D2 Groundwater

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SANTOS GLNG PROJECT - ARCADIA, FAIRVIEW, ROMA CSG FIELDS

Groundwater and Associated Water Management Impact Assessment

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REPORT

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EXECUTIVE SUMMARY

Project Background

Santos is currently producing natural gas and expanding their coal seam gas (CSG) operations in the Surat and Bowen geologic basins of Queensland; the Project is referred to as the Gladstone Liquefied Natural Gas (GLNG) Project.

The Santos CSG operations in the Surat and Bowen geologic basins are divided into three CSG Fields: Roma, Fairview and Arcadia. The current extent of CSG development varies between the Fields, but significant expansion is planned for all Fields over the 25 to 30 year lifecycle of the Project. During CSG development, groundwater is extracted from a CSG reservoir (coal seam or coal measures) to facilitate desorption of the gases (predominantly methane) adsorbed to the coal. The amount of depressurisation required to achieve efficient reservoir pressures can be significant, and typically results in the development of steep hydraulic gradients between the CSG target formation and adjacent water-bearing formations. The groundwater extracted during CSG production is referred to as “associated water” (AW), and management of the large volume of generally poor quality water generated presents environmental risks and operational challenges.

Golder Associates Pty Ltd (Golder) was engaged to evaluate and document the potential impacts to the water resources affected by CSG development in the three CSG Fields of the GLNG Project area. The assessment of groundwater impacts included:

- Review of existing studies and associated relevant literature (including legislation);
- Development of a conceptual hydrogeological model for each of the three CSG Fields;
- Detailed risk assessment of the various activities associated with CSG production in the Project area;
- Identification of the environmental values relevant to the GLNG Project area;
- Discussion of the potential groundwater impacts associated with CSG activities, and the relative risks to environmental values in each Field;
- Discussion of risk control measures adopted or developed to address the principal risk issues associated with CSG activities;
- Discussion of the impacts on environmental values related to groundwater and the implementation of the Associated Water Management Plan;
- Discussion of the Water Monitoring Strategy and Associated Water Management Plan developed for the GLNG Project; and
- Development of recommendations to address data gaps, manage risks or reduce uncertainty in the analysis of potential impacts.

Description of Existing Environment

The GLNG Project area in Central SE Queensland is sparsely developed, and generally comprises rural communities and homesteads that are largely engaged in farming and livestock. The terrain in each Field varies from mountains, large valleys, plateau country and undulating hills depending on the nature of the outcropping geology. Both the Roma and Fairview Fields host regional river catchments, which include intermittent streams and perennial water courses, whereas no major water courses are present in the Arcadia Field.

The geology of the CSG development areas includes a Jurassic to Cretaceous age sequence of alternating sandstone and siltstone formations associated with the Surat Basin, which unconformably overlies Triassic

to late-Permian sedimentary formations of the Bowen Basin. The basins generally comprise southward dipping synclines, with the Surat Basin formations outcropping or subcropping in the Roma and Fairview Fields, and the underlying Bowen Basin formations outcropping in the Arcadia Field to the north. CSG development in the Roma Field targets the Walloon Coal Measures, while the coal seams of the Bandanna Formation are targeted in the Fairview and Arcadia Fields.

The Surat Basin is a sub-basin of the Great Artesian Basin (GAB), one of the largest artesian groundwater basins in the world. The GAB is generally recharged via rainfall on the elevated margins of the basin in what are referred to as the GAB intake beds, with regional groundwater flow predominantly towards the southwest. The CSG fields being developed for the Santos GLNG Project span three of the 25 GAB groundwater management areas (Surat, Surat North and Mimosa) and a portion of the Bowen Basin, of which only the late-Permian formations directly underlying the Surat Basin are administered as part of the GAB. A number of sandstone aquifers of regional importance are present in the stratigraphic sequence beneath the Project area, including the Hutton Formation and the Precipice Sandstone, which provide groundwater supply for drinking water, stock watering, irrigation, and industrial uses. The CSG Fields are located within a portion of the GAB intake beds for southern Queensland.

Risk Assessment and Potential Impacts

The risk-based assessment of CSG development activities within the Project area identified potential impacts associated with certain activities that comprise the principal environmental risk drivers, including:

- Loss of available drawdown in bores, loss of artesian pressure, and loss of baseflow resulting from coal seam depressurisation;
- Contamination of soil, surface water or shallow groundwater resulting from an uncontrolled release from an AW pipeline, or a dam containing oily waste water or brine;
- Over- or under-supply of treated AW for municipal or industrial reuse applications; and
- Environmental impacts related to the quality or quantity of treated discharge released to perennial streams and impacts related to the options identified in the AWMP.

The environmental values associated with groundwater in the Project area include human consumptive uses (drinking water supply, primary industry and other industrial uses), maintenance of aquatic ecosystems (including groundwater dependent ecosystems), and to a lesser extent maintenance of recreational and aesthetic amenity of surface water bodies. Detailed evaluation of the risk drivers in the context of the CSG development activities for each Field indicates that induced inter-aquifer leakage related to coal seam depressurisation, and potential impacts related to management of AW represent the greatest perceived risks to environmental values in each CSG Field. The highest risk rankings generally apply to Fairview Field due to the more advanced current state of CSG development relative to the Roma and Arcadia Fields. The Roma Field has a similar, but slightly subdued, risk profile relative to Fairview Field, and the Arcadia Field currently presents a low risk profile due to its preliminary stage of CSG development and lack of significant surface water features.

Risk Management Strategy

A number of management measures have been adopted or developed by Santos to reduce the key risks associated with CSG development, either through reducing the likelihood of impacts occurring, or early identification of the onset and development of impacts such that potential losses can be evaluated and managed. These include:

- Adoption of appropriate drilling and well installation techniques, 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;

- Incorporation of numerous safety measures 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;

- Development of an Associated Water Management Plan (AWMP) to address the management challenges with AW produced during CSG activities. The Plan was developed following a comprehensive risk-based and consultative process, to determine management options that are viable from the perspective of the available technology, the likely production of AW and environmental impacts. It adopts the preferred reuse-and-recovery principles set out in Queensland State policy, and which emphasise beneficial outcomes for the surrounding communities where possible. The impact assessment that has been undertaken is to determine whether the selected management options are viable (including their priority of use) having regard to the impacts and their management. ; and

- Development of a robust water monitoring program for each of the CSG Fields to document baseline conditions and assess potential changes to water levels, water quality or flow regimes related to CSG development activities. Tiered trigger values have been proposed that would facilitate early detection and management of potential changes to water quality and availability, and allow for development of location-specific tolerance thresholds beyond which any losses incurred can be addressed in a manner that is transparent, timely and mutually acceptable to the relevant stakeholders.

Table of Contents

TABLES

FIGURES

APPENDICES

User Note: This Table of Contents section acts as a reference point for the Record of Issue, Executive Summary and Study Limitations sections as and when they might be required. Therefore, the structure of this section must not be altered in any way.

GLOSSARY

Abstraction	The removal of water from a resource e.g. the pumping of groundwater from an aquifer. Interchangeable with extraction.
Adsorption	The attraction and adhesion of ions from an aqueous solution to the surface of solids.
ADWG	Australian drinking water guidelines
Alluvial	Of, or pertaining to, material transported by water.
Alluvium	Sediments deposited by or in conjunction with running water in rivers or streams,
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.
Aquatic	Associated with and dependant on water e.g. aquatic vegetation.
Aquatic Ecosystems	The abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and their fringing vegetation.
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 saturated, permeable geological unit that is permeable enough to yield economic quantities of water to boreholes.
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 saturated geological unit with a relatively low permeability that retards and restricts the movement of water, but does not prevent the movement of water; while it may not readily yield water to boreholes and springs, it may act as a storage unit.
Artesian aquifer	A confined aquifer under hydrostatic pressure.
Artesian bore	A ‘flowing’ bore, where the piezometric head level is at an elevation higher than ground level, such that water freely flows out of the bore without mechanical assistance.
ATP	Authority to Prospect granted under the Petroleum Legislation
Attenuation	The breakdown or dilution of contaminated water as it passes through the ground.
Available drawdown	The height of water above the depth at which the pump is set in a borehole at the time of water level measurement.
Baseflow	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.

Basin	A depression of large size in which sediments have accumulated.
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.
Bore	An artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer. Interchangeable with boreholes, wells, piezometers.
Borehole	See definition for Bore.
Brackish	Water that contains between 3,000 and 10,000 mg/l of total dissolved solids.
Brine	Water that contains more than 35,000 mg/l of dissolved solids.
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.
Cone of depression	The piezometric groundwater surface which defines the area of influence of a borehole. The shape of a cone with large diameter at top.
Confined aquifer	An aquifer overlain by a confining layer of significantly lower hydraulic conductivity in which groundwater is under greater pressure than that of the atmosphere; the aquifer is bounded above and below by an aquiclude.
Contamination	The introduction of any substance into the environment by human activities.
CSG	Coal Seam Gas.
CSG fields	The PLs and ATPs set out in Table 1 of this report.
DERM	Department of Environment and Resource Management recently created through a merger of the DNRW and the Environmental Protection Agency.
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.
Dissolved solids	Minerals and organic matter dissolved in water.
DNRW	Former Department of Natural Resources and Water recently combined with EPA to create DERM.
Drawdown	The lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure.
Ecosystem	An organic community of plants, animals and bacteria and the physical and chemical environment they inhabit.
EIS	Environmental Impact Statement
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.
Equipotential (f)	A line connecting points of equal hydraulic potential or hydraulic head.

EMP	Environmental Management Plan
EPA	Former Environmental Protection Agency recently combined with DNRW to create DERM
Epeirogenic	The slow movements of the Earth's crust leading to the formation of features.
EPP	Environmental Protection (Water) Policy
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.
Fault	A zone of displacement in rock formations resulting from forces of tension or compression in the earth's crust.
Field	A geographical area under which an oil or gas reservoir lies.
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. Later groundwater flow through the aquifer can be estimated by $Q = K_h \times \frac{\partial h}{\partial x} \times A$ Where: Q = Lateral Groundwater flow (m^3/d) K_h = Horizontal hydraulic conductivity (m/d) A = Cross sectional area of the aquifer (m^2) $\frac{\partial h}{\partial x}$ = gradient
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.
Fresh water	Water that contains less than 1,000 mg/L total dissolved solids.
GAB	Great Artesian Basin
GLNG	Gladstone Liquefied Natural Gas
Groundwater	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 Dependent Ecosystems	Terrestrial or aquatic ecosystems whose ecological function and biodiversity are partially or entirely dependent on groundwater.
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.
Groundwater Management Areas	The primary administrative boundaries defining the regions over which the Great Artesian Basin groundwater resources are regulated.
Groundwater Management Units	The administrative subdivision of the aquifer formations that are regulated within each Groundwater Management Area.

Groundwater resource	All groundwater available for beneficial use, including both human and natural uses.
HDD	Horizontal directional drilling.
Head (hydraulic head, static head)	The energy contained within a column of water resulting from elevation or pressure. The static head is the height at which the surface of a column of water could be supported against the action of atmospheric pressure.
Hydraulic conductivity	A measure of the ease with which water will pass through earth material. It is defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow {m/day}.
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.
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.
Infiltration	The process whereby water enters the soil through its surface. The downward movement of water into the soil profile.
Interstices	Openings or void space in a rock capable of holding water.
Isotropic	The condition of having properties that are uniform in all directions, opposite of anisotropic.
km	Kilometres
Labile	Constantly undergoing or likely to undergo change; unstable.
Lithology	The physical and mineralogical characteristics of a rock. The characteristics, including grain size, of the strata of the subsurface media.
L/s	Litres per second
m AHD	Metres in Australian Height Datum
mg/L	Milligrams per litre
ML	Mega litre
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.
Perennial River	A river which may be dry for part of the year, due to seasonal variations in weather.
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.
Permeable	Materials that liquids flow though with relative ease.

Petroleum Legislation	The *Petroleum and Gas (Production and Safety) Act 2004* (Qld) and the *Petroleum Act 1923* (Qld) and associated Regulations.
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. (activity). Used as an indicator of acidity (pH < 7) or alkalinity (pH > 7).
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 surface	A surface of equal hydraulic heads or potentials, typically depicted by a map of equipotential contours 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.
PL	Petroleum Lease granted under the Petroleum Legislation
Porosity	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.
Potable water	Water that is safe and palatable for human use.
Preferential flow	The preferential movement of groundwater through more permeable zones in the subsurface.
Production bore (or well)	A bore from which abstraction of groundwater may take place, either through pumping or artesian flow.
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).
Rehabilitation	To restore to former condition or status.
Recovery	The rate at which the water level in a pumped bore rises once abstraction has ceased.
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.

River	A physical channel in which runoff will flow; generally larger than a stream, but often used interchangeably.
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 down slope 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.
Saline water	Water that is generally considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids.
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).
Sanitation	The treatment and disposal of waste from the human body and grey water generated through household activity.
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.
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.
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. $\delta h = \pm 1$).
Standing water level (static water level, SWL)	The depth to groundwater measured at any given time when pumping or recovery is not occurring.
Stratigraphy	The study of stratified rocks, especially their age, correlation and character.
Storativity	The volume of water that a saturated confined aquifer releases from storage per unit surface area of the aquifer per unit decline in the water table. Quantifies the aquifers ability to release water.
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.
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) (ie. 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.
Tremie pipe	A narrow diameter pipe, which keeps the sealing materials from becoming bridged inside the well casing and prevents dissolution of liquid grout.
Unconfined aquifer	An aquifer with no confining layer between the water table and the ground surface where the water table is free to fluctuate.
Vibrating Wire Piezometer (VWP)	The sensor of the VWP consists of a pressure transducer with an internal thin resonating wire connected to a sensitive perpendicular diaphragm. Water pressure exerted against the diaphragm wall causes it to deflect and alter the tension of the wire and this in turn causes the wire to resonate at different frequencies. An electromagnetic field induced from coils adjacent to the vibrating wire causes it to be plucked and resonate at a frequency signal which is sent through the signal cable to a readout unit or logger at the ground surface.
Watertable	(a) The upper surface of a body of groundwater occurring in an unconfined aquifer. At the watertable, pore water pressure equals the atmospheric pressure. (b) The surface of a body of groundwater within an unconfined aquifer at which the pressure is atmospheric.
Well field	A group of bores in a particular area usually used for groundwater abstraction purposes.
Yield	The quantity of water removed from a water resource e.g. yield of a borehole.

1.0 INTRODUCTION

1.1 Background

Santos is currently producing natural gas and further expanding their coal seam gas (CSG) Fields in the Surat and Bowen Basins of Queensland (Figure 1). The Project is referred to as the Gladstone Liquefied Natural Gas (GLNG) Project. It is anticipated that the Project will deliver approximately 5,300 petajoules of gas to supply the initial 3 – 4 Mtpa LNG facility (Train 1) over a 20-year Project life.

Golder Associates (Golder) was engaged by Santos to prepare a hydrogeological impact study for their three CSG Fields: Fairview, Arcadia and Roma. Santos is dedicated to the understanding and management of the potential impacts to the local and regional environment arising from the CSG activities.

The objectives of this groundwater impact study are to identify, assess and develop potential mitigation measures or potential groundwater impacts associated with the proposed CSG field development for the GLNG Project.

1.2 Project Description

CSG is methane gas adsorbed in underground coal beds. The methane predominantly occurs in a near-liquid state, lining the inside of pores within the coal matrix. Methane can also occur as a free gas in the open fractures or dissolved in the groundwater.

The extraction of CSG is closely linked to groundwater extraction. When groundwater is abstracted, decreasing water pressure in the coal seam(s) allows the liberation of the CSG. Pumping can continue for several months or up to a few years, and groundwater abstraction rates will typically decrease throughout this time. After a prolonged period of local depressurisation, no further pumping may be necessary as the velocity of the gas acts as a lifting mechanism for the groundwater.

The groundwater pumped out from the well is normally referred to AW of the gas production. The Queensland Government has recently introduced a policy on CSG water, which requires a new approach to AW management. Several re-use options such as production of potable water, irrigation water, controlled release to surface water, or water for the operation of power plants, are available.

Santos CSG operations in the Surat and Bowen Basin are divided into three CSG Fields: Roma, Fairview and Arcadia. Roma, Fairview and Arcadia CSG Fields present different geologic, hydrologic and geomorphologic characteristics. Figure 2 identifies the geographical extent of the three CSG Fields. Fairview and Arcadia Fields are sometimes referenced together as the “Comet Ridge Project”. Table 1 presents a list of Santos operated petroleum tenements proposed to be developed for the GLNG Project. . Note that the Petroleum Leases and Authorities to Prospect listed in Table 1 are those tenements presented as the ‘Reasonably Foreseeable Development Area’ in Section 3.4.2 and Table 3.4.1 in Section 3 of the GLNG EIS. CSG field development to support the initial 3 – 4 Mtpa LNG facility (Train 1) is proposed to be located in the Reasonably Foreseeable Development Area. For the purposes of this report, the tenements in Table 1 are together referred to as the ‘CSG fields’.

Table 1: Roma, Fairview and Arcadia CSG Lease Areas

Roma		Fairview	Arcadia
ATP 336P PLA281, PLA282	PL8	PL90	ATP 526P
PL3	PL9	PL91	ATP 653P
PL4	PL13	PL92	PL233
PL5	PL 93	PL99	PL234
PL6	PLA 309	PL100	PL235
PL7 PLA 250 PLA251	PLA 310	PL232	PL236

1.3 Definition of the Regional Hydrogeology

1.3.1 The Great Artesian Basin (GAB)

The GLNG Project is situated within the Surat Basin, a sub-basin of the Great Artesian Basin (GAB), and the underlying Bowen Basin (Figure 1).

The GAB is one of the largest artesian groundwater basins in the world. It underlies approximately one-fifth of Australia, beneath Queensland, New South Wales, South Australia and the Northern Territory. In places, the GAB is showing signs of overexploitation of its groundwater resources (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 Qld, NSW, SA and the NT to achieve sustainability of the Basin 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). These plans divide the Queensland component of the GAB into 25 Groundwater Management Areas (GMAs). The boundaries of the GMAs are divided based on hydrological, geological, water demand, recharge and discharge characteristics and past management practices (DNRM, 2005). The Santos operated CSG fields lie in or is adjacent to the following GMAs:

- Surat GMA 19
- Surat North GMA 20
- Mimosa GMA 22

The conceptual boundaries of the GMAs follow similarly to the three CSG Fields of the GLNG Project. Figure 2 presents the locations of the three GLNG CSG Fields relative to the management area boundaries. The Roma CSG Field is within the Surat GMA 19, the Fairview Field within Surat North GMA 20, and the Arcadia Field lies within the Mimosa GMA 22 (although the southernmost leases of Arcadia [PL233 and ATP526P] are within Surat North). To the west of the Arcadia Field, the area is considered to be within the surficial outcrops of the Bowen Basin.

1.3.2 The Bowen Basin

With the exception of its upper formations (including the Moolayember Formation, Clematis Sandstone and Rewan Formation), the Bowen Basin formations are not administered under the GAB WRP. The Australian Natural Resources Atlas defines this area as ‘not a major priority’ (ANRA, 2005) and there are no priority issues for groundwater management within the area. The groundwater resources within the Basin are not yet heavily developed, and areas with greater bore concentrations are under observation with monitoring bores.

A sustainable yield has not been assessed for the entire Bowen Basin. A preliminary estimate for the sustainable yield is approximately 260,000 ML/yr (ANRA 2005) based on estimates from the major sub-catchments of the basin including the Mackenzie, Nogoa, Comet and Isaac.

1.3.3 Groundwater Management Units

The hydrostratigraphy of the GAB consists of sequences of aquifers and aquitards. The main sandstone aquifers show continuity and textural similarity across the GAB (DNRM, 2005). The variation of hydraulic parameters and behaviours of the different aquifer systems require differing management approaches. Hence, the stratigraphic sequence within each management area is divided into a number of management ‘units’ based on the distribution of the major aquifers.

Table 2 presents the GAB GMAs and the management units associated with the Santos operated CSG fields. Although the lower, Permian formations of the Bowen Basin are not administered under a WRP or separated into management units, they are utilised by a number of private bore users in the Project area (Section 4.10). They have been included in these discussions as they could potentially be affected by CSG operations.

Table 2: GAB Groundwater Management Areas and Units in the GLNG Project Area

Groundwater Management Area	**Surat**	**Surat North**	**Mimosa**	**Bowen****
CSG Field	**Roma**	**Fairview**	**Arcadia**	
Groundwater Management Units	Surat 1	-	-	-
	Surat 2	-	-	-
	Surat 3	-	-	-
	Surat 4	-	-	-
	Surat 5	Surat North 1	-	-
	Surat 6	Surat North 2	-	-
	Surat 7	Surat North 3	-	-
	Surat 8	Surat North 4	Mimosa 1	Triassic Formations (Bowen 1)**
	-	-	-	Blackwater (Bowen 2)**
	-	-	-	Back Creek (Bowen 3)**

Source: Water Resource (Great Artesian Basin) Plan 2006

**The groundwater management units of the Bowen GMA are not classified in the GAB WRP and are defined for the purpose of this study only.

Table 2 has been designed to represent the units which are equivalent across the individual management areas. For example, Surat 8 comprises the lower Triassic aged Moolayember Formation, Clematis Sandstone and Rewan Formation. These formations also comprise the Surat North 4, Mimosa 1 and (for the purpose of this study) the Bowen 1 management units. Figure 3 presents the stratigraphy sequence of the entire study area and the related units within each management area.

1.3.4 GLNG Project Area Context

Roma CSG Field

The Roma CSG Field is located around the towns of Roma and Wallumbilla. Santos operated leases cover slightly more than 300,000 ha, and are located in an area which is primarily used for cattle grazing or farming.

The land is generally characterised by flat to gently undulating terrain, with a gradual slope towards the south west. The Condamine-Balonne River is a regional river system which straddles the southern boundary of the southern tenement for the Roma Field, generally flowing from east to south west. There are five creeks running through the Roma Field which drain south to the Balonne River, including Dargal Creek, Bungil Creek, Blyth Creek, Wallumbilla Creek, and Yuleba Creek.

The Roma CSG Field is part of the Surat Basin and is underlain by sedimentary formations associated with the GAB, some of which are recognised as regionally significant aquifers. Jurassic to Cretaceous age sedimentary formations subcrop and outcrop across the tenements, but are predominantly overlain by Quaternary alluvium. A basalt intrusion is present at the Grafton Range towards the north of the Roma Field.

The Roma CSG Field includes a combination of gas production and associated transport, storage and processing infrastructure, and ongoing exploratory drilling. The following CSG activities and infrastructure currently occur within the Roma Field:

- Conventional natural gas production, organised into approximately 70 small to medium gas Fields;
- 16 small compressor stations with their own retention ponds;
- Coxon Creek Dam and Hermitage Dam;
- Wallumbilla LPG processing plant located approximately 10 km south of Wallumbilla, designed to recover butane and propane from depressurised raw gas;
- ML1A meter station dehydration unit; and
- CSG exploration activities.

Pilot wells are operational in lease ATP 336P located in the northern part of the Roma Field (Figure 4).

Fairview CSG Field

The Fairview CSG Field is located approximately 25 km northeast of the town of Injune; Santos operated leases cover approximately 139,000 ha. The topography of the area is variable, comprising of high, relatively flat sandstone plateaus intersected by deeply incised gullies, which in turn become broader valleys as they deepen. The plateaus and the larger valleys are generally used for grazing.

The main plateaus of the Fairview CSG Field are the Fairview and Springwater Plateaus, which take their name from the homesteads located on them. Fairview Plateau ranges in elevation from 500 to 530 m AHD, while the Springwater Plateau ranges from 340 m AHD in the east to 420 m AHD in the west. The entire Springwater Plateau and the south side of the Fairview Plateau drain into Hutton Creek, while the northern half of the Fairview Plateau drains north into Baffle Creek and the Dawson River.

The Fairview CSG Fields are directly underlain by the lower GAB formations of the Surat Basin (Hutton, Evergreen and Precipice Sandstone) and the GAB formations of the upper Bowen Basin (Moolayamber Formation and Clematis Sandstone). The CSG bearing formation of interest to Santos in the Fairview CSG Field is the Bandanna Formation from the Blackwater Group (Bowen Basin, Late Permian).

The Fairview CSG Field currently comprises the following activities:

- CSG gas production;
- CSG exploration;
- Two re-injection wells (Fairview 77 and Fairview 82);
- A number of regulated water management dams;
- A number of compressor stations and associated retention ponds;
- Several discharging to grade point activities (5.6ML/day of AW is currently discharged to grade under licence);
- An irrigation project for hardwood plantation and forage crops, with the irrigated water sourced from AW either after reverse osmosis (RO) treatment (trees) or buffering water treatment (other crops). The RO plant is the Pony Hills Treatment Plant and the buffering treatment plant is at Springwater West; and
- Camp facilities and site management facilities with sewage treatment plant.

The Comet Ridge to Wallumbilla Pipeline commences at the Santos Fairview CS2 and travels south and south-west for approximately 35 km to meet the existing Jemena Wallumbilla to Gladstone pipeline corridor.

The Fairview camp and office facilities are supplied by a groundwater well installed at the camp to supply untreated water for non-potable services and amenities; no information is available on the construction of this well. Drinking water for the Fairview camp is town water trucked to site.

Arcadia CSG Field

The Arcadia CSG Field is located directly north of the Fairview CSG Field, and includes the Arcadia Valley and associated mountain ranges. Santos operated lease areas comprise approximately 240,000 ha.

Arcadia Valley is a large north-south oriented valley with a flat valley bottom. The landscape rises gradually to the west, whereas it rises quite steeply to the east. The mountains within the Arcadia CSG tenements include the Carnarvon and Lynd ranges to the south, and the Expedition Range running roughly north-south through the centre of the CSG Field. There are no major rivers running through the tenements. Stock breeding and fattening of cattle are the primary industries in the area. Several CSG wells are located on the eastern hills.

The Arcadia area is located entirely within the Bowen Basin; the northern extent of the Surat Basin is to the south of the Arcadia CSG tenements. The target formation for CSG production is the Late Permian Bandanna Formation of the Blackwater Group.

The Arcadia Field is not yet operational, and activities are currently limited to exploratory drilling and appraisal work.

1.4 Scope of Work

The scope of work includes:

- Acquisition of data from Santos, DERM and from reports in the public domain;
  - Meeting with Santos reservoir engineers and geologists to identify and recover data relevant to the study;
  - Data QA/QC checking, compiling and creation of a meta-database. Data quality checking as to applicability;
- Data Analysis and Development of Conceptual Model:
  - Review of Matrixplus Groundwater Deep Aquifer Modelling Report (2009) and incorporation of the results into this groundwater impact study;
  - Develop and expand the Conceptual Hydrogeological Model for the three GLNG Project CSG Fields. The hydrogeological descriptions divide the stratigraphic sequence of the Project area based on the management units, as outlined in the GABWRP;
  - Examine the geology, water levels and water quality records, hydrochemistry and drilling records. Develop hydrogeological cross sections (based on data provided by Santos) and hydrogeological maps;
- Risk Assessment and Discussion of Potential Impacts to Groundwater Resources
  - Detailed risk assessment of the various activities associated with CSG production in the Project area, using a modified risk assessment framework based on the Santos EHSMS risk assessment protocols;
  - Identify and evaluate the environmental values that are relevant to the GLNG Project area, in accordance with published guidelines in relevant Queensland regulations;

- Discussion of the risks and potential impacts associated with CSG development activities within the GLNG Project area, including review and incorporation of elements of similar assessments included in previous studies for the Project area;
- Provide a preliminary estimation of 'trigger levels' as defined in the Petroleum and Gas (Production and Safety Act 2004), being levels at which groundwater impact might result in the need for groundwater management plans to b implemented by the CSG operators.
- Discussion of contingency water management actions to address the principal risk drivers identified during the risk assessment and discussion of potential impacts.

- Reporting and Deliverables:
  - A report on the groundwater impact study that includes a full description of al the works. Provide developed metadata maps, metadata tables, hydrogeological cross sections and hydrogeological maps for the study area;
  - Review the climatic history of the Project area;
  - A summary of legislative drivers with respect to groundwater;
  - Evaluate groundwater modelling by Matrixplus (2009);
  - Describe the environmental values associated with groundwater environments of the CSG fields;
  - Identify and assess likely impacts of the Project on ground and surface water resources and associated ecosystems, bores and bore users within the area, any State or Nationally significant environmental assets; and
  - Review and identify measures for management and mitigation of ground and surface water risks and impacts, including an assessment of re-injection of AW.

1.5 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 incorporated into DERM, 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.

The Bandanna Formation of the Bowen Basin is the target formation for CSG development activities for the Fairview and Arcadia CSG Fields. In contrast to highly regulated nature of the groundwater resources in the Surat Basin formations, investigation into the groundwater resource potential of the Bowen Basin formations has been limited. Therefore a precautionary approach may be required to preserve the future groundwater resource potential within this basin.

Santos has commissioned, and in some cases completed, a range of water studies relevant to the CSG field development, including:

- Water Monitoring Strategy (WMS) for the GLNG Project (refer to Section 8.11);

- Associated Water Management Plan (AWMP) for the GLNG Project (refer to Section 5.3 for a discussion of the AWMP, and Appendix D2 of the EIS for a full copy of the AWMP).
- Environmental Data Management Plan for all water and associated data;
- GoldSim sector by sector detailed operational simulations for local optimisation and then future use as an operational management tool
- GoldSim Project wide modelling of operations to compare options-scenarios-development methodology using risk-cost criteria;
- Regional Bore Inventory, to assess the available data on groundwater and the status of groundwater use;
- Water balance modelling and seepage modelling studies associated with the AW irrigation trials;
- Surface water studies to identify locations suitable for discharge of treated water for downstream uses such as industrial and/or agricultural);
- Geotechnical and water quality studies to determine the feasibility of using existing lakes to store treated or untreated water;
- Water demand studies to identify, assess and prioritise the potential end users of treated and possibly untreated AW; and
- Potential for water re-injection, to determine the viability of injecting AW, brine or treated water (permeate) into suitable formations.

Selected groundwater studies are listed in Table 3.

Table 3: Selected Water Studies

Title	Subject	Author, date
Santos GLNG Environmental Impact Statement	Groundwater Modelling Impact	Matrixplus, February 2009
GLNG Environmental Impact Statement – Shallow Groundwater	Assessment of potential impacts from the proposed GLNG CSG field activities	URS, January 2009
Environmental Management Plan for Fairview Project Area	Description of environmental values and potential impacts of CSG operations within the Fairview CSG Field.	URS, May 2008
SANTOS TOGA Pty Ltd as Operator under the Comet Ridge Agreement, Fairview CSG Associated Water Management Resource Utilisation Plan	Detailed proposal for beneficial use of approximately 65 GL of AW produced from coal seam gas to irrigate a plantation eucalypt forest and a Leucaena-pasture crop over the period of 10 years	Santos, October 2008
2007 PB Environmental Monitoring Review	For all Santos Australian onshore activities: identifies activities on each site, regulation applying, EMPs in place and monitoring suites implemented.	Parson Brinckerhoff, January 2007

1.6 Limitations of this Report

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2.0 LEGISLATIVE FRAMEWORK

Legislation and regulation requires petroleum tenure holders to manage the AW 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 AW, and the implications for the proposed GLNG Project.

2.1 Legislative Drivers

The relevant legislation assessed for this report includes:

Primary Legislation

- Petroleum Act 1923 (Qld)
- Petroleum and Gas (Production and Safety) Act 2004;
- Environmental Protection Act 1994;
- Environmental Protection (Water) Policy 2009;
- The Interim Policy – Environmental Management for Activities under Petroleum Tenures, 1995;
- Queensland Coal Seam Gas Water Management Policy, October 2008; and
- Management of Water Produced in Association with Petroleum Activities (associated water), December 2007.

Other Legislation

- Water Act 2000;
- Great Artesian Basin Resource Operations Plan 2006;
- Water Resource (Condamine and Balonne) Plan 2004;
- Condamine and Balonne Resource Operation Plan 2008;
- Water Resource (Fitzroy Basin) Plan 1999;
- Fitzroy Basin Resource Operation Plan 2008;
- Water Resource (Moonie) Plan 2003;
- Moonie Resource Operation Plan 2008;

Santos activities in Roma, Arcadia and Fairview are also subject to the requirements of Environmental Authorities (EAs) delivered by DERM.

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.

PRIMARY LEGISLATION AND POLICIES

The primary legislation and policies relating to the extraction and use of water associated with gas extraction are listed below.

2.1.1 Petroleum and Gas (Production and Safety) Act 2004 (P&G Act) and Petroleum Act 1923

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". Similar rights are given under the *Petroleum Act 1923* (Qld) in respect of petroleum tenures regulated by that Act.

The water extraction rights for or during extraction purposes, as defined in the P&G Act, include:

- Taking water when drilling a bore; the bore construction must also comply to the regulation and be completed as a water supply bore;
- No limit applies to the volume of water that may be taken (S 185(3)); and
- The extracted water can be used for domestic and stock purposes on the land covered by the tenure and adjoining land or on any land owned by the land owner (S 186).

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

- Gathering information about, or auditing an existing Water Act bore (termed a water monitoring activity);
- 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.

As mentioned above, a petroleum tenure holder has an obligation under the P&G Act to maintain groundwater supplies if adversely impacted by CSG operations or to "make good" for the water supply.

A petroleum tenure holder may also apply for a water monitoring authority (S 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 in the area of the authority (S 194) i.e. gathering information about, or auditing an existing Water Act bore.

The holder of the tenure must provide a water impact report of its activities (Sections 252 to 257). The P&G Act requires the identification 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. The holder of the tenure may ask the Chief Executive to provide the trigger value.

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*." Hydraulic conductivity, geometry and water levels of the aquifers are defined as the criteria to be considered in the definition of the trigger value. However, no time value over which the pumping is performed to create the associated impact is mentioned in the P&G Act.

Note that the length of time used to estimate the drawdown is not mentioned in the P&G Act but is critical to the establishment of the trigger value. The length of time for evaluation of triggers should consider the regime of 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.

2.1.2 Environmental Protection Act 1994 (Qld)

Section 309Z of the Environmental Protection Act states that conditions may be imposed on an EA (petroleum activities). These conditions may include the carrying out and reporting on a stated monitoring program. There are standard environmental conditions for AW which include the requirement not to release AW to land or waters other than to an evaporation pond that is constructed and managed according to the conditions. The requirement can be addressed by developing and implementing a water quality monitoring program for testing and analysing the quality of the AW, allowing AW that is not a hazardous waste, to be used for purposes such as livestock watering, agricultural purposes, 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 subject to by conditions regulating their design, construction, operation, maintenance and decommissioning.

The holder of an EA is required to 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. Table 1 of Appendix B of the Act (Code of Environmental Compliance) sets out the requirements for monitoring contaminant concentrations in a pond to determine whether it is hazardous.

2.1.3 Environmental Protection (Water) Policy 2009

The *Environmental Protection (Water) Policy 2009* supersedes the *Environmental Protection (Water) Policy 1997*. The purpose of this policy is to provide a framework for achieving the objectives of the *Environmental Protection Act 1994* in relation to Queensland waters. The framework described within the policy includes:

- identifying environmental values for Queensland waters;
- determining water quality guidelines and objectives to enhance or protect the environmental values;
- providing a framework for making consistent and equitable decisions about Queensland waters; and
- monitoring and reporting on the condition of Queensland waters.

This policy has relevance to AW management, including on-site storage, beneficial use, treatment, discharge to surface water, and/or re-injection. 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. The policy includes a four step management hierarchy (Section 13) that describes the decision process for management of waste water release. An environmental plan must be developed and implemented for water management, including plans for managing stormwater, sewage and trade waste for protection of surface and groundwater. Where there will be a release of waste water or contaminants to water, Section 14 of the policy provides the management intent for high ecological value waters; slightly to moderately disturbed waters; and highly disturbed waters.

2.1.4 The Interim Policy – Environmental Management for Activities under Petroleum Tenures, 1995

This interim policy is frequently referred to in many of the EAs issued to Santos.

The role of this policy is to "set out the objectives and procedures for achieving acceptable environmental management of activities on petroleum tenures (excluding pipeline licences)". The management of environmental impacts is defined by the Code of Practice (Environmental Management for Activities Under Petroleum Tenure). Additionally, the Regulator can require an Environmental Management Plan (EMP) for activities which cannot be solely managed by the code of practice.

Under this policy, the holder is required to submit every year a performance report on the activities conducted and the measures taken to comply with the Code of Practice or EMP.

The Code of Practice provides conditions on land management, water management, social responsibility and record keeping. The main conditions applicable to water management are:

- Surface and groundwater should be managed in accordance with the Environmental Protection Policy for Water;
- Discharge of groundwater underlying the tenements should not exceed 250 ML per annum and not cause a reduction of bore water supply over 5% of the initial pressure;
- Clearing of riparian vegetation should be limited to 500 m^2 per location and 500kg/km of watercourse.

When the above conditions cannot be met, an EMP is required.

The Code of Practice also requires any soil contamination to be remediated.

2.1.5 Queensland Coal Seam Gas Water Management Policy, October 2008

This policy was published recently "to provide clear direction for the treatment and disposal of CSG water". The key elements of this policy are:

- Evaporation ponds must not be the primary means of CSG disposal. Existing evaporation ponds are expected to be remediated within three years;
- CSG producers are responsible for treatment and disposal of the CSG water they produce;
- Water management ponds are to be fully lined to a standard defined by the EPA;
- A CSG water management plan is required; and
- Water in excess of capacity of re-injection or treatment should be aggregated for disposal.

2.1.6 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 AW 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 AW, the EPA has granted a general approval under section 66F *Environmental Protection (Waste Management) Regulation* 2000 (Waste Regulation) for the use of AW of certain types. If the AW 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 AW, which can include treated options, non-treated options (direct use, or re-injection. 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 AW 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 useful direction to CSG producers. CSG producers also need to ensure they comply with the terms of their EAs and legislation that regulates water and water related infrastructure, such as the *Water Act 2000* and the *Integrated Planning Act 1997* which may apply in certain circumstances.

OTHER LEGISLATION AND POLICIES

The legislation and policies listed below are relevant to consideration of the impacts of the groundwater extraction and associated water management. Their application is more fully described in Table 4.

2.1.7 Water Act 2000

The *Water Act 2000* (Qld) (Water Act) provides a framework for the sustainable management of water and related resources. It regulates the taking, use and allocation of water through (among other things) water resource plans and resource operations plans. It sets out permitting and licensing requirements for taking or interfering with water, quarry material and other resources. Development approval under the IP Act is also required in respect of certain Water Act activities (including operational works and removing quarry material from a watercourse).

Where water used is not associated water under the *Petroleum and Gas (Production and Safety) Act 2004* (Qld), or is not water necessarily produced as a result of the carrying out authorised activities under the *Petroleum Act 1923* (Qld) ,a water licence, which regulates the taking or interfering with water from a watercourse or overland flowwater, will be required for those activities. A water licence is also required to authorise the access to/supply of treated or untreated associated water to any third party, other than for domestic or stock watering purposes.

2.1.8 Great Artesian Basin Resource Operation Plan 2006

The *Great Artesian Basin Resource Operation Plan 2006* identifies groundwater ”management areas” and management “units” within each management area. For each unit, a specified upper annual take (or allocation) of water has been allocated under the plan. From time to time, DERM may see fit to announce a reduced allocation, typically as a percentage of the full allocation, although other rules may also be imposed.

For example, owing to DERM concerns about the potential impact of CSG water extraction on the aquifers in the Surat Basin, there is currently a moratorium on the granting of further groundwater licences.

2.1.9 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 provides a framework for regulating allocation and sustainable management of all surface water resources (rivers, lakes) and runoffs within the plan area. Water features to which this plan applies include surface watercourses; lakes; and springs and overland flow that are not connected to:

- artesian water; or
- subartesian water which is connected to artesian water.

The plan also provides a framework for the application of the Resource Operation Plan associated with this WRP, and a framework for monitoring requirements associated with water allocations.

Groundwater is only referenced in this plan in the context of assessing whether taking of a surface water allocation may have a 'direct adverse effect on groundwater'. The plan area to which this plan applies is coincident with the Roma tenements. Consideration to the water quality preservation and monitoring aspects of this plan will be addressed in the forthcoming WMS and AW Monitoring Plan for the Roma CSG field, with regard to potential discharge to surface locations or potential accidental releases to surface water from storage dams. Modelling results have indicated that deep aquifer depressurisation will not adversely affect shallow unconsolidated aquifers, spring flow or surface water resources within the Roma tenements.

2.1.9.1 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; and springs and overland flow not connected to artesian water or subartesian water which is connected to artesian water. 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*.

2.1.10 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 Bowen 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 licence 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).

2.1.10.1 Fitzroy Basin Resource Operations Plan 2009

This plan provides the method to implement the day to day management requirements contained in the *Water Resource (Fitzroy Basin) Plan 1999*. This plan applies to surface watercourses; lakes; and springs and overland flow not connected to artesian water or subartesian water which is connected to artesian water. 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*.

2.1.11 Water Resource (Moonie) Plan 2003

The Water Resource (Moonie) Plan 2003 defines the availability of water in the plan area and provides a framework for regulating allocation and sustainable management of all surface water resources (rivers, lakes) and runoffs within the plan area. Water features to which this plan applies include surface watercourses; lakes; and springs and overland flow that are not connected to:

- artesian water; or
- subartesian water which is connected to artesian water.

The plan also provides a framework for the application of the Resource Operation Plan associated with this WRP, and a framework for monitoring requirements associated with water allocations. Groundwater is only referenced in this plan in the context of assessing whether taking of a surface water allocation may have a 'direct adverse effect on groundwater'. The plan area to which this plan applies is located approximately 75 km south of the Roma tenements. It is considered to be of limited relevance to the Santos GLNG project activities as it is well outside the modelled zone of depressurisation in the underlying aquifers, and modelling results indicate that deep aquifer depressurisation will not adversely affect shallow unconsolidated aquifers, spring flow or surface water resources.

2.1.11.1 Moonie Resource Operations Plan 2006

This plan provides the method to implement the day to day management requirements contained in the *Water Resource (Moonie) Plan 2003*. This plan applies to surface watercourses; lakes; and springs and overland flow not connected to artesian water or subartesian water which is connected to artesian water. 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*.

2.1.12 Summary of Legislative Water Monitoring Requirements

As can be seen from the above discussion, the legislation applicable to Santos 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 Santos 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.
Environmental Protection Act 1994, Queensland	Section 309Z can be imposed on a petroleum activity and cause the activity to prepare an environmental report and/or implement water management plans.	Conditions are issued through Environmental Authorities.
Environmental Protection (Water) Policy, 2009, Queensland	In the case of AW recycling, water releases on land, water releases to surface water or stormwater management, 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.	Contamination must be minimised or prevented and any release, or potential release, must be monitored against site baseline conditions. An EA is required for all ponds.
The Interim policy – Environmental Management for Activities under Petroleum Tenures, 1995	An annual performance report on the activities conducted and the measures taken to comply with the Code of Practice or EMP should be submitted	Applies to some of the EAs. Discharge of groundwater underlying the tenements should not exceed 250 ML per annum and not cause a reduction of bore water supply over 5% of the initial pressure
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.	Santos will be responsible for the treatment and disposal of the AW.
Management of Water	To promote the beneficial use of	The management options chosen by

Legislation/Section	Driver	Key Points as they Apply to the Santos Operations
Produced in Association with Petroleum Activities (associated water), December 2007	AW from petroleum activities in Queensland, including the promotion of beneficial use, and re-injection.	Santos 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 Santos wishes to use AW for purposes other than domestic or stock purposes (such as irrigations), the holder must obtain a water licence under the *Water Act 2000*.
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	Santos groundwater CSG bores are not licensed for water extraction with DERM as they are covered by the Petroleum Legislation.
Water Resource (Fitzroy) 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. Santos does not extract water from the Dawson River. Santos groundwater CSG bores are not licensed for water extraction with DERM as they are covered by the Petroleum Legislation.
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 Santos. CSG operations under the authority of the Petroleum Legislation. Santos proposes to utilise a limited water service provider for those activities covered by that requirement.

(*) The Interim Policy – Environmental management for Activities under Petroleum tenures applies to: EA (Approval) n. 150,174;EA (Approval) n. 150,245; EA (Approval) n. 150,288; EA (Approval) n. 170,533; EA (Petroleum Activities) PN PEN100188208; EA (Petroleum Activities) PN PEN200196208; EA (Petroleum Activities) PN PEN200196308; EA (Petroleum Activities) PN PEN200196408; EA (Petroleum Activities) PN PEN200196508 ; EA (Petroleum Activities) PN PEN200196608; EA (Petroleum Activities) PN PEN200194208; EA (Petroleum Activities) PN PEN200214208; EA (Petroleum Activities) PN PEN200214308.

A further discussion of legislative drivers and the GLNG Project monitoring requirements will be provided in the WMS, currently being produced by Santos, along with a summary of the EAs delivered by DERM to Santos for their activities in Roma, Arcadia and Fairview Fields.

3.0 METHODOLOGY

The groundwater impact assessment generally included the following tasks:

- Reviewing, critically evaluating and incorporating results from previous groundwater studies completed on behalf of Santos for the GLNG CSG fields; and
- Researching, preparing and interpreting additional data relevant to the GLNG CSG fields.

3.1 Sources of Data

Data used in the groundwater portion of the study were made available to Golder by Santos and DERM. Once the study area was defined, digital data were requested from DERM (December 2008). 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 DERM Water Entitlements Registration Database (WERD).

Complementary documentation was sought from literature review and previous reports. A data request was distributed to Santos 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 from where the data was obtained.

Table 5: List of Available Data

<table>
<tr><th>Data</th><th>Source</th><th>Comment</th></tr>
<tr><td rowspan="2">Bore names & locations</td><td>Santos</td><td>Data Available</td></tr>
<tr><td>DERM</td><td>Extraction from DERM groundwater database</td></tr>
<tr><td rowspan="3">Hydraulic parameters of coal seam formations and other formations</td><td>Santos</td><td>Estimates of the coal seam permeability and porosity values of specific formations in the Roma CSG field.</td></tr>
<tr><td>Literature Review</td><td>Estimates of hydraulic conductivity for majority of formations (refer Section 4.4.3)</td></tr>
<tr><td>Previous Reports</td><td>Hydraulic parameters provided in Matrixplus (2009) and URS (2009)</td></tr>
<tr><td rowspan="2">Water quality data</td><td>Santos</td><td>Data available as excel spreadsheets. Chemistry data for production wells in the Walloon Formation in Roma and Bandanna Formation in Fairview. No water quality information available for Arcadia</td></tr>
<tr><td>DERM</td><td>Data extracted from DERM groundwater database</td></tr>
</table>

Data	Source	Comment
Conceptual geological sections	Santos	Provided for Fairview.
	DERM	Data extracted from DERM groundwater database for Roma
	Government	Cross section for Arcadia from: Taroom Surficial Geology 1:250,000 Geological Series (Sheet SG 55:8), Bureau of Mineral Resources, Geology and Geophysics (1967)
Water levels	Santos	Initial reservoir pressures (prior to testing and production) available for some production wells
	DERM	Data available from groundwater database
Predicted water use	DERM	Water use extracted from WERD (DERM 2009)
Well field estimates for future production and pressures	Santos	Production Forecast document available in excel spreadsheets.
Well completions information	Santos	Available for selected wells
	DERM	Information available in groundwater database
Purpose of well & status	Santos	Data available as excel spreadsheets
	DERM	Water use extracted from WERD
Property limits /ATP locations	Santos	GIS format – available for this study
Contour map of overburden thickness above coal measures	Santos	Data available for Fairview field as .emf files

3.2 Data Collation and Review

The first stage involved assessing the bores and wells located within the study area. Utilising each bore 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 AW 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).

3.3 Geology and Stratigraphy

The study area is located within both the Surat Basin and Bowen Basin. The literature extensively documents the regional and local geological settings of the Surat Basin, being part of the GAB. Literature is also available for the Bowen Basin; however, much of it focuses is on the Permian coal formations of the Bowen Basin. Less geological information is available on the formations of the lower Permian aquifers, such as the Aldebaran Sandstone.

Santos geologists and engineers were consulted to confirm and identify geological characteristics and features in the local geology of the study area. Stratigraphic information, made available by Santos, focused on the stratigraphy of the coal measures (Walloon Coal Measures in the Roma Field and Bandanna Formation in the Fairview and Arcadia Fields) and the adjoining formations. A comprehensive description of the geology is presented in the URS (2009) Report and the Hydrogeological Framework Report for the Great Artesian Basin (DNRM, 2005).

3.4 Groundwater Levels and Quality

Groundwater level and quality data were obtained primarily from the DERM database. Santos data predominantly represent the coal measures. Groundwater levels collected from Mooga and Gubberamunda Sandstones are also available, collected by the three vibrating wire piezometers (VWPs) installed in the Roma Field. These data were incorporated in the hydrogeological maps.

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

- “water level” table (where the majority of the data was obtained from)
- “aquifer” table
- “strata log” table.

Water levels were assigned to targeted aquifers by relating the open section details of the bore (open, screen or perforation depths) to the stratigraphy and aquifer tables through common features ‘bore construction’ and the ‘formation tops and bottoms’.

Water quality data were extracted from various sources that included databases and excel spreadsheets. 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 their targeted aquifer.

3.5 Bore construction

DERM requires a registered water bore driller to drill water bores. The main intention of this requirement is to prevent adverse impacts of inter-aquifer leakage. Where the drilling of coal seam gas wells is authorised by a PL or ATP under the Petroleum Legislation, wells may be drilled by non-registered water drillers.

Where available, CSG well construction details were assessed to examine if the wells, as drilled and constructed by Santos under the Petroleum Legislation, meet the objectives of the DERM requirements for licence well drillers to perform this work (although not legally required).

3.6 Meta Data Summaries

Metadata is “data about data”. That is, information on the:

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

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

As part of the data quality checking process, each bore, from both DERM and Santos was assigned a "data quality" score for each of the criteria presented in Table 6.

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
	2	Partial information
	3	No data

The data from Santos and DERM were compiled together into one main "metadata table" and two sub-tables. The main metadata table identifies the data available for each bore and when available, provides general information for each bore or well. 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 4a,b,c,d and 5a,b,c,d. The quality checked and sorted metadata used in this study are provided on a CD as Appendix A. Summary tables relating the assessment quality of the DERM bore data (scores) within each of the Groundwater Management Areas are also provided in Appendix A. Quality of the data varies, depending on the classification. For example, bore stratigraphy and construction data in the DERM groundwater database is generally more complete than water quality and water level data.

Table 7: Metadata Summary

Metadata Table	Field	Description
Meta Data Summary Table	Bore Name	Unique name for each bore
	Pipe	Represents casing for DERM bores only. X=no pipe, A= Deepest, B=2nd Deepest, and so on
	Source	DERM or Santos
	Coordinates	Geographic Datum GDA94, latitude and longitude
	Elevation	Of surface or wellhead or reference point, in m AHD
	Area	ATP name – where available
	ATP	ATP name – where 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 m GL
	Formation	Geological formation
	GMA	Surat, Surat North, Mimosa, Bowen
	Unit	Surat 1, Surat 2, etc.,
	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.
Water Levels	Bore Name	Unique name for each bore
	Event date	in ddd/mm/yy format
	Depth to water	In m GL
	Elevation of Water level	In m AHD
	Formation	Geological formation

Metadata Table	Field	Description
	GMA	Surat, Surat North, Mimosa, Bowen
	Unit	Surat 1, Surat 2, etc.,
Water chemistry	Bore Name	Unique name for each bore
	Event date	in dd/mm/yy 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
	GMA	Surat, Surat North, Mimosa, Bowen
	Unit	Surat 1, Surat 2, etc.,

3.7 Development of Conceptual Hydrogeology

A conceptual hydrogeological model (CHM) is a non-mathematical presentation of the hydrogeology of a region. The 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 hydrogeological system. It may also be used to define the baseline groundwater conditions that can be used to assess potential future impacts. The conceptual hydrogeological model is based on geological cross sections and contours maps of the local interpreted hydrostratigraphy. The sections and maps identify the locations, depth and thickness of each formation (in these case, sedimentary layers), areas of outcrop at the surface, salinity and the direction of groundwater flow.

URS (2009) and Matrixplus (2009) previously developed the basis for a CHM for the study area. This current report expands on the discussions of the model results, grouping the existing hydrogeological environments based on the management units as defined in the GABWRP (Section 1.3.1).

For each unit, hydraulic head and salinity data were compiled to create hydrogeological maps. The maps are a representation of the system prior to the development of CSG activities (pre 2000). The mapped area is larger than the likely final extent of the CSG development area and also covers the anticipated areas of impact from Santos operations.

To generate the maps, data that did not have spatial attributes (coordinates or depth) were excluded. 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 DERM 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 DERM database is questionable or not known. The elevation data for the two data sets was cross-checked for consistency.

3.8 Groundwater Modelling

Matrixplus was commissioned to develop groundwater flow models capable of simulating the existing conditions within the Santos operated CSG fields and assessing the potential groundwater impacts of CSG production activities for the Project.

The modelling was completed in two parts, one as the 'Comet Ridge' Groundwater Model, which incorporates both the Fairview and Arcadia Fields (as well as the 'Origin Spring Gully' Field, which is not a Santos operation but is located adjacent to the Fairview Field and was included for analysis of cumulative affects), and the second as the Roma Groundwater Model. The numerical Comet Ridge model was constructed using MODFLOW (McDonald and Harbaugh, 1984) groundwater flow simulation programme. An analytical model was applied for the Roma CSG Field.

The primary objectives of the models were to estimate groundwater drawdown in the CSG and surrounding aquifers, help identify the environmental values that might be affected by CSG activities, and design groundwater monitoring programmes.

The Matrixplus (2009) report outlines the model assumptions and parameters used to develop these models. It also presents recommendations and mitigation measures to minimise impact on surrounding groundwater users as a result of the CSG extraction. A summary of this groundwater modelling is provided in Section 6.

A more detailed groundwater model is currently being developed by Santos to more accurately simulate the cumulative effect of CSG production at the Santos and Origin operated CSG fields, and to provide predictions of the aquifer recovery timeframe following completion of CSG production. The greater level of detail incorporated into the design of this model will more accurately represent hydraulic response to CSG activities within and around the Project area. It will also reduce the level of conservatism incorporated into the Matrixplus model due to the simplifications in their model approach.

3.9 Associated Water Management Impact Assessment

Various studies have been undertaken to determine whether the selected management options for the AWMP are viable (including their priority of use) having regard to their environmental impacts and their management.

These studies are listed in Table 3 of this report. SANTOS TOGA Pty Ltd (2009) provides further detail on the adopted water management approaches for GLNG, their assessed impacts and mitigation approaches. In undertaking the risk assessment outlined in this report and assessing the mitigation measures to be used to support those options, regard was had to those studies (as is set out in Section 8 of this report).

4.0 DESCRIPTION OF THE EXISTING ENVIRONMENT

4.1 Topography

In the northern and central parts of the Fairview CSG Field, the Precipice Sandstone and Evergreen Formation outcrop resulting in raised plateaus with steep escarpments. The typical undulating topography found in the southern parts of the Fairview Field, characterised by rounded hills, is generally created by the Hutton Sandstone; whereas low hill sand scarps are associated with the outcropping sandstones of the Orallo Formation and Mooga Sandstone further south. The Bungil and Wallumbilla Formations give rise to typically flat topography in the southern reaches of the Roma CSG Field where large areas of poorly consolidated tertiary aged sandstone and conglomerate unconformably overlie the Wallumbilla Formation. The drainage channels have been in-filled with alluvial sediments comprising Quaternary aged sand, gravel and clay throughout the Project area.

In the far northern reaches of the Project area, the Arcadia Valley has been in-filled with Cainozoic aged sandy sediments, which are overlain by Quaternary aged alluvial deposits along the drainages. Steep cliffs on either side of the valley are typically carved of the Permian aged Clematis Sandstone or Moolayember Formation.

4.2 Climate

The climate of the GLNG CSG field area is sub tropical, with a dry winter season (April to September). December and January are the wettest and hottest months where temperatures can exceed 40ºC. Recent years have been drier than the long-term average and net evaporation have sensibly increased within the area.

SILO data were purchased for 3 sites in the CSG field area (for Lat, Long: -26.571 148.775 (town of Roma), -25.661, 148.946 (NE of town of Injune), -24.503, 148.622 (town of Rolleston), extracted from Silo on 20090327). The SILO Data Drill (http://www.longpaddock.qld.gov.au/silo/) is maintained by DERM for extracting interpolated rainfall data that are based on observed data collected by the Australian Bureau of Meteorology.

The Data Drill accesses grids of data interpolated from point observations by the Bureau of Meteorology. The data in the Data Drill are all synthetic. The Data Drill does have the advantage of being available (temporally continuous daily data) for anywhere in Australia interpolated to 0.05 degrees spatial resolution (around 5 km; http://www.longpaddock.qld.gov.au/silo/). For a more detailed description please refer to http://www.nrw.qld.gov.au/silo/datadrill/index.html. Both rainfall and evaporation data were obtained from 1889 to early 2009. Average maximum and minimum temperatures, rainfall, total and net evaporation per year has been calculated for the last 120 years.

Climatic conditions are similar at the three CSG Fields, although average temperatures and evaporation have a slightly smaller seasonal variability in the Arcadia CSG Field, probably reflecting its comparative northern location and proximity to the tropics.

The Fairview CSG Field experiences the highest average rainfall, 630 mm/year, followed by Arcadia and Roma CSG Fields with approximately 610 mm/year and 586 mm/year, respectively. While rainfall is similar in winter months for the three CSG Fields, Arcadia and Fairview generally experience higher rainfall than Roma during summer.

The whole study area is in water unbalance between rainfall and evaporation. Arcadia and Roma CSG Fields experience higher evaporation values, about 2080 mm and 2100 mm per year in average, respectively, while in Fairview CSG Field this parameter is about 1998 mm per year.

The same spatial distribution can be observed for net evaporation which is lower in Fairview CSG Field (1370mm) and higher in Arcadia and Roma CSG Fields (1490 mm and 1496 mm respectively). In terms of net evaporation, Roma experiences the highest variability during the year, with a net evaporation ranging between over 190 mm in summer and below 40 mm in winter. Lower seasonal variations occur in Fairview and Arcadia CSG Fields.

Table 8 presents the average minimum and maximum monthly temperatures, the average monthly total rainfall and the total and the average monthly total and net evaporation for the three CSG Fields within the study area. Annual average values are presented for temperature while average annual total amount of rainfall and evaporation are presented in the same table. Maximum values are in red and minimum values in blue.

Table 8: Climate Characteristics within the GLNG Project Area

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temp (C°)	**Max**	**Roma**	34.4	33.4	31.6	28.0	23.6	20.1	19.6	22.0	26.0	29.7	32.4	34.2	**28.5**
		Fairview	33.8	32.6	31.2	27.9	23.9	20.6	20.3	22.5	26.3	29.7	32.0	33.6	**28.4**
		Arcadia	34.3	33.2	32.2	29.4	25.8	22.8	22.5	24.7	28.1	31.2	33.0	34.3	**29.9**
	Min	**Roma**	20.4	19.9	17.6	12.9	8.3	5.2	3.8	5.2	9.0	13.7	16.8	19.1	**12.9**
		Fairview	19.9	19.4	17.1	12.6	8.4	5.1	3.8	5.0	8.9	13.4	16.5	18.7	**12.6**
		Arcadia	21.2	20.8	19.1	15.3	11.2	7.8	6.4	7.7	11.4	15.6	18.2	20.2	**14.9**
Rainfall (mm)		**Roma**	80.1	73.5	61.9	33.4	35.4	34.7	35.1	25.4	28.0	50.9	56.5	71.4	**586.3**
		Fairview	95.9	88.5	63.1	40.3	34.6	35.2	31.0	22.2	25.5	46.1	64.3	82.6	**629.3**
		Arcadia	97.9	87.8	58.3	35.6	33.5	32.8	26.1	20.6	25.2	42.6	60.1	86.8	**607.3**
Evap (mm)	**Tot**	**Roma**	272.1	205.0	206.1	149.5	99.4	72.3	80.4	111.2	163.4	214.7	238.9	269.3	**2082.3**
		Fairview	250.3	191.7	194.6	144.0	99.7	74.9	83.0	113.3	162.7	207.4	226.4	249.8	**1997.8**
		Arcadia	242.9	195.1	202.2	155.3	116.1	91.7	100.9	128.8	173.9	214.9	229.2	246.8	**2097.8**
	Net	**Roma**	192.0	131.5	144.1	116.1	64.0	37.6	45.3	85.8	135.4	163.9	182.5	197.9	**1496.1**
		Fairview	154.4	103.3	131.5	103.8	65.1	39.7	52.0	91.1	137.2	161.2	162.1	167.2	**1368.6**
		Arcadia	145.0	107.3	143.9	119.7	82.6	58.9	74.8	108.2	148.6	172.3	169.1	160.0	**1490.4**

Source of data series: SILO Data Drill (http://www.nrw.qld.gov.au/silo/datadrill)

The yearly climate patterns for Roma and Arcadia CSG Fields, which are the northernmost and southernmost CSG Fields of the study area, are illustrated in Figure 6a and Figure 6b respectively.

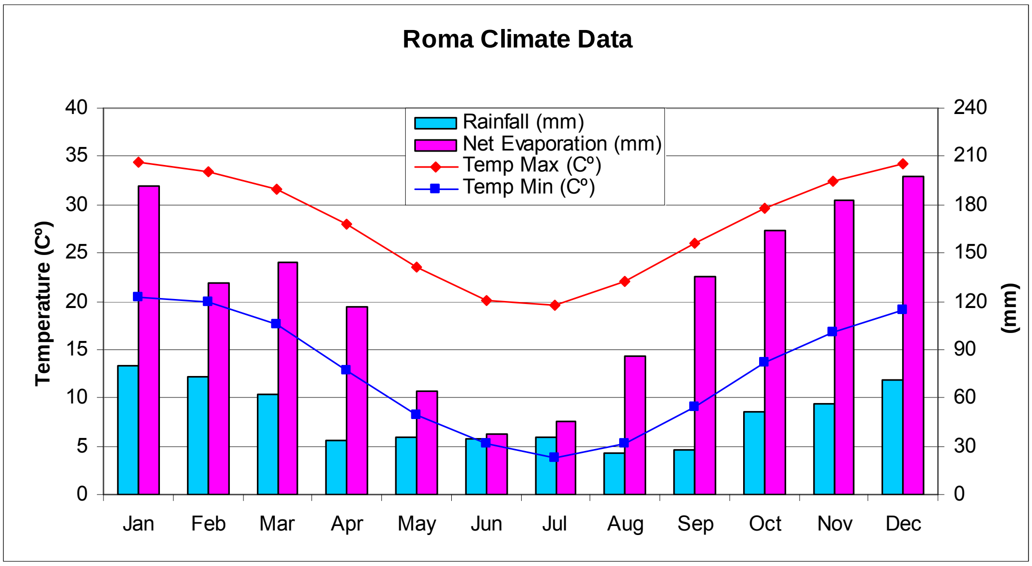


Figure 6a: Rainfall, Temperature and Net Evaporation Monthly Averages for Roma CSG Field.

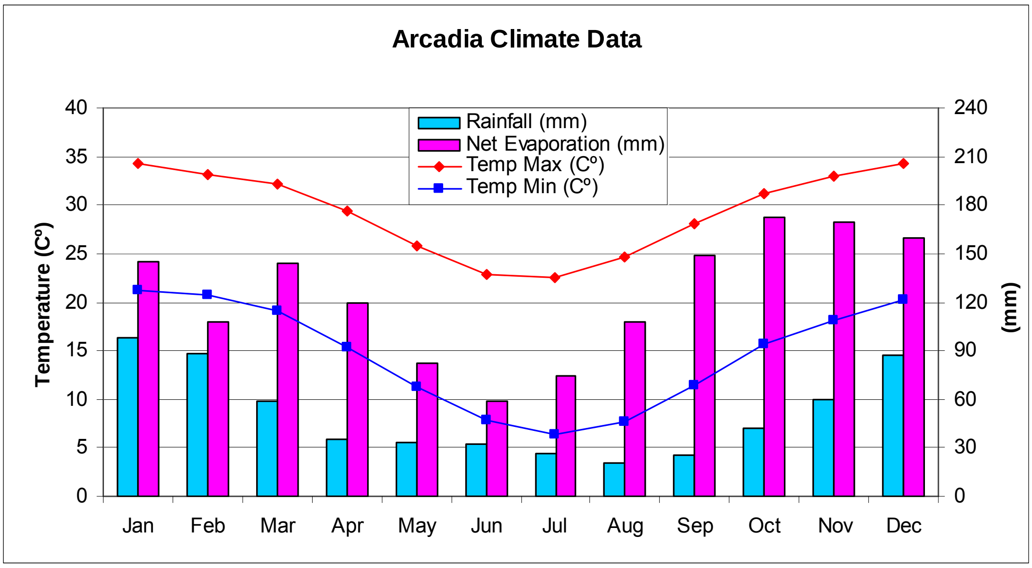


Figure 6b: Rainfall, Temperature and Net Evaporation Monthly Averages for Arcadia CSG Field.

4.3 Geology

4.3.1 Bowen Basin

The Bowen Basin is an Early Permian to Middle Triassic aged basin, which contains shallow marine and continental clastic and volcanic rocks. The Bowen Basin is comprised of two sedimentary depositional centres: the Denison and Taroom Troughs (Figure 7). The main structural feature through the Project Area is the Comet Ridge, located along the western margin of the Taroom Trough in the southern extent of the Bowen Basin. The Comet Ridge comprises mainly Devonian aged rocks and is covered by a relatively thin sequence of gently folded Permian and Triassic rocks which make up the Bowen Basin.

The oldest formation which can be included in the Bowen Basin is the Reids Dome Beds, a unit of highly variable thickness. The Reids Dome Beds are unconformably overlain by the Early Permian aged formations of the Back Creek Group, which include formations of the Cattle Creek Group, the Aldebaran Sandstone, and a number of other formations (Figure 3). The Aldebaran Sandstone is the deepest formation targeted for water within the north-western reaches of the Project area, near the town of Emerald. The other formations within the Back Creek Group are generally of a lower permeability. The Back Creek Group is overlain by shale, siltstone, tuff, bentonite and labile sandstone of the Black Alley Shale.

The Black Alley Shale and the Bandanna Formation are included in the Late Permian aged Blackwater Group. Gas in the Fairview and Arcadia CSG Fields is extracted from the coal seams of the Bandanna Formation, at depths of 500 to 1,000 m below the surface. The thickness of the Bandanna Formation is variable throughout the study area, from approximately 60 to 100 m thick in the Comet Ridge area. Up to six coal seams can be defined within the Bandanna Formation with the average coal thickness of approximately 8 to 9 m in the Fairview Field, generally thinning northward. However, to the east of the Field, 15.3 m of net coal has been intersected (McClure S. et al., 2008).

The Bandanna Formation is unconformably overlain by the oldest formation of the Triassic aged Mimosa Group, the Rewan Formation (Figure 3). This formation is the oldest formation to outcrop within the Arcadia Valley (Figure 8a). The Clematis Sandstone is a prominent formation in the Arcadia CSG field, forming the step cliffs of the Expedition Range, and is overlain by mudstone and sandstone units of the Moolayember Formation. The Arcadia Valley has been in-filled with Cainozoic aged sandy sediments, which are overlain by Quaternary aged alluvium deposits along the drainages.

The unconformable contact between the Moolayember Formation and the overlying Precipice Sandstone forms the boundary between the Bowen and Surat Basin.

4.3.2 Surat Basin

The Surat Basin comprises a sequence of south dipping consolidated Jurassic and Cretaceous sediments. As previously mentioned, the Surat Basin is a sub-basin of the GAB.

Due to compression and erosional processes, the Precipice Sandstone directly overlies, and is in hydraulic connection with, the Bandanna Formation in a limited area of the southwest Fairview Field. The extent of this contact is depicted in the 'Fairview Area Overburden Thickness Map' provided by Santos (Appendix B).

The outcrop region of the Precipice Sandstone crosses through the northern part of the Fairview Field (Figure 8a). The younger Surat Basin formations outcrop progressively south through Roma, including the Evergreen Formation, the Hutton Sandstone and Birkhead Formation, the Springbok Sandstone, Walloon Coal Measures, Westbourne Formation, the Gubberamunda Sandstone and Orallo Formation. The final Surat Basin formations which outcrop within the southern reaches of the Project area include the Mooga Sandstone, and the Bungil and Wallumbilla Formations (Bureau of Mineral Resources, Geology and Geophysics Surficial Geology, 1967) (Figures 8, 9 and 10).

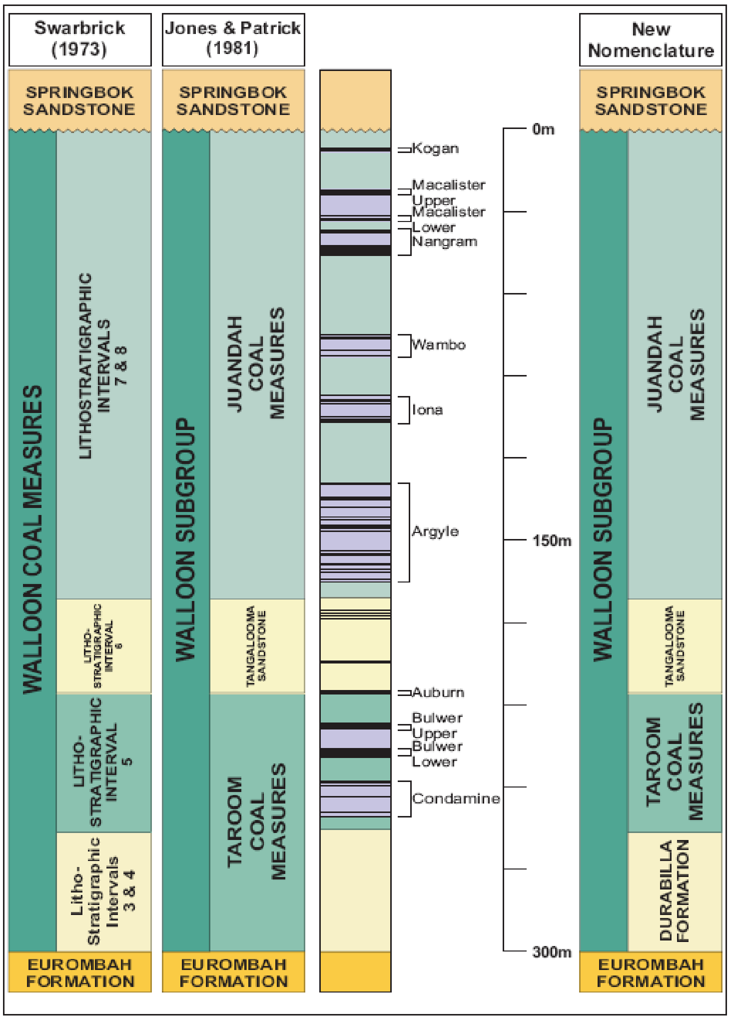
The Walloon Coal Measures (WCM) are the main gas bearing units within the Surat Basin, and are the target formation for CSG operations within the Roma Field. The thickness of the coal measures in the Roma CSG Field ranges from 100 to 460 m, at depths ranging from 170 to 933 m below ground level. The coal seams are separated by silty and tight sandstone, which restricts leakage between seams. There is an unconformable contact between the Springbok Sandstone and the Walloon Coal Measures. They are considered to be in hydraulic connection (Scott S. et al., 2004). Figure 11 describes the detailed stratigraphic sequence within the Walloon Coal Measures.

Conceptual geological cross sections through the three CSG fields are presented on Figures 9, and 10, and 12 to 15. These sections present an interpretation of the key elements of the Bowen and Surat Basin geology within the CSG field area. These interpretations, limited by the amount and quality of data used to generate each section, will need to be updated as more data become available. The locations of these cross sections are presented on the surface geology map (Figure 8a).

Figure 9 extends through the north-central to south-central part of the Roma CSG Field and Figure 10 extends west to east of the Field. These sections were generated using stratigraphy data available in the DERM groundwater database and from Santos CSG well geology logs. Data on the depths of formations below the Walloon Coal Measures were sparse.

Figures 12 and 13 present the north to south and east to west sections through central Fairview. These cross sections were generated by Santos using their geologic model and only extend to the base of the Rewan Formation (equivalent to the top of the Bandanna Formation). A third cross section through Fairview (Figure 14), through the southern portion of the Field, is presented to illustrate the limited southwest contact between the Precipice Sandstone and Bandanna Formation.

Figure 15 presents the conceptual geology from west to east through southern Arcadia. Data on the depths of formations are sparse in this area and Santos was not able to provide stratigraphic information for their Arcadia CSG Field exploration wells. As such, Figure 15 was derived from the Taroom Geological Map (Bureau of Mineral Resources, Geology and Geophysics, 1967) and does not distinguish between the individual formations of Permian age.



Source: Scott S. et al. 2004

Figure 11: Detailed Stratigraphy of the Walloon Coal Measures

4.3.3 Faults and Other Geological Controls

The Roma CSG Field is located in the northern margin of the Surat Basin. In this area, the targeted Walloon Coal Measures and the other main geological units do not indicate deformation or complex faulted geology.

The basement is block-faulted as defined by seismic work (URS, 2008). However the faulting and folding that is recognized in the older subsurface strata is either absent or attenuated in the outcropping Jurassic-Cretaceous sediments. Some features are, however, visible in the outcrop, including the Alicker and Eurombah Anticlines, the Hutton-Wallumbilla Fault and a number of west-northwest trending faults (Figures 8a).

The northwest trending Hutton-Wallumbilla Fault crosses the Roma CSG Field and is downthrown to the west with a displacement of ±450 m in the basement but just 30 m in the overlying sediments. Small northwest trending faults elsewhere in the Field are likely related to the movements that formed the Hutton-Wallumbilla Fault (URS, 2008).

West-northwest trending faults also occur across the Roma CSG Field area. These faults are likely a result of epeirogenic movements (the gradual uplift or subsidence of the Earth's surface) related to the Surat Basin through the Tertiary period (URS, 2008). These faults have limited or no vertical displacement but they leave a clearer topographic imprint than the larger faults in the same region due to their younger age.

The Fairview CSG Field is situated between two large reverse fault systems that are oriented approximately north south (Santos, 2008a). The northwest trending Hutton-Wallumbilla Fault runs to the west of the CSG Field. The Fairview CSG Field is located within an anticline which plunges to the south-southeast and corresponds to a southerly extension of the Comet Ridge in the geological basement. The anticline is complementary to the Mimosa Syncline, located to the east of the Fairview Field.

Both the anticline and syncline developed through the Permian and Triassic periods. In the anticlinal structure there are subsidiary minor folds, but after the period represented by the unconformity at the base of the Jurassic aged Precipice Sandstone, folding on the pre-existing axes has been slight. The warping and minor faulting of the Jurassic succession may be related to the compaction of the underlying thick sequence of Permian and Triassic sediments.

The major structural feature in the Arcadia Valley CSG Field is the Comet Ridge, which comprises mainly Devonian age rocks, and is covered by a relatively thin sequence of Permian and Triassic rocks. The Permian and Triassic sequence of sediments within the Arcadia Valley CSG Field was folded principally during the late Triassic Period, although some of the deformation within the Permian sediments possibly occurred during the period of uplift and emergence in the Lower Permian too.

Fold axes are generally parallel, trending north-west, to the Comet Ridge axis. The amplitude of folding on the Comet Ridge is small and the axes are short and sinuous. The Permian-Triassic folds are truncated by the erosional unconformity surface on which the Precipice Sandstone was deposited. The overlying Jurassic and Cainozoic rocks are not folded.

4.4 Hydrogeological Conceptual Model

4.4.1 Hydrogeological Setting

The Bowen and Surat Basins are structurally separate sedimentary depositional centres; however, they are stratigraphically and hydraulically interconnected (DME, 1997). The Surat Basin is a sub-basin of the GAB, one of the largest artesian groundwater basins in the world.

Both the Surat and the Bowen basins are multi-layered mainly confined systems 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 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 CSG field area, the thickness of the formations remains quite uniform throughout their profile. The formations 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 Surat Basin, which are considered to be the part of the recharge areas of the GAB.

As presented in Section 1.3, 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 Santos GLNG Project spans three management areas (Surat, Surat North and Mimosa) and also includes a portion of the Bowen Basin that is not considered to be part of the GAB. The geological formations present within the GMAs 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 2 and Figure 3.

4.4.2 Hydrostratigraphy

Roma CSG Field

The Roma CSG Field is contained within the areal boundaries of the Surat GMA 19 (Figure 2). The main aquifer units in terms of groundwater development within the Field include:

- Mooga Sandstone (Surat 3);
- Gubberamunda Sandstone (Surat 4);
- Hutton Sandstone (Surat 6); and
- Precipice Sandstone (Surat 7).

Hydrogeological conditions that can increase the hydraulic conductivity and storage within the above formations include: weathering contacts and transitions and openings/discontinuities formed by the west-northwest trending faults.

The Mooga Sandstone and Gubberamunda Sandstone outcrop in a thin band just north of the Roma Gas Field. These outcrops are considered to be part of the recharge area for these aquifers. No springs are mapped through the Mooga outcrop but five springs are mapped in the Gubberamunda. Only a few groundwater bores are completed in the Hutton and Precipice Sandstones in this region due to their greater depths.

Primary aquitards within the Roma Field include the Orallo Formation, the Westbourne Formation, and the Evergreen Formation. The Wallumbilla Formation underlies most of the Roma Field and outcrops through the centre of the Field. The Moolayember Formation is considered as the base aquitard in this area, based on its low permeability and considerable thickness, below which minimal impact is expected.

Fairview CSG Field

The Fairview CSG Field is contained within the conceptual boundaries of the Surat North GMA 20. The primary aquifers, in terms of groundwater development, within the Field include:

- Hutton Sandstone (Surat 6);
- Precipice Sandstone (Surat 7); and
- Clematis Sandstone (Surat 8).

The Hutton Sandstone is not a reliable source due to its non-continuous distribution and poor quality within this area. The Hutton Sandstone is also unsaturated within many parts of the Fairview Field. The Precipice Sandstone has very good aquifer potential and generally produces plentiful supplies of potable sub-artesian water. A number of recharge springs for the Hutton and Precipice Sandstone are present within the Fairview Field boundaries. The narrow outcropping area can be considered as the northern borderline of the Surat Basin, being the oldest and deepest formation of this basin. The Clematis Sandstone can also produce good supplies of potable groundwater. Also within this CSG Field, the alluvium deposits associated with larger streams can provide good supplies of groundwater from shallow depths.

Low permeability formations include the Evergreen and Moolayember Formations, both of which have little potential for water use in the area.

According to information available from DERM (Foster, 2007), alluvial deposits within the Fairview Field have enhanced groundwater potential due to relatively high hydraulic conductivity. Aquifers associated with the sedimentary rocks within the hills of the 'kipper catchments' have lower yields and groundwater quality may be saline due to the depositional nature of the rocks and the reduced rainfall recharge.

Arcadia Valley CSG Field

Within the Arcadia CSG Field the main aquifers include the Precipice Sandstone (Surat 7), which outcrops within the southern portion of the gas Field, the Moolayember Formation (Surat 8), the Clematis Sandstone (Surat 8), and the Aldebaran Sandstone in the northern portion of the gas Field. These aquifers can produce good supplies of potable groundwater to users in the region. Many bores are also completed in shallow Tertiary sediments, basalts and alluvium deposits. The Rewan Formation (Surat 8) acts as effective hydraulic barrier (aquitard), although a few bores are also completed within this formation through the Arcadia Valley.

4.4.3 Hydraulic Parameters

A number of flow and pressure test have been carried out on bores in the area of interest to determine the transmissivity for the water producing aquifers. A total of 239 static (recovery) tests were analysed within the and around the Project area to estimate the parameters for the numerical modelling of the groundwater impact (Matrixplus, 2009). Table 9 lists the details of formations recorded in drilling logs for bores and the resultant parameters for analyses, as presented by Matrixplus (2009).

Additional pumping tests were completed within the Roma CSG Field to determine the conductivity of the coal seams. The results are summarized in Table 10.

Table 9: Geologic Formations and Aquifer Parameters – Comet Ridge (Fairview and Arcadia Valley) and Roma Fields

Formation	Average thickness (m) and [range of depth]	T (m^2/d)	K (m/d)	Parameter Source	No. of Samples Analysed	Yield* (L/s)	Comments
Griman Creek	57 [-480]	--	--	Flow test	--	0.2 - 1.6	--
Surat Siltstone	110 [-150]	--	--	--	1	--	--
Wallumbilla Formation	220 [140-340]	13	0.06	Flow tests	3	1.5	--
Bungil Group	112 [80-230]	4.6	0.04	Flow Tests	2	0.2 - 6.3	--
Minmi Member	22 [20-70]	--	--	--	--	--	Minor Aquifer
Southlands Formation	113	--	--	--	--	1.6	--
Mooga Sandstone	86 [25-200]	19	0.22	Flow Tests	42	0.2 - 16	Aquifer
Orallo Formation	107 [70-270]	--	--	--	--	1.2 - 14	Aquifer
Gubberamunda Sandstone	84 [20-260]	11	0.13	Flow Tests	1	1.0 - 31.0	Aquifer. Most highly developed aquifer in the Surat Basin
Injune Creek Formation	396 [-1000]	32	0.08	Flow Tests	--	0.2 - 3.0	Yields increase with test depths
Westbourne	110	--	0.00	--	--	na	Aquitard/Aquiclu

Formation	Average thickness (m) and [range of depth]	T (m^2/d)	K (m/d)	Parameter Source	No. of Samples Analysed	Yield* (L/s)	Comments
Formation	[60-200]		01				de
Springbok Sandstone	71.5	--	--	--	--	--	Layers of minor aquifers
Walloon Coal Measures	227 [100-460]	0.36	0.00 2	Flow tests	2	na	Gas producing coal seams. T values obtained from Coxon Ck. Gas production tests.
Eurombah	50 [20-80]	6.8	0.14	Flow Tests	2	0.1 - 1.2	K value seems too high
Hutton Sandstone	150 [100-350]	21	0.14	Flow Test	20	0 - 12.0	Aquifer
Evergreen Formation	105 [10-260]	--	0.00 8	AHA Report	--	0.0 - 2.7	Yields increase with test depths
Boxvale Sandstone	46	10	0.2	Flow Tests	2	0.5 - 7.6	Aquifer
Precipice Sandstone	~100 [20-140]	50	0.5	Flow Tests	4	0.3 - 16	Aquifer. T of 50 from model calibration
Moolayember Formation	80 [10-500]	66	0.82	Flow Tests	10	0.0 - 7.0	
Clematis sandstone	144 [10-200]	13	0.09-1.97	Flow Tests	50 7	0.0 - 199.2	Aquifer. Aquifer thickness not available for high T bores. Probably very thick and K of order of 0.2
Rewan Group	173 [50-600]	--	0.00 001	Assumed Negligible	--	0.0 - 12.6	
Bandanna Formation	134 [70-250]	0.1 – 18	0.04	Production & Hyd.Head Contours	Period: Feb-May 2004	--	Gas producing coal seams

Source: Matrixplus (February 2009), except Yield* sourced from DERM groundwater database (2008)

Table 10: Permeability and Transmissivity of the Coal Seams in the Roma Field.

Formation	Aquifer Thickness (net pay) (m)	K (mD)	T (m^2/d)
Upper Juandah	1.3 - 6.36	4 - 1200	0.01 -1.81
Upper Juandah (Lower)	1.2 - 3.8	0.05 – 11.0	0.00005 – 0.04
Lower Juandah (Lower)	1.4 3.5	2 – 130	0.0027 – 0.38
Lower Juandah (Sand)	2.1	26	0.047
Lower Juandah (Upper)	1.05 – 2.9	0.6 – 260	0.005 – 0.33
Taroom (Upper)	1.3 – 2.9	13.7 – 1140	0.03 – 2.07
Taroom (Lower)	0.86 – 3.0	0.1 – 790	0.0007 – 2.05

Source: Matrixplus (February, 2009)

4.4.4 Hydrogeological Mapping of the Groundwater Management Units

As previously mentioned, the conceptual boundaries of the GMAs follow similarly to the three CSG Fields for the GLNG Project. Figure 2 presents the locations of the three GLNG CSG Fields relative to the management area boundaries. Each of these management areas are subdivided into management 'units' based on lithological formations.

The following sections provide a description of potentiometric surfaces and salinities for each of the hydrogeological management units across the CSG field area based on groundwater level measurements received from DERM and Santos.

For simplicity, reference to the management units are based on the classification for Surat GMA 19; however, the unit equivalents in the other GMAs should be kept in consideration (Table 2). For example, when addressing the Clematis Sandstone, the discussion will refer to the Surat 8 unit but the discussion will also applicable to the Mimosa 1 and Surat North 4 units.

The northwest area of the Project extends beyond the boundaries of the GAB and into the Bowen Basin. The Permian formations of the Bowen Basin are not administered under a WRP or separated into management units. However, as they could potentially be impacted by CSG operations, the following sections will also consider these formations, for the most part just the Blackwater Group and the Back Creek Group.

Potentiometric levels are presented in terms of the Australian Height Datum (AHD), as adopted by the National Mapping Council of Australia. Electrical Conductivity (EC) is expressed in micro-Siemens per centimetre (μS/cm) and is used as major indicator of groundwater salinity. Outcrop regions, or areas with little or no data are indicated with 'Area Blanked' on the figures associated with the following discussions (Figures 16 to 25).

It should be noted that data used in the generation of the groundwater contour maps (Figures 16 - 25) 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 conditions.

Shallow formations, such as Alluvium, Volcanics and Tertiary Formations are not included in the following section, as they are spatially fragmented, of variable thickness and saturation and are not connected across the CSG Fields. However, as these formations are still targeted for use within the region or could act as preferential flow paths for surficial contaminants, their importance is considered in the impact and risk assessment discussions within this report (Section 5 and 6).

4.4.4.1 Surat 1

As defined in the GABWRP, groundwater management unit Surat 1 includes the Surat Siltstone and the Wallumbilla Formation (Coreena and Doncaster Members). The geological formations of Surat 1 exist over most of the Roma CSG Gas Field and outcrop in the northern portion of this Field.

Based on data extracted from the DERM groundwater database, there are 57 registered bores within the Project area that have been completed in Surat 1 unit, 42 of which with water level information. The depths of the bores range between 24 m and 170 meters below ground level following the dip of the formation towards the south.

Measured depths to groundwater range between 1.5 m and 92 m GL, equivalent to 225 and 420 m AHD. On average, the potentiometric surface in this unit is approximately 330 m AHD within the Roma CSG Field (Figure 16). Potentiometric heads are highest in the topographically high outcrop regions where recharge occurs. Lateral hydraulic gradients (dh/dx) are from NW to SE and NE to SW, converging in the southern tenements of Roma, where the lowest heads are recorded. The hydraulic gradient through the unit is on the order of 0.001 to 0.004. Based on the hydraulic conductivity presented in Table 9, and an estimated thickness of the Surat 1 unit (based on available stratigraphy in the DERM database), an estimated flow rate through the Surat 1 unit is $1x10^{-2}$ to $3x10^{-2}$ m^3/d per metre width of the aquifer.

EC values were available for 11 bores completed within the Surat 1 unit. Most of these bores are located northwest of the Roma CSG Field, with the exception of one bore located near the town of Roma itself. The salinity of the groundwater ranges between 160 μS/cm in the western bores to greater than 8,600 μS/cm in the east (Figure 16). This can suggest that groundwater is predominantly fresh in the outcrop reaches of the Surat 1 unit but areas of brackish water do exist in the confined areas of the formation, suggesting a longer residence time and/or mixing with older more saline waters down dip of the unit.

4.4.4.2 Surat 2

Groundwater management unit Surat 2 corresponds to the Bungil Formation, which consists of Minmi Member, Nullawart Sandstone Member and Kingull Member. The geological formations of the Surat 2 occur only in the Roma CSG Gas Field. The Kingull Member is considered to be the confining bed of the Bungil formation, while the Minmi and Member and Nullawart Sandstone can be considered as potential water bearing aquifers.

Based on data extracted from the DERM groundwater database, there are over 360 registered bores in the GLNG Project area that have been completed in the Surat 2 Unit, 89 bores with water level information. Depth of these bores range between 24 and 337 m, following the dip of the formations. Five bores have been classified as artesian and are located in the southern part of the Roma CSG Field, where the ground surface is lowest and the Bungil Formation is overlain by Tertiary sediments. Pressure in the artesian bores measured between +0.3 and +35.2 m above ground level.

Groundwater heads range between 250 and 440 m AHD (Figure 17). As is observed in the Surat 1 unit, potentiometric levels are highest in the outcropping areas northwest of the Roma CSG Field. Groundwater flows from the NW to SE and NE to SW. The lowest heads are recorded in the southern tenements of Roma, where most of the artesian wells are identified. The hydraulic gradient through the unit is on the order of $7x10^{-4}$ to $4x10^{-3}$, with an estimated daily groundwater flow rate of $3x10^{-3}$ to $2x10^{-2}$ m^3/d per metre width of the aquifer.

EC values were available for 25 bores in the Surat 2 unit. Salinity varies between 8,800 μS/cm in the recharge areas northwest of the Roma Gas Field to 1,100 μS/cm near the town of Roma (Figure 17). The high salinity in recharge area is inconsistent with the salinity distribution observed in neighbouring units and considered to be invalid. The high EC measurements appear to be controlled by four data points distributed through the northern region of this unit. Possible reasons for these values could be poor well construction or un-proper well development prior to sampling; however, the exact reason for this discrepancy can not be explained based on the limited data available. It may be appropriate to resample these bores to confirm chemistry during the bore inventory.

4.4.4.3 Surat 3

Groundwater management unit Surat 3 corresponds to the Mooga Sandstone. The Mooga Sandstone is considered to be a main aquifer in GLNG Project Area in terms of groundwater extraction. It outcrops in the northern reaches of the Roma CSG Field.

Based on data extracted from the DERM groundwater database, there are 188 registered bores within the Project area that have been completed in Surat 3 unit, 128 of which with water level information. The bore depths range between 13 and 643 m, following the south dip of the formation. Nine of these bores have been classified as artesian wells and are located in the south-eastern portion of the Roma Field. Pressure in these bores ranges between +1 and +45 m above ground level.

Potentiometric heads in this unit range between 246 and 630 m AHD (Figure 18). Potentiometric heads are highest in the outcrop regions of the formation northwest of Roma Gas Field. Groundwater flows in a NW to SE direction and NE to SW direction, similar to Surat Unit 1. The hydraulic gradient through the unit is on the order of $2x10^{-3}$ to $5x10^{-2}$, with an approximate daily groundwater flow rate of $4x10^{-2}$ to $1x10^{-0}$ m^3/d per metre width of the aquifer.

EC measurements are available for 59 of the Surat 3 unit bores. EC ranges between 440 and 5,900 µS/cm without any clear trends across the unit, with the exception that the higher salinity is measured on the western and eastern boundaries of the tenements near Roma (Figure 18).

4.4.4.4 Surat 4

Groundwater management unit Surat 4 includes the Late Jurassic aged Orallo Formation and Gubberamunda Sandstone. Both formations outcrop along the northern reaches of the Roma Gas Field. The Gubberamunda Formation is a major aquifer in the area, and is the source of groundwater for the town of Roma.

There are 110 registered bores in the GLNG Project area that have been completed in the Surat 4 Unit, 65 bores with water levels. Depths of these bores range between 21 m and 767 m following the south dip of the formation. One artesian bore was identified to the southeast of the Roma CSG Field, with a water pressure equal to +29.7 m above ground level.

Potentiometric heads in this unit range between 263 and 446 m AHD, with the greatest heads measured in the outcrop areas northwest of Roma (Figure 19). Potentiometric heads generally decrease from the NW to the east and south east. As the Project area is located within the recharge area of the Great Artesian Basin, it is not unexpected to see that there are a number of springs located in the outcrop regions of the Gubberamunda Sandstone, north of the Roma CSG Field (Figure 8a). The hydraulic gradient through the unit is on the order of 0.001 to 0.004, with an approximate daily groundwater flow rate of $8x10^{-3}$ to $1x10^{-1}$ m^3/d per metre width of the aquifer.

EC measurements were available for 23 bores, of which 19 are completed in the Gubberamunda Sandstone. Salinity increases following the dip of the formations, ranging between 425 and 3,800 µS/cm.

4.4.4.5 Surat 5 (Surat North 1)

Groundwater management unit Surat 5 consists of the Jurassic aged Injune Creek Group, including the Westbourne Formation, Springbok Sandstone, Walloon Coal Measures and Eurombah Formation. The main outcrop area of these formations is located on the southern boundary of the Fairview CSG Field. Surat 5 bores are located in both the Surat GMA and the Surat North GMA (also known as Surat North 1 unit bores).

Based on data extracted from the DERM groundwater database, there are there are 86 registered bores within the GLNG Project area that have been completed in Surat 5 unit, 56 of which with water level information. The majority of these do not specify a completion formation and are generalized as being completed in the Injune Creek Group. Depths of these bores range between 23 m and 550 m. Most of the bores are located near or just south of the outcrop regions, between the Fairview and Roma CSG Fields, where the unit is generally shallower. Two of Surat 5 bores are classified as artesian.

Formation pressures from Roma CSG extraction wells, and thus hydraulic head measurements in the WCM, were not available and could not be included in the hydrogeological interpretation of the Surat 5 unit.

Based on DERM data alone, potentiometric levels in the Surat 5 unit range between 207 and 475 m AHD, with the greatest levels observed in the northwest outcrop region. The hydrogeological map for the Surat 5 unit (Figure 20a) indicates that the direction of groundwater flow is towards the south-southeast, away from the north-western outcrop region. A local zone of easterly flow is observed north of the Roma CSG Field, towards Eurombah creek which drains into the Dawson River. Groundwater flow direction in this zone is consistent with the drainage of the upper Dawson river catchment (URS, 2008), and with the interpreted direction of groundwater flow in the GAB (Habermehl and Lau, 1997). It is assumed that the Injune Creek Group and the shallow alluvium deposits of this river may be in hydraulic communication through this area. It should also be noted that the distribution of bores with water level data are concentrated in the north-eastern portion of the Surat 5 unit, which may suggest extensive groundwater use in this area. The hydraulic gradient through the Surat 5 unit is on the order of 0.002 to 0.004, with an estimated daily groundwater flow rate through the aquifer of $1x10^{-3}$ to $4x10^{-3}$ m^3/d per metre width of the aquifer.

EC measurements were available for 27 DERM Surat 5 bores ranging between 350 and 5,100 μS/cm. The salinity distribution in this unit is presented in Figure 20a.

Salinity data was provided for a number of Roma CSG wells completed in the Walloon Coal Measures and are presented on Figure 20b. Salinity appears to decrease in a southerly direction, however, there is a poor distribution of sample points across the field (i.e. salinity measurements are not available in the southern reaches of the Roma CSG field). It is recommended that Santos expand the number of water quality sampling locations to better understand the salinity distribution across the field.

4.4.4.6 Surat 6 (Surat North 2)

Groundwater management unit Surat 6 corresponds to the Hutton Sandstone, Boxvale Sandstone and the Evergreen Formation. The Hutton Sandstone outcrops across the southern portion of the Fairview Field. Erosional features of this sandstone create the rolling hills visible across region. Within the Project area, 187 registered bores completed in Surat 5 unit, 174 bores of which are completed in the Hutton Sandstone (128 with water level data). Most of the bores completed in this unit are located within, or just south of, the outcrop areas. Depth of the bores range between 29 m and 579 m within this unit.

Potentiometric levels in the Hutton Sandstone range between 134 and 577 m AHD, with the highest levels measured in the outcrop region northwest of the Fairview CSG Field (Figure 21). There are a number of Hutton Sandstone springs located within the Fairview CSG Field boundaries, along a basin fault (Figure 13). Groundwater generally flows in a northwest to south-southeast direction. The hydraulic gradient through the Surat 6 unit is on the order of 0.002 to 0.006, with an estimated daily groundwater flow rate of $5x10^{-2}$ to $2x10^{-1}$ m^3/d per metre width of the aquifer. A local zone of easterly flow is also observed in the Surat 6 unit along the direction of drainage for the upper Dawson river catchment (Figure 21).

EC measurements were available for 23 DERM bores completed in the Surat 6 unit. The salinity of the groundwater is relatively uniform across the Surat 6, ranging between 150 and 3300 μS/cm.

4.4.4.7 Surat 7 (Surat North 3)

Groundwater management unit Surat 7 corresponds to the Precipice Sandstone, which outcrops along the border between the Fairview and Arcadia CSG Fields. There are 31 registered bores within the Project area that have been completed in Surat 7 unit, 15 of which with water level data, with depths ranging between 38 m and 244 m. Most of these bores are situated to the west of the Fairview CSG Field. Artesian wells are identified in areas where the Precipice Sandstone in overlain by the Evergreen Formation and the Hutton Sandstone. Potentiometric heads in the Surat 7 decrease with increasing depth of the formation, from 520 m AHD in the northwest of Fairview to 300 m AHD in the southeast (Figure 22). The estimated daily groundwater flow rate through the aquifer is $2x10^{-1}$ to $8x10^{-1}$ m^3/d per metre width of the aquifer, based on an approximate hydraulic gradient of $3x10^{-3}$ to $6x10^{-2}$.

EC measurements were available for 13 bores completed in the Precipice Sandstone. In general, salinity is observed between 80 and 1,500 µS/cm and increases in a westerly direction (Figure 22). Groundwater from the Precipice Sandstone is considered to be of good quality.

4.4.4.8 Surat 8 (Surat North 4 and Mimosa 1)

The groundwater management unit Surat 8 corresponds to the Triassic aged formations of the Bowen Basin, including the Moolayember Formation, Clematis Sandstone and Rewan Formation. These formations outcrop in the central and northern part of the Arcadia CSG Field. Based on data extracted from the DERM groundwater database, there are over 100 registered bores that have been completed in this unit; however, there are only 13 bores with water level data. All of these bores are located east of the Arcadia CSG Field. These bores are completed to depths between 69 and 427 m. Five of the eight bores completed in the Clematis Sandstone are classified as artesian and are located where the Clematis Sandstone is overlain by the Moolayember Formation. Water pressures in these bores range between +2 to +46 m above ground level. There are many springs located along the Clematis/Moolayember boundary to the Northeast of the Arcadia CSG Field, which follow along the Arcadia Valley sandstone cliff walls.

The potentiometric surface of the Surat 8 unit has been presented for the Clematis Sandstone only because of the lack of water level data available for the other formations of this unit (Figure 23). Potentiometric heads in the Clematis Sandstone range between 100 and 360 m AHD (Figure 23, Clematis Sandstone), increasing with the dip of the Clematis Sandstone beneath the Moolayember Formation (Figure 12). The hydraulic gradient through the Clematis is on the order of 0.004 to 0.006, with an estimated daily groundwater flow rate of $4x10^{-3}$ to 20 m^3/d per metre width of the aquifer, dependant on assumed hydraulic conductivity and aquifer thickness.

Separate EC maps were created for the Moolayember Formation, the Clematis Sandstone and the Rewan Formations due to the great variance in salinity ranges between the three formations; these are presented on Figure 23. Greater EC values were recorded in the lower permeability Moolayember and Rewan Formations, with available EC measurements ranging between 1,280 and 15,000 µS/cm (average of 5,100 µS/cm), and 4,200 and 27,500 µS/cm (average of 15,000 µS/cm), respectively. Salinity of the groundwater in the Clematis Sandstone does not vary greatly with measurements between 131 and 1,260 µS/cm at 48 locations.

4.4.4.9 Blackwater Group

The Blackwater Group includes the Late Permian aged formations of the Bowen basin, namely the Bandanna Formation and Black Alley Shale. The Bandanna formation is targeted for CSG extraction in both the Fairview and Arcadia Fields.

DST pressures, measured between 2006 and 2009, in the Bandanna coal seams from both the Arcadia and Fairview CSG wells were converted to hydraulic heads. Potentiometric levels in the Bandanna Formation range between 162 and 344 m AHD (Figure 24a). An area of low hydraulic heads is visible in the eastern portion of the Fairview CSG Field, which likely represents the initial stages of depressurisation in the Bandanna Formation due to CSG operations. Groundwater flow within the Bandanna Formation is locally directed towards the depressurised zones.

The distribution of salinity in the Bandanna Formation within the Arcadia and Fairview CSG Field wells is presented on Figure 24b. The figure suggests that the high salinity groundwater is present within the eastern reaches of the Fairview field, as the Bandanna Formation deepens, and to the north in the Arcadia field; however, there is a poor distribution of sample points in Arcadia.

Golder understands that additional salinity data is available for CSG wells in the Spring Gully CSG Field (operated by Australia Pacific LNG). It is intended that these salinity maps be regenerated following the collection of this additional data, and the further collection of temporal data through the regional bore inventory (see Recommendations – Section 8).

4.4.4.10 Back Creek Group

The Back Creek Group includes many Early Permian aged formations of the Bowen Basin. Major formations in this group include the Aldebaran Sandstone and the formations of the Cattle Creek Group. Over 80 registered bores are completed in this unit within the GLNG Project area, but only 15 have water level information, all of which are located to the northwest of the Arcadia CSG Field, near the town of Emerald. These bores are located along a north to south line, along the outcropping areas of the Back Creek Group. No artesian wells are identified within this unit.

Piezometric levels range between range between 160 and 350 m AHD (Figure 25). Although a large amount of water level data are not available for this group, a general decrease of heads seems to occur to the east, along the dip of the Back Creek Group.

EC measurements were recorded at 16 bores completed near the outcrop regions of the Back Creek Group in the surroundings of Emerald. Salinity varies between 400 and 4,500 µS/cm, generally increasing away from the outcrop region.

4.4.4.11 Summary

In the southern portion of the GLNG Project area, through the Roma CSG Field, the main aquifers of the GAB outcrop progressively northward, and dip regionally to the south (Figure 9). Numerous sub artesian bores intersect aquifers at shallower depths (Mooga Sandstone and Gubberamunda Sandstone) rather than the deeper resources (Hutton Sandstone). Potentiometric heads in these aquifers are identified as below ground level in the north but are near-surface to artesian in the area south of Roma. Issues such as diminishing flows and pressures in the GAB have been of concern since the early part of the century (Cox and Barron, 1998). Due to the temporal variance of the data used to generate the plots, it is possible that some of the bores classified as artesian have ceased to flow, or have lost some of their artesian pressure.

The primary direction of groundwater flow through most units is from their outcrop areas in the northwest towards the south, following the formation dip; however, easterly flow is observed between the Roma and Fairview CSG Fields towards Eurombah creek and Dawson River. The rate at which groundwater flows is dependant on the permeability and thickness of the aquifer, and the lateral hydraulic gradient for each unit. The greatest flow rates are estimated in the high permeable units such as the Precipice (Surat 7), Hutton (Surat 6) and Mooga (Surat 3), and the lowest flow rate estimated in the Walloon Coal Measures.

A number of springs are located near the outcrop areas of the Hutton Sandstone, many within the boundaries of the Fairview CSG Field (Figure 8a). There are a number of springs located within the Precipice and Gubberamunda Sandstone outcrop areas, also considered to be recharge zones of the GAB.

Salinity of the groundwater in these units is generally fresh to brackish, dependant on location with fresher water generally occurring near the outcrop areas of the aquifers. The Precipice Sandstone (Surat 7) is considered as an important groundwater source within the area.

The lease boundaries of the Arcadia CSG Field are located in the outcrop regions of the Bowen Basin, including the outcrop areas of the Rewan Formation, Clematis Sandstone, and Moolayember Formation. The Clematis Sandstone is considered to be the primary aquifer within the central region of the Arcadia Valley. Direction of groundwater flow is generally west to east, following the dip of the Clematis Sandstone under the Moolayember Formation. Salinity also increases along the dip of the formation.

To the northwest of the Arcadia CSG Field, the Permian Aldebaran Sandstone is considered to be an important aquifer for private groundwater use. Based on limited data, groundwater is fresh to brackish within the unit, with most of the bores situated in the fresher regions of the formations, near the outcrop areas west of Emerald.

Hydraulic heads data (calculated based on DST pressures provided by Santos) indicate that the Bandanna Formation is already experiencing depressurisation within the boundaries of the Fairview CSG Field. The spatial distribution of the data from the target coal seams (WCM and Bandanna Formation) is limited. It is recognised that data will continue to be collected and reinterpreted at a later date.

4.4.4.12 Regional Water Table

The water table is generally a subdued expression of the land surface topography. Water table elevations in the high elevation areas are generally maintained by recharge, while groundwater discharge can occur in the vicinity of flowing streams (most likely to occur only within the Dawson River).

The regional water table is not constrained within a particular stratigraphic unit, but can occur in different aquifers depending upon location. Across much of the GLNG Project area, the water table occurs across the entire sequence of the Surat Basin, from the Precipice to the Wallumbilla Formation (due to the limited data available, the Bowen Basin was not considered).

A regional-scale map of the water table configuration for the Surat Basin within the GLNG Project Area was developed (Figure 26). The *difference in pressure between the aquifers* (i.e., Mooga and Gubberamunda Sandstones) *is less than the resolution of the contour intervals*, thus it is considered accurate to consider these units as a sequence.

The data considered to generate Figure 26 includes groundwater level measurements in the DERM database from Surat Basin water table bores within GLNG Project area. A water table bore was defined as a bore completed in unconfined aquifers (in the outcrop area of a formation), or where the water level occurs within the screened zone of the bore. The measured water level in these wells was assumed to be the same as the water table outside the bore. The locations of major rivers were also considered. It was assumed that these rivers incised the water table through the study area.

The location of groundwater springs (Figure 8a) were not considered to be representative of the water table because the source of the springs is questionable. For example, the distinction of whether these springs are depression, fault or fracture springs is not made.

As with the previous hydrogeological maps, the period of recorded measurements in the DERM groundwater database is great (1900 to 1999); however, it is thought that the calculated levels are representative of steady state within the Project area prior to the influence of CSG operations.

As was observed in the previous hydrogeological maps, and because much of the area is located within the outcrop areas of the major hydrostratigraphic units, the direction of groundwater flow is generally from the elevated areas in the northwest, to the south, towards the areas of lower potential, towards the south and eastern parts of the area. This flow is generally consistent with the Hydrogeology of the GAB (Habermehl and Lau, 1997).

4.4.5 Trends in Groundwater Hydrographs

Roma CSG Field

In 2008, Santos installed three multi-level vibrating wire piezometers (VWPs) within the Roma CSG Field: Dumper Creek 4, Wingnut 3 and Grafton Range 25. Measurements are only available for a short period of time and may not have stabilised yet. Therefore the following interpretation is preliminary.

The VWP Dumper Creek 4 monitors water pressure in the Mooga Sandstone, Gubberamunda Sandstone, Walloon Coal Measures (Lower Juandah, Upper Juandah and Taroom Coal Measures) and the Hutton Sandstone. Data are available from October 2008. All monitored formations, except the Hutton Sandstone, have displayed a decreasing trend in pressure, which may be related to stabilisation following installation. Water pressures in the Mooga Sandstone are generally about 25 and 35 m higher that in the underlying Gubberamunda Sandstone and Walloon Coal Measures, indicating a possible downward gradient between these aquifers. An increasing trend in pressure was initially observed in the Hutton Sandstone, but stabilized by December 2008 at pressures greater than those observed in the shallower formations (Figure 27a).

The VWP Wingnut 3 was installed in September 2008 to monitor water pressure in the Mooga Sandstone, Gubberamunda Sandstone and Walloon Coal Measures (Upper and Lower Juandah and Taroom Coal Measures). Decreasing pressure trends were monitored in all formations, although less evident than in VWP Dumper Creek 4. The Mooga and Gubberamunda Sandstones follow approximately the same trend, with pressures in the Mooga Sandstone being generally about 20 m higher than in the Gubberamunda

Sandstone. Pressures in the Walloon Coal Measures at VWP Wingnut 3 were higher than pressures measured in the upper formations (Figure 27b).

The VWP Grafton Range 25 was installed in July 2008 to monitor water pressure in the Gubberamunda Sandstone and Walloon Coal Measures (Upper Juandah and Taroom Coal Measures). Disturbances from installation might explain pressure variations observed in the first months of monitoring but these stabilized in October. Pressures generally decrease with depth, with the highest water levels measured in the Gubberamunda Sandstone (Figure 27c).

Santos intends to install a distribution of VWP'S across the gas Field to ensure long term monitoring of the major aquifers is complete throughout each stage of their operations.

Fairview CSG Field

Within the Fairview CSG Field, long-term groundwater measurements are available for four registered bores. Two bores are completed in Birkhead Formation (RN13030812 and RN13030813), one in Quaternary deposits (RN13030815) and one in the Hutton Sandstone (RN13030613). These bores are not completed in close proximity to each other, thus precluding an analysis of vertical gradients, but consideration of temporal trends can still be meaningful.

While water levels in the Quaternary deposits east of Fairview decreased between 2004 and 2006, stable water levels were recorded in the Birkhead Formation during the same period (Figure 28a). The decrease in the shallow Quaternary deposits could be attributed to decreased recharge to the formation due to below average rainfall in the region through this monitoring period. The monitoring bore within the Hutton Sandstone is located west of Fairview, close to Injune. Stable water levels, at approximately 416 m AHD, were measured from 1990 to 2006 (Figure 28b).

There are no VWP currently installed within the Fairview CSG Field, however, these area planned to be installed as part of Santos' Water Monitoring Program (Section 8.10).

Arcadia CSG Field

Groundwater levels in the area surrounding the Arcadia CSG Field have been monitored more extensively and regularly than in the Fairview and Roma Fields.

In the southern and central part of the Arcadia CSG Field, water levels have been monitored in Alluvium, Volcanics, Tertiary Deposits and the Rewan and Moolayember Formations. Several long-term monitoring bores are also located to the north and northwest of the Arcadia CSG gas Field.

The observed groundwater level trends in the volcanic sediments vary across the Arcadia CSG Field. Figure 29a presents the observed groundwater levels in two bores completed in the south-central area of the Field. Significant fluctuations are observed, likely related to seasonal demands. In the northern region of the Arcadia CSG Field, water levels in volcanic sediments (RN13020039) have been relatively stable, while a decrease of over 14 m was measured in RN103155 over a period of 12 years (Figure 29b). Increasing water levels in the volcanic sediments were observed in bores RN1302115A and RN1302114A between 1983 and 1994. Levels have been relatively stable since this time (Figure 27b and 27c). The differences in trends may have been caused by changes in groundwater abstraction rates in the different areas around these bores.

Increasing water level trends have been observed since 1983 in Alluvium deposits (RN 1302115B and RN 1302114B) in the northern area of the Arcadia CSG Field, whereas decreasing water level trends have been observed in the Tertiary Deposits (RN 101351 and RN101352) since the 1990s (Figure 29c). The differences in trends may be related to recharge or abstraction rates for irrigation purposes.

Around the town of Emerald, water levels in the Aldebaran Sandstone were monitored in RN47220 from 1971 to 1977, whereas water levels in the Rewan Formation, Back Creek Group and Blackwater Group have been monitored bores since 2005. Groundwater heads in these Permian formations have been stable over the monitoring periods (no figure provided).

There are no VWP currently installed within the Arcadia CSG Field, however, some are planned for installation as part of Santos' Water Monitoring Program (Section 8.10).

4.4.6 Recharge and Discharge

The main source of recharge for the GAB aquifers occurs in the eastern part of the GAB. The recharge beds are located along the western slope of the Great Dividing Range, or in the outcrop regions of the aquifers, some of which occur within the CSG field area.

Recharge will occur by direct infiltration of rainfall into the sedimentary formations; the region receives an average 600 mm per year (Table 8). Application of the GABSIM and GABHYD groundwater flow models, developed by the Bureau of Rural Sciences for the GAB, have indicated that approximately 1% of the current rain which falls in the recharge areas infiltrates into the aquifers (Cox and Barron, 1998). Additional contributions to recharge may include leakage from surface water bodies or overlying formations to the GAB aquifers where downward hydraulic gradients exist (Cox and Barron, 1998).

Prior to development in the GAB, it is estimated that, excluding the Carpentaria Basin, 1,040 ML of water entered the aquifers of the GAB in Queensland each day (NRW, 2006). This, together with the volume of recharge from other States, discharges as surface springs and a natural balance of inflow to outflow was maintained across the GAB. Many artesian bores initially flowed at rates of over 10 ML/d (NRW, 2006). Total outflow from the Basin reached a peak of over 2,000 ML/d around 1915 (NRW, 2006). Since then, artesian pressures and flow rates have declined, while the number of bores has increased. The majority of more recent flow from bores is now between 0.01 and 6 ML/d (NRW, 2006) and the current total outflow from the Basin is approximately 1,500 ML/d (NRW, 2006). Approximately one-third of all artesian bores which flowed when drilled have now ceased to flow and require pumps to bring the water to the surface (NRW, 2006).

In general, discharge in the CSG field area occurs from controlled and uncontrolled flowing artesian bores or pumping from the different beds. Natural discharge occurs from vertical flow to the upper aquifers in the basin margins and at springs. Artesian springs are often connected to a major fault in the basin. A number of active, natural springs are located within the study area (Figure 8a and Figure 26), many located along the outcrop boundaries of the Surat Basin aquifers and the base of the Clematis Sandstone cliffs in the Arcadia valley. Further discussion of springs within the study area is provided in Section 4.7. Discharge within the study area also results from pumping activities.

4.4.7 Inter-Aquifer Flows

Inter-aquifer flows occurs naturally, to some level of magnitude, where there is a hydraulic connection between the aquifer and aquitards (i.e. in porous media systems, a component of vertical hydraulic conductivity, Kv, always exists) and a sufficient vertical hydraulic gradient exists. Such flows will be greatest where the vertical component of hydraulic conductivity, Kv, is large, (say, between two sandy aquifers) but least between aquitards of low Kv, say through a mudstone or siltstone. For example, a mudstone band (aquitards) separating two aquifers would restrict (but not entirely eliminate) water flow from one aquifer to the other simply because its Kv is very low.

Inter-aquifer flow (or vertical leakage) can also be enhanced when a structural overprint, say, where a secondary porosity comprising joints, fractures or faults cross-cuts the bedding within a sedimentary sequence so enhancing the hydraulic conductivity. This typically occurs more readily at basin margins, where the rocks are folded and along fault lines, where the hydraulic conductivity has increased by brittle fracture of the rocks.

In addition, inter-aquifer flow can be initiated or enhanced by groundwater abstraction which induces increased the pressure gradients (hydraulic gradients) between the target abstraction aquifer and surrounding formations.

The most recent groundwater levels measured in VWPs at Roma CSG Field were used to compare water pressure in different formations along the vertical and estimate gradients.

At Dumper Creek 4 and Wingnut 3, the Mooga Sandstone has a higher water pressure than the underlying Gubberamunda Sandstone. The Gubberamunda Sandstone seems to exhibit generally lower pressures when compared with the both overlying and underlying geological units, possibly because it is a highly utilised aquifer within the region.

Water pressure in the Hutton Sandstone is measured at just one location, Dumper Creek 4, and is considerably higher than all the overlying formations (artesian).

Table 11 summarises the most recent groundwater pressure measurements available in the VWPs (which are assumed to be the least influenced measurements, following the stabilisation process after installation), calculated gradients and estimated vertical permeability of aquifers and aquicludes in Roma CSG field.

Table 11: Vertical gradients in Roma CSG area.

	K_v (m/d)	DUMPER CREEK 4	GRAFTON RANGE 25	WINGNUT 3
Mooga Sandstone	10^{-4}	W_L = 276 mAHD		W_L = 361 mAHD
Orallo Formation	N/A	↓ i = 0.10		↓ i = 0.02
Gubberamunda Sandstone	10^{-5}	W_L = 250 mAHD	W_L = 336 mAHD	W_L = 356 mAHD
Westbourne Formation	10^{-8}	↑ i = 0.04	↓ i = 0.04	↑ i = 0.04
Upper Juandah	10^{-7}-10^{-4}	W_L = 260 mAHD	W_L = 328 mAHD	
	N/A	↑ i = 0.12		
Lower Juandah	10^{-5}	W_L = 274 mAHD	↓ i = 0.18	W_L = 367 mAHD
	N/A			↓ i = 0.05
Taroom Coal Measures	10^{-6}-10^{-4}	↑ i = 0.12	W_L = 307 mAHD	W_L = 364 mAHD
	N/A			
Hutton Sandstone	10^{-5}	W_L = 291 mAHD		

Notes:
A ratio K_h/K_v =2000 was assumed.
Gradients are indicative of the mutual relation among aquifers, because of the lack of stratigraphy information.

Based on hydrogeological data available, there is a combination of relatively low gradients (i) among aquifers and low vertical permeability in aquicludes signifying that the primary direction of groundwater flow in the CSG field area is along the aquifers, following the dip of the formation, and that inter-aquifer flow is limited under natural conditions.

Similar comparisons of current groundwater gradients will be made for VWPs installations in the Fairview and Arcadia CSG Fields, once installed and data has stabilised.

4.5 Water Quality Assessment

Groundwater quality from the DERM bores in the CSG field area was assessed based on identified groundwater management units and major aquifers (Table 2). Available chemical data from CSG production wells at the Roma and Fairview CSG Fields were also included in this study. A total of 335 groundwater samples from the DERM database and 97 CSG production well samples were assessed using hydrogeochemical analyses, including Piper and Schoeller plots, scatter plots and statistical analysis.

Groundwater chemical data in the DERM database has been collected over a period of 30 years with the majority of data sampled between 1980 and 1999. The quality of available chemical data cannot be verified, however, the reliability of the data and accuracy has been estimated from cation-anion balance. The methodology is described in detail in the Groundwater Quality Assessment (Golder, 2009b), presented as a supporting document to this report.

4.5.1 DERM Groundwater Data

A detailed description of groundwater quality data in the different groundwater management units is presented in Table 3 of the Groundwater Quality Assessment (Golder, 2009b). Figure 30 compares TDS concentrations in groundwater from all groundwater management units/formations in the GLNG Project area. Water salinity varied from fresh to saline with observed total dissolved solids (TDS) ranging between 51 and 20,082 mg/L. Approximately 33% 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 (47%) with TDS concentration in the range from 1,000 to 3,000 mg/L. Brackish waters with TDS concentrations between 3,000 mg/L and 10,000 mg/L and saline groundwater with TDS between 10,000 mg/L and 100,000 mg/L were less common and contributed to 19% and 1%, respectively.

Spatial salinity trends are presented in Figure 31. Several brackish and saline groundwater types were identified in the northern portion of the CSG field area, to the northwest and northeast of the Arcadia CSG Field. Saline groundwater (TDS >10,000 mg/L) was observed in the Bowen Basin area only, particularly in bores completed in the Rewan Formation (Bowen 1) and alluvium. In addition, TDS concentrations in the Blackwater Group (Bowen 2) were close to the brackish/saline boundary (~ 8,700 mg/L). Brackish groundwater was observed in Tertiary and volcanic formations surrounding the Arcadia CSG Field.

The distribution of brackish waters in the Surat Basin, surrounding the Fairfield and Roma CSG Fields follows a southeast trend in several groundwater management units (Surat 1 to Surat 4). TDS concentrations, in excess of 5,000 mg/L, were observed in the Mooga and Bungil Sandstone.

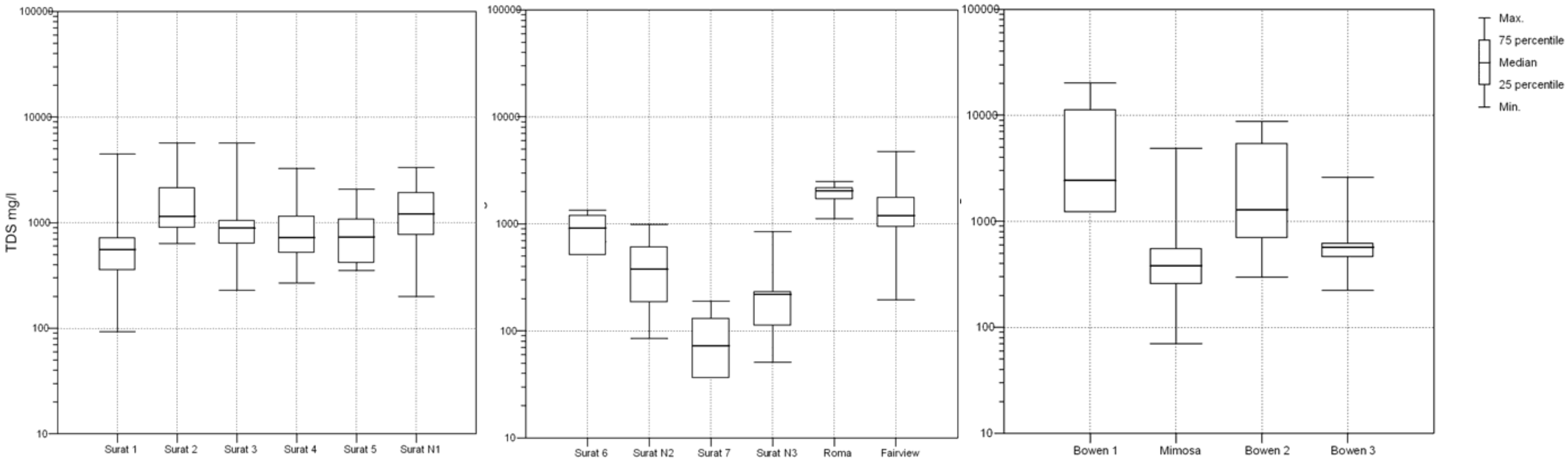
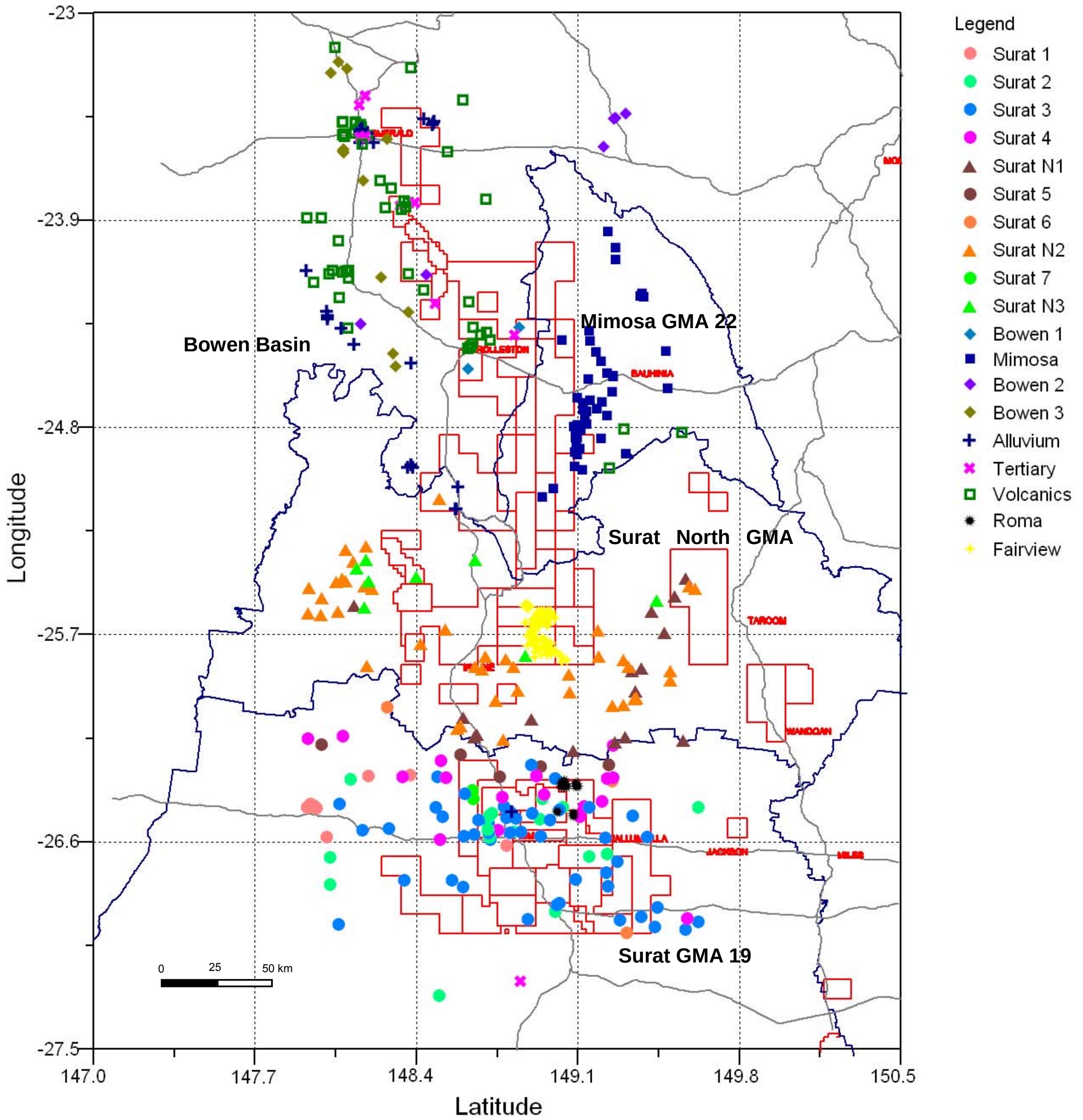


Figure 30: Comparison of Groundwater Salinity in Surat and Bowen Basins and from CSG Fields at Roma and Fairview.



Note: The size of the markers is proportional to the TDS concentration. The size of the markers is proportional to the TDS concentration. For description of the major management units see Table 3 of the Groundwater Quality Assessment (Golder, 2009b).

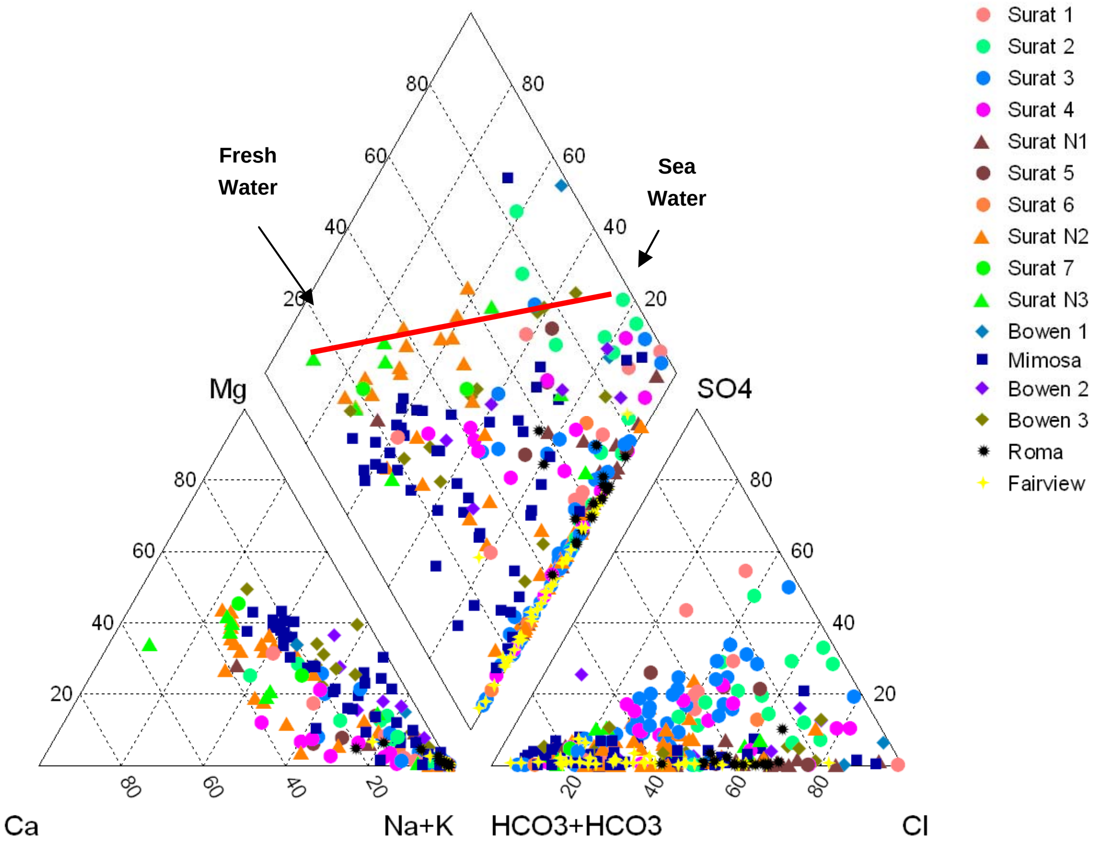
Figure 31: TDS of Groundwater in the GLNG Project Area

The distribution of brackish waters in the Surat Basin, surrounding the Fairfield and Roma CSG Fields, appears to increase to the southeast in several groundwater management units (Surat 1 to Surat 4). TDS concentrations, exceeding 5,000 mg/L, were observed in Mooga Sandstone and Bungil Formation bores.

A Piper Diagram of all groundwater samples within the Project area, excluding shallow formations, is presented as Figure 32. The red line represents conservative (non-reactive) mixing of fresh water and sea water. The position of the markers away from the conservative mixing line is an indication of a geochemical reaction.

The Surat 1 (Doncaster Member), Surat 2 (Bungil Formation) and Surat 3 (Mooga Sandstone) Units appear to have higher concentrations of sulphate and plot in the region typical for average sea water. Higher groundwater salinity in these units might be related to marine depositional environments.

On the other hand, the Surat 6 (Hutton and Boxvale Sandstones and Evergreen Formation), Surat 7 (Precipice Sandstone), Bowen 1 (Mimosa - Clematis Sandstone) and some samples from Bowen 3 (Aldebaran Sandstone) appear to be composed of, or near, fresh water. This could possibly be explained by the units receiving rainfall (fresh water) in their outcrop areas. Groundwater in the deeper units of the Surat Basin (Surat 6 and Surat 7) becomes more saline with increasing depth and distance along the groundwater flow path.



Note: This diagram does not include samples from the Shallow Formations and CSG Production Wells (Description of symbols is presented in Table 3)

Figure 32: Piper Diagram of All Groundwater Samples in the Project Area

4.5.2 Coal Seam Gas Wells

Fairview

Coal Seam Gas at Fairview is extracted from the Bandanna Formation which is part of the Blackwater Group (Bowen 2). There are only six samples from Blackwater Group included in the DERM database, and all located north of the Arcadia CSG Fields.

Groundwater composition in the Fairview CSG Field is presented on Figure 33 and summarised in Table 12. As shown on Figure 33a, the dominant ions are sodium, bicarbonate and chloride, and water types are either sodium-bicarbonate or sodium-chloride-bicarbonate types.

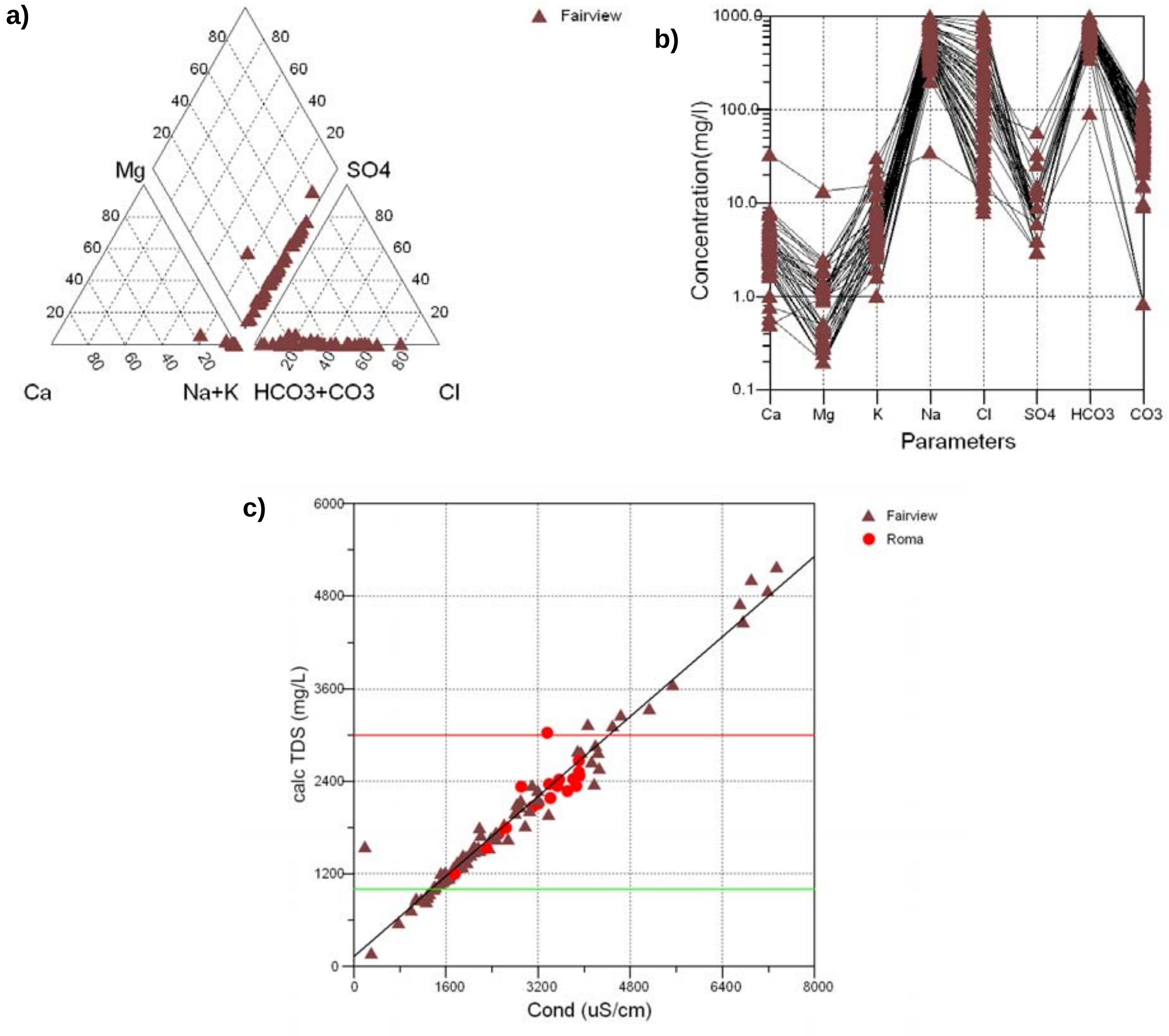
A summary of the groundwater chemical composition is presented in the Shoeller diagram on Figure 33b. Groundwater from the Bandanna Formation varied from slightly alkaline (7.8) to alkaline (9.1). Sodium concentrations ranged from 35 mg/L to 1,849 mg/L; calcium and magnesium concentrations were significantly lower and did not exceed 32 mg/L. Chloride concentrations ranged from 8 mg/L to 1,742 mg/L. Bicarbonate concentrations were in the range from 136 mg/L to 2,440 mg/L. Carbonate concentrations in a majority of samples were generally lower than 140 mg/L. Sulphate concentrations varied from 3 mg/L to 57 mg/L, with most being lower than 14 mg/L.

TDS in Fairview CSG water varied between approximately 177 mg/L and 5,179 mg/L with 23% of samples being fresh, 68% slightly brackish and 9% brackish waters (Figure 33c).

Table 12: Fairview CSG Groundwater Composition Summary

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	# Samples
pH		7.8	9.1	8.6	-	-	-	78
Conductivity	µS/cm	200	7350	2643	1269	2095	4514	79
TDS	mg/L	196	4760	1501	758	1190	2700	54
Cal TDS	mg/L	177	5179	1918	978	1655	3052	72
Ca	mg/L	0.5	33	2.84	0.5	2	5	79
Mg	mg/L	<LOR	13.4	0.84	<LOR	0.48	1	79
Na	mg/L	35	1849	662	323	542	1163	79
K	mg/L	1	31	5.83	2	3.9	13	79
Cl	mg/L	8	1742	306	16.6	131	895	78
HCO_3	mg/L	136	2440	1179	759.8	1077	1698	79
CO_3	mg/L	1	260	83	29.3	80	139	79
SO_4	mg/L	3	57	8.98	3	6	14	41
F	mg/L	0.8	8.1	2.7	1.17	2.3	5.0	78

Note: Q10 -10th percentile; Q50-50th percentile – median; Q90- 90th percentile; LOR – limit of reporting



Note: Scatter plot of Conductivity vs TDS represents data from Fairview and Roma GSG Wells

Figure 33: Fairview CSG Groundwater Diagrams: a) Piper; b) Shoeller; c) Scatter Plot of Conductivity vs TDS

The spatial distribution of water quality is presented in Figure 34. The distribution of the Stiff Diagram indicates higher salinity in the eastern and south eastern portion of the CSG Field. Variability of groundwater composition within the CSG Field is related to the presence of the north-south trending fault and hydraulic connection between Bandanna and fresh Precipice Sandstone to the west and south west of the CSG Field (URS, 2009).

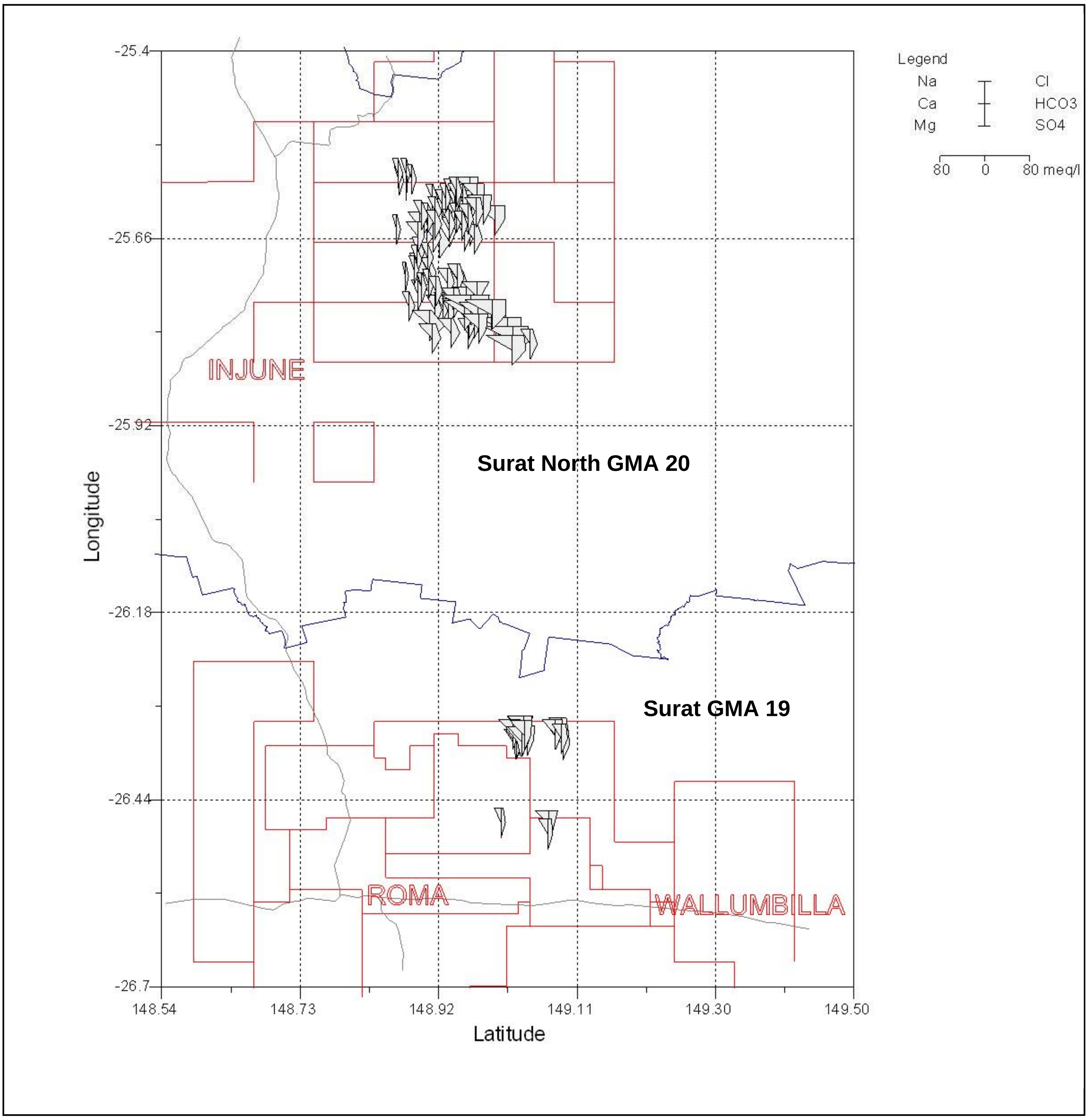


Figure 34: Spatial Distribution of the Stiff Diagrams Showing Overall Groundwater Quality at the Fairview and Roma CSG Fields

Roma

The Roma CSG Field is located on the northern margin of the Surat Basin. The main aquifer units within the Roma area are associated with the Precipice, Hutton, Gubberamunda, and Mooga Sandstones. Only the Mooga Sandstone outcrops in the Roma CSG Field. CSG at Roma is extracted from to Walloon Coal Measures (WCM).

Areas within the Roma CSG Field with chemistry data available for assessment included Coxon Creek (4 samples), Hermitage (11 samples), Pine Ridge (1 sample) and Raslie well (2 samples).

The Piper diagram on Figure 35a shows that most water sampled from the Roma CSG Field is sodium-chloride-bicarbonate type. Scatter plot of TDS and EC (Figure 33c) indicates that groundwater is mostly slightly brackish or brackish with TDS concentrations from 1,119 mg/L to 2,500 mg/L.

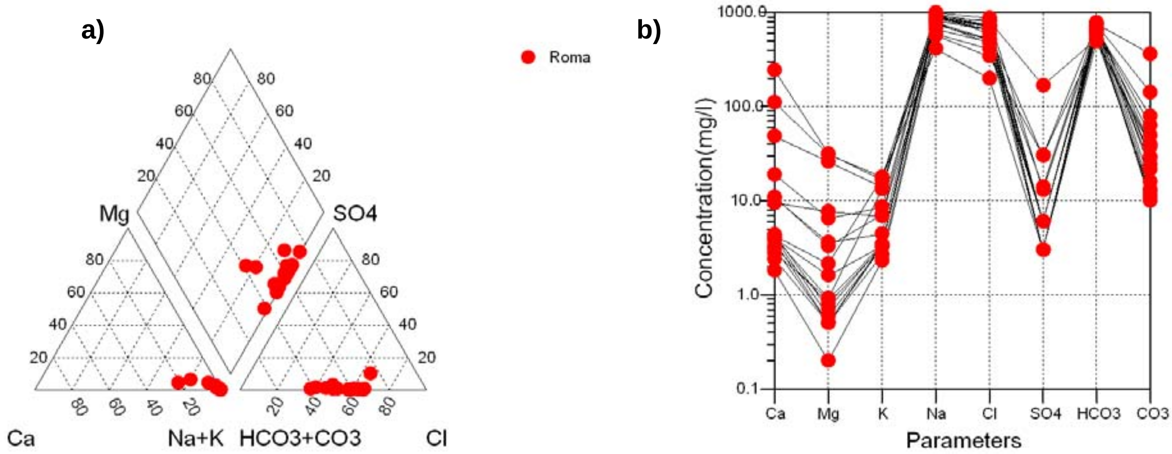


Figure 35: Piper and Schoeller diagrams for Roma CSG wells

A summary of groundwater chemistry is presented in Table 13. The pH range for groundwater sampled from the WCM at the Roma CSG Field varied from slightly alkaline to alkaline (8.2 to 9.7). Sodium concentrations ranged from 411 mg/L to 990 mg/L and calcium concentrations varied from 1.8 mg/L to 242 mg/L. Magnesium concentrations appear to be much lower than other cations and did not exceed 32 mg/L. Chloride concentrations ranged between 199 mg/L and 870 mg/L, bicarbonates from 729 mg/L to 1,152 mg/L. Carbonate concentrations were typically lower than 132 mg/L. Sulphate concentrations varied from 3 mg/L to 168 mg/L.

Table 13: Roma CSG Groundwater Composition Summary

Parameter	Unit	Min	Max	Average	Q10	Q50	Q90	No Samples
pH	-	8.2	9.7	8.57	-	-	-	17
Conductivity	µS/cm	1749	3910	3259	2189.8	3381	3900	18
TDS	mg/L	1119	2500	1985	1423	2030	2420	18
Ca	mg/L	1.8	242	27	2.2712	4.074	60	18
Mg	mg/L	0.2	31.7	6.6	0.44	0.913	27	18
Na	mg/L	411	990	808	538	868	957	18
K	mg/L	2.3	18	7.5	2.58	3.45	17	18
Cl	mg/L	199	870	602	311.7	645	796	18
HCO_3	mg/L	729	1152	977	760	975	1129	18
CO_3	mg/L	14.4	523	79	15	41	132	18
SO_4	mg/L	3.0	168	17	3	6	30	18
F	mg/L	1.1	3.4	1.84	1.14	1.6	2	18

Note: Q10 -10th percentile; Q50-50th percentile – median; Q90- 90th percentile; LOR – limit of reporting

4.5.3 Water Types of the Major Aquifers

A comparison of groundwater in major aquifers is presented in Figure 36. The groundwater samples from the Mooga, Gubberamunda and Hutton Sandstones appear to be similar and were dominated by a range of water types between sodium-bicarbonate to sodium- chloride type waters. The Precipice, Clematis and Aldebaran Sandstones represent a variety of water types which are enriched in calcium and magnesium, compared to the sodium dominant water types observed in the younger litho-stratigraphic units.

During groundwater movement along the flow path from recharge to discharge areas a variety of chemical reactions take place. These reactions vary spatially and temporally depending on the nature of the recharge water composition, geological formation and residence time. The Precipice Sandstone outcrops at the Fairview CSG Field, the Aldebaran Sandstone outcrops west and Clematis Sandstone east of the Arcadia CSG Field. The Mooga and Gubberamunda Sandstones represent deeper formations of the Surat Basin where groundwater chemical composition is affected by longer residence time compared to the aquifers located in the recharge area. The groundwater salinity of the major aquifers increases in the following order:

Precipice < Clematis < Hutton < Aldebaran < Gubberamunda < Mooga Sandstone

The fingerprint diagram on Figure 37 represents the equivalent weight ratios for major cation and anions in selected groundwater samples from the Major Aquifers. Such a diagram is used to identify the relative contribution of particular ions. Sodium is the most dominant cation in all aquifers, followed by Ca and Mg. However, magnesium outranks calcium in the Clematis Sandstone. Bicarbonate dominates with respect to other major anions (chloride and sulphate).

The ion/Cl ratios on Figure 38 and ion/ion ratios on Figure 39 can be used to identify the major hydrogeochemical processes controlling groundwater composition in the major aquifers. High Na/Cl and Na/(Ca+Mg) may be an indication of ion exchange processes particularly in the Gubberamunda and Mooga Sandstones. High Ca/Cl and Mg/Cl ratios in the Precipice, Clematis and Aldebaran Sandstones may be related to carbonate reactions.

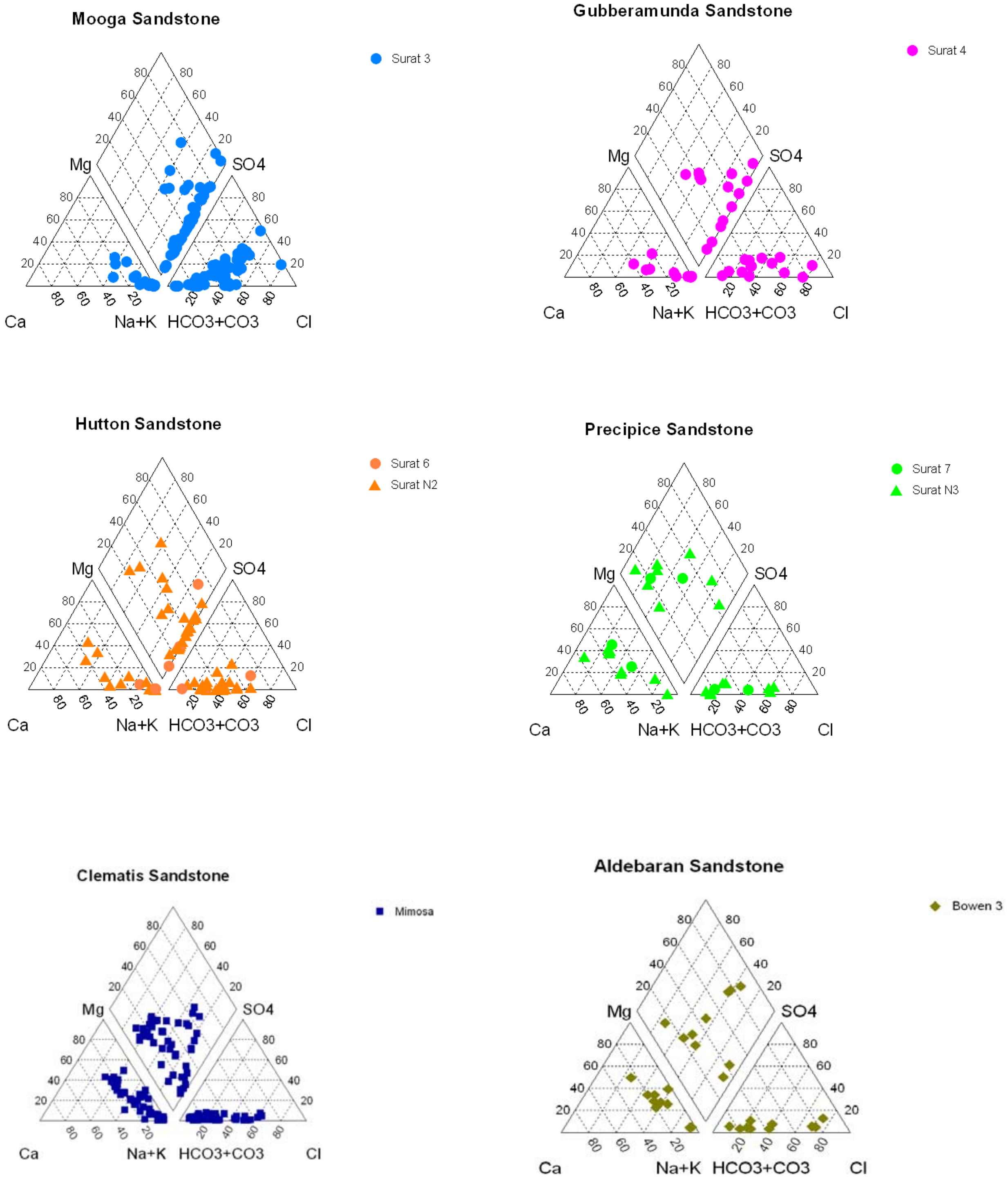


Figure 36: Piper Diagrams of the Major Aquifers in the Project Area

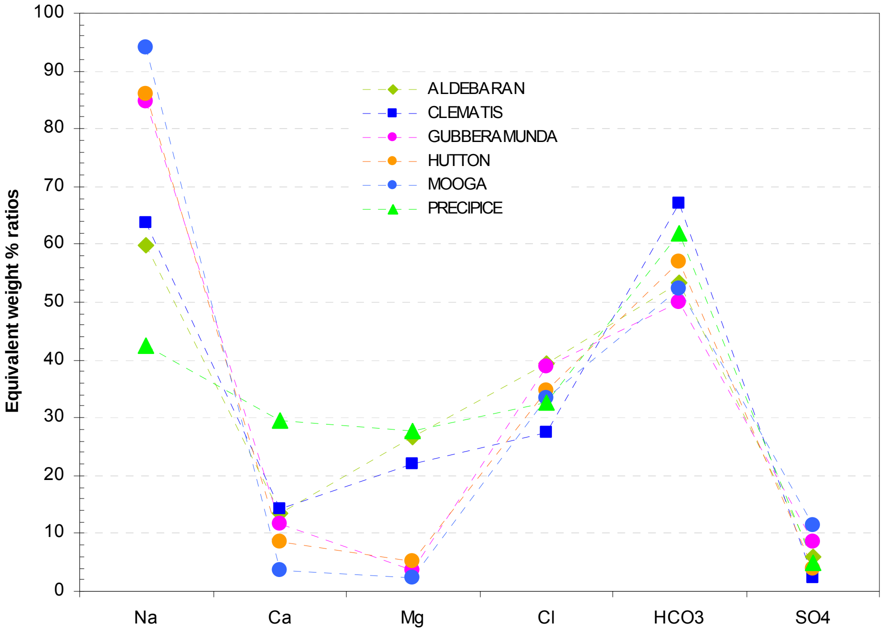


Figure 37: Average Equivalent Weight Percent Ratios for Major Aquifers

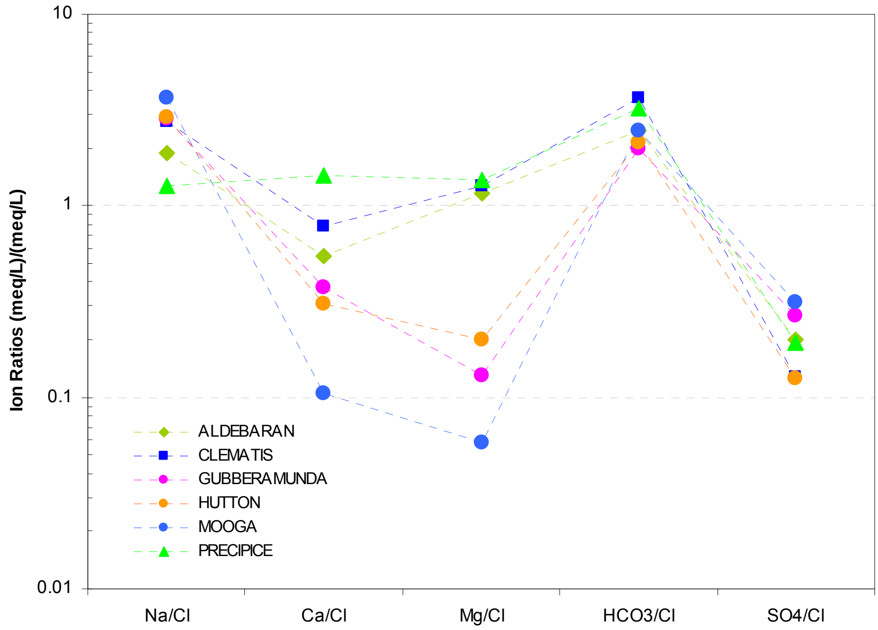


Figure 38: Average Equivalent Ion/Cl Ratios for Major Aquifers

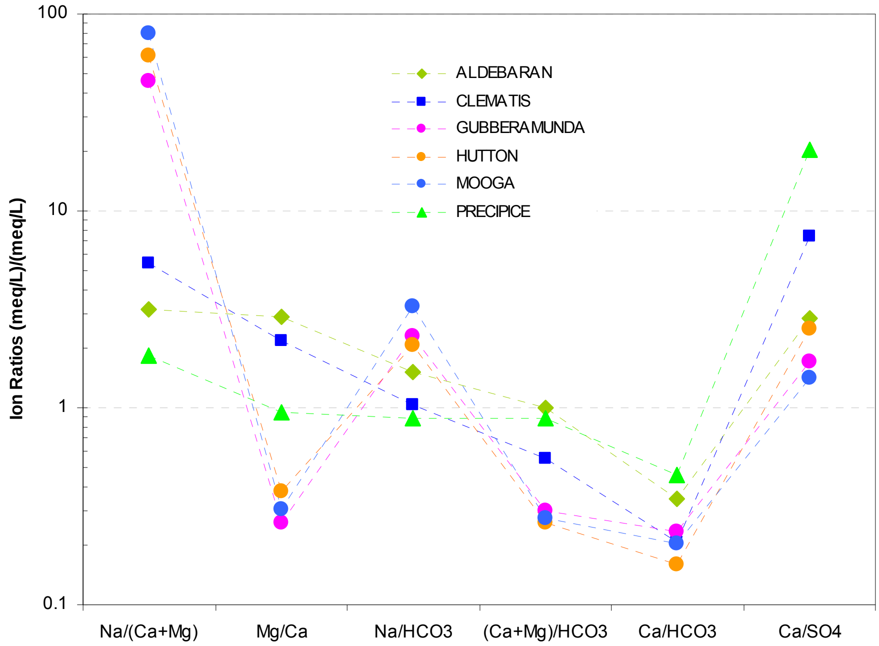


Figure 39: Average Equivalent Ion/Ion Ratios for Major Aquifers

4.5.3.1 Comparison of groundwater quality to regulatory guidelines

Public Supplies and Domestic Use

The Australian drinking water guidelines (ADWG, 2004) establish drinking water regulations for public supplies of drinking water. The regulations specify:

- A health-related guideline value is the concentration that does not result in any significant risk to the health of the consumer over a lifetime of consumption; and
- An aesthetic guideline is the concentration associated with acceptability of water, based on appearance, taste and odour.

The assessment criteria for public supplies and domestic use are presented in Table 14.

Sodium, chloride and pH appear to have the highest percentage of exceedances within the Project area. More than 60% of samples from the DERM database and 99% of CSG water exceed the sodium drinking water standard. Approximately 31% of DERM samples exceeded 1,000 mg/L TDS, compared to 80% of CSG samples. Fluoride concentrations exceeded the drinking water criteria in 6% of DERM samples and in 80% of CSG samples. The pH standard was exceeded in 15% of DERM samples and 77% of CSG wells, with majority of groundwater being slightly alkaline and alkaline rather than acidic.

Metals concentrations were not available for all samples. Copper, iron and manganese did exceed drinking water guidelines in some NWR and CSG samples. Nitrate exceedances were observed in 3% of DERM samples.

Table 14: Comparison of Groundwater Quality with Standards for Drinking Water (ADWG, 2004)

Analyte	Drinking water standard (mg/L; except of pH)	DERM database	CSG production wells
		No of samples exceeded standard***	No of samples exceeded standard***
pH	6.5 - 8.5	51 (15%)	75 (77%)
Chloride	250**	93 (28%)	43 (44%)
Sodium	180**	201 (60%)	96 (99%)
Sulphate	250** 500*	22 (7%) 13 (4%)	0 0
TDS	< 500 – good quality 500-1,000 – acceptable based on taste >1,000 – excessive scaling, corrosion, unsatisfactory taste	107 (32%) 123 (37%) 102 (31%)	2 (2%) 17 (18%) 78 (80%)
Fluoride	1.5*	19 out of 328 (6%)	82 out of 103 (80%)
Copper	0.08	4 out of 45 (9%)	6 out of 47 (13%)
Iron	0.3	15 out of 263 (6%)	51 out of 92 (55%)
Manganese	0.05	42 out of 263 (16%)	17 out of 46 (38%)
Zinc	3	0 out of 46	0 out of 52
Nitrate	11.29	11 out of 326 (3%)	0 out of 59

* - health value, ** aesthetic value; *** values corresponding to the specified TDS range

Agricultural Use

Agricultural use of groundwater includes irrigation and livestock watering. Irrigating with water that has a high content of dissolved salts and excess sodium can adversely impact the soil structure or adversely affect plant growth. This can depend on the amount of salt present in the water, the soil type being irrigated, the climate and the specific plant species and the growth stage.

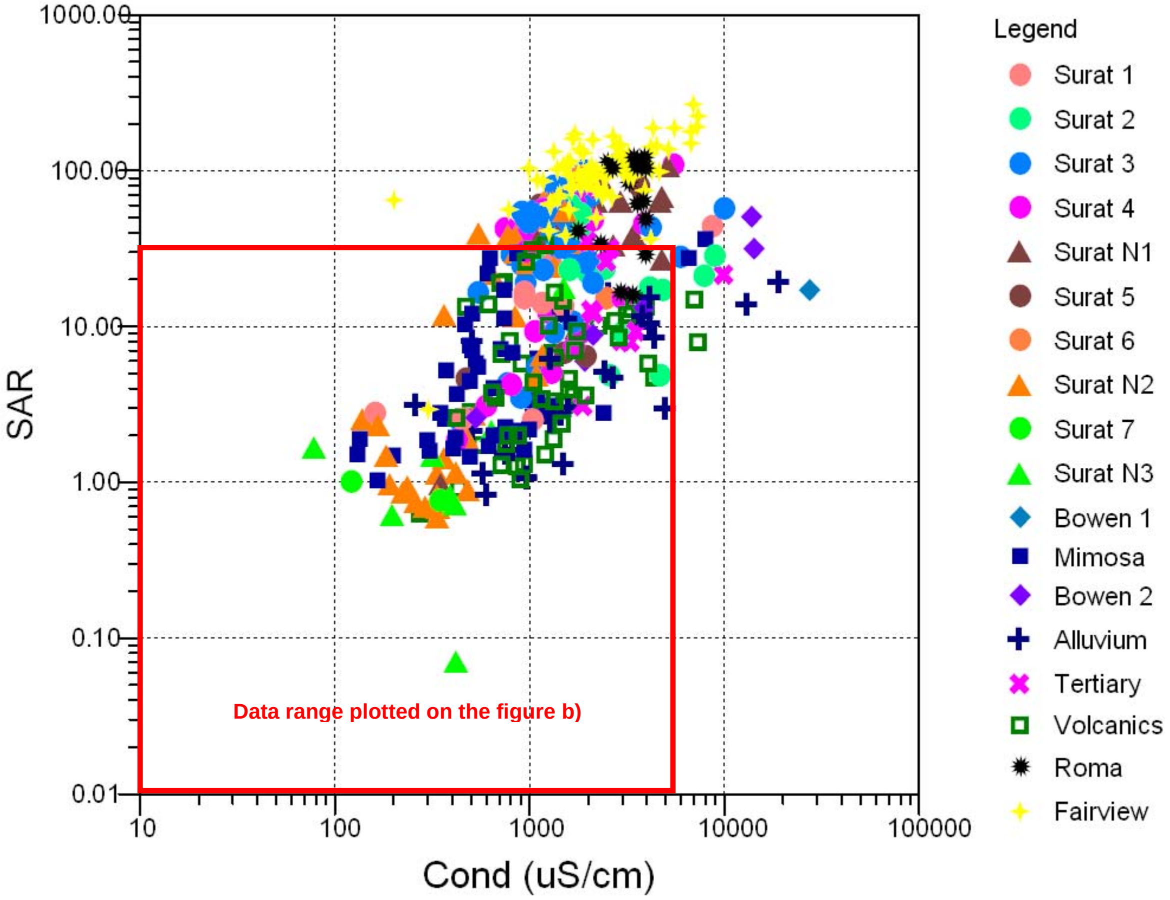
The irrigation water quality classification system is based on two characteristics:

- salinity hazard; and
- sodium (alkali) hazard of the water.

Figure 40 suggests that groundwater collected from bores completed in a variety of formations within the Project Area plot within a wide range of both sodium and salinity hazard classes. With increasing conductivity, the sodium content and subsequently SAR index increases. Groundwater from the Surat 7 (Precipice Sandstone), Surat 6 (Hutton Sandstone), and Mimosa (Clematis Sandstone) management units was classified as having the lowest sodium hazard (S1) and as salinity hazard (C1-C3).

Groundwater from the CSG production wells at Fairview had both SAR and conductivity higher than those plotted in the Wilcox diagram (Figure 40). This water would not be suitable for irrigation without prior treatment. The majority of samples from the Roma CSG Field would also plot above the salinity/sodicity ranges defined in the Wilcox diagram and hence are classified as having very high salinity and sodicity hazards.

a)


1000.00
100.00
10.00
1.00
0.10
0.01
SAR
10
100
1000
10000
100000
Cond (uS/cm)
Data range plotted on the figure b)
Legend
Surat 1
Surat 2
Surat 3
Surat 4
Surat N1
Surat 5
Surat 6
Surat N2
Surat 7
Surat N3
Bowen 1
Mimosa
Bowen 2
Alluvium
Tertiary
Volcanics
Roma
Fairview

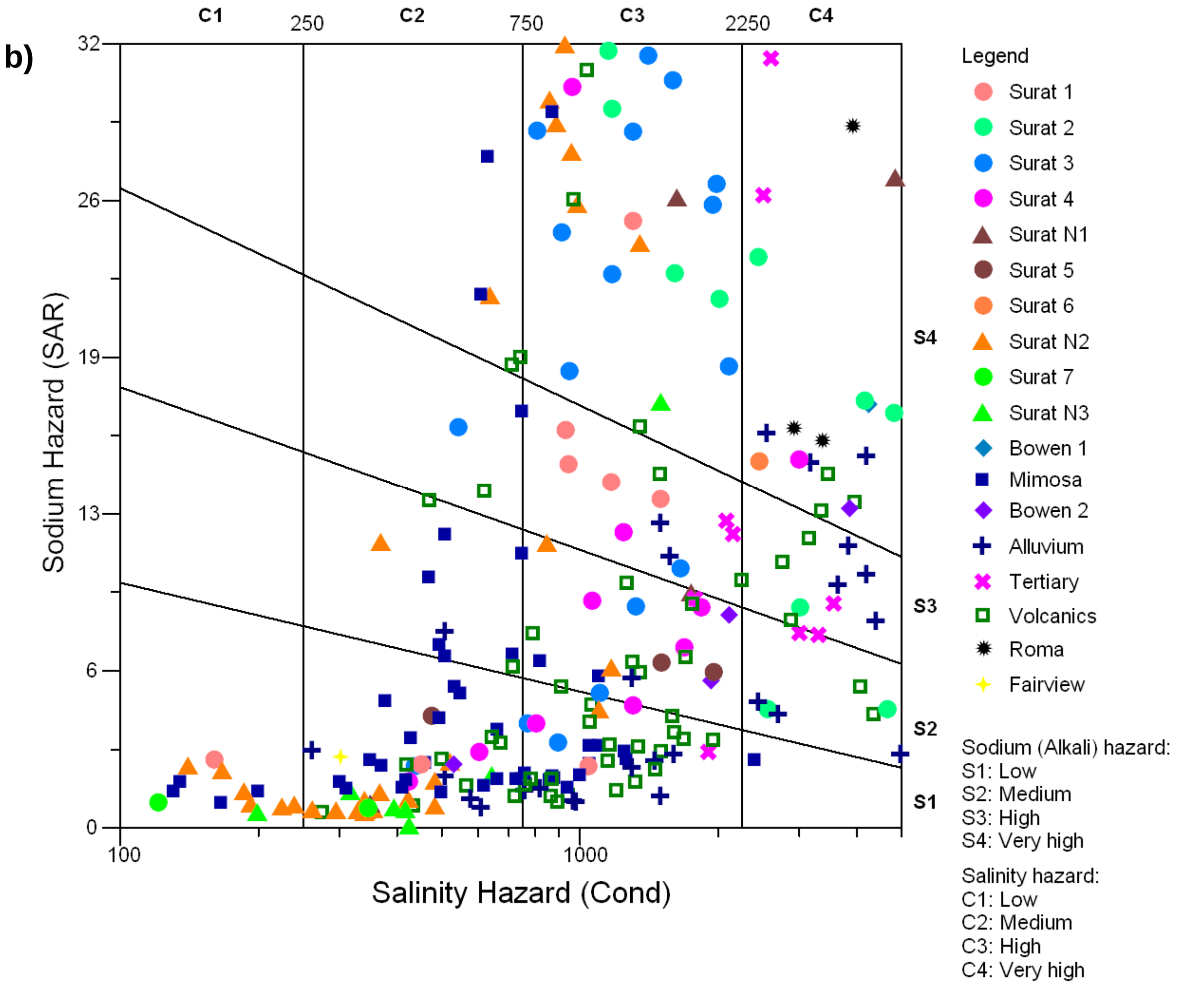


Figure 40: Scatter plot of SAR vs Conductivity (a); and Wilcox Plot (b) showing Salinity and Sodicity Hazard Classes

Groundwater suitability for livestock watering is assessed on the basis of TDS concentrations and the concentration of specific ions, particularly calcium and sulphate. The trigger values for both calcium and sulphate are 1,000 mg/L. Sulphate concentrations above 1,000 mg/L were observed in only 8 samples, including the Bungil Formation (three samples), Alluvium (two samples), Mooga Sandstone, Rewan Formation and Blackwater group. Calcium concentrations exceeding 1,000 mg/L were observed only in one sample from the Rewan Formation. Concentrations of both of these ions did not exceed 60 mg/L in the CSG wells.

Recommended TDS concentrations in drinking water for livestock watering are presented in Table 15. Up to 90% of groundwater samples would be suitable for watering of dairy cattle (TDS <2,500 mg/L) and 97% of groundwater samples would be suitable for watering of beef cattle (TDS < 4,000 mg/L). Groundwater exceeding 13,000 mg/L of TDS was observed only in few samples from alluvium (two samples), the Rewan and Blackwater Formations (one sample each).

Table 15: 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

Many metals and metalloids are essential nutrients for animal health, but elevated concentrations of certain compounds can cause chronic or toxic effects in livestock. Comparison of water quality data in the Project area with the trigger values for metal concentrations below which there is a minimal risk of toxic effects is presented in Table 16 DERM database included limited data for trace metals. No ascendances were observed for aluminium, boron, copper and zinc. Approximately 3% of samples exceeded fluoride trigger value 2 mg/L. GCC water exceeded trigger values for aluminium (23%), lead (30%) and selenium (10%). Approximately 23% of samples exceeded copper trigger value for watering of sheep. The highest amount of ascendances (83%) was observed for fluoride. Approximately 23% of samples with copper concentrations above 0.4 mg/L would not be suitable for watering of sheep.

Table 16: Recommended water quality trigger values for heavy metals and metalloids in livestock drinking water (ANZECC & ARMCANZ, 2000)

Metal or Metalloid	Trigger Value (low risk)[a,b]	DERM database	CSG production wells
		No of samples exceeded standard	No of samples exceeded standard
Aluminium	5	0 out of 45	12 out of 53 (22.6%)
Arsenic	0.5 up to 5[b]	Na	0 out of 50
Boron	5	0 out of 48	0 out of 51
Cadmium	0.01	Na	0 out of 53
Chromium	1	Na	0 out of 53
Cobalt	1		0 out of 53
Copper	0.4 sheep 1 cattle 5 pigs and poultry	0 out of 45	12 out of 52 (23%) 0 out of 52 0 out of 52
Fluoride	2	9 out of 330 (2.7%)	55 out of 66 (83%)
Lead	0.1	Na	11 out of 37 (30%)
Mercury	0.002	Na	0 out of 48
Molybdenum	0.15	Na	0 out of 50
Nickel	1	Na	0 out of 54
Selenium	0.02	Na	5 out of 50 (10%)
Zinc	20	0 out of 46	0 out of 52

Note: a) higher concentrations may be tolerated in some situations; b) may be tolerated if not provided as a food additive and natural levels in the diet are low; na – not analysed

4.5.3.2 Summary of Water Quality Results

The geochemical assessment of groundwater quality was based on a detailed analysis of major groundwater management units, as well as regionally significant aquifers present in the CSG field area:

- Groundwater quality variations throughout the CSG field are attributable to the heterogeneity in sediment depositional environments, sediment composition, groundwater residence time, and depth and direction of groundwater flow;
- The most common groundwater type is sodium-bicarbonate-chloride; however significant variations in dominant ions and water types were observed within the various groundwater management units and major aquifer formations. Groundwater from the Precipice, Clematis and Aldebaran Sandstones and from the Shallow Formations typically contains higher concentrations of calcium and magnesium relative to the Mooga, Hutton and Gubberamunda Sandstones;
- Groundwater salinity varies from fresh to brackish with the majority of groundwater classified as slightly brackish. Saline groundwater (TDS > 10,000 mg/L) was observed in Bowen Basin, in bores completed in the Rewan Formation (Bowen 1) and Alluvium. In addition, TDS concentrations in the Blackwater Group (Bowen 2) were close to the brackish/saline boundary;
- CSG water extracted from both the Bandanna Formation and Walloon Coal Measures is slightly alkaline and on average is slightly brackish. At Fairview, CSG water quality appears to vary with local geology and the existence of a hydraulic connection between the brackish Bandanna Formation and the fresh Precipice Sandstone in the south-western portion of the CSG Field;
- Comparison with regulatory guidelines indicates that approximately 30% of the analysed groundwater samples in the DERM database and 80% groundwater samples from the GSG wells would not be suitable for use as potable water. Groundwater from the Surat 6 and Surat 7 units, and from the Clematis Sandstone is characterised by low salinity and sodium concentrations, and appears to be suitable for irrigation purposes;
- Most CSG AW samples would present a very high salinity and sodicity hazard to soils without prior treatment;
- The majority of groundwater in the CSG field area is suitable for livestock watering without treatment. Up to 90% of the groundwater samples would be suitable for watering of dairy and beef cattle, in accordance with the ANZECC 2000 water quality guidelines for primary industries; and
- The majority of CSG associated water (83%) would not be suitable for livestock watering due to concentration of fluoride higher than 2 mg/L without treatment.

4.6 Water Use

Within the CSG field area, groundwater of the various aquifers is generally of good quality and is used for a range of activities. Figure 41 illustrates the proportional usage of groundwater in each GMA, based on information extracted from the DERM water licensing database - Water Entitlements Registration Database (WERD).

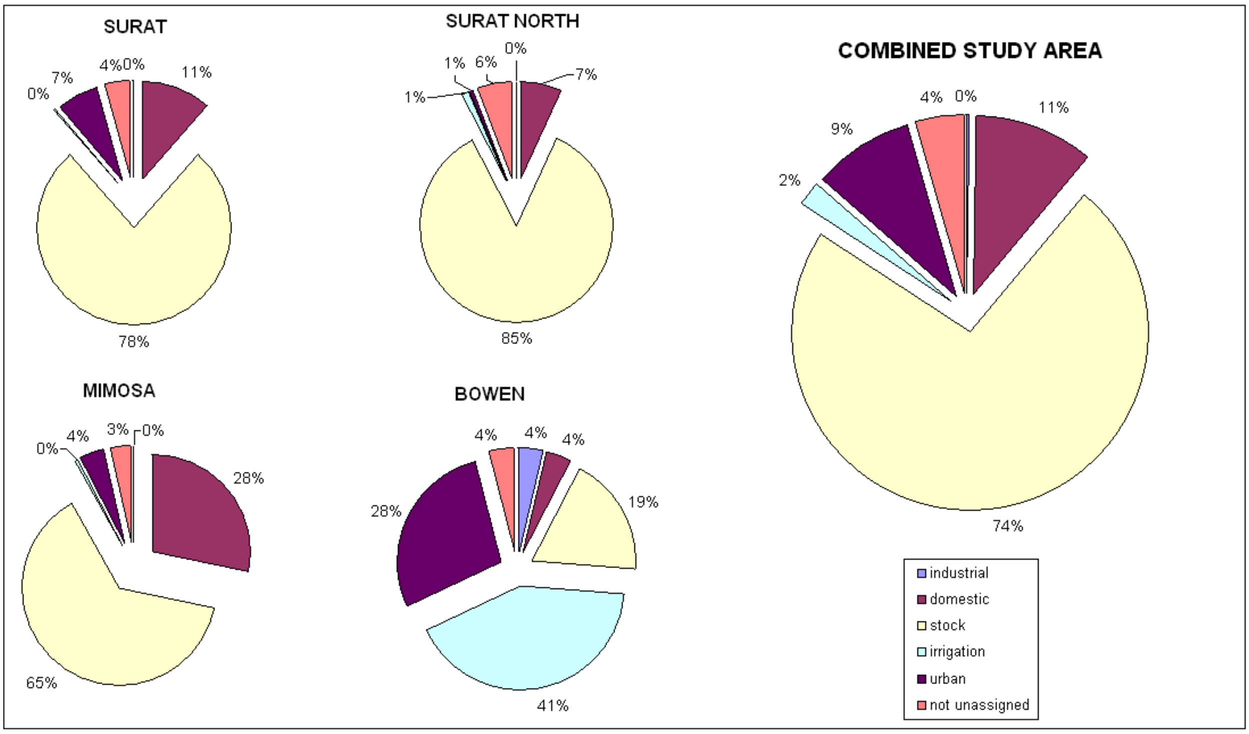


Figure 41: Groundwater Use within the GLNG Project Area

The primary use of water within the Surat, Surat North and Mimosa GMAs is for stock, the secondary use for domestic purposes. Figure 41 suggests that the primary use of groundwater to north and northwest of the Arcadia CSG Field (Bowen Basin) is for irrigation, urban supply and stock. Groundwater bores licensed for urban supply are concentrated around the town of Emerald and the irrigation bores are more spread through the region. Most of the irrigation bores are completed within the shallow alluvium deposits and a few in the Aldebaran Sandstone (Back Creek Group). The 2005 Australian Natural Resources Atlas (ANRA, 2005) confirms the majority of bores in the Bowen Basin are being used for irrigation purposes.

Table 17 provides a summary of the number of the licensed groundwater bores across the CSG field area with their targeted aquifers and defined management units. The information is extracted from WERD. The breakdown of the Management Units is consistent with the Hydrogeological Framework Report (DNRM, 2005).

The number of bores registered in WERD is less than the total number of registered bores within the CSG field area (2,900 vs. 6,400 bores). This is because many bores in the region have either not been licensed or have been removed from WERD following changes in licensing policies. For example, many bores are drilled and used for stock and domestic purposes but they do not appear in WERD. If water level, water quality or yield data for these bores were available and of adequate quality, they were included in this report.

WERD is also limited to officially metered water use information. Small groundwater users (most of them using water for stock and domestic purposes and occasionally irrigation) are only issued with a water licence and do not have flow meters installed. Thus metered information on abstraction from these small users is not available.

Table 17 does not consider bores with non-active licenses, or bores which could not be related to GMAs (i.e. no coordinates provided). Bores which could not be related to aquifers, but coordinates were available, have been accounted under “formation names not specified”. It should be noted that there are a considerable number of bores licensed to extract water within the CSG field area but have not been assigned an allocation (Table 17).

Table 17: Aquifer Usage in the GLNG Project Area

GMA	Management Units[1]	Geological Member	Licensed Users	Licensed Bores with Allocation[2]	Total Allocation (ML/yr)
Surat	-	Tertiary / Alluvium / Griman Creek Formation / Bungil Creek Alluvium	5	4	118
	Surat 1	Surat Siltstone	-	-	-
		Coreena Member	14	0	-
		Doncaster Member	73	3	72
		Wallumbilla Formation	21	0	-
		Formation Names Not Specified	5	0	-
	Surat 2	Bungil Formation	218	1	154
		Minmi Member	3	0	-
		Nullawart Sandstone Member	-	-	-
		Kingull Member	1	0	-
		Formation Names Not Specified	25	0	-
	Surat 3	Mooga Sandstone	318	11	444
		Southlands Formation	26	0	-
		Formation Names Not Specified	100	0	-
	Surat 4	Orallo Formation	27	0	-
		Gubberamunda Sandstone	231	6	640
		Hooray Sandstone	9	0	-
		Formation Names Not Specified	37	0	-
	Surat 5	Westbourne Formation	1	0	-
		Springbok Sandstone	11	0	-
		Birkhead Formation	6	0	-
		Walloon Coal Measures	4	0	-
		Eurombah Formation	2	0	-
		Injune Creek Group	49	0	-
		Formation Names Not Specified	9	0	-
	Surat 6	Hutton Sandstone	36	6	669
		Evergreen Formation	-	-	-
		Boxvale Sandstone Member	-	-	-
		Formation Names Not Specified	4	0	-

	Surat 7	Precipice Sandstone	7	2	1,300
		Formation Names Not Specified	1	0	-
	Surat 8	Moolayember Formation	-	-	-
		Clematis Sandstone	-	-	-
		Rewan Formation	-	-	-
		Formation Names Not Specified	4	0	-
	Total for Surat in GLNG Project Area		**1,247**	**33**	**3,397**
Surat North	-	Carnarvon Creek Alluvium / Eurombah Creek Alluvium / Maranoa River Alluvium / Robinson Creek Alluvium	8	7	1,008
	Surat North 1	Westbourne Formation	1	0	-
		Springbok Sandstone	2	0	-
		Walloon Coal Measures	18	0	-
		Eurombah Formation	8	0	-
		Injune Creek Group	115	0	-
		Formation Names Not Specified	15	0	-
	Surat North 2	Hutton Sandstone	314	5	798
		Evergreen Formation	70	0	-
		Formation Names Not Specified	44	0	-
	Surat North 3	Precipice Sandstone	75	2	120
		Formation Names Not Specified	2	0	-
	Surat North 4	Moolayember Formation	1	0	-
		Clematis Sandstone	3	0	-
		Formation Names Not Specified	1	0	-
	Birkhead Formation[3]		47	1	12
	Boxvale Sandstone Member[3]		20	1	41
	Bungil Formation[3]		6	0	-
	Gubberamunda Sandstone[3]		9	0	-
	Mooga Sandstone[3]		9	0	-
	Total for Surat North in GLNG Project Area		**768**	**16**	**1,979**
Mimosa	-	Basalt / Plant Creek Alluvium / Tertiary Undefined	7	7	194
	Mimosa 1	Moolayember Formation	65	2	200

		Clematis Sandstone	155	4	1,440
		Formation Names Not Specified	10	0	-
	Total for Mimosa in GLNG Project Area		**237**	**13**	**1,834**
Bowen	-	Basalt / Sedimentary Undifferentiated / Tertiary / Alluvium	61	61	8,869
	Rewan Group	Moolayember Formation	1	1	250
		Clematis Sandstone	-	-	-
		Rewan Formation	-	-	-
	Blackwater Group	Bandanna Formation	-	-	-
		Black Alley Shale	-	-	-
		Fair Hill Formation	3	3	159
		Rangal Coal Measures	2	2	36
	Back Creek Group	Peawaddy Formation	1	1	1
		Aldebaran Sandstone	30	18	4,916
		Cattle Creek Group	-	-	-
		Back Creek Group – not specified	24	11	1,673
Total for Bowen in GLNG Project Area			**122**	**97**	**15,904**
GRAND TOTAL for GLNG Project Area:			**2,374**	**159**	**23,114**

1. Management Units as outlined in the Hydrogeological Framework Report (DNRM, 2005). Shallow Aquifers (Alluvium etc.) are not identified as part of management units in this document.
2. Includes issued licences and those under amendment, renewal, transfer and variation
3. Note that there were inconsistencies with WERD, namely the incorrect listing of rock formations within management units. Bore data were grouped based on completion formations and associated management units. The geographic coordinates for several bores placed them in different Management Areas to those noted in the database. Geographic coordinates, where available, were used to determine the location and associated management area for bores noted in this table. Bore data without geographic coordinates were not used. Several locations were classified in the Surat Management Area, but had coordinates placing them in the Surat North Management Area and vice versa. This resulted in rock formations typical to the Surat Management Area being included in the tabled data for the Surat North Management Area.
4. During a telephone conversation between Golder and DERM (February 2009), it was indicated that, where Managements Units were specified they were considered correct, even if the formation was unknown. Consequently, bores with "Formation Name is Not Specified" and "Management Unit" specified, were classified to management units.

The primary aquifers targeted for groundwater extraction in the Surat GMA is the Mooga Sandstone (Surat 3) and Gubberamunda Sandstone (Surat 4), with a significant number of bores also completed in the Bungil Formation (Surat 2) in this management area. This is contrasted with the allocation within the Surat GMA as presented in Figure 42, where the largest allocations are from the Hutton Sandstone (Surat 7) and Precipice Sandstone (Surat 8). The primary use of the bores in the Mooga and Gubberamunda Sandstones are used for domestic and stock whereas the primary use of the Hutton Sandstone and Precipice Sandstone bores are stock intensive and town supply, which generally require nominal allocations and entitlements.

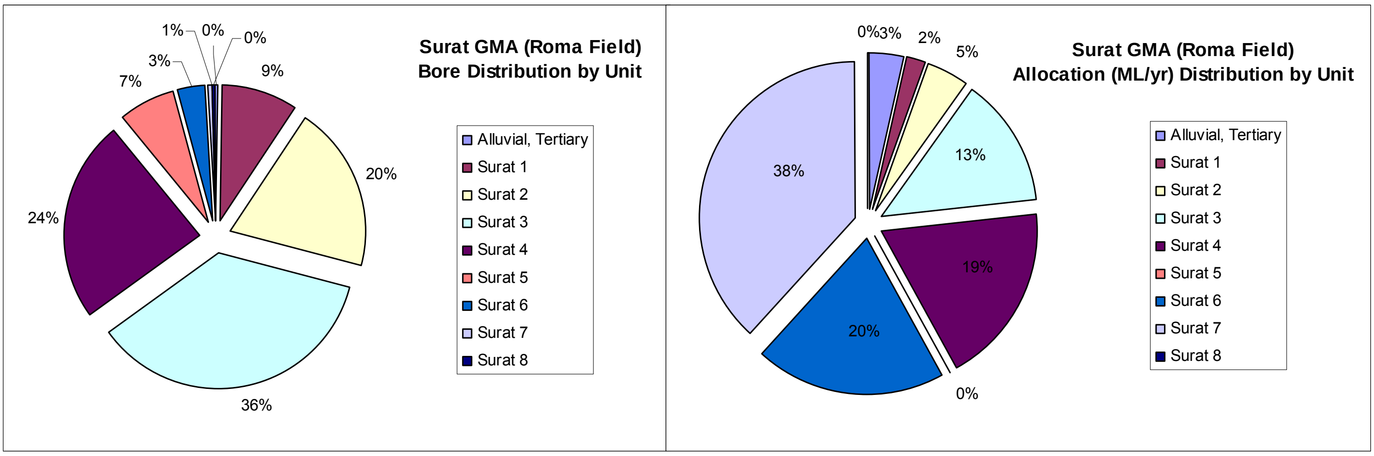


Figure 42: Distribution of Bores and Water Allocation by Unit within the Surat GMA

Figure 42 indicates that the primary aquifers targeted for groundwater extraction in the Surat North GMA is the Hutton Sandstone (Surat North 2). The primary use is town water supply and domestic and stock use (WERD database). The Surat North 1 unit is also heavily targeted; however, bores completed in this unit have no assigned allocation figures. Only 1% of the licensed bores in the Surat North GMA of the GLNG Project Area are completed in the alluvial and tertiary deposits within the region (Figure 43), but significant allocations are provided from these deposits for irrigation use.

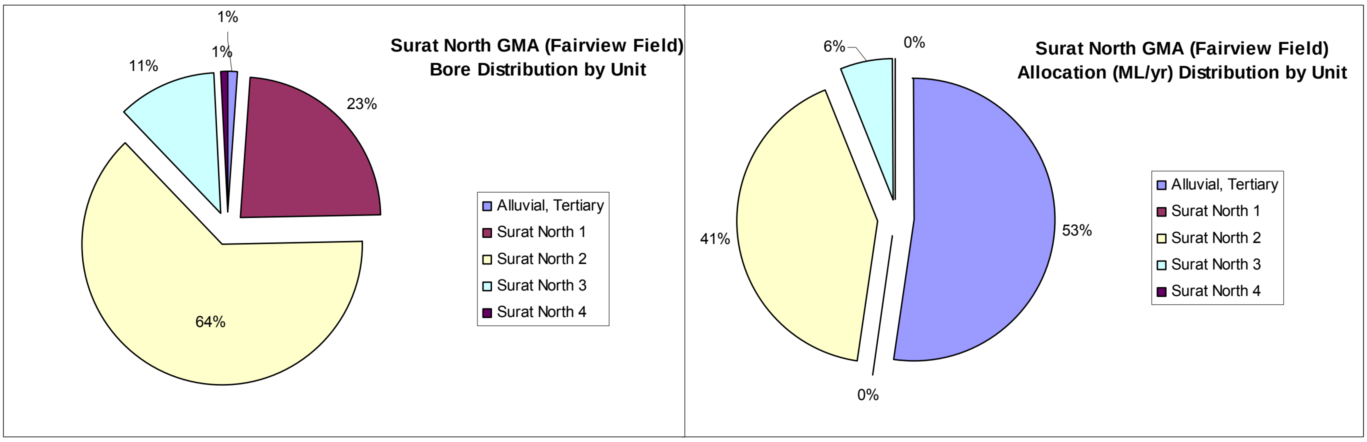


Figure 43: Distribution of Bores and Water Allocation by Unit within the Surat North GMA

Within the Mimosa GMA and outlying Bowen Basin area, the primary target aquifer includes the Clematis Sandstone (Mimosa 1) (Figure 43). Water is assigned for Town Water supply, domestic and stock use. Bores completed in alluvium, tertiary deposits and basalt are assigned large nominal allocations in this area and are used primarily for irrigation.

As for bores in the Permian deposits of the Bowen Basin, (the Aldebaran Sandstone), most bores have been licensed for town supply and irrigation (Figure 44).

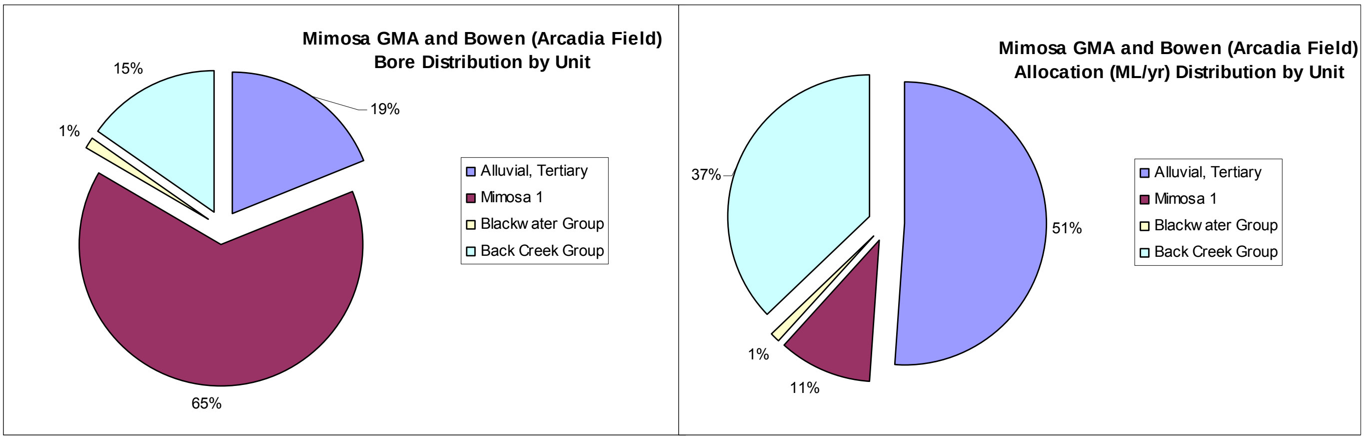


Figure 44: Distribution of Bores and Water Allocation by Unit within the Mimosa GMA and Bowen Basin

Extraction from Coal Measures

Because of its depth, poor water quality and generally low yield, water from the Walloon Coal Measures (WCM) is not typically used by farmers, irrigators or other water users within the Roma CSG Field (Surat GMA 19). Significant extraction from the WCM commenced with the development of CSG exploration. No bores, other than for CSG, are known in the Bandanna Formation (based on data in WERD and the DERM Groundwater Database). CSG production wells are not typically included within these databases. Accordingly, the total number of wells pumping from the targeted CSG formations (Walloon Coal Measures and Bandanna Formation) is expected to be much higher than the estimate presented in Table 17.

The quantity of water extracted from both the WCM and Bandanna Formation, due to CSG operations, is expected to increase significantly over the next 20 years. Using initial production forecasts provided by Santos (based on the current field development plan), it is estimated a combined total of 20,000 ML will be extracted in the year of 2012. Figure 45 presents the predicted extraction volumes for Santos' proposed production wells over the next 40 years within each of the CSG Fields in the GLNG Project area. Figure 45 also presents the volume of unallocated water for the relevant Groundwater Management Areas, defined as the 'General Reserve' in the *Water Resource (Great Artesian Basin) Plan 2006* (Subdivision 2 and Schedule 5). Water entitlements for CSG activities are not subject to the terms of the *Water Act 2000*, and the general reserve volumes are presented for reference only.

Based on these forecasts, the quantity of water extracted by Santos at the Roma CSG field will be equal to or less than the general reserve for the Surat GMA 19 for the full duration of CSG operations (Figure 45a). It should be noted however that the general reserve applies to the entire Surat GMA 19 plan area, and that allocation of the reserve under the WRP is limited to two GMUs: 3000 ML from Surat 6 (Hutton Sandstone and Evergreen Formation) and 2000 ML from Surat 7 (Precipice Sandstone).

A direct comparison of CSG extraction from the Bandanna Formation with legislative restrictions is challenging. The Australian Natural Resources Atlas defines this area as 'not a major priority' (ANRA, 2005) and there are no priority issues for groundwater management within the area. Although there is comparatively little groundwater abstraction from the Permian formations within the Arcadia and Fairview Field areas, consideration of the potential impacts to surrounding aquifers should be made, particularly to overlying aquifers such as the Clematis Sandstone and Precipice Sandstone, which are included in the WRP GAB 2006.

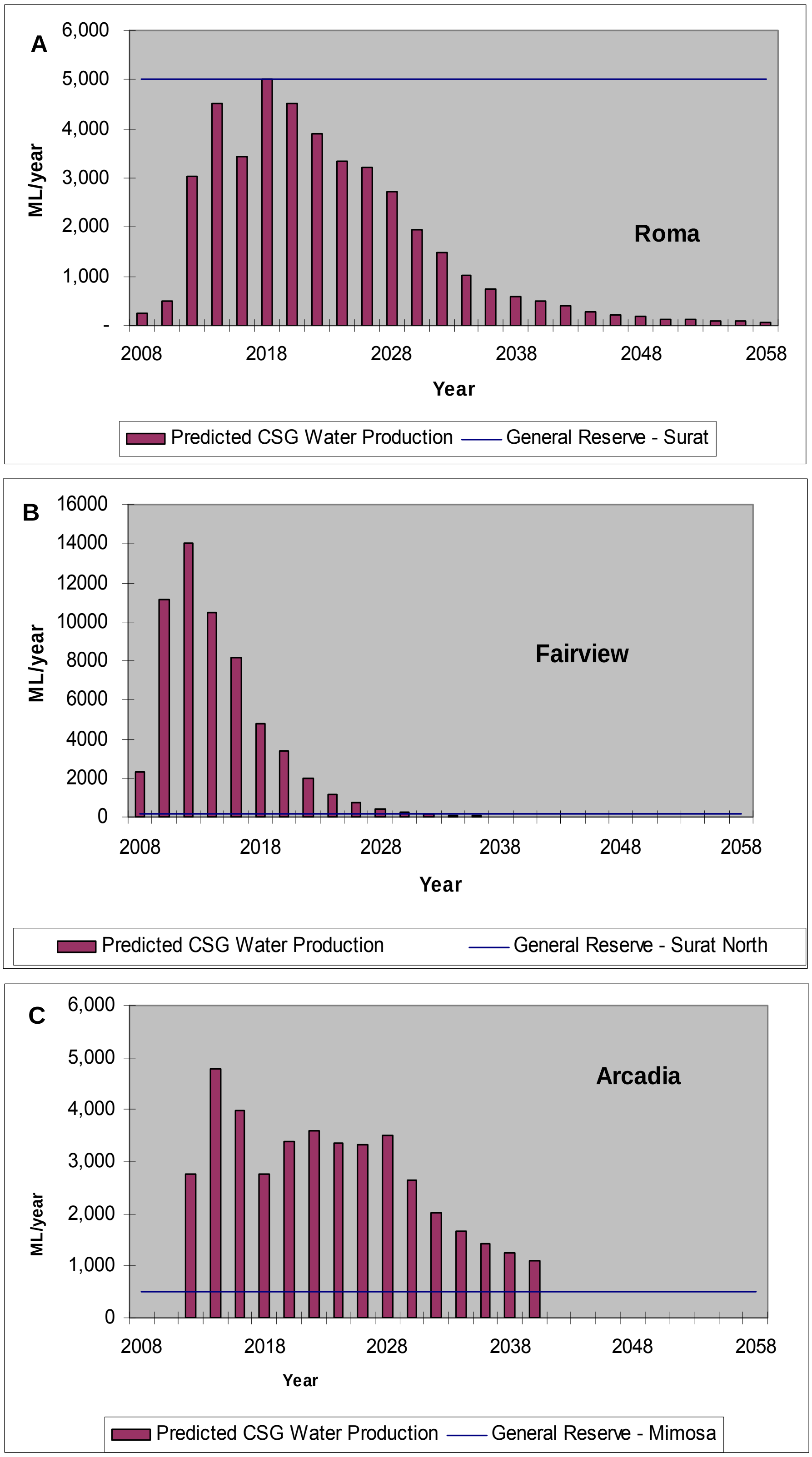


Figure 45: Predicted Extraction of Water from the Target Coal Measures

Approximately 30% of the water to be extracted from the Bandanna Formation will be derived from induced leakage from the Precipice Sandstone (Matrixplus, 2009). A comparison of the predicted extraction within the Fairview CSG Field with the GABWRP general reserve for the entire Surat North GMA 20 is presented in Figure 45b. The general reserve for Surat North is 200 ML/annum, apportioned as 100/ML each to Surat North 2 (Hutton Sandstone and Evergreen Formation) and Surat North 3 (Precipice Sandstone). The quantity of water to be extracted by Santos within the Fairview CSG Field will exceed the GABWRP entitlement by almost two orders of magnitude at the peak of production, and will continue to exceed the general reserve until approximately 2030.

CSG extraction within the Arcadia valley could potentially induce leakage through the Rewan Formation from the Clematis Sandstone. As such, a comparison of the predicted extraction within the Arcadia CSG Field relative to the WRP general reserve for the Mimosa GMA 22 is presented in Figure 45c. The quantity of water to be extracted by Santos within the Arcadia CSG Field exceeds the WRP general reserve (500 ML/annum; Mimosa 1 GMU) by an order of magnitude at the peak of production, and will continue to exceed the general reserve until approximately 2040.

Consideration of potential impacts of pumping for CSG extraction is presented in Sections 7.0 (risk based impact assessment) and 8.0 (discussion of potential impacts). These include mitigation strategies to address the possible exceedences discussed above.

4.7 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) can be defined as those ecosystems whose ecological processes and biodiversity are wholly or partially reliant on groundwater. The extent of GDE dependency on groundwater can range from being marginally or episodically dependent to being entirely dependent on groundwater (SKM, 2001). Examples of GDEs include:

- Terrestrial vegetation supported by shallow groundwater;
- Aquatic ecosystems in rivers and streams that receive groundwater base flow;
- Wetlands, which are often established in areas of groundwater discharge;
- Springs and associated aquatic ecosystems in spring pools; and
- Aquifers and caves, where stygofauna (groundwater-inhabiting organisms) reside.

The *Hydrogeological Framework Report for the Great Artesian Basin Water Resources Plan Area (2005)* includes a discussion of the two types of GDEs that are most relevant to the GLNG project area:

- Springs, including mound springs of the Great Artesian Basin; and
- Rivers receiving baseflow.

In this geographic context, the only potential GDEs of concern under the EPBC Act are mound springs of the GAB. *It is worthy of note therefore, that there are no known mound springs within the footprint of the CSG fields, including the potential area of influence of CSG depressurisation activities*. Therefore there are no GDEs of EPBC concern that will be affected by the GLNG Project CSG field development.

Much of the discussion in the following sections is summarised from the *Hydrogeological Framework Report.* An assessment of GDEs as defined environmental values for the project area is included in Section 8.1.1, and potential risks to GDEs associated with CSG activities are addressed in Sections 8.2 to 8.7.

4.7.1 Springs

Numerous springs and spring complexes have been documented throughout the GAB; with a broad range of classifications (i.e. mound springs, mud springs, boggomoss springs, etc). Two broad classifications of springs that have been adopted in the GAB include recharge springs, which are sustained by recharge rejection in the outcropping portions of GAB formations, and discharge springs, which are springs that are maintained by confined aquifers under artesian pressure. It has been reported that groundwater extraction from bores has resulted in 64% of springs in the discharge areas of the GAB ceasing to flow, and total spring discharge throughout the GAB declining by approximately 30%.

Artesian spring communities that are reliant on the artesian discharge of GAB groundwater are listed at threatened ecological communities under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999. It is noted, however, that no GAB mound springs have been identified within the CSG field area, which have special conservation value due to the unique habitats they provide.

The assessment of the ecological values related to springs is contained in Attachment D5 of the Santos Supplementary EIS and also in Section 8.1.1.

4.7.2 River Baseflow

Groundwater contribution to streamflow, or base flow, typically accounts for a significant fraction of total flow volume in major rivers and streams. Baseflow can sustain streamflow volumes long after rainfall events, or throughout dry seasons, and is therefore critical to the maintenance of aquatic ecosystems in rivers and streams in many Australian environments. Baseflow can occur as springs discharging into a river or stream, or as diffuse influx of groundwater through banks and bed sediments.

The major river systems associated with the GLNG project area include the Upper Dawson River, which transects the Fairview CSG Field, and the Condamine – Upper Balonne Rivers, which cross the Roma CSG fields.

Ecological surveys carried out by URS (2009) identified established aquatic ecosystems associated with major rivers, ephemeral streams and spring pools within the project area. In general, URS reported that water quality was characteristic of a moderately degraded environment, with low dissolved oxygen, high turbidity, and relatively high concentrations of nutrients and pesticides from land use in the vicinity of the rivers and streams.

It should also be noted however, that groundwater modelling studies to date have indicated that there are no expected impacts on spring flows in the CSG field area (Matrixplus, 2009).

5.0 WATER MANAGEMENT ACTIVITIES

The production of CSG generates significant quantities of AW, which must be managed sustainably. The quality of the AW produced from the GLNG Project CSG wells has been measured. To date, the data indicate that the quality of the AW can vary between 'fresh' and 'brackish' (total dissolved solids [TDS] concentrations ranging from approximately 100 to 5,000 mg/L, Section 4.5.2).

Santos is committed to understanding and managing the potential impacts of their operations on local and regional groundwater and surface water resources. To achieve this, Santos is committed to implementing a comprehensive and socially responsible water management program. The program will comply with all of the legislative requirements and any risk management objectives (refer to Section 7.0), and will include a combination of engineering solutions, a robust monitoring program, and a clear decision framework for addressing potential adverse impacts to the hydrological cycle arising from CSG activities. The water management program for the GLNG Project will address the full range of CSG activities that involve water management, including drilling and well installation, coal seam depressurisation, AW gathering, distribution and storage infrastructure, and AW end use activities (described in further detail in Section 5.3).

The key factors to be considered in the development of the water management options include the volume and quality of AW to be generated, legislative and policy requirements, and a viability analysis for various water end use options that considers financial, social and environmental factors. These factors are discussed in the following sections.

5.1 Coal Seam Gas Operations

The five principal CSG operational activities that involve water management 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 (AW) to reduce the hydrostatic component of the gas reservoir pressure (depressurisation) in order to facilitate recovery of the predominantly methane gas.

The AW 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 an estimated 10 to over 60 ML/d of AW to the surface (Santos, 2009). 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 AW will potentially 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, the technical capability, the costs of implementation and operation and the perceived benefits to the community and the environment.

5.2 Legislative and Policy Requirements

Until recently, disposal of CSG AW in evaporation ponds was the preferred management strategy in Australia. However, it has become increasingly apparent over time that the environmental legacy associated with evaporation ponds (significant land take, generation of evaporative brine requiring eventual disposal, potential risks to soil, surface water and shallow groundwater resources) was not sustainable, especially in light of a predicted significant increase in the development of the CSG reserves in Queensland and elsewhere in Australia. The Queensland Government CSG water policy (October 2008, refer to Section 2.0) requires more innovative AW management approaches that reduce potential environmental impacts related to evaporation ponds.

The key implications of the CSG policy framework for the Project are as follows:

- Use of evaporation ponds to manage AW 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 AW is promoted as the *preferred management option*[1];
- If re-injection is not possible (for technical or environmental reasons), beneficial reuse of AW 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 treatment and disposal of AW. Unless CSG producers have arrangements for injection and reuse of untreated CSG water, AW must be treated to a standard defined by EPA guidelines before disposal (re-injection) or supply to other water users; and
- Aggregation of surplus AW 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 CSG industry.

5.3 Associated Water Management

Essential to the program and any of the options implemented is monitoring to inform the water balance, water models and management in terms of effectiveness of the option chosen.

There are two (inter-related) major risk categories for managing water produced from CSG operations:

- risks to the groundwater resource resulting from large-scale aquifer depressurisation; and
- risks associated with managing the AW during and following extraction.

To address the management challenges for AW derived from CSG production, Santos has developed an AWMP (Santos, June 2009). To develop this strategy, a comprehensive list of AW management options were evaluated and prioritised during development of the GLNG Environmental Impact Statement (EIS) (URS, 2009). These options were evaluated during a Project risk assessment workshop (Section 7.0). Options with an unacceptable risk rating were excluded from further consideration. Community consultation workshops were later held to present options for the use of treated water at Roma and Arcadia.

A risk-cost comparison tool was developed to compare the remaining options for water management including the community identified options. The key assessment criteria for the various management options included:

- There is a known and reasonable cost associated with the management option;
- The management option is based on a demonstrated technology;
- The management option is scalable; and
- The management option is achievable (can be permitted) within a timeframe compatible with the GLNG Project schedule.

The assessment concluded that all AW from the GLNG Project that cannot be either discharged to grade or used for irrigation prior to desalinisation will be collected and treated.

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[1] It should be noted that currently, the legislation in Queensland limits the potential for injection of AW. However, Santos operates 2 injection wells at the Fairview CSG field with the approval of the regulators (DERM) and expects that further approvals could be provided if a satisfactory sustainable injection solution were presented.

Discharge to grade will not be employed except for either the disposal of permeate (freshwater), or where currently authorised by DERM and only when it is deemed appropriate and environmentally acceptable.

Water will be collected from wells and transferred to regionally distributed water management ponds. These ponds are to be constructed in the best practice standard and as approved by DERM.

Reverse Osmosis (RO) has been identified as the preferred technology for reducing the TDS in the AW for the GLNG Project, whether for discharge to surface water or to maximise the potential reuse opportunities. The desalinated water produced through RO is referred to as permeate. RO removes most chemical elements from the AW, but may leave a residual quality of sodium (up to 140 mg/L). All RO treatment facilities are to be located on land owned by Santos. Other technologies will be considered via a tender process for water treatment providers.

Table 18 provides a summary of the preferred options for application of AW at the three GNLG CSG Fields.

Table 18: Preferred Options for Associated Water Management

CSG Field	**Proposed Use of Treated Water (→ Order of Decreasing Preference →)**						
	Dust Suppression	Supply Back to Landholders		Municipal/ Industrial Supply	Irrigation Opportunities	Filling of Local Lakes	Controlled Release to Surface Water
		Non-Desal	Desal				
Roma	✓	✓	✓	✓	✓	✓	✓
Fairview	✓				✓		✓
Arcadia	✓	✓	✓			✓	✓

Desal = desalinated water

Roma

Preferred uses for the AW from the Roma CSG Field include:

- Dust suppression on tracks/roads using non-desalinated water and amended water;
- Supply of desalinated and non-desalinated water to local landholders for irrigation and feedlots;
- Municipal and industrial use;
- Maintaining the level of Lake Campbell and related irrigation opportunities; and

Fairview

Preferred uses for the AW from the Fairview CSG Field include:

- Dust suppression on tracks/roads using non-desalinated water and amended water;
- Discharge of suitable water to the Dawson River for downstream municipal and industrial users;
- Irrigation of tree plantations on suitable Santos lands using non-desalinated and amended water;
- Irrigation of forage crops on Santos lands using desalinated and amended water; and
- Irrigation of forage crops and tree plantations on neighbouring landholder properties.

Two types of irrigation schemes are proposed for the beneficial use of the AW from the Fairview CSG field (Santos, 2008). An estimated 70% to 80% of the AW will be used to irrigate hardwood trees. The AW will require treatment to adjust the sodium adsorption ratio (SAR) for sustainable soil chemistry, and the removal of iron and carbonate to reduce the potential for clogging of the drip irritation system. The remainder of the AW from Fairview is intended to be used to irrigate Leucaena. Desalinated water will be used for irrigation of hardwood trees, while for Leucaena irrigation, the water will undergo RO treatment to render the water suitable for irrigation. In both cases the water may require further amendment to adjust the SAR ratio to within an acceptable range.

Arcadia

Preferred uses for the AW from the Fairview CSG Field include:

- Dust suppression using non-desalinated water and amended water;
- Supply of desalinated and non-desalinated water to local landholders for irrigation and feedlots; and
- As a measure of last resort, discharge to Lake Nuga Nuga for environmental flows and downstream users.

Refer to Sections 8.7.2, 9.1.6 and 9.2.

Brine Management

The brine produced as a by-product of the RO process will be temporarily stored in lined ponds on Santos land located near the RO plants. The preferred disposal option for the brine is injection into deep aquifers where technically and economically viable. An alternative management option includes crystallisation and encapsulation of the brine, with further feasibility studies currently being conducted to evaluate the feasibility of these options.

The general approach for the water management strategy is to adopt low risk strategies initially, with known and reasonable costs and achievable timeframes, whilst some of the ‘marginal’ options (including injection) are examined in more detail. A summary of Santos’ risk assessment is provided in Section 7.0 of this report.

6.0 DEEP AQUIFER GROUNDWATER MODELLING

Groundwater models of Santos' CSG fields were developed by Matrixplus Consulting (Matrixplus, 2009) to characterise the existing deep groundwater environment and assess potential impacts to the groundwater resources arising from coal seam depressurisation. The following provides a summary of the key findings and conclusions presented in Matrixplus' modelling report.

The Santos CSG operations in the Surat and Bowen geologic basins are divided into three CSG fields: Roma, Fairview and Arcadia. However, for the purpose of deep aquifer groundwater modelling, the Project was divided into two fields as described in Table 19.

Table 19: GLNG CSG Model Fields

CSG Models	Location	Target CSG Development Formation
Comet Ridge Field (Fairview, Arcadia and Spring Gully fields)	Bowen Basin	Bandanna Formation
Roma Field	Surat Basin	Walloon Coal Measures

The Roma Field model was designed to assess the predicted drawdown in the WCM and associated impacts on adjacent aquifers as result of coal seam depressurisation, whilst the Comet Ridge Field model was designed to assess the predicted drawdown within the Bandanna Formation, including potential interaction between the Precipice Sandstone and the Bandanna Formation, and the potentiometric changes in adjacent aquifers.

Separate approaches were adopted in the modelling of each field:

- Comet Ridge CSG Field was modelled using the USGS modelling code MODFLOW; and
- an in-house analytical solution was prepared with respect to the Roma field.

Data compilation drew on a wide range of sources including:

- the DERM database (which provided stratigraphy, lithology, aquifers, historical water levels and water quality data information);
- DERM information on private landowner well tests;
- historical CSG extraction rates provided by Santos;
- streamflow data for the Utopia Downs stream gauging station 130324A; and
- monthly rainfall records for Injune and Roma.

It should be noted that as the CSG well fields are in early stages of development, the quality and quantity of data available is still limited and certain hydraulic parameters adopted for the models were determined by approximation methods or best estimates, with the recognition that the estimates could be updated at a later stage when more reliable data becomes available.

Predictive simulations were run over 20 years for each model to simulate the time period 2009 to 2028. Sensitivity trials were carried out in the Comet Ridge CSG model to examine the influence of vertical leakage, transmissivity and recharge rate. The models assume that the groundwater heads in the target coal measures are gradually drawn down over a period of 10 years to a threshold operating pressure of 100 psi (689.5 kPa), defined as 70m above the top of the Formation in the Comet Ridge Field Model, and 30 m above the base of the WCM in the Roma Field model.

6.1 Model Development and Assumptions

Roma

Within the Roma CSG field, the natural hydraulic head differences within and between aquifers are less than the differences predicted as a result of CSG operations. Flow within the low permeability units separating the aquifer Formations is assumed to be normal to the direction of flow within the aquifers.

Within the model, the WCM were conceptualised as a single porous layer with the available drawdown ranging between 280 m and 840 m. Prediction of drawdown in the WCM was based on a hypothetical well field development plan (presented in the Matrixplus report, 2009), and on superposition of the analytical groundwater flow equation. Drawdown in the Hutton was calculated based on the predicted drawdown in the WCM.

The following provides a summary of the assumptions used in the implementation of the Roma model:

- Only groundwater flow is considered. The flow of gas within the system is not considered to significantly affect the validity of flow equations used;
- Aquifer parameters are assumed to be uniform across the Roma CSG field;
- The WCM is assumed to have a uniform initial head of 355 mAHD across the Roma CSG Field prior to depressurisation (variations in the initial head were considered to be insignificant relative to the magnitude of predicted drawdown);
- Because of the large number of extraction wells, it is assumed that internal flow boundaries (i.e., faults) will not affect the shape of the final drawdown cone; and
- All wells will pump at a maximum rate of 100 m^3/d. Commencement and threshold are variable between wells.

Because there were no long-term field observations for the Roma CSG field, whole of field calibration was not possible. Sensitivity analysis for the model addressed storativity, as it was considered to be the critical aquifer parameter with results showing an approximately linear relationship with depressurisation. A four-fold increase in storativity resulted in a two-fold difference in predicted depressurisation of the aquifer.

Fairview

Due to the close proximity of the Arcadia and Fairview CSG fields (and Spring Gully CSG field), these fields were included in one groundwater flow model and the effects of their combined groundwater extraction was examined. It was assumed that three numerical model layers would be sufficient to model groundwater movement between the Precipice Sandstone, Triassic sediments (Moolayember, Clematis and Rewan Formations) and the Bandanna Formation.

The main productive aquifers considered included the Hutton Sandstone, Precipice Sandstone and Clematis Sandstone, which all overlie the Bandanna Formation. For the purpose of this model, it was assumed that there are no significant groundwater extractors in the area other than the extraction associated with CSG production.

The Evergreen formation is assumed to be an effective confining unit within the southern portion of the Comet Ridge Field, thus the Hutton Sandstone is considered to have a low likelihood of being impacted by CSG extraction in this area.

The Clematis Sandstone directly underlies the Precipice Sandstone to the west, north and east of the CSG Field; however, the contact between these aquifers is distant enough from the model area that evaluation of impacts to the Clematis Sandstone was not considered to be warranted. The Rewan Formation is assumed to be thick and impermeable over most of the model area and between these Clematis and Precipice Sandstones.

The Precipice Sandstone, on the other hand, is likely to be affected by CSG operations, due to the direct contact between the Precipice Sandstone and the Bandanna Formation in the southwest region of the Fairview CSG field.

The Hutton-Wallumbilla Fault is a physical barrier to horizontal groundwater flow in some areas of the Bandanna Formation. In the southwest section of the Comet Ridge Field, the throw of this fault is such that it effectively makes the Bandanna Formation discontinuous and allows a much closer contact between the Bandanna and the Precipice Sandstone.

The Permian formations underlying the Bandanna Formation were not considered to be significant aquifers for the purposes of the modelling exercise, and were represented as aquitards within the model.

The following assumptions were adopted in the development of the Comet Ridge model:

- Groundwater flow from underlying aquifers to the Bandanna Formation is not significant;
- Groundwater flow alone is considered. The flow of gas within the system is not considered to significantly affect the validity of flow equations used;
- Aquifer parameters are assumed to be uniform across the CSG field, including a constant layer thickness of 100 m and constant storativity;
- The observed variation in well production rates (yields) warranted the application of spatially-variant transmissivity values within the Bandanna Formation. Uniform transmissivity values were assigned to the Precipice Sandstone and to the Rewan Group; and
- Because of the large number of extraction wells, it was assumed that internal flow boundaries (i.e., faults) would not affect the shape of the final drawdown cone. Since the coal seams may be more compartmentalised than the way they were simulated, the model was considered to be conservatively large with respect to extent of drawdown.

Model parameters were calibrated against hydraulic heads measured within the Fairview CSG Field using the PEST parameter optimisation software (Doherty, 2004). Details of this method are provided in Matrixplus, 2009. Due to the uncertainty in production rates in the Spring Gully Field, pressure observations for many wells in the southern part of the Fairview CSG field were omitted from calibration. For 50 water level observations in 39 wells, calibration was acceptable with a correlation coefficient of 0.96 achieved between observed and simulated hydraulic heads.

The sensitivity of predictive model results to various estimates of aquifer parameters was tested. Predicted drawdowns were compared to assess impacts on the Precipice Sandstone for different parameter values. Transmissivity, recharge and vertical leakage were considered. Results indicated that the predicted drawdown in the Precipice Sandstone is relatively sensitive to transmissivity and relatively insensitive to the estimated rates of recharge. The sensitivity of drawdown to vertical leakage is variable, depending on its magnitude, due to the maximum drawdown in the Precipice Sandstone being limited. Lower values of vertical leakage produce greater changes in drawdown but the relative magnitude of these changes is less than those observed for variations in transmissivity.

6.2 Modelling Results

The impacts on the groundwater resources of the areas covered by the wellfields were assessed based on the model simulation results. The following are key findings of the Matrixplus modelling:

- In the Arcadia and Fairview CSG fields (which were modelled in conjunction with the neighbouring Spring Gully CSG field), the radius of influence of drawdown within the Bandanna Formation is expected to extend beyond the boundaries of CSG fields (Figure 3-12, Appendix C), due to the relatively high transmissivity value assigned to the coal measures;

- In the Roma CSG field, the radius of influence of drawdown within the WCM is expected to be confined to an area proximal to the CSG field (Figure 3-16, Appendix C) due to the relatively low transmissivity value assigned to the coal measures;
- Drawdown in the Bandanna Formation is expected to result in inter-aquifer transfer from the overlying Precipice Sandstone. Groundwater head loss within the Precipice Sandstone could range up to a maximum of 15 m at the end of 2013 and up to a maximum of 65 m at the end of 2028 (Figure 3-20, Appendix C), with the greatest drawdown predicted to coincide with the area where the Bandanna Formation subcrops directly into the Precipice Sandstone;
- After 5 years, 24% of the inflow from the Precipice Sandstone is due to extraction from the Spring Gully CSG field, rising to 36% after 20 years. Consequently, the contribution of the extraction from the Spring Gully CSG field to drawdown in the Precipice Sandstone has the same percentages; On this basis, while detailed modelling of the recovery of the wellfield water levels post CSG extraction has not been carried out to date, it can be hypothesised that the time required for 80% recovery of the water levels in the Precipice Sandstone should be approximately twice the life of the fields;
- Owing to a high resistance to vertical flow through the material between the coal seam aquifer and the underlying Hutton Sandstone, the rate of transfer of water from the Hutton Sandstone to the WCM is predicted to be low, and the associated magnitude of depressurisation of the Hutton Sandstone is predicted to be minor. After 20 years of operation the drawdown in the Hutton Sandstone, as a result of inter-aquifer transfer, was predicted to be approximately 3 m at the edge of the Roma wellfield;
- It is expected that the rate of recovery of water levels in the WCM will be very slow and drawdown in the Hutton Sandstone aquifer will continue for many hundreds of years after operations cease. However, while the radius of influence will continue to spread with time, the magnitude of the drawdown will not increase after the wellfield has ceased to operate;
- Although the potential for inter-aquifer transfer from overlying aquifers such as the Gubberamunda is considered to be small, it is recommended that the Gubberamunda Sandstone be monitored during the well field operation to validate this assumption;
- Landholder bores screened in affected aquifers (such as the Hutton Sandstone), which are located within the predicted radius of influence of depressurisation, may experience some degree of reduced groundwater heads. However, Matrixplus reported that there are no known private bores, completed within the WCM, that are expected to be impacted as a result of groundwater withdrawal from the Roma CSG field. Monitoring bores should be installed to assess the drawdown resulting from CSG extraction as the CSG development program progresses;
- Although there are a number of town water supply bores completed in the area, the impacts to these bores, if any, are likely to be minimal around the Roma, Fairview and Arcadia Valley CSG Fields;
- Drawdown of groundwater heads within the Precipice Sandstone as a result of groundwater extraction at the Arcadia and Fairview CSG Fields is not expected to significantly alter the baseflow contributions to the perennial portion of the Dawson River, or the groundwater discharge volumes to springs located in the vicinity of the Fairview Field; and
- Groundwater drawdown and associated inter-aquifer transfer is unlikely to have an adverse impact on the water quality of the CSG aquifer and the deep aquifers surrounding the CSG fields, as inter-aquifer transfer from adjacent affected aquifers will be directed into the coal measures.

6.3 Modelling Review

Golder was commissioned by Santos to perform a peer review of the Matrixplus modelling report. It was concluded that the Matrixplus models provide an adequate representation of aquifer behaviour to achieve the desired purpose at the present time, given the simplifications that were made to the approach and the limited data that were used for model development. A concern, however, is that the modelling does not address the duration and characteristics of aquifer recovery adequately, and should take into account the post-depressurisation impacts. An important consideration under post-depressurisation conditions is that drawdown can be expected to continue to propagate upwards towards shallow aquifer layers beyond wellfield closure as a result of delayed leakage to the deeper depressurised formations.

It was also concluded that the model could be developed on a larger scale that encompasses the entire project area, including Spring Gully, which will allow integration of all of the wellfields so that the cumulative influence of the CSG operations over the entire GLNG Project area can be more accurately represented. Such a model would also be available to test the planning and operational alternatives in assessing requirements of re-injection design.

Recommendations in relation to each model are provided in the following sections.

Roma Model

It is recognised that a sophisticated approach to modelling of the Roma CSG Field by Matrixplus was not justified given the data limitations at this stage. However, the reasons given for adopting a different approach in the case of the Roma model by not using a MODFLOW model are not clear, particularly with respect to the conclusion that drawdown of threshold levels is better controlled than in proprietary numerical models.

The conceptual hydrogeological model for Roma suggests that a numerical approach is more favourable than an analytical one given the need to account for factors such as anisotropy of each layer and the size of the proposed wellfield.

The interpreted faults were considered not to be a significant factor affecting groundwater flow. This was inferred from the small differences in groundwater head across the area, which were evident once bottom hole pressures had been converted to hydraulic head. It should be noted however that as drawdown increases and steep groundwater head gradients are established, the relative influence of geological structure on groundwater flow can play a more significant role.

Comet Ridge Model

As was the case for the Roma Model, it is recognised that a sophisticated approach to modelling by Matrixplus was not justified for the Comet Ridge Model given the data limitations at this stage. While it is recognised that data availability is severely limited, the assumption of a uniform transmissivity distribution, is not consistent with the aquifer parameter lists given in Appendix D of the Matrixplus report from flow and pressure tests.

The aquifer geometry is described in Matrixplus 2009 to be complex, with the presence of geological structure, such as the Hutton/Wallumbilla Fault, increasing it hydrogeological complexity. MODFLOW is a powerful model for aquifer simulation, but it is limited in its capacity to represent complex geometry and geological structures which may control groundwater movement.

- While Golder has not had an opportunity to review the Comet Ridge model directly, it is considered that there is insufficient resolution in the model to accommodate the vertical flow adequately. It is likely that it was necessary to apply a confined, constant transmissivity layer to represent the layers in the MODFLOW model to prevent instability in processing, which resulted from the low vertical resolution.

- The model is used to produce a water balance at 5-yearly intervals using the water budget facility within MODFLOW. This provides a useful check on the overall stability of the model and that convergence is achieved adequately at each of the selected stress periods. However, no clear attempt was made in the reporting to compare a MODFLOW model water balance to the conceptual hydrogeological model as part of the calibration exercise. This is particularly relevant to the boundary conditions applied and the relative magnitude of each flow component associated with these boundary conditions.

- Boundaries applied to the model include no flow boundaries, drainage cell nodes, river cell nodes, time-variant head boundaries and constant head boundaries.
  - The control that constant head cells exercise over groundwater gradient is important, since they can be both sources and sinks within the model domain. Because they can introduce or remove water, they should be tested carefully in water balance calculations. Time variant constant heads are used to control the progression of drawdown during CSG production, but no attempt appears to have been made to compare the volumes to result (given in the water balances in Appendix G) to potential production volumes.
  - MODFLOW drain cells were introduced to ensure model stability at the seepage zones along the northern boundary of outcrops of Precipice Sandstone. These cells will definitely have that effect. However, there was apparently no attempt to quantify (even as a broad estimate) the potential discharge that occurs at the seepage zones that these cells correspond to in the model.
  - Some explanation to justify the selection of heads at the south and west boundary of Layer 1 and west boundary of Layer 3 would be helpful.
  - Golder notes reference to river boundary conditions to the east of the CSG also. This requires detailed explanation because it implies an infinite source of water to the east.
- Although the boundaries and the physical flow components within the model represent a significant control over the water balance, and can provide a reasonable approximation of the piezometric surface of each aquifer, particularly if enough of these boundary conditions are applied to impose the desired outcome, this can be misleading.

  Through non-uniqueness of parameters, it is possible to produce the required surface, without producing a water balance that is consistent with the actual field conditions (i.e. the distribution of flows within the water balance won't necessarily correspond with the field estimates, even if the piezometric surface appears to be correct).

  There are a range of parameters associated with these boundary conditions such as drainage cell conductance, river leakage, river level, etc. that were assumed in the model development but were not tested any further in sensitivity trials. The result is that there can only be very limited confidence in the flow prediction, even if the calibration against head appears favourable.

6.4 Additional Modelling

Santos is currently developing a more sophisticated numerical model to improve on some of the model design constraints in the current Matrixplus model. The new modelling will be designed to more accurately represent the conceptual hydrogeological model for the combined Project areas, and hence provide a better simulation of the hydraulic response to CSG activities within the Project area. The new modelling will comprise a finite element model with a domain that includes all of the Santos GLNG CSG fields as well as the Spring Gully operations to provide a more robust prediction of cumulative depressurisation effects in the project area. This modelling will also be used to simulate the recovery timeframe for the affected aquifers following completion of CSG activities.

7.0 RISK BASED IMPACT ASSESSMENT

Potential impacts related to water management activities arising from CSG operations (refer to Section 5.0) have been systematically evaluated using a risk based assessment framework. The risk-based approach allows the potential risks associated with the water management activities to be considered and classified with respect to multiple evaluation criteria, such that the primary risk-driving activities are identified and prioritised accordingly. This Section describes the drivers, methodology and results of the risk assessment performed for the water management activities associated with the GLNG Project. A detailed discussion of the risks associated with each water management activity is provided in Section 8.0.

7.1 Drivers for Risk Management

This section identifies the potential water-related risks associated with the GLNG Project. The significance of these risks is discussed in the following sections.

The categories under which Project-related risks have been considered include:

7.1.1 Operational

Operational risks include:

- Drilling, bore design, bore completion and bore integrity of CSG exploration and production wells;
- Groundwater extraction associated with CSG operations related to depressurisation of the target coal seams;
- AW gathering, distribution, management, storage and disposal, and re-injection;
- Water treatment operations (RO plants and treatment plant for irrigation or power station supply and sewage treatment for office facilities);
- Inappropriate water treatment to influent requirements; and
- Other project infrastructure such as roads and camp services, irrigation and water supply.

7.1.2 Stakeholder

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.

7.1.3 Regulatory

Regulatory risks include:

- Adherence to the specific conditions of EAs for the operations;
- Adherence to the intent of the applicable legislation; and
- The potential for legislative amendments to be inconsistent with the currently approved practices for water extraction or management.

7.1.4 Planning

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.

7.1.5 Public Health

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; and
- Impact (perceived or actual) of the operations on the suitability of the local water resources for domestic supply.

7.2 Risk Assessment

7.2.1 Definition of risk and risk categories

A risk is defined by the Australia/New Zealand Standard for Risk Management (AS/NZS 4360:2004) as *the chance of something happening that will have an impact on objectives*. It is measured in terms of a combination of the consequences of an event, and the likelihood of an event occurring.

The risk analysis for the GLNG Project water management activities related to development of CSG operations was performed for the risk drivers presented in Section 7.1. The potential risks related to the various Project activities were evaluated and assigned a risk ranking according to the likelihood of the risk occurring, and the associated consequences.

The matrix used to evaluate the risk consequences for the GLNG project is presented in Table 20, which includes a description of the categories of consequences considered, and a description of the relative magnitude of consequences for each category. This matrix was developed on the basis of the standard Santos EHSMS risk assessment matrix (developed in accordance with ANZ 4360:2004).

An analysis of the likelihood and consequence for each risk driver resulted in the risk issue being assigned a risk tolerance Category between one (tolerable) and five (least tolerable), according to the matrix presented in Table 20 and the hierarchy of risk analysis presented in Figure 46. A risk issue assessed as Category 1 is considered to be tolerable in its current state, without the need for mitigation actions to reduce the risk; these generally represent risk issues that are either very unlikely to occur, or that would result in a minor or negligible consequence if they do occur. Risk issues assessed as Category 2 to 5 may still be tolerable but require further evaluation of potential contingency actions or mitigation measures.

Table 20: Risk Matrix and Risk Tolerance Definition

			Consequence				
			I	II	III	IV	V
elihoodLik	**Almost Certain** Is expected to occur in most circumstances	A	2	3	4	5	5
	Likely Could occur in most circumstances	B	1	3	3	4	5
	Possible Has occurred here or elsewhere	C	1	2	3	3	4
	Unlikely Hasn't occurred yet but could	D	1	1	2	2	3
	Remote May occur in exceptional circumstances	E	1	1	1	1	2

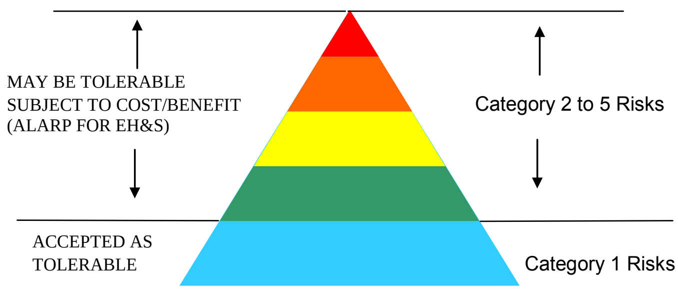

Figure 46: Hierarchy of Risk Tolerance (Santos EHSMS)

7.2.2 Risk assessment based on operational areas

In considering the risk drivers presented in Section 7.1, it was determined that the operational risk drivers were fundamental to the risks associated with each of the other categories (i.e. all Project risks related to water management activities ultimately derive from operational risks). Hence, the operational risk drivers were selected for detailed risk assessment with the inference that the results would, by association, address the risk drivers in each of the other categories.

The risk assessment was completed during a workshop held on 19th January 2009; the detailed results are presented in the Summary of Risk Assessment Results for the GLNG CSG Development Activities (Appendix C). The majority of identified risks were classified as Categories 1 or 2 which are considered to have negligible or minor consequences.

Risks associated with depressurisation of the coal seams were considered separately for each of the three CSG fields (R = Roma; F = Fairview; A = Arcadia). The risk ratings for coal seam depressurisation in the Roma and Arcadia CSG fields were considered to be within Categories 1 and 2. In the Fairview CSG field the risk ratings ranged from Categories 1 to 4 due to current activity at the site (i.e. increased likelihood for certain hazards to occur). Activities classified greater than Category 2 are summarised as follows:

- Loss of available drawdown in bores, or loss of artesian pressure, resulting from coal seam depressurisation (Category 4 for the Fairview CSG field);
- Loss of baseflow resulting from coal seam depressurisation (Category 3 for the Fairview CSG field);
- Contamination of soil, surface water or shallow groundwater resulting from a break in an AW pipeline (Category 3);
- Damage and/or contamination associated with a dam break (Category 3; rating applies to release of oily water or brine only);
- Over- or under-supply of AW for municipal or industrial reuse applications (Category 3); and
- Environmental impacts related to the quality or quantity of treated discharge released to perennial streams (Category 3).

7.2.3 Discussion of risk assessment results

The relative magnitudes of the risks related to water management activities were used as a guide to developing appropriate risk control measures. The results of the risk assessment indicated that the majority of water management activities associated with the GLNG Project currently represent negligible or minor risks to human health, the environment or the commercial viability of the Project. With respect to the water management activities classified as greater than Category 2 risks, two prevailing themes are evident:

- The potential for reduced groundwater availability resulting from coal seam depressurisation; and
- The potential for water quality degradation related to AW management activities.

The two themes described above are consistent with the prevailing risk perceptions of the general public and the regulatory community regarding CSG activities, and hence form the principal focus for development of risk control measures, the most significant of which are the AWMP and the WMS.

The following Section builds upon the results of the risk assessment, identifying the environmental values relevant to the GLNG Project area (Section 8.1), and providing a detailed discussion of the potential risks to these values posed by the CSG water management activities (Sections 8.2 to 8.7). The discussion of potential impacts is followed by a description of the risk mitigation actions proposed to manage the Project risks (Section 9.0), and development of a trigger value framework (Section 9.4), linked to the proposed monitoring strategy (Section 9.4), for implementation of further investigation or ‘make good’ options as warranted (Section 9.5).

8.0 DISCUSSION OF POTENTIAL IMPACTS

This section includes a discussion of the environmental values (EVs) associated with groundwater and surface water relevant to the GLNG Project area, followed by a discussion of potential impacts associated with CSG operations, its infrastructure and AW management.

Management and mitigation of the identified impacts are outlined in Section 8.10.

A discussion of the rationale and recommendations for establishing trigger values for water levels and water quality is presented in Section 9.4. Potential contingency actions to address CSG-related impacts are discussed in Section 9.5.

8.1 Environmental Values

The EVs of a surface water or groundwater resource are defined as "those qualities of the waterway that make it suitable to support particular aquatic ecosystems or human use" (EPP, 2007). The EPP 2007 provides guidelines on determining the EVs that should be considered for a particular project site or area, which follow the framework set out in *Appendix H* of the *Queensland Water Quality Guidelines 2006* (QWQG 2006). The EVs outlined in the QWQG 2006 and EPP 2007 were reviewed for relevance to groundwater resources in the GLNG Project area, and the following EVs were determined to be relevant to all or parts of the CSG fields:

8.1.1 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 turtles, platypus, seagrass and dugongs) and their habitat, food and drinking water;
- Waterways which in this context include: groundwater dependent ecosystems (GDEs), perennial and intermittent surface waters, groundwaters, tidal and non-tidal waters, lakes, storages, reservoirs, dams, wetlands, swamps, marshes, lagoons, canals, natural and artificial channels and the bed and banks of waterways.

Whilst aquatic ecosystems are traditionally associated with surface water bodies rather than groundwater systems, any surface water body with a hydraulic connection to shallow groundwater would be potentially susceptible to impacts to shallow groundwater (either water quality degradation, or lowering of the water table). This EV would be relevant to all GDEs, perennial creeks, rivers, and springs present within the CSG fields.

8.1.2 Primary Industry

Primary industry land uses feature prominently in the rural economy of the CSG fields. Of the primary industry EVs identified in the guidelines, the following are considered to be 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.

On average across the CSG fields, groundwater supply for the above primary industry uses accounts for approximately 87% of licensed groundwater allocations (refer to Section 4.6 for further detail). The majority of these licensed allocations are assigned to the Hutton and Precipice Formations, which are the aquifers that modelling results suggest will be most affected by coal seam depressurisation (refer to Section 6.0 for further details). As such, the EVs associated with primary industry are considered to represent the principal issue of concern with regards to coal seam depressurisation.

An assessment of the potential impact arising from the use of the AW for these purposes needs to be considered, including impacts on soils, water, ecology and ground water.

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 GLNG Project area.

8.1.3 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. Information reported in the Environmental Management Plan for the Fairview Project Area (URS, May 2008) confirms that groundwater is more commonly used for drinking water supply than creeks or rivers for the rural homesteads in this project area. Municipal water supply also accounts for approximately 9% of the licensed groundwater allocation across the CSG field area. As such, groundwater as a drinking water supply is considered to be an important EV for the groundwater resources in the CSG field area.

8.1.4 Industrial Uses

According to groundwater allocation information from the DERM for the CSG field area, industrial uses account for only 2% of the licensed groundwater entitlements. While this represents a relatively minor proportion of the human consumptive uses of groundwater in the development areas, many industrial water applications are particularly sensitive to reliability of supply, and may also have a limited tolerance range for variations in water quality. As such, industrial use has been considered amongst the relevant EVs for the groundwater resources of the GLNG Project area, with the recognition that it comprises a minor component of the overall licensed allocation.

8.1.5 Recreation and Aesthetics

Similar to aquatic ecosystems, the EVs associated with recreation and aesthetics are traditionally more applicable to surface water bodies than groundwater resources. Following the same rationale described for aquatic ecosystems, where surface water and shallow groundwater are 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 GLNG Project area, the most relevant scenario affecting these EVs would be contamination of shallow groundwater from some aspect of CSG activities, which in turn impacts surface water quality and affects the recreational or aesthetic amenity of the surface water body. 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, surfing, windsurfing, diving, 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, rowing 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.

8.1.6 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).

Again, these are issues that are more relevant to surface water bodies than groundwater resources, except for the circumstances previously described regarding the connection of surface water and shallow groundwater. Given the descriptions of this EV category above, 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 CSG field area.

Further details of the environmental values described in this section are provided in the QWQG 2006 and the EPP 2007. The ANZECC 2000 guidelines provide water quality objectives for the various environmental values.

8.2 Drilling and Well Installation

Santos operations within the CSG field 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.

8.2.1 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 (resulting in degradation of water quality); and
- inappropriate control 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, poor planning of drilling programmes, inappropriate drilling techniques and/or drilling fluid selection, and inappropriate abandonment methods.

8.2.2 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 water quality changes, erosion and surface water impacts from uncontrolled overland flow of artesian water into surface water courses.

8.2.3 Environmental Values Affected

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

- Human consumptive uses such as groundwater supply for drinking water and primary industry, which could be affected 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;
- Aquatic ecosystems, which could be affected by degradation of shallow aquifers that contribute baseflow to surface water features, or induced vertical leakage of water table aquifers resulting in reduced spring flow or baseflow contributions to aquatic ecosystems. Aquatic ecosystems would also be vulnerable to uncontrolled discharge of flowing artesian water, particularly where erosive scouring and increased sediment loads are involved.

8.2.4 Potential Risks to Environmental Values

With reference to the risk assessment discussed in Section 7.0, the potential risk issues associated with this water management activity were all rated as Category 2 risks. Of these, the potential to create a preferential pathway between aquifers, resulting in cross-contamination or pressure loss, was considered to represent a Major consequence (consequence level IV), but was unlikely to occur as a result of the drilling and well installation methods adopted by Santos drilling crews, an important risk mitigation measure adopted by Santos to address this risk (further discussed in Section 9.0).

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.

8.3 Coal Seam Depressurisation

As described in Section 1.2, groundwater is extracted from a CSG reservoir (coal seam or coal measures) to facilitate desorption of the gases adsorbed to the coal. Typically the amount of depressurising 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 AW generated, coal seam depressurisation is considered to represent the greatest risk to groundwater resources in the vicinity of the CSG operations.

8.3.1 Associated Risk Issues

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

8.3.2 Discussion of Potential Impacts

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

Loss of available drawdown in bores

Inter-aquifer transfer related to coal seam depressurisation may result in a localised reduction in the available water column for bores screened within the affected aquifers; notably, the Precipice Sandstone in the vicinity of the Fairview and Arcadia CSG extraction bore fields (Matrixplus, 2009). The relative impact to bore owners in the CSG fields will depend on the location of the bores relative to the CSG operations and associated cone of depression in the affected aquifer. The modelling results predicted that depressurisation effects within the Precipice Sandstone would extend beyond the perimeter of the Fairview and Arcadia CSG fields due to the relatively high transmissivity value assigned to the Bandanna Formation. In contrast, due to lower estimated transmissivity values the effects of depressurisation of the Walloon Coal Measures in the Roma Field were predicted to be constrained to the immediate vicinity of the production area, with minor resultant inter-aquifer transfer from the underlying Hutton Sandstone. Hence, water supply bores completed within the primary aquifer formations in the vicinity of the Roma CSG Field operations are predicted to face only a minor risk from loss of available drawdown.

The potential influence of coal seam depressurisation on water supply aquifers in the Roma, Fairview and Arcadia Fields is presented conceptually in Figures 47 to 49. Appendix C presents the modelled drawdown results of the deep groundwater modelling performed for these fields (Matrixplus, 2009). The relative magnitude and radial extent of drawdown for the depressurised coal seams and proximal major aquifer formations are presented diagrammatically, as well as a depiction of planned monitoring infrastructure that will be used to assess the development of potential impacts to the groundwater resource.

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 and appropriately compensated, if warranted. Further discussion of potential management options for affected bore owners is provided in Section 9.5.

Loss of artesian pressure

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 projected inter-aquifer transfer, particularly from the Precipice Sandstone, could result in a local loss of the artesian head in this formation.

Reduced artesian pressure could affect bore owners with bores completed in the artesian portions of the Precipice Sandstone (or any other potentially affected artesian aquifer), resulting in a reduction or loss of natural artesian flow. This issue has been widely observed within the GAB in areas of significant groundwater extraction (predominantly for irrigation purposes), and areas with numerous uncontrolled artesian bores discharging to bore drains.

Subsidence

As depressurisation of coal seams proceeds and the water pressure in the fractures and pores is reduced, there will be an increase in the vertical effective stress. This is the stress due to the weight of the overburden to the surface. An increase in the vertical effective stress at the seam will result in settlement of the coal. Whilst the depressurised coal seams are likely to be the most susceptible to this effect, it could potentially also apply to other depressurised formations affected by CSG activities. This would apply in the case of significantly depressurised un- or poorly consolidated sediments, none of which are expected to exist between the coal seams and surficial alluvium.

For the purposes of the following discussion, it is safe to assume that depressurised coal measures will represent the greatest subsidence risk, and that the incremental increase in subsidence within partially depressurised adjacent formations is negligible in comparison.

Certain assumptions have been made about the lateral and vertical extent of the depressurisation, and hence settlement, of the coal:

- Prior to pumping, the fracture/pore pressure in the coal seam is assumed to be equivalent to the hydraulic head of the water table, and that depressurisation is conservatively estimated to reduce the reservoir water pressure to in the order of 5-10% of the initial pressure over the thickness of the seam. It is unlikely, however, that any particular coal seam would actually be *dewatered*, as opposed to depressurised. That is, depressurisation of the whole vertical extent of the seam does not take place and thus the water pressure in the fractures and pores is not reduced to zero; and

- Depressurisation is assumed to occur over a large aerial extent with the area of influence of each pumping well superimposed on that of the adjacent well. For the purposes of this discussion, the aerial extent of maximum depressurisation has conservatively been assumed to apply to the entire coal seam within the lease area boundaries, whereas in reality the maximum depressurisation values would be realised in the vicinity of the CSG production wells.

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 depressurisation is not great compared with the stiffness of the rock mass. However, for the depth of the coal seams viz., up to 1,400 m for the Arcadia and Fairview Fields and up to 960 m for the Roma Field, elastic settlement of a series of coal seams could occur in some circumstances. In certain circumstances, some amount of elastic settlement could then progress to the surface and result in surface subsidence.

As an indication of the amount of surface subsidence that could occur, the elastic response of the depressurised coal seams was estimated based on an assumed rock mass modulus of 2 GPa and total thickness of coal seams of 10 m for Arcadia and Fairview and 25 m for Roma. The calculated surface subsidence is:

- **Roma Field** – for an average depth to the coal seams of 480 m then calculated subsidence is 55 mm. For the maximum coal depth of 960 m, calculated subsidence is 115 mm; and
- **Arcadia and Fairview Fields** – for an average depth to the coal seams of 650 m then calculated subsidence is 30 mm. For the maximum coal depth of 1,400 m, calculated subsidence is 70 mm.

The impact this amount of elastic subsurface subsidence may have on the overlying rock formations was not assessed. Specifically, will this subsidence result in additional fracturing or opening of existing fractures in the overburden and thus increase the rock mass permeability? If fracturing occurred in aquitards, then there is the risk of increased leakage between aquifers. However, given the calculated subsidence above, this risk is very low.

Monitoring will be carried out, particularly during depressurisation of the coal seams, to verify the above assumptions and the assessed risk. Such a monitoring program will include measurement of water pressure in aquifers in the coal overburden.

Water quality changes

In general, groundwater quality becomes more saline within the GAB aquifer formations with distance from the recharge zone, as increased groundwater residence time and water-rock interactions result in dissolution of soluble minerals from the aquifer matrix (refer to Section 4.4.8 for further details). Induced leakage of groundwater from aquifers in close stratigraphic succession to depressurised coal seams results in the development of a depressurised zone within the local aquifers. This results in two processes that can potentially induce water quality changes within the affected aquifers:

- As a local depressurised zone develops, the induced hydraulic gradients within the affected aquifer result in horizontal groundwater flow from within the radius of influence of the depressurised zone. Water quality may be impacted if the radius of influence of the depressurised zone extends to areas of lower quality groundwater within the affected aquifer (such as areas further down flow path from recharge zones); and
- The development of a local depressurised zone in an affected aquifer can also propagate vertically to adjacent overlying or underlying formations and induce vertical leakage of potentially lower quality groundwater between formations. The extent to which the depressurisation effects are transmitted through a stratigraphic succession is dependent on the relative hydraulic properties of the formations within the succession, or the presence of structural features that may act as preferential vertical flow paths between formations. For the CSG field area, the preliminary modelling results indicated that vertical propagation of depressurisation effects were generally limited to formations in close stratigraphic succession to the depressurised coal seams, and were not transmitted through multiple formations (Matrixplus, 2009).

The net result of both processes can lead to a decline in groundwater quality over time where the necessary conditions exist. Whereas this phenomenon has been observed in many areas of intensive groundwater abstraction from near surface aquifers, the considering the expected vertical gradient between aquifers and the similarity in water quality between those aquifers, changes in water quality owing to these processes are not expected in this regional setting.

It should also be noted that in contrast to intensive groundwater abstraction from aquifers with good quality water, which is typical of most human consumptive groundwater uses, the CSG operations extract water from what are arguably the lowest quality formations in the hydro-stratigraphic sequence. Hence, the risk of induced groundwater quality degradation in adjacent good quality aquifers is lower than for traditional intensive groundwater use scenarios.

Reduction in recharge

The CSG fields of the GLNG Project area are sited within the intake beds of the GAB aquifers, defined as the areas where the relevant GAB aquifers outcrop. Given the overall structure of the GAB, the intake beds are predominantly located along the margins of the basin, and the water that infiltrates into the GAB aquifer formations may eventually migrate for tens to hundreds of thousands of years along regional groundwater flow paths. Recharge at the intake beds not only maintains the storage volumes within the aquifers, but also provides the hydraulic head that maintains the confined water pressure head (and which also sustain local and regional artesian flow conditions) further down flow path in the aquifer and deeper into the GAB.

The discussion of potential reduction to recharge for the affected GAB aquifers requires consideration of two similar but slightly different concepts:

- In a local perspective, the ability for rainfall on the outcropping GAB intake beds to infiltrate down to the 'water table' in the unconfined portion of the GAB aquifer formations; and
- In a regional perspective, the ability for recent recharge to the GAB aquifers to eventually migrate along the regional groundwater flow paths to replenish storage volumes and to provide the hydraulic head to maintain the hydrostatic pressures within the confined portions of the aquifer.

Induced leakage of groundwater from water supply aquifers during CSG operations would not affect the ability of rainfall to infiltrate to the water table in the affected aquifers; in fact conceptually it could even enhance rainfall infiltration by promoting deep drainage of infiltrating recharge water and reducing the potential for recharge rejection by fully saturated formations.

Groundwater modelling by Matrixplus (2009) has predicted that induced leakage related to CSG operations would result in a local zone of depressurisation in adjacent GAB aquifers (the Precipice Sandstone was predicted to be the most affected) as water is released from storage and transferred to the depressurised coal measures. The net result is local interference of recharging groundwater close to the intake beds, which would persist for the duration of the CSG operations and beyond, due to delayed leakage and slow hydraulic equilibration rates in the relatively low permeability formations (according to estimates reported by Matrixplus (2009), the time required for 80% recovery of the water levels in the Precipice Sandstone should be approximately twice the life of the fields).

Hence, CSG operations should not reduce the volume of rainfall recharge infiltrating into the intake beds of the affected GAB aquifers, but modelling predictions suggest that a certain volume of recently recharged water will be intercepted immediately south of the intake beds. Significantly, the modelled extent of depressurisation within the Precipice Sandstone did not extend to the outcrop areas to the north of the CSG fields, where springs are reported to be present (Habermehl, 1980; Radke et al., 2000).

Loss of baseflow (including 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 the surface water ecosystems. For this issue to occur, inter-aquifer transfer 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 transfer are likely to be limited to the aquifers in close stratigraphic succession to the depressurised coal measures, and the shallow groundwater resources and surface water features were unlikely to be affected (Matrixplus, 2009).

Induced gas flows

An unusual and potentially adverse effect of coal seam depressurisation is the incidental production of CSG in water supply bores screened within the depressurised coal measures targeted by CSG operations or nearby in the stratigraphic sequence; similar cases have been reported near CSG operations in North America. Within the CSG fields of the GLNG Project area, the groundwater quality associated with the coal seams precludes most domestic and many primary industry uses; hence very few private bores are completed within these formations.

Although this issue is considered to be very unlikely, routine monitoring of private bores in the vicinity of CSG operations will include monitoring for incidental CSG production and fugitive methane emissions.

8.3.3 Environmental Values Affected

The potential impacts associated with coal seam depressurisation would primarily affect human consumptive uses of groundwater, including drinking water supply, stock watering, irrigation, and potentially industrial uses. The principal concern would be diminished access to the groundwater resource for wells completed within the affected aquifers.

In the event that the effects of depressurisation were projected to the shallow 'water table' aquifers, then the EVs associated with surface water features, including aquatic ecosystems and recreational and aesthetic amenity could be affected. However, the results of the numerical modelling (Section 6.0) suggest that this issue has a low probability of occurring.

8.3.4 Potential Risks to Environmental Values

With reference to the risk assessment discussed in Section 7.0, the potential risk issues associated with this water management activity were rated as Category 1 to 4 risks (low to high). Risks related to coal seam depressurisation were rated separately for each CSG field; in each case the potential consequence was considered to be the same, but the likelihood varied based on the current state of development in each field. Table 22 provides a breakdown by field of the risk rankings for the potential impacts associated with coal seam depressurisation; a detailed discussion of each potential impact is provided in the following sections.

The general trend between the CSG fields is a decrease in risk ranking relative to the current level of CSG development in each field. The two minor exceptions include a marginally greater perceived likelihood of water quality changes and induced gas flows in non-CSG wells in the Roma field relative to Fairview; this discrepancy is attributable to physical differences in the coal measures targeted in each field (Walloon Coal Measures in the Roma field, versus the Bandanna Formation in the Fairview and Arcadia fields). The greatest perceived risks are related to the potential for reduced access to groundwater resources, and the potential for reduced baseflow to rivers, streams and springs, as a result of CSG activities in the Fairview field.

Table 21: Risk Categories for Potential Impacts Related to Coal Seam Depressurisation

Potential Impacts	Fairview	Roma	Arcadia
Loss of available drawdown in bores	4	2	1
Loss of artesian flow	4	2	1
Subsidence	2	2	2
Water quality changes	1	2	1
Reduction in recharge	2	1	1
Loss of baseflow (including non-mound springs)	3	1	1
Impacts on mound springs	1	1	1
Gas flows	1	2	1

8.4 Gathering Systems

Gathering systems comprise the pipelines and associated infrastructure used to transport AW from CSG production bores. Depending on the specific AW 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.

8.4.1 Associated Risk Issues

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

8.4.2 Discussion of Potential Impacts

An uncontrolled release of AW from a gathering system could potentially impact shallow groundwater quality, depending on the size and location of the release, the nature of the soils, and the relative quality of the AW compared to shallow groundwater quality. Related environmental impacts could include surface water contamination, soil contamination, and soil erosion.

The impacts of the construction and the use of this infrastructure has been assessed in Section 6 of the EIS and the EIS Supplement.

8.4.3 Environmental Values Affected

The EVs that would potentially be affected by an uncontrolled release from an AW gathering system are generally those that are associated with shallow groundwater systems. Potential contamination of a groundwater resource supporting municipal supply or primary industry uses would be the main 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, either through direct overland runoff of AW into a surface water body or via infiltration into shallow groundwater and subsequent discharge of a contaminant plume into a surface water body.

8.4.4 Potential Risks to Environmental Values

With reference to the risk assessment discussed in Section 7.0, the potential risk issues associated with this water management activity were rated as Category 1 to 3 risks. The potential for contamination of surface water and shallow groundwater as a result of a ruptured pipeline was considered to represent a moderate consequence (consequence level III) with a ‘possible’ likelihood of occurring, resulting in Category 3 risk ranking. The potential risks related to leaks from various parts of a gathering network were considered to be Category 1 risks because of the small volumes of AW that would be released.

8.5 Water Storages

Water storage structures (ponds and dams) are integral components of the CSG infrastructure supporting extraction activities. The principal use of ponds and dams is for temporary or permanent management of AW generated during CSG production. Other uses include storage of treated effluent from the STPs servicing field camps, storage of permeate and brine from RO water treatment facilities, and storage of oily water associated with compressor stations.

8.5.1 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 a catastrophic failure of the embankment. This would cause seepage into the groundwater aquifers and discharge to surface water courses.

8.5.2 Discussion of Potential Impacts

An uncontrolled discharge from a CSG pond or dam would have a reasonable chance of impacting shallow groundwater quality, 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 a degradation of surface water quality, erosion, overland flow of released water into surface water bodies, and even flood and property damage depending on the nature of the release.

8.5.3 Environmental Values 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.

8.5.4 Potential Risks to Environmental Values

With reference to the risk assessment discussed in Section 7.0, the potential risk issues associated with this water management activity were rated as Category 1 to 3 risks (least to worst). Risks related to water storage were rated separately for the various types of water that might be stored: AW, oily water, permeate and brine (the last two related to RO treatment of associated water). In general the likelihood of the potential impacts was considered to be the same, whilst the consequences varied depending on the contaminating potential of the different water types. Of the various scenarios considered, the highest risk rankings (Category 3) were related to a potential dam break for a dam containing either oily water or brine (considered to have the greatest contaminating potential).

8.6 Project Infrastructure

In addition to water gathering and storage systems, CSG operations are supported by a range of additional infrastructure, including road networks, accommodation and related amenities for employees (including sewage treatment plants (STPs) for sewage and grey water treatment), operations and maintenance facilities, and CSG processing plants. The camp facilities servicing CSG operations in the Fairview Field (Fairview and Springwater camps) support in the order of 100 staff each, and generate sewage and grey water from showers, toilet blocks and kitchen facilities. This waste stream undergoes preliminary on-site treatment in an STP, and is then trucked off-site to the Injune Water Treatment Plant or alternative licensed disposal facilities.

The CSG processing plants generally consist of inlet separation, gas compression and dehydration units (URS, May 2008). Wastewater streams generated include oily washdown water, cooling tower water, and glycol-contaminated water from triethylene-glycol (TEG) units used to remove water vapour from the gas stream:

- Cooling tower water and condensate from the inlet separator are relatively clean, are of low TDS, and are discharged to grade;
- Oily washdown water is currently managed using a temporary evaporation pond, but treatment using reed beds and off-site disposal are being evaluated for future operations; and
- 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.

8.6.1 Associated Risk Issues

The groundwater risks related to 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.

8.6.2 Discussion of Potential Impacts

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

8.6.3 Environmental Values Affected

Whilst there is a potential for impacts to shallow groundwater quality associated with a wastewater release, the supporting project infrastructure is generally located remotely from the EVs within the CSG Fields. One exception is a water supply well located within the Fairview camp that provides water supply for domestic (non-potable) purposes, which is located in close proximity to the STP for the camp. It is considered that this is the only EV that is realistically at risk from potential releases from project infrastructure.

8.6.4 Potential Risks to Environmental Values

With reference to the risk assessment discussed in Section 7.0, the potential risk issues associated with this water management activity were rated as Category 1 to 2 risks. In all cases, either the likelihood or consequence related to various uncontrolled release scenarios was considered to be low, based on the control measures in place for managing each of the waste streams, or the relatively minor volumes or innocuous nature of certain waste streams, or the physical distance from the nearest sensitive receptor.

8.7 Associated Water Management – Dust Suppression, Surface Water and Re-injection

The Queensland Government released a new policy in late 2008 regarding the preferred management options for associated water, in which beneficial reuse and re-injection schemes are supported in favour of the traditional use of evaporation ponds. In line with this policy, Santos has commissioned a range of AW reuse studies to evaluate options for beneficial uses for AW management within the GLNG project area.

- Details of the Santos AWMPs are included in Appendix Q of the EIS and more detailed AWMP included in Attachment D3 in the EIS Supplement.

The following sub-sections relate to the risks and impacts associated with:

- Discharge to surface water (for desalinated water only),
- Dust suppression,
- Re-injection into deep aquifers.

A separate section is dedicated to impacts associated with irrigation.

The primary risk associated with beneficial use and/or disposal of AW under the remaining headings is therefore the potential for water quality impacts to surface water and groundwater receiving bodies.

Further but less significant risks include:

- Variability in the volume and quality of water provided for municipal supply and industrial applications; and,
- Potential for land or soil degradation.

8.7.1 Discussion of Potential Impacts

The potential impacts related to these AW beneficial uses and/or disposal include:

- Contamination of soil, shallow groundwater and surface water bodies from discharge to grade;
- Erosion and sediment transport from discharge to grade locations and from dust suppression activities;
- Potential water quality impacts to deeper GAB groundwater supply aquifers from AW re-injection, if the re-injection wells aren't designed and constructed properly or if water chemistry differences between the injected and receiving groundwater were to cause loss of permeability in the receiving aquifer;
- Impacts to soil structure from irrigation of sodium and bicarbonate-rich associated water; and

- Impacts to municipal supply or industrial applications resulting from inconsistent water supply or variable quality.

8.7.2 Environmental Values Affected

Dust Suppression

Dust suppression provides a beneficial use of AW, whilst being a mitigation measure for the generation of dust, which could potentially be an environmental and health and safety concern.

The application of AW to unsealed roads, road maintenance, construction activities and rig shifts, has the potential to:

- Accumulate salt on the unsealed road surface and potential for salt to impact the surrounding environment via runoff or dust;
- Change the physical properties of the unsealed road surface, with potential for roads to become slippery when wet; and
- Increase dust generation, if AW significantly alters soil particle sizes on the unsealed road surface.

These impacts are considered to be relatively minor and will be managed by a Dust Management Strategy.

Discharge to Surface Water

Aquatic ecosystems associated with creeks and rivers may be affected through discharge to surface water operations, although the results of ongoing river health assessments of the Dawson River in the Fairview Field suggest that increases in median river salinity values downstream from discharge to grade locations are mitigated by spring discharge further downstream.

SANTOS TOGA Pty Ltd (2009) provides further detail on the adopted water management approaches for Fairview, Arcadia Valley and Roma , their assessed impacts and mitigation approaches.

Arising from these studies it is now considered that:

- discharge to the a location well downstream of the Fairview CSG field (Yebna Crossing), could be performed in an environmentally acceptable manner;
- although discharge to Lake Campbell (a man made lake) and Bungil Creek for the Roma CSG fields is considered a measure of last resort (contingency measure only), such a discharge might be managed in an environmentally acceptable manner; and
- although discharge to Lake Nuga Nuga in the Arcadia Valley is considered a measure of last resort (contingency measure only), such a discharge might be managed in an environmentally acceptable manner.

Specific to the potential for discharge of treated water to surface water, the following matters will need to be managed :

- the salinity of desalinated water may not be consistent with relevant water quality guidelines and minimum target values;
- the potential for the degradation of streambed soils if Sodium Adsorption Ratios are not similar to that proposed for irrigation;
- the potential for artificial signalling of instream species behaviours and shift in species composition (e.g. to algae) if the temperature of the water discharged is not as similar as possible to ambient water temperatures;

- a potential reduction in in-stream water quality if dissolved oxygen levels of the desalinated water are not at least as high as those measured in stream (>5 mg/L) ; and,
- the potential for erosion at any discharge point.

Re-injection of Brines or Desalinated Water

Santos proposes that where they are permitted to do so, brine from the desalination plants it will operate will be injected back into the spent coal seams or other deep aquifers that are similarly of negligible potential for beneficial use to the local community or future groundwater users. Further, Santos proposes to reinject some desalinated water into the Gubberamunda Aquifer that supplies the Roma Town Water Supply.

Potential water quality impacts to deeper GAB groundwater supply aquifers from brine or desalinated re-injection could occur, for example:

- Contamination of valuable aquifers; or
- Loss of productivity of aquifers.

Such impacts would occur if one or more the following causes were to arise:

- Poor target aquifer selection;
- The re-injection wells aren't designed and constructed properly;
- Geochemical issues were to arise.

No impacts to the environment are expected from such a proposal, however, since the water will only be injected to aquifers that are demonstrated to be isolated from aquifers of beneficial use to the community or connected in any way to the shallow groundwater and surface water system. Santos will perform detailed injection well design studies in conjunction with pilot project testing to avoid any well design issues.

Finally on this issue, studies have been completed into the appropriate selection of target aquifers for injection, considering these issues.

Municipal and Industrial Supply

By the use of treated AW the impacts on the environment of these types of uses are expected to be low or negligible. The water quality standards (to drinking or industrial standards) will be met before the water is supplied.

The most significant impact will be in the variability of supply. If water supply to these end uses were to be variable once the user(s) had established dependency on them, this would result in potential financial loss or failure of any business relying on the water. The impacts are expected to be low to insignificant however, owing to the fact that treated water supplied to municipal and/or industrial supply would not be a substitute supply but a supplementary supply.

8.7.3 Potential Risks to Environmental Values

With reference to the risk assessment discussed in Section 7.0, the potential risk issues associated with this water management activity were rated as Category 1 to 3 risks. The potential for changes to water quality or flow regimes of surface water features based on discharge of treated water, as well as the potential for under- or oversupply of treated water for municipal or industrial users were considered to represent a minor consequence (consequence level II), but were considered 'likely' to occur, resulting in Category 3 risk rankings for these issues. The risks to surface water quality or flow regimes will be addressed within the WMS for the GLNG Project, whilst risks regarding consistency of supply for beneficial reuse will need to be evaluated further as the CSG development program progresses.

The potential risks related to other AW management options were considered to be Category 1 to 2 risks. It is noted that the potential risks associated with re-injection of treated AW and/or brine have not been included in this risk assessment; these issues require further attention pending technical evaluation of this management option.

8.8 Associated Water Management - Irrigation and Land Management Practices Impacts

Forest Plantation and Forages

The Fairview Irrigation Project as approved will cover 2000 ha of amended CSG water, drip irrigated forest plantation using amended AW, and 234 ha of centre pivot irrigated forages using desalinated CSG water.

Supply to Landholders

Santos also proposes to provide interested local landholders with either amended AW and/or desalinated AW as agreed with the landholder.

The potential impacts arising from poorly designed or managed irrigation practices, using either desalinated water or amended water, include the following:

- Soil Impacts leading to loss of productivity:
  - Loss of soil structure:
  - Salinisation of soil;
  - Soil water logging
  - Perched water tables
- Land degradation impacts:
  - Erosion
  - Weed introduction or uncontrolled spread
- Impacts on Surface Water or Groundwater:
  - Transport of salt to the water table
  - Rise of the water table
  - Transport of salt to surface water

The following discussion provides more detail on the more impacts that are considered more likely (without mitigation) for the GLNG project.

Whereas long-term irrigation with untreated CSG water would likely lead to soil structural decline through increased soil salinity leading to soil dispersion, loss of hydraulic conductivity, reduced infiltration and increased surface run-off, irrigation with amended CSG water as well as application of gypsum along drip irrigated tree lines, management practices which substantially increase surface soil organic matter compared with baseline values and irrigation application rate and frequency will ensure surface and sub-soil structure is sustained or improved.

Irrigation with desalinated water, is unlikely to impact the soil *quality*, however the potential impacts of water logging and water table impacts could still eventuate if irrigation management protocols were not developed and rigorously maintained.

Soil surface run-off in irrigated forest soils will be less than for unirrigated soils owing to the infiltration promotion of deep ripping and rough surfaces along tree planting lines.

Soil erosion in irrigated forest plantation areas will be less than for previous unirrigated grasslands. This is due to reduced run-off and removal of areas of concentrated grazing. Soil erosion on irrigated forage areas will be no different to current erosion on unirrigated buffel dominant pastures.

Sub-surface, lateral movement of soil water for irrigated tree plantation or irrigation forage areas (both surrounded by non-irrigated tree and grassland buffers), will be minimal.

The run-off and sub-surface lateral water movement strategies described above will ensure the flow and water quality attributes of ephemeral streams remain within 10% of long-term baseline values.

The physical separation of irrigated plateaus from the Precipice Sandstone by 136 to 175m of low vertical conductivity aquitards will ensure nil impact of CSG derived salts on groundwater. Seepage modelling indicates only a narrow band of sub root zone stratigraphies will be impacted by the vertical movement of CSG derived and native salts. Perennial streams and springs would only be impacted via ephemeral streams and this pathway will be managed within prescribed limits.

8.9 Summary of Potential Impacts

The discussion of potential impacts to EVs within each of the three CSG fields in the GLNG Project area is summarised in Table 22. An attempt was made to correlate the results of the risk assessment for the operational activities in each Field to the potentially affected EVs. In some cases multiple potential impacts with different risk ratings were relevant to a single EV. In these instances the highest risk rating was generally adopted for conservatism, however lower risk rankings were judgementally applied in cases where a given EV was deemed to be less relevant within a certain Field. Hence the summary of potential impacts in Table 22 should represent a reasonable worst case scenario.

Table 22: Summary of Potential Risks to Environmental Values

Field	Operational Area	Aquatic Ecosystems	Primary Industry	Drinking Water	Industrial	Recreation & Aesthetics
Roma	Drilling and well installation	NR	2	2	1	NR
	Coal seam depressurisation	1	2	2	2	2
	Gathering Systems	3	3	3	2	2
	Water storage	3	3	3	2	2
	Project infrastructure	NR	2	2	1	NR
	Associated water management	3	2	2	1	3
Fairview	Drilling and well installation	NR	2	2	1	NR
	Coal seam depressurisation	3	4	4	3	3
	Gathering Systems	3	3	3	2	2
	Water storage	3	3	3	2	2
	Project infrastructure	NR	2	2	1	NR
	Associated water management	3	2	2	1	3
Arcadia	Drilling and well installation	NR	2	2	1	NR
	Coal seam depressurisation	1	1	1	1	1
	Gathering Systems	2	3	3	2	2
	Water storage	2	3	3	2	1
	Project infrastructure	NR	1	1	1	NR
	Associated water management	3	2	2	1	3

Notes:

NR = Environmental value not considered to be relevant based on the nature of the operational activity or the specific conditions of the CSG field.

9.0 IMPACT MITIGATION AND MANAGEMENT

The principal issues of concern with respect to potential risks to groundwater quality arising from CSG activities have been identified as reduced access to groundwater resources supplying stock, domestic and other licensed uses, and potential impacts to groundwater quality (especially to shallow groundwater resources) associated with an uncontrolled release of poor quality water.

These issues are also amongst the primary concerns of local bore owners and the regulators (eg. DERM). To address these high priority concerns, Santos has adopted a combination of preventative actions and “make good” options to reduce the likelihood of adverse impacts occurring, or to assist those affected if impacts to environmental values of the groundwater resource do arise as a result of CSG operations.

The following sections cover the mitigating engineering and management measures that Santos is applying to manage the potential impacts.

9.1 Engineering and Design

9.1.1 Bore Construction

A representative selection of production well installation records for wells drilled and constructed by Santos within the Roma and Fairview CSG fields was examined to assess whether they were consistent with the objectives of the DERM requirements for licensed well drillers to perform this work, specifically with respect to prevention of inter-aquifer leakage.

A generic schematic of the endorsed drilling and well construction method for minimising inter-aquifer connectivity is presented in Figure 50 (NSW Department of Water and Energy [DWE], 2002) and summarised as follows:

- A large diameter borehole is advanced through the overburden formations overlying the interval of interest. Depending on the target drilling depth and the nature of the overlying formations, this may be achieved using a single-diameter borehole through the entire overburden sequence, or through a staged sequence of progressively smaller diameter “telescoped” boreholes;
- Blank casing is installed and sealed in the borehole by injecting a cement-based slurry under pressure through the centre of the casing, which displaces the drilling fluids in the borehole and acts as a tremie for the cement slurry to seal the borehole annulus. The majority of the cement slurry column inside the casing is then displaced with water, providing a more reliable annular seal, and is left to set;
- The final, and smallest-diameter section of the borehole is then drilled or cored through the cement plug and the lithologic interval of interest. Depending on the lithology of the target interval, this can either be left as an open hole completion, well screen can be installed, or the hole can be abandoned by pressure grouting the entire borehole to ground level. For boreholes completed as wells for ongoing service, a fit-for-purpose wellhead completion must also be considered.

From a review of selected Santos production well completion records, it is concluded that although the drillers are not licensed under the DERM Water Well drillers licensing programme, it was evident that pressure cementing techniques had been adopted for casing off of overburden formations, and the completions were considered to be as a minimum consistent with good industry practice as set out in the *Minimum Construction Requirements for Water Bores in Australia, Ed.2, Revised Sept 2003* (Land and Water Biodiversity Committee, 2003), and as prescribed in DERM’s *Water Act 2000 - Water Bore Drillers’ Licensing Handbook*. Santos has indicated that these drilling methods are uniformly applied to all of their drilling locations, and should therefore minimise the potential for impacts to groundwater resources through CSG drilling activities.

As a further safeguard to assess the potential for leakage through the borehole annulus, multi-level piezometers will be installed adjacent to CSG production wells, with monitoring points in key formations above the target coal seams. The pattern and rate of pressure change observed in the overlying formations would provide a clear indicator of potential short-circuiting through the annulus of the production well boreholes, such that the issue could be appropriately managed in a timely manner.

Finally, upon completion of their service life the CSG production wells (and any other Santos wells that are no longer required), will be decommissioned by pressure grouting in 200 m lifts, with the headworks removed to approximately 2 m below ground level, and the ground surface reinstated to an appropriate condition. This provides for appropriate stewardship of the potential long-term risk of borehole degradation over time, which is so prevalent amongst old GAB bores that have never been reconditioned or appropriately decommissioned.

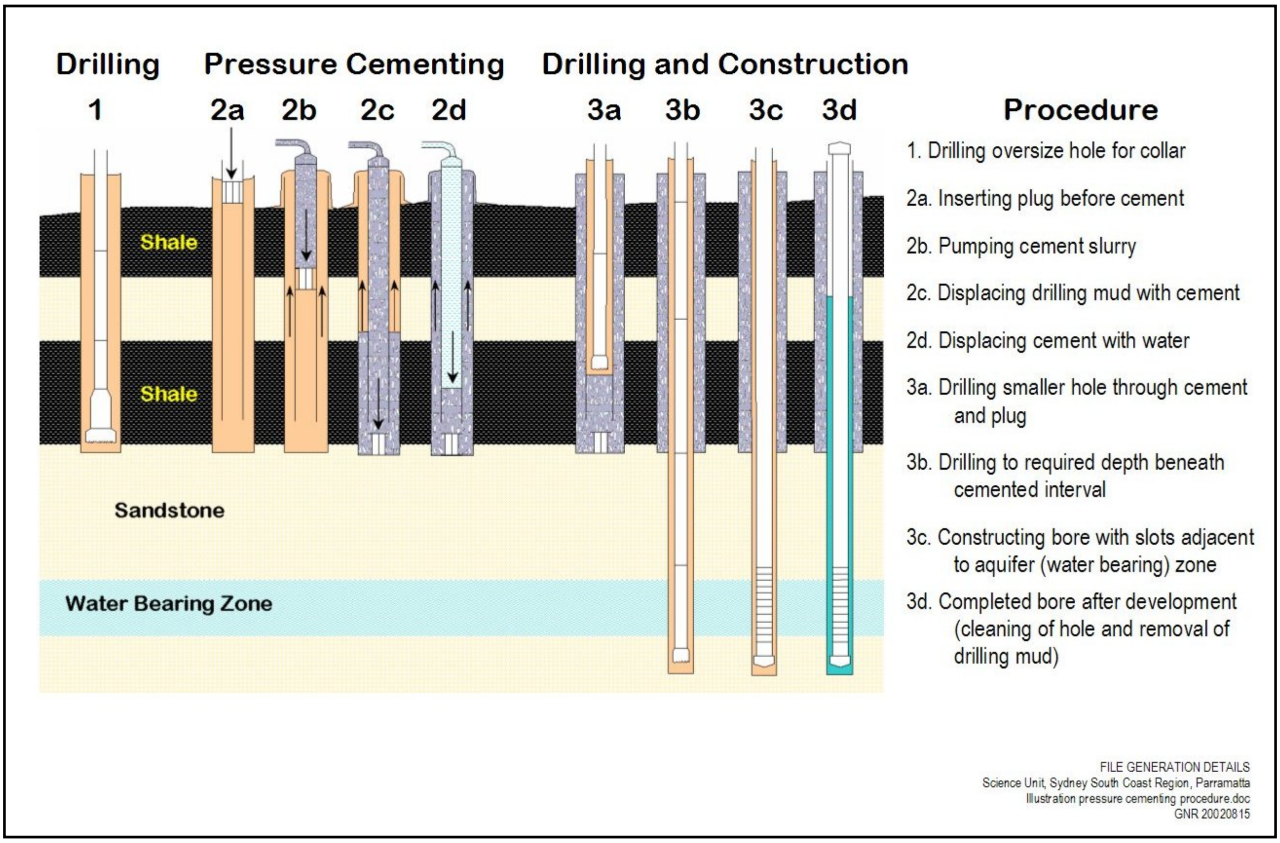

Figure 50: Conceptual Diagram of Pressure Cementing Technique for Borehole Completion (DWE, 2002)

9.1.2 Pond and Dam Construction

Storage of potentially poor quality water in ponds and dams is a necessary component of CSG operations. Poor quality water types would generally include saline AW extracted from CSG production bores, oily water generally associated with compressor stations, and brine from reverse osmosis water treatment plants.

The potential for uncontrolled releases of poor quality water from ponds and dams, either through catastrophic failures (dam breaks) or diffuse seepage through the walls or base of ponds and dams, represents a potential quality risk to receiving surface waters and shallow groundwater. To address this issue, Santos has adopted a number of safety features into the design criteria for new water storage structures to reduce the potential for uncontrolled releases. Using the recently designed Raslie Dam in the Roma CSG field (URS, January 2009) as an example, the safety features incorporated into the dam design include:

- A preliminary geotechnical investigation of the proposed siting to verify that the soil engineering properties are appropriate;

- Design and construction in accordance with regulatory requirements to limit seepage and potential contamination of soil profiles and shallow groundwater;
- Erosion control on the embankments through the use of seeded topsoil covered by an erosional control blanket;
- The dam is sized to safely accommodate the wet season rainfall within its footprint, while maintaining sufficient free board to reduce the chances of overtopping; and
- A spillway designed to accommodate a controlled release of stored water in the event of a catastrophic (1 in 2000 year) flood event, such that the overall integrity of the dam is not compromised.

In addition, shallow groundwater monitoring wells will be installed up and down hydraulic gradient from any water storage features associated with CSG activities to facilitate monitoring of potential changes to groundwater quality or rising water table that could indicate a release from the pond or dam. Application of these features to any new ponds or dams, and retrofitting of existing unlined dams with liner systems, should significantly decrease the likelihood of uncontrolled releases, hence providing a safeguard against impacts to shallow groundwater quality.

9.1.3 Irrigation Water Management

Santos has developed and is applying an irrigation management plan. Santos currently has an approved Resource Utilisation Plan covering 2000 ha of Chinchilla White Gum and 234 ha of irrigated forage crops. The approval requires exhaustive environmental monitoring which as a minimum will be emulated for all subsequent irrigation projects.

The Irrigation Plan includes the following key irrigation risk management practices:

- All irrigation projects and their Beneficial Use Approvals, including the initial Pilot Fairview Irrigation Project, are under-pinned by technically rigorous Resource Utilisation Plans;
- A Technical Steering Committee including 3rd party independent members has been assembled and meets on a monthly basis to assess the results of the irrigation monitoring programme, re-direct and/or improve the irrigation practices as appropriate and provide input to developing irrigation planning for new areas;
- AW treatment and irrigation management frameworks have been developed which:
  - specify treatment of AW to specific target composition combined with and specified application rates to the differing soil and forest, forage or other crop situations over specific time frames;
  - Specify, monitor and manage the:
    - sodium / calcium / magnesium balances and organic matter in soils;
    - bicarbonate concentration of irrigation waters;

    to sustain or improve soil structural and chemical integrity such that irrigation has no impact on future, locally relevant land use options
- Intensive monitoring of:
  - irrigated soil zone;
  - non-irrigated buffer area;
  - below irrigated root zone water seepage; and,

- local ephemeral and perennial streams and springs;
- for both Santos owned irrigation projects and those where water is to be provided to landholders who have been provided treated water by Santos.

- Santos and landholder groundwater monitoring programs will ensure continuous assessment of Santos/landholder/community stakeholder agreed key environmental and other irrigation project performance indicators. Any movement of any environmental performance indicator outside its normal range but within DERM defined limits will trigger adaptive management action.

Specifically, the following management practices have already been developed and applied by Santos, in the initial irrigation area at its Fairview CSG Field.

- Forest plantations and forage areas are only located on slopes of 4 degrees or less (thus preventing significant runoff or soil water flow);
- Buffer zones of nominally 200 m for forage areas (to manage runoff, subsurface migration and weed migration) and 50 m for forest plantations (to manage runoff and subsurface migration);
- Irrigation rates are maintained to ensure that total annual water ingress (including rainfall) for forest remains within 40% or less of annual evapo-transpiration and for forage within 75%;
- Accumulated salt is continuously monitored and will be maintained over the life of the project to less than 50% of the production limiting salt load;
- Management, informed by monitoring will ensure that:
  - SAR of soil solutes remain below 30; and,
  - Exchangeable Sodium Percentages remain below 30%.

9.1.4 Management of Variability in Supply of Associated Water

With respect to the risks presented from the variability in the supply of treated water, the following strategies will be applied:

- Water sent to industrial use or municipal supply will only ever be offered as a supplementary supply, or short term replacement. For example, for sending water to Roma for municipal use, the water would be connected to the raw water delivery system and the availability of treated AW would result in the reduction of use the town water supply bores. No direct supply to the town water supply network is contemplated. Accordingly, industrial supply, which comes from the town reticulation, would not experience any interruption or change in supply.
- A further risk treatment is to use aquifer re-injection to recharge the local aquifers from which Roma draws its municipal and industrial supplies. This would provide an extra barrier for public health protection and also a buffering capacity for supply into the Town water supply.
- With respect to variation in water supply availability for irrigation projects, buffer storages built into the gathering system will provide short to medium term water balance protection. In the longer term. Other risk management measures relating to the change in availability in water supply for irrigation over the life of the project are covered in the irrigation risk management sections of this report.

9.1.5 Re-injection of Brine or Permeate

Any injection wells constructed for the project will be constructed to a design that as a minimum meets the requirements of:

- Santos own best-practice bore construction specifications, as described in the section on Bore Construction above;

- Peer review by senior technical experts in bore construction in DERM.

Bore construction represents a low risk to the successful implementation of such an options however and the following further measures will also be implemented to ensure protection of the EVs listed in the previous sections:

- Water chemistry studies to assess the potential impacts and mitigating strategies relating to geochemical reactions caused by the mingling of injected and receiving waters. Initial studies have been completed already (SANTOS TOGA Pty Ltd., 2009) and indicate that:
  - With respect to potential re-injection of permeate to the water supply aquifers supplying Roma town, this should probably only occur to the Gubberamunda Aquifer and not the Mooga Sandstone.
  - With respect to injection brine to either coal or other deeper aquifers, injection to spent coal seams will be acceptable from a geochemical viewpoint, but there is potential for minor long term loss of near-bore permeability from geochemical interactions for injection to the Timbury Hills formation, This later impact will be studied further including continuation of detailed monitoring already underway (see below). If such impacts become an issue, brine re-injection can be diverted to the coal seams if that if the option that is pursued for brine disposal.

Santos has developed a detailed Water Monitoring Strategy (see below) that covers all aspects of the water cycle, facilities monitoring and performance and sustainability monitoring. This strategy includes a detailed specification for monitoring of water chemistry and injection well performance that will be applied to continuously monitor the performance and impacts of brine and/or permeate re-injection.

9.1.6 Discharge of Treated Water to Surface Water

Santos has performed studies into the viability of discharge of treated water to surface water. Where this is developed further (as seems likely for the option to discharge water for industrial via the Dawson River), the following risk mitigation measures will be employed in the engineering design and operation of the discharge facilities:

- Discharge facilities will be designed according to best practice measures including:
  - Low energy discharge structures (diffusers and other energy dissipating devices);
- Continuous monitoring of the water quality and river height above and below the discharge location and of the discharge prior to release, incorporated with:
  - Automation incorporated to the extent that discharge can be automatically ceased if the system is found to be operating out of specification;
  - Ability for operators to manually cease discharge operations via remote (for example mobile communications); and
  - Buffer storages located at the treatment facilities to manage the potential operational impacts of short to medium term cessation of the discharge to surface water.

Careful consideration of suitable locations for surface water discharge has also been undertaken. Studies to date have now confirmed the following:

- In the Roma region, no opportunities exist for sustainable discharge of water to surface water. Studies have indicated that:
  - Intermittent discharges for a few days should be contemplated on an emergency basis since there are examples of flows of various durations even during the dry season. Calculations suggest that between one and three weeks discharge may be able to be accommodated dependent on the stream and size of discharge planned. There would need to be significant negotiations with

regulators to achieve this approval but the information provided in this report provides a suitable basis to commence these negotiations.

- In order to minimise the footprint of such activities that the preferred option is Bungil Creek as it is the most heavily impacted by landuse and should be the target stream if this option is progressed.
- Accordingly, the only option that may be examined further in future (but is unlikely owing to the high level of demand for beneficial use water in this region) is the discharge of water surplus to needs to the Bungil Creek in emergency situations. In this case the above methodologies would be applied during design and application to manage and minimise environmental impacts;

- In the Fairview CSG Field, an opportunity exists to discharge nominally up to 20 ML/day to the Dawson River for supply to SunWater at the Glebe Weir. A site has been identified based on recently completed ecological studies (SANTOS TOGA Pty Ltd. (2009)). This is the Yebna Crossing site:
  - Discharging immediately downstream of Yebna Crossing (~200 – 300 m) has attractions as the site captures most (or all) of the upstream groundwater discharges into the bed of the river ensuring this site has permanent flows. The site is also well concealed to minimise visual impact; and avoids issues associated with the major road crossing as the stream gradient increases sharply as water moves into the downstream gorge country. The site is also beyond the known limit of springs.
  - Vegetation lies above pool water levels by at least 1 m up to 3 m in this area. This is well outside the range of interaction with any increased discharges.
  - Sites further downstream are in a gorge and would involved significant access issues as well as pump and pipe costs for no additional benefit.
  - This site should be given high priority as a potential discharge location. The recommended discharge point is 200m – 300m downstream of Yebna Crossing.
- In the Arcadia Valley, the last remaining potential discharge (of last resort for emergency situations) is to Lake Nuga Nuga. No other sites are intended to be used. The study conducted into the potential for discharge into Lake Nuga Nuga has concluded that:
  - Adding desalinated water to Lake Nuga Nuga has been evaluated at a preliminary level assuming very conservative assumptions of maximum field discharge and possibly a low estimate of storage capacity.
  - Changes in the hydrology of the lake are likely to be minimal with no shift in seasonality, discharge frequency or inundation of critical littoral zones at the edges of the lake.
  - A permanent pool circa 0.1m deep and 0.7 km2 surface area would arise from desalinated water discharge. This pool would act as refugia for fish and other species in drought periods. The pool would not encroach on private land.
  - Provided suitable measures are taken to control temperature, salinity and microbial activity discharge of desalinated water to Lake Nuga Nuga would result in a small environmental gain.
  - Limited investigation of Arcadia Creek indicates that this system is ephemeral and highly erosive. Discharge to the creek is not recommended.
  - Recreational use of the lake will be unaffected.
  - There will be minimal change to lake inundation levels and/or frequency.

9.2 Associated Water Management Plan

As discussed in Section 5.3, Santos has developed an AWMP to address the management challenges for AW derived from CSG production SANTOS TOGA Pty Ltd. (2009). This plan was developed through both a risk-based assessment process and in consultation with community stakeholders to identify a set of viable, preferred management options for AW generated in each CSG Field.

A risk-cost comparison tool was developed to compare the remaining options for water management including the community identified options. The key assessment criteria for the various management options included:

- There is a known and reasonable cost associated with the management option;
- The management option is based on a demonstrated technology;
- The management option is scalable; and
- The management option is achievable (can be permitted) within a timeframe compatible with the GLNG Project schedule.

In general, on-site reuse options and return of AW for beneficial use in surrounding communities (for both treated and untreated applications) were the preferred management options. For options requiring treatment of AW to render it suitable for a desired use, RO has been identified as the preferred technology for reducing the TDS. RO treatment enables a much broader range of beneficial reuse options, and is a proven technology for managing saline water.

Studies are ongoing to determine a suitable strategy for management of the resultant brine for the RO process. The brine will be stored in highly engineered containment ponds for the short term, with re-injection or solidification of the salts emerging as the most likely long-term management options.

9.3 Water Monitoring Plan

One of the principal defences against potential adverse impacts to groundwater resources associated with coal seam depressurisation is implementing 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 water 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.

A comprehensive Water Monitoring Plan (WMP) has been developed for the GLNG Project, which will act as a specification for establishing the specific water monitoring requirements for each element of project (gathering, ponds, treatment facilities, environmental assets). The WMP includes a detailed presentation of the rationale for groundwater and surface water monitoring, prescription of analytical suites and frequency and geographical spacing of monitoring.

The overarching objective of the WMP is to immediately provide a baseline characterisation of water quality and quantity across the Project area, continue monitoring as required to develop a thorough understanding of water trends, and to assess potential impacts to water quality or quantity arising from CSG activities.

The primary drivers for the monitoring program are:

- Legislative requirements;
- Requirements within the EAs and Beneficial Use (BU) Approvals;
- A risk-based monitoring approach developed by Santos to address CSG activities or infrastructure not specifically regulated elsewhere;
- Santos EHSMS Standards; and,

- Industry codes of practice and guidelines.

The monitoring programmes described in the field-specific WMPs will be implemented on behalf of Santos by a suitably qualified and experienced third-party contractor/consultant, who will analyse the data, interpret the results with regards to the water management objectives for the project, and prepare an annual report for submission to the regulatory authorities as proscribed in the legislative requirements.

The WMPs are considered living documents, subject to periodic review and revision on the basis of the results obtained. It is envisioned that the suitability of the WMPs will be independently reviewed on an annual basis at a minimum (likely in collaboration with annual monitoring data assessment and reporting requirements), and potentially more frequently where data requirements dictate, or as new CSG-related activities arise.

Table 23 presents a summary of the monitoring commitments that Santos has developed for GLNG.

Table 23: Monitoring Summary Table of Facilities and Environmental Assets

Environmental Asset	Sampling Point	Monitoring Suite	Frequency	Monitoring Driver
Regulated Dam	Water's Edge	WL/F	M	L
		SS	Q	
		BSW		
		FS		
		VI	A	
		CSGI	ET	
		HCS		
Hub and Nodal Compressor Stations	Inflow/outlet pipes	FS	As required or per operational specification	O,R,L
		BSW		
		SS		
		CSGI		
		HCS		
Non-Regulated Dam or Associated Water Collection Ponds	Water's Edge	WL/F	M	O,R,L
		BSW	Q	
		FS		
		CSGI	ET	
		HCS		
		VI	A	
Water Treatment Facilities	Inflow/outlet pipes	FS	As required or per operational specification	O,R,L
		BSW		
		CSGC		
		HCS		
		PW		

Environmental Asset	Sampling Point	Monitoring Suite	Frequency	Monitoring Driver
Irrigation Facility	Inflow/outlet pipes, water's edge of any dams, paddock	VI	M	EHSMS, EA, EMP
		WL/F	C	
		SM		
		GWP		
		FS		
		SS	Q	
		SC		
		BSW	M	
		CSGI	ET	
		HCS		
Low Point Drains	Outlet	HS	ET	EHSMS, EA, EMP
Sewage Treatment Plants	Outlet	STP	M	EHSMS, EA, EMP
		SC	A	
Landholder Supply (intended to sample water supplied to a landholder for a beneficial use)	Inflow/outlet pipes, water's edge of any dams, paddock	VS	M or as required for a specific suite	EHSMS, EA, EMP
		BSW		
		FS		
		WL/F		
		SM	Q or as required for a specific suite	
		SS		
		SC		
		CSGI		
		HCS		
Springs	Spring	BSW	A	EHSMS, EA, EMP
		WL/F	C	
		FS	C	
		WL/F	C	
		FS	C	
Rivers/Creeks/ Perennial/ Ephemeral Streams	River monitoring location	FS	C	EHSMS, EA, EMP
		VI	A/ET	
		BSW	M	
		CSGI	ET	
		WL/F	C	

Environmental Asset	Sampling Point	Monitoring Suite	Frequency	Monitoring Driver
Groundwater	Bore/well	FS,WP	BA/C	EHSMS, EA, EMP
		BSW	A	
		GW	BA	
Irrigation Area and Soils	Plantation areas (Trees, forage crops) and facilities	SM	C	EHSMS, EA, EMP,O
		SS	M	
		SC	A	

Table 24: Notes for Monitoring Summary Table (Table 23)

Monitoring Suite Notes	Frequency Notes	Driver Notes
FS - Field Suite	A - Annual	L- Legal
BSW - Base line Surface water (Surface Water Suite)	M - Monthly	R- Risk
GW - Groundwater suite	ET - Event Triggered	O - Operational
WP - Water Pressure	Q - Quarterly	EHSMS – Environmental Health and Safety Management system
HS - Hydrostatic Test	BA - Biannually	EA- Environmental Authority
STP - Sewage Treatment Plant	C - Continuous	EMP – Environmental Management Plan
WL/F - Water level Flow		
CSGI - CSG Indicator suite		
VI - Visual Inspection		OP - Optimisation
SC - Soil Core		
SS - Soil Solute		
SM - Soil Moisture		

9.4 Trigger Levels for Water Management Actions

9.4.1 Water Levels

As described in Section 2.1.11, the *P&G Act 2004*, Part 9, Division 3, Subdivision 1 (Sections 252 to 255), requires petroleum tenure holders to develop a “trigger threshold” for aquifers in the area affected by the exercise of underground water rights for a petroleum tenure. The trigger 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.

In accordance with guidance recently provided by DERM, Santos proposes to adopt the following starting position for trigger thresholds with respect to water levels for aquifers potentially affected by CSG activities:

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

In the event that a trigger threshold is exceeded, the following response actions would be undertaken:

- Identify specific bores affected;
- Repeat measurement to confirm extent of drawdown and available water column;
- Establish whether the trigger level exceedence has resulted in impairment of the affected bore's function such that it is unfit for its intended purpose;
- Establish the primary and secondary contributing factors to the decrease in water levels (eg. CSG activities, non-CSG groundwater extraction, sustained below average rainfall, etc); and
- If CSG activities are determined to be the principal or a significant contributing factor to the impairment of bore function, then the CSG operator and the bore owner/operator would negotiate to establish a suitable course of action (options are discussed in Section 9.5).

For this approach to be successfully implemented, it will be important for baseline water levels to be measured at all relevant bores during the initial bore inventory and subsequent routine monitoring, to provide a reference for assessing future water level changes.

With respect to the application of water level trigger thresholds, it is understood that the rights of CSG operators to continue to exercise their underground water rights under the *P&G Act 2004* would not be compromised. Instead, this framework is intended to create a clearly documented approach to understanding when make good provisions might be applicable.

9.4.2 Water Quality

The principal legislative driver in Queensland for maintenance of groundwater quality is the Environmental Protection Act 1994, which is administered by the 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 EAs 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 tier 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; and
- **Tier 2 trigger level:** A final trigger value representing the threshold at which some form of management action is required to mitigate the risks posed by the changes to water quality (options are discussed in Section 9.5).

A summary of the proposed trigger levels and associated actions is presented in Table 25. This approach to water quality assessment provides advanced warning of potential water quality issues, such that appropriate site-specific triggers for remedial or other options can be evaluated. This may include reference to published guideline values, or development of site-specific assessment criteria for key water quality parameters that are 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 include a detailed framework for deriving site-specific criteria based on the values being protected.

Table 25: 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 reanalyse 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, beyond which the water quality would be unfit for its intended purpose (likely to be direct reference to published water quality guidelines, but may include derivation of site-specific guidelines for key parameters) ■ Report to SANTOS management ■ Report to Regulators
Tier 2	To be determined as Tier 1 action	Evaluate and implement the appropriate management option(s) for the affected bore owners (refer to Section 9.5).

9.5 Options to Make Good

In the event that monitoring results and associated further assessment 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 replacement supply 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
- Provide financial consideration to the bore owner equivalent to the loss incurred due to the diminished bore yield or water quality (e.g. loss of agricultural productivity).

Alternative options may be available on a site-by-site basis, such as capping and piping of flowing artesian bores to increase water use efficiency and reduce non-CSG contributions to aquifer depressurisation.

10.0 SUMMARY

A risk analysis for GLNG Project activities related to development of CSG operations was performed to identify the risk drivers for the Project; these are presented in Section 7.1. Based on outcomes from a Risk Management workshop in early 2009, the majority of identified risks in the Project area were classified as Categories 1 or 2, which have negligible or minor consequences, or have a low probability of occurring.

The highest rankings were assigned to risks associated with depressurisation of the coal seams, uncontrolled releases of poor quality water to the environment, and unreliable supply of AW to beneficial reuse schemes (specifically municipal supply and industrial uses).

The risk ratings for coal seam depressurisation in the Roma and Arcadia CSG Fields were classified within Categories 1 and 2, whereas the depressurisation risk ratings in the Fairview CSG Field ranged from Categories 1 to 4, due to current activity at the site (i.e. increased likelihood for certain risks). Activities assigned with risk ratings greater than Category 2 are summarised as follows:

- Loss of available drawdown in bores, or loss of artesian pressure, resulting from coal seam depressurisation (Category 4 for the Fairview CSG Field);
- Loss of baseflow resulting from coal seam depressurisation (Category 3 for the Fairview CSG Field);
- Contamination of soil, surface water or shallow groundwater resulting from a break in an AW pipeline (Category 3);
- Damage and/or contamination associated with a dam break (Category 3; rating applies to release of oily water or brine only);
- Over- or under-supply of AW for municipal or industrial reuse applications (Category 3); and
- Environmental impacts related to the quality or quantity of treated discharge released to perennial streams (Category 3).

With respect to the water management activities classified as greater than Category 2 risks, two prevailing themes are evident:

- The potential for reduced groundwater availability resulting from coal seam depressurisation; and
- The potential for water quality degradation related to AW management activities.

The two themes described above are consistent with the prevailing risk perceptions of the general public and the regulatory community regarding CSG activities, and hence form the principal focus for development of risk control measures.

10.1 Potential Impacts Arising from CSG Operations

Potential impacts to the groundwater system from CSG operations, particularly to neighbouring users and surrounding ecosystem have been examined. The following provides a summary of the environmental values relevant to the GLNG Project area, and the potential impacts to these values by CSG operational activities.

Environmental Values

The environmental values associated with groundwater in the Project area include human consumptive uses (drinking water supply, primary industry and other industrial uses), maintenance of aquatic ecosystems (including groundwater dependent ecosystems), and to a lesser extent maintenance of recreational and aesthetic amenity of surface water bodies. Induced inter-aquifer leakage related to coal seam depressurisation, and potential impacts related to management of AW represent the greatest perceived risks to environmental values in each CSG Field. The highest risk rankings generally apply to Fairview Field due to the more advanced current state of CSG development relative to the Roma and Arcadia Fields. The Roma

Field has a similar, but slightly subdued, risk profile relative to Fairview Field, and the Arcadia Field currently presents a low risk profile due to its preliminary stage of CSG development and lack of significant surface water features.

Drilling and Well Installation

Santos operations within the GLNG Project area involve drilling of exploration boreholes, CSG production wells and/or monitoring wells. The potential impacts associated with drilling and well installation 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. Degradation of groundwater quality is considered to be the primary risk driver associated with improper drilling, well installation and borehole abandonment techniques.

Coal Seam Depressurisation

One of the highest risk impacts associated with CSG operations is related to coal seam depressurisation, necessary to achieve optimal reservoir pressure for gas extraction. The potential associated impacts include:

- Leakage of groundwater from adjacent water-bearing formations into the CSG production formation (inter-aquifer transfer or leakage);
- Loss of available drawdown in bores within close proximity to the CSG operations;
- Loss of artesian pressure in some aquifers. The CSG Fields of the GLNG Project area are located within recharge beds of the GAB aquifers, thus it is possible that inter-aquifer transfer could result in a local reduction to artesian heads;
- Depressurisation of coal seams will likely increase the vertical effective stress within the coal seams, which may result in settlement of the coal seams;
- 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(s), or can induce leakage of more saline water from overlying or underlying formations;
- Induced leakage of groundwater from the regional water supply aquifers during CSG operations may interfere with the migration of recent recharge water deeper into the GAB aquifers along regional flow paths;
- A reduction or loss of spring flow or baseflow contribution to rivers and creeks could potentially occur as a result of CSG production. However, inter-aquifer transfer from coal seam depressurisation would have to infiltrate through a thick stratigraphic sequence of overburden formations above the coal seams to affect the shallow 'water table' aquifers, which preliminary modelling results have indicated is unlikely (Matrixplus, 2009); and
- Induced gas flows may occur in water supply bores screened within the same formations as the coal measures targeted by CSG operations, or nearby in the stratigraphic sequence. This impact is likely to be more evident in the Roma CSG Field than in Fairview or Arcadia as there are very few private bores screened within the Bandanna Formation.

The potential risk issues associated with coal seam depressurisation were rated as Category 1 to 4 risks, with loss of available drawdown and the potential for reduced baseflow to rivers, streams and springs, representing the greatest perceived risk. Risks related to coal seam depressurisation were rated separately for each CSG Field. The general trend between the CSG Fields is a decrease in risk ranking relative to the current level of CSG development in each Field, with Fairview having the highest risk profile and Arcadia having the lowest.

Gathering Systems

The impacts associated with the gathering systems relevant to groundwater resources, caused by an uncontrolled release of AW to the environment, are generally related to the shallow groundwater systems and could involve changes to shallow groundwater quality, depending on the size and location of the release, the nature of the soils, and the relative quality of the AW compared to shallow groundwater quality. Related environmental impacts could include surface water contamination, soil contamination, and soil erosion.

The potential risk issues associated with this water management activity were rated as Category 1 to 3 risks, with potential for contamination of surface water and shallow groundwater as a result of a ruptured pipeline considered to represent the greatest risk.

Water Storage

The risks associated with surface water storage (ponds and dams) would be an uncontrolled discharge to environment, either through vertical seepage through the base of unlined dams or ponds or through a breach in dam or pond lining, or a catastrophic failure of the embankment causing vertical seepage into the shallow groundwater aquifers. Either situation could potentially have a direct effect on groundwater quality, soil salinity and structure.

The potential risk issues associated with this water management activity were rated as Category 1 to 3 risks. Risks related to water storage were rated separately for the various types of water that might be stored, with the highest risk rankings (Category 3) related to a potential dam break for a dam containing either oily water or brine (considered to have the greatest contaminating potential).

Project Infrastructure

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

The potential risk issues associated with this water management activity were rated as Category 1 to 2 risks, indicating that that the potential impacts associated with uncontrolled releases from project infrastructure are of minor (or localised) consequence or are unlikely to occur.

Associated Water Management

A number of AW management options that are currently used by Santos, or that are being evaluated for future use (Section 8.7 and 8.8). The impact assessment that has been undertaken is to determine whether the selected management options are viable (including their priority of use) having regard to the impacts and their management.

The potential impacts related to AW reuse and disposal include:

- Degradation of land or air quality as a result of poor dust management practices;
- Contamination of soil, shallow groundwater and surface water bodies from accidental release from water management ponds;
- Changes to stream hydrology or the health of the stream ecology as a result of discharge to surface water or lakes;
- Potential water quality impacts to deeper GAB groundwater supply aquifers from brine or desalinated water re-injection, if the re-injection wells aren't designed and constructed properly or if geochemical issues arise;
- Impacts to soil structure from irrigation of sodium and bicarbonate-rich associated water; and
- Impacts to municipal supply or industrial applications resulting from inconsistent water supply or variable quality.

The potential risk issues associated with this water management activity were rated as Category 1 to 3 risks. The potential for changes to water quality or flow regimes of surface water features based on discharge of treated water, as well as the potential for under- or oversupply of treated water for municipal or industrial users were considered to represent the greatest risks related to AW management. It is noted that the potential risks associated with re-injection of treated AW and/or brine have not been included in this risk assessment; these issues require further attention pending completion of the technical evaluation of this management option currently in progress.

10.2 Risk Mitigation Measures

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 to facilitate early identification of any emerging impacts leading to immediate corrective / mitigating impact management action and make good options to assist those affected by CSG operations as required. Preventative measures to reduce the likelihood of risks occurring include:

- 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
- Numerous safety measures have been 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 continually informing AW management decision-making.

10.3 Associated Water Management Plan

A robust AWMP has been prepared by Santos to address the management challenges with AW produced during CSG activities. The Plan was developed following a comprehensive risk-based and consultative process, to determine management options that are viable from both a business and technology perspective, which adopt the preferred reuse-and-recovery principles set out in Queensland state policy, and which emphasise beneficial outcomes for the surrounding communities where possible.

10.4 Water Monitoring Strategy

A robust WMS is being developed for the CSG fields area to provide the rules and rationale upon which the detailed monitoring programmes for each CSG field will be developed. The primary objective of the WMPs for each of the CSG Fields will be to document baseline conditions prior to commencement of CSG activities, and assess potential changes to water levels or water quality related to CSG development activities. The drivers for development of the monitoring program include:

- Legislative requirements;
- Requirements within the EAs; and
- Santos EHSMS risk-based activity assessment.

The monitoring framework established within the WMS will provide the framework for development of comprehensive WMPs for each of the CSG fields, which will be implemented on behalf of Santos by a suitably qualified and experienced third-party contractor/consultant. It is envisioned that the suitability of the WMPs will be independently reviewed on an annual basis at a minimum (informed by regular annual monitoring data assessment and reporting requirements), and potentially more frequently where data requirements dictate, or as new CSG-related activities arise.

10.5 Trigger values

In accordance with guidance recently provided by DERM, Santos proposes to adopt the following starting position for trigger thresholds with respect to water levels for aquifers potentially affected by CSG activities:

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

If and when the trigger values are reached, a series of management actions are initiated that range from determining whether the trigger value exceedance has actually impacted the intended function of the affected bore(s), assessing whether CSG activities are the key contributors to the decline in water levels, and if warranted to negotiate an appropriate make good option on a case-by-case basis.

Trigger values were also proposed to monitor for potential water quality impacts to provide a mechanism for addressing the potential impacts before they reach regulatory thresholds. The trigger levels include:

- **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; and
- **Tier 2 trigger level:** A final trigger value representing the compliance criteria at which some form of remedial action is required to mitigate the risks posed by the changes to water quality.

This approach to water quality assessment provides advanced warning of potential water quality issues, such that appropriate site-specific triggers for management options can be evaluated.

10.6 Options to Make Good

In the event that a bore owner has been unduly impacted by CSG operations, the following "make good" options 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 replacement supply 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
- Provide financial compensation to the bore owner equivalent to the loss incurred due to the diminished bore yield or water quality (e.g. loss of cropping or livestock productivity).

10.7 Conclusions

A number of potential risks related to CSG development activities in the GLNG Project area have been identified, based on consideration of the conceptual hydrogeological model, and risk assessment of CSG development activities. Not surprisingly, the primary risks include decreased access to groundwater resources as a result of coal seam depressurisation, and impacts to groundwater quality resulting from AW management. Whilst neither issue can be eliminated from the CSG development activities, careful management and diligent monitoring can reduce the risk of impacts occurring, and allow for timely development of site-specific remedial options to address potential losses incurred as a result of CSG activities.

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Report Signature Page

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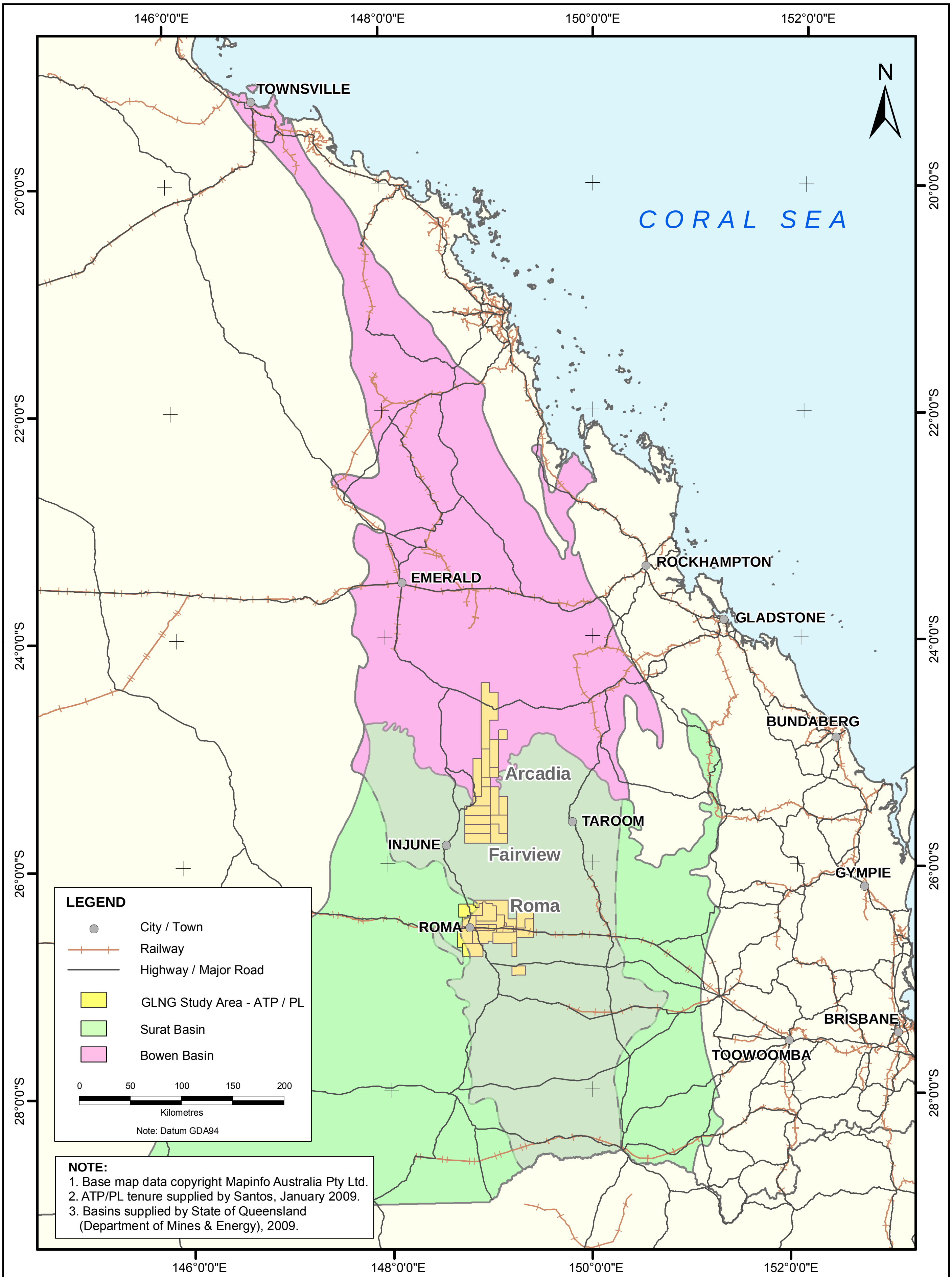

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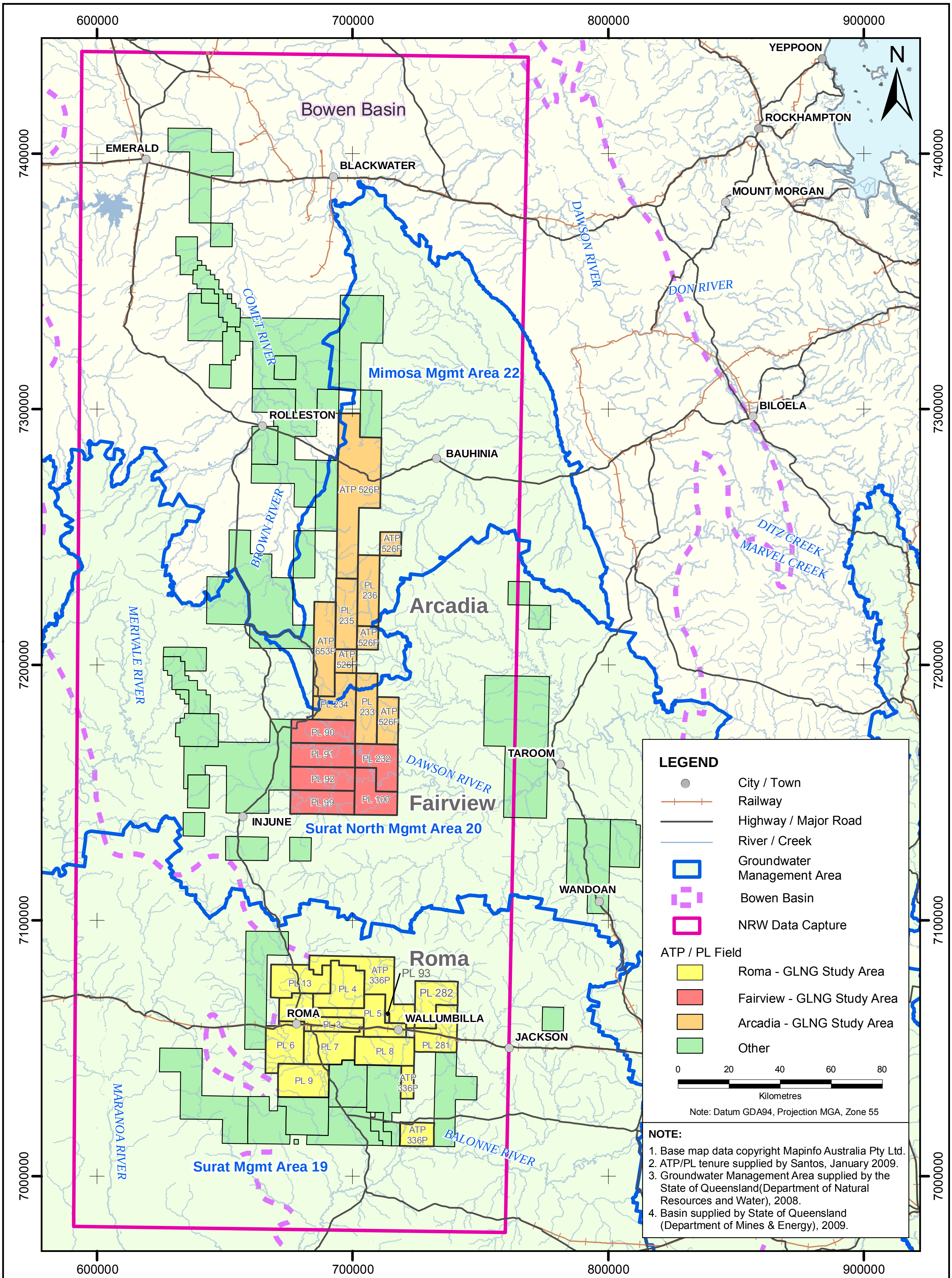

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CHECKED SH*	DATE 26-03-09			
SCALE 1:2,000,000		PROJECT No 087636015_019	FIGURE No 2	REV No 1 A4

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WRP Management Unit Equivalents: Mimosa GMA 22	Surat North GMA 20	Surat GMA 19	Basin	Litho-stratigraphy		Geologic Age	Hydrogeological Characteristics	Main Rock Types
				Alluvium			Aquifer	Unconsolidated sand, gravel and silt
				Tertiary and Volcanics			Aquifer	Unconsolidated sediments
			Surat Basin	Griman Creek Formation		Cretaceous	Aquifer	Lithic glauconitic sandstone, siltstone, mudstone
		SURAT 1	Surat Basin	Surat Siltstone		Cretaceous	Water bearing	Interbedded carbonaceous siltstone, mudstone and lithic sandstone
		SURAT 1	Surat Basin	Wallumbilla Formation	Coreena Member; Doncaster member	Cretaceous	Aquifer	Mudstone, siltstone, sandstone lenses with conglomerate and limestone
		SURAT 2	Surat Basin	Bungil Formation	Minmi Member; Nullawart Sandstone Member; Kingull Member (Kumbarilla Beds)	Cretaceous	Water bearing	Mudstone siltstone and lithic sandstone
		SURAT 3	Surat Basin	Mooga Sandstone	(Kumbarilla Beds)	Cretaceous	Aquifer	Fine to medium grained sandstone and shales
		SURAT 4	Surat Basin	Orallo Formation	(Kumbarilla Beds)	Jurassic	Confining bed	Sandstone carbonaceous siltstones mudstone coal
		SURAT 4	Surat Basin	Gubberamunda Sandstone	(Kumbarilla Beds)	Jurassic	Aquifer	Medium and coarse quartz sandstone
	SURAT NORTH 1	SURAT 5	Surat Basin	Injune Creek Group	Westbourne Formation	Jurassic	Confining bed	Shale, siltstone and fine grained sandstone
	SURAT NORTH 1	SURAT 5	Surat Basin	Injune Creek Group	Birkhead Formation: Springbok Sandstone (Kumbarilla Beds)	Jurassic	Water bearing	Clayey lithic sublabile to very lithic sandstone; calcareous in part; interbedded with carbonaceous mudstone and siltstone. Sublabile, lithic sandstone with calcareous cement
	SURAT NORTH 1	SURAT 5	Surat Basin	Injune Creek Group	Birkhead Formation: Walloon Coal Measures	Jurassic	Target Coal Measure	Thin-bedded, claystone, shale, siltstone, lithic and sublithic to feldspathic arenites, coal seams and partings; minor limestone.
	SURAT NORTH 1	SURAT 5	Surat Basin	Injune Creek Group	Eurombah Formation	Jurassic	Water bearing	
	SURAT NORTH 2	SURAT 6	Surat Basin	Hutton Sandstone		Jurassic	Aquifer	Sandstone, siltstone, shale, conglomerate, coal, oolitic ironstone
	SURAT NORTH 2	SURAT 6	Surat Basin	Evergreen Formation		Jurassic	Confining bed	Clean, fine-medium grained quartz sandstone; fossil wood
	SURAT NORTH 2	SURAT 6	Surat Basin	Evergreen Formation	Boxvale Sandstone (*)	Jurassic		Sandstone, siltstone, shale, mudstone (carbonaceous with minor coal), oolitic limestone
	SURAT NORTH 3	SURAT 7	Surat Basin	Precipice Sandstone		Jurassic	Aquifer	Sandstone, pebbly sandstone, siltstone
MAJOR UNCONFORMITY								
MIMOSA 1	SURAT NORTH 4	SURAT 8	Bowen Basin	Moolayember Formation		Triassic	Confining bed	Micaceous lithic sandstone, micaceous siltstone
MIMOSA 1	SURAT NORTH 4	SURAT 8	Bowen Basin	Mimosa Group	Clematis Sandstone	Triassic	Aquifer	Medium to coarse-grained quartzose to sublabile, micaceous sandstone, siltstone, mudstone and granule to pebble conglomerate
MIMOSA 1	SURAT NORTH 4	SURAT 8	Bowen Basin	Mimosa Group	Showgrounds sandstone	Triassic	Aquifer	White coarse quartzose sandstone.
MIMOSA 1	SURAT NORTH 4	SURAT 8	Bowen Basin	Mimosa Group	Rewan Formation	Triassic	Confining bed	Lithic sandstone, pebbly lithic sandstone, green to reddish brown mudstone and minor volcanilithic pebble conglomerate (at base).
			Bowen Basin	Blackwater group	Bandanna Formation	Late Permian	Target Coal Measure	Sandstone, siltstone, shale, mudstone, coal, tuff, conglomerate
			Bowen Basin	Blackwater group	Black Alley Shale	Late Permian	Confining bed	Shale, siltstone, tuff, bentonite, labile sandstone
			Bowen Basin	Back Creek Group	Peawaddy Formation	Early Permian	Confining bed	Carbonaceous mudstone and siltstone, lithic sublabile sandstone, coquinitic siltstone.
			Bowen Basin	Back Creek Group	Catherine Sandstone	Early Permian	Water bearing	Quartzose to sublabile sandstone, siltstone, mudstone
			Bowen Basin	Back Creek Group	Ingelara Formation	Early Permian	Confining bed	Conglomeratic sandy siltstone, mudstone, sandstone
			Bowen Basin	Back Creek Group	Freitag Formation	Early Permian	Water bearing	Sublabile sandstone, pebbly sandstone, siltstone, mudstone
			Bowen Basin	Back Creek Group	Aldebaran Sandstone	Early Permian	Aquifer	Pebbly quartz sandstone, conglomerate, minor shale, siltstone and coal.
			Bowen Basin	Back Creek Group	Cattle Creek Group	Early Permian	Water bearing	Quartzose to sublabile sandstone and mudstone.
			Bowen Basin	Reids Dome Beds		Early Permian	Water bearing	Siltstone, shale, labile sandstone, lithic conglomerate and coal
THOMSON FOLD BELT				Timbury Hills Formation*		Early Devonian		
				Fork Lagoons Bed		Late Ordovician		

(*)No information on the stratigraphy position, just the group they belong to.

Uncoformity

Golder Associates	CLIENT Santos		PROJECT Santos GLNG Groundwater Impact Study
	DRAWN TP	DATE 03.03.2009	TITLE **Stratigraphic Sequence in the Study Area**
	CHECKED SH	DATE 02.04.2009	
	SCALE N.T.S		PROJECT No 087636015_019; FIGURE No 3; REV No 0; A3

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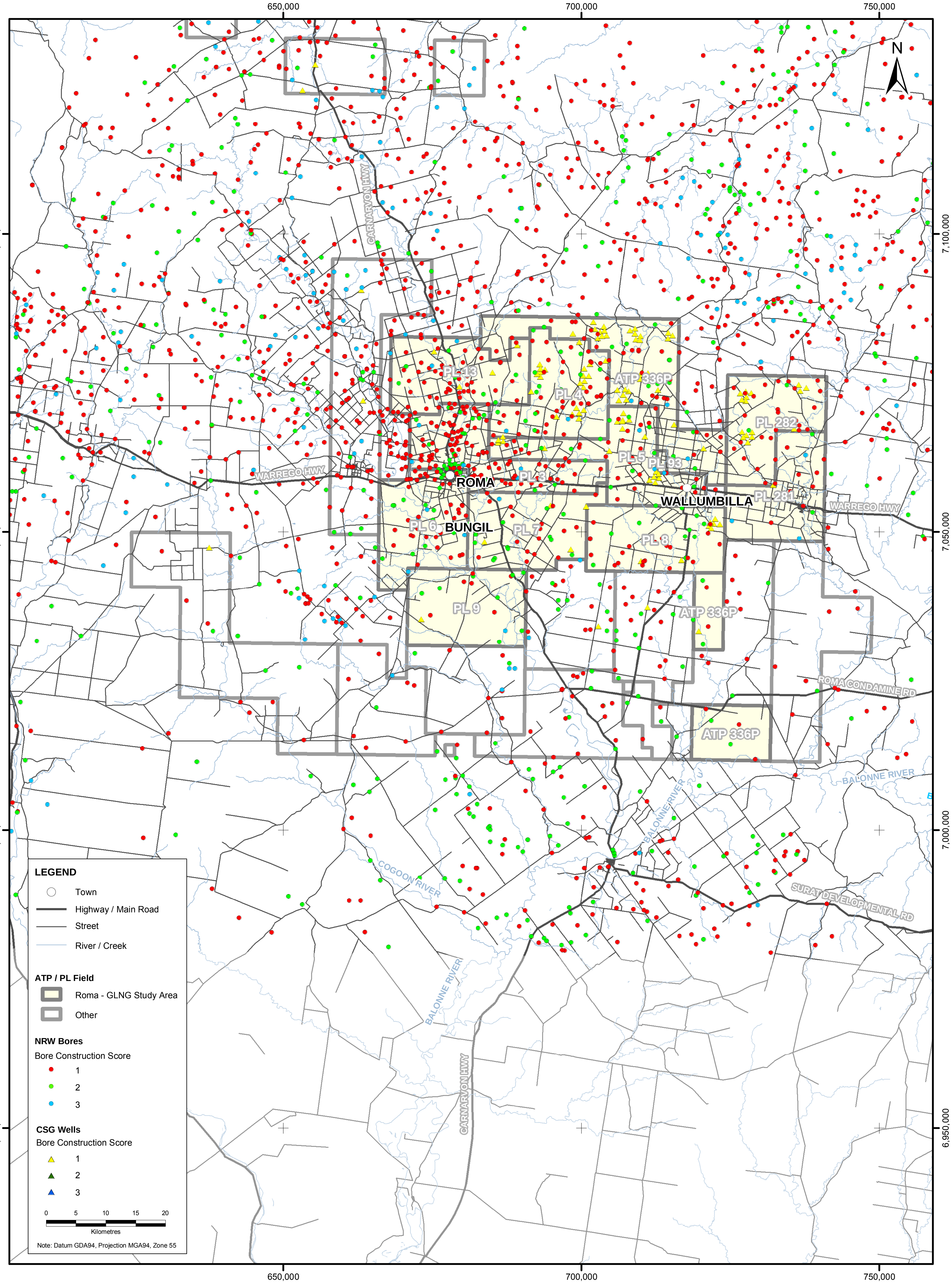

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CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study	
DRAWN: BC	DATE: 02-04-09	TITLE: METADATA MAP - ROMA BORE CONSTRUCTION	
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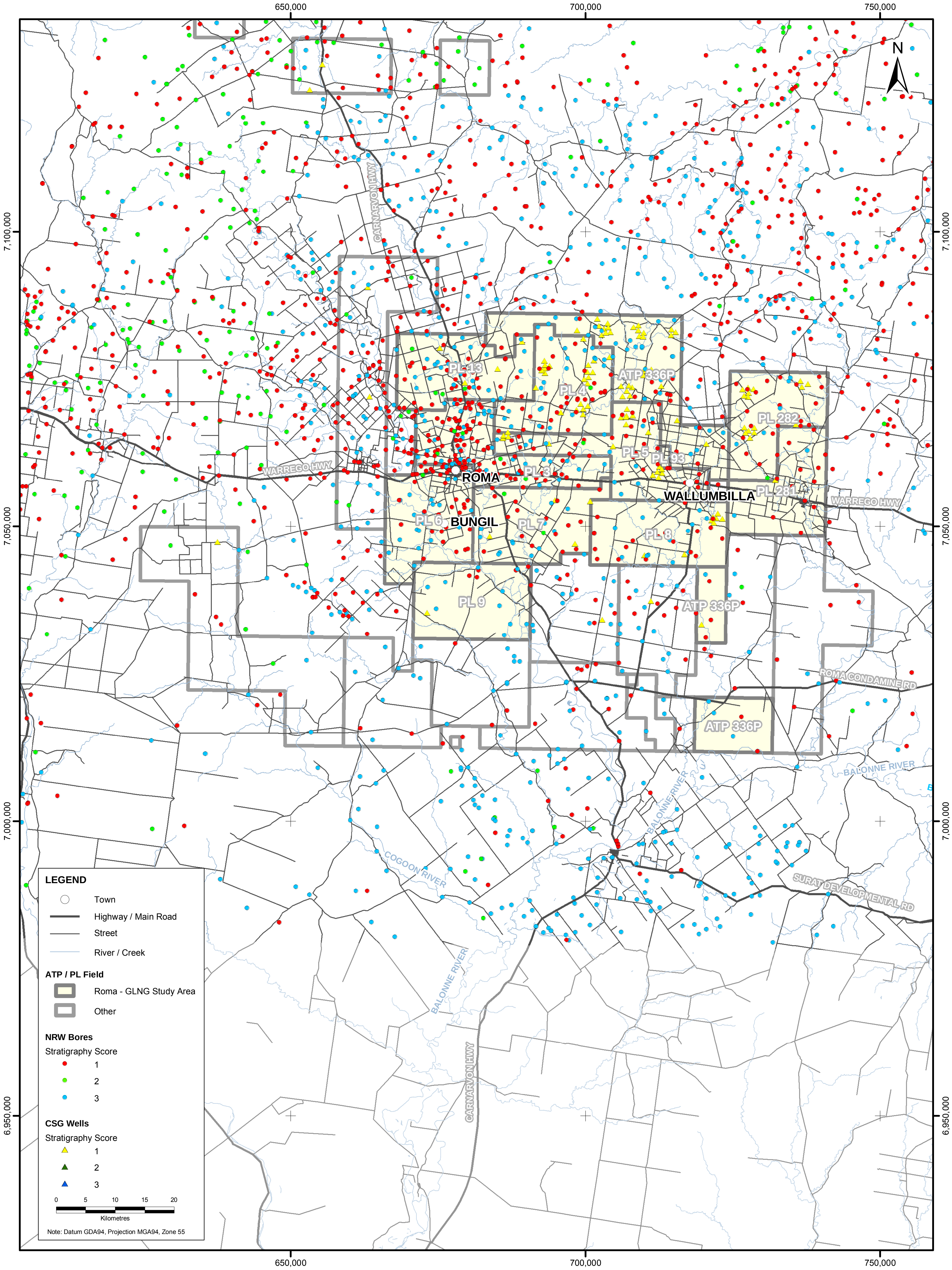

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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN BC	DATE 02-04-09	TITLE	METADATA MAP - ROMA STRATIGRAPHY
CHECKED SH*	DATE 02-04-09		
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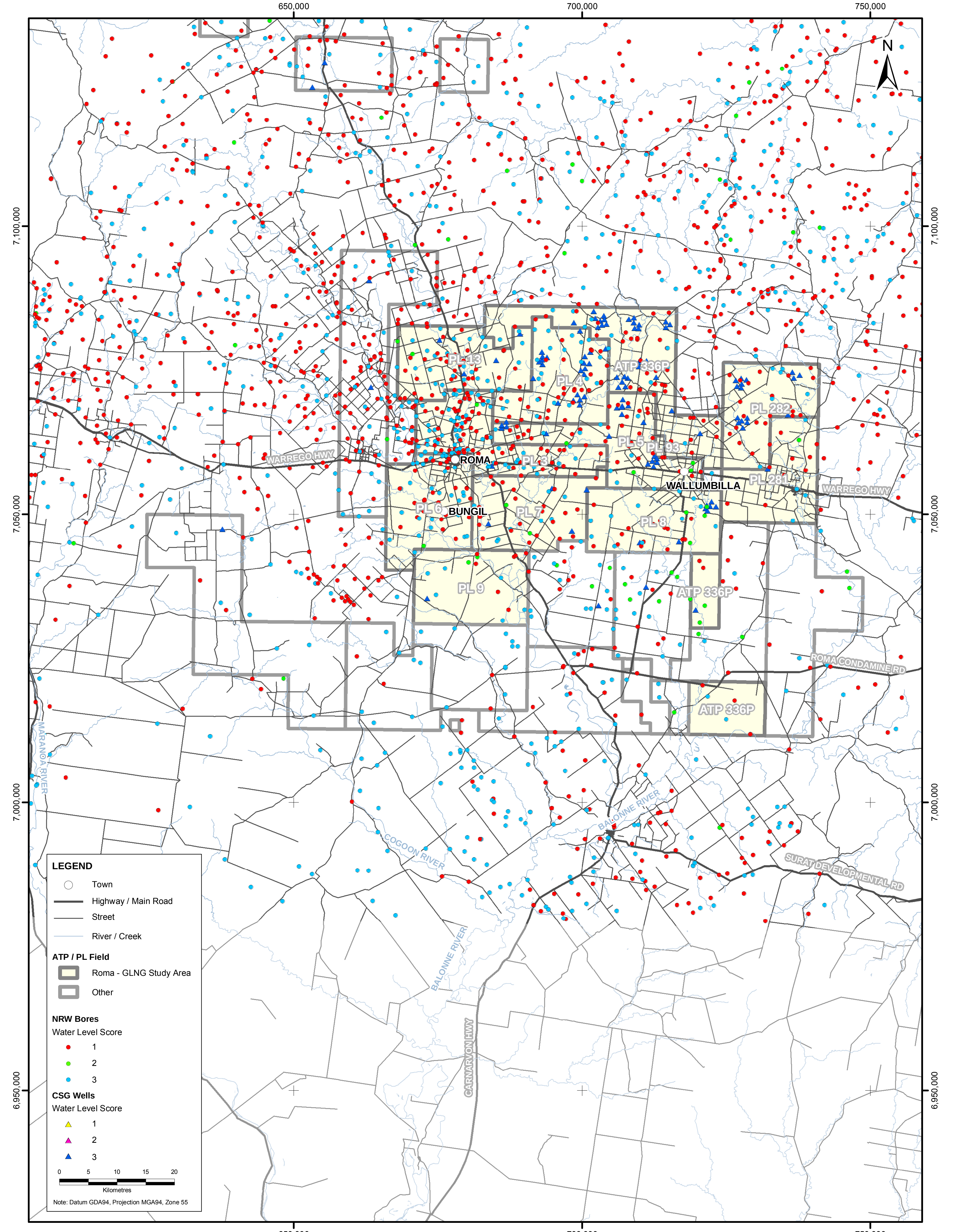

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CLIENT Santos		PROJECT Santos GLNG Groundwater Impact Study	
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CHECKED SH*	DATE 09-04-09		
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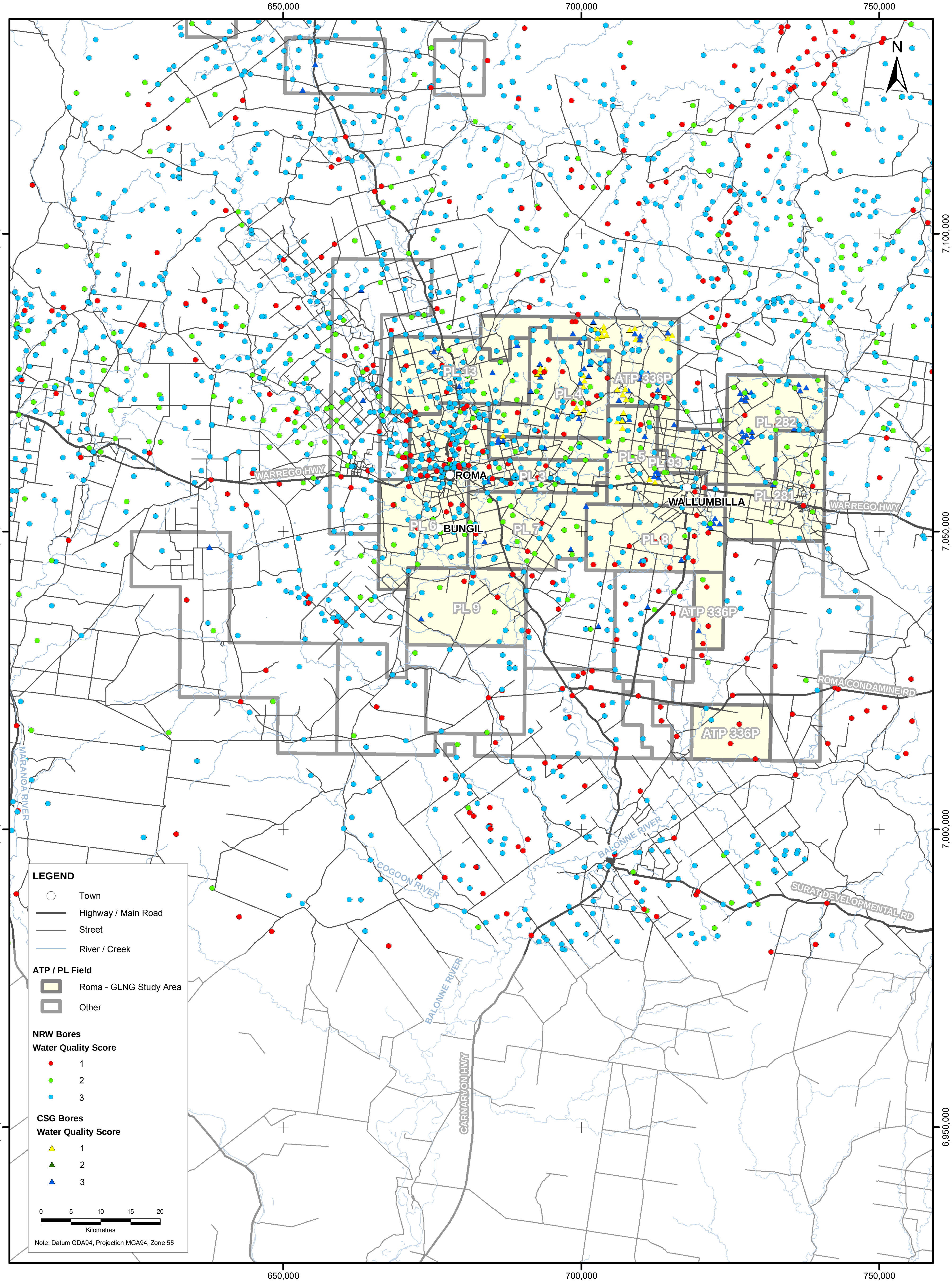

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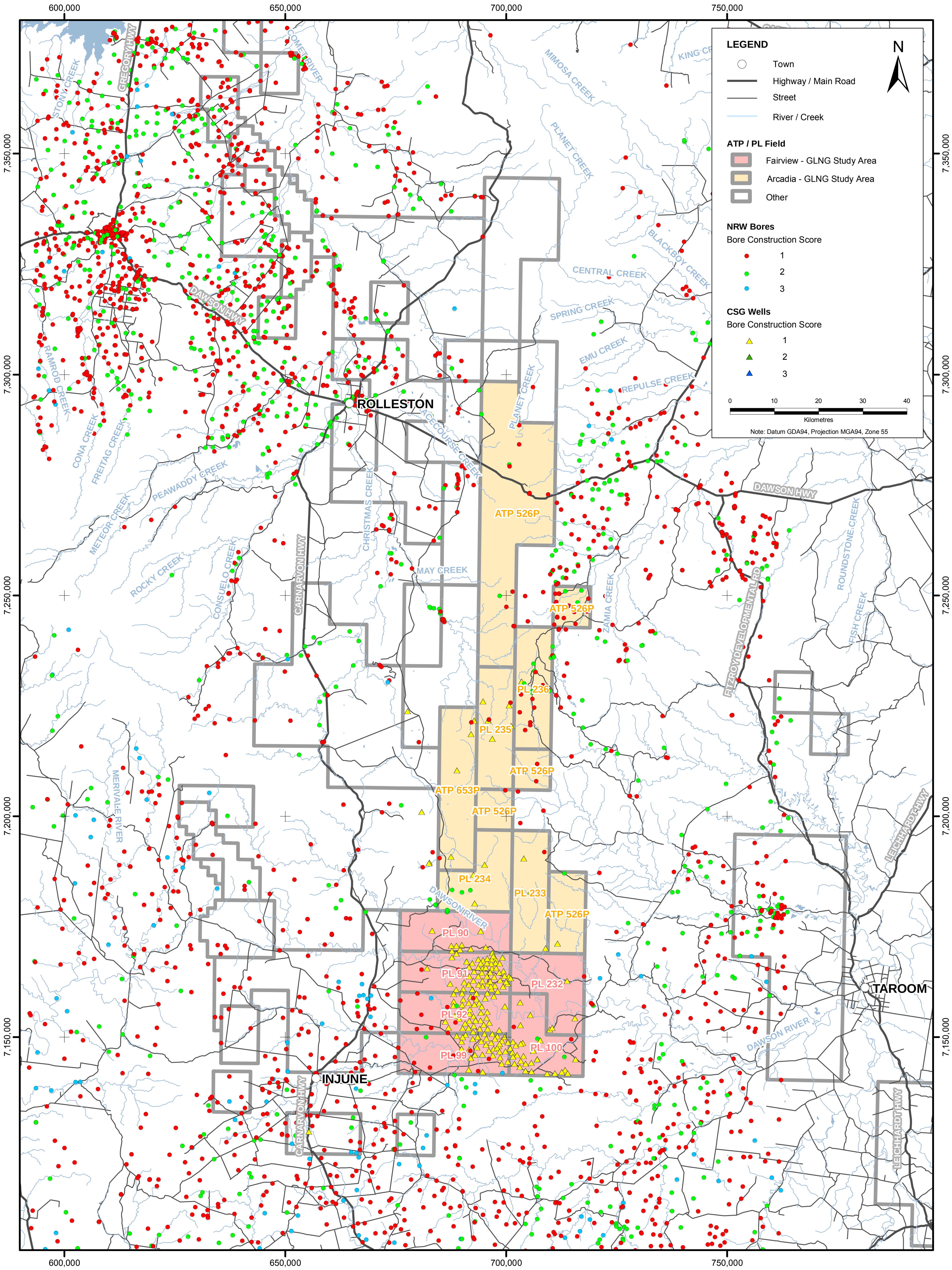

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CLIENT	Santos		PROJECT	Santos GLNG Groundwater Impact Study	
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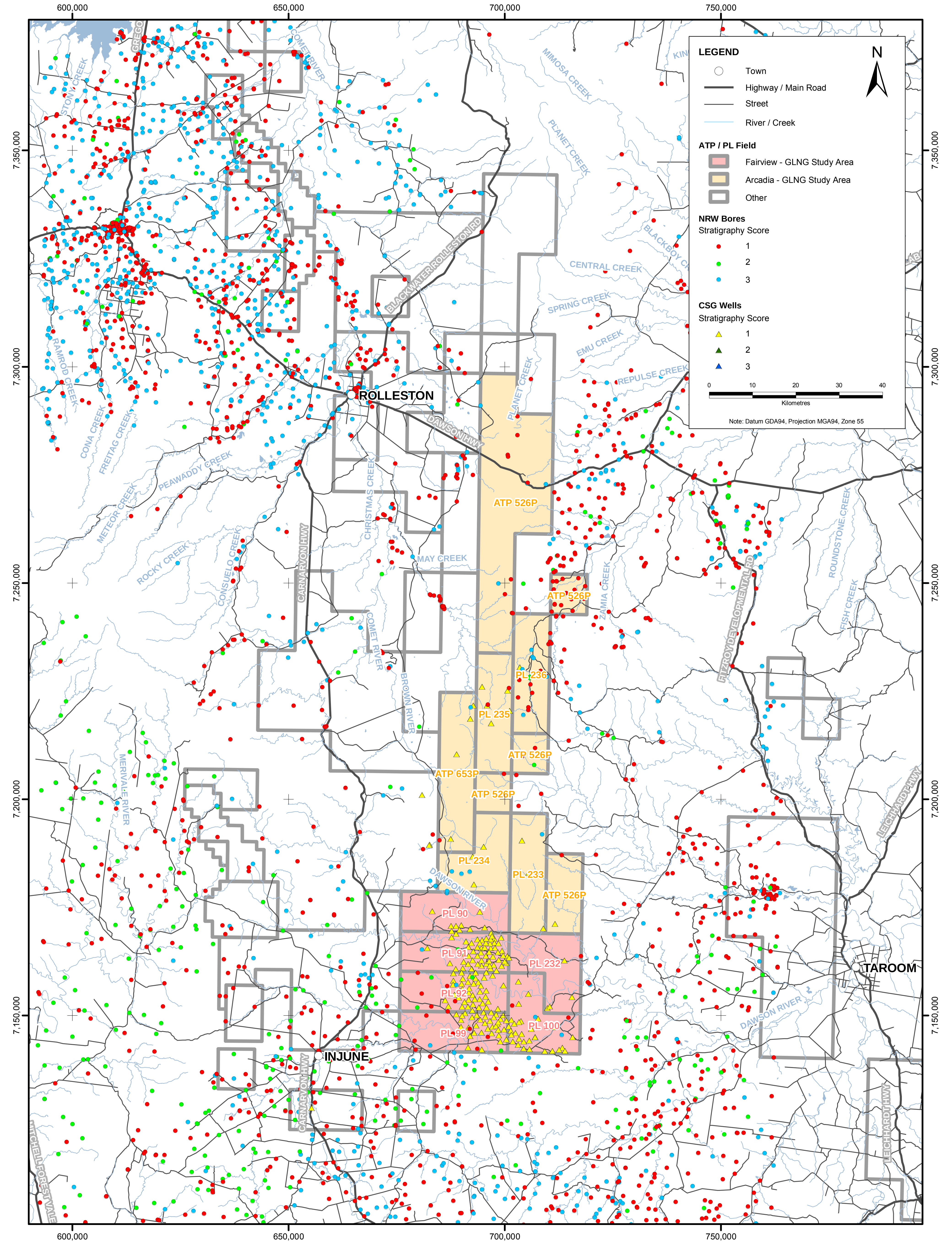

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CHECKED SH*	DATE 01-04-09		
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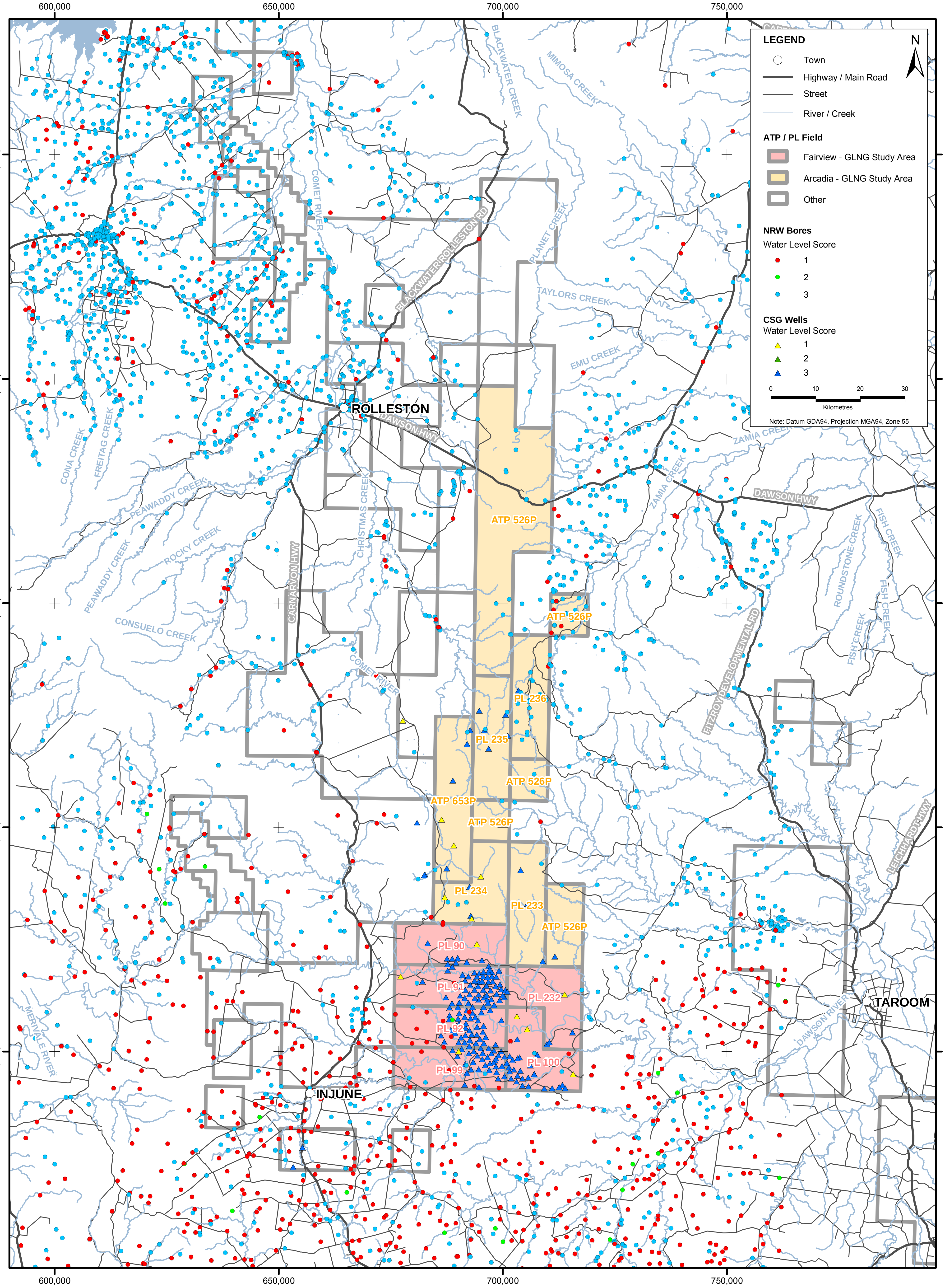

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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
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CHECKED SH*	DATE 09-04-09		
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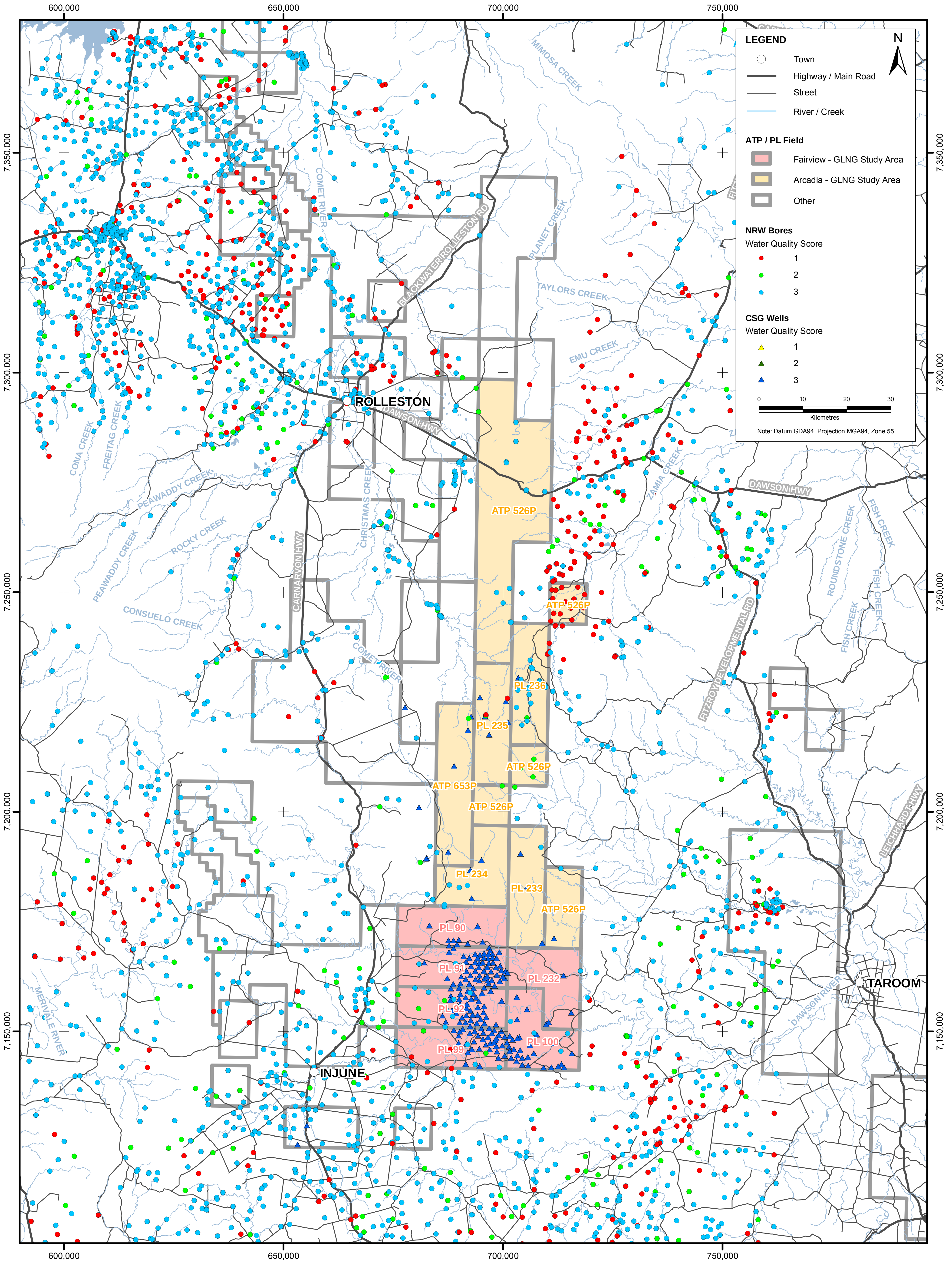

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DRAWN	BC	DATE 01-04-09	TITLE	METADATA MAP - FAIRVIEW ARCADIA WATER QUALITY	
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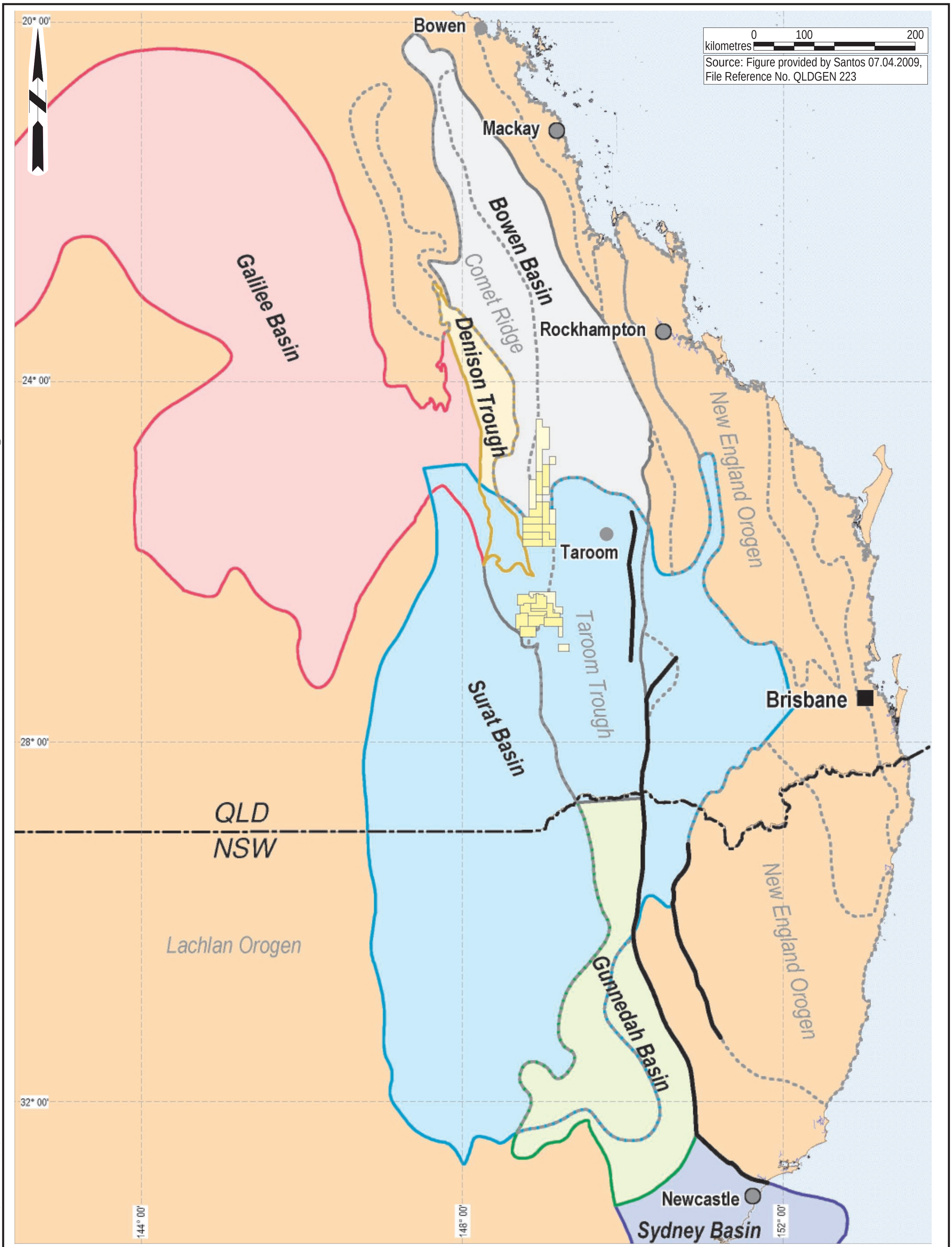

Golder Associates www.golder.com GOLDER ASSOCIATES PTY LTD	CLIENT Santos		PROJECT Santos GLNG Groundwater Impact Study				
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Figure 7

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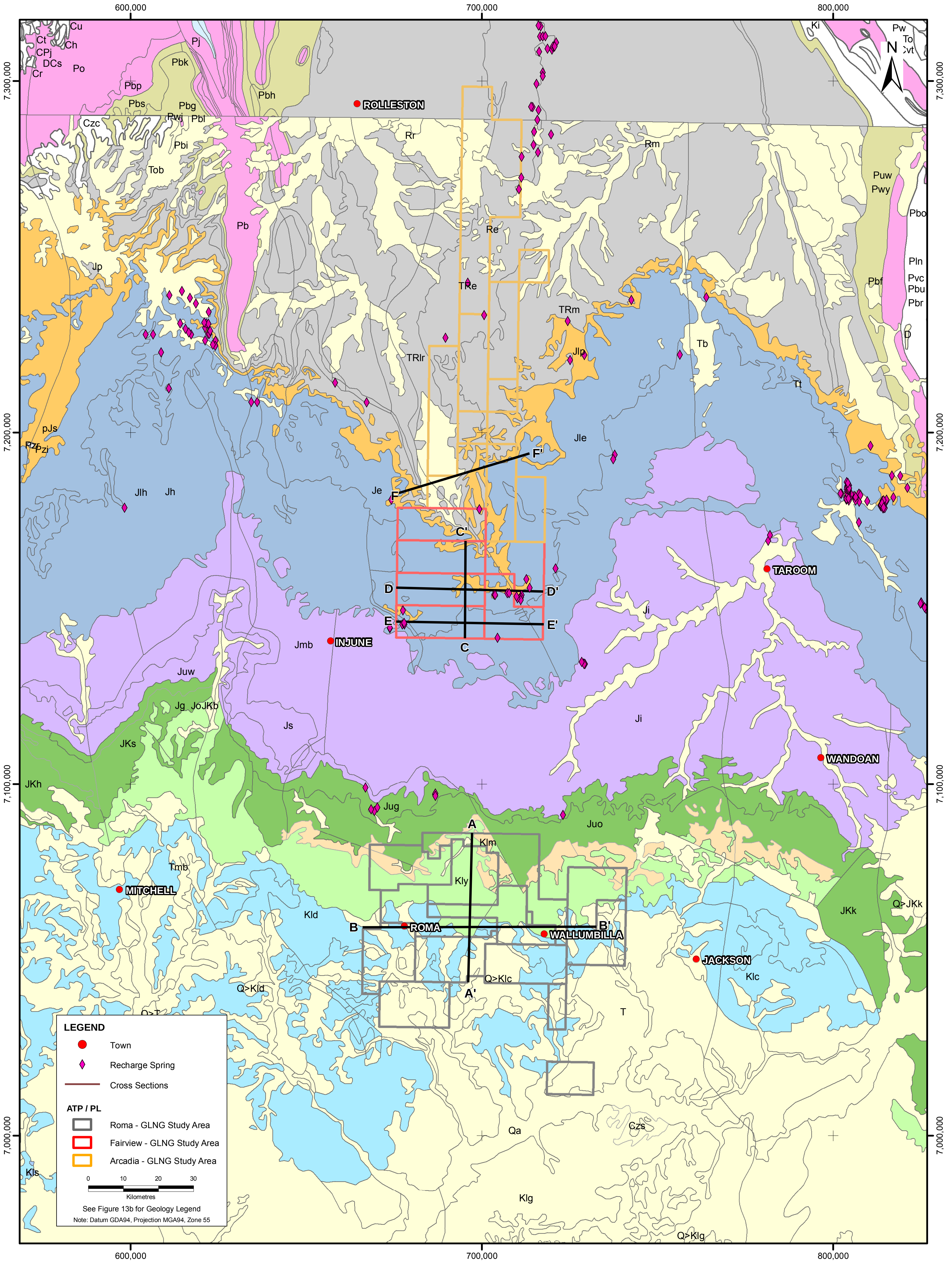

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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
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CHECKED SH*	DATE 01-04-09		
SCALE	1:1,000,000	PROJECT No 087636015_019	FIGURE No 8a / REV No 1 / A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_Geology_F008a_Rev1_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.

WRP Management Unit Equivalents					
Mimosa	Surat North	Surat		Map Symbol	Rock Unit Name
				Q Q>Jht Q>JKk Q>Kg Q>Ku/c Q>Ku/d Q>T Qa T Tb Tp Tt Tmb Kg Czs	Q-NSB Q-NSB>Hutton Sandstone Q-NSB>Kumbarilla beds Q-NSB>Griman Creek Formation Q-NSB>Coreena Member Q-NSB>Doncaster Member Q-NSB>T-NSB Qa-NSB T-NSB Tb-NSB Peak Range Volcanics Tt-NSB Tmb-NSB Griman Creek Formation Cainozoic
		SURAT 1		Ks Po Ku Kuc Kud, Kld	Surat Siltstone Colinlea Sandstone Wallumbilla Formation Coreena Member Doncaster Member
		SURAT 2		Ky, Kly	Bungil Formation
		SURAT 3		JKb	Mooga Sandstone
		SURAT 4		Jg Jo JKk Jkh Jks	Gubberamunda Sandstone Orallo Formation Kumbarilla beds Hooray Sandstone Southlands Formation
	SURAT NORTH 1	SURAT 5		Ji Jib Jis Jiw Jw	Injune Creek Group Birkhead Formation Springbok Sandstone Westbourne Formation Walloon Subgroup
	SURAT NORTH 2	SURAT 6		Je Jh	Evergreen Formation Hutton Sandstone
	SURAT NORTH 3	SURAT 7		Jp	Precipice Sandstone
MIMOSA 1	SURAT NORTH 4	SURAT 8		TRm TRe TRr, TRr	Moolayember Formation Clematis Group Rewan Formation
				Pwj Pbs Pw	Bandanna Formation Black Alley Shale Blackwater Group
				Pbp Pbe Pb Pbg Pbh Pbi Pbk Pbl	Peawaddy Formation Blenheim Subgroup Back Creek Group Frietag Formation Catherine Sandstone Ingelara Formation, Maria Formation Cattle Creek Formation Aldebaran Sandstone

Golder Associates

CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN BC	DATE 01-04-09	TITLE	SURFACE GEOLOGY LEGEND
CHECKED SH*	DATE 01-04-09		
SCALE		PROJECT No 087636015_019	FIGURE No 8b / REV No 1 / A4

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_GeologyLegend_F008b_Rev0_A4.mxd
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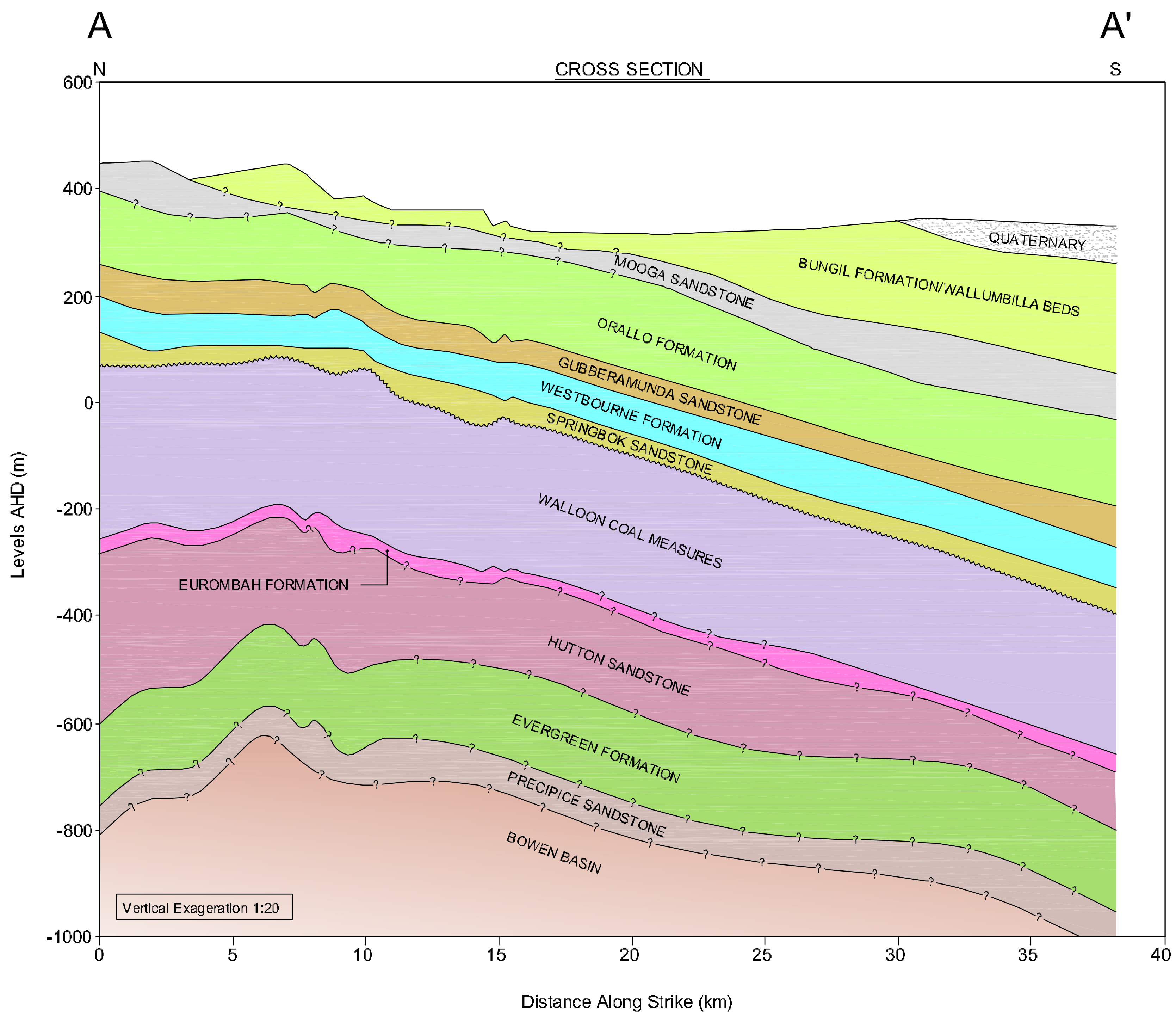

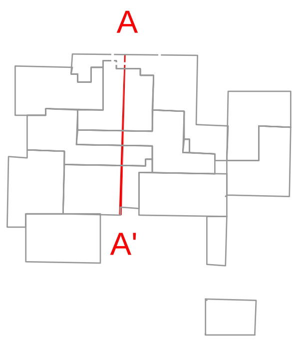

Locality Plan
Scale 1:2,000,000

Notes:

1. Geological data supplied by the State of Queensland (Department of Natural Resources and Water) and by Santos, 2008-2009.
2. Golder accepts no liability for use of this data in any other contract than the report in which it was originally published; 0876326131__004.

1:10,000 V — 200 100 0 200 400m

1:200,000 H — 4000 2000 0 4000 8000 m

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CLIENT	Santos			
DRAWN	GPG	DATE	04/03/09	
CHECKED	*SRH	DATE	04/03/09	
SCALE	1:10,000 V, 1:200,000 H			

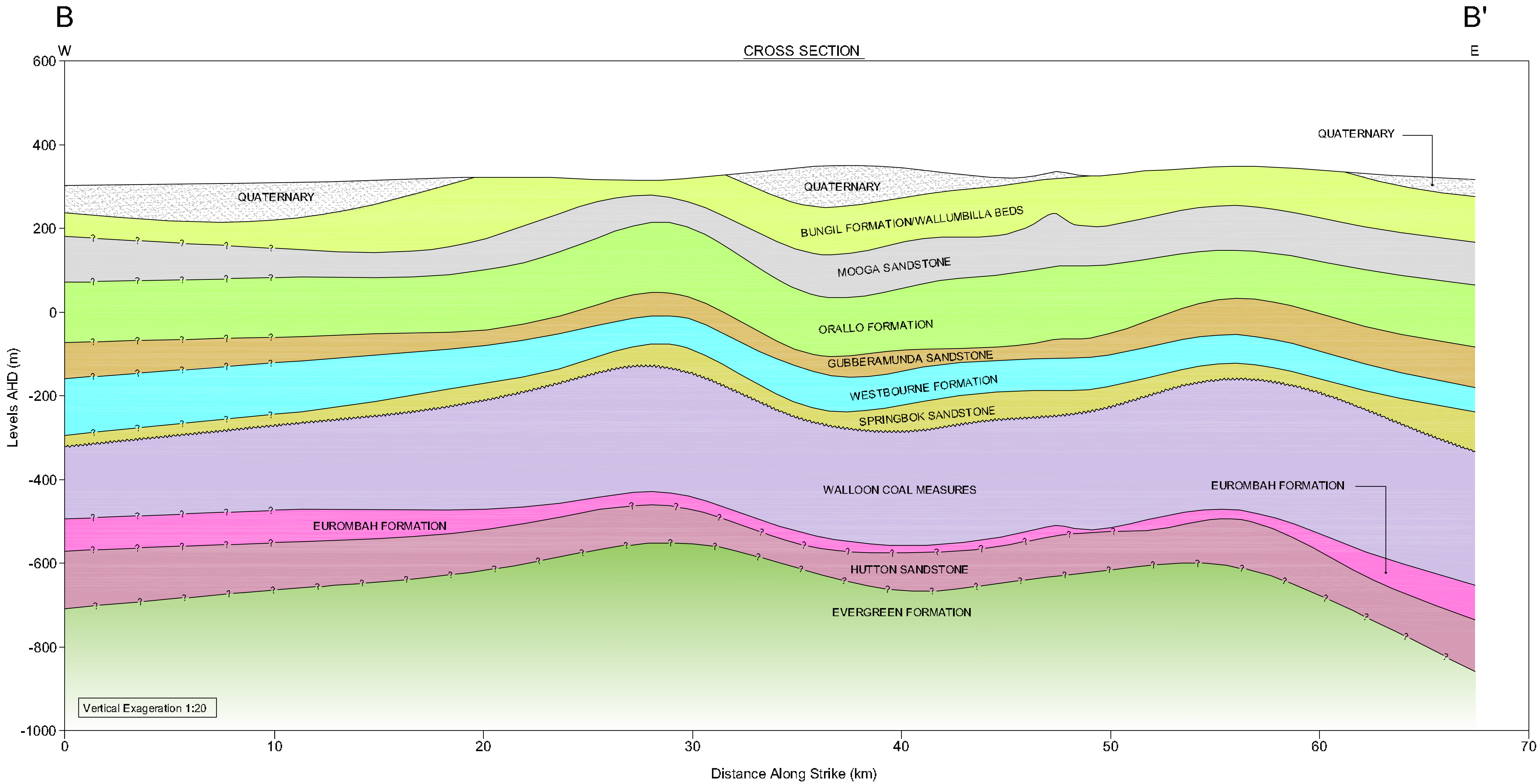
PROJECT: Santos QGC Groundwater Impact Studies

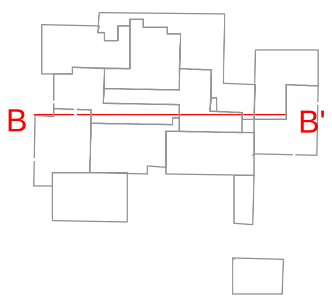
TITLE: CONCEPTUAL GEOLOGICAL CROSS SECTION ROMA (N-S)

PROJECT No	FIGURE No	REV No	
087636015_019	9	A	A3

K:\Sydney\087626131\Figures\087636015_019 -r-fig09.dwg Mar 25, 2009 - 1:05pm

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





Locality Plan
Scale 1:2,000,000

Notes:

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1:10,000 V — 200 100 0 200 400m

1:200,000 H — 4000 2000 0 4000 8000 m

CLIENT	Santos	PROJECT	Santos QGC Groundwater Impact Studies
DRAWN	GPG	DATE	04/03/09
CHECKED	*SRH	DATE	04/03/09
SCALE	1:10,000 V, 1:200,000 H		

TITLE: CONCEPTUAL GEOLOGICAL CROSS SECTION ROMA (E - W)

PROJECT No 087636015_019 | FIGURE No 10 | REV No A | A3

K:\Sydney\087626131\Figures\087636015_019 -r-fig10.dwg Mar 25, 2009 - 1:05pm

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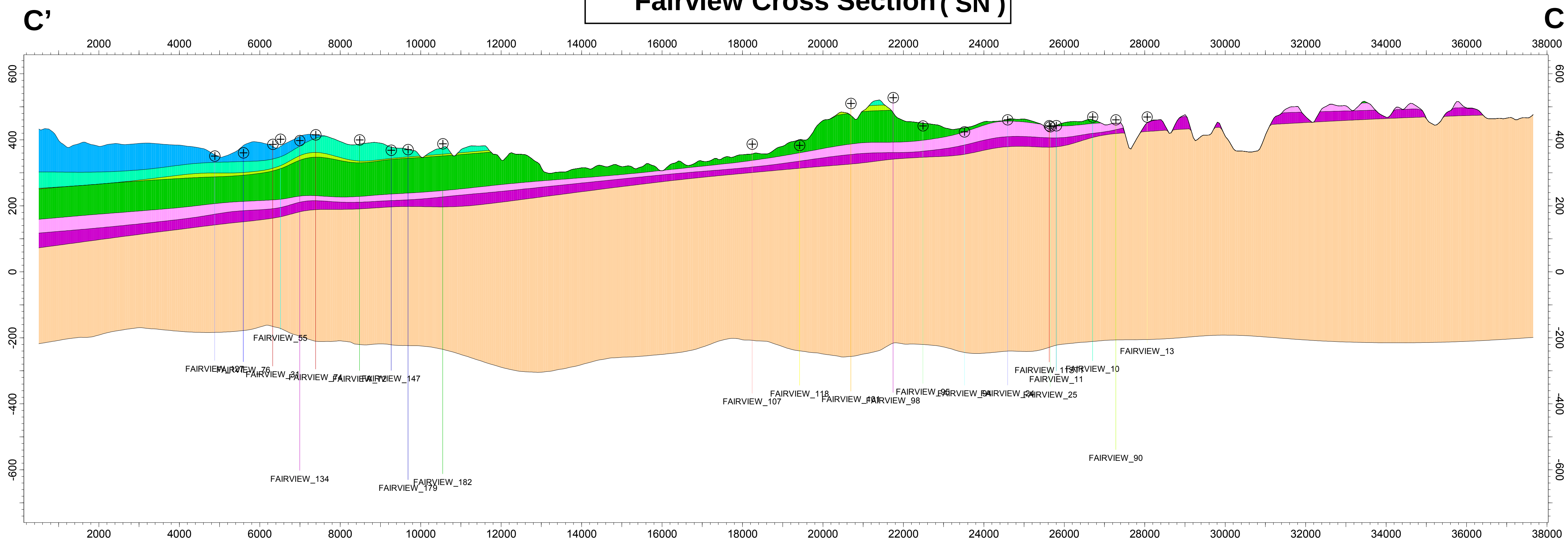
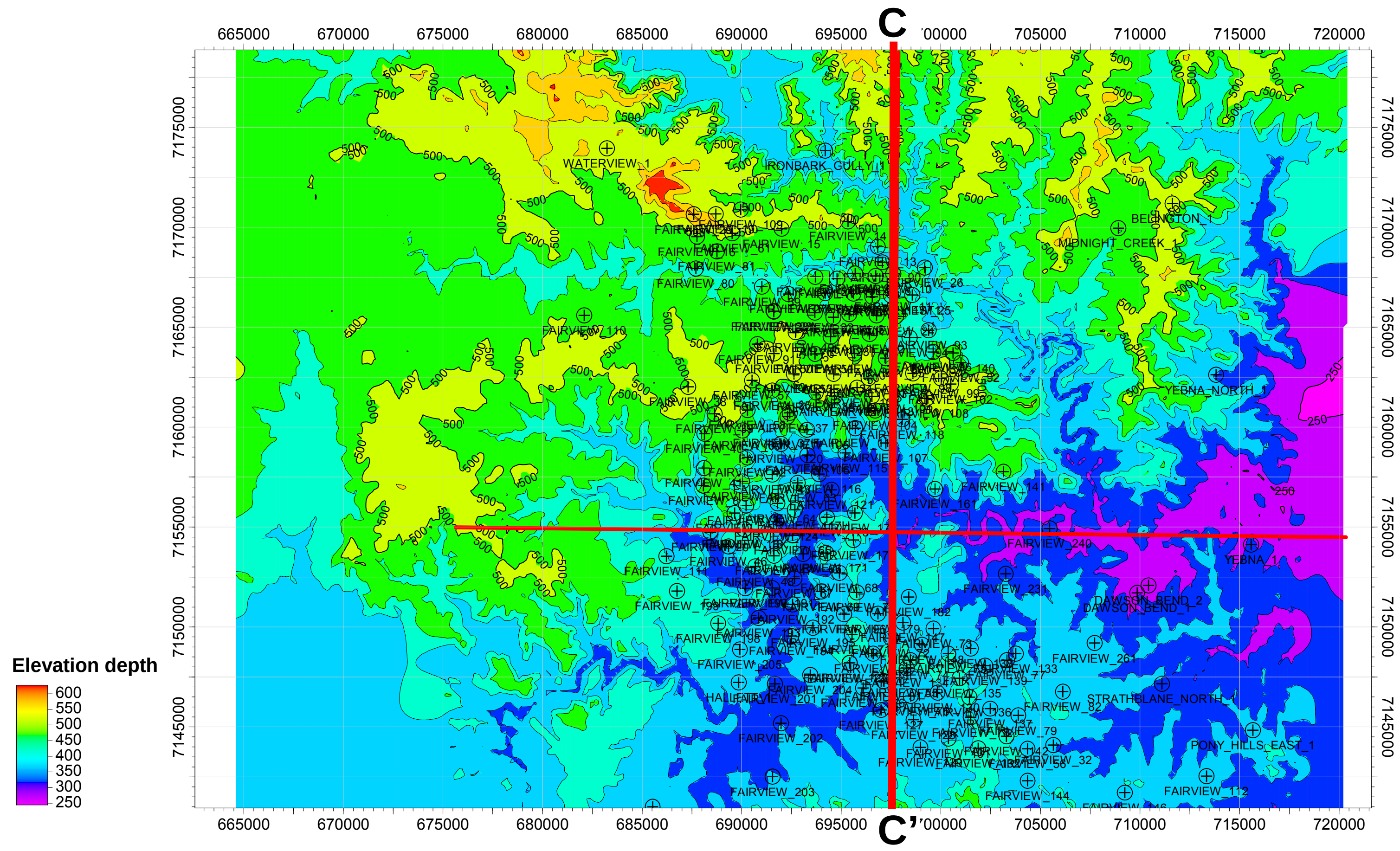
Fairview Cross Section (SN)



Zones
- Hutton
- Upper Evergreen
- Boxvale
- Lower Evergreen
- Upper Precipice
- Lower Precipice
- Rewan



CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN	TP	DATE	03.03.2009
CHECKED	SH	DATE	04.03.2009
TITLE	Conceptual Geological Cross Section Fairview S-N		
SCALE	N.T.S	PROJECT No	087636015_019
FIGURE No	12	REV No	0
A3			

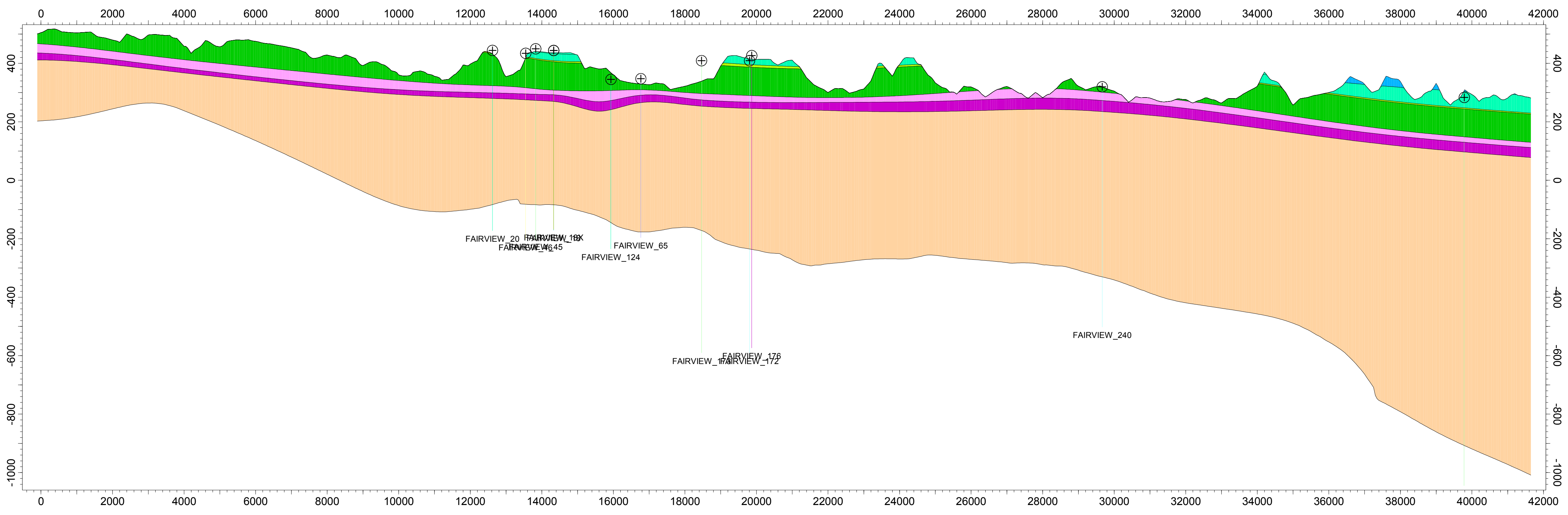
Golder Associates

Note:

Geological Cross Section supplied by Santos, Feb 2009.

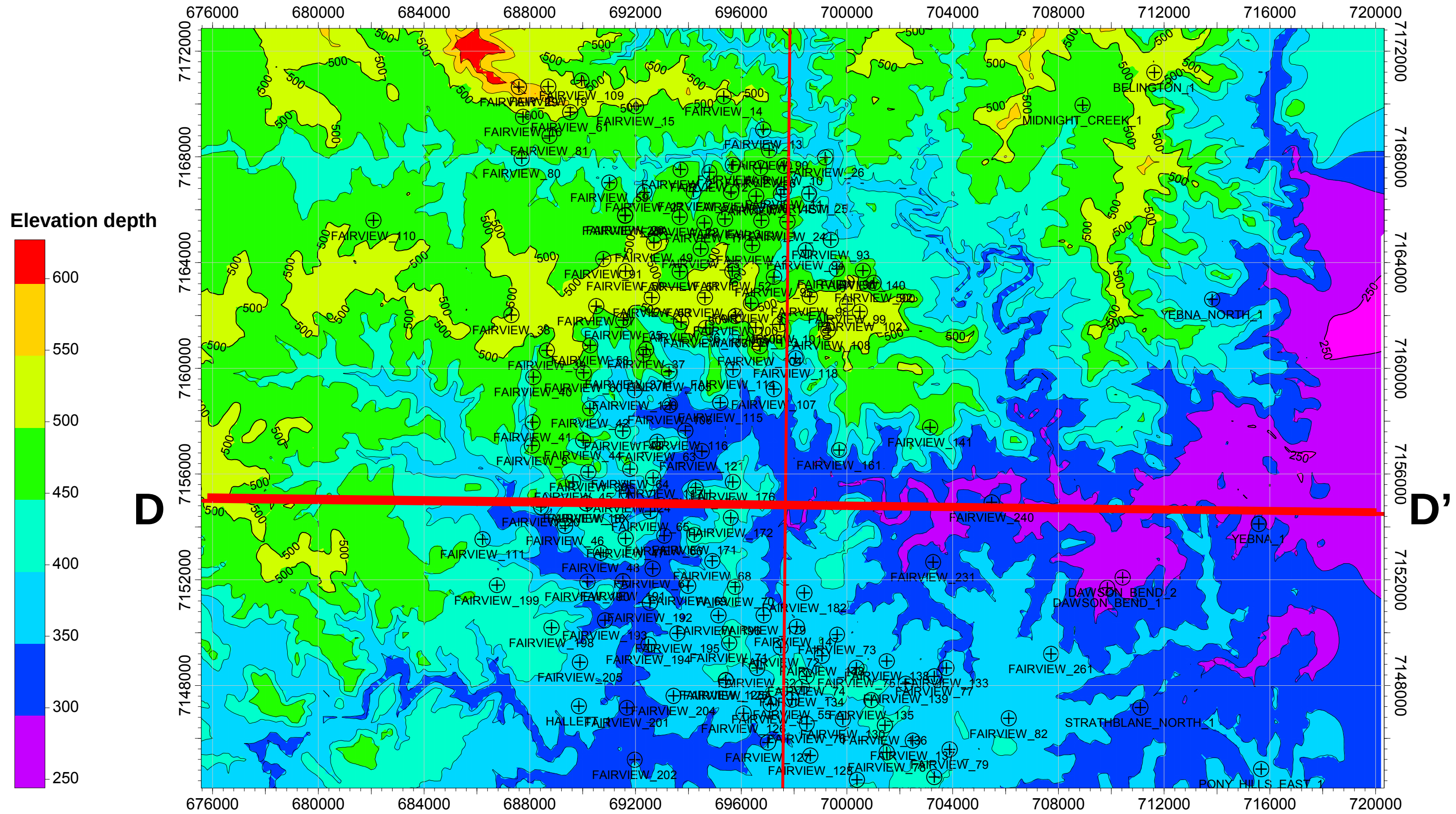
FILE LOCATION: J:\hyd\2008\087626131_Santos_SuratBasin\GW Impact - Correspondence Out\Figures\Figure 9 - Geological Cross Section - Fairview (S-N) .ppt

Fairview Cross Section (WE)



Zones

- Hutton (Jh)
- Upper Evergreen (Je/b - Je)
- Boxvale (Je/b)
- Lower Evergreen (Je)
- Upper Precipice (Jp)
- Lower Precipice (Jp)
- Rewan (incl Mool, Clem)

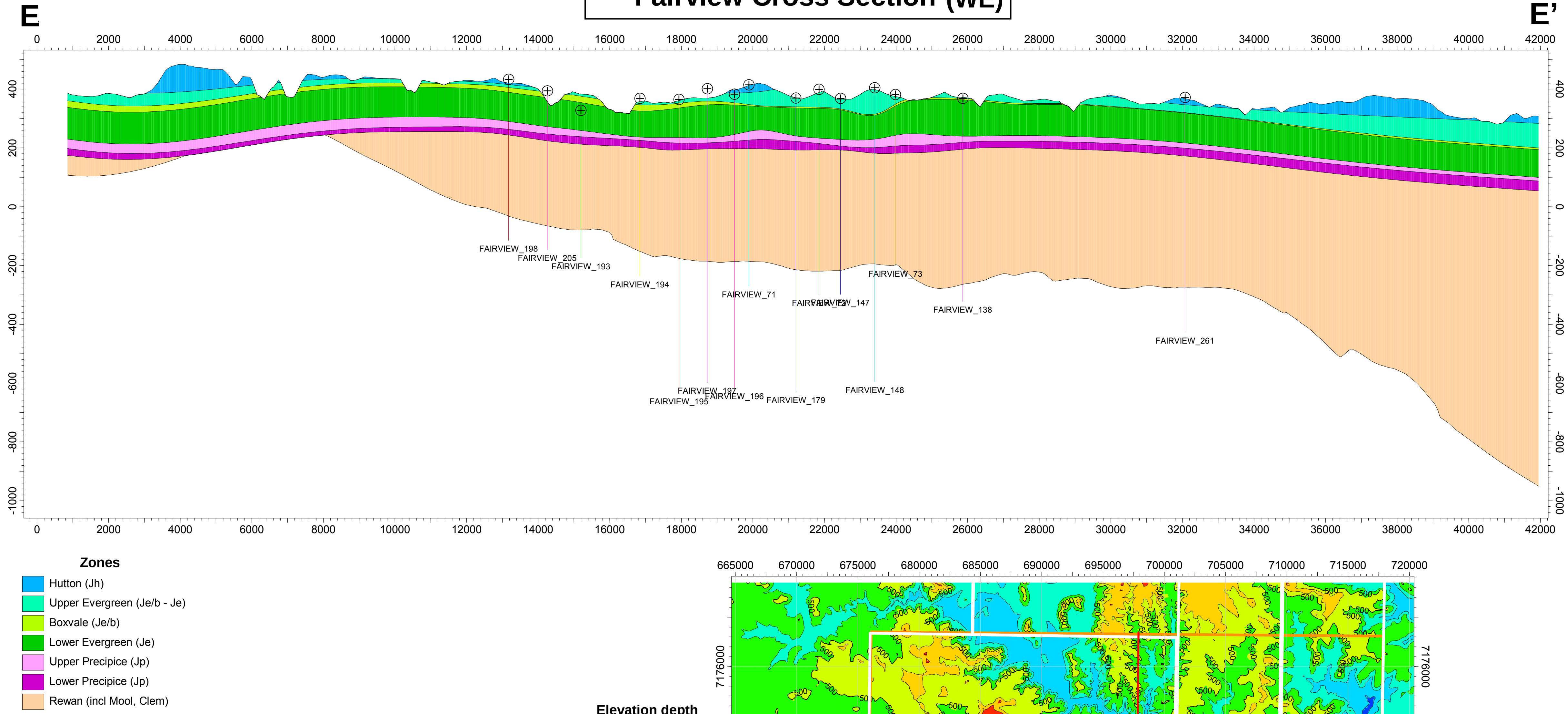


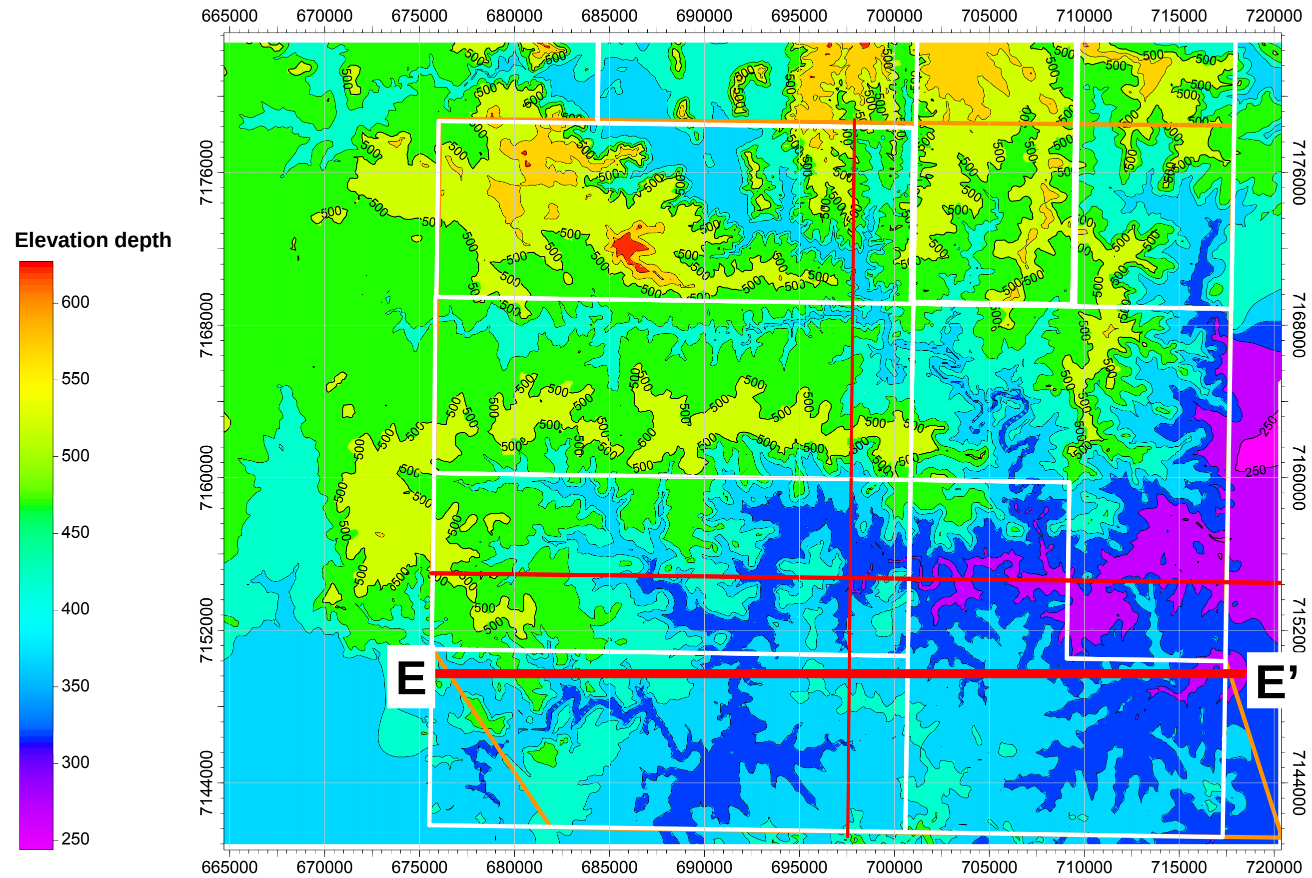
Note:

Geological Cross Section supplied by Santos, Feb 2009.

CLIENT Santos		PROJECT Santos GLNG Groundwater Impact Study	
DRAWN TP	DATE 03.03.2009	TITLE Conceptual Geological Cross Section Fairview W-E (Central)	
CHECKED SH	DATE 04.03.2009		
SCALE N.T.S		PROJECT No 087636015_019	FIGURE No 13 / REV No 0 / A3

FILE LOCATION: J:\hyd\2008\087626131_Santos_SuratBasin\GW Impact - Correspondence Out\Figures\Figure 10 - Geological Cross Section - Fairview (W-E).ppt





CLIENT Santos		PROJECT Santos GLNG Groundwater Impact Study	
DRAWN TP	DATE 03.03.2009	TITLE **Conceptual Geological Cross Section Fairview W-E (South)**	
CHECKED SH	DATE 04.03.2009		
SCALE N.T.S		PROJECT No 087636015_019	FIGURE No 14 · REV No 0 · A3

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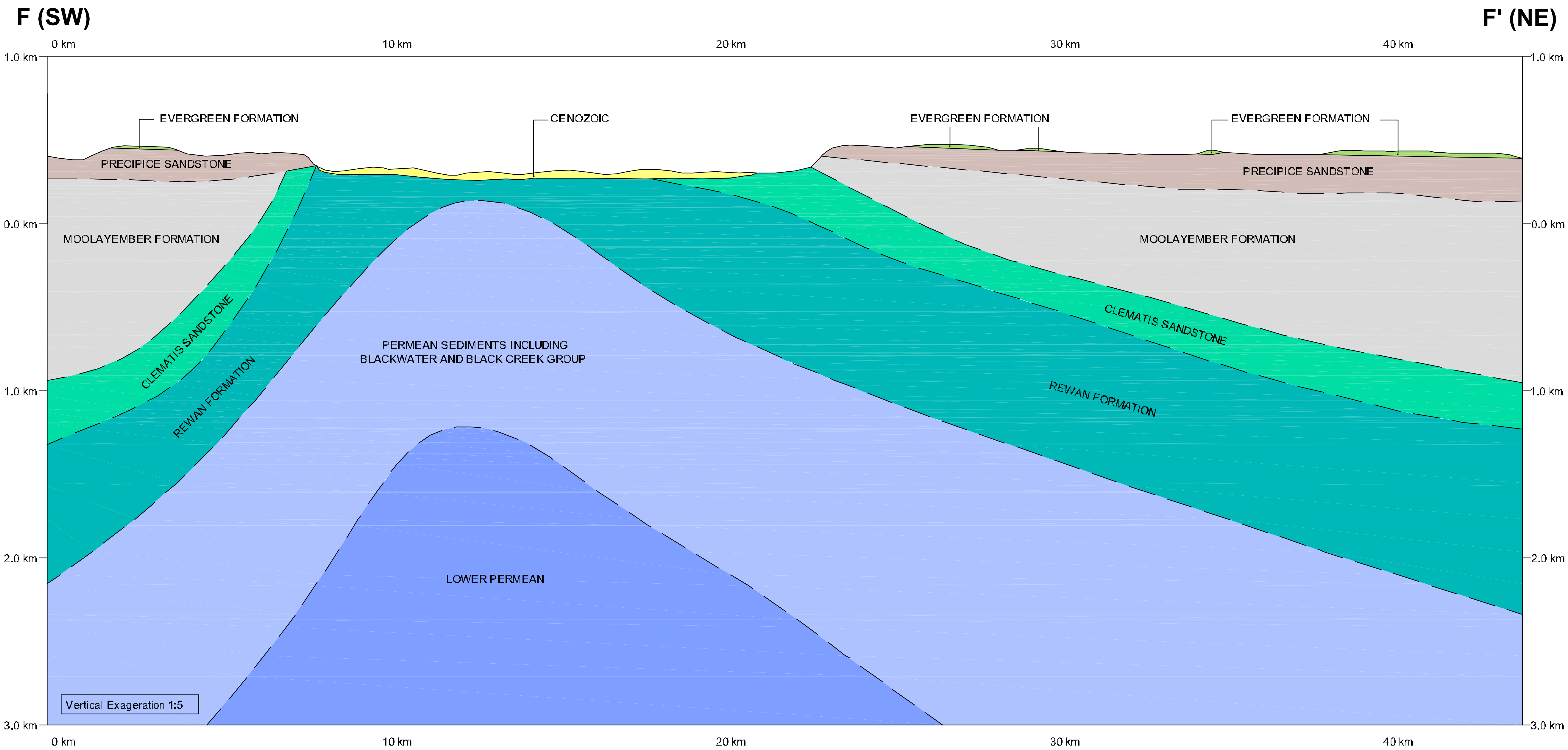
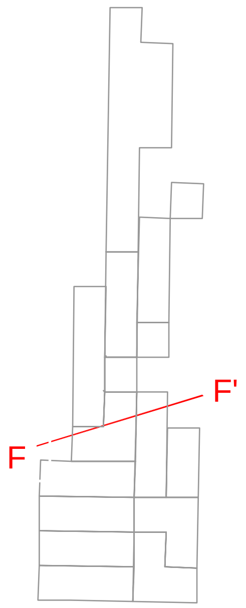
Note:

Geological Cross Section supplied by Santos, Feb 2009.

FILE LOCATION: J:\hyd\2008\087626131_Santos_SuratBasin\GW Impact - Correspondence Out\Figures\Figure 11- Geological Cross Section - Fairview (W-E) - Precipice-Bandanna Contact.ppt



Longitudinal Section 1:5 Vertical Exageration



Locality Plan
Scale 1:2,000,000

Notes:

1. This geological interpretation is based on the Taroom Geological Sheet, Bureau of Mineral resources, Geology and Geophysics (1:250,000 geological series, Sheet SG/55-8) , 1967.
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CLIENT	Santos		PROJECT	Santos GLNG Groundwater Impact Study
DRAWN	GPG	DATE 04/03/09	TITLE	CONCEPTUAL GEOLOGICAL CROSS SECTION ARCADIA (SW - NE)
CHECKED	*SRH	DATE 04/03/09		
SCALE	1:125,000		PROJECT No 087636015_019	FIGURE No 15 · REV No A · A3

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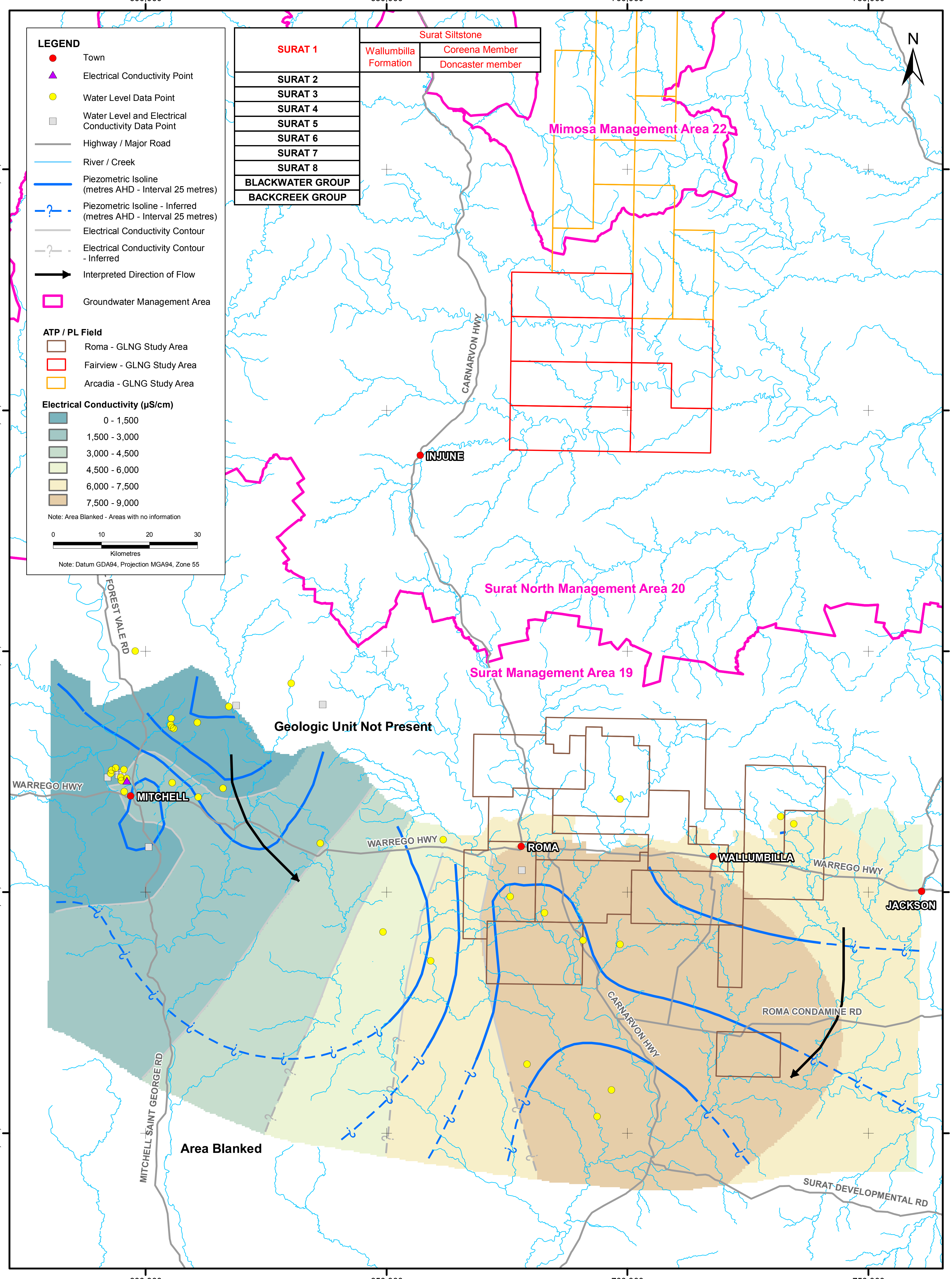

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5. The data used to generate these maps were collected between the years 1900 and 1999, and used to represent the approximate hydrogeological conditions in the study area prior to CSG operation.

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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN BC/BQ	DATE 06-04-09	TITLE	HYDROGEOLOGICAL MAP - SURAT 1 UNIT
CHECKED SH*	DATE 06-04-09		
SCALE	1:750,000	PROJECT No 087636015_019	FIGURE No 16 / REV No 1 / A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S1_F0016_Rev1_A3.mxd
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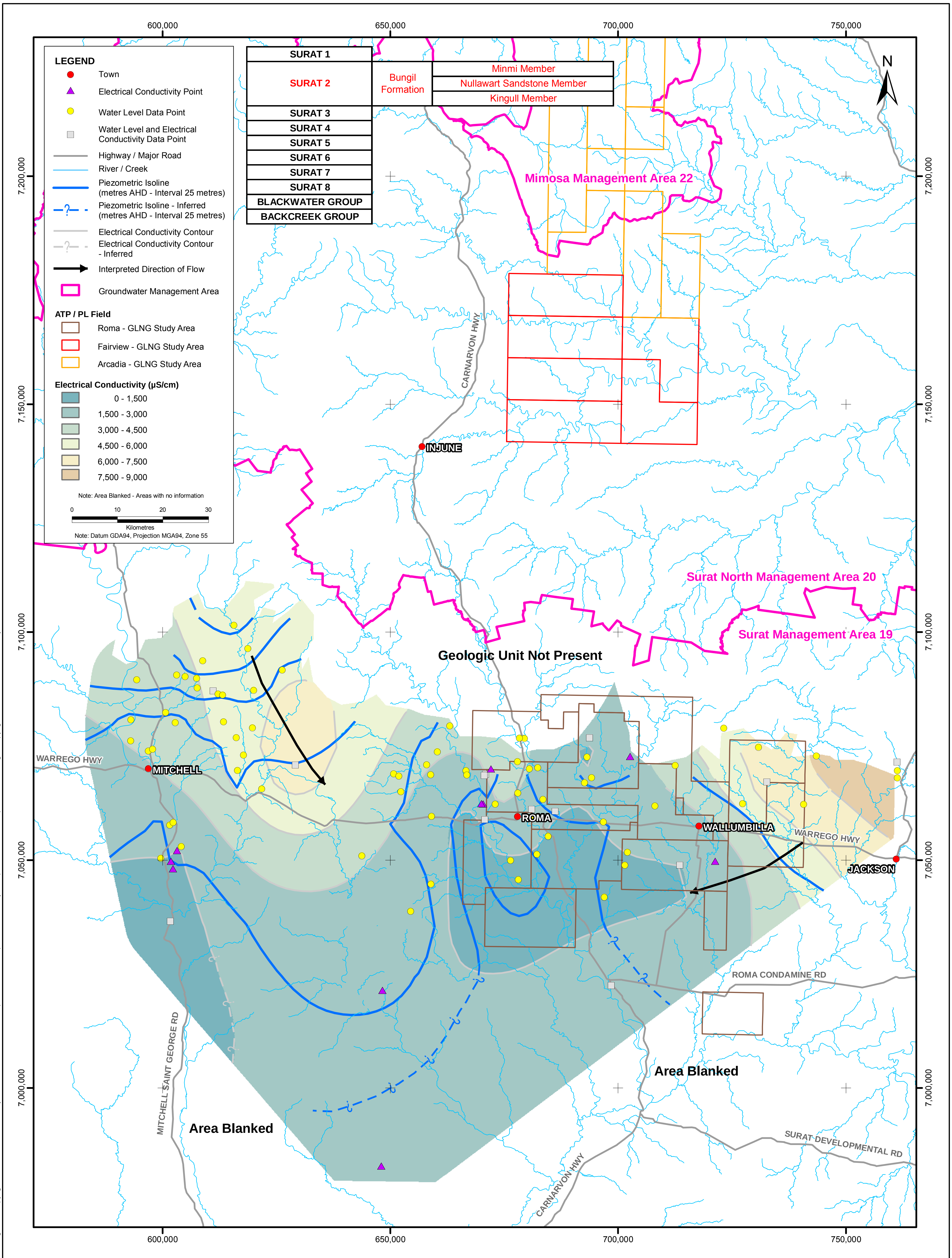

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5. The data used to generate these maps were collected between the years 1900 and 1999, and used to represent the approximate hydrogeological conditions in the study area prior to CSG operation.

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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN BC/BQ/BT	DATE 08-04-09	TITLE	HYDROGEOLOGICAL MAP - SURAT 2 UNIT
CHECKED SH*	DATE 08-04-09		
SCALE	1:750,000	PROJECT No 087636015_019	FIGURE No 17, REV No 1, A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S2_F0017_Rev1_A3.mxd
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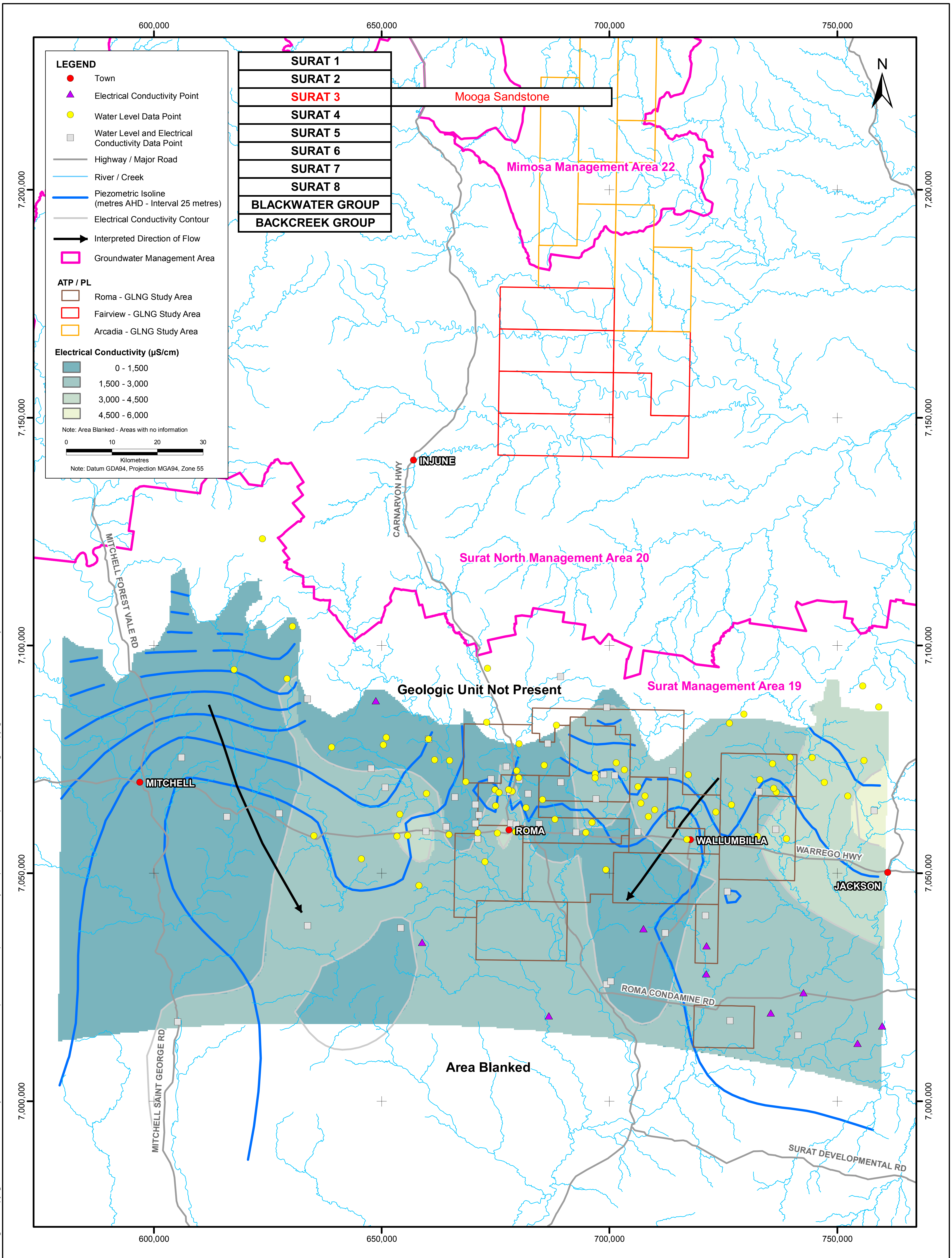

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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN BC/BQ/BT	DATE 08-04-09	TITLE	HYDROGEOLOGICAL MAP - SURAT 3 UNIT
CHECKED SH*	DATE 08-04-09		
SCALE	1:750,000	PROJECT No 087636015_019	FIGURE No 18 / REV No 1 / A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S3_F0018_Rev1_A3.mxd
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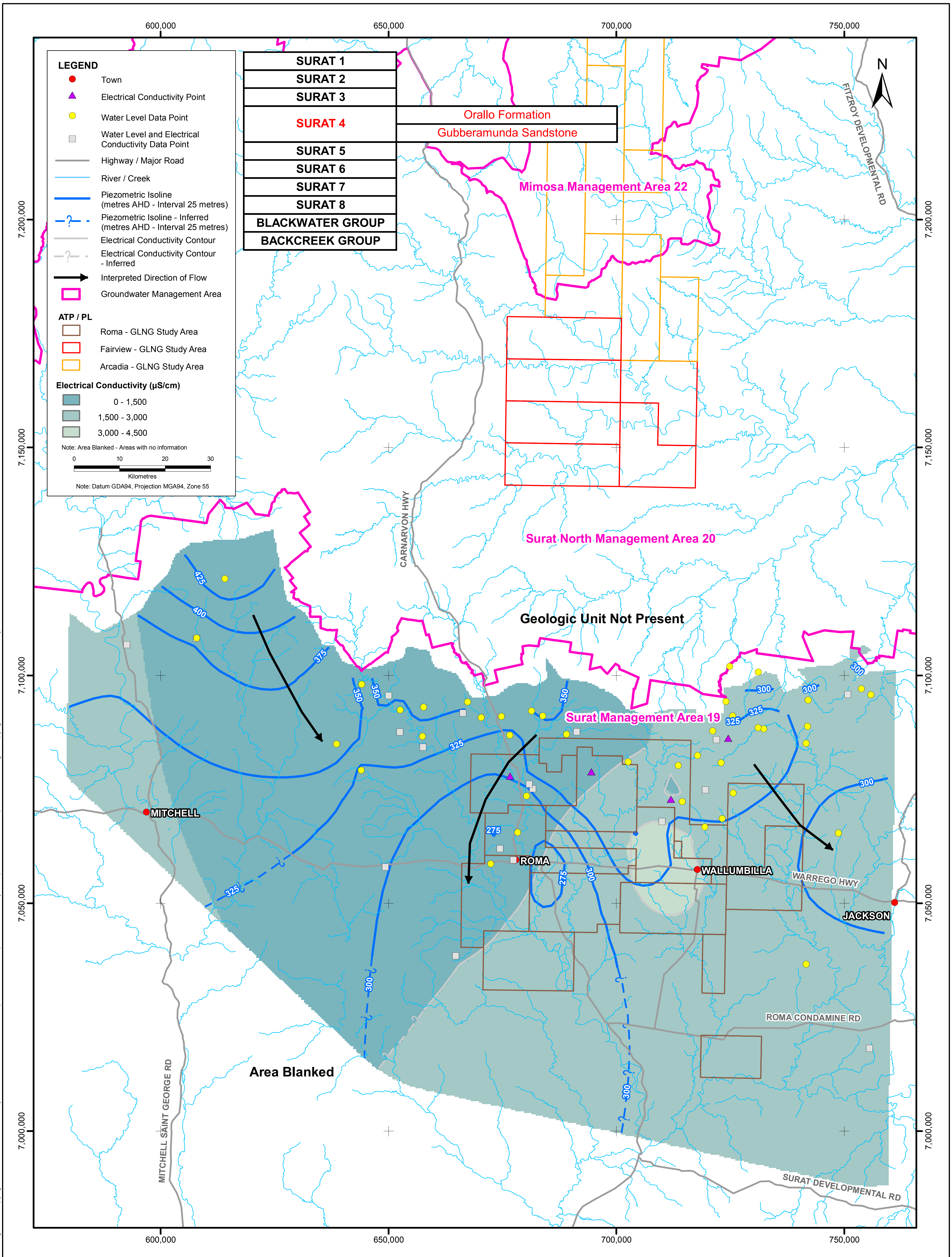

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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN BC/BQ/BT	DATE 08-03-09	TITLE	HYDROGEOLOGICAL MAP - SURAT 4 UNIT
CHECKED SH*	DATE 08-03-09		
SCALE	1:750,000	PROJECT No 087636015_019	FIGURE No 19, REV No 1, A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S4_F0019_Rev1_A3.mxd
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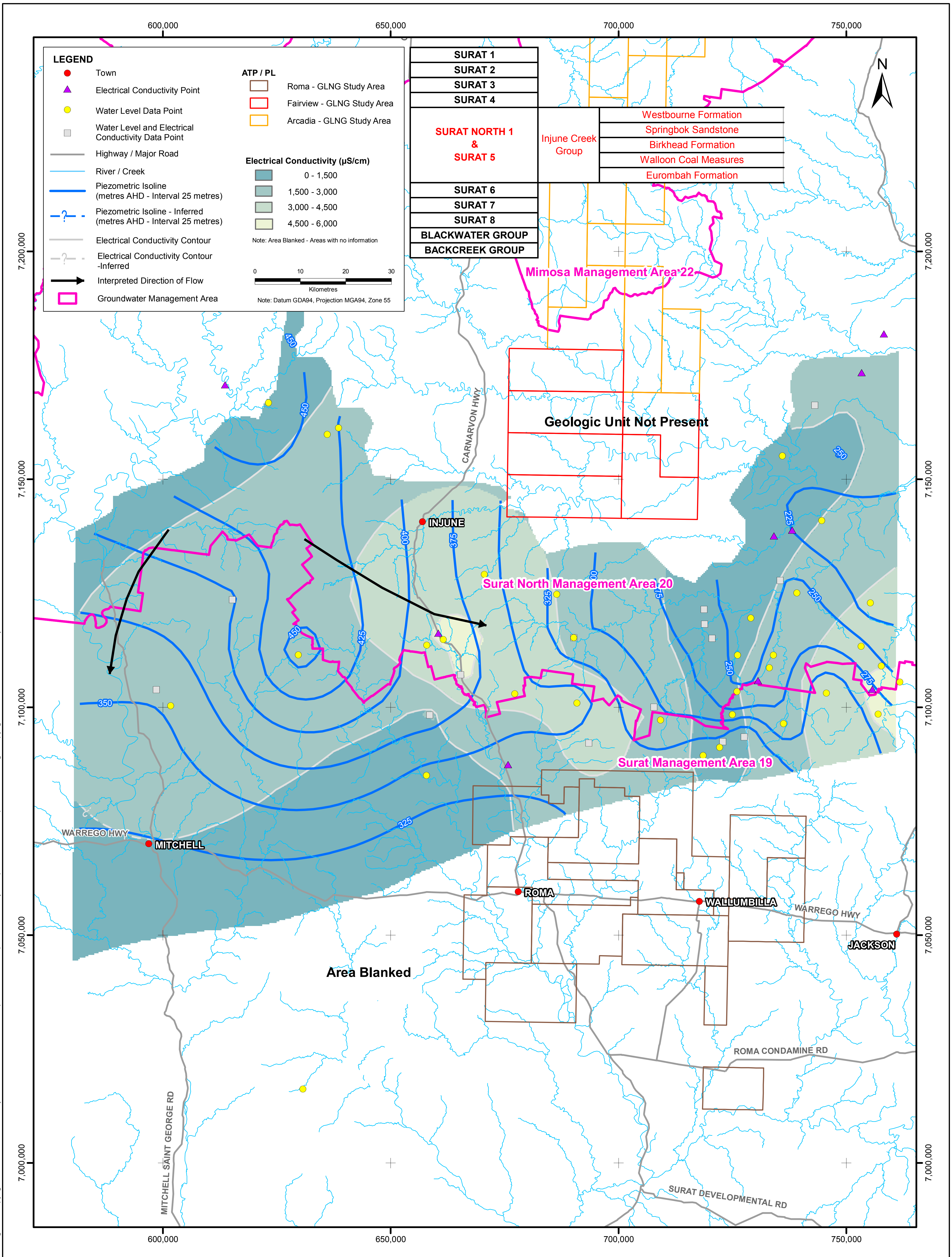

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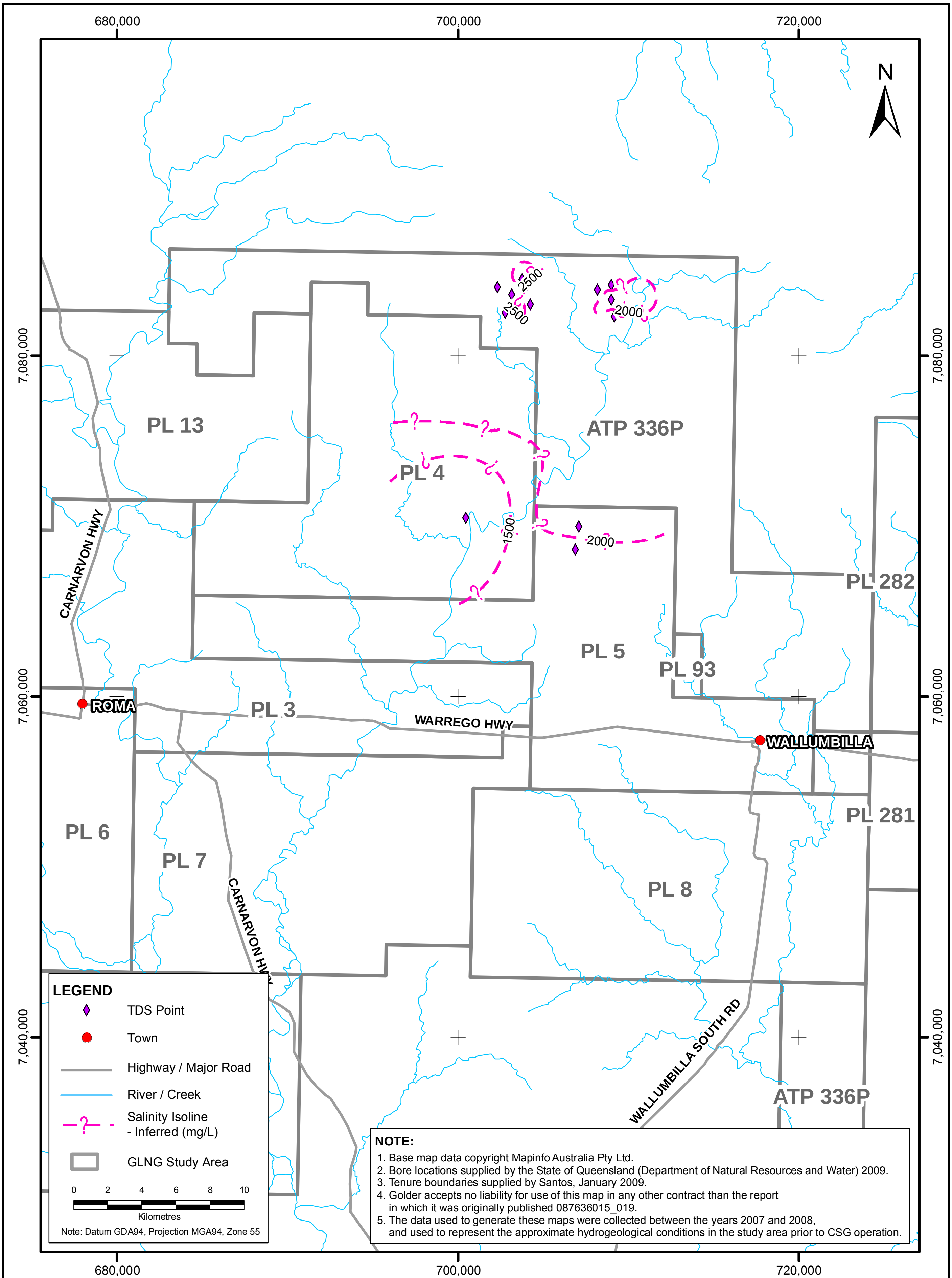
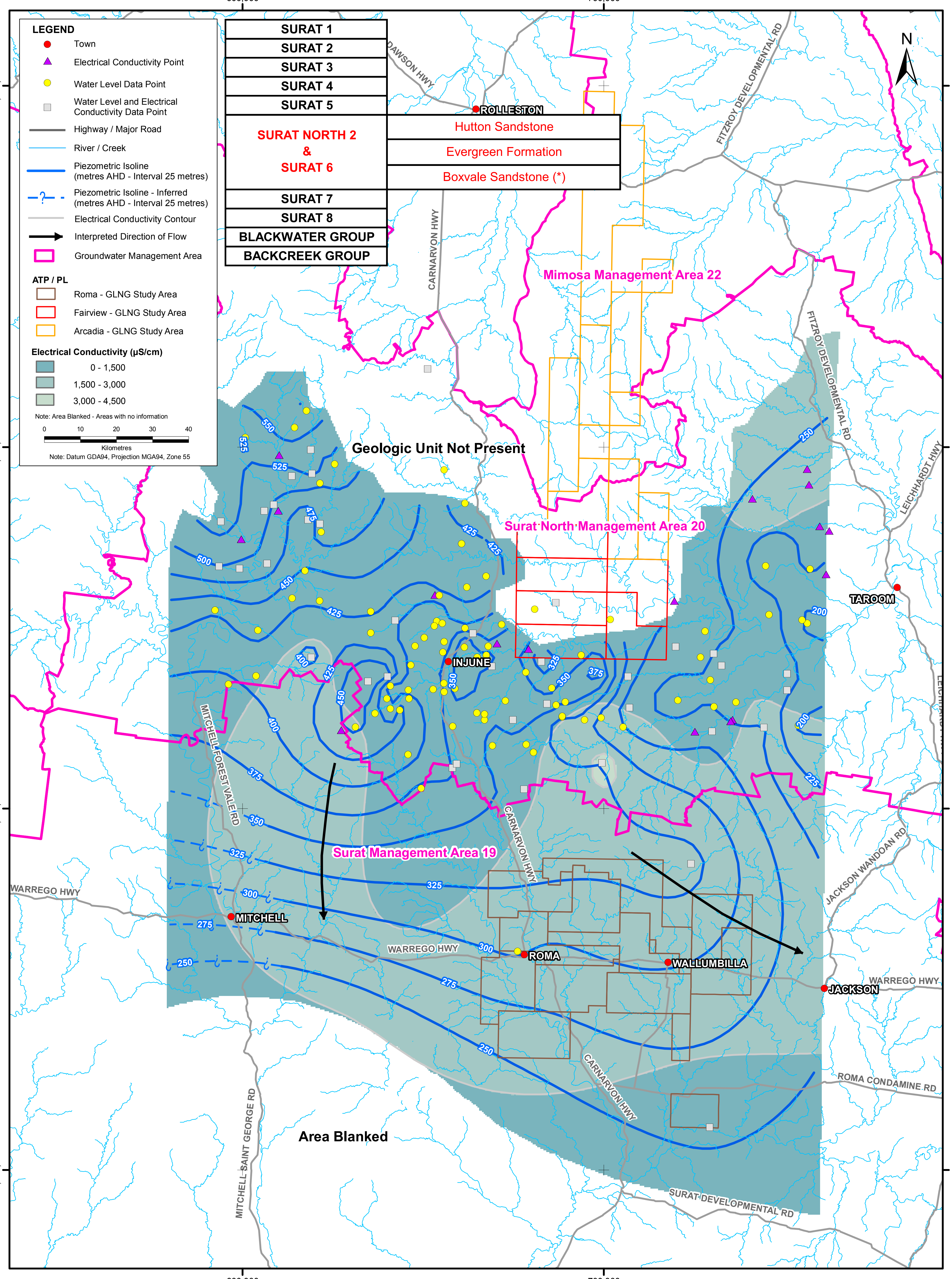
CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN	BC/BQ/BT	DATE 08-04-09	TITLE HYDROGEOLOGICAL MAP - SURAT 5 UNIT
CHECKED	SH*	DATE 08-04-09	
SCALE	1:750,000	PROJECT No 087636015_019	FIGURE No 20a · REV No 1 · A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S5_F0020a_Rev1_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



Golder Associates	CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study
	DRAWN: BC	DATE: 08-04-09	TITLE: SALINITY MAP - WALLOON COAL MEASURES
	CHECKED: SH*	DATE: 08-04-09	
	SCALE: 1:300,000		PROJECT No: 087636015_019 · FIGURE No: 20b · REV No: 0 · A4

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_SalinityMap_Walloon_F0020b_Rev0_A4.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



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CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN	BC/BQ/BT	DATE	08-04-09
CHECKED	SH*	DATE	08-04-09
TITLE	HYDROGEOLOGICAL MAP - SURAT 6 UNIT		
SCALE	1:1,000,000	PROJECT No	087636015_019
FIGURE No	21	REV No	1
A3			

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S6_F0021_Rev1_A3.mxd
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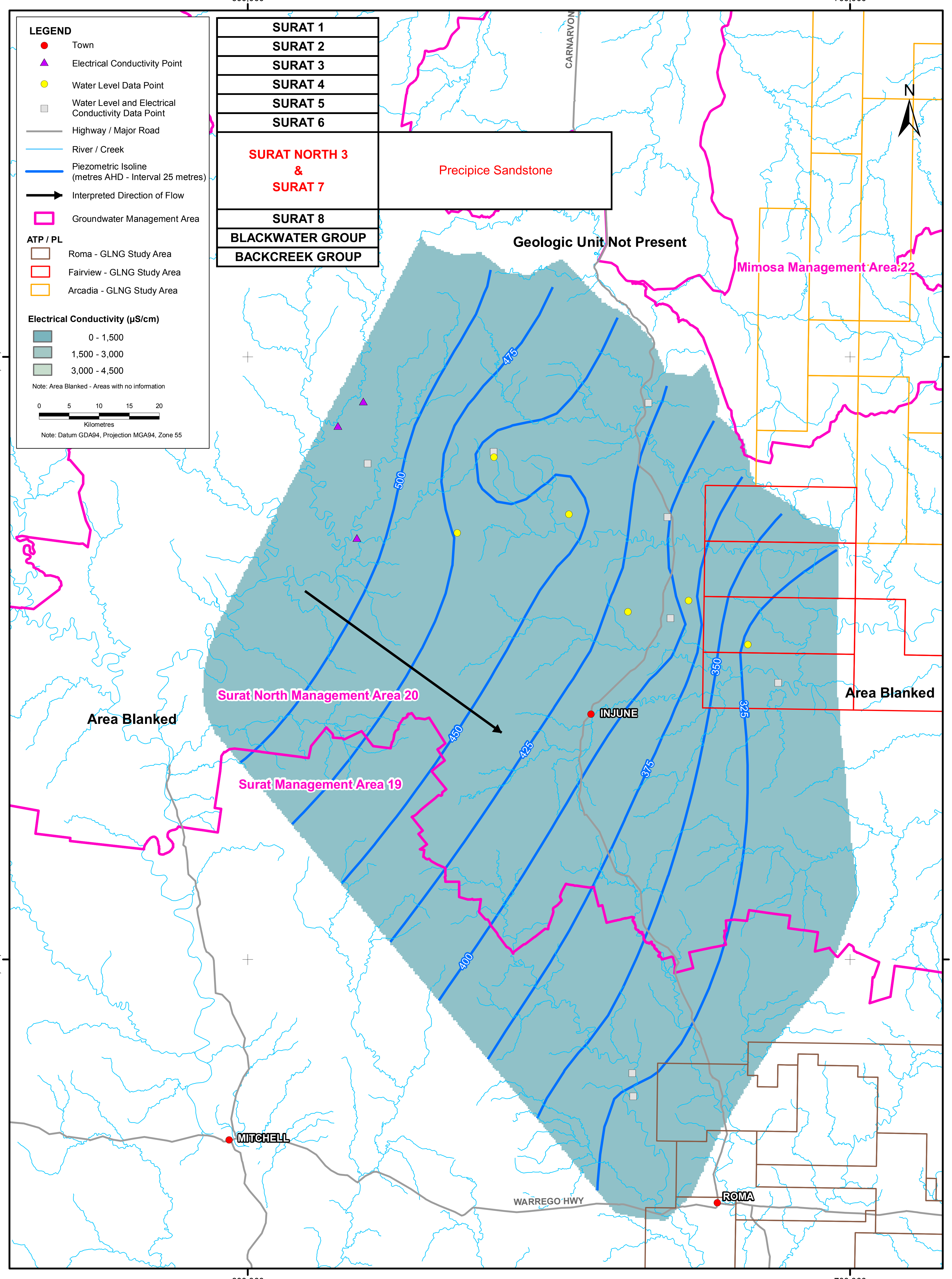

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5. The data used to generate these maps were collected between the years 1900 and 1999, and used to represent the approximate hydrogeological conditions in the study area prior to CSG operation.

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CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study	
DRAWN: BC/BQ/BT	DATE: 08-04-09	TITLE: HYDROGEOLOGICAL MAP - SURAT 7 UNIT	
CHECKED: SH*	DATE: 08-04-09		
SCALE: 1:600,000		PROJECT No: 087636015_019	FIGURE No: 22 / REV No: 1 / A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S7_F0022_Rev1_A3.mxd
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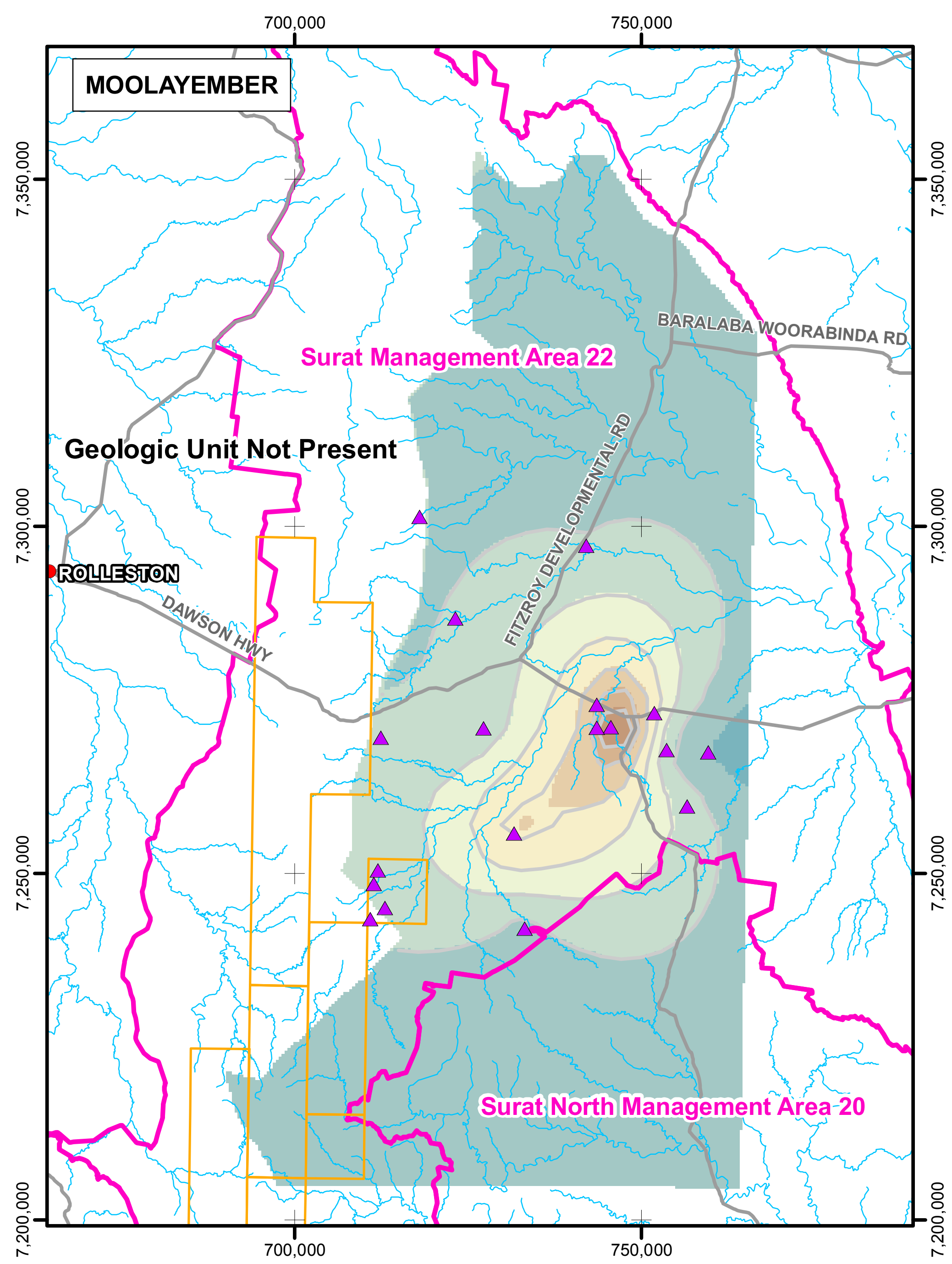
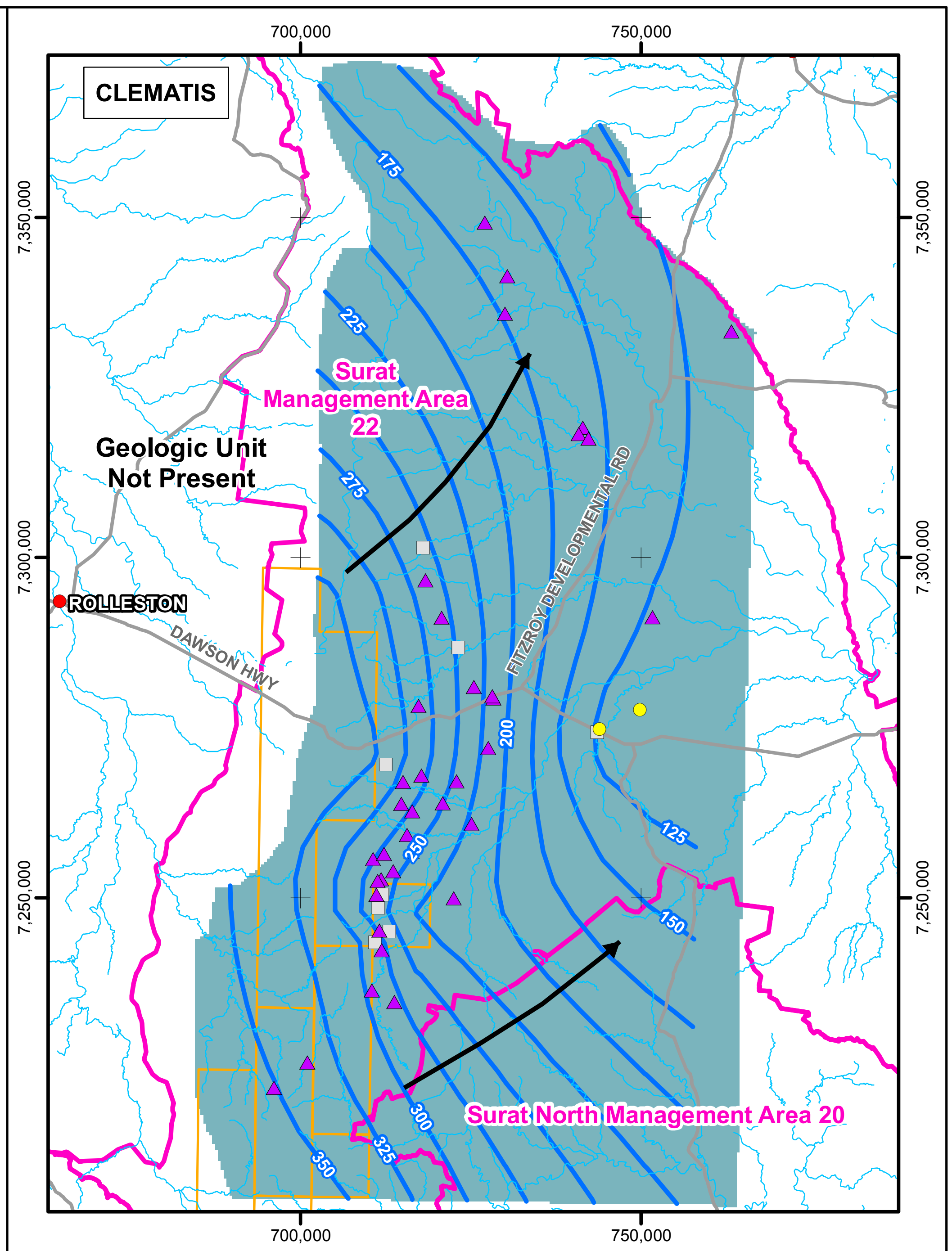




LEGEND

- Town
- Electrical Conductivity Point
- Water Level Data Point
- Water Level and Electrical Conductivity Data Point
- Highway / Major Road
- River / Creek
- Piezometric Isoline (Surat 8) (metres AHD - Interval 25 metres)
- Electrical Conductivity Contour
- Interpreted Direction of Flow
- Groundwater Management Area

ATP / PL

- Roma - GLNG Study Area
- Fairview - GLNG Study Area
- Arcadia - GLNG Study Area

Electrical Conductivity (µS/cm) (Moolayember & Clematis)

- 0 - 1,500
- 1,500 - 3,000
- 3,000 - 4,500
- 4,500 - 6,000
- 6,000 - 7,500
- 7,500 - 9,000

Electrical Conductivity (µS/cm) (Rewan)

- 1500 - 6,000
- 6,000 - 12,000
- 12,000 - 18,000
- 18,000 - 24,000
- 24,000 - 30,000

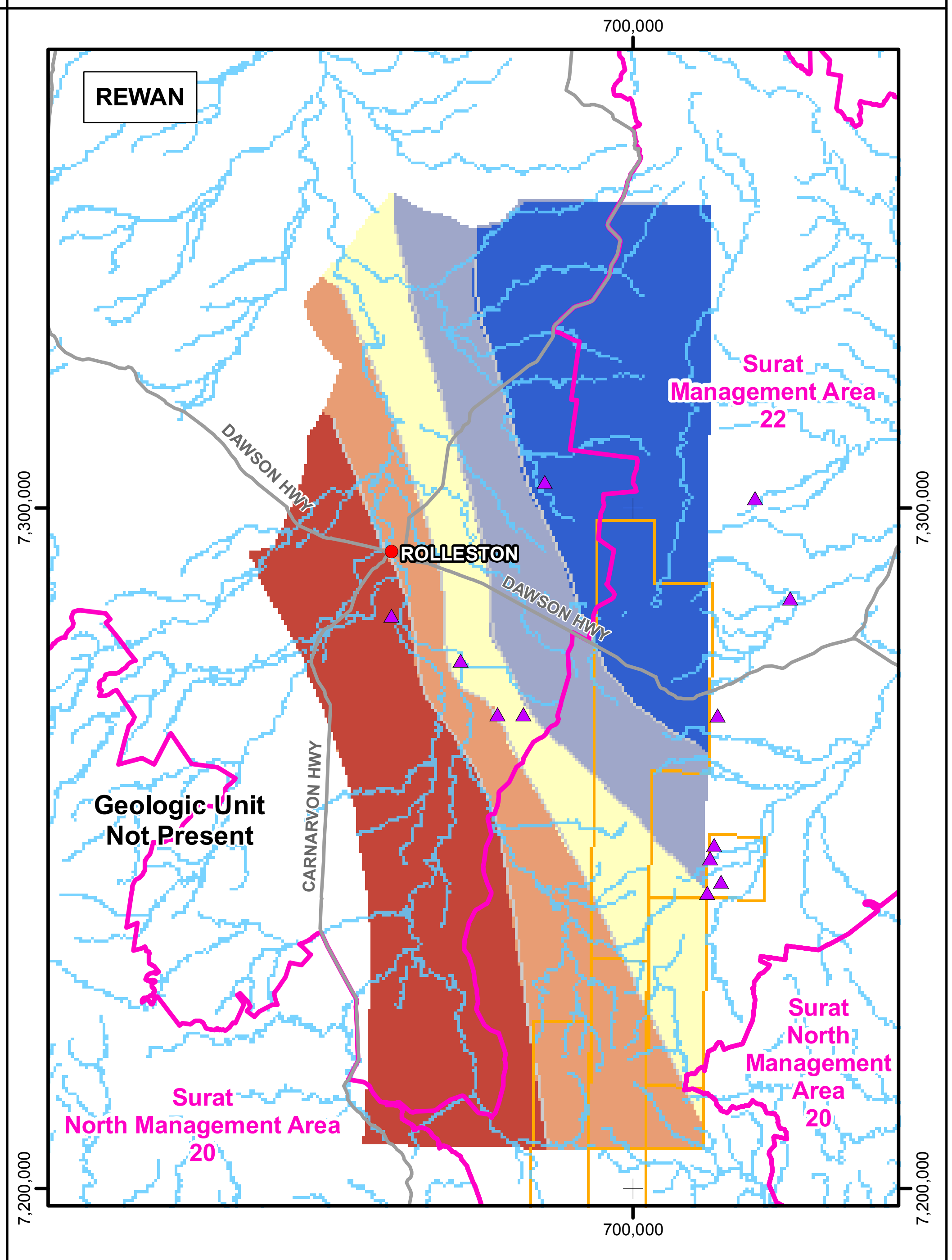
Note: Area Blanked - Areas with no information

SURAT 1		
SURAT 2		
SURAT 3		
SURAT 4		
SURAT 5		
SURAT 6		
SURAT 7		
MIMOSA 1 & SURAT NORTH 4 & SURAT 8	Wandoan Formation	Moolayember Formation
		Clematis Sandstone
		Rewan Formation
BLACKWATER GROUP		
BACKCREEK GROUP		

N

0 10 20 30 40
Kilometres

Note: Datum GDA94, Projection MGA94, Zone 55



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5. The data used to generate these maps were collected between the years 1900 and 1999, and used to represent the approximate hydrogeological conditions in the study area prior to CSG operation.

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CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study	
DRAWN: BC/BQ/BT	DATE: 08-04-09	TITLE: HYDROGEOLOGICAL MAP - SURAT 8 UNIT (MOOLAYEMBER, CLEMATIS, REWAN)	
CHECKED: SH*	DATE: 08-04-09		
SCALE: 1:1,000,000		PROJECT No: 087636015_019	FIGURE No: 23 REV No: 1 A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_S8_F0023_Rev1_A3.mxd
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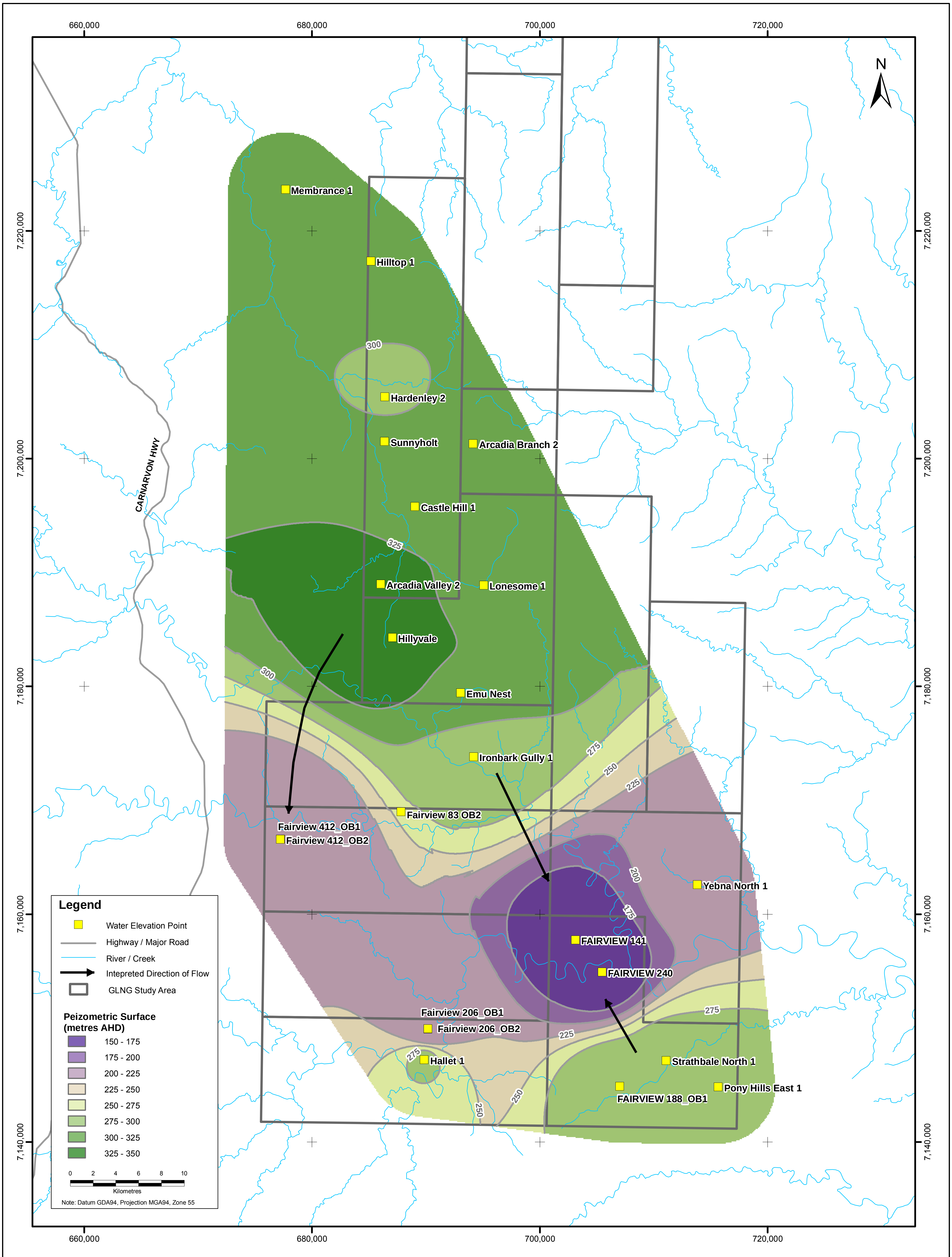

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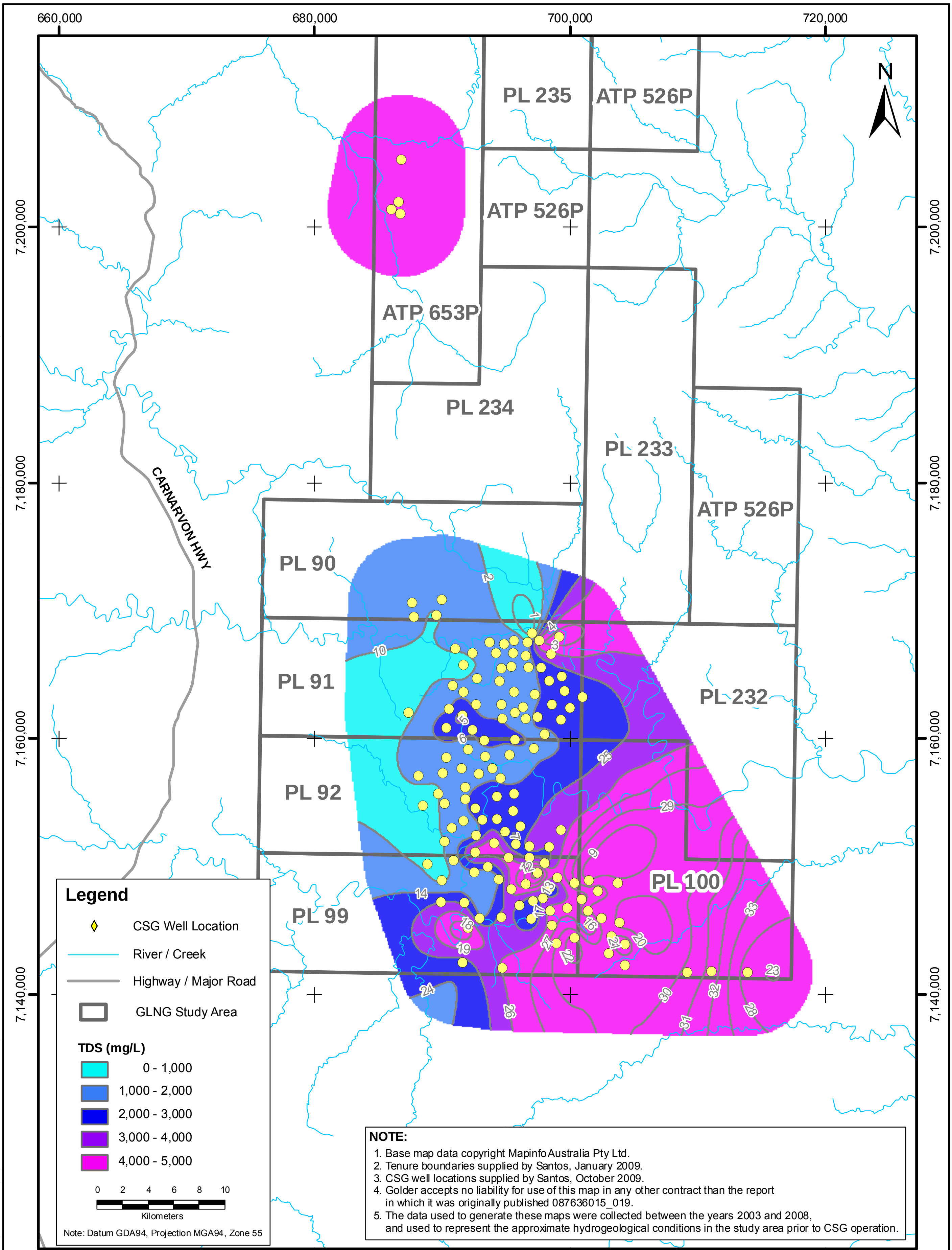
2. Bore locations supplied by the State of Queensland (Department of Natural Resources and Water) 2009.
3. Tenure boundaries supplied by Santos, January 2009.
4. Golder accepts no liability for use of this map in any other contract than the report in which it was originally published 087636015_019.
5. The data used to generate these maps were collected between the years 2006 and 2009, and used to represent the approximate hydrogeological conditions in the study area prior to CSG operation.

Golder Associates

CLIENT	Santos	PROJECT	Santos GLNG Groundwater Impact Study
DRAWN BC	DATE 08-04-09	TITLE	PEIZOMETRIC SURFACE OF THE BANDANNA FORMATION
CHECKED SH*	DATE 08-04-09		
SCALE	1:300,000	PROJECT No 087636015_019	FIGURE No 24a · REV No 0 · A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_Peizometric_Surface_Bandanna_Fig24a_Rev0_A3.mxd
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



Golder Associates

CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study			
DRAWN: BC	DATE: 15-10-09	TITLE: SALINITY MAP BANDANNA FORMATION			
CHECKED: SH*	DATE: 15-10-09				
SCALE: 1:400,000		PROJECT No: 087636015_019	FIGURE No: 24b	REV No: 1	A4

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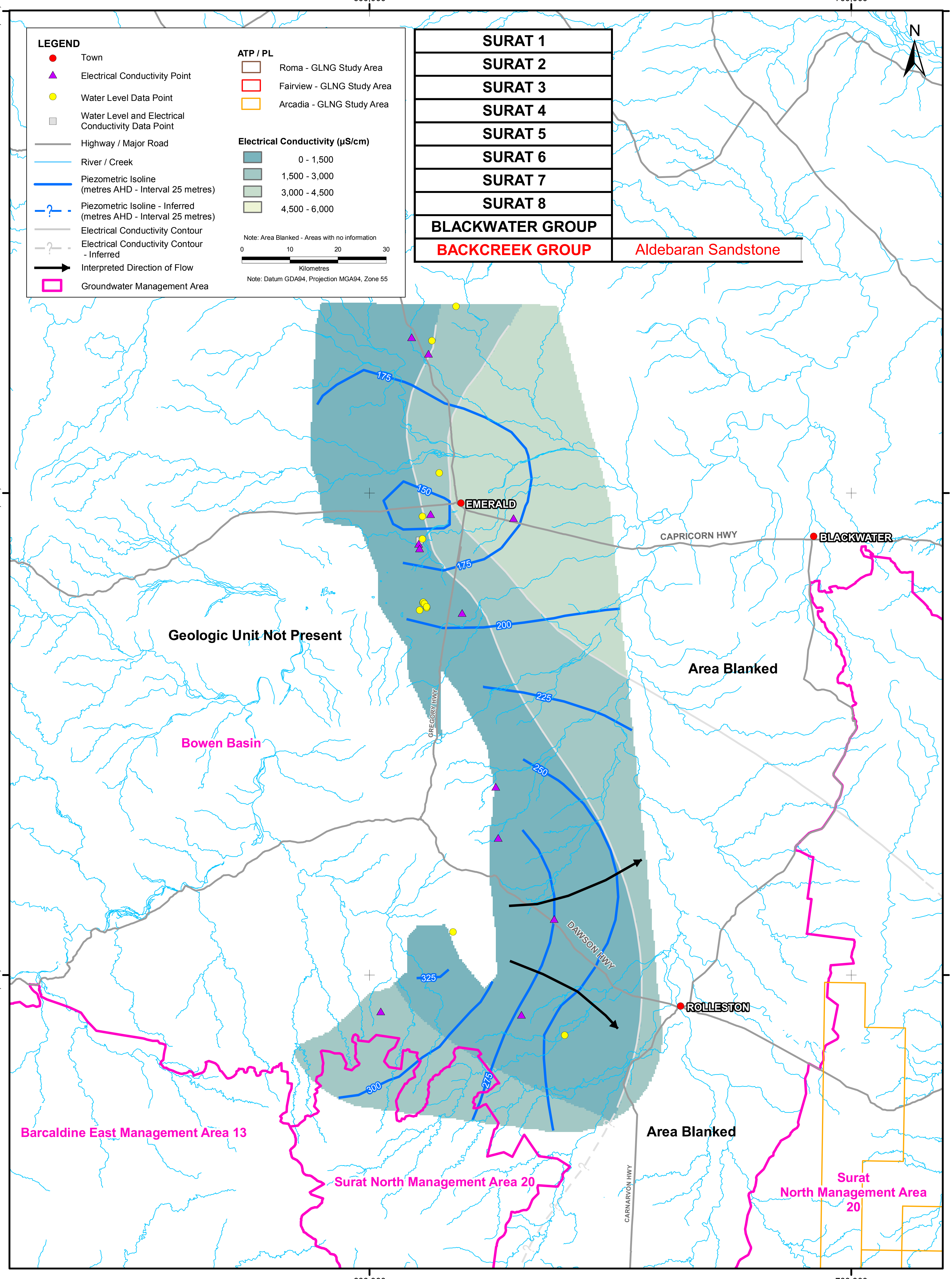
Note: The * beside the typed initials denotes the original drawing issue was signed or initialled by that respective person.



NOTE:
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5. The data used to generate these maps were collected between the years 1900 and 1999, and used to represent the approximate hydrogeological conditions in the study area prior to CSG operation.

Golder Associates

CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study	
DRAWN: BC/BQ	DATE: 08-04-09	TITLE: HYDROGEOLOGICAL MAP - BACK CREEK GROUP UNIT	
CHECKED: SH*	DATE: 08-04-09		
SCALE: 1:750,000		PROJECT No: 087636015_019	FIGURE No: 25 · REV No: 1 · A3

File Location: R:\Hyd\2008\087636015_Santos\GIS\Projects\087636015_019_R_HydrogeologyMap_BackCrk_F0025_Rev1_A3.mxd
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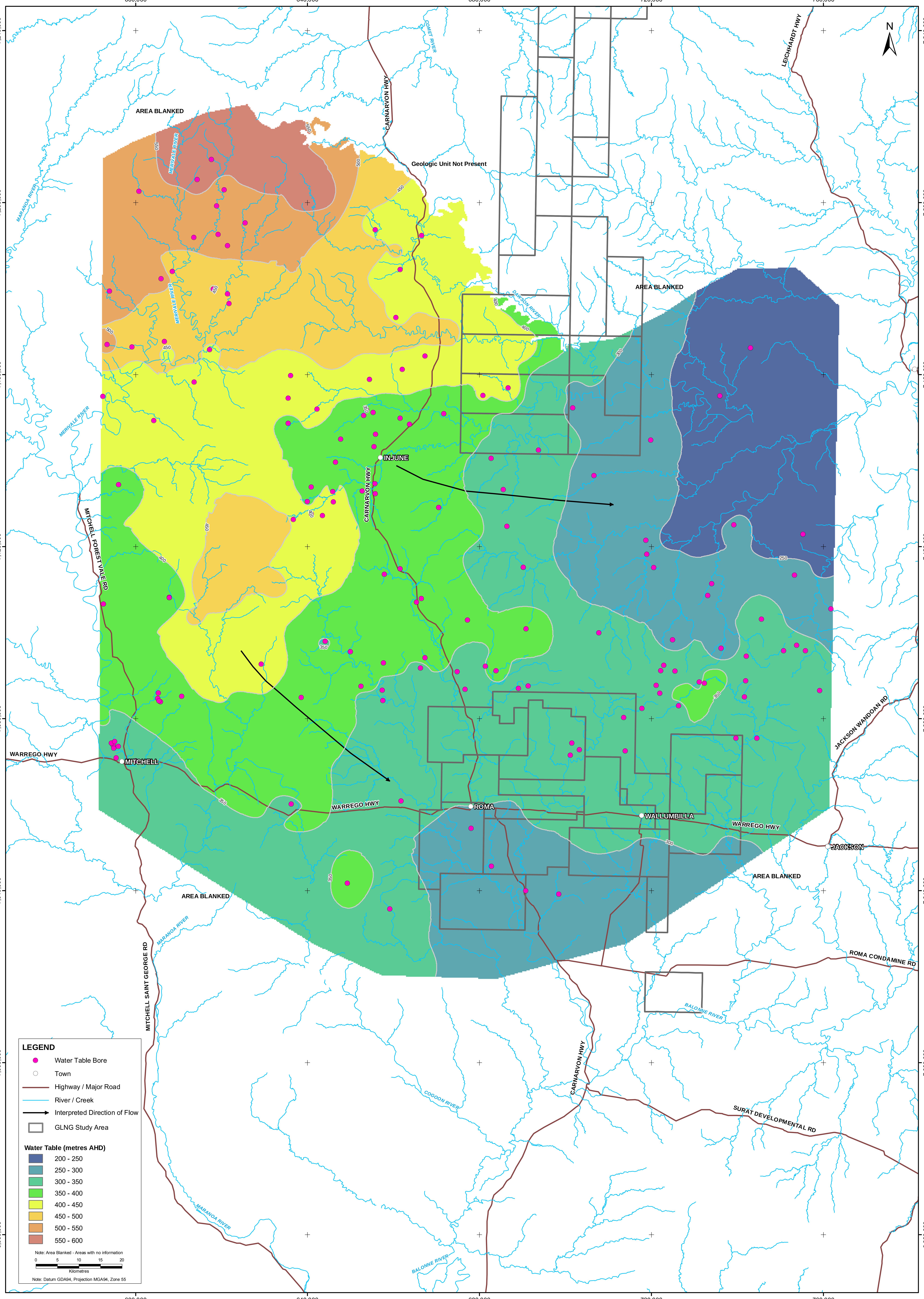

NOTE:
1. Base map data copyright Mapinfo Australia Pty Ltd.
2. Bore locations supplied by the State of Queensland (Department of Natural Resources and Water) 2009.
3. Tenure boundaries supplied by Santos, January 2009.
4. Golder accepts no liability for use of this map in any other contract than the report in which it was originally published 087636015_019.
5. The data used to generate these maps were collected between the years 1901 and 1999, and used to represent the approximate hydrogeological conditions in the study area prior to CSG operation.

Golder Associates

CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study	
DRAWN: BC	DATE: 08-04-09	TITLE: WATER TABLE MAP FOR THE SURAT BASIN WITHIN THE GLNG PROJECT AREA	
CHECKED: SH*	DATE: 08-04-09		
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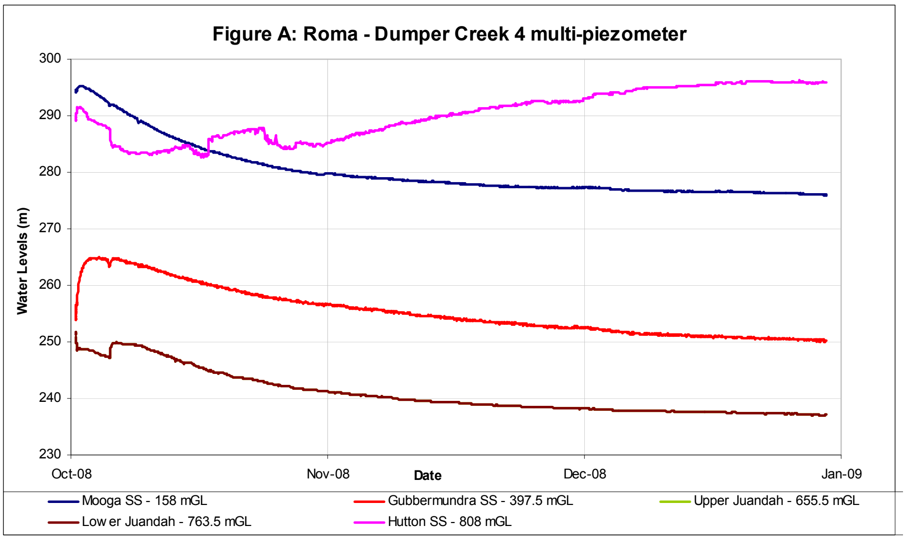
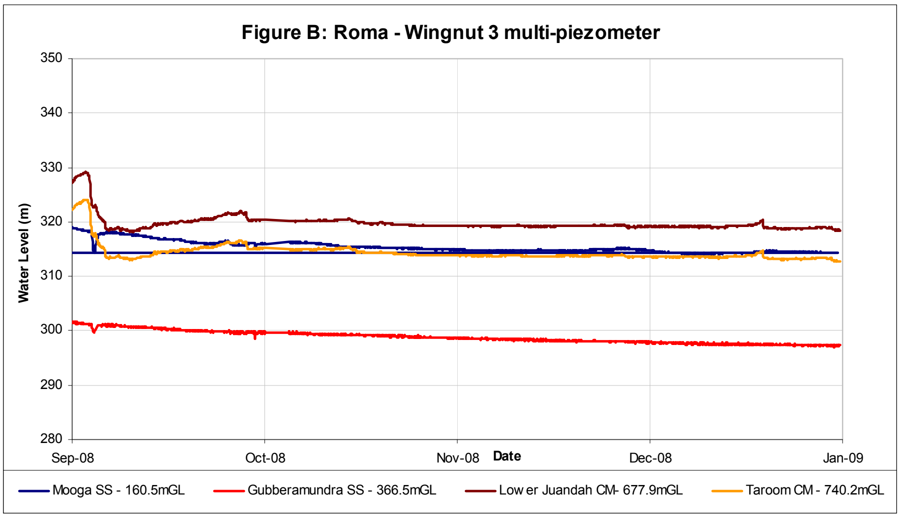
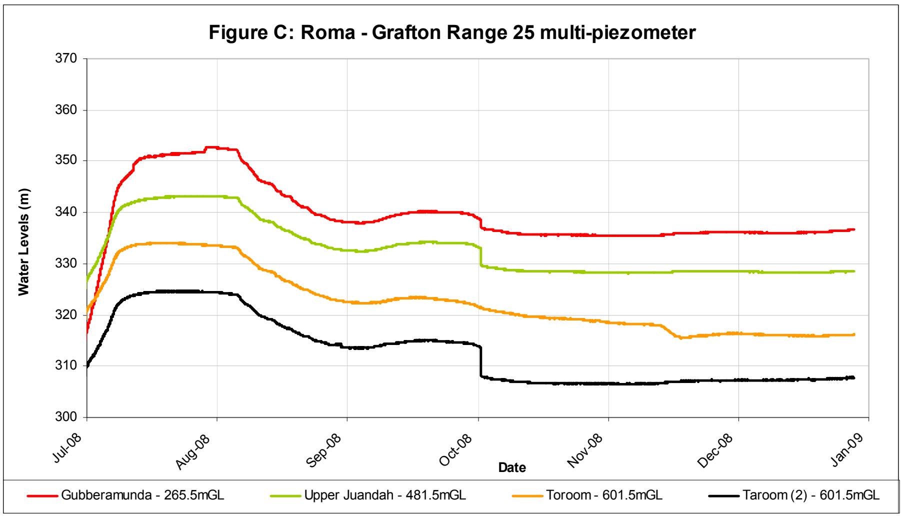


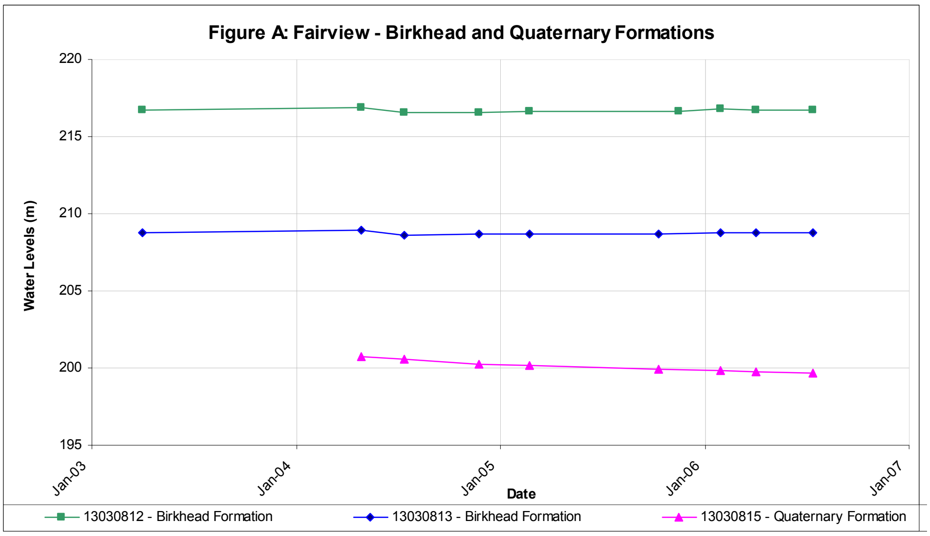


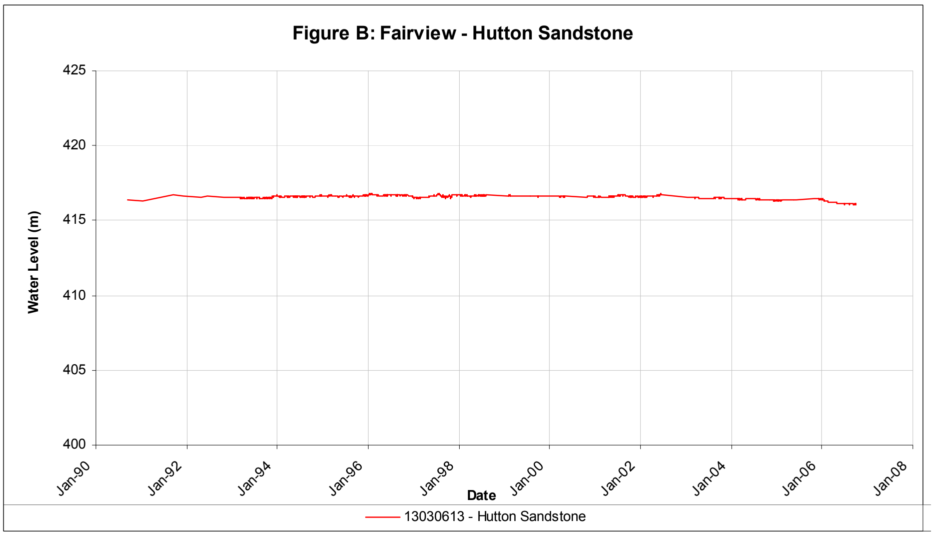


Golder Associates

CLIENT Santos		PROJECT GLNG Project Groundwater Impact Study	
DRAWN TP	DATE 27-03-2009	TITLE WATER LEVELS IN ROMA CSG FIELD	
CHECKED SH	DATE 03-04-2009		
SCALE N.T.S.		PROJECT No 087636015_019	FIGURE No 27 / REV No 0 / A4

FILE LOCATION: J:\hyd\2008\087626131_Santos_SuratBasin\GW Impact - Correspondence Out\Figures

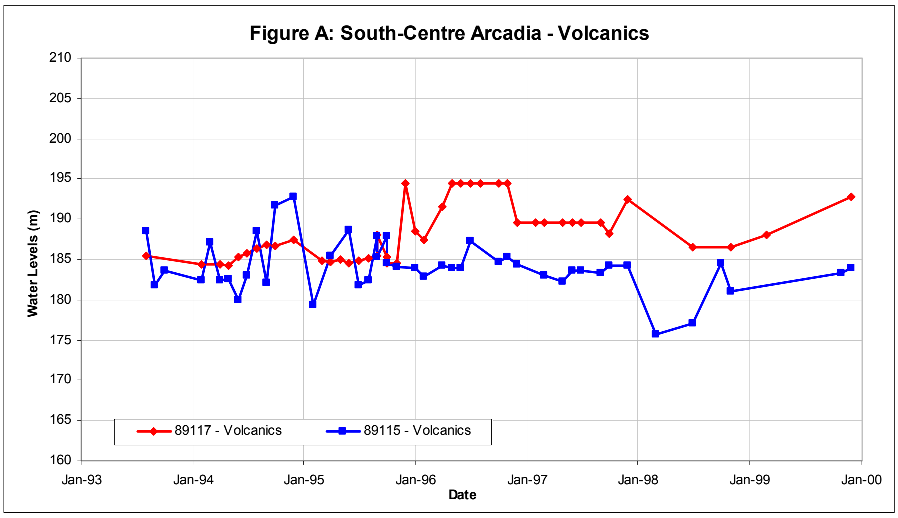


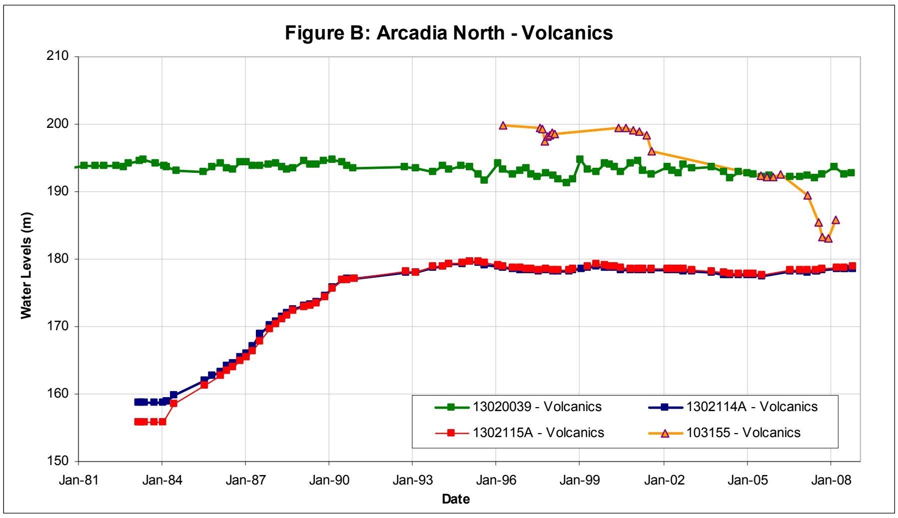


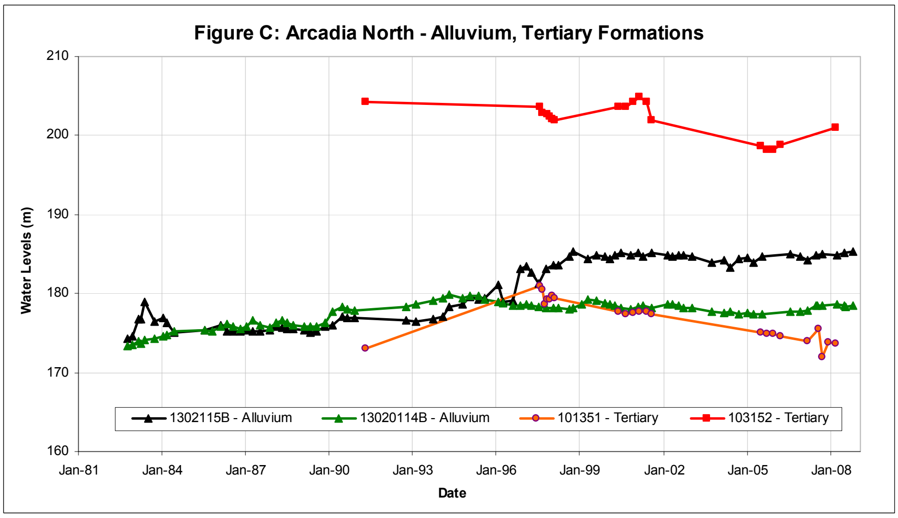
Golder Associates

CLIENT Santos		PROJECT GLNG Project Groundwater Impact Study		
DRAWN TP	DATE 03-03-2009	TITLE WATER LEVELS IN FAIRVIEW CSG FIELD		
CHECKED SH	DATE 04-03-2009			
SCALE N.T.S.		PROJECT No 087626131	FIGURE No 28	REV No 0 A4

FILE LOCATION: J:\hyd\2008\087626131_Santos_SuratBasin\GW Impact - Correspondence Out\Figures\Figure 25 - Temporal Water Levels in Fairview CSG Field.ppt



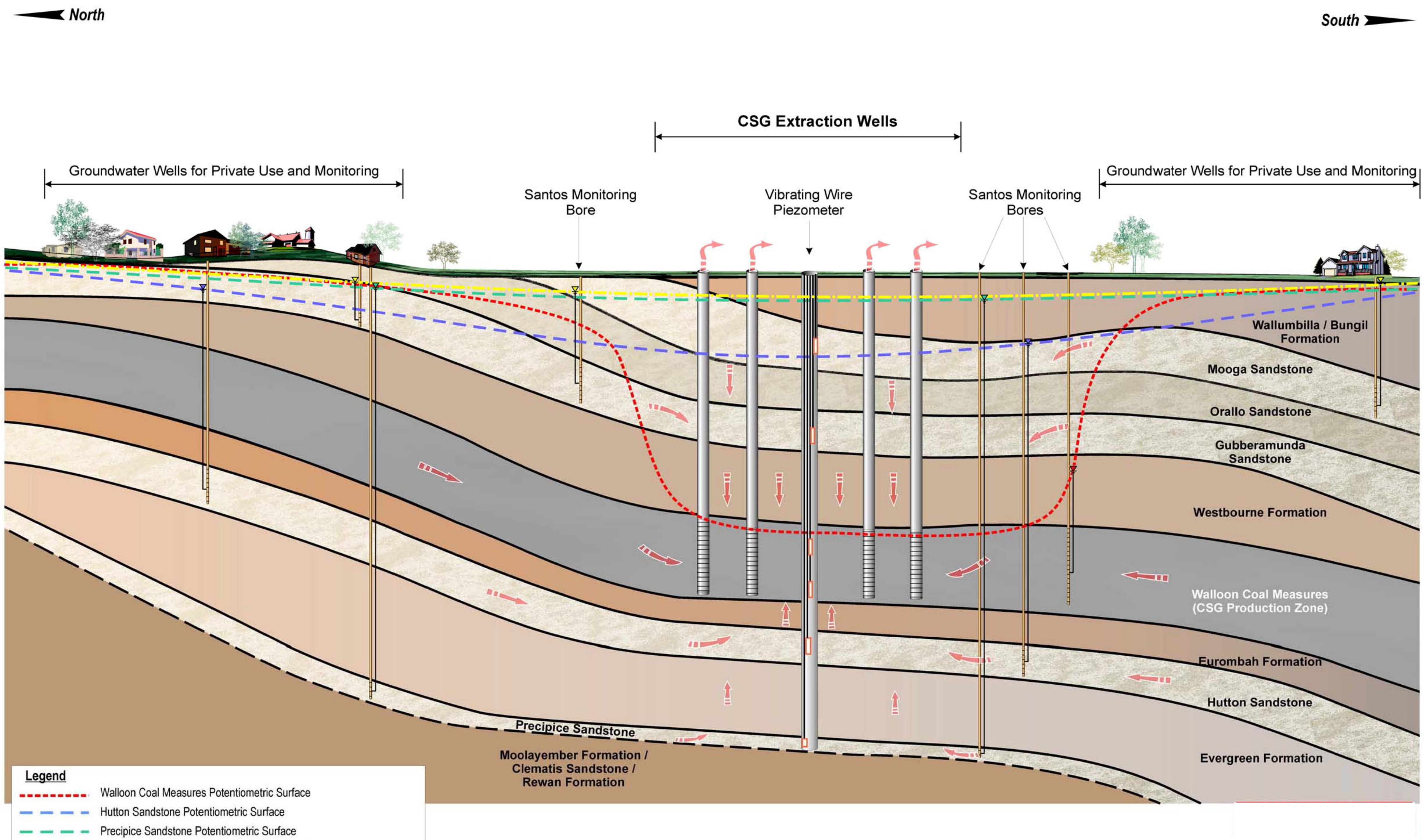




Golder Associates

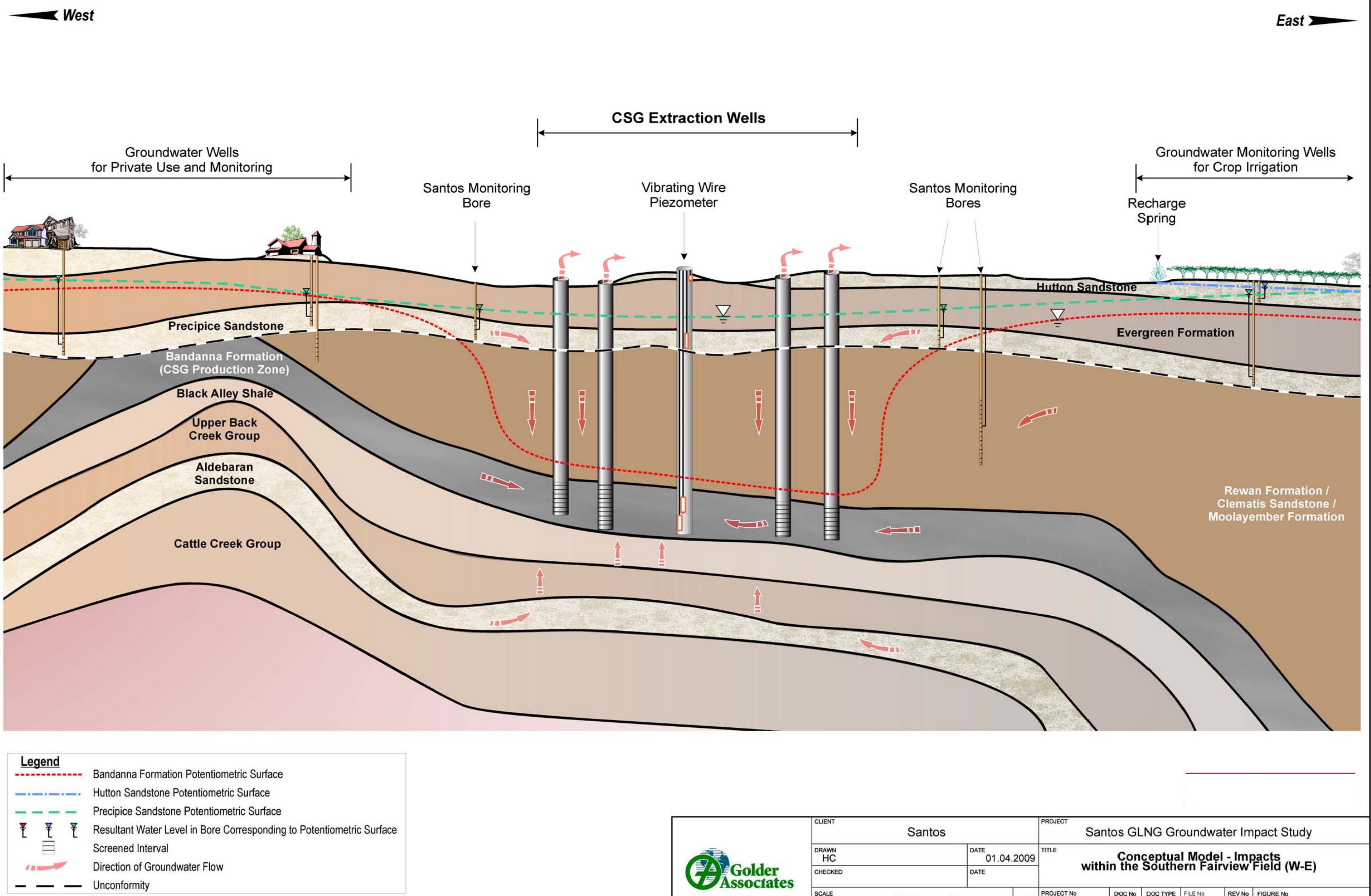
CLIENT Santos		PROJECT GLNG Project Groundwater Impact Study	
DRAWN TP	DATE 27-03-2009	TITLE WATER LEVELS IN ARCADIA CSG FIELD	
CHECKED SH	DATE 03-04-2009		
SCALE N.T.S.		PROJECT No 087636015_019	FIGURE No 29 REV No 0 A4

FILE LOCATION: J:\hyd\2008\087626131_Santos_SuratBasin\GW Impact - Correspondence Out\Figures\Figure 26 - Temporal Water Levels in Arcadia CSG Field.ppt



Golder Associates www.golder.com GOLDER ASSOCIATES PTY LTD	CLIENT Santos		PROJECT Santos GLNG Groundwater Impact Study	
	DRAWN HC	DATE 01.04.2009	TITLE **Conceptual Model - Impacts within the Roma Field (N-S)**	
	CHECKED	DATE		
	SCALE Not to scale	A3	PROJECT No 087636015 / DOC No 019 / DOC TYPE RPT / FILE No. F0001 / REV No D	FIGURE No 47

J:\hyd\2008\087626131_Santos_SuratBasin\Technical Doc\CADD\FIGURES\087626131_004_R_F0001_REV0



Golder Associates www.golder.com GOLDER ASSOCIATES PTY LTD	CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study	
	DRAWN: HC	DATE: 01.04.2009	TITLE: Conceptual Model - Impacts within the Southern Fairview Field (W-E)	
	CHECKED:	DATE:		
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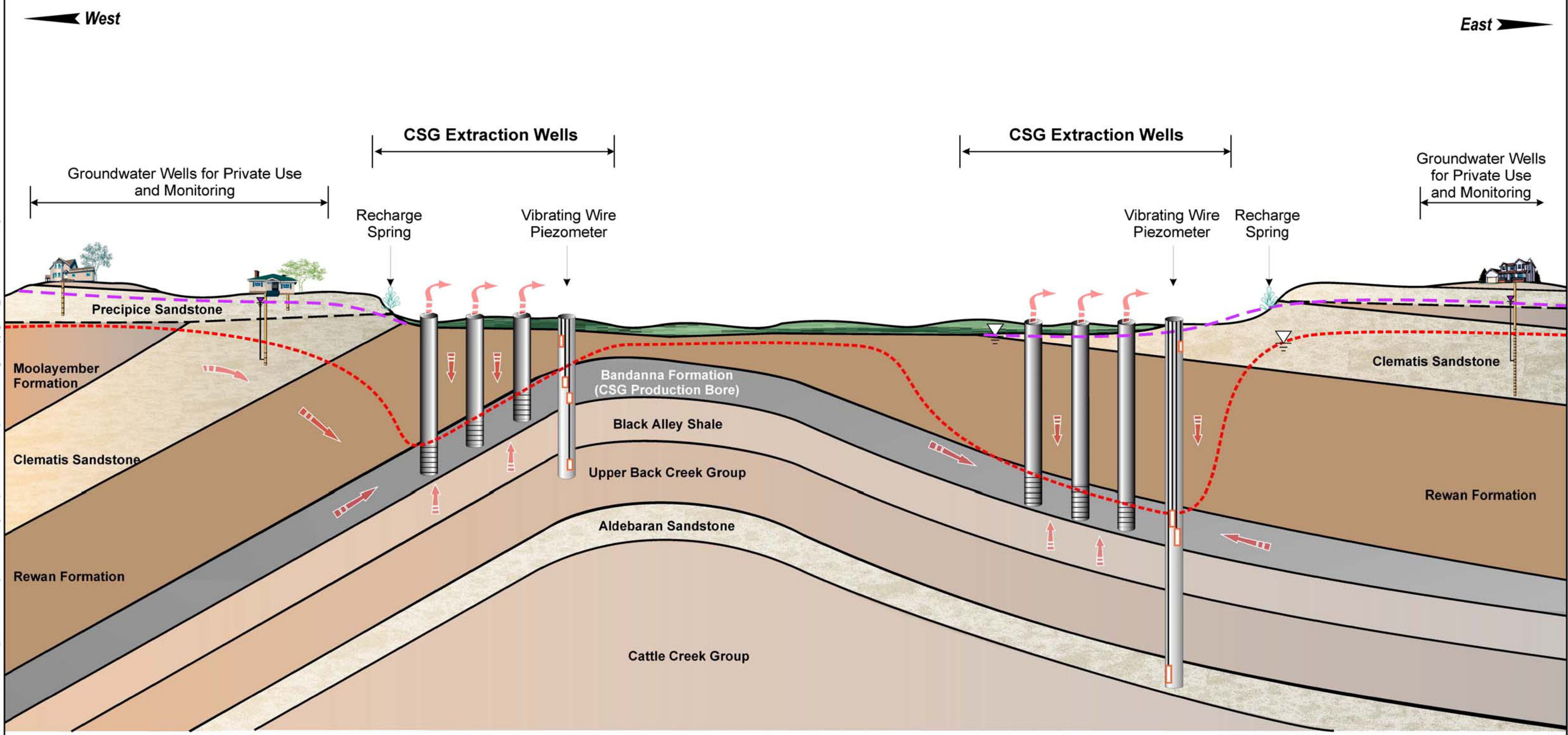

Legend

- Bandanna Potentiometric Surface
- Clematis Sandstone Potentiometric Surface
- Resultant Water Level in Bore Corresponding to Potentiometric Surface
- Screened Interval
- Direction of Groundwater Flow
- Unconformity

Golder Associates www.golder.com GOLDER ASSOCIATES PTY LTD	CLIENT: Santos		PROJECT: Santos GLNG Groundwater Impact Study
	DRAWN: HC	DATE: 01.04.2009	TITLE: Conceptual Model - Impacts within the Arcadia Field (W-E)
	CHECKED:	DATE:	
	SCALE: Not to scale	A3	PROJECT No: 087636015; DOC No: 019; DOC TYPE: RPT; FILE No.: F0003; REV No: D; FIGURE No: 49

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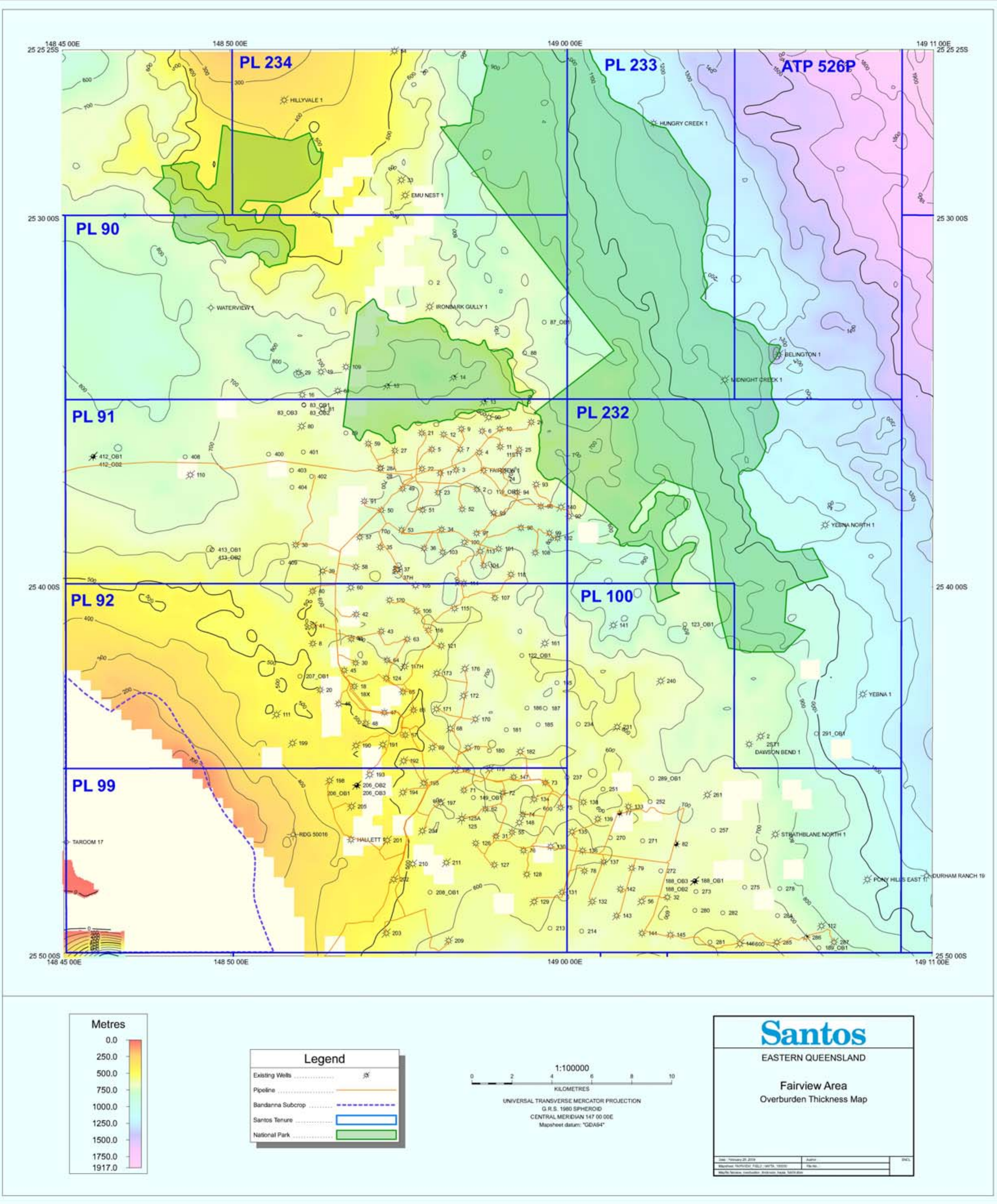
APPENDIX A

Meta Data Tables - See attached CD

APPENDIX B

Geological Information Provided by Santos


PL 234
PL 233
ATP 526P
PL 90
PL 91
PL 232
PL 92
PL 100
PL 99
HILLYVALE 1
EMU NEST 1
HUNGRY CREEK 1
WATERVIEW 1
IRONBARK GULLY 1
BELINGTON 1
MIDNIGHT CREEK 1
YEBNA NORTH 1
YEBNA 1
DAWSON BEND 1
STRATHBLANE NORTH 1
PONY HILLS EAST 1
DURHAM RANCH 19
TAROOM 17
RDG 50016
HALLETT 1
148 45 00E
148 50 00E
149 00 00E
149 11 00E
25 25 25S
25 30 00S
25 40 00S
25 50 00S
Metres
0.0
250.0
500.0
750.0
1000.0
1250.0
1500.0
1750.0
1917.0
Legend
Existing Wells
Pipeline
Bandanna Subcrop
Santos Tenure
National Park
1:100000
KILOMETRES
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
G.R.S. 1980 SPHEROID
CENTRAL MERIDIAN 147 00 00E
Mapsheet datum: "GDA94"
Santos
EASTERN QUEENSLAND
Fairview Area
Overburden Thickness Map

APPENDIX C

Groundwater Deep Aquifer Modelling, Matrixplus 2009:

- Relevant Figures
- Comet Ridge and Roma CSG Fields: Golder Modelling Report Review

MEMORANDUM

TO Shaun Davidge **DATE** 9 April 2009

CC Ray Hatley

FROM Justin Bell / Ewan Wilson **PROJECT No.** 087636015 026 Rev2

COMET RIDGE AND ROMA CSG FIELDS: MODELLING REPORT REVIEW

Introduction

Golder Associates Pty Ltd (Golder) were commissioned by Santos Ltd (Santos) to conduct a review of a groundwater modelling study that was carried out for the Gladstone Liquefied Natural Gas Environmental Impact Statement (GLNG EIS) by Matrix Consulting Pty Ltd (Matrixplus).

The Santos CSG operations in the Surat and Bowen geological basins are divided into three CSG fields: Roma, Fairview and Arcadia. However, for the purpose of deep aquifer groundwater modelling, the Project was divided into two fields as described in Table 1.

Table 1: CSG Fields

CSG Field	Location	Target Aquifer Formation
Comet Ridge Field: Fairview, Arcadia and Spring Gully (Operated by Origin Energy) Fields	Bowen Basin	Bandanna Formation
Roma Field	Surat Basin	Walloon Coal Measures (WCM)

It is proposed that during operations, the Walloon Coal Measures (WCM) and the Bandanna Formation aquifers will be depressurised to a nominated target pressure. The modelling objective was to identify and quantify any potential impacts of depressurisation on adjacent hydrogeological units.

Information Provided

Matrixplus Report

The following report describing the modelling work carried out by Matrixplus was provided to Golder:

Groundwater (Deep Aquifer Modelling) for Santos GLNG Environmental Impact Statement, February 2009 (Reference No. Matrixplus_20090211_Appendix_P2_(deep_aquifer_modelling).doc).

It is referred to in the sections that follow as Matrixplus_2009.

It should be noted that the review only concerns the reporting as provided; hands-on assessment of the model was outside of the scope of work at this stage.

Modelling Approach

Matrixplus_2009 (Section 2.3.7) describes that two previous groundwater flow assessments of the Comet Ridge CSG fields have been conducted. Those assessments concluded that predicted drawdown within the coal measures caused by extraction from CSG wells would be more than 500 m and a maximum predicted drawdown in the Precipice Sandstone of 25 m. No previous modelling was reported to have been undertaken in regard to the Roma CSG field.

Separate approaches were adopted in Matrixplus_2009 for the numerical modelling of each field:

- Comet Ridge CSG field using the USGS model code MODFLOW; and,

- an in-house analytical solution was prepared with respect to the Roma field.

The data compilation exercise, by necessity, drew on a wide range of sources that included the DNRW database (which provided stratigraphy, lithology, aquifers, historical water levels and water quality data information); DNRW information on private landowner well tests; historical CSG extraction rates provided by Santos; streamflow data for the Utopia Downs stream gauging station 130324A; and monthly rainfall records for Injune and Roma.

Predictive trials were run over 20 years for each model to simulate the time period 2009 to 2028. Sensitivity trials were carried out in the Comet Ridge CSG model to examine the influence of vertical leakance, transmissivity and recharge rate.

Modelling Conclusions

The following conclusions based on the modelling and reporting exercise were presented in Matrixplus_2009, Section 5:

- The maximum drawdown of groundwater levels in the Comet Ridge and Roma CSG fields, within the coal seam aquifers, is expected to be in the of the order of 600 m, with the drawdown in some wells located in the extreme east of the Fairview CSG field reaching up to 1000 m;
- In the Comet Ridge CSG fields the transmissivity of the coal seam aquifers is reasonably high. As a result the radius of influence will spread well outside the perimeter of the wellfield;
- Groundwater drawdowns in the coal seam aquifer (i.e. Bandanna Formation) within the Comet Ridge fields will result in inter-aquifer transfer with the overlying Precipice Sandstone. Groundwater head loss within the Precipice Sandstone could range up to a maximum of 15 m at the end of 2013 and up to a maximum of 65 m at the end of 2028;
- Model outputs indicated that at 20 years after operations begin, approximately 50% of the groundwater being extracted from the Comet Ridge wellfields was being drawn from the Precipice Sandstone aquifer. On this basis, while detailed modelling of the recovery of the wellfield water levels post CSG extraction has not been carried out to date, it can be hypothesised that the time required for 80% recovery of the water levels in the Precipice Sandstone should be approximately twice the life of the fields;
- In the Roma CSG field, the cone of depression associated with the WCM (i.e. coal seam aquifer) is confined to a tight area around the wellfield;
- Owing to a high resistance to vertical flow through the material between the coal seam aquifer and the underlying Hutton Sandstone, the rate of transfer of water from the Hutton Sandstone to the WCM and the drawdown impact in the Hutton Sandstone is minor. After 20 years of operation the drawdown in the Hutton Sandstone, as a result of inter-aquifer transfer, is approximately 3 m at the edge of the Roma wellfield;
- It is expected that the rate of recovery of water levels in the WCM will be very slow and drawdown in the Hutton Sandstone aquifer will continue for many hundreds of years after operations cease. However, while the radius of influence will continue to spread with time, the magnitude of the drawdown will not increase after the wellfield has ceased to operate;
- Landholder bores screened in effected aquifers which are located within the predicted radius of influence may experience a level of reduced groundwater heads;

- Drawdown within the Precipice Sandstone at Comet Ridge fields is not expected to significantly alter the baseflow contributions to the Dawson River and groundwater discharge volumes to springs located in the vicinity; and,
- Groundwater drawdown and associated inter-aquifer transfer will unlikely impact the water quality of the CSG aquifer and the aquifers surrounding the wellfields.

Golder Comment

General

The following general comment is provided regarding the modelling work:

- The models do provide an adequate representation of aquifer behaviour to achieve the desired purpose at the present time, given the simplifications that were made to the approach and the limited data that were used for model development;
- An important concern of the modelling exercise is to consider the duration and characteristics of aquifer recovery. This has not been addressed adequately, and in particular it has not allowed for the possibility of any post-depressurisation impacts;
- An important impact under post-depressurisation conditions is that drawdown can be expected to continue in aquifer layers towards the surface beyond wellfield closure as a result of continuing leakage to lower layers that are host to the well intake zones;
- There is also an urgent need to develop a model larger in scale, that encompasses the entire project area including Spring Gully, which will allow integration of all of the wellfields so that groundwater interaction and any consequent impacts of development can be represented and assessed in context; and,
- In addition to providing an essential means of investigating potential impacts of development on the environment and the interests of other stakeholders, such a model will also provide a test bed for assessing planning and operational alternatives in specifying requirements for reinjection design.

The modelling approaches to each field are different, hence further specific comment is provided in relation to each model in the sections that follow.

Roma Model

- It is recognised that a sophisticated approach to modelling of the Roma CSG Field by Matrixplus was not justified given the data limitations at this stage.
- However, the reasons given for adopting a different approach in the case of the Roma model by not using a MODFLOW model are not clear to Golder, particularly with respect to the conclusion that drawdown of threshold levels is better controlled than in proprietary numerical models;
- The conceptual hydrogeological model for Roma suggests that a numerical approach is more favourable than an analytical one given the need to account for factors such as anisotropy of each layer and the size of the proposed wellfield;
- An upgrade of the Roma model to a distributed numerical simulation is essential, given that heterogeneous parameterisation and anisotropy are potentially significant issues affecting local groundwater movement; and,

- It is reported in Matrixplus_2009 that in the development of the Roma Model, interpreted faults were considered not to be a significant factor affecting groundwater flow. This was inferred from the small differences in groundwater head across the area, which were evident once bottom hole pressures had been converted to hydraulic head. It should be noted however that as drawdowns increase and in zones where groundwater head gradients are steep, the presence of geological structure has the potential to play a significant role – this possibility had not been allowed for in the modelling exercise.

Comet Ridge Model

- As was the case for the Roma Model, it is recognised that a sophisticated approach to modelling by Matrixplus was not justified for the Comet Ridge Model given the data limitations at this stage;

- Transmissivity was assumed for purposes of modelling to be uniform in Layers 1 and 2 (Precipice Formation and Rewan Group). While it is recognised that data availability is severely limited, the assumption of a uniform transmissivity distribution, is not consistent with the aquifer parameter lists given in Appendix D of Matrixplus_2009 from flow and pressure tests, which indicate a range of 8 to 200 m^2/d in the Precipice Sandstone, and a range of 13 to 830 m^2/d in the Clematis Sandstone (Rewan Group);

- The aquifer geometry is described in Matrixplus_2009 to be complex, with the presence of geological structure, such as the Hutton/Wallumbilla Fault. MODFLOW is a powerful model for aquifer simulation, but it is limited in its capacity to represent complex geometry and geological structures which may control groundwater movement;

- While Golder has had no hands-on opportunity to review the Comet Ridge model, it is considered that there is insufficient resolution in the model to accommodate the vertical flow adequately. It is likely that it was necessary to apply a confined, constant transmissivity layer to represent the layers in the MODFLOW model to prevent instability in processing, which resulted from the low vertical resolution;

- The model is used to produce a water balance at 5-yearly intervals using the water budget facility within MODFLOW. This provides a useful check on the overall stability of the model and that convergence is achieved adequately at each of the selected stress periods. However, no clear attempt was made in the reporting to compare a MODFLOW model water balance to the conceptual hydrogeological model as part of the calibration exercise. This is particularly relevant to the boundary conditions applied and the relative magnitude of each flow component associated with these boundary conditions (e.g. river cells predict baseflows of 13 ML/d – is this in line with estimates from field data from the Utopia Downs Gauging Station? If not, is it valid to infer anything from the model regarding baseflow impacts?);

- Boundaries applied to the model include no flow boundaries, drainage cell nodes, river cell nodes, time-variant head boundaries and constant head boundaries. The following observations are made in connection with the application of boundaries in this model:

  - Constant head boundaries - it is important to note the control that constant head cells exercise over groundwater gradient, and the fact that they can be both sources and sinks within the model domain. Because they can introduce or remove water, they should be tested carefully in water balance calculations. Time variant constant heads are used to control the progression of drawdown during CSG production, but no attempt appears to have been made to compare the resultant volumes to result (given in the water balances in Appendix G) to potential production volumes;

  - MODFLOW drain cells were introduced to ensure model stability at the seepage zones along the northern boundary of outcrops of Precipice Sandstone. These cells will definitely have that effect.

However, there was apparently no attempt to quantify the potential discharge - even as a broad estimate - that occurs at the seepage zones that these cells correspond to in the model;

- Some explanation to justify the selection of heads at the south and west boundary of Layer 1 and west boundary of Layer 3 would be helpful;
- Golder notes reference to river boundary conditions to the east of the CSG Fields. This requires a detailed explanation because it implies an infinite source of water to the east;

- The following general points are made about all of the above boundaries and the physical flow components that they simulate:
  - Collectively they represent a significant control over the water balance;
  - They can provide a reasonable approximation of the piezometric surface of each aquifer, particularly if enough of these boundary conditions are applied to impose the desired outcome;
  - However, this can be misleading. Through non-uniqueness of parameters, it is possible to produce the required surface, without producing a water balance that is consistent with the actual field conditions (i.e. the distribution of flows within the water balance won't necessarily correspond with the field estimates, even if the piezometric surface appears to be correct);
  - Parameters associated with these boundary conditions including drainage cell conductance, river leakage and river level were assumed or prescribed in model development but were not tested in any sensitivity trials – it should be noted that each of these parameters have the potential to affect the water balance and hence the behaviour of the groundwater system; and
  - The result is that there can only be very limited confidence in the flow prediction, even if the calibration against head appears favourable.

Proposed Work

- Development of a distributed parameter numerical model is essential – it should extend over the entire area that encompasses Santos' operations in the region, and should include the Roma CSG Field and Spring Gully areas;
- It is key that the hydrogeology of the area should be addressed with a single model that represents the interaction of each of the major aquifers in the region;
- Such an integrated modelling approach will ensure that interpretation of flow transfer between wellfields, aquifer units, and adjacent, overlying layers is consistent;
- Integration of the areas included in the model will increase reliability in simulation of groundwater movement, aquifer drawdown and in the estimation of the overall water balance for these aquifers;
- Reliable prediction of discharge and groundwater movement is vital to identifying and assessing potential impacts on all stakeholders and on the environment dependent on the condition of local aquifers;
- The model development should be informed as far as possible by the outcomes of the parallel studies underway which include:

- SEEP/W modelling of the Roma, Fairview and Arcadia fields, borefield inventories. This study has the potential to provide valuable information on recharge and water management affecting the groundwater system in these areas;
- Water management plan (WMP) development for the entire project. This includes studies, methodology, risk management, costs, sustainability - all issues that have affected the development of the long term strategy and covers the requirements of the EIS, EMP, SQAD. The groundwater modelling will have to be aligned with all requirements of the WMP;
- Fairview/Precipice Recharge Studies which are proposed including fieldwork to monitor and manage the impacts should they arise of increased drawdown in the Precipice Formation where it overlies the Bandanna Coals. This investigation will yield essential information which will need to be incorporated into the model;
- GoldSim model development, which is a project wide operational simulation to compare options-scenarios-construction methodologies using risk-cost-liability criteria. Trials conducted using the groundwater models will have to be consistent with the trials and outcomes of the GoldSim modelling used in planning;
- A GLNG-wide Data Management Plan which is under development for the entire Project area is to be developed to support a system for collection and management of all environmental time dependent data. It is expected that data relevant to the ongoing maintenance of any groundwater models will be incorporated into this management plan, to as part of the GLNG water monitoring plan and will include the collection of the following:
  - groundwater levels in both shallow and deep aquifers;
  - coal seam aquifer pressures;
  - groundwater quality (surface water, coal seam and aquifers);
  - location of springs (discharge/recharge);
  - river/stream levies and flow;
  - artesian springs quality and flow; and
  - aquifer testing (to obtain better understanding of aquifer and aquitard hydraulic parameters).

- The GLNG Water Monitoring Plan will also outline the methods to be used for the collection of data regarding spatial and temporal variations in head distribution within multiple formations during the progression of CSG activities, as well as river and stream flow information. It will provide details as to the collection of data, including frequency of sampling, and sampling locations. It will also outline the various analytical suites developed for monitoring according to legislation requirements. The data collected under the GLNG Water Monitoring Plan will be essential to inform development and ongoing maintenance of a more comprehensive numerical model.

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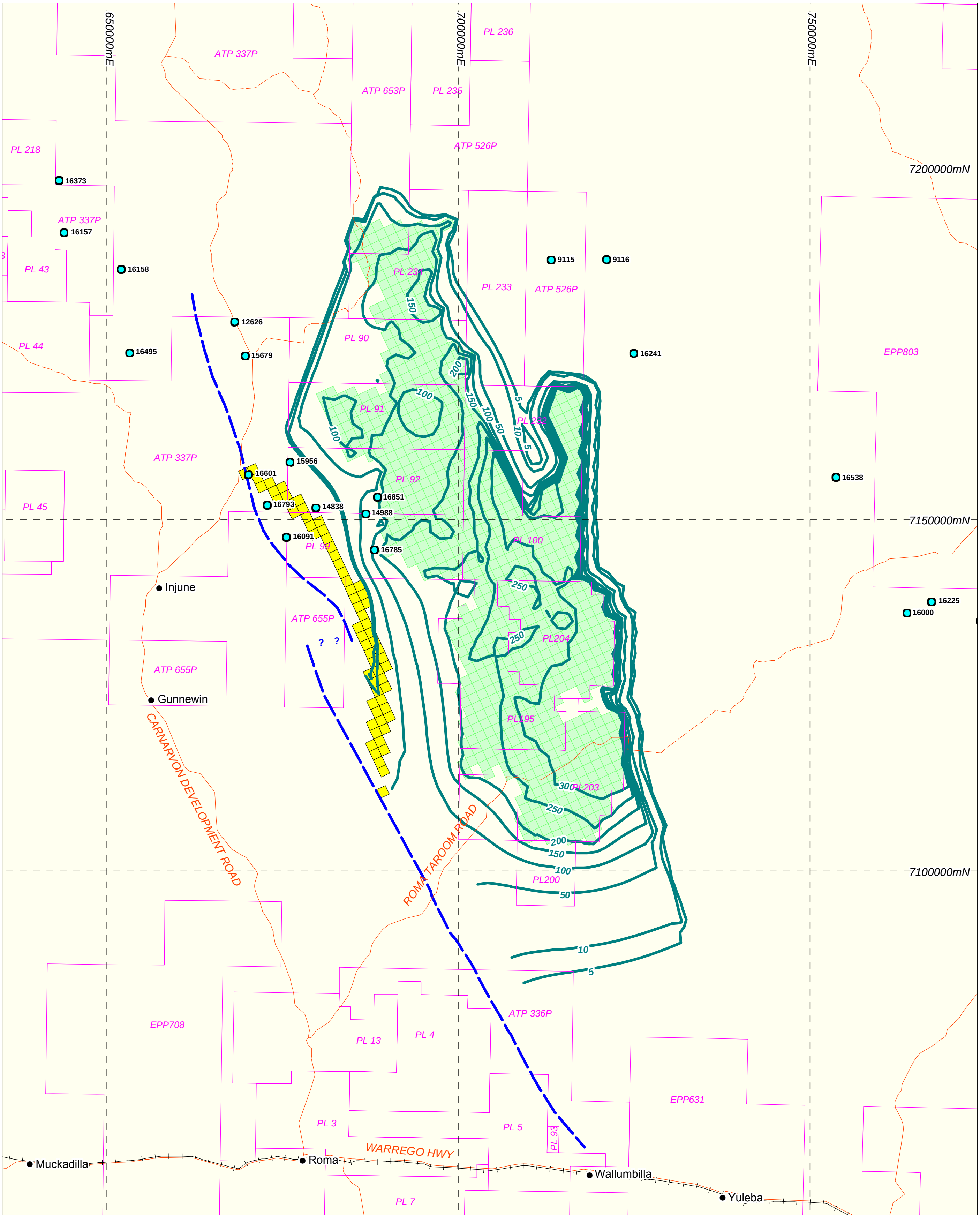

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Town
- Active CSG Field
- Vertical Leakage Cell
- Drawdown Contour (m)
- Hutton Wallumbilla Fault
- DNRW Reg. Bore (Precipice)

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

Santos Ltd

Santos GLNG EIS

5 Year Model Simulated Head Drawdown in the Bandanna Formation at 2013 - Comet Ridge CSG Fields

0 10 20

Kilometres

Scale: 1:750,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-9

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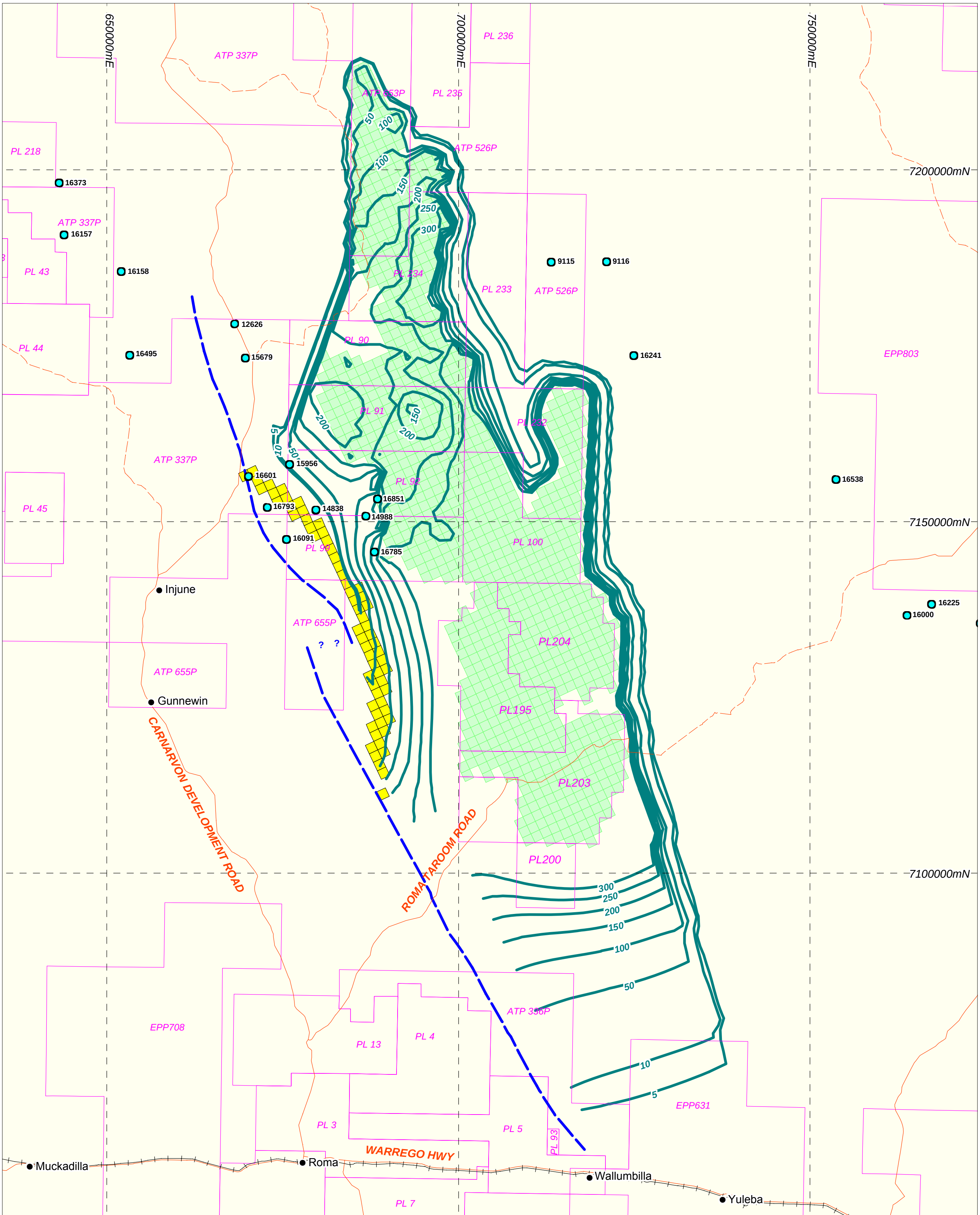

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Town
- Active CSG Field
- Vertical Leakage Cell
- Drawdown Contour (m)
- Hutton Wallumbilla Fault
- DNRW Reg. Bore (Precipice)

Santos Ltd

Santos GLNG EIS

10 Year Model Simulated Head Drawdown in the Bandanna Formation at 2018 - Comet Ridge CSG Fields

0 10 20

Kilometres

Scale: 1:750,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-10

matrixplus

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

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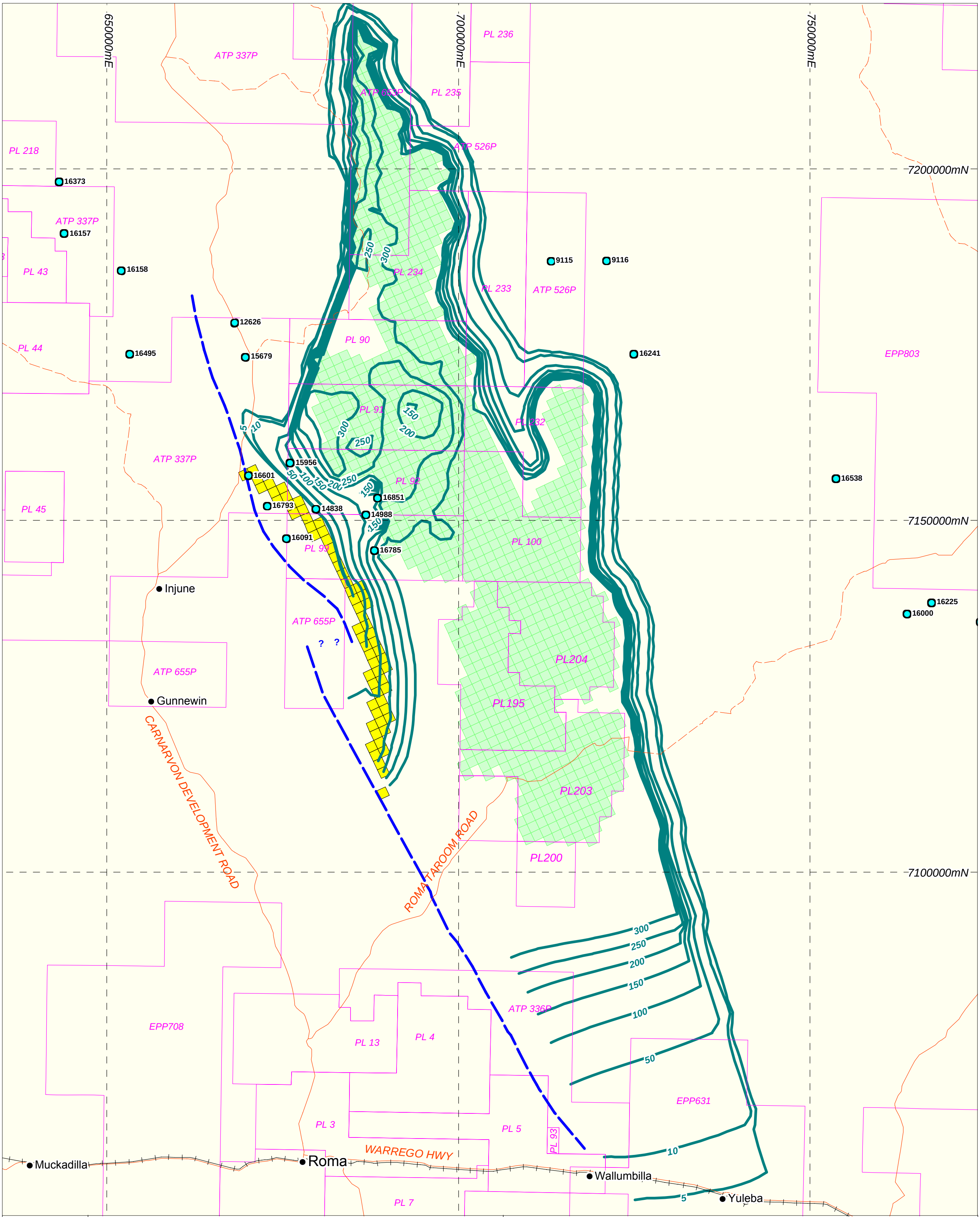

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Town
- Active CSG Field
- Vertical Leakage Cell
- Drawdown Contour (m)
- Hutton Wallumbilla Fault
- DNRW Reg. Bore (Precipice)

Santos Ltd

Santos GLNG EIS

15 Year Model Simulated Head Drawdown in the Bandanna Formation at 2023 - Comet Ridge CSG Fields

0 10 20

Kilometres

Scale: 1:750,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-11

matrixplus

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

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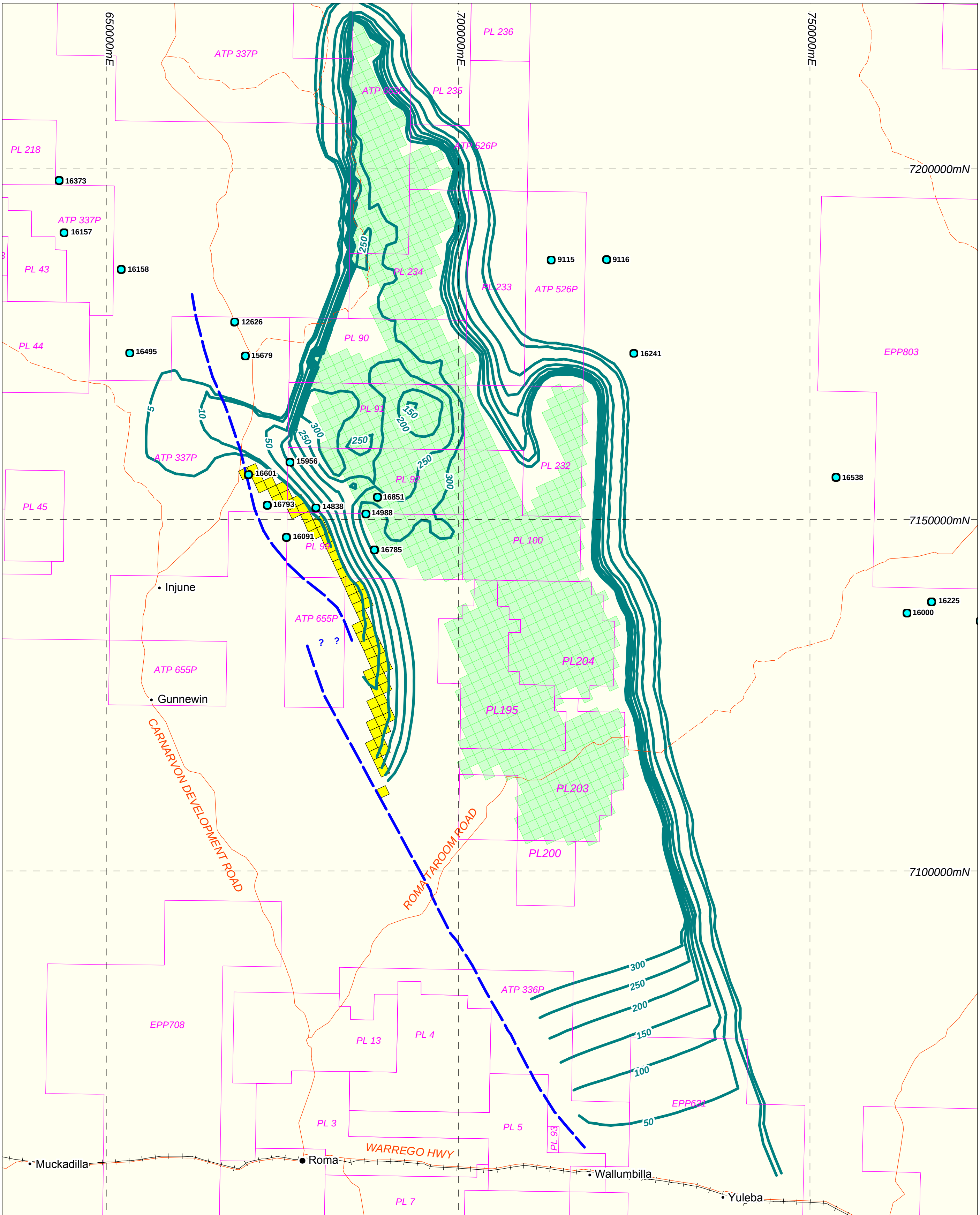

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Town
- Active CSG Field
- Vertical Leakage Cell
- Drawdown Contour (m)
- Hutton Wallumbilla Fault
- DNRW Reg. Bore (Precipice)

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Santos GLNG EIS

20 Year Model Simulated Head Drawdown in the Bandanna Formation at 2028 - Comet Ridge CSG Fields

0 10 20
Kilometres

Scale: 1:750,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-12

matrixplus

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

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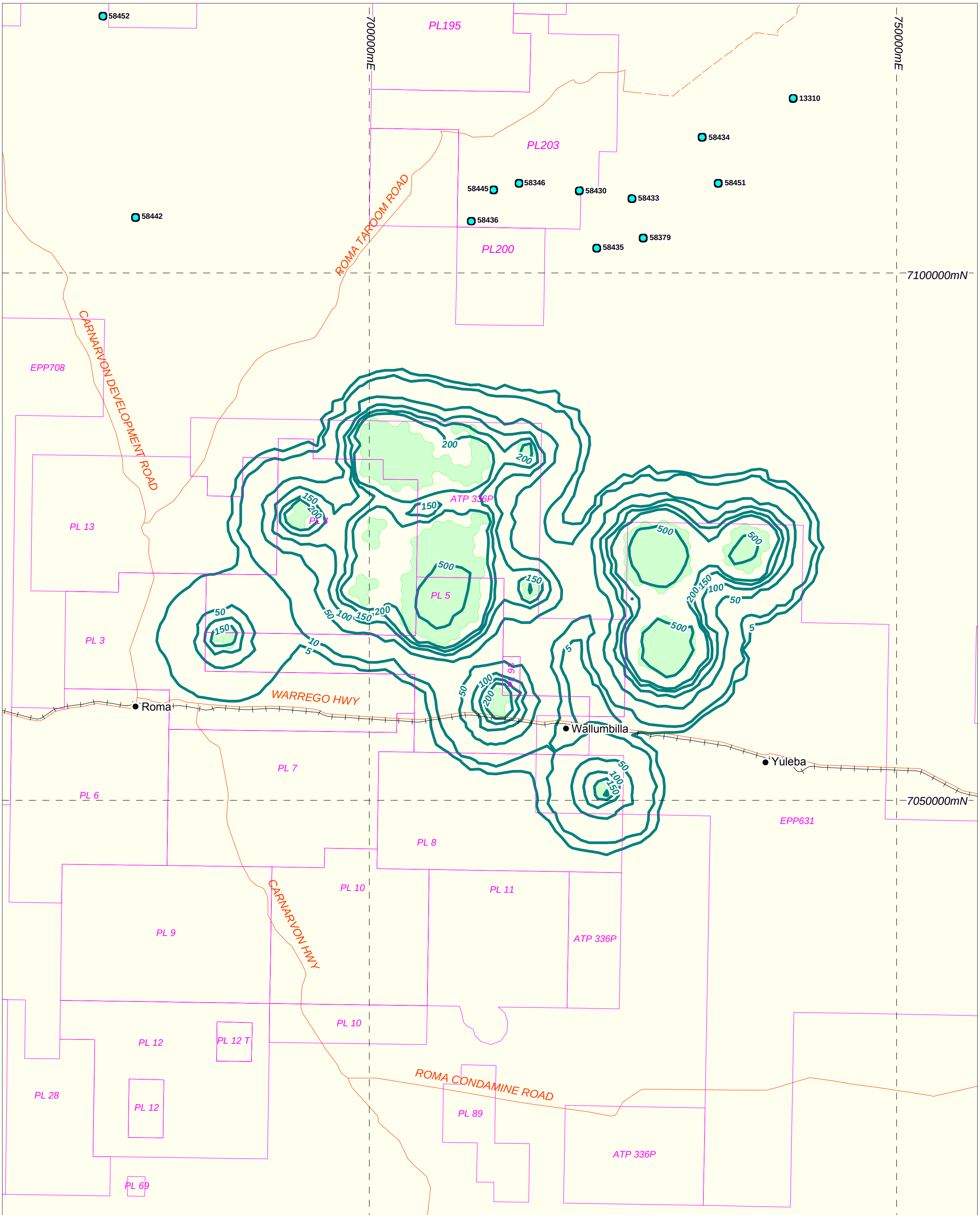

LEGEND

Santos ATP & PL Tenement
Road
Track
Railway
Town
Proposed CSG Field
Drawdown Contour (m)
DNRW Reg. Bore (Walloon)

Data Source:
Topography - Geoscience Australia. Tenement - URS

30/01/2009

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matrixplus

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Santos GLNG EIS

5 Year Model Simulated Head Drawdown in the Walloon Coal Measures at 2013 - Roma CSG Field

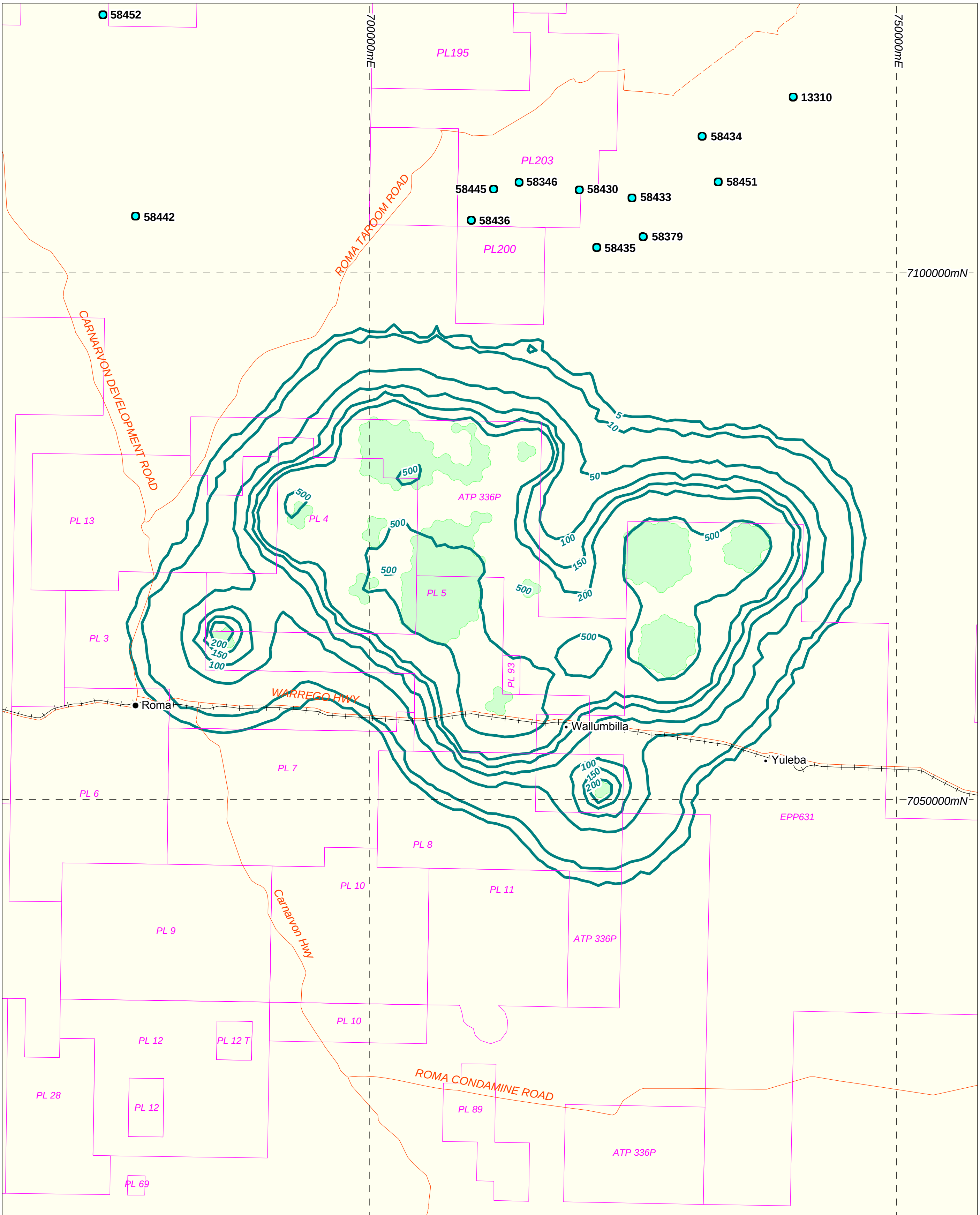
0 10 20

Kilometres

Scale: 1:500,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-13



LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Town
- Proposed CSG Field
- Drawdown Contour (m)
- DNRW Reg. Bore (Walloon)

Santos Ltd

Santos GLNG EIS

10 Year Model Simulated Head Drawdown in the Walloon Coal Measures at 2018 - Roma CSG Field

0 10 20

Kilometres

Scale: 1:500,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-14

matrixplus

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

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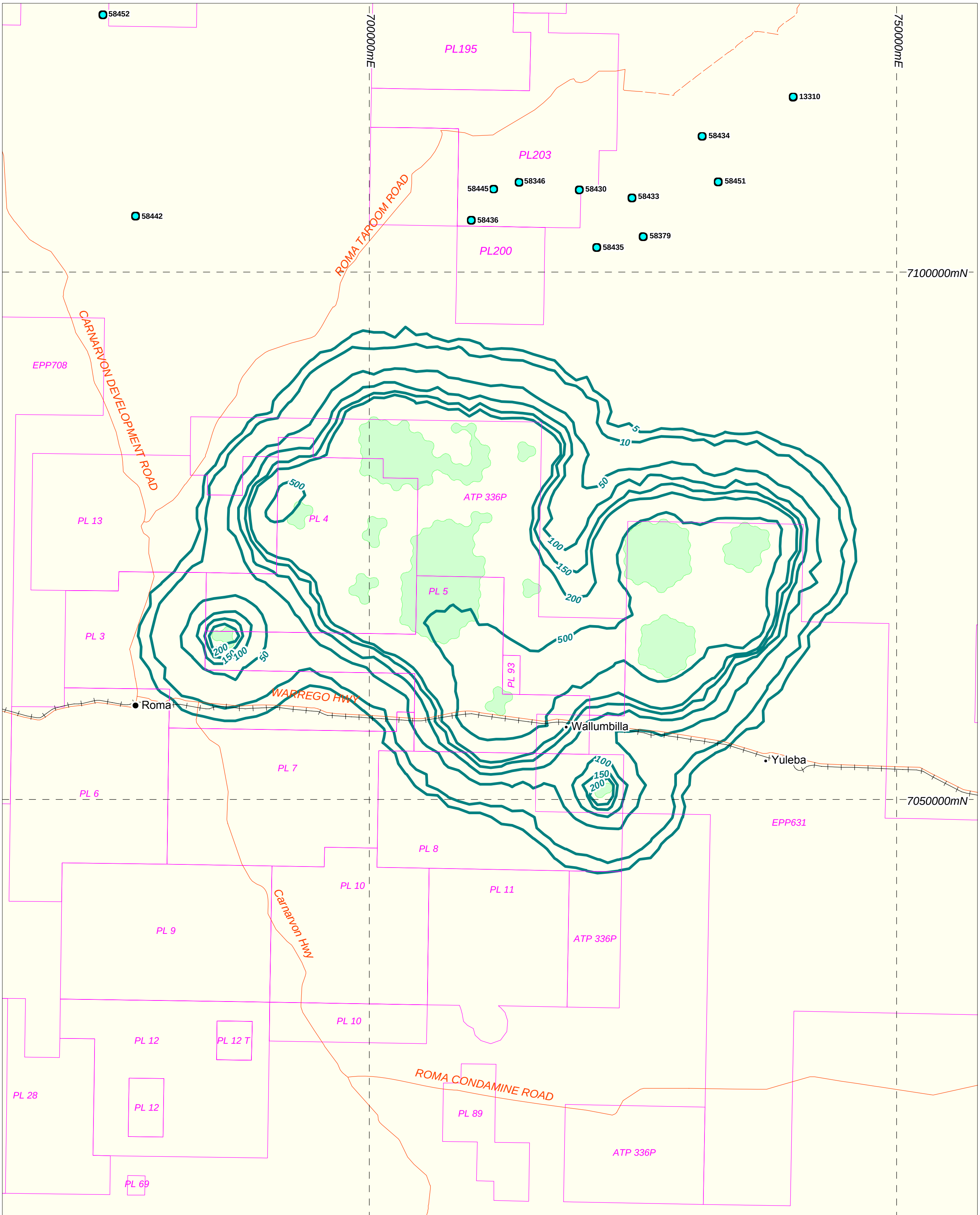


LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Town
- Proposed CSG Field
- Drawdown Contour (m)
- DNRW Reg. Bore (Walloon)

matrixplus

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

Santos Ltd

Santos GLNG EIS

15 Year Model Simulated Head Drawdown in the Walloon Coal Measures at 2023 - Roma CSG Field

0 10 20

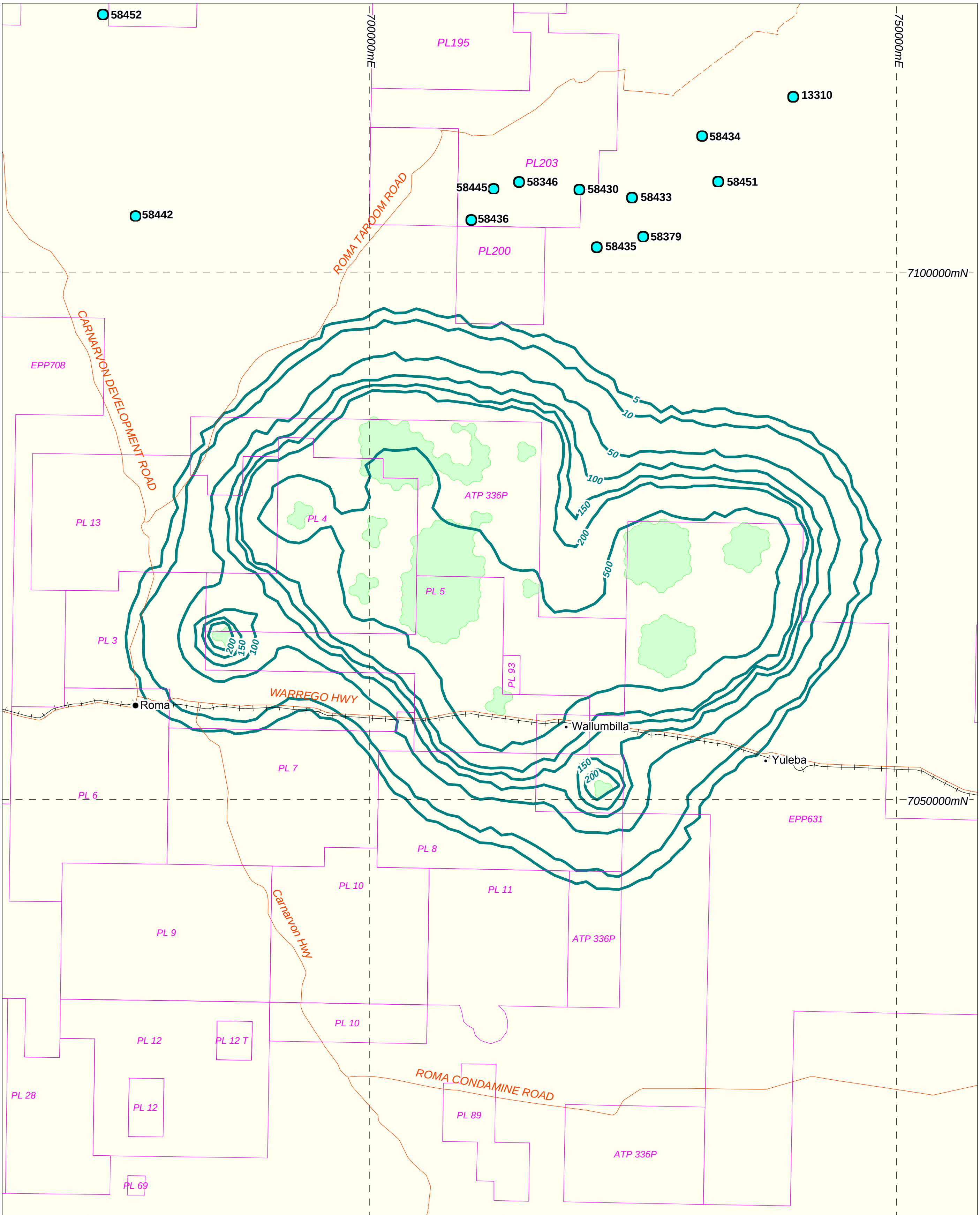
Kilometres

Scale: 1:500,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-15

P:\Projects\Santos\SAN801_GW_Mgt\MapInfo\Workspaces\SAN0801_M009B.wor



P:\Projects\Santos\SAN801_GW_Mgt\MapInfo\Workspaces\SAN0801_M010B.wor

matrixplus

30/01/2009

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Town
- Proposed CSG Field
- Drawdown Contour (m)
- DNRW Reg. Bore (Walloon)

Data Source:
Topography - Geoscience Australia. Tenement - URS

Santos Ltd

Santos GLNG EIS

20 Year Model Simulated Head Drawdown in the Walloon Coal Measures at 2028 - Roma CSG Field

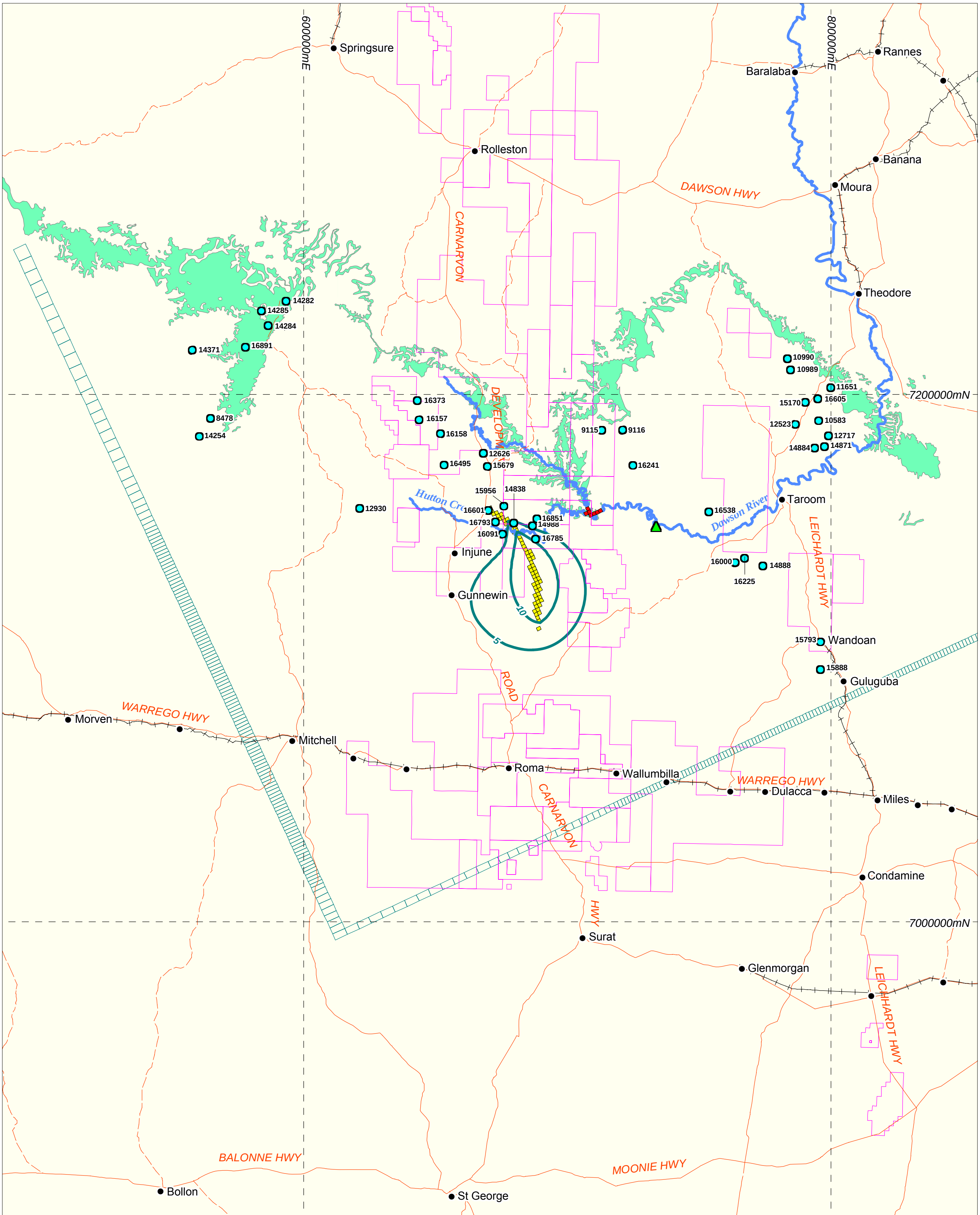
0 10 20

Kilometres

Scale: 1:500,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-16



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matrixplus

30/01/2009

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Watercourse
- Town
- Precipice Sandstone Outcrop
- River Model Cell
- Vertical Leakage Cell
- Model GHB Cells
- Drawdown Contour (m)
- DNRW Stream Gauging Station
- DNRW Reg. Bore (Precipice SS)

Data Source:
Topography - Geoscience Australia. Tenement - URS

Santos Ltd

Santos GLNG EIS

5 Year Model Simulated Head Drawdown in the Precipice Sandstone at 2013 - Comet Ridge CSG Fields

0 40 80

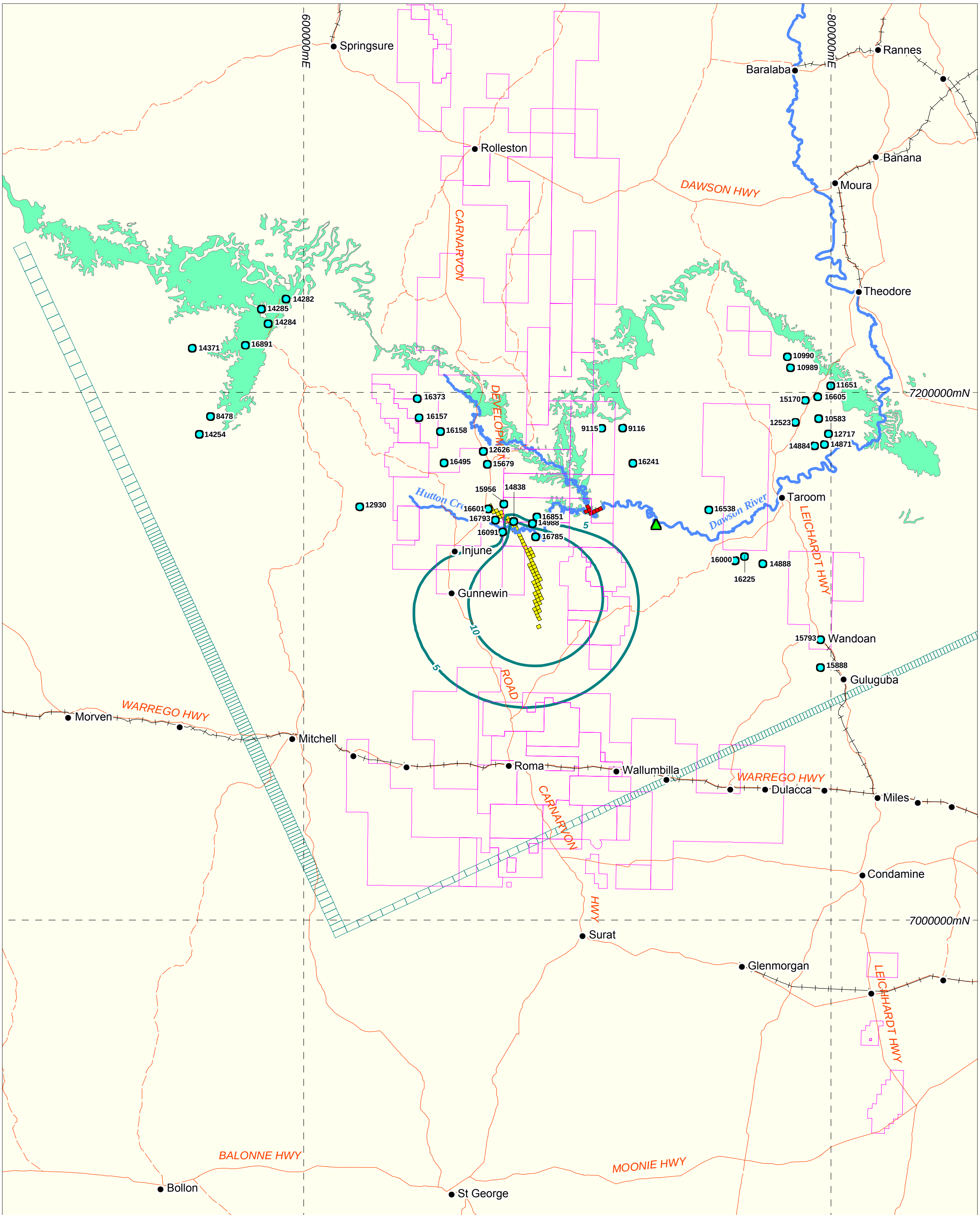
Kilometres

Scale: 1:2,000,000 (A4)

N

Datum: GDA94
Projection: MGA55

FIGURE 3-17



matrixplus

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Watercourse
- Town
- Precipice Sandstone Outcrop
- River Model Cell
- Vertical Leakage Cell
- Model GHB Cells
- Drawdown Contour (m)
- DNRW Stream Gauging Station
- DNRW Reg. Bore (Precipice SS)

Santos Ltd

Santos GLNG EIS

10 Year Model Simulated Head Drawdown in the Precipice Sandstone at 2018 - Comet Ridge CSG Fields

0 40 80

Kilometres

Scale: 1:2,000,000 (A4)

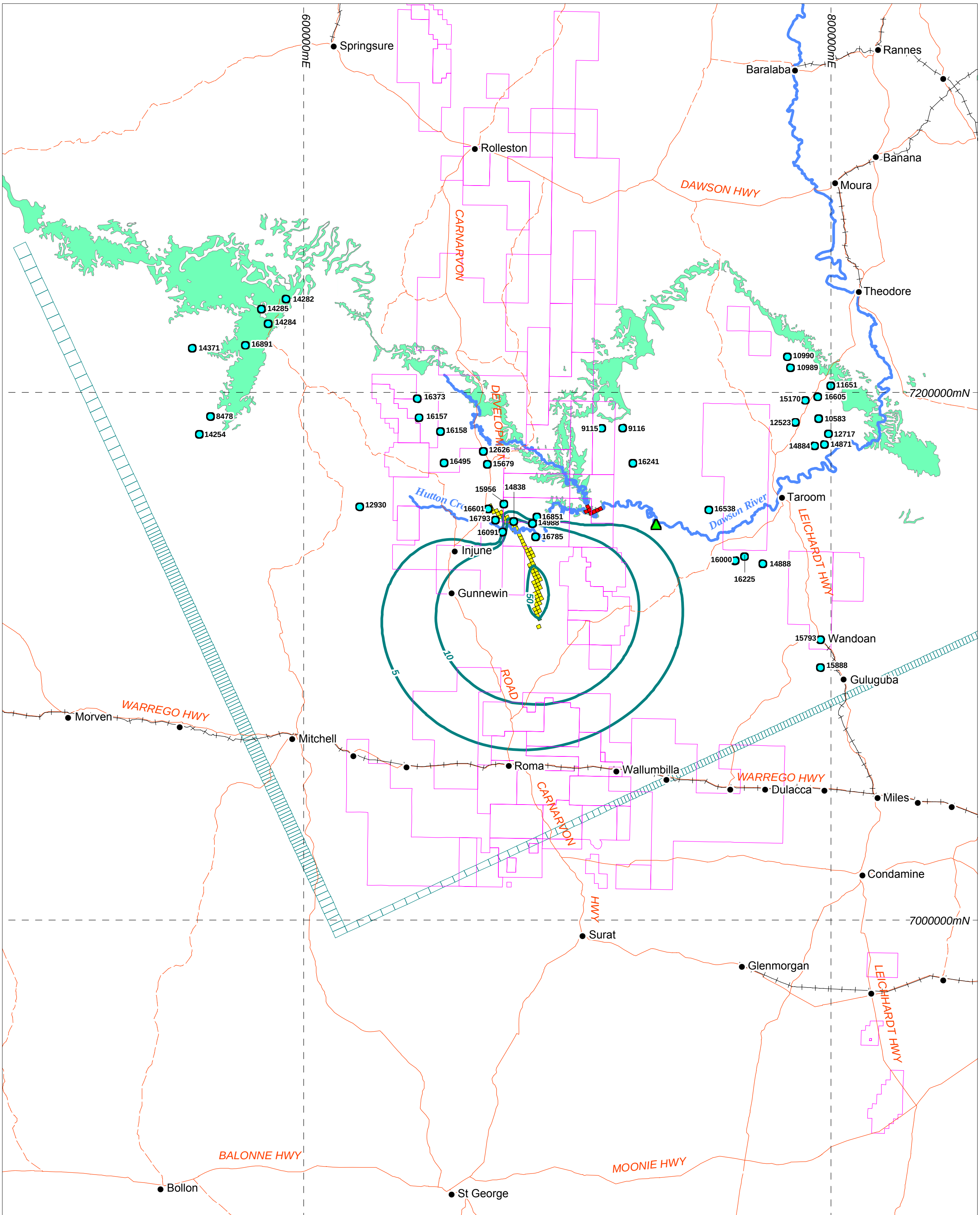
Datum: GDA94
Projection: MGA55

FIGURE 3-18

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

P:\Projects\Santos\SAN801_GW_Mgt\MapInfo\Workspaces\SAN0801_M012B.wor



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LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Watercourse
- Town
- Precipice Sandstone Outcrop
- River Model Cell
- Vertical Leakage Cell
- Model GHB Cells
- Drawdown Contour (m)
- DNRW Stream Gauging Station
- DNRW Reg. Bore (Precipice SS)

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

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Santos GLNG EIS

15 Year Model Simulated Head Drawdown in the Precipice Sandstone at 2023 - Comet Ridge CSG Fields

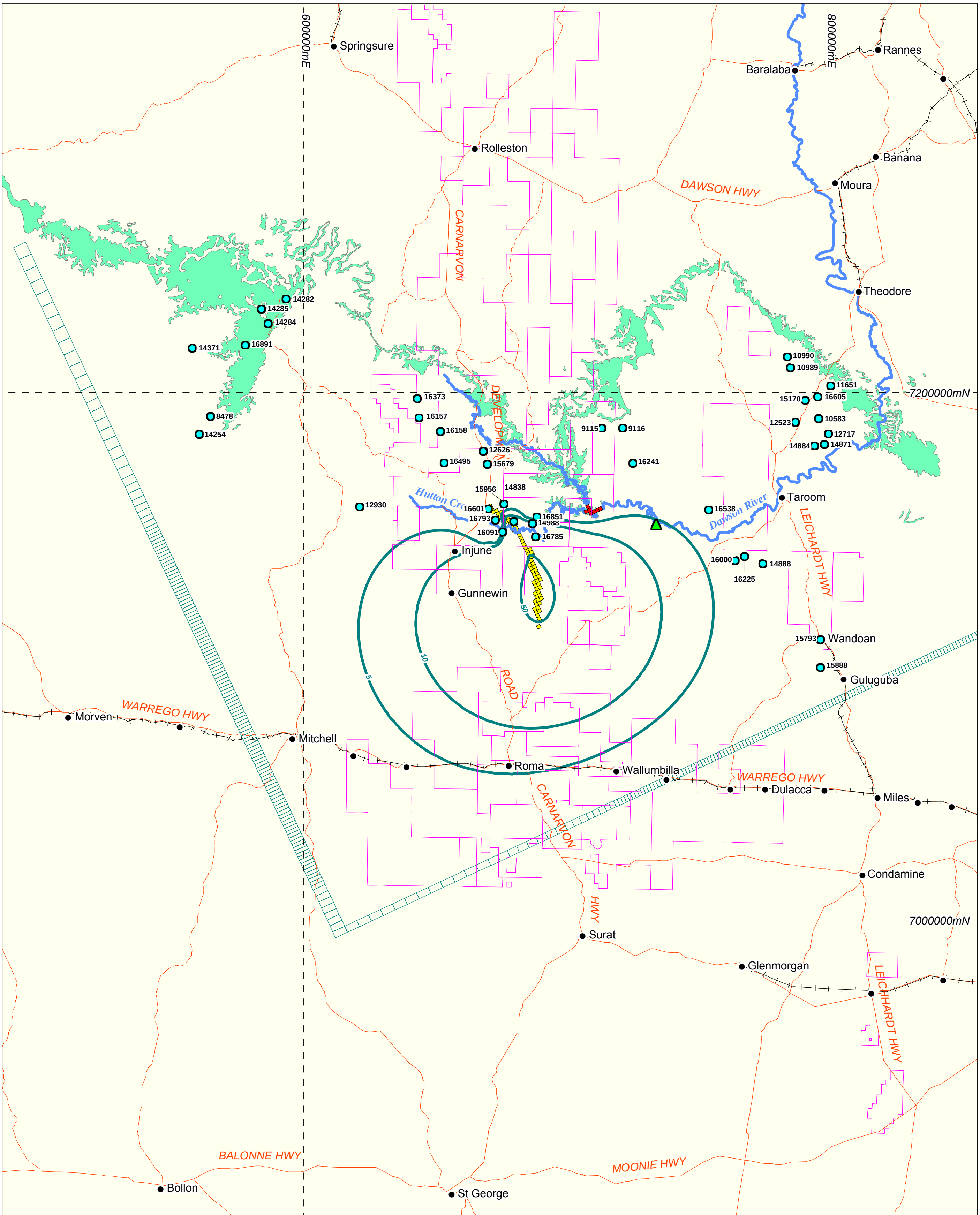
0 40 80

Kilometres

Scale: 1:2,000,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-19



P:\Projects\Santos\SAN801_GW_Mgt\MapInfo\Workspaces\SAN0801_M014B.wor

matrixplus

LEGEND

- Santos ATP & PL Tenement
- Road
- Track
- Railway
- Watercourse
- Town
- Precipice Sandstone Outcrop
- River Model Cell
- Vertical Leakage Cell
- Model GHB Cells
- Drawdown Contour (m)
- DNRW Stream Gauging Station
- DNRW Reg. Bore (Precipice SS)

30/01/2009

Data Source:
Topography - Geoscience Australia. Tenement - URS

Santos Ltd

Santos GLNG EIS

20 Year Model Simulated Head Drawdown in the Precipice Sandstone at 2028 - Comet Ridge CSG Fields

0 40 80
Kilometres

Scale: 1:2,000,000 (A4)

Datum: GDA94
Projection: MGA55

FIGURE 3-20

APPENDIX D

Summary of Risk Assessment Results for the GLNG CSG Development Activities

Risk Assessment Results for the GLNG CSG Development Activities

Operational Area	Item	Risk Issue	Cause	Impact	Consequence *	Likelihood *	Risk Rating *
Drilling, Design, Completion, Integrity		Passage of water between aquifers	Poor design Construction technique, Poor closure technique	Contamination, Pressure Loss, Non-compliance	IV	D	2
		Leakage of introduced fluids including mud	Inappropriate muds or drilling technique	Contamination of aquifers and/or surface water	III	D	2
		Artesian Flows	Over pressure/poor mud control/incorrect drilling assumptions	Erosion, loss of reputation	II	C	2
CSG Wells - Depressurisation of the Coal Seams		Leakage between aquifers	300-500 m of pressure drop in coal seams	Loss of available drawdown in bores	IV	R – D	R – 2
						F – B	F – 4
						A - E	A - 1
				Loss of artesian flow	IV	R – D	R – 2
						F – B	F – 4
						A - E	A - 1
				Subsidence	V	R – E	R – 2
						F – E	F – 2
						A - E	A -2
				Water quality changes	IV	R – D	R – 2
						F – E	F – 1
						A - E	A -1
				Reduction in recharge	III	R – E	R – 1
						F – D	F – 2
						A - E	A -1
				Loss of baseflow (including non-mound springs)	IV	R – E	R – 1
						F – C	F – 3
						A - E	A -1
				Impacts on mound springs	IV	R – E	R – 1
						F – E	F – 1
						A - E	A - 1
				Gas flows in private bores	III	R – D	R – 2
						F – E	F – 1
						A - E	A - 1
Gathering systems		Discharge of associated water to environment	Leak of water pipe or controls	Soil/Shallow GW contamination	I	B	1
				Contamination of local SW	I	D	1
			Break in pipeline	Soil/Shallow GW contamination	III	C	3
				Contamination of local SW	III	C	3
			Leakage from low point drains/separators	Soil/Shallow GW contamination	I	C	1
		Erosion	Design, construction of stream crossings, open areas	Stream water quality	II	C	2

Operational Area	Item	Risk Issue	Cause	Impact	Consequence *	Likelihood *	Risk Rating *
Water storage		Uncontrolled discharge to environment	Seepage - vertical	Shallow groundwater and/or soil contamination	AW - III	D	AW - 2
					Oily – III		Oily – 2
					Permeate – I		Permeate – 1
					Brine - IV		Brine - 2
			Seepage - lateral	Vegetation loss	AW - II	D	AW - 1
				Discharge to water ways	Oily – II		Oily – 1
		Uncontrolled discharge to environment	Seepage - lateral	Discharge to water ways	Permeate – I	D	Permeate – 1
					Brine - III		Brine - 2
			Dam Break	Damage to property, soil, water, surface infrastructure , loss of asset and associated income, fatality.	AW - IV	AW - D	AW - 2
					Oily – III	Oily – C	Oily – 3
					Permeate – IV	Permeate – D	Permeate – 2
					Brine - V	Brine - D	Brine - 3
			Operational Failure Overflow	Damage to property, soil, water, surface infrastructure, and associated income.	AW- III	D	AW- 2
					Oily –III		Oily –2
					Permeate –I		Permeate –1
			Operational Failure Accidental Release		Brine -IV	D	Brine -2
Surface Infrastructure	Road Services	Uncontrolled run-off from roads	Inadequate design and maintenance of stormwater systems	Soil erosion/ contamination	I	B	1
			Inadequate design and management of waterway crossings	Deterioration of water quality	II	C	2
	Camp services	Contaminant releases	Effluent release from sewage treatment	Soil and shallow GW contamination	III	D	2
			Kitchen Waste	Soil and shallow GW contamination	I	C	1

Operational Area	Item	Risk Issue	Cause	Impact	Consequence *	Likelihood *	Risk Rating *
Surface Infrastructure cont.	Camp services	Compressor station hazards	Bulk Fuel and chemical storage	Contamination of GW or SW	III	D	2
			Water treatment - oily water ponds	Contamination of GW or SW	III	B	3
			Washdown areas	Contamination of GW or SW, weeds	I	C	1
	Irrigation	WQ	Variable CSG WQ	Irrigation water may require additional treatment or cant be used	II	D	1
		Water quantity	Variable CSG production	More water than system can dispose of	III	D	2
		Treatment process	Inappropriate dosing	Soil structure and fertility impacts	III	D	2
		Leachate Rates	Application rate too high for soil/geology	Springs, mounding, soil water logging, loss of productivity	II	D	1
	Municipal/ Industrial	WQ	Treatment inappropriate to agreed influent requirements	Adverse impacts on TWS influent WQ	IV	D	2
		Water quantity	Variable water production	Over or under supply	II	B	3
	Treated discharge to SW (perennial streams)	Adverse Env.Impacts in stream	Changing Flow Regime	Localised change in ecosystem	II	B	3
			Changing WQ	Environmental harm	II	B	3
	Stock Water (Associated water or shandy)	WQ	Trace elements (e.g. Fe, F, B) too high for all purposes, TDS too high for any purpose.	Water unsuitable for stock supply	II	C	2

*: evaluated using Santos Risk Management criteria - Dec 2005

At Golder Associates we strive to be the most respected global group of companies specialising in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organisational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

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North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

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