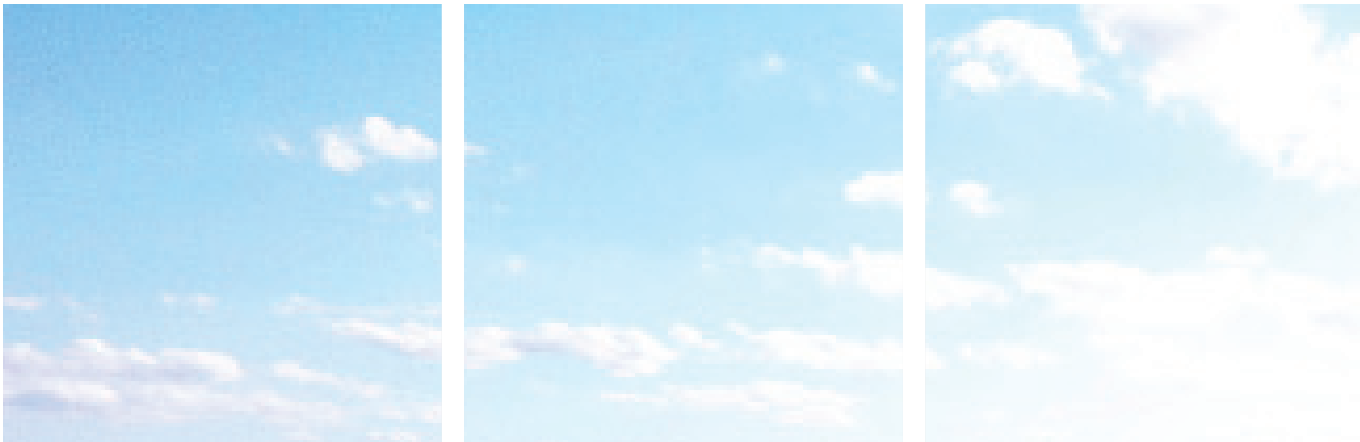

AGL Upstream Investments Pty Ltd

Phase 2 Groundwater Investigations

Stage 1 Gas Field Development Area
Gloucester Gas Project

January 2012

SG140 2162406A

PARSONS BRINCKERHOFF

Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area Gloucester Gas Project

January 2012

AGL Upstream Investments Pty Ltd

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Glossary

Acidity	Base neutralising capacity.
Alkalinity	Acid neutralising capacity.
Alluvium	Unconsolidated sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on river beds, floodplains, and alluvial fans.
Alluvial aquifer	Permeable zones that store and produce groundwater from unconsolidated alluvial sediments. Shallow alluvial aquifers are generally unconfined aquifers.
Ammonia	A compound of nitrogen and hydrogen (NH_3) that is a common by-product of animal waste and landfills but is also found naturally in reduced environments. Ammonia readily converts to nitrate in soils and streams.
Anion	An ion with a negative charge – usually non-metal ions when disassociated and dissolved in water.
Annulus	The void space between two strings of casing in a water bore or gas well.
Anthropogenic	Occurring because of, or influenced by, human activity.
Aquatic ecosystem	The stream channel, lake or estuary bed, water, and (or) biotic communities and the habitat features that occur therein.
Aquiclude	A very low-permeability unit that forms either the upper or lower boundary of a groundwater flow system and does not transmit water or allow water to migrate from upper and lower horizons.
Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.
Aquifer properties	The characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Aquifer, confined	An aquifer that is overlain by low permeability strata. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Aquifer, semi-confined	An aquifer overlain by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the leaky confining layer – also known as a leaky artesian or leaky confined aquifer.

Aquifer, unconfined	Also known as a water table aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of an unconfined aquifer.
Aquitard	A low permeability unit that can store groundwater and also transmit it slowly from one formation to another. Aquitards retard but do not prevent the movement of water to or from adjacent aquifers.
Artesian water	Groundwater that is under pressure when tapped by a bore and is able to rise above the level at which it is first encountered. It may or may not flow at ground level. The pressure in such an aquifer commonly is called artesian pressure, and the formation containing artesian water is a confined aquifer.
Australian Height Datum (AHD)	The reference point (very close to mean sea level) for all elevation measurements, and used for correlating depths of aquifers and water levels in bores.
Background concentration	A natural concentration of a substance in a particular environment that is indicative of minimal influence by human (anthropogenic) sources.
Baseflow	The part of stream discharge that originates from groundwater seeping into the stream.
Baseline sampling	A period of regular water quality and water level measurements that are carried out over a period long enough to determine the natural variability in groundwater conditions.
Bedding plane	In sedimentary or stratified rocks, the division plane which separates the individual layers, beds or strata.
Beneficial aquifer	An aquifer with a water resource of sufficient quality and quantity to provide either ecosystem protection, raw water for drinking water supply, and agricultural or industrial water.
Bore	A structure drilled below the surface to obtain water from an aquifer or series of aquifers.
Boundary	A lateral discontinuity or change in the aquifer resulting in a significant change in hydraulic conductivity, storativity or recharge.
Calcite	The mineral calcite is calcium carbonate and is one of the most widely distributed minerals on the Earth's surface. It is a common constituent of sedimentary rocks, limestone in particular.

Carbon-13 (^{13}C)	A natural, stable isotope of carbon and one of the environmental isotopes. It makes up about 1.109% of all naturally occurring carbon on Earth.
Carbon-14 (^{14}C)	Or radiocarbon is a radioactive isotope of carbon. Its nucleus contains six (6) protons and eight (8) neutrons. Its presence in organic materials is used in radiocarbon dating. It occurs naturally and has a relative abundance up to one part per trillion (0.0000000001%) of all naturally-occurring carbon on Earth. Carbon-14 is one of the most important nuclides in groundwater studies because its half-life of 5,730 years covers a critical time scale of ~500 to 50,000 years, which is ideal for dating regional and intermediate flow systems.
Carbon dioxide (CO_2)	An atmospheric gas comprised of one carbon and two oxygen atoms.
Cation	An ion with a positive charge – usually metal ions when disassociated and dissolved in water.
Chlorine-36 (^{36}Cl)	A naturally occurring radioisotope of chlorine. It has a half-life of 301,000±2,000 years and is suitable for age dating groundwaters up to 1 million years old.
Claystone	A non-fissile rock of sedimentary origin composed primarily of clay-sized particles (less than 0.004 mm).
Coal	A sedimentary rock derived from the compaction and consolidation of vegetation or swamp deposits to form a fossilised carbonaceous rock.
Coal seam	A layer of coal within a sedimentary rock sequence.
Coal seam gas (CSG)	Coal seam gas is a form of natural gas (predominantly methane) that is extracted from coal seams.
Concentration	The amount or mass of a substance present in a given volume or mass of sample, usually expressed as microgram per litre (water sample) or micrograms per kilogram (sediment sample).
Conceptual model	A simplified and idealised representation (usually graphical) of the physical hydrogeologic setting and the hydrogeological understanding of the essential flow processes of the system. This includes the identification and description of the geologic and hydrologic framework, media type, hydraulic properties, sources and sinks, and important aquifer flow and surface-groundwater interaction processes.

Cone of depression A depression of the water table or potentiometric surface that has the shape of an inverted cone, which develops around a production bore/gas well from which water is being drawn. It defines the radius of influence of a pumping test.

Confining layer Low permeability strata that may be saturated but will not allow water to move through it under natural hydraulic gradients.

Contamination Contamination is the presence of a non-natural compound in soil or water, or unwanted compound in chemicals or other mixtures.

Datalogger A digital recording instrument that is inserted in monitoring and pumping bores to record pressure measurements and water level variations.

Detection limit The concentration below which a particular analytical method cannot determine, with a high degree of certainty, a concentration.

Deuterium (^2H) Also called heavy hydrogen, a stable isotope of hydrogen with a natural abundance of one atom in 6,500 of hydrogen. The nucleus of deuterium, called a deuteron, contains one proton and one neutron, where a normal hydrogen nucleus has just one proton.

Discharge The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.

Discharge area An area in which there are upward or lateral components of flow in an aquifer.

Dissolution Process of dissolving a substance into a liquid. If the saturation index is less than zero, the mineral is undersaturated with respect to the solution and the mineral might dissolve.

Dissolved organic carbon (DOC) The combined total of all organic carbon species dissolved in solution. Where dissolved is defined as below 0.45 micrometres.

Drawdown A lowering of the water table in an unconfined aquifer or the pressure surface of a confined aquifer caused by pumping of groundwater from bores and wells.

Dual permeability aquifer An aquifer in which groundwater flow is through both the primary porosity of the rock matrix and the secondary porosity of fractures and fissures.

Electrical Conductivity (EC)	A measure of a fluid's ability to conduct an electrical current and is an estimation of the total ions dissolved. It is often used as a measure of water salinity.
Environmental indicators	A measurable feature or features that provide managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality.
Environmental isotopes	Also known as stable isotopes, they act as 'groundwater signatures' and can be used as natural groundwater tracers.
Equilibrium	A balance between the thermodynamic forces of precipitation and dissolution. A saturation index (SI) of zero indicates apparent equilibrium.
Erosion	The group of processes whereby soil or rock material is loosened and removed from any part of the earth's surface. It includes the processes of weathering, solution, corrosion, abrasion, and transportation. The mechanical wear and transportation are affected by running water, waves, moving ice, or winds, which use rock fragments to grind other rocks.
Falling head test	A hydraulic test on a monitoring bore or piezometer that involves a sudden rise in water level (i.e. a volume of water is quickly added to the water column and the rate of water level decline is measured). Also called a slug test or slug-in test.
Fault	A fracture in rock along which there has been an observable amount of displacement. Faults are rarely single planar units; normally they occur as parallel to sub-parallel sets of planes along which movement has taken place to a greater or lesser extent. Such sets are called fault or fracture zones.
Flow testing	A gas and water appraisal program (generally carried out over several months) to determine the dewatering profile required to flow gas from one or several test production wells completed for exploration purposes.
Fluvial	Pertaining to a river or stream.
Fluvial deposit	A sedimentary deposit consisting of material transported by suspension or laid down by a river or stream.
Formation water	See produced water.
Fracture	Breakage in a rock or mineral along a direction or directions that are not cleavage or fissility directions.
Fractured rock aquifer	These occur in sedimentary, igneous and metamorphosed rocks which have been subjected to disturbance, deformation, or weathering, and which allow water to move

	through joints, bedding planes, fractures and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary rock aquifers.
Fracture stimulation	See hydraulic fracturing.
Global Meteoric Water Line (GMWL)	A line that defines the relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation from a number of global reference sites.
Groundwater	The water contained in interconnected pores or fractures located below the water table in the saturated zone.
Groundwater age classification	Groundwater ages are commonly referred to as: ***Modern*** <100 years ***Sub-modern*** 100-1,000 years ***Old*** >1,000 years
Groundwater dependent ecosystems (GDEs)	Groundwater dependent ecosystems are communities of plants, animals and other organisms whose extent and life processes are dependent (or partially dependent) on groundwater.
Groundwater flow	The movement of water through openings in sediment and rock within the zone of saturation.
Groundwater system	A system that is hydrogeologically more similar than different in regard to geological province, hydraulic characteristics and water quality, and may consist of one or more geological formations.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).
Hydraulic fracturing	A fracture stimulation technique that increases a gas well's productivity by creating a pathway into the targeted coal seam by injecting sand and fluids through the perforated interval directly into the coal seam under high pressure.
Hydraulic gradient	The change in total hydraulic head with a change in distance in a given direction.
Hydraulic head	Is a specific measurement of water pressure above a datum. It is usually measured as a water surface elevation, expressed in units of length. In an aquifer, it can be calculated from the depth to water in a monitoring bore. The hydraulic head can be used to determine a hydraulic gradient

	between two or more points.
Hydrochemistry	Chemical characterisation of water (both surface water and groundwater).
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.
Hydrology	The study of the occurrence, distribution, and chemistry of all surface waters.
Igneous rocks	Rocks that have solidified from molten or partly molten material (magma).
Infiltration	The flow of water downward from the land surface into and through the upper soil layers.
Ion	An ion is an atom or molecule where the total number of electrons is not equal to the total number of protons, giving it a net positive or negative electrical charge.
Isotope	One of multiple forms of an element that has a different number of neutrons than other atoms of that element. Some elements have isotopes that are unstable or radioactive, while others have 'stable isotopes'.
Isotropic	Having hydraulic properties that are the same in all directions.
Lithology	The study of rocks and their depositional or formational environment on a large specimen or outcrop scale.
Local Meteoric Water Line (LMWL)	A line that defines the local relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation. In this report the LMWL used is for coastal Brisbane.
Major ions	Constituents commonly present in concentrations exceeding 10 milligram per litre. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulphate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.
Methane (CH_4)	An odourless, colourless, flammable gas, which is the major constituent of natural gas. It is used as a fuel and is an important source of hydrogen and a wide variety of organic compounds.
MicroSiemens per centimetre (µS/cm)	A measure of water salinity commonly referred to as EC (see also Electrical Conductivity). Most commonly measured in the

	field with calibrated field meters.
Monitoring bore	A non-pumping bore, is generally of small diameter that is used to measure the elevation of the water table and/or water quality. Bores generally have a short well screen against a single aquifer through which water can enter.
Normal faulting	Where the fault plane is vertical or dips towards the downthrow side of a fault.
Numerical model	A model of groundwater flow in which the aquifer is described by numerical equations (with specified values for boundary conditions) that are usually solved in a computer program. In this approach, the continuous differential terms in the governing hydraulic flow equation are replaced by finite quantities. Computational power is used to solve the resulting algebraic equations by matrix arithmetic. In this way, problems with complex geometry, dynamic response effects and spatial and temporal variability may be solved accurately. This approach must be used in cases where the essential aquifer features form a complex system (i.e. high complexity models).
Oxidising conditions	Conditions in which a species loses electrons and is present in oxidised form.
Oxygen-18 (^{18}O)	A natural, stable isotope of oxygen and one of the environmental isotopes. It makes up about 0.2 % of all naturally-occurring oxygen on Earth.
Percent modern carbon (pMC)	The activity of ^{14}C is expressed as percent modern carbon (pMC) where 100 pMC corresponds to 95 % of the ^{14}C concentration of NBS oxalic acid standard (close to the activity of wood grown in 1890).
Permeability	The property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. It is a measure of the relative ease of fluid flow under unequal pressure. The hydraulic conductivity is the permeability of a material for water at the prevailing temperature.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Permian	The last period of the Palaeozoic era that finished approximately 230 million years before present.
pH	potential of Hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline

	and less than 7 is acidic).
Piezometer	See monitoring bore.
Piezometric surface	The potential level to which water will rise above the water level in an aquifer in a bore that penetrates a confined aquifer; if the potential level is higher than the land surface, the bore will overflow and is referred to as artesian.
Porosity	The proportion of open space within an aquifer, comprised of intergranular space, pores, vesicles and fractures.
Porosity, primary	The porosity that represents the original pore openings when a rock or sediment formed.
Porosity, secondary	The porosity caused by fractures or weathering in a rock or sediment after it has been formed.
Porous rock	Consolidated sedimentary rock containing voids, pores or other openings (joints, cleats, fractures) which are interconnected in the rock mass and may be capable of storing and transmitting water
Potentiometric surface	See piezometric surface.
Precipitation	(1) in meteorology and hydrology, rain, snow and other forms of water falling from the sky (2) the formation of a suspension of an insoluble compound by mixing two solutions. Positive values of saturation index (SI) indicate supersaturation and the tendency of the water to precipitate that mineral.
Produced water	Natural groundwater generated from coal seams during flow testing and production dewatering.
Pumping test	A test made by pumping a bore for a period of time and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the bore and the hydraulic characteristics of the aquifer.
Quaternary	The most recent geological period extending from approximately 2.5 million years ago to the present day.
Quality assurance	Evaluation of quality-control data to allow quantitative determination of the quality of chemical data collected during a study. Techniques used to collect, process, and analyse water samples are evaluated.
Radioisotope	Radioisotopes undergo radioactive decay allowing for determination of residence times in aquifers and groundwater systems.

Recharge	The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water reaching the water table or exposed aquifers. The addition of water to an aquifer.
Recharge area	A geographic area that directly receives infiltrated water from surface and in which there are downward components of hydraulic head in the aquifer. Recharge generally moves downward from the water table into the deeper parts of an aquifer then moves laterally and vertically to recharge other parts of the aquifer or deeper aquifer zones.
Recovery	The difference between the observed water level during the recovery period after cessation of pumping and the water level measured immediately before pumping stopped.
Recovery event	A monitoring event (in this case the download of dataloggers and the final water sampling program) completed after the pumping test.
Redox potential (ORP or Eh)	The redox potential is a measure (in volts) of the affinity of a substance for electrons – its electronegativity – compared with hydrogen (which is set at 0). Substances more strongly electronegative than (i.e. capable of oxidising) hydrogen have positive redox potentials. Substances less electronegative than (i.e. capable of reducing) hydrogen have negative redox potentials. Also known as oxidation-reduction potential and Eh.
Redox reaction	Redox reactions, or oxidation-reduction reactions, are a family of reactions that are concerned with the transfer of electrons between species, and are mediated by bacterial catalysis. Reduction and oxidation processes exert an important control on the distribution of species like O_2, Fe^{2+}, H_2S and CH_4 etc in groundwater.
Reducing conditions	Conditions in which a species gains electrons and is present in reduced form.
Residence time	The time that groundwater spends in storage before moving to a different part of the hydrological cycle (i.e. it could be argued it is a rate of replenishment).
RL	Reduced level or height, usually in metres above or below an arbitrary or standard datum.
Salinity	The concentration of dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS).

Salinity classification

Fresh water quality – water with a salinity <800 µS/cm.

Marginal water quality – water that is more saline than freshwater and generally waters between 800 and 1,600 µS/cm.

Brackish quality – water that is more saline than freshwater and generally waters between 1,600 and 4,800 µS/cm.

Slightly saline quality – water that is more saline than brackish water and generally waters with a salinity between 4,800 and 10,000 µS/cm.

Moderately saline quality – water that is more saline than brackish water and generally waters between 10,000 and 20,000 µS/cm.

Saline quality – water that is almost as saline as seawater and generally waters with a salinity greater than 20,000 µS/cm.

Seawater quality – water that is generally around 55,000 µS/cm.

Saturated zone

The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric pressure. The water table is the top of the saturated zone in an unconfined aquifer.

Screen

A type of bore lining or casing of special construction, with apertures designed to permit the flow of water into a bore while preventing the entry of aquifer or filter pack material.

Sandstone

Sandstone is a sedimentary rock composed mainly of sand-sized minerals or rock grains (predominantly quartz).

Screen

A type of bore lining or casing of special construction, with apertures designed to permit the flow of water into a bore while preventing the entry of aquifer or filter pack material.

Sedimentary rock aquifer

These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest volumes of groundwater.

Shale

A laminated sedimentary rock in which the constituent particles are predominantly of clay size.

Siltstone

A fine-grained rock of sedimentary origin composed mainly of silt-sized particles (0.004 to 0.06 mm).

Specific storage	Relating to the volume of water that is released from an aquifer following a unit change in the hydraulic head. Specific storage normally relates to confined aquifers.
Specific yield	The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Specific yield generally relates to unconfined aquifers. Gravity drainage may take many months to occur.
Stable isotope	Stable isotopes are atoms of the same element that have different masses due to differences in the number of neutrons they contain. Stable isotopes are not subject to radioactive decay, meaning they do not breakdown over time.
Standing water level (SWL)	The height to which groundwater rises in a bore after it is drilled and completed, and after a period of pumping when levels return to natural atmospheric or confined pressure levels.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to specific yield.
Stratigraphy	The depositional order of sedimentary rocks in layers.
Surface water-groundwater interaction	This occurs in two ways: (1) streams gain water from groundwater through the streambed when the elevation of the water table adjacent to the streambed is greater than the water level in the stream; and (2) streams lose water to groundwater through streambeds when the elevation of the water table is lower than the water level in the stream.
Tertiary	Geologic time at the beginning of the Cainozoic era, 65 to 2.5 million years ago, after the Cretaceous and before the Quaternary.
Total Dissolved Solids (TDS)	A measure of the salinity of water, usually expressed in milligrams per litre (mg/L). See also EC.
Toxicity	The degree to which a substance is able to damage an animal or plant life form.
Trace element	An element found in only minor amounts (concentrations less than 10 milligram per litre) in water or sediment; includes heavy metals arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.
Tracer	A stable, easily detected substance or a radioisotope added to a material to follow the location of the substance in the environment or to detect any physical or chemical changes it

	undergoes.
Transmissivity	The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Tritium (^3H)	A short-lived isotope of hydrogen with a half-life of 12.43 years. It is commonly used to identify the presence of modern recharge. Tritium is produced naturally in small amounts owing to the interaction of cosmic radiation with atmospheric oxygen and nitrogen in the troposphere, and is also produced by thermonuclear explosions.
Tuff	Tuff is a type of volcanic rock consisting of consolidated explosive ash ejected from vents during a volcanic eruption.
Turbidity	Reduced clarity of surface water because of suspended particles, usually sediment.
Unsaturated zone	That part of an aquifer between the land surface and water table. It includes the root zone, intermediate zone and capillary fringe.
Water bearing zone	Geological strata that are saturated with groundwater but not of sufficient permeability to be called an aquifer.
Water quality	Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Water quality data	Chemical, biological, and physical measurements or observations of the characteristics of surface and ground waters, atmospheric deposition, potable water, treated effluents, and waste water and of the immediate environment in which the water exists.
Water table	The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water.
Well	Pertaining to a gas exploration well or gas production well.
Wellbore	A wellbore is the physical hole that makes up the well and can be cased, open or be a combination of both completions. In this report it generally refers to uncased gas exploration boreholes prior to a gas well being completed.

List of Units

bbls/day	barrels per day
°C	degrees Celsius
L/s	litres per second
m	metres
m AHD	metres Australian Height Datum
mbgl	metres below ground level
mbtoc	metres below top of casing
meq/L	milliequivalents per litre
m/day	metres per day
m^3/day	cubic metres per day
m/year	metres per year
ML	megalitres
ML/day	megalitres per day
Mm	millimetres
µS/cm	microSiemens per centimetre
mg/L	milligrams per litre
mV	millivolt
pMC	percent modern carbon
psi	pounds per square inch
‰	per mil
TU	Tritium unit

List of Abbreviations

AGL	AGL Upstream Investments Pty Ltd
BoM	Bureau of Meteorology
BP	Before present
BTEX	Benzene, toluene, ethyl benzene and xylenes
CSG	Coal seam gas
DO	Dissolved oxygen
EC	Electrical Conductivity
GDE	Groundwater dependent ecosystem
GFDA	Gas Field Development Area
GGP	Gloucester Gas project
GMWL	Global Meteoric Water Line
LMWL	Local Meteoric Water Line
ORP	Oxidation reduction potential
PAH	Polycyclic aromatic hydrocarbons
PEL	Petroleum Exploration Licence
PPL	Petroleum Production Lease
RPD	Relative percentage difference
TPH	Total Petroleum Hydrocarbons

Executive summary

AGL Upstream Investments Pty Ltd (AGL) is proposing to build the Gloucester Gas Project (GGP) which will comprise several stages of development. Only one stage is being considered for development at this time. AGL also holds Petroleum Exploration Licence (PEL) 285, under the *Petroleum (Onshore) Act 1991*, covering the whole of the Gloucester Basin, NSW, approximately 100 km north of Newcastle.

This comprehensive groundwater investigation is to confirm the conceptual model and connectivity of the different groundwater systems across the Stage 1 Gas Field Development Area (GFDA), to establish a dedicated water monitoring network across the area, and to obtain baseline water level and water quality attributes for each of these groundwater systems.

The concept plan for the whole project and the project application for the GGP were lodged and exhibited in late 2009. Concept Plan and Project Approval for the Stage 1 GFDA was granted on 22 February 2011 under Part 3A of the *Environmental Planning and Assessment Act (1979)*.

The proposed GGP involves the dewatering of formation water and the extraction of gas from multiple coal seams within the Gloucester Coal Measures. Target coal seam depths will vary from site to site but are expected to range between 200 and 1000 metres below ground level (mbgl). Baseline groundwater investigations of all the local groundwater systems are required in advance of construction as part of the planning approvals process.

Importance of groundwater studies

Groundwater studies are required to confirm the baseline conditions (pre-development) and to determine the impact (if any) on shallow water resource aquifers and local ecosystems as the project is constructed, commissioned, and then operated.

Groundwater level and quality monitoring programs provide the primary scientific data to determine whether there is an impact from CSG activities on local shallow aquifers. The monitoring and interpretation of groundwater data allows the development of a conceptual hydrogeological model that is used to represent the groundwater regime and describe groundwater flow and linkages between shallow aquifers and deeper coal seam water bearing zones. Groundwater quality monitoring programs (hydrogeochemical and isotope studies) are important verification techniques used to confirm the conceptual model and to assess whether there is any drainage from, or leakage to, the overlying shallow aquifers.

In simple terms, the conceptual (hydrogeological) model is the representation (in words and diagrams) of the different groundwater systems beneath a project area. It is developed from a preliminary (desktop) understanding and confirmed with site specific data. Once there is confidence in the conceptual model a numerical (computer) model can be built to represent the different groundwater systems and to predict their behaviour under a number of different natural and project development scenarios.

As part of ongoing site investigations and required compliance monitoring program, AGL is currently undertaking comprehensive field investigations and baseline monitoring in parallel with supplementary exploration programs and future planning for the GGP. Site investigations are providing detailed data from a number of different sites and depths across the area, and these are refining our knowledge and understanding of groundwater systems and flow processes. The most recent site investigations (the subject of this report) are focussed on the Stage 1 GFDA between the settlements of Gloucester, Stratford and Waukivory, and adjacent to the Avon River and its minor tributaries.

Study Objectives

The following primary objectives were identified for the site investigation program:

- Complete baseline studies to effectively characterise the groundwater systems in the Stage 1 GFDA.
- Provide site specific information on groundwater occurrence and flow by investigating the different groundwater systems, and determining whether the shallow water resource aquifers are connected to the deeper coal seam water bearing zones. The investigations are to include:
  - Drilling to establish test / monitoring bore locations (groundwater, seepage, and gas migration locations)
  - Downhole geophysical logging and surveying
  - Permeability testing
  - Water level monitoring
  - Water quality sampling
  - Isotope sampling
  - Installation of stream gauge stations
  - Miscellaneous gas, rock/soil and water sampling as required.
- Assist in determining the quantity and quality of deep groundwater that is likely to be produced as the CSG scheme is constructed.
- Establish a monitoring network across the Stage 1 GFDA that is spatially diverse and sufficient to cover staged development of the scheme, and is representative of the catchment, local geologies, and complexities associated with the geological structure.
- Prepare a comprehensive technical report that includes a revised conceptual model of groundwater recharge, discharge and flow across the Stage 1 GFDA together with all the Phase 2 site investigation activities, data, results and conclusions.

Investigation methodology

The site investigation studies have mostly involved geological appraisal, drilling, water level monitoring, water sampling, isotope studies, data collation, analysis and reporting. An extensive groundwater and surface water monitoring network has been established across the Stage 1 GFDA. The network and intensive coverage are designed to:

- Enhance the conceptual (hydrogeological) model
- Collect baseline information on natural groundwater and surface water levels (and any seasonal variability) and natural water quality
- Enable monitoring of groundwater and surface water levels and quality in the vicinity of AGL's existing and planned CSG exploration and production wells suitable for assessing ongoing exploration and project start-up activities
- Provide essential data and input parameters for a future numerical groundwater model.

Monitoring network and programs

The adopted methodology aims to establish detailed spatial and depth coverage of the different groundwater systems across the Stage 1 GFDA to confirm the conceptual model and to build a database of information for the pending numerical model.

There was also an increased focus on the Avon River because of the proposed irrigation trials and likelihood of ongoing intensive irrigation; shallow seepage monitoring because of the produced water dams, and monitoring of potential gas migration.

The monitoring network was designed to provide regional groundwater data representative of the wider Stage 1 GFDA. In summary, the network (as at 30 November 2011) comprises:

- twenty two (22) groundwater monitoring bores installed with dataloggers to record water levels
- three (3) stream gauges installed with dataloggers recording salinity and water levels
- two (2) shallow gas monitoring bores
- two (2) seepage monitoring bores to assess potential seepage from the Tiedman produced water dams.

Following the installation of the monitoring network, an extensive field program of hydraulic testing, water level monitoring, water quality sampling, and age dating was completed.

Data collected and analysed from this network provides the primary scientific data to assess the baseline groundwater characteristics across the area and to determine the connectivity of aquifers and the potential for impacts on shallow aquifers used for water supply and connected to permanent creek/river systems.

Updated hydrogeological conceptual model

Water level, water quality and isotope data collected from the newly installed groundwater and surface water monitoring network provides a greater appreciation of groundwater recharge, discharge and flow processes through the different hydrogeological units of the Gloucester Basin. There are few beneficial aquifers. These shallow aquifers are only suitable for stock water supply and limited domestic purposes.

The hydrogeological units, confirmed by these Phase 2 investigations are:

- Alluvial aquifers
- Shallow rock aquifers
- Interburden confining units
- Coal seam water bearing zones.

Only the first two units are beneficial aquifers, with the deeper rock types being either very poor aquifers (coal seams, siltstones and sandstones) or confining layers (claystones, siltstones or indurated sandstones). Rainfall recharge is the primary recharge source to all aquifers and water bearing zones. Recharge rates to the rock aquifers and water bearing zones are low based on water level responses, water quality indicators, and age dating. As the Gloucester Basin is a closed geological basin, the conceptual model suggests that minor discharge of groundwater to the alluvium along the floor of the valley from the shallow and deep sedimentary rocks is likely.

Alluvial aquifers (to maximum 12 m depth)

The alluvium associated with the Avon River and its tributaries is shallow and is an unconfined or semi-confined aquifer across the whole area where it is present. Groundwater level data imply groundwater flow in a northerly direction parallel to the axis of the valley. Recharge to the alluvial aquifer is predominantly via direct rainfall infiltration and also via lateral throughflow from upgradient alluvium. Flooding occasionally provides additional recharge. Small seepage contributions from the underlying bedrock are also likely.

Groundwater discharge from the alluvium is primarily to the rivers as baseflow. Investigations indicate a gaining river system with a hydraulic gradient between the water table and adjacent river levels. This hydraulic connection between the alluvial groundwater and river system is supported by the steady increases in salinity in the river during periods of low rainfall and low flow. A secondary discharge route for shallow alluvial groundwater is likely to be transpiration by riparian vegetation. Minor abstractions by private bores and wells are the only other discharge from these alluvial aquifers.

Groundwater dating indicates that the alluvial aquifer contains modern water with maximum residence times unlikely to be more than a few hundred years, with the youngest water detected in the upstream alluvial deposits.

Shallow rock aquifers (to maximum 150 m depth but mostly less than 100 m depth)

Evidence from the extensive Phase 2 drilling and testing program has led to a slight revision of the conceptual model of groundwater flow within this hydrogeological unit.

The revised conceptual model, supported by the field data, is that the shallow rock unit is a dual permeability aquifer rather than just a fractured rock aquifer. The shallow rock is interbedded sandstone, silt and claystone, and is characterised by lateral groundwater flow within the rock matrix and via bedding plane partings and minor fractures.

Rainfall recharge only appears to occur in outcrop and shallow outcrop areas. In areas where there is a weathered (clayey) profile, brackish to saline water quality suggests there is negligible (vertical) rainfall recharge. Lateral groundwater flow is most likely directed toward the centre of the basin within individual strata and through bedding plane partings and minor fractures. The unit is likely to discharge to the alluvium that has been deposited along the floor of the valley.

Isotopic dating indicates that groundwater in the shallow rock aquifer is in the order of thousands of years old and therefore significantly older than groundwater in the shallow alluvium.

Interburden confining units (generally from 150 to 1000 m depth)

The deeper interburden units typically are of very low permeability. The groundwater is therefore moving very slowly with lateral groundwater flow within the matrix of each rock unit predominating over fracture flow migration.

The low permeability interburden units are locally saturated, but generally act as confining layers between and overlying the coal seams. The layered aquitards of the interburden units create separate and distinct groundwater systems with no connection evident between the deeper coal seam water bearing zones and the shallow rock and alluvial aquifers. Stable isotopes indicate water within these interburden units is of meteoric origin, and radiocarbon data indicates water is thousands to tens of thousands of years old.

Coal seam water bearing zones (generally from 200 to 1000 m depth)

Despite having low permeabilities, the coal seams in the Stage 1 GFDA have a higher permeability than the surrounding interburden and are therefore likely to be conduits for limited groundwater flow at depth. The groundwater is moving very slowly (but sometimes faster than groundwater in the overlying interburden units) with lateral groundwater flow within the cleats in the coal seams predominating over fracture flow migration.

This deep groundwater is derived from rainfall in the outcrop areas and lateral groundwater flow is most likely directed toward the centre of the basin. The unit is likely to discharge to the shallow rock areas toward the centre of the basin (and eventually and indirectly to the alluvium that has been deposited along the floor of the valley). Faults are suspected to be conduits for some of this upward flow but there is no evidence of any upward flows or discharge areas at this time.

Stable isotopes indicate water within these coal seams is of meteoric origin, and radiocarbon data indicates water is thousands to tens of thousands of years old.

Significance of fault zones

Even though several of the completed monitoring bores are located close to faults or straddle fault zones, the available data suggests the faults do not affect the natural groundwater flow characteristics of shallow rock aquifers, interburden confining units or coal seam water bearing zones. However water quality and isotope data on the Tiedman site is less conclusive and may suggest near surface faults are enhanced recharge areas.

Current understanding based on earlier flow testing programs, water level data, water quality data and isotope age dating results from this study is that faults are not major features with respect to natural groundwater flow pathways across the area. However, further studies are under way to better understand groundwater flows within and adjacent to faulted areas when deep coal seams are dewatered.

While the increased risk of drainage of groundwater from shallow aquifers is low, AGL's general development principles in relation to faults are to:

- Use 3D seismic to accurately locate (and avoid) major faults
- Avoid drilling above and through these major structural features
- Step out and find alternative locations in more competent rock where possible
- Design and construct wells with more casing and more cementing in areas/intervals close to faults where broken rock and greater water inflows may be encountered

Maximising CSG production is based on minimising produced water volumes. With a dewatering cap of 2 ML per day for the Stage 1 development, it is important that AGL's wellfield layout is based on dewatering deep coal seams only and avoiding as many faulted areas as possible.

Further conclusions

Other important conclusions (not discussed above) are:

- Water level monitoring suggests that:
  - water levels respond to rainfall and flooding for alluvial aquifers and show seasonal variations

  - there are minor water level variations for shallow rock aquifers that are small lagged rainfall responses
  - there are negligible water level variations and no seasonal trends for interburden confining units and for coal seam water bearing zones
- Water quality monitoring suggests that:
  - alluvial aquifer water quality is fresh to brackish, sodium chloride dominant, with minor dissolved metals
  - shallow rock water quality is brackish, sodium chloride bicarbonate dominant, with minor dissolved metals
  - interburden confining units water quality is brackish to slightly saline, sodium chloride bicarbonate dominant, with minor dissolved metals
  - coal seam water bearing zone water quality is brackish to slightly saline, generally sodium chloride bicarbonate dominant, with minor dissolved metals
- There are no known GDEs or ecosystems that could be affected if there are changes to the deep groundwater regime in the coal seam water bearing zones

Hydrogeological investigations should continue in parallel with any new exploration production testing programs. Additional monitoring bores and baseline monitoring should be installed and monitoring programs commenced to complement these programs.

The overall conclusion of these comprehensive studies is that site investigations and baseline data collected from the substantial surface water and groundwater monitoring network across the Stage 1 GFDA confirms that the characteristics of shallow (beneficial) aquifers are different to the groundwater contained in the deeper rock strata and coals seams. Rainfall recharge is low groundwater flow is mostly lateral within the different strata, and there is no evidence of natural connectivity between shallow and deep groundwater systems.

1. Introduction

AGL Upstream Investments Pty Ltd (AGL) is proposing to build the Gloucester Gas Project (GGP) which will comprise several stages of development. Only one stage is being considered for development at this time. AGL also holds Petroleum Exploration Licence (PEL) 285, under the *Petroleum (Onshore) Act 1991*, covering the whole of the Gloucester Basin, NSW, approximately 100 km north of Newcastle (Figure 1-1). Baseline groundwater investigations are required in advance of construction as part of the planning approvals process.

This comprehensive groundwater investigation aims to confirm the conceptual model and connectivity of the different groundwater systems across the Stage 1 Gas Field Development Area (GFDA), to establish a dedicated water monitoring network across the area, and to obtain baseline water level and water quality attributes for each of these groundwater systems.

Groundwater investigations and the establishment of monitoring networks are being carried out under water licences in preparation for (and prior to the commencement of) the GGP.

1.1 Background

The concept plan for the whole project and the project application for the GGP were lodged and exhibited in late 2009. Concept Plan and Project Approval for the Stage 1 GFDA was granted on 22 February 2011 under Part 3A of the *Environmental Planning and Assessment Act (1979)*.

The initial GGP involves: the Stage 1 GFDA for the extraction of coal seam gas (CSG) from the Gloucester Basin within the PEL 285 area, including the development of CSG wells and associated infrastructure; the development of a central processing facility (CPF); the construction and operation of a high pressure gas transmission pipeline from Stratford to Hexham, NSW; and the Hexham Delivery System (HDS).

The GGP involves the dewatering of formation water and the extraction of gas from multiple coal seams within the Gloucester Coal Measures. Target coal seam depths will vary from site to site but are expected to range between 200 and 1000 metres below ground level (mbgl).

1.2 Importance of groundwater studies

The management of water resources is a critical environmental issue facing Australia and one that is relevant to AGL's business. AGL's long-term vision is to be recognised as a prudent and responsible user of water that seeks to minimise the impact of its operations on local water resources.

Groundwater level and quality monitoring programs provide the primary scientific data to determine whether there is an impact from CSG activities on local shallow aquifers used for water supply and as environmental baseflow to surface water systems. The monitoring and interpretation of groundwater data enhances the development of a conceptual (hydrogeological) model that is used to represent the groundwater regime and describe groundwater flow and linkages between shallow aquifers and deeper coal seam water bearing zones. Groundwater quality monitoring programs (hydrogeochemical and isotope studies) are important verification techniques used to confirm the conceptual model and to assess whether there is any drainage from, or leakage to, the overlying shallow aquifers.

In simple terms, the conceptual (hydrogeological) model is the representation (in words and diagrams) of the different groundwater systems beneath a project area. It is developed from a preliminary (desktop) understanding and confirmed with site specific data. Once there is confidence in the conceptual model, a numerical (computer) model can be built to represent the different groundwater systems and to predict their behaviour under a number of different natural and project development scenarios.

Groundwater studies were initiated in 2006 with the first flow testing programs, and have grown substantially in recent years with the GGP environmental assessment (AECOM, 2009; AECOM, 2010) and specialist studies (URS, 2007; SRK, 2010).

As part of ongoing site investigations and required compliance monitoring program, AGL is currently undertaking comprehensive field investigations and baseline monitoring in parallel with supplementary exploration programs and future planning for the GGP. Site investigations are providing detailed data from a number of different sites and depths across the area, and these are continuing to refine our knowledge and understanding of groundwater systems and flow processes.

These most recent site investigations (the subject of this report) are focussed on the Stage 1 GFDA between the settlements of Gloucester, Stratford and Waukivory, and adjacent to the Avon River and its minor tributaries. AGL commissioned Parsons Brinckerhoff to complete the Phase 2: Detailed Groundwater Investigations (which includes setting up the sub-regional water monitoring network). The (typical) five phases for groundwater investigation work programs are outlined as follows:

Phase 1	Desktop Study (completed; SRK, 2010)
Phase 2	**Detailed groundwater investigation (this report)**
Phase 3	**Modelling** Update of the conceptual model and construction of numerical model(s) (as required) to describe initial steady state impacts then predict groundwater impacts for various development scenarios
Phase 4	**Monitoring program (under way)** Long-term monitoring and compliance reporting
Phase 5	**Project updates (under way)** Further investigations and additions to the monitoring network as required

In this instance for the initial GGP, desktop studies were completed in 2007 and 2010, detailed site investigations are ongoing but were initiated in 2006 (with the bulk of studies in 2010 and 2011), while monitoring programs were initiated in April 2010, expanded in December 2010, and are ongoing.

The desktop studies and initial site investigation data were considered adequate for the Environmental Assessment (AECOM, 2009) and the submissions report (AECOM, 2010) because of the dominance of surface water, the limited use of groundwater across the region, the poor groundwater quality, and the relatively small volumes of produced water from initial flow testing programs (see Section 2.2).

Groundwater technical studies, conceptual models, water monitoring networks and management were subsequently given a high profile in the Part 3A project approval conditions. In addition to this comprehensive technical report which addresses most of these conditions, additional studies and reports, and groundwater management plans associated with ongoing exploration activities will also be available in 2012.

PARSONS BRINCKERHOFF

GLOUCESTER GAS PROJECT: PHASE 2 GROUNDWATER INVESTIGATIONS
AGL ENERGY LTD

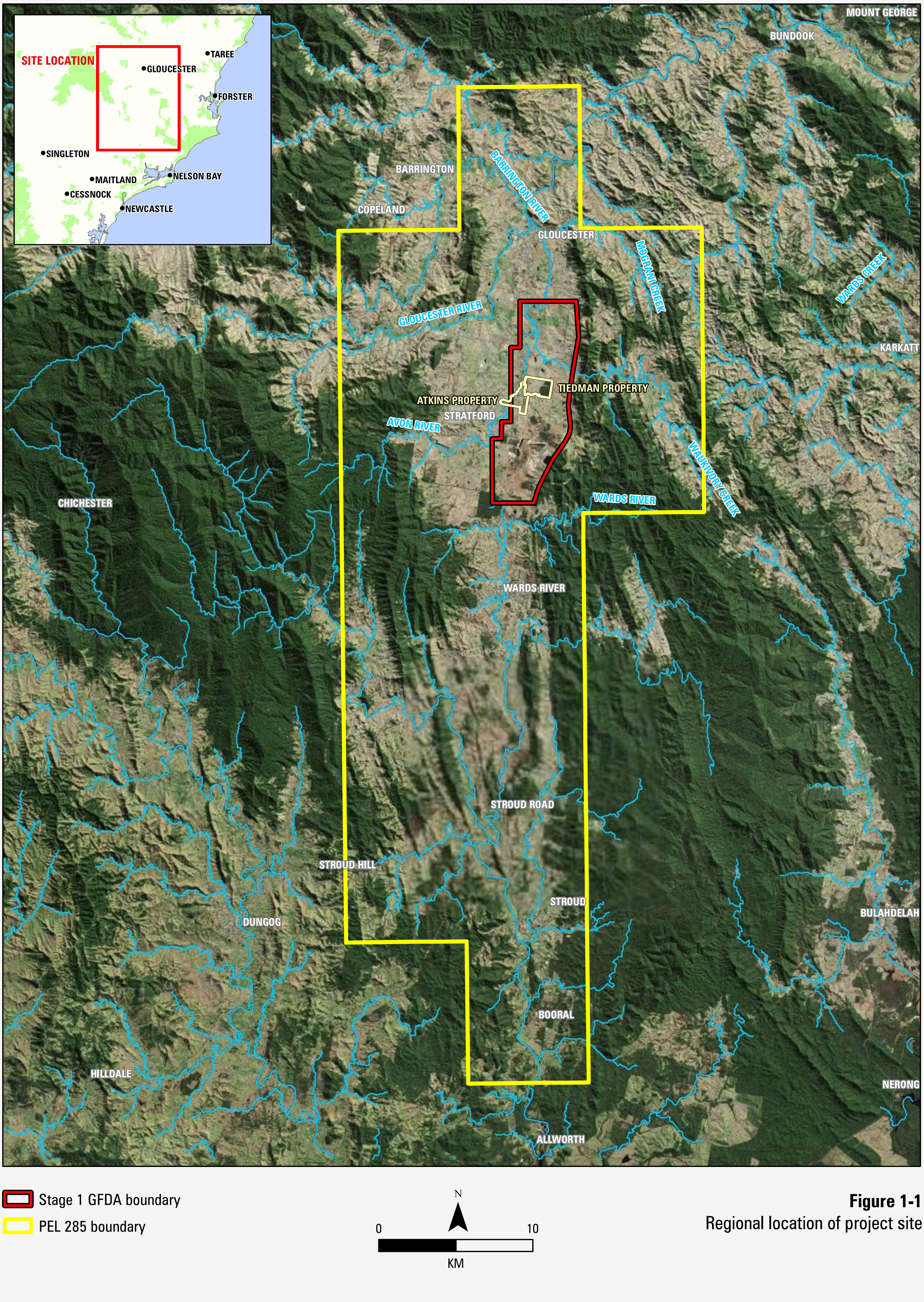

Figure 1-1
Regional location of project site

\\APSYDNAS02\proj\A\AGL_Energy\2162406_HYG_GLOUSTER_BASIN_CSM_ASS\10_GIS\Projects\ESRI\2162406A_GIS_F002_C.mxd Author: kumarg 06/01/2012

1.3 Project approvals

AGL was granted Concept Plan approval for the whole of the GGP (PEL 285 area) and project approval for the proposed GGP – Stage 1 GFDA in February 2011. This project approval was granted by the Planning Assessment Commission. An approval under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* and a Petroleum Production Lease (PPL) will also need to be granted over the Stage 1 GFDA for the production project to commence.

There are substantial water resource protection and water management conditions in the Part 3A project approval. This comprehensive groundwater study addresses the detailed data collection, data analysis, conceptual model development and monitoring network requirements of the Part 3A project approval. Specific requirements are discussed in more detail in Section 4.1.

In addition to the planning approvals, water management approvals are also required under NSW's water legislation. All the investigations carried out to date have been carried out under test/monitoring bore licences issued under the *Water Act 1912*.

Water management in NSW is undertaken under two primary instruments administered by the NSW Office of Water (NOW), the *Water Act 1912*, and the *Water Management Act 2000*. The *Water Management Act 2000* comes into force on a water source basis and applies once a water sharing plan for that water source commences.

The GGP lies within the Gloucester Geological Basin which is located within the New England Fold Belt. Although discrete, the Gloucester Geological Basin shares many of the features of the Sydney-Gunnedah Basin to the south (Lennox, 2009). For the purpose of groundwater management in NSW, the Permian rocks of the Gloucester Geological Basin are defined as a 'porous rock aquifer'. The Gloucester Basin is likely to be managed under a Macro Groundwater Sharing Plan for coastal areas north of Sydney, titled Water Sharing Plan (WSP) for Northern Fractured and Porous Rock Groundwater Sources in NSW. This plan is scheduled to commence in 2013. Prior to commencement, the plan will be released as a draft for comment. Currently the Gloucester Geological Basin is managed under the *Water Act 1912*. Note that this proposed WSP is different to the Lower North Coast Unregulated and Alluvial WSP (which applies to the alluvial aquifers of the Avon River catchment) which commenced on 1 August 2009 under the *Water Management Act 2000*.

Current groundwater works within the Gloucester Basin are required to comply with the *Water Act 1912* and therefore all monitoring bore construction activities (and earlier core hole and exploration drilling) have been licensed under the *Water Act 1912.* Any consumptive uses of water (such as for industrial and irrigation reuse) requires renewable bore licences or water access licences. In the future, operation of the GGP will need to comply with the requirements of the *Water Management Act 2000*, the respective WSPs, and relevant policies and regulations.

Under the *Water Management Act 2000*, NOW are developing an Aquifer Interference Policy to manage the taking and disposal of groundwater in the course of carrying out other activities such as mining or coal seam gas extraction. This policy is expected to be released in early 2012 and is expected to have additional approval implications for this project.

The WSP for the Coastal Porous Rock Groundwater Sources will define the groundwater that is available within the Gloucester Groundwater Source. The volume will be based on an assessment of the annual average recharge to the outcropping areas of the water source, and termed the Long Term Average Annual Extraction Limit (LTAAEL). The LTAAEL for the Gloucester Groundwater Source has not yet been published.

The NOW has recently published the NSW policy for managing buried groundwater sources (NSW Office of Water 2011b). One of the key components of this policy is to identify those groundwater systems that do not outcrop and to provide an alternate mechanism for making water available for allocation from these groundwater sources (as direct rainfall recharge does not occur). This is done by allowing one off access to 0.002% of the groundwater storage of that source. The policy states that access to storage may be considered in the future for some water sources that are currently not defined as being 'buried' based on the technical water source definition. The Gloucester Basin Water Source is listed as one of the water sources that may be allowed to access storage in the future.

Extraction of groundwater as part of the operation of the initial GGP is expected to require a water access licence from the Gloucester Groundwater Source and an aquifer interference approval that aligns with the Aquifer Interference Policy.

1.4 Report structure

This document provides a comprehensive technical report on the Phase 2 investigation program supporting an updated conceptual model of the study area (the initial GGP area). The report collates geological logs of newly constructed groundwater monitoring bores, hydraulic testing results, surface water monitoring programs, initial baseline water level trends and analysis, and baseline water quality results and interpretation. The structure of the report is as follows:

- **Section 2**: summarises previous studies and field programs that describe the geological and groundwater characteristics and beneficial uses across the area.
- **Section 3:** characterises the catchment and the Stage 1 GFDA, and presents the current geological and hydrogeological conceptual models
- **Section 4:** details the investigation, scope of works and methodology used to achieve the study objectives
- **Section 5:** presents an updated geological model of the Stage 1 GFDA
- **Section 6:** presents the results of hydraulic testing of the encountered aquifers, water bearing zones, aquitards and aquicludes
- **Section 7:** presents initial baseline water level monitoring results
- **Section 8:** presents baseline water quality and isotope monitoring results
- **Section 9:** discusses the few coal and gas samples collected
- **Section 10:** discusses all data and information collected to date and develops an updated conceptual model of the study area
- **Section 11:** presents the conclusions of the current investigations.

2. Previous studies

This chapter summarises previous studies, field programs, and earlier conclusions that describe the geological and groundwater characteristics of the Stage 1 GFDA. Recommendations regarding additional studies are included where relevant.

2.1 Previous desktop studies

In addition to the Environmental Assessment for the GGP (AECOM 2009), two site specific groundwater studies have been completed for the Stage 1 GFDA. Both were desktop studies with minimal field investigations:

URS 2007 Hydrogeological Review – Proposed Coal Seam Gas Exploration Areas, Gloucester-Stroud Basin, NSW: for Lucas Energy

SRK 2010 Gloucester Basin Stage 1 Gas Field Development Project – Preliminary Groundwater Assessment and Initial Conceptual Model: for AGL

2.1.1 URS hydrogeological review

As part of earlier investigations for the previous PEL holder, Lucas Energy, URS Australia (URS) completed a desk top study (URS, 2007) to: assess the hydrogeological characteristics of three exploration areas within the Gloucester Basin (Stratford, Craven, and the Weismantel exploration area); identify potential impacts on the local groundwater system (and users) and surface water flows resulting from the groundwater abstraction necessary to exploit the potential gas resource; and provide recommendations for future monitoring to enable assessment and management, as required, of potential effects on the local hydrogeological and surface water systems resulting from CSG extraction. Conclusions from URS (2007) were:

- Groundwater is present in unconfined and confined aquifers within shallow alluvial soils and deeper coal seams and other rocks interbedded with the coal seams.
- Groundwater is abstracted and used, generally for irrigation and stock watering. Most of the groundwater is abstracted from shallow alluvial soils or relatively shallow bedrock material (less than 40 mbgl).
- The hydraulic conductivity of the coal seam water bearing zones is generally low to moderate, with the interbedded rocks forming leaky confining layers or aquitards. The conductivity of the coal seams and interbedded rocks is, however, likely to vary significantly near to fault and fracture planes, where secondary permeability may be well developed. This is apparent at the Stratford exploration area. The hydraulic conductivity of the unconfined alluvial aquifers is not known, but is likely to vary depending on the parent rock material.
- The continuity and hydraulic connection within a given aquifer depends on the presence and extent of faulting.
- Recharge of groundwater occurs across the basin; however the majority of recharge to the deep coal seams and other water bearing zones is likely to occur on the basin

margins, where these rocks outcrop . Streams may also form a source of recharge to shallow aquifers, where groundwater elevations are lower than the base of the stream or river.

- Groundwater flow will initially follow topography (from the basin margins towards the centre of the basin) and may discharge into local streams and rivers, depending on the relative elevations of the potentiometric head/water level in the aquifer and the river bed. Groundwater may flow vertically between aquifers, facilitated by the presence of fractures/faults, leaky confining layers and differences in potentiometric head.

- Typical groundwater yields from the various aquifers and water bearing units are not known, but were relatively high in the Stratford area where hydraulic fracturing was undertaken and well developed secondary permeability was present; and

- Groundwater abstraction undertaken in the Stratford exploration area did not appear to affect water levels in the shallow alluvial aquifer. However, this relationship will be area specific and would need to be monitored over longer pumping events to assess whether dewatering of the shallow aquifer could occur as a result of groundwater pumping from deep coal seams.

On the basis of these conclusions, URS (2007) recommended the following works as part of the ongoing assessment of the feasibility of CSG extraction at the Stratford, Craven, and Weismantel exploration areas:

- Update the geological and hydrogeological model as the exploration programs progress.

- Confirm location, use, and if possible construction of existing registered and unregistered bores in the vicinity of each exploration area.

- Install a network of nested piezometers (within the target coal seams and aquifers being beneficially used by surrounding property owners/operations) to allow monitoring of changes in water levels in response to pumping as part of future CSG extraction trials. This monitoring will assist in determining the effective area of influence able to be induced by a given extraction well, and assess changes in water levels in other aquifers in response to extraction. The water levels in these bores should be monitored prior to, during and following pilot extraction (flow testing).

- Monitoring of water levels in nearby existing bores prior to, during and following the extraction trial to assess potential effects on water levels in other aquifers in areas surrounding the extraction points.

- Periodic collection of samples of groundwater from the extraction well/s through the course of future trials to assess for potential impacts.

- Seal/cap coreholes in the vicinity of the exploration areas prior to conducting further pilot CSG extraction trials.

2.1.2 SRK preliminary assessment

The SRK (2010) report is the principal Phase 1 groundwater assessment report for the GGP and provides the initial hydrogeological conceptual model and recommendations which are the precursor to these comprehensive Phase 2 studies. The main objective of the report was to summarise the available hydrological and hydrogeological information, identify gaps in the information, and provide inputs and guidance for subsequent work programs.

The geological appraisal covers the whole of the Gloucester Basin however the bulk of the hydrogeological assessment is for the Stage 1 GFDA.

Summary conclusions and recommendations from SRK (2010) were:

1. Long-term site-specific climate data are incomplete. More complete information, combined with monitoring data will improve the understanding of the hydrogeology of the area. An onsite record of daily rainfall, temperature and evaporation should be stored in a database format. The meteorological station located at the Stratford mine site or the Gloucester Post Office station (site number 060015) can be used for this purpose.

2. Detailed geological and structural models of the basement rocks surrounding the area are not available. To inform the location of any future groundwater monitoring bores, a geological 2D or 3D model should be developed as more information becomes available to assess the spatial distribution of faults and fractures, intrusive dykes, as well as formation thickness.

3. Reliable long-term surface water monitoring data in the vicinity of the Stage 1 GFDA are not available and the northern part of the project area is not monitored. Several gauging boards on the Avon River, and several monitoring points on the main creeks surrounding the project area, should be installed to collect both water level and water quality data sets. A comprehensive monitoring program, including water quality analysis (physiochemical properties, EC, pH, major cations and anions, trace metals, nutrients, and total dissolved organic carbon) will provide a better understanding of natural variations and will assist in determining any potential impacts of CSG activities. Permanent gauging boards up and downstream of the proposed main irrigation areas (as detailed in Parsons Brinckerhoff, 2011) are also recommended.

4. Reliable long-term monitoring data in the shallow aquifers (alluvial and fractured aquifers) in and surrounding the Stage 1 GFDA are not available. A comprehensive monitoring program will provide better understanding of natural variations and will assist in determining any potential impacts of CSG activities on shallow aquifers, primarily used by local landowners. Monitoring bores should be installed in the alluvial and shallow fractured rock aquifers within the Stage 1 GFDA. The number of monitoring bores required will depend on the geological and hydrogeological site conditions. An initial network should be established on AGL's Tiedman property in the vicinity of the Stratford wells. Regional shallow boreholes within a 600 to 800 m radius from CSG wells could also augment a dedicated monitoring network.

5. Reliable long-term monitoring data of the deep coal seam water bearing zones in the Stage 1 GFDA are not available. Vibrating wire piezometers (VWPs) should be installed in the targeted coal seams as well as above and below the coal seams in order to determine the impact of CSG extraction on the deep aquifers. Monitoring sites should be based on the geological model and hydrogeological site conditions.

6. The thickness of unconsolidated alluvial sediments, the hydraulic characteristics of these sediments and the underlying Permian rocks in the Stage 1 GFDA are reasonably well known. However, the hydraulic characteristics of the contact between the alluvial and fractured Permian aquifers/water bearing zones is an important consideration and at present unknown. It is recommended to core a number of deep holes (150-200 m depth)

and perform continuous packer testing to obtain hydraulic values for the unconsolidated sediments, underlying Permian rocks and any intrusive rocks.

7. The impacts of long-term irrigation of untreated/treated produced CSG water are unknown. Additional shallow monitoring bores should be constructed in the alluvial areas (near creeks and rivers) where irrigation is proposed to monitor both shallow groundwater, and upstream and downstream water quality.

8. Baseline water level monitoring programs are required to establish the natural variability and impacts (if any) associated with CSG production and irrigation development. A number of baseline monitoring locations should be established in the Stage 1 GFDA to obtain the required data.

9. The hydraulic characteristics of the faults and fractures in the Stage 1 GFDA are not tested. The current understanding of the system considers that the fracture network may contain large volumes of water and may act as preferred pathways for groundwater recharge and the connectivity of aquifers. Therefore, the structural hydraulic characteristics should be investigated. Two bores should be drilled into identified faults and a 72 hour pumping test carried out to estimate hydraulic parameters of these structures. Geochemical parameters should also be recorded during the test, and the water should be sampled regularly for laboratory analyses (composition and isotope characteristics).

10. The hydrochemical characteristics of the aquifers are not well understood. A comprehensive baseline assessment of water quality (composition and isotopic characteristics) from groundwater monitoring bores installed in the shallow (alluvial and fractured) aquifers as well as pilot production wells within the Stage 1 GFDA will establish the origin, age and quality of each aquifer and identify any interconnectivity or recharge flow path.

11. The occurrence and extent of free gas seeping out of the coal seams as they are depressurised in the outcrop areas is not well understood. A suitable (up dip) site (to a maximum depth of 20 m) with multiple monitoring levels should be identified and instrumented. Comparison of the composition and isotopic characteristics of any up dip gas migrating with those of the coal seam gas will establish their origin.

12. The regional surface and groundwater survey was incomplete. Additional regional surface water and groundwater monitoring points should be surveyed and a dedicated submersible pump should be used for future groundwater sampling. It is recommended that at least two groundwater monitoring sites should target the alluvial aquifers within the Stage 1 GFDA, and at least one spring and one borehole located in the Alum Mountain Volcanic formation be surveyed.

13. The current conceptual model has been constructed using the limited available information. The model should be revised and updated once additional information is available from the geological and hydrogeological investigations.

2.2 Previous CSG pilot/flow testing programs

Nine (9) gas wells were flow tested as part of the Stratford pilot testing program between 2006 and December 2009. All wells apart from Stratford 1 were fracture stimulated. There are multiple perforations in each of the gas production wells, sometimes over vertical distances of more than 200m. Top and bottom perforation intervals are provided in Table 2-1. Testing was not continuous over this three to four year period and most wells commenced (or recommenced) dewatering at different times. The location of these gas wells is shown on Figure 2-1.

Produced water volumes

Produced water volumes from the gas production wells were generally low (less than 200 bbls/day, i.e. instantaneous rates of less than 0.35 L/s). The exception to this was the Stratford 3 site where the high permeability of the shallow Bowens Road Coal Seam at this location produced a significantly larger quantity of produced water (up to 800 bbls/day) compared to other production wells that were perforated against this horizon.

Nonetheless, water production (dewatering) profiles at all sites reduced during the period of each flow test, and the conclusion was that all produced water was derived from the coal seams and there was no leakage from overlying aquifers.

Water levels

The drawdown level at each of the gas production wells is reasonably well known and in most cases was very close to the top or within the perforated interval at each well site. Details are provided in Table 2-1. There was no dedicated monitoring bore network in place at the time of the testing program so there is no confirmation that water levels in shallower aquifers did not react to pumping.

However other data sets suggest that there was no leakage from overlying aquifers because:

- Produced water volumes at all sites (except Stratford 3) diminished to less than 50 bbls/day (less than 0.11 L/s) at most sites after only a few weeks/months pumping (i.e. there was no evidence of pulsating or increased water inflows).
- The salinity of the produced water was reasonably consistent (within ±20% of initial samples) at most sites during the period of testing.

Water quality

Water quality trends are a secondary proof that assists with assessing the connectivity of aquifers. In this instance at Stratford, the water quality data is complicated by there being multiple perforated intervals in each of the completed gas wells. Given there are uncertain water contributions from individual coal seams, and these zones extend over 200 m vertical distances in some wells, there were complexities in the observed water quality trends.

The existing data from the flow testing programs suggests that water quality from gas wells with deeper perforated intervals is more saline than shallower wells (suggesting longer residence times and limited connectivity).

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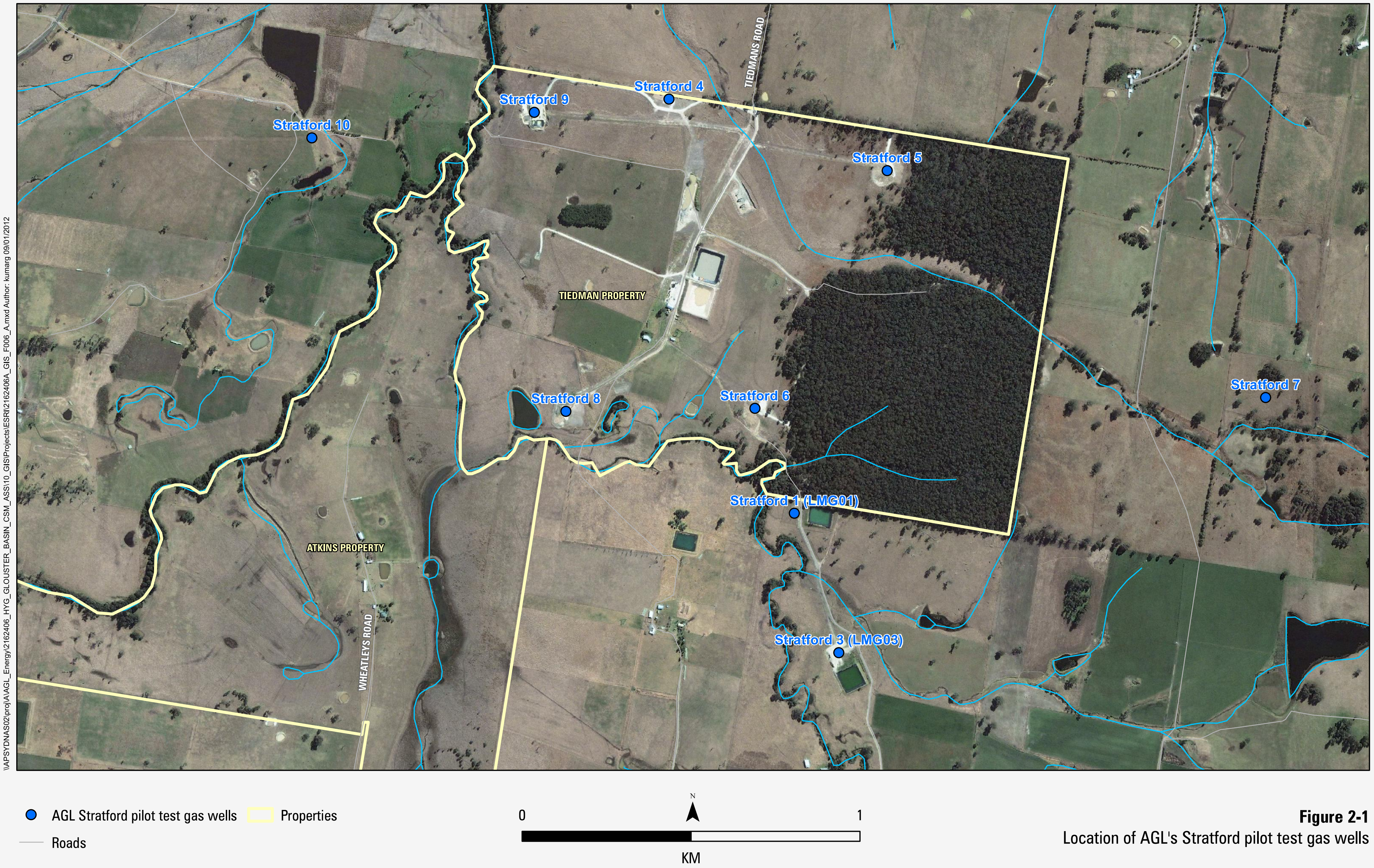

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Figure 2-1
Location of AGL's Stratford pilot test gas wells

Table 2-1 Summary Results from Stratford Pilot Well Program

Well ID	Start Water Level (mbgl)	Max Drawdown Level (mbgl)	Pump Intake Setting (mbgl)	Perforated Interval/s (mbgl) #	Produced Water Volumes (ML)	Start Salinity (EC) (µS/cm) ^	Peak Salinity (EC) (µS/cm) *	Final Salinity (EC) (µS/cm)*
Stratford 1	99.1	522.5	535		0.03	3100	3460 (0.25)	2880 (1)
Stratford 3	nr	nr	441	166 to 407	17.92	3000	3450 (5)	3450 (5)
Stratford 4	nr	750.1	788	515 to 739	1.2	8190	10600 (6)	8240 (9)
Stratford 5	17.9	524.4	545	312 to 515	1.58	4320	6950 (1)	4080 (7)
Stratford 6	85.6	501.1	519	149 to 502	3.53	3230	4090 (0.5)	2760 (6)
Stratford 7	nr	nr	812.3	359 to 847	0.12	nr	nr	nr
Stratford 8	nr	558.9	713	555 to 700	0.33	5720	12060 (2)	5400 (7)
Stratford 9	99.6	893.1	923	905 to 914	0.03	7580	7580 (0)	7210 (2)
Stratford 10	nr	nr	nr	807 to 1106.7	0.25	nr	nr	nr
TOTALS					**24.99**			

Notes: mbgl - metres below ground level # - top of first perforations to base of last perforations nr - not recorded
^ - Initial salinity after flowback water has been removed * - (z) number of months after initial salinity reading

2.3 Previous water sampling programs

There are numerous historical water quality results from test production wells when undergoing flow testing (although none are as comprehensive as those undertaken as part of this current baseline study). None of this data has been consolidated into a single technical report, however (as background) it is worthwhile identifying some of the characteristics of the very deep water quality from previous sampling in this report.

The most recent sampling of deep coal seam gas water quality was in October 2010 when water samples were obtained from the Stratford 1, Stratford 3, and Craven 6 gas production wells. Details are provided in Summary Table 1 with the ALS water quality results presented in Appendix A. No heavy metals, nutrients or isotope water samples were submitted for analysis.

The water quality characteristics of these deep coal seams (generally from below 350m) are:

- Water salinity is brackish to slightly salty
- The water type is sodium-bicarbonate-chloride dominant
- There are no TPH/BTEX compounds present.

3. Site characterisation

This chapter characterises the catchment and the Stage 1 GFDA, and presents the current geological and hydrogeological conceptual models.

3.1 Site location

The Stage 1 GFDA is located in Gloucester shire in the northeast part of the Gloucester Geological Basin near the small settlement of Stratford, approximately 100 km north-northeast of Newcastle, New South Wales (Figure 3-1). The Phase 2 investigations focus on the AGL owned Tiedman and Atkins properties in the central area of the Stage 1 GFDA with additional investigation sites located adjacent to Waukivory Road at the northern boundary and on the Rombo property adjacent to the southern boundary of the Stage 1 GFDA.

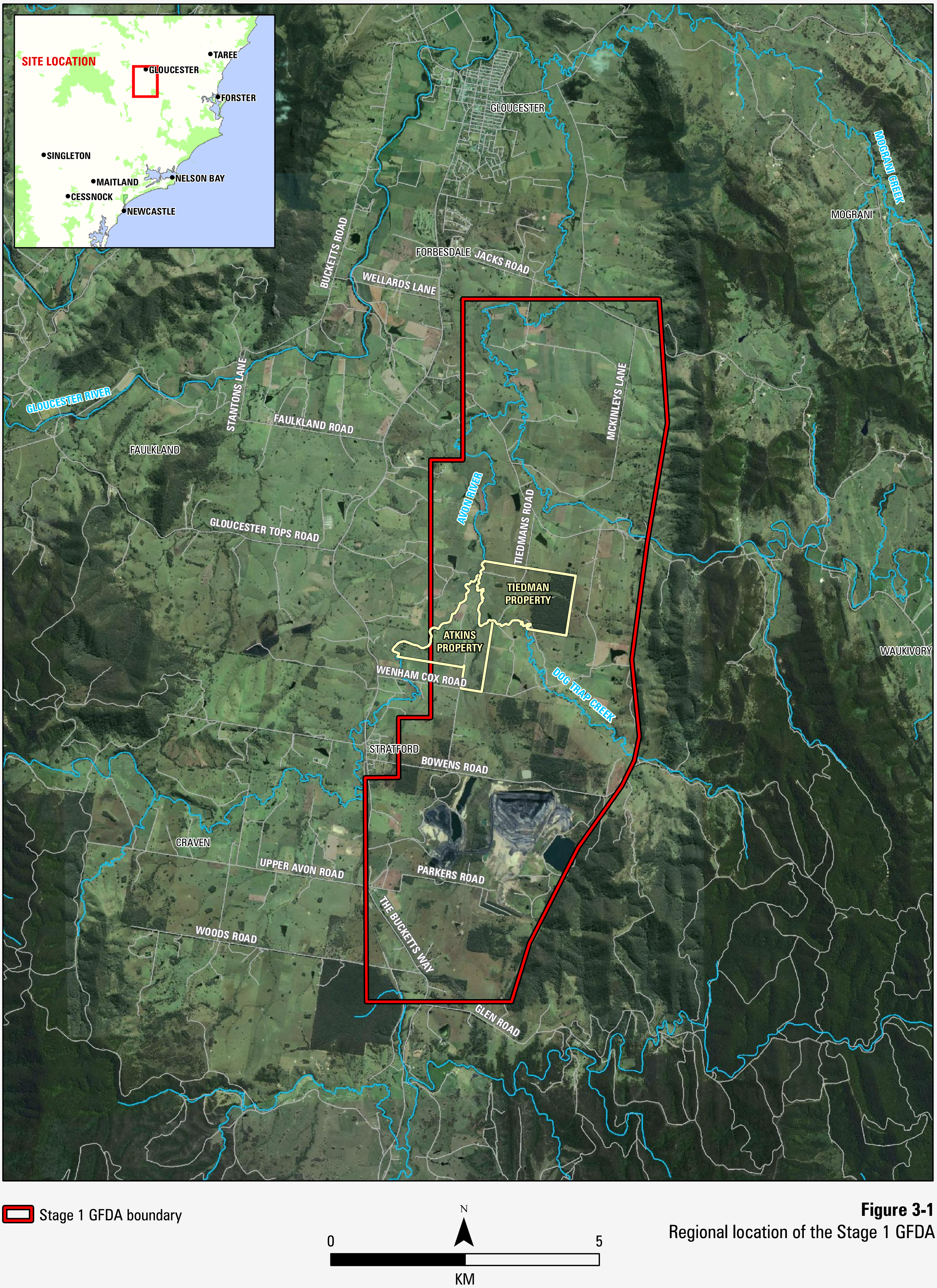

Figure 3-1
Regional location of the Stage 1 GFDA

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3.2 Topography and surface hydrology

The Stage 1 GFDA represents approximately 25% of the surface area of the Gloucester Basin, a north-south trending topographic trough bound to the west by the Gloucester and Barrington Tops and to the east by the Mograni Range. The gently undulating valley floor slopes toward the north from a topographic high in the south. Elevations within the Stage 1 GFDA decrease gradually westward from 170 m AHD at the base of the ridgeline to 110 m AHD in the Avon River floodplain.

The Stage 1 GFDA is located within the Avon River catchment, a sub-catchment of the Manning River catchment. The Avon River is the primary watercourse in the area and flows northward through the central flat lands and the centre of the Stage 1 GFDA. Several tributaries of the Avon River are also located in the Stage 1 GFDA, including Dog Trap Creek, Avondale Creek, Waukivory Creek and some smaller unnamed tributaries. Figure 3-2 shows the local topography and surface water system.

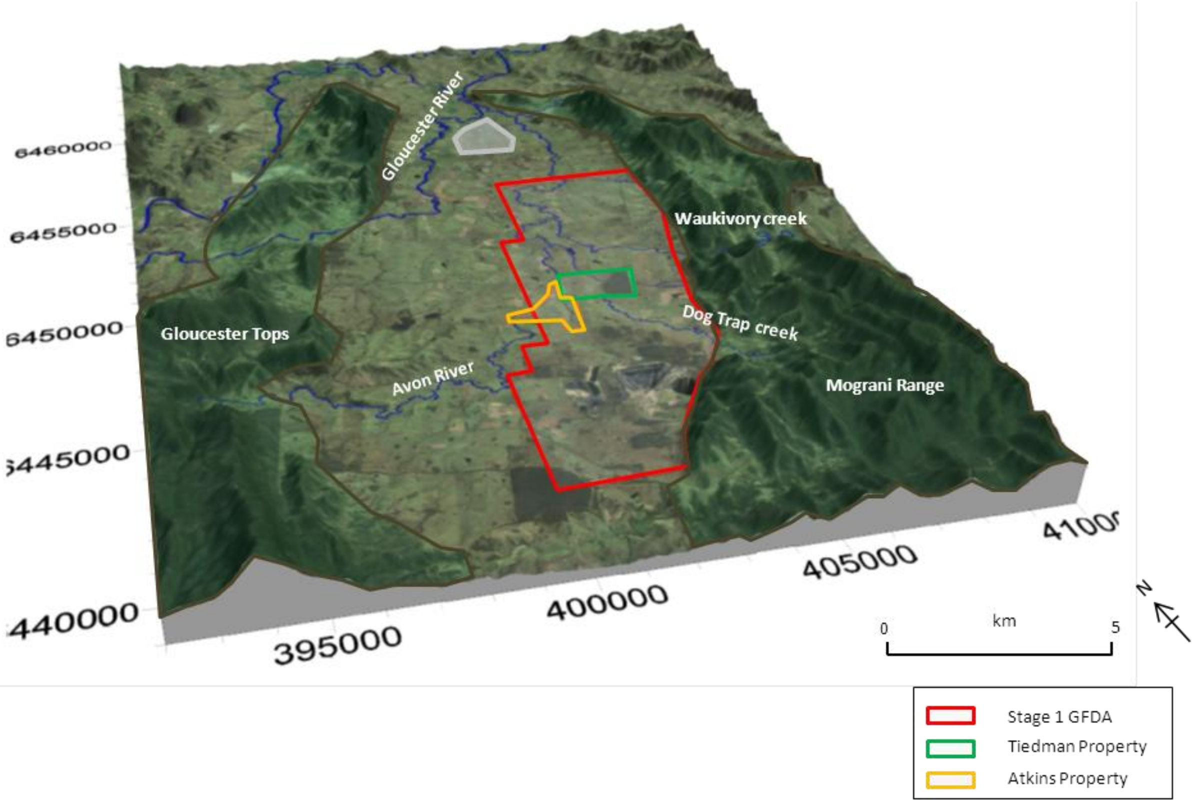


Figure 3-2 Site topography and surface water

3.3 Climate and rainfall

All climate and rainfall data presented in this report have been obtained from Bureau of Meteorology (BoM) monitoring sites within the local region. The future ongoing monitoring programs will be enhanced by data from a weather monitoring station on the Tiedman property (installed and operational from July 2011) within the Stage 1 GFDA providing site-specific climate monitoring of wind, relative humidity, temperature, rainfall, and barometric pressure.

Continuous rainfall data from the Gloucester Hiawatha Station (BoM Station 060112), the closest station to the project area (7 km northwest of the Tiedman property) is available from 1976 and is used in this report. Mean monthly precipitation for all monitored years is presented and compared to data from the Gloucester Post Office Station (BoM station 060015), 12 km north of the Tiedman property, in Figure 3-3.

The calculated mean annual rainfall recorded since monitoring commenced in 1976 is 1021.1 mm (from the Hiawatha Station). Historically, the period between July and September records the lowest monthly rainfall, while the period between January and March typically has the highest monthly rainfall.

Evaporation data for the area has been obtained from the Chichester Dam site (BoM station 061151) located approximately 32 km southeast from the Stage 1 GFDA. Mean monthly evaporation data is plotted with rainfall data in Figure 3-3.

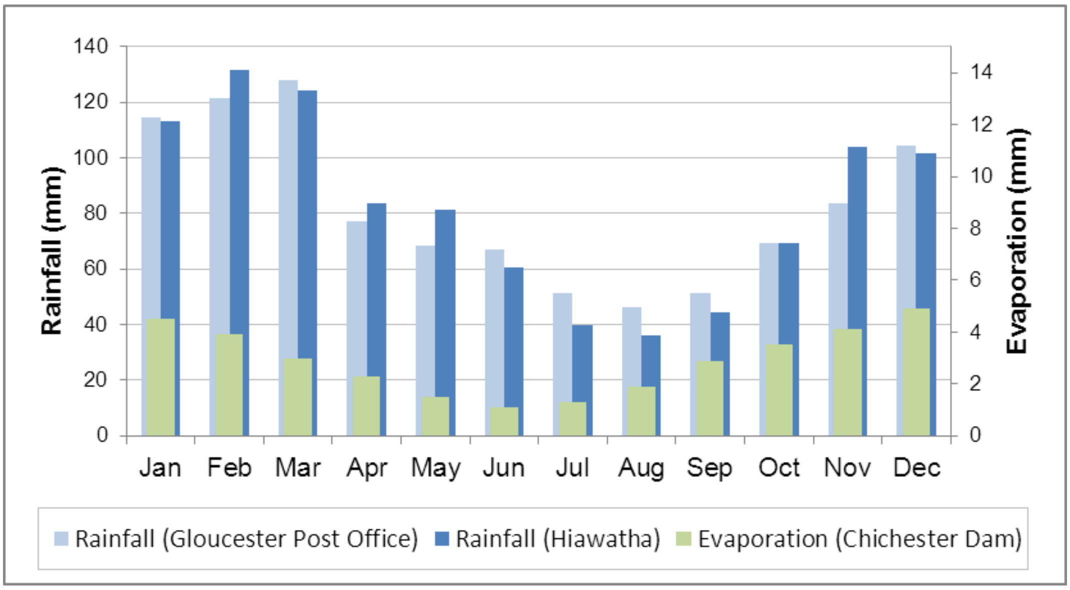


Figure 3-3 Long term mean monthly precipitation for Gloucester Hiawatha, Post Office, and evaporation at Chichester Dam for all monitoring years (1888-2011)

The cumulative deviation of rainfall from the mean (over the recorded period) has also been plotted (Figure 3-4) representing discrete rainfall events as a continual trend over time. Periods of below average rainfall are plotted as downward trending slopes while periods of above average rainfall are upward trending slopes. The cumulative deviation plot for Gloucester Hiawatha (BoM station 060112) shows periods of below average or average rainfall between 1979 and mid-1987, 1991 and 1997, and late-2001 and mid-2007. Rainfall was mostly above average for the periods mid-1987 to 1990, 1998 to late-2001, and mid-2007 to the present.

Figure 3-4 Monthly cumulative deviation rainfall for Hiawatha (BoM Station 060112) for all monitoring years (1977-2010)

The mean maximum and minimum temperatures for the area have been recorded at the nearest BoM long term temperature monitoring station at Dungog Post Office (BoM Station 061017) since 1897 (located approximately 40 km southwest of Stratford, NSW). Figure 3-5 presents the mean, highest, and lowest temperatures for each month since monitoring commenced.

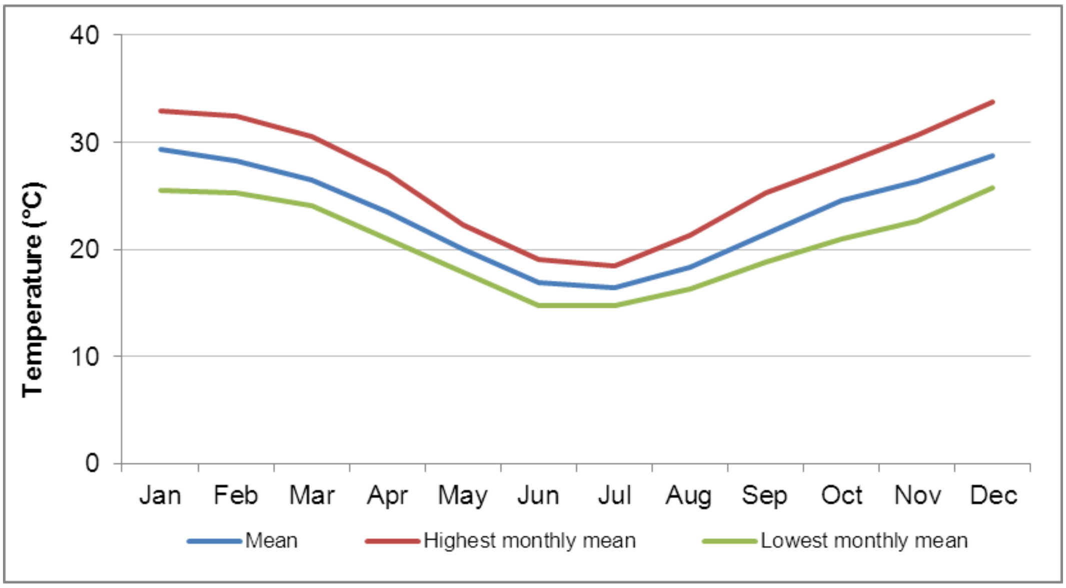


Figure 3-5 Long term mean monthly temperature for Dungog Post Office (BoM Station 061288) for all monitoring years (1897-2011)

3.4 Land use

The Stage 1 GFDA is located south of the town of Gloucester, and east of the minor settlements of Stratford and Craven on land currently used for grazing and rural residential properties (AECOM, 2009). The Gloucester Tops National Park and Barrington Tops State Forest are located to the west of the Gloucester Basin and form significant recreational and environmental reserves. The Glen Nature Reserve is located on the Wards River, west of Craven to the south of the Stage 1 GFDA.

Coal mining and exploration is currently undertaken in Gloucester Shire by Gloucester Coal Ltd (production and exploration) and Gloucester Resources Ltd (exploration). Coal from the main Gloucester Coal operations at Stratford (ML1360/ML1409/ML1447) is processed at Stratford Colliery, located within the Stage 1 GFDA, while the Duralie mine (ML1427) is located 25 km to the south. Gloucester Resources Limited (GRL) is targeting the Permian coal measures of the Gloucester Basin in a 2,918 km^2 area within EL6523, in part overlain by the alluvial plains of Waukivory Creek and the Avon River.

Agriculture is the principal source of employment within Gloucester Shire, with over 20% of the workforce employed in this industry, currently centred on beef cattle enterprises (Hunter Development Brokerage 2006 *in* AECOM, 2009). NSW DPI mapping of Agricultural Suitability classifies land according to its agricultural capacity as shown in Table 3-1.

Table 3-1 Agricultural land suitability classes

Class	Description
Class I	Land capable of regular cultivation for cropping (cereals, oilseeds, fodder etc.) or intensive horticulture (vegetables, orchards). Has very good capability for agriculture, where there are only minor or no constraints to sustained high levels of production. Will include irrigated areas with high production.
Class II	Land suitable for cultivation for cropping but not suited to continuous cropping or intensive horticulture. Has a capability for agriculture but where constraints limit the cropping phase to a rotation with improved pastures and thus reduce the overall level of production.
Class III	Land suitable for grazing. Well suited to pasture improvement and can be cultivated for an occasional cash crop or forage crop in conjunction with pasture management. Overall level of production is moderate as a result of high environment costs which limit the frequency of ground disturbance. Has moderate capability for agriculture. Pasture lands are capable of sustained high levels of production although conservation measures may be required.
Class IV	Land suitable only for rough grazing or land not suitable for agriculture. Agricultural production is very low to zero. Sever or absolute constraints to production imposed by environmental factors.
Class V	Land suitable only for rough grazing or land not suitable for agriculture. Agricultural production is very low to zero. Sever or absolute constraints to production imposed by environmental factors.

Source: NSW Department of Primary Industries, as cited by Hunter Development Brokerage Pty Ltd, 2006 *in* AECOM 2009

According to the DPI mapping and classification system, there is no Class I land within the Gloucester Shire and only 0.2% of mapped land within the Shire is of Class II. Land comprising the Stage 1 GFDA is mostly classified as suitable for grazing, ranging from Class III to Class IV.

3.5 Geological setting

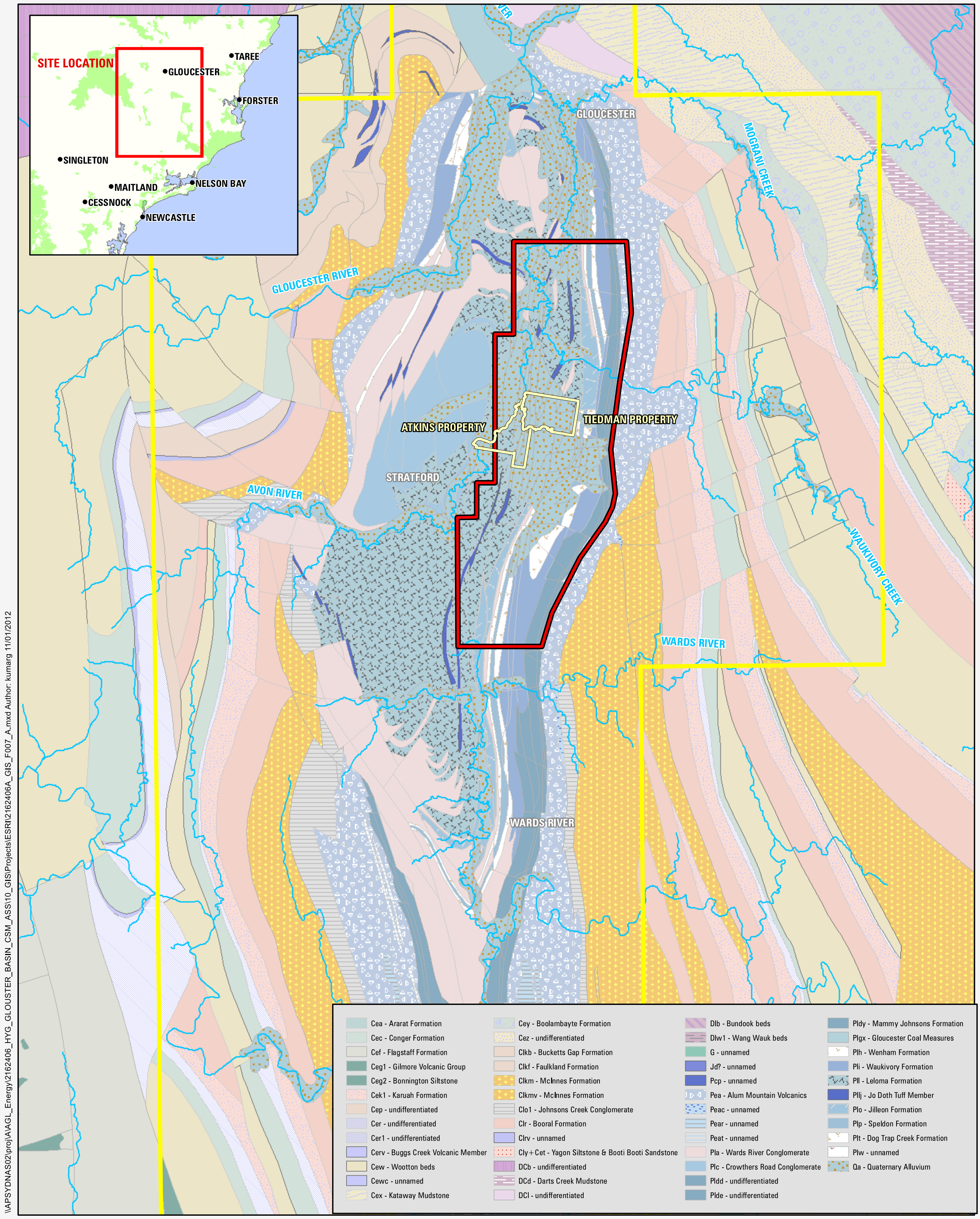
3.5.1 Regional Geology

The Gloucester Basin represents a complex geological system formed by the interplay of extensional tectonic faulting and high rates of sediment supply.

The basin is a synclinal intermontane structure formed in part of the New England Fold Belt between a major Permian plate margin and the Sydney-Gunnedah Basin. Although it is a discrete structural-sedimentary entity in its own right it shares many of the features of the Sydney-Gunnedah Basin to the south (Lennox, 2009). The basin stratigraphy comprises a sequence of early Carboniferous to late Permian volcanics and sediments representing distinct depositional settings and events. The stratigraphy dips steeply (up to 90°) on the flanks of the basin, dipping towards the north-south trending synclinal basin axis and flattening toward the centre of the basin (SRK, 2010).

To the west of the Gloucester Basin lies the basalt capped plateau between Barrington Tops and Gloucester Tops. The plateau physiographically dominates the region and is responsible for the surrounding radial drainage pattern (Roberts *et al*, 1991b). Early Permian and Carboniferous hard resistive volcanics form the ridgelines of the basin: the Mograni Range to the east; and the Gloucester Tops to the west.

Surficial Quaternary sediments, non-uniform in thickness, have been deposited on the valley floor and overly the eroded Permian sequences along the flanks of the basin.



Note: The extent of the alluvium in the vicinity of the Stage 1 GFDA, as defined above by Roberts et al. (1991a), has been remapped based on the detailed drilling records from the current investigation. The revised extent is shown in Figure 10-4.

Stage 1 GFDA boundary
PEL 285 boundary

N
0 5 10
KM

Figure 3-6
Regional Geology

3.5.2 Stratigraphy of the investigation area

3.5.2.1 Overview

The Gloucester Basin is divided into three major Permian stratigraphic units each representing a distinct depositional setting: the Gloucester Coal Measures, the Dewrang Group, and the Alum Mountain Volcanics. The generalised stratigraphy of the basin underlying the Stage 1 GFDA is summarised in Table 3-2.

Table 3-2 Stratigraphy of the Gloucester Basin

Period	Group	Sub-Group	Formation	Approx thickness	Coal seam	Depositional Environment	Tectonic Events
Upper Permian	Gloucester Coal Measures	Craven	Crowthers Road Conglomerate	350		Marine regression, progradation of alluvial fans	Uplift to west of Gloucester Basin
			Leloma	585	Linden		
					JD		
					Bindaboo		
					Deards		
			Jilleon	175	Cloverdale		
					Roseville		
					Tereel/Fairbairns		
			Wards River	Variable			
			Wenham	23.9	Bowens Road		
					Bowens Road		
		Speldon Formation				Marine transgression but also some progradation of alluvial fans in the west related to uplift	Extension (normal fault development) and regional subsidence. Uplift to west of Basin
		Avon	Dog Trap Creek	126	Glenview		
			Waukivory Creek	326	Avon		
					Triple		
					Rombo		
					Glen Road		
					Valley View		
					Parkers Road		
	Dewrang	Mammy Johnsons		300	Mammy Johnsons	Marine transgression, regression and further marine transgression	Extension (normal fault development) and regional subsidence
		Weismantel		20	Weismantel		
		Duralie Road		250			
Lower Permian	Alum Mountain Volcanics				Clareval	Arc-related rift	Rift?
					Basal		

Modified from AECOM, 2009; and SRK, 2005.

3.5.2.2 Surficial deposits

Quaternary sediments along the valley floor comprise unconsolidated alluvial sediments (sand, gravel, silt and clay). The thickness of these sediments varies and generally conforms to the shape of the valley floors (SRK, 2010).

In the Stage 1 GFDA, Quaternary alluvium occurs along the floodplains of the Avon River and the ephemeral Dog Track, Avondale, and Waukivory Creeks. The deposits typically comprise a shallow clay layer underlain by medium to coarse mixed gravels to bedrock.

3.5.2.3 Gloucester Coal Measures

The Gloucester Coal Measures contain mainly continental sediments of Upper Permian age dominated by alluvial fans in the southwest and north of the basin (Lennox, 2009). Coal seams vary laterally in thickness and extent. The Coal Measures comprise three main sub-groups:

Craven Sub-Group

The Craven Sub-Group is a series of five formations that make up the upper part of the Gloucester Basin.

- Crowthers Road Conglomerate – a massive polymictic boulder to pebble conglomerate with lithic sandstone and mudstone, deposited in a series of alluvial fans in the west of the Basin.
- Leloma Formation - contains siltstone, sandstone, numerous thin coal seams (including the Deards and Bindaboo Coal Seams) and claystone bands, including the Jo Doth Tuff.
- Jilleon Formation - a fine grained sandstone, shale and mudstone sequence, containing thin coal seams (including the Cloverdale Coal Seam at its base and the Roseville Coal Seam near the top).
- Wards River Conglomerate - a widespread boulder to pebble alluvial fan conglomerate with volcanic and lithic sandstone clasts, and minor sandstone, shale and rare carbonaceous shale.
- Wenham Formation – a fine grained sandstone containing palaeosols and the Bowens Road Coal Seam. The Wenham Formation is considered to represent a depositional hiatus following regression of the marine environment.

The Jilleon and Leloma formations dominate the surficial geology of the Stage 1 GFDA. Variation in stratigraphic thickness during deposition of the Craven Sub-Group depends on the rate of subsidence (if any) and rate of sediment supply. The Cloverdale Coal Seam has a number of splits indicating that sediment supply interrupted coal development (SRK, 2005).

Speldon Formation

The Speldon Formation forms the upper part of a marine transgression sequence (AECOM, 2009), containing distinct beds of sandstone, bioturbated mudstone and conglomerate. There are a number of growth faults that may have tectonic control reported in the formation, creating a variety of local depositional environments (SRK, 2005).

Avon Sub-group

- Dog Trap Creek Formation – an alternating sequences of shale, siltstone and sandstone. Indicates a marine transgression following the deposition of the Avon Coal Seam (AECOM, 2009). A number of growth faults have been reported in the Dog Trap Creek Formation (SRK, 2005).
- Waukivory Creek Formation – a fluvial sandstone, mudstone and minor claystone. Contains numerous coal seams (including the Avon Coal Seam) and minor tuffs.

3.5.2.4 Dewrang Group

The Dewrang Group are largely marine sandstones unconformable on the Alum Mountain Volcanics with three significant formations of Mid-Late Permian in age:

- Mammy Johnsons Formation – a high energy near shore lithic sandstone and mudstone sequence containing the Mammy Johnsons Coal Seam.
- Weismantel Formation – a thick bituminous coal sequence grading up to shale, sandstone and laminated mudstone deposited in a marine environment.
- Duralie Road Formation – a conglomerate with primarily volcanic clasts, thickly bedded lithic fluvial sandstone and mudstone.

3.5.2.5 Alum Mountain Volcanics

The Alum Mountain Volcanics is a sequence of Early Permian age bimodal volcanics and sedimentary rocks deposited in an intermontane rift basin setting, where flows of basalt and rhyolite are interbedded with pebble conglomerate, sandstone, mudstones and coal seams (Roberts *et al*, 1991a). The volcanics are unconformable on underlying Late Carboniferous conglomerate (SRK, 2005).

3.5.3 Geological structure of the investigation area

The Gloucester-Stroud Syncline is the largest structure in the surrounding region, being more than 55 km long (Roberts *et al*, 1991a). The syncline trends northwards and dips of up to 60° are displayed on the flanks of the basin. The syncline is a fault bounded trough, active during the Permian, as revealed by seismic surveys (Roberts *et al*, 1991b).

SRK (2005) divides the tectonic and structural development of the Basin into two stages:

- Early – Middle Permian dextral tectonic margin, resulting in reactivation of NNW-striking faults as strike-slip dextral and formation of NE and EW striking normal faults, particularly around the margins of a circular basement feature (suspected deep intrusion) in the northern part of the Basin.
- Late Permian NE shortening during the early stages of the Hunter Bowen Orogeny, resulting in reverse and thrust faulting on NNW faults and some NNE faults.

Combining structural domains with the known distribution of stratigraphy, SRK (2005) divides the Basin into three structure/stratigraphic domains:

1. An eastern domain containing a number of coal seams in the Avon and Craven Sub-Groups.

2. A western domain where the surface mapping indicates sequences of Waukivory Formation and Wards River Conglomerate that mark periods of prograding fluvial systems that have significantly reduced the thickness of coal seams.

3. Major fault zones that separate the eastern and western domains.

Recent seismic data acquired by AGL maps a number of westerly dipping thrust faults striking north-south, and north-south striking high angle oblique faults. The resolution of the vertical seismic profiles is good to depths of approximately 1 km, however the technique returns poor resolution in the top 200 m. This inhibits the ability to map these fault structures through the shallow surface rock and currently lineament traces can only be inferred.

The seismic sections presented in Figures 3-7 and 3-8 show the subsurface bedding and structure to depths of 1,900 mbgl beneath the Tiedman property in the centre of the Stage 1 GFDA. These sections are input into 3D seismic computer models and are used to enhance the geological model (Section 5), site gas production wells, and to verify the locations of monitoring bores.

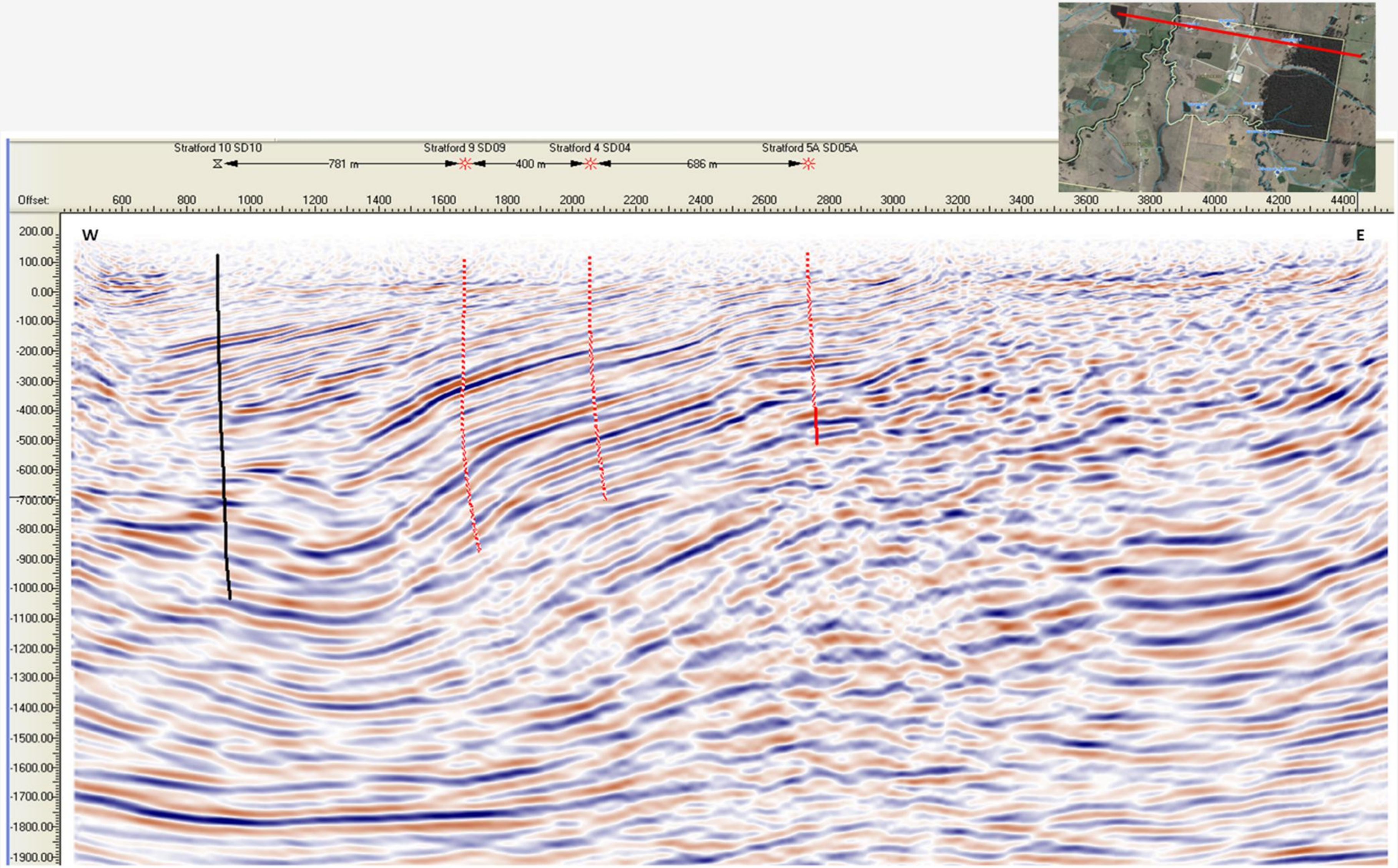


Figure 3-7 W-E seismic section through the Stage 1 GFDA

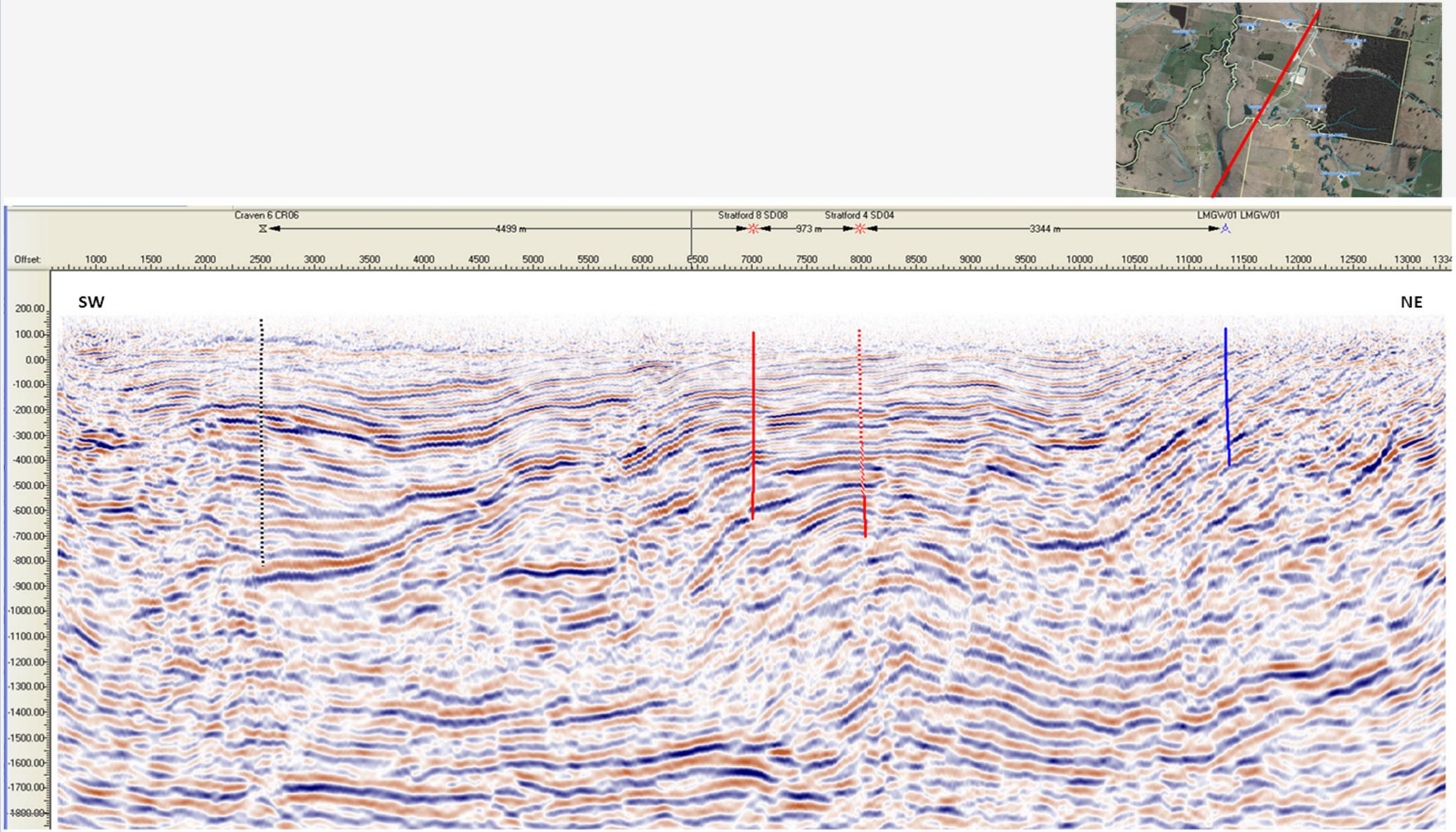


Figure 3-8 SW-NE seismic section through the Stage 1 GFDA

3.6 Hydrogeological setting

The conceptual hydrogeological model presented by SRK (2010) for the Gloucester Basin was developed based on previously described regional and site-specific geological information and hydrogeological data. The hydrogeological understanding prior to this comprehensive investigation is summarised below.

3.6.1 Hydrogeological units

AECOM (2009) defines a total of three hydrogeological units in the Stage 1 GFDA:

- A shallow alluvial aquifer (fresh to brackish water quality)
- A shallow bedrock aquifer (brackish to saline water quality)
- A deep bedrock aquifer (saline and alkaline water quality).

SRK (2010) added a fourth hydrogeological unit, the confining units of the Gloucester Coal Measures, Dewrang Group and the Alum Mountain Volcanics. This effectively is the subdivision of the deep bedrock 'aquifer' into separate confining units and water bearing zones.

Table 3-3 summarises the hydraulic properties for the four hydrogeological units prior to this Phase 2 investigation. The two shallow units are defined as the main water resource aquifers across the area. The subdivision of the hydrogeological units is supported by the Phase 2 investigations undertaken as part of this study. Recent drilling and testing has confirmed that the deep bedrock (including the coal seams) is not an aquifer in the water resource sense and is best described as saturated low permeability strata that include some localised water bearing zones.

Table 3-3 Hydrogeological units of the Stage 1 GFDA (after SRK, 2010)

Hydrogeological unit	Aquifer type	Formation name	Hydraulic conductivity (m/day)
Alluvial aquifers	Unconfined	-	0.1 - 5
Upper Permian weathered and fractured aquifers (<150 m depth)	Confined/ unconfined	Individual formations within the Gloucester Coal Measures	0.04 - 3
Coal seam water bearing zones	Confined/ unconfined	Coal seams of the Gloucester Coal Measures and Dewrang Group	~8.6×10^{-2} at 100 m ~6.1×10^{-3} to 2.3×10^{-2} at 300 m ~4.8×10^{-4} at 500 m
Interburden confining units	Confined/ unconfined aquitard	Confining units of the Gloucester Coal Measures, Dewrang Group and the Alum Mountain Volcanics	No data

3.6.1.1 Alluvial aquifers

The properties of the alluvial aquifers vary on a regional and local scale depending on the extent and thickness of the alluvial deposits and the nature of the sediments. The alluvium was deposited by streams flowing from the ranges across the valley floor and, within the Stage 1 GFDA, is associated with the Avon River, its tributaries, and associated floodplains. Groundwater flow in the alluvial aquifer is expected to follow valley topography. The majority of recharge for the alluvial aquifers within the Stage 1 GFDA is expected to be from direct infiltration of rainfall. Shallow groundwater may discharge into local creeks and rivers, or, streams may provide a source of recharge to the alluvial aquifer, depending on the elevations of the aquifer water level and the river bed.

Regionally, the alluvium is considered to form porous, granular, unconfined aquifers. The water quality data reported from the Mammy Johnson River alluvial aquifer (approximately 10 km to the south of the Stage 1 GFDA) indicates that the groundwater is slightly acidic (6 < pH < 6.4) and fresh (145 < EC < 900 µS/cm) (SRK, 2010). In the alluvial aquifer of the Gloucester River (approximately 2 km to the northwest of the Stage 1 GFDA), groundwater is also reported as being slightly acidic (6 < pH < 6.2) and fresh (589 < EC < 800 µS/cm) (SRK, 2010). The alluvial aquifer water type is classified as a mixture of sodium-chloride, bicarbonate, calcium and magnesium types (SRK, 2010).

3.6.1.2 Weathered and fractured Permian aquifers

SRK (2010) describes a locally confined to unconfined, weathered and fractured upper Permian aquifer. The basal depth is around 150 mbgl and groundwater is primarily present in fractures, joints and bedding planes of the bedrock. Recharge of the aquifer occurs along the margins of the basin via direct infiltration of rainfall into the exposed strata. Groundwater flows from the margins of the basin towards the centre.

Fractures and faults present in these shallow formations and the underlying coal seams could enhance the hydraulic conductivity of the formations by orders of magnitude and act as conduits for groundwater flow and leakage from depth (SRK, 2010). If fractures and faults are closed or not interconnected they may in fact impede groundwater flow.

At the Duralie Mine site (approximately 10 km to the south of the Stage 1 GFDA) claystone layers separate the upper Permian and alluvial aquifers. Hydraulic conductivities of 0.04 – 3 m/day were established at the Duralie Mine for the Mammy Johnsons, Weismantel and Duralie Road Formations. Water quality is slightly acidic to neutral (5.6 < pH < 7.7) and fresh to slightly saline (215 < EC < 9,600 µS/cm), with a sodium-chloride water type (SRK, 2010).

3.6.1.3 Coal seam water bearing zones

The coal seam water bearing zones of the Gloucester Coal Measures and the Dewrang Group have a low primary permeability; however cleats and fractures provide secondary permeability (AECOM, 2009). Permeability of the coal seam water bearing zones decreases with depth, and faulting and the low hydraulic conductivities of the overburden may compartmentalise the groundwater flow in the coal seams (AECOM, 2009).

Groundwater within the coal seams is typically slightly alkaline and brackish to slightly saline (3,000 < EC < 9,500 µS/cm) with EC measurements increasing with depth. Recharge of coal seams is low, as indicated by the groundwater quality, and occurs where the formations outcrop on the basin ridgelines (SRK, 2010). It is suspected that artesian conditions may occur in coal seams towards the centre of the Basin.

3.6.1.4 Interburden confining units

Various indurated sandstone and siltstone units separate the coal seams of the Dewrang Group and Gloucester Coal Measures. These units are expected to have much lower hydraulic conductivities than the coal seams, and therefore likely act as aquitards rather than aquifers or water bearing zones.

3.6.2 Structural controls

A large number of faults have been reported across the area as evident in the seismic sections presented in Section 3.5. Some have been geologically mapped and intersected by drilling whilst others have been identified as lineaments. Little information exists concerning the hydraulic properties of these faults. An inferred normal fault, intersected at 325 mbgl in the Bowens Road Coal Seam of cored well PGSD3 provided a hydraulic conductivity of ~5.8 x 10^{-2} m/day, approximately one order of magnitude higher than those estimated for the coal seams at a similar depth (~8.6 x 10^{-3} – 1.2 x 10^{-2} m/day) (Pacific Power 1999 *in* SRK 2010). However, this is still a relatively low permeability zone and would not be described as a beneficial aquifer in the water resource sense.

3.6.3 Groundwater levels

Regional groundwater levels in the alluvial aquifer ranged from 98 m AHD north of the Stage 1 GFDA to 130 m AHD to the south of the Stage 1 GFDA in May 2010 (SRK, 2010). Alluvial aquifer groundwater levels indicate groundwater flow from south to north and from the ridgelines to the centre of the Basin. The groundwater flow pattern is controlled by topography, and recharge and discharge points. Groundwater levels in the alluvial aquifer should fluctuate and be consistent with rainfall patterns and stream stage heights.

Groundwater levels in the upper Permian aquifer were variable, ranging between 105 and 126 m AHD across the Stage 1 GFDA (SRK, 2010). Groundwater levels in the weathered and fractured upper Permian aquifer should show a more subdued or longer term response to rainfall.

3.6.4 Recharge and discharge

Ridges and outcrops are generally considered as being zones of preferred rainfall recharge. Aquifers, including the alluvial sediments along the valley floor, are recharged via direct infiltration of rainfall. Shallow fractured aquifers and deeper confined coal seam water bearing zones are recharged at the margin of the basins where individual formations outcrop. Some recharge into deeper formations may also occur through vertical leakage or fault areas where high hydraulic conductivity zones occur (SRK, 2010).

As the Gloucester Basin is a closed feature bound by impermeable volcanic rocks, discharge from the water bearing units is likely to occur by seepage to springs, rivers and streams, as well as evapotranspiration from terrestrial vegetation. Most groundwater is expected to discharge in the lower catchment areas of the Avon River and Gloucester River in the vicinity of Gloucester.

Groundwater discharge to streams is likely to be diffuse over a large area unless there are substantial fault systems contributing. Correlation between water quality and stream flow typically show a reduction in surface water salinity after periods of rain followed by a general increase in salinity as the stream flow reduces and groundwater baseflows increase. The surface water is generally fresh (100 < EC < 600 µS/cm) and near neutral to slightly alkaline suggesting any baseflow contribution from groundwater discharge is small.

3.6.5 Local groundwater use

Surface water is used for most land uses across the catchment given the reliable coastal rainfall patterns and falls averaging just under 1000 mm per year. Rainwater tanks, farm dams and river pumps are common throughout the Stage 1 GFDA. Consequently groundwater use is minimal. Low groundwater yields to bores and wells, and marginal to poor water quality also preclude widespread groundwater use across the area.

There are 65 registered bores within and immediately surrounding the Stage 1 GFDA and (in addition) there are likely to be some unregistered bores in the area (AECOM, 2009). A few unregistered bores were located as part of the SRK (2010) water sampling program. Thirty-five of the 65 registered bores are noted as being for abstraction purposes with the uses listed as being for stock watering, irrigation, domestic, industrial, waste disposal, mining and monitoring (AECOM, 2009).

At bores where construction details were noted, groundwater is abstracted from the shallow alluvial aquifer and the shallow bedrock aquifer. Bores installed in the alluvial aquifer are typically less than 10 m deep and bores installed in the shallow bedrock aquifer are typically between 20 m and 40 m deep (AECOM, 2009), and are not known to exceed 66 m in depth (SRK, 2010).

The shallow alluvial and shallow weathered and fractured bedrock aquifers are the only aquifers being tapped by bores for water supply purposes in the area surrounding the Stage 1 GFDA.

Based on the SRK (2010) desktop study (and water samples collected during that study) and information on yields and water quality observed during the Stratford flow testing programs, the bedrock aquifers of the Gloucester Basin are poor groundwater resources with limited beneficial uses.

Most groundwater in the shallow rock aquifers is brackish to slightly saline and suitable only for stock watering and limited domestic purposes. Water quality in the deeper coal seam water bearing zones is slightly to moderately saline and is unsuitable for most consumptive uses without treatment. None of these groundwater systems are drinking water sources.

3.6.6 Groundwater dependent ecosystems

This inland coastal catchment (and the Avon River catchment in particular) is characterised by sedimentary rocks and minor alluvium deposited along the valley floor. There are no known wetlands, lakes or other surface features that are indicative of shallow groundwater processes and possible groundwater dependent ecosystems (GDEs). Surface water features in the Avon River catchment are mostly fluvial and all are strongly influenced by surface water runoff (AH Ecology 2012).

Being a closed basin, some groundwater discharge to the alluvial sediments (and eventually the downstream river segments) is postulated. The downstream Avon River appears to be a connected-gaining stream with the adjacent alluvium; however, the corresponding baseflow contributions are expected to be small as there are no visible discharges to the Avon River in the main area of investigation. A secondary discharge route for shallow alluvial groundwater is likely to be transpiration by riparian vegetation but again the volumes are expected to be small given the salinity of the groundwater in the bedrock aquifers and water bearing zones. Based on an aerial mosaic review of the catchment, there are no other features suspected to be groundwater dependent.

The Lower North Coast Unregulated and Alluvial water sharing plan (WSP) commenced on 1 August 2009. In the plan there is provision for high priority GDEs to be nominated. Two karst systems were nominated (Gloucester Caves) and these are located much lower in the catchment and are supplied with groundwater from different water source areas that are located outside of the Gloucester Basin, so have no relevance to this project.

Upon inspection of the Avon River catchment and its features, there are no known ecosystems that could be affected if there are changes to the deep groundwater regime in the coal seam water bearing zones. Also the groundwater that is discharging to the alluvium and to the creeks/rivers is brackish to saline, and is unlikely to sustain any ecosystems because of its poor quality.

4. Investigation scope of works, methodology, and completions

This chapter introduces the Part 3A approval requirements (with respect to groundwater and water management) and then details the investigation objectives, scope of works and methodology adopted in this investigation to achieve the study objectives.

4.1 Part 3A approval requirements

The GGP was approved by the Planning Assessment Commission on the 22 February 2011. The project approval for the Stage 1 GFDA has multiple conditions relating to groundwater and water management. These conditions are summarised below:

- Condition 3.5 (Gas well construction, operation and decommissioning)
- Condition 3.6 (Plug and abandon old exploration wells within 500m radius of new wells)
- Condition 3.7 (No fracture stimulation fluids with BTEX)
- Condition 3.8 (Updated conceptual model required)
- Condition 3.9 (Submit updated conceptual model for approval)
- Condition 3.10 (Submit Field Development Plan)
- Condition 3.11 (Obtain water licence/s and do not exceed 2 ML/d)
- Condition 3.12 (Develop Extracted Water Management Strategy)
- Condition 3.13 (Ensure all water storage ponds are lined)
- Condition 4.1 (Develop Groundwater Monitoring Program)
- Condition 4.2 (Develop Numerical Hydrogeological Model).

Those conditions that this detailed technical report support or inform are primarily Conditions 3.8 and 4.1 (although there are other relevant conditions as well). A detailed schedule of all the water management conditions (and sub-conditions), which ones are addressed in this report, and the report sections that expressly deal with those conditions/sub-conditions is provided in Table 4-1.

Table 4-1 Schedule of water management conditions and technical studies completed

Condition	Sub-condition	Addressed in this Report	Report Section
Condition 3.5 (Gas well construction, operation and decommissioning)	Not applicable	No	Not applicable
Condition 3.6 (Plug and abandon old exploration wells)	Not applicable	No	Not applicable
Condition 3.7 (No fracture stimulation fluids with BTEX)	Not applicable	No	Not applicable
Condition 3.8 (Data and investigations for updated conceptual model)	(a) (b) (c)	Yes Yes Introduced	Section 5.5 Sections 6, 7, and 8 Sections 7 and 10
Condition 3.9 (Submit updated conceptual model)	(a) (b) (c) (d)	Introduced No No No	Section 3.6.5 Not applicable Not applicable Not applicable
Condition 3.10 (Field Development Plans)	Not applicable	No	Not applicable
Condition 3.11 (Water licences and dewatering not exceed 2 ML/d)	Not applicable	Introduced	Section 1.3
Condition 3.12 (Extracted Water Management Strategy)	(a) to (i)	No	Not applicable
Condition 3.13 (Lined water storage ponds)	Not applicable	No	Not applicable
Condition 4.1 (Groundwater Monitoring Program)	(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)	Yes Introduced No No No Introduced No No No No	Sections 4.4 and 4.5 Sections 4.4 to 4.7 Not applicable Not applicable Not applicable Section 4.4.3.5 and 9 Not applicable Not applicable Not applicable Not applicable
Condition 4.2 (Numerical Hydrogeological Model)	Not applicable	No	Not applicable

The specific requirements of Condition 3.8 are:

Prior to the commencement of construction the project, the Proponent shall in consultation with NOW update the conceptual hydrogeological model developed during the assessment stage of the project (referred to in the document listed in condition 1.1d based on baseline *data gathered from (but not necessarily limited to), the pre-construction investigations identified below:*

a) seismic surveys of the site to identify geological features of risk;

b) preliminary field sampling of hydraulic conductivity, groundwater levels, groundwater quality and surface water quality based on a packer, pump and slug testing program and surface water sampling; and

c) long-term baseline monitoring (i.e. at least six months) at groundwater and surface water locations determined in consultation with NOW, to ensure representative baseline data on pre-construction conditions (including seasonal variability) in relation to the shallow rock and alluvial beneficial aquifers, deeper coal seam water bearing zones, groundwater users and surface waters.

The specific requirements of Condition 4.1 are:

Prior to the commencement of construction of the Project, the Proponent shall develop a ***Groundwater Monitoring Program*** *in consultation with NOW and to the satisfaction of the Director-General, covering the operation of the Stage 1 Gas Field Development Area. The program shall detail the monitoring strategy that would be implemented to measure dewatering and water quality impacts of gas well development on beneficial aquifers (including associated groundwater users, surface waters and groundwater dependent ecosystems) during the implementation of the Field Development Plan for the Stage 1 Gas Field Development Area and measure any residual impacts following the decommissioning of wells. The program shall:*

a) identify surface and groundwater monitoring locations demonstrating their appropriateness for obtaining representative water quality and water level data on operational impacts in relation to beneficial aquifers, groundwater users and surface waters. In the first instance the monitoring locations shall focus on the first phase of gas well development in the Field Development Plan, as identified under condition 3.10 and shall be updated as well development progresses;

b) provide details of the monitoring points (including location, depth of monitoring, duration and frequency of monitoring and parameters to be monitored);

c) identify performance criteria for gas well development, including monitoring criteria to detect early indicators of drawdown impacts to beneficial aquifers or of cumulative drawdown effects and hold points for further development where adverse impacts are identified;

d) identify the frequency of reporting on monitoring results including at a minimum prior to the commencement of each phase of the Field Development Plan (subsequent to the first phase) in accordance with the requirements of condition 3.10;

e) include provisions for the monitoring of coal seam dewatering rates and hold points in the case that water volumes are greater than the predicted two mega litres per day (unless managed in accordance with condition 3.12g;

f) include provisions for monitoring the potential for gas migration to the surface;

g) provide detailed specifications (including information on toxicity and/or carcinogenicity) of fraccing fluids to be used in gas well development, with annual updates;

h) include provisions for ongoing monitoring, post decommissioning of wells to determine any residual impacts;

i) identify a procedure for contingency or remedial action where adverse impacts are identified including compensation to groundwater users and/or rehabilitation measures where affects to groundwater dependent ecosystems/ communities are attributed to the project; and

j) identify mechanisms for the regular review and update of the program in consultation with NOW as required.

In submitting the program for the Director-General's approval, the Proponent shall provide written evidence of consultation with NOW on the robustness and acceptability of the monitoring program, including issues raised by NOW and how these have been addressed.

The monitoring program shall be updated in consultation with NOW to the satisfaction of the Director-General, prior to the commencement of each phase of the Field Development Plan, taking into account the recommendations of the Numerical Hydrogeological Model developed in accordance with condition 4.2.

4.2 Objectives and scope of works

The objectives and scope of works for this detailed site investigation were based on the conclusions and recommendations of the desktop studies (URS, 2007; SRK, 2010), and the issues and requirements emerging from the Part 3A planning and EPBC approvals processes.

The following primary objectives were identified for the site investigation program:

- Complete baseline studies to effectively characterise the groundwater systems in the Stage 1 GFDA.
- Provide site specific information on groundwater occurrence and flow by investigating the different groundwater systems, and determining whether the shallow water resource aquifers are connected to the deeper coal seam water bearing zones. The investigations are to include:
  - Drilling to establish test / monitoring bore locations (groundwater, seepage, and gas migration locations)
  - Downhole geophysical logging and surveying
  - Permeability testing
  - Water level monitoring
  - Water quality sampling
  - Isotope sampling
  - Installation of stream gauge stations
  - Miscellaneous gas, rock/soil and water sampling as required.

- Assist in determining the quantity and quality of deep groundwater that is likely to be produced as the CSG field is developed.
- Establish a monitoring network across the Stage 1 GFDA that is spatially diverse and sufficient to cover staged development of the field, and is representative of the catchment, local geology, and complexities associated with the geological structure.
- Prepare a comprehensive technical report that includes a revised conceptual model of groundwater recharge, discharge and flow across the Stage 1 GFDA together with all the Phase 2 site investigation activities, data, results and conclusions.

The adopted Phase 2 groundwater investigation program of fieldwork, data collection, analysis and reporting (for the current Parsons Brinckerhoff studies) is summarised in Figure 4-1.

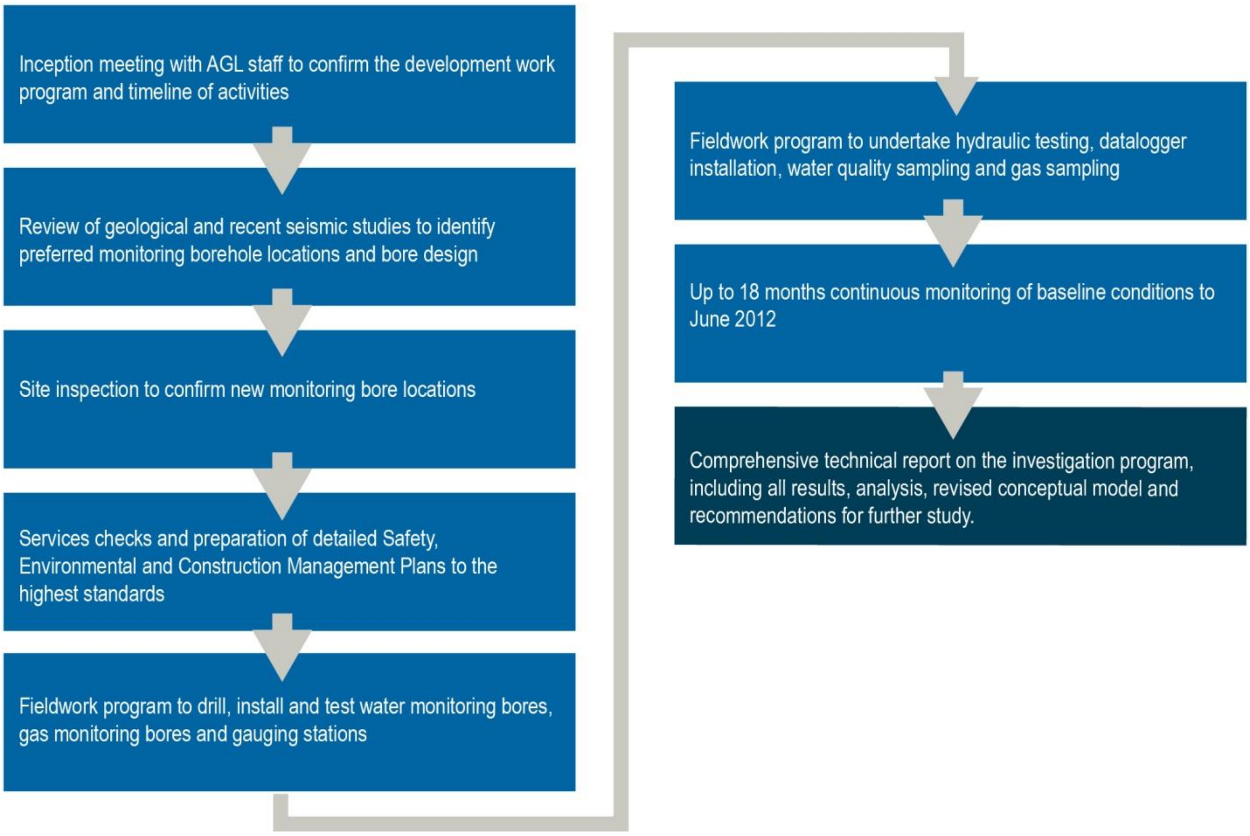


Figure 4-1 Summary of investigation objectives and scope

4.3 Methodology & overview of program

The site investigation studies have mostly involved geological appraisals, drilling, water level monitoring, water quality sampling, isotope studies, data collation, analysis and reporting. Parsons Brinckerhoff also established an extensive groundwater and surface water monitoring network across the Stage 1 GFDA. The network and intensive coverage are designed to:

- Enhance the conceptual (hydrogeological) model

- Collect baseline information on natural groundwater and surface water levels (and any seasonal variability) and natural water quality
- Enable monitoring of groundwater and surface water levels and quality in the vicinity of AGL's existing and planned CSG exploration and production wells suitable for assessing ongoing exploration and project start-up activities (such as the Tiedman irrigation trial to beneficially reuse produced water)
- Provide essential data and input parameters for a future numerical groundwater model.

To enhance the conceptual model and provide baseline information prior to the start of production and irrigation activities, the monitoring network (Figure 4-2) is focussed on AGL's Tiedman and Atkins properties in the centre of the Stage 1 GFDA. There are monitoring bores in the alluvium, shallow fractured rock aquifers, and deeper coal water bearing zones.

The adopted methodology was to establish detailed spatial and depth coverage of the different groundwater systems to confirm the conceptual model across the Stage 1 GFDA and to build a database of information for the pending numerical model. Two of the nested monitoring bore locations at the central location were also located either side of a fault structure on the Tiedman property to assess whether such faults influenced groundwater flow.

There was also an increased focus on the Avon River at this central area because of the proposed irrigation trials and likelihood of ongoing intensive irrigation; shallow seepage monitoring because of the produced water dams, and monitoring of potential gas migration.

The monitoring network was also designed to provide regional groundwater data representative of the wider Stage 1 GFDA. The network extends to AGL's Rombo property at Craven (southern boundary), and the Waukivory area closer to Gloucester (northern boundary). An additional monitoring site to the west is located adjacent to AGL's Stratford 10 core hole site on the Bignell property which is the western boundary of the Stage 1 GFDA.

In summary, the network (as at 30 November 2011) comprises:

- Twenty two (22) groundwater monitoring bores installed with dataloggers to record water levels
- Three (3) stream gauges installed with dataloggers recording salinity and water levels
- Two (2) shallow gas monitoring bores
- Two (2) seepage monitoring bores to assess potential seepage from the Tiedman produced water dams.

Following the installation of the above monitoring network, Parsons Brinckerhoff completed an extensive field program of hydraulic testing, water level monitoring, water quality sampling and analysis. The following sections provide completion details of the monitoring network and the investigation methodology.

Data collected and analysed from this network provides the primary scientific data to assess the baseline groundwater characteristics across the area and to determine the connectivity of aquifers and the potential for impacts on shallow aquifers used for water supply and connected to permanent creek/river systems.

At the time of writing, the groundwater monitoring network is being augmented with:

- An additional monitoring bore on the Tiedman property
- A test bore and two monitoring bores into the fault zone on the Tiedman property
- An extra four monitoring bores at Forbesdale to the north of the Tiedman property in association with a proposed Waukivory flow testing program.

These additional investigation activities are important to further refine the conceptual model and to provide data for numerical modelling prior to the construction of the GGP. Results will be reported separately later in 2012.

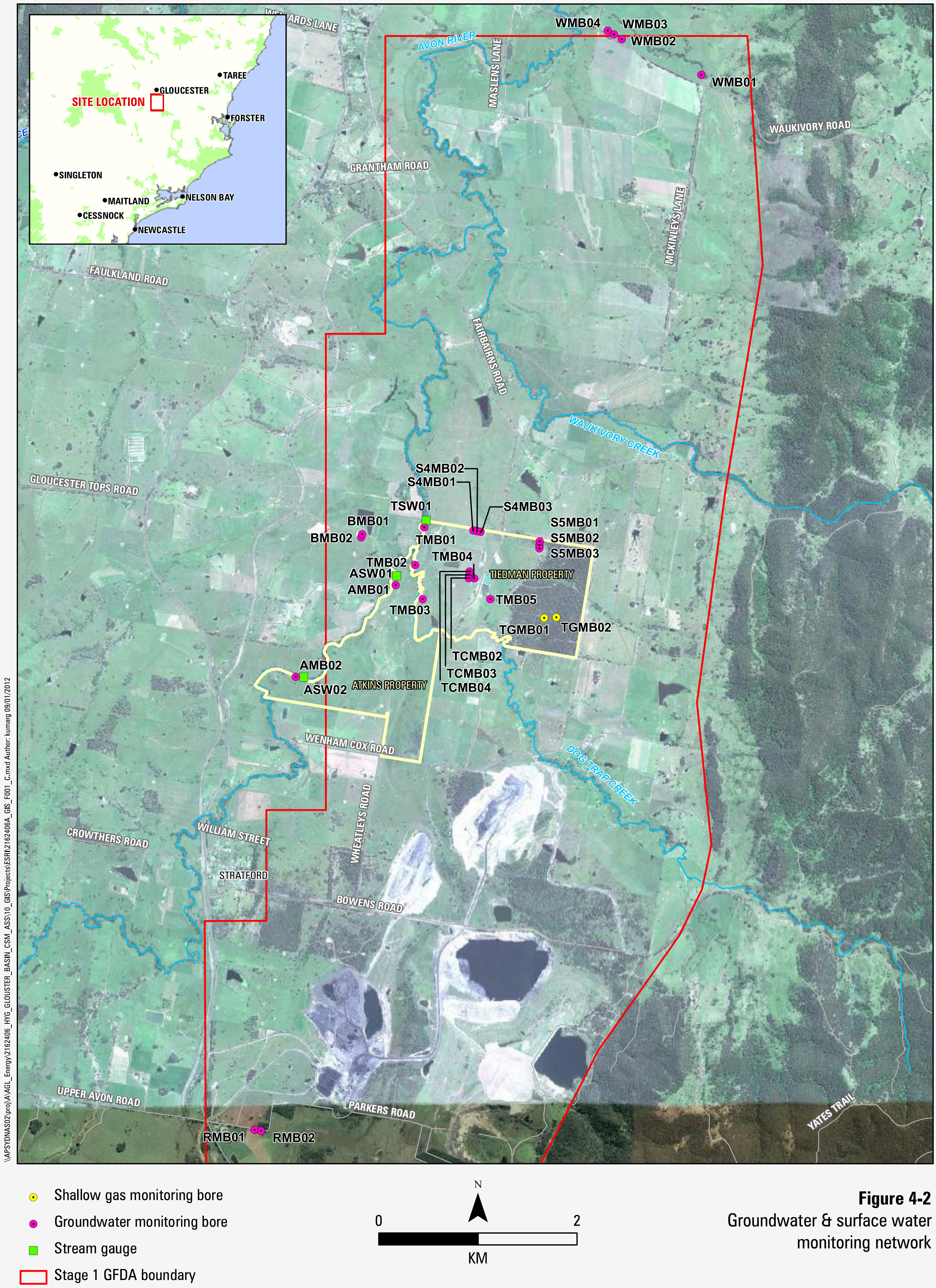


Figure 4-2
Groundwater & surface water monitoring network

4.4 Groundwater monitoring bore drilling program

Three types of groundwater monitoring bores were constructed as part of this baseline investigation:

- Bores targeting the shallow alluvial sediments of the Avon River and its tributaries.
- Bores targeting the shallow bedrock.
- Bores targeting the upper coal seams of the Gloucester Coal Measures.

The locations of all bores constructed during this investigation are shown in Figure 4-2, the construction details are summarised in Table 4-2. Geological (gINT) logs were produced for each monitoring bore and are included in Appendix B.

Table 4-2 Groundwater monitoring bore construction details

Monitoring Bore	Location	Total depth (m)	Screened interval (mbgl)	Lithology	Formation
S4MB01	Tiedman	66	58 - 64	Sandstone	Leloma Formation
S4MB02	Tiedman	97	89 - 95	Sandstone / siltstone	Leloma Formation
S4MB03	Tiedman	170	162 - 168	Coal	Jilleon Formation - Cloverdale Coal Seam
S5MB01	Tiedman	60	52 - 58	Sandstone / siltstone	Jilleon Formation
S5MB02	Tiedman	114	110 - 102	Siltstone	Jilleon Formation
S5MB03	Tiedman	166	158 - 164	Coal / shale	Jilleon Formation - Roseville Coal Seam
TMB01	Tiedman	12	7 – 10	Clay	Avon River Alluvium
TMB02	Tiedman	15.5	9 – 12	Mixed gravels	Avon River Alluvium
TMB03	Tiedman	12.5	5 – 11	Mixed gravels & sand	Avon River Alluvium
TMB04 (seepage monitoring)	Tiedman	15	8 – 14	Siltstone	Leloma Formation
TMB05 (seepage monitoring)	Tiedman	10	6 - 9	Siltstone	Leloma Formation
TCMB02	Tiedman	183	175 - 181	Sandstone	Leloma Formation
TCMB03	Tiedman	268	260 - 266	Coal & sandstone	Jilleon Formation - Cloverdale Coal Seam
TCMB04 (core hole)	Tiedman	334.7	327.3 – 333.3	Coal	Jilleon Formation - Roseville Coal Seam
TGMB01 (gas monitoring)	Tiedman	6	3 - 6	Weathered rock	Jilleon Formation
TGMB02 (gas monitoring)	Tiedman	15.4	12.3 – 15.3	Weathered coal	Jilleon Formation - Roseville Coal Seam
AMB01	Atkins	12.6	8 - 10	Mixed gravels	Avon River Alluvium
AMB02	Atkins	11.5	6.5 – 11	Mixed gravels	Avon River Alluvium

Monitoring Bore	Location	Total depth (m)	Screened interval (mbgl)	Lithology	Formation
BMB01	Bignell	30	15 - 29	Sandstone / siltstone	Leloma Formation
BMB02	Bignell	138	124 – 136	Sandstone	Leloma Formation
WMB01	Waukivory	8.5	5 - 8	Mixed gravel / sand	Alluvium
WMB02	Waukivory	23	15 - 21	Sandstone	Wenhams Formation
WMB03	Waukivory	36	32 - 34	Coal	Wenhams Formation - Bowens Road Coal Seam
WMB04	Waukivory	80.5	67 - 79	Sandstone	Wenhams Formation
RMB01	Rombo	51	42 - 48	Sandstone	Leloma Formation (upper)
RMB02	Rombo	93	85 - 91	Sandstone	Leloma Formation (upper)

Note: mbgl = metres below ground level

With the exception of monitoring bore TCMB04, the drilling of all groundwater monitoring bores was undertaken by Highland Drilling using an air rotary drilling rig. In this technique air was forced down the drill pipe, escaping through small ports at the bottom of the drill bit, thereby lifting cuttings to the surface and cooling the bit. A small amount of water (from an onsite rainwater dam) was introduced to control dust. No drilling fluids or additives were used.

TCMB04 was drilled as a HQ core hole by John Nitschke Drilling (JND) using a mud rotary/core drilling rig. The 96 mm diameter HQ core hole was initially drilled using a hollow, cylindrical diamond encrusted drill bit rotating and extracting solid 3 m long continuous core samples that travel up through the drill pipe to the surface. The borehole was then reamed to its final diameter (150 mm) using a mud rotary method. Mud rotary drilling is similar to the air rotary drilling method with the only major difference being that water, not air, is the medium by which fragments travel back to the surface. Mixing water with the cuttings yields a mud slurry. Small volumes of biodegradable, non-toxic and non-corrosive weighting agents were added to the mud slurry to further assist the removal of cuttings and to stabilise the borehole during drilling.

The drilling program began on 7 December 2010 and was completed on 22 March 2011.

4.4.1 Approvals, licences and permits

4.4.1.1 Groundwater Licences

Test (monitoring bore) licences under the *Water Act 1912* were obtained by AGL prior to the monitoring bore drilling program. Drilling and completion of the groundwater monitoring bores was carried out in accordance with the NOW bore licence conditions and followed a detailed design and specification compliant with the:

Minimum Construction Requirements for Water Bores in Australia, Edition 2. (Land and Water Biodiversity Committee 2003)

Test bore licences (20BL172619, 20BL172626, 20BL172631, 20BL172632, 20BL172667, 20BL172670 and 20BL172682) for the drilling and the construction of monitoring bores were issued by NOW prior to the drilling and bore construction program. Standard conditions for the construction of test and monitoring bores are attached to each licence. No other approvals were required to construct these water monitoring bores. Licence details are summarised in Table 4-3 and full copies are provided in Appendix C.

Table 4-3 Monitoring bore licences

NOW Licence No.	No. of locations	Local bore ID		Site location (property)	Lot	DP	Bore type
20BL172619	8 bores	TGMB01 TGMB02 TMB02 TMB03 TMB04	TMB05 TCMB02 TCMB03 TCMB04	Tiedman	84	979859	MB
20BL172626	7 bores	TMB01 S4MB01 S4MB02 S4MB03	S5MB01 S5MB02 S5MB03	Tiedman	85	979859	MB
20BL172631	1 bore	AMB01		Atkins	49	979859	MB
20BL172632	1 bore	AMB02		Atkins	50	979859	MB
20BL172667	2 bores	BMB01	BMB02	Bignell	96	979859	MB
20BL172670	4 bores	WMB01 WMB02	WMB03 WMB04	Waukivory	890	1134032	MB
20BL172682	2 bores	RMB01	RMB02	Rombo	2	556576	MB

Note: MB = monitoring bore

The licence conditions require that the driller's Form As and the initial water level and water quality data be supplied to NOW. These compliance details were forwarded by AGL to NOW in June 2011.

4.4.2 Health, Safety & Environment

4.4.2.1 Safety Management Plan (SMP)

The installation of the monitoring bores was conducted in accordance with the Safety Management Plan (SMP) approved by AGL and developed for the project by Parsons Brinckerhoff in collaboration with Highland Drilling (Parsons Brinckerhoff 2011b). The SMP should be read in conjunction with the following AGL documents which together cover the health, safety and environmental working procedures for AGL's Gloucester Gas Project – Phase 2, Detailed Groundwater Investigations:

1. Occupational Health and Safety Management Plan (OHSMP), Gloucester Gas Operations, *AGL 2010*

2. Gloucester Gas Operations Emergency Response Plan, *AGL 2010*

3. Upstream Gas Golden Rules, *AGL 2010*

All fieldwork undertaken at the Gloucester drill sites was covered under the aforementioned documents including exploratory drilling and subsequent testing, and groundwater monitoring and sampling.

4.4.2.2 Parsons Brinckerhoff Health, Environment and Safety Plan (HESP)

Highland Drilling were contracted to complete the drilling operations under supervision from Parsons Brinckerhoff. During the design phase of the project, Parsons Brinckerhoff developed a comprehensive site specific HESP for the supervision of drilling work and groundwater monitoring activities at the Gloucester sites: *Health, Environment and Safety Plan (HESP) AGL – Gloucester Groundwater Investigations (OH_5391, November 2010)* (Parsons Brinckerhoff 2010).

All site operations were subsequently undertaken in accordance with Highland Drilling's environmental management systems as detailed in a site specific Construction and Environment Management Plan (CEMP).

4.4.2.3 Construction and Environment Management Plan (CEMP)

The CEMP was submitted to Parsons Brinckerhoff for approval by AGL prior to the commencement of any fieldwork programs. All Highland Drilling and Parsons Brinckerhoff staff and site visitors were required to undergo a drill site induction during which they were given an overview of the commitments under the CEMP and how it applied to their specific duties.

A detailed **water management plan** was a critical part of the CEMP detailing the stringent measures implemented to ensure compliance to zero discharge of produced (drilling) waters to adjacent land and surface water receivers. Drainage of these waters from within the fenced drill site areas may have presented an environmental impact unless correctly managed. To mitigate these impacts the following water management plan was implemented:

- All water utilised during the drilling process was supplied by AGL from onsite rainwater dams.
- All water produced during the drilling operations was managed as surface water.
- Drill pads were constructed by AGL and comprised graded and levelled gravel surrounded by a levee bund and windrow fencing.
- A shallow PVC lined drainage ditch was dug along the inner toe of the bund with a spillway located in the down gradient corner. This allowed any rain and surface water runoff to be channelled along the ditch, over the spillway, and to a PVC lined sump located outside the bund. A pump was on site to convey water from this sump into the AGL in-ground drainage lines ensuring the sump did not overflow.
- Water airlifted from the bores was discharged into a bunded cuttings tank (3 m^3) sunk into the drill pad. An earth bund was created surrounding the top of the bore surface casing to direct drilling water and fines into the bunded cuttings tank.
- Highland Drilling supplied a pump suitable for conveying drilling waters out of the cuttings tank and into two inline settlement tanks (7 m^3 each) located off the drill pad.

- From the second of these inline tanks, water free of sediment was pumped to the AGL in-ground static drainage lines for flow to the Tiedman produced water storage dams.
- The capacity of the onsite control system was not exceeded during the drilling. However, if any bore produced groundwater volumes which were above the capacity of the system, a contingency was in place to allow work on that bore to cease until excess water in the tanks were pumped through the drainage lines.
- If instantaneous flows exceeded the capacity of the drainage lines, AGL ensured that sufficient storage was available to contain all water discharges and temporary storage was provided by a 25,000 L agricultural tank located at each drill site.

Typical drill pad layout and implemented controls are shown in Figure 4-3.

Figure 4-3 Typical drill pad layout

Water make during the drilling of the shallow alluvial bores was, as expected, minimal and no control measures were required.

Run-off waters from rainfall events were diverted from the drilling areas (where required) by the construction of diversion bunds on the up-gradient side of the site. Water from the drill pads and any access tracks constructed was diverted away by sand bag bunds, silt fencing and other control structures so as to direct water onto adjacent grassed areas and not erode the drill pads, fire trail and track areas.

A continuous water quality monitoring program was carried out in conjunction with the drilling program. Produced formation waters (airlifted during drilling) were subject to:

- field testing for electrical conductivity (EC), pH, dissolved oxygen, redox and temperature
- visual inspection for turbidity.

This water was collected in tanks and then was either pumped via water gathering lines or trucked (if outside of the Tiedman property) to the produced water storage dams on the Tiedman property.

4.4.3 Monitoring bore completions

4.4.3.1 Alluvial monitoring bores

Six shallow alluvial groundwater monitoring bores were completed in the Avon River alluvium; three on the Tiedman property, two on the Atkins property, and one adjacent to Waukivory Creek off Waukivory Road to the north. Drilling through the shallow, unconsolidated geology, typically through alluvial clays, sand, and mixed gravels was undertaken with a 200 mm rotary drill bit to first refusal at solid bedrock. On reaching total depth, the bores were airlifted until the discharge water flowed free of sediment and water quality field parameters (temperature, electrical conductivity (EC), pH, dissolved oxygen and oxidation reduction potential (redox)) stabilised.

Each monitoring bore was installed with 50 mm internal diameter, Class 18 uPVC screwed casing and screen (0.5 mm aperture, machine slotted). A washed and graded (3-5 mm) gravel filter pack was placed against the screened section, sealed with a bentonite plug and cement grouted to the surface.

4.4.3.2 Nested monitoring bores in the shallow rock

Nested groundwater monitoring bores facilitate the analysis of aquifers and water bearing zones at different depths from the same location. Table 4-2 summaries the nested bore locations drilled for the current project and Figure 4-4 shows a schematic cross-section of the S5MB nested monitoring site on the Tiedman property.

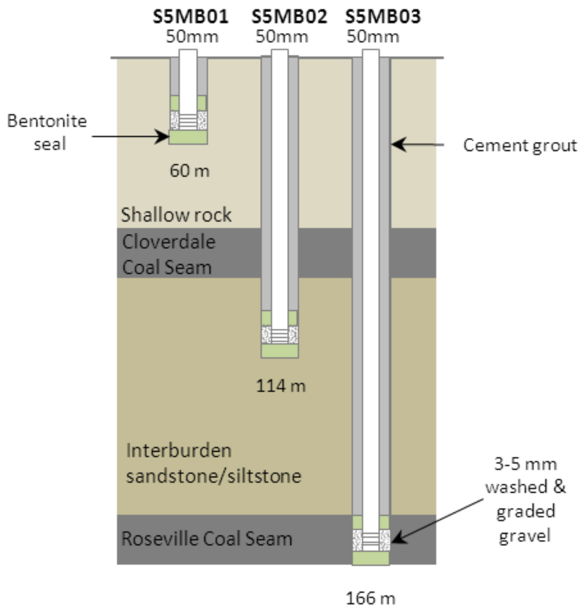


Figure 4-4 Schematic cross section of the S5MB nested monitoring site

Drilling through the sedimentary rock geology, typically through weathered clay in the first 6 m, was undertaken with a 200 mm drill bit. This unstable section of the borehole was then lined with a 158 mm internal diameter steel riser pipe of various lengths depending on the geology. Drilling of the remaining bore through the solid rock was undertaken using a 140 mm percussion hammer drill bit; the target geology and total depth (TD) was confirmed by the supervising Parsons Brinckerhoff hydrogeologist. Airlift development was continuous during drilling and the boreholes were further developed at termination until the discharge water was free of sediment and water quality field parameters stabilised.

A detailed log of the lithology recorded at one metre intervals was produced, and instantaneous water flow was recorded at the end of each drill rod (every 6 m) where applicable. Groundwater field parameters were also recorded using a calibrated YSI water quality meter. The field parameters measured included: temperature, EC, pH, dissolved oxygen and oxidation reduction potential (redox).

Following the completion of the bores to TD, Parsons Brinckerhoff hydrogeologists finalised the specifications and design of the monitoring bore installations. Each bore was installed with 50 mm internal diameter, Class 18 uPVC screwed casing and screen (0.5 mm aperture machine slotted) with a minimum 1 m sump and end plug. Casing with uPVC was not recommended for the bore installations deeper than 200m since differential hydrostatic pressures can cause collapse of the tube, particularly when the annulus is backfilled with grout as the strength of uPVC is likely to be further diminished by the elevated temperatures as the grout cures. For these reasons bores TCMB02 and TCMB03 were installed with 50 mm threaded galvanised steel, and screened with a 0.5 mm aperture stainless steel screen.

The screen length was determined based on the encountered strata, and was typically between 3 and 12 m. A washed and graded (3-5 mm) gravel filter pack was installed around the screen and extended 2 m above the screened section. A plug (minimum 2 m thick) of coated bentonite pellets was installed above the gravel pack and cement grout tremmied in a controlled manner to the surface. The bentonite seal and cement grout ensures hydraulic isolation of the screened section preventing any flow of groundwaters through the annulus of the bore column. The individual bore logs (Appendix B) detail the strata encountered and exact construction details for each monitoring bore.

Following the construction of each monitoring bore, the site was reinstated and a lockable steel monument was welded over the bores and surrounded at its base by a concrete slab.

4.4.3.3 Tiedman Core hole

With the objective of retrieving a continuous undisturbed core sample for logging and analysis, TCMB04 was drilled as a core hole to a TD of 333.5 m targeting the geologies above the basal Roseville Coal Seam. A 96 mm diameter HQ core hole was subsequently reamed to a final diameter of 120 mm.

Due to predicted elevated gas reservoir pressures in the coal seams at depth, a blowout preventer (BOP) was constructed at the surface prior to coring. The BOP provided an automated system continuously monitoring pressure levels during drilling. At a threshold level the BOP is set to deploy, killing any potential gas surges released from the coal seams.

Core samples were extracted from the drill rods, washed and the lithology logged and photographed by Parsons Brinckerhoff hydrogeologists and geotechnical engineers. Due to the drilling technique, water flows and water quality parameters were not recorded during the drilling process.

TCMB04 was installed with 50 mm internal diameter, galvanised steel casing with a 0.5 mm aperture machine slotted stainless steel screen (6 m long), a 2 m sump and end plug. A gravel filter pack comprising washed and graded (3-5 mm) gravel was installed around the screen and extended 13.4 m above the screen section. A 3 m plug of coated bentonite pellets was installed above the gravel pack and cement grout tremmied in a controlled manner to the ground surface. The bore log for TCMB04 is included in Appendix B and core photographs in Appendix D.

On completion of JND's drilling program at TCMB04, Highland Drilling undertook airlift development of the bore until the discharge water flowed free of sediment and water quality field parameters (temperature, electrical conductivity (EC), pH, dissolved oxygen and oxidation reduction potential (redox)) stabilised.

Following the construction of this monitoring bore, the site was reinstated and a pressure sealed wellhead fitted.

4.4.3.4 Seepage monitoring bores

To allow assessment of potential seepage from the two 20 ML Tiedman produced water storage dams, seepage monitoring bores were drilled and constructed in the same manner as the shallow alluvial bores with the screen section targeting the unsaturated shallow weathered rock.

4.4.3.5 Shallow gas monitoring bores

Two shallow gas monitoring bores were constructed to assess whether methane gas is present and migrating upwards through the soil and weathered rock profile above the water table in the eastern area of the Tiedman property where coal seams outcrop.

The bores were drilled using air rotary and constructed as per the design specification for the nested and alluvial bores. The bores were screened across the soil and uppermost weathered rock at TGMB01 (between 3 and 4 mbgl) and the Roseville Coal Seam close to outcrop at TGMB02 (from 12 – 15 mbgl). Bore logs are included in Appendix B.

4.5 Stream gauge installation

To assess the connectivity between shallow alluvial groundwater and stream flow, three stream gauging stations including gauge boards and dataloggers with salinity and water level monitoring capabilities, were installed on the Avon River by Thiess Services in March 2011 under the supervision of Parsons Brinckerhoff. These sites are:

- TSW01 on the Tiedman property downstream of the confluence with Dog Trap Creek and adjacent to monitoring bore TMB01
- ASW01 on the Atkins property upstream of the confluence with Dog Trap Creek and adjacent to monitoring bore AMB01
- ASW02 further upstream on the Atkins property adjacent to monitoring bore AMB02.

Dataloggers were installed at each location to continuously monitor water levels and salinity and are verified by manual gauge readings and electrical conductivity (EC) monitoring.

To achieve the above objective, an initial desktop surface water assessment with follow up site inspection determined the best locations for stream gauging on the Avon River. The assessment included a review of all available existing and historical water level and quality data presented by SRK (2010).

The following points were considered when choosing optimum locations for the gauging stations:

- The gauging stations are located close to the river bank ensuring safe access for maintenance/downloads
- Three (1 m long) gauge boards are staggered up the bank to enable them to be easily read under high flow conditions
- The boards are located in naturally sheltered locations to provide some protection from floods and bank erosion
- Where possible the stations were located upstream of a hydraulic control and where the stream cross section is stable and with a constant profile.

All stations were located so as to be unaffected by backwater effects such as inflowing tributaries.

To protect against flood damage the dataloggers, batteries and solar chargers are located in lockable high density fibre glass cabinets raised approximately 1.5 m above ground on the river banks.

4.6 Survey

The registered surveyors, CalCo, surveyed the coordinates of all new groundwater and shallow gas monitoring bores and the three stream gauges under the supervision of Parsons Brinckerhoff (Table 4-4).

All monitoring bore and stream gauge locations were surveyed to MGA, a grid coordinate system based on the Universal Transverse Mercator projection and the Geocentric Datum of

Australia 1994. Bores were also surveyed for surface elevation to Australian height datum (AHD).

Table 4-4 Monitoring bores and stream gauge survey coordinates

Site	Easting	Northing	Ground level (m AHD)	Top of casing level (m AHD)
S4MB01	402581.88	6449409.72	118.38	119.19
S4MB02	402586.77	6449408.93	118.44	119.09
S4MB03	402591.97	6449407.80	118.37	119.00
S5MB01	403155.95	6449250.26	129.98	130.50
S5MB02	403153.44	6449244.99	129.87	130.40
S5MB03	403151.16	6449240.20	129.79	130.32
TGMB01	403323.57	6448544.53	133.66	134.43
TGMB02	403330.40	6448543.13	133.83	134.63
TCMB02	402502.45	6448904.37	123.16	123.85
TCMB03	402503.18	6448909.64	123.18	123.81
TCMB04	402503.94	6448914.72	123.31	124.50
TMB01	401996.98	6449419.72	106.82	107.60
TMB02	401905.11	6449100.64	106.81	107.50
TMB03	401969.53	6448755.04	106.48	107.10
TMB04	402558.15	6448921.75	124.47	125.26
TMB05	402650.15	6448725.39	118.63	119.46
AMB01	400693.93	6447945.89	111.48	112.17
AMB02	401658.98	6448639.75	107.88	108.57
BMB01	401366.35	6449378.80	108.95	109.48
BMB02	401367.82	6449384.06	108.83	109.37
WMB01	404790.96	6454007.18	111.06	111.92
WMB02	403908.31	6454390.98	106.13	106.86
WMB03	403917.64	6454387.50	106.39	107.08
WMB04	403903.48	6454392.67	106.12	106.80
RMB01	400215.31	6443387.34	128.68	129.38
RMB02	400220.05	6443387.11	128.49	129.23
Stream gauge TSW01	401993.98	6449416.72	102.30*	na
Stream gauge ASW01	401711.09	6449092.17	102.42*	na
Stream gauge ASW02	400698.06	6447963.38	104.59*	na

Note: m AHD = metres Australia Height Datum; * = zero gauge height.

4.7 Groundwater level monitoring

Following the completion of each monitoring bore, *in situ* pressure transducers (dataloggers) were suspended from a galvanised steel wire in the water column in all monitoring bores (except the shallow seepage and gas monitoring bores) and programmed to record a groundwater level (or standing water level (SWL)) measurement every six hours. To calibrate the level recorded by the dataloggers, manual measurements are recorded quarterly using an electronic dip meter.

A barometric logger installed above the water table at S4MB01 records changes in atmospheric pressure. Data from this logger is used to correct for the effects of changing barometric pressure on groundwater levels.

4.8 Hydraulic testing

A program of field and laboratory hydraulic testing was conducted following the installation of the new monitoring bores to establish the hydraulic conductivity of each screened aquifer or water bearing zone.

Field measurements of hydraulic conductivity were obtained from the analysis of rising and falling head tests. Prior to the installation of the monitoring bore casing at TCMB04 the open bore was subjected to rigorous hydraulic testing with a multi-level packer test targeting both aquiclude/aquitard layers and encountered water bearing zones. The core samples from TCMB04 were also subject to laboratory permeability testing.

4.8.1 Rising/falling head testing

Hydraulic conductivity testing in the form of falling and rising head (‘slug’) tests are simple field procedures designed to calculate the approximate hydraulic conductivities of water bearing formations adjacent to monitoring bore screens. Information from the slug tests provides important data for a comparative assessment of the alluvial, shallow rock, interburden units, and coal seam formations across the Stage 1 GFDA.

A falling head test is achieved by introducing a ‘slug’ to displace the water column within the monitoring bore causing the water level to instantaneously rise and flow from the bore into the aquifer via the well screen. A rising head test is the opposite, where a volume of water is instantaneously removed from the groundwater monitoring bore, causing the water level to fall, drawing water into the bore from the aquifer. Forcing the water out of and into the monitoring bore sometimes produces slightly different results and therefore by comparing the results for each test a degree of confidence in the accuracy of the test can be achieved. Details are shown in Figure 4-5.

At the commencement of the testing, the standing water level (SWL) of the groundwater was measured from a fixed reference point at the top of casing and the datalogger reprogrammed to either 1 or 5 second intervals to measure the groundwater level changes. The slug tests were then undertaken as follows:

- A falling head test was the first of the three tests to be performed. The slug was placed into the water column. The change in the water level was recorded manually and electronically as the water level returned to the SWL.

- After the water level had returned to the SWL, a rising head test was performed by removing the slug. Again the change in water level was recorded manually and electronically as it recovered to the SWL.

- Finally, a second falling head test was performed.

The slug consists of a sealed concrete filled conjugate tube (1.6 m long) used to displace the water in the groundwater monitoring bores. Hydraulic testing was undertaken at all the groundwater monitoring bores during April 2011.

Test data were processed and analysed using the appropriate Bouwer and Rice (Bouwer 1989), or Butler (1988) method with AQTESOLV Version 4.5, with the results presented as estimates of hydraulic conductivity (as m/day) for the aquifers tested.

Details of the set-up for falling and rising head tests are shown in Figure 4-5.

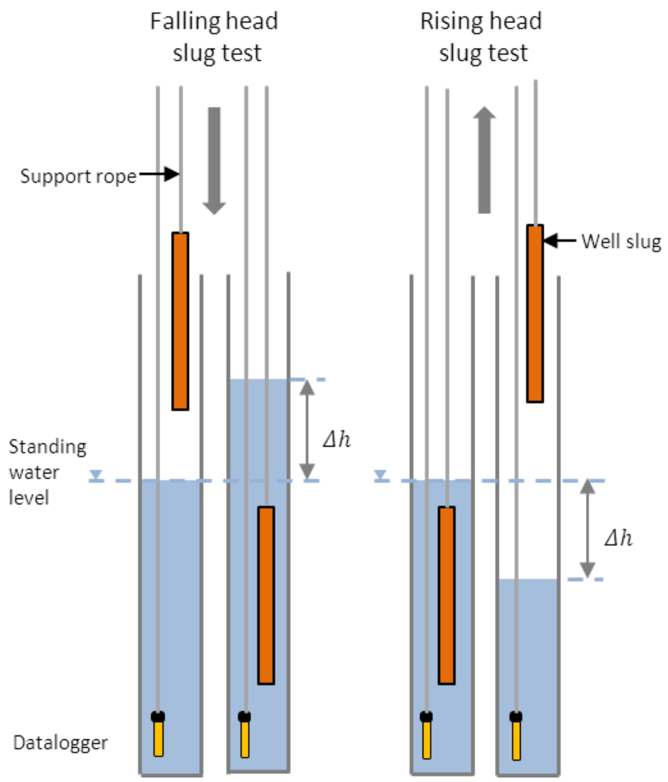


Figure 4-5 Slug testing: rising and falling head test (after Waterra 2011)

4.8.2 Packer testing

Packer testing was undertaken to assess the hydraulic conductivity of strata intersected by the core hole (TCMB04). The objective of the packer test was to establish estimates of hydraulic conductivity for both the permeable and less permeable strata encountered in the borehole. The packer test involves the injection of water under increasing pressure into a sealed isolated test zone of the borehole and the subsequent measurement of the rate of water flow into the formation (or pressure build up and decay) over time. Prior to the installation of the monitoring bore casing, a multi-level packer test was undertaken at bore TCMB04 on 26 February 2011 targeting five different horizons.

To assist with the geological logging of the bore and to identify suitable horizons for the packer test, downhole geophysical logging was undertaken by Groundsearch Australia after completion of the core hole to the target depth. Specifically gamma, density, neutron and velocity logs were run to total depth. A composite log is shown in Appendix E and Table 4-5 below lists the test horizons, selected to test a range of water bearing zones and tight bedrock.

Table 4-5 TCMB04 Packer test zones

Test zone (mbgl)	Lithology
150.5 – 154	Interburden: sandstone/siltstone units between the Bindaboo & Deards Coal Seams
217.75 – 221.25	Interburden: sandstone/siltstone units between the Deards & Cloverdale Coal Seams: suspected fracture zone evident in core
235 – 238.5	Interburden: sandstone/siltstone units between the Deards & Cloverdale Coal Seams
270 – 273.5	Cloverdale Coal Seam
305 – 308.5	Interburden: sandstone/siltstone units between the Roseville and Cloverdale Coal Seams

mbgl = meters below ground level

A double packer system was used for the tests. Rubber packers are inflated against the wall of the bore creating a hydraulic seal above and below an open test zone (Figure 4-6).Under supervision from Parsons Brinckerhoff and AGL the packer assembly was secured to the drill rods and lowered into the open bore straddling the deepest test interval first. Once at the required depth, the packer was inflated with water from a holding tank so that a 3.5 m test zone was sufficiently sealed.

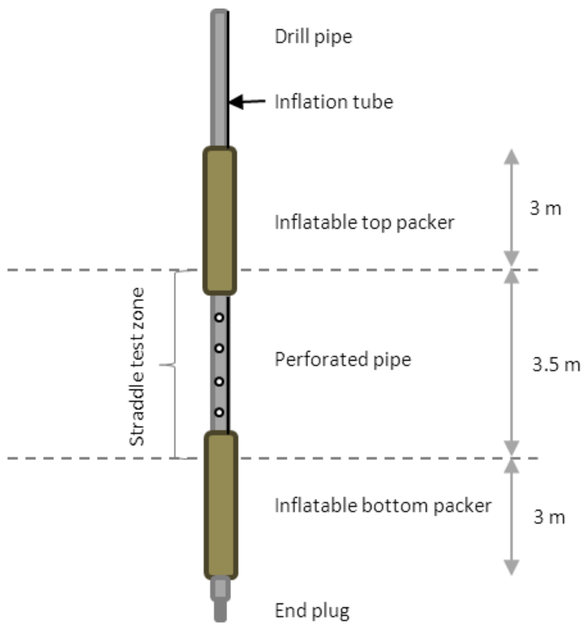


Figure 4-6 Double packer test with wireline assembly

A five step pressure test was carried out at each test zone, comprising three ascending pressure steps and two recovery pressure steps. For the first step, water from the holding tank was injected under pressure into the test zone until the flow had attained a steady state. Steady state conditions were assumed when three consecutive equal flow rate readings, recorded manually every 30 seconds, were observed. The pressure is then increased to the next step.

Table 4-6 shows the pressure steps applied for each test based on estimates made from the known and assumed properties of the test rock.

Table 4-6 Pressure steps applied for each packer test

Step	Pressure (psi)
One	100
Two	150
Three	210
Four	150
Five	100

Flow was recorded by electronic dataloggers and verified by manual measurements. For each pressure step, test parameters were used to determine the hydraulic conductivity of the test zone and data were plotted on a flow rate versus pressure chart. The shape of the plot, especially the decreasing pressure curve, is compared to a selection of type curves to evaluate hydraulic conditions.

Following the first test, the packers were deflated and raised to the second deepest test interval. This procedure continued until all five intervals were tested.

4.8.3 Laboratory permeability testing

Porosity and permeability (vertical and horizontal) tests were performed by Core Laboratories Australia on six core samples from TCMB04. Core was selected from each of the packer tested intervals and also from the Roseville Coal Seam (Table 4-7).

Table 4-7 Core samples from TCMB04

Sample	Depth (mbgl)	Rock type	Formation
1	153	Sandstone/siltstone	Between the Bindaboo & Deards Coal Seams
2	219	Sandstone	Between the Deards & Cloverdale Coal Seams
3	236	Siltstone	Between the Deards & Cloverdale Coal Seams
4	270.4	Coal	Cloverdale Coal Seam
5	307.1	Sandstone	Between the Cloverdale & Roseville Coal Seams
6	333.3	Coal	Roseville Coal Seam

Vertically and horizontally orientated, 25 mm diameter cylindrical samples were drilled out of each core sample and dried in a convection oven at 95°C for 24 hours (samples were considered dry when weights of the samples were stable), before being cooled to room temperature inside a desiccator. Permeability measurements were made on all samples at 800 psi confining stress in an automated core measurement system (CMS^{TM}300). Porosity data (on horizontal samples) was obtained by combining pore volumes from the CMC^{TM}300 data with grain volumes determined from an Ultrapore^{TM} porosimeter.

4.9 Groundwater quality monitoring

4.9.1 Sampling methods

Three methods were used to obtain groundwater quality samples from the monitoring bores. Methods were selected based on the permeability of the screened formation of each bore determined from the hydraulic testing. Higher yielding monitoring bores were purged and sampled using a submersible pump. Lower yielding bores were sampled using a low flow pump or disposable bailer (seepage monitoring bores). In summary:

- Submersible pumps were used in monitoring bores: AMB01, AMB02, TMB01, TMB02, TMB03, TCMB04, BMB01, RMB01, WMB01, WMB02 and WMB04.
- Disposable bailers were used in shallow (seepage) monitoring bores: TMB04 and TMB05.
- A micro-purge™ low flow sampling pump was used in monitoring bores: S4MB01, S4MB02, S4MB03, S5MB01, S5MB02, S5MB03, BMB02, RMB02, TCMB02, TCMB03 and WMB03.

Submersible pumps and disposable bailers were used to purge a minimum of three well volumes from the monitoring bores prior to sampling to allow a representative groundwater sample to be collected. If purged until dry the bore was allowed to recharge before the remaining water was removed. Water quality parameters were measured during and following purging to monitor water quality changes and to indicate representative groundwater suitable for sampling and analysis.

For lower yielding bores and selected deeper bores with high purge volumes, a micro-purge™ low flow sampling system was deployed. The micro-purge™ system allows groundwater to be drawn into the pump intake directly from the screened portion of the aquifer, eliminating the need to purge relatively large volumes of groundwater from these bores. Water quality parameters were monitored during the micro-purge™ pumping to ensure that a representative groundwater sample was collected.

The following physical water quality parameters were measured in the field using a calibrated YSI water quality meter:

- Electrical conductivity (EC) - µS/cm
- Temperature - ^{o}C
- Dissolved oxygen (DO) - % saturation and mg/L
- Oxidation reduction potential (ORP) – mV
- pH - pH units.
- Total dissolved solids (TDS) – mg/L.

4.9.2 Chemical analysis of water

The first sampling event took place between 4 April and 11 May 2011, with all groundwater and seepage monitoring bores sampled. Groundwater samples collected in the field were analysed for a broad chemical suite designed specifically to assess the chemical characteristics of the water bearing zones at the monitoring sites. In addition, samples were also analysed for stable isotopes (oxygen-18 [$\delta^{18}O$], deuterium [$\delta^{2}H$] and carbon-13 [$\delta^{13}C$]) and radioisotopes (radiocarbon [14C] and tritium [3H]). Table 4-8 outlines the chemical and isotopic suites analysed.

Table 4-8 Laboratory chemical and isotope analytical suite

Category	Parameters	
General parameters*	electrical conductivity (EC)	total dissolved solids (TDS)
	pH Temperature	Redox potential Dissolved oxygen
Major ions*	*Cations* calcium magnesium sodium potassium	*Anions* chloride bicarbonate sulphate dissolved silica
Metals and minor / trace elements*	aluminium arsenic barium boron beryllium bromine cadmium cobalt copper iron	manganese molybdenum nickel lead selenium strontium uranium vanadium zinc
Nutrients*	ammonia phosphorus (total) phosphorus (reactive)	nitrate nitrite Total organic carbon (TOC)
Hydrocarbons*	Phenol compounds Polycyclic aromatic hydrocarbons (PAH)	Total petroleum hydrocarbons (TPH) Benzene, toluene, ethyl benzene and xylenes (BTEX)
Dissolved gases	Methane	
Isotopes	oxygen-18 deuterium	Radiocarbon (^{13}C and ^{14}C) Tritium (^{3}H)

Note: * indicates the 'basic' analytical suite

Groundwater samples were collected in the sample bottles listed in Table 4-9, with appropriate preservation when required. Samples undergoing dissolved metal analysis were filtered through 0.45 µm filters in the field prior to collection.

Table 4-9 Sample containers for chemical and isotopic analytes

Category	Sample container
Physical properties (turbidity)	1 x 1 L plastic, unpreserved
Major cations/anions & silica	1 x 250 mL plastic, unpreserved
Dissolved metals	1 x 60 mL plastic, preserved with nitric acid, field filtered
Nutrients	1 x 125 mL plastic, preserved with sulphuric acid
Total organic carbon	1 x 40 mL amber glass, preserved with sulphuric acid
Methane	2 x 40 ml amber glass, preserved with sulphuric acid
Phenols/PAH/TPH (C_{10}-C_{36})	1 x 500 mL amber glass, unpreserved
TPH (C_6-C_9)/BTEX	2 x 40 mL amber glass, preserved with hydrochloric acid
Oxygen-18 and deuterium	30 mL nalgene, unpreserved (no head space)
Radiocarbon	500 mL nalgene, unpreserved
Tritium	1 L nalgene, unpreserved

Samples were sent to the following laboratories under appropriate chain-of-custody protocols (documentation and laboratory results are provided in Appendix F – I)

- Australian Laboratory Service (ALS) Environmental Pty Ltd, Smithfield, Sydney – chemistry analysis. NATA certified laboratory (Appendix F).
- GNS Stable Isotope Laboratory, Lower Hutt, New Zealand – oxygen-18 and deuterium analysis (Appendix G)
- Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand – carbon-13 and carbon-14 analysis (Appendix H)
- ANSTO Tritium Laboratory, Lucas Heights, NSW - tritium analysis (Appendix I)
- GNS Tritium and Water Dating Laboratory, Lower Hutt, New Zealand – tritium analysis (Appendix J) (one sample only – TCMB02).

4.9.3 Quality assurance

A full outline of field and laboratory QA/QC procedures is provided in Appendix J and a summary is provided in the following section.

4.9.3.1 Field QA/QC

The field sampling procedures conformed to Parsons Brinckerhoff's Quality Assurance/Quality Control protocols to prevent cross-contamination and preserve sample integrity. The following QA/QC procedures were applied:

- One duplicate per twenty samples was collected as a control for chemical analysis
- Samples were collected in appropriate bottles with appropriate preservation solutions
- Samples were kept chilled (<4°C) at all times

- Samples were delivered to the laboratories within the specified holding times
- Unstable parameters were analysed in the field (field parameters).

To assess the performance of the field QA/QC program, in particular the assessment of the reproducibility of the analytical measurements or precision given the adopted field and laboratory methods, the relative percentage difference (RPD) was calculated for the primary and duplicate samples.

4.9.3.2 Laboratory QA/QC

The laboratories conduct their own internal QA/QC program to assess the repeatability of the analytical procedures and instrument accuracy. These programs include analysis of laboratory sample duplicates, spike samples, certified reference standards, surrogate standards/spikes and laboratory blanks.

4.10 Surface water quality monitoring

4.10.1 Rivers

Water samples were collected in combination with the groundwater sampling event at three locations on the Avon River (Figure 4-2) in April 2011 using a rinsed bucket attached to a rope. The rope was extended to a minimum distance of 1 m from the bank, allowing a representative sample to be collected.

Surface water samples were analysed for the basic analytical suite listed in Table 4-8. The basic analytical suite included the general water quality parameters, major ions, hydrocarbons, dissolved metals and minor trace elements, but excluded methane and isotopes.

4.10.2 Tiedman and Stratford storage dams

AGL is currently seeking approval (Parsons Brinckerhoff, 2011) under Part 5 of the EP&A Act for the development of an expanded irrigation system on the Tiedman property to allow irrigation of produced waters currently stored in the Tiedman dams. The proposal covers the irrigation of up to 40 ha of land on the Tiedman property over a three year period using a maximum of 70 ML of produced waters (blended with water from the Avon River). Most of this water (approximately 50 ML) is currently stored on-site; however, small additional volumes generated from new pilot test programs under exploration program approvals in 2011/12 and 2012/13 could increase the volume to approximately 70 ML.

Produced water is currently stored for irrigation in the following on-site dams (Figure 4-7):

- Tiedman North (20 ML capacity)
- Tiedman South (20 ML capacity)
- Stratford 1 (8 ML capacity)
- Stratford 3 (8 ML capacity).

A third 20 ML storage dam on the Tiedman property is also planned as part of new exploration programs and the expanded irrigation system.

A water quality investigation was carried out to assess the stratification, composition and suitability of stored waters within AGL's Tiedman North and Tiedman South dams for irrigation.

Both dams were profiled for salinity and pH using a calibrated Troll 9500 depth profiler on 10 January 2011. A kayak was used to access and profile several locations within each dam to assess the spatial and depth variability in water quality. To further investigate vertical stratification of the stored waters, two water samples were taken from each dam during the profiling; one shallow surface sample was collected using a rinsed bucket, attached to a rope and a second sample taken at depth (2-3 m below the water surface), and obtained with a point source stainless steel bailer (with double check valves).

AGL's Stratford 1 and Stratford 3 storage dams to the south of the Tiedman property were sampled on 4 August 2011. Due to the much smaller size of the dams, one surface sample was taken from each dam, collected using a rinsed bucket attached to a rope. The bucket was cast out approximately 2 m from the bank of each dam to obtain a representative sample.

Field parameters (EC, pH, temperature, dissolved oxygen, redox, TDS) were recorded for all samples and they were analysed in the laboratory for the basic analytical suite listed in Table 4-8.

Roads
Dams
Properties

0 1
KM

\\APSYDNAS02\proj\A\AGL_Energy\2162406_HYG_GLOUSTER_BASIN_CSM_ASS\10_GIS\Projects\ESRI\2162406A_GIS_F003_A.mxd Author: kumarg 09/01/2012

Figure 4-7
Storage dam locations

4.11 Shallow gas monitoring

IsoTubes and an IsoTube Wellhead Sampler were installed and used to obtain a gas sample from each of the two shallow gas monitoring bores on 31 May 2011. The IsoTube Wellhead Sampler was attached to a sampling port on the well cap. The IsoTube was attached to the Wellhead Sampler and purged and filled. IsoTubes are durable and allow for safe sampling and transport of gas samples.

Gas samples were analysed at a certified laboratory, Isotech Geotech, Welshpool, Western Australia for composition, including C_1-C_5, C_{6+}, O_2+Ar, CO_2 and CO, by a gas chromatograph. Due to insufficient concentrations of methane, the hydrogen and carbon isotopes of methane were not analysed. Appendix K contains the laboratory documentation and results for the two gas samples analysed.

4.12 Coal analysis

The drilling of the Tiedman core hole (TCMB04) was completed on 22 February 2011. To allow comparison of the solid coals with the formation waters from the coal seams, a coal sample was taken from the final metre of core, within the Roseville Coal Seam. The sample was analysed in the ALS laboratory for BTEX, TPH, PAH and phenolic compounds.

The coal analysis was undertaken to determine the source of minor hydrocarbons detected in groundwater monitoring of coal seams in the study area. Laboratory results from the analysis of the initial sample from the Roseville Coal Seam returned levels of all analytes below the laboratory detection limits.

Two further coal samples (one repeat from the Roseville Coal Seam (333 mbgl) and one from the Cloverdale Coal Seam (270 mbgl)) were taken from the stored TCMB04 core on 11 May 2011. In addition to the standard preparation, these two samples were crushed in the laboratory prior to extraction to refine the analysis.

Appendix L contains the laboratory documentation and results for the three solid coal samples analysed.

5. Updated geological model

This chapter presents an updated geological model of the Stage 1 GFDA based on the completed groundwater drilling program, geophysical logging and latest seismic interpretations.

Interpretation of the geological and geophysical logging of the strata encountered during the drilling of the new groundwater monitoring bore network has enabled a refinement of the shallow (<300 mbgl) geological model across the Stage 1 GFDA. Also 3D seismic surveys completed in 2009 have been used to gain a better understanding of the structural complexity and mapping of the location, dip and strike of major faults.

The cross sections presented in Figures 5-1 – 5-4 detail the latest understanding of the stratigraphy and geological structure. Appreciation of the local geology and the hydraulic properties of the encountered formations are crucial to the interpretation of water level and quality results presented in the following sections and the subsequent refinement of the conceptual model.

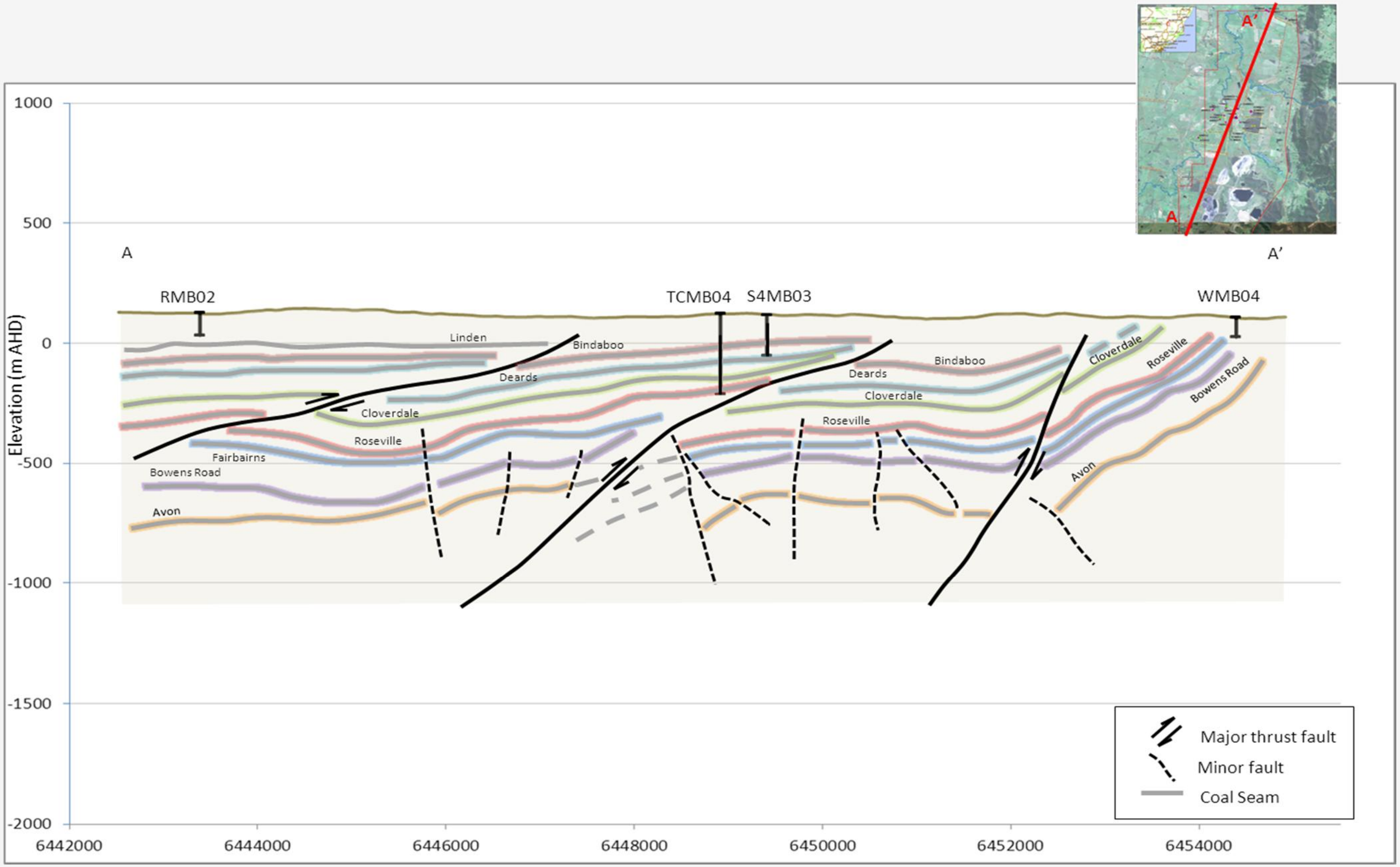


Figure 5-1 Simplified regional NE-SW geological cross-section through the Stage 1 GFDA

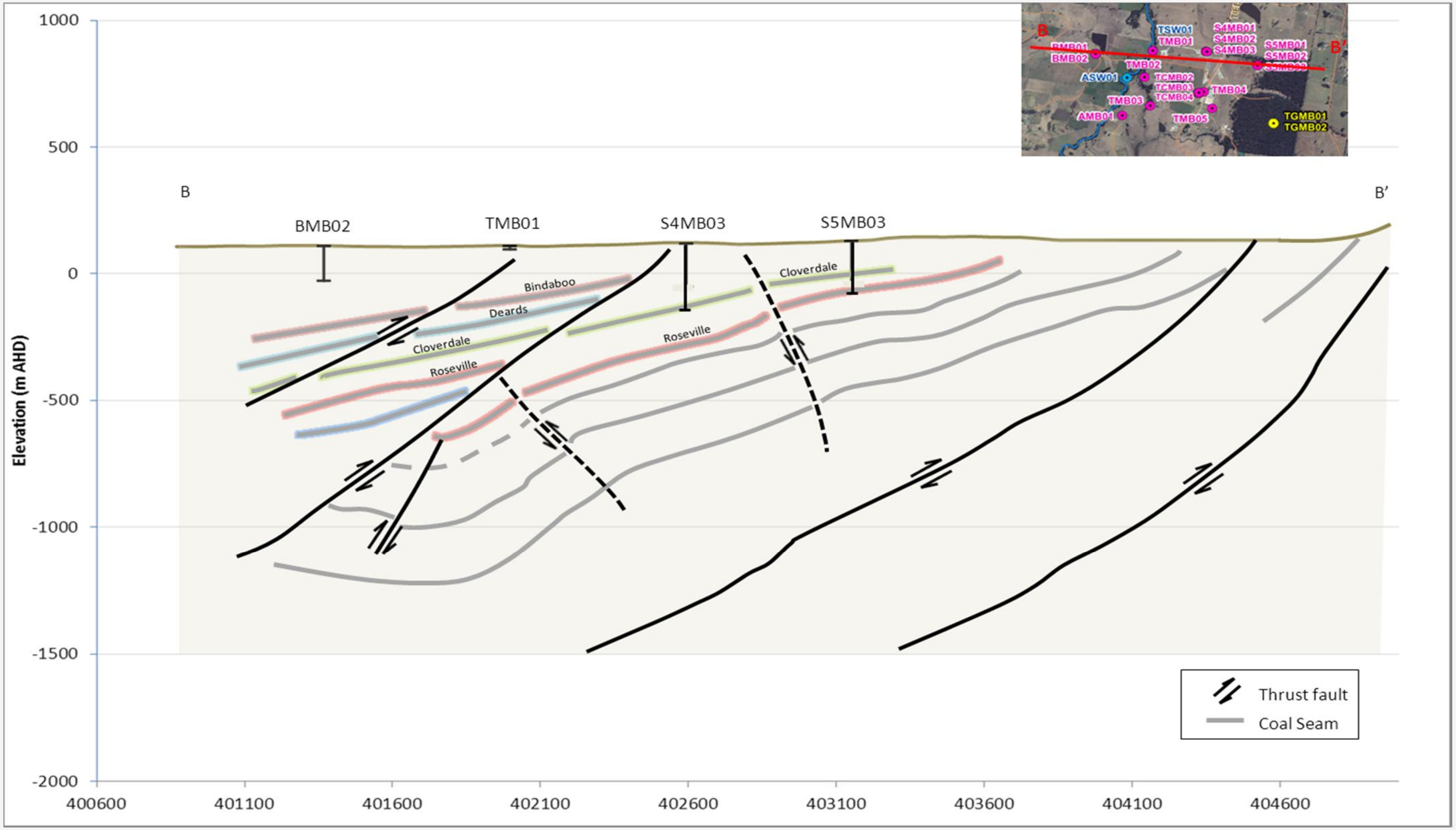


Figure 5-2 Simplified regional E-W geological cross-section through the Stage 1 GFDA

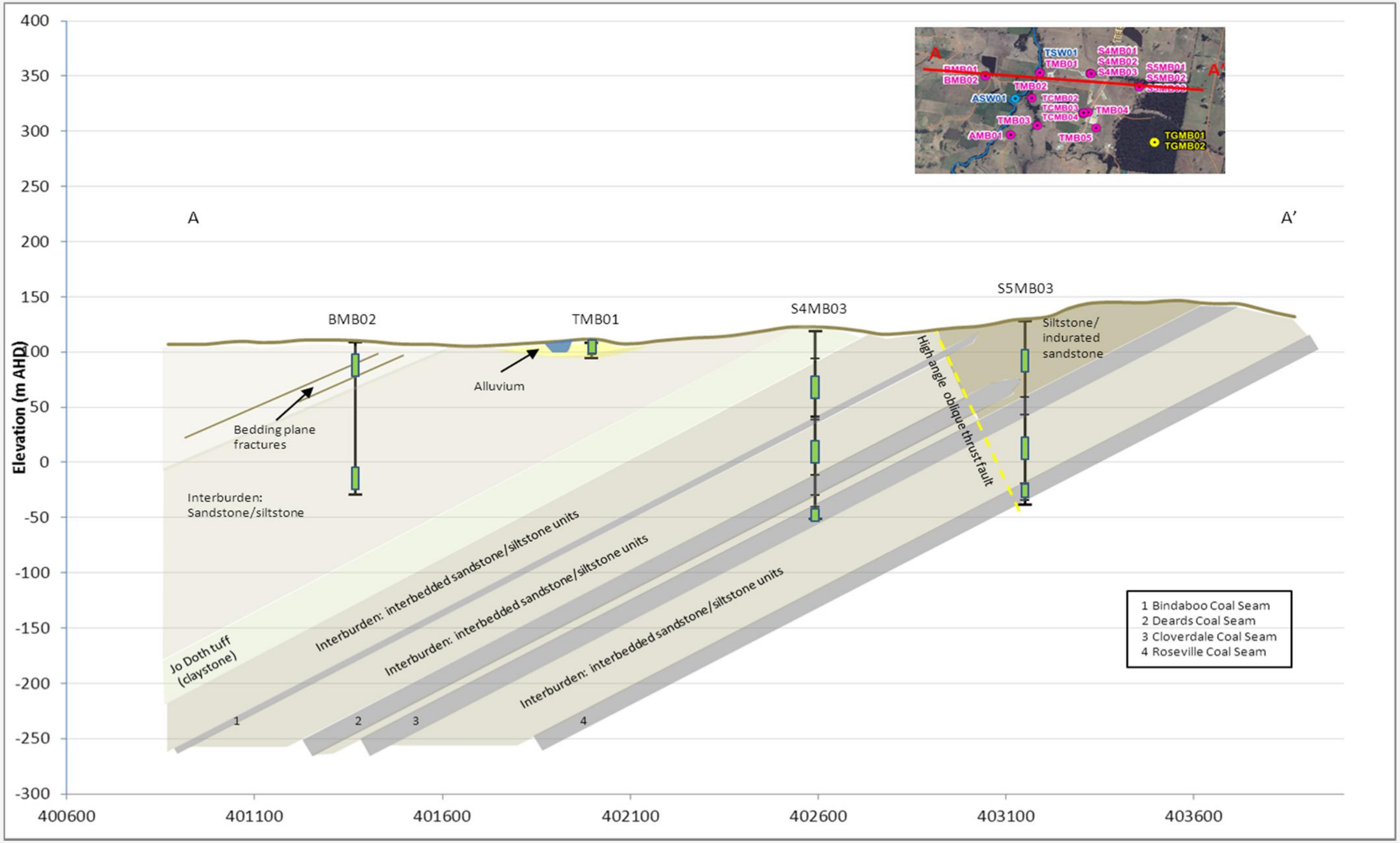


Figure 5-3 Geological cross-section through the Tiedman property (W-E)

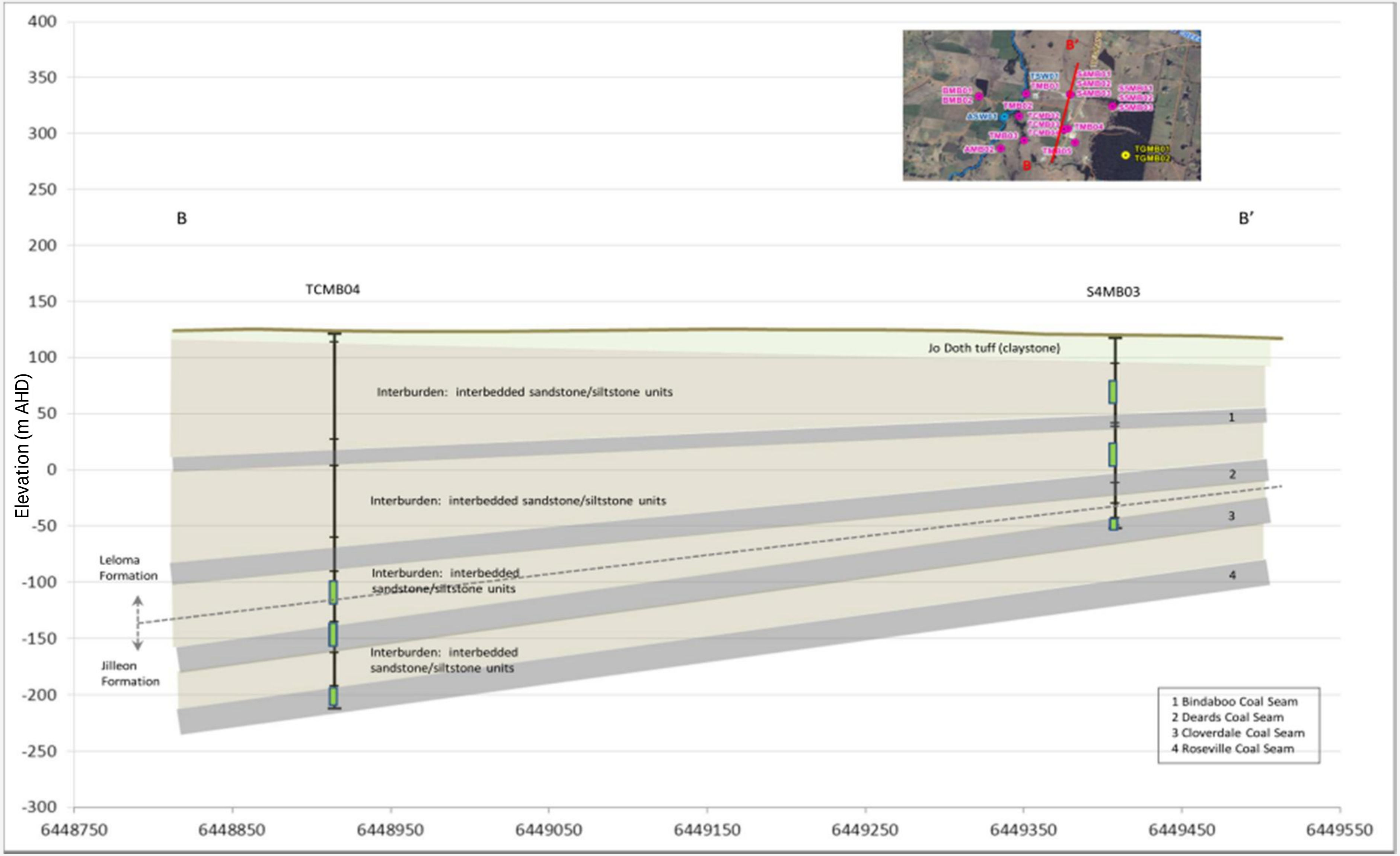


Figure 5-4 Geological cross-section through the Tiedman property (N-S)

Four key hydrostratigraphic units (equivalent to the hydrogeological units of SRK, 2010) are defined to assist discussion of the hydraulic testing, water level monitoring and water quality analysis results (Table 5-1).

Table 5-1 Four key hydrostratigraphic units

Unit	Formation name	General lithology
Alluvium	-	Clay/mixed gravels
Shallow Rock	Individual (upper) formations within the Gloucester Coal Measures	Interbedded sandstone/siltstone with bedding plane fractures
Interburden	Confining units of the Gloucester Coal Measures, Dewrang Group and the Alum Mountain Volcanics	Interbedded indurated sandstone/siltstone and claystone
Coal Seams	Coal seams of the Gloucester Coal Measures and Dewrang Group	Coal/shale

5.1 Alluvium

The shallow Avon River alluvial monitoring bores typically intercepted 3-4 m of stiff organic alluvial clay underlain by coarse sands and poorly sorted mixed gravels to the hard siltstone bedrock. The typical thickness of alluvium encountered in the vicinity of the Tiedman and Atkins properties was approximately 12 m.

5.2 Shallow rock

A distinction is made between the shallow interbedded sandstone/siltstone between and directly overlying the Leloma and Jilleon Formation coal seams and the shallow rock of the upper Leloma toward the centre of the basin. Although interbedded, the shallow rock typically has a more dominant sandstone content with suspected bedding plane fractures.

5.3 Interburden

The majority of the Stage 1 GFDA is underlain by interbedded indurated fine to medium grain sandstone and very fine grain siltstone units providing confining layers between and directly overlying the major coal seams. No significant fractures were encountered in these rock units.

5.4 Coal seams

Four main coal seams were intercepted in the monitoring bore drilling program beneath the Tiedman property; the Bindaboo, Deards, Cloverdale, and Roseville coal seams. The seams vary in thickness from 3 to 18 m and typically comprise thin coals interbedded with dark organic siltstones and shale.

5.5 Geological structure

The shallow strata of the Gloucester Coal Measures dip steeply to the west beneath the Stage 1 GFDA with the sub-crop younger to the west and south. The bedding plane fractures within the shallow rock are likely to have opened as result of synclinal folding during the evolution of the basin.

Recent seismic data acquired by AGL maps a number of north-south striking thrust faults, and east-west striking sub-vertical normal faults. The major thrusts dip toward the west, and in some cases, have up to 230m of vertical displacement, confirmed by well data. Back thrusts dip to the east and displacement appears minimal. It is likely that most fault systems in the basin will have an oblique slip component due to the complex geometries present.

The resolution of the vertical seismic profiles is accurate to depths of approximately 1 km; however, the acquisition techniques used returns poor resolution data in the top 200 m. This inhibits the ability to map these fault structures accurately through the shallow sub-surface and currently lineament traces can only be inferred. The resolution of the seismic data allows for identification of faults when displacement is greater than approximately 10 m.

Incorporating the recent 3D seismic survey with existing 2D seismic data coverage has allowed for a more comprehensive structural interpretation of the basin, in particular the Stage 1 area. Figure 5-1 shows a section from southwest to northeast which goes through the Rombo monitoring sites to the south, through the Tiedman property, and to the Waukivory monitoring sites to the northeast. This section shows three major westerly dipping thrust faults that become more shallowly dipping toward the centre of the basin. Steeply dipping normal faults with a likely oblique slip component trending east west do not penetrate to the surface and vertical displacement on these features appears minimal based on the seismic data. Figure 5-2 shows an east-west cross section through the Stratford Pilot area with four major westerly dipping thrust faults and two easterly dipping north south trending back thrusts.

Borehole breakout has been observed to be generally minimal and shallower than 400 m. Principal stress direction as observed from borehole breakout is generally in an east-west or north-east to south-west orientation however it is observed to be locally variable most likely due to the proximity of faults.

6. Hydraulic testing results

This chapter presents the results of hydraulic testing of the targeted aquifers, water bearing zones, aquitards and aquicludes from all 22 of the dedicated monitoring bores constructed across the Stage 1 GFDA.

6.1 Rising/falling head testing

Falling and rising head slug tests were conducted at all monitoring bores to estimate the horizontal hydraulic conductivity of each of the screened water bearing zones. Test results were analysed in AQTESOLV Version 4.5 using the Bouwer and Rice (Bouwer, 1989) or the Butler method (Butler, 1998). Results are presented as estimates of hydraulic conductivity (as m/day) in Table 6-1.

Table 6-1 Hydraulic conductivity results from slug tests

Monitoring Bore	Screened section (mbgl)	Lithology	Formation	Hydraulic conductivity (m / day)
S4MB01	58 – 64 (6m)	Sandstone	Leloma Formation	4×10^{-5}
S4MB02	89 – 95 (6 m)	Sandstone / siltstone	Leloma Formation	5×10^{-3}
S4MB03	162 – 168 (6 m)	Coal	Jilleon Formation - Cloverdale Coal Seam	0.01
S5MB01	52 – 58 (6 m)	Sandstone / siltstone	Jilleon Formation	2×10^{-6}
S5MB02	100 – 112 (12 m)	Siltstone	Jilleon Formation	7.9×10^{-4}
S5MB03	158 – 164 (6 m)	Coal / shale	Jilleon Formation - Roseville Coal Seam	0.01
TCMB02	175 – 181 (6 m)	Sandstone	Leloma Formation	1.1×10^{-4}
TCMB03	260 – 266 (6 m)	Coal & sandstone	Jilleon Formation - Cloverdale Coal Seam	1.6×10^{-3}
TCMB04	327.3 – 333.3 (6 m)	Coal	Jilleon Formation - Roseville Coal Seam	2.3×10^{-3}
BMB01	15 – 29 (14 m)	Sandstone / siltstone	Leloma Formation	0.12
BMB02	124 – 136 (12 m)	Sandstone	Leloma Formation	1.5×10^{-3}
TMB01	7 – 10 (3 m)	Clay	Avon River Alluvium	0.32
TMB02	9 – 12 (3 m)	Mixed gravels	Avon River Alluvium	50 – 100
TMB03	5 – 1 (6 m)	Mixed gravels & sand	Avon River Alluvium	20 – 50
AMB01	8 – 10 (2 m)	Mixed gravels	Avon River Alluvium	100 – 500
AMB02	6.5 – 11 (4.5 m)	Mixed gravels	Avon River Alluvium	50 – 100
WMB01	5 – 8 (3 m)	Mixed gravel & sand	Alluvium	50 – 150
WMB02	15 – 21 (6m)	Sandstone	Wenhams Formation	0.9

Monitoring Bore	Screened section (mbgl)	Lithology	Formation	Hydraulic conductivity (m / day)
WMB03	32 – 34 (2m)	Coal	Wenhams Formation - Bowens Road Coal	0.03
WMB04	67 – 79 (12 m)	Sandstone	Wenhams Formation	2 – 20
RMB01	42 – 48 (6 m)	Sandstone	Leloma Formation (upper)	0.01
RMB02	85 – 91 (6 m)	Sandstone	Leloma Formation (upper)	0.01

The following summary observations are drawn from these data:

- Alluvium: The hydraulic conductivity in the mixed gravels within the alluvium is high (20 to 500 m/day).
- Shallow rock: The hydraulic conductivity for the shallow interbedded sandstone and siltstone units ranges from 0.01 to 20 m/day. The large range in these values is due to the likely contribution of secondary permeability in the form of localised bedding plane fracture flow.
- Interburden: The hydraulic conductivity for the interbedded indurated sandstone and siltstone units between and overlying the coal seams ranges from 2×10^{-6} to 1.5×10^{-3} m/day. The very low values returned for S4MB01 and S5MB01 are consistent with the recorded low inflows during drilling.
- Coal Seams: The hydraulic conductivity of the various coal seams ranges from 0.03 m/day to 2.3×10^{-3} m/day.

Appendix M includes worksheets for each analysis, with details and a graphical fit for each of the measurements.

6.2 Quality Assurance

6.2.1 Raw measurements

Figure 6-1 presents an example of the raw pressure logger measurements during the slug tests (for BMB01). It shows successive recoveries from two falling and rising head tests. The recovery-curves are analysed relative to the equilibrium standing water level. Each of the recoveries were analysed individually using the Bouwer and Rice method (Bouwer, 1989) or the Butler method (Butler, 1998) in AQTESOLV software for aquifer testing.

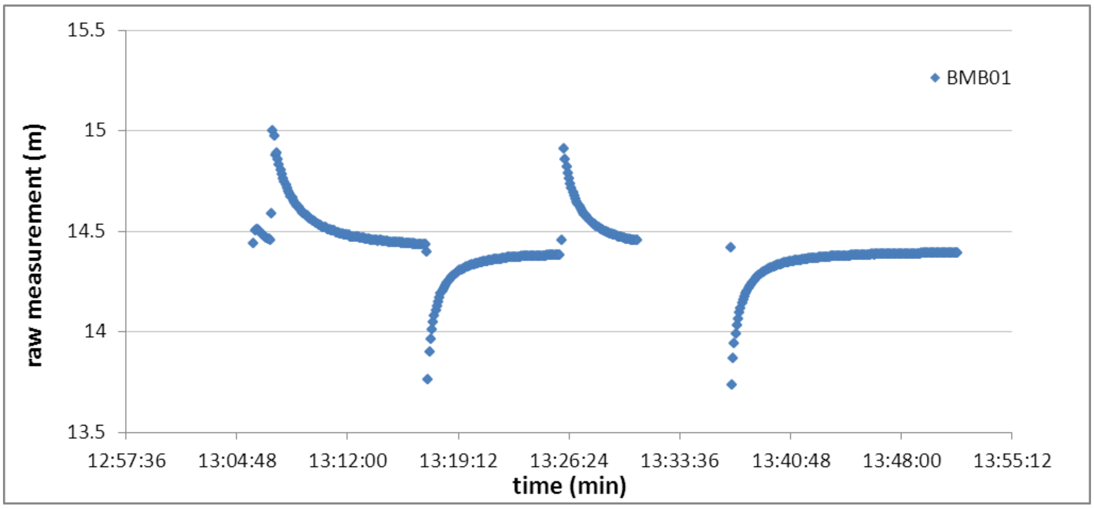


Figure 6-1 Example of raw measurements during the test procedure

6.2.2 Correction for slowly recovering bores

For slowly recovering bores (Figure 6-2) the piezometric head typically does not fully recover back to equilibrium before the start of the next test. To correct for this effect it is assumed that the last measurement recorded before the end of the rising head test (or second falling head test) became the new equilibrium state. This assumption may lead to a small underestimation of the hydraulic conductivity of no more than 10%.

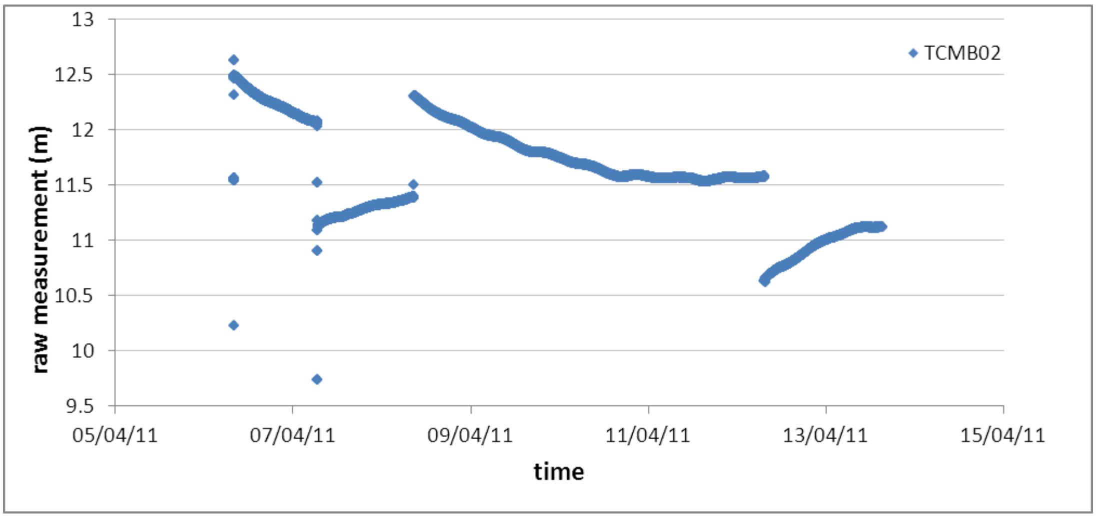


Figure 6-2 Example of a slow recovery

6.2.3 Oscillation effect in high hydraulic conductivity bores

The groundwater monitoring bores TMB02, TMB03, AMB01, AMB02 and WMB01 have screens targeting highly permeable alluvial aquifers. In such formations it is common to obscure water level oscillations following slug insertion or removal (Figure 6-3). Butler (1998) provides a method to calculate aquifer permeability based on the amplitude and wavelength of these oscillations.

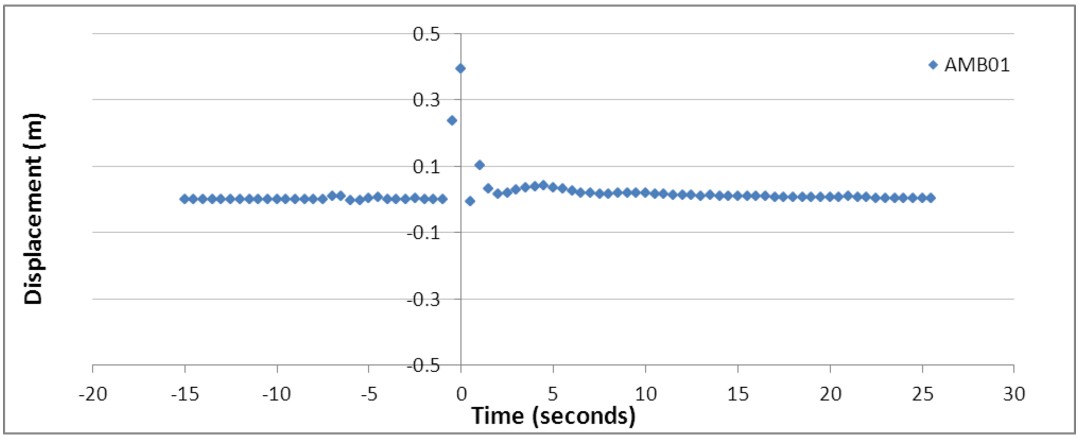


Figure 6-3 Oscillation following rapid recovery in highly permeable aquifers

6.3 Packer testing

6.3.1 Hydraulic conductivity results

The results presented in Table 6-2 summarise the calculations to determine the hydraulic conductivity of the five tested zones.

Table 6-2 TCMB04 Packer test results

Test	Test zone depth (mbgl)	Rock type	Formation	Step	Pressure (psi)	Flow rate (l/s)	K m/d (USBR, 1977)	K m/d (Thiem, 1906)
1	305-308.5	sandstone	Interburden between the Cloverdale & Roseville Coal Seams	1	90	0.05	6×10^{-3}	7×10^{-3}
				2	160	0.03		
				3	200	0.06		
				4	150	0.03		
				5	100	0.02		
2	270-273.5	coal	Cloverdale Coal Seam	1	100	0.07	8×10^{-3}	9×10^{-3}
				2	150	0.06		
				3	200	0.07		
				4	150	0.03		
				5	100	0.02		
3	235-238.5	siltstone	Interburden between the Deards & Cloverdale Coal Seams	1	100	0.04	6×10^{-3}	7×10^{-3}
				2	155	0.06		
				3	200	0.05		
				4	150	0.04		
				5	100	0.02		
4	217.75-220.25	sandstone	Interburden between the Deards & Cloverdale Coal Seams	1	110	0.05	6×10^{-3}	7×10^{-3}
				2	140	0.04		
				3	220	0.05		
				4	155	0.03		
				5	105	0.02		
5	150.5-154	sandstone /siltstone	Interburden between the Bindaboo & Deards Coal Seams	1	110	0.05	7×10^{-3}	8×10^{-3}
				2	140	0.05		
				3	220	0.05		
				4	150	0.05		
				5	100	0.02		

Note: Hydraulic conductivity calculated using both the USBR (1977) and Thiem (1906) methods.

Two methods were used to calculate the results in Table 6-2 based the geometry and variables presented in Figure 6-4:

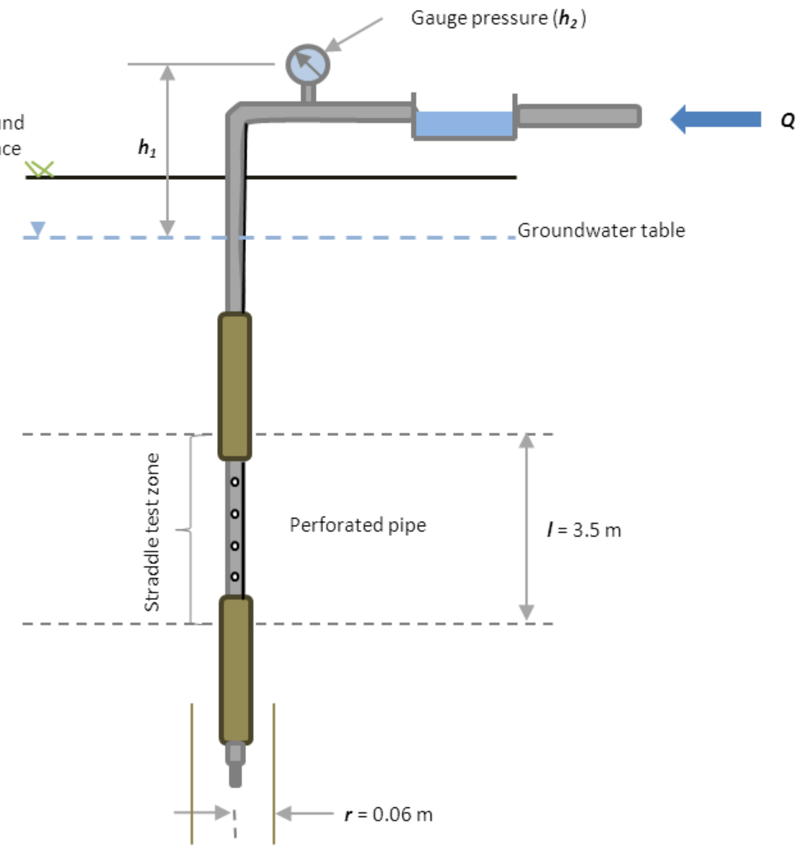


Figure 6-4 Packer test geometry and variables

6.3.1.1 Method 1 (USBR, 1977)

The hydraulic conductivity is given as (USBR, 1977):

$$K = \frac{Q}{C_s r H}$$

Where:

K = Hydraulic conductivity (m/d)

Q = steady injection flow rate to the bore (m^3/d)

C_s = conductivity coefficient for semispherical flow in a saturated material through partially penetrating cylindrical test bores. Values for C_s are found from the graph shown in Figure 6-5 for different values of l/r.

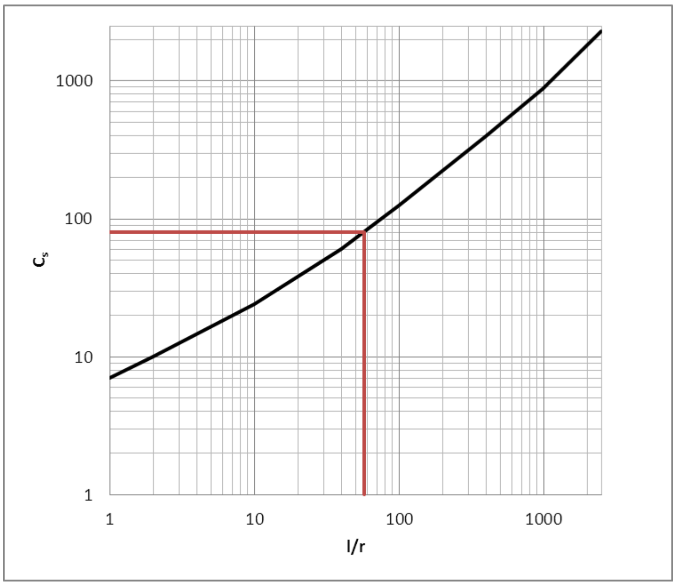


Figure 6-5 Conductivity coefficients for semispherical flow in saturated materials through a partially penetrating cylindrical test well

r = radius of the test bore (m)

$H = (h_1 + h_2 – L)$ effective head between pressure gauge and top of test section (L = head loss in pipe due to friction; head loss assumed negligible for Q < 0.25 l/s in a ½ inch pipe) (m)

6.3.1.2 Method 2 (Thiem 1906)

The data from the packer test can also be used to determine the effective transmissivity (T) by means of the Thiem (1906) equation:

$$T = \frac{Q \ln \frac{R}{r}}{2\pi H}$$

Where:

T = transmissivity (m^2/day)

Q = steady injection flow rate to the bore (m^3/d)

R = radius of influence (m). A value of 10 m is assumed based on Royal (2011)

r = radius of bore (m)

H = effective head pressure (net injection pressure (m))

6.3.2 Observations

6.3.2.1 Flow conditions

In addition to the calculated permeability values, by plotting flow rate versus pressure, the flow conditions during each test can by analysed. Charts for the five tests are presented in Appendix N along with type curves for hypothetical tests (Kresic, 2007).

The charts for the TCMB04 packer tests do not closely follow any of the type curves; however do they indicate a progressive decrease in permeability with pressure (and time) potentially indicating incomplete blocking of fractures by transported material.

6.3.2.2 Limitations

The following limitations which each impact the integrity of the test are considered when interpreting the packer test results (Powers *et al.,* 2007):

- Damage to the wellbore caused by the drilling process blocking discrete fractures and fissures in the rock. This may lead to an underestimate of the actual permeability of the total rock unit.
- Stress relief from drilling causing local changes in permeability around the borehole. May lead to both under and overestimates of permeability.
- Failure to obtain a good packer seal allowing leakage from the test zone. May lead to an overestimate of permeability.

6.4 Laboratory permeability testing

Table 6-3 details the results of laboratory permeability testing on core samples from TCMB04.

Table 6-3 Laboratory permeability testing results

Sample Number	Formation	Orientation	Depth (m)	Hydraulic conductivity (m/d)	Porosity (%)	Comments
1	Interburden between Bindaboo & Deards Coal Seams	Horizontal	153.00	0.001	10.4	
		Vertical	153.00	0.001		
2	Interburden between Deards & Cloverdale Coal Seams	Horizontal	219.00	0.001	8.0	
		Vertical	219.00	0.001		
3	Interburden between Deards & Cloverdale Coal Seams	Horizontal	236.10	0.002	8.8	
		Vertical	236.10	0.002		

Sample Number	Formation	Orientation	Depth (m)	Hydraulic conductivity (m/d)	Porosity (%)	Comments
4	Cloverdale Coal Seam	Horizontal	270.40	1.82*	8.3*	Coal
		Vertical	270.40			Failed
5	Interburden between Cloverdale & Roseville Coal Seams	Horizontal	307.10	<0.001	6.0	
		Vertical	307.10	<0.001		
6	Roseville Coal Seam	Horizontal	333.30			Failed
		Vertical	333.30	0.067	7.3	Coal

Note: *Hydraulic conductivity and porosities are abnormally high and may relate to the core drying out and the cleats expanding.

6.5 Discussion

The permeability results presented from the various methods discussed above indicate distinct hydraulic properties for each of the four hydrostratigraphic units defined in Section 5. Table 6-4 presents a summary of these units and confirms their hydrogeological classification.

Table 6-4 Hydrogeological units of the Stage 1 GFDA (updated)

Hydrogeological unit	Aquifer type	Formation name	Hydraulic conductivity (m/day)
Alluvial aquifers	Semi-confined, clay capped, porous, granular	Quaternary alluvium	0.3-500
Shallow rock units	Confined/ unconfined	Gloucester Coal Measures	0.01-20
Coal seam water bearing zones	Confined	Coal seams of the Gloucester Coal Measures	0.002-0.03 (1.82 lab*)
Interburden confining units	Confined/ unconfined aquitard	Confining units of the Gloucester Coal Measures	4×10^{-5}-0.006

Note: *Hydraulic conductivity is abnormally high and may relate to the core drying out and the cleats expanding.

These data confirm that high permeability aquifers only occur in the alluvium and shallow rock geologies and that the coal seams can be poor aquifers at shallow depth but are low permeability water bearing zones at depth.

The calculated hydraulic conductivities for each unit presented above are consistent with the observed water make recorded during drilling (detailed in the bore logs in Appendix B).

7. Water level monitoring

This chapter presents the initial baseline water level monitoring results.

Baseline groundwater levels are electronically measured every six hours using automated dataloggers installed in each monitoring bore. The electronic data is corrected for barometric pressure changes. Hydrographs of the continuous groundwater elevations for all groundwater monitoring bores and stream gauges are shown in Appendix O (Figures AO-1 to AO-22), and include rainfall data (from BoM station 060112 - Hiawatha) and manual measurements. Manual measurements from all monitoring bores (taken on 1 and 2 June 2011) are summarised in Table 7-1.

Sections 7.2 and 7.3 present initial baseline groundwater and surface water level monitoring results from early January to early December 2011. All monitoring is continuing and will be subject to full baseline review in the subsequent Baseline Monitoring Report to be issued mid-2012.

Table 7-1 Manual groundwater levels (June 2011)

Monitoring bore	Location	SWL (m btoc)	SWL (m AHD)	Ground elevation (m AHD)
AMB01	Atkins	4.64	103.93	111.48
AMB02	Atkins	6.03	106.14	107.88
S4MB01	Tiedman	6.28	112.91	118.38
S4MB02	Tiedman	5.51	113.58	118.44
S4MB03	Tiedman	4.27	114.73	118.37
S5MB01	Tiedman	39.61	90.9	129.98
S5MB02	Tiedman	17.91	112.49	129.87
S5MB03	Tiedman	17.74	112.58	129.79
TMB01	Tiedman	4.05	103.55	106.82
TMB02	Tiedman	4.43	103.07	106.81
TMB03	Tiedman	3.06	104.04	106.48
TMB04*	Tiedman	12.105	113.15	124.47
TMB05*	Tiedman	5.86	113.6	118.63
TCMB02	Tiedman	9.85	114.01	123.16
TCMB03	Tiedman	11.43	112.38	123.18
TCMB04	Tiedman	12.66	111.84	123.31
WMB01	Waukivory	4.11	107.81	111.06
WMB02	Waukivory	4.91	101.95	106.13
WMB03	Waukivory	5.15	101.93	106.39
WMB04	Waukivory	4.82	101.98	106.12
RMB01	Rombo	4.34	125.04	128.68
RMB02	Rombo	3.89	125.34	128.49
BMB01	Bignell	5.7	103.78	108.95
BMB02	Bignell	5.63	103.74	108.83

Note: *includes seepage monitoring bores m btoc = metres below top of casing
m AHD = metres Australian Height Datum

7.1 Baseline groundwater level monitoring

7.1.1 Alluvial aquifers

A relatively rapid response to rainfall recharge was observed at monitoring bores TMB01, TMB02 (Figure 7-1) and WMB01 (Appendix O, AO-12) during 2011. The magnitude of the increase in the groundwater elevations was largest and most rapid at TMB01, where SWLs rose by over 2 m following the heavy rainfall and flooding event in June 2011.

A more subdued and gradual response to rainfall recharge was observed at TMB03 (Figure 7-1). Such a muted response suggests that recharge to the alluvial aquifer via rainfall is indirect and occurring upgradient, or is slowed by the overlying semi-confining clay layers. Reference to the bore logs (Appendix B) indicates that clay above the alluvial mixed gravels is likely to be retarding rainfall recharge at this monitoring location and to a lesser extent at TMB02.

At alluvial monitoring bores AMB01 and AMB02 (Figure 7-1) only a muted response to rainfall recharge was noted, however the June flood event is clearly visible with levels in both bores increasing (by approximately 1 m in AMB01) and remaining elevated with a slight downward trend to December 2011 . The lithological logs for these groundwater monitoring bores (Appendix B) indicate that a 5 m confining clay above the screened section at AMB01 and 2 m of clay at AMB02 are likely to be retarding direct rainfall recharge with the exception of during a major flood event.

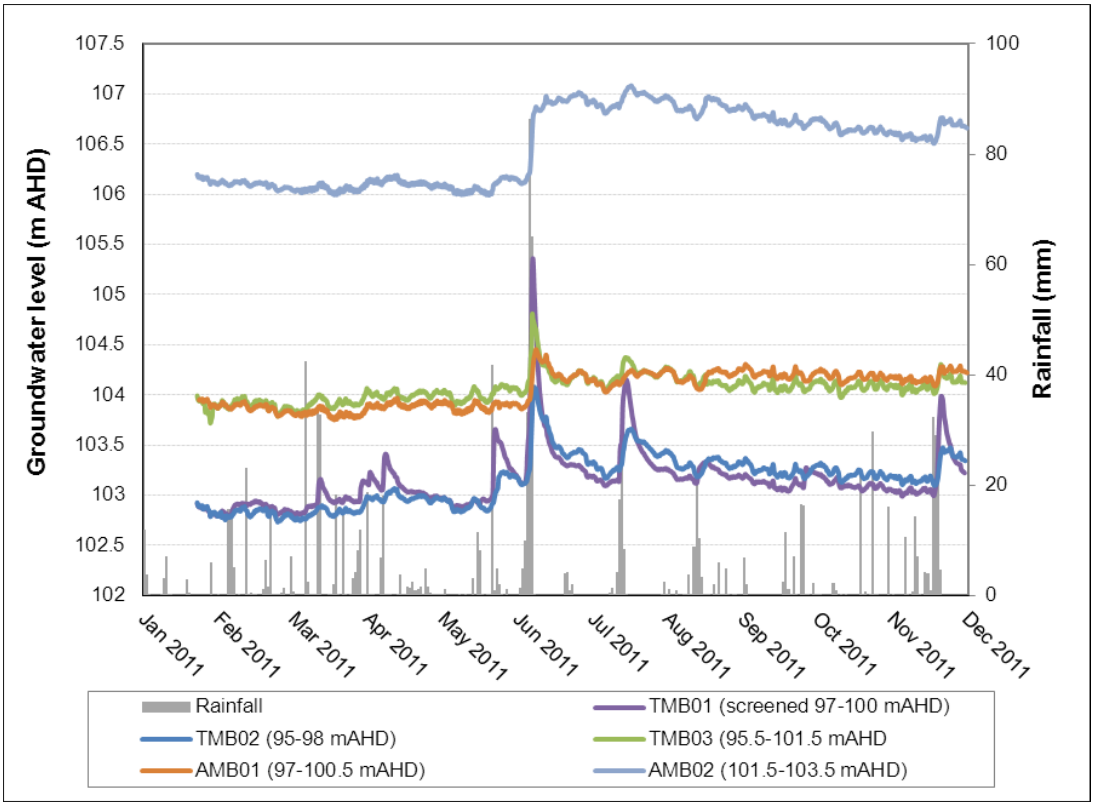


Figure 7-1 Combined groundwater levels and rainfall at the Tiedman/Atkins alluvial bores

7.1.2 Shallow rock units

Waukivory groundwater monitoring bores WMB02 and WMB04 intersect the shallow rock of the Wenham Formation. Groundwater elevations at these locations were static in early 2011 then rose slightly in the second half of 2011, indicating a lagged seasonal variation and minimal response to rainfall recharge (Appendix O, AO -13 and AO-15).

The shallow rock units of the Leloma Formation, intersected by BMB01, RMB01, and RMB02 also show a minimal and lagged response to rainfall recharge. The greatest variability that may indicate some upgradient recharge is observed in RMB01 (Appendix O, AO-16).

7.1.3 Interburden units

The interbedded indurated sandstone/siltstone units of the Leloma and underlying Jilleon Formation are intersected by monitoring bores S4MB01, S4MB02, S5MB01, S5MB02, and TCMB02. These bores show negligible seasonal variation and no response to rainfall recharge, however, the effects of dewatering during groundwater sampling and slug testing are pronounced and these responses are indicative of the very low permeability of the units (Appendix O, AO-10).

7.1.4 Coal seams

The Cloverdale Coal Seam, intersected by monitoring bores S4MB03 and TCMB03, the Bowens Road Coal Seam intersected by WMB03, and the Roseville Coal Seam intersected by monitoring bore TCMB04 all show very little fluctuation and no response to rainfall recharge (Appendix O). However, again, the effects of slug testing and sampling on the groundwater elevations at these locations is visible and indicative of the low permeability and confined nature of these units (labelled on the figures in Appendix O).

The Roseville Coal Seam is also intersected by groundwater monitoring bore S5MB03 and while there is no detectable response to rainfall, a slight increase (by 0.3 m) in groundwater elevation during the monitoring period is observed.

7.2 Aquifer interactions

Baseline groundwater level monitoring from the nested bore sites provides information on the unconfined groundwater levels and potentiometric surfaces in underlying water bearing zones, and the potential for linkages between those zones. Hydrographs are presented below for each nested site.

7.2.1 Stratford 4 Monitoring Bores (S4MB)

Groundwater level monitoring at the nested Stratford 4 site indicates three distinct groundwater regimes likely to be hydraulically isolated by a confining interburden of low permeability siltstones and indurated sandstones. The potentiometric level in the confined Cloverdale Coal Seam (S4MB03) is a higher elevation (c.115 m AHD) than the overlying interburden water bearing zones at S4MB02 (c. 113.5 m AHD) and the shallow water table at S4MB01 (c.113 m AHD). The upward gradient indicates a potential for vertical leakage from the deep to shallow water bearing zones, however, the hydraulic stratification/isolation is attributed to the presence of strong confining layers which are likely to inhibit leakage.

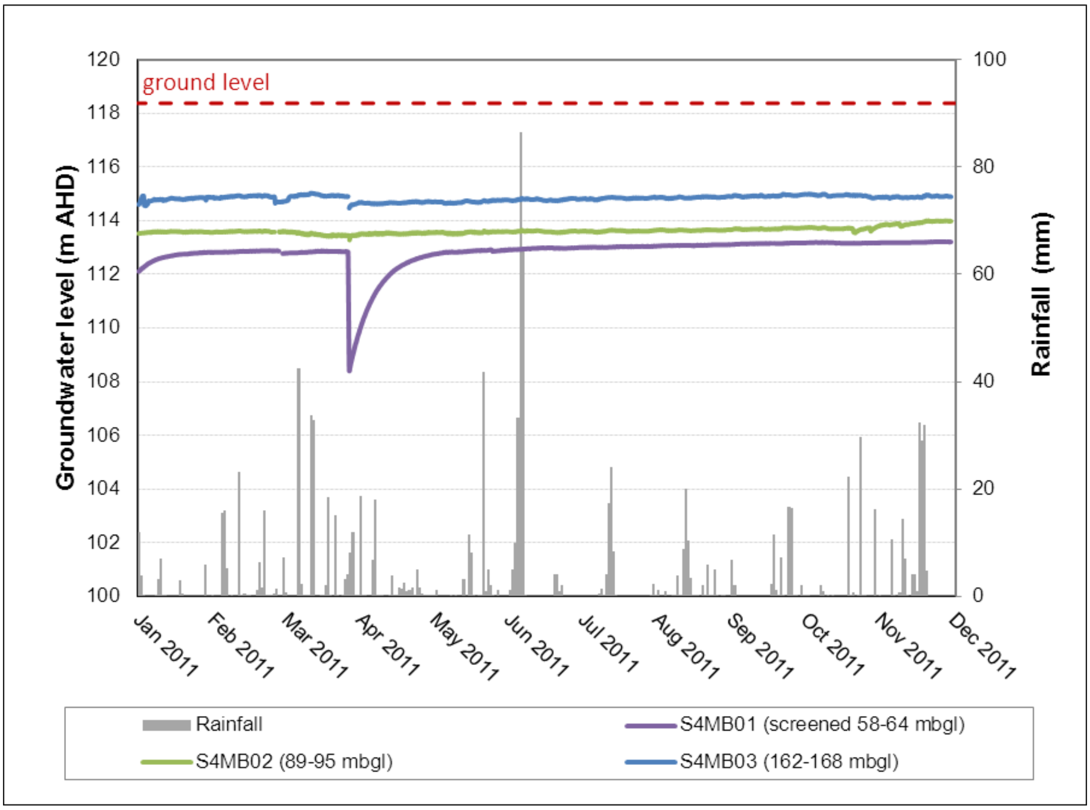


Figure 7-2 Groundwater levels at Stratford 4

7.2.2 Stratford 5 Monitoring Bores (S5MB)

Groundwater monitoring at the nested Stratford 5 site identifies a downward head gradient between the shallow interbedded sandstone/siltstone unit water table (S5MB01, c.115 m AHD); and the potentiometric surface of the underlying siltstone/sandstone interburden (S5MB02) which is the same as the Roseville Coal Seam (S5MB03, c.112 m AHD) (Figure 7-3). Initial monitoring in all three bores shows static water levels indicating strong confining layers above the water bearing zones. Although the head gradient is indicative of potential downwards leakage, the very slow recovery of S5MB01 in response to the slug test suggests that this strata is itself a tight confining layer with very little potential for groundwater movement both, laterally and vertically.

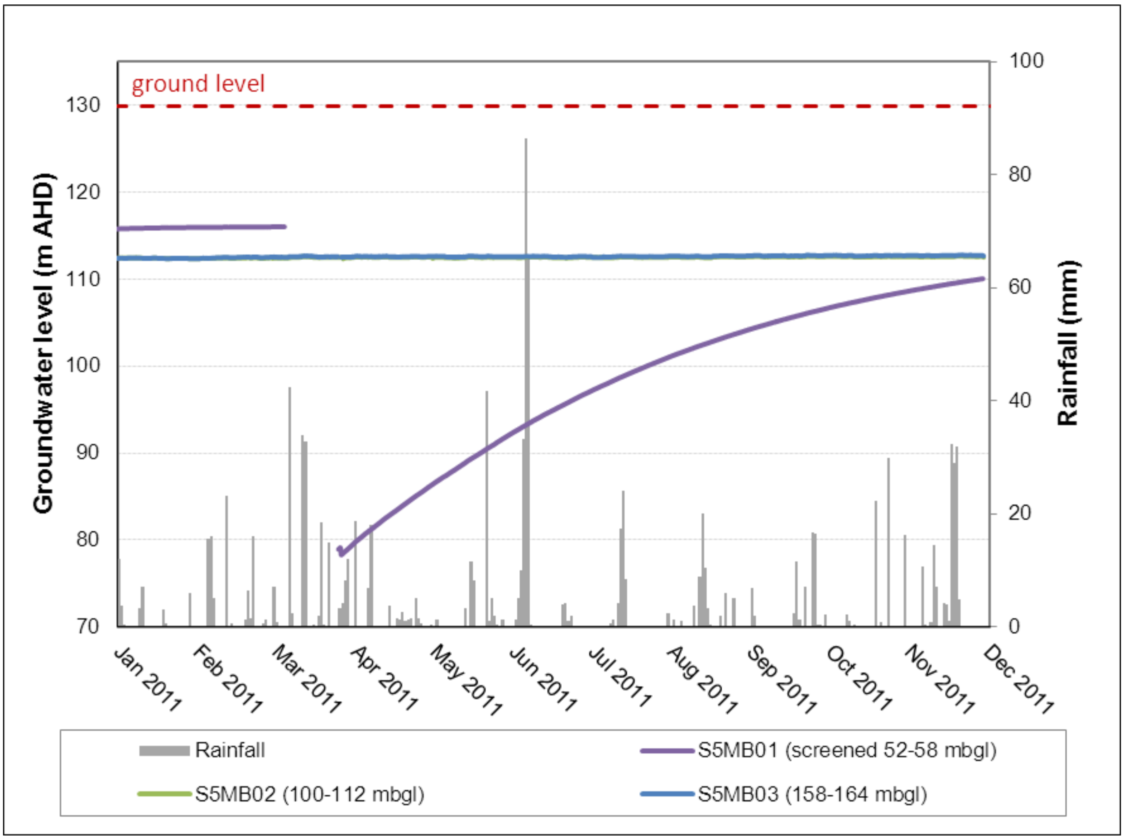


Figure 7-3 Groundwater levels at Stratford 5

7.2.3 Tiedman core hole monitoring bores (TCMB)

Groundwater level monitoring at the Tiedman core hole site nested bores (Figure 7-4) indicates a downward head gradient between the potentiometric surfaces of the interbedded siltstone/sandstone interburden unit (TCMB02), and the Cloverdale Coal Seam (TCMB03), and Roseville Coal Seam (TCMB04). Although the bores all show the effects of slug testing and there is potential for downward leakage, minimal fluctuations are evident emphasising the low hydraulic conductivity, isolation and confining nature of the layers at this location.

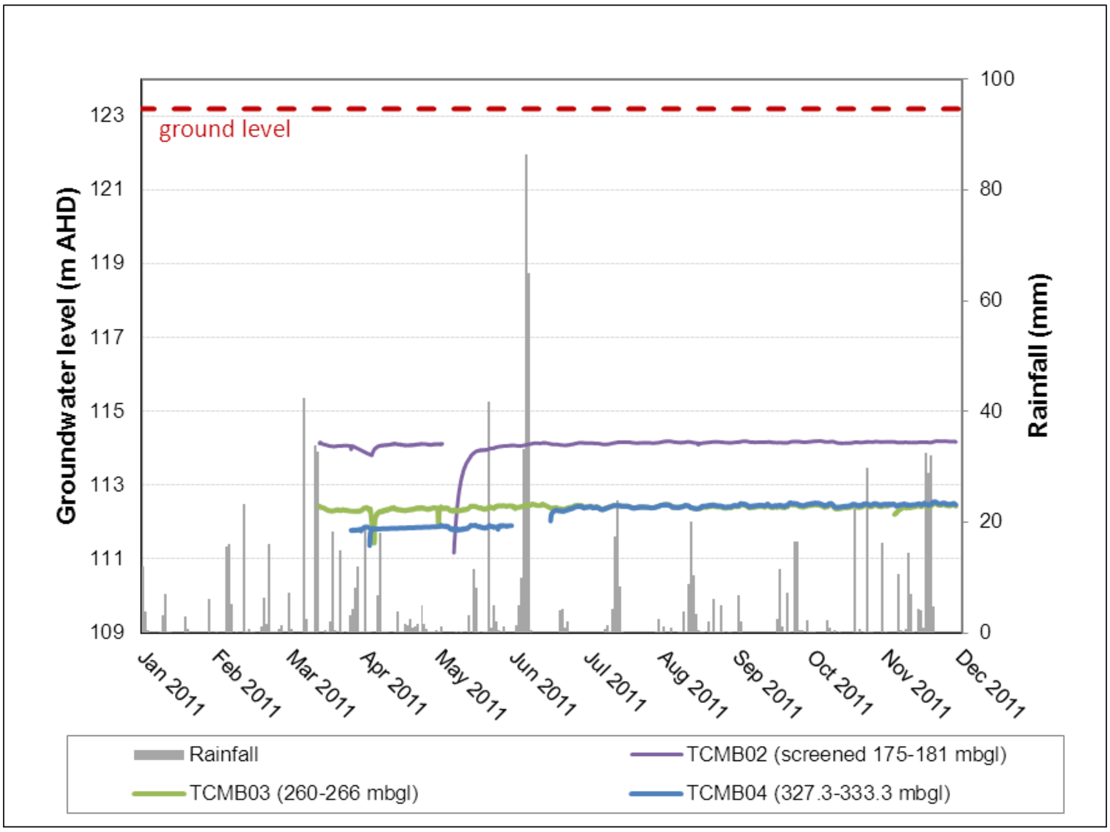


Figure 7-4 Groundwater and rainfall levels at Tiedman core hole site

7.2.4 Bignell monitoring bores

The monitoring bores at the Bignell site indicate a uniform piezometric pressure within the shallow rock aquifer (targeted by both bores BMB01 and BMB02) to depth (Figure 7-5). The effects of sampling and slug testing are more pronounced in the deeper bore (BMB02) indicating a relatively lower hydraulic conductivity in the deeper zone.

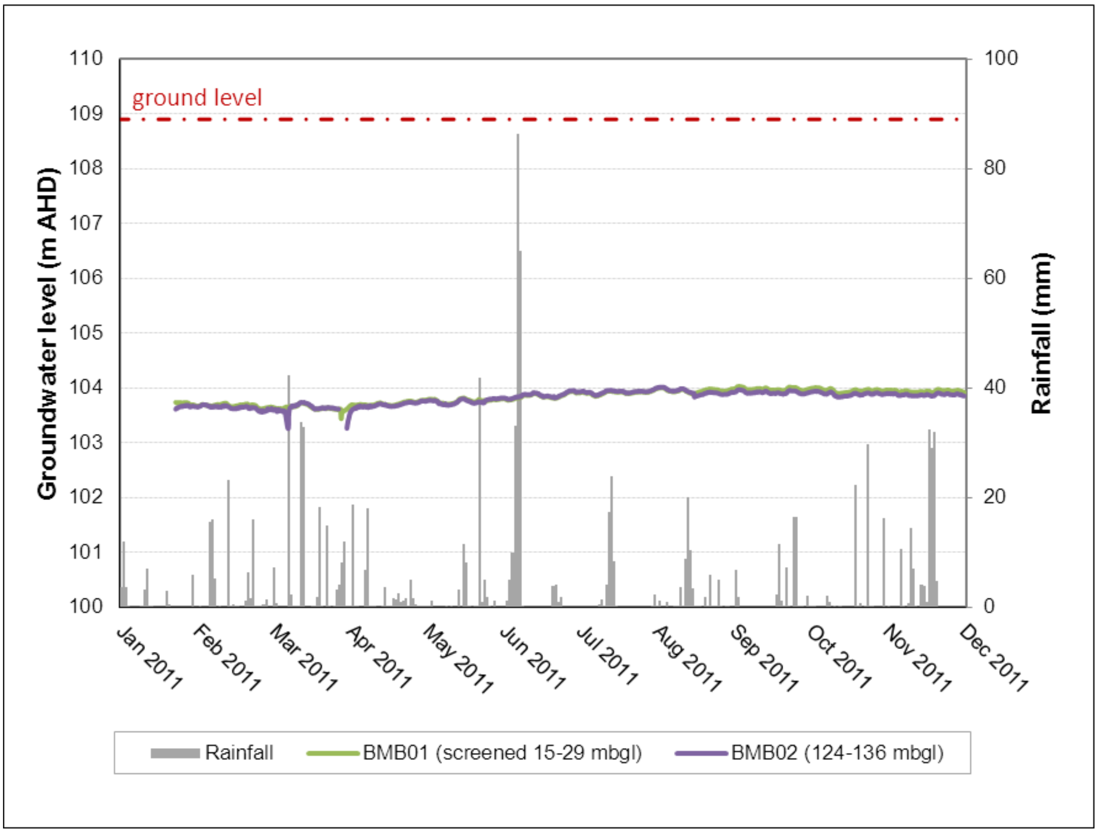


Figure 7-5 Groundwater and rainfall levels at Bignell

7.2.5 Waukivory Road monitoring bores

Groundwater monitoring at the Waukivory Road site indicates a shallow alluvial water table (WMB01, c.108 m AHD) hydraulically isolated from the underlying Bowens Road Coal seam and shallow rock units (c.102 m AHD) (Figure 7-6). The head gradient between the water level of the alluvial aquifer and the potentiometric surface of the deeper water bearing zones indicates an elevated alluvial aquifer with a potential for downward leakage (although these bores are located 950 m apart).

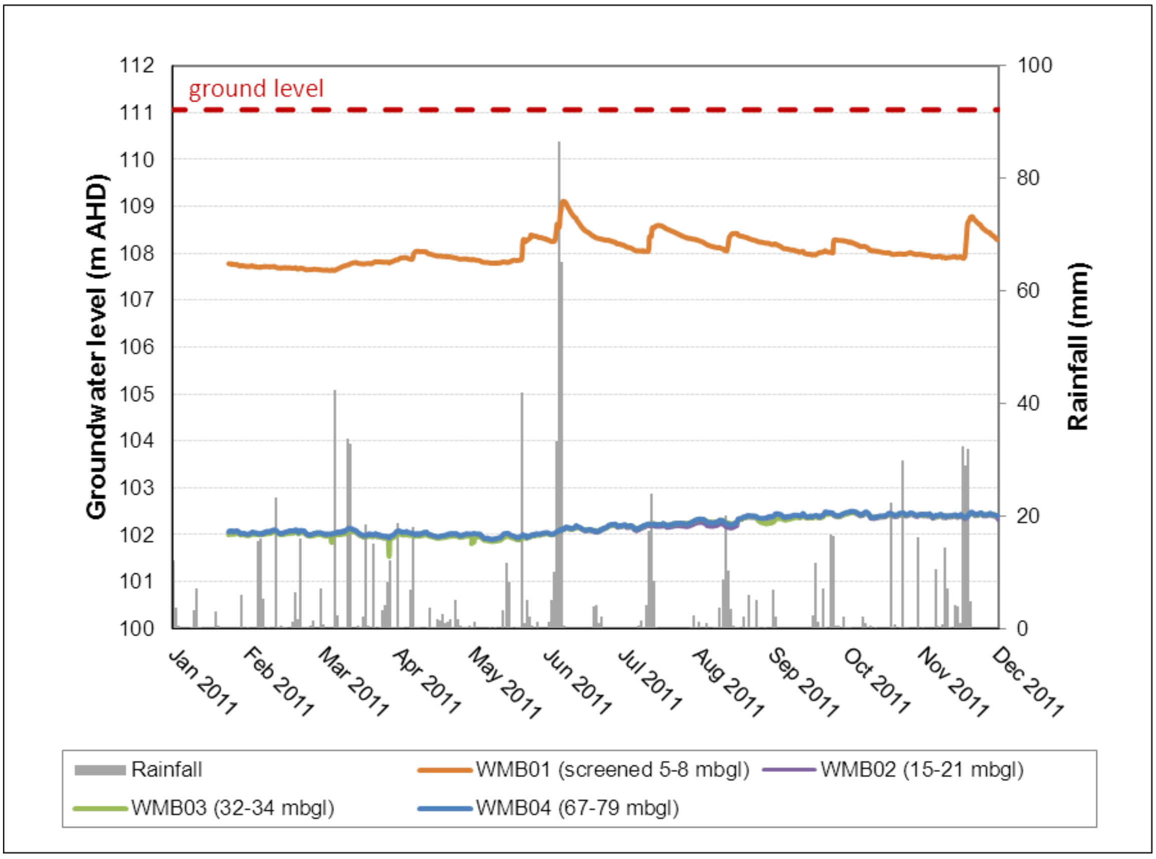


Figure 7-6 Groundwater levels at the Waukivory Road site

7.2.6 Rombo monitoring bores

Groundwater levels from the monitoring bores within the shallow rock units at the Rombo site indicate two hydraulically isolated water bearing zones (Figure 7-7). The potentiometric surface of the deeper rock aquifer (RMB02, c. 125.4 m AHD) is higher than the water level of the shallower rock aquifer (RMB01, c. 125 m AHD) indicating an upward vertical gradient and a potential for upwards leakage. Both hydrographs show minimal impact of rainfall recharge, however there is a distinct rising trend over the last 6 months and the water level fluctuations are comparable.

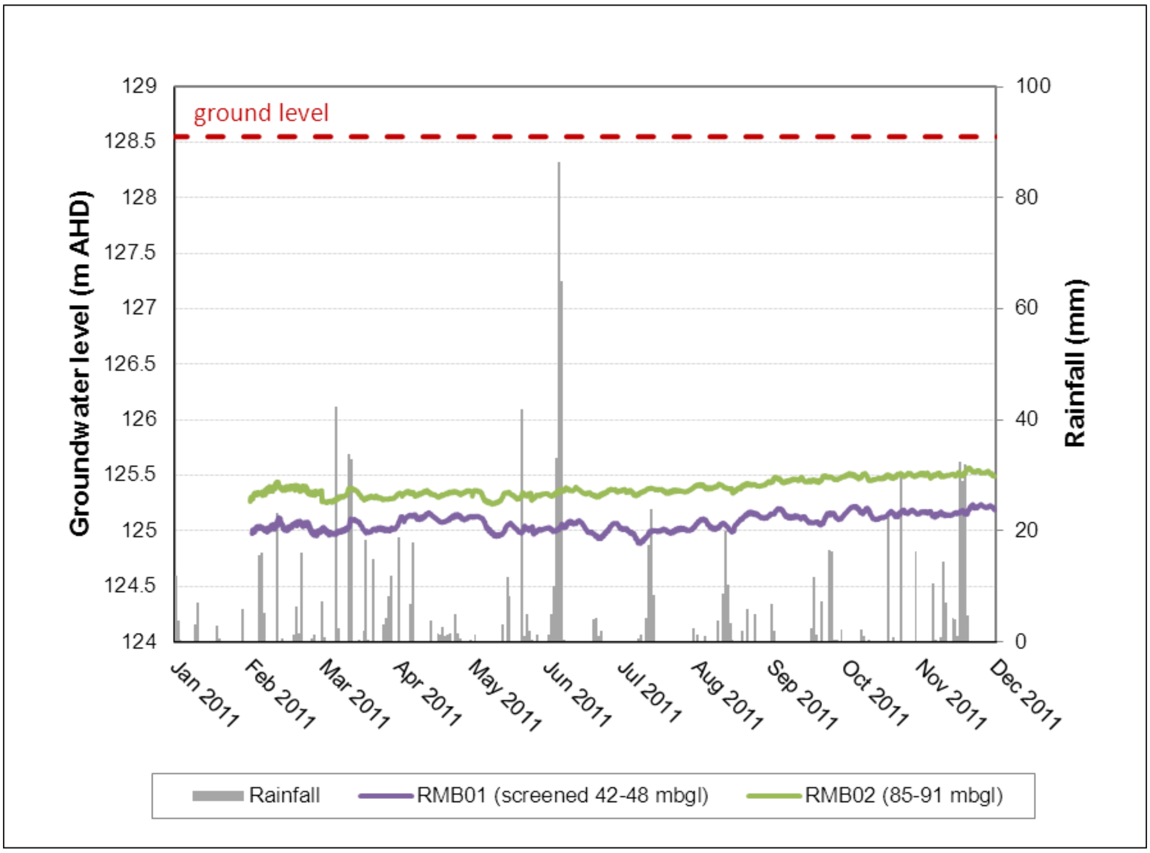


Figure 7-7 Groundwater levels at the Rombo site

7.3 Fault zone effects

Groundwater levels in different strata at the S4MB and S5MB monitoring bores do not provide any clear evidence to determine whether the high-angle oblique thrust fault trending north-south between the two locations is a conduit for groundwater or an impediment for groundwater flow. Due to these uncertainties it is recommended that a specific study be undertaken to further investigate potential fault zone effects between these locations. The proposed works include:

- Surface geophysical survey to map the fault zone in the shallow subsurface
- Drilling of one test production bore to target the fault
- Drilling of two test monitoring bores; one along the strike of the fault, and one perpendicular to the strike

- 72 hour duration pumping test (and associated recovery) whilst monitoring groundwater levels in the new monitoring bores as well as the S4MB, S5MB and TCMB bores
- Geochemical parameters be recorded during the test, and water should be sampled regularly for laboratory analyses (chemical composition and isotope characteristics).

This investigation will determine whether this type of fault is open or closed, will provide permeability data to compare with the adjacent (non-fractured) bedrock, will determine the shape of the drawdown cone (and whether groundwater flow is towards or contained within the fault), and will provide an insight into the source of the groundwater, water migration and connectivity with deeper water bearing zones. This investigation program has already commenced and will be reported in early 2012.

7.4 Baseline surface water level monitoring

Initial baseline surface water levels from the three Avon River stream gauges are shown in Figure 7-8. All three show sharp increases in level in response to rainfall and flooding, and a slight decrease in level during the dry period from April to late May 2011.

Groundwater/surface interactions are discussed in detail in Section 10.

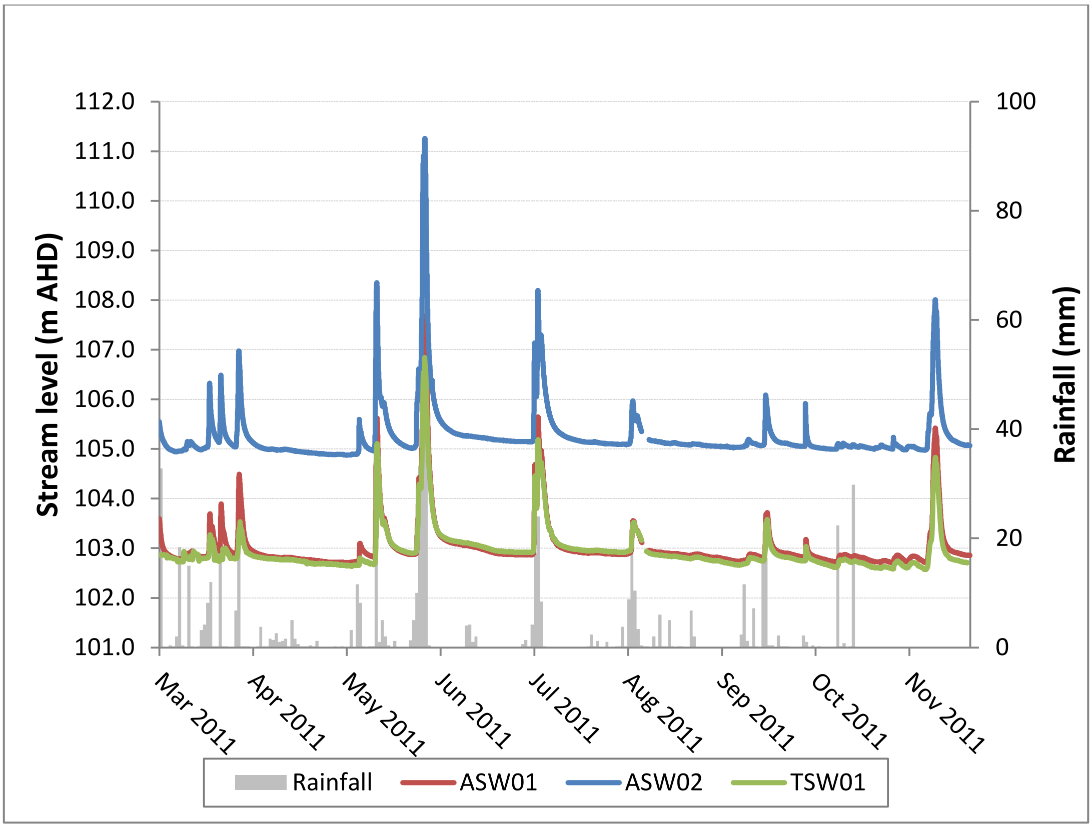


Figure 7-8 Surface water levels from the Avon River stream gauges

8. Water quality monitoring

This chapter presents the baseline water quality monitoring results from the entire groundwater monitoring network (including the seepage monitoring sites), all the Avon River monitoring locations, and all the produced water holding dams. Only one monitoring round was completed as part of this study.

All results have been compared against the ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers) because the rivers are the ultimate receiving waters for both surface water runoff and groundwater discharge. However, these water guidelines are often naturally exceeded in catchments with rocks deposited in marine environments, hence they are only guidelines and not strict criteria that should be used to evaluate individual results. This is the case for the Avon River catchment which is contains shallow marine and estuarine sedimentary rocks and is a known saline catchment. Water quality results for the holding dams have also been compared to the ANZECC (2000) guidelines for Primary Industries (Irrigation) as water from these dams will be used for irrigation.

8.1 Groundwater quality

All 24 monitoring bores were sampled in April 2011, except TCMB02 and TCMB04, which were sampled in May and June 2011 respectively.

Full water quality results are presented in Summary Tables 2 and 3. Major ion chemistry for all groundwater samples is shown on the Piper diagram in Figure 8-1. A Piper diagram is a graphical representation of the chemistry of a water sample and can be used to graphically show the relative concentrations of major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-} and SO_4^{2-}).

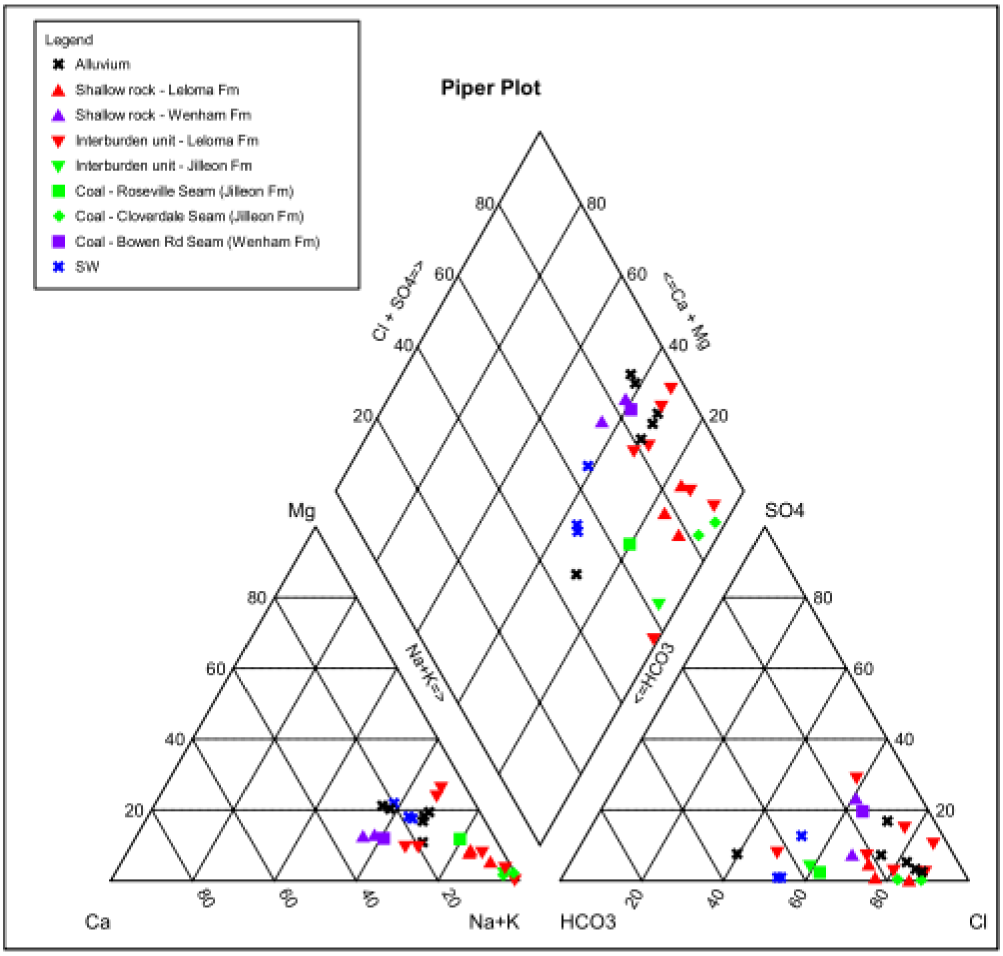


Figure 8-1 Piper diagram showing major ion composition of groundwater and surface water

8.1.1 Alluvial aquifers

8.1.1.1 Chemistry

Monitoring bores screened in the alluvium include the Tiedman monitoring bores (TMB01, TMB02 and TMB03), the Waukivory monitoring bore (WMB01) and Atkins monitoring bores (AMB01 and AMB02).

Water quality results for the alluvial monitoring bores are summarised and compared to the ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers) in Table 8-1. Full water quality results are provided in Summary Tables 2 and 3. Major ion chemistry is shown in the Piper diagram in Figure 8-1 and on the cross-section in Figure 8-2.

Table 8-1 Water quality summary – alluvial aquifers

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[C]
Water Quality parameters				
Field EC	µS/cm	125-2,200[b]	387-**5,810**	**3,046**
Field pH	pH units	6.5 – 8.0[b]	**6.13**-6.93	**6.48**

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[C]
Major ions				
Calcium	mg/L		14-184	112
Magnesium	mg/L		5-169	80
Sodium	mg/L		61-1,130	531
Potassium	mg/L		1-5	3
Chloride	mg/L		54-2,140	1,012
Sulphate	mg/L		14-198	110
Total alkalinity as $CaCO_3$	mg/L		102-508	255
Metals				
Aluminium	mg/L	0.055 (pH>6.5)	<0.01	<0.01
Arsenic	mg/L	0.013 (AsV), 0.024 (AsIII)	0.001-0.005	0.003
Barium	mg/L	-	0.066-0.58	0.287
Beryllium	mg/L	ID	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001-0.0002	0.0002
Copper	mg/L	0.0014	0.001-**0.002**	**0.002**
Lead	mg/L	0.0034	<0.001	<0.001
Manganese	mg/L	1.9	0.17-**3.5**	1.3
Molybdenum	mg/L	ID	<0.001-0.001	<0.001
Nickel	mg/L	0.011	0.001-0.009	0.004
Selenium	mg/L	0.011 (total)	<0.001	<0.001
Strontium	mg/L	-	0.235-4.85	2.372
Uranium	mg/L	ID	<0.001-0.015	0.004
Vanadium	mg/L	ID	<0.001	<0.001
Zinc	mg/L	0.008	**0.014-0.036**	**0.022**
Iron	mg/L	ID	0.24-6.05	2.37
Bromine	mg/L	ID	0.3-3.7	1.8
Nutrients				
Nitrite as N		0.02[b]	<0.01	<0.01
Nitrate as N		0.7	<0.01	<0.01
Ammonia as N	mg/L	0.02[b]	**0.04-0.26**	**0.14**
Total Phosphorus as P	mg/L	0.05[b]	**0.06-0.28**	**0.14**
Reactive Phosphorus as P	mg/L	0.02[b]	**0.02-0.05**	**0.03**
Total Organic Carbon	mg/L		3-5	4
Gases				
Methane	µg/L	-	<10-19	10
Phenolic compounds	µg/L		nd	nd
Polycyclic aromatic hydrocarbons[c]	µg/L		nd	nd

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[C]
Monocyclic aromatic hydrocarbons	µg/L			
Benzene	µg/L	950	<1	<1
Toluene	µg/L	ID	<5	<5
Ethyl Benzene	µg/L	ID	<2	<2
m&p-Xylenes	µg/L	ID	<2	<2
o-Xylenes	µg/L	350	<2	<2
Total Petroleum hydrocarbons				
C_6-C_9	µg/L	-	<20	<20
C_{10}-C_{14}	µg/L	-	<50	<50
C_{15}-C_{29}	µg/L	-	<100-250	127
C_{29}-C_{36}	µg/L	-	<50-280	196

[a] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).

[b] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.

[c] To calculate the average, values below detection limit are included in the calculation as half the LOR.

'ID' indicates insufficient data for trigger value to be established.

BOLD indicates a value outside of the ANZECC (2000) guideline trigger values.

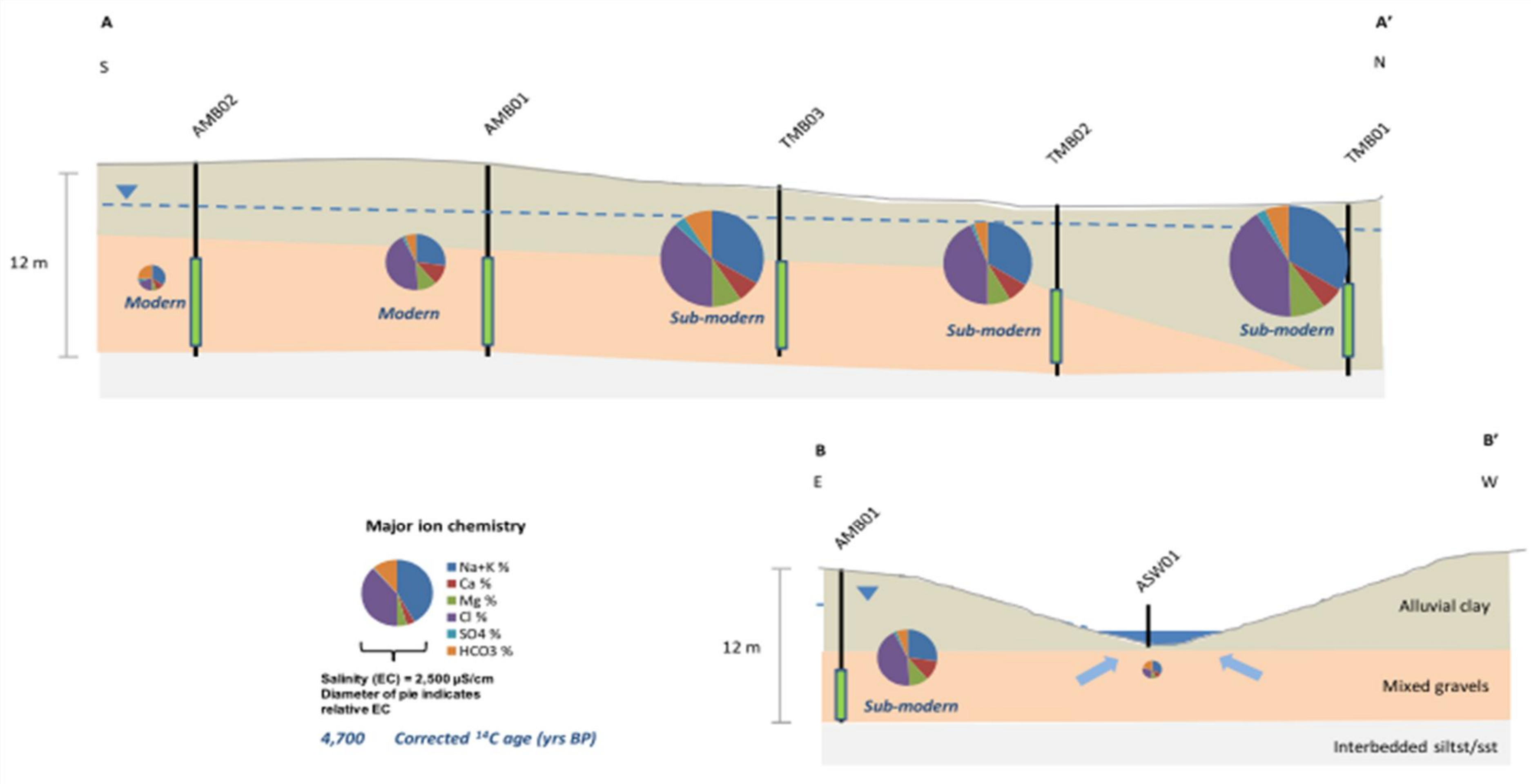


Figure 8-2 Cross-section showing major ion chemistry and age of alluvial aquifers

Alluvial groundwater salinity is typically brackish (<4,800 µS/cm), however fresh water quality is observed at AMB02 (387 µS/cm). Electrical conductivity (EC) values are generally above the ANZECC (2000) guideline values for lowland rivers in south-east Australia (125 - 2,200 µS/cm). TMB01 has the highest recorded EC in the alluvial monitoring bores; and this is likely due to the screened lithology of clays at TMB01. In general, the higher salinities within the alluvial aquifers are due to the high clay content which impedes vertical rainfall recharge (as seen in the hydrographs in Section 6). Each of the monitoring bores is also located close to the eastern edge of the alluvial flats and could therefore be influenced by saline seeps from the underlying bedrock.

The pH conditions in alluvial monitoring bores range from slightly acidic (pH 6.13) to neutral (pH 6.93), and generally within the ANZECC (2000) guideline values for lowland rivers in south-east Australia (pH 6.5-8.0).

Redox values range from -141 mV (TMB01) to +26 mV (AMB02) in the alluvial monitoring bores, with values generally <0 mV. Dissolved oxygen concentrations are low ranging from 11% saturation (TMB02) to 21% saturation (AMB02).

Generally, the major ion chemistry within the alluvial aquifers is dominated by sodium (Na^+) and chloride (Cl^-), with increasing calcium (Ca^{2+}) dominance at AMB01 and WMB01, and elevated bicarbonate (HCO_3^-) at AMB02. The dominance of sodium (Na^+) and chloride (Cl^-) reflects the high clay content of the alluvium within the vicinity of the Tiedman and Atkins sites and rainfall recharge.

The major findings of dissolved metal analysis for alluvial monitoring bores are as follows:

- Strontium, barium and iron concentrations are elevated.
- Zinc concentrations are above the ANZECC (2000) guideline (0.008 mg/L) for all locations.
- Copper concentrations are above the ANZECC (2000) guideline (0.0014 mg/L) for all locations, except TMB01 and TMB02.
- Manganese concentrations are elevated in all bores, but are only above the ANZECC (2000) guideline (1.9 mg/L) at AMB01 (3.5 mg/L).

Concentrations of these metals are not unexpected, given the brackish salinities and clayey nature of the Avon River alluvium, and the variety of sedimentary rocks across the catchment. The concentrations are natural and are just above the respective guideline values.

Nutrient concentrations (ammonia as N, total phosphorus as P and reactive phosphorus as P) are slightly elevated at the alluvial monitoring bores. Ammonia and total phosphorus exceed the ANZECC (2000) guidelines (0.02 mg/L and 0.05 mg/L respectively) at all alluvial monitoring bores. Reactive phosphorus concentrations exceeded the ANZECC (2000) guideline (0.02 mg/L) at TMB02 and TMB03. Nitrate and nitrite concentrations are not detected. Total organic carbon concentrations are low in the alluvial monitoring bores, ranging from the LOR (<1 mg/L) to 5 mg/L (TMB01).

Dissolved methane concentrations are less than the laboratory limit of reporting (LOR) (<10 µg/L) for all alluvial monitoring bores, except at TMB02, which had a methane concentration of 19 µg/L.

Concentrations of total petroleum hydrocarbons (TPH) are detected at three of the alluvial monitoring bores: TMB02, TMB03 and WMB01. TPH concentrations for these three bores ranged from 160 - 250 µg/L for C_{15}-C_{28} fraction and 100 - 280 µg/L for C_{29}- C_{36} fraction.

BTEX, phenolic compounds and polycyclic aromatic hydrocarbons are not detected (i.e. are less than the LOR) at the alluvial monitoring bores.

8.1.1.2 Isotopes

The isotope results ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $a^{14}C$ and ^{14}C age) for alluvial monitoring bores are summarised in Table 8-2 and full results are provided in Summary Table 3.

Table 8-2 Isotope summary – alluvial aquifers

Parameters	Units	Minimum	Maximum	Average
Oxygen-18 ($\delta^{18}O$)	‰	-4.90	-3.49	-4.45
Deuterium ($\delta^{2}H$)	‰	-26.3	-17.0	-23.4
Carbon-13	‰	-15.6	-12.2	-13.4
$a^{14}C$	pMC	71.84	102.18	85.58
Uncorrected ^{14}C age	yrs BP	modern	2,598	1,350
Corrected ^{14}C age	yrs BP	modern	submodern	submodern
Tritium	TU	0.03*	0.88	0.376

*This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefore has an unacceptable level of uncertainty. Hence the data should only be used as an indicator of true concentration.

The stable isotope values of alluvial water samples range from -26.3‰ (AMB02) to -17.0‰ (AMB01) for $\delta^{2}H$, and from -4.90‰ (AMB02) to -3.49‰ (AMB01) for $\delta^{18}O$. The stable isotope values for alluvial groundwater samples are compared to the Global Meteoric Water Line (GMWL) ($\delta^{2}H‰ = 8.13\ \delta^{18}O + 10.8$) (Rozanski et al., 1993) and Local Meteoric Water Line for Brisbane ($\delta^{2}H‰ = 7.7\delta^{18}O + 12.6$) on the plot of $\delta^{2}H$ vs. $\delta^{18}O$ in Figure 8-3. The alluvial groundwater samples plot on or close to the meteoric water lines, indicating all alluvial water samples are of meteoric (rainfall) origin.

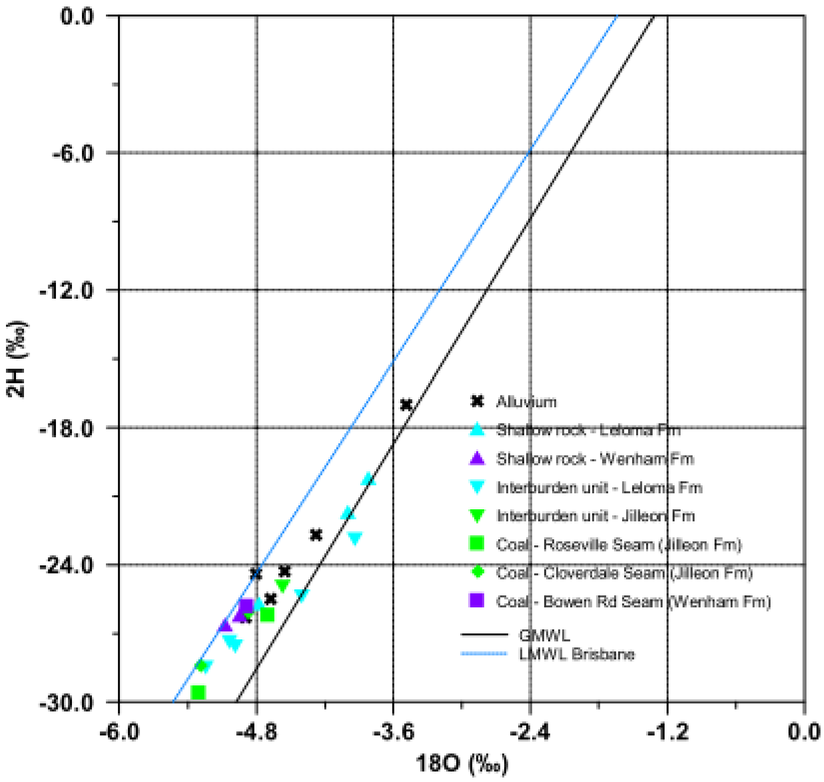


Figure 8-3 A bivariate plot of δ^2H vs. δ^{18}O for groundwater samples

Carbon-14 activities (a^{14}C) for alluvial monitoring bores range from 71.84±0.25 pMC (TMB02) to 102.18±0.29 pMC (AMB02). A a^{14}C > 100 pMC implies that the alluvium (in the vicinity of AMB02) contains a component of modern water recharged during or since the atmospheric nuclear tests in the 1950s. The ^{14}C activities correspond to apparent (uncorrected) ages ranging from modern (<50 yrs BP) (AMB01) to 2,598±30 (TMB02). Three correction models are applied (Fontes-Garnier (1979); Tamers (1975) and Ingerson and Pearson (1964)) to apparent radiocarbon data to account for potential dilution of ^{14}C signature by incorporation of inactive carbon. The three models showed good agreement for corrected radiocarbon ages. The corrected groundwater ages range from modern (AMB01 and AMB02) to submodern (>50 to <1,000 yrs BP) (TMB01, TMB02, TMB03, and WMB01).

Tritium values range from 0.03±0.03 TU (TMB01) to 0.88±0.06 TU (AMB02) and TMB03 are below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) in monitoring bores TMB01, TMB02 and TMB03 confirming that groundwater at these monitoring locations are submodern. Tritium values at AMB01 and AMB02 are above the MDA confirming that at these locations shallow groundwater is modern.

8.1.2 Shallow rock aquifers

8.1.2.1 Chemistry

Monitoring bores screened in the shallow rock aquifers include the Rombo monitoring bores (RMB01 and RMB02) (Leloma Formation), the Waukivory monitoring bores (WMB02 and WMB04) (Wenham Formation), and the Bignell monitoring bore BMB01 (Leloma Formation).

Water quality results for the shallow rock monitoring bores are summarised and compared to the ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers; Table 8-3). Full water quality results are provided in Summary Tables 2 and 3. Major ion chemistry is shown on the cross-sections in Figures 8-4 and 8-5, and the Piper diagram in Figure 8-1.

Table 8-3 Water quality summary – rock aquifers

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Water Quality parameters				
Field EC	µS/cm	125-2,200[b]	**3,867-9,371**	**6,236**
Field pH	pH units	6.5 – 8.0[b]	6.62-7.49	7.01
Major ions				
Calcium	mg/L		59-295	167
Magnesium	mg/L		40-100	58
Sodium	mg/L		462-1,990	911
Potassium	mg/L		4-13	8
Chloride	mg/L		933-3,240	1,386
Sulphate	mg/L		5-591	240
Total alkalinity as $CaCO_3$	mg/L		420-1,040	593
Metals[c]				
Aluminium	mg/L	0.055 (pH>6.5)	<0.01-0.02	0.011
Arsenic	mg/L	0.013 (AsV), 0.024 (AsIII)	<0.001-**0.021**	0.009
Barium	mg/L	-	0.063-17.5	0.347
Beryllium	mg/L	ID	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001-0.0002	0.0001
Copper	mg/L	0.0014	<0.001-**0.006**	0.001
Lead	mg/L	0.0034	<0.001	<0.001
Manganese	mg/L	1.9	0.05-0.382	0.217
Molybdenum	mg/L	ID	<0.001-0.003	0.001
Nickel	mg/L	0.011	<0.001-0.005	0.001
Selenium	mg/L	0.011 (total)	<0.01	<0.01
Strontium	mg/L	-	2.62-16.7	4.82
Uranium	mg/L	ID	<0.001-0.012	0.003
Vanadium	mg/L	ID	<0.01	<0.01
Zinc	mg/L	0.008	0.007-**0.028**	**0.010**
Iron	mg/L	ID	0.07-3.61	1.48
Bromine	mg/L	ID	1.5-8.1	3.00
Nutrients[c]				
Nitrite as N		0.02[b]	<0.01	<0.01
Nitrate as N		0.7	<0.01	<0.01

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Ammonia as N	mg/L	0.02[b]	**0.31-3.08**	**1.2**
Total Phosphorus as P	mg/L	0.05[b]	0.04-**0.11**	**0.068**
Reactive Phosphorus as P	mg/L	0.02[b]	0.01-**0.09**	**0.04**
Total Organic Carbon	mg/L		1-52	14
Gases				
Methane	µg/L	-	49-34,500	140
Phenolic compounds	µg/L		nd	nd
Polycyclic aromatic hydrocarbons	µg/L		nd	nd
Monocyclic aromatic hydrocarbons	µg/L			
Benzene	µg/L	950	<1	<1
Toluene	µg/L	ID	<5-6	<5
Ethyl Benzene	µg/L	ID	<2	<2
m&p-Xylenes	µg/L	ID	<2	<2
o-Xylenes	µg/L	350	<2	<2
Total Petroleum hydrocarbons				
C_6-C_9	µg/L	-	<20	<20
C_{10}-C_{14}	µg/L	-	<50	<50
C_{15}-C_{29}	µg/L	-	<100-240	172
C_{29}-C_{36}	µg/L	-	<50-200	124

[a] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).
[b] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.
[c] To calculate the average, values below detection limit are included in the calculation as half the LOR.
'ID' indicates insufficient data for trigger value to be established.
BOLD indicates a value outside of the ANZECC (2000) guideline trigger values. nd – not detected above LOR

Groundwater salinity in the shallow rock aquifers is typically brackish (<4,800 µS/cm) to slightly saline (<10,000 µS/cm), with the field EC values ranging from 3,867-9,371 µS/cm. The EC values in all rock aquifer monitoring bores are above the ANZECC (2000) guideline values for lowland rivers in south-east Australia (125-2,200 µS/cm). Elevated salt concentrations are natural for these sedimentary rocks. Groundwater salinity at the Bignell site is lower than southern (Rombo) and northern (Waukivory) monitoring sites.

The pH conditions in the shallow rock aquifers are circum-neutral, with pH values ranging from 6.62-7.49. The pH values are within ANZECC (2000) guideline values for lowland rivers in south-east Australia (pH 6.5-8.0).

Redox values (-251 to -47 mV) indicate reducing conditions occur within the shallow rock aquifers. Dissolved oxygen concentrations are low ranging from 13.1% saturation to 27.5% saturation.

The major ion chemistry in the shallow rock aquifers is generally dominated by sodium (Na^+), chloride (Cl^-) and bicarbonate (HCO_3^-), with increasing calcium (Ca^{2+}) dominance at the Waukivory monitoring bores (WMB02 and WMB04) and RMB01. An increasing dominance of sulphate (SO_4^{2-}) is observed at WMB02, where groundwater is characterised as Na-Ca-Cl-SO_4 type water.

The major findings of dissolved metal analysis for shallow rock monitoring bores are as follows:

- Arsenic concentrations are elevated in the majority of bores, with concentrations in RMB02 (0.021 mg/L) exceeding the ANZECC (2000) guideline value.
- Barium and strontium concentrations are elevated in all bores, with the highest values of strontium (16.7 mg/L) and barium (17.5 mg/L) detected at the southern site (Rombo – RMB01).
- Manganese concentrations are elevated at all bores (0.050 – 0.382 mg/L), but do not exceed ANZECC (2000) guidelines.
- Iron concentrations are elevated at all bores, with the highest concentrations occurring at the northern site (Waukivory) (1.48 mg/L).
- Copper concentrations are elevated at the southern site (Rombo – RMB01), and are above the ANZECC (2000) guideline value.
- Zinc concentrations are elevated above the ANZECC (2000) guideline value in the southern and northern bores (Rombo and Waukivory). Zinc concentrations in the central site (BMB01) are less than the LOR.
- Bromine concentrations are highest at the southern site, with concentrations of 8.1 mg/L and 4.9 mg/L in RMB01 and RMB02, respectively.

These concentrations are natural and are not considered unusual for these types of sedimentary rocks.

Ammonia concentrations are above the ANZECC (2000) guideline value in all monitoring bores, with the highest concentrations occurring in the southern (Rombo) monitoring bores (3.08 mg/L in RMB01 and 1.74 mg/L in RMB02). Total and reactive phosphorus concentrations are elevated above ANZECC (2000) guideline values at the southern and northern monitoring sites (Rombo and Waukivory), with the highest concentrations occurring in the Rombo monitoring bores. Total organic carbon concentrations are also detected in the Rombo monitoring bores, with concentrations of 10 mg/L and 52 mg/L detected in RMB01 and RMB02, respectively.

Dissolved methane concentrations are generally low in the shallow rock monitoring bores (<200 µg/L), with the exception of RMB01 (34,500 µg/L).

Phenolic compounds and PAHs are not detected in any monitoring bores. Toluene is detected at concentrations just above the LOR (6 µg/L) in RMB02. Low concentrations (<240 µg/L) of TPH (C_{15} – C_{36}) are detected in the Waukivory monitoring bores (WMB02 and WMB04), and BMB01. Hydrocarbons in these types of formations can be naturally occurring (Volk et al., 2011) and these concentrations of hydrocarbons are not considered unusual for these types of sedimentary rocks based on early works in the Gloucester Basin by Thornton (1982) and Hunt et al. (1983).

8.1.2.2 Isotopes

The isotope results ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $a^{14}C$ and ^{14}C age) for the shallow rock aquifer monitoring bores are summarised in Table 8-4 and full results are provided in Summary Table 3.

Table 8-4 Isotope summary – shallow rock aquifers

Parameters	Units	Minimum	Maximum	Average
Oxygen-18 ($\delta^{18}O$)	‰	-5.08	-3.82	-4.53
Deuterium ($\delta^{2}H$)	‰	-26.6	-20.2	-24.1
Carbon-13	‰	-16.5	-1.9	-10.0
$a^{14}C$	pMC	5.51	39.12	21.95
Uncorrected ^{14}C age	yrs BP	7,479	23,232	14,616
Corrected ^{14}C age	yrs BP	4,300	19,600	12,000
Tritium	TU	0.03*	0.39	0.11*

*This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefore has an unacceptable level of uncertainty. Hence the data should only be used as an indicator of true concentration.

The stable isotope values of shallow rock aquifers range from -26.6‰ (WMB04) to -20.2‰ (BMB01) for $\delta^{2}H$, and from -5.08‰ (WMB04) to -3.82‰ (BMB01) for $\delta^{18}O$. The stable isotope values for shallow rock monitoring bores are compared to the GMWL and LMWL on the plot of $\delta^{2}H$ vs. $\delta^{18}O$ in Figure 8-3. The isotopic signatures of monitoring bores BMB01 and RMB02 are the most enriched of all the shallow rock monitoring bores, and samples from these bores plot on the GMWL. Samples from the Waukivory shallow rock monitoring bores (WMB02 and WMB04) have isotopic signatures that plot close to the LMWL and are similar to the isotopic signature of groundwater from the Bowen Road Coal Seam at the Waukivory site (WMB03). The isotopic signature of RMB01 is more depleted than RMB02.

Carbon-14 activities ($a^{14}C$) for shallow rock monitoring bores range from 5.51±0.07 pMC (WMB04) to 39.12±0.13 pMC (BMB01). These ^{14}C activities correspond to apparent (uncorrected) ages ranging from 7,555±30 yrs BP (WMB02) to 23,232±95 yrs BP (WMB04). Radiocarbon ages are corrected to account for the potential dilution of the ^{14}C signature by incorporation of old carbon into groundwater from processes such as dissolution of carbonate minerals and production of methane. Several methods are used to account for carbonate dissolution; applied (Fontes-Garnier (1979); Tamers (1975) and Ingerson and Pearson (1964)); and dilution factors for methanogenesis are calculated using the equations cited in Clark and Fritz (1997). The corrected radiocarbon ages ranged from 4,300 yrs BP (WMB02) to 19,600 yrs BP (RMB01).

The corrected radiocarbon ages for the shallow rock aquifers at the Waukivory site showed an increase in age with depth, with monitoring bores WMB02 and WMB04 having corrected ^{14}C ages of 4,300 yrs BP and 19,600 yrs BP, respectively. The Bignell monitoring bore, BMB01, had a similar corrected ^{14}C age as WMB01 at 5,600 yrs BP. At the Rombo monitoring site, an age inversion is evident, with older water occurring in the shallower monitoring bore.

Tritium values range from 0.03±0.03 (RMB01 and BMB01) to 0.39±0.05 (RMB02) and are close to or below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit).

8.1.3 Interburden units

8.1.3.1 Chemistry

Monitoring bores which are screened in the inter-bedded sandstone/siltstone interburden units are all located in the central investigation site (focused on the Tiedman property) and include the Bignell monitoring bore (BMB02), the Stratford 4 monitoring bores (S4BM01 and S4BM02), the Stratford 5 monitoring bores (S5BM01 and S5BM02), and Tiedman core hole site monitoring bore (TCMB02). All these bores are screened within the Leloma Formation.

Water quality results for the interburden monitoring bores are summarised and compared to the ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers; Table 8-5). Full water quality results are provided in Summary Tables 2 and 3. Major ion chemistry is shown on the cross-section in Figures 8-4 and 8-5 and Piper diagram in Figure 8-1.

Table 8-5 Water quality summary – inter-bedded sandstone/siltstone water bearing zones

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Water Quality parameters				
Field EC	µS/cm	125-2,200[b]	**2,395-6,100**	**4,280**
Field pH	pH units	6.5 – 8.0[b]	7.30-**10.15**	7.06
Major ions				
Calcium	mg/L		6-131	54
Magnesium	mg/L		2-60	26
Sodium	mg/L		385-1,140	720
Potassium	mg/L		6-88	24
Chloride	mg/L		570-1,160	802
Sulphate	mg/L		31-790	198
Total alkalinity as $CaCO_3$	mg/L		204-806	474
Metals[c]				
Aluminium	mg/L	0.055 (pH>6.5)	<0.01-**1.36**	**0.404**
Arsenic	mg/L	0.013 (AsV), 0.024 (AsIII)	0.002-**0.018**	0.006
Barium	mg/L	-	0.099-1.79	0.75
Beryllium	mg/L	ID	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001-**0.881**	**0.147**
Copper	mg/L	0.0014	<0.001-0.0002	**0.0002**
Lead	mg/L	0.0034	<0.001-0.004	0.0014
Manganese	mg/L	1.9	0.046-0.32	0.182
Molybdenum	mg/L	ID	0.003-0.035	0.012
Nickel	mg/L	0.011	0.004-**0.016**	0.008
Selenium	mg/L	0.011 (total)	<0.001	<0.001

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Strontium	mg/L	-	0.931-10.8	5.284
Uranium	mg/L	ID	<0.001-0.042	0.009
Vanadium	mg/L	ID	<0.001	<0.001
Zinc	mg/L	0.008	0.007-**0.046**	**0.022**
Iron	mg/L	ID	<0.05-3.38	1.17
Bromine	mg/L	ID	0.8-3.3	1.67
Nutrients[c]				
Nitrite as N		0.02[b]	<0.01-0.04	0.011
Nitrate as N		0.7	<0.01-0.01	0.01
Ammonia as N	mg/L	0.02[b]	**0.36-10.3**	**2.89**
Total Phosphorus as P	mg/L	0.05[b]	0.01-**0.44**	**0.17**
Reactive Phosphorus as P	mg/L	0.02[b]	0.01-**0.14**	**0.06**
Total Organic Carbon	mg/L		5-98	39
Gases				
Methane	µg/L	-	3,720-31,800	12,786
Phenolic compounds	µg/L			
Phenol	µg/L		<1.0-6.4	nc
Polycyclic aromatic hydrocarbons	µg/L		nd	nd
Monocyclic aromatic hydrocarbons	µg/L			
Benzene	µg/L	950	<1-3	<1
Toluene	µg/L	ID	<5-9	<5
Ethyl Benzene	µg/L	ID	<2	<2
m&p-Xylenes	µg/L	ID	<2	<2
o-Xylenes	µg/L	350	<2	<2
Total Petroleum hydrocarbons				
C_6-C_9	µg/L	-	<20	<20
C_{10}-C_{14}	µg/L	-	<50	<50
C_{15}-C_{29}	µg/L	-	<100-540	210
C_{29}-C_{36}	µg/L	-	<50-160	67

[a] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).
[b] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.
[c] To calculate the average, values below detection limit are included in the calculation as half the LOR.
BOLD indicates a value outside of the ANZECC (2000) guideline trigger values.
nd – not detected above LOR

Groundwater salinity in the interburden water bearing zones is typically brackish (<4,800 µS/cm) to slightly saline (<10,000 µS/cm), with the field EC values ranging from 2,395-6,100 µS/cm. The EC values in all monitoring bores are above the ANZECC (2000) guideline values for lowland rivers in south-east Australia (125-2,200 µS/cm). The highest salinity occurred at the Stratford 5 shallow monitoring bore, S5MB01.

The pH values range from near-neutral (pH 7.3) to alkaline (pH 10.15), with the highest pH occurring at TCMB02. The pH values at BMB02, S5MB01 and TCMB02 are above the ANZECC (2000) pH criteria.

Redox values range from -362 to -202 mV, indicating reducing conditions are present in all monitoring bores.

Major ion compositions in monitoring bores typically varied from Na-Cl to Na-Cl-HCO_3, with increasing dominance of calcium (Ca^{2+}) at S4BM01, and sulphate (SO_4^{2-}) at S5MB01.

The major findings of dissolved metal analysis for interburden monitoring bores are as follows:

- Elevated concentrations of aluminium (above ANZECC (2000) guidelines) are detected in some bores.
- Arsenic was detected at a concentration above the ANZECC (2000) guideline at S5MB01.
- Elevated concentrations of barium and strontium occurr in all bores with the highest concentrations occurring in S4MB02 for barium (1.79 mg/L) and S4MB01 for strontium (10.8 mg/L).
- Elevated cadmium concentrations are detected in S5MB01 (0.881 mg/L); and concentrations are above ANZECC (2000) guidelines in 50% of bores.
- Manganese concentrations are elevated in all bores but did not exceed the ANZECC (2000) guideline values. The highest concentration was detected in S4MB01 (0.320 mg/L).
- Zinc and nickel concentrations are elevated and are above ANZECC (2000) guideline values in some bores.
- Elevated iron concentrations occur in most bores, with the highest concentration of 3.3 mg/L in S5MB01.

The concentrations are natural and are not considered unusual for these types of sedimentary rocks.

Ammonia concentrations are above the ANZECC (2000) guideline values in all monitoring bores. The highest concentration of ammonia (10.3 mg/L) occurs at TCMB02 (highest of all bores). Total and reactive phosphorus concentrations are also elevated above ANZECC (2000) guideline values in the majority of bores. Total organic carbon concentrations vary between 5 and 98 mg/L.

Dissolved methane was not detected in S5MB01, but is detected in the other monitoring bores, ranging from 3,720 µg/L (S4MB01) to 31,800 µg/L (S5MB02).

Phenol is detected in two monitoring bores; TCMB02 (6.4 µg/L) and S5MB01 (1.3 µg/L). Benzene and toluene are detected in S5MB02 at concentrations just above LORs (3 µg/L and 9 µg/L, respectively). Toluene is also detected in TCMB02 at a concentration of 9 µg/L. Polycyclic aromatic hydrocarbons (PAHs) are not detected in any monitoring bore. Total petroleum hydrocarbons (TPHs) are detected at low concentrations in the C_{15}-C_{36} fractions in the majority of monitoring bores.

Hydrocarbons in these types of formations can be naturally occurring (Volk et al., 2011) and these concentrations of hydrocarbons are not considered unusual for these types of sedimentary rocks based on early works in the Gloucester Basin by Thornton (1982) and Hunt et al. (1983).

8.1.3.2 Isotopes

The isotope results ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $a^{14}C$ and ^{14}C age) for monitoring bores screened in the interburden water bearing zones are summarised in Table 8-6 and full results are provided in Summary Table 3.

Table 8-6 Isotope summary – interburden units

Parameters	Units	Minimum	Maximum	Average
Oxygen-18 ($\delta^{18}O$)	‰	-5.25	-3.94	-4.70
Deuterium ($\delta^{2}H$)	‰	-28.4	-22.8	-26.0
Carbon-13	‰	-31.8	-4.4	-16.5
$a^{14}C$	pMC	4.36	53.24	26.94
Uncorrected ^{14}C age	yrs BP	5,004	25,110	12,451
Corrected ^{14}C age	yrs BP	4,700	19,200	10,500
Tritium	TU	0.04*	0.29	0.12*

*This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefore has an unacceptable level of uncertainty. Hence the data should only be used as an indicator of true concentration.

The stable isotope values of the interburden monitoring bores range from -28.4‰ (S4MB02) to -22.8‰ (S5MB01) for $\delta^{2}H$, and from -5.25‰ (S4MB02) to -3.94‰ (S5MB01) for $\delta^{18}O$. The stable isotope values for interburden monitoring bores are compared to the GMWL and LMWL on the plot of $\delta^{2}H$ vs. $\delta^{18}O$ in Figure 8-3. Monitoring bores plot on or close to the meteoric water lines, indicating all alluvial water samples are of meteoric (rainfall) origin.

Carbon-14 activities ($a^{14}C$) for interburden monitoring bores range from 4.36±0.06 pMC (TCMB02) to 53.24±0.16 pMC (S5MB01). These ^{14}C activities correspond to apparent (uncorrected) ages ranging from 5,004±25 yrs BP (S5MB01) to 25,110±110 yrs BP (TCMB02). The corrected radiocarbon ages ranged from 4,700 yrs BP (S5MB01) to 19,200 yrs BP (TCMB02). Groundwater ages increase with depth at the Stratford 4 and Stratford 5 monitoring locations.

Tritium values range from 0.04±0.04 (S4MB02) to 0.29±0.04 (S5MB01) and are below the the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) for all monitoring bores except S5MB01.

8.1.4 Coal seams

8.1.4.1 Chemistry

Five monitoring bores are screened in coal seams in the Stage 1 GFDA including two into the Cloverdale Coal Seam (S4MB03 and TCMB03), two into the Roseville Coal Seam (S5MB03 and TCMB04), and one into the Bowens Road Coal Seam (WMB03). All monitoring bores, with the exception of WMB03, are located at the central Tiedman site. WMB03 is located at the northern monitoring site (Waukivory).

Water quality results for the coal seam monitoring bores are summarised and compared to the ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers) in Table 8-7. Full water quality results are provided in Summary Tables 2 and 3. Major ion chemistry is shown on the cross-sections in Figures 8-4 and 8-5 and the Piper diagram in Figure 8-1.

Table 8-7 Water quality summary – coal seams

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Water Quality parameters				
Field EC	µS/cm	125-2,200[b]	**3,014-4,999**	**4,012**
Field pH	pH units	6.5 – 8.0[b]	6.76-**11.13**	**8.69**
Major ions				
Calcium	mg/L		2-259	71
Magnesium	mg/L		6-68	34.5
Sodium	mg/L		653-734	693.4
Potassium	mg/L		11-36	15
Chloride	mg/L		678-1,060	867
Sulphate	mg/L		2-436	103
Total alkalinity as $CaCO_3$	mg/L		274-711	481
Metals				
Aluminium	mg/L	0.055 (pH>6.5)	<0.01-**3.87**	**1.09**
Arsenic	mg/L	0.013 (AsV), 0.024 (AsIII)	<0.001-0.004	0.002
Barium	mg/L	-	0.054-1.54	0.672
Beryllium	mg/L	ID	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001-**0.0004**	0.0002
Copper	mg/L	0.0014	<0.001-**0.004**	**0.002**
Lead	mg/L	0.0034	<0.001-0.005	0.001
Manganese	mg/L	1.9	<0.001-0.64	0.22
Molybdenum	mg/L	ID	<0.001-0.006	0.003
Nickel	mg/L	0.011	<0.001-0.157	0.034
Selenium	mg/L	0.011 (total)	<0.001	<0.001
Strontium	mg/L	-	0.125-6.01	2.82
Uranium	mg/L	ID	<0.001-0.005	0.002
Vanadium	mg/L	ID	<0.01	<0.01
Zinc	mg/L	0.008	0.006-**0.33**	**0.089**
Iron	mg/L	ID	0.13-4.99	1.43
Bromine	mg/L	ID	0.9-2.2	1.5
Nutrients				

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Nitrite as N		0.02[b]	<0.01	<0.01
Nitrate as N		0.7	<0.01-0.01	<0.01
Ammonia as N	mg/L	0.02[b]	**0.78-1.56**	**1.20**
Total Phosphorus as P	mg/L	0.05[b]	0.03-**0.2**	**0.11**
Reactive Phosphorus as P	mg/L	0.02[b]	0.02-**0.09**	**0.05**
Total Organic Carbon	mg/L		4-32	17
Gases				
Methane	µg/L	-	655-39,500	21,931
Phenolic compounds	µg/L		nd	nd
Polycyclic aromatic hydrocarbons	µg/L		nd	nd
Monocyclic aromatic hydrocarbons	µg/L			
Benzene	µg/L	950	<1	<1
Toluene	µg/L	ID	<5-31	9
Ethyl Benzene	µg/L	ID	<2	<2
m&p-Xylenes	µg/L	ID	<2	<2
o-Xylenes	µg/L	350	<2	<2
Total Petroleum hydrocarbons				
C_6-C_9	µg/L	-	<20-80	<20
C_{10}-C_{14}	µg/L	-	<50	<50
C_{15}-C_{29}	µg/L	-	<100-140	<100
C_{29}-C_{36}	µg/L	-	<50-100	<50

[a] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).
[b] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.
[c] To calculate the average, values below detection limit are included in the calculation as half the LOR.
'ID' indicates insufficient data for trigger value to be established.
BOLD indicates a value outside of the ANZECC (2000) guideline trigger values.
nd – not detected above LOR

Groundwater salinity in the coal seam water bearing zones is typically brackish (<4,800 µS/cm) to slightly saline (<10,000 µS/cm), with the field EC values ranging from 3,014-4,999 µS/cm. The EC values in all monitoring bores are above the ANZECC (2000) guideline values for lowland rivers in south-east Australia (125-2,200 µS/cm). Salinities increase with depth, with higher EC values occurring in the Roseville Coal Seam than the Cloverdale Coal Seam.

The pH in the Bowens Road Coal Seam (WMB03) is slightly acidic (pH 6.76). The pH values in the Cloverdale and Roseville Coal Seams are slightly alkaline (pH 7.3) to alkaline (pH 11.13). The highest pH values are observed at TCMB03 and TCMB04, and may be indicative of grout influence. However, similarly high pH values have been observed in monitoring bores to the north of the site in the Gloucester Resources exploration area (Parsons Brinckerhoff, 2011) and therefore may be natural.

Redox values are generally negative (-304.3 to -78.1 mV) indicating reducing conditions. The higher redox value at TCMB04 (+78.2 mV) is probably an artefact of sampling (samples are collected using a submersible pump rather than a micro purge^{TM}) at this location and therefore are not truly indicative of the redox conditions within the coal seam.

Major ion chemistry within the Cloverdale Coal Seam is dominated by sodium (Na^+) and chloride (Cl^-) (Na-Cl type water), while within the Roseville Coal Seam, sodium (Na^+), chloride (Cl^-) and bicarbonate (HCO_3^-) are the dominant ions (Na-Cl-HCO_3 type water). Water within the Bowens Road Coal Seam has a greater relative proportion of calcium than the other seams, and can be classified as Na-Ca-Cl type water. Groundwater within the Roseville Coal Seam has low calcium (Ca^{2+}) and magnesium (Mg^{2+}), typical of coal seams where bicarbonate enrichment arising from sulphate reduction drives the inorganic precipitation of calcite and dolomite (as indicated by saturation indices for S5MB03 and TCMB04). Although calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations are low in the Cloverdale Coal Seam, bicarbonate (HCO_3^-) concentrations are lower than the Roseville Coal Seam, and waters remained undersaturated with respect to calcite and dolomite.

The major findings of dissolved metal analysis for coal seam monitoring bores are as follows:

- Aluminium concentrations within the Cloverdale and Roseville coal seams are elevated and are generally above the ANZECC (2000) guideline value.
- Barium and strontium concentrations are elevated in all bores, with the highest strontium concentration occurring in the Bowens Road Coal Seam (WMB03) (6.01 mg/L) and the highest barium concentration occurring in the Cloverdale Coal Seam at S4MB03 (1.54 mg/L).
- Cadmium was slightly above the ANZECC (2000) guideline value in the Cloverdale Seam (0.004 mg/L) and copper was above ANZECC (2000) guideline value in the Roseville Seam (0.004 mg/L).
- Manganese concentrations are slightly elevated in all bores but did not exceed ANZECC (2000) guideline values. The highest concentrations occurred at S5MB03 (0.137 mg/L).
- Zinc concentrations are elevated in all bores, and are above the ANZECC (2000) guideline value in the majority of monitoring sites.
- High iron concentrations (4.99 mg/L) are detected in the Bowens Road Coal Seam (WMB03).

The concentrations are natural and are not considered unusual for Permian coal seams.

Ammonia concentrations are above the ANZECC (2000) guideline value in all coal seams, with the highest concentrations occurring in the Roseville Coal Seam. Reactive and total phosphorus concentrations are above the ANZECC guideline values in the Cloverdale Seam. Total phosphorus concentrations are also above the guideline value in the Bowens Road Coal Seam.

Dissolved methane concentrations are low in the (shallow) Bowens Road Coal Seam (WMB03) (655 µg/L) but higher in the (deep) Cloverdale and Roseville Coal Seams ranging from 12,100 to 39,500 µg/L.

Polycyclic aromatic hydrocarbons (PAHs) are not detected in any coal seams. Phenolic compounds are not detected, with one exception. 2-methylphenol is detected in TCMB03 at a concentration just above the detection limit (1.2 µg/L). Toluene is detected in WMB03 at 31 µg/L and in TCMB03 at 5 µg/L. Total petroleum hydrocarbons (TPH) are detected at low concentrations in the C_6-C_9 fraction, and C_{15}-C_{36} fractions in the Bowens Road Coal Seam (WMB03).

Hydrocarbons in these types of formations can be naturally occurring (Volk et al., 2011) and these concentrations of hydrocarbons are not considered unusual for these types of sedimentary rocks based on early works in the Gloucester Basin by Thornton (1982) and Hunt et al. (1983).

8.1.4.2 Isotopes

The isotope results ($\delta^{18}O$, δ^2H, $\delta^{13}C$, $a^{14}C$ and ^{14}C age) for coal seam monitoring bores are summarised in Table 8-8 and full results are provided in Summary Table 3.

Table 8-8 Isotope summary – coal seams

Parameters	Units	Minimum	Maximum	Average
Oxygen-18 ($\delta^{18}O$)	‰	**-5.31**	**-4.70**	**-5.02**
Deuterium (δ^2H)	‰	-29.6	-25.8	-27.2
Carbon-13	‰	-18.0	-12.0	-14.4
$a^{14}C$	pMC	3.77	30.27	14.27
Uncorrected ^{14}C age	yrs BP	9,541	26,270	17,674
Corrected ^{14}C age	yrs BP	9,300	21,600	13,600
Tritium	TU	0.01*	0.19*	0.06*

*This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefore has an unacceptable level of uncertainty. Hence the data should only be used as an indicator of true concentration.

The stable isotope values of the coal seam monitoring bores range from -29.6‰ (TCMB04) to -25.8‰ (WMB03) for δ^2H, and from -5.31‰ (TCMB04) to -4.70‰ (S5MB03) for $\delta^{18}O$. The stable isotope values for coal seam monitoring bores are compared to the GMWL and LMWL on the plot of δ^2H vs. $\delta^{18}O$ in Figure 8-3. All coal seam samples plot between the GMWL and LMWL, indicating that the water in coal seams is of meteoric origin. However, the spread of results show that even within the same coal seam, there is variability of stable isotope signatures, which is not unexpected given the structural complexity of the area.

Carbon-14 activities ($a^{14}C$) for coal seam monitoring bores ranged from 3.77±0.06 pMC (TCMB03) to 30.27±0.11 pMC (S5MB03). These ^{14}C activities correspond to apparent (uncorrected) ages ranging from 9,541±30 yrs BP (S5MB03) to 26,270±130 yrs BP (TCMB03). Corrected ages range from 9,300 yrs BP to 21,600 yrs BP. Since methanogenesis in these coal seams is primarily by CO_2 reduction, only a small change in corrected age is observed in those bores where methanogenesis is the primary process affecting DIC (Saliege and Fontes 1984).

Tritium was not analysed for TCMB04. Tritium values for the other monitoring bores range from 0.01±0.04 (S4MB03 and TCMB03) to 0.19±0.05 (WMB03) and are below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit).

8.2 Aquifer and deeper water bearing zone interactions

Baseline groundwater chemistry and isotope sampling from the nested monitoring bore sites provides information on major ion, trace metal chemistry, stable isotope composition and water residence times of the various aquifers, interburden units and coal seams, and the potential for linkages between these various units. Major findings for each site are discussed in the following sections. Groundwater major ion chemistry and ages are summarised for two cross-sections (east-west and north-south) in Figures 8-4 and 8-5 respectively.

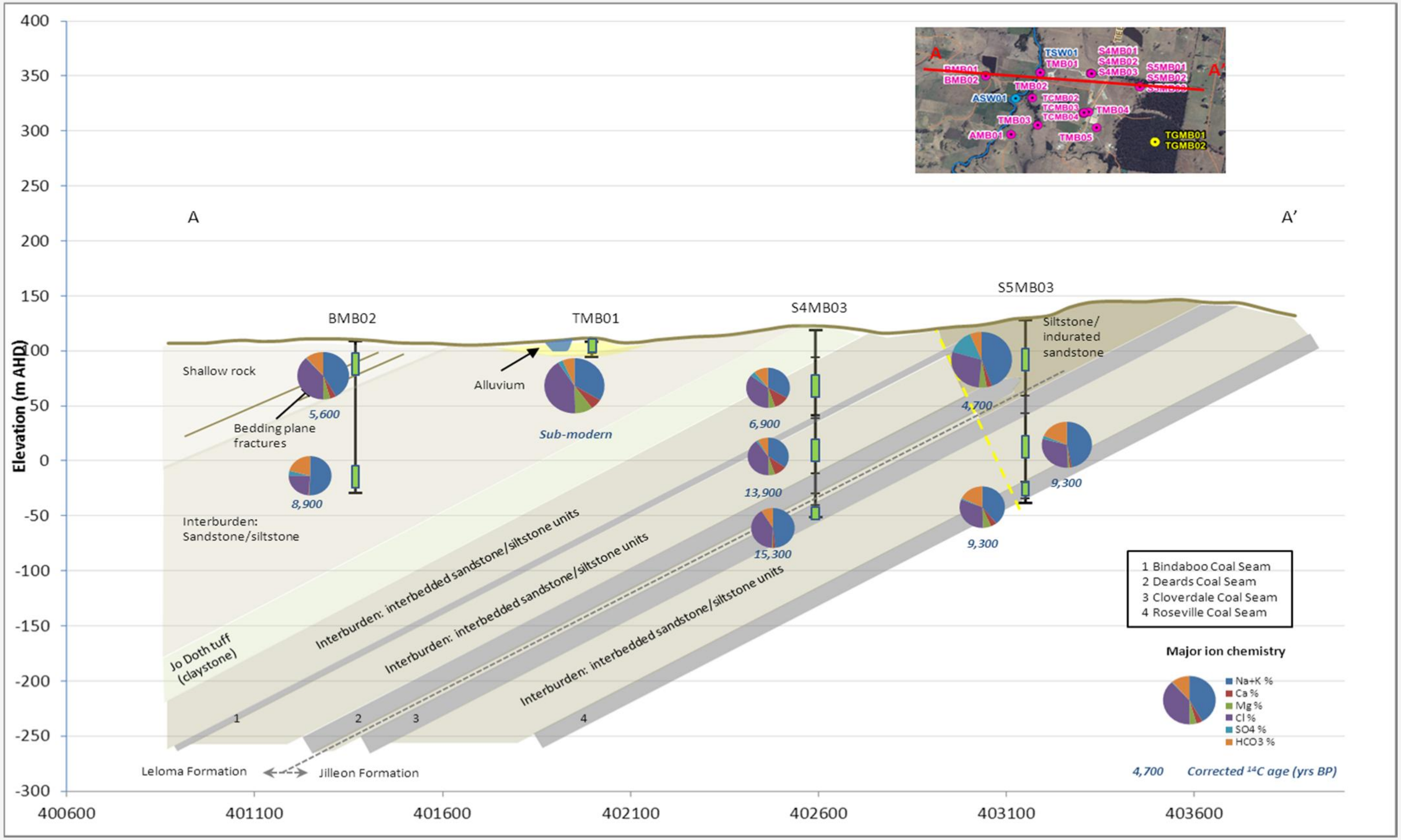


Figure 8-4 Cross-section through the Tiedman property (W-E) showing major ion chemistry and groundwater age

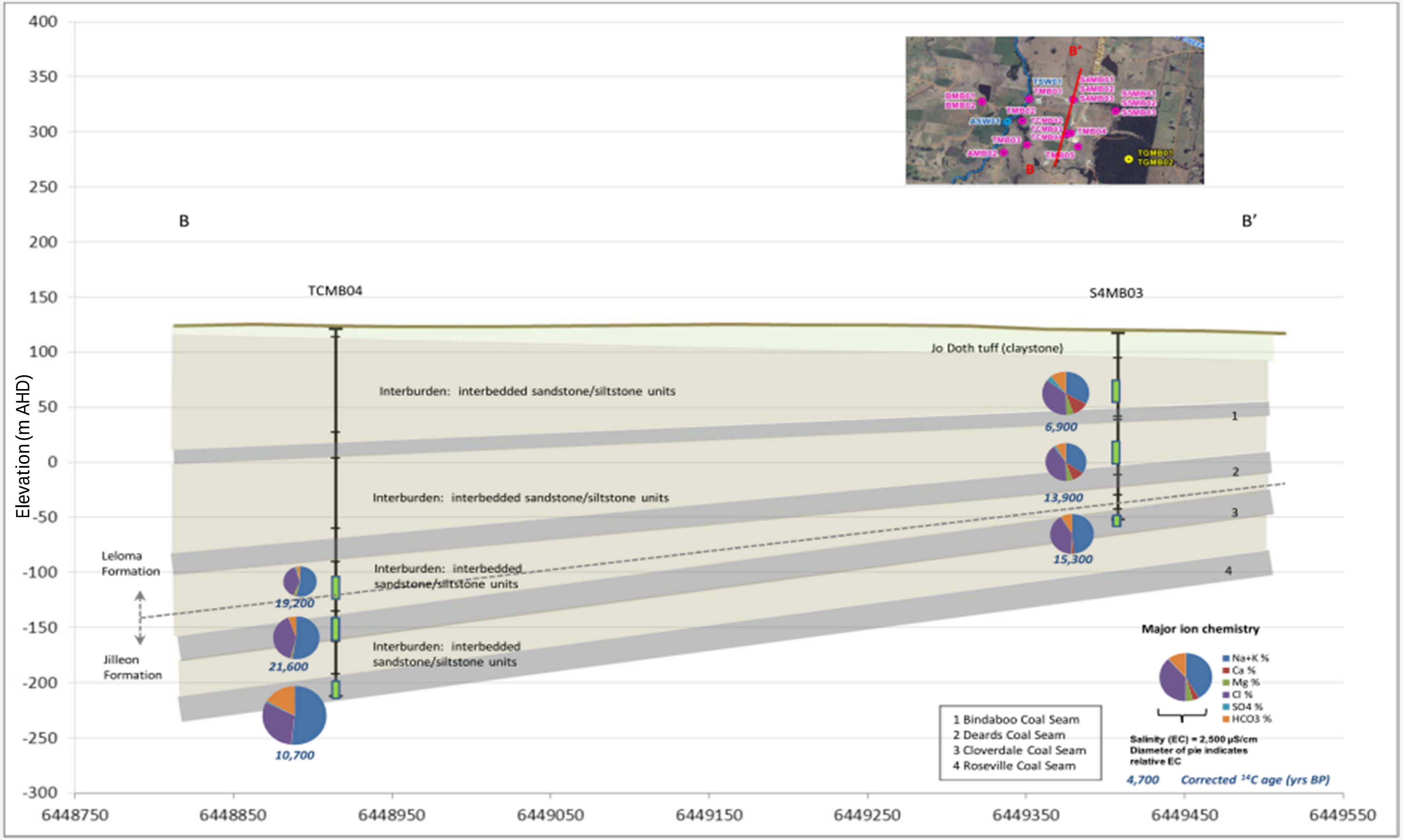


Figure 8-5 Cross-section through the Tiedman property (N-S) showing major ion chemistry and groundwater age

8.2.1 Stratford 4 Monitoring Bores (S4MB)

Variability of chemistry within the interburden and coal units at the Stratford 4 monitoring location is shown on Figures 8-4 and 8-5. At the Stratford 4 monitoring location there are distinct geochemical differences between groundwater from the interburden confining units (S4MB01 and S4MB02) and the Cloverdale Coal Seam (S4MB03) indicating limited connection between them under natural conditions. The interburden monitoring bores have brackish water quality (<4,800 µS/cm), circum-neutral pH values, and water type is characterised as Na-Ca-Cl-HCO_3 in the shallower monitoring bore, and Na-Ca-Cl in the deeper monitoring bore. Slightly elevated concentrations of trace metals barium, cadmium, manganese, strontium, iron and zinc are naturally occurring.

The Cloverdale Coal Seam is characterised by brackish water, alkaline pH and sodium-chloride type water. Trace metals (aluminium, barium, cadmium, manganese, strontium, iron and zinc) also occur, but concentrations are generally lower than the confining units.

Ratios of major ions and calculated saturation indices suggest that water-rock process such as silicate weathering and reverse ion exchange, sulphate reduction and precipitation of carbonate minerals are driving chemical evolution of waters in the confining units.

Dissolved methane is detected in all monitoring bores, with concentrations increasing with depth. Isotopic analysis ($\delta^{13}C$ and $\delta^{2}H$) of methane samples from the Cloverdale Coal Seam, indicate methane is biogenic, and produced by CO_2 reduction.

Tritium and radiocarbon data indicates that water within the interburden units and Cloverdale Coal Seam is old (6,900 to 15,300 yrs BP), with groundwater residence time increasing with depth.

8.2.2 Stratford 5 monitoring bores (S5MB)

Groundwater in the shallow interburden monitoring bore (S5MB01) is distinctly different from the deep interburden monitoring bore (S5MB02) and the Roseville Coal Seam monitoring bore (S5MB03), as shown on Figure 8-4 indicating limited connection between them under natural conditions. The shallow monitoring bore is characterised by brackish salinity, alkaline pH and Na-Cl-SO_4 type water. Slightly elevated concentrations of the trace metals, aluminium, arsenic, cadmium, copper, lead, nickel and zinc) above ANZECC (2000) guideline values for freshwater ecosystems naturally occur in the shallow interburden unit. Strontium, iron, barium and uranium are also naturally elevated. Total organic carbon is higher than in the deeper monitoring bores at this site.

Groundwater from the deeper interburden unit (S5MB02) has a lower salinity (EC) than the shallower unit but is still classified as brackish. The pH is also lower than the shallow interburden monitoring bore, but is still slightly alkaline. Sulphate concentrations are also significantly lower, and water chemistry is characterised as Na-Cl-HCO_3 type water. Aluminium and zinc concentrations are elevated above ANZECC (2000) guideline values for freshwater ecosystems. Strontium, iron, and barium are also naturally elevated. Concentraitons of dissolved methane were also elevated in the interburden unit and were higher than the underlying Roseville Coal Seam.

The Roseville Coal Seam (S5MB03) is characterised by brackish and near-neutral groundwater. Both salinity and pH are lower than the overlying interburden unit. The chemical composition is similar to the overlying interburden unit (Na-Cl-HCO_3). Slightly elevated concentrations of metals and metalloids (barium, boron, iron, manganese, strontium, and zinc) are also present, as well as dissolved methane.

Groundwater chemistry, stable isotope composition and groundwater age is similar for the deep interburden monitoring bore (S5MB02) and the Roseville Coal Seam monitoring bore (S5MB03), supporting the groundwater level data which indicates a potential hydraulic connection between the two units. Groundwater chemistry and stable isotope composition in the shallow interburden monitoring bore is distinctly different from the two deeper monitoring bores, supporting the hydraulic testing data which indicates that the strata in the upper interburden has a very low permeability with little potential for groundwater movement both laterally and vertically. Groundwater within the upper interburden is also younger (4,700 yrs BP) than within the deeper interburden unit (9,300 yrs BP) and the Roseville Coal Seam (9,300 yrs BP).

Groundwater chemistry, stable isotope composition and age is distinctly different on either side of the high-angle oblique fault running through the Tiedman property (Figure 8-4) indicating that the geological structure is compartmentalised at this location (see Section 5.6). Radiocarbon data indicates that groundwater downgradient of the fault (in the interburden and Cloverdale Coal Seam) is older than in the interburden and the deeper Roseville Coal Seam upgradient of the fault (S5MB monitoring bores) (4,700 to 9,300 yrs BP). The upgradient monitoring bores are in closer proximity to the outcropping recharge zones.

8.2.3 Tiedman core hole monitoring bores (TCMB)

Major ion chemistry and groundwater age of the Tiedman core hole monitoring bores is shown in Figure 8-5. The interburden monitoring bore (TCMB02) is characterised by brackish, alkaline water that is Na-Cl dominant. The Cloverdale and Roseville coal seams at this location have similar salinity and major ion chemistry (Na-Cl and Na-Cl-HCO_3 type water) as the Stratford 4 and Stratford 5 monitoring locations, but pH values are more alkaline and dissolved methane concentrations are higher.

Groundwater in both the Cloverdale and Roseville Coal Seams at this location has older radiocarbon ages than the equivalent seams at Stratford 4 and Stratford 5 monitoring locations, suggesting an increase in groundwater age with depth and along the regional flow paths.

8.2.4 Bignell monitoring bores

Major ion chemistry and groundwater age of the Bignell monitoring bores is shown in Figure 8-4. Groundwater from both bores is brackish, slightly alkaline, and dominated by sodium (Na^+), chloride (Cl^-) and bicarbonate (HCO_3^-). Both monitoring bores plot on the GMWL and groundwater ages (5,600 years for BMB01 and 8,900 years for BMB02) are similar supporting the groundwater level data which indicates a potential hydraulic connection between the two units.

8.2.5 Waukivory Road monitoring bores

Groundwater in the alluvium is brackish, slightly acidic and chemically characterised as Na-Ca-Cl type water. Although hydraulic gradients indicate the potential for downward leakage from the alluvium to the shallow bedrock, the chemistry and radiocarbon ages suggest that substantial leakage is unlikely to be occurring.

Groundwater in the fractured rock monitoring bores (WMB02 and WMB04) is brackish to slightly saline and slightly acidic. Groundwater is Na-Ca-Cl dominant, with increasing bicarbonate concentrations at depth. Dissolved methane concentrations are low.

Groundwater within the Bowens Road Coal Seam (WMB03) is also brackish but has an alkaline pH. Major ion chemistry is Na-Ca-Cl dominant. Dissolved methane concentrations are low. Although major ion chemistry is similar in the fractured rock and Bowens Road Coal Seam, groundwater ages show a clear increase with depth (4,300 yrs BP in WMB02 to 19,600 yrs BP in WMB04).

8.2.6 Rombo monitoring bores

There is no shallow alluvium at this site. Groundwater in the shallow monitoring bore (RMB01) is slightly saline, neutral and Na-Cl dominant. Strontium and barium concentrations are the highest of all monitoring locations.

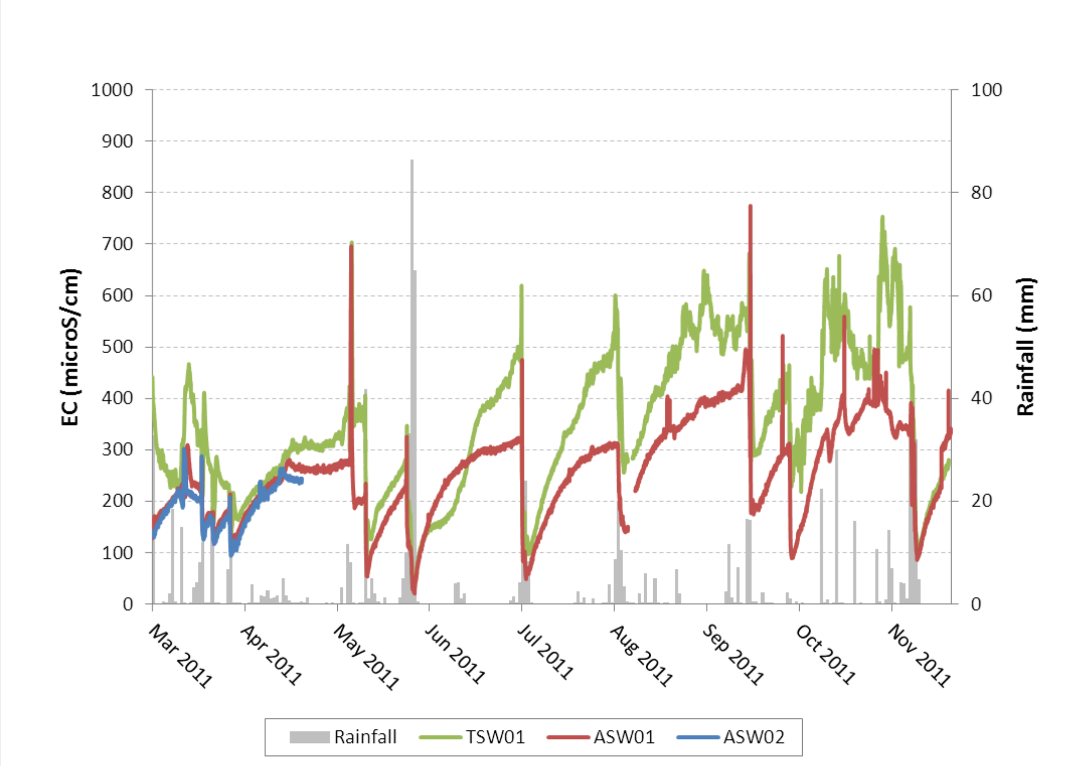
Groundwater in the deeper monitoring bore is slightly saline, slightly alkaline, and is Na-Cl-HCO_3 dominant. Groundwater levels indicate there is potential for upward leakage, however an age anomaly at this location (older water in the shallow monitoring bore (17,700 yrs BP) suggest that any upward leakage may not be significant.

8.3 Surface water quality

Surface water chemistry and salinity is monitored at three locations on the Avon River within the Stage 1 GFDA: TSW01, ASW01 and ASW02. Locations ASW01 and ASW02 (upstream of ASW01) are located on the Atkins property and TSW01 is downstream of ASW01 on the Tiedman's property (Figure 3-1).

Salinity (electrical conductivity) has been measured at the three locations using Solinist EC loggers set to 15 minute intervals from 23 March 2011. The EC data is compared to rainfall from BoM Station 060112 – Hiawatha in Figure 8-6. Surface water salinity (EC) is well correlated with rainfall and flow, with EC generally decreasing with rainfall (and flow). However there is always a spike in river salinity immediately after a major rainfall event which indicates high salinity runoff from the catchment in the first surface water flush. Electrical conductivity values are similar at ASW01 and ASW02 throughout the monitoring period, and are highest at the downstream monitoring location (TSW01). During the monitoring period the following salinity ranges are observed:

- TSW01 – 25.7 to 753.5 µS/cm
- ASW01 – 20.2 to 774.4 µS/cm
- ASW02 – 93.8 to 301.9 µS/cm.



Note: Data download from the EC probe at ASW02 was unsuccessful in early December 2011. These data will be updated in the subsequent monitoring report (mid-2012).

Figure 8-6 EC levels and rainfall at TSW01, ASW01, ASW02

Surface water sampling was undertaken in April 2011 at three monitoring locations on the Avon River within the Stage 1 GFDA: TSW01, ASW01 and ASW02. Locations ASW01 and ASW02 (upstream of ASW01) are located on the Atkins property and TSW01 is downstream of ASW01 on the Tiedman property (Figure 3-1).

A summary of major water quality results for surface water monitoring locations (EC, pH, water type, and elevated nutrients and trace metals) is provided in Table 8-9. The complete results are listed in Summary Tables 2 and 3. Major ion chemistry for surface water is compared to groundwater in Figure 8-1.

Table 8-9 Surface water quality

Location	EC (µS/cm)	pH	Water type	Trace metals/nutrients above ANZECC (2000) guidelines
ASW01	161	6.86	Na-Cl-HCO_3	Al, Cu, Zn, RP, TP
ASW02	158	6.62	Na-Cl-HCO_3	Al, Cu, Zn,NH_3-N, RP, TP
TSW01	324	7.38	Na-Mg-Cl-HCO_3	Cd, Cu, Zn,NH_3-N, RP, TP

At the time of sampling, salinity was fresh at all surface water monitoring locations, but showed a slight increase in a downstream direction. The pH was slightly acidic at ASW01 and ASW02 and slightly alkaline downstream at TSW01.

Surface water temperatures ranged from 18.06°C (ASW02) to 19.02°C (ASW01). Redox at all surface water sites ranged from -80.4 mV (TSW01) to +139.9 mV (ASW02). Dissolved oxygen concentrations are below ANZECC (2000) guideline values (85-110 % saturation) at all the surface water sites, ranging from 54% saturation (ASW01) to 66% saturation (ASW02).

Surface water near the Atkins property was classified as Na-Cl-HCO_3 type water. Major ion composition of surface water at the Tiedman property was similar, but with an increasing relative proportion of magnesium.

The major findings of dissolved metal analysis at the Avon River sites are as follows:

- Dissolved metal concentrations, including aluminium, barium, manganese, strontium, zinc and iron, are slightly elevated at all sites.
- Concentrations of zinc and copper are above the ANZECC (2000) guidelines (0.008 mg/L and 0.0014 mg/L respectively) for all sites.
- Concentrations of aluminium are above the ANZECC (2000) guideline (0.055 mg/L) at ASW01 and ASW02.
- The cadmium concentration at TSW01 (0.0006 mg/L) also exceeded the ANZECC (2000) guideline (0.0002 mg/L).

Nutrient concentrations were slightly elevated at the surface water monitoring locations. Ammonia ranged from 0.02 mg/L (ASW01) to 0.04 mg/L (ASW02) and exceeded the ANZECC (2000) guideline (0.02 mg/L) at TSW01 and ASW02. Nitrate concentrations ranged from below detection limits (0.01 mg/L) to 0.03 mg/L. Total and reactive phosphorus concentrations exceeded ANZECC (2000) guidelines (0.05 mg/L and 0.02 mg/L respectively) for all surface water monitoring locations.

Total organic carbon concentrations at the surface water monitoring locations ranged from 9 mg/L (TSW01) to 31 mg/L (ASW02).

Methane was not analysed for surface water samples.

TPH, BTEX, phenolic compounds and polycyclic aromatic hydrocarbons were below LORs at the surface water monitoring locations.

8.4 Tiedman and Stratford dam water quality

8.4.1 Summary

Monitoring of the north and south Tiedman produced water holding dams occurred on the 10 January 2011 and included water quality profiling and sampling. Two samples are collected from each holding dam; one from near the surface and one from depth. Profiling data for both holding dams is presented in Appendix P.

Sampling of the two Stratford holding dams, Stratford 1 and Stratford 3, was undertaken on 4 August 2011. Three surface water samples were collected from Stratford 1 and two from Stratford 3. All samples were analysed for field parameters, however, only one sample per dam was analysed for laboratory analytes. Samples were collected from near surface in both holding dams.

Water quality results for the Tiedman and Stratford holding dams are summarised and compared to ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers) and irrigation in Table 8-10. The complete results are listed in Summary Table 4 for the Tiedman dams and Summary Table 5 for the Stratford dams. Major ion chemistry for all four dams are compared on the Piper diagram in Figure 8-7.

Table 8-10 Water quality parameters for Tiedman and Stratford dams

Parameters	Units	ANZECC (2000) guidelines[a]	ANZECC (2000) irrigation guidelines[d]	Range	Average[c]
Water Quality parameters					
Field EC	µS/cm	125-2,200[b]		1,514-**3,994**	**2,526**
Field pH	pH units	6.5 – 8.0[b]		**9.82-10.56**	**10.15**
Major ions					
Calcium	mg/L			1-5	2.5
Magnesium	mg/L			1-2	1
Sodium	mg/L		230-460[e]	*372-776*	*599*
Potassium	mg/L			8-320	125
Chloride	mg/L		350-700[e]	252-663	465
Sulphate	mg/L			4-29	15.5
Total alkalinity as $CaCO_3$	mg/L			424-1,330	872
Metals					
Aluminium	mg/L	0.055 (pH>6.5)	20	0.02-**0.48**	**0.13**
Arsenic	mg/L	0.013 (AsV), 0.024 (AsIII)	2	0.003-0.009	0.007
Barium	mg/L	-		0.086-0.426	0.248
Beryllium	mg/L	ID	0.5	<0.001	<0.001
Cadmium	mg/L	0.0002	0.05	<0.0001-**0.0003**	0.0002
Copper	mg/L	0.0014	5	<0.001-**0.143**	**0.026**
Lead	mg/L	0.0034	5	<0.001	<0.001
Manganese	mg/L	1.9	10	<0.001-0.006	0.004
Molybdenum	mg/L	ID	0.05	0.011-0.025	0.021
Nickel	mg/L	0.011	2	<0.001-0.004	0.003
Selenium	mg/L	0.011 (total)	0.05	<0.001	<0.001
Strontium	mg/L	-		0.157-0.427	0.293
Uranium	mg/L	ID	0.1	<0.001-0.001	<0.001
Vanadium	mg/L	ID	0.5	<0.01	<0.01
Zinc	mg/L	0.008	5	<0.001-0.028	0.015
Iron	mg/L	ID		0.025-0.12	0.07
Bromine	mg/L	ID		0.4-1.9	1.25
Boron	mg/L	0.37	2.0-4.0[e]	0.33-**0.83**	**0.66**
Nutrients					

Parameters	Units	ANZECC (2000) guidelines[a]	ANZECC (2000) irrigation guidelines[d]	Range	Average[c]
Nitrite as N		0.02[b]		<0.01	<0.01
Nitrate as N		0.7		<0.01-0.03	0.02
Ammonia as N	mg/L	0.02[b]		<0.01-3.6	0.95
Total Phosphorus as P	mg/L	0.05[b]	0.8-12	<0.01-3.61	1.70
Reactive Phosphorus as P	mg/L	0.02[b]		<0.01-1.06	*0.28*
Total Organic Carbon	mg/L			35-120	60
Gases					
Methane	µg/L	-		na	na
Phenolic compounds	µg/L			nd	nd
Polycyclic aromatic hydrocarbons	µg/L			nd	nd
Monocyclic aromatic hydrocarbons	µg/L				
Benzene	µg/L	950		<1	<1
Toluene	µg/L	ID		<5	<5
Ethyl Benzene	µg/L	ID		<2	<2
m&p-Xylenes	µg/L	ID		<2	<2
o-Xylenes	µg/L	350		<2	<2
Total Petroleum hydrocarbons					
C_6-C_9	µg/L	-		<20	<20
C_{10}-C_{14}	µg/L	-		<50	<50
C_{15}-C_{29}	µg/L	-		<100	<100
C_{29}-C_{36}	µg/L	-		<50	<50

[a] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).

[b] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.

[c] To calculate the average, values below detection limit are included in the calculation as half the LOR.

[d] ANZECC (2000) guidelines for agricultural irrigation water – short term trigger value

[e] ANZECC (2000) - guideline level for moderately salt tolerant crops

'ID' indicates insufficient data for trigger value to be established.

BOLD indicates a value outside of the ANZECC (2000) guideline trigger values.

Italics indicates a value outside ANZECC (2000) short term trigger values for agricultural irrigation water

nd – not detected above LOR

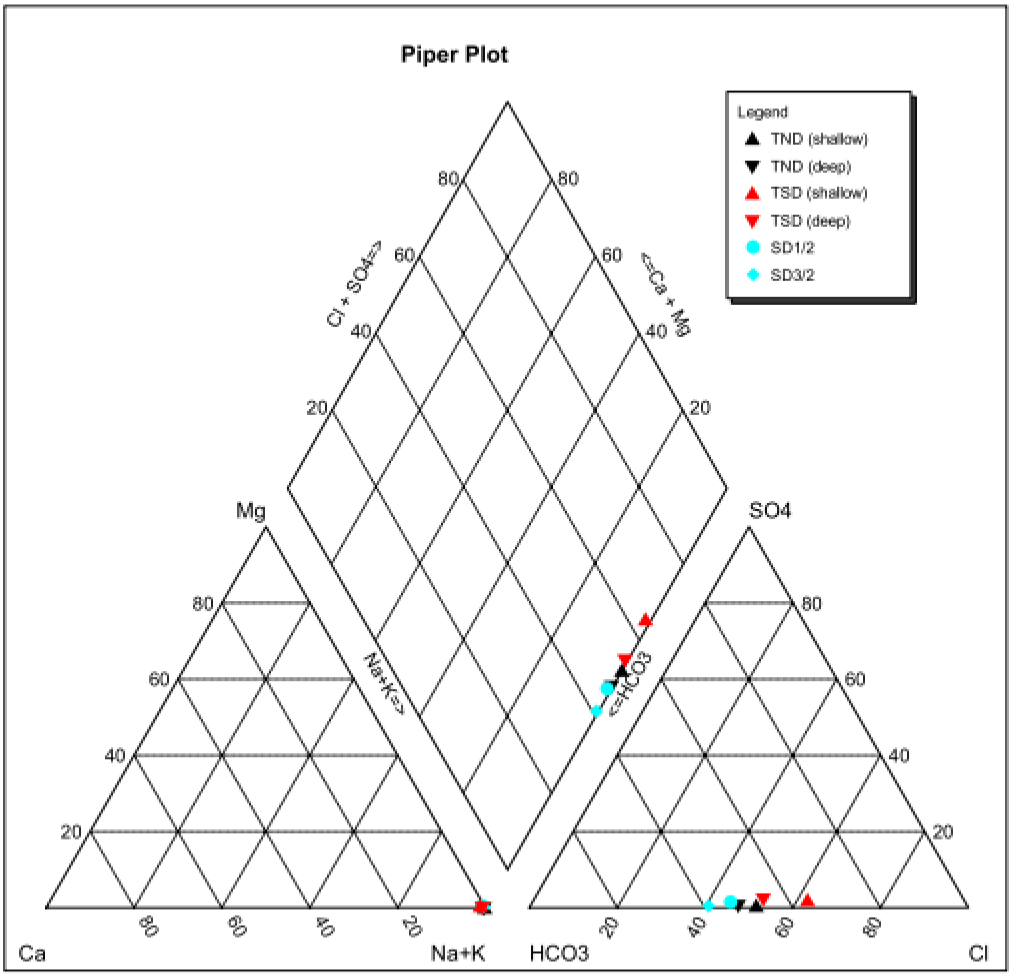


Figure 8-7 Piper diagram showing major ion composition of holding dams

8.4.2 Tiedman Dams

Salinity conditions are brackish in both Tiedman North and South dams, with higher salinity in the North holding dam. The results of depth profiling (Appendix P), showed a slight decreasing salinity trend with depth. Electrical conductivity (EC) ranged between 3,944 µS/cm and 4,360 µS/cm for the North dam; and ranged between 2,249 µS/cm and 2,777 µS/cm for the South dam.

The pH conditions are alkaline for both holding dams, with slightly higher pH values occurring in the South holding dam. The results of profiling (Appendix P) indicate very little variation in pH in the North holding dam, with pH values ranging from 9.59 – 9.80. The pH values in the South holding dam showed more variation, with pH values ranging from 9.83 – 10.51. There are no distinct trends with depth in either holding dam.

Major ion chemistry in both dams is dominated by sodium (Na^+), chloride (Cl^-) and bicarbonate (HCO_3^-), with increasing dominance of potassium (K^+) in the North holding dam. In the Tiedman North holding dam, a slight change in water type is observed with depth, with an increasing relative percentage HCO_3^- at depth.

Strontium and barium concentrations are slightly elevated in the Tiedman North and South holding dams. Concentrations of zinc and copper are above the ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers) (0.008 mg/L and 0.0014 mg/L respectively) for both holding dams. Details are shown in Table 8-10. Concentrations of aluminium are above the ANZECC (2000) guideline (0.055 mg/L) at both holding dams, except the shallow sample for the South holding dam (0.05 mg/L). The cadmium concentration in the shallow South holding dam sample (0.0003 mg/L) just exceeds the ANZECC (2000) guideline (0.0002 mg/L).

Boron concentrations are slightly elevated and exceed the ANZECC (2000) guideline (0.37 mg/L) at both North (0.79 - 0.83 mg/L) and South (0.7 mg/L) holding dams.

Nutrients are low with the exception of phosphorus and ammonia. Ammonia concentrations exceed the ANZECC (2000) guideline (0.02 mg/L) in both the deep samples in the South dam (0.36 mg/L) and the North dam (0.19 mg/L); however ammonia concentrations are below the LOR (0.01 mg/L) in both shallow holding dam samples. Total phosphorus concentrations exceed the ANZECC (2000) guideline (0.05 mg/L) in both holding dam samples.

Methane was not analysed for holding dam samples.

TPH, BTEX, phenolic compounds and polycyclic aromatic hydrocarbons are not detected in the Tiedman holding dams.

When considering end uses for this produced water, the most appropriate water quality criteria are the ANZECC (2000) irrigation guidelines. These are also shown in Table 8-10. Water quality results for the Tiedman holding dams are all below the ANZECC (2000) irrigation guidelines, except for sodium.

8.4.3 Stratford Dams

Both Stratford holding dams (Stratford 1 and 3) are brackish and alkaline, with the EC and pH results higher at Stratford 3. The pH results from all Stratford holding dam sampling locations are above the ANZECC (2000) guideline for freshwater ecosystems (pH 6.5 – 8). The water type for both Stratford holding dams is Na-HCO_3-Cl.

Boron concentrations are above the ANZECC (2000) guideline (0.37 mg/L) at Stratford 3 (0.59 mg/L). The results for the remaining dissolved metal analytes are either low and below the guideline criteria or are below the LOR. Dissolved metal analyte concentrations are comparable between the two Stratford holding dams.

Phosphorus levels are elevated above the ANZECC (2000) criteria (0.05 mg/L) at both Stratford holding dams and ammonia levels exceeded the guideline values at Stratford 1 (0.85 mg/L). Total organic carbon measurements are elevated and comparable at both Stratford holding dams.

Dissolved methane was not analysed for holding dam samples.

TPH, BTEX, phenolic compounds and polycyclic aromatic hydrocarbons are not detected in either of the Stratford holding dams.

When considering end uses for this produced water, the most appropriate water quality criteria are the ANZECC (2000) irrigation guidelines. These are also shown in Table 8-10. Water quality results for the Stratford holding dams are all below the ANZECC (2000) irrigation guidelines, except for sodium.

8.4.4 Seepage assessment

Two seepage monitoring bores, TMB04 and TMB05, were drilled to the north-west and south-east of the Tiedman South dam (Figure 8-8). Monitoring bores were drilled into siltstone of the Leloma Formation and were dry upon completion in January 2011. However seepage water was present when the sampling program commenced in April, 2011. The two bores are sampled with a disposable polyethylene bailer.

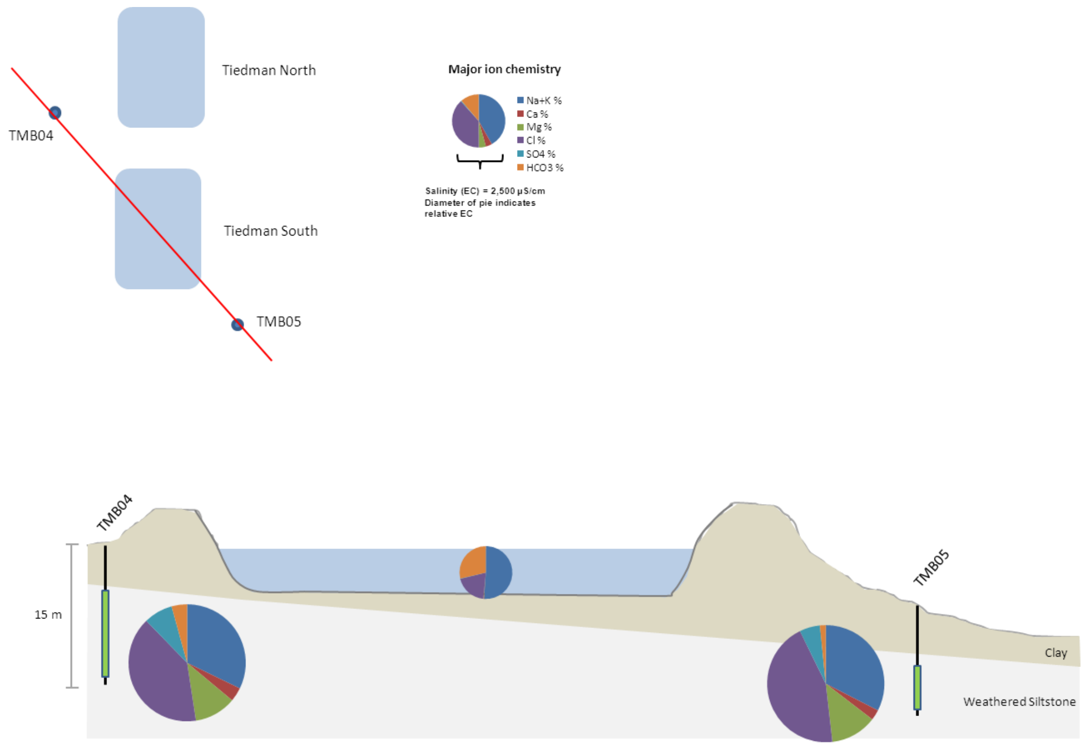


Figure 8-8 Cross-section showing major ion composition of Tiedman South holding dam and seepage monitoring bores

The salinity of seepage water from both bores is slightly saline, with EC values of 8,341 µS/cm for TMB04 and 8,654 µS/cm for TMB05. The pH conditions are slightly acidic, with pH values of 6.59 and 6.18 for TMB04 and TMB05, respectively. The pH and EC of seepage water is significantly different to values for the dam water from the Tiedman South dam, which has an EC of 2,610 µS/cm and pH of 10.03 at depth.

Major ion chemistry of the seepage water is dominated by sodium (Na^+), magnesium (Mg^{2+}) and chloride (Cl^-) (Na-Mg-Cl type water) in contrast to the pond water which is dominated by sodium (Na^+), chloride (Cl^-) and bicarbonate (HCO_3^-) (Na-Cl-HCO_3 type water). Seepage water also has very high concentrations of dissolved silica (47.8 mg/L and 41.8 mg/L for TMB04 and TMB05, respectively). Dam water silica concentrations are low (15.1 mg/L Tiedman South dam (deep)).

Seepage water has elevated concentrations of several dissolved metals and these concentrations are compared to dam water concentrations in Table 8-11. There are very distinct geochemical differences between the trace metal chemistry of seepage water and Tiedman South dam water as indicated in Table 8-11.

Table 8-11 Trace metal concentrations, seepage water (TMB04 and TMB05) and dam water

Parameter (mg/L)	TMB04	TMB05	Tiedman South dam (Deep)
Barium	0.107	0.104	0.241
Cobalt	0.098	0.265	<0.001
Manganese	10.4	22.2	0.005
Nickel	0.041	0.113	0.004
Strontium	1.14	1.24	0.300
Uranium	0.005	0.002	0.001
Zinc	0.029	0.208	0.026
Iron	5.52	64.2	0.09
Bromine	3.5	2.2	0.9

Ammonia and total phosphorus concentrations in the seepage water are significantly lower than the dam water. In TMB04, which had the highest concentrations of both analytes, ammonia concentrations are 0.22 mg/L and total phosphorus concentrations are 0.57 mg/L. In the dam water, ammonia concentrations are 3.6 mg/L and total phosphorus concentrations are 3.16 mg/L.

The distinct differences in major ion and trace metal chemistry, in addition to different nutrient concentrations, indicates that seepage water in TMB04 and TMB05 is not derived from leakage from the Tiedman storage dams. The high salinity, high silica concentrations and high concentrations of certain trace metals including iron and manganese, indicates that water in these monitoring bores is derived from pore water from the weathered siltstones and clays of the Leloma Formation at these locations.

9. Coal and gas chemistry

This chapter discusses the few coal and gas samples collected during this investigation program.

9.1 TCMB04 coal analysis

The initial results for the analysis of coal from the Roseville Coal Seam in the TCMB04 core indicated BTEX, TPH, PAH and phenolic compounds were not detected. The Roseville Coal sample, collected on the 22 February 2011, was not crushed prior to extraction and analysis and hydrocarbons and other analytes may not have been extracted.

Two further samples were taken from the TCMB04 core on the 11 May 2011, one from the Roseville Coal Seam and one from the Cloverdale Coal Seam. These samples were crushed, extracted, and then analysed. BTEX, TPH, PAH and phenolic compounds were not detected in either sample.

9.2 Gas sampling

Samples were collected from the two shallow gas monitoring wells, TGMB01 and TGMB02 on the Tiedman property, on 31 May 2011. The results are presented in Table 9-1 and in the laboratory report in Appendix K. Concentrations of oxygen (O_2), Argon (Ar), nitrogen (N_2), are typical of air, while carbon dioxide (CO_2) concentrations are slightly elevated. Methane concentrations were too low to perform any isotopic analysis of C or H isotopes.

Table 9-1 Gas sample composition (ppm)

Analyte	TGMB01	TGMB02
O_2 + Ar	217,700	216,600
CO_2	560	1,200
N_2	781,700	782,100
C_1	16	138

10. Updated hydrogeological conceptual model

This chapter discusses all data and information collected to date and develops an updated conceptual model of the study area. The new conceptual model has evolved from the preliminary data assessments and the initial conceptual model (SRK, 2010). Once there is sufficient confidence in the conceptual model then a numerical (computer) model can be built to represent the different groundwater systems and to predict their behaviour under a number of different natural and project development scenarios.

This transition from conceptual to numerical modelling should occur after sufficient baseline data is available to build and calibrate a reliable model. This is usually a minimum 12 months of continuous water level data that includes some seasonal variability. Most of the required data sets for a numerical model are also summarised in this chapter.

10.1 Hydrogeological units

Water level, water quality and isotope data collected from the newly installed groundwater and surface water monitoring network provides an enhanced appreciation of groundwater recharge, discharge and flow processes through the different hydrogeological units of the Gloucester Basin.

These hydrogeological units, broadly introduced in SRK (2010) and confirmed by these Phase 2 investigations are:

- Alluvial aquifers
- Shallow rock aquifers
- Interburden confining units
- Coal seam water bearing zones.

Only the first two units are aquifers, with the deeper rock types being either very poor aquifers (coal seams, siltstones and sandstones) or confining aquitard/aquiclude layers (claystones, siltstones or indurated sandstones). Permeability characteristics are provided in Table 10-1.

Table 10-1 Hydrogeological units of the Stage 1 GFDA (updated)

Hydrogeological unit	Aquifer type	Formation name	Hydraulic conductivity (m/day)
Alluvial aquifers	Semi-confined, clay capped, porous, granular	Quaternary alluvium	0.3-500
Shallow rock aquifers	Confined/ unconfined	Permian Gloucester Coal Measures	0.01-20

Hydrogeological unit	Aquifer type	Formation name	Hydraulic conductivity (m/day)
Interburden confining units	Confined/ unconfined aquitard	Confining units of the Gloucester Coal Measures	4×10^{-5}-0.006
Coal seam water bearing zones	Confined	Coal seams of the Gloucester Coal Measures	0.002-0.03

Figure 10-1 presents a summary of the hydraulic conductivities derived from the various testing methods.

Figures 10-2 and 10-3 show annotated cross-sections through the central area of the Stage 1 GFDA and summarise the current hydrogeological conceptual model of the area.

Permeability		Pervious				Semi-Pervious						Impervious	
Aquifer		Good					Poor					None	
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt,							
Unconsolidated Clay & Organic					Peat			Layered Clay			Fat / Unweathered Clay		
Consolidated Rocks		Highly Fractured Rocks			Oil Reservoir Rocks			Fresh Sandstone			Fresh Limestone,	Fresh Granite	
κ (millidarcy)	115,740,741	11,574,074	1,157,407	115,741	11,574	1,157	116	12	1	0.1	0.01	10^{-3}	10^{-4}
K (cm/s)	1,000	100	10	1	0.1	0.01	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
K (m/d)	100,000	10,000	1,000	100	10	1	0.1	0.01	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}

Alluvial aquifer
Shallow rock aquifers
Coal seam water bearing zones
Interburden confining units

Figure 10-1 Aquifer permeability summary

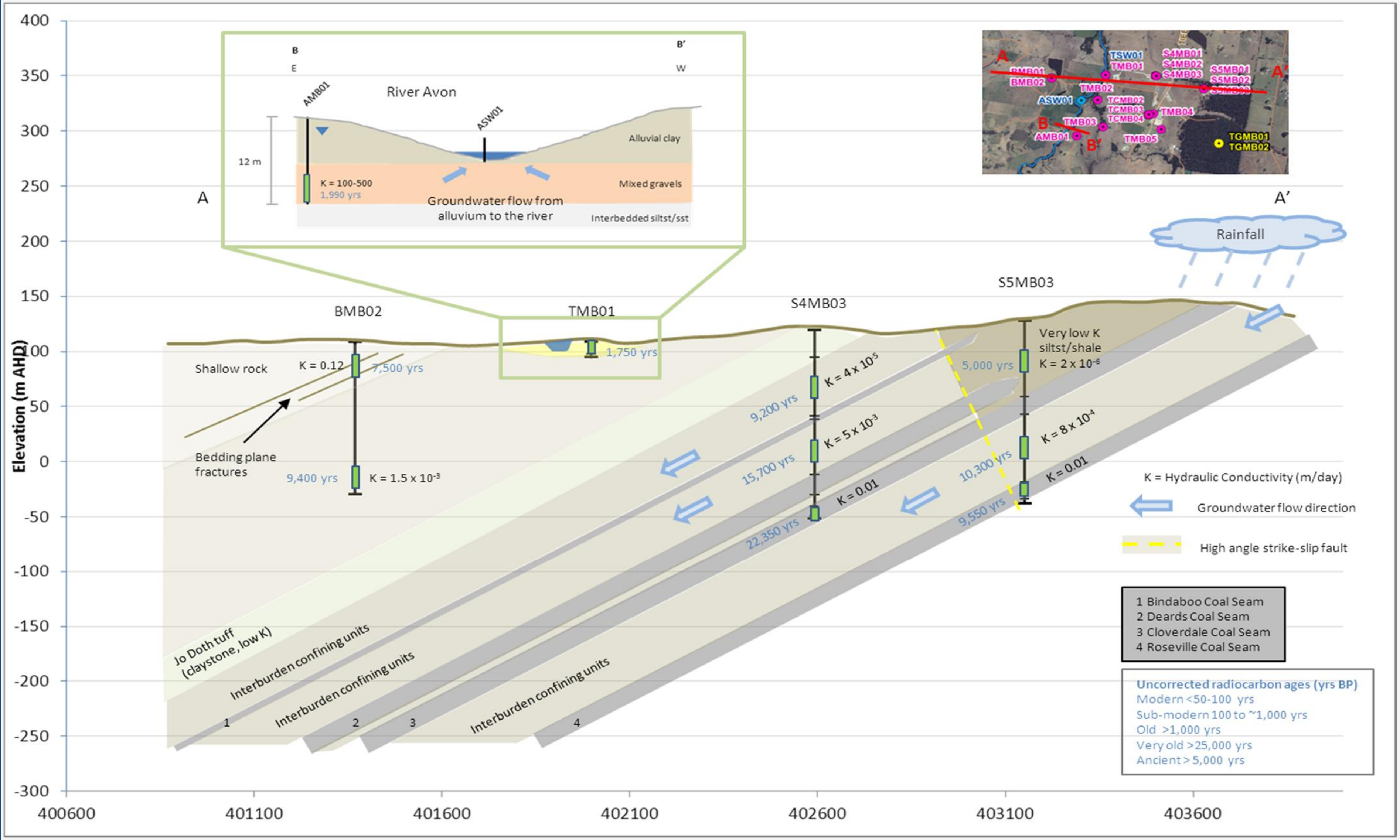


Figure 10-2 Conceptual cross-section through the Tiedman property (W-E)

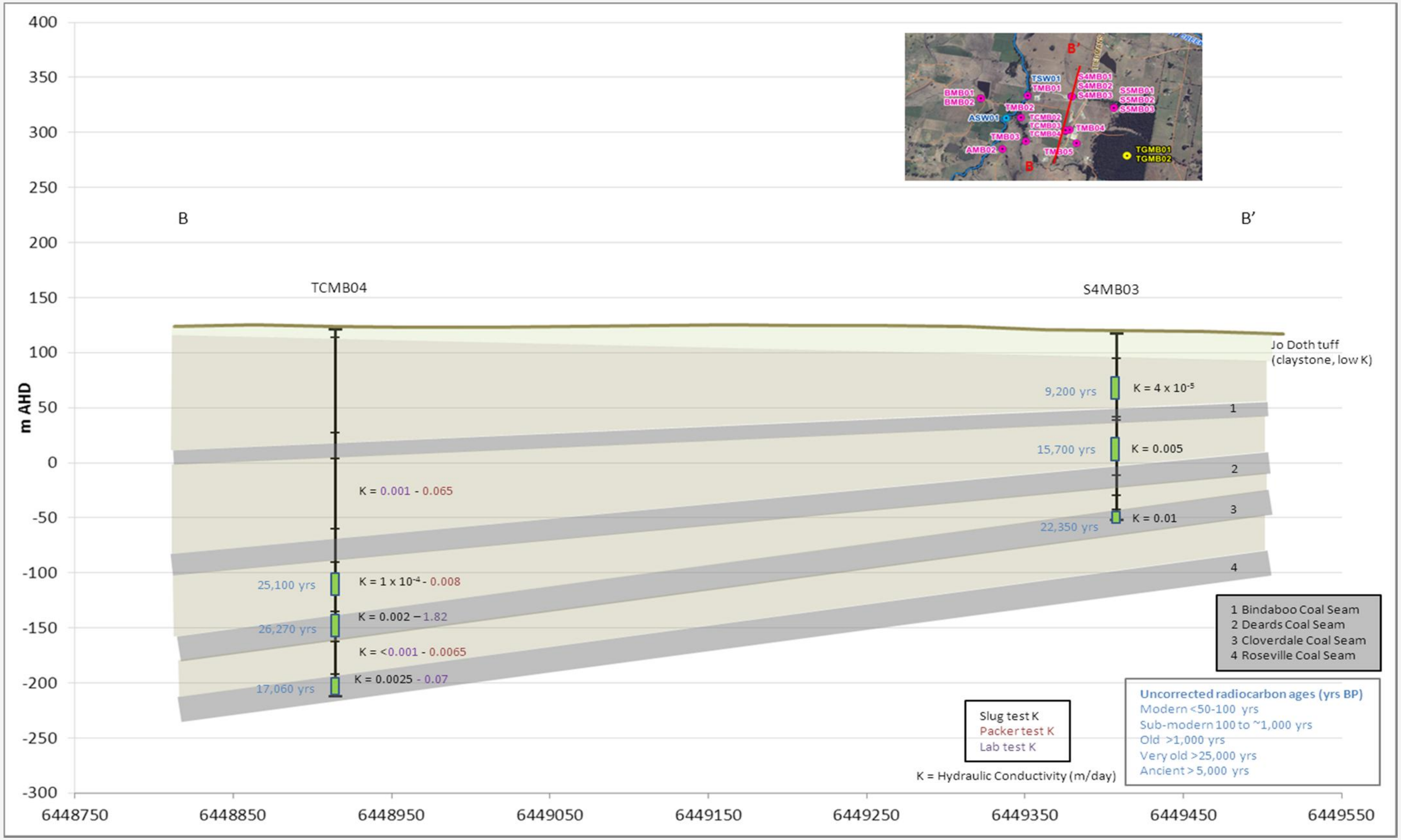


Figure 10-3 Conceptual cross-section through the Tiedman property (SW-NE)

10.2 Alluvial aquifers

The alluvium, associated with the Avon River and its tributaries is shallow (maximum 12 m thickness) and is an unconfined or semi-confined aquifer across the whole area where it is present. Groundwater level data imply groundwater flow in a northerly direction parallel to the axis of the valley (Figure 10-4). Recharge to the alluvial aquifer is predominantly via direct rainfall infiltration and also via lateral through flow from alluvium upgradient. Flooding occasionally provides additional recharge. Small seepage contributions from the underlying bedrock are also likely.

The alluvium typically comprises a clay to around 5-6 mbgl underlain by mixed gravels to a siltstone bedrock. A muted response to rainfall shown in the alluvial water levels at some locations supports a hypothesis that this surface clay layer is retarding direct rainfall recharge to the gravels (supported by sub-modern water >50 to 100 yrs BP). There is also a clear recharge response in all alluvial bores to the flooding event that occurred at the end of May 2011.

Isotopic evidence indicates that younger water is present upgradient in the alluvium. Detectable tritium is above the quantification limit in the alluvium on the Atkins property indicating recharge in that area.

Groundwater discharge from the alluvium is primarily to the rivers as baseflow. Hydrographs indicate a gaining river system and hydraulic gradients are evident between the shallow alluvial deposits and adjacent river stage levels (Figure 10-5). This hydraulic connection between the alluvial groundwater and river system is supported by the steady increases in salinity in the river during periods of low rainfall and low flow. It is likely that this increase is a result of saline water discharging from the alluvium, which at the Tiedman property is significantly more saline than the surface water. Elevated concentrations of strontium, barium and iron (typical markers of groundwater) in the surface water provide further evidence to support the hypothesis of shallow alluvial groundwater discharging to the Avon River. A secondary discharge route for shallow alluvial groundwater is likely to be transpiration by riparian vegetation. Minor volumetric abstractions by private bores and wells are the only other discharge from these alluvial aquifers.

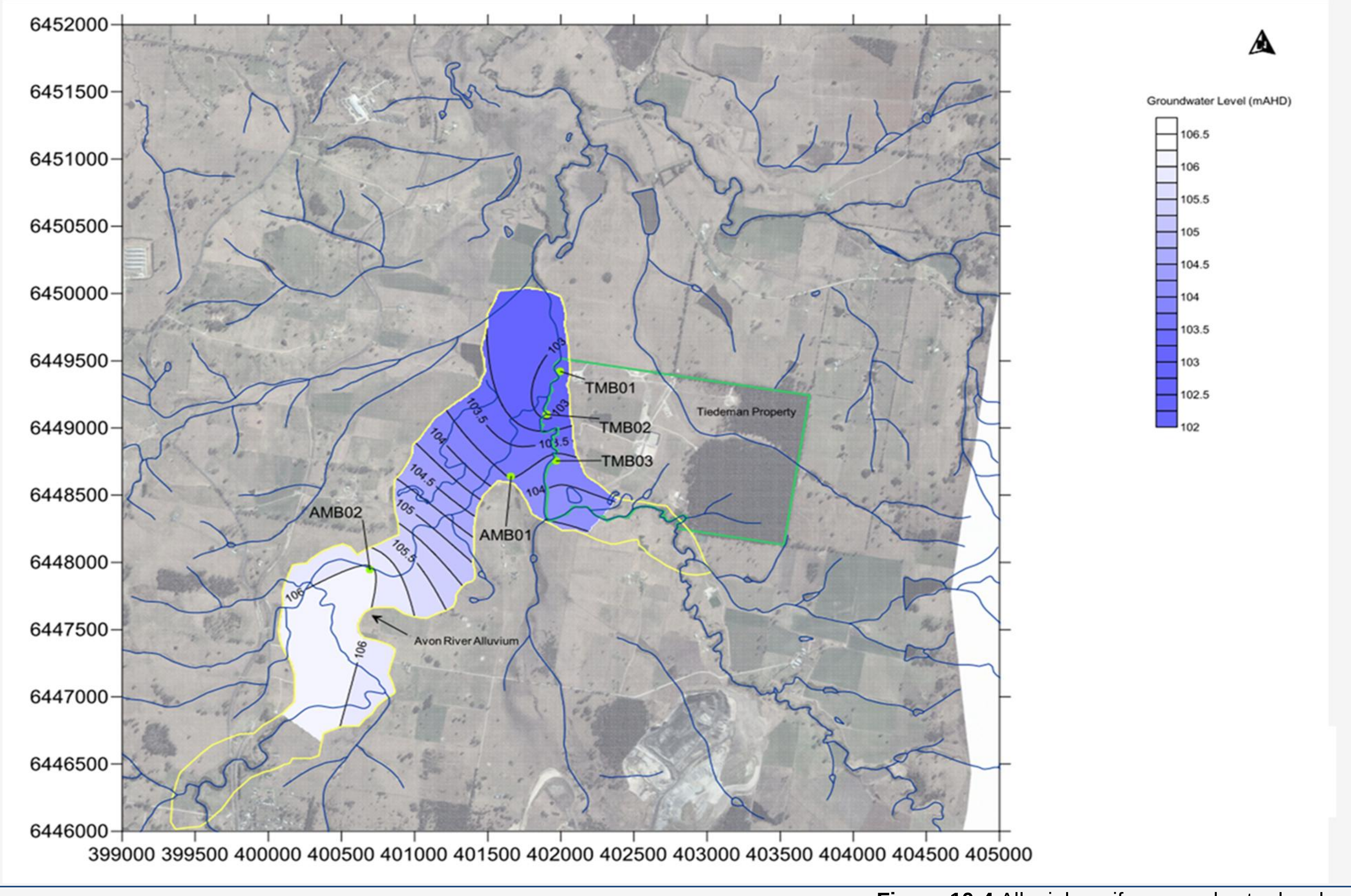


Figure 10-4 Alluvial aquifer groundwater level contours

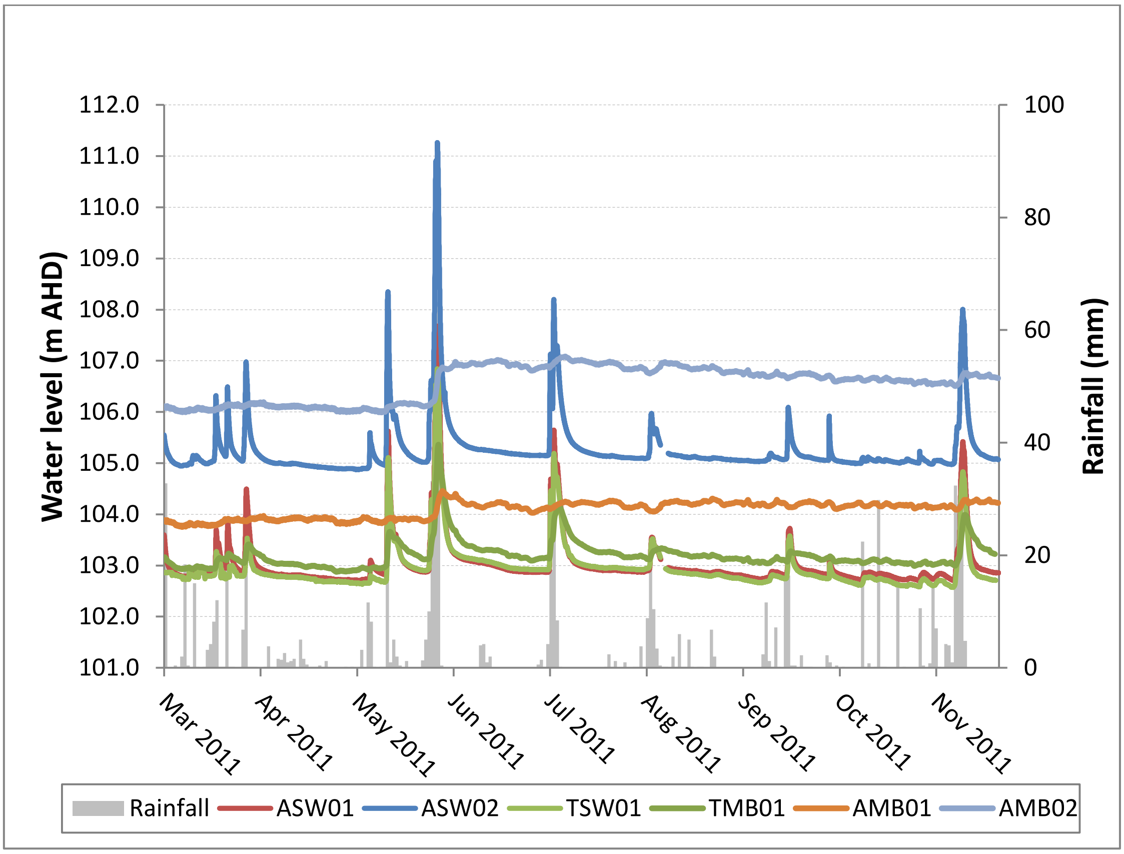


Figure 10-5 Alluvial groundwater levels and river levels

Groundwater dating indicates that the alluvial aquifer contains modern water with maximum residence times unlikely to be more than a few hundred years, with the youngest water (<50 yrs BP) detected in the upstream alluvial deposits. There is minimal groundwater use from the alluvial aquifer and this hydrogeological unit is considered to be full and overflowing.

10.3 Shallow rock aquifers

SRK (2010) presented a fractured and weathered rock aquifer to depths of around 150 m across the entire Stage 1 GFDA. Evidence from the extensive Phase 2 drilling and testing program has led to a slight revision of this conceptual model with fractured and weathered domains being more restricted or localised than initially thought.

The current hypothesis, supported by the field data, is that the shallow rock unit, dominantly fine to medium grained sandstone, is a dual permeability aquifer. The shallow rock is interbedded sandstone, silt and claystone, and is characterised by lateral groundwater flow via bedding plane partings and minor fractures. The shallow rock aquifer extends beneath the alluvium onto the Tiedman property. However further east the steep structure of the underlying units (up to 60° dips) brings the interburden units and coal seams to outcrop at the surface.

Based on minimal fluctuations in water levels, rainfall recharge appears low and is localised to outcrop and shallow outcrop areas in the east. In areas where there is a weathered (clayey) profile, brackish to saline water quality suggests there is negligible (vertical) rainfall recharge. Lateral groundwater flow is most likely directed toward the centre of the basin through bedding plane partings and minor fractures. The unit is likely to discharge to the alluvium that has been deposited along the floor of the valley. This discharge is likely to be minor in the Stage 1 GFDA due to low recharge and the presence of low permeability siltstone and claystone underlying the alluvium.

Elevated strontium and barium concentrations are characteristic of these aquifers, and minor trace elements are naturally occurring. Dissolved methane concentrations are typically low. Isotopic dating indicates that groundwater in the shallow rock aquifer is in the order of thousands of years old and therefore significantly older than the shallow alluvium. There is only minor groundwater use from these rocks and this hydrogeological unit is also considered to be full and overflowing.

10.4 Interburden confining units

The deeper interburden units typically are of very low permeability. The groundwater is therefore moving very slowly with lateral groundwater flow within each rock unit predominating over fracture flow migration. Groundwater is brackish to slightly saline, and chemistry varies from Na-Cl dominant to Na-Cl-HCO_3 dominant.

The low permeability interburden units are locally saturated, but generally act as confining layers between and overlying the coal seams. The layered aquitards of the interburden units create separate and distinct groundwater systems with no connection evident between the deeper coal seam water bearing zones and the shallow rock and alluvial aquifers.

Stable isotopes (^{18}O and ^{2}H) indicate water within these interburden units is of meteoric origin, and radiocarbon data indicates water is thousands to tens of thousands of years old.

10.5 Coal seam water bearing zones

Despite having low permeabilities, the coal seams in the Stage 1 GFDA have a higher permeability than the surrounding interburden and are therefore likely to be conduits for limited groundwater flow at depth. The groundwater is moving very slowly (but sometimes faster that groundwater in the overlying interburden) with lateral groundwater flow within the cleats in the coal seams predominating over fracture flow migration.

Water salinity in the coal seam water bearing zones is brackish to slightly saline and chemical composition ranges from Na-Cl type water in the Cloverdale Seam to Na-Cl-HCO_3 in the Roseville Seam. Strontium and barium concentrations are elevated, with slightly elevated concentrations of other trace metals including aluminium, cadmium, copper, nickel and zinc. Dissolved methane concentrations are elevated in the Roseville and Cloverdale coal seams. These water attributes are typical of groundwater that has been in residence for long periods within the Permian coal seams.

This deep groundwater is derived from rainfall in the outcrop areas and lateral groundwater flow is most likely directed toward the centre of the basin. The unit is likely to discharge to the shallow rock areas toward the centre of the basin (and eventually and indirectly to the alluvium that has been deposited along the floor of the valley). Faults are suspected to be conduits for some of this upward flow but there is no evidence of any upwards flows or discharge areas at this time.

Stable isotopes (^{18}O and ^{2}H) indicate water within these coal seams is of meteoric origin, and radiocarbon data indicates water is thousands to tens of thousands of years old.

10.6 Groundwater dependant ecosystems

There may be some uptake of shallow groundwater from the alluvium by native riparian vegetation along the Avon River and its tributaries in the Stage 1 GFDA. Minor diffuse discharge of saline groundwater from the shallow rock is thought to occur through the base of the alluvium as there are shallow groundwater and stream salinity increases during dry periods. Groundwater discharge is diffuse as it does not discharge at any one point in the landscape.

There are no other known ecosystems or species in the catchment associated with shallow water tables or groundwater discharge areas. Surface water flows dominate the catchment so it is extremely unlikely that any ecosystems or species could be groundwater dependent (or even partially dependent) (AH Ecology 2012).

Consequently there are no known ecosystems that could be affected if there are changes to the deep groundwater regime in the coal seam water bearing zones.

10.7 Significance of fault zones

Even though several of the completed monitoring bores are located close to faults or straddle fault zones, the available data suggests the faults do not affect the natural groundwater flow characteristics of shallow rock aquifers, interburden confining units or coal seam water bearing zones. Water quality and isotope data on the Tiedman site is less conclusive and may suggest near surface faults are enhanced recharge areas.

Current understanding based on earlier flow testing programs, water level data, water quality data and isotope aging results from this study is that faults are not major features with respect to natural groundwater flow pathways across the area. However, further studies are under way and planned to better understand groundwater flows within and adjacent to faulted areas when deep coal seams are dewatered.

While the increased risk of drainage of groundwater from shallow aquifers is low, AGL's general development principles in relation to faults are to:

- Use 3D seismic to accurately locate (and avoid) major faults
- Avoid drilling above and through these major structural features
- Step out and find alternative locations in more competent rock where possible
- Design and construct wells with more casing and more cementing in areas/intervals close to faults where broken rock and greater water inflows may be encountered.

Maximising CSG production is based on minimising produced water volumes. With a dewatering cap of 2 ML per day for the Stage 1 development, it is important that AGL's wellfield layout is based on avoiding as many faulted areas as possible.

11. Conclusions

The primary objectives of this study were to:

- Complete baseline studies to effectively characterise the groundwater systems in the Stage 1 GFDA.
- Provide site specific information on groundwater occurrence and flow by investigating the different groundwater systems, and determining whether the shallow water resource aquifers are connected to the deeper coal seam water bearing zones.
- Assist in determining the quantity and quality of deep groundwater that is likely to be produced as the CSG field is developed.
- Establish a monitoring network across the Stage 1 GFDA that is spatially diverse and sufficient to cover staged development of the field, and is representative of the catchment, local geology and complexities associated with the geological structure.
- Prepare a comprehensive technical report that includes a revised conceptual model of groundwater recharge, discharge and flow across the Stage 1 GFDA together with all the Phase 2 site investigation activities, data, results and conclusions.

Baseline studies have been completed across many different geological strata and the four different groundwater systems to depths in excess of 330 m. These cover all the shallow aquifer systems (alluvial and shallow rock aquifers) to 100 m depth, plus interburden confining layers and coal seam water bearing zones.

More than 2,000 m of drilling and 22 dedicated monitoring bores, two seepage monitoring bores, two gas monitoring bores and three stream gauging stations have been installed to date. There are six nested monitoring bores at which groundwater conditions are monitored at multiple depths. Substantial geological and hydrogeological data has been collected, collated, and analysed across the Stage 1 GFDA. Important conclusions are:

- There are few beneficial aquifers. These are shallow aquifers in the alluvium and shallow rock, and are only suitable for stock water supply and limited domestic purposes
- Hydraulic testing suggests that permeability values range from:
  - 0.3 to 500 m/day for alluvial aquifers
  - 0.01 to 20 m/day for shallow rock aquifers
  - 4×10^{-5} to 0.006 m/day for interburden confining units
  - 0.002 to 0.03 m/day for coal seam water bearing zones
- Water level monitoring suggests that:
  - water levels respond to rainfall and flooding for alluvial aquifers and show seasonal variations

    - there are minor water level variations for shallow rock aquifers that are small lagged rainfall responses
    - there are negligible water level variations and no seasonal trends for interburden confining units
    - there are negligible water level variations and no seasonal trends for coal seam water bearing zones.
- Water quality monitoring suggests that:
    - alluvial aquifer water quality is fresh to brackish, sodium-chloride dominant, with minor dissolved metals, minor detection of naturally occurring TPH, and no detection of dissolved methane or BTEX compounds
    - shallow rock water quality is brackish, sodium-chloride-bicarbonate dominant, with minor dissolved metals, low to moderate dissolved methane concentrations, and minor detections of naturally occurring TPH and toluene
    - interburden confining units water quality is brackish to slightly saline, sodium-chloride-bicarbonate dominant, with minor dissolved metals, moderate to high dissolved methane concentrations, and minor detections of naturally occurring phenol, TPH, benzene and toluene
    - coal seam water bearing zone water quality is brackish to slightly saline, generally sodium-chloride-bicarbonate dominant, with minor dissolved metals, generally high dissolved methane concentrations, and minor detections of naturally occurring TPH and toluene.
- Environmental isotopes show that all groundwater in all groundwater systems is derived from rainfall
- Radioisotopes show that the alluvial aquifers contain modern and sub-modern water (less than a few hundred years old) but all other groundwater systems contain water that is thousands to tens of thousands of years old
- The oldest groundwater is usually (but not always) the deepest groundwater at the nested monitoring bore sites
- Stream gauge data indicates that the Avon River is a gaining stream with respect to the water table in the adjacent alluvium (in the central Stage 1 GFDA)
- River water quality increases in salinity during periods of lower rainfall and low flow due to natural groundwater discharges
- Shallow aquifer zones (alluvial and shallow rock) are not naturally connected to the deeper water bearing zones in the coal seams
- The interburden confining units are effective confining units that separate shallow groundwater aquifers from deep coal seam water bearing zones
- The very deep coal seams (that will be targeted for CSG development) are expected to be:

  - even lower permeability than the shallower coal seams because of deeper burial and greater compressional stresses
  - sodium-chloride-bicarbonate dominant and slightly more saline
  - older than the groundwater sampled during this study.

- A substantial monitoring network has been established across the Stage 1 GFDA. This is sufficient to monitor water levels and water quality in shallow aquifers, and to monitor any (unlikely) connectivity issues should leakage occur during dewatering of the very deep coal seams in the Stage 1 GFDA
- A few additional monitoring bores are required to assess water level and water quality trends in the vicinity of fault systems
- The conceptual model for groundwater recharge, discharge and flow through the different groundwater systems that comprise the Stage 1 GFDA is similar to that described in the most recent SRK, 2010 study:
  - there are only two beneficial use aquifers (alluvial aquifers to 12 m and shallow rock aquifers to maximum 150 m but more commonly less than 10 0m depth)
  - rainfall and floods recharge the alluvium with alluvial aquifers contributing baseflow discharges to permanent streams
  - very small percentages of rainfall recharge the (dual permeability) shallow rock aquifer with slow throughflow and then low discharge to the base of the central alluvium along the floor of the valley
  - negligible percentages of rainfall recharge the interburden confining units with very slow flow through individual strata
  - very small percentages of rainfall recharge the coal seam water bearing zones with very slow flow through individual coal seams
  - the available data suggests faults do not affect the natural groundwater flow characteristics of shallow rock aquifers, interburden confining units or coal seam water bearing zones.
- Further studies are under way to better understand groundwater flows within and adjacent to faulted areas when deep coal seams are dewatered
- There are no known GDEs or ecosystems that could be affected if there are changes to the deep groundwater regime in the coal seam water bearing zones

Hydrogeological investigations should continue in parallel with any new exploration production testing programs. Additional monitoring bores and baseline monitoring should be installed and monitoring programs commenced to complement these programs.

12. Statement of limitations

12.1 Scope of services

This report has been prepared in accordance with the scope of services set out in the contract, or as otherwise agreed, between the client and Parsons Brinckerhoff (scope of services). In some circumstances the scope of services may have been limited by a range of factors such as time, budget, access and/or site disturbance constraints.

12.2 Reliance on data

In preparing the report, Parsons Brinckerhoff has relied upon data, surveys, plans and other information provided by the client and other individuals and organisations, most of which are referred to in the report (the data). Except as otherwise stated in the report, Parsons Brinckerhoff has not verified the accuracy or completeness of the data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in the report (conclusions) are based in whole or part on the data, those conclusions are contingent upon the accuracy and completeness of the data. Parsons Brinckerhoff will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to Parsons Brinckerhoff.

12.3 Environmental conclusions

In accordance with the scope of services, Parsons Brinckerhoff has relied upon the data and has conducted environmental field monitoring and/or testing in the preparation of the report. The nature and extent of monitoring and/or testing conducted is described in the report.

On all sites, varying degrees of non-uniformity of the vertical and horizontal soil or groundwater conditions are encountered. Hence no monitoring, common testing or sampling technique can eliminate the possibility that monitoring or testing results/samples are not totally representative of soil and/or groundwater conditions encountered. The conclusions are based upon the data and the environmental field monitoring and/or testing and are therefore merely indicative of the environmental condition of the site at the time of preparing the report, including the presence or otherwise of contaminants or emissions.

Within the limitations imposed by the scope of services, the monitoring, testing, sampling and preparation of this report have been undertaken and performed in a professional manner, in accordance with generally accepted practices and using a degree of skill and care ordinarily exercised by reputable environmental consultants under similar circumstances. No other warranty, expressed or implied, is made.

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The scope of services did not include any assessment of the title to or ownership of the properties, buildings and structures referred to in the report nor the application or interpretation of laws in the jurisdiction in which those properties, buildings and structures are located.

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Summary Table 1

AGL Pilot test wells water quality results

SUMMARY TABLE 1: LABORATORY RESULTS AGL TEST PRODUCTION WELLS

Analyte	Units	LOR	ANZECC 2000 Guidelines	STRAT1	STRAT3	CRAV6
Sample date				26/10/2010	26/10/2010	26/10/2010
General Parameters						
pH	pH units	0.01	6.5 - 8.0*	na	na	na
Conductivity	µS/cm	1	125 - 2200*	2160	2300	6440
Total Dissolved Solids	mg/L	1	-	1410	1500	4180
Calculated Total Dissolved Solids#	mg/L	-	-			
Laboratory Analytes						
Hydroxide Alkalinity as CaCO3	mg/L	1	-	<1	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	1	-	212	220	270
Bicarbonate Alkalinity as CaCO3	mg/L	1	-	393	463	2850
Total Alkalinity as CaCO3	mg/L	1	-	605	683	3120
Sulfate as SO4 2-	mg/L	1	-	21	10	<1
Chloride	mg/L	1	-	332	338	515
Calcium	mg/L	1	-	2	3	10
Magnesium	mg/L	1	-	<1	1	3
Sodium	mg/L	1	-	504	524	1620
Potassium	mg/L	1	-	12	27	11
Silica	mg/L	0.1	-			
Ions						
Total Anions	meq/L	0.01	-	21.9	23.4	76.9
Total Cations	meq/L	0.01	-	22.4	23.7	71.4
Ionic Balance	%	0.01	-	1.01	0.62	3.77
Dissolved Metals						
Aluminium	mg/L	0.01	0.055	na	na	na
Arsenic	mg/L	0.001	0.013 (As V)	na	na	na
Beryllium	mg/L	0.001	ID	na	na	na
Barium	mg/L	0.001	-	na	na	na
Cadmium	mg/L	0.0001	0.0002	na	na	na
Cobalt	mg/L	0.001	ID	na	na	na
Copper	mg/L	0.001	0.0014	na	na	na
Lead	mg/L	0.001	0.0034	na	na	na
Manganese	mg/L	0.001	1.9	na	na	na
Molybdenum	mg/L	0.001	ID	na	na	na
Nickel	mg/L	0.001	0.011	na	na	na
Selenium	mg/L	0.01	0.011 (total)	na	na	na
Strontium	mg/L	0.001	-	na	na	na
Uranium	mg/L	0.001	ID	na	na	na
Vanadium	mg/L	0.01	ID	na	na	na
Zinc	mg/L	0.005	0.008	na	na	na
Boron	mg/L	0.05	0.37	na	na	na
Iron	mg/L	0.05	ID	na	na	na
Bromine	mg/L	0.1	ID	na	na	na
Nutrients						
Ammonia as N	mg/L	0.01	0.02*	na	na	na
Nitrite as N	mg/L	0.01	-	na	na	na
Nitrate as N	mg/L	0.01	0.7	na	na	na
Nitrite + Nitrate as N	mg/L	0.01	0.04*	na	na	na
Total Phosphorous	mg/L	0.01	0.05*	na	na	na
Reactive Phosphorous	mg/L	0.01	0.02*	na	na	na
Total Organic Carbon	mg/L	1	-	na	na	na
Dissolved Gases						
Methane	µg/L	10	-	na	na	na
Phenolic compounds						
Phenol	µg/L	1	320	na	na	na
2-Chlorophenol	µg/L	1	490	na	na	na
2-Methylphenol	µg/L	1	-	na	na	na
3-&4-Methylphenol	µg/L	2	-	na	na	na
2-Nitrophenol	µg/L	1	ID	na	na	na
2.4-Dimethylphenol	µg/L	1	ID	na	na	na
2.4-Dichlorophenol	µg/L	1	160	na	na	na
2.6-Dichlorophenol	µg/L	1	ID	na	na	na
4-Chloro-3-Methylphenol	µg/L	1	-	na	na	na
2.4.6-Trichlorophenol	µg/L	1	20	na	na	na
2.4.5-Trichlorophenol	µg/L	1	ID	na	na	na
Pentachlorophenol	µg/L	2	ID	na	na	na
Polycyclic aromatic hydrocarbons						
Naphthalene	µg/L	1	0.016	na	na	na
Acenaphthylene	µg/L	1	-	na	na	na
Acenaphthene	µg/L	1	-	na	na	na
Fluorene	µg/L	1	-	na	na	na
Phenanthrene	µg/L	1	ID	na	na	na
Anthracene	µg/L	1	ID	na	na	na
Fluoranthene	µg/L	1	ID	na	na	na
Pyrene	µg/L	1	-	na	na	na
Benz(a)anthracene	µg/L	1	-	na	na	na
Chrysene	µg/L	1	-	na	na	na
Benzo(b)fluoranthene	µg/L	1	-	na	na	na
Benzo(k)fluoranthene	µg/L	1	-	na	na	na
Benzo(a)pyrene	µg/L	0.5	ID	na	na	na
Indeno(1.2.3.cd)pyrene	µg/L	1	-	na	na	na
Dibenz(a.h)anthracene	µg/L	1	-	na	na	na
Benzo(g.h.i)perylene	µg/L	1	-	na	na	na
Total petroleum hydrocarbons						
C6-C9 Fraction	µg/L	20	ID	<20	<20	<20
C10-C14 Fraction	µg/L	50	ID	<50	<50	<50
C15-C28 Fraction	µg/L	100	ID	<100	<100	<100
C29-C36 Fraction	µg/L	50	ID	<50	<50	<50
C10-C36 Fraction (sum)	µg/L	50	-	<50	<50	<50
Aromatic Hydrocarbons						
Benzene	µg/L	1	950	<1	<1	<1
Toluene	µg/L	2	ID	<5	<5	<5
Ethyl Benzene	µg/L	2	ID	<2	<2	<2
m&p-Xylenes	µg/L	2	ID	<2	<2	<2
o-Xylenes	µg/L	2	350	<2	<2	<2
Isotopes						
Oxygen-18	‰	0.01	-	na	na	na
Deuterium	‰	0.1	-	na	na	na
Carbon-13	‰	0.1	-	na	na	na
Radiocarbon	pMC	0.1	-	na	na	na
Radiocarbon Age (uncorrected)	yrs BP	1	-	na	na	na
Tritium	TU	0.01	-	na	na	na

exceeds guideline limits

na - not analysed

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems.

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems

Calculated using Aquachem

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Summary Table 2

Field results April 2011 groundwater monitoring event

SUMMARY TABLE 2: FIELD RESULTS APRIL 2011 GROUNDWATER MONITORING EVENT

Other Field Data	Units	Guidelines	TMB01	TMB02	TMB03	TMB04	TMB05	WMB01
Date			**07/04/11**	**07/04/11**	**07/04/11**	**13/04/11**	**13/04/11**	**07/04/11**
Depth	mbgl		12	15.5	12.5	15	10	8.5
Groundwater Level	mbtoc		4.63	4.59	3.19	12.16	5.83	4.11
Water Quality Parameters	**Units**							
Temperature	°C	ID	18.4	18	18.3	20.83	19.02	20
Conductivity	µS/cm	125 - 2200*	5810	3010	4720	8341	8654	2100
Dissolved Oxygen	%	85 - 110*	na	10.9	14.2	29.6	29.5	na
Dissolved Oxygen	mg/L	-	1	na	1.42	2.56	2.65	1.39
pH		6.5 - 8*	6.8	6.48	6.93	6.59	6.18	6.37
TDS	mg/L	ID	na	na	na	5858	6334	na
Redox	mV	ID	-141	-9	-42	-134.1	-54	40
Water Type			Na-Cl	Na-Cl	Na-Cl	Na-Mg-Cl	Na-Mg-Cl	Na-Ca-Cl

Other Field Data	Units	Guidelines	WMB02	WMB03	WMB04	BMB01	BMB02	AMB01
Date			**07/04/11**	**07/04/11**	**07/04/11**	**07/04/11**	**06/04/11**	**08/04/11**
Depth	mbgl		23	36	80	30	138	12.6
Groundwater Level	mbtoc		4.94	4.65	4.86	5.86	5.785	4.85
Water Quality Parameters	**Units**							
Temperature	°C	ID	20.06	21.32	20.05	20.9	20.82	19.04
Conductivity	µS/cm	125 - 2200*	5361	4810	3867	4340	3408	2248
Dissolved Oxygen	%	85 - 110*	13.1	11.9	22.2	27.5	1.9	20
Dissolved Oxygen	mg/L	-	1.51	na	2.03	2.39	0.17	1.9
pH		6.5 - 8*	6.62	6.76	6.66	7.49	8.32	6.13
TDS	mg/L	ID	3698	na	2775	3027	2407	1649
Redox	mV	ID	-46.6	-192.9	-62.1	-74.5	-274.2	-77.1
Water Type			Na-Ca-Cl-SO4	Na-Ca-Cl	Na-Ca-Cl-HCO3	Na-Cl-HCO3	Na-Cl-HCO3	Na-Ca-Mg-Cl

Other Field Data	Units	Guidelines	AMB02	RMB01	RMB02	S4MB01	S4MB02	S4MB03
Date			**08/04/11**	**12/04/11**	**12/04/11**	**06/04/11**	**06/04/11**	**06/04/11**
Depth	mbgl		11.5	51	93	66	97	170
Groundwater Level	mbtoc		6.12	4.315	3.945	6.38	5.675	4.085
Water Quality Parameters	**Units**							
Temperature	°C	ID	18.22	21.16	24.38	20.2	20.92	20.31
Conductivity	µS/cm	125 - 2200*	387	9371	8239	2809	2395	3014
Dissolved Oxygen	%	85 - 110*	20.9	13.3	19.4	10.5	0.55	4.9
Dissolved Oxygen	mg/L	-	1.93	1.13	1.55	0.94	0.2	0.43
pH		6.5 - 8*	6.18	6.96	7.33	7.34	7.3	8.09
TDS	mg/L	ID	289	6499	na	2011	1689	2159
Redox	mV	ID	26.2	-86.7	-251.3	-201.6	-210	-169.4
Water Type			Na-HCO3-Cl	Na-Cl	Na-Cl-HCO3	Na-Ca-Cl-HCO3	Na-Ca-Cl	Na-Cl

Other Field Data	Units	Guidelines	S5MB01	S5MB02	S5MB03	TCMB02	TCMB03	TCMB04
Date			**05/04/11**	**05/04/11**	**04/04/11**	**13/05/11**	**14/04/11**	**24/06/11**
Depth	mbgl		60	114	166	183	268	335
Groundwater Level	mbtoc		51.74	18.05	17.85	9.805	11.525	12.66
Water Quality Parameters	**Units**							
Temperature	°C	ID	19.48	20.13	24.76	17.51	16.46	17.63
Conductivity	µS/cm	125 - 2200*	6,100	4290	3883	2396	3352	4999
Dissolved Oxygen	%	85 - 110*	84.1	21.1	35.3	11.1	5.4	27.69
Dissolved Oxygen	mg/L	-	7.77	1.89	2.89	1.01	0.52	2.51
pH		6.5 - 8*	8.61	7.73	7.3	10.15	10.19	11.13
TDS	mg/L	ID	na	3076	2541	na	na	3248
Redox	mV	ID	-217.2	-237.2	-78.1	-362	-304.3	72.8
Water Type			Na-Cl-SO4	Na-Cl-HCO3	Na-Cl-HCO3	Na-Cl	Na-Cl	Na-Cl-HCO3

Other Field Data	Units	Guidelines	TSW01	ASW01	ASW02
Date			**07/04/11**	**08/04/11**	**08/04/11**
Water Quality Parameters	**Units**				
Temperature	°C	ID	18.66	19.02	18.06
Conductivity	µS/cm	125 - 2200*	353	158	168
Dissolved Oxygen	%	85 - 110*	60.6	54.2	66
Dissolved Oxygen	mg/L	-	5.62	14.7	6.22
pH		6.5 - 8*	7.38	6.82	6.62
TDS	mg/L	ID	na	116	125
Redox	mV	ID	-80.4	15	139.9
Water Type			Na-Mg-Cl-HCO3	Na-Cl-HCO3	Na-Cl-HCO3

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Summary Table 3

Laboratory results April 2011 groundwater monitoring event

SUMMARY TABLE 3:LABORATORY RESULTS APRIL 2011 GROUNDWATER MONITORING EVENT

Analyte	Units	LOR	ANZECC 2000 Guidelines	Monitoring round - April 2011										
				TMB01	TMB02	TMB03	TMB04	TMB05	WMB01	WMB02	WMB03	WMB04	BMB01	BMB02
Sample date				07/04/11	07/04/11	07/04/11	13/04/11	13/04/11	07/04/11	07/04/11	07/04/11	07/04/11	07/04/11	07/04/11
Lithology				Clay	Mixed gravels	Mixed gravels & sand	Siltstone	Siltstone	Mixed gravel/sand	Sandstone	Coal	Sandstone	sandstone/siltstone	Sandstone
Formation				Avon R Alluvium	Avon R Alluvium	Avon R Alluvium	Leloma Fm	Leloma Fm	Avon R Alluvium	Wenham Fm	Bowens Rd	Wenham Fm	Leloma Fm	Leloma Fm
Screen Depth				7-10	9-12	5-11	8-14	8-9	5-8	15-21	32-34	67-79	15-29	124-136
Aquifer				Alluvial	Alluvial	Alluvial	Confining - Leloma Fm	Confining - Leloma Fm	Alluvial	Fractured rock - Wenham Fm	Coal - Wenham Fm	Fractured rock - Wenham Fm	Fractured Rock - Leloma Fm	Confining - Leloma Fm
General Parameters														
pH	pH units	0.01	6.5 - 8.0*	na	na	na	6.87	6.41	na	na	na	na	na	na
Conductivity	µS/cm	1	125 - 2200*	7530	3520	5830	8300	8770	2450	4960	4490	3690	3870	3250
Total Dissolved Solids	mg/L	1	-	4030	1910	3430	4640	5150	1560	3180	2740	2310	2120	1980
Calculated Total Dissolved Solids#	mg/L	-	-	4472	2108	3545	5290	5397	1542	3363	3031	2495	2464	2402
Laboratory Analytes														
Hydroxide Alkalinity as CaCO3	mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	42
Bicarbonate Alkalinity as CaCO3	mg/L	1	-	472	176	508	365	146	141	420	380	484	431	703
Total Alkalinity as CaCO3	mg/L	1	-	472	176	508	365	146	141	420	380	484	431	745
Sulfate as SO4 2-	mg/L	1	-	182	40	194	654	485	198	591	436	137	18	129
Chloride	mg/L	1	-	2140	1060	1500	2430	2830	621	1130	1060	933	1040	570
Calcium	mg/L	1	-	184	106	162	132	104	103	295	259	236	59	6
Magnesium	mg/L	1	-	169	70	124	239	278	58	80	68	56	40	2
Sodium	mg/L	1	-	1130	533	868	1250	1330	312	670	653	462	733	779
Potassium	mg/L	1	-	3	4	2	23	18	5	9	11	8	4	6
Silica	mg/L	0.1	-	38.1	35.1	33	47.8	41.8	35.1	32.1	32.4	30.8	18.3	16.5
Ions														
Total Anions	meq/L	0.01	-	73.8	34.2	56.6	89.4	92.8	24.5	52.6	46.5	38.8	38.2	33.6
Total Cations	meq/L	0.01	-	72.4	34.4	56.1	81.2	86.4	23.7	50.7	47.2	36.7	38.2	34.5
Ionic Balance	%	0.01	-	0.92	0.31	0.45	4.82	3.59	1.61	1.89	0.71	2.82	0.03	1.17
Dissolved Metals														
Aluminium	mg/L	0.01	0.055	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.09
Arsenic	mg/L	0.001	0.013 (As V)	0.004	0.003	0.002	0.003	0.004	<0.001	<0.001	0.001	0.004	0.003	0.002
Beryllium	mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	mg/L	0.001	-	0.197	0.541	0.189	0.107	0.104	0.151	0.063	0.089	0.15	0.414	0.341
Cadmium	mg/L	0.0001	0.0002	0.0002	<0.0001	0.0002	0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Cobalt	mg/L	0.001	ID	0.004	0.003	0.005	0.098	0.265	0.002	<0.001	0.001	<0.001	<0.001	<0.001
Copper	mg/L	0.001	0.0014	0.001	0.001	0.002	0.002	0.001	0.002	0.001	<0.001	<0.001	<0.001	0.001
Lead	mg/L	0.001	0.0034	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	0.001	1.9	1.01	1.2	1.49	10.4	22.2	0.422	0.382	0.64	0.14	0.16	0.046
Molybdenum	mg/L	0.001	ID	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.016
Nickel	mg/L	0.001	0.011	0.004	0.001	0.002	0.041	0.113	0.003	<0.001	0.157	0.001	<0.001	0.006
Selenium	mg/L	0.01	0.011 (total)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	-	4.81	2.39	4.05	1.14	1.24	0.964	4.26	6.01	5.82	2.62	0.931
Uranium	mg/L	0.001	ID	0.006	<0.001	0.015	0.005	0.002	<0.001	<0.001	0.005	<0.001	<0.001	0.004
Vanadium	mg/L	0.01	ID	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	0.008	0.016	0.014	0.02	0.029	0.208	0.024	0.014	0.015	0.01	<0.005	0.021
Boron	mg/L	0.05	0.37	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	0.05	ID	2.42	3.78	0.82	5.52	64.2	0.24	3.61	4.99	1.79	0.45	<0.05
Bromine	mg/L	0.1	ID	3.7	2.2	2.7	3.5	2.2	1.2	2.3	2.2	1.5	3.3	1.6
Nutrients														
Ammonia as N	mg/L	0.01	0.02*	0.12	0.26	0.12	0.22	0.21	0.04	0.81	1.44	1.94	0.31	0.36
Nitrite as N	mg/L	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04
Nitrate as N	mg/L	0.01	0.7	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Nitrite + Nitrate as N	mg/L	0.01	0.04*	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
Total Phosphorous	mg/L	0.01	0.05*	0.22	0.11	0.06	0.57	0.32	0.06	0.06	0.06	0.06	0.04	0.15
Reactive Phosphorous	mg/L	0.01	0.02*	<0.01	0.05	0.03	0.01	0.02	0.02	0.03	0.02	0.05	0.01	0.14
Total Organic Carbon	mg/L	1	-	5	<1	<1	12	32	3	1	18	1	1	24
Dissolved Gases														
Methane	µg/L	10	-	<10	19	<10	<10	<10	<10	49	655	186	190	16400
Phenolic compounds														
Phenol	µg/L	1	320	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-Chlorophenol	µg/L	1	490	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-Methylphenol	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
3-&4-Methylphenol	µg/L	2	-	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
2-Nitrophenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4-Dimethylphenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4-Dichlorophenol	µg/L	1	160	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.6-Dichlorophenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-Chloro-3-Methylphenol	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4.6-Trichlorophenol	µg/L	1	20	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4.5-Trichlorophenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Pentachlorophenol	µg/L	2	ID	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Polycyclic aromatic hydrocarbons														
Naphthalene	µg/L	1	0.016	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Acenaphthylene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Acenaphthene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Fluorene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Phenanthrene	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Anthracene	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Fluoranthene	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Pyrene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benz(a)anthracene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chrysene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(b)fluoranthene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(k)fluoranthene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(a)pyrene	µg/L	0.5	ID	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Dibenz(a.h)anthracene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(g.h.i)perylene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total petroleum hydrocarbons														
C6-C9 Fraction	µg/L	20	ID	<20	<20	<20	<20	<20	<20	<20	80	<20	<20	<20
C10-C14 Fraction	µg/L	50	ID	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15-C28 Fraction	µg/L	100	ID	<100	160	200	<100	<100	250	220	140	240	200	120
C29-C36 Fraction	µg/L	50	ID	<50	110	100	<50	<50	280	130	100	200	190	70
C10-C36 Fraction (sum)	µg/L	50	-	<50	270	300	<50	<50	530	350	240	440	390	190
Aromatic Hydrocarbons														
Benzene	µg/L	1	950	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	µg/L	2	ID	<5	<5	<5	<5	<5	<5	<5	31	<5	<5	<5
Ethyl Benzene	µg/L	2	ID	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
m&p-Xylenes	µg/L	2	ID	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
o-Xylenes	µg/L	2	350	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Isotopes														
Oxygen-18	‰	0.01	-	-4.56	-4.68	-4.28	na	na	-4.81	-4.95	-4.89	-5.08	-3.82	-4.4
Deuterium	‰	0.1	-	-24.3	-25.5	-22.7	na	na	-24.4	-26.2	-25.8	-26.6	-20.2	-25.3
Carbon-13	‰	0.1	-	-12.9	-14.4	-12.8	na	na	-12.4	-15	-18	-13.7	-16.5	-4.4
Radiocarbon	pMC	0.1	-	79.88 ± 0.27	71.84 ± 0.25	89.96 ± 0.3	na	na	86.44±0.21	38.76±0.13	19.29±0.1	5.51±0.07	39.12±0.13	30.89±0.12
Radiocarbon Age (uncorrected)	yrs BP	1	-	1745 ± 25	2598 ± 30	791 ± 25	na	na	1111±20	7555±30	13161±40	23232±95	7479±25	9377±30
Tritium	TU	0.01	-	0.03±0.03^	0.16±0.04^	0.16±0.04^	na	na	*	0.04±0.04^	0.19±0.05^	0.06±0.04^	0.03±0.04^	0.18±0.04^

Analyte	AMB01	AMB02	RMB01	RMB02	S4MB01	S4MB02	S4MB03	S5MB01	S5MB02	S5MB03	TCMB02	TCMB03	TCMB04	TSW01	ASW01	ASW02
Sample date	08/04/11	08/04/11	12/04/11	12/04/11	06/04/11	06/04/11	06/04/11	05/04/11	05/04/11	05/04/11	13/05/11	14/04/11	24/06/11	07/04/11	08/04/11	08/04/11
Lithology	Mixed gravels	Mixed gravels	Sandstone	Sandstone	Sandstone	Sandstone/siltstone	Coal	Sandstone/siltstone	Siltstone	Coal/shale	Sandstone	Coal & sandstone	Coal			
Formation	Avon R Alluvium	Avon R Alluvium	Upper Leloma	Upper Leloma	Leloma Fm	Leloma Fm	Cloverdale Coal Seam (Jilleon Fm)	Leloma Fm	Jilleon Fm	Roseville Seam Jilleon Fm	Leloma Fm	Jilleon Fm	Roseville Coal Seam Jilleon Fm			
Screen Depth	8-10	6.5-11	42-48	85-91	58-64	89-95	162-168	52-58	100-112	158-164	175-181	260-266	327.3-333.3			
Aquifer	Alluvial	Alluvial	Confining - Leloma Fm	Confining - Leloma Fm	Confining - Leloma Fm	Confining - Leloma Fm	Coal - Jilleon Fm	Confining - Leloma Fm	Confining - Jilleon Fm	Coal - Jilleon Fm	Confining - Leloma Fm	Coal - Jilleon Fm	Coal - Jilleon Fm			
General Parameters																
pH	na	na	6.88	7.25	na	na	na	na	na	na	na	9.97	11.2	na	na	na
Conductivity	2340	417	11100	8380	2890	2460	3200	6100	4340	3770	3200	3020	3650	324	161	158
Total Dissolved Solids	1350	414	6090	4850	1820	1540	1800	3830	2550	2210	1850	1790	1850	236	199	192
Calculated Total Dissolved Solids#	1438	357	6832	5907.57	1917	1565	2092	3808	3043	2716	1669	1728	2162	236	140	137
Laboratory Analytes																
Hydroxide Alkalinity as CaCO3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	102	<1	<1	<1
Carbonate Alkalinity as CaCO3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	309	359	428	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	132	102	832	1040	307	204	274	364	806	711	111	149	<1	52	30	29
Total Alkalinity as CaCO3	132	102	832	1040	307	204	274	364	806	711	420	508	530	52	30	29
Sulfate as SO4 2-	34	14	5	214	103	38	5	790	94	43	31	2	31	18	<1	<1
Chloride	696	54	3420	2440	731	693	911	1160	913	886	743	801	678	56	24	24
Calcium	102	14	173	77	131	96	22	62	22	69	9	3	2	12	5	5
Magnesium	56	5	100	56	34	29	6	60	13	56	15	8	<1	8	3	3
Sodium	279	61	1990	1780	425	385	702	1140	924	706	672	672	734	38	17	16
Potassium	2	1	13	12	24	6	5	88	12	23	6	8	28	4	7	7
Silica	47.6	40.7	17.6	22.9	38.1	24.8	34.5	22.9	21.6	21.8	24.4	11.4	25.1	17.8	22.1	22.1
Ions																
Total Anions	23	3.87	113	94.2	28.9	24.4	31.3	56.3	43.8	40.1	30	32.8	30.4	2.99	1.29	1.26
Total Cations	21.9	3.81	104	86.2	28.4	24.1	32.3	59.8	42.7	39.4	31	30.3	32.7	3.08	1.43	1.37
Ionic Balance	2.39	0.83	4.37	4.46	0.82	0.66	1.55	2.98	1.28	0.94	1.66	4.04	3.74	1.4		
Dissolved Metals																
Aluminium	<0.01	<0.01	<0.01	0.02	0.1	<0.01	0.38	1.36	0.46	0.02	0.01	0.1	3.87	0.02	0.66	0.17
Arsenic	0.005	0.003	0.001	0.021	0.005	0.002	0.002	0.018	0.004	0.004	0.007	<0.001	<0.001	<0.001	0.002	0.001
Beryllium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	0.58	0.066	17.5	0.76	0.878	1.79	1.54	0.099	0.418	1.04	0.972	0.637	0.054	0.044	0.053	0.045
Cadmium	0.0002	0.0002	0.0002	0.0002	0.881	0.0006	0.0004	0.0003	<0.0001	0.0002	0.0001	<0.0001	0.0001	0.0006	<0.0001	0.0002
Cobalt	0.027	0.002	0.001	<0.001	0.002	<0.001	<0.001	0.005	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Copper	0.002	0.002	0.006	0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.002	0.002	<0.001	0.004	0.003	0.003	0.007
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001	<0.001
Manganese	3.5	0.17	0.05	0.184	0.32	0.226	0.083	0.212	0.108	0.137	<0.001	0.02	<0.001	0.046	0.035	0.031
Molybdenum	<0.001	<0.001	0.003	<0.001	0.003	0.003	<0.001	0.035	0.005	0.006	0.01	0.004	0.005	<0.001	<0.001	<0.001
Nickel	0.009	0.002	0.002	0.005	0.01	0.004	0.002	0.016	0.005	0.005	0.004	<0.001	0.003	0.002	0.002	0.003
Selenium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	1.78	0.235	16.7	6.58	10.8	7.83	1.72	8.59	1.96	5.2	1.59	1.04	0.125	0.16	0.115	0.07
Uranium	<0.001	<0.001	<0.001	0.012	0.002	0.001	<0.001	0.042	0.005	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Vanadium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.036	0.02	0.028	0.007	0.007	0.007	0.006	0.046	0.024	0.04	0.028	0.036	0.35	0.027	0.017	0.031
Boron	<0.05	<0.05	<0.05	0.09	0.06	<0.05	<0.05	0.14	0.08	0.07	<0.05	<0.05	0.06	<0.05	<0.05	<0.05
Iron	6.05	0.9	1.63	0.07	0.54	0.73	0.41	3.38	1.15	0.18	<0.05	0.13	<0.05	0.26	1.37	0.77
Bromine	0.9	0.3	8.1	4.9	1.2	1	1.4	3.3	2.1	1.6	0.8	0.9	1.2	0.2	0.2	0.2
Nutrients																
Ammonia as N	0.22	0.06	3.08	1.74	1.17	1.14	0.98	2.91	1.45	1.56	10.3	0.78	1.24	0.03	0.02	0.04
Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.03	0.02	<0.01
Nitrite + Nitrate as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.03	0.02	<0.01
Total Phosphorous	0.28	0.1	0.11	0.11	0.07	0.03	0.11	0.3	0.44	0.13	0.01	0.2	0.03	0.08	0.3	0.24
Reactive Phosphorous	<0.01	<0.01	0.09	0.05	0.06	0.01	0.05	0.03	0.06	<0.01	0.04	0.09	0.02	0.06	0.15	0.16
Total Organic Carbon	3	4	10	52	11	5	6	98	8	4	89	23	32	9	22	31
Dissolved Gases																
Methane	<10	<10	34500	134	3720	6830	31400	<10	31800	12100	5180	26000	39500	---	---	---
Phenolic compounds																
Phenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.3	<1.0	<1.0	6.4	<1.0	<1.0	<1.0	<1.0	<1.0
2-Chlorophenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-Methylphenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.2	<1.0	<1.0	<1.0	<1.0
3-&4-Methylphenol	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
2-Nitrophenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4-Dimethylphenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4-Dichlorophenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.6-Dichlorophenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-Chloro-3-Methylphenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4.6-Trichlorophenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2.4.5-Trichlorophenol	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Pentachlorophenol	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Polycyclic aromatic hydrocarbons																
Naphthalene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Acenaphthylene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Acenaphthene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Fluorene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Phenanthrene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Anthracene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Fluoranthene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Pyrene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benz(a)anthracene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chrysene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(b)fluoranthene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(k)fluoranthene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(a)pyrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Dibenz(a.h)anthracene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(g.h.i)perylene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total petroleum hydrocarbons																
C6-C9 Fraction	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
C10-C14 Fraction	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15-C28 Fraction	<100	<100	<100	<100	<100	<100	<100	540	160	<100	250	<100	<100	<100	<100	<100
C29-C36 Fraction	<50	<50	<50	<50	<50	<50	<50	160	100	<50	<50	<50	<50	<50	<50	<50
C10-C36 Fraction (sum)	<50	<50	<50	<50	<50	<50	<50	700	260	<50	250	<50	<50	<50	<50	<50
Aromatic Hydrocarbons																
Benzene	<1	<1	<1	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1	<1	<1
Toluene	<5	<5	<5	6	<5	<5	<5	<5	9	<5	9	5	<5	<5	<5	<5
Ethyl Benzene	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
m&p-Xylenes	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
o-Xylenes	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Isotopes																
Oxygen-18	-3.49	-4.9	-4.78	-4	-5.04	-5.25	-5.3	-3.94	-4.57	-4.7	-4.99	-4.88	-5.31	na	na	na
Deuterium	-17	-26.3	-25.7	-21.7	-27.3	-28.4	-28.4	-22.8	-24.9	-26.2	-27.5	-26.1	-29.6	na	na	na
Carbon-13	-15.6	-12.2	-2.9	-1.9	-17.5	-18.8	-14.4	-31.8	-14.4	-14.8	-12.3	-12.8	-12	na	na	na
Radiocarbon	77.48±0.24	102.18±0.29	6.5 ± 0.07	19.87 ± 0.1	31.61±0.12	14.04±0.09	6.15±0.07	53.24±0.16	27.5±0.11	30.27±0.11	4.36±0.06	3.77±0.06	11.87±0.08	na	na	na
Radiocarbon Age (uncorrected)	1990±25	-232±25	21894 ± 85	12921 ± 40	9193±30	15711±50	22340	5004±25	10312±35	9541±30	25110±110	26270±130	17060±55	na	na	na
Tritium	0.65±0.05	0.88±0.06	0.03±0.03^	0.39±0.05	0.05±0.04^	0.04±0.04^	0.01±0.04^	0.29±0.04	0.09±0.04^	0.03±0.03^	0.055±0.014^	0.01±0.04^	na	na	na	na

exceeds guideline limits   ID - Insufficient data   na - not analysed

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems.

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems

Calculated using Aquachem   * Sample misplaced by lab

^ This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefore has an unacceptable level of uncertainty. Hence the data should only be used as an indicator of true concentration.

PARSONS BRINCKERHOFF

Summary Table 4

Tiedman Dams laboratory and field results

SUMMARY TABLE 4: TIEDMAN HOLDING DAM WATER QUALITY RESULTS

Analyte	Units	LOR	ANZECC 2000 Guidelines	Dam Samples							
				Tiedeman North Dam	Tiedeman South Dam	North Dam (Deep)	North Dam (Shallow)	South Dam (Deep)	South Dam (Shallow)	North Dam	South Dam
Sample date				**26/10/10**	**26/10/10**	**10/01/11**	**10/01/11**	**10/01/11**	**10/01/11**	**20/01/11**	**20/01/11**
General Parameters											
pH	pH units	0.01	6.5 - 8.0*								
Conductivity	µS/cm	1	125 - 2200*	4280	2790	4180	4240	2610	2650	na	na
Total Dissolved Solids	mg/L	1	-	2780	1810	2600	2500	1910	1640	na	na
Calculated Total Dissolved Solids#	mg/L	-	-								
Laboratory Analytes											
Hydroxide Alkalinity as CaCO3	mg/L	1	-	<1	<1	<1	<1	<1	<1	na	na
Carbonate Alkalinity as CaCO3	mg/L	1	-	454	314	341	457	231	354	na	na
Bicarbonate Alkalinity as CaCO3	mg/L	1	-	901	464	989	872	577	395	na	na
Total Alkalinity as CaCO3	mg/L	1	-	1360	778	1330	1330	808	748	na	na
Sulfate as SO4 2-	mg/L	1	-	<5	22	14	12	29	23	na	na
Chloride	mg/L	1	-	569	425	634	663	466	489	na	na
Calcium	mg/L	1	-	<1	3	2	1	3	5	na	na
Magnesium	mg/L	1	-	<1	1	<1	<1	1	2	na	na
Sodium	mg/L	1	-	769	624	776	768	602	604	na	na
Potassium	mg/L	1	-	323	43	317	320	40	42	na	na
Silica	mg/L	0.1	-	-	-	20.8	21.8	15.1	15.7	na	na
Ions											
Total Anions	meq/L	0.01	-	43.1	28	44.8	45.5	29.9	29.2	na	na
Total Cations	meq/L	0.01	-	41.7	28.5	42	41.6	27.5	27.8	na	na
Ionic Balance	%	0.01	-	1.7	0.85	3.24	4.45	4.26	2.56	na	na
Dissolved Metals											
Aluminium	mg/L	0.01	0.055			0.13	0.48	0.07	0.05	na	na
Arsenic	mg/L	0.001	0.013 (As V)	na	na	0.008	0.008	0.009	0.007	na	na
Beryllium	mg/L	0.001	ID	na	na	<0.001	<0.001	<0.001	<0.001	na	na
Barium	mg/L	0.001	-	na	na	0.228	0.086	0.241	0.265	na	na
Cadmium	mg/L	0.0001	0.0002	na	na	0.0002	<0.0001	0.0002	0.0003	na	na
Cobalt	mg/L	0.001	ID	na	na	<0.001	<0.001	<0.001	<0.001	na	na
Copper	mg/L	0.001	0.0014	na	na	0.003	0.143	0.002	0.009	na	na
Lead	mg/L	0.001	0.0034	na	na	<0.001	<0.001	<0.001	<0.001	na	na
Manganese	mg/L	0.001	1.9	na	na	0.004	0.006	0.005	0.003	na	na
Molybdenum	mg/L	0.001	ID	na	na	0.024	0.024	0.025	0.024	na	na
Nickel	mg/L	0.001	0.011	na	na	0.004	0.002	0.004	0.004	na	na
Selenium	mg/L	0.01	0.011 (total)	na	na	<0.01	<0.01	<0.01	<0.01	na	na
Strontium	mg/L	0.001	-	na	na	0.229	0.157	0.3	0.361	na	na
Uranium	mg/L	0.001	ID	na	na	<0.001	<0.001	0.001	0.001	na	na
Vanadium	mg/L	0.01	ID	na	na	0.01	0.01	<0.01	<0.01	na	na
Zinc	mg/L	0.005	0.008	na	na	0.017	0.018	0.026	0.028	na	na
Boron	mg/L	0.05	0.37	na	na	0.83	0.79	0.7	0.7	na	na
Iron	mg/L	0.05	ID	na	na	0.11	0.12	0.09	<0.05	na	na
Bromine	mg/L	0.1	ID	na	na	1.9	1.8	0.9	0.9	na	na
Mercury	mg/L	0.0001	0.0006	na	na						
Nutrients											
Ammonia as N	mg/L	0.01	0.02*			0.19	<0.01	3.6	<0.01	na	na
Nitrite as N	mg/L	0.01	-	na	na	<0.01	<0.01	<0.01	<0.01	na	na
Nitrate as N	mg/L	0.01	0.7	na	na	0.02	<0.01	0.01	0.03	na	na
Nitrite + Nitrate as N	mg/L	0.01	0.04*	na	na	0.02	<0.01	0.01	0.03	na	na
Total Phosphorous	mg/L	0.01	0.05*	na	na	3.61	2.12	3.16	0.46	na	na
Reactive Phosphorous	mg/L	0.01	0.02*	na	na	<0.01	0.05	0.36	<0.01	na	na
Total Organic Carbon	mg/L	1	-	na	na	35	52	120	52	na	na
Dissolved Gases											
Methane	µg/L	10	-	na	na	na	na	na	na	na	na
Phenolic compounds											
Phenol	µg/L	1	320	na	na	na	na	na	na	na	na
2-Chlorophenol	µg/L	1	490	na	na	na	na	na	na	na	na
2-Methylphenol	µg/L	1	-	na	na	na	na	na	na	na	na
3-&4-Methylphenol	µg/L	2	-	na	na	na	na	na	na	na	na
2-Nitrophenol	µg/L	1	ID	na	na	na	na	na	na	na	na
2.4-Dimethylphenol	µg/L	1	ID	na	na	na	na	na	na	na	na
2.4-Dichlorophenol	µg/L	1	160	na	na	na	na	na	na	na	na
2.6-Dichlorophenol	µg/L	1	ID	na	na	na	na	na	na	na	na
4-Chloro-3-Methylphenol	µg/L	1	-	na	na	na	na	na	na	na	na
2.4.6-Trichlorophenol	µg/L	1	20	na	na	na	na	na	na	na	na
2.4.5-Trichlorophenol	µg/L	1	ID	na	na	na	na	na	na	na	na
Pentachlorophenol	µg/L	2	ID	na	na	na	na	na	na	na	na
Polycyclic aromatic hydrocarbons											
Naphthalene	µg/L	1	0.016	na	na	na	na	na	na	<0.1	<0.1
Acenaphthylene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Acenaphthene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Fluorene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Phenanthrene	µg/L	1	ID	na	na	na	na	na	na	<0.1	<0.1
Anthracene	µg/L	1	ID	na	na	na	na	na	na	<0.1	<0.1
Fluoranthene	µg/L	1	ID	na	na	na	na	na	na	<0.1	<0.1
Pyrene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Benz(a)anthracene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Chrysene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Benzo(b)fluoranthene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Benzo(k)fluoranthene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Benzo(a)pyrene	µg/L	0.5	ID	na	na	na	na	na	na	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Dibenz(a.h)anthracene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Benzo(g.h.i)perylene	µg/L	1	-	na	na	na	na	na	na	<0.1	<0.1
Total petroleum hydrocarbons											
C6-C9 Fraction	µg/L	20	ID	<20	<20	na	na	na	na	<20	<20
C10-C14 Fraction	µg/L	50	ID	<50	<50	na	na	na	na	<50	<50
C15-C28 Fraction	µg/L	100	ID	<100	<100	na	na	na	na	<100	<100
C29-C36 Fraction	µg/L	50	ID	<50	<50	na	na	na	na	<50	<50
C10-C36 Fraction (sum)	µg/L	50	-	<50	<50	na	na	na	na	<50	<50
Aromatic Hydrocarbons											
Benzene	µg/L	1	950	<1	<1	na	na	na	na	<1	<1
Toluene	µg/L	2	ID	<5	<5	na	na	na	na	<5	<5
Ethyl Benzene	µg/L	2	ID	<2	<2	na	na	na	na	<2	<2
m&p-Xylenes	µg/L	2	ID	<2	<2	na	na	na	na	<2	<2
o-Xylenes	µg/L	2	350	<2	<2	na	na	na	na	<2	<2
Isotopes											
Oxygen-18	‰	0.01	-	na	na	na	na	na	na	na	na
Deuterium	‰	0.1	-	na	na	na	na	na	na	na	na
Carbon-13	‰	0.1	-	na	na	na	na	na	na	na	na
Radiocarbon	pMC	0.1	-	na	na	na	na	na	na	na	na
Radiocarbon Age (uncorrected)	yrs BP	1	-	na	na	na	na	na	na	na	na
Tritium	TU	0.01	-	na	na	na	na	na	na	na	na

exceeds guideline limits   ID - Insufficient data

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger va

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems

\# Calculated using Aquachem

NA - not analysed

Other Field Data	Units	Guidelines	North Dam (Deep)	North Dam (Shallow)	South Dam (Deep)	South Dam (Shallow)
Date			**10/01/11**	**10/01/11**	**10/01/11**	**10/01/11**
Depth	mbgl					
Groundwater Level	mbtoc					
Water Quality Paramete	**Units**					
Temperature	°C	ID	26.16	23.8	23.51	26.8
Conductivity	µS/cm	125 - 2200*	2414	3994	2538	2766
Dissolved Oxygen	%	85 - 110*	95.4	31.2	56	133.4
Dissolved Oxygen	mg/L	-	7.95	2.5	4.62	10.46
pH		6.5 - 8*	9.82	9.82	10.03	10.28
TDS	mg/L	ID				
Redox	mV	ID				
CO2 titration	mg/L	-				
			North Dam (D)	North Dam (S)	South Dam (D)	South Dam (S)
			10/01/11	10/01/11	10/01/11	10/01/11
Water type			Na-K-HCO3-Cl	Na-K-Cl-HCO3	Na-Cl-HCO3	Na-Cl-HCO3

Summary Table 5

Stratford Dams laboratory and field results

SUMMARY TABLE 5: STRATFORD HOLDING DAM WATER QUALITY RESULTS

Analyte	Units	LOR	ANZECC 2000 Guidelines	Dam sample	
				S1/2	S3/2
Sample date				**04/08/11**	**04/08/11**
General Parameters					
pH	pH units	0.01	6.5 - 8.0*		
Conductivity	µS/cm	1	125 - 2200*	1680	2110
Total Dissolved Solids	mg/L	1	-	972	1170
Calculated Total Dissolved Solids#	mg/L	-	-	1281	1662
Laboratory Analytes					
Hydroxide Alkalinity as CaCO3	mg/L	1	-	<1	<1
Carbonate Alkalinity as CaCO3	mg/L	1	-	125	359
Bicarbonate Alkalinity as CaCO3	mg/L	1	-	298	232
Total Alkalinity as CaCO3	mg/L	1	-	424	592
Sulfate as SO4 2-	mg/L	1	-	11	4
Chloride	mg/L	1	-	252	286
Calcium	mg/L	1	-	2	2
Magnesium	mg/L	1	-	1	1
Sodium	mg/L	1	-	372	473
Potassium	mg/L	1	-	8	22
Silica	mg/L	0.1	-		
Ions					
Total Anions	meq/L	0.01	-	15.8	20
Total Cations	meq/L	0.01	-	16.6	21.3
Ionic Balance	%	0.01	-	2.3	3.2
Dissolved Metals					
Aluminium	mg/L	0.01	0.055	0.02	0.02
Arsenic	mg/L	0.001	0.013 (As V)	0.004	0.003
Beryllium	mg/L	0.001	ID	<0.001	<0.001
Barium	mg/L	0.001	-	0.244	0.426
Cadmium	mg/L	0.0001	0.0002	<0.0001	<0.0001
Cobalt	mg/L	0.001	ID	<0.001	<0.001
Copper	mg/L	0.001	0.0014	<0.001	<0.001
Lead	mg/L	0.001	0.0034	<0.001	<0.001
Manganese	mg/L	0.001	1.9	<0.001	0.004
Molybdenum	mg/L	0.001	ID	0.016	0.011
Nickel	mg/L	0.001	0.011	<0.001	0.001
Selenium	mg/L	0.01	0.011 (total)	<0.01	<0.01
Strontium	mg/L	0.001	-	0.286	0.427
Uranium	mg/L	0.001	ID	<0.001	<0.001
Vanadium	mg/L	0.01	ID	<0.01	<0.01
Zinc	mg/L	0.005	0.008	<0.005	<0.005
Boron	mg/L	0.05	0.37	0.33	0.59
Iron	mg/L	0.05	ID	<0.05	<0.06
Bromine	mg/L	0.1	ID	0.4	1.6
Mercury	mg/L	0.0001	0.0006	<0.0001	<0.0001
Nutrients					
Ammonia as N	mg/L	0.01	0.02*	0.85	<0.01
Nitrite as N	mg/L	0.01	-	na	na
Nitrate as N	mg/L	0.01	0.7	na	na
Nitrite + Nitrate as N	mg/L	0.01	0.04*	na	na
Total Phosphorous	mg/L	0.01	0.05*	0.18	1.06
Reactive Phosphorous	mg/L	0.01	0.02*	na	na
Total Organic Carbon	mg/L	1	-	44	55
Dissolved Gases					
Methane	µg/L	10	-	na	na
Phenolic compounds					
Phenol	µg/L	1	320	<1	<1
2-Chlorophenol	µg/L	1	490	<1	<1
2-Methylphenol	µg/L	1	-	<1	<1
3-&4-Methylphenol	µg/L	2	-	<2	<2
2-Nitrophenol	µg/L	1	ID	<1	<1
2.4-Dimethylphenol	µg/L	1	ID	<1	<1
2.4-Dichlorophenol	µg/L	1	160	<1	<1
2.6-Dichlorophenol	µg/L	1	ID	<1	<1
4-Chloro-3-Methylphenol	µg/L	1	-	<1	<1
2.4.6-Trichlorophenol	µg/L	1	20	<1	<1
2.4.5-Trichlorophenol	µg/L	1	ID	<1	<1
Pentachlorophenol	µg/L	2	ID	<2	<2
Polycyclic aromatic hydrocarbons					
Naphthalene	µg/L	1	0.016	<1	<1
Acenaphthylene	µg/L	1	-	<1	<1
Acenaphthene	µg/L	1	-	<1	<1
Fluorene	µg/L	1	-	<1	<1
Phenanthrene	µg/L	1	ID	<1	<1
Anthracene	µg/L	1	ID	<1	<1
Fluoranthene	µg/L	1	ID	<1	<1
Pyrene	µg/L	1	-	<1	<1
Benz(a)anthracene	µg/L	1	-	<1	<1
Chrysene	µg/L	1	-	<1	<1
Benzo(b)fluoranthene	µg/L	1	-	<1	<1
Benzo(k)fluoranthene	µg/L	1	-	<1	<1
Benzo(a)pyrene	µg/L	0.5	ID	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	µg/L	1	-	<1	<1
Dibenz(a.h)anthracene	µg/L	1	-	<1	<1
Benzo(g.h.i)perylene	µg/L	1	-	<0.5	<0.5
Total petroleum hydrocarbons					
C6-C9 Fraction	µg/L	20	ID	<20	<20
C10-C14 Fraction	µg/L	50	ID	<50	<50
C15-C28 Fraction	µg/L	100	ID	<100	<100
C29-C36 Fraction	µg/L	50	ID	<50	<50
C10-C36 Fraction (sum)	µg/L	50	-	<50	<50
Aromatic Hydrocarbons					
Benzene	µg/L	1	950	<1	<1
Toluene	µg/L	2	ID	<5	<5
Ethyl Benzene	µg/L	2	ID	<2	<2
m&p-Xylenes	µg/L	2	ID	<2	<2
o-Xylenes	µg/L	2	350	<2	<2
Isotopes					
Oxygen-18	‰	0.01	-	na	na
Deuterium	‰	0.1	-	na	na
Carbon-13	‰	0.1	-	na	na
Radiocarbon	pMC	0.1	-	na	na
Radiocarbon Age (uncorrected)	yrs BP	1	-	na	na
Tritium	TU	0.01	-	na	na

exceeds guideline limits   ID - Insufficient data

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) fo

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems

Calculated using Aquachem

NA - not analysed

Other Field Data	Units	Guidelines	S1/1	S1/2	S1/3	S3/1	S3/2
Date			**04/08/11**	**04/08/11**	**04/08/11**	**04/08/11**	**04/08/11**
Water Quality Parameters	**Units**						
Temperature	°C	ID	12.33	12.51	14.84	13.72	15.24
Conductivity	µS/cm	125 - 2200*	1505	1514	1514	1938	1931
Dissolved Oxygen	%	85 - 110*	115.4	117.6	158.6	152	164.8
Dissolved Oxygen	mg/L	-	12.24	12.09	14.59	15.45	16.48
pH		6.5 - 8*	8.69	10.37	10.71	10.95	10.56
TDS	mg/L	ID	978	985	982	1262	1256
Redox	mV	ID	38.7	48.6	47.4	37.5	40.3
Water type				Na-HCO3-Cl			Na-HCO3-Cl

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