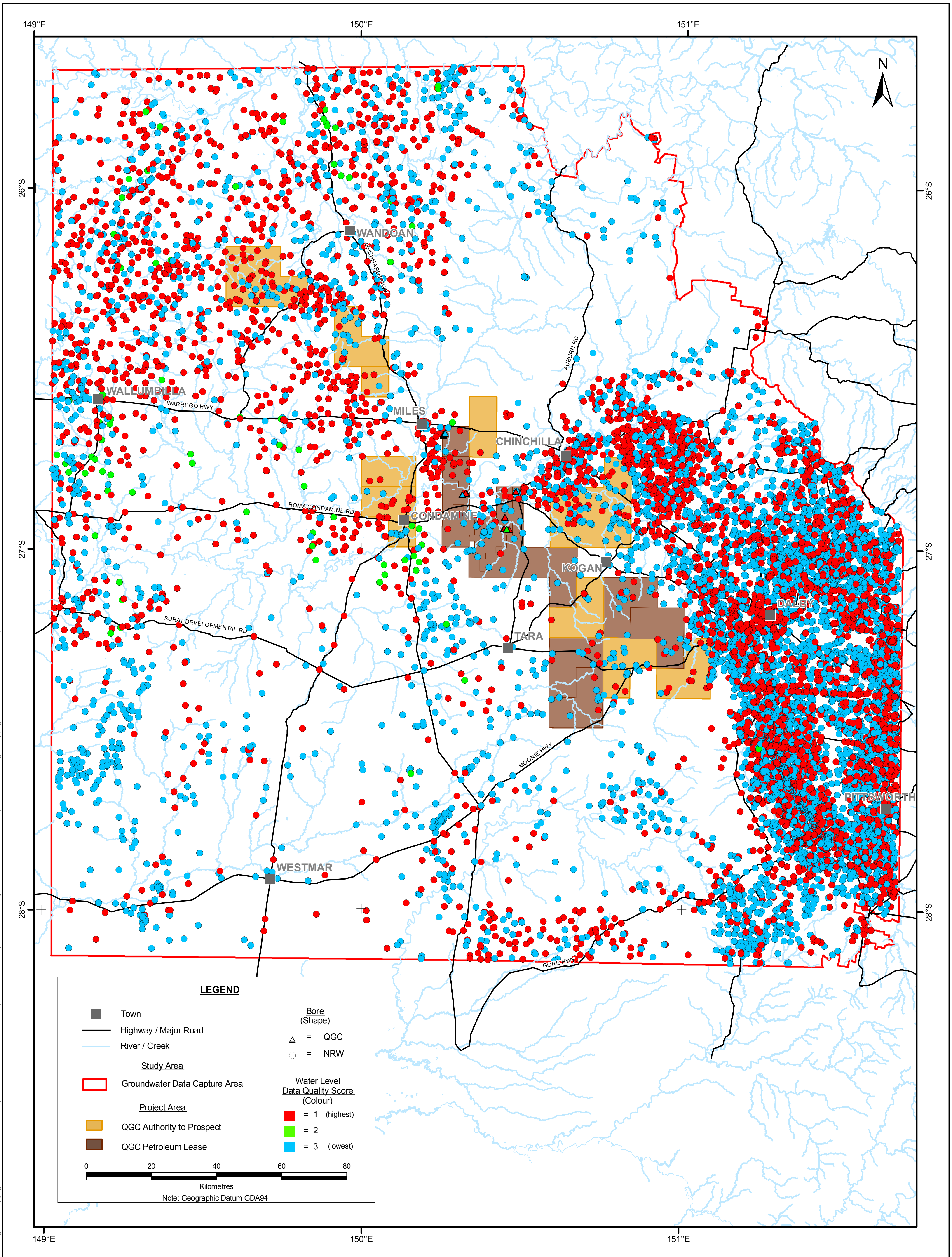

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DRAWN DK/BQ	DATE 04-06-09	TITLE	LEVEL OF DATA RELIABILITY - WATER LEVEL DATA
CHECKED RKH *	DATE 04-06-09		
SCALE	1:1,050,000	PROJECT No 087633050_016	FIGURE No 8 · REV No 1 · A3

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3.3 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. 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 an illustration of the conceptualisation in the form of a drawing.

The CGM model provides 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; and
- geological and man-made influences on the groundwater systems.

The purpose of the conceptual model is to provide a *visualisation* of the groundwater flow and 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 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.

After completing the literature and data review, a CGM was developed for the study area. The geological formations were grouped into six major hydrogeological units (groupings of units), which are detailed in Section 4.0.

For each unit, hydraulic head and salinity data (supplied by NRW and QGC) was compiled to create hydrogeological maps. The maps represent the hydrogeological system within the Groundwater Model Domain Area, prior to developing the proposed CSG fields. This area is larger than the likely final extent of the CSG development area and includes the area with a higher probability of impact from QGCs' operations.

To generate the maps, data that did not have spatial attributes (i.e., coordinates, depth of targeted layer) were excluded from the assessment. Individual data points were assessed, and in most cases removed if the value for that point was significantly different to those from the local area. Areas with no information (i.e. formation too deep for the completion of private bores) or where the aquifer was non-existent (i.e. beyond the outcrop region), were not included..

Many of the NRW bores do not have ground elevation information. Thus, for consistency, all bores were allocated a ground elevation by means of a 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 NRW database is questionable or not known. 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.

3.3.1 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 has involved the development of three computer-based groundwater models to represent the three project-defined CSG development areas (CDA, NWDA and SEDA). These models employ numerical mathematical techniques to simulate the behaviour of a groundwater system under proposed future CSG extraction operations. They were employed in this study to provide predictions of the impact of extracting CSG and groundwater from the Walloon Coal Measures on the existing environment values including other groundwater users (Appendix D).

Therefore, the modelling work sought to allow the:

- Development of an *idealised* regional groundwater model for each CSG development area.
- Interpretation of both the conceptual model 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 future CSG operations, and for the post-production period of groundwater recovery.
- Development of recommendations for groundwater management and monitoring associated with the QGC CSG operations.
- Determination of the trigger levels, defined in the *Petroleum and Gas Act 2004.*

The numerical groundwater model was developed using the MODFLOW computer 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.

A summary of the groundwater modelling methods employed and their results are presented in Section 5.0, with a full description of the methods used for the modelling provided in Appendix D.

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

3.4 Bore Inventory Field Investigations

The Queensland Government Department of Natural Resources and Water (NRW) bore database was interrogated, data was reviewed, and bore data selected to assess its usefulness for the field inventory investigations.

The field investigations involved visiting bore owners on-site to collect information on bore depth, water table, bore construction, water yields, pump installations, uses and other information (factual and anecdotal).

Bores to be assessed in the field were chosen to be suitably representative of the different aquifer units within the study area. The bores were located within the following aquifer units: Alluvium; Intermediate (particularly the Gubberamunda Sandstone); Walloon Coal Measures (and in particular the Springbok Sandstone); Hutton; and Precipice Sandstone.

The purpose of the field work was to develop a baseline dataset and to assess bores as potential monitoring locations. The field work was undertaken by various Golder staff and Unidel Land Liaison Officers.

The findings of the field work have been reported separately by Golder (Golder, 2009b) with a summary presented in Section 8.2.2.

4.0 DESCRIPTION OF THE EXISTING ENVIRONMENT

The existing environment, as it relates to groundwater, is described in this section to fulfill the terms of reference for the EIS. It provides a baseline dataset of specific information, from which future effects and potential impacts may be assessed, if required.

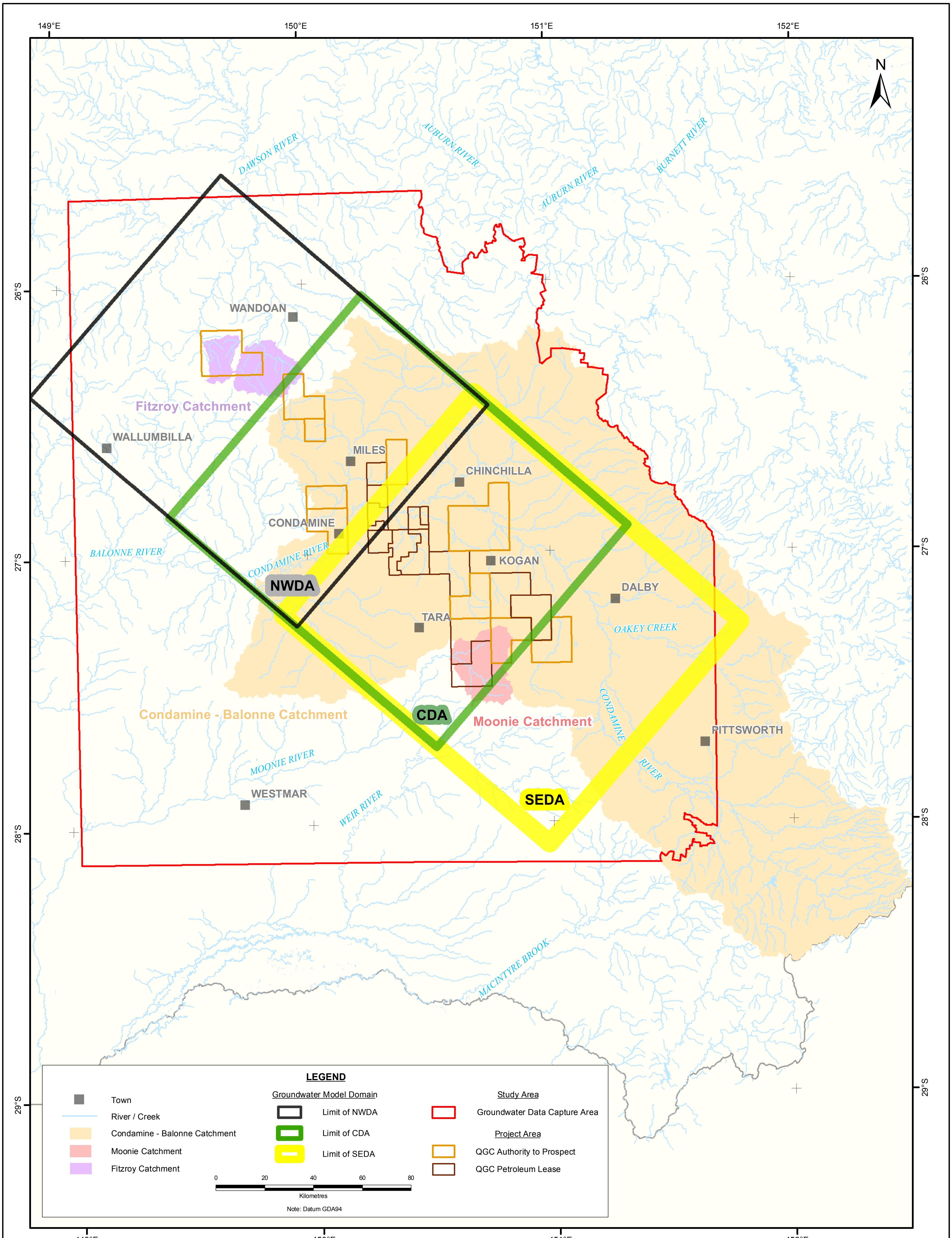
Within the study area, the existing natural environment mostly consists of areas that have been moderately to severely modified by agricultural and pastoral activities. The areas of highest environmental value are limited to the less disturbed areas. Their attributes are described in the following sections.

4.1 Topography and Drainage

The topography across the study area is generally flat, ranging between 200 and 400 m AHD and sloping gently towards the south west. A ridge, which is part of the Great Dividing Range, and is aligned northwest to southeast and rises up to 1100 m AHD defines the northeast boundary of the study area.

The Condamine River is the major river in the region, which flows northwest and southwest through the Central Development Area (CDA). The Condamine River is part of the Condamine and Balonne catchment which flows into the Murray Darling Basin. A local plateau, reaching 400m AHD, divides the Moonie and the Balonne river catchments in the southwest part of the study area, with the Balonne River flowing north and Moonie River flowing south.

In the north, tributaries of the Dawson River, which is part of the Fitzroy river catchment, flow in a northerly direction beyond the limits of the study area. Figure 9 indicates the locations of the rivers in proximity to the QGC tenements.



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DRAWN	DK/BQ	DATE	10-06-09
CHECKED	RKH *	DATE	10-06-09
TITLE	SURFACE WATER DRAINAGE AND MAJOR CATCHMENTS		
SCALE	1:1,400,000	PROJECT No	087633050_016
FIGURE No	9	REV No	2
	A3		

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0009_Rev2_SWdrainageCatchments_A3.mxd
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4.2 Climate

The climate for the study area is sub tropical with a dry winter season. Table 9 presents the combined mean monthly rainfall and evaporation data for the Roma Airport, Miles Post Office and Dalby Airport weather stations (averaged). The yearly climate pattern is illustrated in Figure 10. The histogram represents the mean rainfall and the curve represents the mean temperature.

The dry season takes place during winter, from April to September. December and January are the hottest months, where the temperature can exceed 40ºC. 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 9.3mm per day in summer (January) to 2.9mm per day in winter.

Table 9: Mean Climate Characteristics for the Project Area

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall in mm													
Average	82.6	82.3	47.0	30.8	38.2	34.9	29.3	24.8	26.4	59.2	69.8	87.0	610.2
Evaporation in mm/day													
Average	9.3	7.8	7.0	5.6	3.7	2.8	2.9	4.1	6.1	7.5	8.4	9.2	6.2
Temperature in °C													
Maximum	33.3	32.1	30.9	27.7	23.5	20.1	19.7	21.8	25.7	28.9	30.8	32.5	27.3
Minimum	19.8	19.4	16.8	12.5	8.1	5.3	3.8	4.9	8.9	13.3	16.3	18.4	12.3
Average	26.5	25.7	23.9	20.1	15.8	12.7	11.7	13.4	17.3	21.1	23.6	25.5	19.8

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

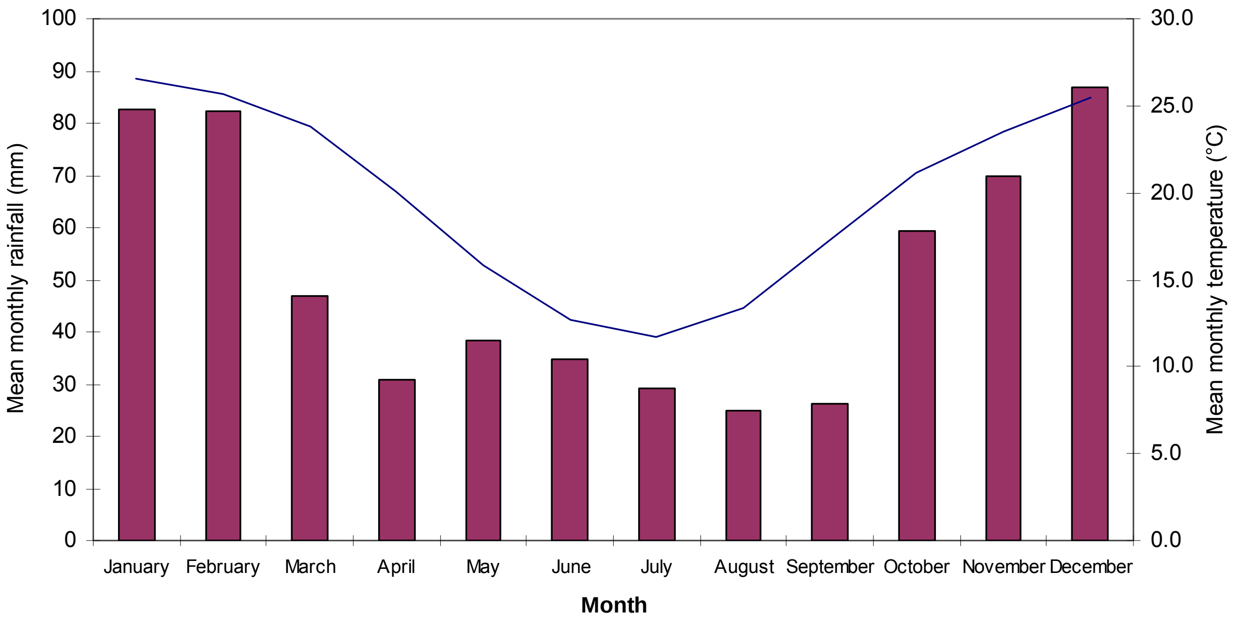


Figure 10: Mean Climate BOM Statistics for Roma Airport, Miles Post Office and Dalby Airport Weather Stations

Source: Averaged climate statistics derived from BOM climatic data for the Roma Airport, Miles Post Office and Dalby Airport weather stations.

4.2.1 Climate Change

The CSIRO (2008) has estimated the effects of different climate change scenarios for the region:

In the *median* climate change scenario by 2030:

- average annual runoff is reduced by 9%;
- average surface water availability in the Condamine-Balonne is reduce by 8%; and
- total end-of-system flow falls by 12%.

In the *high* climate change scenario by 2030:

- average surface water availability decreases by 26%;
- diversions decrease by 16 percent;
- end-of-system flows decrease by 35%; and
- the relative level of use under the current water sharing arrangements increases by 60%.

Irrespective of the scenario, groundwater extractions will remain important for the viability of the region, and demand for groundwater will remain high. Rainfall recharge to groundwater could either increase or decrease as a result of climate change; however, it is thought that any change would not exceed 10% (CSIRO, 2008). While climate change impacts on groundwater resources will be minor, changes to extraction rates are likely to be large in comparison (CSIRO, 2008). Protecting the ground and surface waters of the Surat Basin from unsustainable use is a major objective of government and the community.

4.3 Geology

The QGC LNG Project is located within the eastern portion of the Great Artesian Basin (GAB). An overview of the regional and local geology underlying the study area are provided below and set the scene of the development of the conceptual groundwater model and, then, the numerical model for groundwater impact assessment.

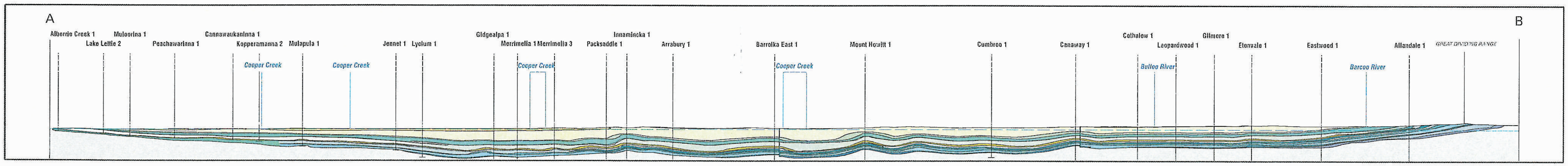
4.3.1 Regional Geology of the Surat Basin

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 laid down under widely differing depositional environments (Great Artesian Basin Consultative Council, 1998). In the Surat Basin this sequence is dominated by fluvial quartzose sands. The Surat Basin stratigraphy overlies parts of the Bowen Basin sequences in the Project Area.

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 of basement until the early Jurassic period. At that time, deposits covered the whole of the GAB in continuous layers. QGC LNG Project lies within the Surat Basin. Figure 11 shows a schematic cross section through the GAB.

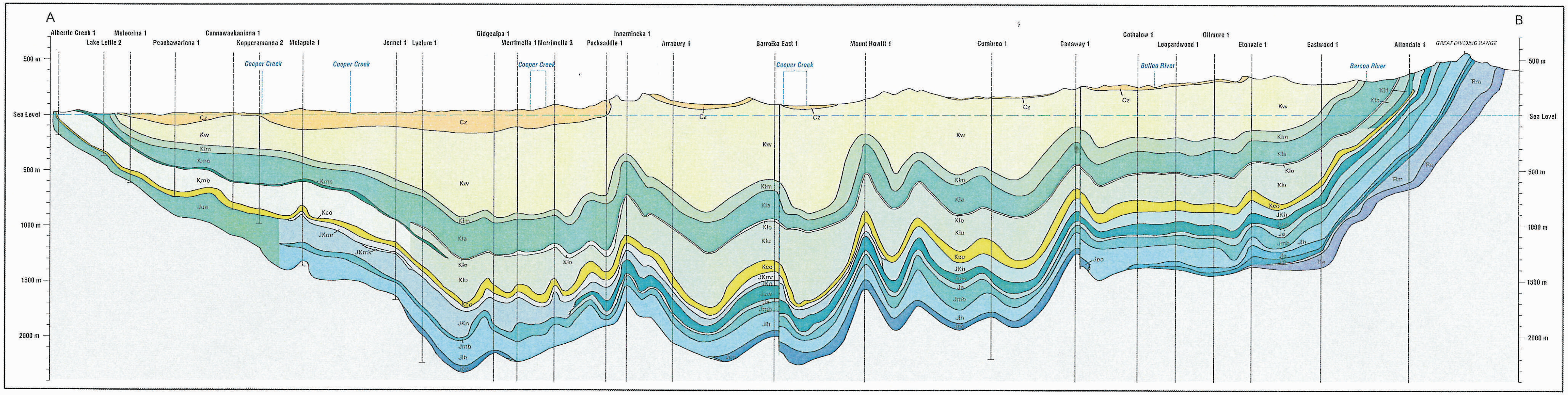
The QGC LNG Project lies within the Surat Basin, which comprises a sequence of layers dominated by fluvial quartzose sands. The Surat Basin stratigraphy overlies parts of the Bowen Basin sequences in the project area.

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	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN	BQ	DATE	03-06-09
CHECKED	RKH*	DATE	03-06-09
TITLE	REGIONAL GEOLOGY CROSS SECTION		
SCALE	Not To Scale	PROJECT No	087633050_016
FIGURE No	11	REV No	1
A3			

File Location: R:\Env\2008\087633050\GIS\Projects\CorelDraw\087633050_016_R_F0011_REV1_RegionalGeologyCrossSec_A3.cdr
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4.3.2 Geology in the 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 of the study area, which was largely derived from PB (2004) and AGE (2007 (unpublished)), 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 12). The Tertiary sediments predominantly include unconsolidated alluvial sediments (sand, gravel and silts) associated with the major drainage systems as infill alluvium. The Condamine River is an example of unconsolidated alluvial sediments in the Project Area.

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

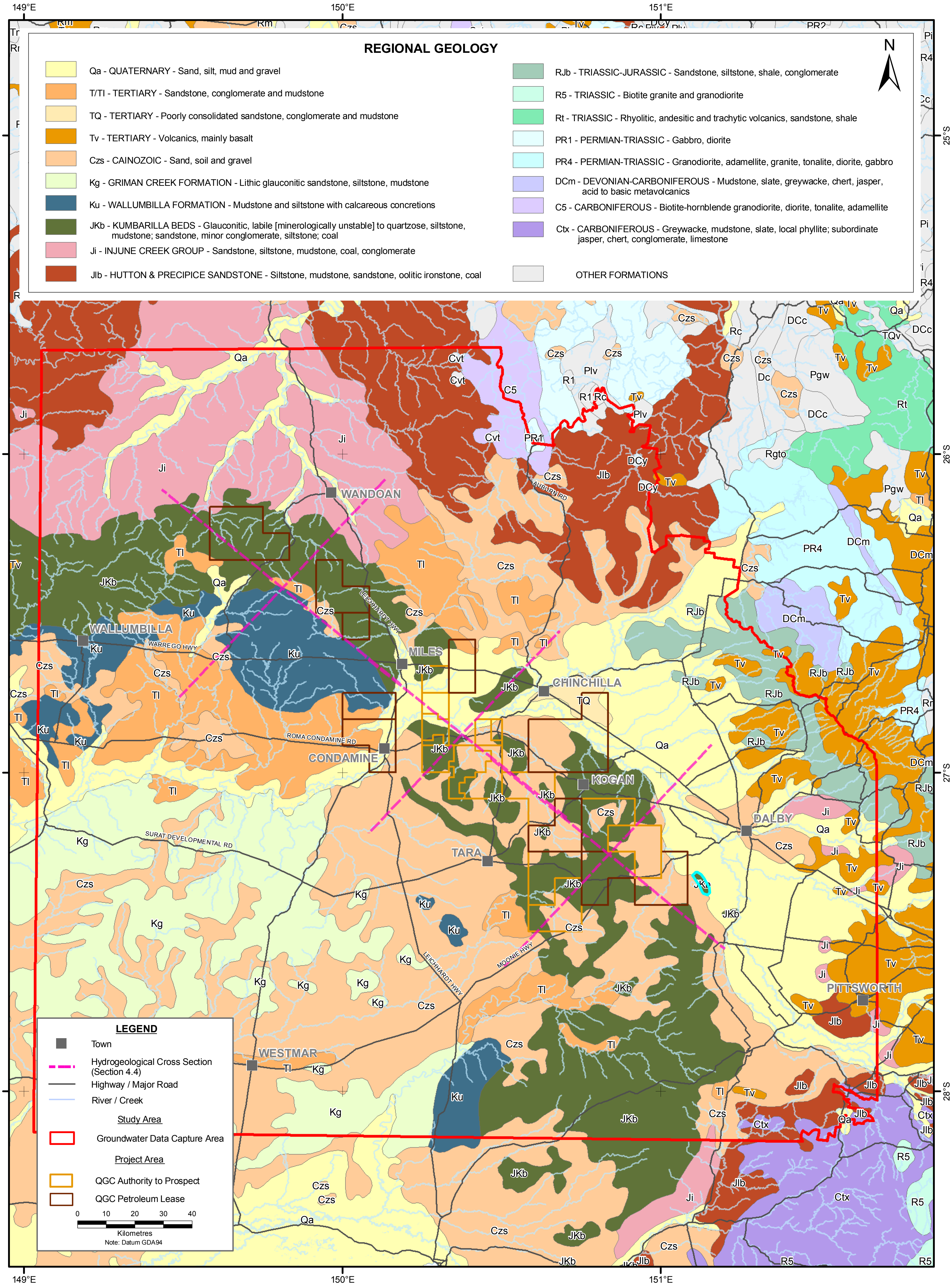
4.3.2.2 Surat Basin Stratigraphy

The study area is located within the Surat Basin that is one of the major sedimentary sub-basins of the GAB, extending over parts of both Queensland and New South Wales. The basin is primarily composed of fluvial quartzose sands. Figure 13 presents the dominant Jurassic-Cretaceous stratigraphy underlying the study area, primarily within the area of the tenements.

The lower most layer of the Surat Basin geological sequence is the Precipice Sandstone, which unconformably lies over the Triassic sediments of the Bowen Basin (The Moolayember Formation, Clematis Sandstone and Rewan Formation). Part of the outcrop region of the Precipice Sandstone crosses through the north-eastern part of the Project Area.

The outcrop region of the Precipice Sandstone crosses through the north-eastern part 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).



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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN	DK/BQ	DATE	04-06-09
CHECKED	RKH *	DATE	04-06-09
TITLE	SURFACE GEOLOGY IN THE STUDY AREA		
SCALE	1:1,250,000	PROJECT No	087633050_016
FIGURE No	12	REV No	2
	A3		

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0012_Rev2_SurfaceGeology_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

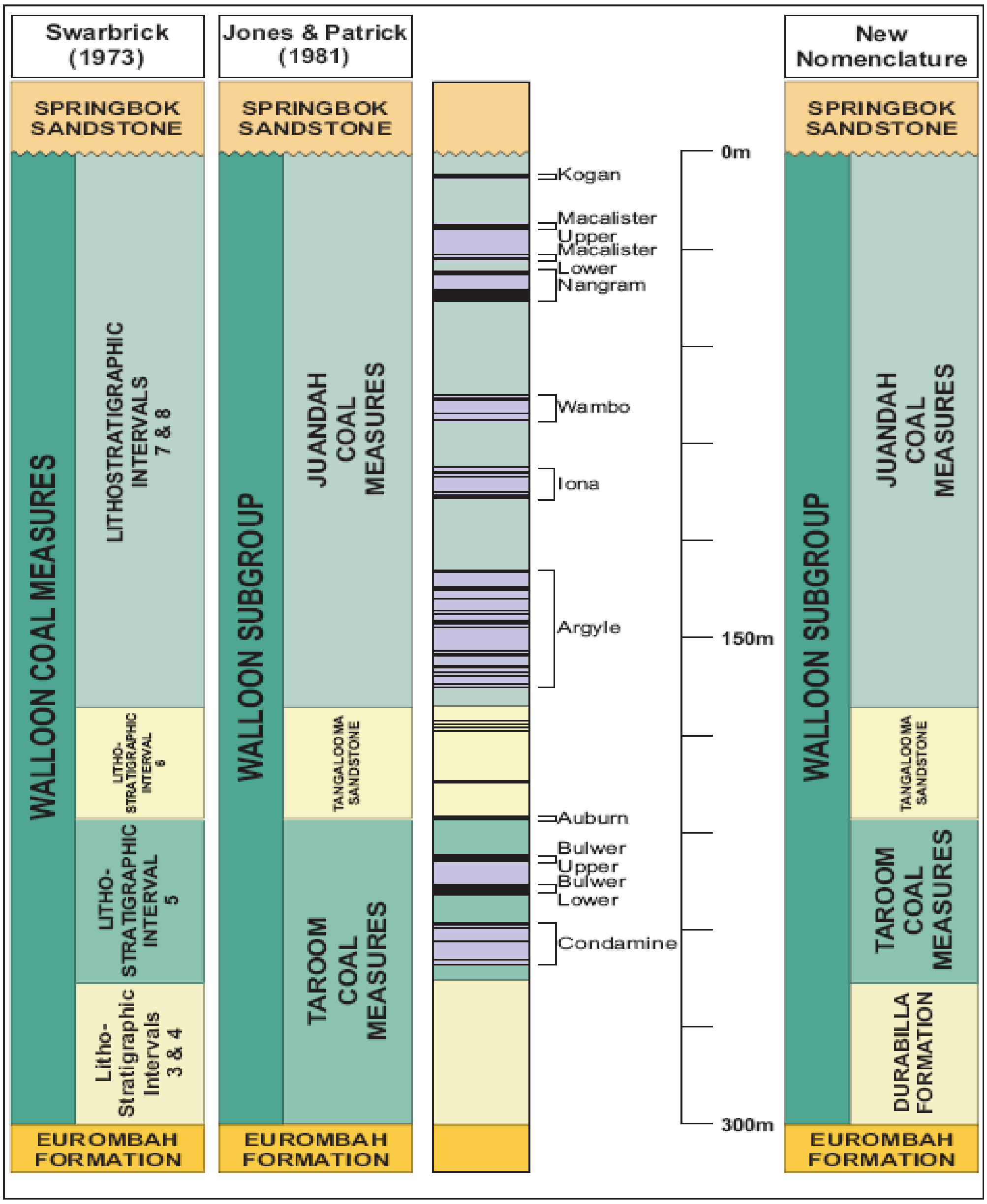
Litho-stratigraphy			Age (Million years before present)	Found in study area	Main Rock Types
Condamine Alluvium				✓	Unconsolidated sand, gravel and silt
Tertiary Sediments and Main Range Volcanics (East)					Unconsolidated sediments
Griman Creek Formation			Cretaceous (66 - 144)	✓	Sandstone, siltstone, 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 13: Stratigraphy in the Study Area.

The Walloon Coal Measures (WCM) are the main coal seam gas bearing units within the Surat Basin, and are the target formation for QGC - CSG operations within the Project Area.

The thickness of the WCM stratigraphy in the Project Area ranges from 100 to 460 m, at depths ranging from 170 to 933 m below ground level. 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 Walloon Coal Measures is presented in Figure 14. Of particular note there is an unconformable contact between the Springbok Sandstone and the WCM, and between the Precipice and the upper Bowen Basin Formations. These unconformable contacts can bring higher permeability layers within each formation into 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 14: 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 15). 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 the following table and presented in Figure 15.

Table 10: Key Structural Features Affecting QGC CSG Fields

Structural Element	Description
Kumbarilla Ridge	An anticlinal structure (upward folded rock sequence) affecting the eastern edge of the SEDA.
Chinchilla - Goondiwindi Slope	A fault-fold structure separating the Kumbarilla Ridge and Kogan Nose anticlines. Located in the central portion of the SEDA.
Kogan Nose	A tight anticlinal fold structure affecting the central-western portion of the SEDA (closely paralleling the Kumbarilla Ridge anticline)
Goondiwindi - Moonie Fault	A fault structure which dislocates the stratigraphic sequence along an alignment which separates the SEDA and the CDA). The throw on this fault to the north-west but the amount is not accurately known.
Undulla Nose	The ‘nose’ is a horst type uplift structure that has resulted in fracturing and faulting of the sedimentary layers above the nose (AGE, 2007). The “nose” is believed to have structurally affected the WCM geology in the CDA.
Leichardt-Burunga Fault	A fault structure that separates the NWDA and the CDA. It is considered to be an extension of the Goondiwindi - Moonie Fault to the south-east. The throw on this fault is to the east but the amount 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 cause significant faulting and fracturing of the Surat Basin stratigraphy.
Wallumbilla Fault	A fault structure, which together with the Arcadia Anticline, marks the western edge of the NWDA.

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

The three major development areas (CDA, SEDA and NWDA) appear to be separated by these structural features (fault/s, fold/s or monocline/s) as alluded to in Figure 15. It supports the hypothesis that the CSG presence and availability within each area are somewhat structurally (QGC and

AGE, 2007), and potentially hydrogeologically, isolated from each other. In addition, a structural feature (a south plunging anticlinal nose bounded by the Undulla and Leichhardt Faults), referred to as the “Undulla Nose” is believed to structurally affect the WCM geology in the CDA resulting in a densely fractured geological overprint to the sedimentary layers within the area covered by the nose (AGE, 2007). This is believed to result in an enhanced permeability and porosity within the affected rocks, and, as a consequence, has increased CSG resources and extractability (see Section 4.4.3).

4.4 Hydrogeological Setting

4.4.1 General Great Artesian Basin Setting

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 (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, thus they are considered to be aquitards. Within the Project Area, the thickness of the formations remains quite uniform throughout their profile, and are also laterally continuous and hydraulically connected.

The GAB aquifers are recharged by infiltration (rainfall), and leakage from streams into outcropping sandstone formations, mainly on the 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 Roma and Fairview CSG Fields are 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.

As presented earlier (Section 1.4.1), the GABWRP divides the GAB into 25 Groundwater Management Areas (GMAs), based on hydrological, geological, water demand, recharge and discharge characteristics and past management. The QGC CSG fields are located in, or adjacent to the following GMAs:

- Surat East;
- Eastern Downs;
- Surat North; and
- Surat.

The geological formations present within the GMA’s are sub-divided into stratigraphical management ‘units’, based on the variation of hydraulic parameters and behaviours of the different aquifer systems. These subdivisions are presented in Table 1 and Figure 3 and also provide a breakdown of the GMU’s within the four GMA’s considered in this study.

These key features of the Surat Basin hydrogeological system are described in greater detail in the sections which follow.

4.4.2 Local Hydrogeological Setting – Project Area

The majority of the Project Area is located in the Surat Basin, with a small section of the study area located within the Clarence Moreton Basin (the Clarence Moreton Basin, over which the far eastern portion of the study area lies, is connected to the Surat Basin over the Kumbarilla Ridge, as shown in Figure 15). It is contained within the areal boundaries of the Surat GMA 19, with small sections in GMA 20 (Surat North), GMA 21 (Surat East) and GMA 24 (Eastern Downs) (refer to Figure 1 to Figure 3). These GAB hydrogeological groundwater management areas represent the hydrogeological data capture areas for this study.

It is evident from the data captured 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. From this process, a sensible hydrogeological or groundwater model (Sections 5.3) can be developed to provide an uncomplicated and visually comprehendible overview of the system operating in the Study Area. These groupings do not necessarily refer to the depth of the aquifer, but rather a combination of the rocks genesis, its lithology and distinctness. The regional outcrop and subcrop areas of most of the formations occur on the northern margin of the Study Area. These grouping are illustrated in Table 11 and, where appropriate, described in the text which follows the table.

Table 11: Primary Hydrostratigraphic Zones Identified in the Project Area

Hydrogeological Units and Sub-units			Formation Name
A	1	Quaternary Alluvium Units	Shallow Quaternary & Tertiary alluvium including the Condamine Alluvium (aquifers).
	2	Shallow Unit	Main Range Volcanics
B			Griman Creek Formation
			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 Unit	Hutton Sandstone (aquifers) Evergreen Formation (aquitard)
	6	Precipice Unit	Precipice Sandstone (aquifers)
C	Bowen Basin sequences		

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

The stratigraphic units which comprise this hydrostratigraphy (above) have previously been detailed in Figure 13. This figure describes components of the stratigraphic column with particular focus on the dominant Jurassic-Cretaceous stratigraphy underlying the Project Area, primarily within the area of the tenements.

4.4.3 Hydrostratigraphy

Of specific note are the following characteristics for the hydrostratigraphic zones identified in Table 12 which have assisted with the construction of the *conceptual groundwater model* (CGM) provided in Section 5.3:

- **Quaternary Alluvium Unit:** This unit comprises the most recent Quaternary and Tertiary unconfined alluvium aquifers. The most prevalent of these being the *Condamine River Alluvium (CRA).* The CRA is a highly developed and exploited water resource with a high density of extraction bores on the Condamine River floodplain. Groundwater is good quality and suitable for most purposes; however, the aquifer system is under stress with the resource being over-allocated and over-abstracted (The Australian Natural Resources Atlas, 2005).

- **Shallow Unit**: In the western region of the study area, 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.

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

- **Intermediate Unit**: The Intermediate Unit includes the major artesian sandstone aquifers above the Walloon Coal Measures with the exception of the Springbok Sandstone. The Intermediate Unit aquifers are confined to unconfined in the study area and include the Mooga and Gubberamunda Sandstones, both reasonably important aquifers in the area south and southwest of the QGC tenements. The Gubberamunda unit ranges in thickness from 40m to 140m.

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

  - *Coal seams* which comprise 10 to 16% of the full thickness of the WCM and include up to 40 to 45 individual coal seams of varying thicknesses (Figure 14). 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) and a porosity of approximately 1.2%. As such they permit groundwater flow and are moderate aquifers, constrained only by their low storage capacity (water filled pore space voids, largely occurring as a consequence of the density of a network of structural micro-fractures, referred to as 'cleats').

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

  - The *Springbok Formation*, the topmost in the Walloon Unit, includes aquifer beds. NRW 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; available values 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. NRW 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 conductivities are up to 0.7 m/day. The Marburg Sandstone is hydrogeologically equivalent to the Hutton Sandstone within the eastern region of the general study area. The Evergreen Formation, which underlies the Hutton Sandstone (grouped here with the Hutton), is considered a major confining bed within the Surat Basin (NRW, 2005) and is significantly less hydraulically conductive than the neighbouring Hutton Sandstone and Precipice Sandstones (Table 12).
- **Precipice Formation Unit**: This unit typically forms the basal Jurassic artesian aquifer in the Surat Basin. NRW 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 east of the study area. Typical conductivities are around 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 column. 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 Walloon Coal Measures and between the Precipice and the lower Bowen Basin Formations (Figure 13).

As noted in Section 4.3.2.3, a number of dominant structural features overprint the stratigraphy described above. These include a number of fold and fault structures which are known to affect the Surat Basin hydrostratigraphy and the groundwater flow behaviour which operate in the Project Area. The implications of these structural elements on the hydrogeological systems operating in the Study area are discussed in detail in Section 4.4.5.

Reference to groundwater quality is made in general terms only in this section, with a detailed treatment of groundwater quality being presented in Section 4.5.

4.4.3.1 Identification of Key Aquifers

In the Project Area, within the Surat Basin stratigraphy, aquifers comprise between 38% and 52% of the sequence, and aquitard units comprise the remainder.

From the key hydrostratigraphic zones identified in Table 12 the major Surat Basin aquifer units in terms of groundwater development within the Project Area (from the base of the sequence upward) have been identified as:

- Precipice Sandstone aquifer;

- Hutton Sandstone aquifer;
- Springbok Sandstone aquifer;
- Gubberamunda Sandstone aquifer; and
- 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. All the other units are regarded as aquitards.

The *Condamine River Alluvium* (unconformably overlying the WCM) is another important aquifer in the area. This aquifer system is a shallow, unconsolidated, alluvial aquifer unit that unconformably overlies the Surat Basin Formations (lying in direct contact with many of the aquifers and aquitards of that bedrock sequence). It is easily accessible and highly developed as a water resource bearing unit.

Within the study area, there are also minor aquifers, which supply 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 (Section 4.5), but they are used by farmers and landowners in the Project area (particularly in the eastern portion of the Project area and near Dalby and to the south of Dalby), and for industrial and domestic activities. They have also become further utilised by the broader CSG industry in the region.

The interpreted occurrence of these aquifers in the Project Area is presented in Figure 13 and Table 12.

4.4.3.2 Typical Hydrogeological Parameters

The hydrogeological parameters (primarily, thickness, porosity, hydraulic conductivity and storativity, and typical water yield) for the major Surat Basin aquifer and aquitard units, present in the Project Area, have been compiled in Table 12. The data was sourced from numerous government agency reports, publications, reports and datasets. 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. The parameter values presented in Table 12 reflect this heterogeneity and are indicative of the Project Area in general and are *not* specific to any one individual location.

Table 12: Aquifer Characteristics in the Project Area

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

na: data not available for the purpose of the report
Kh hydraulic conductivity in the horizontal (x) direction
Kv hydraulic conductivity in the vertical (z) direction
1: Great Artesian Basin Resource Operation Plan, February 2007
2: QGC, Kenya Pond Groundwater Investigation Report, September 2007
3: Habermehl M.A, 2002, Hydrogeology, Hydrogeochemistry and Isotope Hydrology of the Great Artesian Basin, Bureau of Rural Sciences
4: NRW database
5: Great Artesian Basin Resource Operation Plan, February 2007
6: Australian Government Department of the Environment and Water Resources - Groundwater Management Unit: Unincorporated Area - Clarence Moreton
7: Previous Groundwater Impact Study data
8: QGS; R.A. Freeze, J.A Cherry, 1979, Groundwater
9: Suggested by AGE.
10: Provided through previous work in Surat Basin;
11: R.A. Freeze, J.A Cherry, 1979, Groundwater
12. Quarantotto, P. (1986). Hydrogeology of the southeastern Eromanga Basin, Queensland. BMR Record 1986/38.

These parameters reflect a variety of lateral and vertical variability observed in the stratigraphy, and also take into account the highly variable structural overprint of folding, faulting and fracturing which affects the stratigraphy. For example, one such feature, the “Undulla Nose” is believed to structurally affect the CDA WCM geology is a way that enhances its permeability and porosity, inter-formational connectivity and groundwater availability, as well as CSG resources and extractability. Outside of the Central Development Area in the northwest and southeast; measurements of hydraulic conductivity fall considerably, by up to two orders of magnitude. The structural affects on the groundwater systems operating in the Project Area are further discussed in Section 4.4.5.

4.4.4 Structural Implication for Hydrogeology

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 15, which follows:

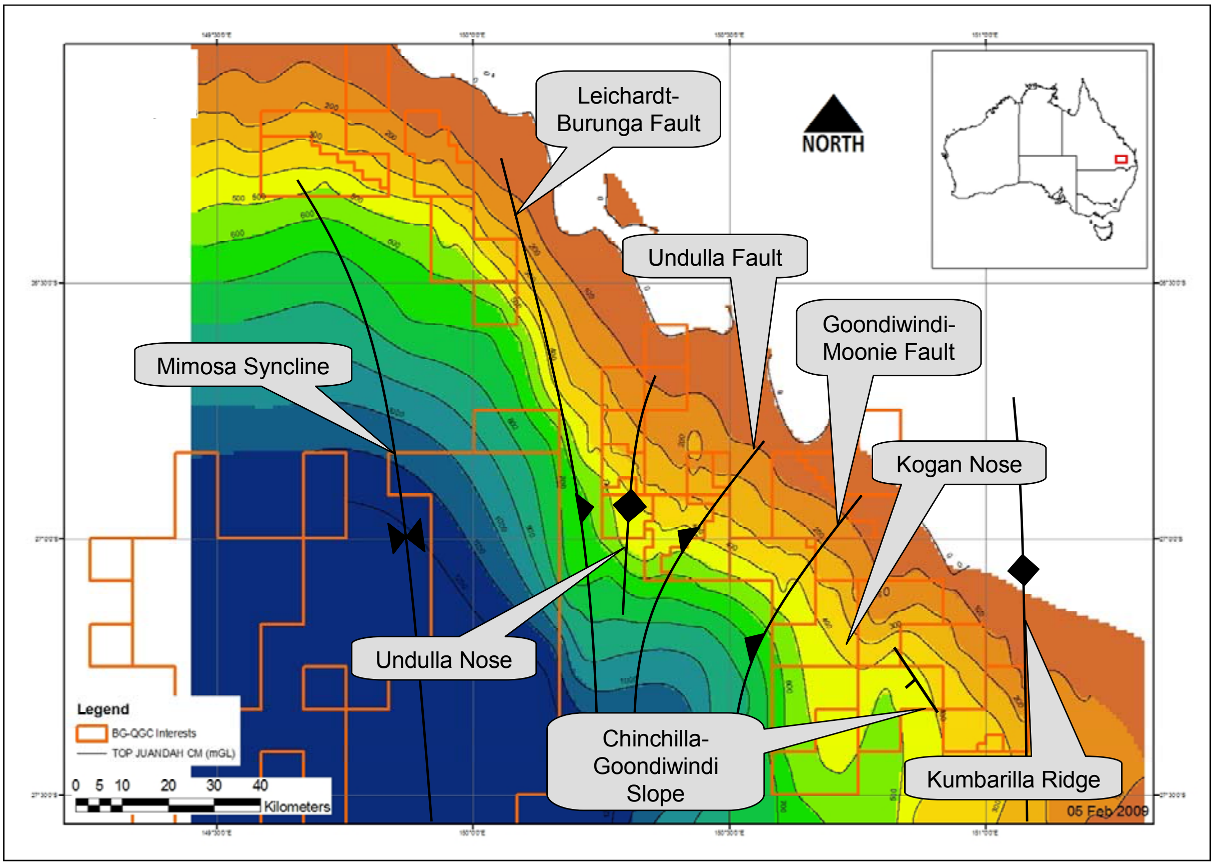


Figure 15: Major Structural Features Affecting the Project Area

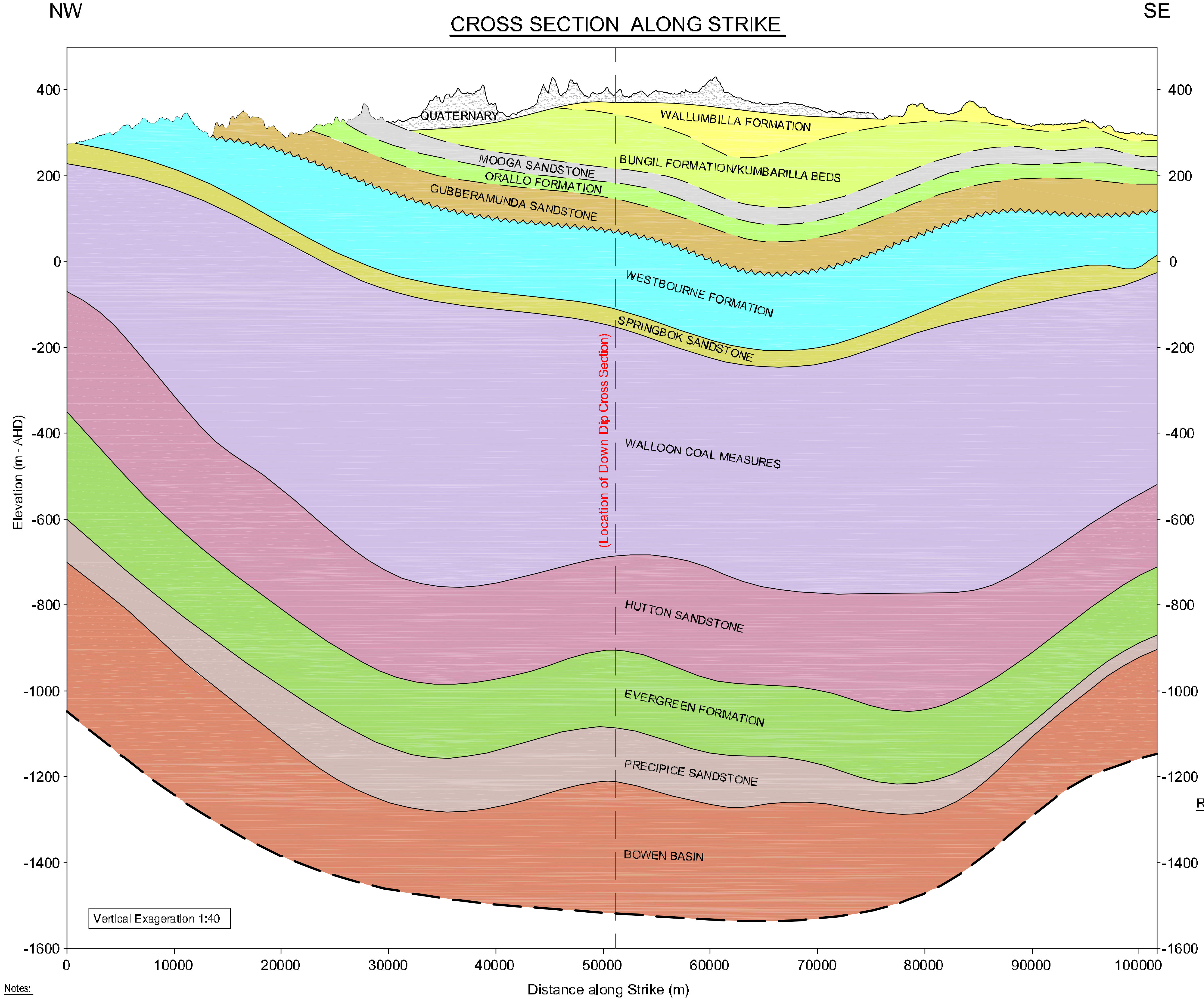
These structural features include a number of folds (anticlinal and synclinal features), faults and fracture zones and are known or are inferred to have important ramifications in regard to hydrogeological behaviour and groundwater flow in the Project Area. These include:

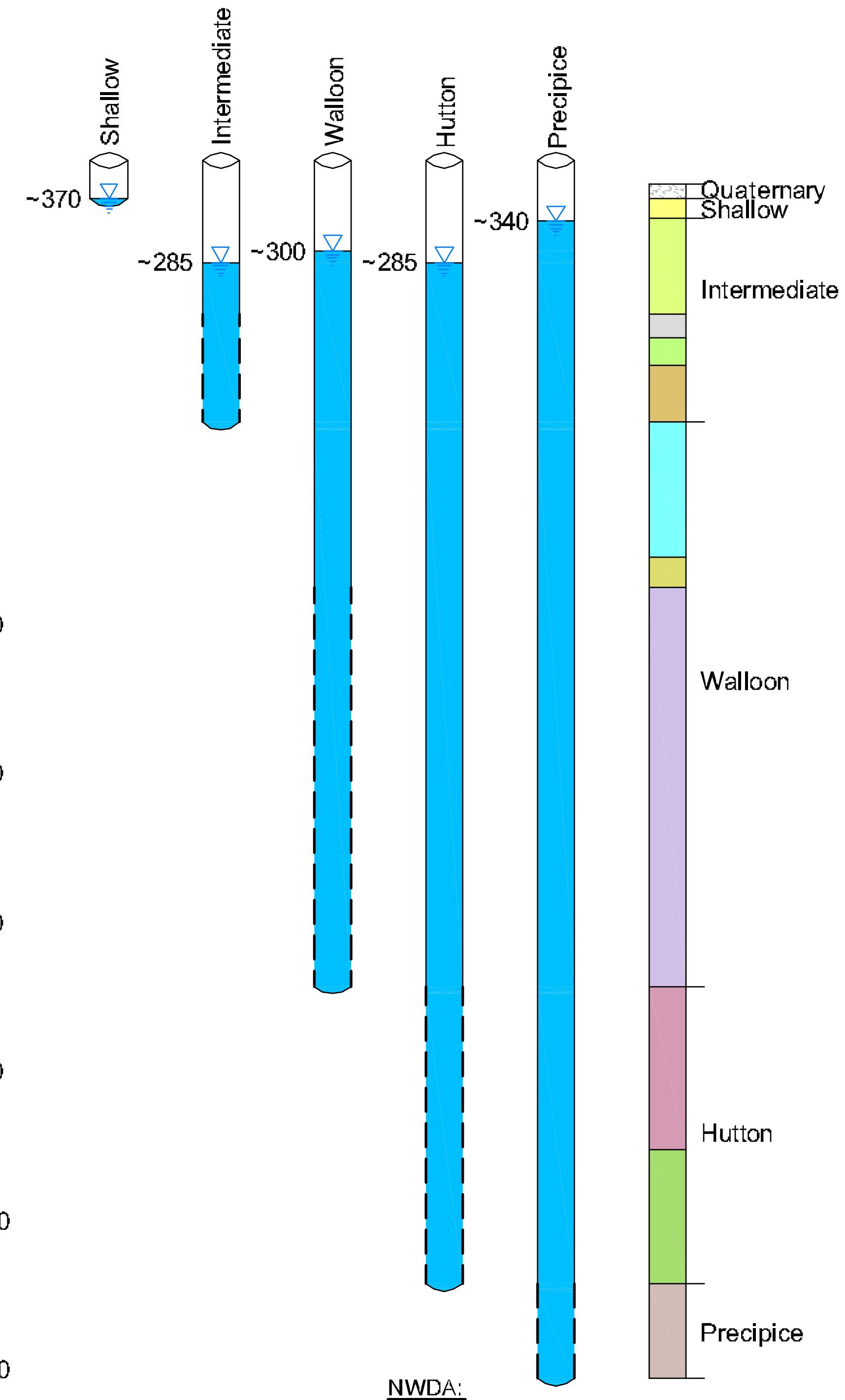
- *Kumbarilla Ridge*: This anticlinal structure (upward folded rock sequence) affecting the eastern edge of the SEDA. This open anticlinal fold is considered to mark the eastern hydrogeological boundary of the Project Area and is inferred to present a low-flow boundary.
- *Chinchilla - Goondiwindi Slope*: A fault-fold structure separating the Kumbarilla Ridge and Kogan Nose anticlines. Located in the central portion of the SEDA. This structure is likely to locally affect the structural integrity of the lithology, causing fracturing and enhanced hydraulic conductivity in the stratigraphic units affected.
- *Kogan Nose*: A tight anticlinal fold structure affecting the central-western portion of the SEDA (closely paralleling the Kumbarilla Ridge anticline). Also likely to give rise to fracturing and enhanced hydraulic conductivity in the stratigraphic units affected.
- *Goondiwindi - Moonie Fault*: A structural fault structure dislocating the stratigraphic sequence along an alignment which separates the SEDA and the CDA. The dislocation along this extensive fault lineament is inferred to be sufficiently large to reduce hydraulic connection between the SEDA and the CDA areas, enhancing the compartmentalisation of these to portions of the Project Area.
- *Undulla Nose*: The 'nose' is an uplift structure (of the horst and graben type) that has also resulted in a fractured environment of the sedimentary layers above the nose (AGE, 2007). It is believed to structurally affect the WCM geology in the CDA in a way that enhances the CSG resources and its extractability. This effect is believed to arise from the fact that the Undulla Nose is a south plunging anticlinal nose bounded by the Undulla and Leichhardt-Burunga Faults. The uplift tectonic forces that caused the nose structure to form also resulted in a fractured environment developing though the sedimentary layers above the nose (the coal measures are draped over the fault lineaments). The fractured environment of this sedimentary sequence has resulted in an overall higher hydraulic conductivity (as has been observed in drill stem testing undertaken by QGC), porosity and storativity in all the lithological units (both aquifer and aquitard units) which comprise the sequence. As a result, it is also possible that hydraulic connection of previously vertically isolated aquifers and aquitards has occurred, giving rise to the potential for of intra-formational groundwater flow under suitable hydraulic gradient conditions.
- *Leichardt-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 Project Area it is apparent the three development areas are separated into three compartments, each partially hydraulically isolated from each other. Restricted groundwater flow between the three compartments is inferred, a fact which is used in the construction of the conceptual groundwater model and defines the numerical groundwater modelling domains. By virtue of these structural overprints, the hydrogeology within each 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.

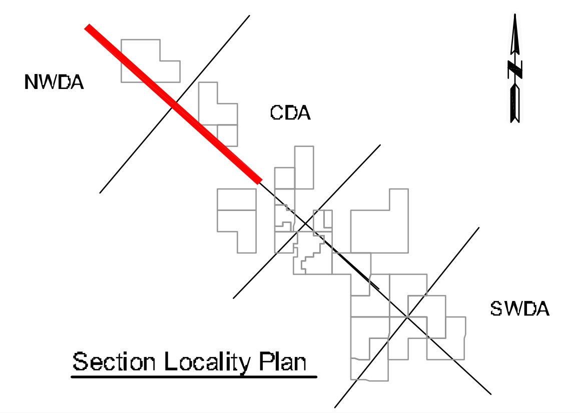
4.4.5 Hydrogeological Cross Sections

As a means of graphically presenting the hydrostratigraphy described above, interpreted hydrogeological cross sections, centralised around the three CSG development areas (CDA, SEDA and NWDA), have been prepared and are illustrated in Figure 16 to Figure 21. Both the along strike and down dip representations are presented. The exact locations of the cross sections are illustrated in Figure 3.





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



Section Locality Plan

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

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CHECKED	*SRH	DATE	20/11/08
TITLE	HYDROGEOLOGICAL SECTION NORTHWEST ALONG STRIKE - NWDA		
SCALE	1:10,000 V, 1:400,000 H	PROJECT No	087633050-16
FIGURE No	16	REV No	1
A3			

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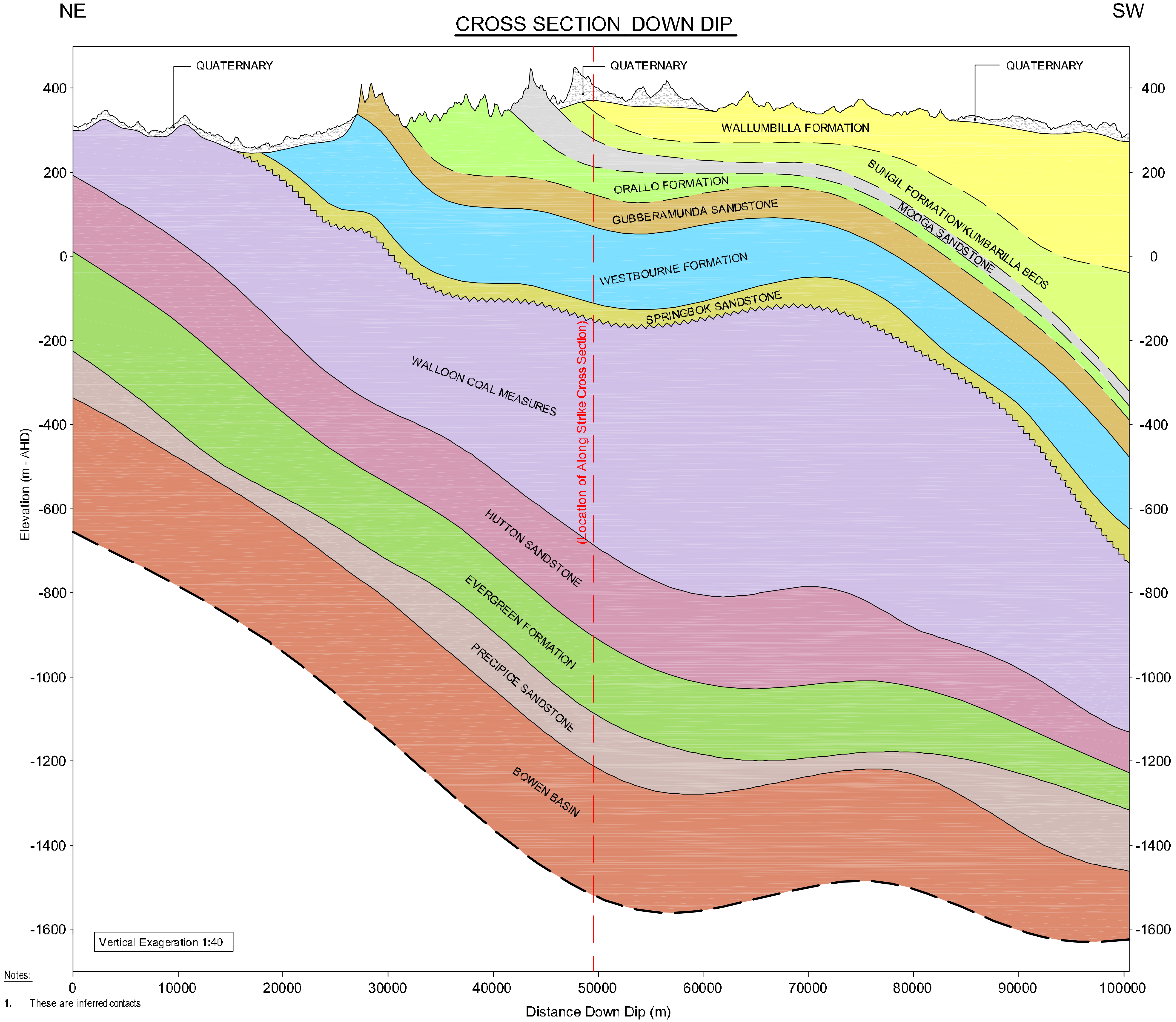
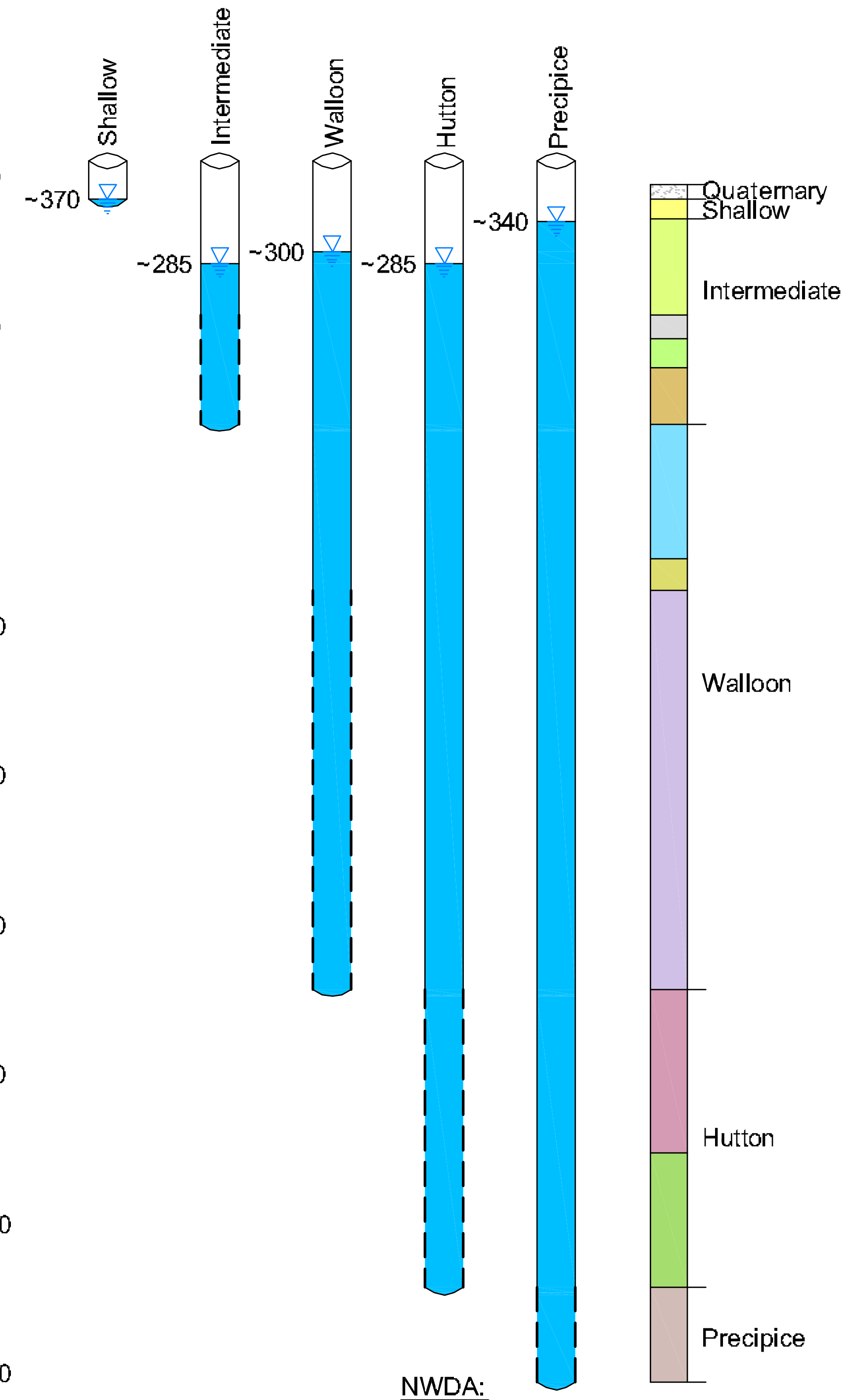
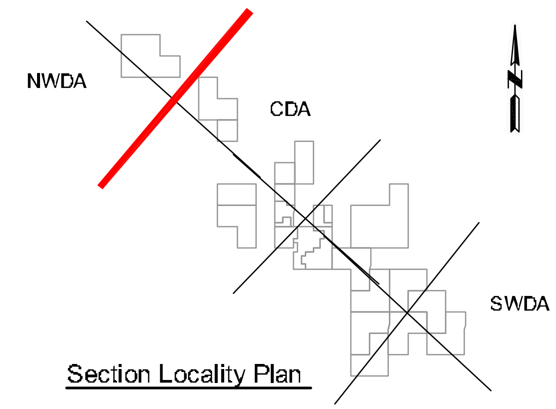




NWDA:
Representitive piezometric levels in the main groundwater units



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CLIENT	QGC	PROJECT	QGC LNG Water Studies
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CHECKED	*SRH	DATE	20/11/08
TITLE	HYDROGEOLOGICAL SECTION NORTHWEST DOWN DIP - NWDA		
SCALE	1:10,000 V, 1:400,000 H	PROJECT No	087633050-16
FIGURE No	17	REV No	1
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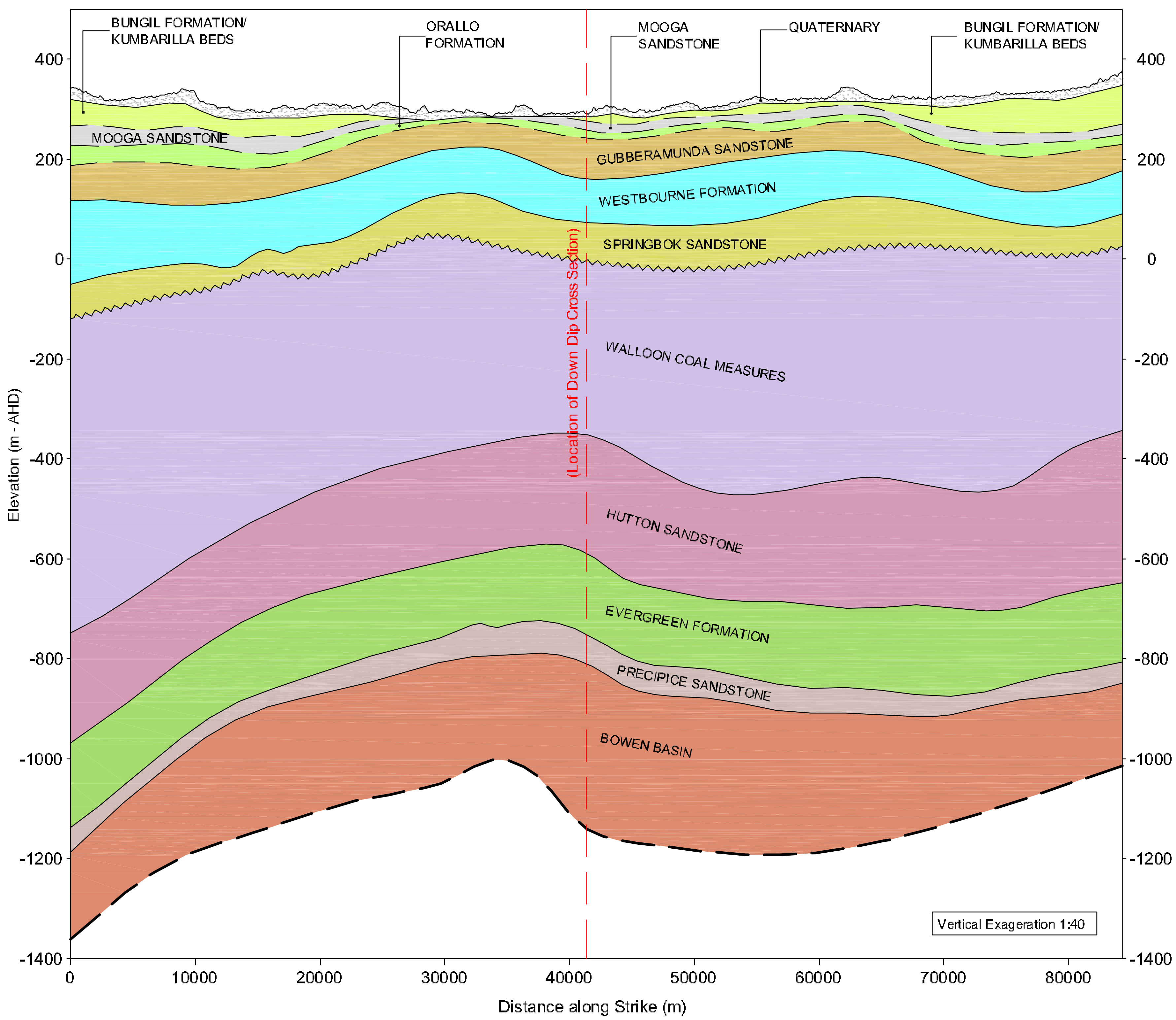
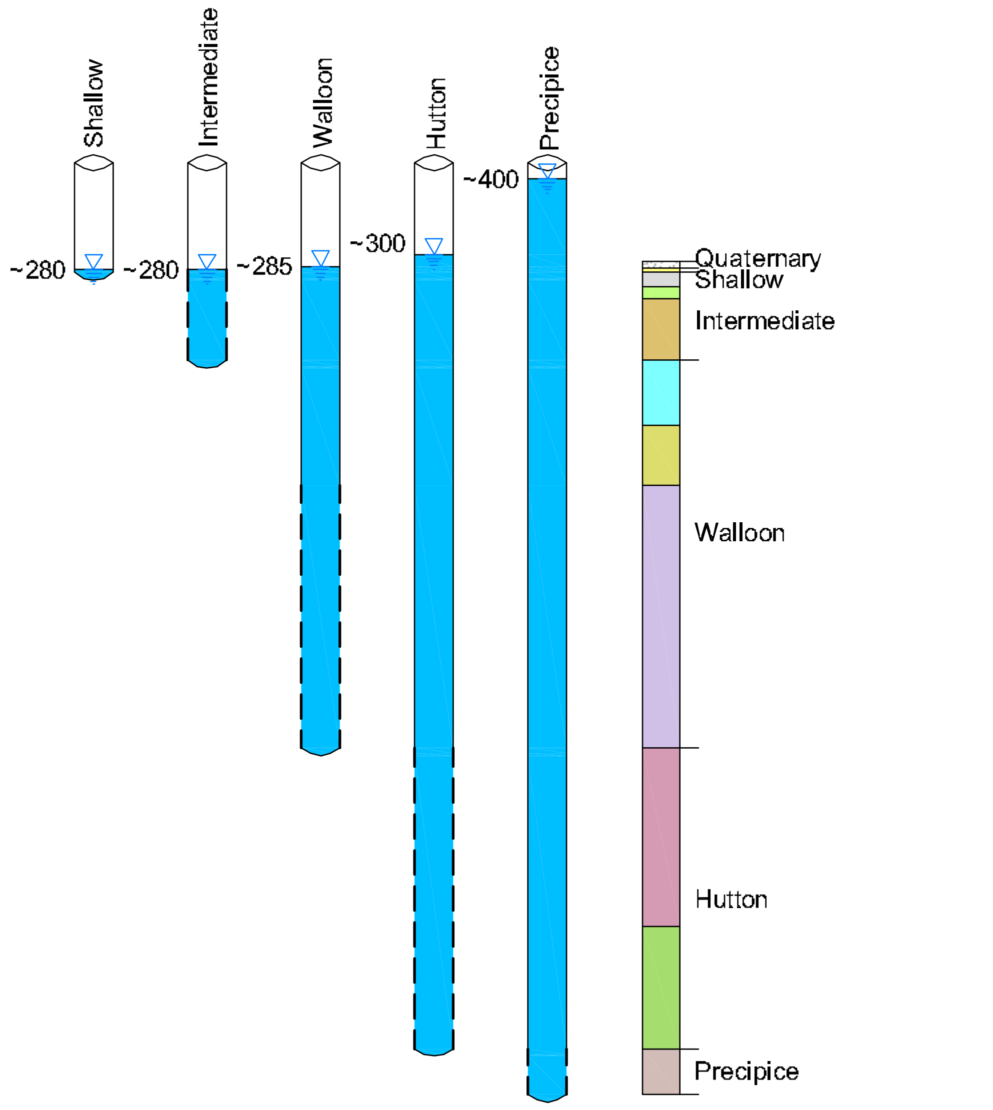
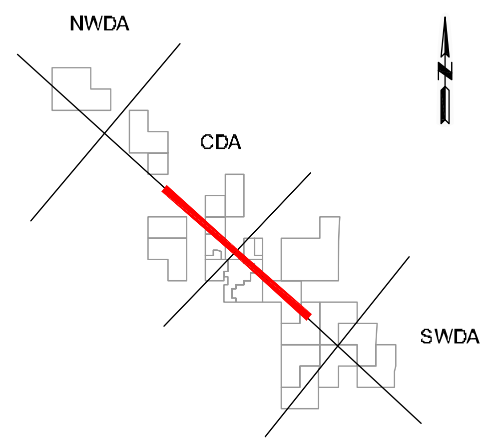
CROSS SECTION ALONG STRIKE





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



Section Locality Plan

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1:10,000 V — 200 100 0 200 400m

1:400,000 H — 8000 4000 0 8000 16000m

Golder Associates	CLIENT: QGC			PROJECT: QGC LNG Water Studies	
	DRAWN: GPG	DATE: 20/11/08		TITLE: HYDROGEOLOGICAL SECTION CENTRAL ALONG STRIKE - CDA	
	CHECKED: *SRH	DATE: 20/11/08			
	SCALE: 1:10,000 V, 1:400,000 H			PROJECT No: 087633050-16	FIGURE No: 18 / REV No: 1 / A3

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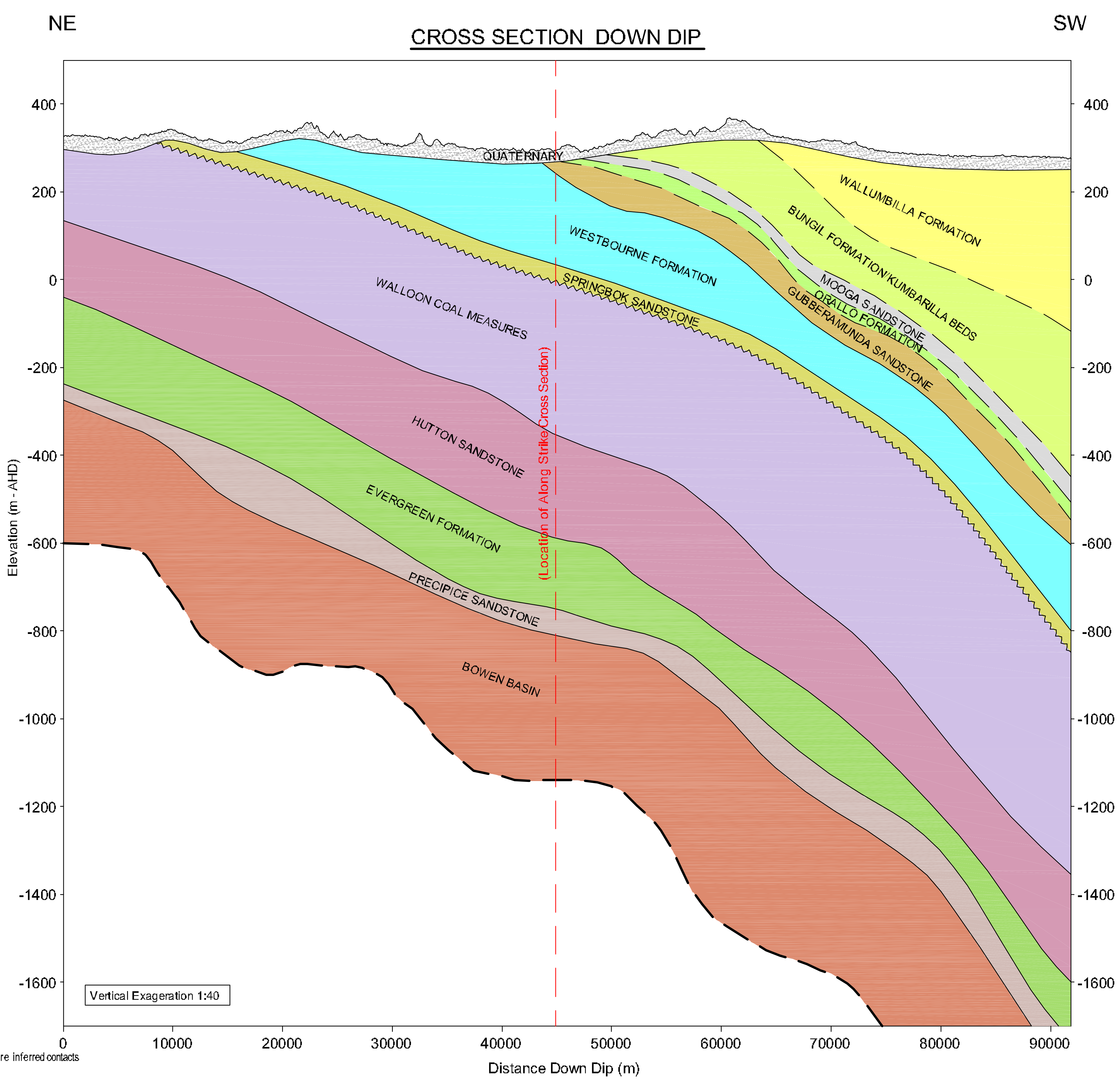

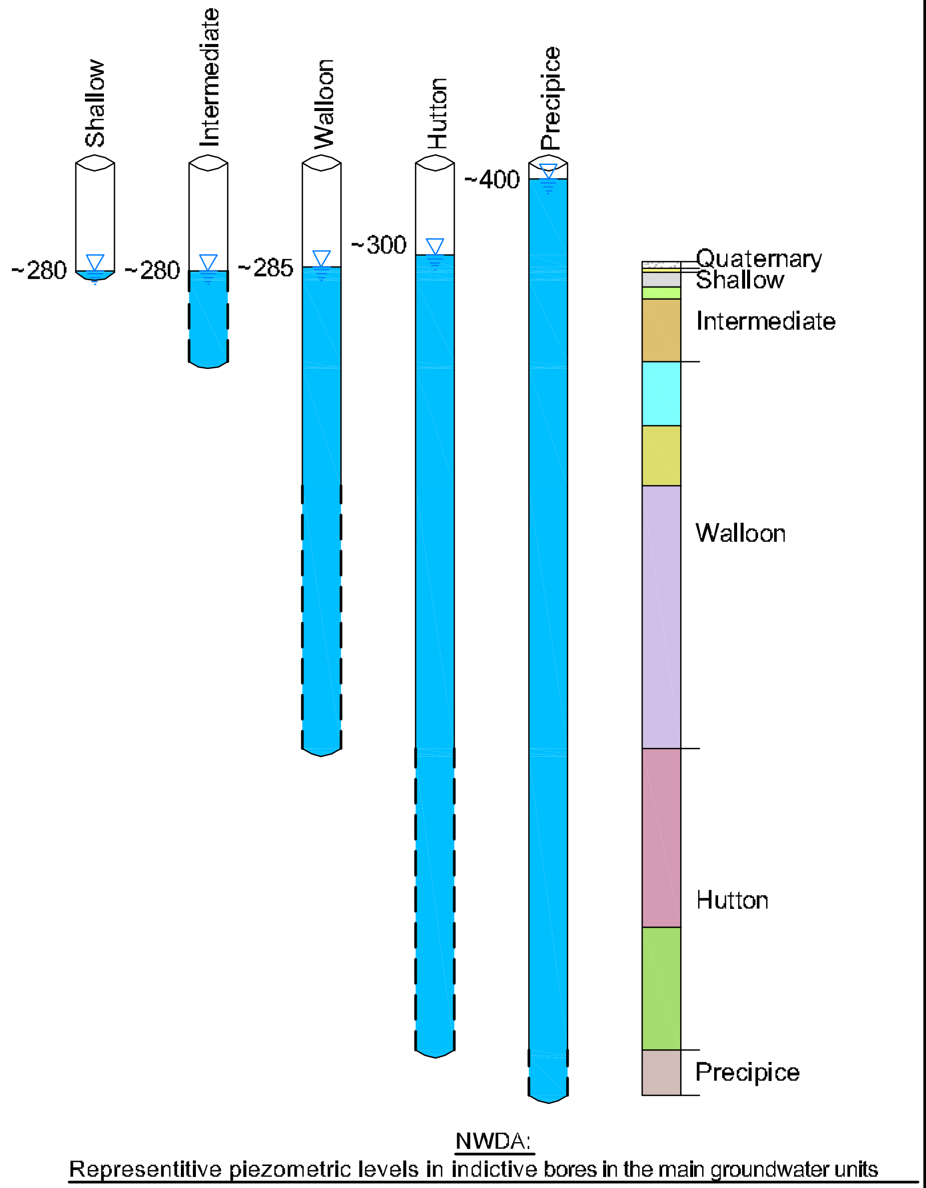

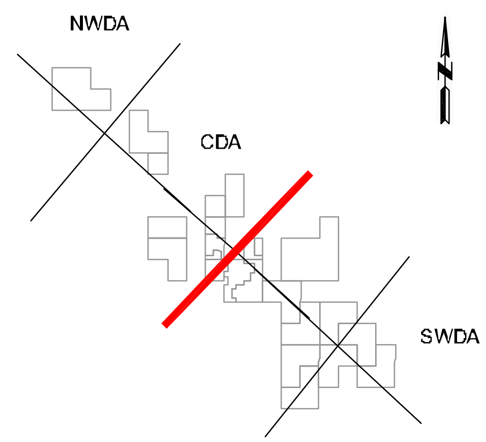

Section Locality Plan

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1:10,000 V — 200 100 0 200 400m

1:400,000 H — 8000 4000 0 8000 16000m

CLIENT	QGC	PROJECT	QGC LNG Water Studies
DRAWN	GPG	DATE	20/11/08
CHECKED	*SRH	DATE	20/11/08
TITLE	HYDROGEOLOGICAL SECTION CENTRAL DOWN DIP - CDA		
SCALE	1:10,000 V, 1:400,000 H	PROJECT No	087633050-16
FIGURE No	19	REV No	1
A3			

K:\Env\2008\087633050\Figures\087633050-016-R-FIG19.dwg Jun 05, 2009 – 5:04pm

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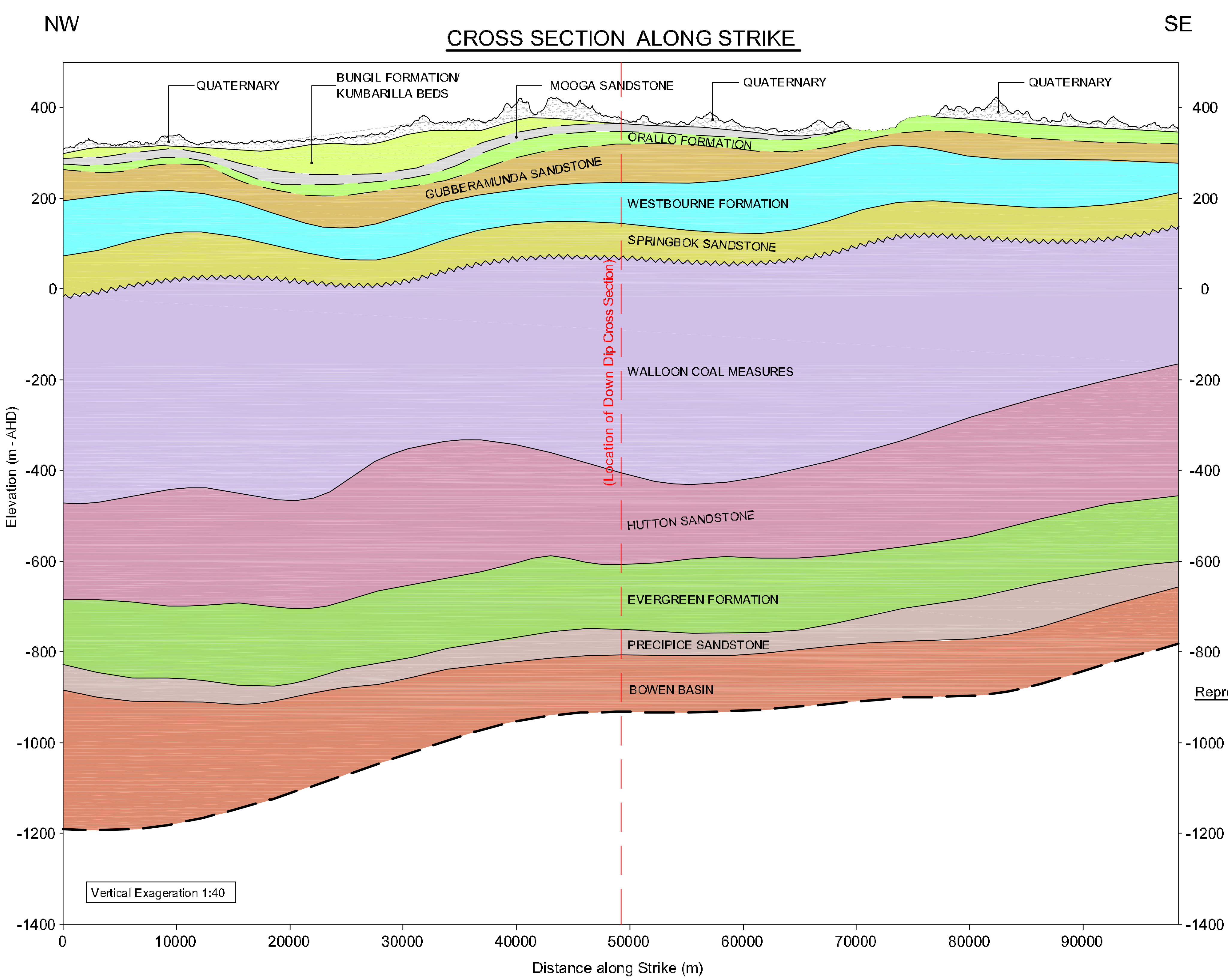
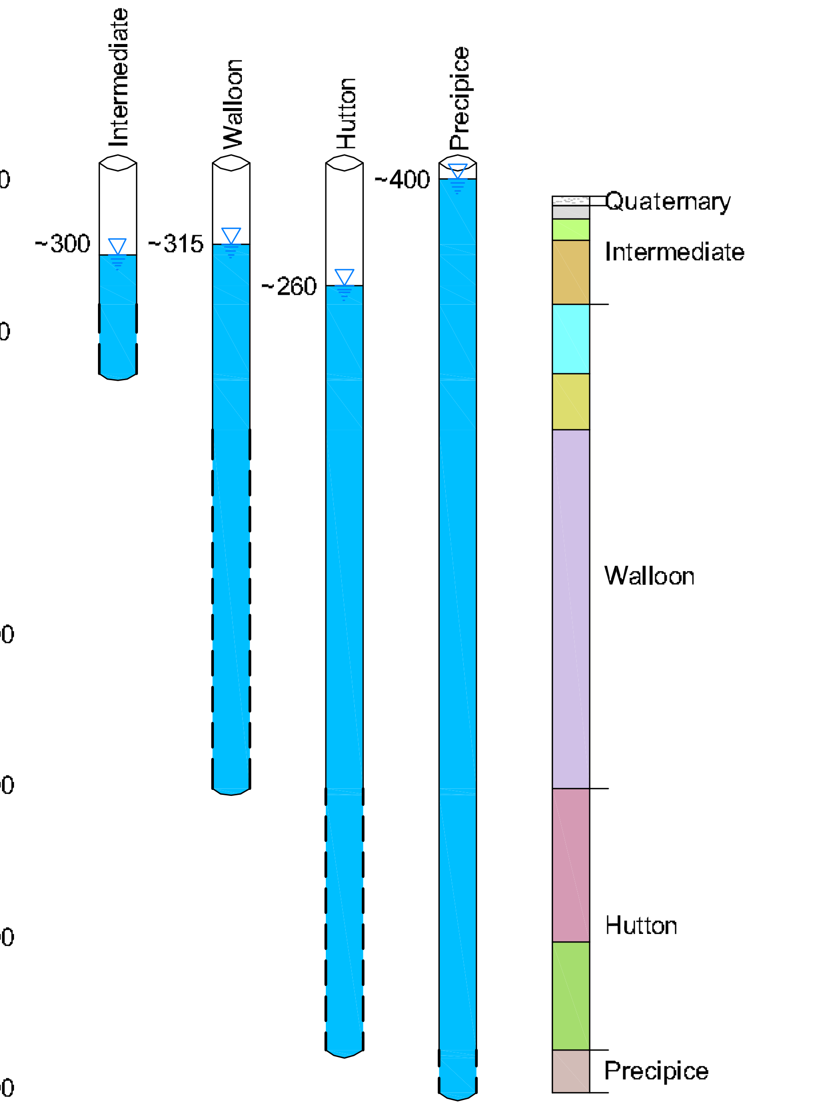
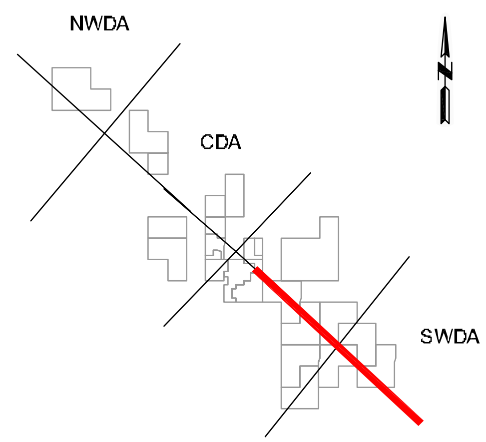




NWDA:
Representitive piezometric levels in indictive bores in the main groundwater units



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1:10,000 V — 200 100 0 200 400m

1:400,000 H — 8000 4000 0 8000 16000m

CLIENT	QGC	PROJECT	QGC LNG Water Studies
DRAWN	GPG	DATE 20/11/08	TITLE HYDROGEOLOGICAL SECTION SOUTHEAST ALONG STRIKE - SEDA
CHECKED	*SRH	DATE 20/11/08	
SCALE	1:10,000 V, 1:400,000 H	PROJECT No 087633050-16	FIGURE No 20 — REV No 1 — A3

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K:\Env\2008\087633050\Figures\087633050-016-R-FIG20.dwg Jun 05, 2009 - 5:04pm

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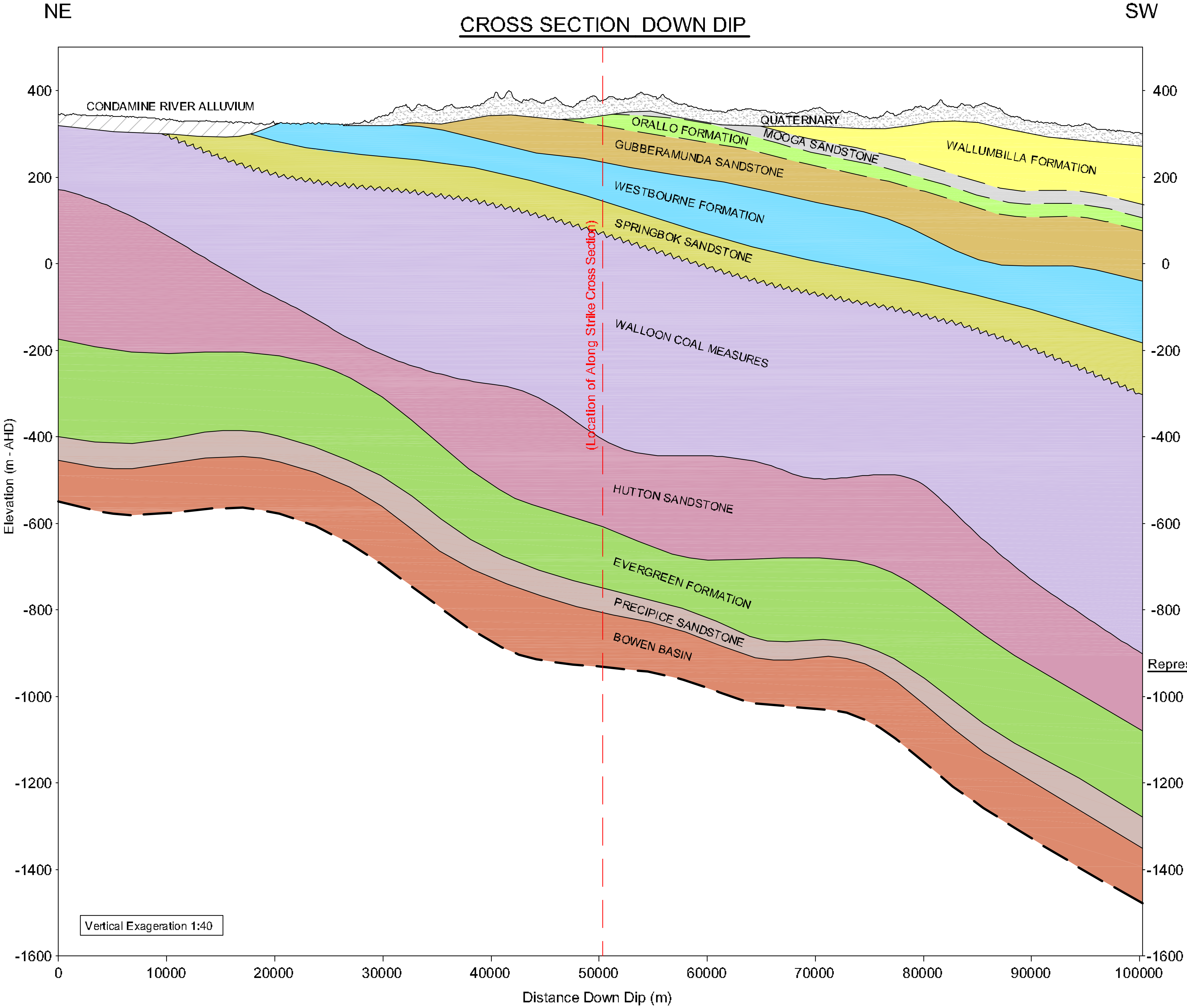
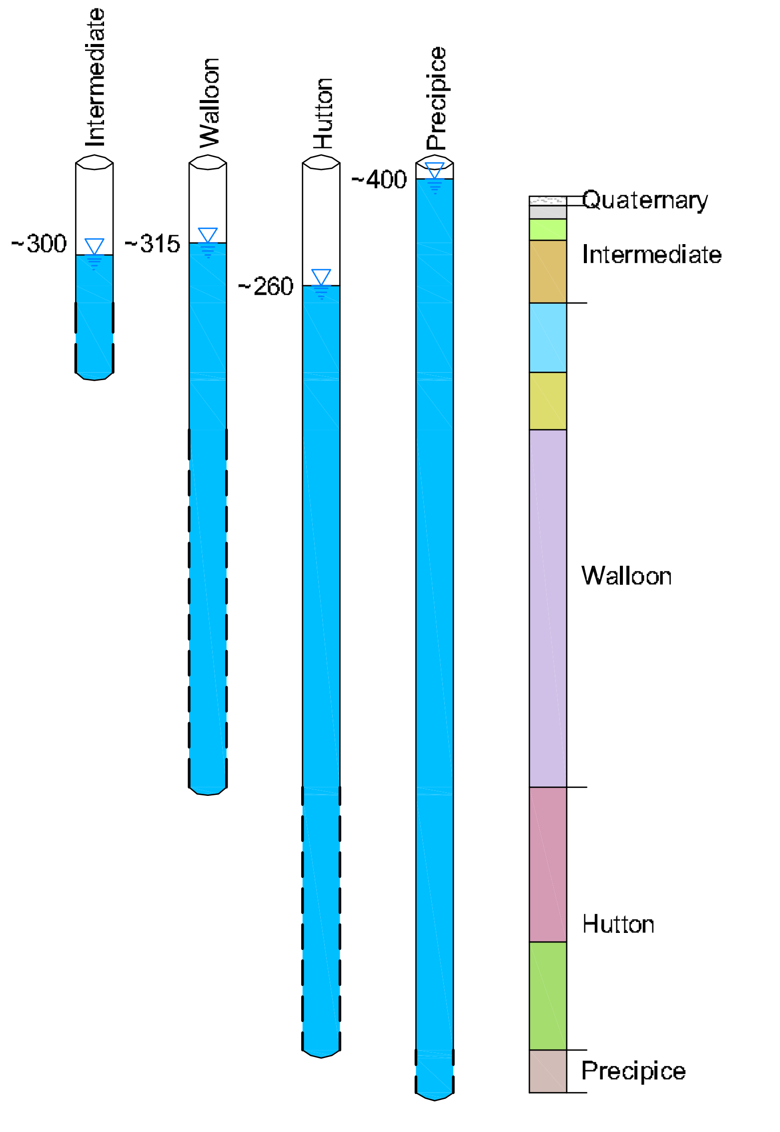
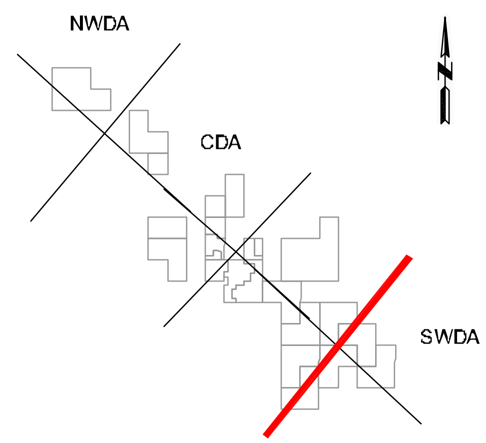




NWDA:
Representitive piezometric levels in indictive bores in the main groundwater units



Section Locality Plan

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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	PROJECT	QGC LNG Water Studies
DRAWN	GPG	DATE	20/11/08
CHECKED	*SRH	DATE	20/11/08
TITLE	HYDROGEOLIGICAL SECTION SOUTHWEST DOWN DIP - SEDA		
SCALE	1:10,000 V, 1:400,000 H	PROJECT No	087633050-16
FIGURE No	21	REV No	1
A3			

NOTE: THE * BESIDE THE TYPED INITIALS DENOTES THE ORIGINAL DRAWING ISSUE WAS SIGNED OR INITIALLED BY THAT RESPECTIVE PERSON.

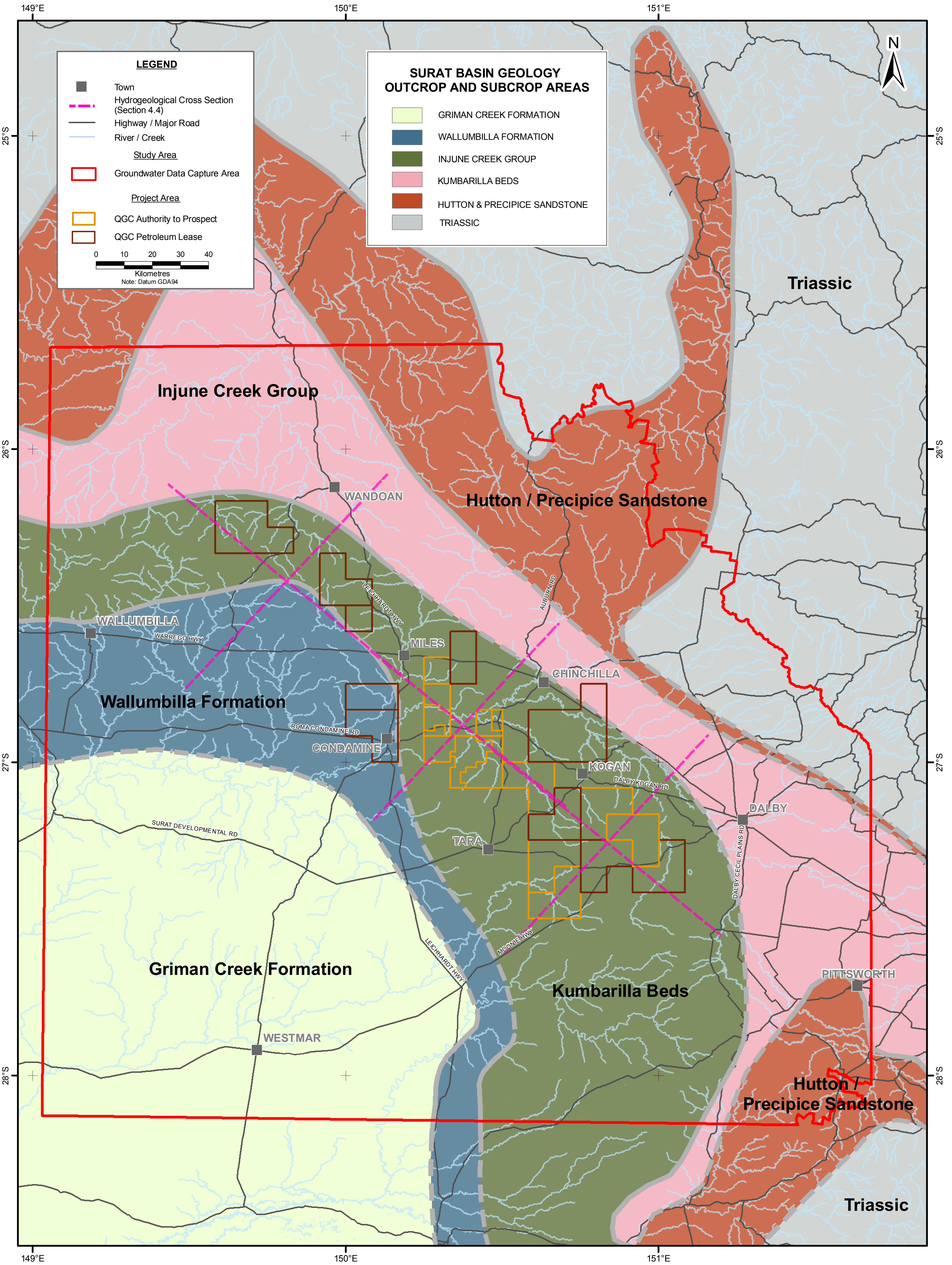
4.4.6 Recharge and Discharge

Most recharge for the GAB aquifers (including the Intermediate, Walloon, Hutton and Precipice Units in this region) occurs on the eastern and north-eastern margins of the GAB. 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. *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. *Discharge springs are those emanating from the GAB aquifers other than recharge springs*, however, there are no discharge springs within the study area.

Discharge of the GAB also occurs from controlled and uncontrolled flowing artesian bores that pump water from the different aquifers (NRW database indicates that historically artesian bore 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 only discharge in the study area 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 study area (Figure 22). Recharge zones of the Walloon (Injune Creek Group), Hutton, and Precipice Units are located north-northeast of the tenements. Recharge to the Shallow Unit and the Condamine River Alluvium can be expected to occur from surface water infiltration and leakage from creek beds. No discharge zones, including Artesian springs, are present within the Project Area.



Note
1. Base map data copyright Mapinfo Australia Pty Ltd.
2. Outcrop and Subcrop Areas derived from geology data copyright the State of Queensland (Department of Mines and Energy), 2008.
3. Authority ToProspect & Petroleum Leases data supplied by Queensland Gas Company (QGC), files received dated 17-09-2008.

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CLIENT	Queensland Gas Company		PROJECT	QGC - LNG EIS Groundwater Study	
DRAWN	DK/BQ	DATE 05-06-09	TITLE	GENERALISED SUBCROP ZONES IN THE STUDY AREA	
CHECKED	RKH *	DATE 05-06-09			
SCALE	1:1,250,000		PROJECT No 087633050_016	FIGURE No 22	REV No 1 A3

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0022_Rev1_SubcropZones_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

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 23 to Figure 27. Contours were generated using the water levels and electrical conductivity data available from both the NRW groundwater database and from QGC. The data was contoured using computer programming methods (Surfer® and ArcGIS®) with plots of equipotential curves defining inferred regions of similar value. Where anomalous areas were detected some discretionary data exclusions were required to produce a sensible and realistic result.

Potentiometric contours for water level 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 isocon 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 poor quality water.

The map of the Precipice Sandstone Unit indicates the limited data available for that unit within the area (Figure 28).

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 may not necessarily represent ambient (natural) conditions.

Regular 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.

4.5.1 Shallow GAB and Condamine River Alluvium Aquifers

Figure 23 and Figure 24 present the potentiometric surfaces of the Condamine River Alluvium and Shallow GAB aquifers, respectively.

Limited data is 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 possible.

Groundwater elevations in the Condamine River Alluvium mimic topography with flow direction normal to topographical contours. Groundwater flow is directed from the higher elevations to the east of the study area towards the valley of the Condamine River. Groundwater flows in a north to northwest direction through the region.

The potentiometric surface of the Main Range Volcanics is not presented in Figure 23 due to its limited extent and overlap with the Condamine River Alluvium.

Higher salinity levels in a few locations are attributed to high pumping rates and aquifer stress. Groundwater quality in all of the shallow flow units is generally fresh.

4.5.2 The Intermediate Aquifers

The distribution of piezometric levels in the Intermediate Unit ranges between 280 to 300 metres AHD in the CDA (Figure 25). Groundwater flow tends to be from east to west, down dip; however, a low hydraulic gradient exists among a high density grouping of Intermediate bores in the northern part of the study area, west of Miles. Artesian bores of the Mooga and Gubberamunda Sandstones are identified in the NRW database in the south of the CDA and SEDA (their current status as ‘artesian’ is not know).

Based on the data available, salinity generally varies between 3,000 to 6,000 µS/cm across the unit. Rare occurrences of EC values up to 20,000 µS/cm have been reported from the Orallo Formation in the CDA region.

4.5.3 The Walloon Coal Measures

Figure 26 presents the potentiometric surface of the WCM Unit prior to major CSG operations in the area. Groundwater elevations vary between 290 to 310 metres AHD across the tenements, 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 24,000 µS/cm, with the highest salinities observed near the town of Chinchilla. Water from the WCM is generally not used for human and livestock consumption.

4.5.4 The Hutton Aquifer

Based on available data, the direction of groundwater flow through the Hutton Unit is inferred to be towards the west-southwest (down dip). Recharge areas of the Hutton occur in the elevated ridges along the eastern portion of the study area. The distribution of piezometric levels across the tenements varies between 260 and 300 metres AHD.

As with the Walloon Unit, there appears to be a zone of relatively high salinity water around Kogan, extending northward up to beyond Chinchilla (based on contour plots presented in Figure 26 and Figure 27 and which are based on a small number of bores showing above average salinity water present there). Groundwater is less saline away from this zone to the west and south-east. 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 QGC tenements and that there may be a mixing process between the formations (AGE 2007 (unpublished); PB 2004).

4.5.4.1 The Precipice Aquifer

Water level and water quality data for the Precipice Unit were limited to the central part of the study area. As a consequence, the hydrogeological map (Figure 28) showing this data only provides numerical data (not contoured). Groundwater elevations for the unit are approximately 200 metres AHD in the northern part of the study area.

Salinity in this unit is generally less than 5,000 µS/cm (Section 4.6). From the small number of data available for the Precipice Aquifer, the highest EC reported in 3,840 µS/cm.

4.5.5 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 or along strike.

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), described previously, see Section 4.4.3 and Table 12).

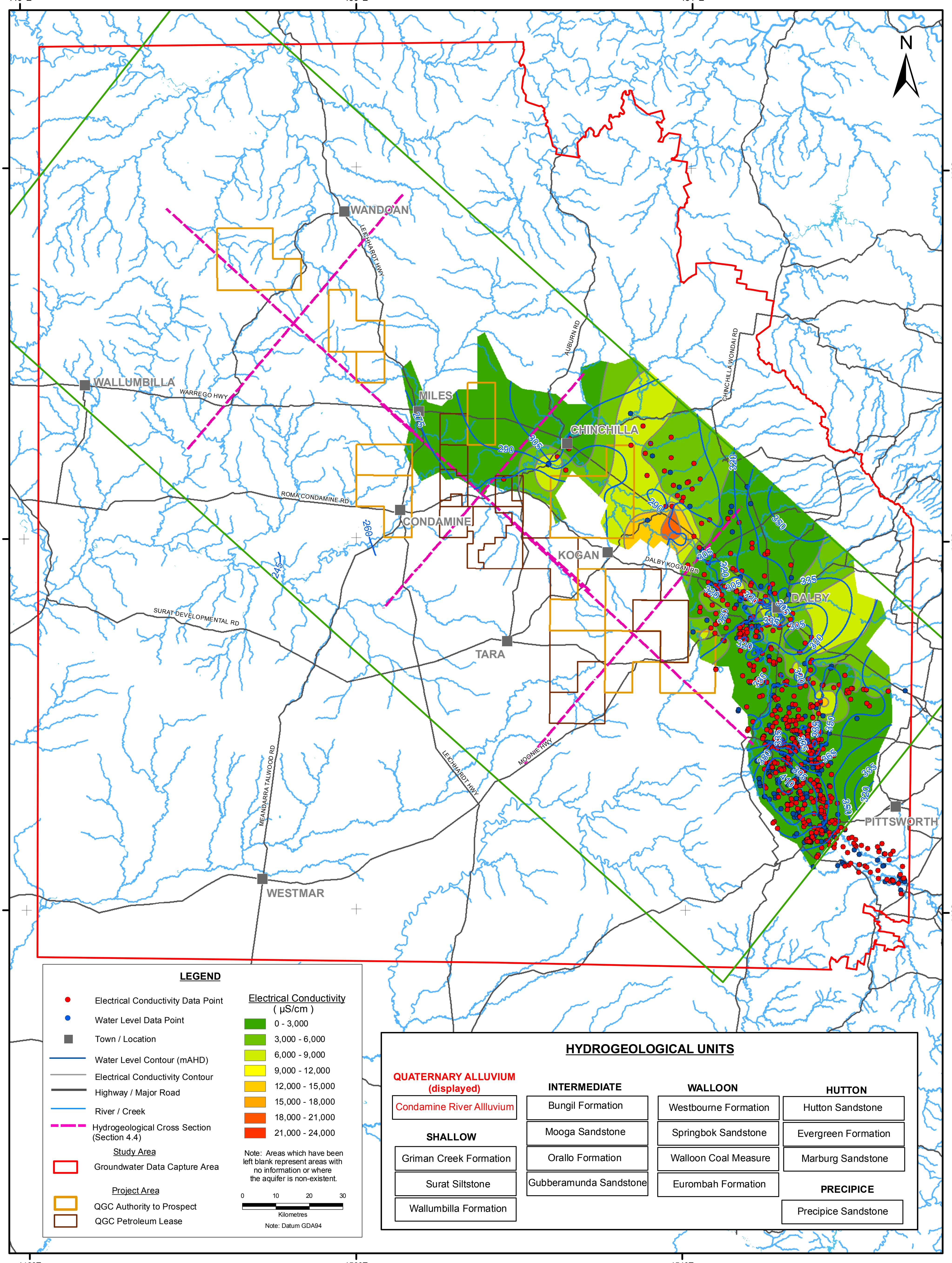
It is noted that, within the GAB, inter-aquifer flows occur naturally where there is direct aquifer connectivity and where favourable hydrogeological conditions exist. This situation frequently occurs at the margins of the GAB or locally in association with existing faults. Inter-aquifer flow can be 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 NRW database does indicate that historically some artesian wells existed in the area, although there 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 water head of 275 metres AHD across most of the study area, and the Intermediate Unit has a head of about 300 metres AHD.

In the CSG development areas, hydraulic heads vary between 290 and 310 metres AHD. Greater hydraulic heads are recorded in the WCM Unit bores in the eastern part of the study area, where surface elevations are higher.

Water head (piezometric levels) in the Hutton Sandstone and WCM are similar. There are higher water levels in the eastern ranges of the study area and shallow gradients in the northwest, where the surface terrain is subdued. However, based on the available data, the present direction of groundwater movement is inferred to be downward 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 23 to Figure 27 suggest hydraulic connection via favourable hydrogeological conditions (e.g. coincident areas of higher hydraulic conductivity in adjacent layers) does occur, to varying degrees, across the study area.



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CLIENT: Queensland Gas Company		PROJECT: QGC - LNG EIS Groundwater Study	
DRAWN: DK/BQ	DATE: 10-06-09	TITLE: HYDROGEOLOGICAL MAP CONDAMINE RIVER ALLUVIUM	
CHECKED: RKH *	DATE: 10-06-09		
SCALE: 1:1,050,000		PROJECT No: 087633050_016	FIGURE No: 23 / REV No: 2 / A3

File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0023_Rev2_CondamineHydroMap_A3.mxd
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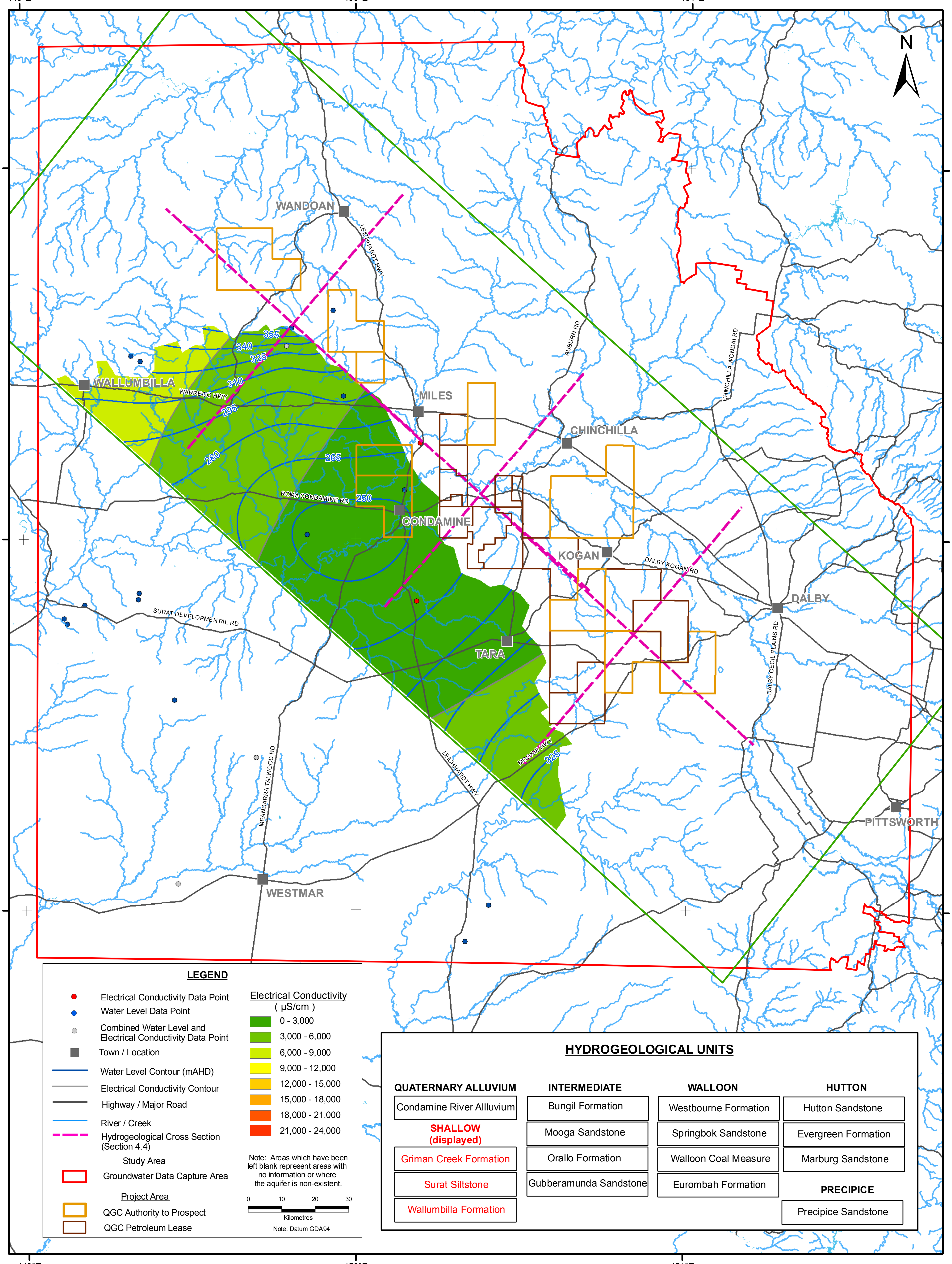

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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN	DK/BQ	DATE	10-06-09
CHECKED	RKH *	DATE	10-06-09
TITLE	HYDROGEOLOGICAL MAP SHALLOW UNIT		
SCALE	1:1,050,000	PROJECT No	087633050_016
FIGURE No	24	REV No	2
A3			

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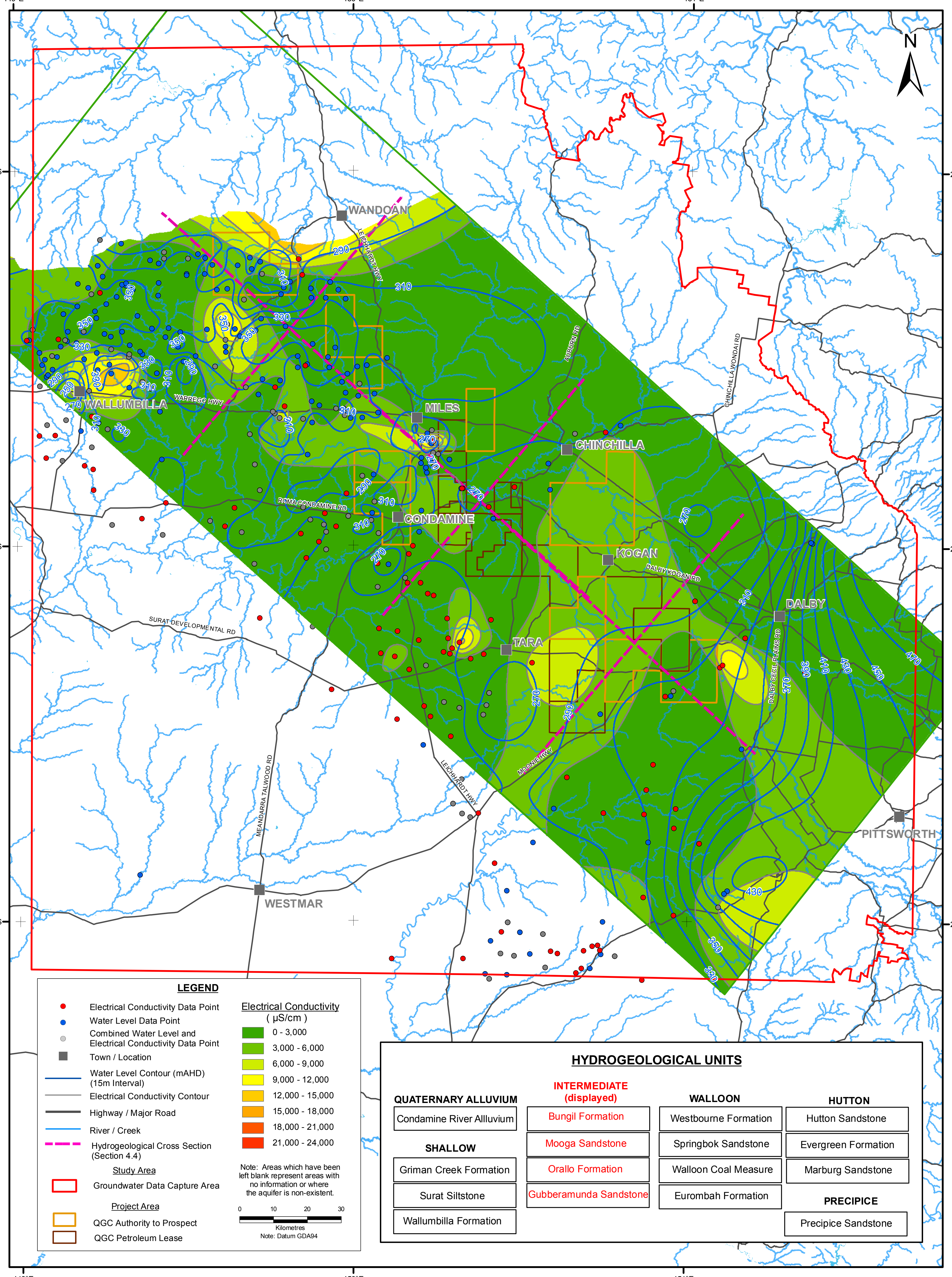

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CLIENT: Queensland Gas Company		PROJECT: QGC - LNG EIS Groundwater Study	
DRAWN: DK/BQ	DATE: 10-06-09	TITLE: HYDROGEOLOGICAL MAP INTERMEDIATE UNIT	
CHECKED: RKH *	DATE: 10-06-09		
SCALE: 1:1,050,000		PROJECT No: 087633050_016	FIGURE No: 25 / REV No: 2 / A3

File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0025_Rev2_IntermediateHydroMap_A3.mxd
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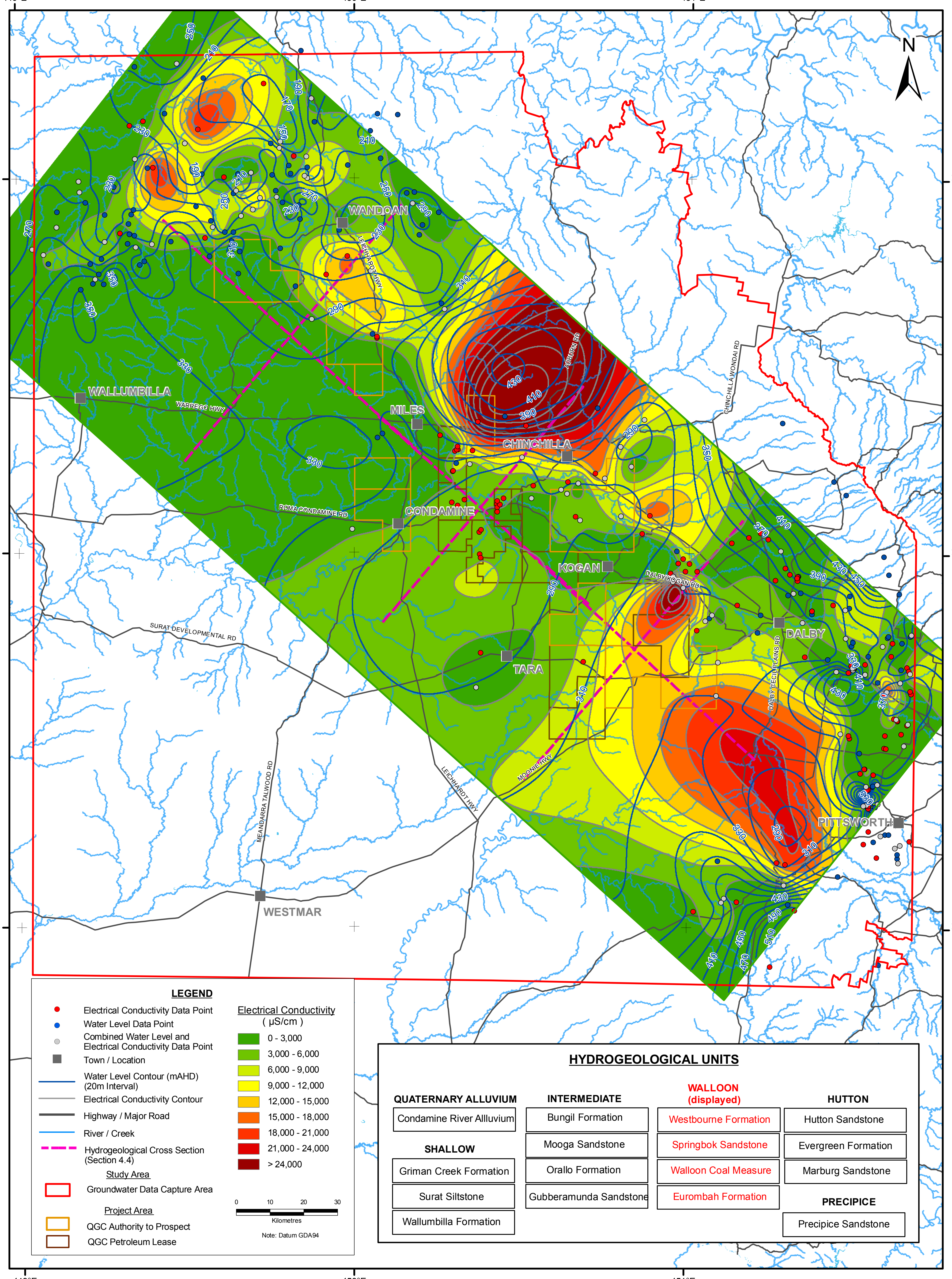

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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN	DK/BQ	DATE	10-06-09
CHECKED	RKH *	DATE	10-06-09
TITLE	HYDROGEOLOGICAL MAP WALLOON UNIT		
SCALE	1:1,050,000	PROJECT No	087633050_016
FIGURE No	26	REV No	2
A3			

File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0026_Rev2_WalloonHydroMap_A3.mxd
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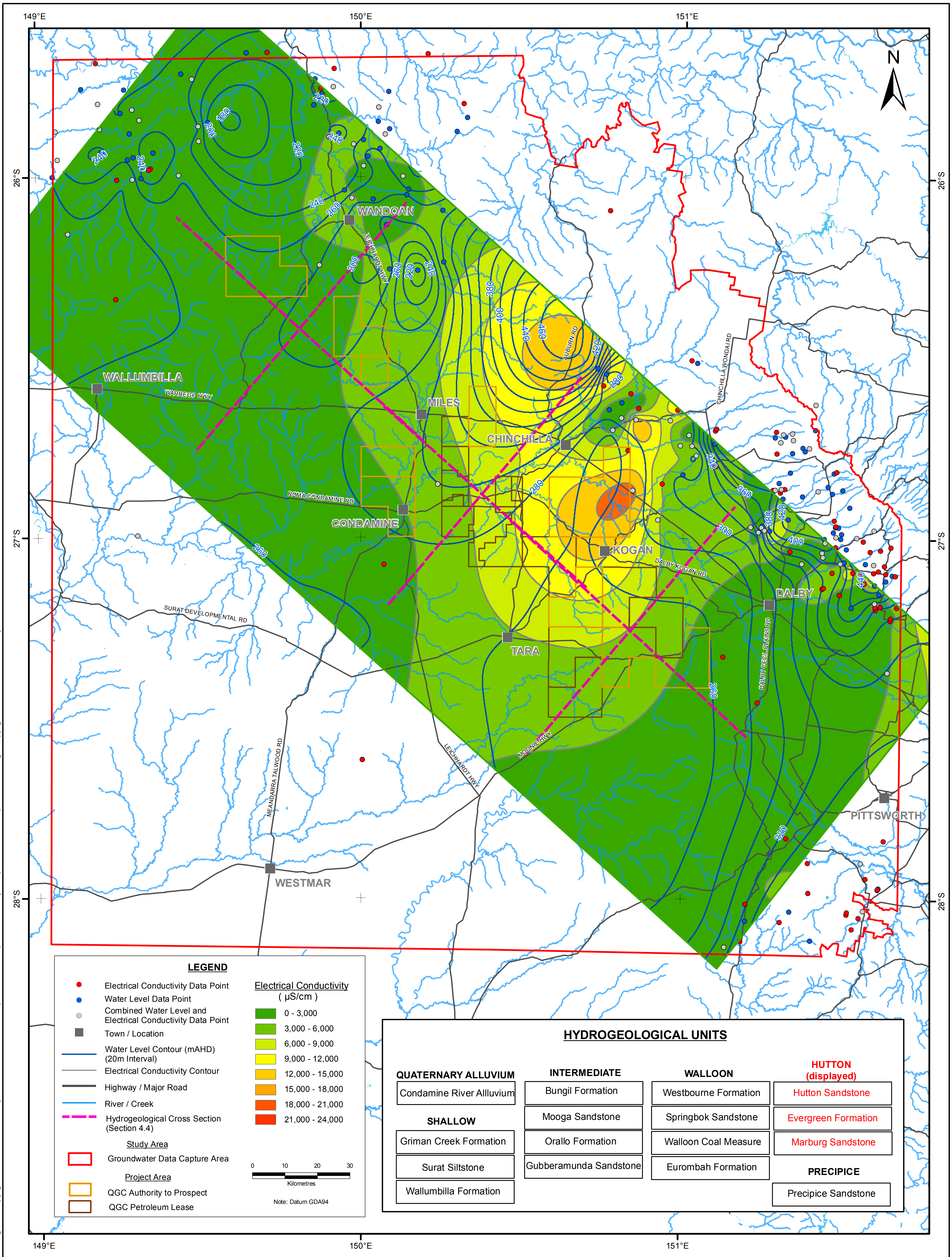

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CLIENT: Queensland Gas Company		PROJECT: QGC - LNG EIS Groundwater Study	
DRAWN: DK/BQ	DATE: 10-06-09	TITLE: HYDROGEOLOGICAL MAP HUTTON UNIT	
CHECKED: RKH *	DATE: 10-06-09		
SCALE: 1:1,050,000		PROJECT No: 087633050_016	FIGURE No: 27 · REV No: 2 · A3

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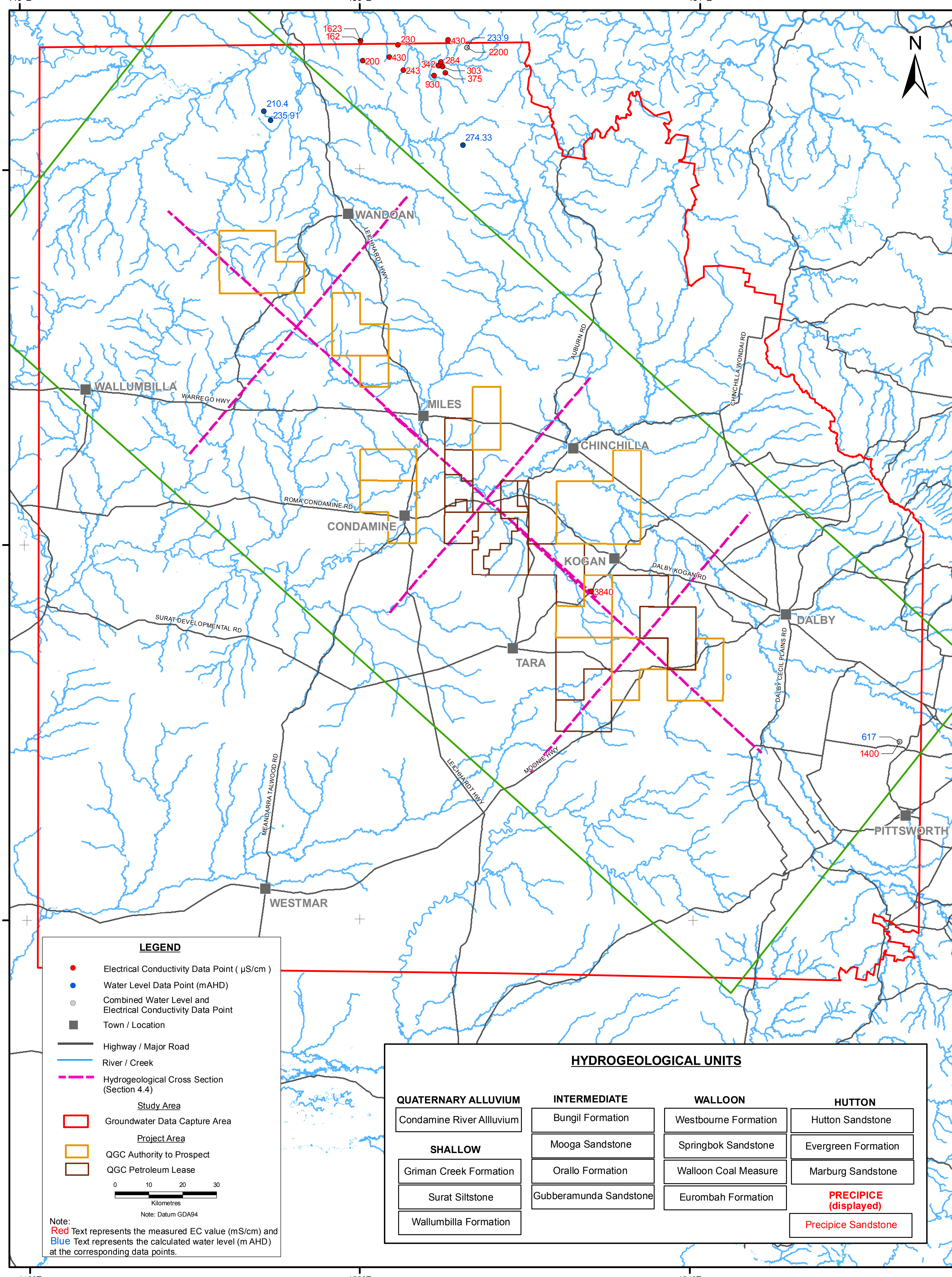

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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN DK/BQ	DATE 10-06-09	TITLE	HYDROGEOLOGICAL MAP PRECIPICE UNIT
CHECKED RKH *	DATE 10-06-09		
SCALE	1:1,050,000	PROJECT No 087633050_016	FIGURE No 28 · REV No 2 · A3

File Location:R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0028_Rev2_PrecipiceHydroMap_A3.mxd
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4.5.6 Temporal Piezometric Trends

Spatial and temporal analysis of historical piezometric head data can be used to determine variations in groundwater pressure response to groundwater extraction over time. Available water level data measurements collected over time are sparse and are limited to a few monitored bores. These include the WCM, Intermediate Aquifers and Condamine River Alluvium (Quaternary Alluvium Unit):

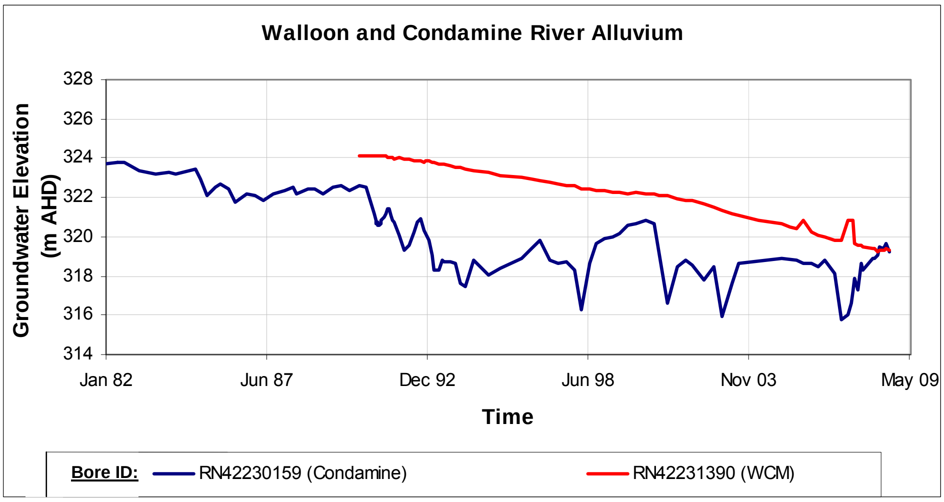
Figure 29 compares typical WCM and Condamine River Alluvium (Quaternary Alluvium Unit) groundwater level responses over time. The graph (A) shows a decrease in the water level elevations in both aquifer systems.

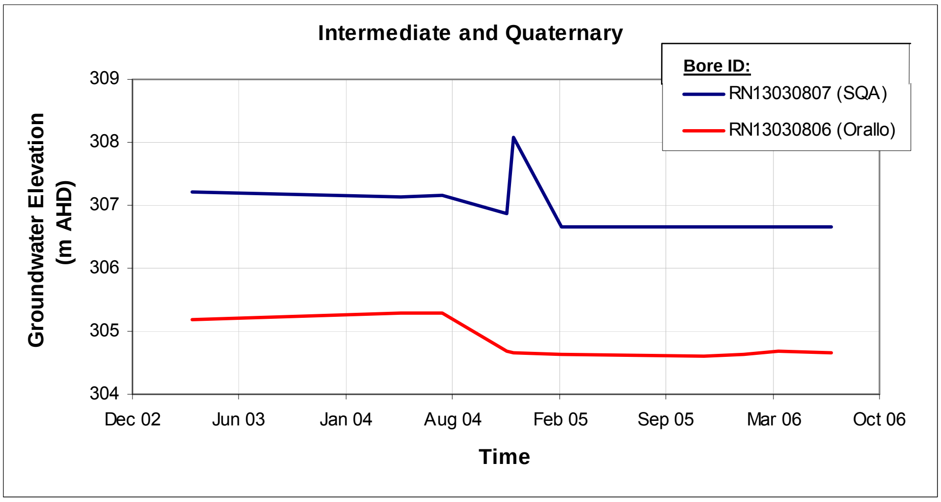
The Condamine River Alluvium groundwater level shows a decline of approximately four metres since January 1982. This variation is likely to relate to abstraction of water for irrigation purposes, as well as long-term residual recharge due to low rainfalls. The piezometric heads in the WCM Unit have declined by about six meters since the early 1990s.

In the north of the study area there are three bores completed in the Intermediate Unit (Orallo and Gubberamunda formations). At least ten records have been collected for each of these bores since 2003. Groundwater levels in these formations have remained relatively stable over that time (Figure 29, Graph B). The difference in head between the Orallo and Quaternary formations in this area suggests a downward direction of flow.

Within the WCM Unit, temporal piezometric levels show variable trends of pressure at different locations across the study area (Figure 29 Graph C). The hydraulic heads in some bores have remained stable over the last 15 years (RN42231256 and RN 42231257) and a drawdown of 5 and 13 metres has been measured in others (RN42231258 and RN42231390) located to the north, near the Condamine River floodplain where intensive agriculture and irrigation occur (and unrelated to CSG operations).

The location of the bores with temporal water level data is presented on Figure 30.





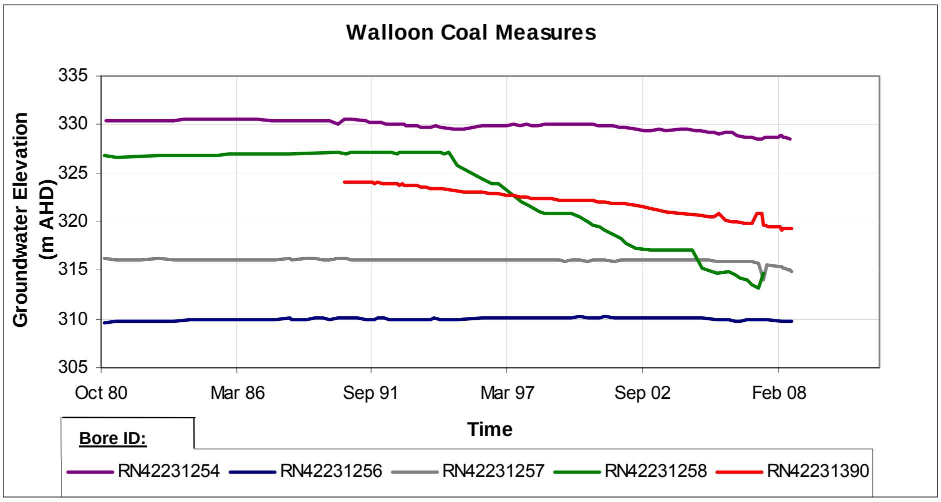
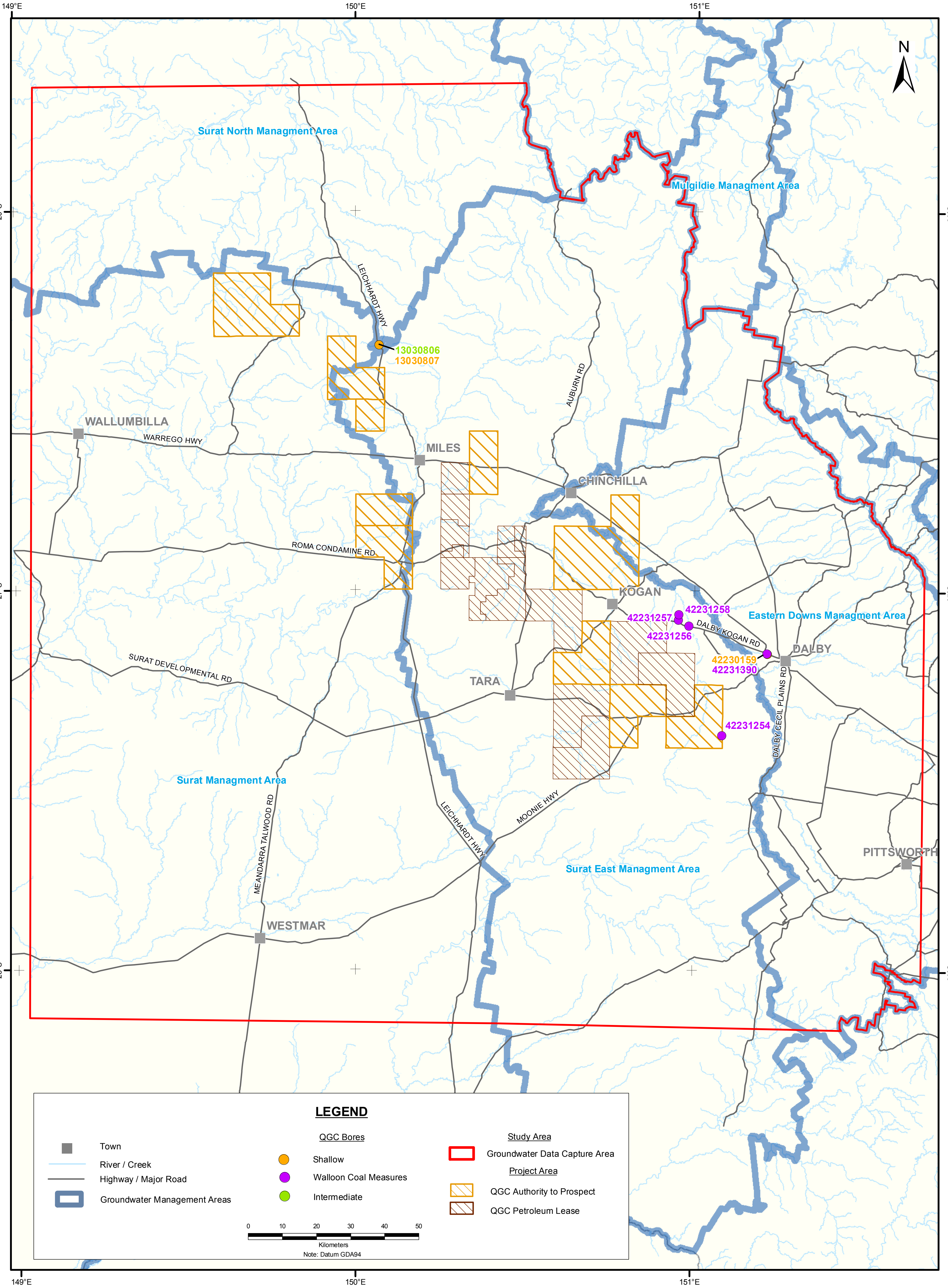


Figure 29: Temporal Piezometric Trends



Notes:
1. Base map data copyright Mapinfo Australia Pty Ltd
2. Authority To Prospect & Petroleum Leases data supplied by Queensland Gas Company (QGC), dated 15-10-2008 and 23-10-2008.

Golder Associates

CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS WATER STUDIES
DRAWN	DK/BQ	DATE	05-06-09
CHECKED	RKH *	DATE	05-06-09
SCALE	1:1,050,000		
TITLE	TEMPORAL PIEZOMETRIC TRENDS – LOCATION OF BORES		
PROJECT No	087633050_016	FIGURE No	30
REV No	0		A3

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0030_Rev0_PiezometricTrends_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

4.6.1 Introduction

This section provides a summary of the detailed assessment of groundwater quality matters presented in Appendix E.

4.6.2 Great Artesian Basin Groundwater Quality

As discussed in Section 4.4.6, recharge to the GAB aquifers takes place in outcrop areas along the eastern margins of the Surat Basin, on the western slopes of the Great Dividing Range (GAB Resource Study, 1998). As fresh water seeps into the recharge areas and flows through the different aquifers, it encounters different minerals along its path of flow. Heterogeneity in groundwater quality throughout the GAB is a result of the:

- sediment deposition and composition of the aquifers
- groundwater residence time
- source of the groundwater
- inter-aquifer/aquitard mixing of groundwater
- depth and direction of groundwater flow.

The groundwater of the GAB aquifers is dominated by a sodium-bicarbonate (Na-HCO3) type chemistry. In certain areas of the GAB chloride and sulphate dominate the chemistry.

High sodium concentrations are generally attributed to its dissolution, which takes place as recharge water encounters sodium feldspars as it flows through the aquifer. Sodium concentrations can also increase when fresh water comes in contact with clays or shales. In this case, ion exchange processes can take place between these minerals and the water itself. Calcium and magnesium cations in groundwater are exchanged for sodium ions in clays, so the resulting groundwater will have low calcium and magnesium concentrations with enhanced sodium concentrations.

The main mechanism for high bicarbonate content in groundwater is the dissolution of carbonate by oxygenated recharge waters (Freeze and Cherry, 1979). As a result, the groundwater will have a fairly alkaline pH.

Other ions that may be present in GAB water are chloride and sulphate. A major rise in relative sea level in Early Cretaceous times led to a deposition of marine sediments in the Surat Basin. Dissolution of minerals of marine origin such as albite and halite are mainly responsible for chloride concentrations in groundwater. Dissolution of sulphate minerals like gypsum and anhydrite are responsible for the sulphate in groundwater. In addition, sulphate concentrations can increase from weathering and oxidation of pyrite, marcasite and similar sulphide minerals.

4.6.3 Groundwater Quality in the Study Area

Similarities in chemical composition of CSG associated water from various parts of the world indicate that standard water types can be expected within CSG beds, independent of lithology formation or age (Van Voast, 2003). In basins where coal is in stratigraphic association with marine or marine-transitional beds, chloride and sodium are the substantial components of the water produced in CSG extraction (i.e., as associated water). Elevated concentrations of bicarbonates, regardless of the methane origin, suggest that biochemical reduction of sulphates is the primary bicarbonate producer in the formation waters.

CSG waters usually have low calcium, magnesium, and sulphate concentrations because ion concentration in these waters is directly related to the methanation process (Taulis *et al.,* 2007). Coal bed methane generally exists in areas where sodium and bicarbonate dominate the water chemistry in the coal seam (Van Voast, 2003). The distinctive groundwater composition, inherent to methane occurrence, is due to geochemical processes that include sulphate reduction and production of bicarbonates, and depletion of calcium and magnesium through precipitation and/or ion exchange reactions.

Groundwater quality from aquifers in the study area was assessed by analysing available sampling results. Appendix E presents the complete groundwater quality assessment.

In general, groundwater in GAB aquifers is characterised by sodium-bicarbonate type chemistry throughout the eastern and central parts of the study area. Sodium-sulphate-chloride type water chemistry dominates the western part of the study area. Along the regional groundwater flow path, from the north-eastern outcrop margins to the south-western discharge areas, concentrations of sodium and bicarbonate increase (Herzeg, 1991).

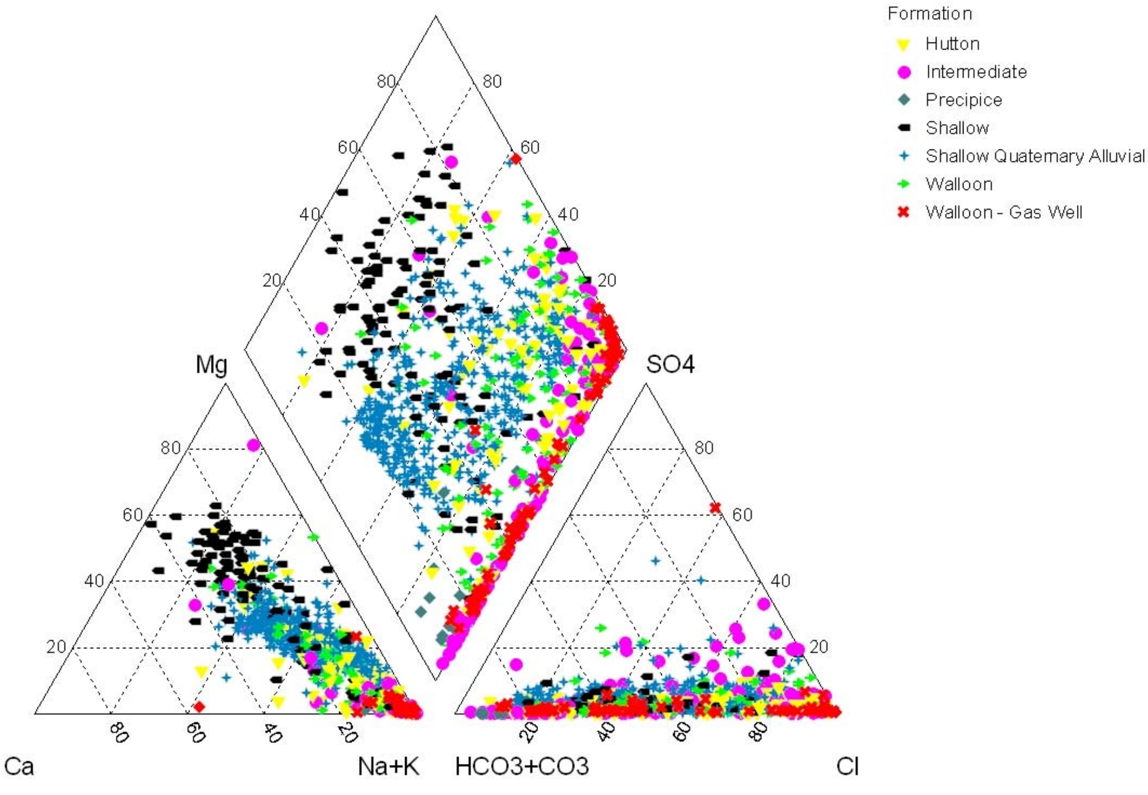


Figure 31: Piper Plot of All Groundwater Samples

The Piper Plot (Figure 31) compared all the groundwater units/formations in the study area for water chemistry. Sodium content in groundwater is listed below from *lowest to highest* concentrations for the aquifers (and wells):

- Shallow Unit;

- Shallow Quaternary Alluvial;
- Walloon Unit = Hutton/Precipice;
- Intermediate Unit; and
- Production wells.

The *Intermediate Unit* appears to have the highest proportion of sulphates and CSG production wells the lowest.

Observed groundwater pH ranges from slightly acidic (pH 5.5) to alkaline (pH 11.4), with both the minimum and maximum pH observed in the Walloon unit. The majority of groundwater samples were neutral or alkaline, with pH values ranging from 7 to 9. A sample collected from the Pinelands production well had a pH of 12 which is assumed to be affected by well construction.

Water quality in the main aquifers varies from fresh to saline with calculated total dissolved solids (TDS) varying between 53 mg/L and 31,884 mg/L. Approximately 41% of the groundwater samples could be classified as fresh with TDS values less than 1,000 mg/L. The majority of groundwater samples were slightly brackish (46%) with TDS concentration ranging from 1,000 to 3,000 mg/L. Brackish and saline groundwater was less common. Twelve percent (12%) of analysed samples were brackish and 2% of analysed samples were saline.

Groundwater quality in the production wells shifts from brackish and sodium-chloride type water in the north western tenements to fresh/slightly brackish and sodium-bicarbonate type water in the south eastern tenements. Higher salinity levels in the northwest are attributed to the deeper burial of the WCM in comparison to the eastern study area.

Section 1.1.3 of Appendix E provides further details in relation to the piper plot presented as Figure 31

4.7 Water Use

Existing uses for groundwater throughout the study area vary proportionally across the groundwater management units. Figure 32 illustrates groundwater use (by percentage), excluding CSG extraction. The main uses for groundwater are stock, irrigation and domestic. Other uses include town supply, industrial uses and aquaculture (Australian Natural Resources Atlas, 2005). It is likely that demands for water for these uses will also increase over time. Many of the GMU's are already over abstracted or approaching their maximum abstraction levels, as identified in the GAB WRP (2006). A new moratorium was placed in July 2008 against new water license applications in the Main Range Volcanics and Condamine River Alluvium (and tributaries).

The primary use of water in the Eastern Downs is irrigation, whereas stock use dominates the other GMAs. The majority of the irrigation bores in the Eastern Downs are completed in the Condamine River Alluvium. To a lesser degree, east of the Condamine River, irrigation bores are completed in the Main Range Volcanics, Walloon Coal Measures, and Hutton/Marburg Sandstone.

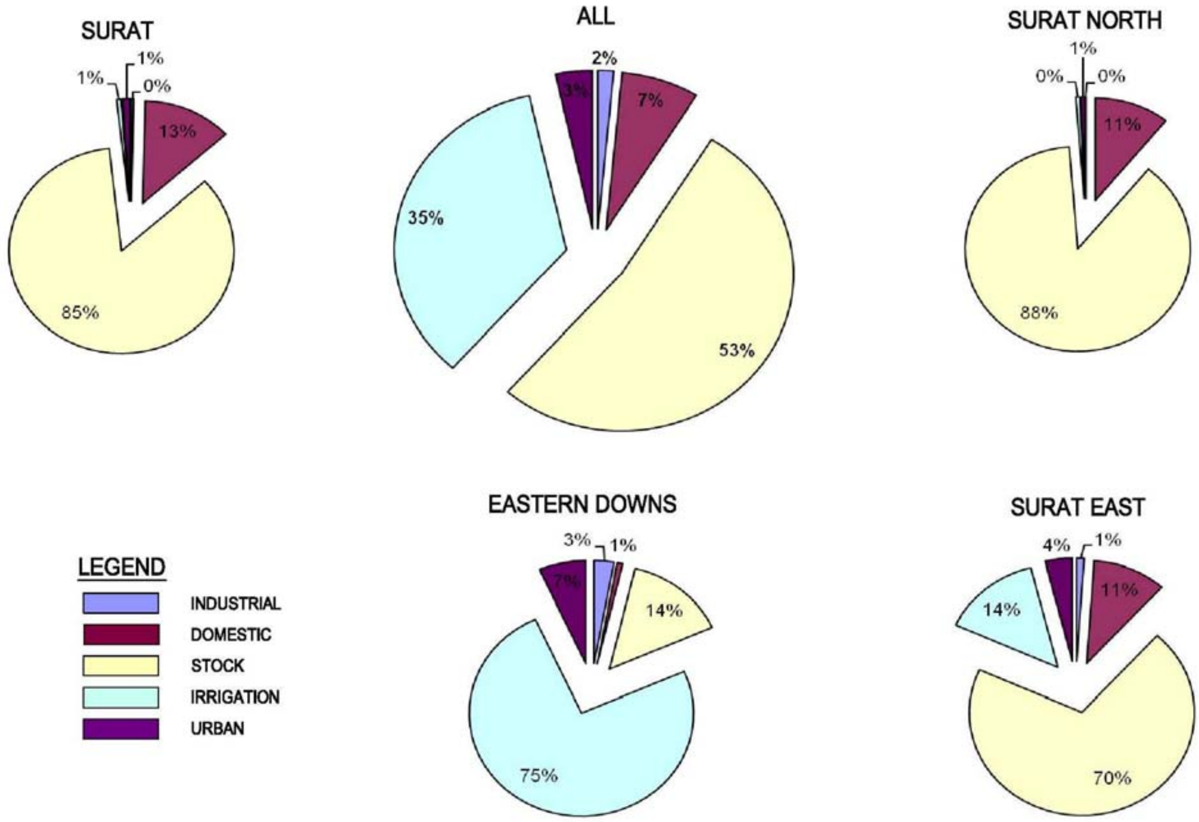


Figure 32: Groundwater use in the study area

Water from the WCM Unit is not typically used by farmers or other water users in the north of the study area because of its depth, poor water quality and generally low yield.

4.7.1 Water allocation, entitlement and extraction

4.7.1.1 Water allocation and entitlement

The majority of the Project Area is contained within the areal boundaries of the following groundwater management areas: Surat GMA 19, with small sections in GMA 20 (Surat North), GMA 21 (Surat East) and GMA 24 (Eastern Downs) (refer to Figure 1 and Figure 3). These GAB GMAs represent the hydrogeological data capture areas for this study.

Information on the number, location and entitlements was extracted from the Queensland NRW 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 in the Project Area is provided in Table 13;
- Table 13 summarises the targeted aquifers exploited by the respective bore in each groundwater management unit;
- Entitlements are currently estimated at over 280,000 ML of groundwater (this may not represent an actual of the amount of groundwater which might be extracted in any one year ;
- Figures 38 to 42 illustrate the number of bores screened in each aquifer;

- The Management Units in Table 13 follow those outlined in the Hydrogeological Framework Report (Department of Natural Resources and Mines, 2005);
- The number of bores registered in WERD is less than the total number of water bores in the study 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 13 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 and occasionally irrigation) 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 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;
- The Walloon Unit (Walloon Coal Measures) is also used within the Surat East GMA;
- The primary aquifers targeted in the Eastern Downs and Surat East GMAs are the Condamine River Alluvium and the Main Range Volcanics. The water is primarily used for irrigation;
- In the Surat North GMA, the Hutton Sandstone unit is the major target aquifer, with extraction primarily from the Birkhead Formation and other undifferentiated formations of the Injune Creek Group (to which the WCM are associated); and
- The Hutton Sandstone and Precipice Units are more intensely used to the north of QGC's production areas where the depth to the units decreases as they approach the regional subcrop/outcrop zones.

Table 13: Aquifer Usage in the Study Area

GMA	Management Units[1]	Geological Member	Hydrogeological Unit[2]	Licensed Users [3]	Registered Bore[3]	Licensed Bores with Entitlement[4]	Entitlements (ML/yr) [5]
Surat	-	Quaternary	SQA	1	2	0	0
		Griman Creek	Shallow	2	7	1	100
	Surat 1	Surat Siltstone	Shallow	0	0	0	0
		Coreena Member		2	2	0	0
		Doncaster Member		4	4	0	0
		Wallumbilla Formation		5	3	2	0
	Surat 2	Bungil Formation	Intermediate	46	45	3	50
		Minmi Member		0	0	0	0
		Nullawart Sandstone					

GMA	Management Units[1]	Geological Member	Hydrogeological Unit[2]	Licensed Users [3]	Registered Bore[3]	Licensed Bores with Entitlement[4]	Entitlements (ML/yr) [5]
		Member					
		Kingill Member					
	Surat 3	Mooga Sandstone	Intermediate	100	98	9	997
	Surat 4	Orallo Formation	Intermediate	15	15	2	733
		Gubberamunda Sandstone		51	50	10	2,459
	Surat 5	Westbourne Formation	Walloon	0	0	0	0
		Springbok Sandstone		0	0	0	0
		Birkhead Formation		1	1	0	0
		Walloon Coal Measures		4	4	0	0
		Eurombah Formation		2	2	0	0
		Undifferentiated		16	16	1	395
	Surat 6	Hutton Sandstone	Hutton	5	5	0	0
		Evergreen Formation		0	0	0	0
		Boxvale Sandstone Member		0	0	0	0
	Surat 7	Precipice Sandstone	Precipice	0	0	0	0
	Surat 8	Moolayember Formation	Basement	0	0	0	0
		Clematis Sandstone					
		Rewan Formation		0	0	0	0
Surat North	-	Quaternary	SQA	0	0	0	0
	Surat North 1	Westbourne Formation	Walloon	0	0	0	0
		Springbok Sandstone		1	1	0	0
		Walloon Coal Measures		3	3	1	570
		Eurombah Formation		14	14	1	290
		Undifferentiated		33	33	3	650
	Surat North 2	Hutton Sandstone / Marburg Sandstone	Hutton	70	70	4	1,762
		Evergreen Formation		6	6	2	680

GMA	Management Units[1]	Geological Member	Hydrogeological Unit[2]	Licensed Users [3]	Registered Bore[3]	Licensed Bores with Entitlement[4]	Entitlements (ML/yr) [5]
	Surat North 3	Precipice Sandstone	Precipice	23	23	2	865
	Surat North 4	Moolayember Formation	Basement	1	1	0	0
		Clematis Sandstone		2	2	0	0
Surat East	-	Condamine River Alluvium	SQA	119	165	80	32,984
		Quaternary		3	4	3	2,904
		Main Range Volcanics	Shallow	0	3	0	0
		Doncaster Member		3	3	0	0
		Wallumbilla Formation		2	2	0	0
	Surat East 1	Kumbarilla Beds	Intermediate	224	246	31	6,287
	Surat East 2	Walloon Coal Measures	Walloon	88	106	17	2,581
	Surat East 3	Hutton Sandstone	Hutton	13	16	16	2,413
		Evergreen Formation		5	5	2	900
	Surat East 4	Precipice Sandstone	Precipice	2	2	2	1,800
	Surat East 5	Moolayember Formation	Basement	0	0	0	0
		Clematis Sandstone		0	0	0	0
Eastern Downs	-	Condamine River Alluvium	SQA	549	1289	349	154,752
		Other Alluvium		155	1422	103	23,388
		Main Range Volcanics	Shallow	321	726	198	27,681
	Eastern Downs 1	Walloon Coal Measures	Walloon	82	280	56	7,411
	Eastern Downs 2	Marburg Sandstone	Hutton	89	324	53	7,371
	Eastern Downs 3	Helidon Sandstone	Precipice	1	1	1	400

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.

5. Summation of the annual entitlements is over 280,000 ML/yr.

Note: CSG production wells are not typically included in the NRW databases. The total number of wells pumping from the WCM Unit is expected to be much higher than the estimate presented in Table 13 of approximately 11,000 ML/year (see below).

4.7.1.2 Estimate CSG Water extraction

Initial production forecasts provided by QGC indicate that over 30,000 ML of water will be extracted from 1,400 QGC wells planned to be in operation by 2013.

The predicted extraction volumes for QGC's proposed CSG wellfield (up to 6,000 wells) over the next 20 years are provided in Figure 33. This plot includes the current WCM entitlements in the study area (calculated from Table 13). This forecast assumes that no additional entitlements will be granted within the WCM over the next 20 years, and that any additional extraction will be associated with CSG activities. *These predictions do not account for other CSG operators in the area*, who are also expected to have great water demands from the GAB.

The estimated production figures presented here were used in the calibration of the numerical groundwater model described in Section 5.4.

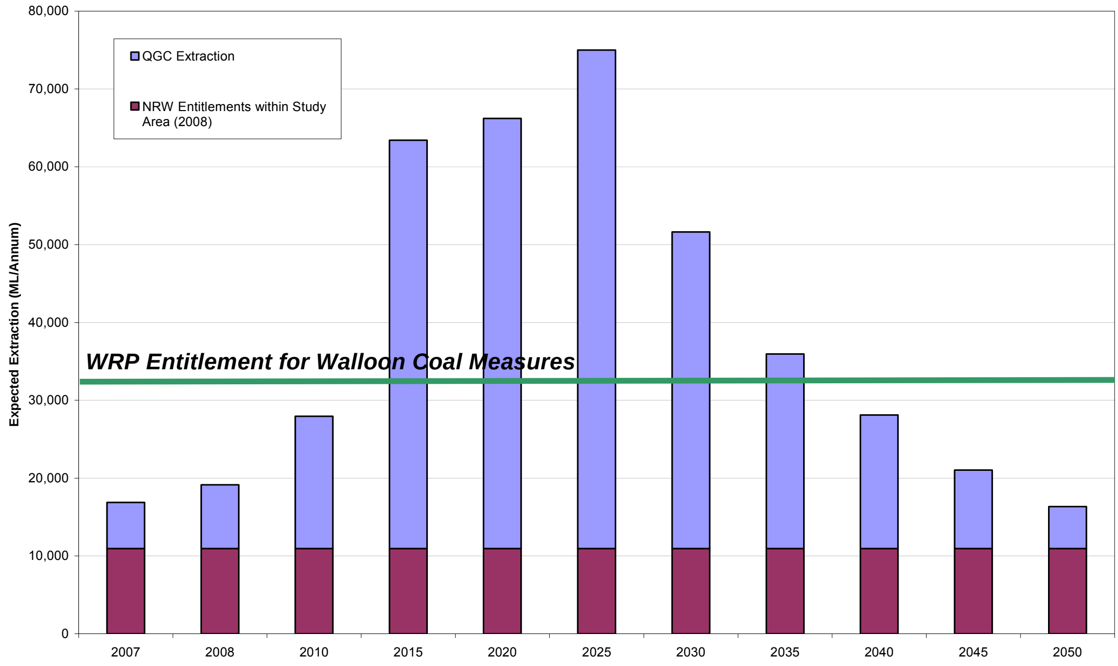


Figure 33: Extraction of Water from the Walloon Coal Measures

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 system has 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 models are based on the CGM and provide the ability to predict the groundwater systems responses to CSG extraction.

5.3 Conceptual Groundwater Model (CGM)

To better understand and describe the groundwater regime operating in the Project Area, a CGM has been developed for this study. It 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 study 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 16 to Figure 21, 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 14 and as a graphic representation in Figure 34.

Table 14: Conceptual Groundwater Model – Surat Basin Bedrock Hydrogeological System

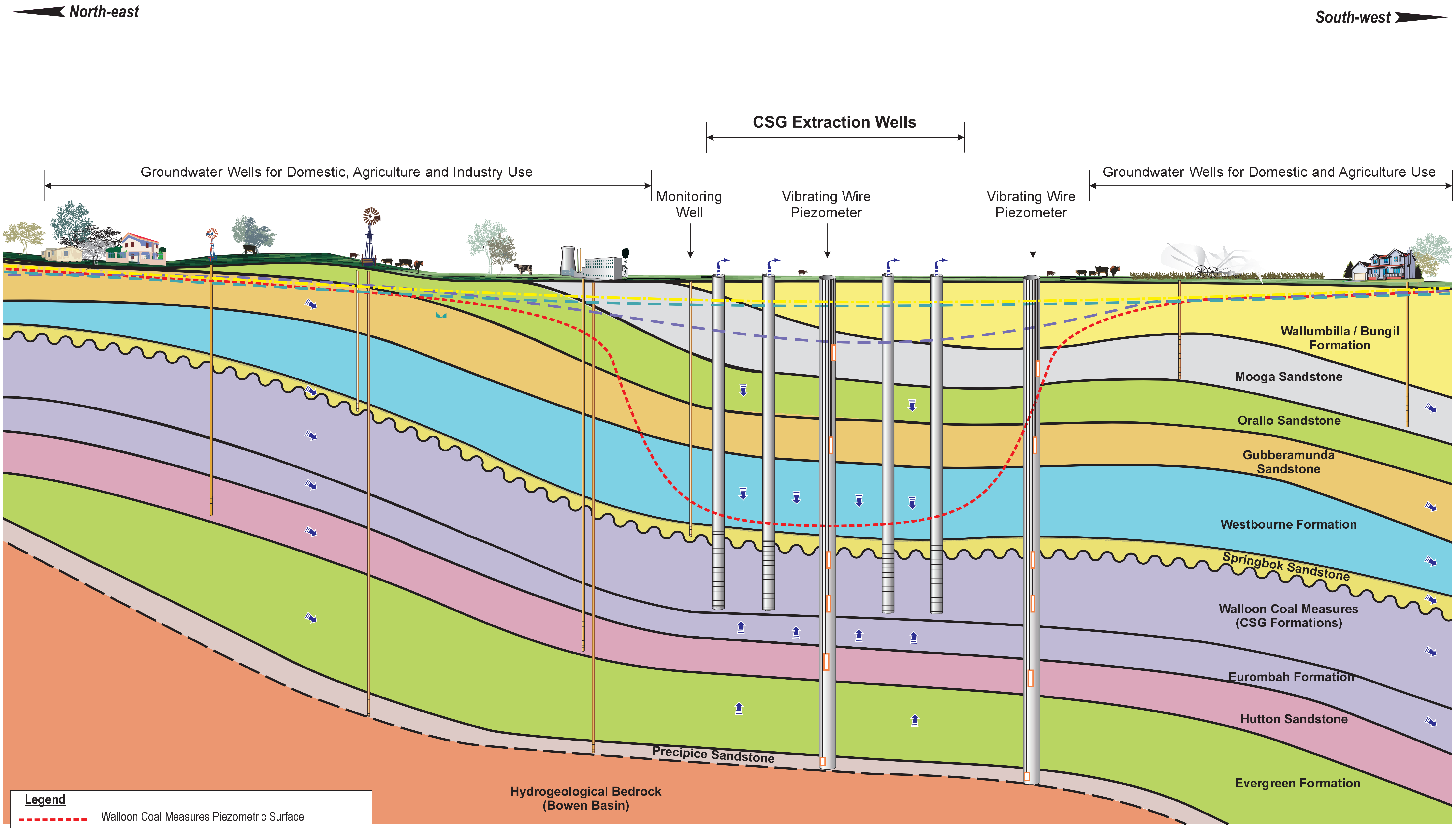
Component	Description
Geological System	The Surat Basin geology, present within the Project Area, comprises a multi-layered sedimentary sequence of beds, bands and units comprising combinations of sandstones, mudstones, siltstones, coal seams and volcanics (with rare limestones) rock-types. Five groupings of stratigraphies are distinguished: Shallow Unit, Intermediate Unit, Walloon Unit, Hutton Unit and Precipice 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 most 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 Project Area (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 13. 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. An exception to this is the more intense folding and accompanying fracturing of the stratigraphy (including the WCM) present within the CDA. The structural combination manifests itself as an anticlinal structure which is referred to as the “Undulla Nose”. The other 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 always present in the north eastern part of the Project Area. The Intermediate and Walloon Units outcrop (or subcrop) in

Component	Description
	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 layer 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 “Undulla Nose”, an anticlinal structure affecting the CDA, has resulted in enhanced permeability and storage capacity of the coal measures (and by inference, the surrounding sequences). It is inferred to result in increased vertical hydraulic conductivity within the affected lithologies and hence facilitate enhanced intra-formational flow connectivity. Other structural features present in the Project Area are considered to have less regional impact on the hydraulic conductivity of the hydrostratigraphy than does the Undulla Nose. 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 north-eastern region of the Project Area are typically unconfined to semi-confined, depending on depth of burial of a particular aquifer. They are heavily developed for their water resources (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, Section 5 and Appendix D). 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, and 10-30% for the other

Component	Description
	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 (e.g. the Condamine Alluvials). 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 Project Area 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 16 to Figure 21. The contoured piezometric surfaces generally reflect the groundwater flow gradients described as follows: *Shallow Aquifers*: water elevations in the Condamine River Alluvium mimic topography with flow direction normal to topographical contours. *Intermediate Aquifers*: around 280 to 300 metres AHD within the CDA. *WCM*: varies between 290 to 310 metres AHD. *Hutton Sandstone Aquifer*: varies between 260 and 300 metres AHD. *Precipice 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. The Undulla Nose structures are known to provide enhanced CSG availability and accessibility, accompanied by

Component	Description
	higher groundwater production. 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 Project Area typically range between 3,000 and 24,000 µS/cm (water is generally not used for human and livestock consumption, but industrial use is possible). *Hutton Sandstone Aquifer*: salinity levels across the Project Area generally range between 2,000 and 20,000 µS/cm. *Precipice Aquifer:* Salinity in this unit is generally less than 6,000 µS/cm.
Environmental Values (Refer Section 6.2)	The key groundwater uses and environmental values (refer to Section 6.2 for detailed discussion), identified within the Project Area, 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 6.0 and/or 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. This analysis is presented in the sections which follow (Section 6.0).



Legend

- Walloon Coal Measures Piezometric Surface
- Springbok Sandstone Piezometric Surface
- Hutton Sandstone Piezometric Surface
- Gubberamunda Formation Piezometric Surface
- Direction of Groundwater Flow
- CSG Goundwater Extraction
- Unconformity
- Bedrock Nonconformity

Golder Associates www.golder.com GOLDER ASSOCIATES PTY LTD	CLIENT: Queensland Gas Company		PROJECT: QGC - LNG EIS Groundwater Study
	DRAWN: HC /BQ	DATE: 05.06.2009	TITLE: CONCEPTUAL GROUNDWATER MODEL SHOWING POTENTIAL IMPACT SCENARIO
	CHECKED: RKH	DATE: 05.06.2009	
	SCALE: Not to scale	A3	PROJECT No: 087633050 · DOC No: 016 · DOC TYPE: RPT · FIGURE No: F0034 · REV No: 3 · FIGURE 34

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5.4 Numerical Model – Groundwater Impact Prediction

The second component of conceptualisation of the groundwater system (Section 5.2) has involved the development of predictive groundwater flow models for the Project Area. This assessment has included the construction of *three* separate and independent computer-based numerical groundwater models to represent the three project-defined CSG development areas (CDA, NWDA and SEDA).

These models employ 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 D).

Therefore, the modelling work sought to allow the:

- Development of an *idealised* regional groundwater model for each CSG development area;
- 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;
- Development of recommendations for groundwater management and monitoring associated with the QGC CSG operations; and
- Determination of the trigger levels, defined in the *Petroleum and Gas Act 2004.*

5.4.1 Numerical Modelling – Concept, Goal and Setup

The numerical groundwater models 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, refered to as a 'cell' (cubes or tabular blocks). The x and 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 Project Area was divided into three areas, each of which were considered geographically and geologically distinct, being delineated by inferred and actual structural breaks. Each area was modelled separately and independently. Therefore, interference effects from the other development areas 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. Also, interference effects from the operations of other CSG operators adjacent to the three development areas were not consider in this assessment.

Figure 35 presents the location of the full extent of the groundwater model domains (with reference to petroleum leases, the Project Area and the Study Area). These domains encompass the location of the three development areas (CDA, NWDA and SEDA and the associated QGC's petroleum leases) used to prepare the groundwater models and the groundwater impact assessment, as well as the *idealised representation* of the zone of depressurisation for each development area. The modelling domains were 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 models were constructed from site specific data provided by QGC and general data obtained from the literature and NRW sources.

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 NRW sources (for each of the CDA, NWDA and SEDA), as described in Sections 4 and 5.

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

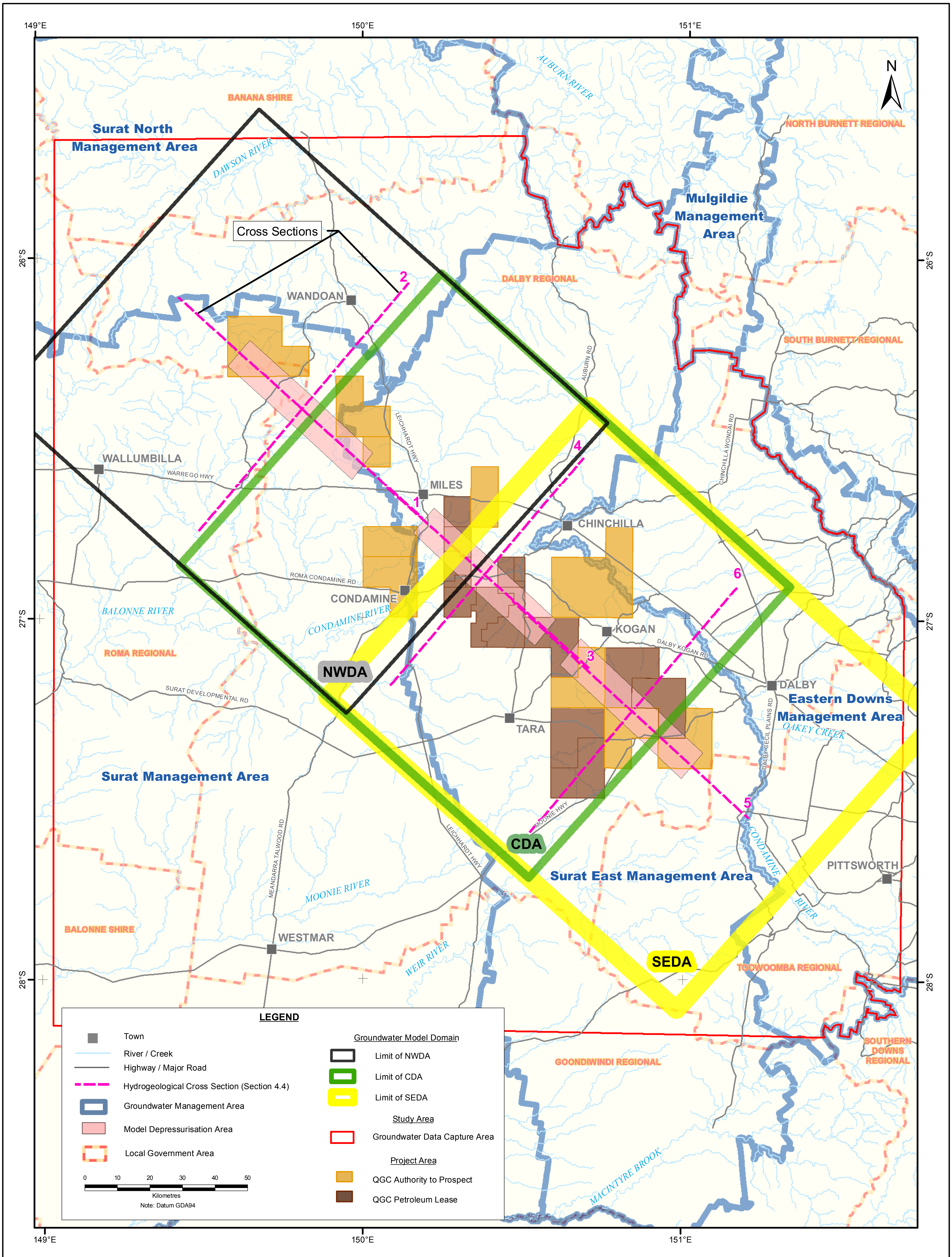
5.4.1.3 Model Hydrogeological Parameters

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 NRW (the authority responsible for managing the Great Artesian Basin).

5.4.1.4 Inclusion of Structural Geology and Boundaries

As mentioned previously (Sections 4.4.4 and 5.3), the key structural features, present within the Project Area, support the hypothesis that the three development areas are treated as separate (three compartments), each partially hydraulically isolated from the other. Restricted groundwater flow between the three compartments is implied. The three development areas therefore define the three numerical groundwater modelling domains.



Notes:
1. Base map data copyright Mapinfo Australia Pty Ltd
2. Authority To Prospect & Petroleum Leases data supplied by Queensland Gas Company (QGC), dated 15-10-2008 and 23-10-2008.

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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS Groundwater Study
DRAWN	PB/DK/BQ	DATE	10-06-09
CHECKED	RKH *	DATE	10-06-09
TITLE	GROUNDWATER MODEL AREAS		
SCALE	1:1,050,000	PROJECT No	087633050_016
FIGURE No	35	REV No	0
A3			

File Location: R:\Env\2008\087633050\GIS\Projects\ArcGIS\087633050_016_R_F0035_Rev0_GWmodelAreas_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

5.4.1.5 Model Construction and Modelled Processes

The individual models were conceptualised as rectangular strips running parallel to the regional strike of the geology. Each 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 models. The boundary dimensions of each 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, each 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 production areas (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. 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 each of the modelled development areas.

The proposed *depressurisation schedules* for 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 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 model construction had been completed, models are usually 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.

Due to the absence of suitable monitoring data in the *current* CSG development area (CDA) and in the greenfields development areas in the north west (NWDA) and the south east (SEDA), the traditional calibration process could not be used.

The approach adopted for the numerical modelling for this 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 (up to 6000) 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. 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 were used to frame two simulation scenarios: a modelled *potential minimum parameter* set; and a modelled *potential maximum parameter* set.

Since groundwater extraction is a crucial consideration in assessing the validity of the modelling process, it is important to understand and have confidence in the methodology used to estimate the QGC associated water production rate figures. QGC have provided their methodology as follows (John Bailey, QGC, email 19 February 2009):

> *"The water production schedule was initially derived from an assessment of currently installed and producing wells (many of which have been producing for 2+ years, and therefore represent a satisfactorily long statistic) which have been classified into categories according to their gas yield - Type 1 (high yielding wells), Type 2 (intermediate yielding wells) and Type 3 (low yielding wells) and Type 4 (low gas high water wells). Each type has an assumed profile for associated water production correlated to their peak gas production rate. This data set of well categories was then applied to the QGC tenements - with Type 1, 2 , 3 and 4 wells being locally applied in accord with known or predicted information about reservoir performance variability across the proposed development area. In this way QGC was able to build up a schedule of production based on 2203 Type 1 wells, 2935 Type 2 wells, 750 Type 3 wells and 265 Type 4 wells. Estimated areal production rates reflect these Well type production rates over a 30 year period from initial production. The ongoing production testing and appraisal programme during 2009/2010 will progressively increase the confidence in the water production forecasts, but at this time an uncertainty band of +/- 50% should be assumed."*

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 models 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 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 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 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 D).

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 areas (the tenements). Simulation results are summarised below (refer to Appendix D for detailed discussion and Figures D-13 to D-16):

General Comments

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

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

- greatest beneath the depressurisation area (idealised representation of the CSG wellfield, namely within the QGC tenement boundaries);
- in each modelled case (CDA, SEDA and NWDA), the modelled potential maximum parameter set is typically associated with the maximum predicted drawdown and the modelled potential minimum parameter dataset is associated with the minimum predicted drawdown;
- are greatest within the Springbok Sandstone aquifer largely because it has been modelled as being in patchy hydraulic contact with the WCM units which are being pumped for CSG recovery (no laterally extensive aquitard separates it from the WCM unit);
- the Gubberamunda Aquifer is least affected by extraction of groundwater from the WCM (drawdowns are negligible or not within the resolution of the model);
- the Hutton and Precipice are drawn down to a minor to moderate extent as a result of the CSG groundwater extraction; and
- 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.

Specific to each development area, the following conclusions can be reached:

Central Development Area (CDA)

- Drawdown in the Springbok Sandstone is predicted to range from a minimum of approximately 5 m to an expected maximum of about 55 m at a distance of 1.8 km (nominal edge of the depressurisation area, i.e. boundary of the tenements) measured in a south-east direction. Recovery of the aquifer is predicted to commence immediately after groundwater extraction terminates;
- The predicted drawdown in the Hutton Sandstone (Figure D-7, Appendix D) ranges from less than 0.5 m to an expected maximum of 2.5 m. Recovery of the Hutton Sandstone is predicted to commence about 50 years after groundwater extraction terminates;
- The predicted drawdown in the Precipice Sandstone ranges from less than 0.2 m to an expected maximum of 1.8 m (Figure D-7, Appendix D). Recovery of the Precipice Sandstone is predicted to commence at about 60 years after groundwater extraction terminates;
- The maximum predicted drawdown occurs in the Coal Seams and the Springbok Sandstone aquifers. The high drawdown in the Springbok aquifer is due to a high induced downward gradient between the Springbok and Walloon Coal Measures, which are separated by a thin aquitard;
- Similarly, the lower aquifer units (Hutton and Precipice) are separated by a thicker aquitard unit, which reduces the upward gradient into the lower Coal Seam;
- Throughout the simulation, the predicted aquifer drawdown in the Intermediate Unit (Mooga, Orallo, and Gubberamunda Sandstone) was minimal;
- The modelled drawdown within the Springbok Sandstone, *near the centre of the depressurisation area*, is expected to range between 10 m and 85 m (within and beneath the tenement boundaries). The drawdown also decreases continuously away from the centre of the depressurisation area; and

- The predicted drawdown for the Gubberamunda Sandstone, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone is presented in Figures D-13 to D-16 (Appendix D).

North West Development Area (NWDA)

- Drawdown in the Springbok Sandstone (Figure D-17) is predicted to range from less than 0.5 m to an expected maximum of about 2 m at a distance of 1.8km from the edge of the depressurisation zone (nominal edge of the depressurisation area, i.e. boundary of the tenements). Recovery of the aquifer is predicted to commence 75 years after groundwater extraction terminates;
- The predicted maximum drawdown in the Gubberamunda, Hutton Sandstone and the Precipice Sandstone is insignificant (Figure D-18, Appendix D);
- 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 (Section 4.4.4);
- The modelled drawdown within the Springbok Sandstone is expected to range between less than 0.5 m and 2 m, near the centre of the depressurisation area. Drawdown, again, continuously decreases away from the centre of the depressurisation area (Figure D-18, Appendix D); and
- The predicted drawdown for the Gubberamunda Sandstone, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone is presented in Figures D-13 to D-16 (Appendix D).

South East Development Area (SEDA)

- Drawdown in the Springbok Sandstone aquifer is predicted to range between less than 2 m up to an expected maximum of about 23 m at a distance of 1.8 km, in a southeast direction, from the edge of the depressurisation zone (nominal edge of the depressurisation area, i.e. boundary of the tenements). Recovery of the aquifer is predicted to commence 5 years after groundwater extraction terminates;
- The model predicts that drawdown in the Hutton Sandstone may range from less than 2 m up to an expected maximum of about 8 m (Figure D-12, Appendix D). Recovery of the Hutton Sandstone is predicted to commence about 15 years after groundwater extraction terminates;
- The modelled drawdown in the Precipice Sandstone ranges from less than 0.5 m to an expected maximum of about 6 m. Recovery of the Precipice Sandstone is predicted to begin at about 25 years after groundwater extraction terminates;
- The predicted maximum drawdown in the Springbok Sandstone in the SEDA is less than the CDA. This is because the SEDA has a thicker aquitard unit between the Springbok and the WCM, compared to the CDA and is less structurally affected (Section 4.4.4). The higher drawdown predicted for the Hutton and Precipice Sandstone in the SEDA model, compared to the CDA, is likely due to the larger drawdown required for the WCM in SEDA (351m in the SEDA versus 180m in the CDA);
- The modelled drawdown in the Springbok Sandstone is expected to range from 1 m up to 36 m, near the centre of the depressurisation area after 40 years of groundwater extraction (Figure D-14, Appendix D). Again, drawdown continuously decreases away from the centre of the depressurisation area; and

- The predicted drawdown for the Gubberamunda Sandstone, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone is presented in Figures D-13 to D-16 in Appendix D.

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), Kv/Kh 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 three development areas were modelled independently;
- The model did not consider the influence that may occur from other neighbouring CSG extraction operations; and
- 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).

6.2 Environmental Values Considered

The EVs outlined in the QWQG 2006 and EPP 2007 were reviewed for relevance to *groundwater environment* in the QGC Project Area, and the following EVs were determined to be relevant to all or part of the QGC CSG fields.

- primary industry uses:
  - irrigation, suitable supply for crops/pastures/parks/gardens and recreational areas;
  - farm or domestic water supply (other than drinking water); and
  - 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; and
- aquatic ecosystems (including perennial and intermittent surface waters, groundwaters, wetlands and reservoirs in the area) which might be dependant on groundwater for their sustenance.

The values listed above are discussed in further detail in the text which follows, and have been included in this report because they are considered important values within the government policy and reflective of the existing environment. These are also listed uses from the WERD.

Note: Further details of the environmental values are outlined in the *Queensland Water Quality Guidelines (2006).* ANZECC (2000) provides water quality objectives for the different environmental values (surface water).

6.2.1 Primary Industry

Primary industry land uses of groundwater in the Project Area feature prominently in the pastoral and irrigation economy. Of the primary industry EVs identified in the guidelines, the following are considered to be most relevant to the Project Area:

- irrigation – suitability of water supply for crops, pastures, parks, gardens and recreational areas;
- 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); and
- stock watering – suitability of water supply for the production of healthy livestock.

Groundwater supply for the primary industry uses, listed above, accounts for over 90% of licensed groundwater allocations across the Project area (refer to Section 4.7 for further detail). The majority of these licensed allocations are assigned to the Alluvium unit (primarily the Condamine River Alluvium in the eastern margin of the Project Area). This aquifer is not expected to be impacted by CSG production (refer to Section 5.0), however, there are a number of licensed wells in the area that are completed in the Springbok (and to a lesser degree, the Hutton and Precipice Formations). These are the aquifers that modelling results suggest will be most affected by coal seam depressurisation (refer to Section 5.4.2 for further details). As such, the EVs associated with primary industry are considered to represent the principle issue of concern with regards to CSG depressurisation operations.

The two additional primary industries identified in the QWQG 2006, aquaculture and aquatic food production from natural waterways, are not considered to be relevant to the groundwater resources of the Project area (largely for reasons discussed to Section 5.0).

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. Dalby Regional Council reports that a number of towns in the region are supplied with treated bore water (Dalby Regional Council, 2009). These include: Chinchilla, Kogan, Dalby, Jandowae, Bell, Warra, Kaimkillenbun, Jimbour, Miles, Dulacca, Condamine, Tara, Meandarra, Glenmorgan, Moonie, The Gums, Westmar, Flinton and Wandoan.

Although municipal water supply only accounts for approximately 3% of the licensed groundwater allocation across the Project area, groundwater as a drinking water supply is still 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 the NRW for the Project area, industrial uses account for only 1% of the licensed groundwater entitlements. 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 reliability of supply (e.g. Kogan Power Station), 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 Project area, with the recognition that it comprises a minor component of the overall licensed allocation.

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 Project Area, the most relevant scenario affecting these EVs would be contamination of shallow groundwater 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 (as described in Section 6.2.5). 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 Project area.

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 (as described in Section 6.2.5) 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 Project Area, since the creeks and rivers present within the Project 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 (Section 5.4.2).

Stygofauna, while strictly speaking do not fall within the typical surface water aquatic ecosystem category of EVs, they comprise very small animals (small, aquatic groundwater invertebrates) and microbes that live below the Earth’s surface in groundwater (aquifer) systems and caves, and as such, need to be considered as an EV. They comprise crustaceans of many types as well as other groups such as fish, worms, snails, arachnids, mites and insects, and, terrestrial air-breathing subterranean animals. Stygofauna can live within freshwater aquifers and within the pore spaces of limestone, calcrete or laterite, but are also found in marine caves and wells along coasts. They are poorly understood in Australia, but in the general absence of significant development of these particular environments (rock-types) this EVs are not consider to be of relevance in the Project Area.

7.0 POTENTIAL IMPACTS

7.1 Introduction

This section includes a discussion of the Project related risks and their potential *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. Mitigation, monitoring and management of the impacts is then discussed in Section 8.0.

Before the assessment of potential impacts to groundwater-related EVs can be considered, it is important to establish two key aspects of CSG operations, namely:

- What CSG Operations are involved and the risks their pose; and
- What are the key drivers for impact management and monitoring.

Having established these aspects, integral to effective and responsible environmental monitoring and management is the setting of trigger mechanisms and the area over which they apply. The rationale for establishing trigger values for groundwater levels and groundwater quality is presented in Section 8.2.3, and potential contingency actions to mitigate against CSG-related groundwater impacts are discussed in Section 8.0.

7.2 Coal Seam Gas Operations

The five principal CSG operational activities that involve water management and monitoring aspects include:

- Drilling, design, and construction of CSG production wells;
- Coal seam depressurisation;
- Water gathering and distribution systems;
- Water storage and treatment systems; and
- Surface Infrastructure related to CSG activities (camp services, compressor stations, etc).

Groundwater extraction is a fundamental and unavoidable aspect of CSG production. The procedure for recovering CSG involves drilling and completing a series of production wells into targeted coal measures and pumping out groundwater (associated water) to reduce the hydrostatic component of the gas reservoir pressure (depressurisation) in order to facilitate recovery of the predominantly methane gas.

The ‘associated’ water is considered to be a by-product of these operations; however, it may be approved as a ‘resource’ on a case-by-case basis. The CSG extraction process will generate up to 200 ML/d of associated water, through the period 2010 to 2032 (Figure 33). To effectively manage the large volumes of water, it is likely that a combination of management approaches will be required. Also, the quality of the associated water will limit opportunities for direct reuse and re-injection. Water treatment would be required to facilitate a number of beneficial reuse options.

The selected water end use option(s) will depend on compliance with regulatory requirements, technical capability, the costs of implementation and operation, and the perceived benefits to the community and the environment.

7.3 Drivers for Impact Management and Monitoring

The *potential risks* arising from project-related activities, and which might require management and monitoring, are discussed in this section. Establishing these risks will provide the impetus for QGC to establish a water monitoring program for the purpose of understanding, reducing or accepting risk associated with the CSG operations. The significance of the risks will be discussed in the following section.

The categories under which Project related risk-based management and monitoring have been grouped are as follows:

- Operational risks;
- Stakeholder risks;
- Regulatory risks;
- Planning risks; and
- Public health risks.

NOTE: A risk is defined as "…the chance of something happening that will have an impact on objectives and is measured in terms of a combination of the consequences of an event, and the likelihood of an event occurring.

The potential risks related to the various Project activities were considered for the key areas of (a) health and (b) the natural environment (other areas usually assessed as part of an RA, including safety, reputation and financial consideration of risk, were not considered for this assessment).

The following sections expand on these specific risks areas and the key Project activities considered likely to cause potential adverse impacts.

7.3.1 Operational Risks

The five principal CSG operational activities, identified in Section 7.2, and which are considered to pose operational risks and, therefore, might require water management and monitoring, are:

- *Extraction Facilities* (i.e. borehole drilling activities, bore design, bore completion and bore integrity related to both CSG exploration work and, production well installation, operation and abandonment);
- *Extraction Activities* (groundwater extraction associated with CSG operations and depressurisation of the targeted coal seams);
- *Surface infrastructure related to the handling of the associated water (i.e.* water gathering, distribution, management, storage and disposal);
- *Associated water treatment* (water treatment operations, including RO plants and other treatment plant for beneficial re-use, blending and/or disposal);
- *Associated water disposal facilities* (for example, associated water reinjection (untreated or treated) installations, where approved); and
- *Support and related infrastructure* (other surface infrastructure such as roads and camp services, irrigation and water supply).

The key operational activities defined in this list are discussed individual as follows:

7.3.2 Stakeholder Risks

Stakeholder risks include:

- Pumping of CSG bores and the potential or perceived impacts on the local water supply availability or quality;
- Releases, either planned or otherwise to local water courses and shallow groundwater systems; and
- Community perceptions of the impact of the CSG Operations on the shallow and deep aquifer systems.

7.3.3 Regulatory Risk

Regulatory risks to be managed with the assistance of water monitoring include those associated with:

- adherence to the specific conditions of EAs for the operations;
- adherence to the intent of the applicable legislation; and
- adherence to updated legislation by updating practices for water extraction or management.

7.3.4 Planning Risk

Planning risks include:

- Providing the environmental monitoring data required to support new EA applications for expansion of CSG operations;
- Planning and design for new or augmented water management infrastructure; and
- Input to development of strategic water management plans, for example input to predictive water management modelling.

7.3.5 Public Health Risk

Public health risks include:

- Supply of water to the workers at the site of the CSG Operations;
- Quality of water supplied from the CSG bores to irrigation, town water supply or farmers (treated or untreated); and
- Impact (perceived or actual) of the operations on the suitability of the local water resources for domestic, irrigation or industrial supply.

7.4 Assessment of Potential Impacts to Environmental Values

The environmental values associated with a groundwater resource (and surface water) have previously been defined as comprising primary industry, drinking water, other industrial uses, recreation uses, cultural and spiritual values and aquatic systems, with the key CSG related activities likely to impact these EVs being drilling and well installation activities, coal seam depressurisation, gathering systems, the water storage systems, surface infrastructure, and the associated water management (water re-use and disposal systems).

A detailed assessment of each of these activities follows.

7.4.1 Extraction Facilities - Drilling and well installation activities

QGC operations within the Project area involve drilling of exploration boreholes and completion of selected boreholes as either CSG production wells or monitoring wells. With the exception of shallow groundwater monitoring wells, 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 2009b) 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 Project Area are very 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, stock watering and primary industry water usage, 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 are applied; and
- Aquatic and stygofauna 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 Project Area.

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 the primary risk driver associated with improper drilling, well installation and borehole abandonment techniques.

7.4.2 Extraction Activities - Coal Seam Depressurisation

As described in Section 1.0, 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. 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.

Discussion of Potential Impacts and Environmental Values Potentially Affected

The potential impacts related to coal seam depressurisation and induced inter-aquifer transfer is discussed in the following sections:

Loss of available drawdown in bores

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; notably, the Springbok Sandstone (CDA and SEDA), and to a lesser extent the Hutton and Precipice Sandstone (CDA) in the vicinity of the QGC CSG extraction bore wellfields (Section 5.4.2).

The relative impact to bore owners in the CSG fields *will* depend on the location of the bores relative to the CSG operations and the associated cone of depression in the affected aquifer. The modelling results (Appendix D) predicted that depressurisation effects within the Springbok Sandstone would extend beyond the perimeter of the CSG fields due to the relatively high hydraulic connectedness of this aquifer to the WCM units, particularly in the CDA and SEDA areas. Hence, water supply bores completed within these aquifer formations in the vicinity of the CDA and SEDA CSG field operations may face a risk from loss of available drawdown (Sections 5.4, 8.3 and 97).

The potential influence of coal seam depressurisation on water supply aquifers in CDA and SEDA is presented conceptually in Appendix D. This appendix 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.

Water supply bores within and in close proximity to the CSG operations 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. Further discussion of potential 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 artesian pressure for bore owners with bores completed in the artesian portions of the Springbok Sandstone (and to a lesser extent, Precipice and Hutton Formations) in the CDA and SEDA, resulting in a potential reduction or loss of natural artesian flow.

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. However, for the depth of the coal seams in the three development areas, viz., up to a maximum of 1,360 m for the North West Development Area (NWDA), 950 m for the Central Development Area (CDA) and 670 m for the South East Development Area (SEDA), 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, we have estimated the elastic response of the dewatered coal seams based on the following assumptions:

- the dewatering assumptions indicated previously (WCM depressurisation to approximately 100KPa or approximately 70m above the top of the WCM unit);
- a rock mass modulus of 2 GPa;
- a total thickness of coal seams of about 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 for the three development areas.

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.

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 CSG fields of the Project Area are located within the intake beds of the 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.

Induced gas flows

A potential adverse side effect of coal seam depressurisation is CSG production in water supply bores and wells screened within the coal measures targeted by CSG operations.

Within the range of predicted drawdowns from the indicative numerical modelling, these effects are considered unlikely. The degree of depressurisation is of such a magnitude as to induce desorption of CSG from such wells located outside of the perimeters of the CSG wellfields. Wells screened within the coal measures within the wellfield may be impacted by CSG release in these bores. Monitoring for methane and other CSG gases in water supply bores and wells screened within the coal measures of the CSG operations should be undertaken.

7.4.3 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, re-injection bores, 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 environmental values 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.

7.4.4 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 RO water treatment facilities, and storage of oily water associated with compressor stations.

Associated Risk Issues

The primary risk issue for water storages 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 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.

7.4.5 Project-related Surface Infrastructure

The groundwater risks from surface infrastructure, 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.

7.4.6 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 (Section 2.6), in which re-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 re-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 re-injection, singularly or in combination (as is appropriate to the water quality and quantity).

Associated Risk Issues

The primary risk associated with re-injection, reuse and/or disposal of associated water is the potential for the groundwater (largely shallow, but indirectly deep aquifers) to have changed water quality.

There may also be a change in the volume and quality of water provided for municipal supply and industrial reuse applications.

Discussion of Potential Impacts

The potential impacts related to associated water reuse and disposal 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 re-injection, if the re-injection wells are not designed and constructed properly
- impacts to soil structure from irrigating with sodium-rich associated water
- 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 re-injection wells.

Aquatic ecosystems associated with creeks and rivers 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 QGCs CGS 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 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.

The following sections describe the basis and mechanisms required to ensure early detection of groundwater impacts, which would trigger appropriate and responsible management and mitigation actions. The key instrument, and its associated commitment, is the *Water Monitoring Plan* (WMP).

8.2.1 Requirement for a Water Monitoring Plan

The drivers for development of an appropriate monitoring program include:

- Legislative requirements and requirements within the Environmental Authorities (EAs); and
- Outcome of this assessment (primarily impacts prediction) and its commitments.

A discussion on the regulatory requirements follows.

8.2.1.1 Legislation Requirements and Environmental Authorities

The specific legislation and environmental authorities applicable to QGC operations provide guidelines for project owners to develop and manage their own monitoring programs. They do not (in most cases) provide clear direction as to the location, periodicity and parameters for monitoring.

The National Water Initiative

The National Water Commission (NWC) released the National Water Initiative (NWI) that has a series of requirements, including the implementation of water accounting. As the NWI water accounting framework is introduced to the various industry sectors, QGC will need to implement a rigorous water abstraction and water discharge monitoring program. QGC will be required to report to the NWC and to the Bureau of

Meteorology, who have been legislated to manage the water resources information. The timing for these requirements as it applies to the Project is not currently known.

Water Resource (Condamine and Balonne) Plan 2004

The Water Resource (Condamine and Balonne) Plan 2004 defines the availability of water in the plan area and regulates the taking of water from all surface water bodies (rivers, lakes, runoff). The Plan identifies water monitoring requirements relative to the quantity, the quality of the water and its associated natural ecosystems.

Monitoring requirements include (S 54):

- Water monitoring for:
  - Volume, frequency, duration and season of streamflows;
  - Taking water; and
  - Water quality.
- Natural ecosystems monitoring for the condition of riverine habitats including:
  - Waterholes and lake ecosystems;
  - Stream bed habitats;
  - Upper and in channel riparian zones;
  - Floodplains; and
  - Wetlands.

Water infrastructure operators must develop and undertake monitoring programs in the water supply scheme in which they manage the water (S 55).

This includes monitoring for:

- Water quantity (flow of water at gauging stations, volumes of water and the times when the water supply is taken, inflows of water to ponds or weirs, level of the water). Monitoring must also measure the quantity of water released from a pond or weir for consumption, environment, operation of fishways, and any purpose stated by the chief executive;
- Water quality (temperature, biological, chemical and physical measurements); and
- Operation of outlet works for a pond including multi level off takes.

The monitoring information (S 55) must be given to the Chief Executive as a report (S 56). The report should be annual and should be submitted no longer than 3 months after the beginning of the following year.

Environment Protection Act 1994

Conditions (S 98) may be imposed on an environmental authority (petroleum activities) (EA) and this may include carrying out and reporting on a stated monitoring program. There are standard environmental conditions for associated water. This includes the requirement not to release associated water to land or waters other than to an evaporation pond that is constructed and managed according to the conditions. This requirement can be addressed by developing and implementing a water quality, monitoring program for testing and analysing the quality of the associated water. This would allow associated water that is not a hazardous waste to be used for purposes such as livestock watering, agriculture, dust suppression and release to land or surface waters.

If water is to be used for irrigation, a land and water management plan (LWMP) would be required under the Water Act which may have a monitoring component attached.

Dams and evaporation ponds are also covered by conditions by which they must be designed, constructed, operated, maintained and decommissioned according to set objectives.

The holder of the EA (Condition 21) must develop and implement a monitoring program that will demonstrate compliance with the environmental conditions. The monitoring and inspections must be documented. The monitoring program should focus on areas that have potential to cause environmental harm e.g. groundwater bores. The WMP (Code of Environmental Compliance) sets out the requirements for monitoring of levels of contaminants in a pond for determining whether it is hazardous.

Environmental Protection (Water) Policy 1997

This Act has a monitoring component (S 26) relating to monitoring the release of waste water on land or into water. The administering authority would decide on the level of monitoring dependant on the activity, the risk of harm to environmental values, and the frequency needed.

Impact monitoring may also be required (S 27) if an administering authority is making a decision about an activity involving a release or potential release of waste water.

The direct release of water to surface water and to groundwater is regulated under Sections 18 to 20. The release of water to surface water is only permitted after an assessment of the water quality and the impact of mixing the released water with the existing water quality. The Environmental Protection Agency (EPA) may control the releases. The release of water to groundwater is only permitted after an assessment of the impact on the environment and will only be allowed under certain aquifer conditions.

Section 21, which regulates the accidental release of water to groundwater, requires that infiltration of released water to soil and groundwater is minimised or prevented and any release or potential release monitored against site baseline conditions.

EA No 150 161 (Section 124 Environmental Protection Act 1994)

The monitoring requirements included in this EA are:

- All piezometer installation, plant maintenance and monitoring must be completed by a qualified person of appropriate qualifications and experience in the fields of hydrology and ground water monitoring;
- All water sampling must be performed in accordance with the current edition of the Queensland EPA Water Quality Sampling Manual. Sampling methodology records (including anomalies) must be kept;
- Water samples must be analysed by a National Association of Testing Authorities (NATA) accredited laboratory;
- An annual report (for the entire pond operation period) should summarise all monitoring, analysis and interpretations of results. A similar report is to be submitted when a change of greater than 10% (not related to climatic variability) in water level and/or groundwater quality is detected; and/or when requested by the administering authority; and

- Their design must ensure that there will be no environmental harm caused to existing groundwater aquifers, contamination of surface waters or significant impact on vegetation. A proposed groundwater monitoring program must be submitted with a risk assessment for proposed evaporation ponds. Existing evaporation ponds must have a monitoring plan already in place. The following must be recorded:
  - quality of water contained in the pond (pH, EC dissolved Na, Mg, K, Ca, SO4, HCO3 and Cl);
  - environmental impact risk analysis, including procedures and structures that are in place to minimise or prevent ground water and land contamination;
  - groundwater and soil monitoring methodology in place. including field and laboratory procedures;
  - signs of water seepage or leakage should be investigated and status of each pond catalogued on the pond register should be recorded and kept on file until requested by the administering authority;
  - maintenance procedural methodology; and
  - indicators of land/ground water salinisation must be investigated for each existing evaporation pond and the status for each pond should be recorded and kept on file until requested by the administering authority.

EA No 150 386 (Section 124 Environmental Protection Act 1994)

The EA outlines criteria for dams and evaporation ponds. A list of analytes and criteria are provided, which outline the assessment process for the determination if content of dam is hazardous waste. If contents can not comply with the limits in the table, the water within the dam is considered hazardous. All of the analytes listed in Table 1 of the EA must be included in the water quality sampling analytical suite.

PEN 100068707 (Previously EA No 1502 272) (Section 124 Environmental Protection Act 1994)

The monitoring requirements included in the EA are:

- All water sampling must be performed in accordance with the current edition of the Queensland EPA Water Quality Sampling Manual. Soil Sampling must be in accordance with the EPAs Guidelines for the Assessment of Contaminated Land in Queensland; and
- Water samples must be analysed by a National Association of Testing Authorities (NATA) accredited laboratory.

EA No 150 361. (Section 124 Environmental Protection Act 1994)

The EA applies to ATP47P. This EA covers petroleum activities, but specifically addresses waste disposal within the evaporation dam.

The monitoring requirements included in the EA are:

- Associated water should be monitored and compared to the accepted ANZECC 2000 Water Quality Guidelines or subsequent versions thereof to determine appropriate disposal of alternative uses (i.e., stock and domestic).

8.2.1.2 *Study Outcome - Potential Impacts to Groundwater Related EVs*

Section 7 has succinctly presented the outcome of this groundwater study and has detailed the potential impact which may arise from the proposed CSG extraction in the Project Area. These have indicated the requirement for a robust water monitoring program, which complies with all applicable regulatory requirements and triggers appropriate actions when adverse impacts are detected.

8.2.2 Baseline Conditions Setting for Monitoring Outcomes Assessment

In developing a WMP, the 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.

This study and its accompanying documents provide the framework of baseline conditions. With regard to assessing impact to water-related EVs, the pertinent accompanying documents describing baseline conditions are the G*roundwater Bore Inventory* and the *Surface Water Studies* reports, as follows:

- Golder 2009a – Coal Seam Gas Field Component for Environmental Impact Statement - CSG Surface Water Studies, Surat Basin, Queensland. (087633050 014 Rev1 QGC surface water studies report);
- Golder 2009b – Bore Inventory Report for Coal Seam Gas Operations, Chinchilla, Surat Basin, QLD. Golder Report No. 087633050_019 RevA

For the purposes of setting baseline groundwater conditions, the key accompanying document is the *Groundwater Bore Inventory*, which is summarised below. This document and the pre-operational WMP monitoring records will provide the definitive baseline conditions against which all potential impacts will be assessed.

Baseline for Monitoring - Groundwater Bore Inventory

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, 2009) to provide baseline information for future monitoring and management of their proposed operation.

The objective of the Groundwater Bore Inventory (GBI) was to identify a number of privately owned bores within a 10km radius of existing and proposed QGC CSG activities (the tenement boundaries were used to define these activities). 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 were selected to be assessed, of which 205 were successfully located, the properties concerned visited and the bores assessed. The remaining 116 bores were either not located, their owner could not be contacted, or their owner/s refused to participate in the GBI process. An additional 49 bores (not on the original list) were also visited and sampled for water quality assessment.

A land owner participation rate of 50% was set as the goal for the GBI at the beginning of the programme; 77% was achieved.

A wide range of valuable data has been obtained throughout this 10 week field programme which potentially can be utilised as baseline monitoring data for future comparison of groundwater conditions throughout the Surat and Eastern Downs Management Areas.

The field report produced at the completion of the GBI was strictly a factual one (i.e., it contains details of the raw data collected in the field). It will provide a basis for assessing future monitoring and management needs, and as a reference point for later assessments and deliberations.

8.2.3 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 WMP are:

- Water level or piezometric head
- 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. The regulatory setting which mandates that a trigger level should apply is also described.

8.2.3.1 Water Levels Trigger Levels

As described in Section 2.5, the P&G Act requires petroleum tenure holders to develop a “trigger threshold” for aquifers in the area affected by the exercise of underground water rights for a petroleum tenure. The trigger value is defined as “*the water level drop in the aquifers that the Chief Executive considers would be a level that causes a significant reduction in the maximum pumping rate or flow rate of the existing Water Act bores in the area affected by the exercise of the underground water rights*.” The P&G Act requires trigger levels to be developed at which groundwater impact might result in the need for groundwater management plans to be implemented by the CSG operators.

Development of appropriate trigger values requires careful consideration of the site-specific context to which they are being applied. Arbitrary drawdown levels have often been applied as trigger values; however these are of limited value for evaluating a bore owner’s reduction in access to groundwater, when applied as blanket conditions across large areas or multiple aquifers.

Trigger levels expressed as a percentage of available drawdown prior to the inception of CSG activities, defined as the height of the water column above the top of the aquifer or screened zone in a bore, are more appropriate for broad application to bores with significant variability in completion depth and available water columns. However even this approach is subject to variability, as the prevailing site-specific hydrogeological conditions will dictate the percentage decrease in the water column that is tolerable, before pump performance or artesian pressures are physically or economically compromised.

To reduce the uncertainty associated with a blanket application of set trigger values, a tiered approach to the development of trigger values is proposed:

- **Tier 1 Trigger Level:** A conservative initial trigger value, defined as 10% of the available drawdown, designed to provide an early warning of potential drawdown impacts before they occur.
- **Tier 2 Trigger Level:** A final trigger value representing the level of drawdown at which some form of compensatory action is required for the affected bore owners (refer to Section 2.5.4).

A summary of the proposed trigger levels and associated actions is presented in Table 15. The Tier 1 trigger level of 10% of available drawdown is considered to be sufficiently small, so that the physical or economic performance of the groundwater extraction pumps would not be compromised. It would also provide enough advanced warning to assess the situation and develop Tier 2 trigger levels appropriate for the affected bores.

For this approach to be successful, baseline water levels need to be collected from all relevant bores during the initial bore inventory, and subsequent routine monitoring, to provide a reference for assessing future water level changes. The trigger levels would be considered following each routine monitoring event proposed in the WMP for the Project.

Table 15: Trigger Levels for Water Level Assessment

Trigger Level	Value	Actions Triggered
Tier 1	10% of available drawdown for a given bore, prior to inception of CSG activities	■ Measure and record available drawdown in bores selected for monitoring in the Water Monitoring Plan (in preparation, Golder 2009c). ■ Identify specific bores affected. ■ Repeat measurement to confirm extent of drawdown and available water column. ■ Assess all potential contributing factors to the decrease in water levels (e.g. CSG activities, non-CSG groundwater extraction, sustained below average rainfall, etc). ■ Assess local hydrogeology in the vicinity of the affected bore(s). This would also include well construction, age, performance, water quality, presence of other wells/user in the vicinity and their history. ■ Develop an appropriate Tier 2 trigger level on the basis of the assessment.
Tier 2	To be determined from Tier 1 action	■ Evaluate and implement the appropriate compensatory action(s) for the affected bore owners.

Table 16 presents the initial estimates of trigger values based on the average depths of the wells.

To establish a conservative initial trigger value, the following should be noted:

- Only wells having depth, geology and groundwater level information should be used to approximate trigger values.
- The average depth of bores/wells completed in the potentially impacted aquifer, namely, the Springbok Sandstone, is greater than the average depth of bores completed in the Walloon Coal Measures (WCM). This is because a significant number of Walloon bores are located in the eastern part of the Project Area where the bores are shallower (closer to the subcrop areas).
- For the Hutton and Precipice Units, it is recommended that sub-artesian bores adopt the same trigger levels as for the WCM. This is because it is considered appropriate to protect the artesian bores, where/if present, in the aquifer by ensuring sub-artesian water pressures are preserved, wherever possible. Only rare examples of artesian bores are noted within the Study Area, and as such, this is rarely likely to be a consideration. Refer to the bore inventory Golder (2009b).
- The recommended trigger levels are provided for aquifers that may be affected by the CSG water production (Springbok Sandstone, and to a lesser extent, the Hutton and Precipice Units). It is not considered appropriate to apply a management strategy based on water pressures for the WCM within the footprint of the CSG well field.

The predicted impact to the Condamine River Alluvium and the Main Range Volcanics is considered negligible to non-existent (Section 5.4.2) because of their relative distance and proximity to QGC petroleum leases, and the sub-cropping aquifers in contact with them, are highly unlikely to be impacted. These aquifers are heavily used for irrigation purposes and have already been monitored. They exhibit highly variable (seasonal and drought conditions) fluctuations (Section 4.5.6).

Table 16: Preliminary Tier 1 Trigger Values for average sub-artesian potentially impacted

Hydrogeological Unit	Average Depth of Bores* (m)	Average Height of Water Column (m)	10% Tier 1 Trigger level (m)
Condamine River Alluvium / Quaternary Deposits / Main Range Volcanics	50	32	3
Shallow GAB – all units	120	97	10
Intermediate Unit – Mooga	240	210	21
Intermediate Unit - Gubberamunda	230	195	20
Intermediate Unit – All	200	170	17
Walloon Unit - Springbok	280	210	20
Walloon Unit - WCM	115	90	10
Hutton***	300	260	10**
Precipice	485	430	10**

* Bores from the NRW database

** The average trigger levels for the Hutton and Precipice are set equal to the WCM to protect the artesian bores (where present) and preserve sub-artesian water pressures.

*** Although the Marburg Sandstone is considered to be hydraulically connected to the Hutton, it was not considered in the calculation for trigger values as it is primarily found beyond the expected area of impact.

The Tier 1 Trigger Values presented in Table 16 are based on the average depth of wells within the Study Area. In the north and northeast portion of the Study Area, where the GAB beds outcrop or subcrop, the difference in the depth of bores completed in the same formation, but at different locations within the Study Area, can vary greatly due to the dipping nature of these sedimentary beds. For example, the depth for registered bores completed within the Hutton ranges between 45 metres and greater than 800 metres. The trigger value for a shallow bore will be less than for a deeper bore.

As a consequence of these variables, it is considered important that trigger values be set on a bore to bore basis (i.e. site-specific assessment needs to be made), not assigned a ‘blanket’ value for a particular formation or aquifer unit. The values presented in Table 16 are therefore provided as a *guide* for management decisions and planning for monitoring.

An ongoing groundwater monitoring program, as outlined in Section 8.0, will be required to ensure that the impacts of drought or wet periods can be assessed independently of the impacts of CSG water extraction. QGC is currently developing this detailed water monitoring plan (WMP).

8.2.3.2 Groundwater Quality

The principal legislative driver in Queensland for maintenance of groundwater quality is the *Environmental Protection Act 1994*, which is administered by Queensland EPA, 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.

A similar two tiered 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 baseline values, designed to provide an early warning of potential water quality impacts before they occur.
- **Tier 2 Trigger Level:** A final trigger value representing the compliance criteria at which some form of compensatory or remedial action is required to mitigate the risks posed by the changes to water quality.

A summary of the proposed trigger levels and associated actions is presented in 17. This approach to water quality assessment provides advanced warning of potential water quality issues, so that appropriate site-specific triggers for remedial or compensatory options can be evaluated. This may include reference to published guideline values, or development of site-specific assessment criteria for key water quality parameters, relevant to the specific environmental values at risk (whether ecological, human health or other licensed water uses). The development of site-specific assessment criteria is encouraged in the ANZECC 2000 guidelines, which includes a detailed framework for deriving site-specific criteria based on the values being protected.

Table 17: Trigger Values for Water Quality Assessment

Trigger Level	Value	Actions Triggered
Tier 1	10% increase in concentration of physical or chemical parameters relative to baseline conditions	■ Identify specific bores affected. ■ Resample and re-analyse to confirm extent of change to water quality – include revised analytical suite if warranted. ■ Assess all potential contributing factors to the change in water quality (e.g. CSG activities, non-CSG groundwater extraction, sustained below average rainfall, etc). ■ 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 (likely to be direct reference to published water quality guidelines, but may include derivation of site-specific guidelines for key parameters).
Tier 2	To be determined from Tier 1 action	■ Evaluate and implement the appropriate compensatory action(s) for the affected bore owners (refer to Section 8.2).

8.2.4 Application of Trigger Values

8.2.4.1 Induced Drawdown Predicted

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

The predictive groundwater modelling (Section 5.4 and Appendix D) has provided a *range of groundwater drawdown estimates* in various key modelled aquifers arising from CSG extraction within each development area over the proposed 40 years of operation.

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.

Since these estimates 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 2009b).

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 (summarised in Section 8.2.5);
- Define the need for monitoring and the basis for a Water Monitoring Plan (to provide forewarning of the above) (summarised in Sections 8.2.6 to 8.2.8);
- Select monitoring locations within *and* surrounding the CSG extraction areas for purpose built designing and installing appropriate monitoring installations (summarised in Sections 8.2.6);
- Select the aquifer layers for targeted monitoring of water level (piezometric head) and/or water quality (summarised in Section 8.2.7); and
- Define a pool of existing bores (domestic, industrial, stock or irrigation) from which an appropriate number might be selected for ongoing monitoring (summarised in Section 8.2.8).

The largest induced drawdown impacts are likely to occur within the Springbok Sandstone aquifer, particularly in the CDA and SEDA areas. 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.

Each of these topics is discussed in the following text.

8.2.5 Environmental Values Potentially Impacted

The potential impacts and likely EVs affected have been presented in detail in Section 7.4. They can be summarised as being loss of available drawdown in bores, loss of artesian flow, subsidence, water quality, changes, reduction in recharge and loss of baseflow; and induced gas flows.

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 matters are further explained below.

8.2.6 Potential Monitoring Locations

On the basis of this impact assessment, Golder recommends that purpose built monitoring point installations be implemented including:

- multi-level, vibrating wire piezometer (VWP) monitoring installations, which not only monitor the Springbok Sandstone, but also the Gubberamunda Sandstone, Precipice Sandstone and Hutton Formation aquifers. The VWPs should be located on the perimeter of the Project Area (edge of the tenements) based on a nominal spacing of 10km to 20km intervals, with more frequent spacing associated with the CDA boundary areas, intermediate spacing on the SEDA boundary areas, and greatest spacing on the NWDA boundary areas (based on the modelled impacts)
- monitoring of the unconfined aquifers under, and adjacent to, CSG water evaporation and containment ponds

8.2.7 Aquifers Considered for Targeted Monitoring

Potential inter-aquifer transfer related to coal seam depressurisation predicted to result in measurable reductions in the available water column for bores screened within specific aquifers; notably, the Springbok Sandstone (CDA and SEDA), and to a lesser extent the Hutton and Precipice Sandstone (CDA) in the vicinity of the QGC CSG extraction bore wellfields (Section 5.4.2).

Water supply bores, screened in these aquifers, within and in close proximity to the CSG operations will need to be monitored as CSG production develops. The monitoring should enable early identification of potential losses resulting from a reduced water column in the bores and implementation of mitigation measures, if warranted. Further discussion of potential management options for affected bore owners is provided in Section 8.3.

This study recommends precautionary monitoring and management of the three key aquifers namely, the Springbok Sandstone, Precipice Sandstone and Hutton Formation aquifers, using the guideline Tier 1 Trigger Values presented in Tables 15 to 17. The installation of the recommended VWP monitoring points should therefore include VWP pressure transducer devices (i.e., the pressure measuring devices which measure the static water head pressure at depth) within each of these aquifer layers.

In addition, when establishing the network of VWP monitoring installations, QGC should also consider including VWP pressure transducers in the:

- Gubberamunda Sandstone, since this aquifer, while considered here to be unlikely to be impacted, is a significant aquifer and a heavily used resource in the Study Area
- The CSG-bearing formations (i.e., the Walloon Coal Measures) as a basis for measuring the actual regional depressurisation halo, its area of affect and the rate of its progression with time.

8.2.8 Monitoring of Existing Bores

This study also recommends that an appropriate selection of *existing bores* (irrigation, farm or domestic water supply, stock watering and other industrial bores), screened in the key identified aquifers (Springbok

Sandstone, Precipice Sandstone and Hutton Formation) should be included in the monitoring program to assess any groundwater impacts *within and outside* the CSG extraction operation area (CDA, SEDA and NWDA).

The relative impact to bore owners in areas within and surrounding the CSG field *will* depend on the location of the bores relative to the CSG operations and the associated cone of depression in the affected aquifer. Water supply bores completed within the key aquifer formations, primarily in the vicinity of the CDA and SEDA CSG operations, are predicted to face a risk from loss of available drawdown.

The potential extent of influence of the coal seam depressurisation operations on the key water supply aquifers identified (particularly in the CDA and SEDA areas) is presented conceptually in Appendix D.

Existing bores and wells, located within and in the immediately surrounding area to the Project Area, which this study considers should form the pool of bores that should be considered for ongoing monitoring (Figures 38 to 41). The details of these bores are provided in Appendix F.

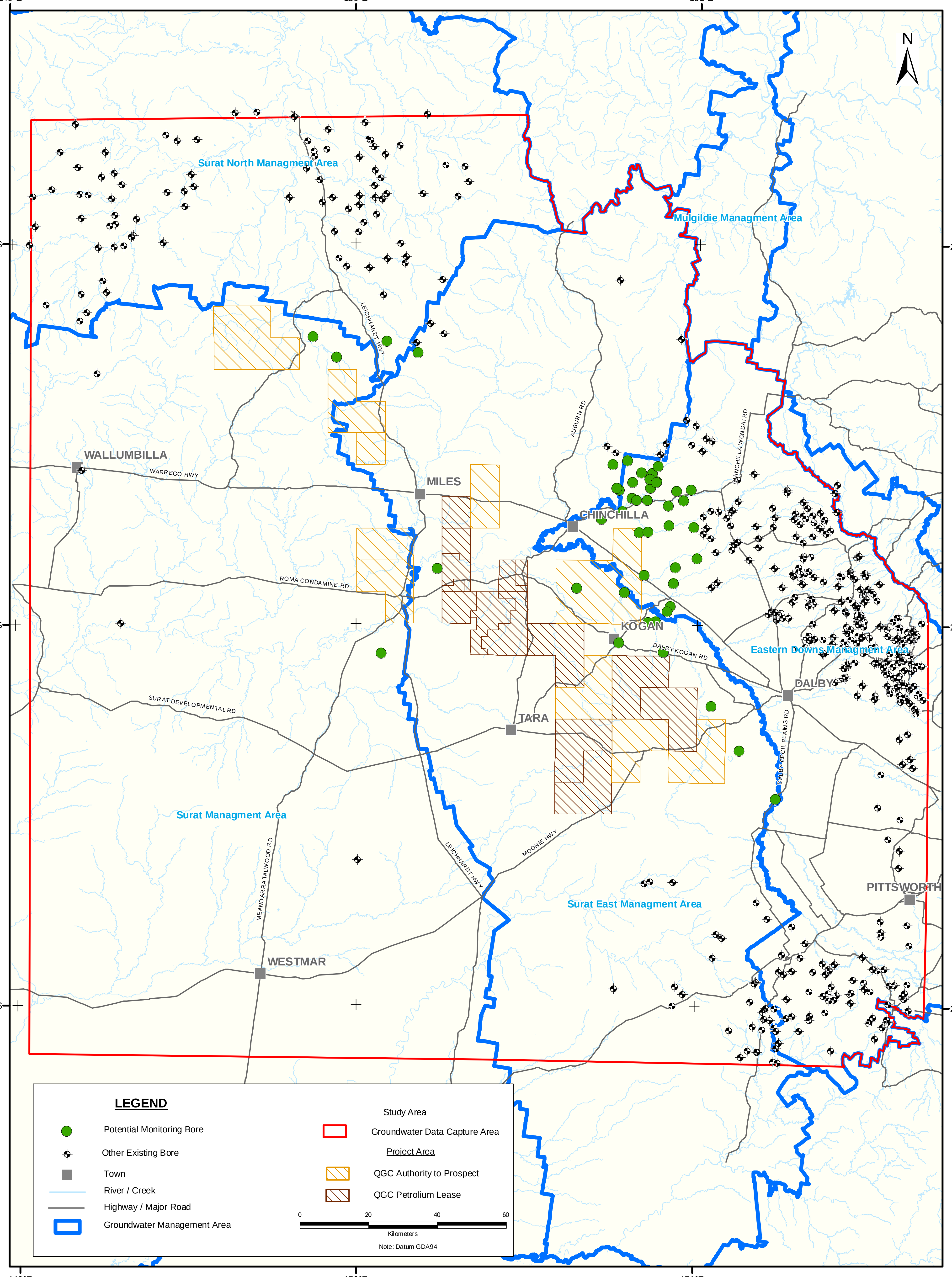
As discussed previously, these figures illustrate that, for the most impacted aquifer, the Springbok Sandstone, there are only two registered wells located within the Project Area. On this basis, this report recommends that the owners of these bores be approached to include them in QGC's Water Monitoring Plan (WMP) (Golder, 2009 [in preparation]).

Existing bores and wells screened within the Precipice Sandstone and Hutton Formation (as well as the Gubberamunda Sandstone and WCM) are more numerous. With the approval of the bore owners, an appropriate selection of these wells should be routinely monitored for water level and water quality. A number of existing wells have been visited as part of the "Groundwater Bore Inventory" (Golder, 2009b) and will be incorporated into the WMP, as applicable.

The number and distribution (density) of bores selected for monitoring should be *at least* located on a nominal spacing of 10km to 20km intervals in the areas within and beyond the perimeter of the Project Area (edge of the tenements). More frequent spacing should be considered on the CDA boundary areas, intermediate spacing on the SEDA boundary areas, and greatest spacing on the NWDA boundary areas (based on the modelled impacts).

The monitoring program should be implemented as soon as possible, so as to establish baseline conditions for the region.

The requirement to monitor potential impacts to the groundwater regimes and groundwater-related EVs is formalised in a WMP. The WMP brings together the all of the concepts present in the previous headings in this section. It will also include monitoring of potential impacts to surface water conditions. The intent, framework and contents of the monitoring program, formalised in a WMP, is summarised in Sections 8.2.9 and 10.0 of this report.



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

CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS WATER STUDIES
DRAWN	DK	DATE	09-06-09
CHECKED	RH	DATE	09-06-09
TITLE	PRIVATE BORES SCREENED IN THE HUTTON FORMATION AQUIFER		
SCALE	1:1,050,000	PROJECT No	087633050
FIGURE No	36	REV No	2
A3			

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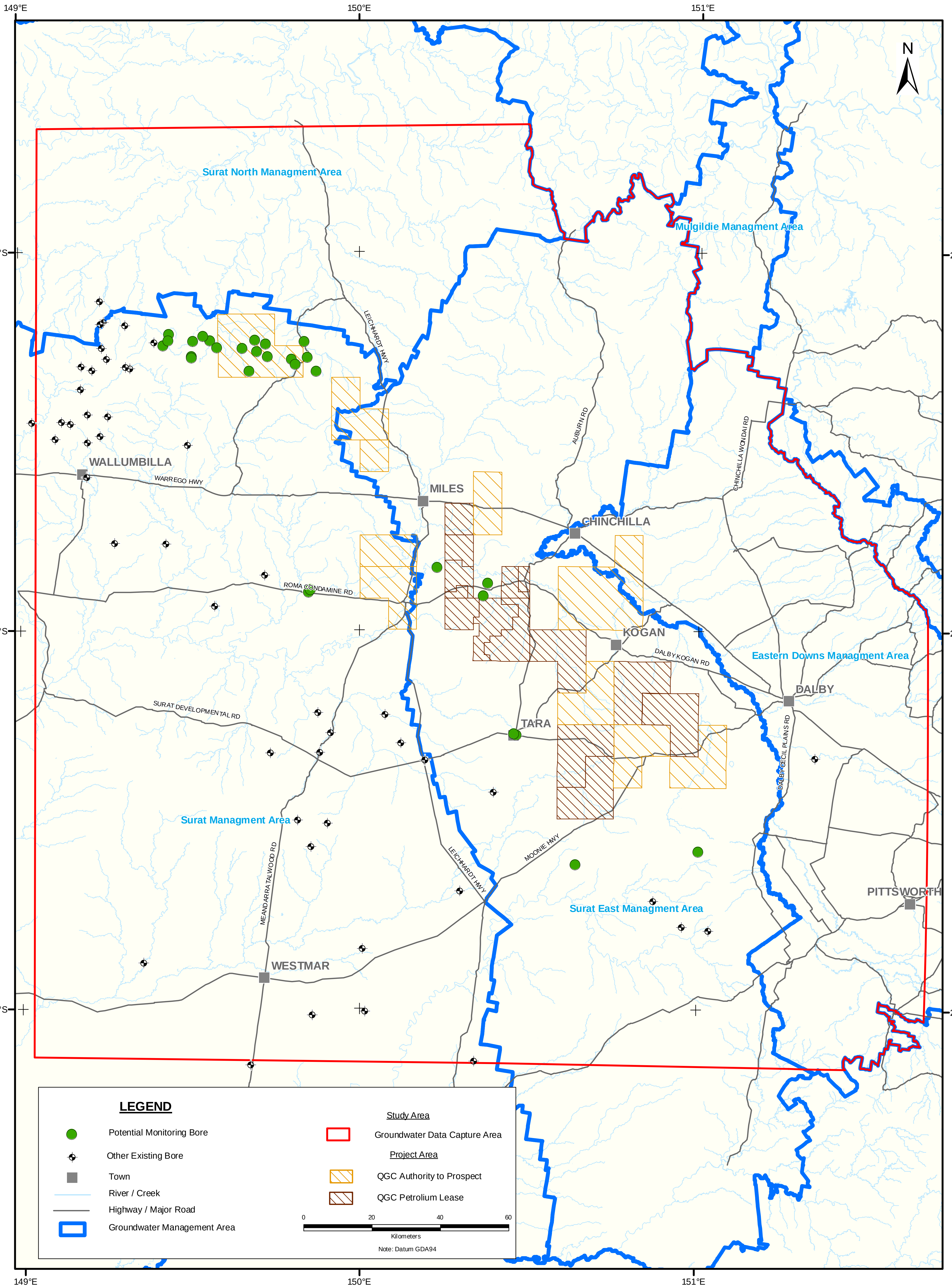

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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS WATER STUDIES
DRAWN DK	DATE 09-06-09	TITLE	PRIVATE BORES SCREENED IN THE INTERMEDIATE - GUBBERAMUNDA FORMATION AQUIFER
CHECKED RH	DATE 09-06-09		
SCALE	1:1,050,000	PROJECT No 087633050	FIGURE No 37 · REV No 2 · A3

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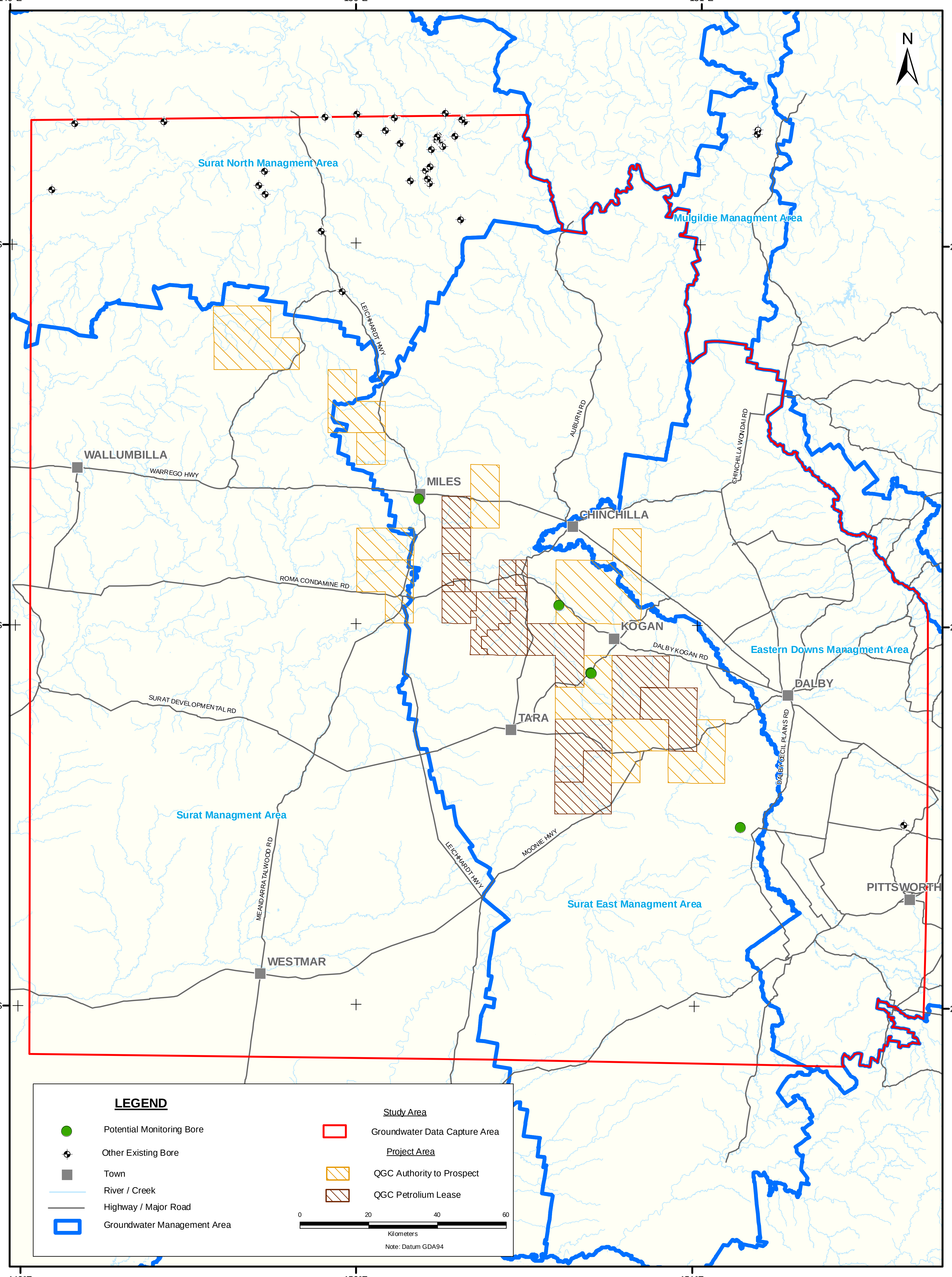

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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS WATER STUDIES
DRAWN DK	DATE 09-06-09	TITLE	PRIVATE BORES SCREENED IN THE PRECIPICE FORMATION AQUIFER
CHECKED RH	DATE 09-06-09		
SCALE	1:1,050,000	PROJECT No 087633050	FIGURE No 38 · REV No 2 · A3

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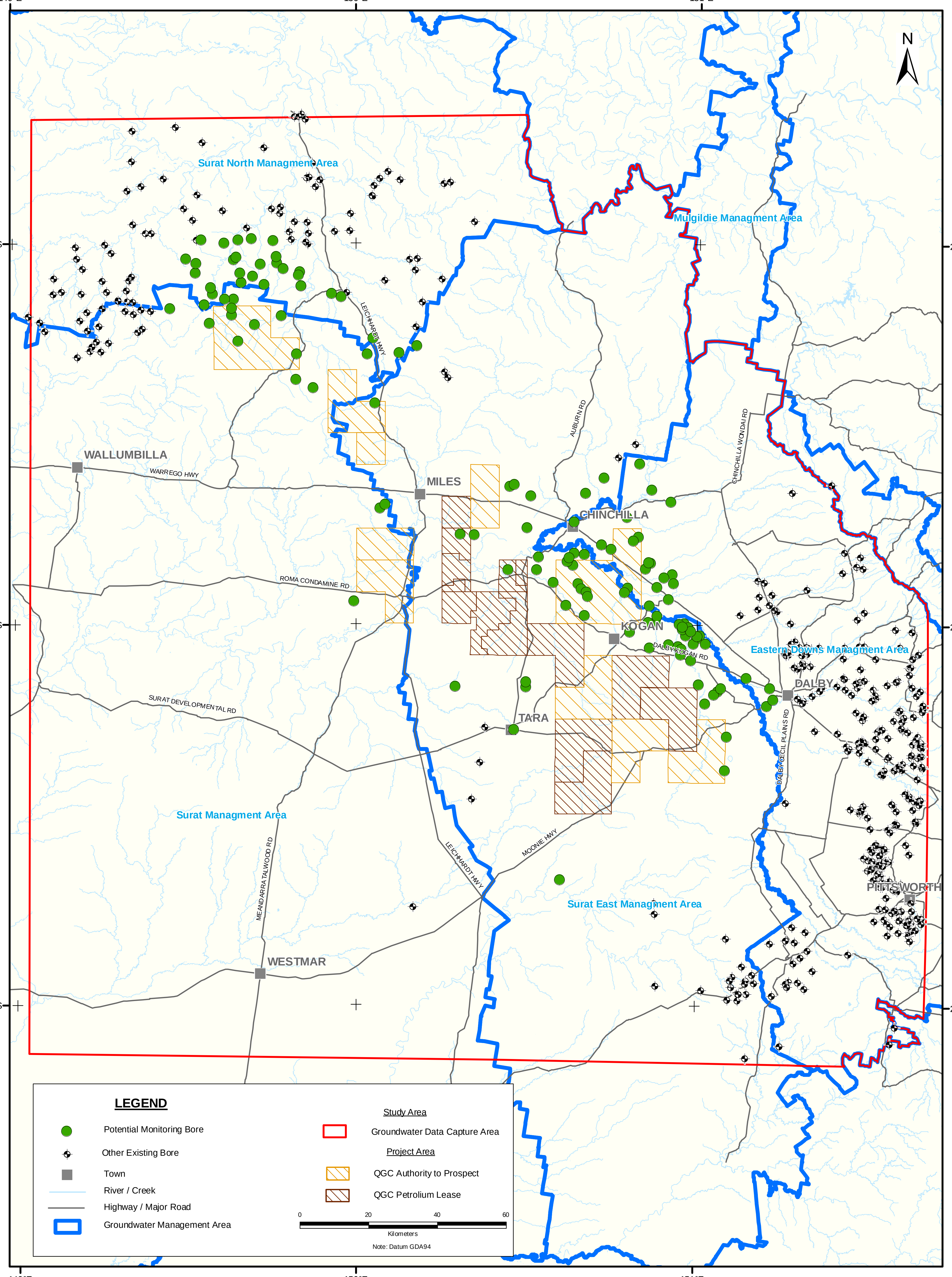

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CLIENT	Queensland Gas Company	PROJECT	QGC - LNG EIS WATER STUDIES
DRAWN DK	DATE 09-06-09	TITLE	PRIVATE BORES SCREENED IN THE WALLOON FORMATION AQUIFER
CHECKED RH	DATE 09-06-09		
SCALE	1:1,050,000	PROJECT No 087633050	FIGURE No 39 / REV No 2 / A3

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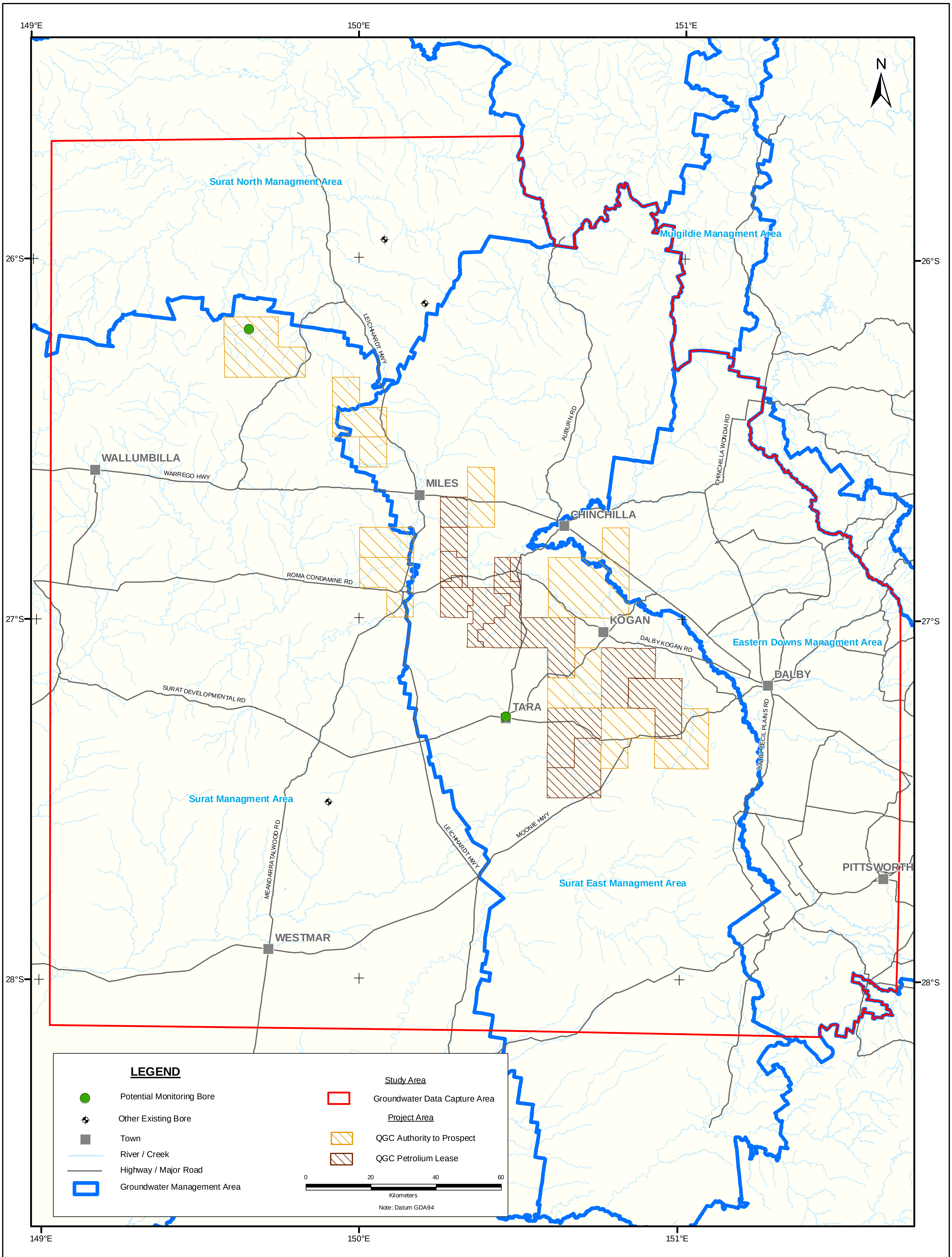

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Golder Associates

CLIENT	Queensland Gas Company		PROJECT	QGC - LNG EIS WATER STUDIES	
DRAWN	DK	DATE 09-06-09	TITLE	PRIVATE BORES SCREENED IN THE WALLOON - SPRINGBOK FORMATION AQUIFER	
CHECKED	RH	DATE 09-06-09			
SCALE	1:1,050,000		PROJECT No 087633050	FIGURE No 40	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.

8.2.9 Proposed *Water Monitoring Plan*

A WMP is being developed by Golder for the Surat Basin operations of QGC that will be presented in a separate document (in preparation, 2009).

The plan will combine both groundwater and surface water monitoring requirements, focussing largely on groundwater monitoring, with some surface water monitoring. It is based on the discussion provided in Sections 8.2.1 to 8.2.8.

The WMP will provide:

- A description of the drivers for the plan, including a review of the relevant legislation, current environmental authorities for the project, and current and emerging policy with respect to water and CSG operations;
- The development of a risk analysis that identifies areas of differing risk arising from the operations. For each risk area, a risk management approach has been developed;
- A description of the underlying principles by which the specifics of the plan have been developed; and
- The details of a monitoring plan for the present operations and known future operations.

The plan will be derived from a risk based approach, and is a response to the current expected likelihood and consequence of environmental impacts. Water monitoring is a work in progress, and requires reviewing annually. Reviewing the plan regularly will ensure it is current, complies with any updated environmental authorities or any additional legislative requirements, and is adjusted to suit the monitoring results achieved.

The monitoring results will be used:

- to guide ongoing operations and closure design;
- as an early warning system to identify potential impact; and
- for improving CSG water management by utilising the data produced from the monitoring program.

The plan will cover monitoring for each of the primary aquifer zones, using purpose-built monitoring installations (VWPs) and privately owned bores (primarily in Springbok Sandstone, Precipice Sandstone and Hutton Formation aquifers as well as precautionary monitoring in the Gubberamunda Sandstone and WCM units) and surface water.

It is recommended that monitoring be conducted within and in areas surrounding the Project Areas (CDA, SEDA and NWDA) based on the modelling predictions presented in Section 5.0 and trigger values discussed in Section 8.2.3.

Therefore, the WMP will include, as a minimum:

- Information relating to a Project Area perimeter monitoring program, including bore locations for monitoring the Springbok Sandstone, the WCM units, Gubberamunda Sandstone, Precipice Sandstone and Hutton Formation aquifers, and the Shallow Alluvial aquifer. The program should include multi-level, vibrating wire piezometer (VWP) monitoring installations;.
- Monitoring locations for each of the QGC development areas (NWDA, CDA, and SEDA);
- A selection of *existing bores* (irrigation, farm or domestic water supply, stock watering and other industrial bores) to be used for assessing groundwater impacts both within and outside the CSG extraction areas. Figure 38 to Figure 42, and Appendix F provide the full list of registered bores considered appropriate for monitoring and from which the selection of bores for ongoing monitoring might be chosen;

- An appropriate monitoring program for the existing bores, including the monitoring of water levels/pressures, field water quality parameters and sampling and analysis of groundwater analytes including:
  - basic groundwater parameters, major ions and the base suite of metals for the sandstone aquifers
  - basic groundwater parameters, major ions, the base suite of metals, and a suite of parameters known to be associated with CSG water for the CSG aquifers and shallow monitoring bores associated with the ponds.
- A monitoring regime for any unconfined aquifers under and/or adjacent to CSG associated water storage facilities; and
- Annual monitoring reviews, to be prepared, providing the data in tables and graphs, and other useable formats, so that updating of the hydrogeological conceptual model and risk assessment can continue. The creation of maps of hydrogeological data from single monitoring events will greatly assist the future improvement of the hydrogeological database, in contrast to the discontinuous groundwater level and water quality dataset assembled for this report.

QGC have established an initial network of groundwater monitoring bores at the following locations in the CDA:

- Kenya and Rhynie associated water storages;
- Pond A Berwyndale South;
- Condamine Power Stations Saline Effluent Pond #1; and
- Wambo Downs #2 Pond Area (former pond that has been rehabilitated).

Bores at these locations have been constructed to monitor the Mooga, Orallo and Gubberamunda formations. No unconfined shallow groundwater systems exit at these sties.

These current monitoring networks will be incorporated into the proposed WMP.

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 (a comprehensive WMP) 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. Sections 8.1 to 8.3 provide a monitoring strategy to provide early warning of pending adverse impacts. This sections described 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
- 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 6.0). 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

The Walloon Coal Measures (WCM) support approximately 11 GL/annum of extraction entitlements across the Groundwater Management Units (GMU) encountered within the Study Area (although 90% of these entitlements are associated with the shallower outcrop areas to the east).

Additionally, 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 5.0 and Appendix D), which has showed 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 WMP 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 Project Area 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 5.0 and Appendix D) 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

Section 8.2.7 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.

In the case of the Project Area, based on the assumed extent of depressurisation of the WCM coal seams, 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 re-injection strategies to manage or minimise (reduce) depressurisation and, consequential subsidence effects.

8.3.3 Management of Associated Water

The Queensland Government's recently released water management policy framework for the CSG industry (October 2008) provided direction to producers is to achieve environmentally sustainable outcomes and encourage greater beneficial use of CSG produced water. As indicated in Section 2.6, 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;
- Re-injection of associated water is promoted as the *preferred management option;*
- If re-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.

Of these, *underground injection* into deeper aquifers is a management option for disposal of CSG associated water and is considered to be an environmentally safe option, and is discussed in the following sections.

8.3.3.1 Underground Injection (Re-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 (Section 2.6). 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.

The evaluation of suitable formations for associated water injection requires a reasonable level of knowledge regarding the hydraulic properties and existing water quality of the formations involved. Further, there are various site-specific factors that can complicate the efficiency of underground water injection, and as such prospective injection locations will require technically robust field trials to assess the achievable injection rates. Technical considerations for development of an injection feasibility study are provided in the following sections. Some of the required information to evaluate this water management option is not currently available for the Project Area, and is the subject of ongoing study currently underway.

Injection of associated water can be grouped generally as:

- re-injection into a coal seam aquifer; and
- re-injection into a non-coal seam aquifer.

CSG water could not be re-injected into the producing environment because the production of CSG requires a reduction in the hydrostatic pressure. Re-injection, especially during active production of methane may increase hydrostatic pressure, leading to a decrease in gas production.

Alternatively, injection of CSG water into non-producing deeper or shallower coal aquifers may avoid a detrimental effect on gas production.

Application of underground injection includes both technical and regulatory considerations. The following technical aspects must be considered:

- *Formation suitability* – requires characterisation of reservoir hydraulic characteristics (porosity, permeability, storage capacity), depth, relative location to producing wells, significance of local fracturing and faulting, and presence of active and abandoned wells within the area;
- *Isolation* – the receiving formation must be vertically and laterally separated or otherwise confined from utilised groundwater resources, including CSG production formations;
- *Reservoir pressure* – static pressure within the receiving formation may limit the rate at which fluids can be injected and/or may limit the total volume of injected fluids; and
- *Water quality* – the chemical compatibility of formation water and injected water will play a part in the feasibility assessment of the injection plan. The quality of the water re-injected should be equal or better than that in the receiving aquifer (e.g., locations within the WCM and the Hutton Units where poor quality water appear to exist and which could be improved by the injection of the associated water from the CSG operations – see Figure 25 and Figure 26). Siltation or clogging may arise as a consequence of specific water quality characteristics, and give rise to a rapid decline of the injected aquifers capability to receive injected associated water (treatment may be required, as might be additional injection wells to make up capacity).

Hydraulic Properties of Receiving Aquifers

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 modeling 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 Project Area, 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.

Re-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 re-injection well fields.

Since the hydrogeology of the selected receiving aquifer system is critical in defining how many wells might be required, what design is appropriate and at what sustainable flow rates they might operate, the design and nature of such a wellfield cannot be provided at this stage. Considerable exploration and field testing will be required to locate and design suitable re-injection wellfields.

Depleted gas wells that are sufficiently remote, where they will not interfere with the current production area, may be considered for re-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 for the Project Area.

Groundwater Compatibility

The quality of associated water must be evaluated for compatibility with groundwater in the receiving formation to ensure that the beneficial use(s) of the current resource is not degraded. A comparison of the average TDS of groundwater from the CSG production wells and the surrounding formations in the Project Area is provided in Table 18 (also refer to Section 4.6, Appendix E and Figure 23 to Figure 27). Whilst TDS provides a good initial screening parameter for compatibility of different water types, detailed evaluation of specific water quality parameters should also be performed once the data is available.

Based on the reported TDS for the CSG production wells, the associated water is generally of poorer quality than the average water quality for each of the primary production aquifers in the Project Area. Therefore, the following considerations should be taken into account:

- re-injection of associated water into the coal seams via depleted gas wells should represent a compatible environment for direct injection (but it is likely that installation of specific injection wells would also be required to address the volumes of water requiring management);
- treatment may be required to render the associated water suitable for injection into aquifers with higher quality groundwater resources;
- injection into sparsely accessed formations should be considered, with a contingency to provide an alternative supply to the few users accessing the specific formation, if their water quality becomes degraded; and
- numerical groundwater and hydrogeochemical model simulations should be considered to assess whether mixing of untreated associated water with existing higher quality formation water results in a level of degradation that is still compatible with the predominant licensed use(s) of the resource. There should be a contingency to provide alternative supply to users for whom the degraded water quality is no longer suitable for their intended use.

Table 18: Comparison of salinity (TDS, mg/L) in groundwater in Study Area

Formation/Unit	Min	Max	Average	Q10	Q50	Q90	Number of Samples
Quaternary Alluvium	219	7683	1277	521	849	2501	525
Shallow Aquifers	297	14651	1309	482	1078	1816	128
Intermediate Unit	147	13293	2274	787	1711	3962	134
Walloon Unit	**164**	**21263**	**2820**	**603**	**1725**	**5960**	**139**
CSG Production Wells	792	10177	4091	1536	2680	8416	57
Hutton	120	11867	2125	600	1594	3589	106
Precipice	175	11730	1604	194	324	4008	15

Feasibility of Large Scale Injection

The feasibility of a full-scale re-injection program would require extensive field trials and predictive modelling to assess the efficacy of the re-injection process, and to evaluate the potential influence injection would have on adjacent aquifers and local or regional groundwater flow patterns.

Studies are currently underway to progress this issue.

Treatment before Injection

Typically coal seam water is brackish to saline (typically range between 3,000 and 24,000 µS/cm), as is the case with the reported water quality from the CSG wells in the Project Area (Section 4.6, Section 5 and Appendix E). Such water is unsuitable for direct re-injection into aquifers of better quality. There are two primary reasons why brackish or saline water is considered unsuitable for re-injection:

- it may adversely affect the existing water quality within the aquifer and therefore any beneficial uses of the resource; and
- such water often generates engineering problems that impede re-injection, such as clogging.

However, treating water prior to re-injection will control excessive solids, corrosion, and generally mitigate chemical reactions that form precipitates or growth of microbes.

Treatment of CSG water will also increase the options available for returning it to the environment. Options include:

- aquifer storage and recovery in shallow and deep formations;
- injection into formations exhibiting hydrologic interconnection with surface water bodies; and
- infiltration to the water table through holding ponds.

Studies are currently underway to progress this issue.

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. These will be managed using a combination of industry best-standard preventative measures (compliant with the pertinent legislative framework described in Section 2) 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 wholly owned subsidiary of the BG Group plc, 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 12 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;
- 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. This study has been prepared to support the EIS.

This report considers the groundwater aspects of the development of the CSG fields component of the Project (Figure 2) as part of the broader EIS development process. It describes the likely impacts on groundwater resources within, and around, the proposed development area. The report recognises that groundwater is part of the larger hydrological cycle that interlinks strongly with surface water. The effect of the upstream surface water component of the Project is covered in another Golder report (refer to Golder report "Chinchilla, Surat Basin Qld - QGC Water Studies Upstream - Surface Water Impact Assessment", February 2009).

9.1 This CSG Project

The procedure for recovering CSG gas involves drilling a series of wells into the resource coal seams and pumping out groundwater (CSG water) to lower the coal reservoir pressure in order to release the methane gas from the coal.

QGC currently have 6 ATPs and 14 PL in the Project area and have defined three main gas reserve development areas (Figure 3), as follows:

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

To extract the CSG resource, QGC's upstream component of the Project will comprise developing:

- up to a total of 6,000 production wells over 20 years;
- associated surface equipment, gas and water gathering systems, and gas processing and compression infrastructure; and
- management, storage and disposal, including beneficial use, of CSG water.

9.2 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 (NRW, 2006). It is also located primarily within the Queensland Government 'Condamine Balonne Water Management Areas' (surface water) and in or adjacent to the following 'Groundwater Management Areas': Surat East, Eastern Downs, 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, this report seeks to provide information and answers on the following key inputs to the EIS:

- *The existing environment and environmental values – a statement of the current situation in the Project area;*
- *Potential impacts on environmental values - from proposed CSG operations; and*
- *Mitigation measures - that are recommended to monitor, manage and mitigate the potential impacts defined.*

These key items, together with the legislative context within which the site and the methods that were employed to obtain baseline information, are discussed individually in the report in the following sections.

9.3 Legislative Framework

The legislation, including plans and policies in Queensland for managing groundwater and CSG water, once it reaches the surface, are summarised below. The report provides discussion on the following acts, plans and policies:

- *Water Act 2000;*
- *Water Resource (Great Artesian Basin) Plan 2006* and Great Artesian Basin Resource Operations Plan 2007;
- *Petroleum Act 1923;*
- *Petroleum and Gas (Production and Safety) Act 2004;*
- *Queensland Coal Seam Gas Water Management Policy 2008;*
- *Water Supply (Safety and Reliability) Act 2008;*
- *Environmental Protection Act 1994;*
- *Environmental Protection (Water) Policy 1997;*
- *Management of Water Produced in Association with Petroleum Activities (associated water), December 2007;*
- *Water Resource (Condamine and Balonne) Plan 2004 and Condamine and Balonne Resource Operations Plan 2008;*
- *National Water Initiative;*
- *Water Resource (Moonie) Plan 2003;*
- *Water Resource (Fitzroy Basin) Plan 1999; and*
- *Water Fluoridation Act 2008.*

9.4 Study Methods and Data Assessment

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

- obtaining, preparing and interpreting available data from relevant sources, including the QGC, NRW, EPA, AGE, WERD databases, and a literature review – to provide background for the study and an understanding of 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 may affect the environment and other groundwater users.
- developing a detailed conceptual groundwater model, followed by numerical groundwater modelling – to obtain an estimate of the magnitude of the likely impact on the environment and 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 each of the three development areas was developed using a model. The indicative-level computer-based numerical modelling methods were performed within a defined groundwater model domain area for each development area. The three model domains were designed to extend beyond the predicted area of groundwater impact likely to be associated with the operation of the CSG field.

The details of the data collection and assessment studies are provided in report Sections 2 to 7.

9.5 The Existing Environment and Environment Values

The existing environment, as it relates to groundwater, has been described. It provides a baseline dataset of specific information from which effects and potential impacts may be assessed, if required at some future time.

The following specific baseline information is discussed in the body of the report:

- topography and drainage
- climate
- geology, including regional geology of the Surat Basin and geology in the Project Area
- hydrogeological setting, including aquifer occurrence, hydrogeological units, conceptual groundwater model (CGM)
- groundwater quality in the Project Area
- existing water use and allocations
- the proposed estimate of QGC's CSG water extraction
- environmental values (EV)

The groundwater resource, existing water use and allocations, and environmental values are the most important baseline information considerations for this report.

Conceptual Groundwater Model (CGM)

To better describe the groundwater conditions operating in the Project Area, a CGM has been developed for this study. The CGM for the study 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.

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

- **Quaternary Alluvium:** This unit comprises the most recent Quaternary and Tertiary unconfined alluvium aquifers. The most prevalent of these being the **Condamine River Alluvium.** The Condamine River Alluvium is a highly developed aquifer, with a high density of extraction bores within the Condamine River flood plain.

- **The Shallow Unit**: In the western region of the Project Area, 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. To the east of the Condamine River, the shallow unit comprises the basalts and associated rocks of the late Tertiary Main Range Volcanics (MRV). The MRV are mainly located on the western escarpment of the Great Dividing Range and typically unconformably overlying the deeper hydrogeological units.

- **The Intermediate Unit**: This unit includes the major sandstone aquifers 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, both reasonably important aquifers in the area south and southwest of the QGC tenements.

- **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. 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, the coal seams within this formation are considered to be aquifers and are able to transmit water easily (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. The aquifer is subartesian in the Project Area. The Marburg Sandstone is hydrogeologically equivalent to the Hutton Sandstone within the eastern region of 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 east of the study area. Typical conductivities are around 0.1 to 10 m/day and yields range between 0.1 and 30 L/s.

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

- Pre coal seam groundwater pressures (levels) in the Intermediate to Hutton units generally range between 260 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 the QGC tenements, and that there may be mixing processes occurring between the formations (AGE 2007, PB 2004).

9.6 Water Use

Water use within the Study Area is widespread, and is occurring from almost all aquifers. Primarily, the water is used for irrigation on the Condamine River Alluvium, in the eastern margins of the Study Area. 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 now exceeds the allocation from the groundwater management units that contain the Walloon Coal Measures and will increase over the next 20 years.

9.7 Environmental Values and Potential Impacts on the Environmental Values

There is a wide range of uses for water in the Study Area. The important environmental values to the Project include:

- aquatic ecosystems, including groundwater dependant ecosystems (GDEs), wetlands and reservoirs in the area;

- drinking water uses;

- 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.

- other industrial uses;

- cultural and spiritual values;

- aquaculture;

- scenic visual amenity; and

- recreational values.

9.7.1 Potential Groundwater Impacts

Potential impacts to the groundwater system, related environmental values, neighbouring users, and the ecosystem have been examined in this study. 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. These models were used to estimate the 'order of magnitude' of drawdowns in the aquifers in the region, arising from the QGC CSG operations.

Based on the predictive groundwater modelling, there is considered to be 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.

General Comments

Groundwater drawdown impacts, within the 5 key aquifer units identified as vulnerable, can be summarised as follows (with specific comments for each development area following). Estimated groundwater drawdowns:

- decline with distance from the CSG wellfield boundaries;
- decline gradually after cessation of the CSG groundwater extraction;
- are greatest beneath the depressurisation area (idealised representation of the CSG wellfield, namely within the QGC tenement boundaries); and
- are greatest within the Springbok Sandstone aquifer largely because it is possibly in direct hydraulic contact with the WCM units which are being pumped for CSG recovery.

The Gubberamunda Aquifer is unlikely to be measurably affected by extraction of groundwater from the WCM (drawdowns are negligible or not within the resolution of the model). The Hutton and Precipice are drawn down to a minor to moderate extent as a result of the CSG groundwater extraction.

Specific to each development area, the following conclusions can be reached:

Central Development Area (CDA)

- Drawdown in the Springbok Sandstone is predicted to range from approximately 5 m to an expected maximum of about 55 m at 1.8 km from the edge of the depressurisation area (i.e. boundary of the tenements). Recovery of the aquifer is predicted to commence immediately after groundwater extraction terminates (40 years after pumping commenced);
- The predicted drawdown in the Hutton Sandstone (Figure D-7, Appendix D) ranges from less than 0.5 m to an expected maximum of 2.5 m. Recovery of the Hutton Sandstone aquifer is predicted to commence about 50 years after groundwater extraction terminates;
- The predicted drawdown in the Precipice Sandstone ranges from less than 0.2 m to an expected maximum of 1.8 m. Recovery of the Precipice Sandstone is predicted to commence at about 60 years after groundwater extraction terminates;
- The maximum predicted drawdown occurs in the Walloon Coal Measures seams and the Springbok Sandstone aquifers;
- Throughout the simulation, the predicted aquifer drawdown in the Intermediate Unit (Mooga, Oralla, and Gubberamunda Sandstone) was minimal; and

- The modelled drawdown within the Springbok Sandstone, *near the centre of the depressurisation area*, is expected to range between 10 m and 85 m (within and beneath the tenement boundaries). The drawdown also decreases continuously away from the centre of the depressurisation area.

South East Development Area (SEDA)

- Drawdown in the Springbok Sandstone aquifer is predicted to range from less than 2 m to an expected maximum of 23 m at 1.8 km from the edge of the depressurisation area (i.e. boundary of the tenements). Recovery of the aquifer is predicted to commence 5 years after groundwater extraction terminates;
- The model predicts that drawdown in the Hutton Sandstone may range between less than 2 m to an expected maximum of about 8 m. Recovery of the Hutton Sandstone is predicted to commence about 15 years after groundwater extraction terminates;
- The modelled drawdown for the Precipice Sandstone ranges from less than 0.5 m to an expected maximum of about 6 m. Recovery of the Precipice Sandstone is predicted to begin at about 25 years after groundwater extraction terminates;
- The predicted maximum drawdown in the Springbok Sandstone in the SEDA is less than in the CDA; and
- The modelled drawdown in the Springbok Sandstone is expected to range from 2 m to 36 m, near the centre of the depressurisation area, after 40 years of groundwater extraction. Again, drawdown continuously decreases away from the centre of the depressurisation area.

North West Development Area (NWDA)

- Drawdown in the Springbok Sandstone is predicted to range between less than 0.5 m to an expected maximum of about 2 m at 1.8 km from the edge of the depressurisation area (i.e. boundary of the tenements). Recovery of the Springbok Sandstone aquifer is predicted to commence 75 years after groundwater extraction terminates;
- The predicted maximum drawdown in the Gubberamunda, Hutton Sandstone and the Precipice Sandstone is insignificant;
- The predicted maximum drawdown in the Springbok Sandstone in the NWDA is less than the CDA and SEDA; and
- The modelled drawdown within the Springbok Sandstone is expected to range between less than 0.5 m and approximately 2 m, near the centre of the depressurisation area. Drawdown, again, continuously decreases away from the centre of the depressurisation area (Figure D-18).

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 and in particular the Condamine River is unlikely to occur.

9.7.2 Mitigation Measures

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 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.

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 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;
- Provision of bulk water of suitable quality to the bore owner to compensate for loss of yield in their water supply bore (this may be treated associated water); or

9.7.3 Monitoring Program

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 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.

This study recommends that the monitoring program incorporate the following key components:

- The installation of a multi-level, vibrating wire piezometer (VWP) monitoring network, which not only monitor water levels and piezometric heads in the most vulnerable aquifer, Springbok Sandstone, but also the Shallow Alluvials, Gubberamunda Sandstone, Precipice Sandstone and Hutton Formation aquifers. These VWPs would be located on the perimeter of the Project Area (edge of the tenements) based on a nominal spacing of 10km to 20km intervals, with more frequent spacing associated with the CDA boundary areas, intermediate spacing on the SEDA boundary areas, and greatest spacing on the NWDA boundary areas (based on the modelled impacts)
- An appropriate selection of *existing bores* (irrigation, farm or domestic water supply, stock watering and other industrial bores), screened in the key identified aquifer (Springbok Sandstone, Precipice Sandstone and Hutton Formation) should be included in the monitoring program to assess any groundwater impacts *within and outside* the CSG extraction operation areas (CDA, SEDA and NWDA). With the approval of the bore owners, an appropriate selection of these wells should be routinely monitored for water level and water quality.
- Monitoring of the unconfined aquifers where they exist under, and/or adjacent to, CSG associated water storage dams and ponds, and evaporation and containment ponds. These ponds pose the greatest risks to shallow groundwater systems, if present.

The monitoring program should be implemented as soon as possible, so as to establish baseline conditions for the region.

A *Water Monitoring Plan (WMP)* for the QGC's CSG operations, currently in preparation (Golder 2009b), will provide the basis and mechanisms required to ensure early detection of groundwater impacts, which would trigger appropriate and responsible management and mitigation actions. Its framework is summarised in Section 8.

9.7.4 Management and Mitigation

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. 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.
- The management of associated water (including re-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 Section 2) 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.

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. NRW), 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.

It is recognized that data, such as formation pressures and water quality from the CSG wells, will continue to be collected and that the maps generated within this report can be reinterpreted at a later date.

Data collected from the monitoring program(s), including the *Water Monitoring Plan* currently being developed, 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.

10.2 Groundwater Bore Inventory

The bore inventory has identified a limited selection owners/wells to help with groundwater monitoring and baseline conditions setting (Golder, 2009b).

The objective of the groundwater bore inventory was to identify a number of privately owned bores within 5 to 10 km of existing and proposed CSG extraction activities. There are very few monitoring locations for the Hutton Sandstone and Precipice Units that are ideally located with respect to monitoring water pressure impacts potentially associated with CSG water extraction. There are a few bores near the tenements that are completed in the Intermediate Unit (Gubberamunda and Mooga Sandstones) that could be used to monitor potential pressure changes within this Unit.

The results from the bore inventory should also be used to relate the bore water levels recorded within the NRW registered bore database to current piezometric conditions. It is recommended that vibrating wire piezometers (VWP) be installed to monitor impacts in the WCM and adjacent aquifers/primary aquifers not only within the CSG tenements areas (Project Area) but within the zone of potential groundwater impact.

10.3 Water Monitoring Program

It is recommended that a regional monitoring program (described in Section 9) be implemented 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.

A regional groundwater monitoring program should be implemented that includes a variety of shallow, intermediate and deep monitoring locations. The monitoring program should be implemented as soon as possible, so as to establish baseline conditions for the region.

On the basis of these recommendations, a WMP is currently being developed (Golder 2009b). The WMP will describe the required and recommended monitoring for each of the primary aquifer zones, using purpose-built monitoring installations (VWPs) and privately owned bores (primarily in Springbok Sandstone, Precipice Sandstone and Hutton Formation aquifers, as well as precautionary monitoring in the Gubberamunda Sandstone and WCM units) and surface water. For example, monitoring should be conducted within and in areas surrounding the Project Areas (CDA, SEDA and NWDA) based on the modelling predictions presented in Section 5.0.

Therefore, the WMP will include, as a minimum:

- Information relating to a Project Area perimeter monitoring program, including bore locations for monitoring the Springbok Sandstone, the WCM units, Gubberamunda Sandstone, Precipice Sandstone and Hutton Formation aquifers. The program should include multi-level, vibrating wire piezometer (VWP) monitoring installations;
- Monitoring locations for each of the QGC development areas (NWDA, CDA, and SEDA);
- A selection of *existing bores* (irrigation, farm or domestic water supply, stock watering and other industrial bores) to be used for assessing groundwater impacts both within and outside the CSG extraction areas;
- An appropriate monitoring program for the existing bores, including the monitoring of water levels/pressures, field water quality parameters and sampling and analysis of groundwater analytes including:
  - basic groundwater parameters, major ions and the base suite of metals for the sandstone aquifers; and
  - basic groundwater parameters, major ions, the base suite of metals, and a suite of parameters known to be associated with CSG water for the CSG aquifers and shallow monitoring bores associated with the ponds.
- A monitoring regime for any unconfined aquifers under and/or adjacent to CSG associated water storage facilities; and
- Annual monitoring reviews, to be prepared, providing the data in tables and graphs, and other useable formats, so that updating of the hydrogeological conceptual model and risk assessment can continue. The creation of maps of hydrogeological data from single monitoring events will greatly assist the future improvement of the hydrogeological database, in contrast to the discontinuous groundwater level and water quality dataset assembled for this report.

10.4 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 model developed for this study 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. The model would ideally include the planned extraction from QGC wellfields to the south east of the Chinchilla development area. An updated groundwater model would potentially prove useful in developing long term water 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 (NRW and EPA).

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Report Signature Page

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APPENDIX A

Scope of Works

PROJECT GROUP

SCOPE OF WORK
WATER STUDIES - UPSTREAM COMPONENT

A	23 Jul 08	Issued for Review	SF	MH	MH
REV	DATE	DESCRIPTION	PREPARED	CHECKED	APPROVED

Queensland Gas Company
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Level 11 307 Queen Street
BRISBANE QLD 4000
Phone: 07 3004 1000
Fax: 07 3012 8411

Document No	Rev.
PRO-G-PLN-002	B

Table of Contents

1 Introduction

1.1 Preamble

You are invited to submit a Proposal for the provision of consultancy services for work as set out in *Section 2: Scope of Works* to assist with the preparation of environmental assessment documentation for the upstream components of the proposed Queensland Curtis Liquefied Natural Gas Project (QC LNG).

1.2 Background and Proponent

BG Group ("BG") and Queensland Gas Company ("QGC") (referred to as "the Proponents") have initiated the environmental impact assessment procedures of the Queensland *State Development and Public Works Organisation (SDPWO) Act 1971* for the development of existing 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 in Central Queensland.

The Proponents anticipate that the Project will be declared a "significant project", for which an Environmental Impact Statement (EIS) will be required.

1.3 The Proposal

The upstream component of QC LNG covers the expansion of QGC's existing coal seam gas (CSG) operations in the Surat Basin, to provide gas for the LNG plant and domestic gas markets. Over the minimum 20-year life of the Project, this expansion will comprise the development of:

- An initial 1,500 commercial gas production wells for the first LNG train (approximately 600 wells to be available at start-up), with an additional 1,500 wells per subsequent LNG train;
- Associated surface equipment, gas and water gathering systems and gas processing and compression infrastructure;
- Beneficial use of associated water..

1.4 Project Location

QGC currently holds nine Authorities to Prospect (ATP) covering 7,500 km^2 in the Surat Basin (refer Figure 1). Thirteen Petroleum Leases (PL) (including current applications) and four pipeline licences are held within the QGC acreage. These tenures are subject to one Project Environmental Authority under the *Environmental Protection Act 1994 (Qld)* for activities in the Walloon Fairway area (excluding PL 201 and PLA 180).

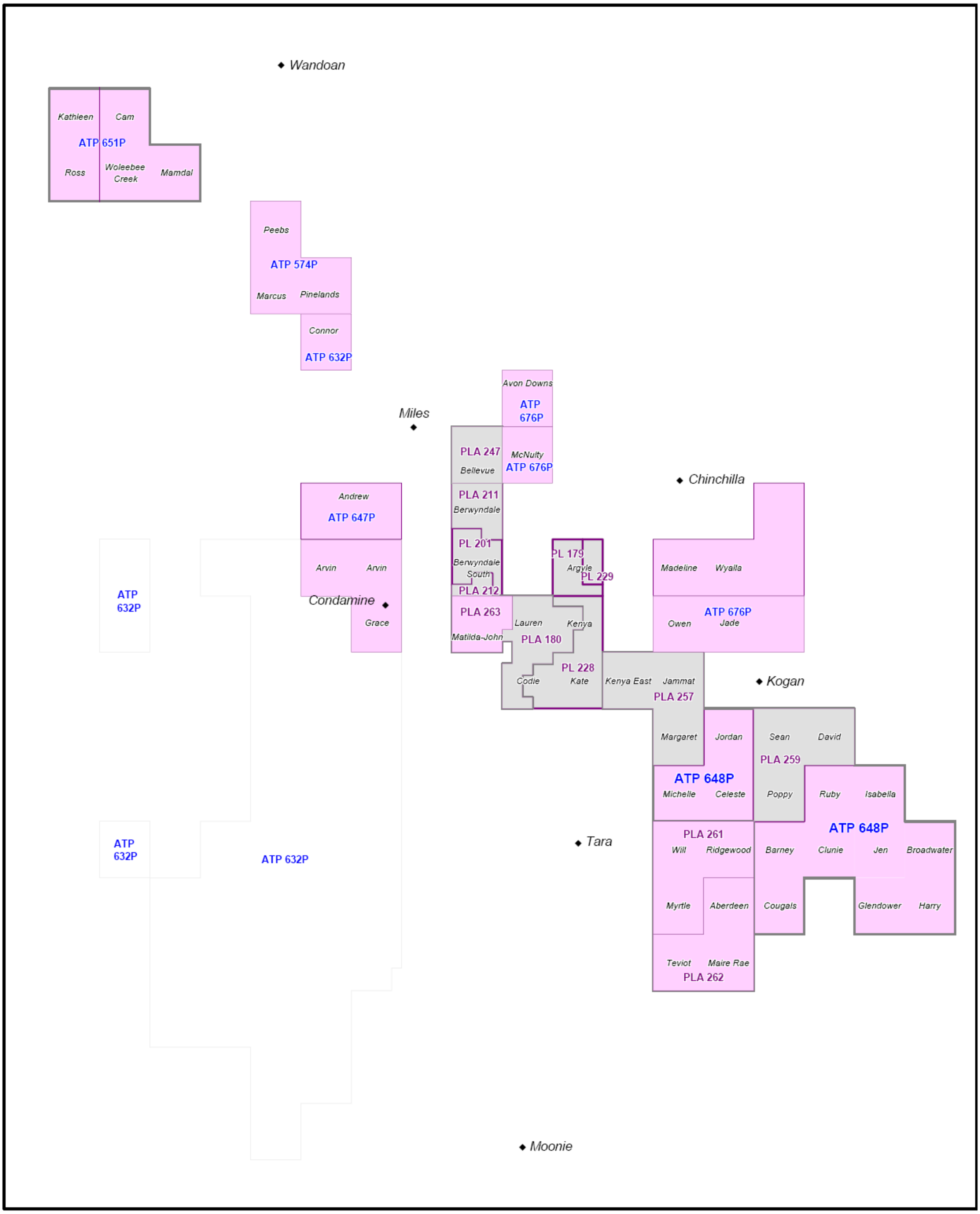
The QGC tenures are all located within the Surat Basin, a resource region in southern Queensland. The tenures are within the Dalby Regional Council and in the vicinity of Miles, Chinchilla, Condamine and Tara Townships. The Condamine River bisects the tenure areas and the predominant land use is rural for dry land cropping and grazing.

1.5 Approvals Process

Major project status has been declared under the SDPWO Act in Queensland and a referral is being made to the Australian government.

It is anticipated that the Environmental Impact Statement will be carried out under the SDPWO Act and the bilateral agreement between the Queensland and Australian Governments.

An Environmental Authority under the *Environmental Protection Act 1994* will be required in support of a petroleum lease under the *Petroleum and Gas (Production and Safety) Act 2004*.



NORTH

QUEENSLAND GAS COMPANY

QGC

LEGEND:

- Town
- Authority to Prospect (ATP)
- Petroleum Leases Granted (PL) and Petroleum Lease Applications (PLA) Administered Under EP Act
- Petroleum Lease Applications to be Submitted 2008

QGC Acreage

0 15 30

Kilometres

Scale: 1:600,000 (A3)

Figure 1 QGC Tenements (Pink and Gray Areas being considered for EIS)

2 Scope of Work

Proposals are sought to carry out studies to assess the environmental issues and impacts associated with development in relation to surface and ground water. The Terms of Reference (ToR) are not as yet available and proposals should 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 successful consultant will be given the opportunity to review their scope of work and cost estimate once the final ToR are available.

Your 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. You may identify a potential need for additional studies to be undertaken/completed beyond the timeframe available for the initial EIS studies (see Point 5).

2. Names and resumes (no more than 1 page each) of proposed personnel.

3. Hourly rates (excluding GST) for all staff involved in the work.

4. Day rates (excluding GST) for field work for all staff nominated for the Project.

5. Schedule illustrating how the work will be undertaken to enable completion of the environmental studies by 21 November 2008.

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

   Desktop studies

   Fieldwork

   Computer modelling, if required

   Report Writing

   Project Management

   Quality Control

   Administration Tasks (e.g. printing, binding).

7. A description of the approach taken to assess impacts on groundwater resources, how existing data might be utilised, approach to groundwater system modelling; and techniques to be used to assess accuracy/sensitivity of model predictions.

8. Timing and availability.

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

It is anticipated that desktop work can commence in August with field work being undertaken in September/October.

2.1 GIS

Consultants are advised that the Project will populate a single GIS database. 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.

2.2 Deliverables

2.2.1 Requirements

The consultant is required to provide a technical report related to the area of expertise. The report will need to clearly identify the environment values of the area, the potential impacts of the proposal on those values and the recommended management measures to minimise adverse impacts.

The report shall include, as a minimum:

- Executive summary – to be included in the Draft Report. This should be set out in two parts:
    - Environmental Values of the Area; and
    - Potential Impacts and Mitigation.
- Description of standard methodology that will be used;
- Summary of the desktop studies to be undertaken;
- Findings from the field studies, if required;
- Environmental values of the area;
- Potential impacts of the proposal on the environmental values being studied;
- Interpretation of the assessment in relation to upstream development activities, if necessary:
    - what are the issues/constraints for construction and operation of well sites, access tracks and gas and associated water gathering infrastructure;
    - do any areas require special measures (engineering solutions are not required just identification of issues that will need to be addressed);
    - if special environmental measures are required, what are they and where do they need to be applied;
- Mitigation measures to minimise adverse impacts. Specialists must confine comments to their area of expertise. They must consult with Unidel concerning usual practices and policies for impact avoidance and mitigation;
- Environmental protection objectives for enhancing or protecting each environmental value, including proposed indicators to be monitored. Monitoring parameters, points, frequency recommendations to be made (as well as data interpretation and reporting procedures where applicable);
- Additional supporting information is to be included in appendices and in electronic form (e.g. results of database searches);
- Constraints are to be clearly identified via GPS points;
- Where possible, location of constraints shall be summarised in tables and on maps; and

- Any additional approvals that may be required.

2.2.2 Number of Copies

Reports are to be provided as: 1 soft copy of each draft, 1 soft copy of each final report and 2 hard copies 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 full EIS. A full pdf version of the final report is also required. Digital files of all illustrations, maps and/or diagrams shall also be provided.

2.3 Content of Reports

This section sets out the requirements for the studies to support the environmental assessment. The studies will be required to address the Terms of Reference once issued however the following requirements should address the key material.

An indication is to be provided of the quality and quantity of water resources in the vicinity of the Project area covering both surface waterways and groundwater.

2.3.1 Surface Waterways

- Catchments and sub catchments within the upstream project area should be identified and described;
- A general description of surface water and drainage patterns within the area should be provided;
- Identify any Water Resource Plans (WRP) relevant to the affected catchments and address in relation to the Project;
- Environmental values of the surface waterways affected by the Project are to be described in terms of:
    - Values identified in the EPP Water or any WRP.
    - Catchment management initiatives
    - National Water Initiative (C'wth)
    - Physical integrity, fluvial processes and morphology of watercourses
    - Hydrology of waterways;
- Description of watercourse characteristics (e.g. bank stability, riparian health) at sealed road crossing points of main watercourses;
- Present and potential water uses upstream and downstream should be discussed in relation to the potential for project development works to impact upon the existing uses;
- History and likelihood of flooding within the project development area should be discussed and mitigation measures provided where relevant;
- Identify constraints to well development and operation, access track construction, water and gas gathering pipeline installation and other infrastructure (e.g. compressor stations, construction camps) development in the area;
- Describe the assessment methodology; and
- Data should be provided to support the creation of maps and figures to illustrate outcomes of the report as set out in Section 2.1.

2.3.2 Groundwater

- Identify groundwater aquifers associated with the project area and describe in terms of depth, quality, volume, flow direction, current usage and any potential future usage;
- Ground water data should be provided, from existing data sources, and tabulated in relation to location, geology, aquifers, depth, water quality and major usage as per Table 1;

Table 1: Ground Water

Map Ref	Location	Geology	Aquifers	Depth	Water Quality	Major Usage
A	MacArthur Basin/Pine Creek Geosynclines	Folded siltstone, sandstone and dolomite	Fractured rocks	25m	Fresh, salty adjacent to the coast	Stock
B						
C						

- A detailed description of the hydrogeology of aquifers potentially impacted by the various spatial areas of the proposed development;
- Establish a clearly defined set of baseline groundwater/aquifer conditions to enable a meaningful assessment of potential future impacts;
- Environmental values of the ground water affected by the Project are to be described in terms of:
    - Values identified in the EPP Water.
    - National Water Initiative (C'wth)
    - Sustainability, including both quality and quantity
    - Physical integrity, fluvial processes and morphology of groundwater resources;
- Based on the proposed development program for the production area, determine the likely quality and quantity of associated water produced in association with the CSG extraction. This should include a review of annual associated water production estimates prepared by QGC and the calculation of annual groundwater production over time (if required) from the producing wellfields and any other overlying aquifers;
- Assess the impact, if any, of the above water extraction on the existing aquifers;
- Advise the key Queensland legislation requirements in relation to extraction of water from deep aquifers and discuss the implications for the proposed project development work;
- Determine the extent of and information requirements for any licensing or permitting requirements under Queensland legislation, with respect to groundwater extraction and/or management;
- Where there is potential for project activities to intersect groundwater (e.g. drilling of wells) information regarding groundwater flow directions, interaction with groundwater and possible sources of recharge should be described;
- Review production well designs and assess the potential for groundwater discharged in association with the CSG extraction process to mix with shallow aquifers (based on design plans provided by the proponent);
- Potential for pollution and any other potential impacts should be identified and mitigation and rehabilitation measures recommended;

- Review potential for associated water reinjection including studies carried out by QGC to date, target aquifers, cost effectiveness and likely timeframes and incorporate findings with respect to impact assessment and mitigation where appropriate;
- Assess potential for and nature and extent of (where relevant) any land settlement as a result of the proposed operations and assess the potential impact on land uses and properties in the vicinity of the gas fields;
- Assist with the development of a draft groundwater management and monitoring regime for the development (based on identified regulatory and license requirements) that includes:
    - An assessment of the background water quality from within aquifers potentially impacted by the proposed development
    - A process for management and monitoring of production bore water quanitity and quality
    - A groundwater monitoring scheme incorporating existing and where necessary proposed monitoring bores
    - Management and monitoring of any springs or wetlands potentially impacted by the proposed development; and
- Data should be provided to support the creation of maps and figures to illustrate outcomes of the report as set out in Section 2.1.

2.4 Follow-up Studies

If additional surveys are required, opportunity to quote for this work will be provided. However, the current hourly rates should be provided as a guide for any future costs.

3 Management

3.1 Project Management

Unidel requires fortnightly reporting against:

- Activities completed in 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, Unidel will contact the consultant to clarify.

The consultant will be required to:

- nominate a point of contact for the project;
- provide Unidel with a Health, Safety and Environment procedure for field work;
- liaise with Unidel to coordinate entry onto private land. The consultant must ensure that any sub-consultants or others acting on their behalf comply with this requirement. At no time is private property to be entered without owner awareness and prior consent;

- be guided in the field by a Unidel Land Officer; and
- comply with Unidel Field Protocols when completing the field investigations. These protocols have been prepared to ensure that any disruption to landholders, their property and daily activities are minimised.

3.2 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.

3.3 Information to be supplied by Unidel

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.

- Initial Advice Statement;
- EPBC Referral;
- Draft Report on Groundwater Impact Study for the Coal Seam Gas Operations Chinchilla. Surat Basin Queensland (Golder Associates, May 2008) (this existing report considered <50% of the area and well intensity being considered for this EIS assessment);
- Draft TOR (once available);
- Area Maps;
- Project development scenario including information regarding the nature and scale of field development activities e.g. current and predicted water production data and indicative location; and
- Aerial photography (where required to assist with investigations and report preparation); and
- Where possible, selected geological information will be made available on request.

APPENDIX B

Data Request

TECHNICAL MEMORANDUM

DATE 19/08/2008 **PROJECT No.** 087633050_001

TO Steve Fox
Unidel Energy and Infrastructure on behalf of QGC

CC David Salmon, Mel Vanderwal, Sarah Hill

FROM Shaun Davidge **EMAIL** sdavidge@golder.com.au

REQUEST FOR TECHNICAL DATA – QGC ENVIRONMENTAL IMPACT STUDY

Golder has now commenced the QGC Environmental Impact Study. This memorandum is to request the required technical data to progress the study.

Please note:

- Golder is not interested in any commercial in confidence (CiC) information that can be gained from any of this data;
- Golder will hold all data that may have any potential CiC in confidence from any Golder staff not on the project team;
- Golder will discuss with QGC what data may be reported and how, so that data that either party may wish to keep confidential from the other cannot be interpreted from the data deliverables of the final report;
- We will maintain all electronic data on a secure project directory that only has access from registered project team members; and
- Where the data we have requested is considered by QGC to be particularly voluminous or if there is any question as to the value of the data to this study, please discuss this with us. We would prefer to receive too much data and make a decision to not use certain data in the analysis, than proceed with the study in the absence of any data that might have been key, but was not provided us for whatever reason.

Golder requests:

1) Maps

For each map requested, could you please provide both a pdf file of the full map, and all MapInfo (or ESRI files required to generate the map, with all attributes that you have for the spatial data)

- Lease Information:
  - Please show the extent of the leases that you intend to be covered in the investigation. We will use this map to generate coordinates of the corners of the search area from the NRW database. Please indicate the lease numbers, status, ownership;

  - Any other land ownership data that you have on record. This will assist in the performance of a bore/well inventory as Golder has suggested.

- Regional base map data:
  - Topography;
  - Roads;
  - Rail;
  - Towns;
  - Rivers and creeks, drainage lines, surface water;
  - Shire boundaries;
  - Catchment and sub catchment boundaries;
  - Hydrography;
  - Groundwater Dependent Ecosystems.

- Gas wells and or exploration holes and monitoring bores:
  - Existing gas wells, including attribute data (depth, no. of seams, other attributes you maintain in your mapping system);
  - Proposed wells, either exploratory or proposed gas wells;
  - Monitoring bores;
  - Bores owner by others, including water wells.

- Geology Information:
  - Maps of interpreted RL and depth of the geological units included in the geological model. Of most importance is the data relating to the top and bottom of the aquifers (sandstone beds) at any depth, and any coal seams from which gas is being produced;
  - Regional geology maps, both surficial and sub-crop geology;
  - Soil maps;
  - Any other geological mapping of even minor relevance.

- Site Infrastructure:
  - Locations of all and any water infrastructure:
    - Ponds, Evaporation ponds - indicating if possible which are in use and which are not;
    - Water gathering and distribution systems (pipes, pumps, directions of flow);
    - Any water treatment plants, either existing or planned, for domestic supply or other purposes.
  - Other site infrastructure:
    - Lay down areas;
    - Offices;
    - Sewage treatment plant(s).

- Plans for new infrastructure:
  - Power stations, other?

2) Other Geology Data:

- Interpreted geological cross sections;
- Geological reports;
- Interpreted Stratigraphy.

3) Well Completion Data:

- Well interpreted geological logs;
- Well casing completion data;
- Where available, geophysical logs (except where the interpreted geology included consideration of the geophysical data)
  - This data will be used to:
    - Assess opportunities created by the well completion for water to pass between the different aquifers, or aquifers and the coal seams, or the coals seams – all of which might create the pathway for depressurisation of aquifers at any level;
    - Further assist the interpretation of associated data (for example water flows or pressure monitoring.

4) Surface Water Data:

- Any or all gauging station data;
- River corridor surveys;
- Water quality data;
- Flood historical data;
- Pond reports.

5) Time Dependent Water Data:

preferably in a database or Excel spreadsheet

- Water production (at the well head, and preferably summary data for each cluster of wells or wellfield):
  - Historic records;
  - Predicted water production.
- Water levels:
  - From all gas wells where it is measured, and if available, target water levels that may have been determined by the reservoir engineers as suitable to optimise gas production;
  - From all other monitoring locations (bores, wells, surface water, especially rivers).
- Water quality records (major parameters and any specific “parameters of concern”).

6) Other Data:

- Any reports that may have bearing on current or future water production, or aid in the interpretation of the hydrogeology;
- Digital Elevation Model;
- New Oil Well data from DME;
- Any or all available meteorological data;

Golder understands that data from new QGC wells completed within the last 18 months will be collated and available shortly. As part of this request, We assume that the data from these wells will be made available including:

  - Oxygen isotope data;
  - Geology;
  - Water quality;

- …

Shaun Davidge
Principal Hydrogeologists

SRH/SD

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APPENDIX C

Groundwater MetaData (On CD)

APPENDIX D

Groundwater Modelling

30 June 2009

QGC GROUNDWATER MODEL

Groundwater Modelling for CSG Extraction - QGC

Submitted to:
BG-QGC Pty Ltd

REPORT

Report Number: 087633050 017 R Rev 2

A world of capabilities delivered locally

Golder Associates

Table of Contents

TABLES

FIGURES

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 wells being developed (up to 6,000 production wells) and management, storage and beneficial use of associated water for the expansion.

Golder Associates Pty Ltd (Golder) was commissioned by QGC to examine the effects of the CSG field expansion on the groundwater environment. One part of this project was to develop a hydrogeological model to understand the potential impacts of the project. This report forms Appendix D of the broader QGC Groundwater Study (Golder 087633050 016 R Rev 1).

The aim of this report is to:

- provide input into the risk management strategy being developed for the proposed CSG operations
- make groundwater impact predictions for the current and proposed CSG operations.

1.1 Study Area

The study area encompasses the current QGC development areas, 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 and west of Dalby (Figure 3, in the 087633050 016 document). The CSG development area was divided into three areas, and each area was modelled separately. The three project-defined CSG development areas for the study were defined as the:

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

1.2 Project objectives

The objectives of the modelling program were to:

- Develop an *idealised* regional groundwater model for each development area.
- 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 in the Surat Basin.
- Develop recommendations for groundwater management and monitoring associated with the QGC CSG operations.

2.0 METHODS

The study area was divided into three areas as outlined in Section 1.7 of the Groundwater Study report. Each of the three areas was considered geologically and hydrogeologically distinct, being delineated by inferred and actual structural breaks. Each area was modelled separately and independently. Therefore, interference effects from the other areas were not considered in the study.

The models were constructed from site specific data provided by QGC. Where site specific information was not available; published sources of information were utilised. The geological and conceptual groundwater model (CGM) developed in Section 4.0 (Description of the existing environment) of the main report were used to develop the numerical models 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.

A model had previously been created in September 2008 (Golder 031-077636015/6005-4000 Rev 2). That model was refined, based on QGC's and Australasian Groundwater and Environmental Consultants (AGE) comments. AGE was engaged as the third party reviewer for this study. The results of the new prediction simulations are presented in this report.

2.1 Selection of Groundwater Modelling Software

The software was required to provide several functions. MODFLOW was selected as the modelling software that met the criteria (below). It 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 the MODFLOW model software were that:

- the software could provide industry standard model code that would not be challenged by NRW or other potential reviewers
- the code had the ability and flexibility to simulate the boundary conditions identified in the conceptualisation
- the model could be adopted for a multi-layering environment
- the model was able to include sufficient definition of aquifer geometry, so that the model could be developed from an initial "simplified model" to a more complex and sophisticated model in the future (if required)
- flexible stress periods and time stepping could be undertaken
- the model was easy to establish and run.

The difference between MODFLOW96 and MODFLOW2000 or MODFLOW2005 relates primarily to the groundwater flow package, namely Block-Centred Flow in MODFLOW96 compared to Layer Property Flow in MODFLOW2000 and onwards. Given this is a simplified model, using only the CHB stress package, the difference in groundwater flow package is not relevant.

3.0 REFINEMENTS FROM THE PREVIOUS MODEL TO THE CURRENT MODEL

An initial preliminary modelling program was undertaken on the centrally located development area, the CDA, and which was reported on separately in "Groundwater Impact Study for the Coal Seam Gas Operations Chinchilla, Surat Basin Queensland" submitted to Queensland Gas Company and Origin Energy (Report 031-077636015/6005-4000 Rev2, dated September 2008). That report identified a number of potentially enhancing refinements which would improve the models estimation.

The improvements that were adopted, were also guided by comments and considerable discussion with QGC hydrogeologists and reservoir engineers, and QGC's appointed third party reviewer, AGE (Mr Errol Briese and Mr Andrew Durick). In summary, the refinements to the current model included:

- The regional dip of 1.3% to the southwest was applied. This added slope to the model layers across the model domain so that they more closely reflect the regional geology. (The previous model was flat)
- Model domains were expanded outward to ensure the boundary conditions had reduced potential to constrain the model outcomes.
- Input parameters were modified on the advice of the AGE reviewers (hydraulic conductivity, vertical to horizontal hydraulic conductivity ratios, storage coefficients and porosity). The ranges of values were generally agreed to be reasonable for the rock-types and this location in the GAB.
- Sequencing of the pumping of the CSG-bearing formations (the Walloon Coal Measures, WCM) to make the modelling approach more closely resemble reality. The model resolution (arising from the broad range of input parameters which could be justifiably used in the modelling) made this subtlety in model design indiscernible and so was not pursued further.
- The thickness and parameter values of the relevant aquitards were modified as more data was received from the QGC drill-stem testing program as well as extended discussion of literature values amongst QGC and AGE.

The original modelling project was conducted on the CDA area only; the current modelling project was conducted on three development areas, the CDA, SEDA and NWDA. Each development area was prepared as a separate and isolated model and did not take into account interference effects from the other models.

The outcome of the current modelling is commensurate with the degree of reliability of the estimate ("order of magnitude"), given the uncertainty of values provided for the model. Ultimately the modelling program's purpose was to develop a risk assessment tool to help define groundwater impact management zones, rather than quantitatively defining groundwater drawdown at specific locations.

4.0 AQUIFER CHARACTERISTICS IN THE STUDY AREA

The information presented in Table 1 for hydraulic conductivity, transmissivity and storage form the basis, upon which the model conceptualisation was prepared. The tabulated information was obtained from:

- available literature
- communication with QGC, and their third party reviewers, AGE
- information provided by NRW; as the authority responsible for managing the Great Artesian Basin (GAB).

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 - 2.5×10^{-3} to 6×10^{-6} (average 1.8×10^{-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	5×10^{-3}	10 to 30% (3)	
Intermediate Unit	Bungil Formation		50	5×10^{-3}	10 to 30% (3)	0.63 to 6.3 L/s (4)
	Mooga Sandstone		50	5×10^{-3}	10 to 30% (3)	0.2 to 8 L/s median 1.3L/s (4)
	Orallo Formation		50	5×10^{-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	5×10^{-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	5×10^{-3}	10 to 30% (3)	
	Springbok Sandstone		150	5×10^{-4}	10 to 30% (3)	
	Walloon Coal Measures	Kh - 1.4 (7) (median for coal beds)	50	5×10^{-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	5×10^{-4}	18-26% (10)	0.1 L/s to 600 L/s, median at 1.5 L/s (4)
	Evergreen Formation	Kv - 10^{-1} to 10^{-4} (3)	150	5×10^{-4}		0.6 to 6.5 L/s , median 0.6 L/s (4)
Precipice Unit	Precipice Sandstone	0.1 to 10 (10)	150	5×10^{-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

5.0 MODEL CONCEPTUALISATION

With the objectives for the modelling study identified in Section 1.2, the key constructs for the models were identified as:

- Three development areas were considered for this modelling study, namely, the NWDA, CDA and SEDA; each constituted a separate and independent model.
- The purpose of modelling was to assess the potential consequences of the extraction of groundwater during liberation of CSG.
- The model domain and input parameters for each model were based on the Conceptual Groundwater Model (CGM) that was developed from available geological and hydrogeological data. The CGM is presented in Section 5.0 of the main report.
- The models were defined as "bathtub" models:
  - The models do not incorporate recharge, and they have not been formally calibrated, as they would in a more detailed and higher resolution modelling project. The absence of long-term groundwater level monitoring data (at this stage) has precluded appropriate calibration to be able to be carried out. It is noted that long term flow data from relevant water courses will also be required to be obtained.
  - A constant head boundary was applied around the external borders (that were appropriately placed to reflect the expected distance outside the depressurisation area that would be unlikely to be influenced by CSG extraction activity).
  - The values for the constant head boundaries for each model were assigned, based on available regional groundwater level data for the three development areas. They were set to be 305 mAHD for the CDA, 295 mAHD for the NWDA and 315 mAHD for the SEDA.
- Each model was constructed as a rectangular strip running parallel to the regional strike of the geology. Each model was established with a total length of 144 km, including 50 km of CSG activities (extraction area, referred to as the depressurisation area), and a width of 120 km, including 10 km of CSG activities. The model domains were positioned so that the CSG extraction activities were located in the centre of each model area.
- Given the stratigraphy of the model is sloped and the model extent is significant, it was necessary to assign fixed head boundary conditions so that they were above the bottom of individual cells.
- The layer thicknesses in each model were set, based on the stratigraphy in each development area.
- The depressurisation area, the idealised representation of QGC production areas (tenements/lease, current and proposed) of each model, was considered as one single area with time-varying-specified-heads used to simulate the proposed pumping schedule of the project area. The effect of sequential pumping different sub-areas within the overall production area was found to be indiscernible at the resolution of the current model.
- The elevation of each layer was made flat within each individual development area, as a simplification, prior to applying the time-varying-specified-head boundary conditions.
- The CSG extraction *depressurisation schedules* for the defined piezometric heads (lying within the defined depressurisation area) in the Walloon Coal Measure (WCM) 'aquifer' layers were provided by QGC. As described in the preceding bullet point, this was simplistically simulated by having the modelled piezometric head 'dragged' down in the model's central area (to represent the operation areas in the central portion of the model domains) according to the depressurisation timeframes as a method to simulate the groundwater extraction over time.

6.0 MODEL CONSTRUCTION

Each model was defined with 18 layers, 272 columns and 234 rows; the same model structure was adopted for each model. The nominal dimensions of cells representing the well field area in each model were 250 m by 250 m, increasing in width beyond the well field with an expansion factor of 1.5 towards the edges. The model dimensions were 144 km long (NW-SE direction) by 120 km wide (NE-SW direction). Within this rectangle, each CSG well field was represented by a central rectangle of 50 km by 10 km; each area being larger than the likely extent of the CSG development area.

The layouts for each modelled CSG development area are presented in Figures D-1 to D-3. These areas each represent an idealised CSG extraction field, crudely representative of the distributed existing and potential future (ATPs) petroleum leases from which QGC propose to extract CSG.

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. Layers in the model were dipped in a south west direction, as described above.

Each model domain comprised the Intermediate, Walloon, Hutton and Precipice aquifer units. Layer 1 of the model represents the shallow, unconfined aquifers near the surface. 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). Table 2 presents the layer elevation and thicknesses of the CDA, SEDA and NWDA models. Note that the Top and Bottom elevations presented in Table 2 are with respect to the centre of each model (NE-SW direction).

Table 2: Layer Elevations and Thicknesses

			CDA			SEDA			NWDA		
Layer Number	Description	Modelled Unit	Top	Bot	*Thk*	Top	Bot	*Thk*	Top	Bot	*Thk*
1	Aquifer	Unconfined Shallow / Intermediate Unit	319	301	*18*	350	320	*30*	350	310	*40*
2	Aquifer	Intermediate Unit	301	283	*18*	320	290	*30*	310	270	*40*
3	Aquifer	Intermediate Unit	283	265	*18*	290	260	*30*	270	230	*40*
4	Aquifer	Intermediate Unit	265	247	*18*	260	230	*30*	230	190	*40*
5	Aquitard	Confining unit	247	229	*18*	230	200	*30*	190	150	*40*
6	Aquifer	Intermediate Unit	229	211	*18*	200	115	*85*	150	75	*75*
7	Aquitard	Westbourne Formation	211	106	*105*	115	0	*115*	75	-105	*180*
8	Aquifer	Springbok	106	66	*40*	0	-75	*75*	-105	-208	*103*
9	Aquitard	Confining unit	66	56	*10*	-75	-105	*30*	-208	-218	*10*
10	Aquifer	Upper representative Coal Seam	56	46	*10*	-105	-115	*10*	-218	-228	*10*
11	Aquitard	Confining unit	46	-272	*318*	-115	-255	*140*	-228	-408	*180*
12	Aquifer	Lower representative Coal Seam	-272	-282	*10*	-255	-295	*40*	-408	-418	*10*
13	Aquitard	Confining unit	-282	-382	*100*	-295	-395	*100*	-418	-468	*50*
14	Aquifer	Hutton Sandstone	-382	-461	*79*	-395	-473	*78*	-468	-543	*75*
15	Aquifer	Hutton Sandstone	-461	-540	*79*	-473	-551	*78*	-543	-618	*75*
16	Aquifer	Hutton Sandstone	-540	-619	*79*	-551	-629	*78*	-618	-693	*75*
17	Aquitard	Evergreen Formation	-619	-788	*169*	-629	-799	*170*	-693	-863	*170*
18	Aquifer	Precipice Formation	-788	-851	*63*	-799	-861	*62*	-863	-924	*61*

Note: Top is Top Elevation (mAHD); Bot is Bottom Elevation (mAHD); and *Thk* is Thickness (m). It is noted that Top and Bottom elevations are with respect to the centre of each model (NE-SW direction).

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. Accordingly, in the model, the WCM was assumed to be confined by upper and lower bounding aquitards (Layer 9 and 13). The upper WCM coal seams were represented by Layer 10 within the model and the lower seams (Taroom Coal Measures) were represented by Layer 12. Layer 11 was assumed to be an aquitard between the extraction zones. This aquitard represents mudstones, shales and sandstones (i.e. Tangalooma Sandstone) within the study area.

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.

A constant head boundary condition was assigned around the outside of each model domain. Based on the interpretation of regional geology within each area, the constant head cells in the northeast section of the model domain were adjusted as appropriate, for the uppermost layers, so that the prescribed head (mAHD) was above the defined base of the corresponding model cell. Total head in an aquifer is the sum of the elevation head and the pressure head. In a CSG well undergoing pumping, the pressure head is equal to the pressure exerted by the fluid level inside in the well, and the casing pressure from methane gas. Based on this assumption, the starting total head in the WCM aquifers was estimated to be equal to about 305 m AHD over the central part of the CDA, which is also very close to, or often the same as, the aquifer pressure in overlying and underlying sandstone aquifers. This value was adopted as the starting head for the CDA model. The initial heads of the NWDA and the SEDA were adopted as 295 m AHD and 315 m AHD respectively, based on an average of measured groundwater levels in those areas.

The centrally located *depressurisation area* of the models (regarded in this modelling study as the *idealised representation* of QGC production areas, i.e. the QGC tenements/lease, current and proposed), were considered as one single area with time-varying-specified-heads used to simulate the proposed pumping schedule of each project area. To assess the affect of sequencing the pumping of the CSG-bearing formations WCM over time, the centrally located depressurisation area was subdivided into four quadrants, each starting and stopping production in accordance with the general plan of production proposed by QGC. It was found, however, that the model resolution (given the broad range of input parameters that could be justifiably used in the modelling) made this subtlety in model design indiscernible. As such, further attempts at sequencing were not made.

Dewatering of each of the three development areas was conducted in accordance with QGC's proposed production schedule. It is planned that 50% depressurisation will occur within the first four to seven years of production. 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), is proposed to continue from year 7 to year 40 (the end of well field production life). The adopted depressurisation curves for CDA, SEDA and NWDA are presented in Figures D-4 to D-6. At the end of the well field production life, each model was allowed to recovery for the next 150 years. Table 3 presents a summary of the depressurisation adopted in this modelling exercise.

Table 3: 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.

Each groundwater model was developed based on the assumption of single-phase flow of groundwater in porous media. Therefore, an implicit assumption is that gas and water within the WCM are validly represented by the adopted governing equation. In reality, there may be areas where gas and water exist as two separate phases. In that case, the application of a single-phase groundwater model code such as MODFLOW, to a multi-phase problem, may introduce further uncertainty to model predictions. This is considered acceptable at this level of modelling (low resolution) for the following reasons:

- The change in permeability brought about by the progressive formation of a CSG gas 'bubble' in the pore spaces in the coal, as desorption begins in earnest, constrains ('throttles back') the flow of *groundwater* to the CSG well. This can be considered as imposing a reduction in the *effective* hydraulic conductivity on the coal seam aquifers.

- The predicted future associated water production curves have been calculated from actual production data provided by QGC current productions wells. The curves have the reduction of hydraulic conductivity (described above) in the coal seams, where gas generation and extraction is taking place built into them. Beyond the desorption 'front' (away from the well field and towards the lease boundary) where gas generation is not occurring, the drawdown cone is defined by the standard theory of groundwater flow. i.e. based on an extraction rate (Q) being actually pumped from the well.

In summary, the model is a reasonable approximation of the drawdown impacts because:

a) The relationship between the actual quantity of groundwater extracted from the coal seam aquifer/s (beyond the coal desorption front) and the drawdown (piezometric head decline) is fixed, as per the standard theory of groundwater flow. The introduction of a gas phase merely constrains the flow of water to the CSG well screens from the aquifer (locally lowering the hydraulic conductivity with respect to water flow) where pressure conditions are low enough for gas desorption/ generation. Beyond that, and away from the edge of the production field, groundwater flow within the models are based on the actual groundwater being extracted.

b) The cone of drawdown is of primary interest for developing a risk management strategy (in relation to the groundwater impacts to surrounding aquifers and the groundwater users exploiting them) and is governed largely by the actual groundwater extracted.

The numerical models approximate (b) with reasonable certainty (to "order of magnitude" resolution), accepting that there is limited available hydrogeological parameters (range of K, S, T and ϕ), used for the numerous aquifers and aquitards that comprise the stratigraphy (and encase the CSG containing seams) in the study area.

This modelling study has applied *ranges* of K values, Kv/Kh and S values (in the absence of site specific data that are applicable to the local lithologies. This was based on evidence from the literature for GAB data and generic data for specific rock types). It was considered that any deviation from rigid predictions of two-phase flow, and associated drawdown profiles and inter-aquifer flow, would not be significant in the context of the range of predicted outcomes (estimation of impacts from CSG extraction) provided by the modelling results.

7.0 MODEL SIMULATION METHODOLOGY

At this stage, a long term regional groundwater level time-series is *not* available to allow formal model calibration. Currently, there is also limited information from test pumping of the WCM aquifer, regionally, and other important hydrogeological units; therefore selected model simulation parameter sets are non-unique.

There were, however, detailed predictions available from QGC reservoir engineers that were developed using standard reservoir engineering methodologies for calculation of required gas and groundwater production rates from the reservoir materials concerned. Those predictions reflect QGC's expectation of the inter-relationship between pressure decline and expected gas and associated water production and were developed based on an assessment of currently installed and producing CSG wells, as discussed below.

Because the purpose of producing predictions of drawdown was to provide input into the risk management strategy to be adopted for the CSG operations, rather than an absolute and quantitative prediction of drawdown magnitude at specific locations (at this stage), QGC's estimates of groundwater extraction (associated water production) with respect to pressure decline were used to frame multiple simulation scenarios, ultimately bounded by a modelled *potential minimum parameter set*; and a *modelled potential maximum parameter set*.

Since groundwater extraction (total volumetric extraction rate) is a key consideration in assessing the validity of the modelling process, it is important to understand and have confidence in the methodology used to estimate the QGC associated water production rate figures. QGC have provided their methodology as follows (John Bailey, QGC, email 19 February 2009):

> *"The water production schedule was initially derived from an assessment of currently installed and producing wells (many of which have been producing for 2+ years, and therefore represent a satisfactorily long statistic) which have been classified into categories according to their gas yield - Type 1 (high yielding wells), Type 2 (intermediate yielding wells) and Type 3 (low yielding wells) and Type 4 (low gas high water wells). Each type has an assumed profile for associated water production correlated to their peak gas production rate. This data set of well categories was then applied to the QGC tenements - with Type 1, 2 , 3 and 4 wells being locally applied in accordance with known or predicted information about reservoir performance variability across the proposed development area. In this way QGC was able to build up a schedule of production based on 2203 Type 1 wells, 2935 Type 2 wells, 750 Type 3 wells and 265 Type 4 wells. Estimated areal production rates reflect these Well type production rates over a 30 year period from initial production. The ongoing production testing and appraisal programme during 2009/2010 will progressively increase the confidence in the water production forecasts, but at this time an uncertainty band of +/- 50% should be assumed."*

The depressurisation schedule estimates (extraction rates, inclusive of the ±50% accuracy provision, as defined by QGC) were used as the basis to align 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 "calibration" 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 ……. until the modelled extraction rate approximately matched the range of QGC predicted extraction rates (depressurisation schedule).

The simulation iterations involved varying 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 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. Model groundwater extraction rates were then calculated by the model for the 40 years of wellfield operations, 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 is progressing. Ongoing iterations of the model or its replacement will be required to verify recovery progress.

On this basis, the modelled potential minimum parameter set and modelled potential maximum parameter set used in each model area are presented in Table 4, Table 5 and Table 6 for CDA, SEDA and NWDA respectively.

Table 4: Model hydraulic Parameters- Modelled Potential Maximum and Minimum Parameter Sets for CDA

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	2.50E-03	5.00E-06	500	5.00E-04	2.50E-04	5.00E-07	1000	5.00E-05
10	Aquifer	Upper Representative Coal Seam	1.36E+00	4.53E-01	3	5.00E-04	1.40E-02	4.67E-03	3	5.00E-05
11	Aquitard	Confining unit	5.00E-03	1.00E-05	500	5.00E-04	5.00E-04	1.00E-06	1000	5.00E-05
12	Aquifer	Lower Representative Coal Seam	1.36E+00	4.53E-01	3	5.00E-04	1.40E-02	4.67E-03	3	5.00E-05

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)
13	Aquitard	Confining unit	2.50E-03	5.00E-06	500	5.00E-04	2.50E-04	5.00E-07	1000	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 5: Model hydraulic Parameters- Modelled Potential Maximum and Minimum Parameter Sets for SEDA

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-04	5	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	1.25E-03	2.50E-06	500	5.00E-04	2.50E-04	5.00E-07	500	5.00E-05
10	Aquifer	Upper Representative Coal Seam	1.95E-01	6.50E-02	3	5.00E-04	1.40E-03	4.67E-04	3	5.00E-05

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)
11	Aquitard	Confining unit	2.50E-03	5.00E-06	500	5.00E-04	5.00E-04	1.00E-06	500	5.00E-05
12	Aquifer	Lower Representative Coal Seam	1.95E-01	6.50E-02	3	5.00E-04	1.40E-03	4.67E-04	3	5.00E-05
13	Aquitard	Confining unit	1.25E-03	2.50E-06	500	5.00E-04	2.50E-04	5.00E-07	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: 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

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)
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

8.0 MODEL RESULTS

8.1 Predicted Drawdown

8.1.1 Results of CDA Modelling

The model was run for the potential maximum and potential minimum parameter datasets. The predicted drawdown envelope for the Springbok, Hutton and Precipice Sandstones are presented in Figure D-7.

The model was executed for 40 years of depressurisation, followed by 150 years of recovery with no pumping. From Figure D-7, 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 CDA. For the modelled potential maximum parameter dataset, drawdown in the Springbok Sandstone is predicted to reach about 55 m at a distance of 1.8 km from the south east edge of the depressurisation zone. Recovery of the aquifer is predicted to commence immediately after pumping terminates (40 years). Figure D-7 indicates that the predicted maximum drawdown is about 2.5 m in the Hutton Sandstone and that recovery is predicted to commence about 50 years after pumping terminates (90 years). The maximum predicted drawdown of the Precipice Sandstone is about 1.8 m. Recovery of the Precipice Sandstone is predicted to commence at about 60 years after pumping terminates (100 years).

The predicted drawdown from the centre of the depressurisation area, in a southeast direction, for Year 10, 25 and 40 for the Gubberamunda Sandstone, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone is presented in Figures D-8 to D-11. As expected, the maximum predicted drawdown occurs in the Coal Seams and the Springbok Sandstone aquifers. The high drawdown in the Springbok aquifer is due to a high induced downward gradient between the Springbok and Walloon Coal Measures that are separated by a thin aquitard. Similarly, the lower aquifer units (Hutton and Precipice) are separated by a thicker aquitard unit, which reduces the upward connectivity (flow) into the lower WCM seam. Throughout the simulation, the predicted aquifer drawdown in the Intermediate Unit (Mooga, Oralla, and Gubberamunda Sandstone) was minimal.

Figure D-9 indicates that the modelled maximum drawdown within the Springbok Sandstone, near the centre of the depressurisation area, could vary between 10 m and 85 m. The drawdown also decreases continuously away from the centre of the depressurisation area.

8.1.2 Results of SEDA Modelling

The model was run for the potential maximum and minimum parameter datasets for the SEDA. The predicted drawdown envelopes for the Springbok, Hutton and Precipice Sandstones are presented in Figure D-12.

As expected for the SEDA, 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 23 m at a distance of 1.8 km, in a southeast direction, from the edge of the depressurisation zone. Recovery of the aquifer is predicted to commence 5 years after pumping terminates (45 years). The model predicts that drawdown in the Hutton Sandstone may reach about 8 m (Figure D-12). The model indicates that recovery of the Hutton Sandstone is predicted to commence about 15 years after pumping terminates (55 years). The maximum modelled drawdown for the Precipice Sandstone is about 6 m for the simulation, considering the potential maximum model parameter dataset. The modelled recovery for the Precipice Sandstone is predicted to begin at about 25 years after pumping terminates (65 years).

The predicted maximum drawdown in the Springbok Sandstone in the SEDA is less than the CDA. This is because the SEDA has a thicker aquitard unit between the Springbok and the Upper Coal Seam Unit, compared to the CDA. The higher drawdown predicted for the Hutton and Precipice Sandstone in the SEDA model, compared to the CDA, is likely to be due to the larger drawdown required for the WCM in the SEDA

(1 m versus 180 m in the CDA). Therefore pumping from the WCM will potentially generate more impact in deeper aquifers such as the Hutton and Precipice Sandstone aquifers.

The predicted drawdown for the Gubberamunda Sandstone, Springbok Sandstone, Hutton Sandstone and Precipice Sandstone is presented in Figures D-13 to D-16. The drawdown is from the centre of the depressurisation area in a southeast direction for Years 10, 25 and 40.

Figure D-14 indicates that the modelled drawdown within the Springbok Sandstone could vary between approximately 2 m and 36 m, near the centre of the depressurisation area after 40 years of pumping. Again, drawdown continuously decreases away from the centre of the depressurisation area.

8.1.3 Results of NWDA Modelling

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 D-17.

For the NWDA, (Figure D-17), 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 D-17 indicates that the predicted maximum drawdown in the Hutton Sandstone and the Precipice Sandstone is insignificant.

The predicted drawdown for the Springbok Sandstone is presented in Figure D-18. The drawdown is from the centre of the depressurisation area, in a southeast direction, for Years 10, 25 and 40.

Figure D-18 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, again, continuously decreases away from the centre of the depressurisation area.

8.2 Predicted Water Budget

The model simulated total extraction rates for the Upper and Lower Coal Seams for the CDA, SEDA and NWDA (Figure D-19 to D-21). In Figure D-19 to D-21, the shape of the modelled groundwater extraction rate follows the reciprocal of the time-varying-specified-head boundary condition applied to the CDA, NWDA and SEDA. The time-varying-specified head boundary conditions are presented in Figure D-4 to D-6. The expected extraction rates, supplied by QGC, for each development area, are also provided for comparison. It is noted that the model mass balance error was checked for each numerical simulation prior to extracting the results.

From Figure D-19 to D-21, 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 CDA, NWDA and SEDA. This generally matches the expected extraction rates provided by QGC with respect to the NWDA and SEDA, however, the expected peak extraction for the CDA is 20 years whereas in Figure D-19, the model simulation indicates it may occur earlier.

The predicted groundwater extractions from the WCM (Layers 10 and 12), for the three modelled areas at Year 40, are presented in Table 7, 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 8 for *Year 40* (nominally).

Table 7: Predicted Groundwater Extraction Rate at *Year 40*

Modelled Area	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*
CDA	96.0	9.4	15.2
SEDA	70.7	10.8	6.7
NWDA	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 8: Predicted rate of groundwater transfer from Springbok Formation, Hutton Sandstone and Precipice Sandstone at *Year 40*

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
CDA	56.8	17.1	10.2	4.8	<0.1	<0.1
SEDA	27.0	12.4	7.1	0.8	<0.1	<0.1
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.

9.0 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 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 three development areas were modelled independently.
- The model did not consider the influence that may occur from other neighbouring CSG extraction operations.
- 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.

10.0 RECOMMENDATIONS

To improve the model in the future, the following 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 geometry of the model domain, for example, could be evaluated in more detail in a future modelling exercise.
- The number of model layers may be able to be reduced to 13 layers (and perhaps even less), based on layer thicknesses and applied hydraulic parameters for current model.
- Once appropriate calibration data is available, a single model for all three development areas should be considered. A combined model could then predict the expected drawdown influences occurring between development areas, however, influences from neighbouring CSG activities also need to be considered.
- 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. More importantly, the model could 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. Another calibration dataset will become available from the results of the monitoring program associated with the existing CSG activities.
- 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 pumping test program to estimate hydraulic parameters for every aquifer is vital. This data would provide a solid foundation for increasing the confidence in model predictions.

Report Signature Page

K.A.D

Susantha Kumarapeli
Hydrogeologist

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Principal Hydrogeologist

SK,HRB,RKH/JRB,SH,HW,RKH/sk,sh,rkh,hw,jrb

A.B.N. 64 006 107 857

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FIGURES

FIGURES

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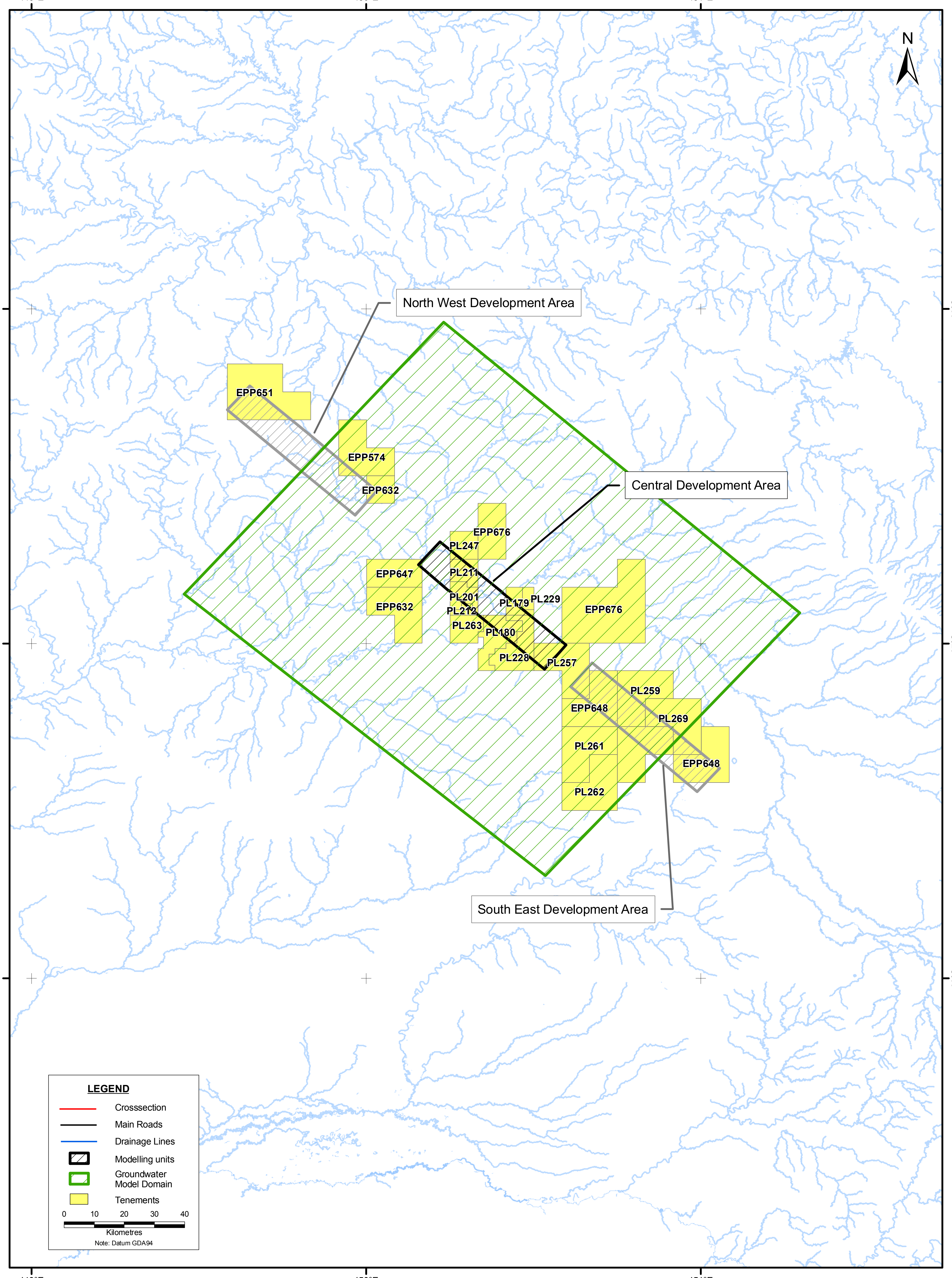
Date: ……………30 June 2009…………………….



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CHECKED: RKH*	DATE: 22-04-09				
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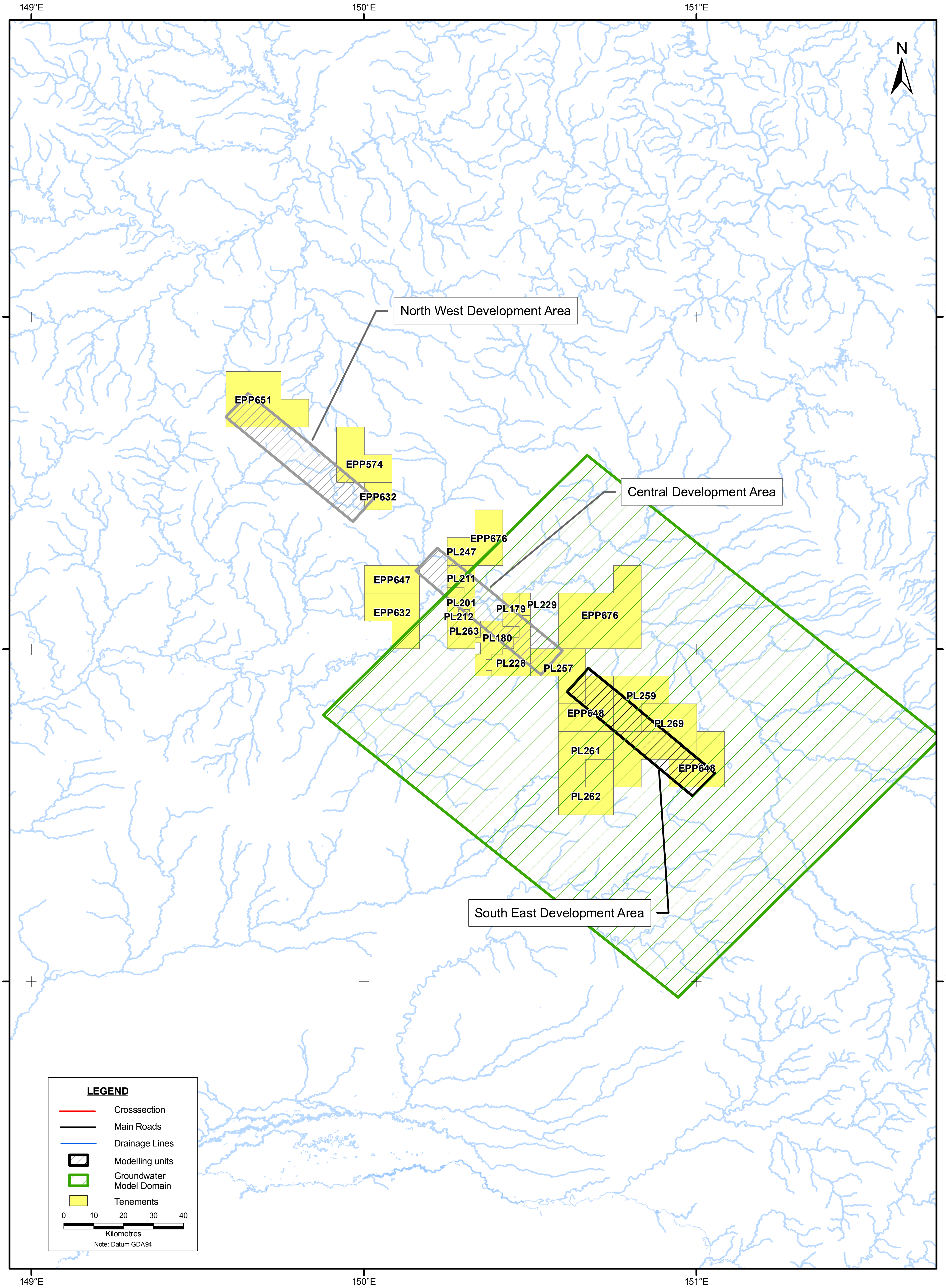

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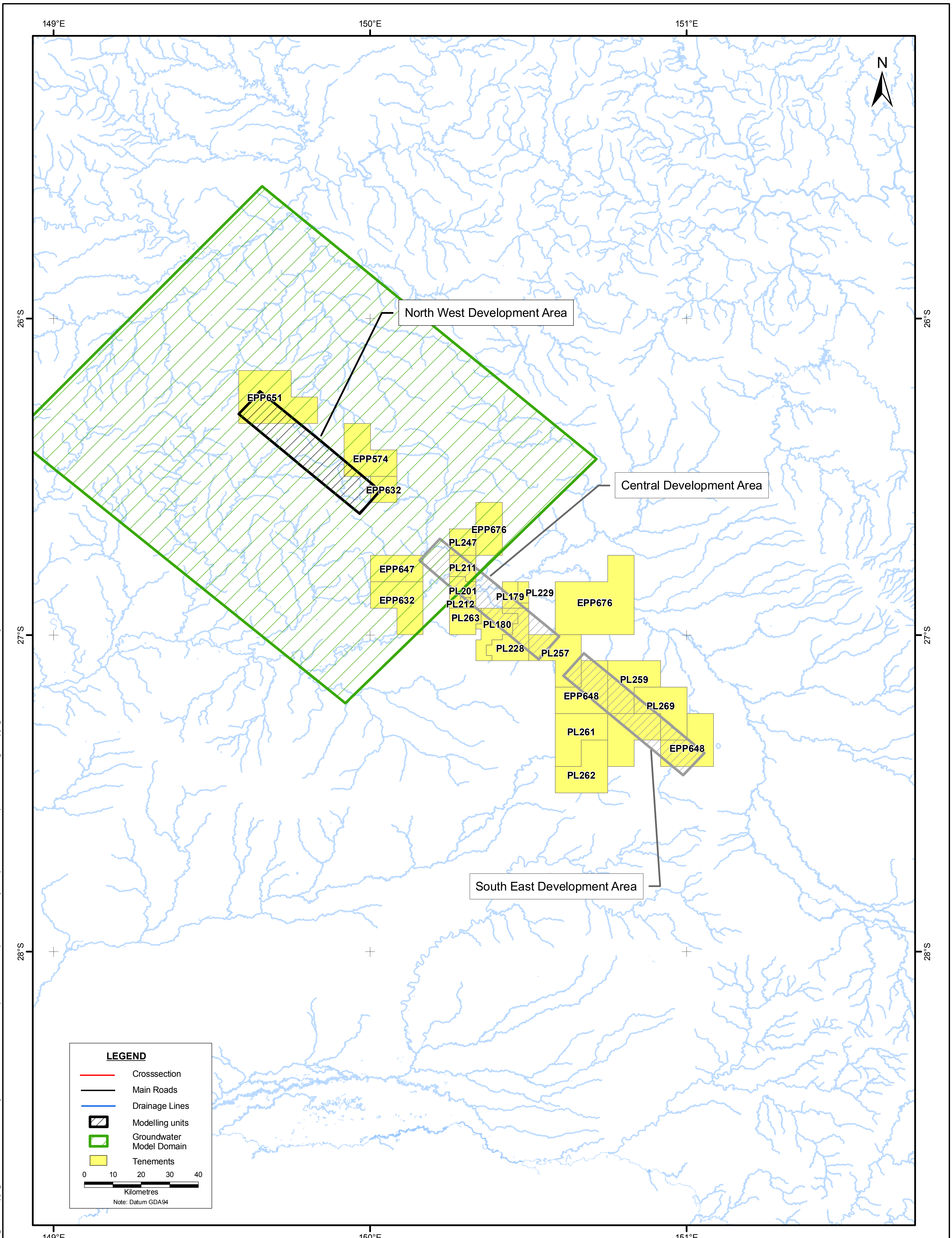

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DRAWN DK/BQ	DATE 22-04-09	TITLE	**MODEL DOMAIN - NORTH WEST DEVELOPMENT AREA (NWDA)**
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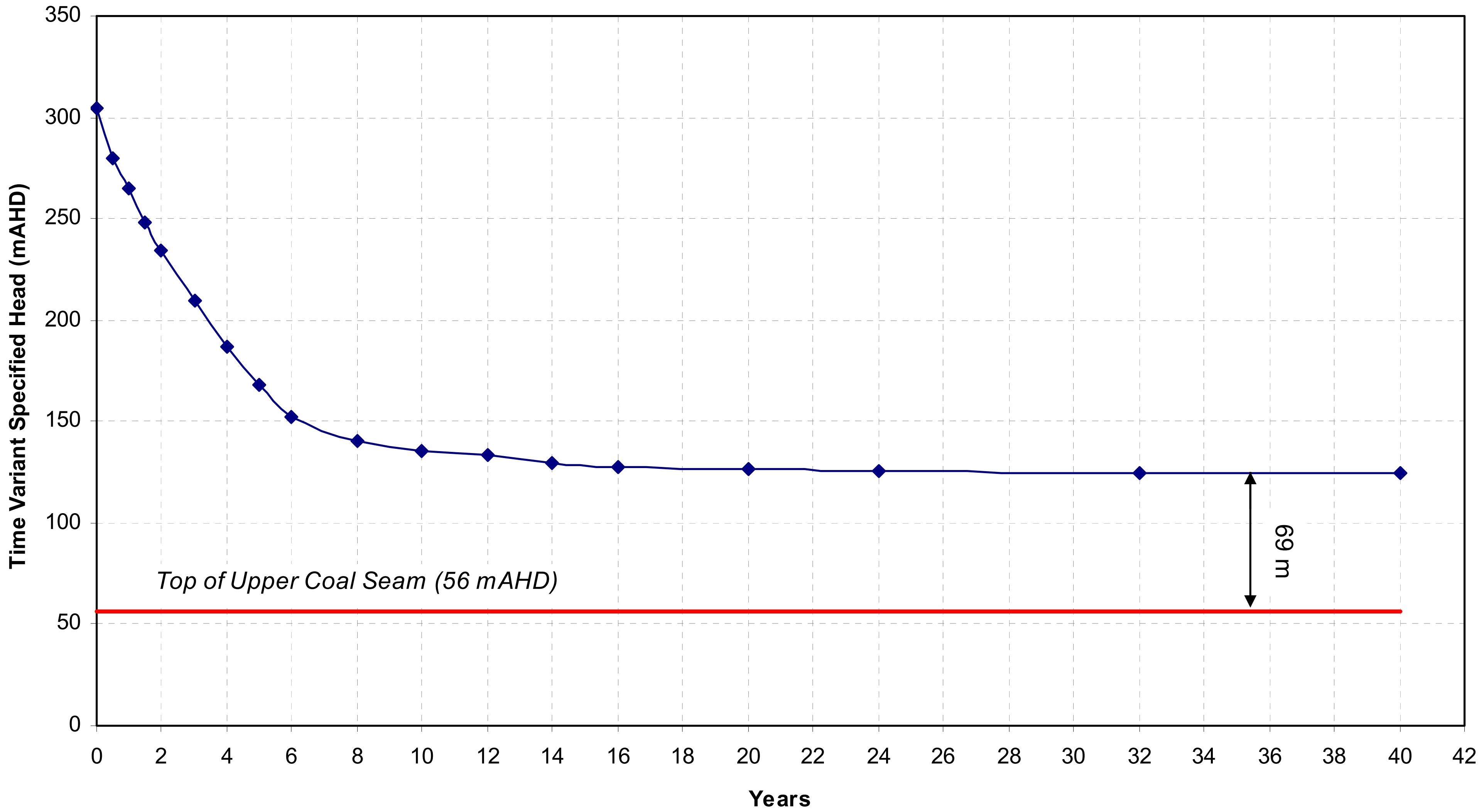

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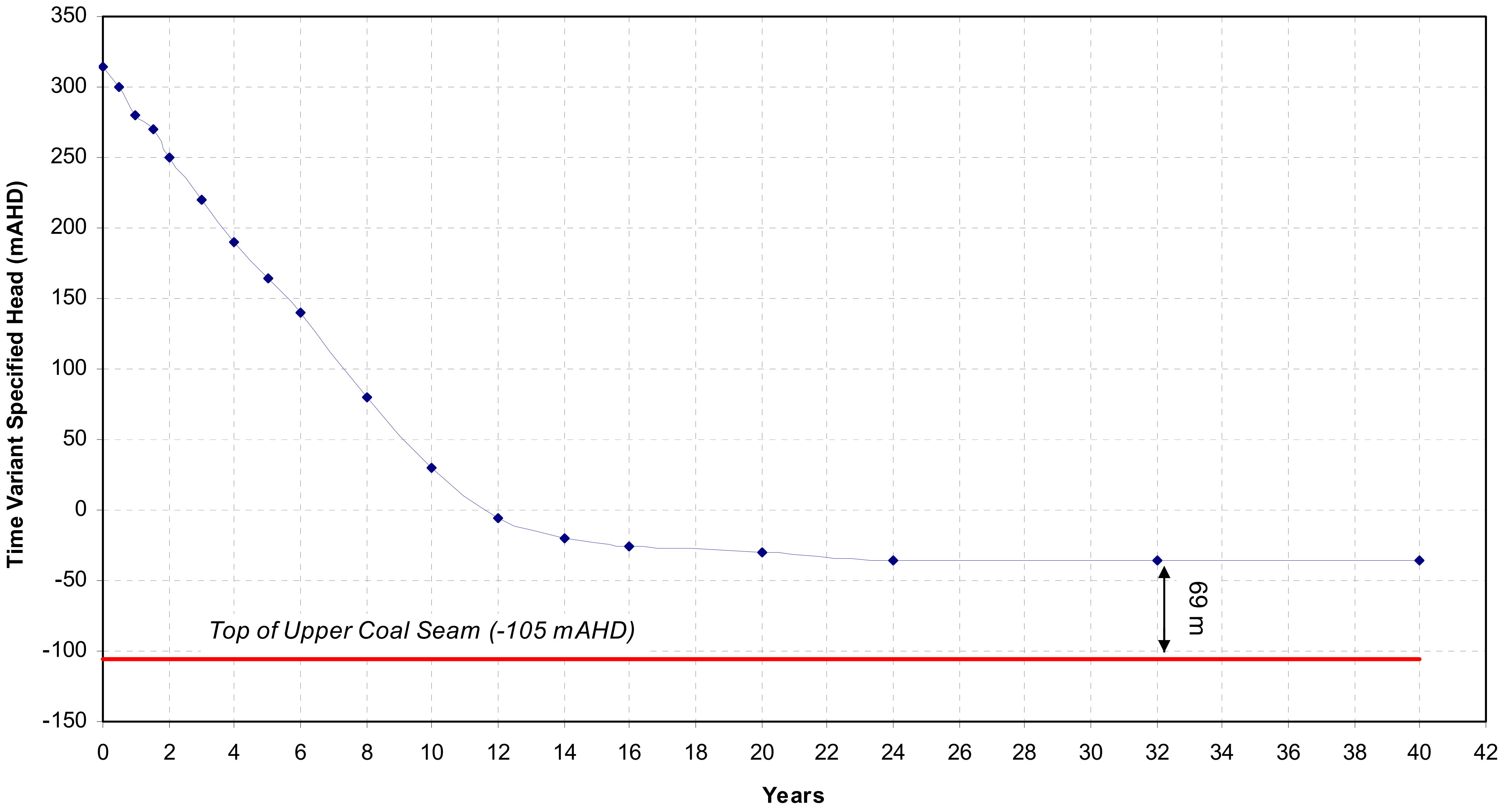

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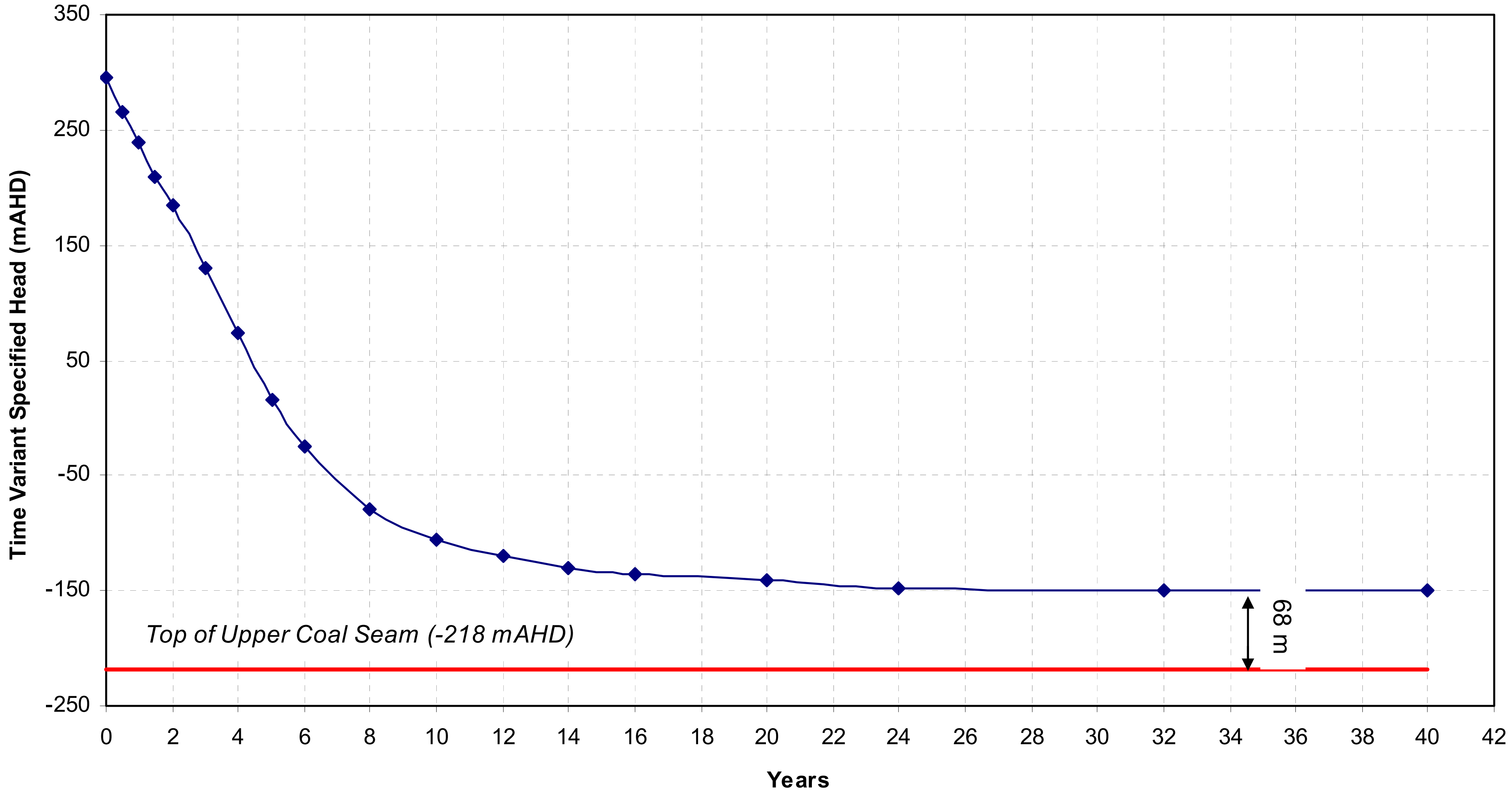

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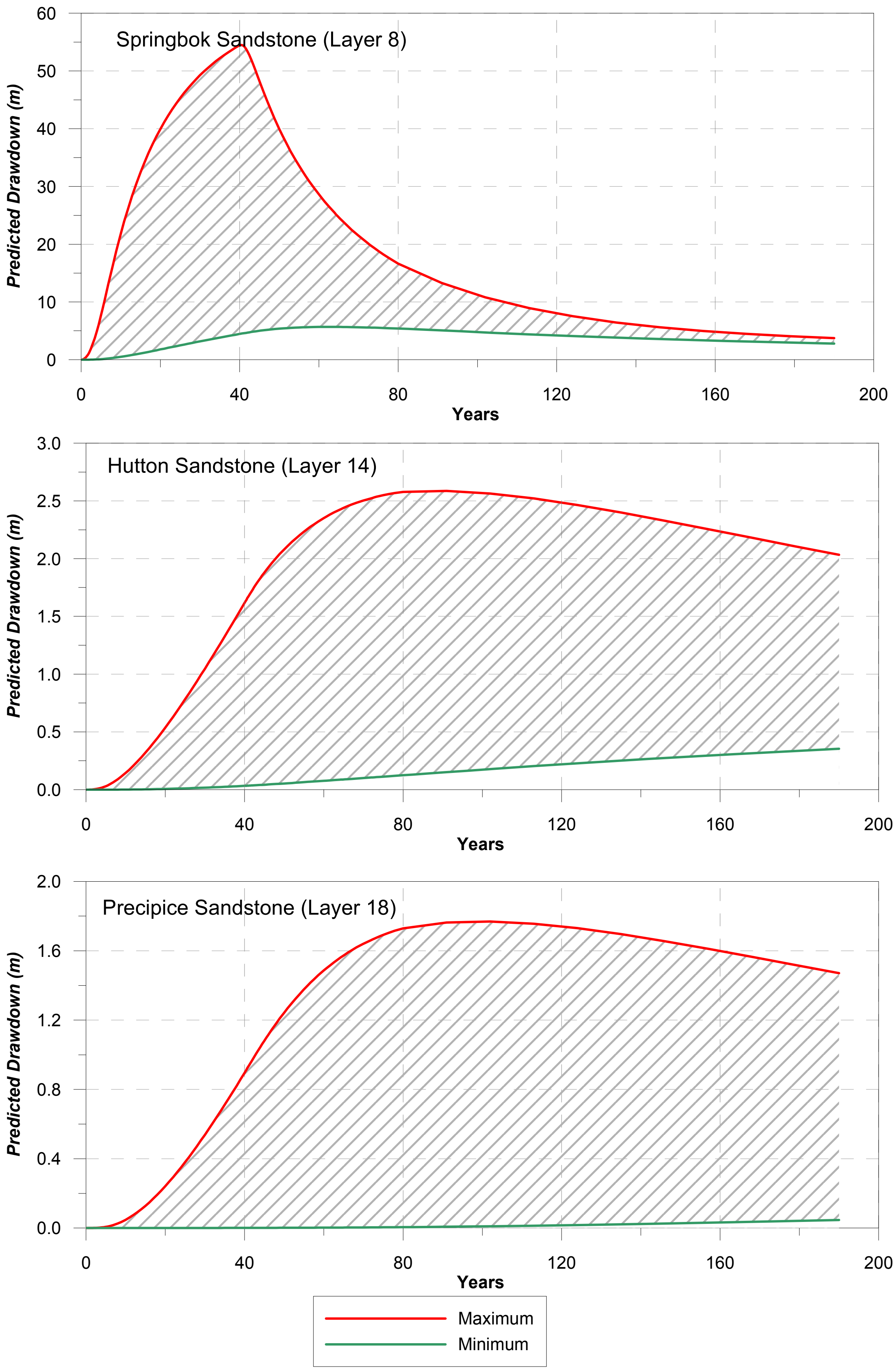

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CLIENT Queensland Gas Company		PROJECT Queensland Gas Company – LNG EIS WATER STUDIES	
DRAWN AB	DATE April 2009	TITLE Modelled Time Vs Drawdown at 1.8km from Edge of CDA (Springbok, Hutton & Precipice Sandstone)	
CHECKED SK	DATE April 2009		
SCALE N/A		PROJECT No 087633050	FIGURE No D-7 · REV No U · A4

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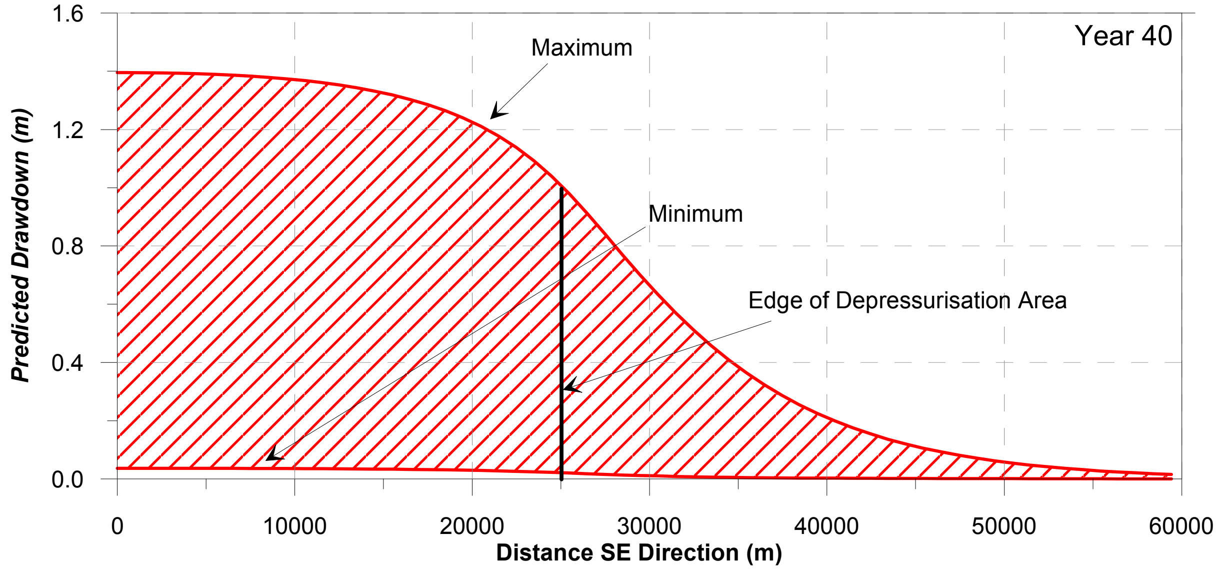

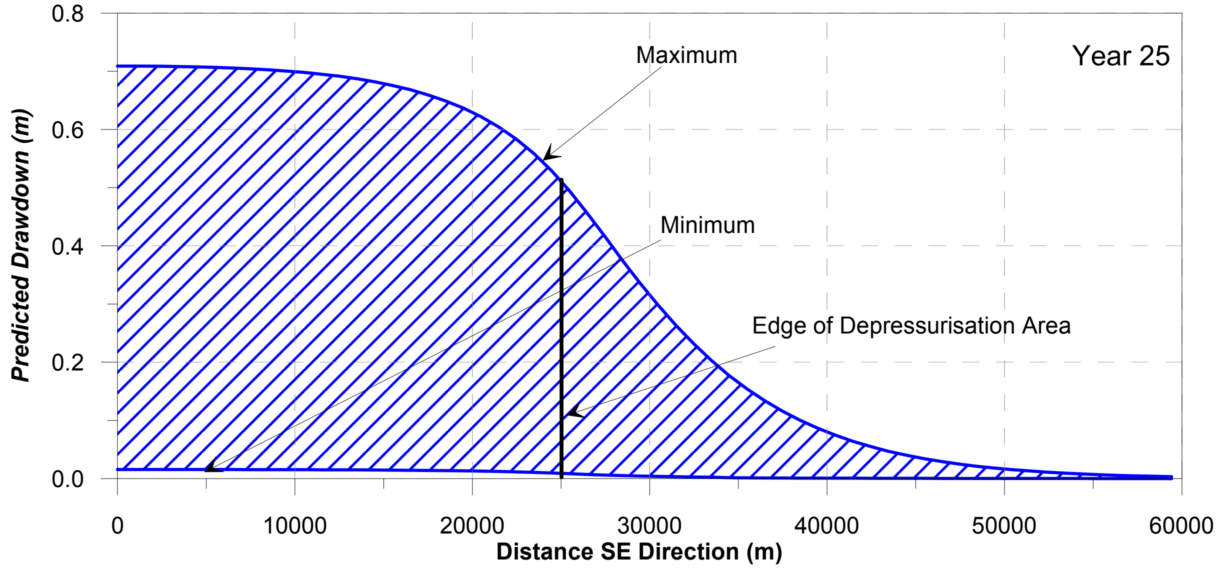

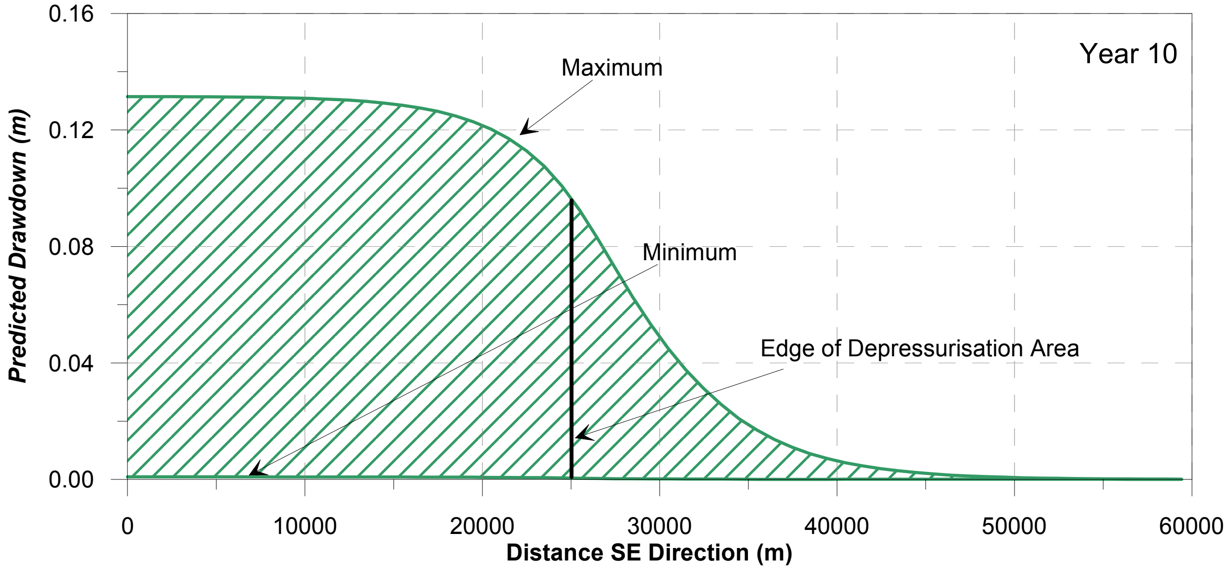

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CLIENT Queensland Gas Company		PROJECT Queensland Gas Company – LNG EIS WATER STUDIES	
DRAWN AB	DATE April 2009	TITLE Modelled Drawdown Vs Distance from Centre of CDA (Gubberamunda Sandstone)	
CHECKED SK	DATE April 2009		
SCALE N/A		PROJECT No 087633050	FIGURE No D-8 · REV No U · A4

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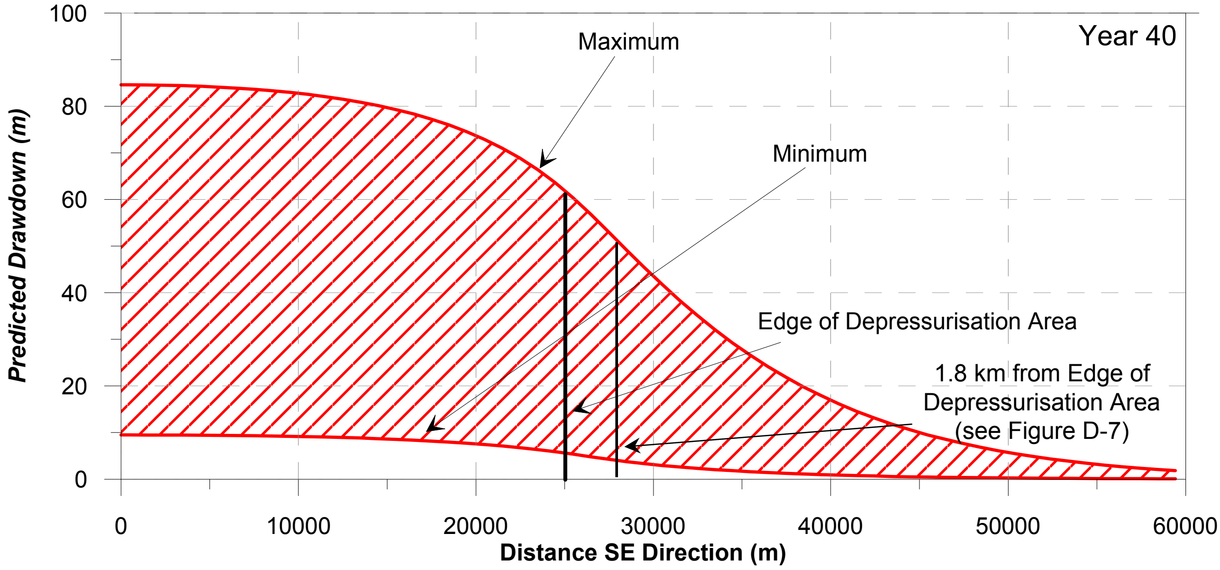

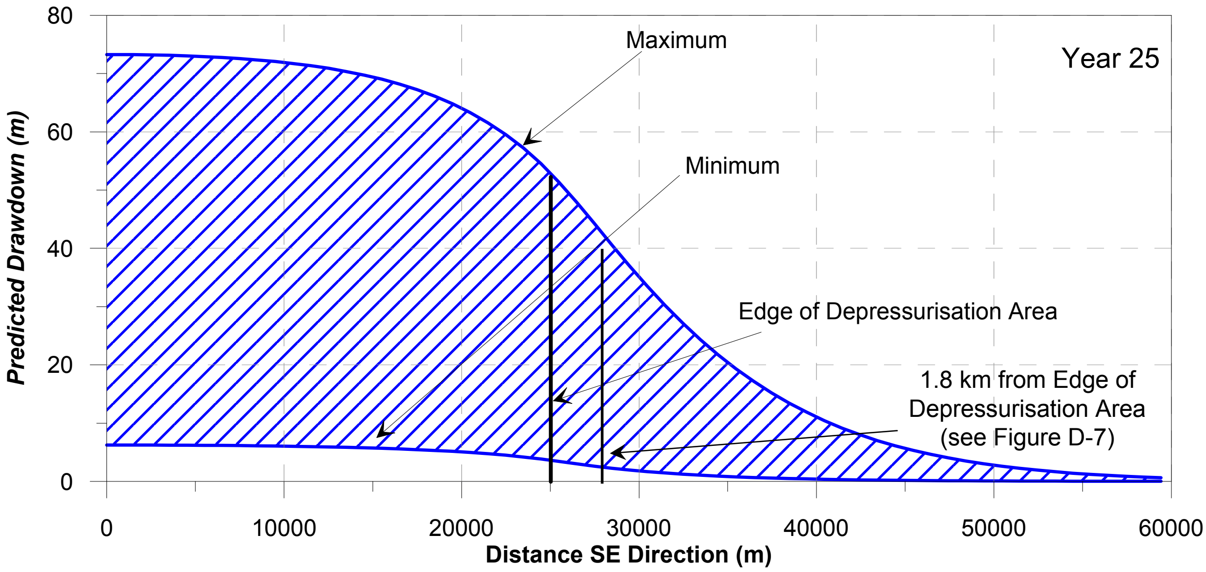

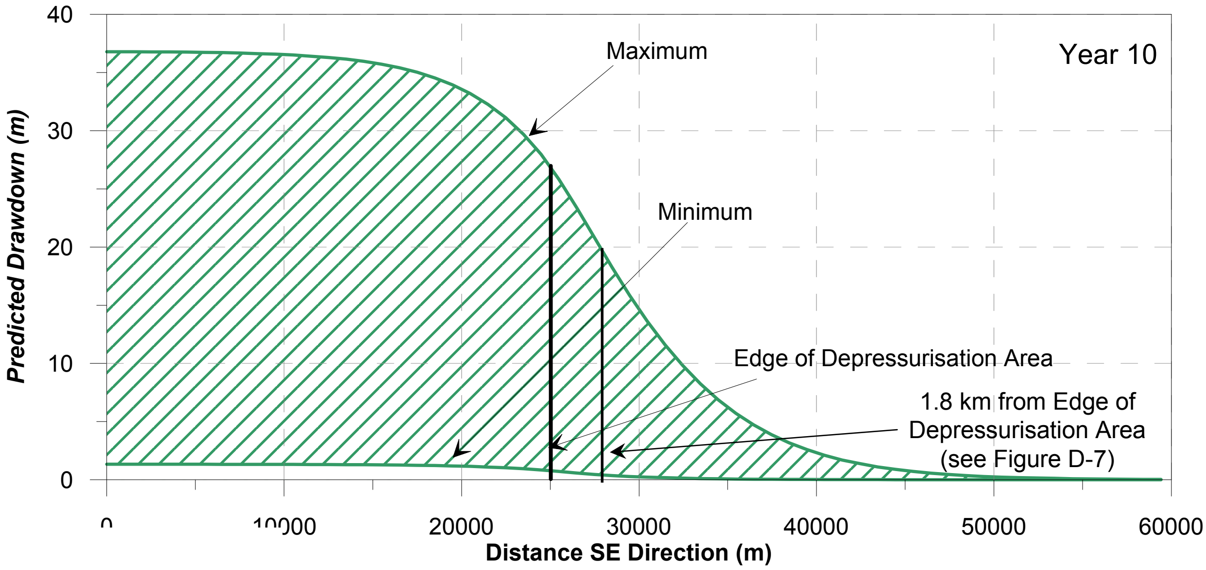

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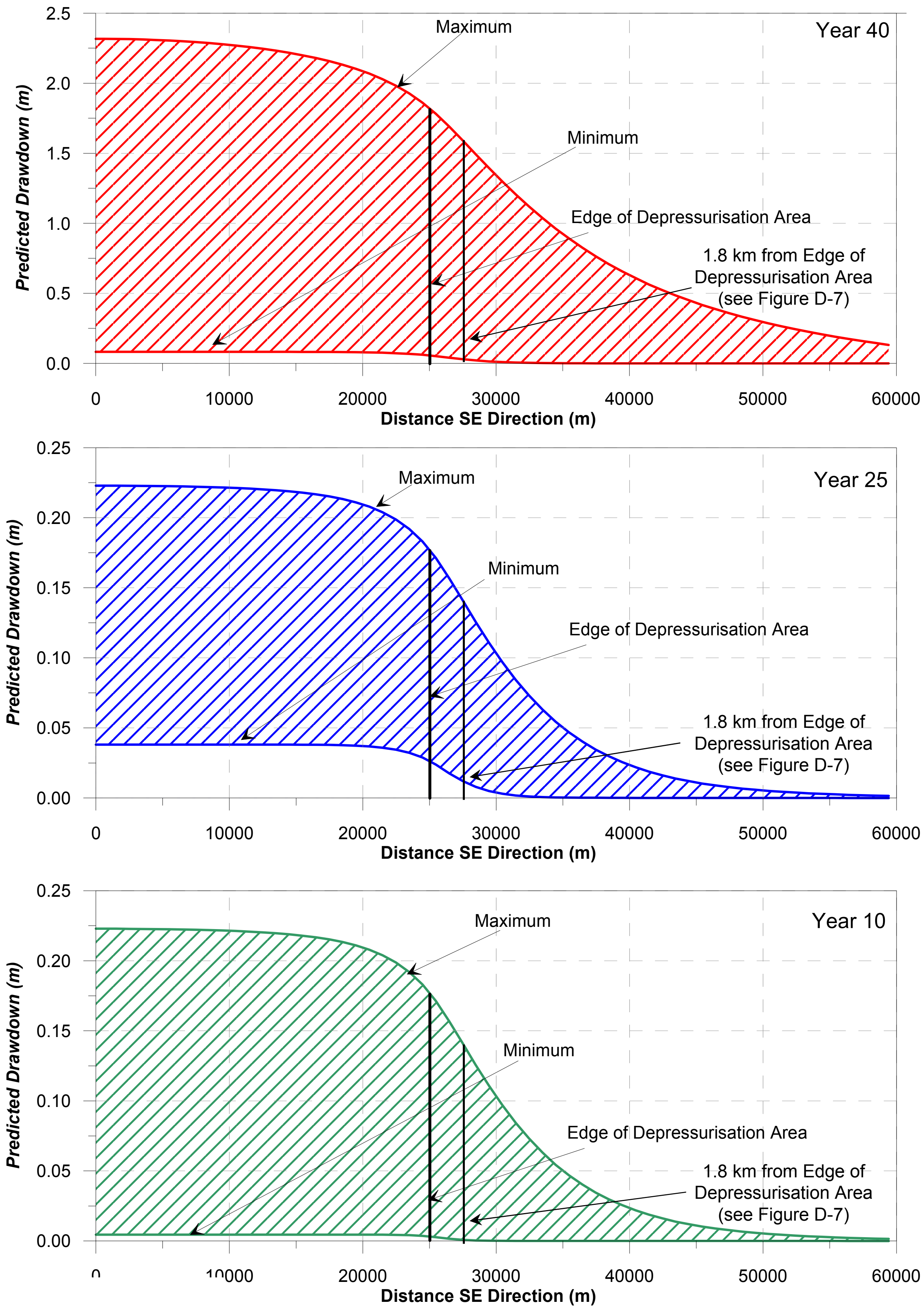

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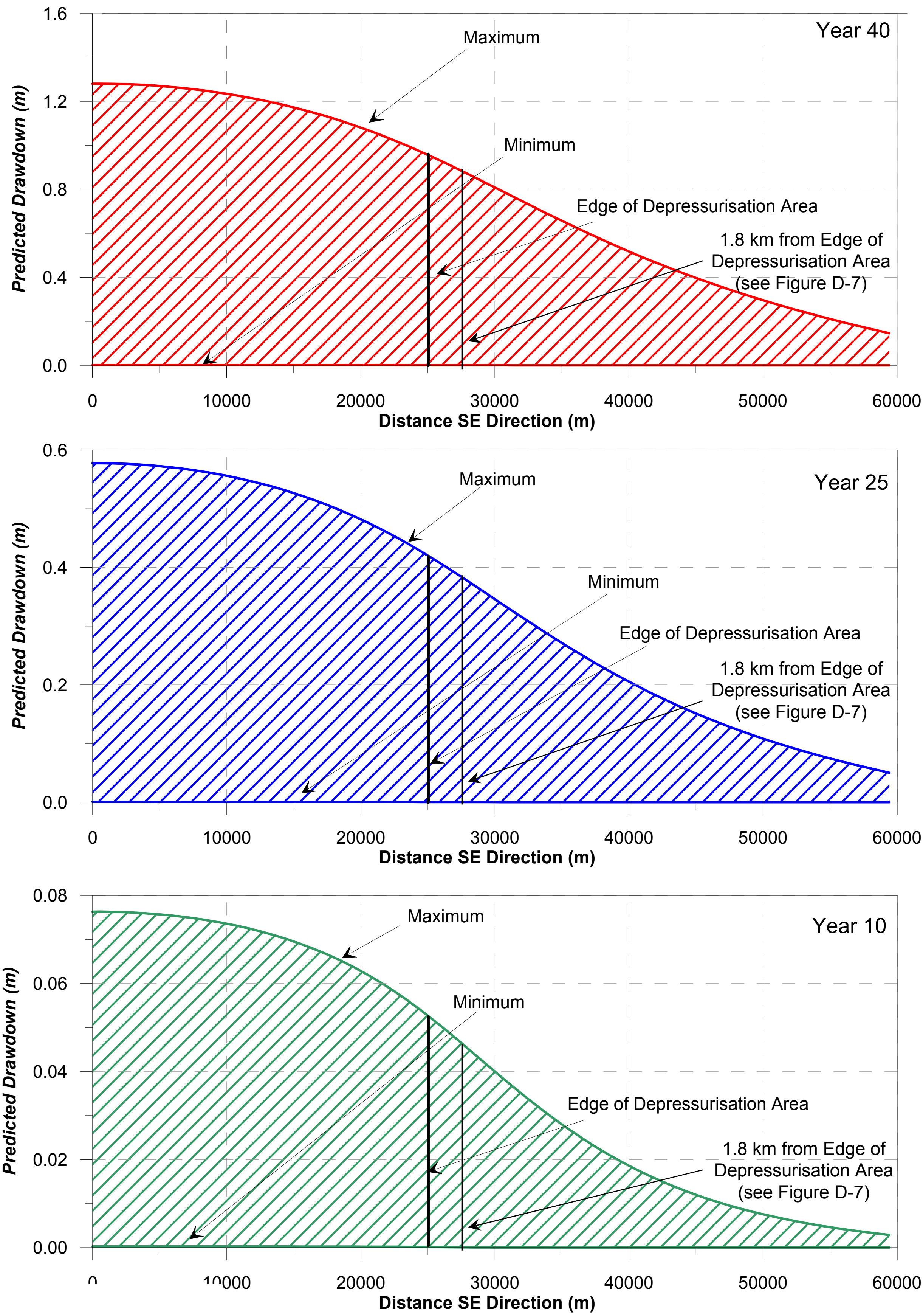

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	CHECKED SK	DATE April 2009	
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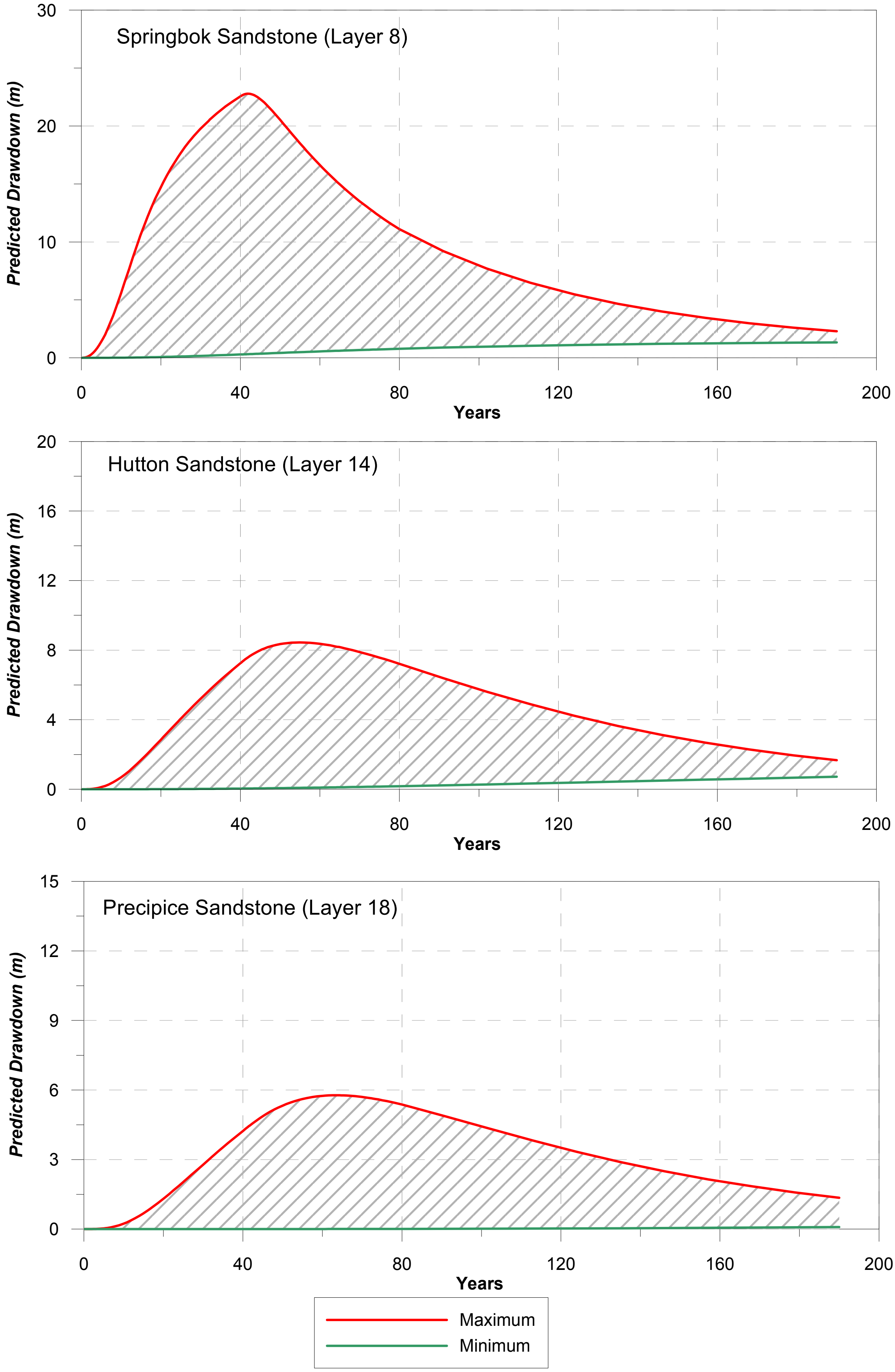

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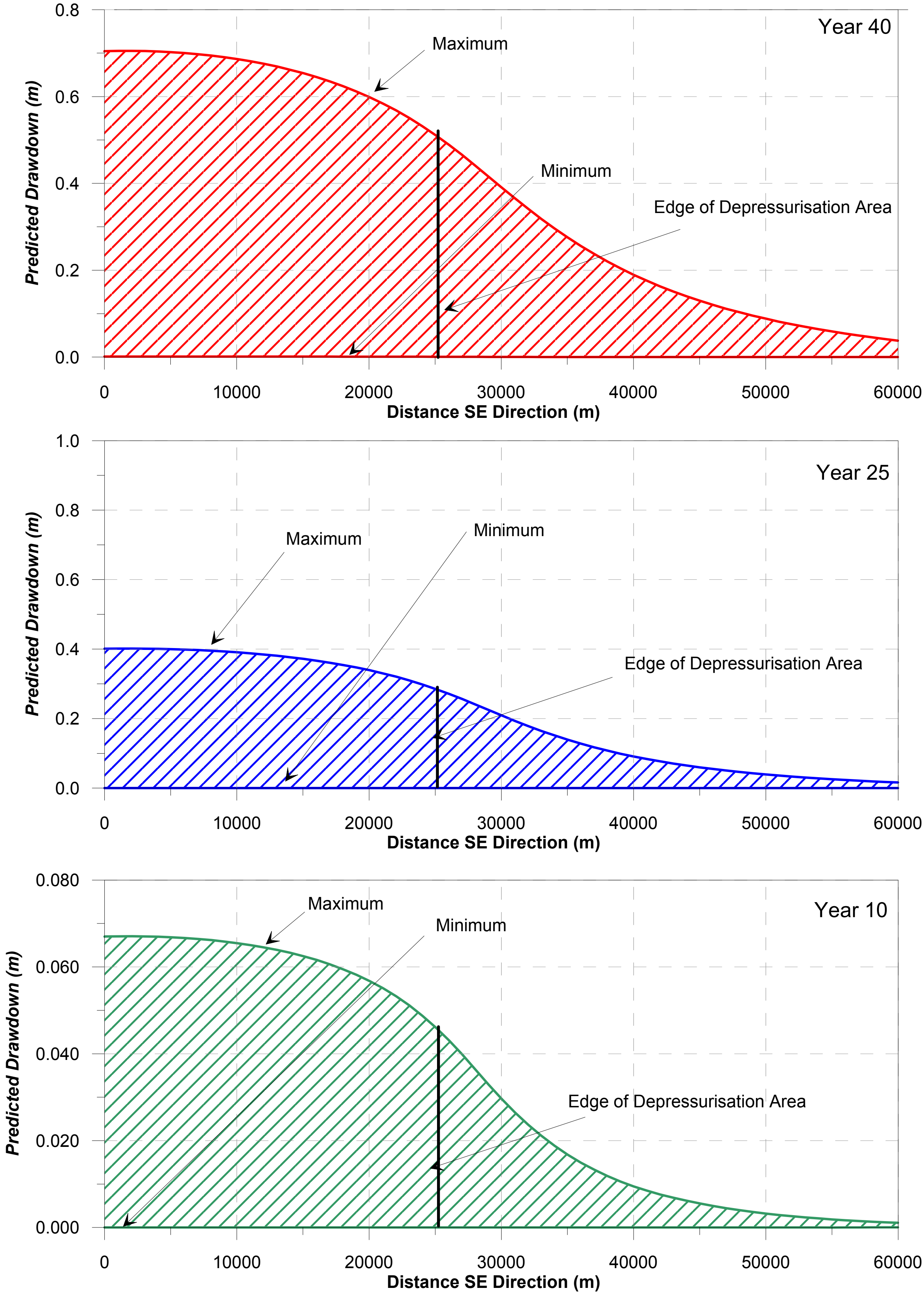

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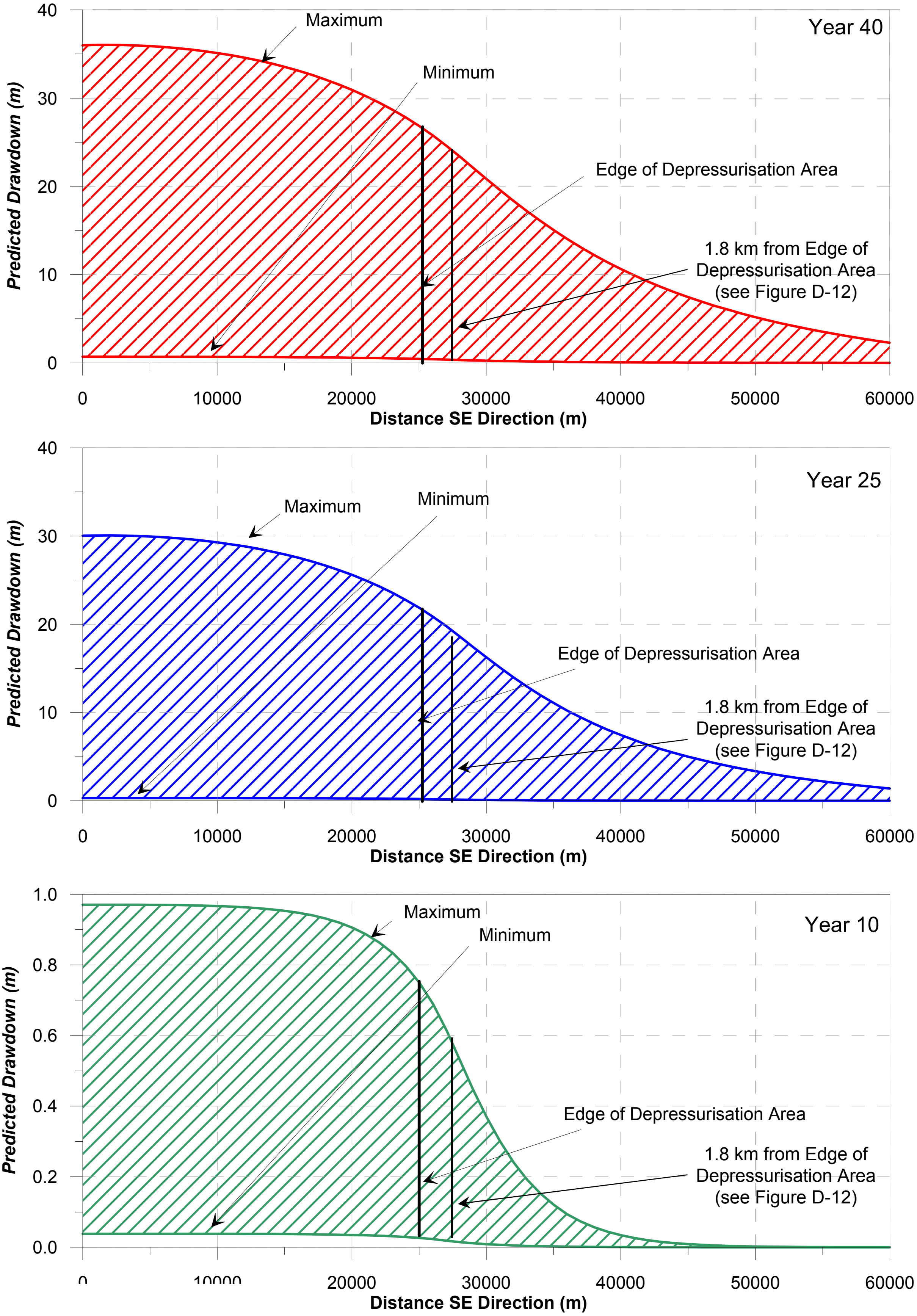

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CHECKED: SK	DATE: April 2009		
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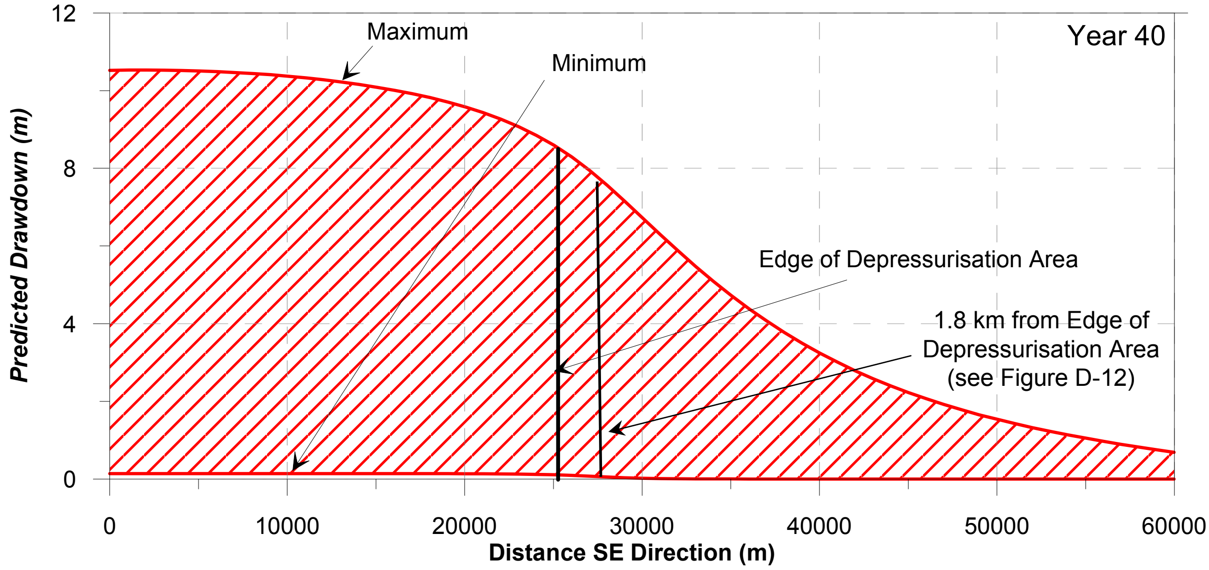

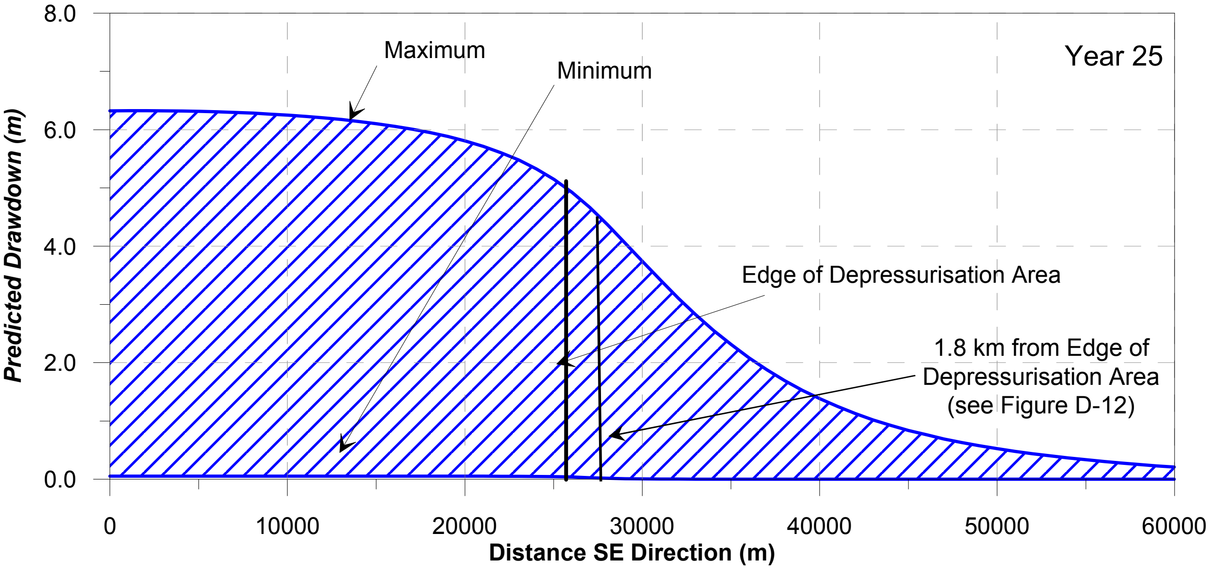

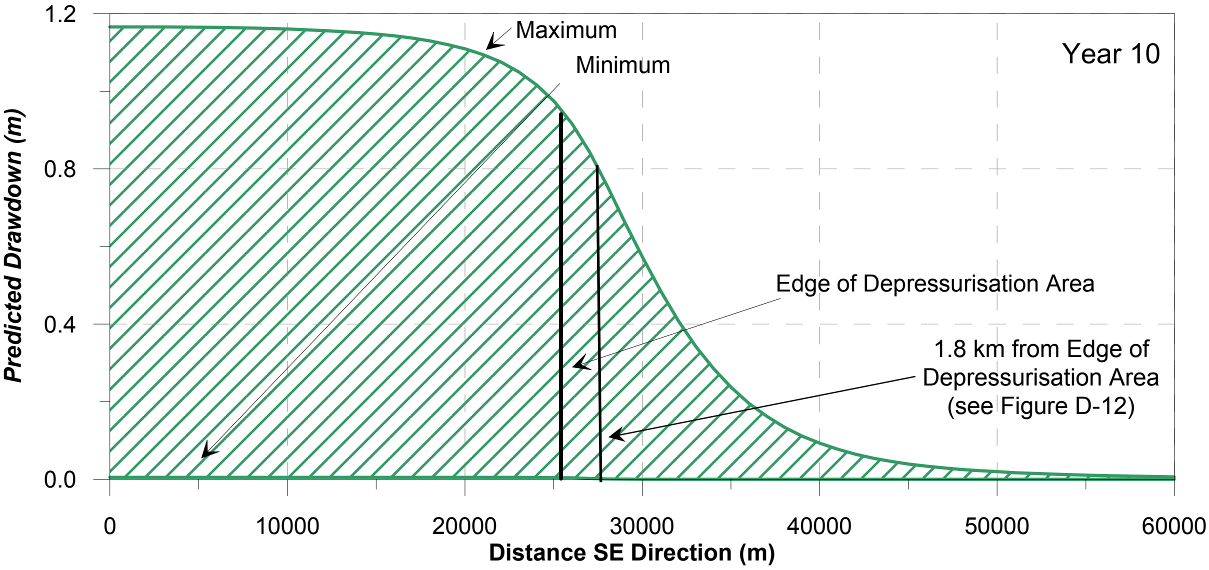

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	CHECKED SK	DATE April 2009	
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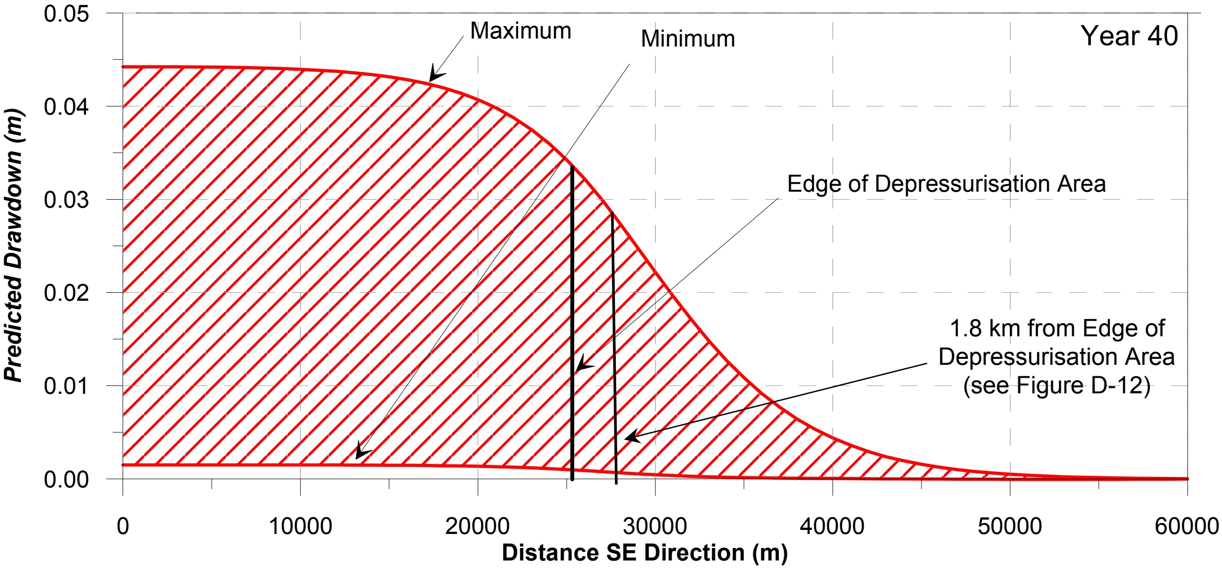

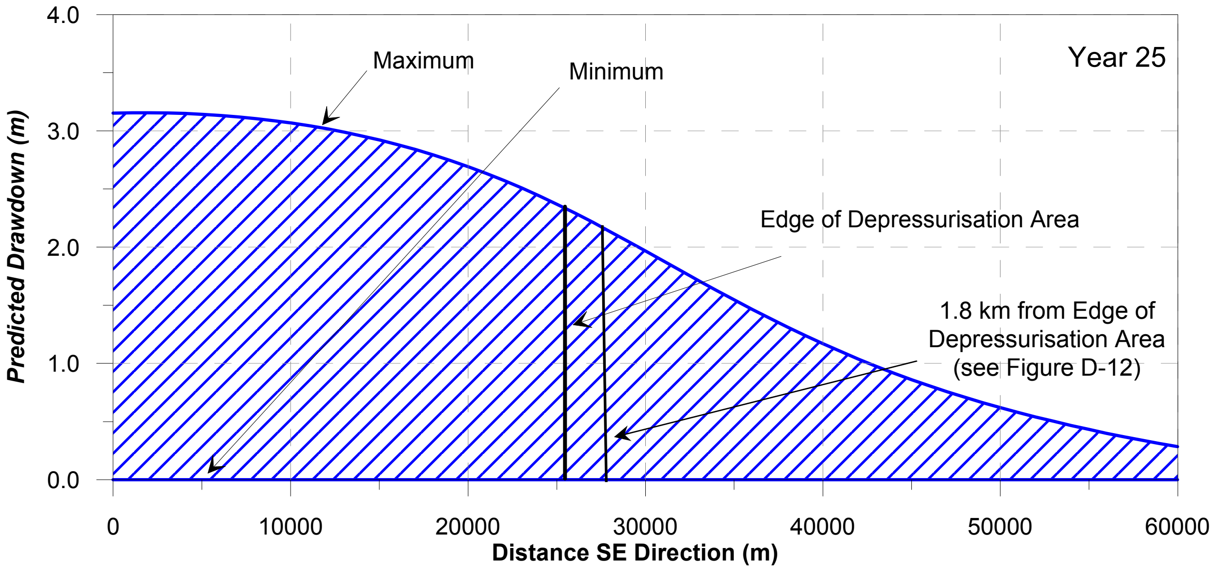

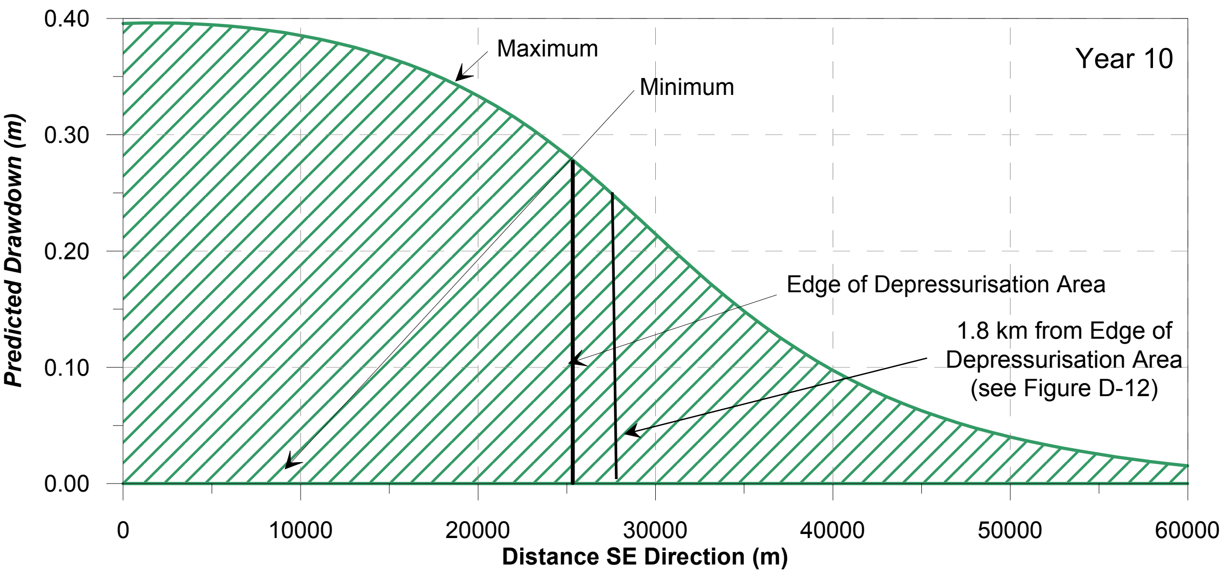

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	CHECKED SK	DATE April 2009	
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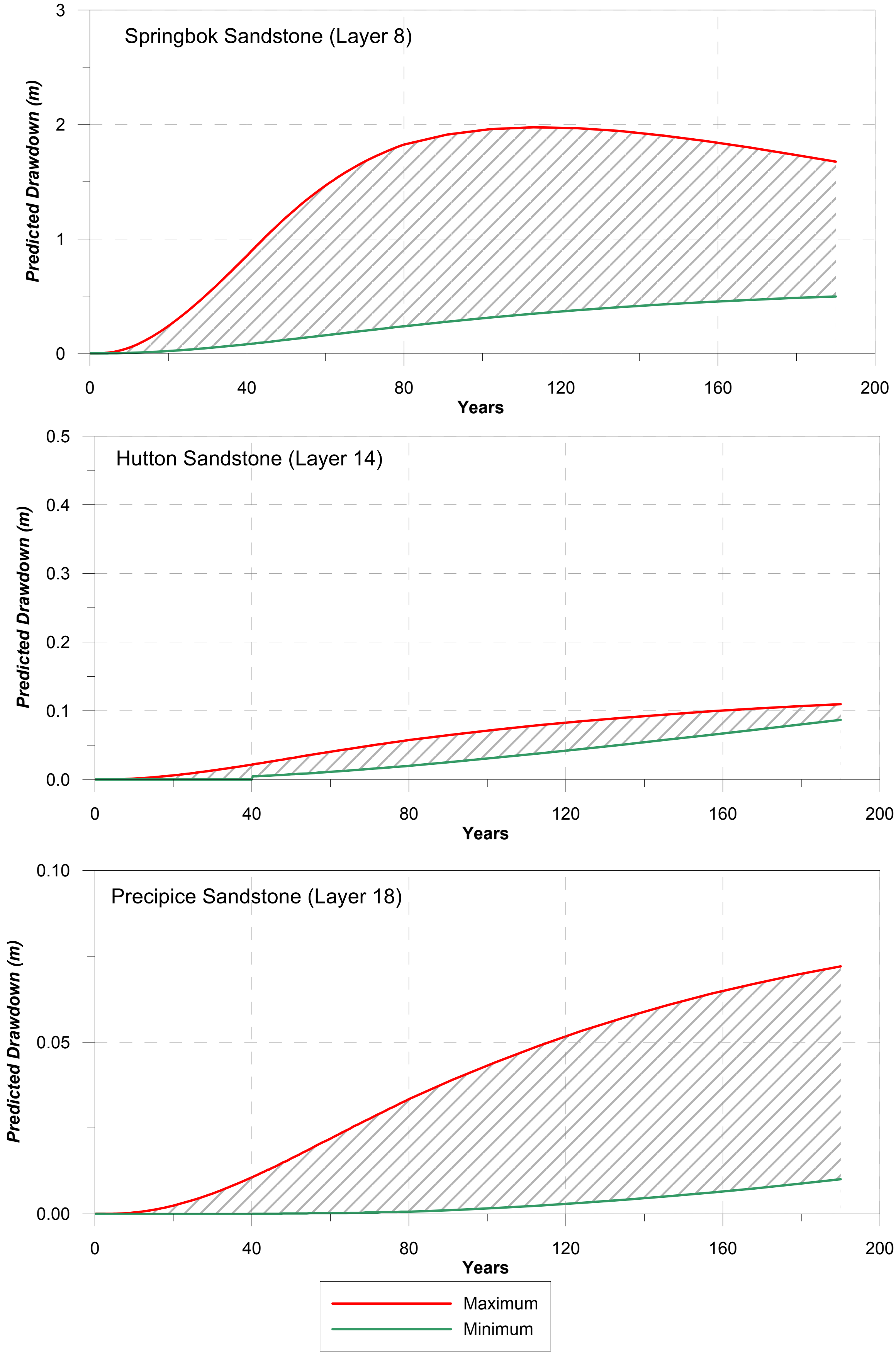

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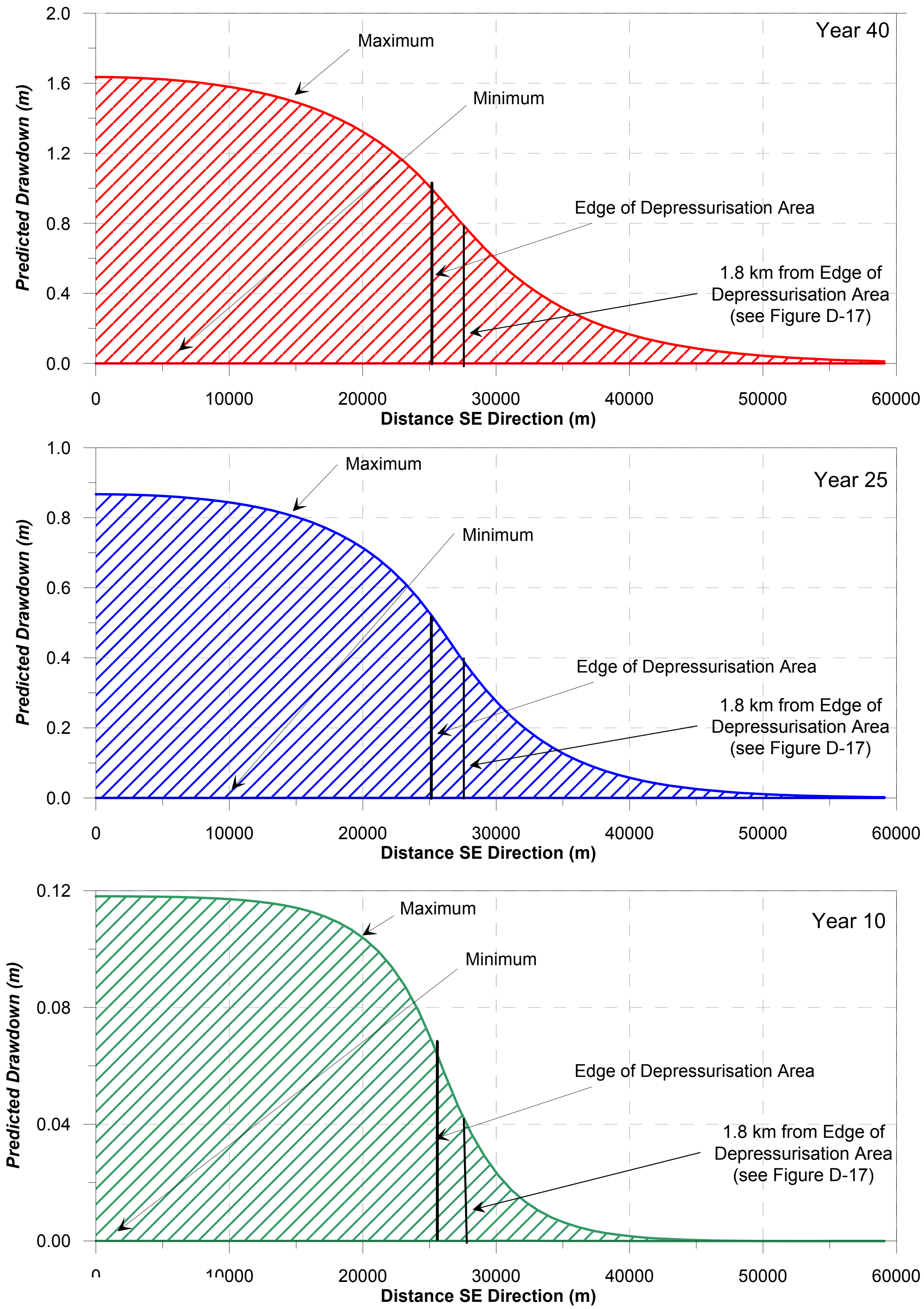

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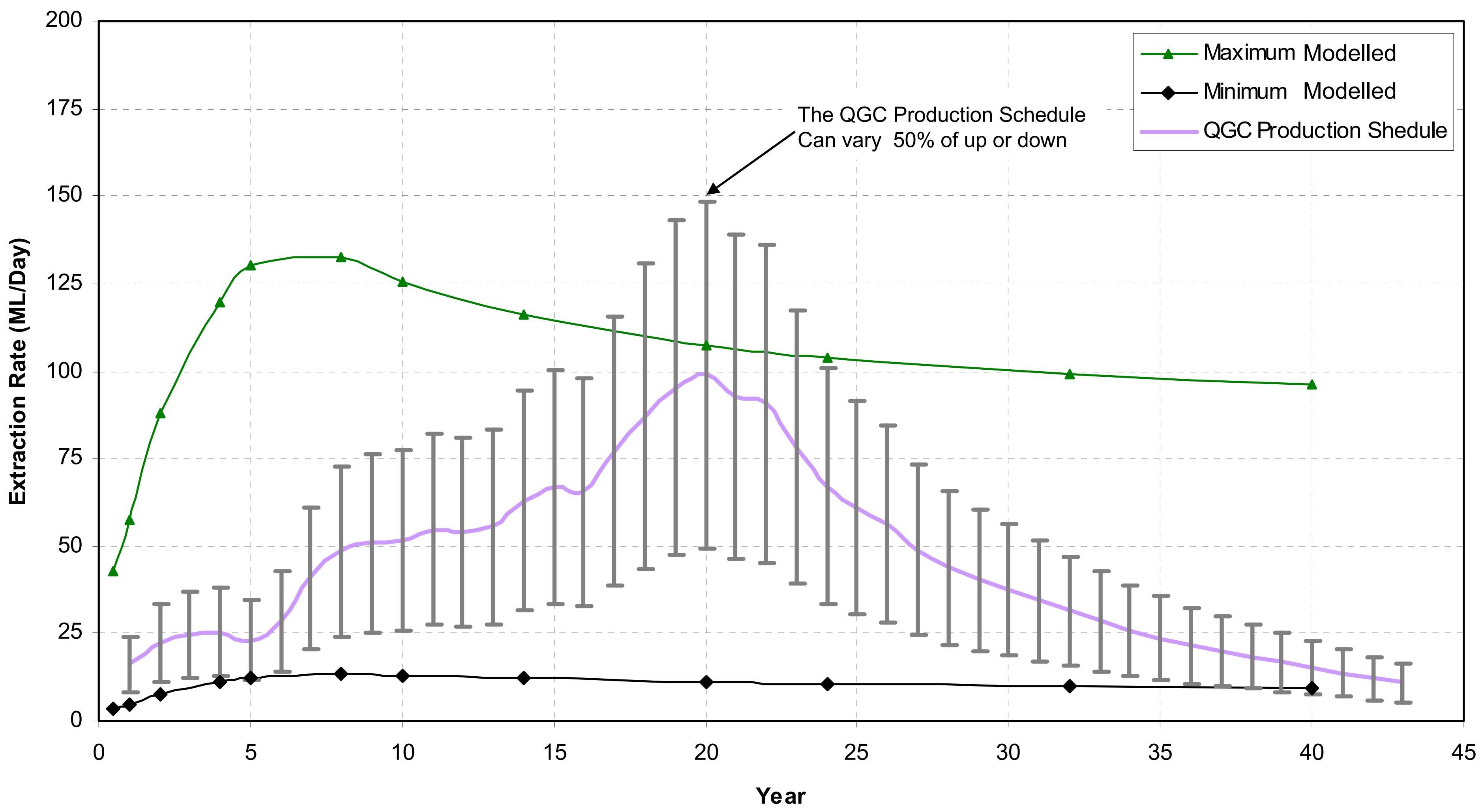

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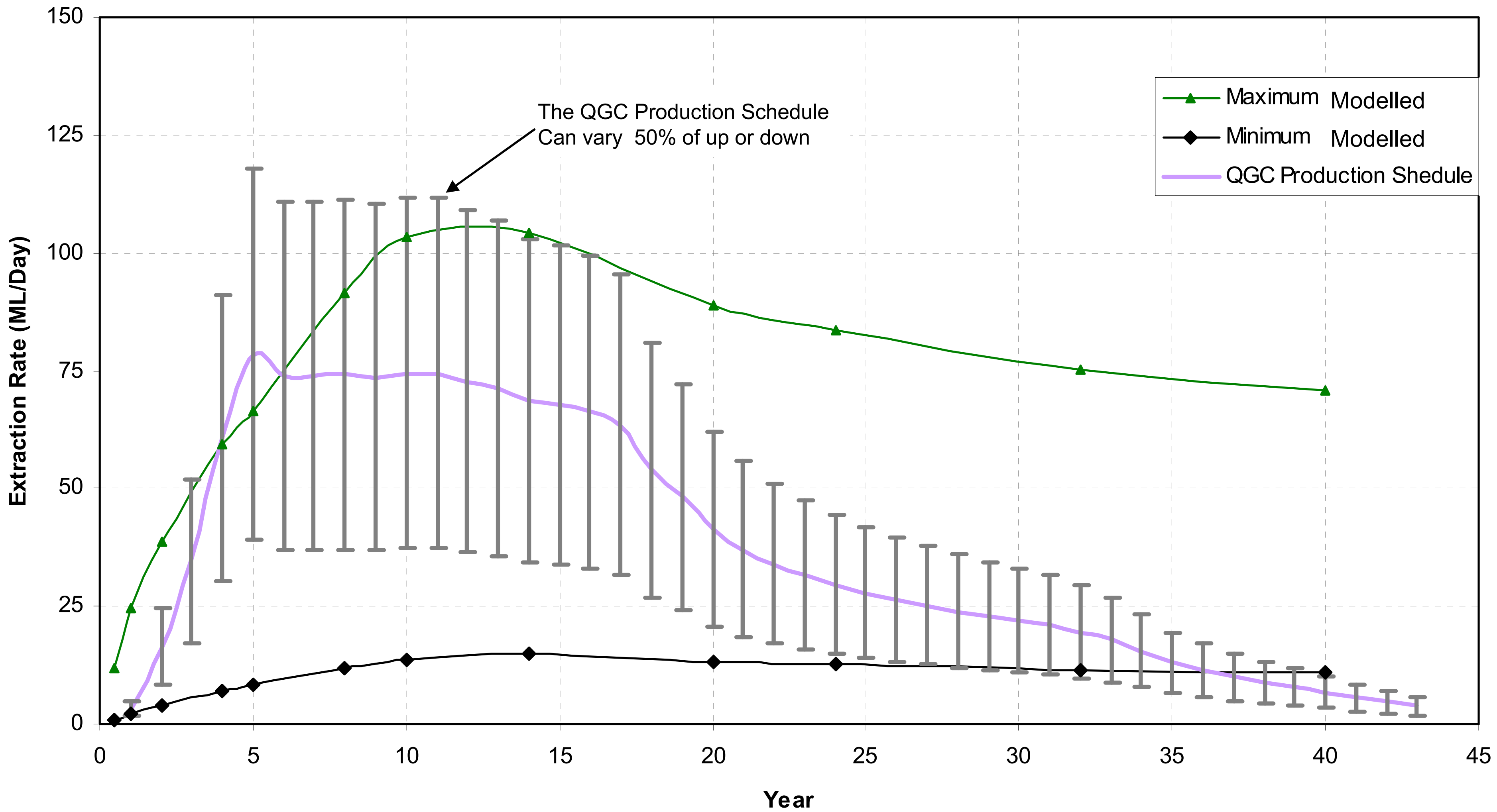

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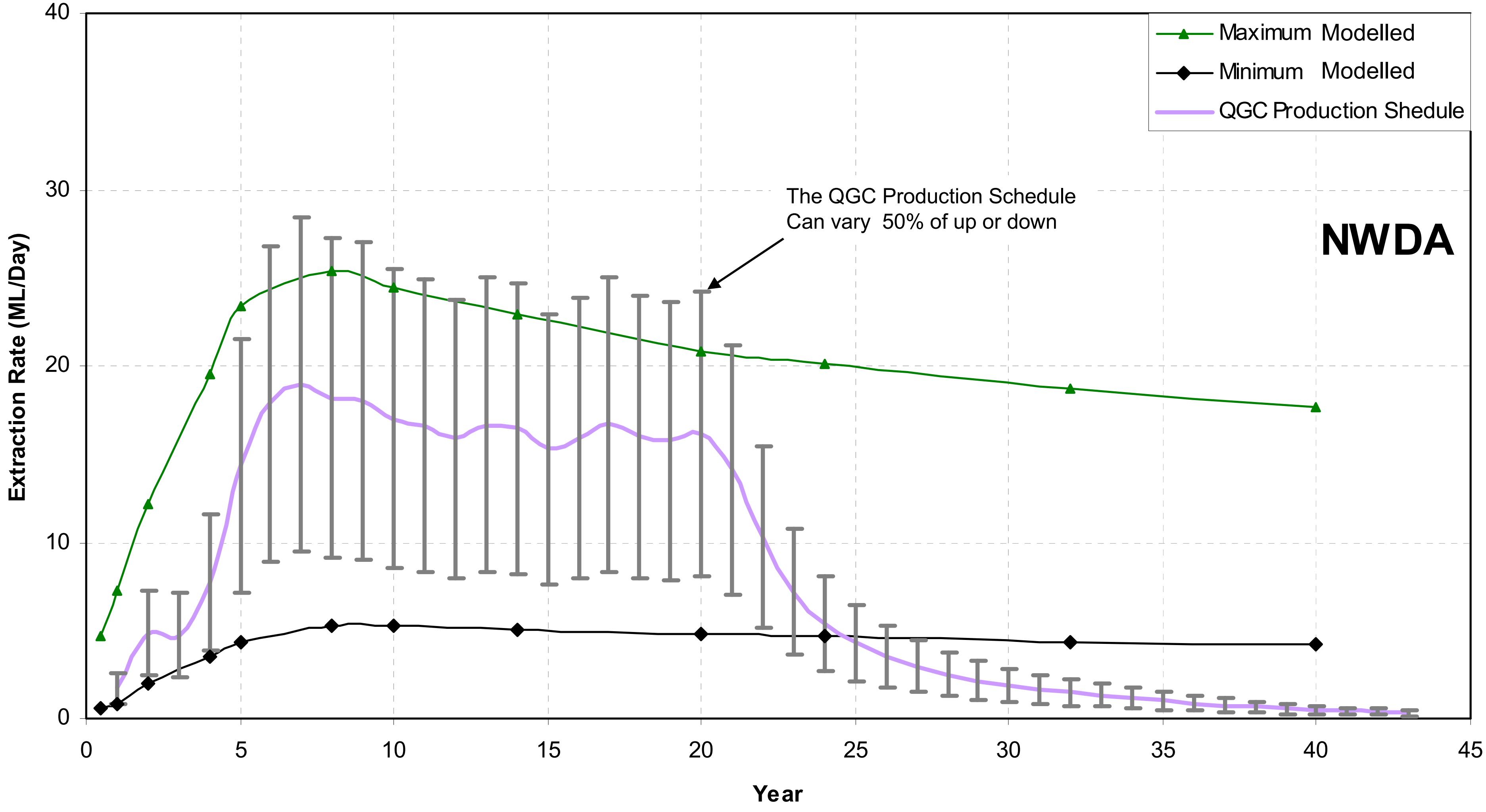

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APPENDIX E

Groundwater Quality Assessment

3 December 2008

QGC - Groundwater Quality Assessment

Submitted to:
QGC

Report Number: 087633050

REPORT

A world of capabilities delivered locally

Golder Associates

Table of Contents

TABLES

FIGURES

APPENDICES

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1.0 METHODOLOGY

1.1.1 Data quality

Most of the dissolved solids in groundwater are positively charged (cations) and negatively charged (anions). The most abundant cations present in water are calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) and the most abundant anions are bicarbonate (HCO3), chloride (Cl), and sulphate (SO4). To maintain solution electroneutrality there must be a charge balance between cations and anions in solution.

About 95 percent of analytical data had ion balances within the ± 5 percent range, indicating that the major-ion analyses were of good quality. Approximately 3 percent had ion balances from ±5% up to ± 20%. These samples were considered acceptable in this study because the ion balances are still relatively low which can be related to unmeasured constituents such as organic anions, nutrients, and trace metals may contribute to higher ion balances. A further 2 % of groundwater samples with ionic balance greater than ±20% (25 samples) were excluded from interpretations.

1.1.2 Water quality description

Groundwater quality assessment included 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

Total Dissolved Salts (or Solids; TDS) and Electrical Conductivity (EC) are measures of salt content of water. TDS are reported as a concentration value (in mg/L) and can be measured by evaporating a known volume of water to dryness or calculated from chemical analyses by summing all major ions. Only 70% of data appear to have measured TDS values, therefore calculated TDS was used for interpretations.

Variety of salinity classes based on TDS concentration has been published in literature. Defined classes 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). For this study we have adopted water salinity classes from Fetter (1994) as presented in Table 2. Brackish water was further divided 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 10,0000
Saline	10,000 to 100,000

Salinity Classes (modified from Fetter, 1994)	
Water type	**TDS (mg/L)**
Brine	more than 100,000

Electrical conductivity (EC) measures the charge carrying ability (ie 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 0.6

1.1.3 Major ion chemistry

Based on the dominant dissolved cation and anion, expressed in milliequivalents per liter (meq/L) several water types can be distinguished. A milliequivalent (meq) is a measurement of the molar concentration of the ion, normalized by the ionic charge of the ion. The dominant dissolved ion must be greater than 50 percent of the total. For example sodium-bicarbonate-type water contains more than 50 percent of the total cation milliequivalents as sodium and more than 50 percent of the total anion milliequivalents as bicarbonate. If no cation or anion is dominant (greater than 50 percent), water is classified as mixed and the two most common cations or anions in decreasing order of abundance are used to describe the water type.

Cation and anion concentrations for each ground-water sample are converted to total meq/L and plotted as percentages of their respective totals in two triangles of the Piper diagram (Figure 1). The cation and anion relative percentages in each triangle are then projected into a quadrilateral polygon that describes the water type or hydrochemical facies. The Piper diagram therefore has the potential to represent a large number of analyses and is convenient for showing differences between groundwater qualities within the studied area.

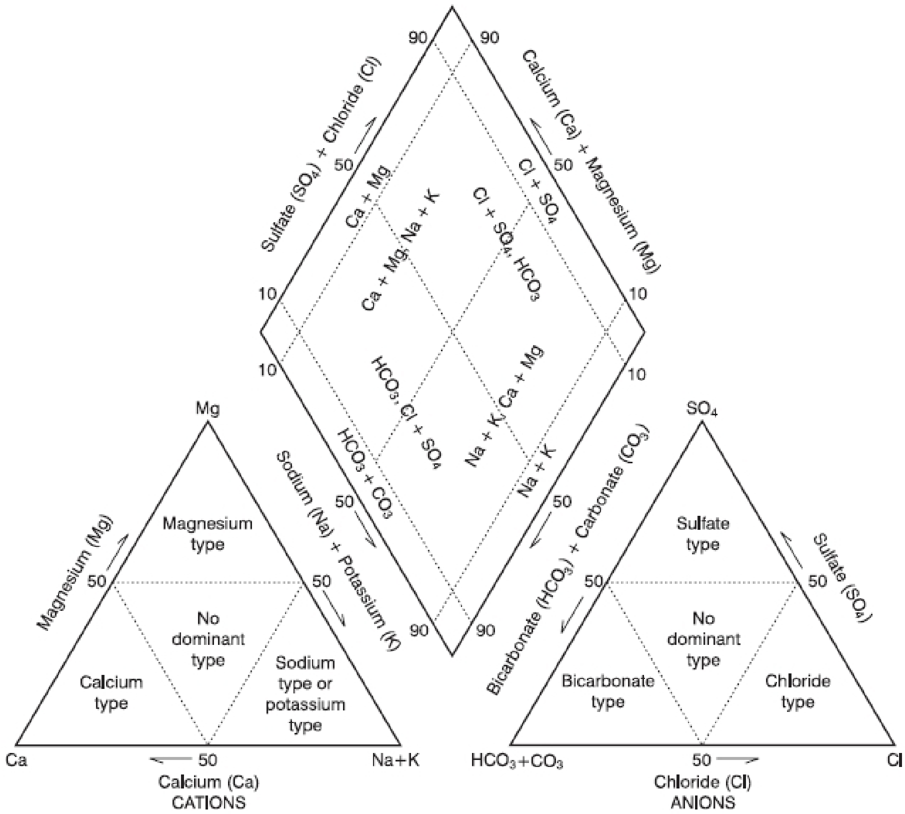

Figure 1: Classification of hydrochemical facies using the Piper plot

Groundwater quality in the study area was assessed for all major aquifers including Shallow, Intermediate, Walloon, Hutton Sandstone and Precipice Units. The database of 1114 groundwater samples was assessed using standard Piper plots, scatter plots and statistical analysis. The majority of water quality data have been collected from the Shallow aquifer (663) compared to Intermediate (135), Walloon (141) and Lower aquifers including the Hutton (108) and Precipice Formation (16). Groundwater chemical analyses have been collected over the period of 60 years with the majority of data sampled between 1980 and 2000.

Groundwater quality assessment for individual aquifer units are presented in the sections below.

2.0 GROUNDWATER QUALITY WITHIN THE STUDY AREA

2.1.1 Shallow Unit

Groundwater in this group comprise Main Range Volcanics, Doncaster , Wallumbilla and Griman Creek Formations and ten Quaternary alluvium aquifers including Condamine, Canal, Cattle, Charleys, Jimbour, Moola, Myall, Oakey, Spring, Stuart and Thanes. Shallow aquifers Shallow Quaternary Alluvia are described separately in the following sections.

2.1.1.1 Shallow Aquifers

The majority of samples from this group are from Main Range Volcanics (122), limited groundwater quality data were available for Doncaster (1), Griman Creek (2) and Wallumbilla aquifers (3).

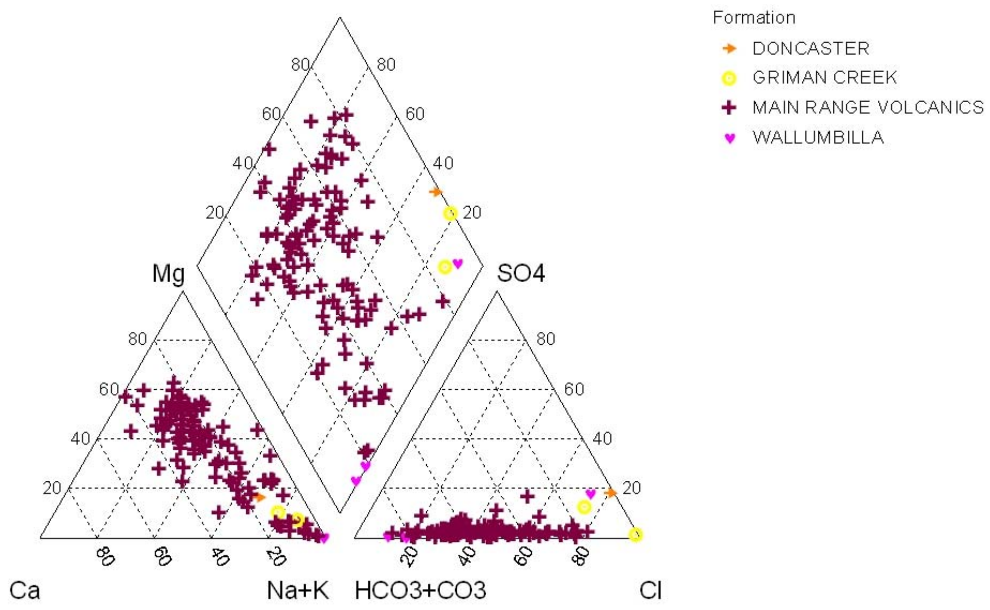

Figure 2: Piper Plot - Shallow Unit excluding Quaternary Alluvial Aquifers

The relative ionic composition of ground-water samples collected from wells in the study area is plotted on a trilinear diagram in Figure 2. Compared to Griman and Doncaster alluvial aquifers groundwater from the Main Range Volcanics appears to have the higher proportions of magnesium, calcium.

The pH of groundwater in the Shallow Aquifers varied from slightly acidic (pH 6.2) to alkaline (pH 9.4) and measured conductivity ranged from 355 µS/cm to 15,500 µS/cm (Figure 3). Sodium concentrations in shallow aquifers varied from 6 mg/L to 3,969 mg/L, however the majority of the observed concentration varied from 57 mg/L up to 396 mg/L (Table 3). The highest concentration of sodium was observed in the Doncaster, Griman and Wallumbilla aquifers. Bicarbonate concentrations ranged from below detection to 1,250 mg/L (436 mg/L average) and carbonates from below detection up to 109 mg/L. Chloride concentrations in 90% of samples varied from 78mg/L to 723 mg/L. Sulphate concentrations in majority of samples did not exceed 49 mg/L. Fluoride concentrations reached up to 4.5 mg/L. The highest concentration of fluoride was observed in the Wallumbilla aquifer.

Table 3: Summary of groundwater quality in Shallow Aquifers (Q10 -10th percentile, Q50-median, Q10-90th percentile; LOR – limit of reporting)

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
pH	-	6.2	9.4	7.5	-	-	-	117
Conductivity	µS/cm	355	15500	1686	612	1400	2546	119
Calc TDS	mg/L	297	14651	1309	482	1078	1816	128
Ca	mg/L	1.5	762	80	10	63	136	128
Mg	mg/L	0.3	520	78	4.8	68	141	121
Na	mg/L	6	3969	220	57	110	396	128
Cl	mg/L	31	7170	401	78	216	723	127
HCO_3	mg/L	<LOR	1250	436	182	446	689	128
CO_3	mg/L	<LOR	109	7.0	0.51	2.7	11	91
SO_4	mg/L	<LOR	2156	43.6	2.35	12.3	49	115
F	mg/L	<LOR	4.5	0.4	0.1	0.3	1.0	118

2.1.1.2 Quaternary Alluvial Aquifers

Quaternary alluvial aquifers included 450 samples from Condamine, 37 samples from Oakey, 13 samples from Moola, 11 samples from Myal, 9 samples form Canal, 4 samples from Thanes, 3 samples from Jimbour, 2 samples from Cattle and Charleys and one sample from Spring and Stuart Creek alluvial aquifers.

The relative ionic composition of ground-water samples from alluvial aquifers is plotted on a Piper diagram in Figure 3. The majority of the Condamine River Alluvium is dominated by sodium and bicarbonate. Moola alluvium appears to have a higher proportion of magnesium. Identified groundwater groups include a range of water types from sodium- magnesium- bicarbonate-chloride to sodium-bicarbonate and sodium-chloride waters.

The pH of groundwater in the alluvial aquifers varied from slightly acidic (pH 6.2) to alkaline (pH 8.9) and conductivity ranged from 335 µS/cm to 13,500 µS/cm (Table 4).

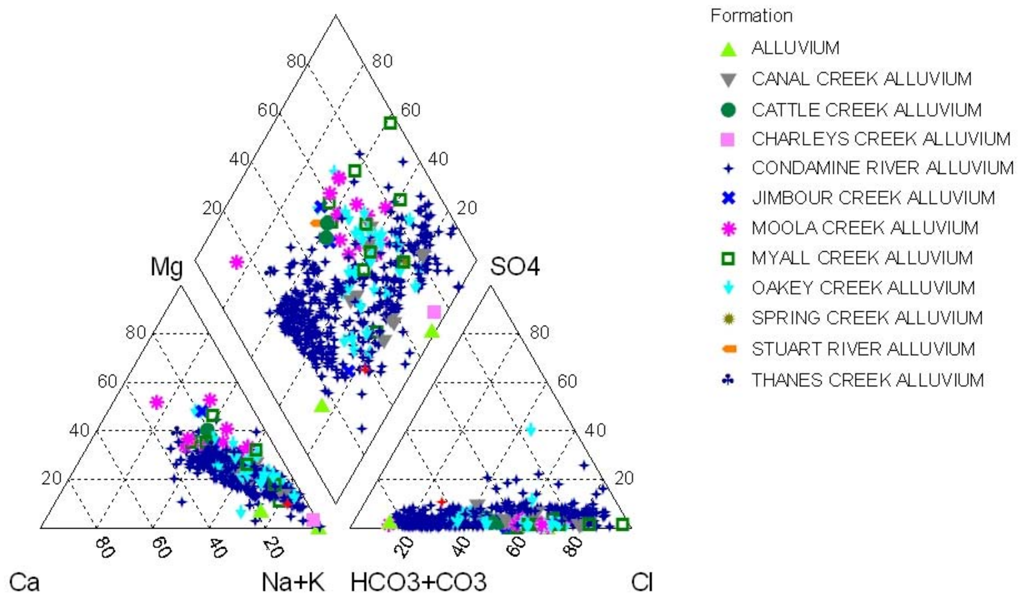

Figure 3: Piper Plot - Shallow Quaternary Alluvia

Statistical analysis of groundwater chemical composition is presented in Table 4. Sodium concentrations in the majority of samples ranged from 79 mg/L to 672 mg/L. The highest sodium concentration (2220 mg/L) was observed in the Condamine River alluvium. In majority of samples magnesium and calcium concentrations did not exceed 100mg/L. Bicarbonate concentrations ranged from below detection to 1,036 mg/L (411 mg/L average) and carbonates from below detection up to 373 mg/L. Chloride concentrations in 90% of samples varied from 34mg/L to 4,800 mg/L. Sulphate concentrations in the majority of samples did not exceed 110 mg/L. Fluoride concentrations ranged from below detection up to 1.95 mg/L.

Table 4: Summary of groundwater quality in Quaternary Alluvial aquifers (Q10 -10th percentile, Q50-median, Q10-90th percentile; LOR – limit of reporting)

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
pH	-	6.5	8.9	7.7	-	-	-	484
Conductivity	µS/cm	335	13500	1767	640	1050	3700	492
Calc TDS	mg/L	219	7683	1277	521	849	2501	525
Ca	mg/L	1.2	650	52.7	20	42	89	525

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
Mg	mg/L	<LOR	590	47.3	15	33	92	510
Na	mg/L	25	2220	290	79	150	672	524
Cl	mg/L	34	4800	405	53	155	1041	525
HCO_3	mg/L	<LOR	1036	411	250	408	590	520
CO_3	mg/L	<LOR	373	13.4	0.76	3.4	15	416
SO_4	mg/L	<LOR	710	41.8	3.07	15	110	487
F	mg/L	<LOR	1.95	0.2	0.1	0.15	-	475

Groundwater salinity distribution in the Shallow Unit (Shallow and Quaternary alluvia) is presented in Figure 4. Based on calculated TDS concentrations, groundwater in shallow aquifers is mostly fresh (54%) to slightly brackish (40%). Brackish groundwater was observed in a few wells (6%) located west and south west of the studied area (Doncaster Formation; Griman and Myall Creek Alluvium).

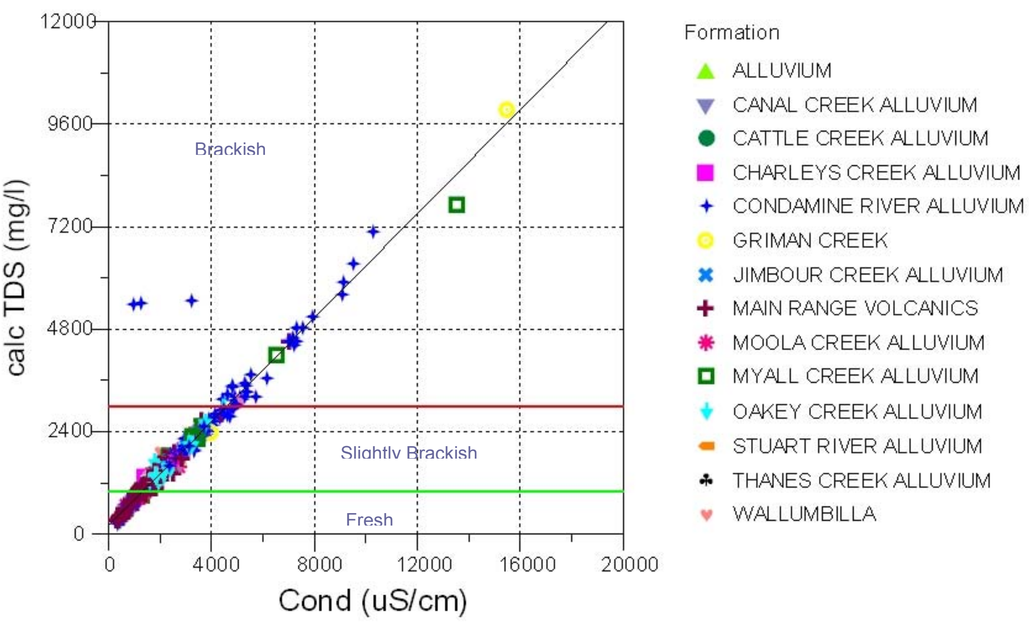

Figure 4: TDS vs Conductivity for Shallow Unit and Shallow Quaternary Alluvia

2.1.2 Intermediate Unit

The Intermediate Unit is represented by the Mooga Sandstone, Orallo Formation, Gubberamunda Sandstone and Kumbarilla Formation and Southlands Formation. The majority of groundwater samples were collected from the Mooga (60) and Kumbarila (34) Formations. Only one sample of groundwater was available for the Southland Formation.

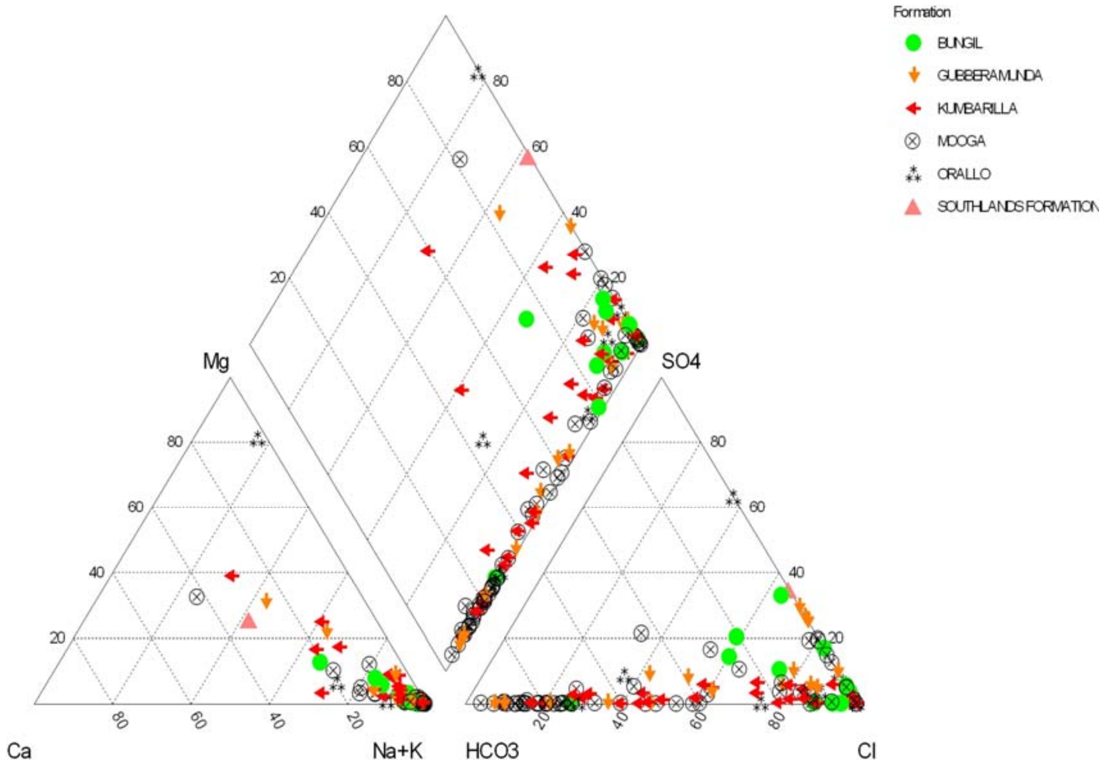

Figure 5: Intermediate Unit

Groundwater in this aquifer unit is generally dominated by sodium-bicarbonate-chlorite; sodium-bicarbonate, sodium-chloride-bicarbonate and sodium-chloride waters (Figure 5). Groundwater from the Bungil Formation can be classified as sodium-chloride type. The majority of Mooga groundwater is sodium-bicarbonate(-chloride) types. The Kumbarilla Formation plots in the area of sodium-chloride(-bicarbonate) types.

The pH of groundwater in the Intermediate Unit ranged from slightly acidic to alkaline with the majority of values from 7 to 9. The relationship between EC and TDS are presented in Figure 6. Groundwater in the intermediate aquifer is mostly slightly brackish (65%) and brackish (19%). Only 16% of samples could be classified as fresh groundwater.

Groundwater chemical composition is summarised Table 5. Sodium concentrations in the Intermediate Unit fall in the range from 31 mg/L to 4,290 mg/L (727 mg/L average). Bicarbonate concentrations ranged from below detection to 1,250 mg/L (461 mg/L average) and carbonates from below detection to 558 mg/L. Chloride concentrations in 90% of samples varied from 67mg/L to 1936 mg/L. Sulphate concentrations in the majority of samples did not exceed 220 mg/L. Fluoride concentrations varied from below detection up to 7.6 mg/L with majority of samples having the concentration range from 0.1 to 3 mg/L.

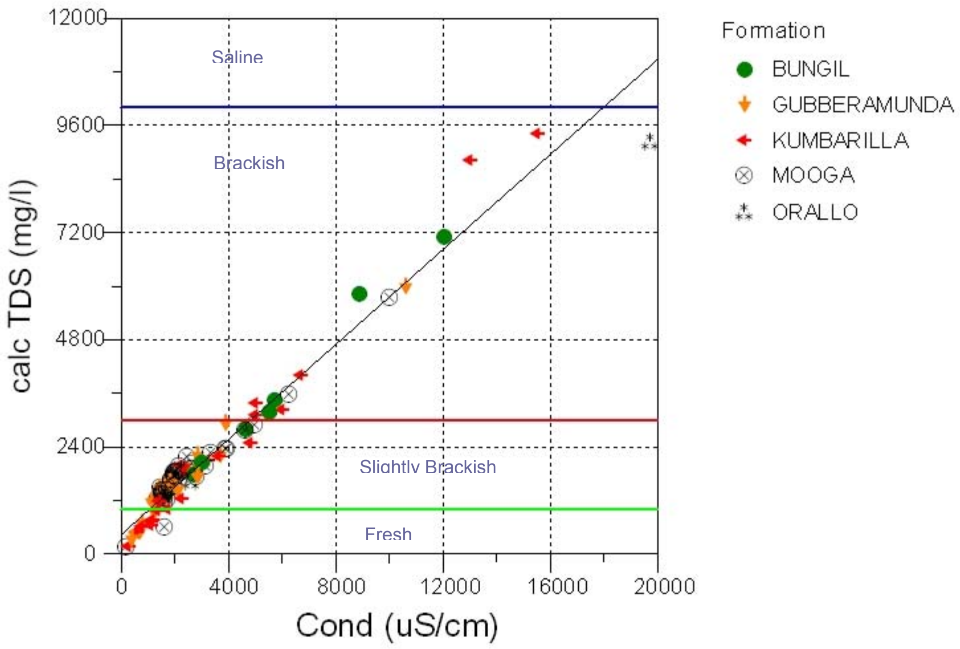

Figure 6: TDS vs EC for groundwater from Intermediate Unit

Table 5: Summary of groundwater quality in Intermediate Unit (Q10 -10th percentile, Q50-median, Q10-90th percentile; LOR – limit of reporting)

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
pH	-	5.6	11	7.5	-	-	-	117
calc TDS	mg/L	147	13293	2274	787	1711	3962	134
Conductivity	µS/cm	176	19700	2381	1098	1775	4985	106
Ca	mg/L	<LOR	688	46.3	1.6	4.4	112	132
Mg	mg/L	<LOR	502	21.6	<LOR	1.4	68	132
Na	mg/L	31	4290	727	187.4	510	1433	134
Cl	mg/L	<LOR	7631	836	66.8	350	1936	134
HCO_3	mg/L	<LOR	1250	461	<LOR	382	1001	133
CO_3	mg/L	<LOR	558	71	0.9	20.8	249	121
SO_4	mg/L	<LOR	2198	106	<LOR	4.4	220	131
F	mg/L	<LOR	7.6	1	0.1	0.6	3	126

2.1.3 Walloon Unit

The aquifers within the Walloon Unit include Birkhead, Eurombah, Injune Creek and the Walloon Coal Measures (WCM). Piper diagram showing data grouping is presented on Figure 7. 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 sodium-chloride types with a small proportion of sodium-bicarbonate-chloride and sodium-chloride-bicarbonate types.

Most of the groundwater samples from the Walloon Coal Measures (WCM) can be classified as sodium-chloride-bicarbonate type (32%) followed by sodium-chloride (24%) and sodium-bicarbonate types (17%).

The remaining groundwater samples (27%) appear to have variable composition due to contribution of calcium and magnesium. Those wells are generally located in the north-east portion of the studied area.

The pH of groundwater from the Walloon Formation ranged from 5.8 to 11.4 with an average of 7.4.The lowest pH was observed in groundwater from the Birkhead beds and the highest pH from WCM.

Conductivity of the Walloon Formation varied from 270 μS/cm to 31,000 μS/cm with an average of 3960 μS/cm (Table 6). The scatter plot of TDS concentration and EC presented on Figure 8 indicates that groundwater from the WCM, Injune Creek and Erombah is mostly brackish. The most saline groundwater was observed in Birkhead and WCM Formations.

The summary of groundwater chemical composition is presented in Table 6. Sodium concentrations for the Walloon Formation fall in the range from 56 mg/L to 6,950 mg/L (873 mg/L average), while bicarbonate concentrations ranged from below detection to 1,850 mg/L (420 mg/L average) and carbonates from below detection to 362 mg/L. Chloride concentrations vary from 35 mg/L to12,770 mg/L with an average of 1318 mg/L. Ninety percent of samples appear to have concentration of sulphate lower than 121 mg/L. Fluoride concentrations varied from below detection to 4.3 mg/L.

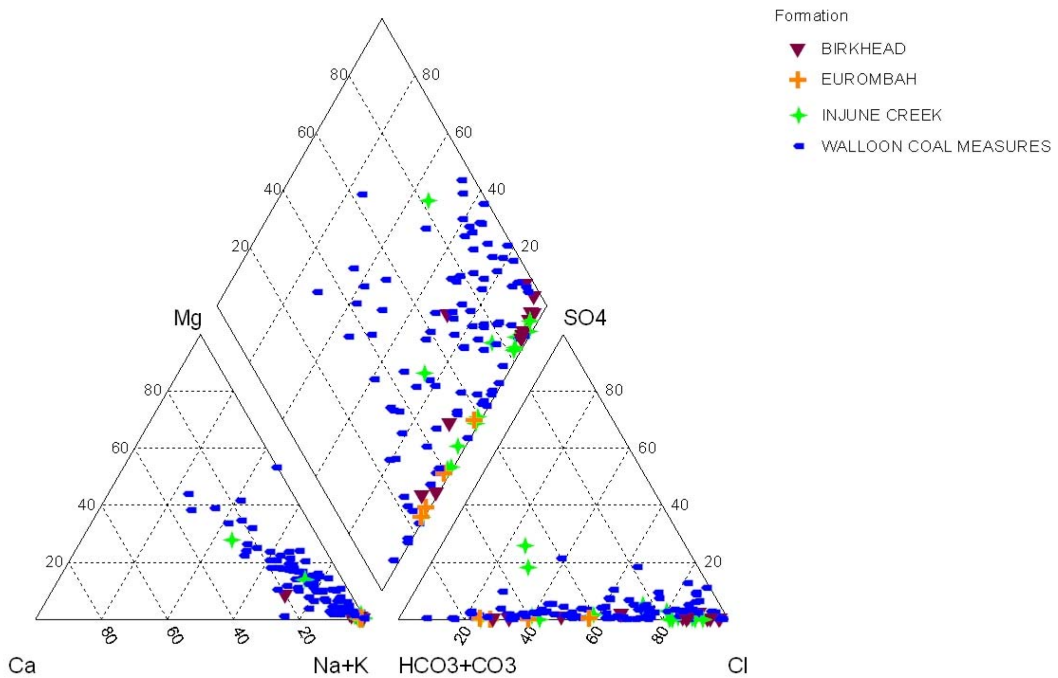

Figure 7: Piper diagram of the Walloon Unit

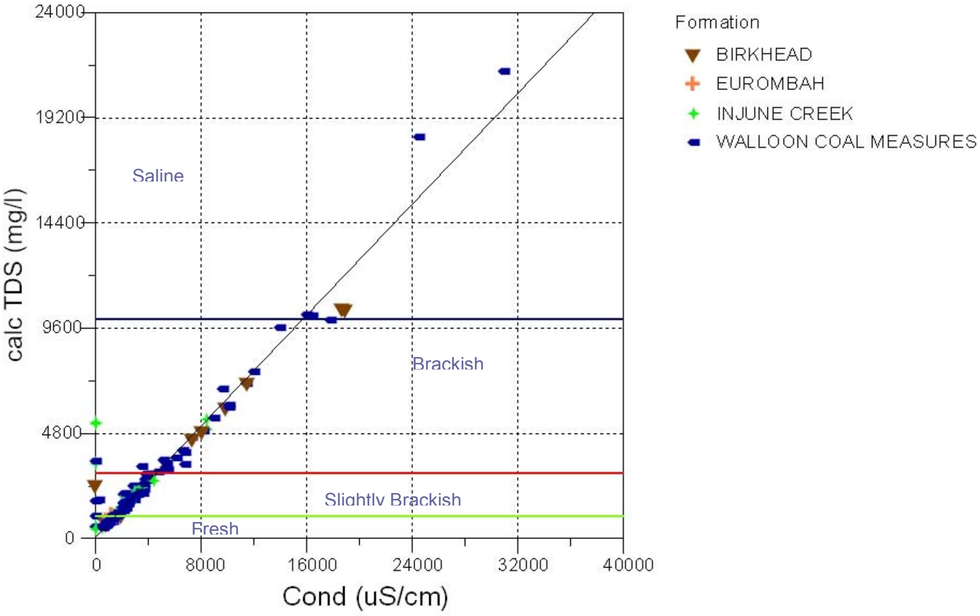

Figure 8: Conductivity vs TDS in groundwater from Walloon Units (excluding production wells)

Table 6: Summary of groundwater quality in the Walloon Unit (Q10 -10th percentile, Q50-median, Q10-90th percentile; LOR – limit of reporting)

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
pH	-	5.5	11.4	7.4	-	-	-	120
calc TDS	mg/L	164	21263	2820	603	1725	5960	139
Conductivity	µS/cm	270	31000	3960	545	2280	9900	121
Ca	mg/L	<LOR	925	72	2.9	28.6	147	138
Mg	mg/L	<LOR	850	54	0.81	14.4	125	131
Na	mg/L	56	6950	873	135	513	2031	139
Cl	mg/L	35	12770	1318	95.9	560	3355	139
HCO_3	mg/L	<LOR	1850	420	175	375	785	136
CO_3	mg/L	<LOR	362	29	0.98	5.85	79	109
SO_4	mg/L	<LOR	1650	61	<LOR	10	121	125
F	mg/L	<LOR	4.3	0.63	0.1	0.3	1	122

2.1.4 Hutton and Precipice Formations

Major aquifers within the Hutton Unit include Evergreen, Hutton Sandstone and Marburg Sandstone. Major ion composition indicates that groundwater from the Marburg sandstone aquifer is dominated by sodium-chloride type (Figure 9). With the exception of one sample, groundwater from the Hutton Formation appears to have a range of water types between sodium-bicarbonate to sodium-chloride. The majority of groundwater from the Precipice Formation is sodium-bicarbonate type.

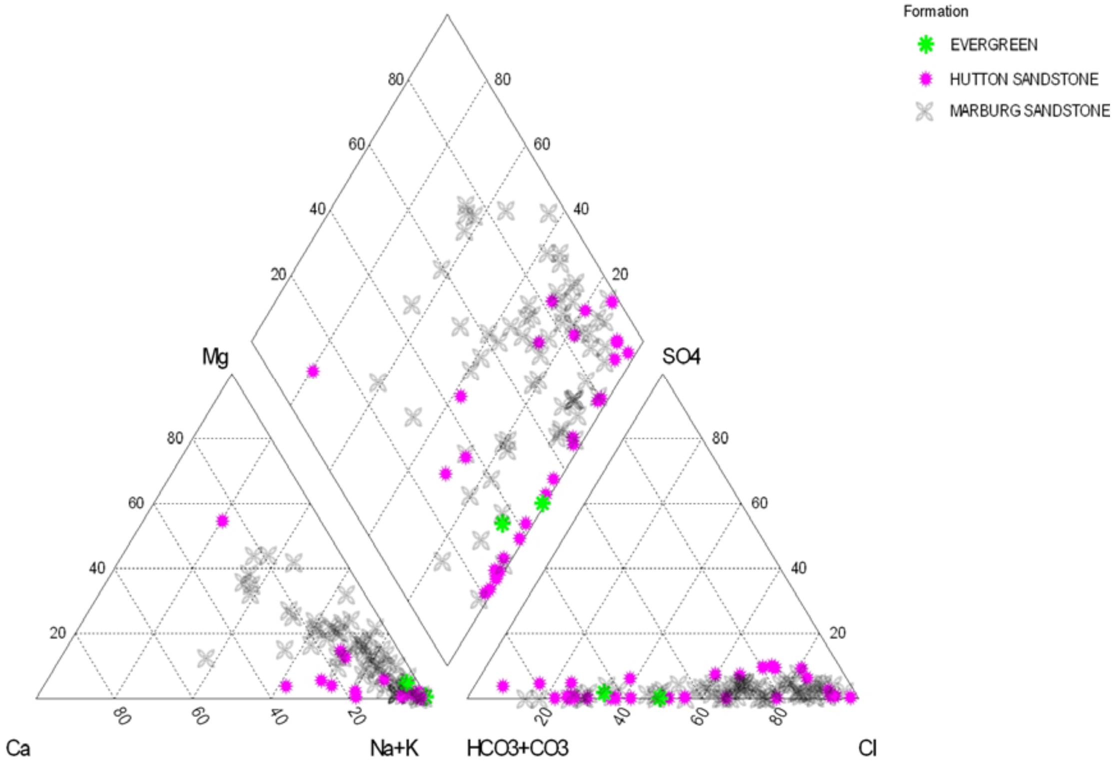

Figure 9: Piper diagram of Hutton Formation

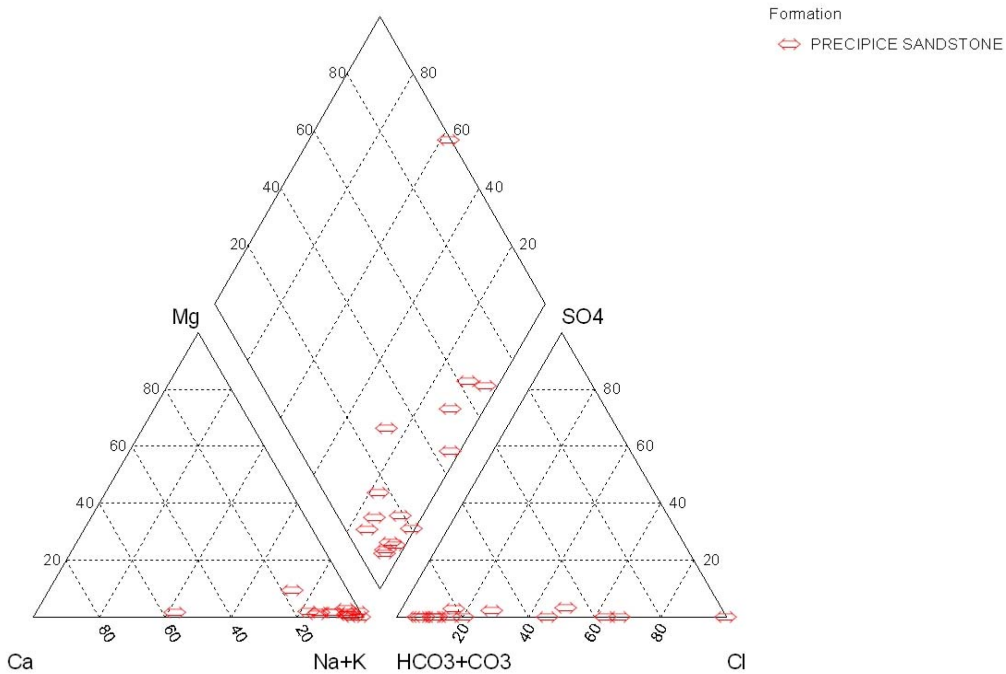

Figure 10 Precipice Formation

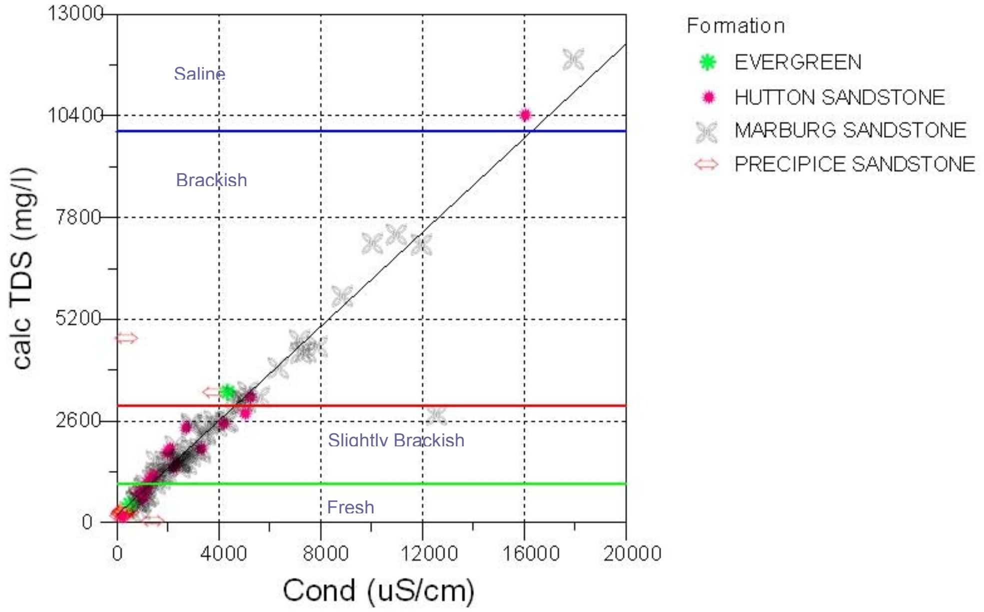

Figure 11: TDS and Conductivity of Hutton and Precipice Formations

TDS concentrations on Figure 11 indicate that groundwater from the Hutton, Evergreen, and Precipice Formations is mostly fresh to slightly brackish. The Marburg Sandstone aquifer appears to have variable salt content ranging from fresh to saline with the majority of groundwater plotting in the slightly brackish field.

The range of major ion concentrations in groundwater from the Hutton Formation is summarised in Table 7 and from the Precipice beds in Table 8. As already described above, groundwater composition in both formations is dominated by sodium, chloride and bicarbonate. Sulphate concentrations in the Precipice Formation appear to be the lowest from all the studied aquifers.

Table 7: Summary of groundwater quality in Hutton Formation (Q10 -10th percentile, Q50-median, Q10- 90th percentile; LOR – limit of reporting)

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
pH	-	6.2	9.4	7.46	-	-	-	99
calc TDS	mg/L	120	11867	2125	600	1593.5	3589	106
Conductivity	µS/cm	167	18000	3018	810	2050	6872	74
Ca	mg/L	1.5	287	60	3	33	171	106
Mg	mg/L	<LOR	400	51	1	16.5	131	106
Na	mg/L	24	4000	608	139	490	1101	106
Cl	mg/L	12	6300	885	120	540	1850	106
HCO_3	mg/L	<LOR	1447	420	22	384	735	106
CO_3	mg/L	0	583.4	48	0.62	5.6	194	77
SO_4	mg/L	<LOR	440	48	<LOR	21	126	96
F	mg/L	<LOR	4.5	0.7	0.1	0.3	2	98

Table 8: Summary of groundwater quality in Precipice Formation (Q10 -10th percentile, Q50-median, Q10- 90th percentile; LOR – limit of reporting)

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
pH	-	6.7	8.8	7.38	-	-	-	15
calc TDS	mg/L	175	11730	1604	194	324	4008	15
Conductivity	µS/cm	200	3840	507	200	264	680	12
Ca	mg/L	1	2332	172	1	6	86	15
Mg	mg/L	<LOR	43	5	<LOR	1	8	15
Na	mg/L	42	2003	368	49	73	1118	15
Cl	mg/L	8	7313	625	8	32	694	15
HCO_3	mg/L	<LOR	3103	389	<LOR	148	728	15
CO_3	mg/L	0.1	182	32	0.14	1.1	93	14
SO_4	mg/L	<LOR	19	3	<LOR	<LOR	8	15
F	mg/L	0.17	0.9	0.53	0.17	0.54	-	15

2.1.5 CSG Production Wells

Production wells included the Aberdeen, Argyle, Berwyndale and Berwyndale South, Lawton, Pinelands, Ridgewood and Trafalga wells. Samples were also taken from the Avon Downs and Berwyndale South ponds. The Piper diagram showing data grouping is presented in Figure 12. Groundwater from production wells includes water types ranging from sodium-bicarbonate to sodium-chloride waters. Groundwater from Avon Downs, Lawton, Pinelands and Trafalga are classified as sodium-chloride type. Sodium-bicarbonate types were observed at Aberdeen and Argyle wells.

The pH of groundwater from the poduction wells ranged from 7.6 to 12 with an average of 8.2.The highest pH was observed at Pinelands Well 3. Conductivity varied from 1,200 µS/cm to 20,000 µS/cm with an average of 6,249 µS/cm (Table 9). Scatter plot of TDS concentrations and observed EC presented in Figure 13 indicate that groundwater from production wells is mostly slightly brackish to brackish. Groundwater from Aberdeen Well 1 had the lowest concentration of TDS and can be classified as fresh water. Groundwater salinity in production wells increased in the order of Aberdeen < Argyl < Berwyndale < Pinelands = Ridgewood < Lawton < Trafalga.

A summary of groundwater chemical composition is presented in Table 9. Sodium concentrations ranged from 290 mg/L to 4,000 mg/L, calcium ranged from 1mg/L to 240 mg/L with the majority of concentrations between 3 mg/L and 68 mg/L. Magnesium concentrations appear to be much lower and did not exceed 30 mg/L. Chloride ranged from 150 mg/L to 5,700 mg/L. Bicarbonate concentrations were in the range from 5 mg/L to 1,546 mg/L. Sulphate concentrations varied from 2 mg/L to 350 mg/L with the majority of the data in the range from 5 mg/L to 50 mg/L.

Table 9: Summary of groundwater quality for CSG Production Wells

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	Num Samples
pH	-	7.6	12	8.2				57
calc TDS	mg/L	792	10177	4091	1535.8	2679.5	8416	57
Conductivity	µS/cm	1200	20000	6249	1880	3500	13300	57
Ca	mg/L	1	240	27.9	3	10.5	68	57
Mg	mg/L	1	30	5.1	1	1.5	15	57
Na	mg/L	290	4000	1454	498	935	3030	57
Cl	mg/L	150	5700	1705	210	600	4790	57
HCO_3	mg/L	5	1546	719	195	654.5	1288	57
CO_3	mg/L	1	1793	128	4.7	63	242	57
SO_4	mg/L	2	350	30.6	5	10	50	57

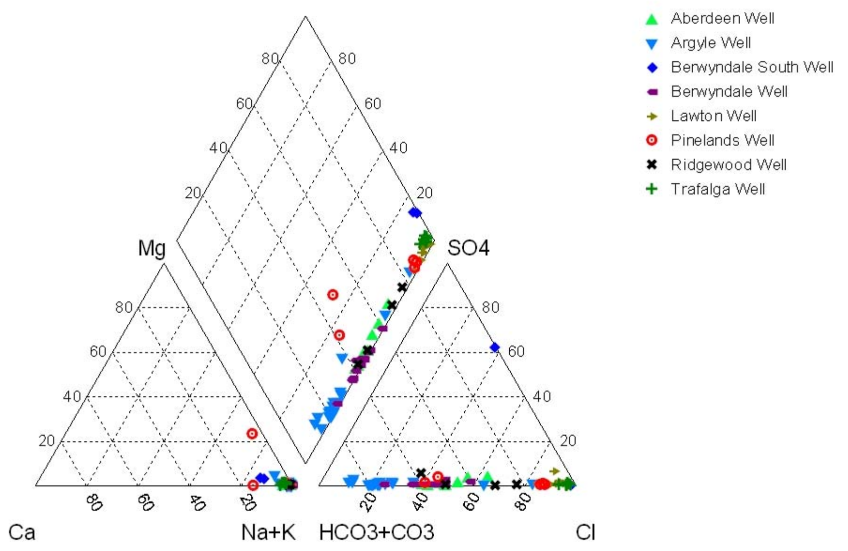

Figure 12: Piper diagram of groundwater from productions well

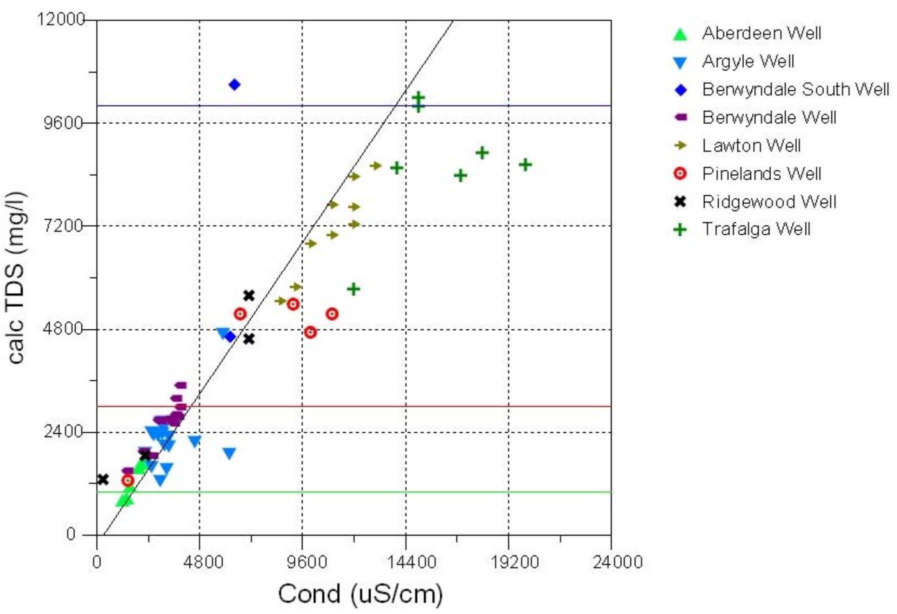

Figure 13: Conductivity vs TDS in groundwater from production wells

2.1.6 Spatial and vertical trends

In general, groundwater in GAB aquifers is characterised by sodium-bicarbonate type throughout the eastern and central parts of the basin and sodium-sulphate-chloride type in the western part. Sodium and bicarbonate increase in concentration from the north-eastern outcrop margins to the south-western discharge areas along the regional groundwater flowpath (Herzeg, 1991).

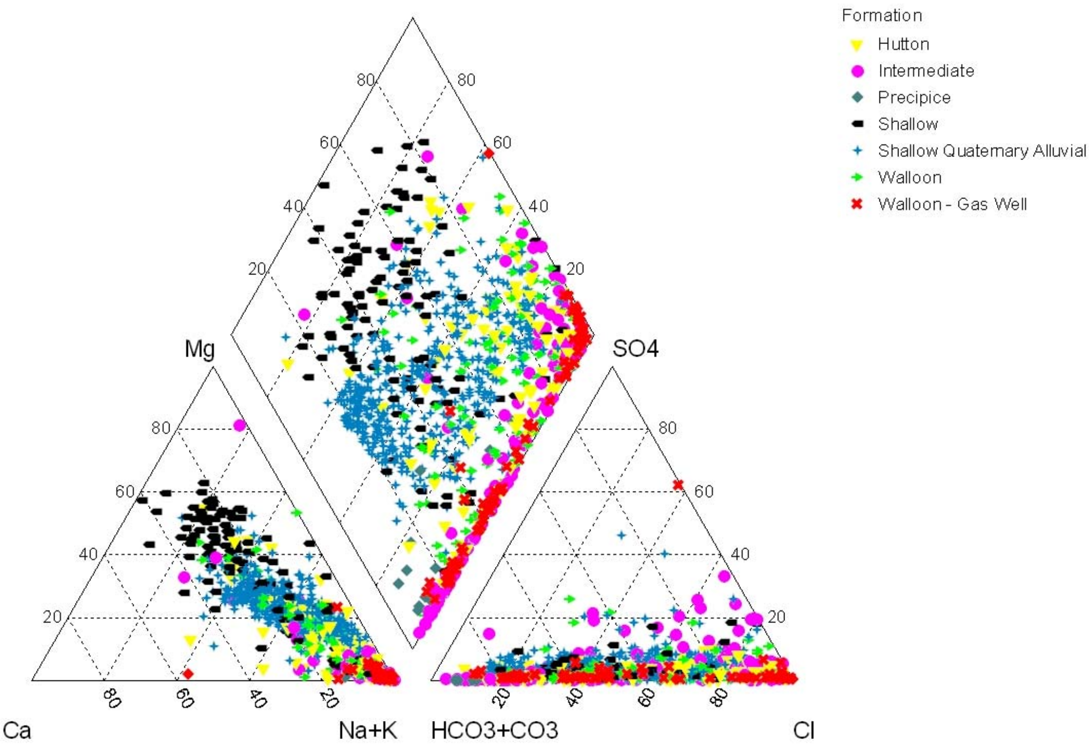

Figure 14: Piper plot of all groundwater samples

Figure 14 compares all groundwater units/formations in the studied area. Sodium content in groundwater is generally increasing in the order Shallow Unit < Shallow Quaternary Alluvia < Walloon Unit = Hutton/Precipice < Intermediate Unit < Production Wells. The Intermediate Unit appears to have the highest and CSG Production Wells the lowest proportion of sulphates.

Observed groundwater pH ranged from slightly acidic (pH 5.5) to alkaline (pH 11.4). Both minimum and maximum pH values were observed in the Walloon unit. The majority of groundwater samples were neutral to alkaline with pH values in the range from 7 to 9. One groundwater sample from production wells appears to have pH of 12 (Pinelands well) which was considered to be affected by well construction.

Water quality in the main aquifers varies from fresh to saline with calculated total dissolved solids (TDS) varying between 53 mg/L and 31,884 mg/L. Approximately 41 % of the groundwater samples can be classified as fresh with TDS values less than 1,000 mg/L. The majority of groundwater samples are slightly brackish (46%) with TDS concentration in the range from 1,000 to 3,000 mg/L. Brackish and saline groundwater is less common and contributed to 12% and 2% of the all analysed samples, respectively.

Groundwater quality in the production wells changes from brackish and sodium-chloride type in the north-western portion of the studied area to fresh and slightly brackish and sodium-bicarbonate type in the south-eastern portion of the studied area. Increased salinity in the north-western potion can be explained by deeper burial of WCM compared to the eastern and south-eastern portion of the studied area.

2.2 Geochemical Processes

Groundwater quality variations throughout the GAB are due to heterogeneity in sediment deposition and composition, groundwater residence time, and depth and direction of groundwater flow. Chemical model accounting for observed water-quality in the studied area include dissolution and precipitation of minerals, cation exchange reactions with clay and redox processes involving organic matter, sulphate and carbon dioxide.

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. Figure 15 indicates that sodium concentrations in groundwater are generally higher than can be expected for marine sediments and lower than it would be expected by dissolution of halite. This could be attributed to cation exchange reactions where calcium and magnesium in the water are exchanged for sodium that was adsorbed to aquifer solids such as clay minerals, resulting in higher sodium concentrations. As shown in Figure 16 reverse cation exchange (Na to solution, Ca and Mg to clays) is controlling groundwater composition in the majority of Walloon and Intermediate and Lower Units (Hutton and Precipice).

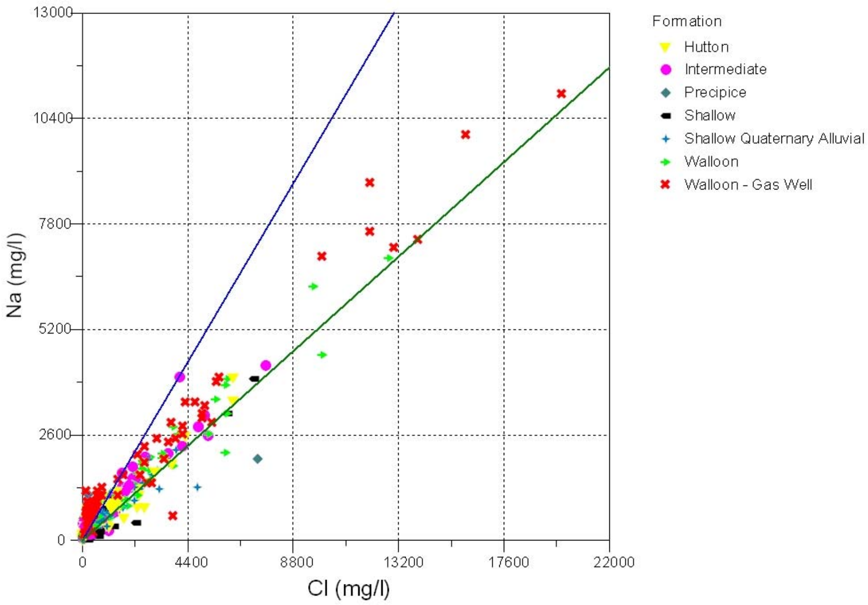

Figure 15: Na vs Cl scatter plot (blue line – halite dissolution, green line - seawater line)

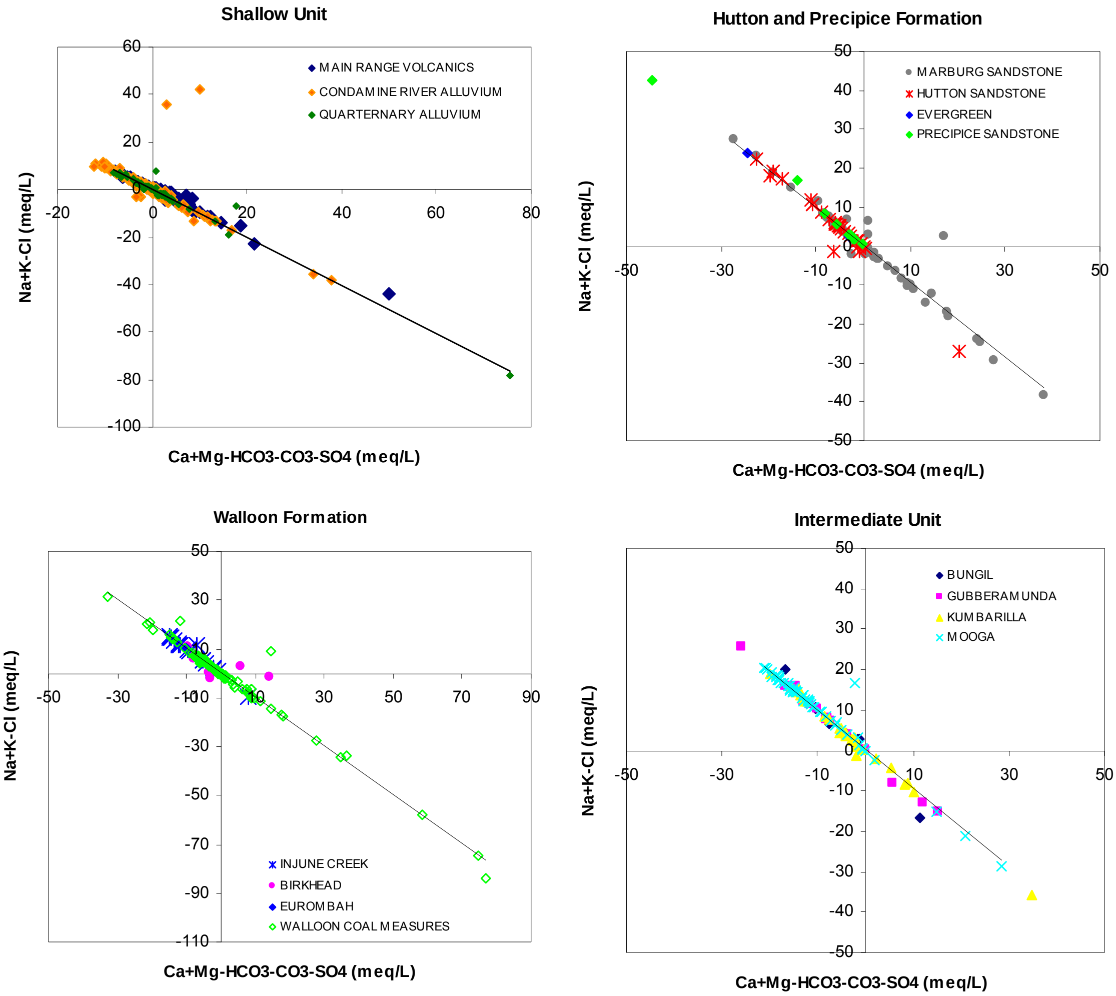

Figure 16: Ion Exchange Reactions in the Studied Aquifers (excluding production wells)

Compared to conservative chloride, which does not participate in chemical reactions, concentration of sulphate in groundwater may be affected by precipitation/dissolution of common sulphate minerals (gypsum and anhydrite) and redox reactions related to the anaerobic decomposition of organic matter.

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 this distinctive type include sulphate reduction and production of bicarbonates and depletion of calcium and magnesium through precipitation and/or ion exchange reactions. Similarities in chemical composition of CSG production water from various parts of the world indicate that standard water type can be expected within CSG beds irrespective 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).

2.3 Comparison of groundwater quality to regulatory standards

2.3.1 Public Supplies and Domestic Use

Australian drinking water guidelines (2004) established drinking-water regulations for public supplies of drinking water. The regulations specify:

- A health-related guideline value, which is the concentration which does not result in any significant risk to the health of the consumer over a lifetime of consumption.
- An aesthetic guideline value is the concentration associated with acceptability of water based on appearance, taste and odour.

Assessment criteria for public supplies and domestic use compared to collected data are presented in Table 10. Dissolved solids, sodium and chloride appear to have the highest percentage of exceedance (Table 10). More than 60 percent of samples exceeded drinking water standards with the majority of groundwater samples from Shallow Quaternary Alluviums, Walloon Formation and Intermediate Unit. Fluoride concentrations were above the 1.5 mg/L acceptance criteria in 7% of samples with majority of exceedances in groundwater from the Intermediate Unit.

Table 10: Comparison of ground-water-quality samples with standards for drinking water (ADWG, 2004)

Analyte	Drinking water standard (mg/L; except of pH)	No of samples exceeded standard
Chloride	250**	51% (564 out of 1113)
Fluoride	1.5*	7% (66 out of 965)
Sodium	180**	60% (664 out of 1113)
Sulphate	250** 500*	3.4% (35 out of 1037) 1.2 % (12 out of 1037)
TDS	< 500 – good quality 500-1,000 – acceptable based on taste >1,000 – excessive scaling, corrosion, unsatisfactory taste	7 % (81 out of 1114)*** 34% (380 out of 1114)*** 59% (653 out of 1114)***
pH	6.5 - 8.5	12% (129 out of 1119)

* - health value, ** aesthetic value, ***number of samples complying with standard

Hardness is a water-quality characteristic commonly used to characterize the suitability of water for public-supply and domestic use. Hardness is characterized on the basis of four classes as presented in Table 11 (ADWG, 2004). Approximately 21% of analysed samples represent soft groundwater and 24% are of good quality. The majority of groundwater in the studied area would be classified as hard to very hard with increased (35%) or severe (19%) scaling.

Table 11: Hardness classification of groundwater quality

Total Hardness as CaCO3 (mg/L)	Hardness Classes	Percent of Samples
<60	Soft, but possibly corrosive	21
60-200	Good quality (moderately hard)	24
200-500	Increasing scaling problem (hard)	35
>500	Severe scaling (very hard)	19

2.3.2 Agricultural Use

Agricultural use includes crops irrigation and livestock watering. The irrigation quality classification system is based on two characteristics:

- salinity hazard; and
- sodium (alkali) hazard of the water.

Both parameters are divided into 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:

$$SAR = Na/\sqrt{(Ca+Mg)/2}$$

The characteristics of the salinity and sodium hazard classes are presented in Table 12 and Table 13. Salinity hazard and sodium hazard are combined into a single plot to evaluate the suitability of water for irrigation (Figure 17). Approximately 22 % of groundwater samples produced SAR values above 32 and these are not included in the plot.

Table 12: 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 13: 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 17 suggests that samples collected from wells completed in all aquifers plot in a wide range of both sodium and salinity-hazard classes, however most samples cluster in or near the high salinity hazard (C3-C4) and low to high sodium hazard (S1-S3) class. Most of the shallow aquifer samples plot in the range of high salinity - low sodium hazard. Increasing trend of sodium hazard with increasing salinity can be observed for Shallow Quaternary Formations. Precipice Formation can be classified as groundwater with the lowest salinity hazard (C1-C2 class).

In summary, approximately 98% of groundwater from Production Wells, 75% of groundwater from Intermediate Unit, 40% from Walloon Unit were classified as S4 class and would not be suitable for irrigation. On the other hand only 2% of groundwater from Shallow Quaternary Alluvia and 7% of Shallow Unit would pose very high sodium hazard (Class S4).

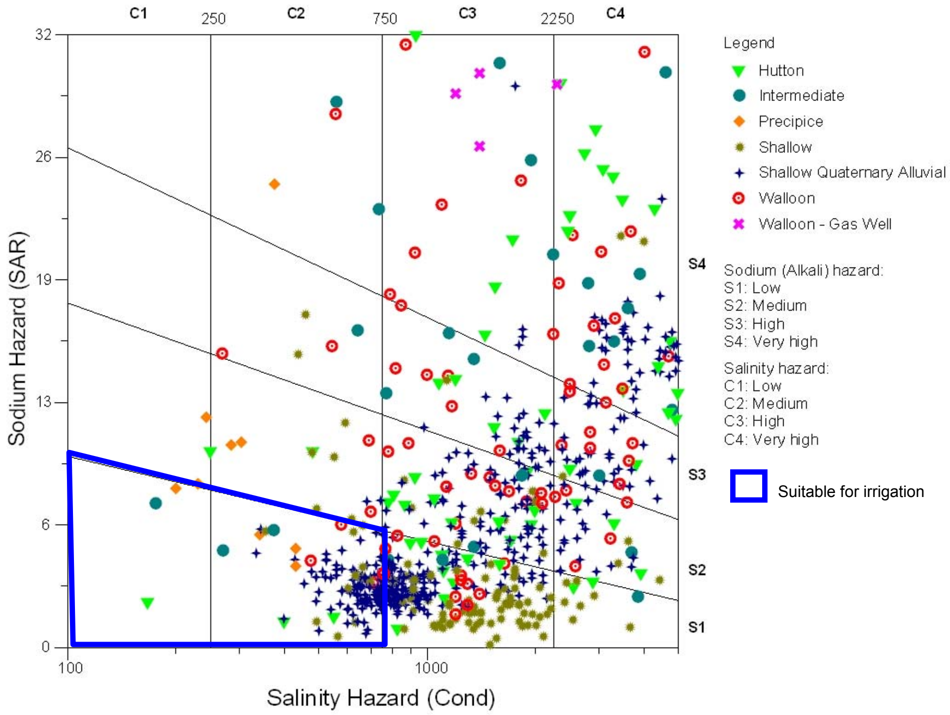

Figure 17: Salinity and sodium hazard classes

Recommended concentrations of TDS in drinking water for livestock are given in Table 14. Up to 80% of groundwater samples would be suitable for watering of dairy cattle (TDS <2,500 mg/L) and 91% of groundwater samples for watering of beef cattle (TDS < 4,000 mg/L). Groundwater exceeding 13,000 mg/L of TDS was observed in few samples from Walloon Unit, Doncaster and Mooga Formations.

Table 14: 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

3.0 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 F

List of Registered Bores in the Water Management Zone

APPENDIX F - LIST OF EXISTING REGISTERED BORES CONSIDERED FOR MONITORING

This study has recommended (Sections 8 and 10) that:

- An appropriate selection of *existing bores* (irrigation, farm or domestic water supply, stock watering and other industrial bores), screened in the key identified aquifer (Springbok Sandstone, Precipice Sandstone and Hutton Formation) should be for ongoing routine monitoring to assess any groundwater impacts *within and outside* the CSG extraction operation area (CDA, SEDA and NWDA).

Therefore, it is recommended that as part of the water management and monitoring strategy for the Project, water level and water quality monitoring be carried out in and beyond the boundaries of the CSG well fields. Table F-1 and Figure 38 to Figure 42 present those private bores from which the selection should be made for ongoing monitoring.

As part of the 'Groundwater Bore Inventory' (Golder, 2009c), a number of these bores have been visited and specific bore information collected. The following presents an interpretation of the information presented in Table F-1:

- Twelve of the bores identified in the list are not available for monitoring (i.e., the landowner has declined to participate). A majority of these wells are completed in the WCM and are located east of CDA and north of SEDA. The owners of one Precipice and three Hutton Unit bores refused access to their site and the bore concerned.

- Twelve bores completed in the Gubberamunda Sandstone are potentially available for long-term monitoring. These bores are all located in the NWDA. It is recommended further Gubberamunda bores be identified for monitoring, which are located near the CDA and SEDAs.

- Nineteen bores completed in the WCM are potentially available for long-term monitoring. One of these bores are located near the NWDA, the rest to the north and northeast of the CDA and SEDA.

- There are three bores on the list that are completed in the Springbok Sandstone. Two of the bores were monitored as part of the bore inventory, and it is recommended that these bores be considered as part of the long-term monitoring program. The landowner could not be contacted for the third Springbok Sandstone bore.

- Many of the wells identified as being completed in the Injune Creek Group, could potentially span across the Springbok and/or Walloon Coal Measures. This can not be confirmed due to the incompleteness of the stratigraphic information available for many of the bores.

- Three bores were identified in the Precipice Sandstone. One was not part of the original bore inventory, and the landowner refused participation for another. RN58285, located in the NWDA, is considered to be a useful bore to monitor. Pumping test data was provided for this bore and a note that gas was present was recorded (also noted was the fact that Pure Energy has CSG extraction bores on the same property). A fourth Precipice bore (no associated RN), located north of EPP651 in the NWDA, was identified through the bore inventory. Field chemistry parameters were collected; however, a water level could not be measured.

- Fourteen bores completed in the Injune Creek Group are potentially available for long-term monitoring. All of these bores are located west of the CDA and within the NWDA.

- Ten bores completed in the Hutton Sandstone (or the equivalent Marburg Sandstone in the South-eastern portion of the study area) are potentially available for long-term monitoring. These bores are distributed across the Project area.
- In addition to including privately owned bores in QGC's monitoring program, this study has further recommended that a number of multilevel vibrating piezometers (VWPs) be drilled and completed in the representative aquifers (Precipice, Hutton, WCM, Springbok and Gubberamunda) within and/or on the Project Area boundaries to ensure the development areas are sufficiently monitored.

Table F-1: Registered bores considered for future ongoing monitoring

Registered Number	Completion Aquifer[1]	Latitude	Longitude	Drilled Date	Potential Monitoring Point[2]
		GDA94			
Hutton Unit					
7138	Marburg Sandstone	-26.70	150.78	01/01/1937	Unable
9577	Marburg Sandstone	-26.76	150.83	01/01/1930	No
10939	Marburg Sandstone	-26.95	150.92	01/08/1946	**Yes**
11169	Marburg Sandstone	-26.96	150.91	24/04/1947	**Yes**
12053	Marburg Sandstone	-26.83	151.00	29/06/1951	nc
12058	Marburg Sandstone	-26.87	150.84	01/03/1951	nc
15755	Marburg Sandstone	-26.57	150.79	06/02/1964	nc
15769	Marburg Sandstone	-26.65	150.77	24/07/1964	nc
15867	Marburg Sandstone	-26.67	150.85	12/04/1964	**Yes**
16845	Marburg Sandstone	-27.46	151.24	01/07/1966	nc
21094	Marburg Sandstone	-26.67	150.96	01/01/1956	nc
21763	Marburg Sandstone	-26.74	150.99	01/01/1958	nc
21825	Marburg Sandstone	-26.85	150.93	01/01/1930	nc
24517	Marburg Sandstone	-26.67	150.81	22/11/1960	**Yes**
30995	Marburg Sandstone	-26.65	150.98	31/01/1969	nc
32314	Marburg Sandstone	-26.89	150.93	18/04/1969	nc
32537	Marburg Sandstone	-26.69	150.91	30/05/1969	nc
38634	Marburg Sandstone	-26.63	150.81	26/08/1972	nc
38906	Marburg Sandstone	-26.62	150.88	23/09/1972	nc
52790	Marburg Sandstone	-26.58	150.75	10/07/1977	nc
55015	Marburg Sandstone	-27.33	151.13	01/03/1978	nc
64329	Marburg Sandstone	-26.60	150.87	01/10/1982	nc
64836	Marburg Sandstone	-26.76	150.85	11/08/1986	**Yes**
83166	Marburg Sandstone	-26.64	150.86	17/09/1987	nc
87546	Marburg Sandstone	-26.60	150.84	27/12/1991	nc
87827	Marburg Sandstone	-26.62	150.86	27/05/1993	nc
87912	Marburg Sandstone	-26.72	150.72	07/02/1986	**Yes**
94261	Marburg Sandstone	-27.05	150.77	02/09/1994	Unable
94982	Marburg Sandstone	-26.65	150.94	12/08/1997	nc
107088	Marburg Sandstone	-26.74	150.92	21/04/1998	Unable
107857	Marburg Sandstone	-26.90	150.65	26/07/2002	nc

Registered Number	Completion Aquifer[1]	Latitude	Longitude	Drilled Date	Potential Monitoring Point[2]
		GDA94			
119000	Marburg Sandstone	-27.21	151.04	n/a	nc
119058	Marburg Sandstone	-26.64	150.76	23/04/2003	nc
137004	Marburg Sandstone	-26.63	150.88	04/08/2005	nc
137249	Marburg Sandstone	-26.67	150.82	27/08/2006	nc
137687	Marburg Sandstone	-26.58	150.88	17/08/2007	nc
13455	Hutton Sandstone	-27.08	150.07	30/06/1956	**Yes**
15508	Hutton Sandstone	-26.26	150.09	17/05/1963	nc
31371	Hutton Sandstone	-26.99	150.88	22/11/1970	**Yes**
58294	Hutton Sandstone	-26.25	149.87	10/04/1987	**Yes**
58335	Hutton Sandstone	-26.29	150.18	17/02/1988	nc
87436	Hutton Sandstone	-26.91	150.79	13/01/1994	No
94029	Hutton Sandstone	-27.07	150.90	10/08/1994	nc
94039	Hutton Sandstone	-26.99	150.86	31/05/1993	nc
123199	Hutton Sandstone	-26.30	149.94	14/04/2007	**Yes**
58604	Evergreen Formation	-26.85	150.24	04/11/1994	nc
87436	Evergreen Formation	-26.91	150.79	13/01/1994	No
94029	Evergreen Formation	-27.07	150.90	10/08/1994	nc
Precipice Unit					
107588	Precipice Sandstone	-27.13	150.69	31/08/1999	No
107689	Precipice Sandstone	-27.53	151.13	06/04/2002	nc
58285	Precipice Sandstone	-26.13	149.53	n/a	**Yes**
	Precipice Sandstone	-26.08	149.72	n/a	**Yes**
Walloon Unit					
15854	Birkhead Formation	-25.99	149.76	01/05/1964	nc
17753	Birkhead Formation	-25.99	149.70	13/11/1967	nc
34708	Birkhead Formation	-26.10	149.67	14/01/1970	No
35966	Birkhead Formation	-26.29	149.83	15/07/1970	**Yes**
58259	Birkhead Formation	-26.13	149.93	16/07/1986	nc
58297	Birkhead Formation	-26.05	149.72	07/04/1987	nc
58300	Birkhead Formation	-26.27	150.18	07/04/1987	nc
58537	Birkhead Formation	-26.04	149.65	13/02/1993	nc
58462	Eurombah Formation	-26.00	149.62	15/08/1991	nc
11000	Injune Creek Group	-26.69	150.07	04/01/1947	**Yes**
11001	Injune Creek Group	-26.68	150.08	23/05/1947	**Yes**
11590	Injune Creek Group	-26.08	149.53	07/06/1948	nc
12763	Injune Creek Group	-26.14	149.96	07/09/1954	nc
13462	Injune Creek Group	-26.42	150.06	21/11/1957	nc
14308	Injune Creek Group	-26.76	150.30	28/05/1960	nc
14743	Injune Creek Group	-26.11	149.84	17/07/1957	nc
14744	Injune Creek Group	-26.07	149.84	31/07/1958	nc
14745	Injune Creek Group	-26.13	149.58	12/11/1957	**No**[3]
14893	Injune Creek Group	-26.21	149.57	28/09/1961	**Yes**
15761	Injune Creek Group	-26.05	149.77	05/03/1964	nc

Registered Number	Completion Aquifer[1]	Latitude	Longitude	Drilled Date	Potential Monitoring Point[2]
		GDA94			
15810	Injune Creek Group	-26.77	150.34	05/09/1964	nc
15855	Injune Creek Group	-26.08	149.83	01/05/1964	nc
15892	Injune Creek Group	-26.07	149.79	30/09/1964	nc
16080	Injune Creek Group	-26.03	149.77	07/11/1964	nc
16135	Injune Creek Group	-26.15	149.64	30/06/1964	**Yes**
16946	Injune Creek Group	-26.17	149.46	23/09/1964	nc
17461	Injune Creek Group	-26.25	150.05	08/07/1967	nc
31421	Injune Creek Group	-26.94	149.99	13/10/1969	**Yes**
31995	Injune Creek Group	-26.16	149.56	26/08/1969	**Yes**
33435	Injune Creek Group	-26.15	149.62	08/09/1969	**Yes**
33821	Injune Creek Group	-26.12	149.58	07/02/1970	**No**[3]
34718	Injune Creek Group	-26.11	149.73	07/02/1970	**Yes**
34929	Injune Creek Group	-26.09	149.70	30/01/1970	nc
37555	Injune Creek Group	-26.29	150.12	18/12/1971	nc
43483	Injune Creek Group	-26.38	149.87	08/03/1973	**Yes**
43540	Injune Creek Group	-26.29	150.03	30/04/1973	nc
44246	Injune Creek Group	-26.04	149.64	07/10/1973	nc
44605	Injune Creek Group	-26.08	149.66	11/12/1973	**Yes**
58064	Injune Creek Group	-25.99	149.66	04/04/1982	nc
58129	Injune Creek Group	-26.11	149.84	06/02/1983	nc
58309	Injune Creek Group	-26.26	149.66	07/06/1987	**Yes**
58320	Injune Creek Group	-26.04	149.50	31/07/1987	nc
58600	Injune Creek Group	-26.05	149.53	10/02/1994	nc
58609	Injune Creek Group	-26.19	149.78		Unable
58612	Injune Creek Group	-25.99	149.55	22/08/1994	nc
123018	Injune Creek Group	-26.21	149.70	22/03/2007	Unable
5336	Walloon Coal Measures	-27.16	150.50	08/05/1937	Other
5390	Walloon Coal Measures	-26.82	150.53	03/03/1962	**Yes**
8425	Walloon Coal Measures	-26.86	150.53	01/01/1966	No
8685	Walloon Coal Measures	-26.84	150.64	01/01/1936	**Yes**
9718	Walloon Coal Measures	-27.15	150.50	08/05/1937	Other
10598	Walloon Coal Measures	-26.90	150.88	10/11/1945	No
10678	Walloon Coal Measures	-26.89	150.65	01/01/1945	**Yes**
10790	Walloon Coal Measures	-26.91	150.66	11/11/1946	**Yes**
11075	Walloon Coal Measures	-26.87	150.93	11/11/1947	nc
11637	Walloon Coal Measures	-26.88	150.90	23/07/1950	Unable
12026	Walloon Coal Measures	-26.73	150.64	02/05/1952	nc
12646	Walloon Coal Measures	-27.06	150.86	12/08/1953	nc
13463	Walloon Coal Measures	-27.17	151.06	06/12/1957	Unable
13540	Walloon Coal Measures	-27.21	151.21	02/05/1958	nc
13554	Walloon Coal Measures	-27.16	150.29	23/02/1958	nc
13600	Walloon Coal Measures	-26.83	150.62	11/04/1958	No
13895	Walloon Coal Measures	-27.03	151.01	24/03/1959	nc

Registered Number	Completion Aquifer[1]	Latitude	Longitude	Drilled Date	Potential Monitoring Point[2]
		GDA94			
14148	Walloon Coal Measures	-27.00	150.96	03/06/1960	nc
15118	Walloon Coal Measures	-26.81	150.64	09/02/1962	**Yes**
15822	Walloon Coal Measures	-27.04	151.00	28/06/1964	nc
15866	Walloon Coal Measures	-26.72	150.79	09/04/1964	Unable
15868	Walloon Coal Measures	-26.91	150.67	06/04/1964	**Yes**
16223	Walloon Coal Measures	-26.80	150.75	01/01/1965	**Yes**
17301	Walloon Coal Measures	-26.93	150.68	01/08/1952	No
18151	Walloon Coal Measures	-27.05	151.02	20/05/1967	nc
21008	Walloon Coal Measures	-26.77	150.83	01/04/1951	No
24494	Walloon Coal Measures	-26.65	150.86	01/01/1954	nc
30254	Walloon Coal Measures	-26.66	150.51	14/06/1968	nc
30997	Walloon Coal Measures	-27.21	151.02	03/03/1969	nc
31371	Walloon Coal Measures	-26.99	150.88	22/11/1970	**Yes**
32314	Walloon Coal Measures	-26.89	150.93	18/04/1969	nc
32628	Walloon Coal Measures	-26.90	150.80	14/06/1969	Unable
33830	Walloon Coal Measures	-26.75	150.50	01/10/1969	**Yes**
35141	Walloon Coal Measures	-27.18	151.05	11/06/1970	nc
35243	Walloon Coal Measures	-26.95	150.86	16/04/1970	nc
35405	Walloon Coal Measures	-27.03	150.97	28/06/1970	nc
35563	Walloon Coal Measures	-27.05	150.99	01/08/1970	nc
35842	Walloon Coal Measures	-26.19	149.64	14/07/1970	Unable
37188	Walloon Coal Measures	-27.02	150.80	12/09/1971	nc
37479	Walloon Coal Measures	-26.17	149.64	16/05/1973	**Yes**
37649	Walloon Coal Measures	-27.03	151.00	01/03/1972	nc
48523	Walloon Coal Measures	-26.66	150.67	20/05/1976	nc
55365	Walloon Coal Measures	-27.17	151.07	02/04/1979	nc
56714	Walloon Coal Measures	-26.79	150.72	05/08/1980	No
58307	Walloon Coal Measures	-26.36	149.82	24/05/1987	Unable
64244	Walloon Coal Measures	-26.58	150.83	07/10/1982	nc
71470	Walloon Coal Measures	-27.14	151.15	26/04/1986	nc
71488	Walloon Coal Measures	-26.64	150.45	31/07/1986	**Yes**
71534	Walloon Coal Measures	-26.62	150.72	22/07/1986	nc
83068	Walloon Coal Measures	-26.84	150.86	13/11/1986	**Yes**
83118	Walloon Coal Measures	-26.68	150.92	18/11/1986	nc
83222	Walloon Coal Measures	-27.67	150.60	30/01/1988	nc
83312	Walloon Coal Measures	-26.85	150.85	28/04/1987	**Yes**
86828	Walloon Coal Measures	-27.06	150.94	01/05/1994	**Yes**
87320	Walloon Coal Measures	-26.98	150.88	21/10/1993	nc
87436	Walloon Coal Measures	-26.91	150.79	13/01/1994	No
87471	Walloon Coal Measures	-27.16	151.00	22/06/1993	nc
87505	Walloon Coal Measures	-26.98	150.67	02/10/1991	**Yes**
87718	Walloon Coal Measures	-26.82	150.62	11/01/1993	nc
87761	Walloon Coal Measures	-26.78	150.81	02/03/1993	Unable

Registered Number	Completion Aquifer[1]	Latitude	Longitude	Drilled Date	Potential Monitoring Point[2]
		GDA94			
87777	Walloon Coal Measures	-27.00	150.95	28/04/1998	nc
87835	Walloon Coal Measures	-27.01	150.96	11/05/1993	nc
87897	Walloon Coal Measures	-26.95	150.62	01/11/1993	**Yes**
87934	Walloon Coal Measures	-26.84	150.86	10/09/1993	**Yes**
94039	Walloon Coal Measures	-26.99	150.86	31/05/1993	nc
94110	Walloon Coal Measures	-27.05	150.92	31/08/1994	**Yes**
94143	Walloon Coal Measures	-26.93	150.92	10/05/1995	nc
94586	Walloon Coal Measures	-27.01	150.97	15/10/1994	nc
94587	Walloon Coal Measures	-27.02	150.98	13/10/1994	nc
107260	Walloon Coal Measures	-26.63	150.46	29/03/2000	No
107761	Walloon Coal Measures	-26.89	150.58	n/a	**Yes**
107873	Walloon Coal Measures	-27.00	150.96	26/06/2004	nc
137140	Walloon Coal Measures	-26.86	150.45	14/05/2007	nc
137526	Walloon Coal Measures	-27.19	151.22	20/04/2007	nc
42230204	Walloon Coal Measures	-26.82	150.67	26/02/1966	nc
42231254	Walloon Coal Measures	-27.38	151.08	19/06/1980	nc
42231255	Walloon Coal Measures	-27.29	151.09	30/06/1980	nc
42231256	Walloon Coal Measures	-27.09	150.98	27/05/1980	nc
42231257	Walloon Coal Measures	-27.08	150.95	20/07/1980	nc
42231258	Walloon Coal Measures	-27.06	150.95	20/05/1980	nc
42231390	Walloon Coal Measures	-27.17	151.21	20/12/1988	nc
14141	Westbourne Formation	-27.28	150.46	19/11/1960	nc
48507	Springbok Sandstone	-27.27	150.46	02/01/1977	**Yes**
48806	Springbok Sandstone	-26.20	149.66	22/04/1974	Unable
58486	Springbok Sandstone	-25.96	150.08	4/06/1992	**Yes**
Intermediate Unit					
14141	Gubberamunda Sandstone	-27.28	150.46	19/11/1960	nc
14892	Gubberamunda Sandstone	-26.23	149.56	31/08/1961	**Yes**
15498	Gubberamunda Sandstone	-26.24	149.72	20/02/1963	**Yes**
15499	Gubberamunda Sandstone	-26.23	149.69	04/03/1963	**Yes**
15558	Gubberamunda Sandstone	-26.26	149.70	14/03/1963	Unable
16292	Gubberamunda Sandstone	-26.28	149.51	04/06/1965	nc
16391	Gubberamunda Sandstone	-26.24	149.51	23/08/1965	nc
17689	Gubberamunda Sandstone	-27.62	150.64	09/12/1967	nc
17853	Gubberamunda Sandstone	-26.25	149.42	09/03/1968	nc
17947	Gubberamunda Sandstone	-26.22	149.44	22/04/1968	nc

Registered Number	Completion Aquifer[1]	Latitude	Longitude	Drilled Date	Potential Monitoring Point[2]
		GDA94			
17948	Gubberamunda Sandstone	-26.23	149.44	07/04/1968	nc
31934	Gubberamunda Sandstone	-26.25	149.58	20/08/1969	**Yes**
35916	Gubberamunda Sandstone	-26.83	150.23	01/09/1970	nc
36363	Gubberamunda Sandstone	-26.25	149.66	28/09/1970	**Yes**
36485	Gubberamunda Sandstone	-26.28	149.51	02/10/1970	nc
36486	Gubberamunda Sandstone	-26.22	149.54	25/09/1970	**Yes**
43507	Gubberamunda Sandstone	-26.28	149.73	05/03/1973	**Yes**
44279	Gubberamunda Sandstone	-26.28	149.80	08/08/1973	**Yes**
44280	Gubberamunda Sandstone	-26.30	149.81	01/11/1973	**Yes**
48507	Gubberamunda Sandstone	-27.27	150.46	02/01/1977	nc
48837	Gubberamunda Sandstone	-26.32	149.87	15/03/1945	**Yes**
58375	Gubberamunda Sandstone	-26.90	149.85	20/07/1989	nc
58579	Gubberamunda Sandstone	-26.91	150.36	23/12/1993	nc
107624	Gubberamunda Sandstone	-26.88	150.38	05/01/2001	nc
123012	Gubberamunda Sandstone	-26.89	149.86	04/11/2005	nc
123082	Gubberamunda Sandstone	-26.31	149.68	19/12/2006	**Yes**
137640	Gubberamunda Sandstone	-27.58	151.00	10/07/2007	nc
13030808	Gubberamunda Sandstone	-26.28	149.85	18/02/2003	Unable
13030809	Gubberamunda Sandstone	-26.24	149.84	18/02/2003	**Yes**

1. Completion Aquifer (the aquifer in which the bore is screened in, or open to) was assigned based on bore completion and stratigraphy information available in the NRW groundwater database.

2. **Yes** = bore visited as part of the bore inventory. These bores could potentially be included in the long-term monitoring program.

No = Landowner declined to participate. These bores should not be considered for monitoring.
Unable = Unable to contact landowner during inventory

nc = bores not considered as part of the 2008/2009 bore inventory.

3.. Access not permitted to these bores, however, allowed monitoring of the new Precipice bore completed on the property

APPENDIX G

Limitations

LIMITATIONS

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