AGL Upstream Investments Pty Ltd

Updated Conceptual Hydrogeological Model of the Gloucester Basin

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PARSONS BRINCKERHOFF

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Glossary

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.
Anisotropy	The condition under which one or more of the hydraulic properties of an aquifer vary according to the direction of flow.
Aquatic ecosystem	The stream channel, lake or estuary bed, water, and (or) biotic communities and the habitat features that occur therein.
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.
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.
Baseflow	The part of stream discharge that originates from groundwater seeping into the stream.
Bedding plane	In sedimentary or stratified rocks, the division plane which separates the individual layers, beds or strata.
Beneficial aquifers	Aquifers found in the alluvium and fractured rock less than 75m from surface.
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.
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. Deep coal seams are those greater than 150 m below ground level (mbgl).
Coal seam gas (CSG)	Coal seam gas is a form of natural gas (predominantly methane) that is extracted from coal seams.
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.
Confining layer	Low permeability strata that may be saturated but will not allow water to move through it under natural hydraulic gradients.
Deep coal measures	Generic term for all sedimentary rock units within the Gloucester Basin that are deeper than 150 mbgl. It includes two hydrogeological units – the interburden confining units and coal seam water bearing zones.
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.
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.
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.
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.
Gigalitre (GL)	A thousand megalitres (or a billion litres).
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.
Heterogeneous	Pertaining to a substance having different characteristics in different locations.
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 gradient	The change in total hydraulic head with a change in distance in a given direction.
Hydraulic head	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.
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.
Hydrogeological unit	A rock or soil unit with similar hydraulic properties. The hydrogeological unit often corresponds to the lithological or geological unit, but not always. For instance, a fault zone or weathered zone may form a hydrogeological unit that is discordant with respect to geological unit boundaries.
Hydrology	The study of the occurrence, distribution, and chemistry of all surface waters.
Interburden	Indurated sedimentary rocks (primarily sandstone and siltstone units) deeper than 150 mbgl that are typically very low permeability, and form aquitards and confining layers.
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).
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.
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.
Quaternary	The most recent geological period extending from approximately 2.5 million years ago to the present day.
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.
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).
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 slightly saline 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.
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).
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.
Shallow rock aquifer	In this report shallow rock aquifer is the hydrogeological unit that extends from the ground surface to a depth of approximately 150 mbgl that has elevated permeability and storage due to fracturing of the rock mass, compared with the deeper coal measures. It is the collective of shallow sedimentary rock and fractured rock aquifers in the shallow part of the Gloucester Basin.
Siltstone	A fine-grained rock of sedimentary origin composed mainly of silt-sized particles (0.004 to 0.06 mm).
Slickenside	A polished and striated rock surface caused by movement on a fault plane
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.
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.
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. These zones typically occur greater than 150 mbgl.
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.

Executive summary

AGL Upstream Investments Pty Ltd (AGL) is proposing to build the Gloucester Gas Project (GGP) which comprises several stages of development facilitating the extraction of coal seam gas (CSG) from the Gloucester Basin. NSW Project Approval PA 08_0154 (Part 3A Approval) (conditions 3.8 and 3.9) and Commonwealth EPBC Approval 2008/4432 (condition 16) require that the conceptual hydrogeological model developed during the assessment stage of the project is updated in consultation with DPI Water (previously NSW Office of Water (NOW)) based on additional baseline data gathered. This report presents the updated conceptual hydrogeological model for the Gloucester Basin which primarily focuses on the Stage 1 gas field development area (GFDA), building on previous conceptual hydrogeological models and incorporating data from current and ongoing hydrogeological investigations across the Basin.

The purpose of this report is to document all aspects of the conceptual model, including all information required by DPI Water, for submission to the Department of Planning and Environment (DPE). Approval from the Secretary of the DPE is required to satisfy Part 3A Condition 3.9. The information in this report will feed into the development of the Numerical Hydrogeological Model required under Part 3A Condition 4.2 and EPBC Condition 18.

The hydrology of the Gloucester Basin is dominated by surface water flows with groundwater flows (and interaction with surface water) being a very small component of the water balance. There are four key hydrogeological units of which only the two shallow systems contain beneficial aquifers. The beneficial aquifers are contained within the alluvium and the shallow fractured rock to around 75m depth. There are no beneficial aquifers in the deep coal seams or interburden rocks. The groundwater systems are low permeability (and low yielding) and generally contain brackish to moderately saline groundwater. Groundwater flow within the deep systems is very slow and there is no evidence of enhanced connectivity between shallow aquifers and the deeper water bearing zones.

Stage 1 of the Gloucester Gas Project proposes a comprehensive groundwater monitoring strategy (the Groundwater Modelling and Monitoring Plan (GMMP)), which commenced in the exploration phase (under the Surface and Groundwater Management and Produced Water Management Plans). The Stage 1 GMMP will contain Trigger Action Response Plans (TARPS) to address any unexpected or unusual groundwater monitoring results, which will also build on the knowledge gathered during the exploration phase.

Given there is no evidence of enhanced connectivity between surface water or beneficial aquifers, and deeper water bearing zones, this report recommends that discrete development phases for gas well development in Stage 1, and milestones for associated changes to the groundwater monitoring strategy, are not warranted.

The current level of knowledge about the hydrogeology of the Gloucester Basin, which includes more than four years of data, local numerical modelling and several flow/pilot tests, as well as the proposed wellfield construction methodology, risk mitigation measures and monitoring strategy, indicates that a single phase development approach will achieve the objective of avoiding and minimising impacts to groundwater resources.

What is a Conceptual Model?

A conceptual (hydrogeological) model is an idealised representation (i.e. a picture in either words or diagrams) of our hydrogeological understanding of the key flow processes of the groundwater system or systems being investigated.

A sound conceptual model is required prior to developing numerical models that represent the groundwater system/s to an adequate level of detail. Calibrated numerical models can then provide a predictive scientific tool to quantify the impacts on the groundwater system/s of specified hydrological and pumping stresses such as those associated with irrigation, mining and infrastructure projects.

What progress has been made since the Part 3A Project Approval was granted?

A large number of water studies has been completed across the Stage 1 GFDA and beyond since February 2011 including:

- Establishment of a large groundwater and surface water monitoring network
- Collection of more than four years of continuous surface water and groundwater level/pressure data to confirm the conceptual hydrogeological model and understanding of surface water-groundwater interaction
- Water quality and isotope data providing independent verification of the conceptual model
- Geophysical surveys
- Fault investigations
  - Pumping test/flow test programs (Stratford fault investigation)
  - Waukivory pilot investigation
- Property surveys to assess private groundwater use
- Preliminary modelling
  - Cross sectional models (Stratford and Waukivory)
  - Preliminary water balance modelling
- Irrigation program trials

In addition the NSW Aquifer Interference policy has been introduced and there is significantly more regulatory rigour around all the water management aspects of CSG developments.

What are the next steps?

This conceptual model report is the first of several models, strategies and plans to be submitted and approved by the Secretary of the DPE prior to the commencement of construction of the Stage 1 development. The following documents will be submitted for approval/satisfaction sequentially:

- The Conceptual Model Report. The updated conceptual hydrogeological model will inform the numerical modelling. Therefore, confidence is required regarding the conceptual model before proceeding with the numerical modelling.
- The Groundwater Monitoring and Modelling Plan (GMMP) will be developed iteratively with the numerical modelling. The GMMP is expected to be submitted prior to the Field Development Plan (FDP) and numerical modelling reports.
- The FDP will inform, and is an input into, the numerical modelling. The FDP and the numerical modelling will be submitted together.
- The Numerical Hydrogeological Model will be developed in consultation with DPI Water on the basis of the information and recommendations contained in the Conceptual Model Report and the FDP, and submitted for the Secretary's satisfaction along with the FDP.

In addition a Conceptual Field Development Plan (CFDP) has been prepared by AGL as a companion document to this Conceptual Model Report. The CFDP is not a requirement of the Part 3A Approval and does not require DPE approval. Taking into account the recommendations of the Conceptual Model Report and to maximize project efficiencies, AGL is proposing a single phase of construction for the Stage 1 development. The CFDP and the conceptual model demonstrate how the single phased Stage 1 development will avoid and minimise adverse impacts to beneficial aquifers, and satisfactorily manage risks to groundwater in accordance with the requirements of the Part 3A Approval.

The following sub-sections describe the physical setting of the whole Gloucester Basin with a focus on the Stage 1 GFDA and outline the current conceptual hydrogeological model.

Geology

The Gloucester Basin is a broad north-south elongated basin underlain by Permian sedimentary and volcanic rocks that have been folded and faulted into a synclinal (canoe-shaped) structure. The Basin is bounded to the west by the elevated topography of the Gloucester and Barrington Tops, and to the east by the Mograni Range. These topographic divides also correspond to outcrops of the largely impermeable Alum Mountain Volcanics which forms the hydrogeological basement to the Basin. By contrast, the coal measures and near surface rocks within the Basin are slightly more permeable, mainly due to sparse fracturing in near-surface rocks and cleating within coal seams, which form weak water bearing horizons. In hydrogeological terms, the Basin is conceptualised as an essentially closed groundwater basin; all surface water and most discharging groundwater exits the Basin via the Avon and Gloucester Rivers to the north and the Wards River system to the south.

Hydrogeological Units

Four main hydrogeological units influence groundwater flow within the Basin:

1. **Alluvial deposits** adjacent to major creeks and rivers comprising unconsolidated sand, gravel and clay. These systems are heterogeneous but generally permeable with rapid recharge, through-flow and discharge associated with interactions with streams, and to a lesser extent with the underlying less permeable shallow rock.

2. **Shallow fractured rock** comprising variably weathered and fractured sedimentary rocks extending to approximately 150 m below the surface, across all sub-cropping Permian units. The shallow rock zone is highly heterogeneous with relatively impermeable domains separated by more permeable domains, but on the whole it is more permeable that the deeper coal measures.

3. **Deep Coal Measures interburden**. Predominantly sandstone and siltstone units form the interburden to coal seams and are typically of very low permeability, forming aquitards and confining layers. Permeability of the interburden decreases with depth.

4. **Deep coal seams**. Coal seams tend to be slightly more permeable than interburden and commonly form weak water bearing zones. Permeability and storage are provided by small fractures and cleats in the coal. As with the interburden, drill-stem tests clearly show that the permeability of coal seams generally decreases with depth.

Groundwater Recharge, Discharge and Flow

Rainfall is the primary recharge source to the aquifers and water bearing zones within the Gloucester Basin. Minor recharge from streams may occur during periods of high rainfall/surface flow and flooding when there is the potential for the rivers to lose water, particularly in upper catchment areas.

Groundwater outflow predominantly occurs as discharge to gaining streams (baseflow) and, to a lesser extent, direct evapotranspiration losses from the water table where the groundwater is shallow (i.e. close to the creeks and towards the northern and southern Basin outflow points). Monitoring data suggests that most baseflow to the perennial streams is derived from groundwater discharge from the alluvium via relatively short flow paths. By contrast groundwater discharge from the shallow rock and underlying coal measures is via longer flow paths to the base of the alluvium and is expected to be a minor component of stream baseflow.

Regional groundwater flow is controlled by gravitational flow from elevated areas where groundwater is recharged, to low-lying areas where groundwater discharges to streams and to the atmosphere via evapotranspiration. The Basin can be divided into two distinct groundwater flow systems: the northern Gloucester Basin in which groundwater predominantly flows to the north, and the southern Gloucester Basin in which groundwater generally flows in a southerly direction. The boundary between the two flow systems, under natural conditions, corresponds with the catchment divide between the Avon River and Wards River.

The permeability and groundwater flow characteristics of rocks within the Basin are controlled by multiple factors including lithology, depth and the degree of fracturing and potentially faulting. In this sense hydrogeological units and flow systems do not always correspond with defined geological boundaries.

Surface water and groundwater have distinct hydrochemical and isotopic characteristics and define a number of compositional groups. Surface water tends to be of low salinity (<800 µS/cm) relative to adjacent groundwater (locally exceeding 6000 µS/cm). Stream salinities increase during periods of low flow but the water salinity is still fresh to marginal. This indicates that streams are somewhat disconnected from the groundwater systems and that the baseflow that sustains the connected pools during periods of drought is derived from storage within the alluvium.

Most groundwater flow in the Basin occurs in the uppermost aquifer units: the alluvium and to a lesser extent, the shallow fractured rock where it is most permeable.

Groundwater Connectivity

A large number of faults of varying orientations are known to occur within the Basin, many of which are not apparent at the surface or in drill logs. Information from ongoing fault investigations by AGL suggests that in the near surface (shallow rock) faults are represented by broad fractured zones with enhanced permeability and groundwater flow. However in the deeper coal measures (>150 mbgl) faults are likely to be barriers to horizontal flow due to juxtaposition of water bearing units against low permeability interburden. The range in permeability in the deep coal measures (including fractured zones) is well characterised by permeability testing carried out during exploration drilling.

Monitoring of shallow groundwater systems during flow testing of gas wells intersecting deep coal seams has not shown any indication of drawdown or enhanced connection via faulting over the timescale of the tests. Simulations of such tests using numerical models suggest that drawdown impacts within beneficial aquifers are likely to take many years (if ever) to manifest and are likely to be negligible in terms of drawdown at the water table. This is due to the very low permeability of the coal measures and the contrast in storage characteristics between the deep confined units and the shallow unconfined systems.

The potential for longer term drawdown or vertical groundwater movement cannot be further assessed until production commences and long term monitoring data is collated and reviewed.

Water and Salt Balances

Water and salt balances for the Gloucester Basin provide an indication of the main fluxes and storages of water and salt in the Basin. Approximately 322 gigalitres (GL) of rain falls on the Gloucester Basin each year. Of that total, approximately 150 GL (47 %) flows overland, bypassing the groundwater system, and is discharged via the Avon River and Wards River systems; a further 159 GL (49 %) is returned to the atmosphere via evapotranspiration (ET) or otherwise lost from the system. Surface water flows and ET losses therefore dominate the hydrological system, together accounting for 96% of rainfall. Approximately 3.5% of rainfall (~11 GL per year) infiltrates the unsaturated zone to recharge the water table. Recharge rates are higher in the alluvial deposits (4% to 13% of rainfall) and significantly lower in areas where the less permeable shallow fractured rock unit outcrops (~0.5% to 1% of rainfall).

Based on a salt concentration of 20 mg/L and rainfall of 1049 mm per year, it is estimated that average rainfall across the Gloucester Basin delivers 6399 tonnes of salt annually. Under equilibrium, a similar amount of salt is exported via stream flow (the Avon and Wards Rivers). However with land clearing for agriculture and grazing, a greater amount of salt is currently exported via stream flow and sediment loss.

Salt extracted from produced water in the initial years of production is estimated to represent approximately 17% of the average salt load in rainfall (over the whole basin annually); or approximately the same volume of salt that falls on the Stage 1 area as rainfall in an average year. CSG produced water volumes are estimated to decrease significantly after the first couple of years of production to around 3% of the average salt load in rainfall over the whole basin. The exact water production profile will not be known until production commences, however rates are estimated to be less than 10% of the initial flow rates after Year 5. Salt will be removed from extracted water by the proposed desalination plant, crystallised, transported and landfilled outside of the Basin.

Removal of salt from the Basin due to CSG activities in the Stage 1 GFDA will result in a net reduction in salt accumulation in the northern part of the Basin. This reduction will ultimately manifest as a small decrease in the salt flux from the shallow fractured rock to the base of the alluvium, and ultimately to the Avon River system over future decades.

Water Usage

The Basin is relatively undeveloped in terms of groundwater and surface water use. Less than 750 ML of groundwater is used each year from beneficial aquifers for agriculture, mining and stock/domestic use. Most of this groundwater is captured and used by the open cut coal mines. There are no known groundwater dependent ecosystems apart from dependencies on stream baseflow contributed by diffuse groundwater discharge. This baseflow is a small component of total stream flow.

Within the Avon River catchment there is a total of 43 surface water licences with 1996 ML/year in surface water entitlements and 246 ML/year of basic landholder rights. Of this volume, 95% is used for irrigation purposes. Total water entitlements represent 2% of the mean annual flow at the DPI Water stream gauge 208028 on the Avon River.

The Stage 1 development is capped at a maximum dewatering volume of approximately 730 ML per annum (on average 2 ML per day (ML/d)), and will most likely be less than 1 ML/d. Dewatering volumes will be greatest in the initial years of the project and will diminish substantially with time because of the dewatering of the targeted coal seams and the low permeability strata overlying the targeted coal seams. Most groundwater will be derived from the deep coal measures at depths greater than 250 m.

Wellfield Conceptualisation

During operation, the produced water pumped from the deep confined coal measures will be initially derived from storage, and over the following years and decades will be derived from lateral flow through the deep coal seams and minor vertical flow through the overlying interburden.

Water table aquifers in the alluvium and in the uppermost fractured rock (based on the available investigation data) will be the least impacted and are expected to have negligible drawdown. Although property surveys have not identified any private groundwater users in the Stage 1 GFDA, if there were any groundwater users with shallow water supply bores it is highly unlikely that they would experience any water level decline outside of the normal seasonal variations.

Natural groundwater recharge and the high storage characteristics of the shallow and deep groundwater systems are expected to mitigate any vertical groundwater movement associated with CSG depressurisation. Preliminary numerical modelling suggests that the drawdown impacts to the water table and surface water systems are expected to be negligible. Nevertheless, these potential impacts will be closely monitored and modelled in detail via the extensive monitoring network and by using numerical modelling methods.

The numerical modelling will allow some of the uncertainties relating to structure and hydraulic properties to be explored using sensitivity analyses and stochastic approaches. Modelling will quantify the possible range of drawdowns in both shallow and deeper groundwater systems. Given that drawdowns are likely to be negligible within beneficial aquifers (based on the available investigation data and preliminary modelling results) and take many years to propagate, the monitoring and modelling program will be maintained during the Stage 1 development.

1. Introduction

This report presents the updated conceptual hydrogeological model for the groundwater systems of the Gloucester Basin. It builds on previous conceptual hydrogeological models (SRK Consulting 2010, Parsons Brinckerhoff 2012a, Parsons Brinckerhoff 2013a) and incorporates the results of several major investigations carried out over the last two years.

1.1 Gloucester Gas Project

AGL Upstream Investments Pty Ltd (AGL) is proposing to build the Gloucester Gas Project (GGP) which comprises several stages of development facilitating the extraction of coal seam gas (CSG) from the Gloucester Basin. Concept Plan Approval for CSG development across the whole Basin and Project Approval (Part 3A Approval) for the Stage 1 Gas Field Development Area (GFDA) was granted on 22 February 2011 under Part 3A of the *Environmental Planning and Assessment Act (1979)* (EP&A Act). In addition the project received approval under the *Environment Protection and Biodiversity Conservation Act (1999)* (EPBC Act) (EPBC Approval) on 11 February 2013.

AGL holds Petroleum Exploration Licence (PEL) 285, under the *Petroleum (Onshore) Act 1991*, covering the whole of the Gloucester Basin, approximately 100 km north of Newcastle, NSW. PEL 285 expired on 15 April 2012 and was renewed on 6 August 2014. The Stage 1 GFDA in relation to the PEL 285 boundary is shown in Figure 1.1.

The GGP will involve the pumping of deep groundwater 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 250 and 1,000 metres below ground level (mbgl). The current GGP includes the construction, operation and decommissioning of 110 coal seam gas wells and associated infrastructure, including gas and water gathering lines, within the Stage 1 GFDA. The CSG wellfield will be developed in one phase with progressive development of the proposed 110 wells. The drilling program will be 6 to 12 months in advance of the fracture stimulation program.

This conceptual model report should be read in conjunction with the Conceptual Field Development Plan (CFDP) (AGL, 2015b) which describes the proposed single phase of development for Stage 1 and the expected low to negligible risk to groundwater resources and users.

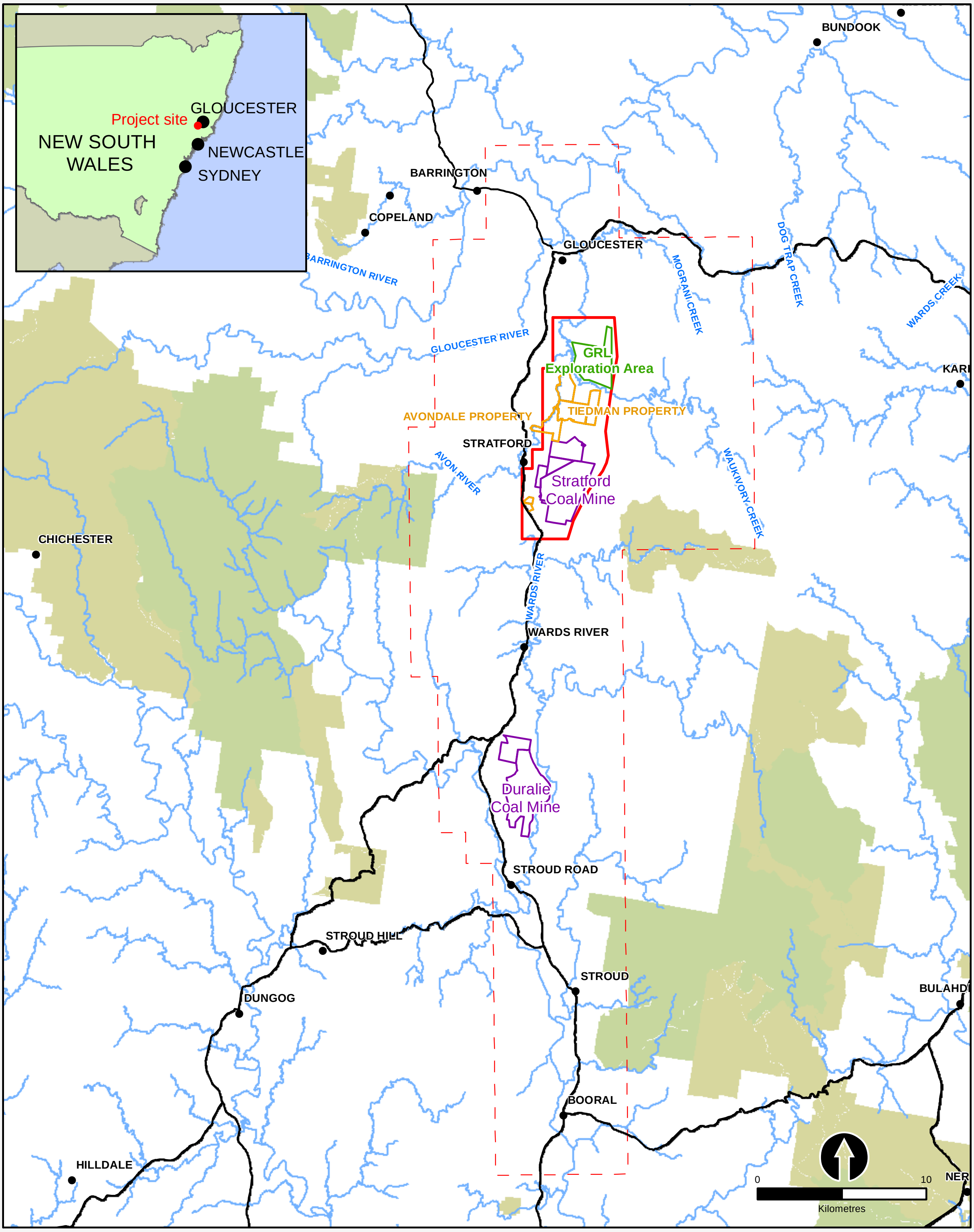
A dedicated water monitoring network is in place which has collected baseline water level and water quality data for the different groundwater and surface water systems within the Gloucester Basin. There are now more than 50 dedicated water monitoring locations and more than four years of baseline monitoring (water levels and water quality) across the Gloucester Basin.

NSW Project Approval PA 08_0154 (Part 3A Approval) (conditions 3.8 and 3.9) and Commonwealth EPBC Approval 2008/4432 (condition 16) require that the conceptual hydrogeological model developed during the assessment stage of the project is updated based on additional baseline data gathered. The collection and interpretation of groundwater and surface water level and quality data enhances and verifies the understanding of the conceptual model, and is the primary scientific data to determine whether there are any impacts resulting from CSG activities on groundwater and surface water systems.

This report (and the accompanying Technical Peer Review) are the documents submitted to the NSW Department of Planning and Environment (DPE) to comply with Condition 3.9 of the Part 3A approval and to the Commonwealth Department of Environment (DoE) to comply with Condition 16 of the EPBC approval.

PARSONS BRINCKERHOFF

HYDROGEOLOGICAL CONCEPTUAL MODEL OF THE GLOUCESTER BASIN
AGL UPSTREAM INVESTMENTS PTY LTD



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- AGL owned properties
- GRL exploration area boundary
- Mining Lease Boundary
- PEL 285 boundary
- Stage 1 GFDA boundary
- Towns
- Major roads
- Rivers and streams
- National Park, Nature Reserve or State Conservation Area
- NSW State Forest

Figure 1.1
Regional location

1.2 Purpose

The purpose of this report is to document all aspects of the conceptual model, including all updates required by DPI Water, for submission to the DPE. Approval from the Secretary of the DPE is required to satisfy Part 3A Condition 3.9 prior to the finalisation and submittal of the numerical model/s required under Part 3A Condition 4.2 and EPBC Condition 18.

1.3 Report structure

This document provides an updated Conceptual Hydrogeological Model of the Gloucester Basin. The report outlines all the relevant studies and data sets used to develop the current conceptual model. The structure of the report is as follows:

- Chapter 2: Provides planning approval context to the proposed development, and a summary of previous studies and reviews across the Gloucester Basin.
- Chapter 3: Provides contextual overview of the Gloucester Basin including topography, drainage and rainfall.
- Chapter 4: Provides a summary of the geology of the Gloucester Basin.
- Chapter 5: Provides a summary of the groundwater and surface water monitoring network.
- Chapter 6: Provides an overview of the hydrology of the Gloucester Basin.
- Chapter 7: Provides a detailed understanding of the hydrogeology of the Gloucester Basin.
- Chapter 8: Provides a review of the understanding of the role of faulting in groundwater flow.
- Chapter 9: Provides a summary of the water and salt balance for the Gloucester Basin.
- Chapter 10: Presents the updated conceptual hydrogeological model.
- Chapter 11: Presents the framework for numerical modelling.
- Chapter 12: Presents the conceptual model conclusions.
- Chapter 13: Is the list of references for this report.

1.4 Compliance with modelling guidelines

The conceptual hydrogeological model will form the basis for the development and calibration of a numerical groundwater model, and this document has therefore been prepared in accordance with the Australian Groundwater Modelling Guidelines (Waterlines Report Series No.82) (Barnett et al, 2012a).

Section 3 of the Australian Groundwater Modelling Guidelines provides guidance on conceptualisation, and specifies that development of the conceptual model should consider:

- Hydrostratigraphy.
- Aquifer properties.
- Conceptual boundaries.
- Stresses.
- Physical processes.

These criteria have been addressed throughout the report (predominantly in Chapter 10). There are also five guiding principles for conceptualisation of groundwater flow processes. The fifth guiding principle requires an ongoing process of refinement. The guidelines also state that the conceptual model should be updated, based on insights obtained during the subsequent stages of the modelling process or when additional data becomes available. Additional data and preliminary modelling completed since mid-2013 are the primary reasons for this updated conceptual model report.

The conceptual model was first articulated in 2010 (SRK Consulting. 2010), and has been progressively updated as field programs have been completed across the Basin. Since the Part 3A project approval in 2011, the conceptual model has been developed in consultation with DPI Water. The most recent conceptual models were provided in Parsons Brinckerhoff, 2012a and Parsons Brinckerhoff, 2013a. The progressive development of this conceptual model is an example of the adaptive management approach required under the modelling guidelines that is being applied to the GGP.

1.5 Other water plans and models

This conceptual model report is the first of several models, strategies and plans to be submitted and approved by the Secretary of the DPE prior to the commencement of construction of the Stage 1 development. The following documents need to be submitted and approved sequentially:

- The conceptual model will inform the numerical modelling. Confidence is required regarding the conceptual model before proceeding with the numerical modelling.
- The Groundwater Monitoring and Modelling Plan (GMMP) will be developed iteratively with the numerical modelling. The GMMP is expected to be submitted prior to the Field Development Plan (FDP) and numerical modelling reports.
- The FDP will inform, and is an input into, the numerical modelling. The FDP and the numerical modelling will be submitted together.

The sequencing of other models and associated water plans required under the Part 3A approval) is shown in Figure 1.2.

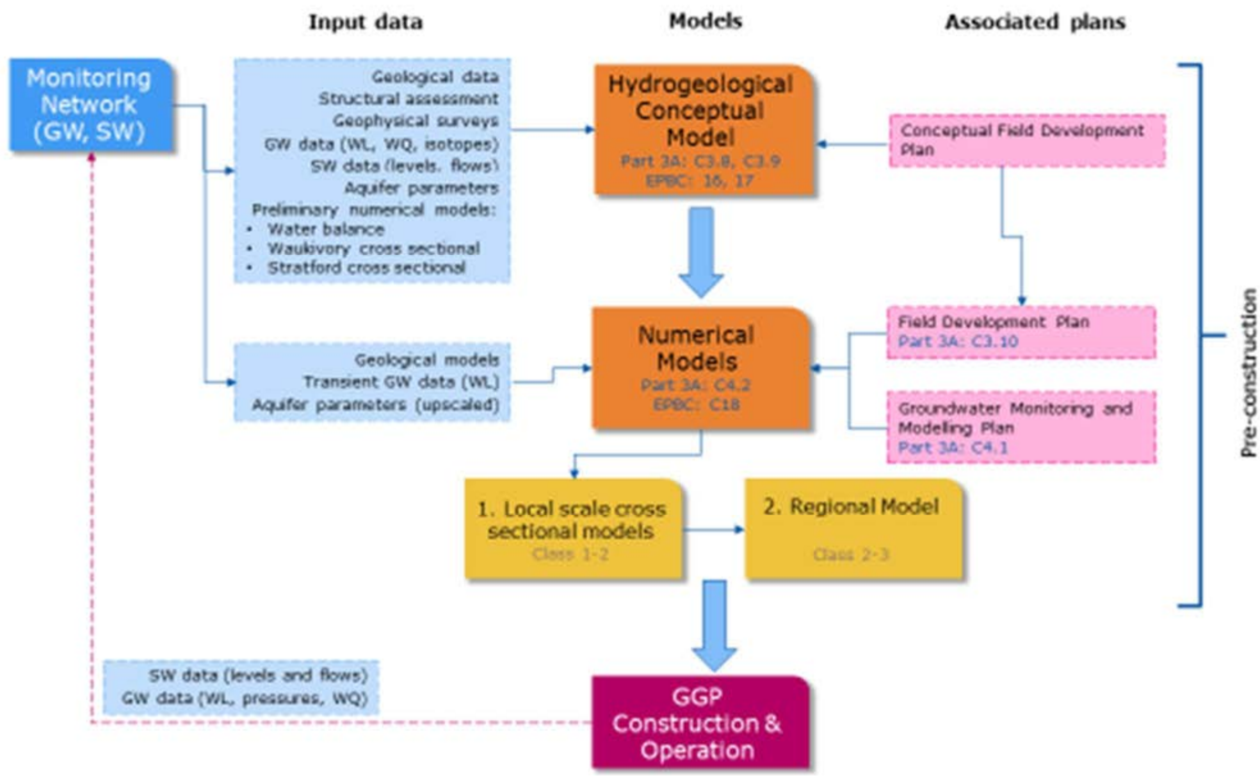

Figure 1.2 **Linkages between the Conceptual Model, Numerical Model/s and Associated Plans**

1.5.1 Field development plans

A CFDP (AGL, 2015b) has been prepared by AGL to inform the FDP and the conceptual model. This plan is submitted to DPE in conjunction with this conceptual model report. AGL is proposing a single phase of construction for the Stage 1 development, consequently the CFDP and the conceptual model have been written to demonstrate how the Stage 1 development will avoid and minimise adverse impacts to beneficial aquifers, and satisfactorily manage risks to groundwater in accordance with the requirements of the Part 3A Approval.

In addition the CFDP:

- Provides an overview of the proposed drilling, fracture stimulation, and commissioning program for the Stage 1 GFDA.
- Considers the minimum impact requirements of the NSW Aquifer Interference (AI) Policy (NOW, 2012) against the proposed development activities.

The CFDP is not required to be approved by DPE however the main field development plan (FDP) that is required under Condition 3.10 of the Part 3A approval needs to be approved by the Secretary of the DPE prior to commencement of construction (or each phase of construction). The FDP is currently under development and is an input into (and will be submitted with) the numerical modelling.

The proposed FDP also informs the numerical modelling and will comprise:

- Wellfield layout.
- Gas well and fracture stimulation design.
- Explanation of the construction program (drilling and then completions).
- Scheduling of drilling and completions programs.
- An assessment of 'minimal impact considerations' under the AI policy.

1.5.2 Numerical models

A sound conceptual model is required prior to developing numerical models that represent the groundwater system/s to an adequate level of detail. Calibrated numerical models can then provide a predictive scientific tool to quantify the impacts on the groundwater system/s of specified hydrological and pumping stresses such as those associated with irrigation, mining and infrastructure projects.

The conceptual model informs the numerical modelling and should be agreed between the proponent, technical peer reviewers and regulatory agencies prior to the numerical modelling.

In addition, numerical modelling should satisfy requirements of NSW AI Policy. Under the policy, numerical modelling should be of sufficient scope and complexity to identify and assess potential impacts to groundwater, connected surface water systems, groundwater dependent ecosystems, and sites of cultural significance and water users.

In this regard, AGL is proposing:

- Local scale cross-sectional modelling to inform model construction and calibration of the numerical model/s required under Condition 4.2 of the Part 3A approval.
- Regional scale impacts modelling to address Condition 4.2 of the Part 3A approval and satisfy requirements of the NSW AI Policy.

The numerical models will also be adaptive management tools used to optimise water management outcomes and minimise any water resource impacts associated with the GGP.

1.5.3 Groundwater monitoring and modelling plan

The groundwater monitoring and modelling plan (GMMP) required under Condition 4.1 is another major plan that informs the numerical modelling. The GMMP outlines the monitoring network and data sets that are required to manage and protect water resources. As well as the criteria that are listed in GMMP guidelines (NOW, 2014) it will include but will not be limited to these Part 3A condition requirements:

- Description of the monitoring network and the locational principles.
- Nominated data types and the frequency of data collection.
- Frequency of reporting.
- Frequency of modelling reviews.
- Performance criteria relating to drawdowns.
- Assessment criteria relating to drawdowns, water quality, and water production rates.
- Trigger Action Response Plans (TARPs) relating to unacceptable drawdowns, water quality changes and water production rates affecting beneficial aquifers, groundwater users and/or groundwater dependent ecosystems.
- Provision for monitoring gas migration to surface.
- Water quality specifications for the proposed fracture stimulation fluids (plus annual updates).
- Provision for ongoing monitoring post decommissioning of wells.
- A schedule for updating the GMMP periodically (either as required because of monitoring data trends, gaps in the monitoring network or modelling outcomes).

The monitoring network for the Stage 1 development will provide the required data to assess the potential for enhanced connectivity between surface water, beneficial aquifers, and deeper water bearing zones.

2. Background

This chapter provides the planning approval and regulatory context for the project and in particular, the conditions that relate to this conceptual model report. For the individual conditions and sub-conditions in each approval that mention the conceptual model report, there is a reference to the appropriate report section. A summary of the independent peer reviews undertaken on previous groundwater studies (and their comments on conceptualisation) is provided in Section 2.4. Information on previously published reports that are relevant to this conceptual model are summarised in Section 2.3.

In addition, the conceptual model has been reviewed by DPI Water (previously NSW Office of Water (NOW)) and their specific requirements have been taken into account in preparing this updated conceptual hydrogeological model report (see Section 2.5).

2.1 Part 3A EP&A Act Approval context

Stage 1 of the GGP was approved by the NSW Planning Assessment Commission on 22 February 2011 under the then Part 3A of the *Environmental Planning and Assessment Act 1979*. Project Approval PA 08_0154 (Part 3A Approval) for the Stage 1 GFDA has several conditions relating to groundwater and surface water management. The conditions and sub-conditions are detailed in Appendix A. Table 2.1 summarises these conditions and the shaded rows identify the conceptual model conditions and where they are addressed in this report. This report focusses on Conditions 3.8 and 3.9 of the Part 3A approval (shaded in Table 2.1).

Table 2.1 Part 3A EP&A Act Approval (Groundwater Management) Conditions

Part 3A condition	Sub-condition	Addressed in this report	Report section
Condition 3.5 (Gas well construction, operation and decommissioning)	Not applicable	No	Not applicable [(a)]
Condition 3.6 (Plug and abandon old exploration wells within 500m radius of new wells)	Not applicable	No	Not applicable [(a)]
Condition 3.7 (No fracture simulation fluids with BTEX)	Not applicable	No	Not applicable [(a)]
Condition 3.8 (Data and investigations for updated conceptual model)	a) Seismic surveys	Yes	Section 4
	b) Field sampling of hydrogeological and hydrological parameters	Yes	Sections 5, 6 and 7
	c) Long term baseline monitoring (at least 6 months)	Yes	Sections 5, 6 and 7
Condition 3.9 (Submit updated conceptual model)	a) Updated assessment of the potential for drawdown	Yes	Section 10.6.1
	b) Optimal areas for gas well location within the Stage 1 GFDA (gas migration and beneficial aquifers)	Yes	Section 10.6.2 and 10.6.4
	c) Recommendations for phased gas well development	Yes	Section 10.6 and 10.6.5
	d) Independent peer review	No	Covered elsewhere [(b)]

Part 3A condition	Sub-condition	Addressed in this report	Report section
Condition 3.10 (Submit field development plan)	a) Must be consistent with condition 3.9 b) For all phases is prepared in consultation with NOW and is consistent with conditions 3.5, 4.1 and 4.2	Introduced	Section 1.5 [c]
Condition 3.11 (Obtain water licence/s and dewatering not to exceed 2 ML/d)	Not applicable	No	Not applicable [a]
Condition 3.12 (Develop extracted water management strategy)	a) to i) – Not applicable	No	Not applicable [a]
Condition 3.13 (Ensure all water storage ponds are lined)	Not applicable	No	Not applicable [a]
Condition 4.1 (Develop groundwater monitoring program)	a) Identify surface and groundwater monitoring locations	Yes	Sections 5, 6 and 7
	b) Provide details of monitoring points	Yes	Section 5, 6 and 7
	c) Identify performance criteria for gas well development	No	Not applicable[a]
	d) Identify the frequency of reporting on monitoring results	No	Not applicable [a]
	e) Provisions for the monitoring of coal seam dewatering rates	No	Not applicable [a]
	f) Provisions for the monitoring of potential gas migration	No	Not applicable [a]
	g) Provide details of fraccing fluids to be used	No	Not applicable [a]
	h) Include provisions for ongoing monitoring	No	Not applicable [a]
	i) Procedure for contingency or remedial action	No	Not applicable [a]
	j) Regular review and update of the program in consultation with NOW	No	Not applicable[a]
Condition 4.2 (Develop numerical hydrogeological model)	Not applicable	Introduced	Section 11

[a] Not applicable to this report (addressed in other reports or conditions)

[b] This report has been peer reviewed separately by Dr Noel Merrick who was approved by the Director General of the Department of Planning and Infrastructure (DoPI) in March 2013.

[c] The conceptual field development plan is a companion report to this conceptual model report. The full field development plan will be submitted in conjunction with the numerical modelling.

A whole of geological basin approach has been adopted for this conceptual model report with a primary focus on the Stage 1 development area. To describe the recharge, discharge and flow processes for the different groundwater systems (to the satisfaction of regulators and community) it is necessary to adopt an area that is greater than the Stage 1 GFDA boundary. As the numerical (regional) model is being built for the whole Gloucester Basin, this conceptual model report has the same perspective.

2.2 EPBC Act approval context

Stage 1 of the GGP project was approved by the DoE (previously the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC)) on 11 February 2013. The EPBC Approval for the Stage 1 GFDA has several conditions relating to the protection of water resources. The conditions and sub-conditions are detailed in Appendix A. Table 2.2 summarises these conditions and the shaded rows identify the conceptual model conditions and where they are addressed in this report.

Table 2.2 EPBC Act Approval (Protection of Water Resources) Conditions

EPBC condition	Sub-condition	Addressed in this report	Report section
Condition 15 (Comply with Part 3A EP&A Act conditions)	Not applicable	See Table 2.1	See Table 2.1
Condition 16 (Develop conceptual hydrogeological model)	Not applicable	Yes	Sections 4, 5, 6, 7, and 10
Condition 17 (Revise the water balance model) [(a)]	a) Take into account the following inputs:		
	i) Field-based investigation of the spatial distribution of strata and structures	Introduced	Section 8
	ii) Investigation of age, depth and location of groundwater	Introduced	Section 7.7
	iii) Baseline investigation of gas occurrence	Introduced	Section 7.6.2
	iv) Pilot testing of Stratford and Waukivory pilot wells	Introduced	Section 8.3 and 8.4
	v) Baseline data associated with Phase 1 and 2 studies	Introduced	Sections 3, 4, 5, 6, 7, 8 and 9
	vi) Assessment of a representative site for fault testing	Introduced	Section 8.3 and 8.4
	b) Extend to 1000 metres below ground level	Introduced	Sections 4, 5, 6, 7, 8 and 9
	c) Ensure all hydrological inputs and outputs are accounted for	No	Not applicable
	d) List of information sources	No	Not applicable
Condition 18 (develop numerical hydrogeological model)	Not applicable	Introduced	Section 11
Condition 19 (Use the models to complete a risk analysis on the potential impacts on the habitats of the green and golden bell frog and giant barred frog)	(a) to (d)	No	Not applicable
Condition 20 (Provide details on any hydraulic fracturing agents likely to be used)	(a) to (e)	No	Not applicable
Condition 21 (Develop extracted water management strategy)	Not applicable	No	Not applicable

EPBC condition	Sub-condition	Addressed in this report	Report section
Condition 22 (Ensure that no more than 2 ML/d of groundwater is extracted)	Not applicable	No	Not applicable
Condition 23 (Ensure all water storage ponds are lined)	Not applicable	No	Not applicable
Condition 24 (Develop an acid sulphate soils management plan)	Not applicable	No	Not applicable
Condition 25 (Develop a watercourse crossing management strategy)	Not applicable	No	Not applicable

(a) A separate Water Balance report was prepared for the Department of Environment (DoE) in June 2013.

2.3 Data sources

Important studies carried out for the GGP and within the Gloucester Basin are outlined in Table 2.3.

Table 2.3 Previous technical reports

Report	Area covered	Summary
Geology of the Camberwell, Dungog and Bulahdelah 1:100,000 Geological Sheets, Roberts (1991)	Gloucester Basin	Geology of the Camberwell, Dungog and Bulahdelah 1:100,000 Geological Sheets
Gloucester Basin Geological Review, SRK (2005)	Gloucester Basin	Lucas Energy Pty Ltd, the PEL holder prior to AGL, commissioned SRK Consulting to undertake a desktop geological review of the Gloucester Basin to identify areas that have been least disturbed by faulting and contains thick sequences for coal, for the purposes of CSG exploration.
Hydrogeological Review of the Gloucester-Stroud Basin, URS (2007)	Gloucester Basin	Lucas Energy Pty Ltd, the PEL holder prior to AGL, commissioned URS Australia Pty Ltd to undertake a desktop review of the hydrogeological conditions at three CSG exploration areas within the Gloucester-Stroud Basin.
CSG pilot/flow testing programs, AGL (2012)	Stage 1 GFDA	Nine gas wells were flow tested by Lucas/AGL as part of the Stratford pilot testing program between 2006 and December 2009. Produced water volumes, water levels and water quality were assessed as part of the study.
Stroud Gloucester Trough: Review of the Geology and Coal Development, Lennox (2009)	Gloucester Basin	Summary of the work carried out in the period 1980-1985, including mapped geology at a scale of 1:10,000, photogeological studies, logged core, review of electric bore logs and measured sections at several locations within the Gloucester Basin.
Seismic Surveys, AGL (2009, 2010 and 2012)	Stage 1 GFDA (2009 & 2010) Gloucester Basin (2012)	Seismic data collected by AGL mapped a number of north-south striking thrust faults, and east-west striking sub-vertical normal faults across the Stage 1 GFDA.

Report	Area covered	Summary
Gloucester Basin Stage 1 Gas Field Development Project: Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model, SRK (2010)	Stage 1 GFDA	Hydrogeological assessment of the Gloucester Basin, in particular the Stage 1 GFDA, including a desktop review, initial site visit, data collection and initial conceptual hydrogeological model.
A Hydrogeological Assessment of the Duralie Extension Project: Environmental Assessment, Heritage Computing (2009)	Duralie Mine Lease	Hydrogeological assessment of the Gloucester Basin, in particular the Duralie Mining Complex, including characterisation of the existing groundwater regime, collation and review of baseline geological and groundwater data; and development of conceptual and numerical groundwater models.
A Hydrogeological Assessment in Support of the Stratford Coal Project: Environmental Impact Statement, Heritage Computing (2012)	Stratford Mine Lease	Hydrogeological assessment of the Gloucester Basin, in particular the Stratford Mining Complex, including characterisation of the existing groundwater regime, collation and review of baseline geological and groundwater data; and development of conceptual and numerical groundwater models.
Rocky Hill Coal Project: Groundwater Assessment, AGE (2013)	Gloucester Resources Ltd Exploration Area	Groundwater impact assessment including a review of studies undertaken in the Gloucester Basin, conceptualisation of the groundwater regime, development of a groundwater flow model and simulation of the impact of the proposal on the groundwater regime.
Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area, Parsons Brinckerhoff (2012a)	Stage 1 GFDA	Comprehensive groundwater investigations to confirm the conceptual model and connectivity of different groundwater systems across the Stage 1 GFDA, establishment of a dedicated monitoring network across the area; and collection of baseline water level and water quality attributes for each of these groundwater systems.
2012 Gloucester Groundwater and Surface Water Monitoring – Annual Status Report, Parsons Brinckerhoff (2012b)	Stage 1 GFDA	Annual review of the monitoring network established across the Stage 1 GFDA, detailing groundwater and surface water level and water quality trends for the period January 2011 to June 2012.
Conceptual Hydrogeological Model of the Gloucester Basin, Parsons Brinckerhoff (2013a)	Gloucester Basin	Updated conceptual hydrogeological model for the Gloucester Basin, building on previous conceptual hydrogeological models and incorporating data from current and ongoing hydrogeological investigations in the basin.
Water Balance for the Gloucester Basin, Parsons Brinckerhoff (2013b)	Gloucester Basin	Updated quantitative water balance for the whole Gloucester Basin. The water balance is an estimation of the storage and flow of water within a defined area, within a given timeframe.
Hydrogeological Investigation of a strike-slip fault in the Northern Gloucester Basin, Parsons Brinckerhoff (2013c)	Stage 1 GFDA	Following GGP referral to SEWPaC under the EPBC Act, an extension of the baseline Phase 2 Groundwater Investigations for the Stage 1 GFDA was carried out, assessing the connectivity between a strike-slip fault and shallow and deep groundwater systems.
2013 Gloucester Groundwater and Surface Water Monitoring – Annual Status Report, Parsons Brinckerhoff (2013d)	Stage 1 GFDA	Annual review of the monitoring network established across the Stage 1 GFDA, detailing groundwater and surface water level and water quality trends for the period July 2012 to June 2013.
Tiedman Irrigation Trial – Baseline Water Monitoring Program, Parsons Brinckerhoff (2013e)	Stage 1 GFDA	Report on groundwater and surface water monitoring to establish baseline water level and quality, prior to commencement of the Tiedman irrigation program. AGL proposed to irrigate 70 ML of produced water, stored in the Tiedman dams, blended with fresh water from sources including the Avon River.

Report	Area covered	Summary
Tiedman Irrigation Trial – August 2013 Water Compliance Report, Parsons Brinckerhoff (2013f)	Stage 1 GFDA	Compliance report on groundwater and surface water monitoring to identify any potential changes in water level and quality trends as a result of the Tiedman irrigation program.
Waukivory Pilot REF Groundwater Modelling, Parsons Brinckerhoff (2013g)	Stage 1 GFDA	Predictive numerical modelling for the Waukivory pilot testing program
Gloucester Gas Project: Hydrology Study, Parsons Brinckerhoff (2014a)	Avon River catchment	Characterisation of the surface water features across the Gloucester Basin, particularly in the vicinity of the Stage 1 GFDA, including a review of all surface hydrology and water quality data available.
Drilling Completion Report: Waukivory Groundwater Monitoring Bores, Parsons Brinckerhoff (2014b)	Waukivory	Report on the completion of nested groundwater monitoring bores adjacent to AGL's Waukivory Pilot Project. Including hydraulic conductivity testing and initial baseline groundwater level and quality data collected at the site to February 2014.
Drilling Completion Report : Faulkland and Bucketts Water Groundwater Monitoring Bores, Parsons Brinckerhoff (2014c)	Faulkland and Bucketts Way	Report on the completion of two nested monitoring sites (Faulkland and Bucketts Way) beyond the Stage 1 GFDA. Including hydraulic conductivity testing and initial baseline groundwater level and quality data collected at the site to July 2014.
2014 Gloucester Groundwater and Surface Water Monitoring – Annual Status Report, Parsons Brinckerhoff (2014d)	Gloucester Basin	Annual review of the monitoring network established across the Gloucester Basin, including bores outside of the Stage 1 GFDA, detailing groundwater and surface water level and water quality trends for the period July 2013 to June 2014.
2013 Flow Testing of Craven 06 and Waukivory 03 Gas Wells, Parsons Brinckerhoff (2014e)	Craven and Waukivory	AGL has undertaken flow testing programs to assess gas flow potential and volume of water produced by coals within the Permian Coal Measures. Produced water volumes and water quality and isotope samples from flow testing of gas wells Craven 06 and Waukivory 03 in 2013 were analysed.
Tiedman Irrigation Program – Water Compliance Report for the Period 1 July to 31 December 2013 , Parsons Brinckerhoff (2014f)	Stage 1 GFDA	Compliance report on groundwater and surface water monitoring to identify any potential changes in water level and quality trends as a result of the Tiedman irrigation program.
Tiedman Irrigation Program – Water Compliance Report for the Period 1 January to 4 July 2014, Parsons Brinckerhoff (2014g)	Stage 1 GFDA	Compliance report on groundwater and surface water monitoring to identify any potential changes in water level and quality trends as a result of the Tiedman irrigation program.
(DRAFT) Numerical Groundwater Modelling of the Gloucester Basin – Local-scale fault modelling, Parsons Brinckerhoff (2015a)	Stage 1 GFDA	Numerical models were developed using FEFLOW for two cross-sections within the Stage 1 GFDA for which the geology and groundwater conditions are well known (Stratford and Waukivory). The potential role of faults in groundwater flow and in influencing depressurisation associated with CSG extraction was explored.
Tiedman Irrigation – Water Compliance Report for the Period 5 July to 31 December 2014, Parsons Brinckerhoff (2015b)	Stage 1 GFDA	Compliance report on groundwater and surface water monitoring to identify any potential changes in water level and quality trends as a result of the Tiedman irrigation program.
(DRAFT) Drilling Completion Report: Wards River Groundwater Monitoring Bores, Parsons Brinckerhoff (2015c)	Wards River	Report on the completion of nested groundwater monitoring bores at Wards River. Including hydraulic conductivity testing and initial baseline groundwater level and quality data collected at the site.

Report	Area covered	Summary
Waukivory Pilot Project: Surface Water and Groundwater Monitoring Report to 31 December 2014, Parsons Brinckerhoff (2015d)	Waukivory	Report on the groundwater and surface water monitoring results and interpretation for the Waukivory Pilot Project. Including baseline data, and data collected during fracture stimulation and commencement of the flowback phase.
2014 Flow Testing of Craven 06 Gas Well, Parsons Brinckerhoff (2015e)	Craven	AGL has undertaken flow testing programs to assess gas flow potential and volume of water produced by coals within the Permian Coal Measures. Produced water volumes and water quality and isotope samples from flow testing of gas well Craven 06 in 2014 were analysed.
Waukivory Pilot Project: Surface Water and Groundwater Monitoring Report to 31 March 2015, Parsons Brinckerhoff (2015f)	Waukivory	Report on the groundwater and surface water monitoring results and interpretation for the Waukivory Pilot Project. Including data collected during the flowback phase, including flowback water quality and volumes recovered from the pilot wells.
WKMB06A and WKMB06B Drilling Completion Report, Parsons Brinckerhoff (2015i)	Waukivory	Drilling completion report for recently completed monitoring bores into alluvium and thrust fault zone at Waukivory pilot site.
Waukivory Pilot Project: Surface Water and Groundwater Monitoring Report to 30 June 2015, Parsons Brinckerhoff (2015j)	Waukivory	Report on the groundwater and surface water monitoring results and interpretation for the Waukivory Pilot Project. Including data collected during the flowback phase, including flowback water quality and volumes recovered from the pilot wells.
Tiedman Irrigation – Water Compliance Report for the Period 5 July to 30 June 2015, Parsons Brinckerhoff (2015k)	Stage 1 GFDA	Compliance report on groundwater and surface water monitoring to identify any potential changes in water level and quality trends as a result of the Tiedman irrigation program (which ended on 30 April 2015).
(FINAL DRAFT) GGP – Extracted Water Management Strategy, AGL (2015c)	Stage 1 GFDA	Strategy report for the extraction, transport, and storage of extracted water and the treatment, storage, reuse and stream discharge of treated water generated from the Stage 1 development.
GGP – Part 3A Project Conceptual Field Development Plan, AGL (2015b)	Stage 1 GFDA	Companion report to this conceptual model report that introduces one development phase and demonstrates how the Stage 1 GFDA development will avoid and minimise adverse impacts to beneficial aquifers, and satisfactorily manage risks to groundwater.

2.4 Peer reviews

Several peer reviews have been undertaken on previous studies in the Gloucester Basin. The peer reviews and key comments are provided in Table 2.4; full peer reviews are provided in Appendix B.

Table 2.4 Summary of peer reviews

Peer review	Reviewer	Reports covered by review	Key comments
Peer Review of Groundwater Studies - Gloucester Community Consultative Committee (GCCC) (SKM, 2012b)	Dr Richard Evans	Hydrogeological Review of the Gloucester-Stroud Basin, URS (2007) Gloucester Basin Stage 1 Gas Field Development Project: Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model, SRK (2010) Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area, Parsons Brinckerhoff (2012a)	'This review concludes that the conceptualisation presented in the Parsons Brinckerhoff (2012a) report is broadly considered to be appropriate, and the fundamentals of the conceptual model are reasonable'. 'The Parsons Brinckerhoff (2012a) study has largely gathered sufficient information to enable development of a suitable conceptual model (which will be supplemented by current/proposed investigation programs), however some further work is recommended as a result of this review'.
Gloucester Gas Project - Groundwater Peer Review (Heritage Computing, 2013)	Dr Noel Merrick[(a)]	Hydrogeological Conceptual Model of the Gloucester Basin, Parsons Brinckerhoff (2013a)	'The updated conceptual model has a very strong scientific basis. This reviewer attests to the *robustness and technical veracity of the model*' (Part 3A Approval, Condition 3.9d). 'The development of the conceptual model has highlighted an uncertainty in the hydraulic role of faults and has confirmed the very wide range in hydraulic properties of host lithologies within the Gloucester Basin'.
Independent Peer Review – Gloucester Shire Council (Jacobs SKM, 2014)	Dr Richard Evans	Hydrogeological Conceptual Model of the Gloucester Basin, Parsons Brinckerhoff (2013a) Water Balance for the Gloucester Basin, Parsons Brinckerhoff (2013b) 2013 Gloucester Groundwater and Surface Water Monitoring – Annual Status Report, Parsons Brinckerhoff (2013d)	'In general, the conceptualisation and water balance as presented in the reviewed reports is considered to be appropriate. The fundamentals of the conceptual model and water balance are reasonable'. 'The fundamentals of the conceptual model and water balance provide a foundation on which the numerical model can be developed'.

[(a)] Dr Noel Merrick was approved as a Peer Reviewer by the Director General of the Department of Planning and Infrastructure (DoPI) in March 2013.

These expert hydrogeologists have concluded that the conceptual model is sound and that further investigative work can progress with the numerical modelling.

2.5 DPI Water technical reviews

AGL has updated the conceptual model in consultation with DPI Water and the DoE. The last conceptual model report (Parsons Brinckerhoff, 2013a) was published in July 2013 and AGL has received no comments since its release (apart from DPI Water comments).

DPI Water has been consulted on the groundwater investigation activities and the evolution of the conceptual model since 2011 when the first monitoring bores were constructed and the first revised conceptualisation of the different groundwater systems was presented (Parsons Brinckerhoff, 2012a). Discussions with DPI Water in 2014 on the last conceptual model report (Parsons Brinckerhoff, 2013a) recommended that AGL include additional information on:

- Potential connectivity (in the vicinity of major faults) between shallow alluvial aquifers, rivers and deeper aquifers and water bearing zones.

- Fugitive gas emissions in steeply dipping coal seam (outcrop) areas when targeted coal seams are depressurised.
- Learnings from the Waukivory pilot testing program.
- Progressing the five recommendations around faulting investigations outlined in the hydrogeological investigation of a strike-slip fault (Parsons Brinckerhoff, 2013c).

Additional investigations have been completed (to address the specific fault study recommendations) and new data have been collected since the last conceptual model report. A summary of this work is provided in Table 2.5. Latest DPI Water comments on RevD (Final Draft) of this report (DPI Water, 2015) have been added to the table and included in the RevE (Final) report version. Conceptualisation is ongoing, and the model will be reviewed again based on insights obtained during the subsequent stages of the modelling process or when additional monitoring data becomes available.

The updated conceptual model has been finalised at twelve months into the Waukivory pilot testing program (i.e. after the fracture stimulation and flowback program) so that the numerical groundwater modelling phase can proceed with confidence.

Table 2.5 Summary of DPI Water issues and associated work programs

Issue/recommendation	Relevant investigations	Where additional explanation can be located in this report
NSW Office of Water recommendations (2014)		
Potential connectivity (in the vicinity of major faults)	Literature review into the influence of faulting on groundwater flow. Hydrogeological investigation of a strike-slip fault in the northern Gloucester Basin. Information from the Waukivory Pilot Project baseline and flowback programs. Local-scale fault modelling to investigate the role of faults on groundwater drawdown during coal seam gas development.	Sections 8.1 and 8.2 Section 8.3 Section 8.4 Section 8.5
Fugitive gas emissions in steeply dipping coal seam (outcrop) areas	Shallow gas monitoring at TGMB01 and TGMB02.	Sections 7.6.2 and 10.6.2
Learnings from the Waukivory pilot testing	Pilot testing program has been delayed and information from the baseline and flowback programs is available but not the entire pilot testing program at this time.	Site explanation and preliminary flowback and pilot test assessment is at Section 8.4 Conceptual model and numerical modelling will be reviewed again at the completion of the program
Strike-slip fault investigation (Parsons Brinckerhoff, 2013c) recommendations		
Undertake local scale numerical modelling to simulate the responses and distinguish between the potential causes of observed trend	Completed – information to be included in the numerical modelling reports.	Section 8.5.2
Refine conceptual models and re-calibrate any local fault-scale numerical model of depressurisation using the results from any longer term flow tests	Ongoing – no substantial changes to the conceptualisation at this time. Preliminary results from Waukivory pilot testing included. Most information will be included in the numerical modelling report.	Sections 8.4 and 8.5

Issue/recommendation	Relevant investigations	Where additional explanation can be located in this report
Because depressurisation effects may take some time to become apparent in the shallow rock environment, longer duration flow tests are required (6 months to a year). Such testing should be carried out during future (long term) pilot testing programs, and the first stage of gas field development within an adaptive management framework	Noted. This will be addressed in the GMMP. Waukivory pilot testing is expected to be 6 to 12 months duration. Wards River pilot (planned to the south) is expected to be at least 6 months duration.	Section 8.4
Depressurisation effects from flow testing should be monitored with at least one array of vibrating wire piezometers installed to the full depth of the gas production zones, ideally at a distance of 200 to 500 m from the gas well (we understand that this is to occur by late-2013 at the nearby Pontilands 03 (PL03) corehole site)	Noted. This is addressed in the Waukivory technical reports. Vibrating wire piezometers installed at PL03 site (~2200 m distant from WK13). Packers and piezometers installed and operational in WKMB05 (~150 m distant from WK13).	Section 8.4
Undertake methane isotope sampling and analysis during flow tests. The aim would be to obtain site specific data on methane abundance and provenance, and the role of faults in methane migration, during extended gas flow testing	Methane isotope sampling and analysis was undertaken during the strike-slip fault investigation (Parsons Brinckerhoff, 2013c). Baseline sampling for methane isotopes completed prior to Waukivory pilot testing in monitoring bores (Parsons Brinckerhoff, 2015d). Another monitoring event is planned post Waukivory pilot testing program.	Section 7.6.2
DPI Water recommendations (2015)		
The diagram that describes the conceptual hydrogeological model of the Basin be updated to better present the conceptualisation and groundwater flow processes	Nothing specific	Replacement figure (Fig 10.1) prepared for Chapter 10
All the hydraulic and formation properties that define the hydrostratigraphic units should be delineated, presented in a summary table, and adequately discussed.	Nothing specific	Updated Table 7.2 and Section 7.2, plus additional summary comments in Section 11.3.2
Minor technical issues and further discussion across various sections of the report as outlined in Attachment A of DPI Water (2015)	Comments reference both a number of previous studies and suggested future studies.	Various but including Section 8.2.3.3 (Fault damage zones), Section 8.3.2 (Stratford 29-day flow test) and Section 8.5.2 (Stratford 4 flow test modelling)

3. Physical setting

This chapter provides an overview of the physical characteristics of the Gloucester Basin including topography, drainage and climate.

3.1 Topography and drainage

The Gloucester Basin is a narrow, north-south trending, elongated basin approximately 40km long and 10km wide, extending from Gloucester in the north to Stroud in the south. A major surface water divide, just north of Wards River, separates the Basin into two major catchment areas (Figure 3.1).

The Gloucester Basin is located high in the Manning River and Karuah River coastal catchments. The area occupied by the Permian Coal Measures (about 220 km^2) is small in comparison to the size of these catchments.

In the southern catchment area, surface water flow is generally to the south, and is part of the Karuah River catchment. In the northern catchment area, surface water flow is generally to the north, and is part of the Manning River catchment. Figure 3.2 illustrates the surface water catchments, and the surface water divide between the Wards River catchment (part of the Karuah River catchment) and the Avon River catchment (part of the Manning River catchment).

The Gloucester Basin is topographically enclosed to the west by the Gloucester and Barrington Tops, and to the east by the Mograni Range.

3.2 Rainfall

The Bureau of Meteorology (BoM) operates four weather stations within the Gloucester Basin and AGL operates one weather station on its Tiedman property (Figure 3.2). Average rainfall and the period of monitoring for the BoM stations are presented in Table 3.1.

Table 3.1 BoM stations in the Gloucester Basin (BoM, 2015a)

BoM station number	Location name	Monitoring period	Long term average annual rainfall (mm)[a]
60015	Gloucester Post Office	1888 to 2014	979
60112	Gloucester Hiawatha	1976 to 2014	1014
60042	Craven (Longview)	1961 to 2014	1057
61071	Stroud Post Office	1889 to 2014	1144

(a) Long-term average (LTA) annual rainfall (mm) over the stated monitoring period

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HYDROGEOLOGICAL CONCEPTUAL MODEL OF THE GLOUCESTER BASIN
AGL UPSTREAM INVESTMENTS PTY LTD

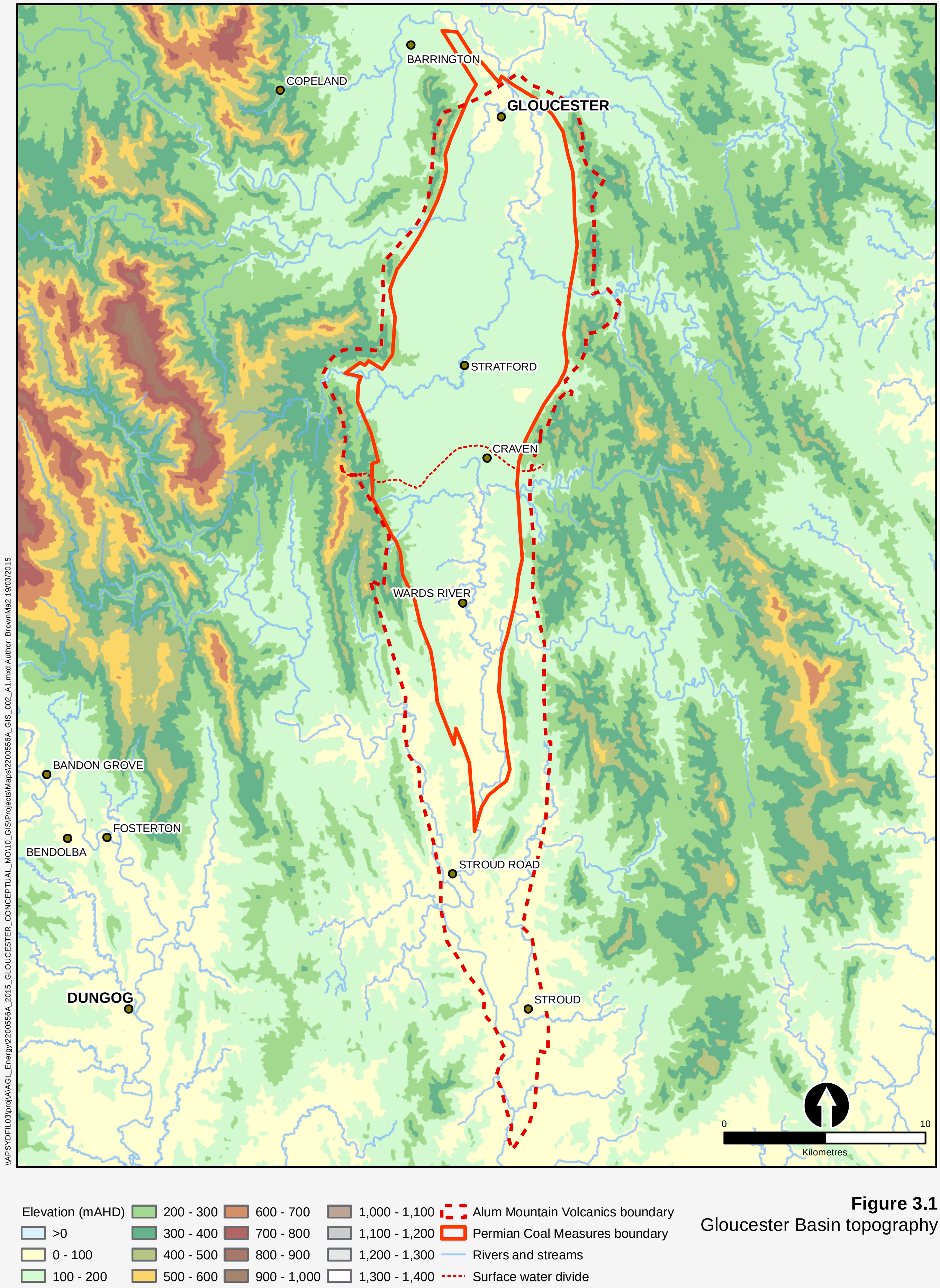


Figure 3.1
Gloucester Basin topography

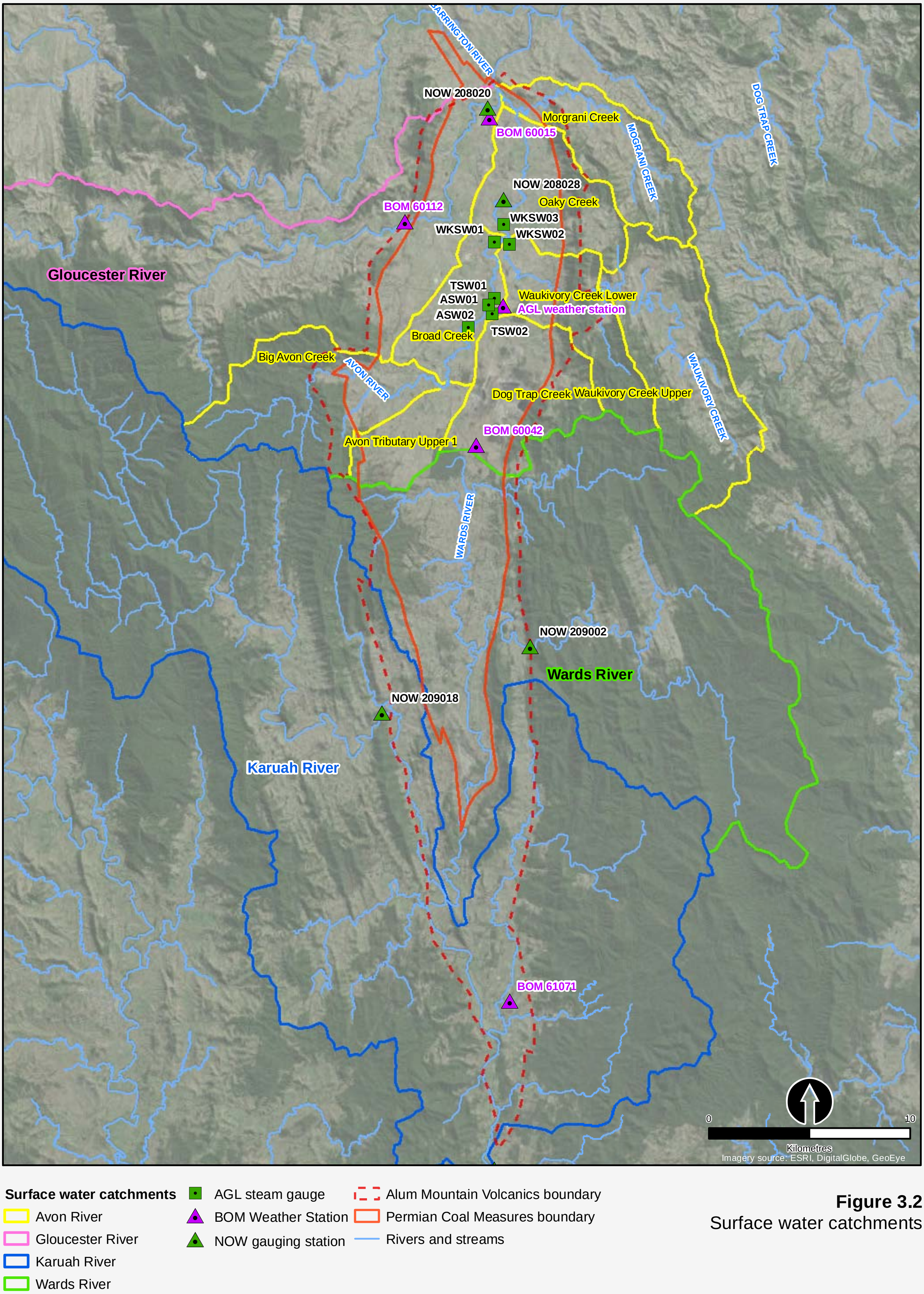
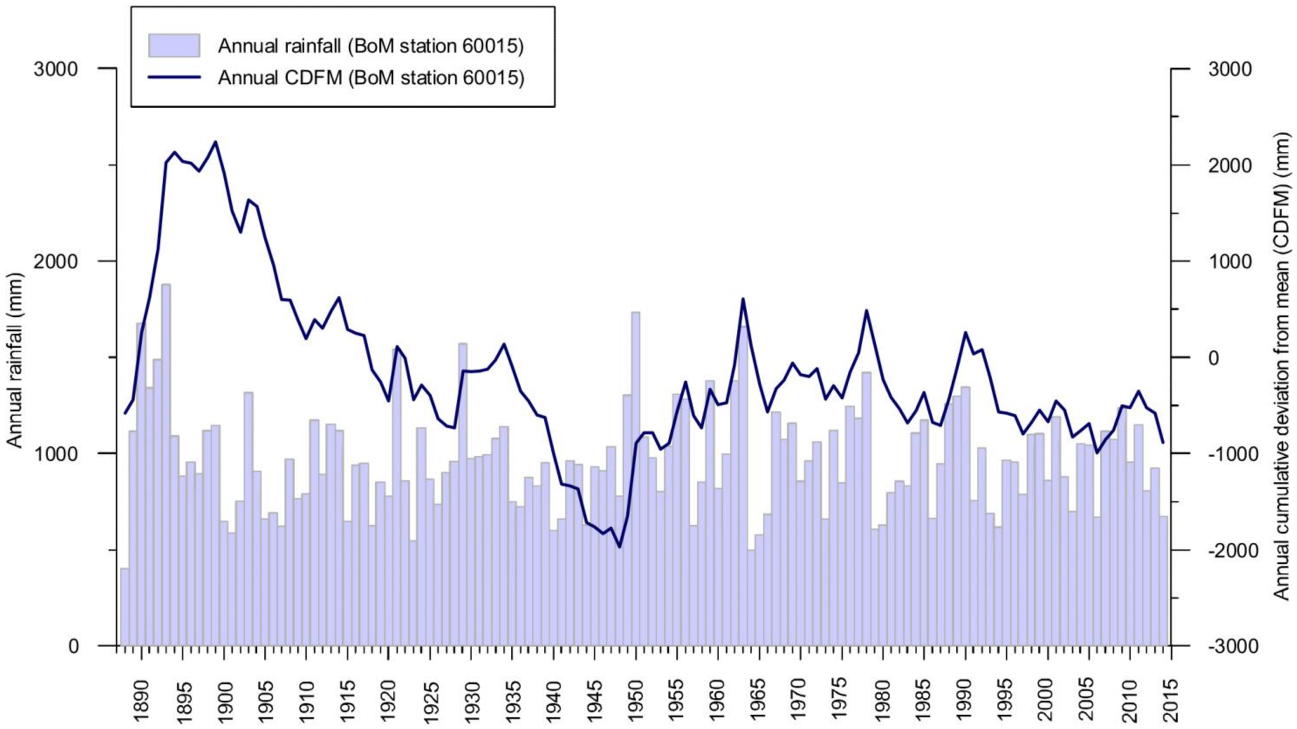
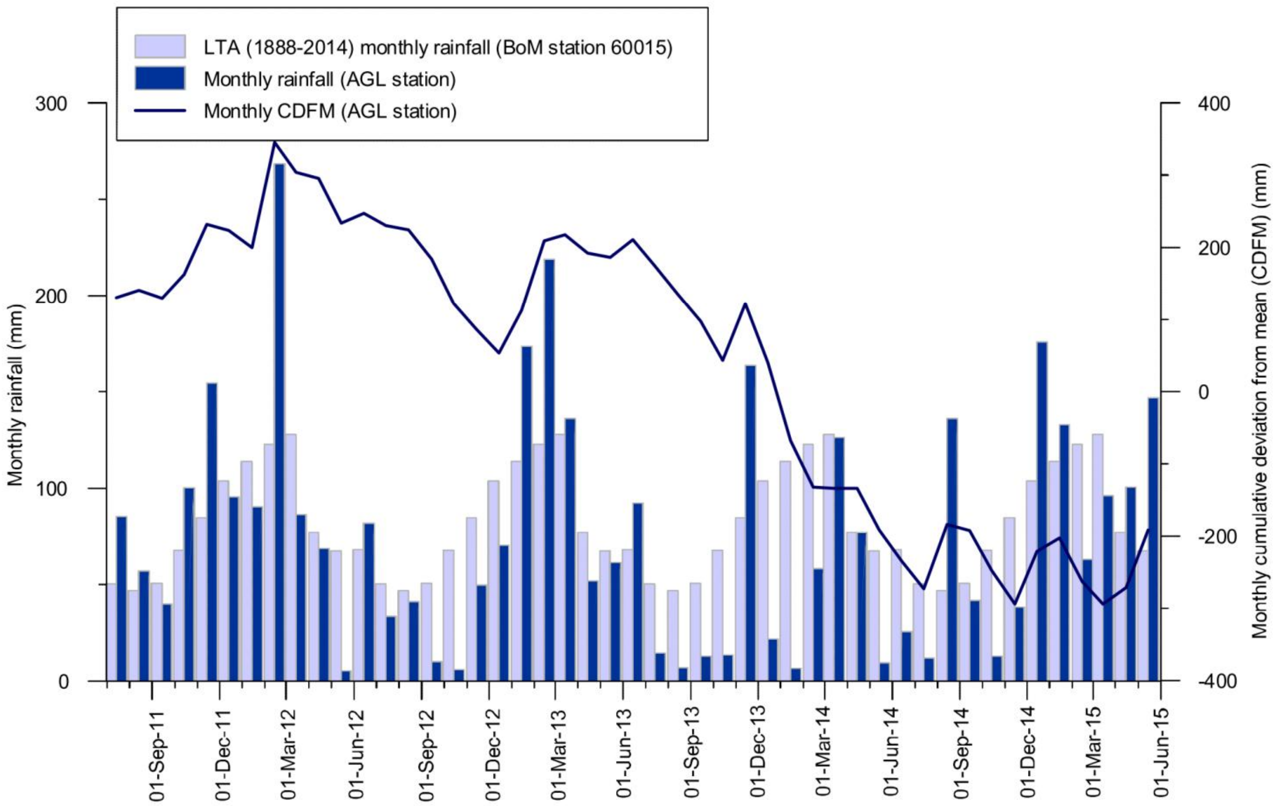


Figure 3.2
Surface water catchments



a. Long term annual rainfall, and cumulative deviation from the annual mean rainfall (CDFM) at Gloucester Post Office BoM station 060015 (BoM, 2015a)



b. Monthly rainfall and cumulative deviation from the monthly mean rainfall (CDFM) at the AGL Gloucester station since installation in July 2011 (AGL, 2015a)

Figure 3.3 Gloucester rainfall data

The long-term, annual cumulative deviation from mean (CDFM) rainfall for Gloucester Post Office is plotted in Figure 3.3a. The long-term cumulative rainfall residual plots are formulated by subtracting the average annual rainfall for the recorded period from the actual annual rainfall and then accumulating these residuals over the assessment period. Periods of below average rainfall are represented as downward trending slopes while periods of above average rainfall are represented as upward trending slopes.

The cumulative deviation plot for Gloucester Post Office (Figure 3.3a) shows that over the last 60 years, short (2-3 year) drought periods have occurred about every 10 to 15 years, however there have been no long-term deviations from mean conditions such as the prolonged drought periods that characterised the first half of last century. 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.

Rainfall data for the AGL weather station for the period July 2011 (installation) to June 2015 are presented in Figure 3.3b. For most of this period rainfall was below the monthly average rainfall, as indicated by the downward sloping cumulative deviation curve. Rainfall significantly above the monthly average occurred in February 2012, February 2013, November 2013, August 2014, December 2014 and May 2015.

3.3 Evapotranspiration

Evapotranspiration is the collective term encompassing the transfer of water, as water vapour, to the atmosphere from both vegetated and clear land surfaces (BoM, 2015b). Evapotranspiration rates are affected by climate and the availability of water and vegetation.

The average, annual evapotranspiration for the whole Gloucester Basin is approximately 750 mm; this was obtained from the average, areal, actual evapotranspiration maps created by the BoM from data collected between 1961 and 1990 (Figure 3.4) (BoM, 2015b).

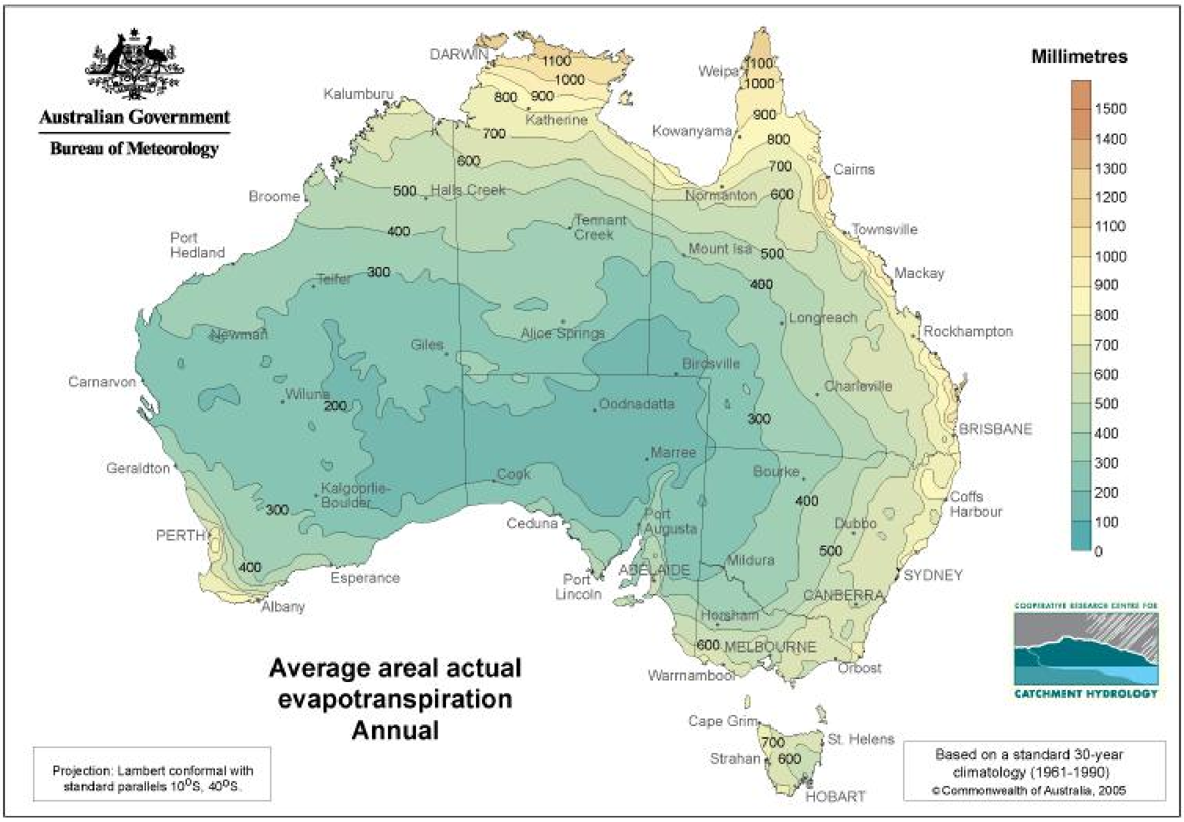


Figure 3.4 **Average, areal, actual evapotranspiration (BoM, 2015b)**

4. Geology

This chapter provides an overview of the geology and geological structure of the Gloucester Basin.

4.1 Overview

The Gloucester Basin represents a complex geological system formed by the interplay of extensional tectonic faulting and high rates of sedimentation. The Basin stratigraphy comprises a thick succession of Permian sedimentary rocks representing deposition in both terrestrial and marine environments during a complex period of subsidence, uplift and relative sea level change (marine transgression and regression).

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 (Lennox 2009). The north – south trending synclinal nature of the Gloucester Basin resulted from the collision between the East Australian and Pacific Plates.

Following a period of extension during the Early Permian the Gloucester Basin has undergone periods of normal and reverse faulting, with large scale tilting associated with late stage compressional movements towards the end of the Permian (Hughes 1995). Reverse faults dominate present day structure. A comparison with the contemporary horizontal stress field map (Hillis *et al* 1998) indicates the Basin is likely to be under compression in an east-west orientation.

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. Early Permian and Carboniferous hard resistive volcanics form the ridgelines of the Basin: the Mograni Range to the east; and the Gloucester and Barrington Tops to the west.

Overlying the Permian stratigraphy is a thin sequence of surficial Quaternary sediments. The Quaternary sediments are non-uniform in thickness, and comprise unconsolidated alluvial sediments (sand, gravel, silt and clay) along the drainage channels and colluvial deposits across the rest of the plain sourced from the surrounding outcropping Permian deposits.

4.2 Stratigraphy of the investigation area

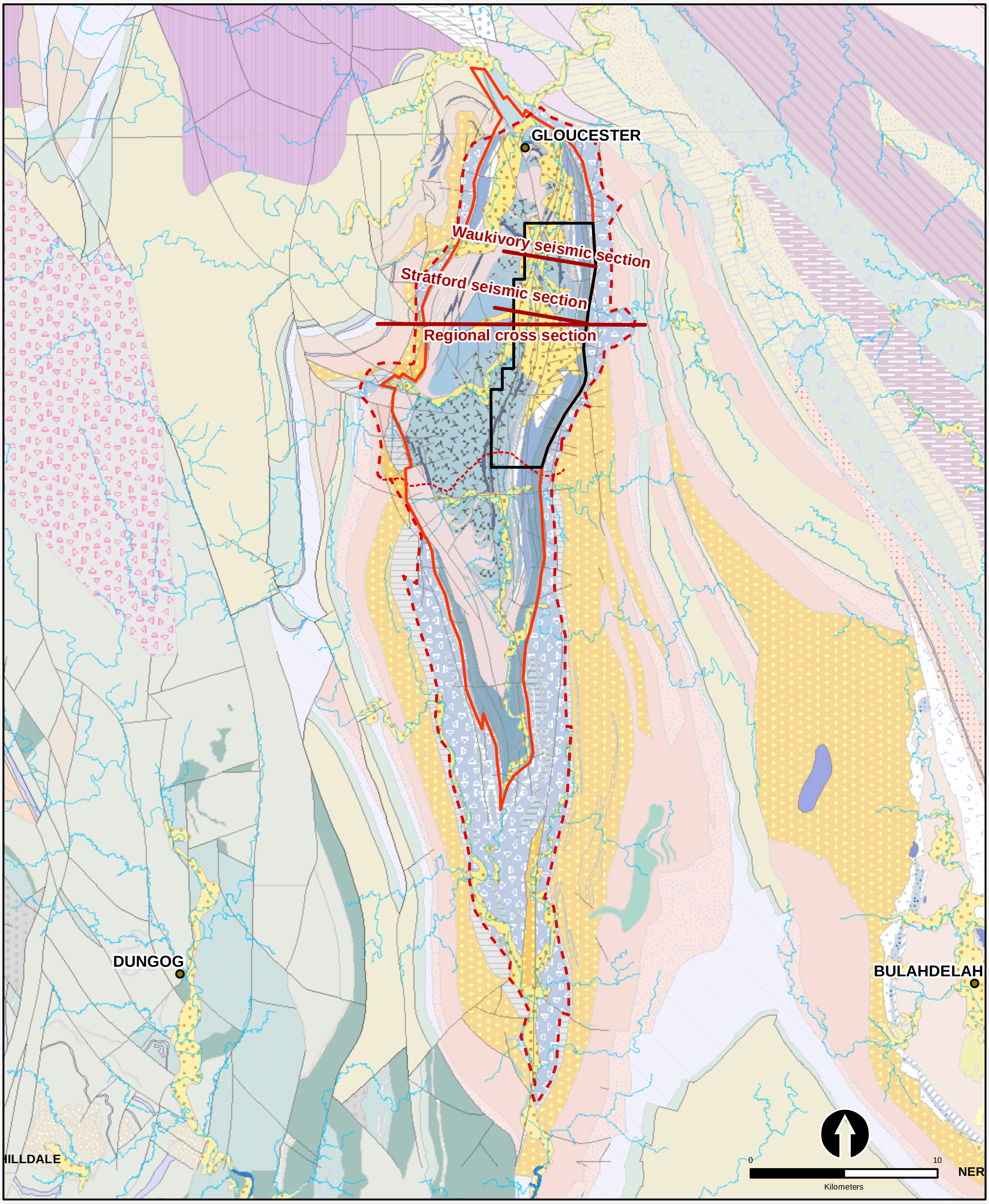
The Gloucester Basin is divided into three major Permian stratigraphic units each representing a distinct depositional setting: the Gloucester Coal Measures, the Dewrang Group, and the Alum Mountain Volcanics. The generalised stratigraphy of the Basin is summarised in Table 4.1. A geological map of the Basin is shown in Figure 4.1, and a regional geological cross-section through the Gloucester Basin is shown in Figure 4.2.

The CSG development across the Stage 1 GFDA is targeting the intermediate and deep coal seams in the Gloucester Coal Measures generally below depths of 250 m to around 1000 m.

Table 4.1 Stratigraphy of the Gloucester Basin

Period	Group	Sub-group	Formation	Approx. thickness (m)	Coal seam	Depositional Environment	Tectonic Events
Upper Permian	Gloucester Coal Measures	Craven	Crowthers Road Conglomerate	350		Marine regression, pro-gradation of alluvial fans	Uplift to west of Gloucester Basin
			Leloma	585	Linden		
					JD		
					Bindaboo		
					Deards		
			Jilleon	175	Cloverdale		
					Roseville		
					Tereel/Fairbairns		
			Wards River Conglomerate	Variable			
			Wenham	23.9	Bowens Road		
					Bowens Road Lower		
		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)



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Stage 1 GFDA boundary
Alum Mountain Volcanics boundary
Permian Coal Measures boundary
Cross/Seismic section line
Surface water divide
Rivers and streams

Gloucester Basin Geology

Qa	Quaternary Alluvium	Pllj	Jo Doth Tuff Member	Plt	Dog Trap Creek Formation	Peat	Unnamed Welded Tuff Member
		Plo	Jilleon Formation	Pli	Waukivory Creek Formation	Peac	Unnamed Basal Sequence
		Plw	Wards River Conglomerate	Pldy	Mammy Johnsons Formation		Carboniferous geology
G	Unnamed microgranite	Pla	Wards River Conglomerate	Plde	Weismantels Formation	Clo1	Johnsons Creek Conglomerate
	Permian Geology	Plgx	Gloucester Coal Measures	Pldd	Duralie Road Formation	Clkm	McInnes Formation
Plc	Crowthers Rd Conglomerate	Plh	Wenham Formation	Pea	Alum Mountain Volcanics	Clr	Booral Formation
Pll	Leloma Formation	Plp	Speldon Formation	Pear	Unnamed Rhyolite Member		Fault

Figure 4.1
Geology

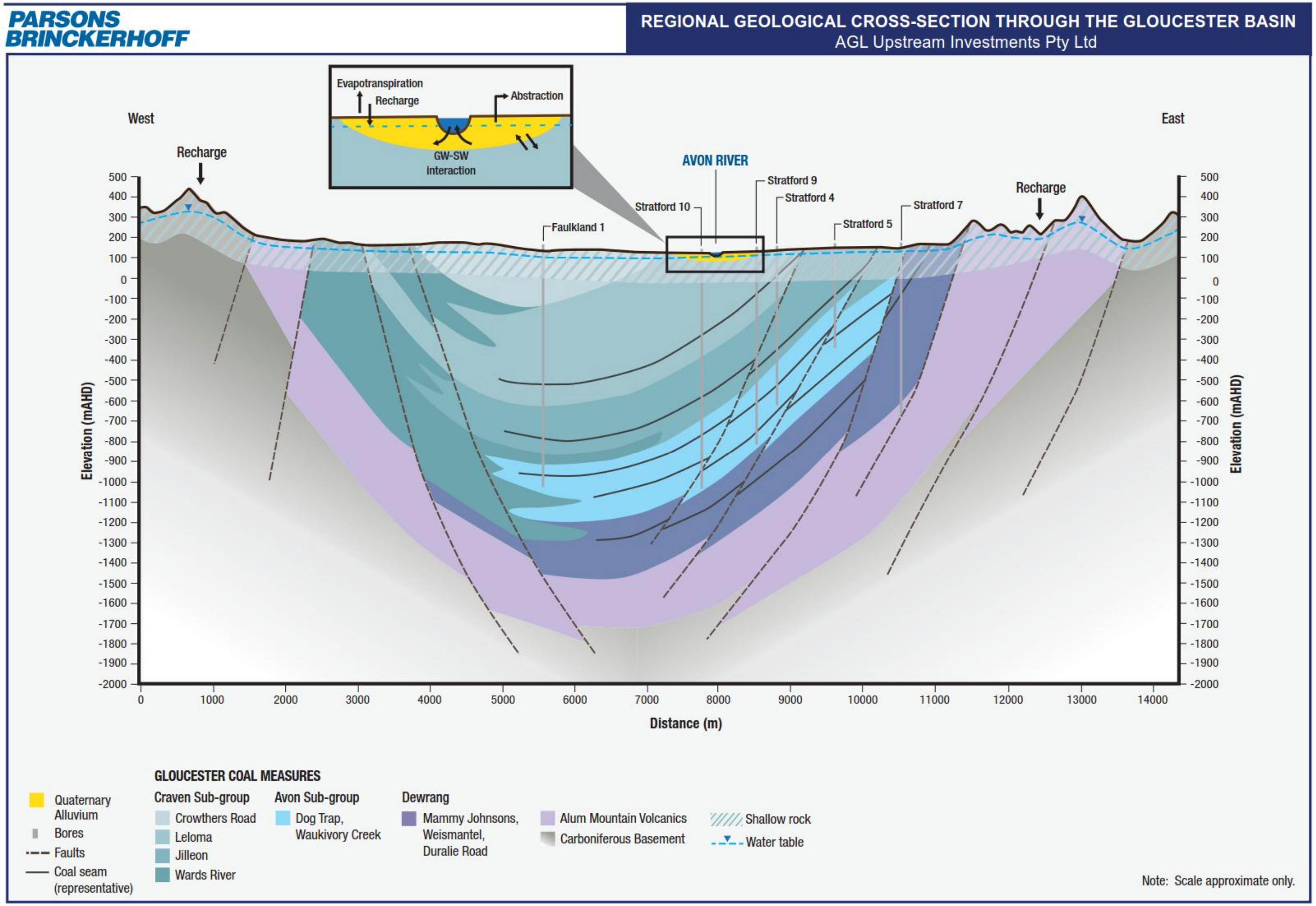

Figure 4.2 **Regional geological cross-section through the Gloucester Basin**

4.3 Structural development

The tectonic development and structural setting of the Gloucester-Stroud Syncline is discussed by Roberts et al. (1991) based on regional geological mapping and seismic profile interpretation. Subsequent structural interpretations have been carried out by SRK (2005) and Lennox (2009). The following summary is based on those reports.

The Gloucester-Stroud Syncline is the largest structure in the surrounding region, being more than 55 km long and 24 km wide with steeply dipping limbs containing a stratigraphic section up to 8 km thick (Roberts et al, 1991). The syncline has a sinuous axial trace that trends generally northerly (355°) but that swings eastwards (022°) between Stratford and Gloucester. The syncline is doubly plunging, closing at both ends forming a tight canoe-like structure. The axial plane is inclined slightly to the east; bedding in the limbs of the syncline tends to dip steeply toward the axis at more than 60°, with some bedding sub-vertical or slightly overturned.

The syncline is a fault bounded trough, active during the Permian. Roberts et al (1991) identify up to six deformation events that were important in the depositional and structural development of the Basin. SRK (2005) simplified the structural development into two main stages:

1. 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. The majority of the Coal Measures were deposited during this complex phase.
2. 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.

In addition, SRK (2005) identifies a possible basement structure or intrusion overlapping with the northern part of the Basin that appears to have influenced the structural development of the Basin. The margin of that structure coincides with arcuate and east-west faulting in the mid part of the Basin (e.g. west of Stratford) and may account for the contrasting deformation styles in the Carboniferous basement rocks to the north and south of this approximate line.

4.4 Faulting

Faulting in the Gloucester Basin is discussed by Roberts et al. (1991) who identify five distinct types or styles of faulting based on mapping and seismic interpretations:

1. Low-angle, west-dipping broadly meridional (N-S) thrust faults.
2. Sinistral shear zones striking between 300° and 350°.
3. Meridional reverse faults.
4. East-west striking normal faults.

5. Shears or normal faults striking between 040° and 060°.

These contrasting fault types reflect different episodes of deformation throughout the complex structural history of the Basin (Roberts et al. 1991), and the possible influence of basement structures (SRK, 2005). Lennox (2009) provided a spatial analysis of faults and other linear features based on air photo and seismic interpretations which follows a broadly similar classification (Figure 4.3).

Geological mapping of the Basin (Roberts et al. 1991) shows that the geological structure within the Stage 1 GFDA is dominated by moderately to steeply west-dipping strata intersected by near-vertical sinistral strike-slip faults with significant vertical components (Style 2, Figure 4.3) and westerly-dipping thrust faults (Style 1, Figure 4.3). Simular faulting and folding styles extend to the southern part of the basin. A geological cross-section through the Gloucester Basin with representative faulting is shown in Figure 4.2.

Recent (deep, high resolution) seismic data acquired by AGL in the period from 2009 to 2012 identify 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 1000 m, however the technique returns poor resolution in the top 200 m. This inhibits the ability to map these fault structures through the shallow fractured rock 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.

Seismic sections presented in Figures 4.4 and 4.5 show the subsurface bedding and structure to depths of 2,000 mbgl through the Stratford and Waukivory pilot testing locations respectively. The seismic sections have been interpreted to identify westerly dipping thrust faults and easterly dipping north-south trending strike-slip faults with minimal vertical offset.

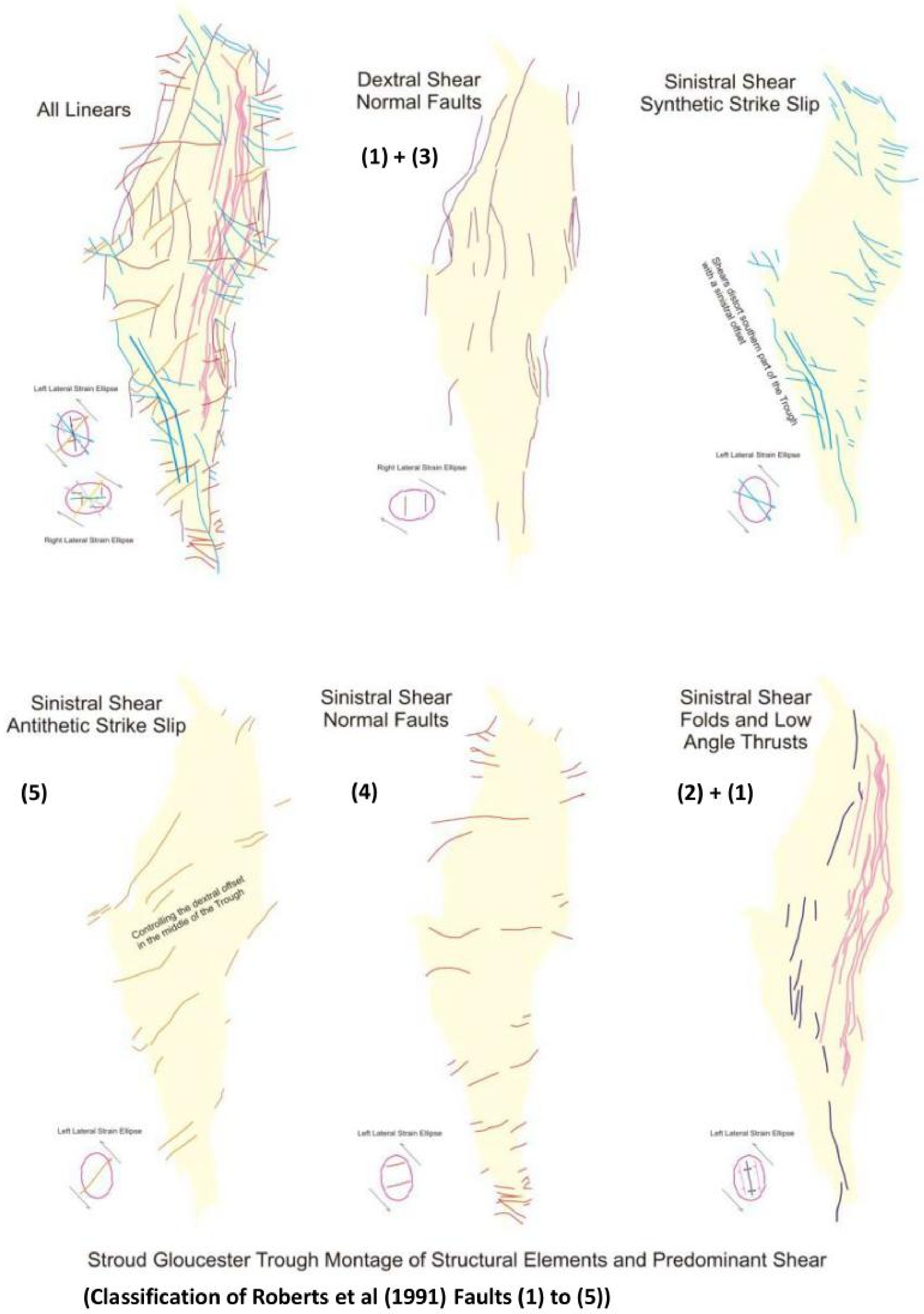

Figure 4.3 Major sets and styles of faulting in the Gloucester Basin (after Lennox, 2009)

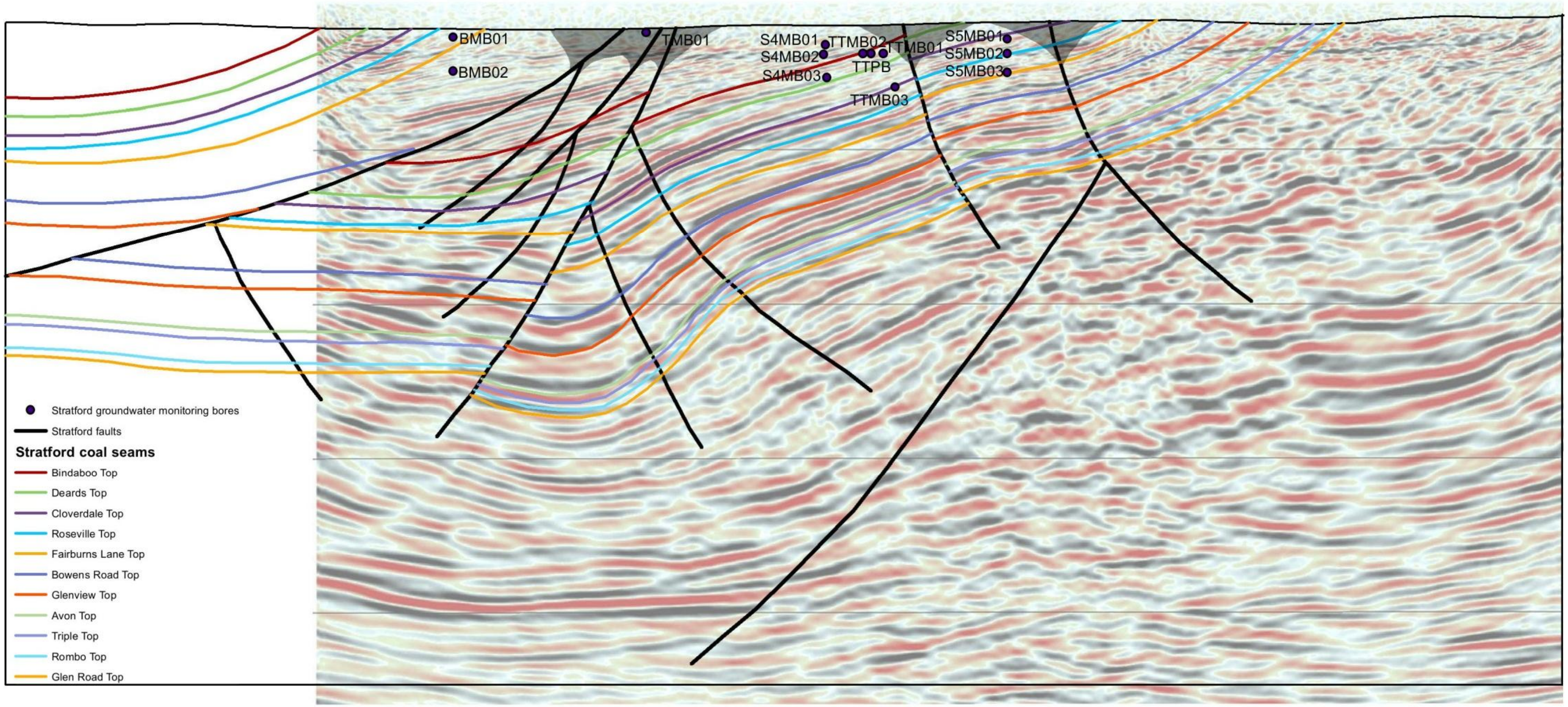

Figure 4.4 Stratford interpreted seismic section (from Parsons Brinckerhoff, 2015a) (line of section shown on Figure 4.1)

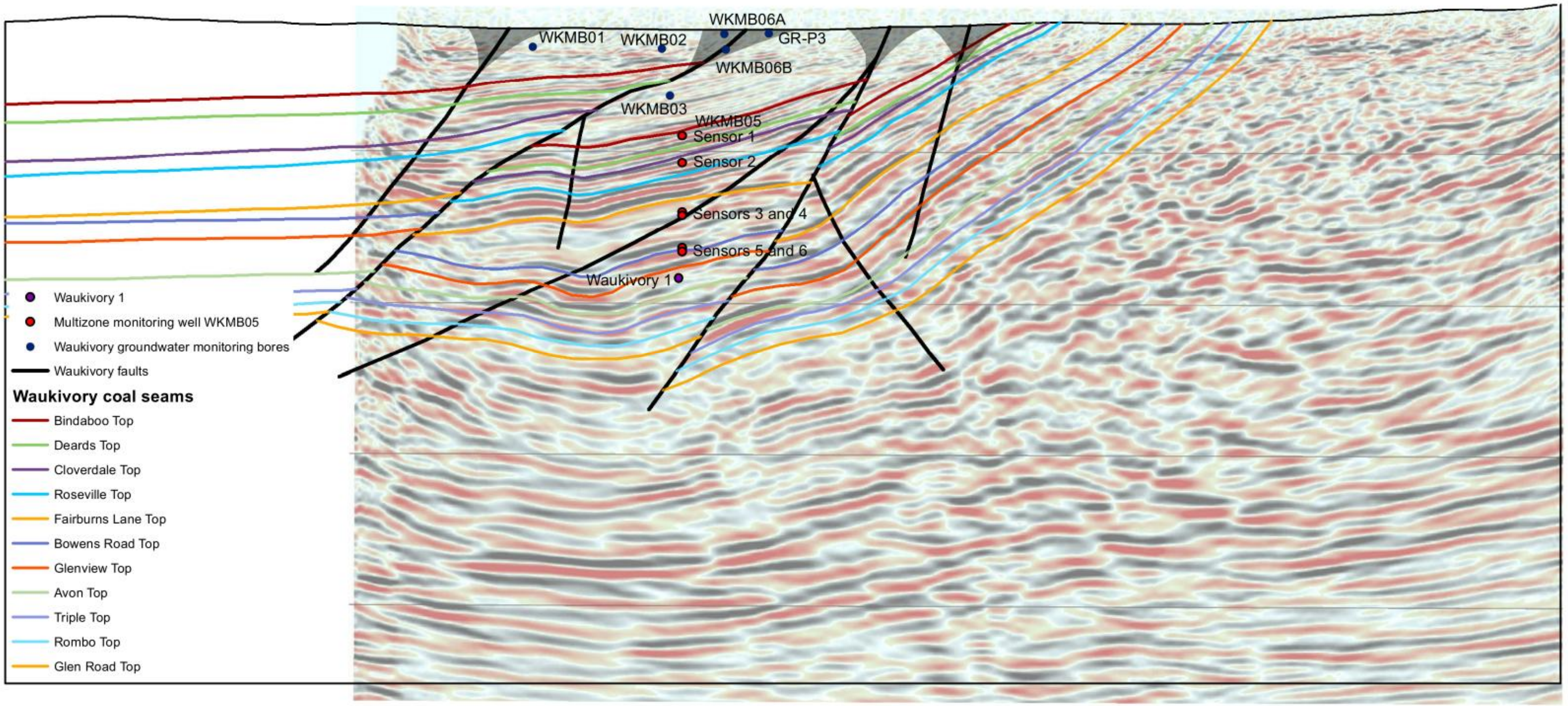

Figure 4.5 Waukivory interpreted seismic section (from Parsons Brinckerhoff, 2015a) (line of section shown on Figure 4.1)

5. Monitoring of surface water and groundwater

This chapter provides a summary of the groundwater and surface water monitoring network in the Gloucester Basin and a summary of the monitoring programs carried out.

5.1 Monitoring network

AGL's groundwater and surface water monitoring locations are shown in Figure 5.1. Installation of the monitoring network commenced in 2011, and there are now more than 50 dedicated water monitoring locations and more than four years of baseline monitoring (water levels and water quality) across the Gloucester Basin. Several high rainfall events and extended dry periods have occurred to provide a dataset that is representative of seasonal variability. Details of the current monitoring network are provided in the 2014 annual monitoring report (Parsons Brinckerhoff, 2014b), and groundwater and surface water hydrographs for the full monitoring network are provided in Appendix C.

There are currently seven AGL stream gauges in the Gloucester Basin; five on the Avon River, one on Dog Trap Creek, and one on Waukivory Creek.

The groundwater monitoring network comprises five types of groundwater monitoring installations:

1. Bores targeting the shallow alluvial sediments of the Avon River and its tributaries, and Wards River.
2. Bores targeting the shallow fractured rock.
3. Bores targeting the interburden and coal seams of the Gloucester Coal measures.
4. A vibrating wire piezometer (VWP) array installed to monitor piezometric pressure (pore pressure) in the interburden and a deep coal seam of the Gloucester Coal Measures.
5. A multi-zone monitoring well installed to monitor piezometric pressure in the interburden at four different depths (including a fault zone) and two deep coal seams of the Gloucester Coal Measures.

Monitoring bores are often installed in "nested" sites which comprise several bores targeting different depths and hydrogeological units at the one location.

Additional monitoring in the Gloucester Basin associated with Stratford Mine, Duralie Mine and the Rocky Hill Coal Project are shown in Figures 5.1 and 7.17.

5.2 Monitoring program

Details of the monitoring program at Gloucester are provided in the 2014 Groundwater and Surface Water Monitoring Status report (Parsons Brinckerhoff, 2014b). Groundwater level monitoring commenced in January 2011 and surface water level monitoring commenced in March 2011. The majority of the monitoring network has been in place since January 2011.

Pressure transducers (dataloggers) are installed in each of the groundwater monitoring bores to monitor groundwater levels every six hours. Dataloggers installed in the vibrating wire piezometer and multi-zone monitoring site monitor piezometric pressure every six hours. At the stream gauges, dataloggers are installed to monitor water levels and salinity every 15 minutes.

Water quality monitoring has been undertaken since the installation of the monitoring network in 2011. Comprehensive sampling events across the network occur on a bi-annual basis. Details of groundwater and surface water quality monitoring are presented in the Phase 2 groundwater investigations report (Parsons Brinckerhoff, 2012a), the 2012 annual monitoring report (Parsons Brinckerhoff, 2012b), the 2013 annual monitoring report (Parsons Brinckerhoff, 2013d) and the 2014 annual monitoring report (Parsons Brinckerhoff, 2014d).

Water quality results are also presented in the drilling completion report for the Waukivory (Parsons Brinckerhoff, 2014b), Faulklands and Bucketts Way (Parsons Brinckerhoff, 2014c) and Wards River (Parsons Brinckerhoff, 2015c) monitoring sites.

Details of water quality monitoring undertaken at selected monitoring sites as part of the Tiedman Irrigation Program are presented in the 6-monthly irrigation program reports (Parsons Brinckerhoff 2013e, 2013f, 2014f, 2014g and 2015b). Specialist water quality monitoring associated with the pilot testing programs at Craven and Waukivory are presented in Parsons Brinckerhoff 2014e, 2015d, 2015e, and 2015f.

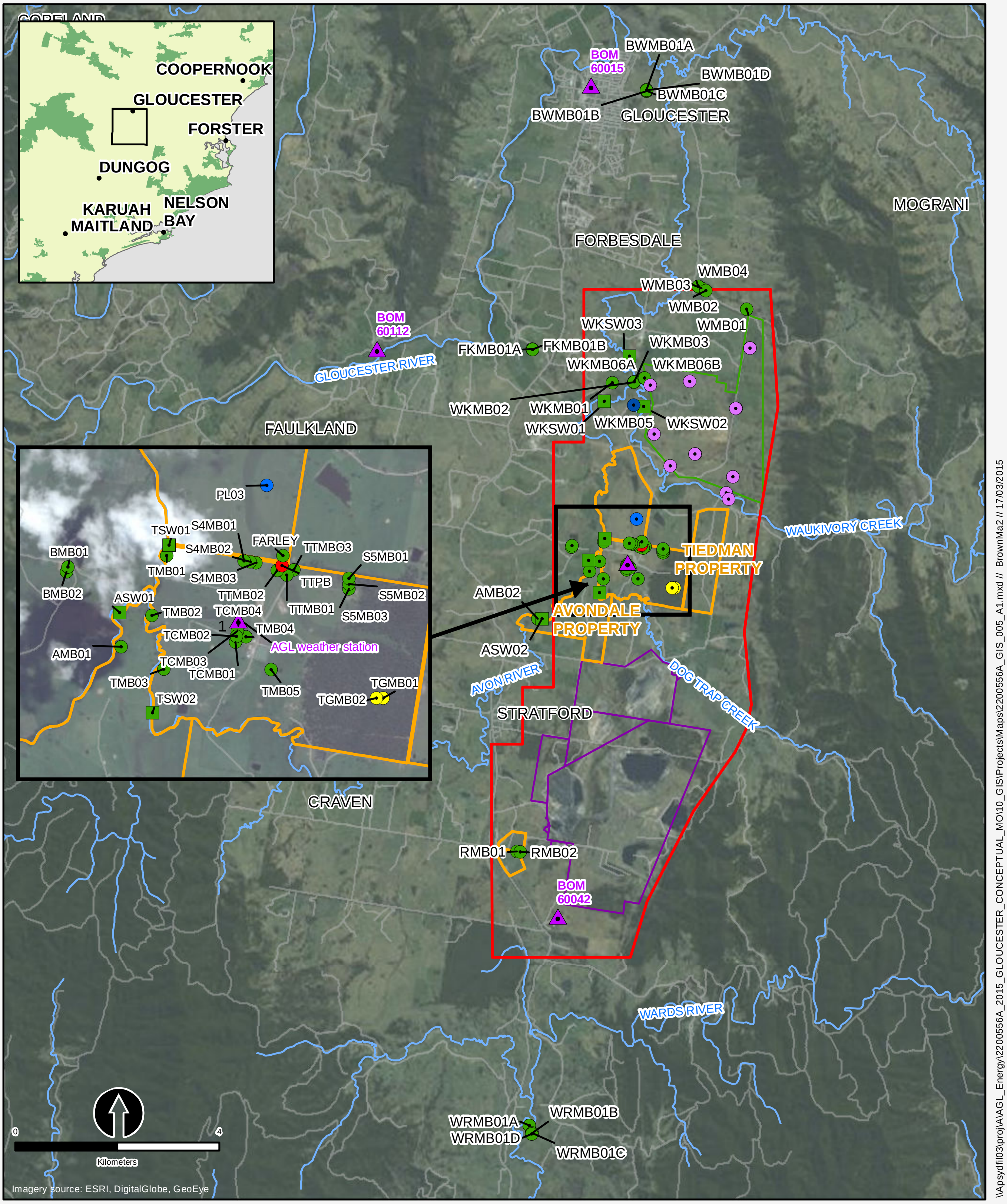

Figure 5.1
Groundwater and surface water monitoring network

GRL groundwater monitoring bore
Multizone monitoring well
Shallow gas monitoring bore
Groundwater monitoring bore
Test production bore
VWP Monitoring Piezometers
Stream gauge
BOM Weather Station
AGL owned properties
GRL exploration area boundary
Mining Lease Boundary
Stage 1 GFDA boundary
Rivers and streams
Roads

6. Surface water

This chapter provides an overview of the hydrology of the Gloucester Basin.

6.1 Surface water flow

A representative surface water hydrograph from ASW02 on the Avon River (upstream of Dog Trap Creek) is shown in Figure 6.1; surface water hydrographs for the full monitoring network are shown in Appendix C. All AGL stream gauges on the Avon River, Dog Trap Creek and Waukivory Creek show rapid responses to rainfall events, and relatively steep recession curves. This is characteristic of rapid runoff responses from a relatively small upstream catchment and limited riverbank storage and groundwater contributions. Stream levels and flow decrease over several weeks following each rainfall event to a relatively consistent base level that represents a small baseflow component in the Avon River and its tributaries.

A hydrograph for the NOW stream gauge 208028 on the Avon River including an approximation of the baseflow component from 2005 to 2015 is shown in Figure 6.2. Stream baseflow is the component of stream flow that is derived from groundwater discharge. Baseflow can be estimated by separating the overland flow component (transient flood peaks) from the stream hydrograph.

The hydrograph for gauge 208028 indicates that the Avon River at this location flows 95% of the time. Periods of 'no flow' or very low flow, when the river is characterised by multiple disconnected pools, correspond to anomalously low rainfall, particularly in the months leading up to summer (Figure 6.2b). It is apparent that periodic and relatively frequent high rainfall events (>80 mm in a week) and associated significant stream flow events (> ~3000 ML/d) are required to recharge the alluvial groundwater system and sustain baseflow recessions over the following months. This suggests that the alluvial system is of limited storage and is rapidly depleted and replenished in response to rainfall variations.

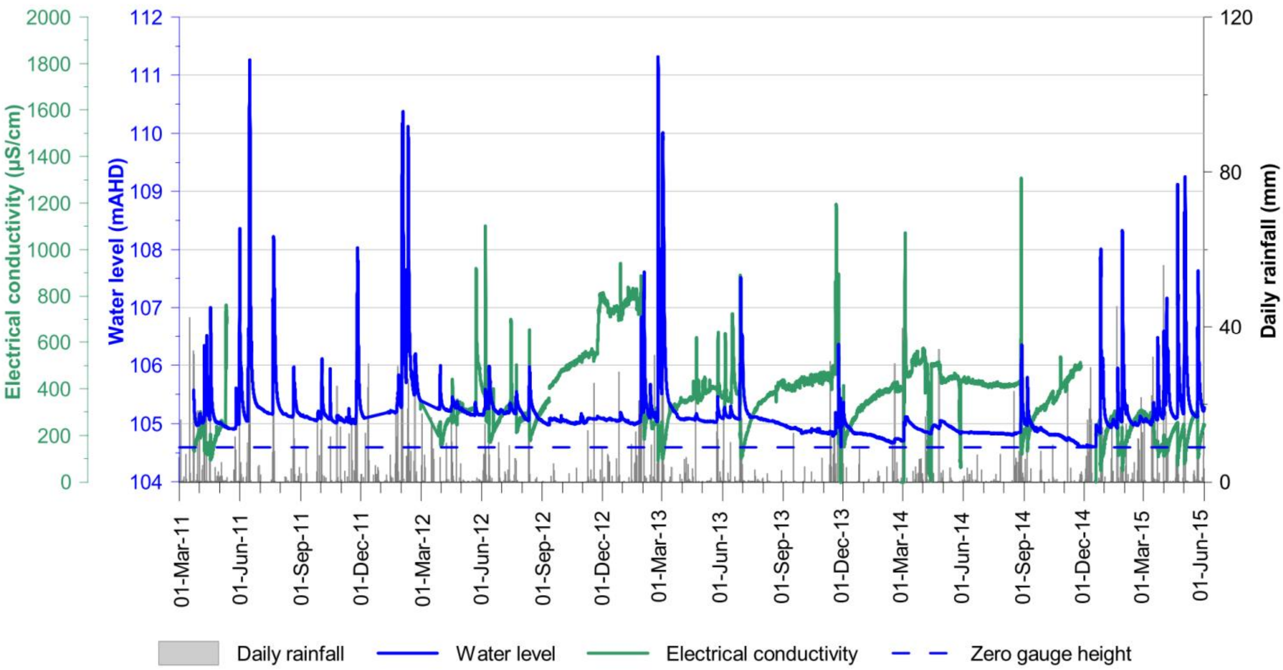

Figure 6.1 Avon River (ASW02) stream levels, electrical conductivity and rainfall

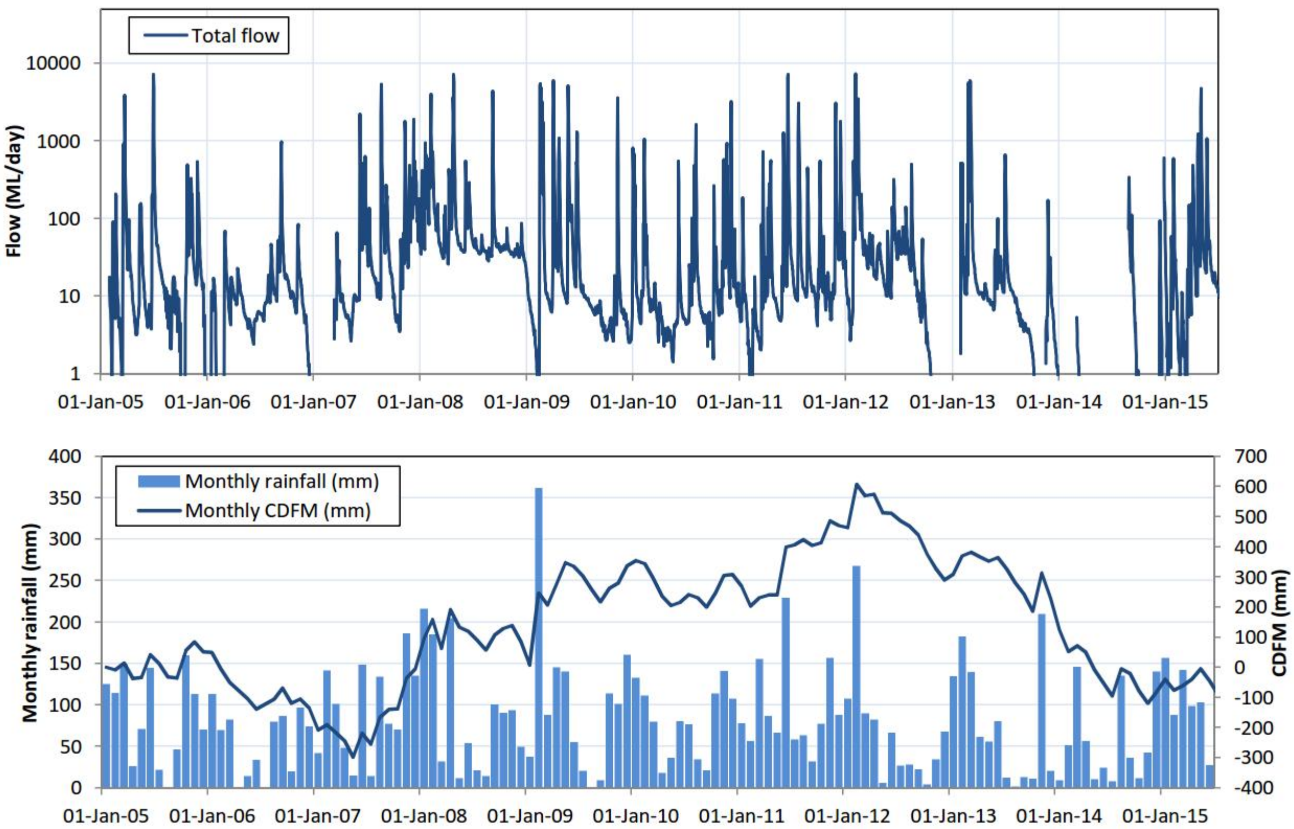

Figure 6.2 **a) Avon River hydrograph at NOW station 208028; b) Monthly rainfall and cumulative deviation from the mean monthly rainfall (CDFM) at Gloucester Post Office BoM station 060015**

Table 6.1 **Estimates of stream baseflow at four gauging stations**

Location	Flow record	Catchment Area (km^2)	Time without flow (%)	Mean baseflow (ML/day)	Mean total flow (ML/day)	Baseflow index (%)
Avon River D/S Waukivory Creek (208028)	01/01/2004 – present	225	5%	18.9	322.4	6%
Mammy Johnsons River at Pikes Crossing (209002)	01/01/1967 – present	156	10%	11.0	152.7	7%
Karuah River at Booral (209003)	01/01/1968 – present	974	2%	82.8	753.6	11%
Karuah River at Dam Site (209018)	01/01/1979 – present	300	1%	42.4	266.8	16%

The baseflow component was estimated at four gauging stations for streams with catchments that overlap with the Gloucester Basin (Table 6.1). The baseflow component was approximated by integrating flow below a line that links the hydrograph recession lows (approximated by a moving monthly minimum flow). The baseflow index is the proportion of total flow that can be attributed to baseflow. For the catchments analysed, baseflow accounts for between 6% and 16% of total flow. The Avon River baseflow estimate is considered to be the most representative of the Gloucester Basin.

At selected AGL stream gauges on the Avon River (TSW01, ASW01 and ASW02) and Dog Trap Creek (TSW02) water levels have been converted to estimated stream flow using theoretical rating curves, based in surveyed stream profiles and a number of assumptions regarding streambed characteristics. Flow duration curves have then been calculated (Figure 6.3). Theoretical flow modelling was undertaken using HEC-RAS software and flow parameters taken from a calibrated model of a locally gauged stream of similar profile and morphology.

Theoretical flow duration curves for the AGL stream gauges show that the Avon River at ASW01 and Dog Trap Creek at TSW02 have no flow for 94% and 98% of the time respectively. The Avon River at TSW01 has no flow 30% of the time, and ASW02 has no flow for 3% of the time.

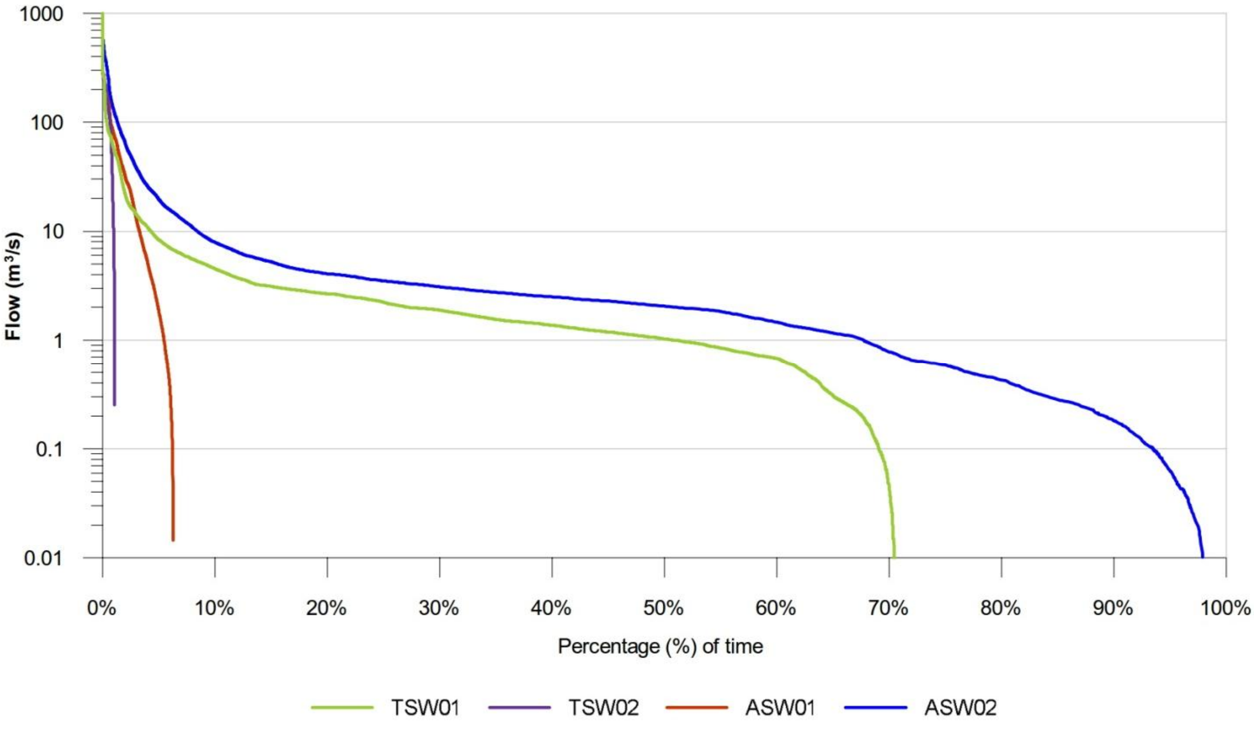

Figure 6.3 Estimated flow duration curves for selected Avon River and Dog Trap Creek gauges

6.2 Surface water quality

Surface water salinity, measured as electrical conductivity (EC), is inversely correlated with rainfall and flow (Figure 6.1). In general, surface water EC sharply decreases after rainfall events as relatively fresh runoff is routed into streams. However, an initial spike (sudden transient increase) in EC is often observed in the initial runoff phase as readily dissolvable salts are flushed from the ground surface and shallow soils. After the initial salinity spike and reduction in EC levels, the EC then gradually increases as flow decreases during periods of recession, and as groundwater discharge starts to become a more dominant component of flow. Evaporative concentration of salts may also be taking place in residual and connected pools.

Surface waters are generally dominated by sodium, chloride and bicarbonate, with magnesium and calcium ions also dominant at most locations at some points in time (Parsons Brinckerhoff 2012a, 2013d, 2013e, 2013f, 2014f, 2014g, 2015b, 2015d).

Dissolved methane concentrations from surface water monitoring locations on the Avon River (TSW01-02 and ASW01-02) were negligible, ranging from <10 µg/L (practical limit of reporting) to 15 µg/L (Parsons Brinckerhoff 2013d). Baseline dissolved methane concentrations were higher in the Waukivory Pilot Area, ranging from <10 µg/L to 1,570 µg/L (Parsons Brinckerhoff 2015d).

6.3 Surface water use

Within the Avon River catchment there are a total of 43 surface water licences with 1,996 ML/year in surface water entitlements. Of this volume, 95% is used for irrigation purposes (DWE, 2009). There are also basic landholder rights totalling 246 ML/year within the Avon River catchment. Total water entitlements represent 2% of the mean annual flow at NOW stream gauge 208028 on the Avon River (Table 6.2). Further details on the Lower North Coast Water Sharing Plan, the Karuah Water Sharing Plan and licensed water use are provided in the Hydrology study (Parsons Brinckerhoff, 2014a).

Table 6.2 Avon River water use

Water source	Surface water entitlement (ML/year)	Basic landholder rights (ML/year)	Total water entitlement (ML/year)	Mean annual flow (ML/year)	Total water entitlement (% of mean annual flow)
Avon River	1,996	246	2,242	110,099 at Waukivory Gauge (208028)	2.0

7. Groundwater

This chapter provides an overview of the hydrogeology of the Gloucester Basin.

7.1 Hydrogeological units

Four broad hydrogeological units have been identified within the Gloucester Basin (Table 7.1). The permeability and groundwater flow characteristics of rocks within the Gloucester Basin are controlled by several factors including lithology, depth and the degree of fracturing and faulting. In this sense hydrogeological units and flow systems do not always correspond with defined geological boundaries.

Table 7.1 Four hydrogeological units

Unit	Aquifer type	Formation name	General lithology	Hydraulic characteristics
Alluvial aquifers	Unconfined and semi-confined, clay capped, porous, granular	Quaternary alluvium	Clay/mixed gravels	Heterogeneous, highly variable permeability associated with varying lithology
Shallow fractured rock aquifers (<150m)	Semi-confined, fractured rock	Upper Permian Coal Measures, Alum Mountain Volcanics	Interbedded sandstone/siltstone with bedding plane fractures	Heterogeneous, high and low permeability domains associated with fault zones and fracturing
Deep coal measure Interburden confining unit	Confined, fractured rock	Upper Permian Coal Measures	Interbedded indurated sandstone/siltstone and claystone	Low permeability associated with sparse fractures, permeability decreases with depth
Deep coal seam water bearing zones	Confined, fractured rock	Upper Permian Coal Measures	Coal/shale	Low permeability associated with cleating and fractures in coal seams, permeability decreases with depth

The four hydrogeological units are summarised as follows:

1. **Alluvial deposits** adjacent to major creeks and rivers comprising unconsolidated sand, gravel and clay. The deposits are typically 12–15 m thick. These systems are heterogeneous but generally permeable with rapid recharge, through-flow and discharge associated with interactions with streams, and to a lesser extent with the underlying less permeable shallow rock. Hydraulic conductivity measurements range from 0.3 to 300 metres per day (m/d), averaging around 10 m/d.
2. **Shallow fractured rock** comprising variably weathered and fractured sedimentary rocks extending to approximately 150 m below the surface, across all sub-cropping Permian units. The shallow rock zone is heterogeneous with relatively impermeable domains separated by more permeable domains, but on the whole it is more permeable than the deeper coal measures. The domains of higher permeability are due to a higher density of fracturing associated with an irregular weathering profile and the near-surface expression of faulting. Shallow aquifers observed during drilling occur within 75 m of surface. Groundwater flow within this zone is more strongly controlled by weathering and fracturing than the attitude of geological strata. Hydraulic conductivity of the shallow rock ranges from 10 m/d to $1x10^{-6}$ m/d at a depth of 150 m, but is typically in the order of 10^{-3} to 10^{-4} m/d.
3. **Deep Coal Measures interburden**. Predominantly sandstone and siltstone units form the interburden to coal seams and are typically of very low permeability, forming aquitards and confining layers. The

permeability of the interburden decreases with depth such that, at the maximum depth of CSG production, it is likely to be in the order of 10^{-5} to 10^{-7} m/d, or less.

4. **Deep coal seams**. Coal seams tend to be slightly more permeable than interburden and commonly form weak water bearing zones. Permeability and storage are provided by small fractures and cleats in the coal. As with the interburden, drill-stem tests clearly show that the permeability of coal seams generally decreases with depth. At the maximum depth of CSG production, the permeability of coal seams is very low (10^{-4}–10^{-6} m/d), but may be an order of magnitude higher than the interburden.

The Alum Mountain Volcanics underlie the Permian Coal Measures, and form the impermeable base of the Gloucester Basin. The Alum Mountain Volcanics outcrop in the eastern and western boundaries of the Basin, forming the elevated topography of the Gloucester and Barrington Tops to the west, and the Mograni Range to the east.

The only beneficial aquifers are contained within the alluvium and the shallow fractured rock to around 75m depth. There are no beneficial aquifers in the deep coal seams or interburden rocks. Both the yields from the alluvial aquifer and the fractured rock aquifers are too low, and the total dissolved solids (TDS) of the groundwater are too high to classify the shallow aquifers of the Gloucester Basin as a highly productive groundwater source (based on NOW, 2012). Only ‘less productive groundwater sources’ exist across the Stage 1 GFDA (AGL, 2015b).

7.2 Hydraulic properties

A summary of the range of hydraulic properties, including horizontal and vertical hydraulic conductivity and storage properties for each hydrogeological unit in the Gloucester Basin are presented in Table 7.2. The results of slug testing, packer testing, test pumping and laboratory testing carried out on groundwater monitoring bores to a depth of 300m in the Gloucester are presented in Figure 7.1.

Hydraulic testing results for the alluvium are within the range of 10 m/d to 100 m/d, with the exception of two tests. The shallow rock to 150 m depth is highly heterogeneous, consisting of high and low conductivity domains associated with fault zones and fracturing, with a range of $1x10^{-6}$ m/d to 10 m/d (Figure 7.1). Due to the high variability in hydraulic conductivity in the alluvium and shallow rock, and the large number of monitoring bores screened in these hydrogeological units, detailed calibration of the regional numerical model will be undertaken for these model layers. The alluvium will be represented as one model layer, and the shallow rock will be represented as two model layers (to 60 mbgl and 150 mbgl) in the regional model. Spatially variable grids of hydraulic conductivity will be developed for these hydrogeological units. This approach will enable both horizontal variability in hydraulic properties, and vertical head differences observed within the alluvium and shallow rock monitoring bores, to be represented.

Data for the Gloucester Basin show a logarithmic decrease in hydraulic conductivity with depth in the coal seams and interburden of the deep coal measures (Figure 7.2). This relationship of decreasing hydraulic conductivity with depth is also comparable with data from the Hunter Valley and Sydney Basin (Tammetta, 2009) (Figure 7.3). The laboratory permeability testing of core samples of interburden defines a narrower range (10^{-6} to 10^{-4} m/day) with no obvious depth trend. The DST permeability data converges with the laboratory core data at about 700 m. This indicates that the bulk-rock permeability is controlled by fractures above about 700 m and that the decreasing permeability with depth is due to progressive closing of fractures with increasing lithostatic pressure. The hydraulic conductivity of the coal seams is approximately an order of magnitude higher than the interburden.

It is noted that the relationships of decreasing hydraulic conductivity with depth highlighted in Figures 7.2 and 7.3 are a good representation of the trend, but other relationships are also possible. The coal seams and interburden of the deep coal measures will be represented by several layers in the regional numerical model. Due to the steeply dipping geology of the coal measures, and therefore the model layers, it will not be appropriate to use a single value of hydraulic conductivity for each model layer. A depth dependent function will be used to develop spatially variable grids of hydraulic conductivity for each of the coal seam and interburden layers based on the depths of the model cells. This depth dependent function will initially be based on the relationships shown in Figures 7.2 and 7.3, and will then be tested and varied throughout the model calibration process. Sensitivity and uncertainty analysis will also be undertaken to determine the importance of hydraulic properties on model calibration and model predictions.

Analysis of core samples was undertaken as part of the Stratford groundwater assessment (Heritage Computing, 2012) to determine vertical and horizontal hydraulic conductivity (Table 7.3). The vertical hydraulic conductivity tests were taken perpendicular to the bedding planes, and the horizontal hydraulic conductivity was taken parallel to the bedding planes. The anisotropy ratio between horizontal hydraulic conductivity (arithmetic mean) and vertical hydraulic conductivity (harmonic mean) varies from 2 to 30 (Heritage Computing, 2012). The vertical hydraulic conductivity is an order of magnitude lower that the horizontal hydraulic conductivity on average.

Table 7.2 Hydraulic conductivity summary in the Gloucester Basin (interpreted to 1000 mbgl)

Hydrogeolog-ical unit	Depth (mbgl)	Horizontal hydraulic conductivity range (m/d)[a]	Vertical hydraulic conductivity range (m/d)[c]	Specific storage (Ss) (m^{-1}) [d]	Specific yield (Sy) (%) [d]
Alluvial aquifers	0 to 15	10 – 100[b]	1 to 10	N/A (unconfined)	5 to 30
Shallow fractured rock aquifers	0 to 150	$1x10^{-6}$ – 10	$1x10^{-7}$ – 1	$5x10^{-5}$ to $5x10^{-6}$	$1x10^{-4}$ to 3
Deep coal measure interburden confining unit	150	$5x10^{-3}$ (maximum)	$5x10^{-4}$ (maximum)	$5x10^{-5}$ to $5x10^{-6}$	$1x10^{-4}$ to 3
	1000	$1x10^{-7}$ (decreases with depth to a minimum at 1000 mbgl)	$1x10^{-8}$ (decreases with depth to a minimum at 1000 mbgl)		
Deep coal seam water bearing zones	150	$1x10^{-1}$ (maximum)	$1x10^{-2}$ (maximum)	$5x10^{-5}$ to $5x10^{-6}$	0.1 to 3
	1000	$1x10^{-6}$ (decreases with depth to a minimum at 1000 mbgl)	$1x10^{-7}$ (decreases with depth to a minimum at 1000 mbgl)		

(a) Horizontal hydraulic conductivity estimates from hydraulic testing on groundwater monitoring bores (Parsons Brinckerhoff 2012a, 2013c, 2014b, 2014c, 2015c), drill stem tests on exploration bores (AGL, 2013) and comparative hydraulic conductivity data from the Gloucester Basin, Sydney Basin and Hunter Valley (Tammetta, 2009).

(b) The alluvium is highly heterogeneous. All but two slug tests yielded hydraulic conductivities in the range 10 to 100 m/d. The two outlier values are considered anomalous and have been removed from this summary table.

(c) Based on analysis of core samples (Table 7.3), the vertical hydraulic conductivity is an order of magnitude lower than the horizontal hydraulic conductivity on average (Heritage Computing, 2012).

(d) Based on literature data from Mackie (2009).

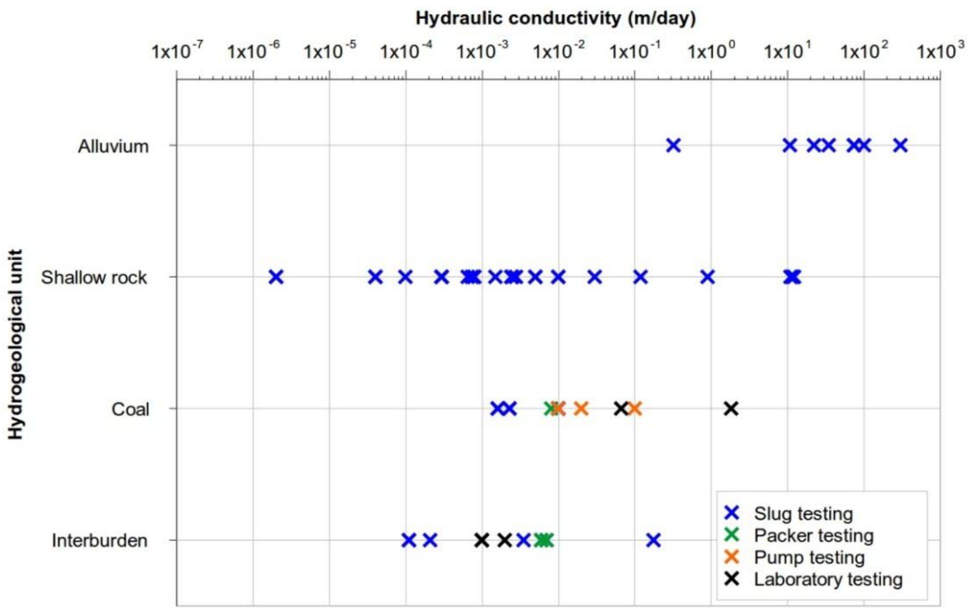

Figure 7.1 **Horizontal hydraulic conductivity summary from hydraulic testing of groundwater monitoring bores to 300 m in the Gloucester Basin (Parsons Brinckerhoff 2012a, 2013c, 2014b, 2014c, 2015c)**

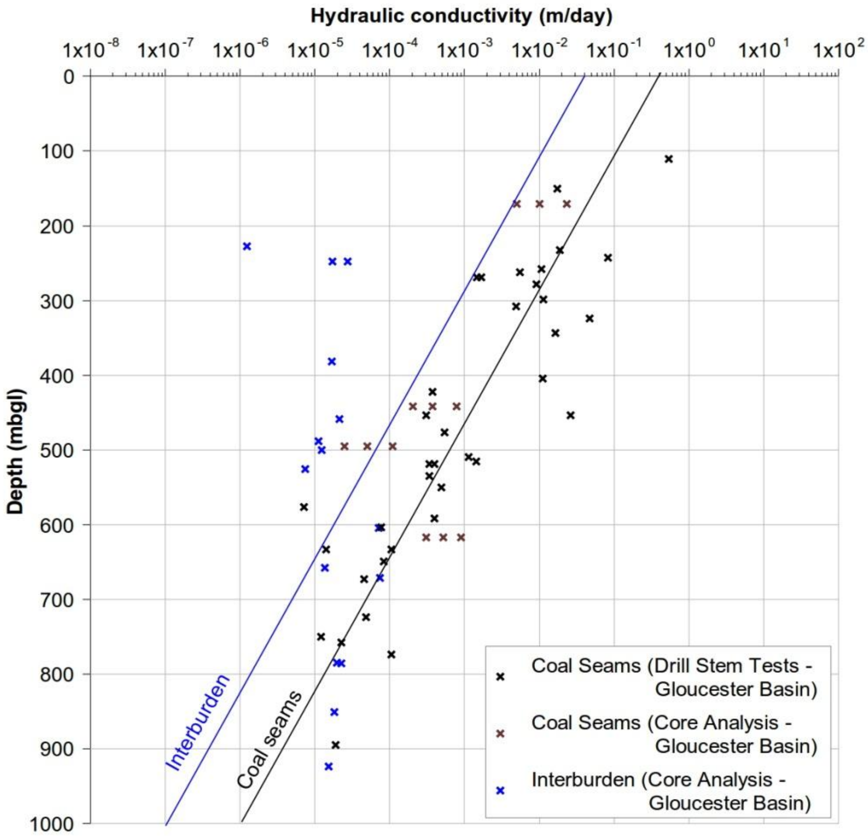

Figure 7.2 **Horizontal hydraulic conductivity in the Gloucester Basin (AGL, 2013)**

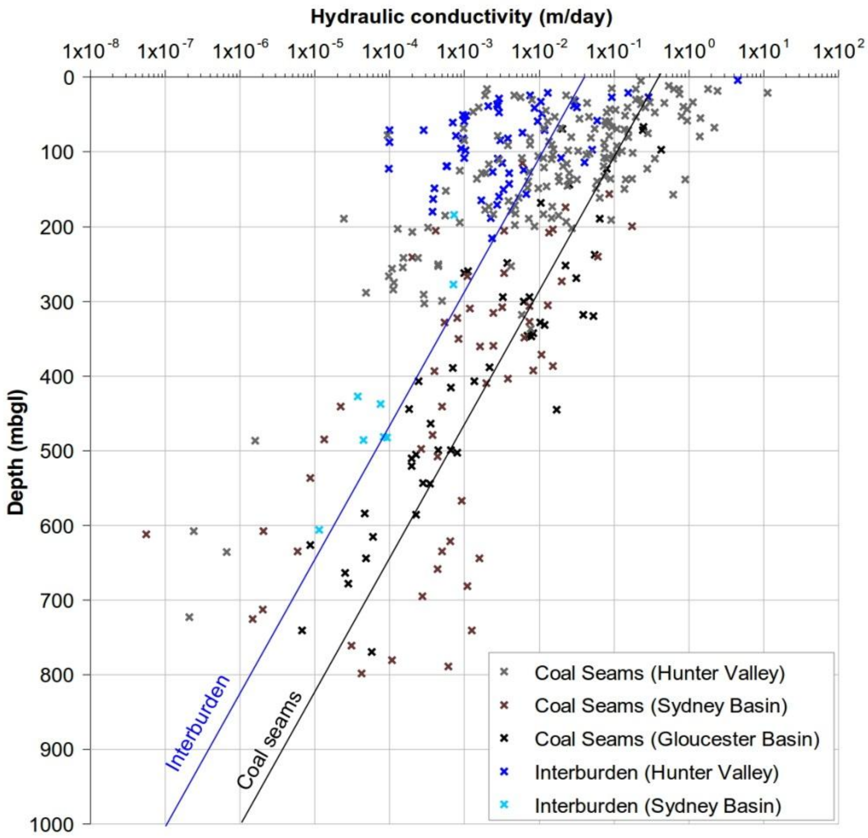

Figure 7.3 **Horizontal hydraulic conductivity in the Gloucester Basin, Sydney Basin and Hunter Valley (Tammetta, 2009)**

Table 7.3 **Summary of horizontal and vertical conductivity from core analysis (Heritage Computing, 2012)**

	Clareval Formation (Interburden)	Dog Trap Creek Formation (Interburden)	Duralie Road Formation (Interburden)	Mammy Johnsons Formation (Interburden)	Waukivory Creek Formation (Interburden)
Horizontal hydraulic conductivity (m/d) – Arithmetic mean	$1.5x10^{-6}$	$7.5x10^{-5}$	$3.16x10^{-5}$	$2.0x10^{-6}$	$6.3x10^{-4}$
Vertical hydraulic conductivity (m/d) – Harmonic mean	$8.1x10^{-7}$	$4.1x10^{-6}$	$1.1x10^{-6}$	$1.6x10^{-7}$	$2.2x10^{-4}$
Anisotropy ratio	1.9	18.3	28.7	12.5	2.9

7.3 Groundwater levels

Groundwater level trends in monitoring bores vary depending on the lithology and depth of screened interval. Temporal trends are described for each hydrogeological unit in this section, with reference to representative hydrographs. Groundwater hydrographs for the full monitoring network are shown in Appendix C. All monitoring bores are located in the (north flowing) Avon River catchment with the exception of the WRMB sites which are located in the (south flowing) Wards River catchment. Detailed discussion of groundwater levels trends since installation of the monitoring network commenced in 2011 are included in the 2012 annual monitoring report (Parsons Brinckerhoff, 2012b), the 2013 annual monitoring report (Parsons Brinckerhoff, 2013d) and the 2014 annual monitoring report (Parsons Brinckerhoff, 2014d). The 2015 annual monitoring report is in preparation.

7.3.1 Alluvium

Representative hydrographs from alluvial monitoring bores TMB01, TMB02 and AMB01 in the centre of the Stage 1 area are shown in Figure 7.4. Groundwater levels in monitoring bores screened within the alluvial aquifers show characteristic quick responses to rainfall events. This indicates rapid shallow aquifer recharge via direct rainfall infiltrations and/or enhanced infiltration during creek high flow and flood events.

The groundwater level hydrographs can be divided into two main response types:

1. Rapid recharge response followed by a relatively steep groundwater recession curve (TMB01, TMB02). These monitoring bores show rapid response to most rainfall events followed by a return to near-previous levels over a period of one to two months (i.e. a short term increase in storage). These responses imply a relatively direct recharge from rainfall and/or flooding and relatively high permeability of the alluvium. During extremely dry periods when there are very low stream levels, accelerated drainage of alluvial groundwater (from storage) is observed at the TMB01 site.
2. A threshold response followed by a longer recession curve (AMB01). These monitoring bores show rapid recharge responses to the larger rainfall events, but slower responses to smaller rainfall events. In addition, the recession curves are flatter such that the groundwater level may take several months to recover to pre-existing levels and typically does not fully recover before the next major recharge event (i.e. longer term increase in storage). These responses imply rapid recharge during surface runoff and flooding events, but less significant recharge by rainfall alone. The shallow recession curves imply lower permeability of the alluvium at these locations. This is supported by drilling logs at these locations which indicate clay-rich alluvium, or thick clay layers overlying coarser grained alluvial deposits.

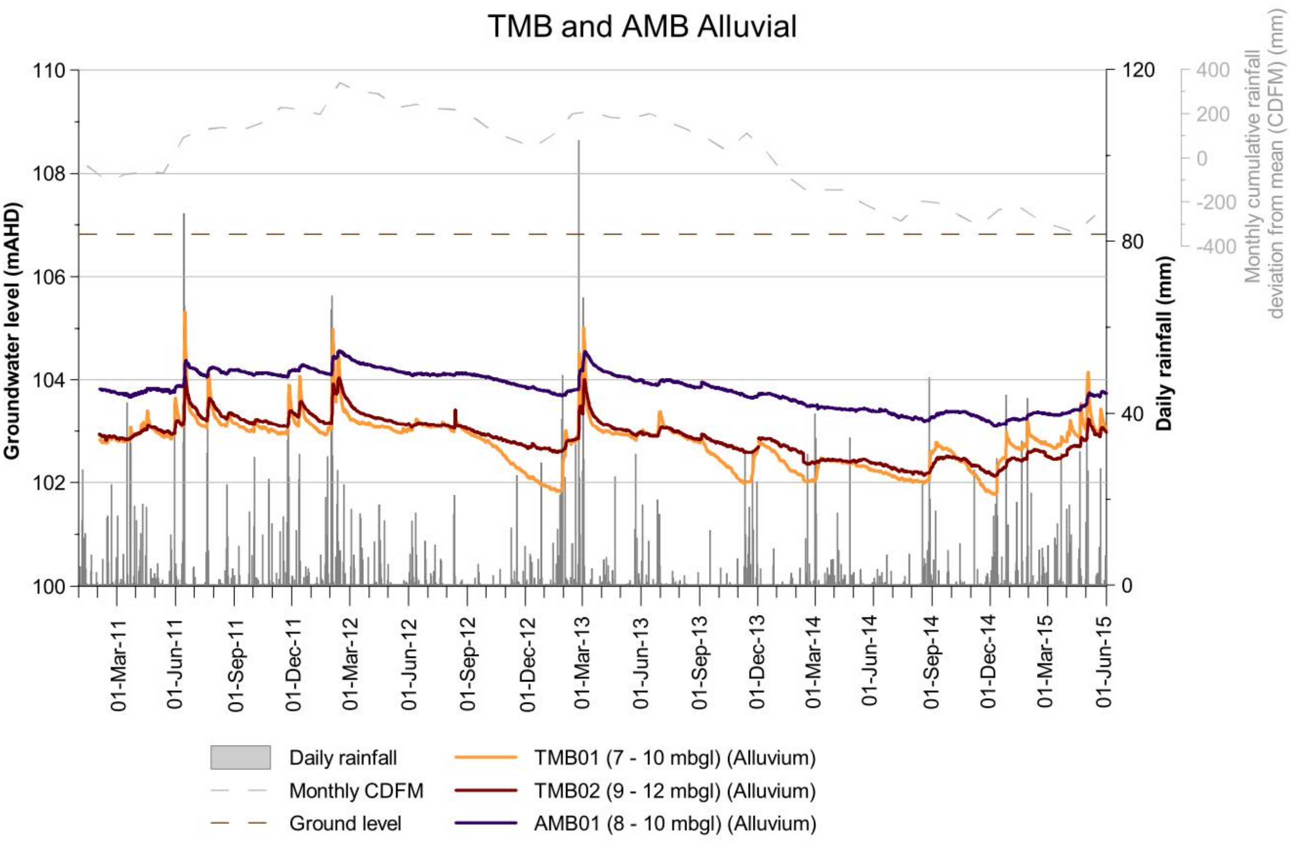

Figure 7.4 Groundwater levels and rainfall at the TMB and AMB alluvial monitoring bores

7.3.2 Shallow fractured rock

Representative shallow rock hydrographs from the BMB nested monitoring site in the central west of the Stage 1 GFDA are shown in Figure 7.5. Groundwater levels show a delayed response to periods of higher than average rainfall (as indicated on the cumulative deviation from mean monthly rainfall plot), indicating that groundwater levels are responding to slow rainfall recharge over a broad area, assumed to be up-gradient of the monitoring locations. At the BMB site this groundwater level response is delayed approximately 1 to 2 months after periods of higher than average rainfall. There are no strong responses to individual rainfall events.

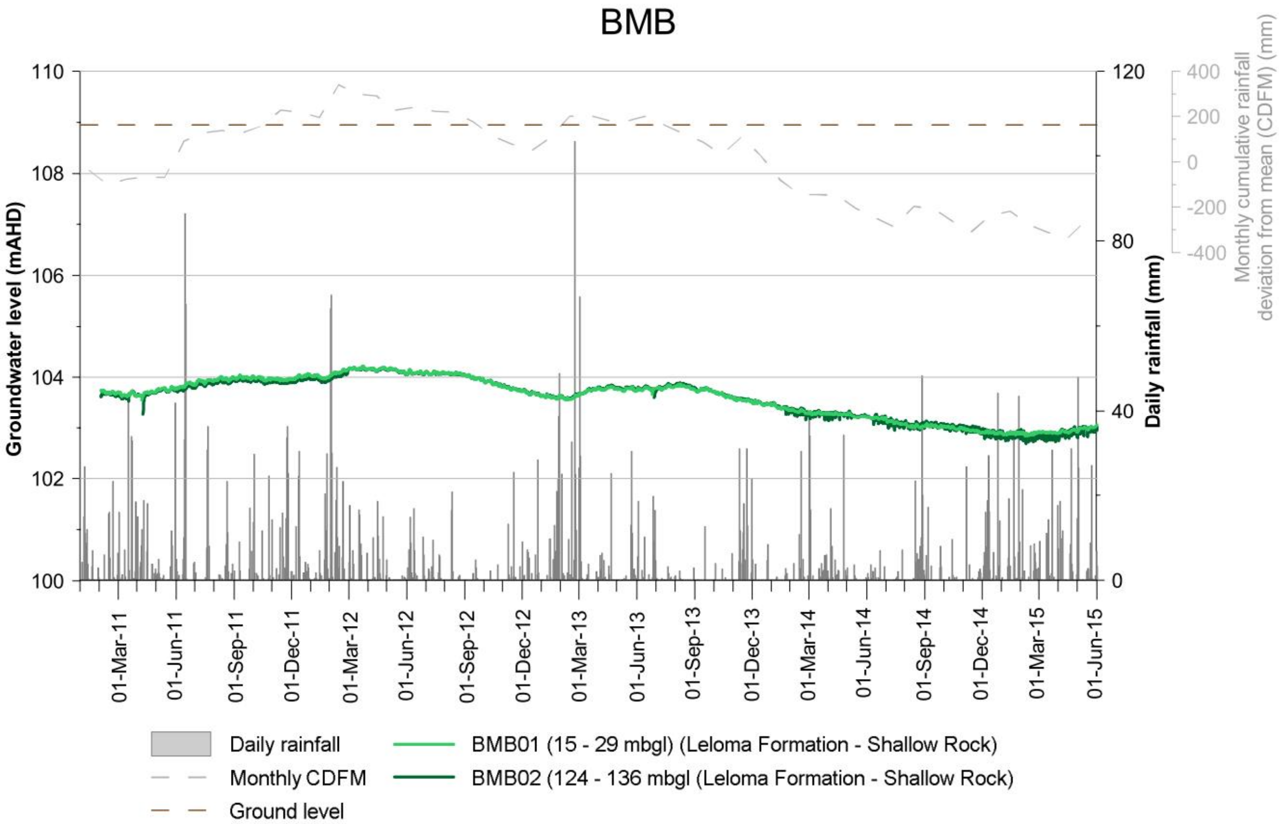

Figure 7.5 Groundwater levels and rainfall at the BMB shallow rock monitoring bores

7.3.3 Deep coal seams

Representative coal seam hydrographs from the TCMB nested monitoring site are shown in Figure 7.6. Groundwater levels in TCMB03 do not show an overall change in groundwater levels since installation in 2011. A gradual increase in groundwater levels of about 0.5 m since installation in 2011 is observed in coal seam monitoring bore TCMB04. This bore is the deepest conventional monitoring bore in the network (screened from 327 to 333 mbgl) and may reflect a delayed response to a longer-term period of higher than average rainfall from 2006 to 2012. Monitoring bores screened within the deep coal seams do not show a change in groundwater levels in response to rainfall events.

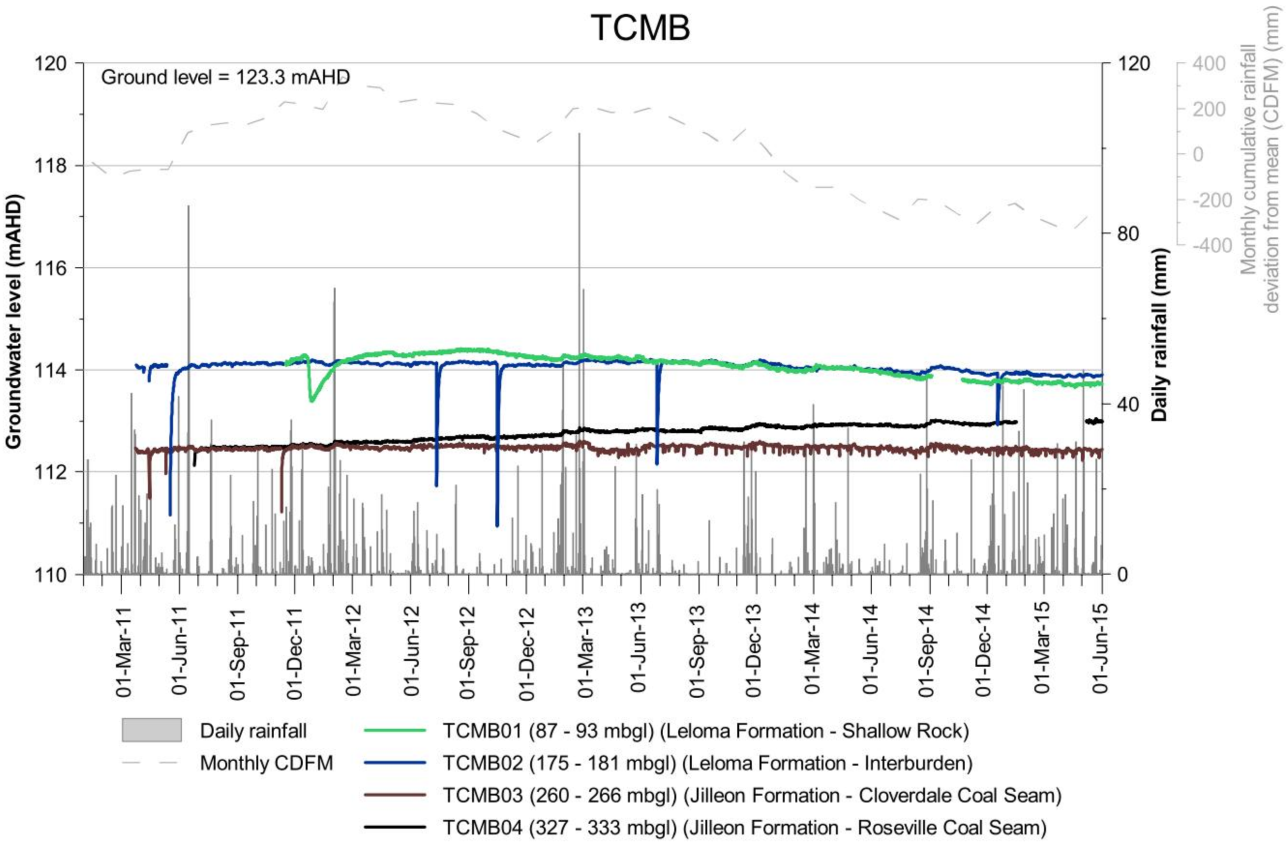

Figure 7.6 **Groundwater levels and rainfall at the TCMB interburden and coal seam monitoring bores**

7.3.4 Deep coal measures interburden

A representative interburden monitoring bore (TCMB02) from the TCMB nested monitoring site is shown in Figure 7.6. Groundwater levels in monitoring bores screened in the interburden do not show an overall increase or decrease since installation of the monitoring network in 2011, and there are no strong responses to rainfall events.

7.3.5 Deep groundwater responses

Multi-zone monitoring well WKMB05 is installed within the Stage 1 GFDA at Waukivory to monitor piezometric pressure of deep groundwater at six sensors between 340 mbgl and 712 mbgl. A plot of sensor depth against pressure (metres H_2O) for WKMB05 is shown in Figure 7.7. Piezometric levels since installation in November 2014 are shown in Figure 8.8.

Figure 7.7 shows that WKMB05 sensors 1 to 4 align closely to the hydrostatic pressure profile, with the increase in pressure at sensors 3 and 4 indicating that there is an upward vertical gradient at depth. This is to be expected at the axis of the Gloucester Basin where groundwater generally discharges. Preliminary numerical modelling for the Basin (Parsons Brinckerhoff, 2015a) indicates that approximately 10 m increase in pressure head at a depth of about 600 mbgl can be expected where sensors 3 and 4 are located. Piezometric levels in sensors 1 to 4 vary from about 5 m above ground level (sensor 1) to about 17 m above ground level (sensor 4) (Figure 8.8).

Piezometric levels in WKMB05 sensors 5 and 6 are about 45 m and 70 m respectively above ground level (Figure 8.8), and therefore higher than the modelled hydrostatic profile at this location (Figure 7.7). It is possible that the lower two sensors are influenced by the fracture stimulation conducted as part of AGL's Waukivory Pilot Testing Program (Parsons Brinckerhoff, 2015d), as discussed further in Section 8.4.

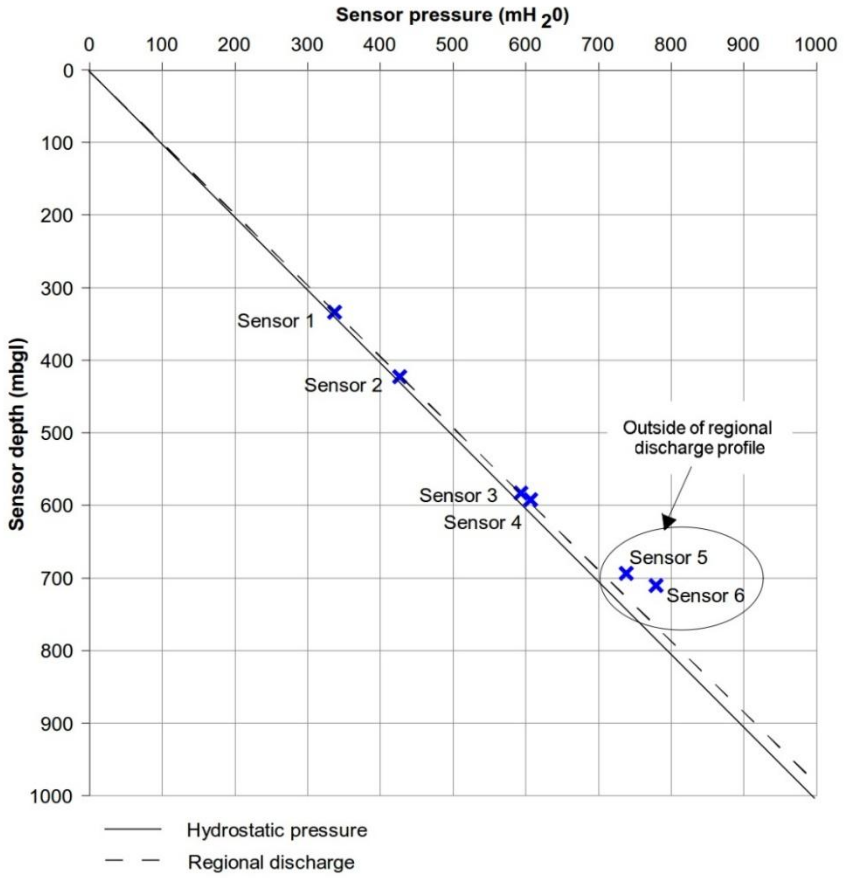

Figure 7.7 Sensor depth (mbgl) vs sensor pressure (mH_20) at WKMB05

7.3.6 Vertical head differences

Vertical head differences were noted at nine of the eleven nested bore installations, and at multi-zone monitoring well WKMB05, as shown in Table 7.4. Due to the very low permeability of the interburden units, vertical flow is likely to be limited and slow, despite the vertical head differences. Lateral flow within each of the geological units is concluded to be the primary groundwater flow mechanism when there are no stresses on the shallow or deep groundwater systems.

Table 7.4 Vertical head differences at the nested monitoring bore installations

Monitoring site	Head Difference	Comments
TCMB	Downward	~ 1.5 m between the shallow rock and deeper coal seams
TTMB	Downward	~ 2 m to ~ 2.5 m between the shallow rock and the deeper rock
FKMB	Downward	~ 12.5 m between the shallower and the deeper monitoring bore in the shallow rock; this is the most significant gradient across the monitoring sites, however it is also the most elevated site
BWMB	Slight Downward	~ 0.5 m between the alluvium/shallow rock and the deep interburden
S4MB	Upward	~ 1 m to ~ 2 m between the deeper coal seam and the shallow rock

Monitoring site	Head Difference	Comments
S5MB	Slight Upward Downward	~ 0.5 m between the deeper coal seam at S5MB03 and the shallow rock at S5MB02 until July 2013; ~ 2 m between the shallow rock at S5MB02 and the deeper coal seam at S5MB03 after July 2013 Note - the shallow rock monitoring bore at S5MB01 shows a slow response to sampling and therefore may not be representative of water table trends
RMB	Slight Upward	~ 0.5 m between the deeper and the shallower monitoring bore in the shallow rock
WKMB	Upward	~ 2.5 m to ~ 3 m between the interburden and the shallow rock
WRMB	Upward	~ 1.5 m between the deeper and shallow monitoring bore in the shallow rock
BMB	No gradient	0 m
WMB	No gradient	0 m
WKMB05[(a)]	Upward	~ 12m from the deep interburden (sensor 4 = 714 mbgl) to the shallow interburden (sensor 1 = 340 mbgl)

(a) Sensors 5 and 6 at WKMB05 have been excluded from the vertical head difference analysis as these sensors appear to be influenced by a different pressure source that would be consistent with influence from deep fracture stimulation conducted as part of AGL's Waukivory Pilot Testing Program (Parsons Brinckerhoff, 2015d).

7.3.7 Spatial trends

There is evidence for a groundwater flow divide, just north of Wards River, following the approximate location of the surface water divide. This separates the Gloucester Basin into a northern sub-basin where regional groundwater flow is predominantly from south to north, and a southern sub-basin where regional groundwater flow is predominantly from north to south. Locally, groundwater flow can be east to west or west to east as groundwater also flows laterally from rock outcrop areas towards the centre of the Basin and discharges to the Avon River and Wards River (Figure 7.8).

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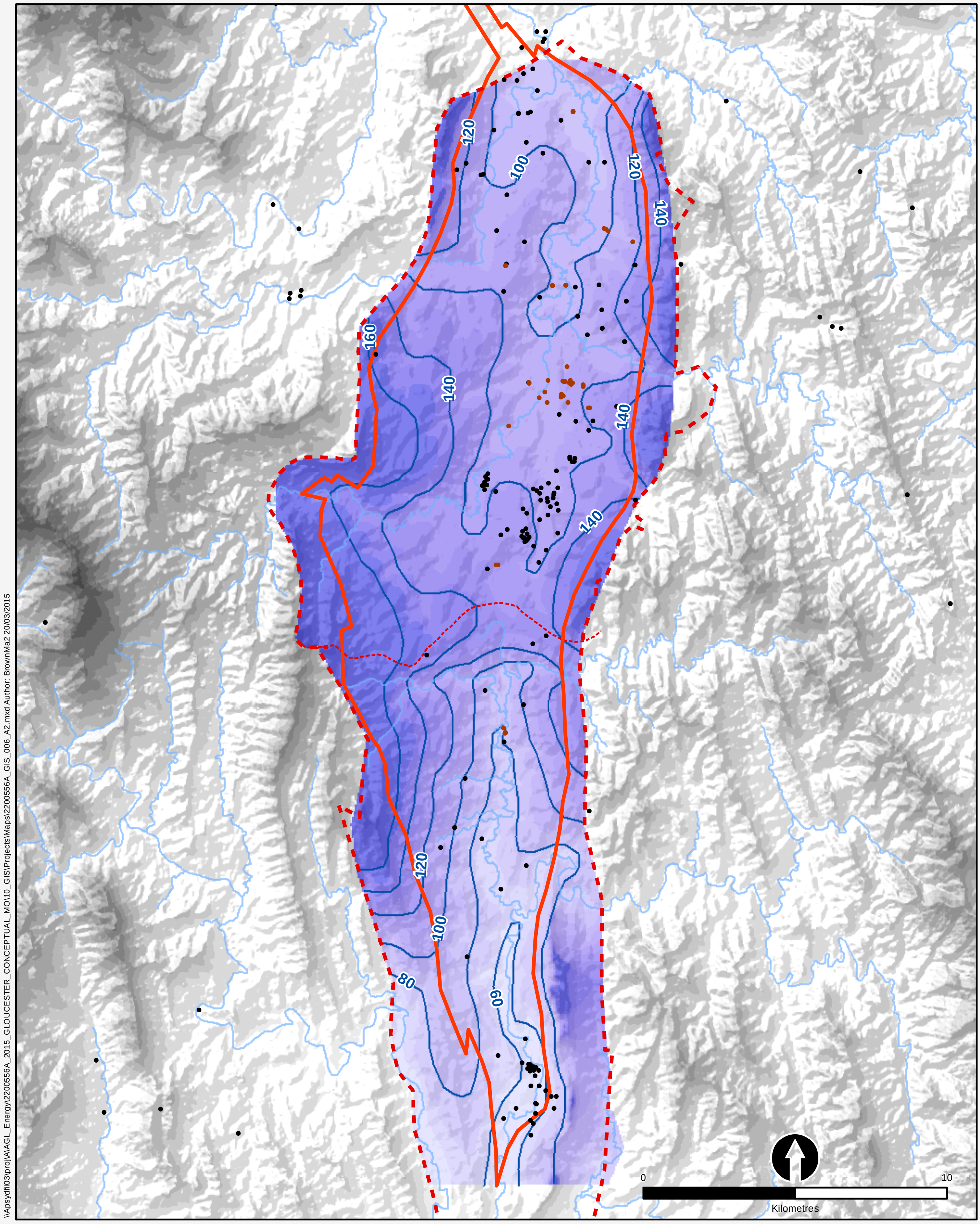
HYDROGEOLOGICAL CONCEPTUAL MODEL OF THE GLOUCESTER BASIN
AGL UPSTREAM INVESTMENTS PTY LTD



Water levels m(AHD)
- 41 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120
- 120 - 130
- 130 - 140
- 140 - 150
- 150 - 160
- Alum Mountain Volcanics boundary
- Permian Coal Measures boundary
- Surface water divide
- Rivers and streams
- Contour
- AGL bores
- All other bores

Figure 7.8
Interpreted regional groundwater contours

7.4 Groundwater – surface water interaction

A comparison of stream gauge data from the Avon River with adjacent groundwater levels at a representative site (ASW02 and AMB02) is shown in Figure 7.9. Groundwater levels are typically higher than adjacent stream levels (by between one and two metres), indicating that streams are discharge features for shallow groundwater in the Stage 1 GFDA. It is only during relatively short periods of high stream levels and flow, associated with rainfall events and floods, that the shallow alluvial groundwater is recharged from the streams.

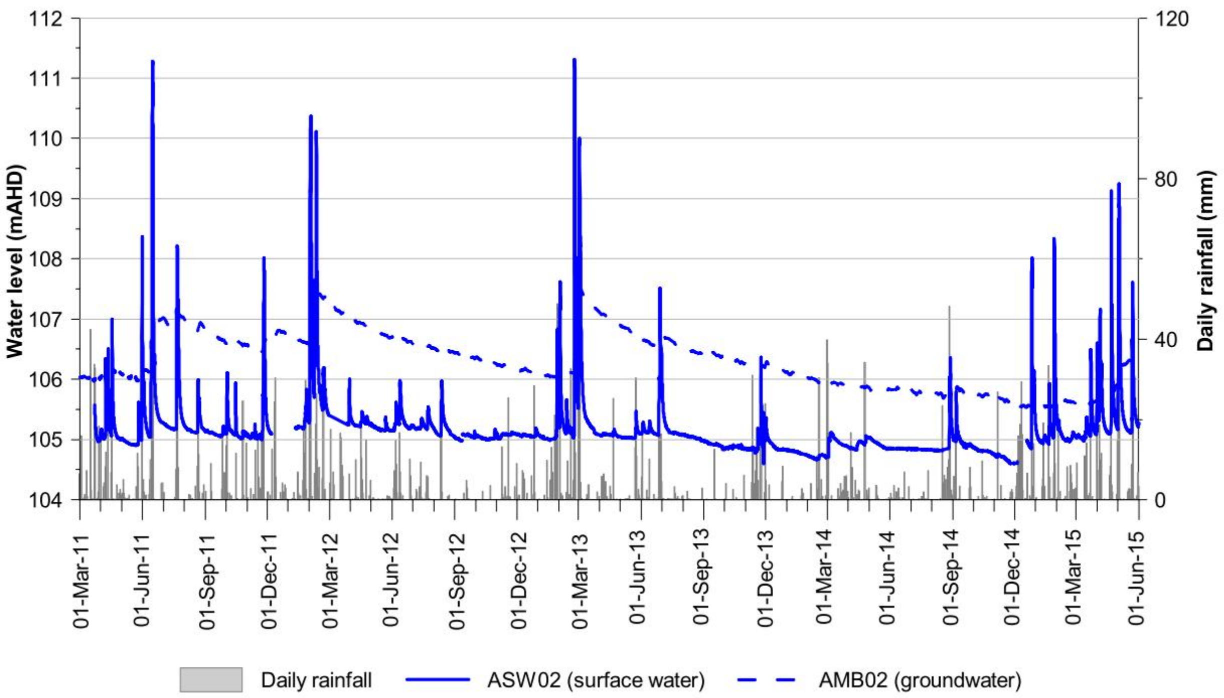


Figure 7.9 Surface water levels for the Avon River (solid line) and groundwater levels in the adjacent alluvium (dashed line)

7.5 Groundwater dependent ecosystems

7.5.1 Groundwater dependent ecosystem atlas

Groundwater dependent ecosystems (GDEs) are communities of plants, animals and other organisms that depend on groundwater for survival (Department of Land and Water Conservation, 2002). A GDE may be either entirely dependent on groundwater for survival, or may use groundwater opportunistically of for a supplementary source of water (Hatton & Evans, 1998).

GDEs can potentially include wetlands, mound springs, river base flows, cave ecosystems, playa lakes and saline discharges, springs, mangroves, river pools, billabongs and hanging swamps and near-shore marine ecosystems. The GDE Atlas (Bureau of Meteorology, 2012) categorises groundwater dependent ecosystems into three classes:

1. Ecosystems that rely on the surface expression of groundwater – this includes all the surface water ecosystems that may have a groundwater component, such as rivers, wetlands and springs. Marine and estuarine ecosystems can also be groundwater dependent.
2. Ecosystems that rely on the subsurface presence of groundwater – this includes all vegetation ecosystems.

3. Subterranean ecosystems – this includes cave and aquifer ecosystems.

Ecosystems that rely on the surface expression of groundwater

Groundwater discharge can be important in maintaining baseflow in rivers and streams, and ecosystems associated with these discharge areas may have a high dependency on groundwater for their water requirements. The GDE Atlas does not identify any ecosystems that rely on the surface expression of groundwater within the Gloucester Basin (Figure 7.10). Groundwater discharge (baseflow) is a small component of total stream flow. This discharge is expected to manifest as minor seepage over broad areas as there is no strong discharge expression in the landscape.

Ecosystems that rely on the subsurface presence of groundwater

Ecosystems that rely on the subsurface presence of groundwater are most likely to occur in areas where groundwater is close to the surface. Shallow groundwater may be important for sustaining terrestrial and riparian vegetation, particularly deep rooted varieties, although it is noted that there is little undisturbed native vegetation over much of the Gloucester Basin. The GDE Atlas identifies some vegetation ecosystems that rely on the subsurface presence of groundwater within the Stage 1 GFDA and the broader Gloucester Basin (Figure 7.10). The area identified within the Stage 1 GFDA is on the Tiedman property and relates to natural vegetation cover. There is no known regional groundwater dependence for this residual vegetation cover as water levels are more than 10m below ground level in the bedrock, although there may be some occasional perched water dependency in the weathered zone from recent rainfall.

There are no cave or aquifer ecosystems associated with the groundwater systems located within the Stage 1 GFDA. The known GDEs (from local studies) have dependencies on stream baseflows and possibly riparian vegetation along the perennial and ephemeral water courses. The sensitive receptors for deep groundwater discharge are:

- The beneficial aquifers.
- The baseflows to the Avon River.

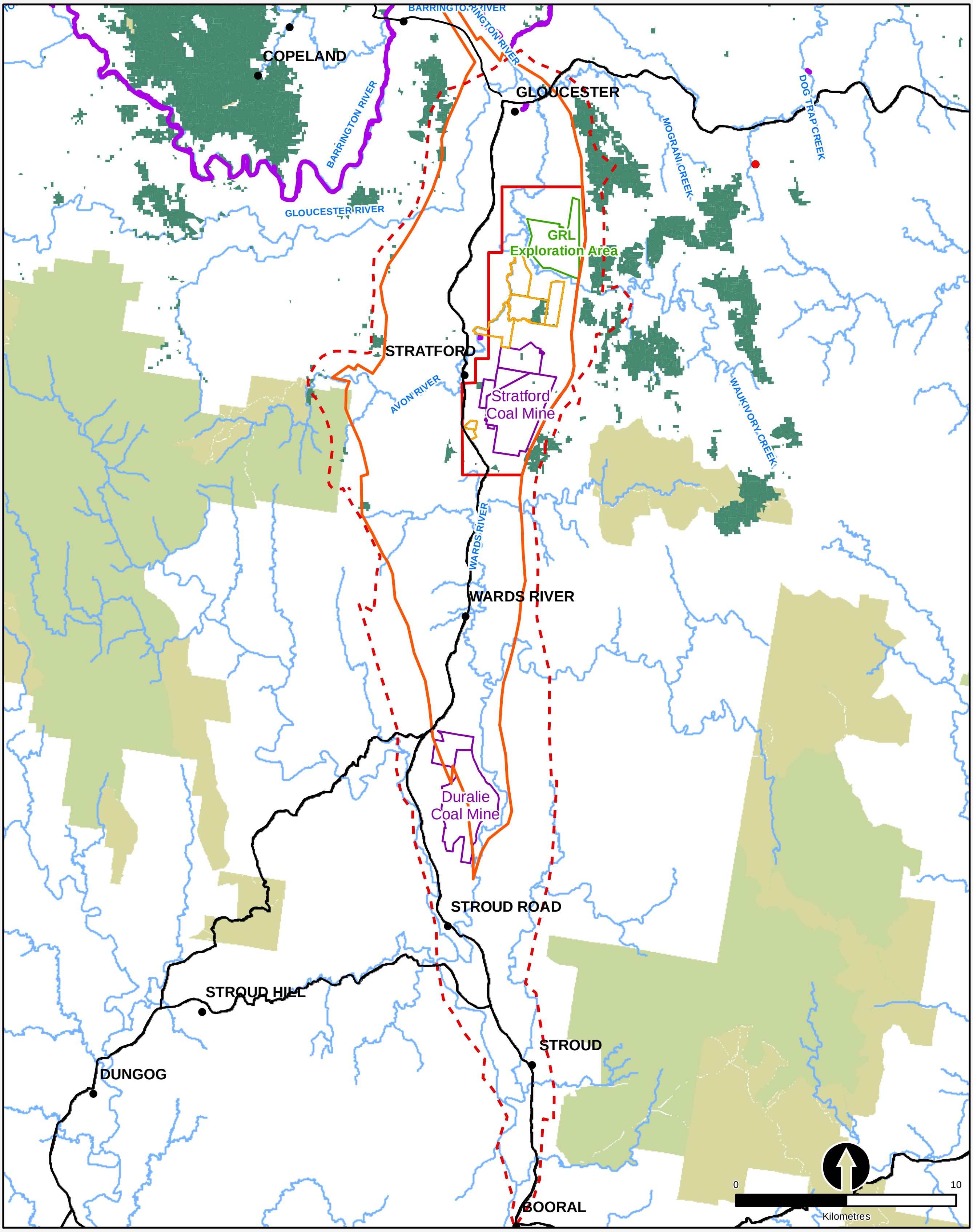
7.5.2 Water Sharing Plan listings

There are two Water Sharing Plans (WSPs) and one under development that cover the Gloucester Basin:

1. Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources (2009).
2. Draft North Coast Fractured and Porous Rock Groundwater Sources (under development).
3. Water Sharing Plan for the Karuah River Water Source (2004).

It is noted that there are no GDEs identified in the Water Sharing Plans within the Gloucester Basin (Figure 7.10).

The Aquifer Interference (AI) Policy lists the minimal impact considerations for less productive groundwater sources as less than or equal to 10% cumulative variation in the water table, 40m from any high priority groundwater dependent ecosystem or high priority culturally significant site (as listed in the schedule of the relevant water sharing plan). A discussion of the minimum impact considerations under the AI policy is provided in AGL, 2015b.



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Alum Mountain Volcanics boundary
AGL owned properties
GRL exploration area boundary
Mining Lease Boundary
Permian Coal Measures boundary
Stage 1 GFDA boundary
GDEs dependent on surface groundwater (BOM)
GDEs dependent on subsurface groundwater (BOM)
National Park, Nature Reserve or State Conservation Area
NSW State Forest
GDEs in Water Sharing Plans (NOW)
Major roads
Rivers and streams
Towns

Figure 7.10
Groundwater Dependent Ecosystems

7.6 Groundwater quality

Groundwater quality data presented below have been summarised from previous groundwater monitoring investigations in the Gloucester Basin (Parsons Brinckerhoff 2012a, 2013c, 2013d, 2013e, 2014e, 2014f, 2014g, 2015b, and 2015d). Groundwater salinity is typically brackish to slightly saline for the alluvium, shallow fractured rock and deep coal measures. The EC is plotted against the sodium adsorption ratio (SAR) in Figure 7.11 to provide an indicator of water quality. Figure 7.11 shows groundwater typically has high SAR values combined with elevated EC indicating poor suitability for irrigation.

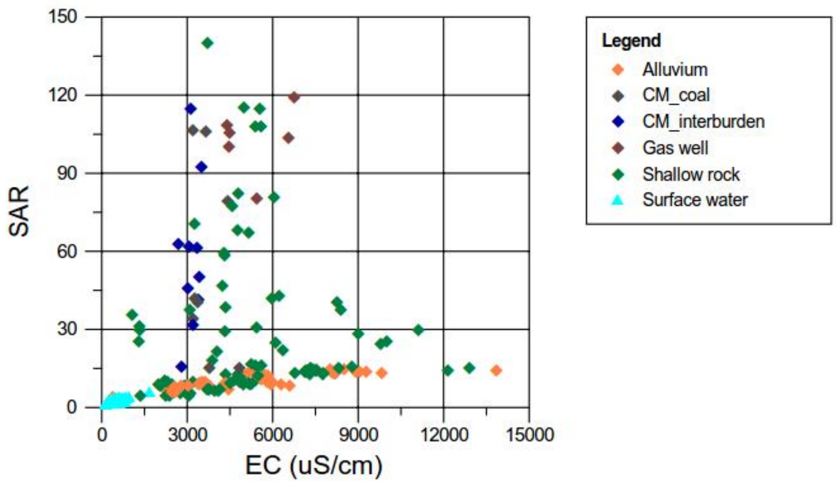


Figure 7.11 SAR vs EC for groundwater and surface water

Groundwater and surface water types are presented in the Piper plot in Figure 7.12. Groundwater is dominated by sodium and chloride, with bicarbonate dominant in groundwater from gas wells and some shallow rock, coal measures and alluvial locations. The bivariate plots in Figure 7.12 show that groundwater and surface water can be subdivided into at least three distinct types or groupings on the basis of major ion chemistry:

1. Surface water is characterised by low salinity and Ca/Cl ratios that are highly variable but generally elevated relative to deep groundwater and the seawater ratio.
2. Groundwater with brackish to moderate salinity and a similar range in Ca/Cl ratios to the surface waters. This group includes samples from alluvium and some shallow rock monitoring bores.
3. Groundwater with slight to moderate salinity and low Ca/Cl ratios. This group includes samples from deeper groundwater (including gas wells) and some shallow rock monitoring bores.

The elevated Ca/Cl in the first two groups indicates addition of Ca^{2+} ions through mineral dissolution, whereas the low Ca/Cl and elevated Na/Cl in the third group indicates an enrichment in Na+ ions relative to modern rain water and runoff (also evident in the SAR-EC plot in Figure 7.12) through a process such as ion exchange. Similar groupings are noted in groundwater quality data collected in the northern Gloucester Basin by GRL Limited (Parsons Brinckerhoff, 2015g). The groupings indicate distinct hydrochemical processes and environments, and the potential for water quality data to be used as a natural tracer with respect to groundwater-surface water interaction.

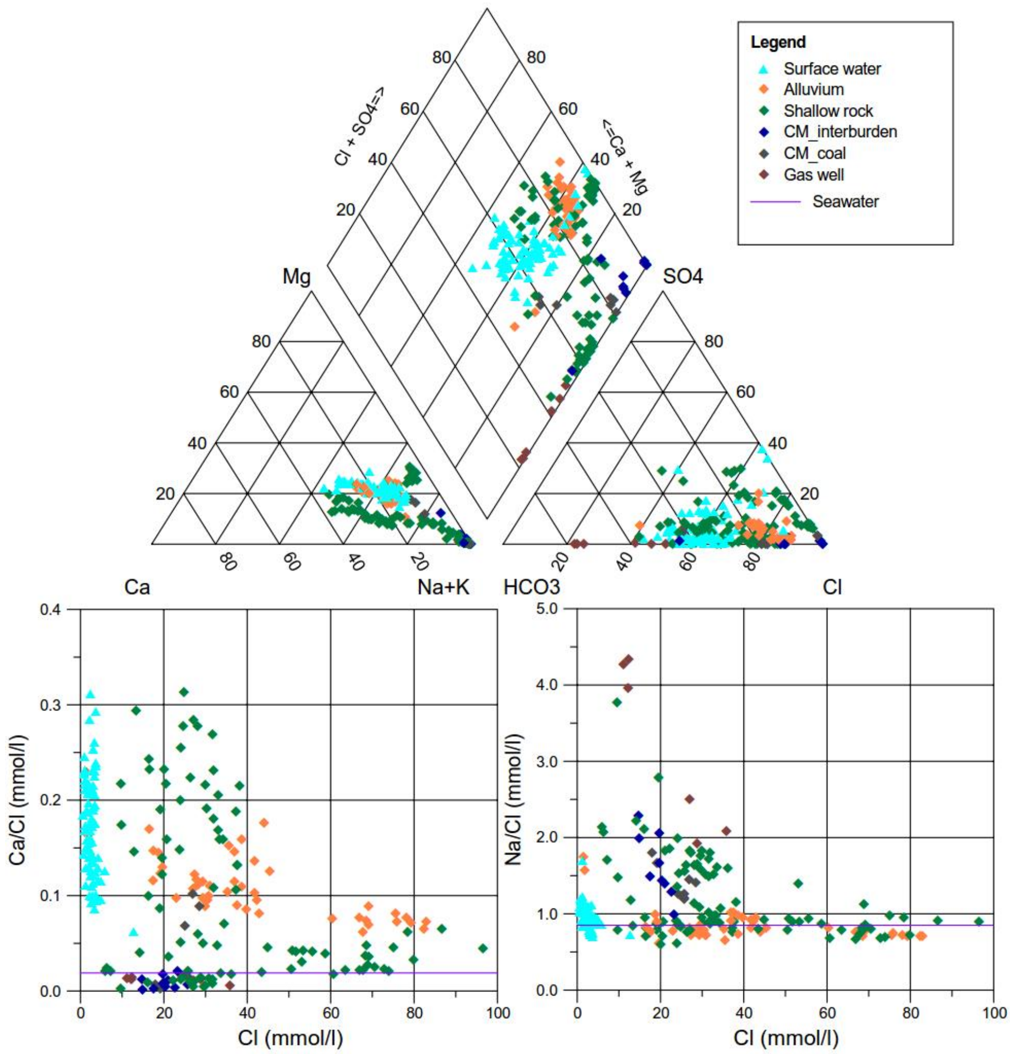


Figure 7.12 Piper plot and bivariate plots of ion/chloride ratios vs chloride for calcium and sodium

Minor detections of naturally occurring hydrocarbons (associated with the underlying coal seams) including, phenol, TPH and toluene have been recorded at groundwater monitoring locations for the alluvial, shallow rock and coal measures (including interburden) hydrogeological units across the Gloucester Basin (Parsons Brinckerhoff 2012a).

7.6.1 Stable isotopes

Stable isotope results for groundwater are compared to the Global Meteoric Water Line (GMWL) ($\delta 2H = 8.13\ \delta 18O + 10.8$) (Rozanski *et al.*, 1993) in Figure 7.13. The majority of groundwater samples plot on or next to the GMWL indicating meteoric origin. Stable isotope composition of the gas wells (CR06, WK03 and S4) are more depleted than the shallow coal seams and interburden, possibly reflecting different (colder) palaeoclimatic conditions at the time of recharge.

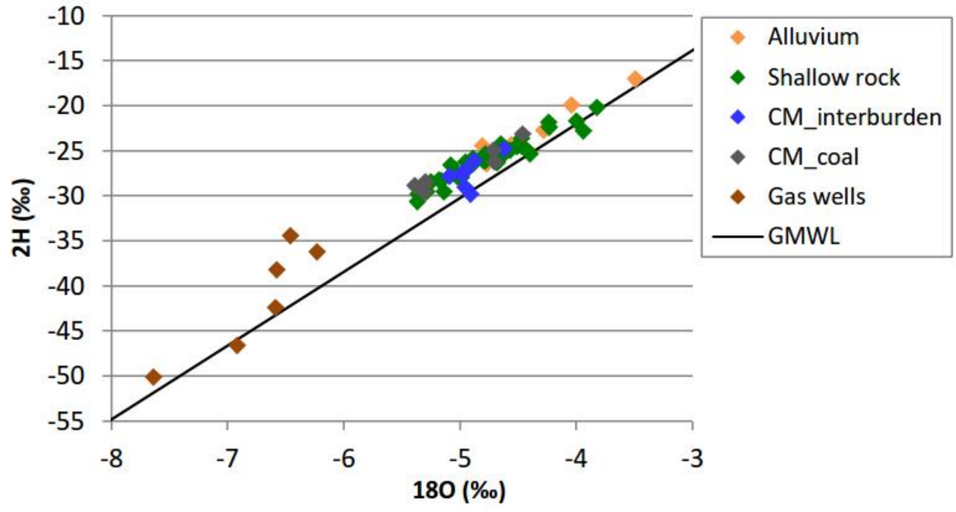


Figure 7.13 Bivariate plot of δ2H vs δ18O showing stable isotope composition

7.6.2 Methane in groundwater

Dissolved methane sampling of groundwater has been carried out by Parsons Brinckerhoff (2012a, 2013c, 2013d, 2015d). Dissolved methane concentrations tend to increase with depth and are highest in coal seams; results for the different hydrogeological units are shown in Figure 7.14.

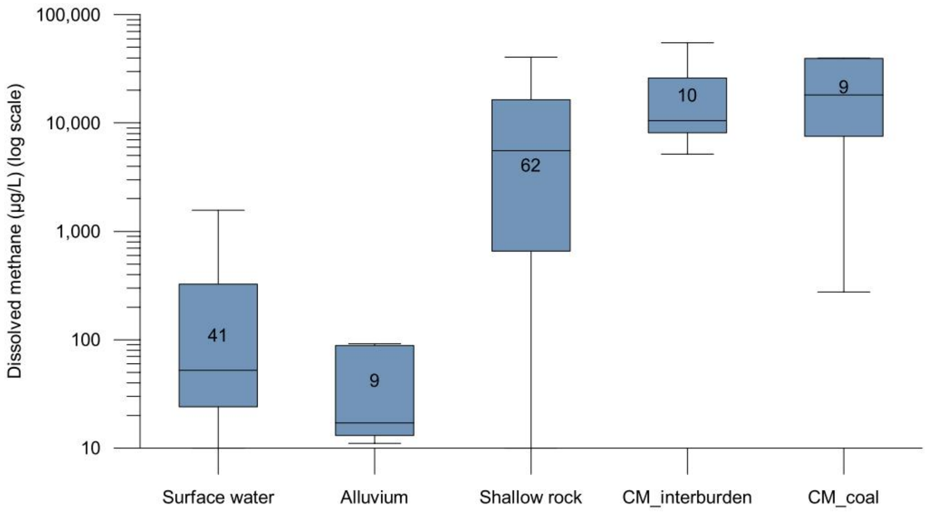


Figure 7.14 Concentration of dissolved methane in groundwater

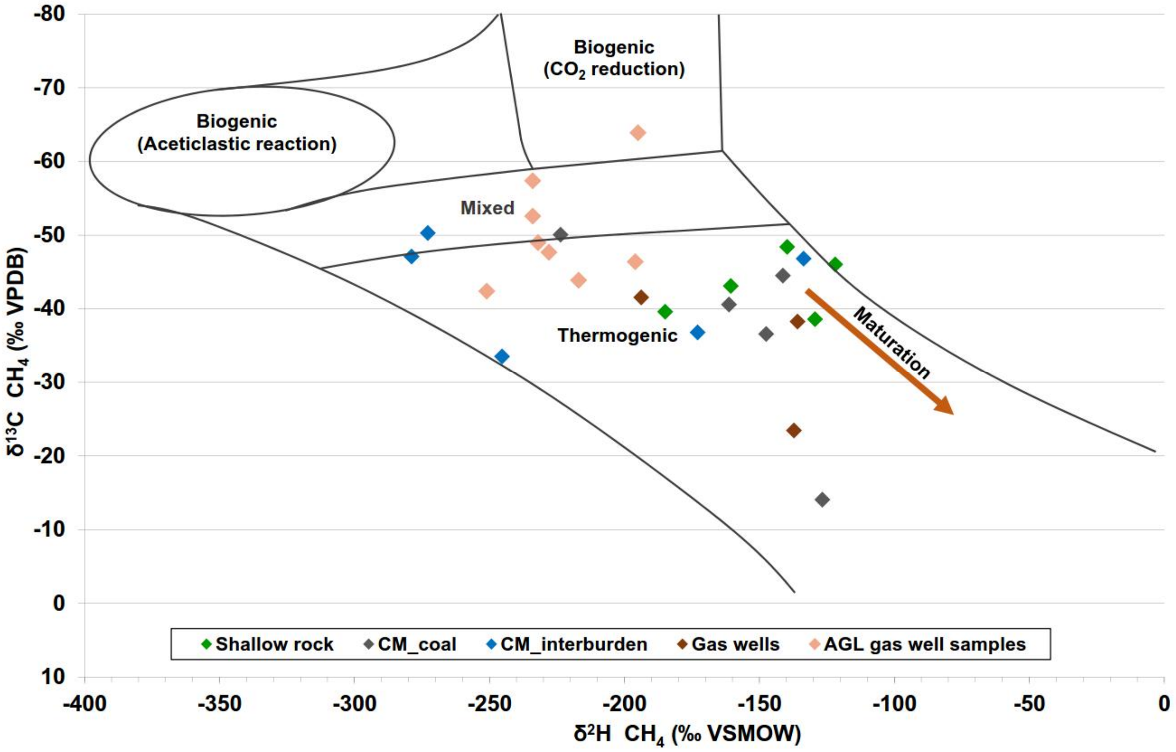


Figure 7.15 Carbon-13 (δ 13C-CH4) and deuterium (δ2H-CH4) in methane gas in groundwater

Compound specific isotope analysis of dissolved methane (carbon-13 (δ13C-CH4) and deuterium (δ2H-CH4)) was carried out by Parsons Brinckerhoff (2013c). The results indicate that dissolved methane in all strata is primarily of thermogenic origin (Figure 7.15), that is, methane that is produced at elevated pressures and temperatures during the coalification process. At a few locations methane isotopic signatures indicate methane had a mixed biogenic/thermogenic origin. There is no apparent trend of methane isotopic composition with depth or dissolved methane concentration (Parsons Brinckerhoff 2013c).

Shallow gas monitoring has been undertaken at two sub-surface locations (TGMB01 and TGMB02) (Figure 5.1) to assess for fugitive gas emissions in steeply dipping coal seam (outcrop) areas. Methane has not been detected at these locations since monitoring commenced in 2013 (Parsons Brinckerhoff, 2015h).

7.7 Groundwater age and residence time

Radiocarbon analysis of groundwater samples was carried out as part of the Phase 2 Groundwater Investigations (Parsons Brinckerhoff 2012a). This analysis identified that the alluvial aquifers contain modern and sub-modern water, <1000 years before present (BP) on average. Groundwater in the shallow rock system was found to contain water that was on average 12,000 years BP. Groundwater in the interburden units was on average 10,500 years BP, and groundwater in the shallow coal seams was on average 13,600 years BP. Groundwater age was found to increase with depth at the nested monitoring bore sites.

Further investigation of groundwater age, based on radiocarbon and tritium analysis, was carried out as part of the hydrogeological investigation of a strike-slip fault in the northern Gloucester Basin (Parsons Brinckerhoff, 2013c). Radiocarbon ages within the Tiedman fault zone were generally slightly older (25,000 to >30,000 years BP) than in monitoring bores at equivalent depths/formations outside of the high permeability zone (5,000 to 22,000 years BP). These data suggest there may be some contribution of slightly deeper, older waters within the shallow fault zone, however there is no indication of very old groundwater from the much deeper coal seams and aquitards migrating within this fault zone.

Groundwater in the deeper interburden and coal seams (below 300 m) was analysed at the gas well CR06 in 2013 and 2014 (Parsons Brinckerhoff 2014e and 2015e) and groundwater was found to be >30,000 and >40,000 years BP, respectively. It should be noted that these results are at the limit of radiocarbon dating.

More recently chlorine-36 isotope dating was used to better estimate the age of the groundwater from the deep coal seams and deep coal measure interburden (intervals deeper than 300 mbgl). Results to date suggest:

- 332,000 ± 27,000 year BP water at Waukivory 03 (northern Gloucester Basin);
- 468,000 ± 34,000 year BP water at Craven 06 (central Gloucester Basin) – 2013;
- 385,000 ± 32,000 year BP water at Craven 06 (central Gloucester Basin) – 2014; and
- 395,000 ± 40,000 year BP water at WKMB04 (northern Gloucester Basin).

These much older groundwater ages suggest much slower water migration in the deeper groundwater systems and no apparent influence from overlying aquifers.

7.8 Geothermal gradient

Temperature logs from gas exploration logs show a steady increase in temperature with depth, reaching 45°C to 47°C at depths of between 950 m and 1000 m. Assuming a near-surface ground temperature of ~20°C, this implies a geothermal gradient in the order of 2.7 °C/100m, which is within the range of other sedimentary basins in Australia (Cull and Conley, 1983).

7.9 Groundwater use

The locations of groundwater bores registered with DPI Water in the Gloucester Basin are shown in Figure 7.16. Many of these locations are monitoring bores or test bores/wells for coal mining and CSG exploration activities.

7.9.1 Mining

Groundwater modelling carried out as part of the hydrogeological assessment of the Duralie Extension Project (Heritage Computing, 2009) predicts that pit inflows to the Duralie Mine open cuts are expected to vary between approximately 0.2 and 1 ML/day during mining operations.

Groundwater modelling carried out as part of the hydrogeological assessment in support of the Stratford Coal Project (Heritage Computing, 2012) predicts that total pit inflows will peak at 1.35 ML/day in Year 2 of mining, for all of the open cuts at the Stratford Mining Complex. Minimum pit inflows are predicted to be 0.74 ML/day at the end of mining (Year 11). Pit inflows are predicted to be reduced by a maximum of 0.5 ML/day if CSG depressurisation in the Stage 1 GFDA are coincident with mining at the Stratford Mining Complex.

Bores associated with Stratford Mine, Duralie Mine and the Rocky Hill Coal Project are shown in Figure 7.16.

7.9.2 Coal seam gas

Coal seam gas (water) pumping is deemed to be industrial and irrigation use as water that is pumped as part of exploration (appraisal) programs and production programs is mostly reused for drilling, fracture stimulation, industrial recycling and irrigation purposes. The longer term reuse of produced waters (after desalination) at Gloucester will mostly be for working water, irrigation and stock purposes (AGL, 2015c).

The GGP will involve the depressurisation of deep groundwater 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 250 and 1,000 mbgl. The GGP includes the construction, operation and decommissioning of not more than 110 coal seam gas wells and associated infrastructure, including gas and water gathering lines, within the Stage 1 GFDA. The volumetric rate of groundwater extraction will not exceed 2 ML/d (averaged over a 12 month period), as specified in the Part 3A Approval (condition 3.11) and EPBC Approval (condition 22).

7.9.3 Stock and domestic

A search of the DPI Water groundwater database indicates that there are 188 registered bores in the Gloucester Basin, within the Alum Mountain Volcanics boundary (Figure 7.16). Of the 188 registered bores, 24 are registered for stock and domestic use. A further four are registered for irrigation, five bores are registered for commercial and industrial use, four are registered for mining use, 121 for test and monitoring associated with mining in the area, and 30 are registered with unknown use. All those bores registered for industrial, mining, test and monitoring purposes are associated with either mining or coal seam gas developments.

The depth of the 24 private bores registered for stock and domestic use ranges between 4 and 66 mbgl, and therefore these bores are assumed to intersect the alluvium and shallow fractured rock within the Gloucester Basin. Beneficial aquifers are not expected to exceed a depth of 75m across the Basin. It is assumed that annual stock and domestic bore use is approximately 1 ML/bore, therefore the total groundwater use could be as high as 24 ML per annum from these 24 bores.

Gloucester Shire Council (on behalf of AGL) commissioned property surveys of water sources on private properties across the Gloucester Basin in 2014. The surveys located 12 water bores and 12 springs or spring fed dams (mostly beyond the Stage 1 GFDA). The surveys confirmed that groundwater is predominantly used for stock and garden purposes, and many bores are capped and not in use. The above estimate of stock and domestic consumptive use of groundwater is therefore considered conservatively high.

7.9.4 Gloucester Shire Council property surveys

Gloucester Shire Council completed water surveys of farming properties in private ownership within the Stage 1 GFDA in March 2014 and areas beyond the Stage 1 GFDA in October 2014. The surveys were voluntary so not all properties were visited across the Basin. Properties owned by GRL, Yancoal and AGL were not included in the water surveys. However GRL has confirmed that there are no existing groundwater supply works on their properties and similarly there are no existing groundwater supply works on AGL's properties. The surveys involved sighting all private water supply infrastructure and taking water samples from:

- All groundwater assets (if present).
- At least one surface water site.
- One rainwater tank water site.

The surveys did not locate any private groundwater bores or shallow wells/excavations within the Stage 1 GFDA, however a number of bores and wells were located in the beyond Stage 1 surveys. Summary details of the property surveys are provided in Table 7.5 (Stage 1 GFDA) and Table 7.6 (beyond Stage 1 area).

Table 7.5 Summary statistics from the Stage 1 GFDA property surveys

Attributes	Number / Description
Number of properties surveyed	19
Number of bores and wells	Zero
Number of springs/spring fed dams	2
Number of dams [(a)]	14
Number of surface water sites [(a)]	10
Number of rainwater tanks [(a)]	14
Typical usage	Springs – Stock Dams – Stock and irrigation Creeks and rivers – Stock and irrigation Rainwater tanks – Domestic

(a) These are the sampled sites only and not necessarily the total number of sites.

There is negligible groundwater used for water supply in the Stage 1 GFDA. The two identified spring locations intercept either perched groundwater or shallow groundwater (from fractured rock) in the landscape. Water from rivers and creeks or overland flow captured and stored in farm dams is the primary source of supply for agriculture and grazing. Tank water is used for potable and non-potable domestic purposes.

Table 7.6 Summary statistics from the beyond Stage 1 GFDA property surveys

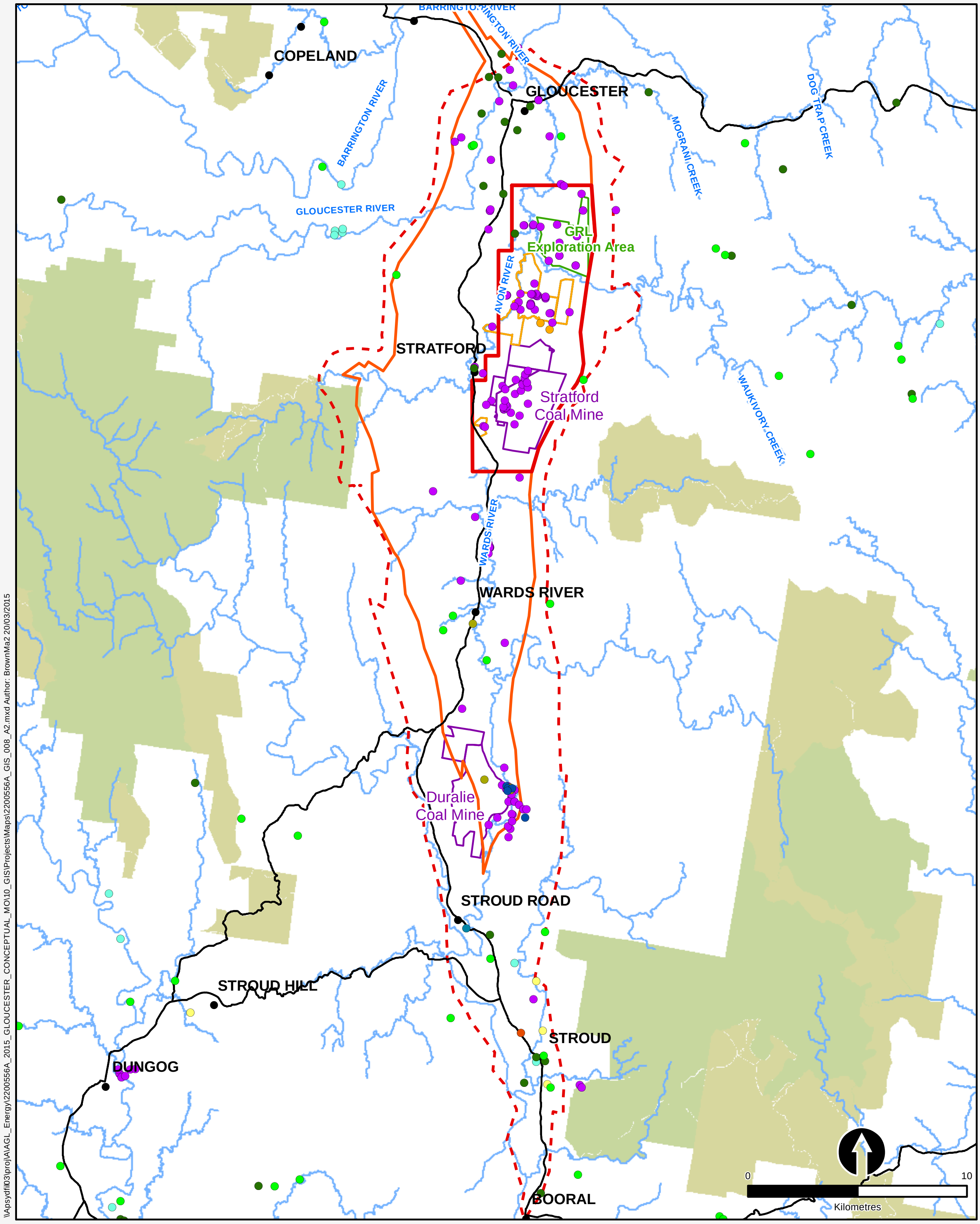
Attributes	Number / Description
Number of properties surveyed	57
Number of bores and wells	12
Number of springs/spring fed dams	10
Number of dams [(a)]	34
Number of surface water sites [(a)]	31
Number of rainwater tanks [(a)]	54
Typical usage	Springs – Stock Bores – Stock and garden Dams – Stock and irrigation Creeks and rivers – Stock and irrigation Rainwater tanks – Domestic

(a) These are the sampled sites only and not necessarily the total number of sites.

PARSONS BRINCKERHOFF

HYDROGEOLOGICAL CONCEPTUAL MODEL OF THE GLOUCESTER BASIN

AGL UPSTREAM INVESTMENTS PTY LTD



NOW registered bores

- Commercial
- Dewatering (groundwater)
- Domestic
- Farming
- Fire fighting
- Industrial
- Irrigation
- Test or monitoring bore
- Stock
- Waste disposal

- Stage 1 GFDA boundary
- AGL owned properties
- Alum Mountain Volcanics boundary
- GRL exploration area boundary
- Mining Lease Boundary
- Permian Coal Measures boundary
- National Park, Nature Reserve or State Conservation Area
- NSW State Forest
- Major roads
- Rivers and streams
- Towns

Figure 7.16
NOW registered bores

8. Influence of faulting on groundwater flow

This chapter provides an overview of the likely influence of faulting on groundwater flow and the different groundwater systems of the Gloucester Basin.

8.1 Faults and groundwater flow

Folding and faulting of sedimentary rocks can give rise to complex hydrogeological systems. In broad terms, fault zones can act as barriers to groundwater flow or as groundwater conduits depending on the nature of the fault zone and the material within it (Fetter, 2001). If the fault zone consists of finely ground rock and clay (fault gouge), the material may have very low hydraulic conductivity compared with the host rock and form a barrier to flow. Such low-permeability faults may be apparent from significant differences in groundwater level across the fault, or appear as hydraulic boundaries in aquifer (pumping) tests.

Conversely, if a fault zone consists of one or more continuous open fractures, then it may act as a conduit. Under natural conditions, evidence for such conduit faults may be seen in geophysical surveys (contrasting conductivity), perturbations in groundwater levels and temperature, or the occurrence of fault related springs and discharge zones. When the groundwater system is pumped, such as in an aquifer test or extended flow test, a conduit fault may manifest as an apparent recharge boundary (source of recharge) and/or cause anomalous drawdown in monitoring bores connected to the fault.

On a regional (or basin) scale the influence of faulting on groundwater flow depends on numerous factors including the permeability of the fault(s) and their orientation with respect to the geological strata and dominant recharge and discharge zones (Tóth, 2009). The potential regional effects of faulting if the faults acted as conduits would include:

- Concentration of flow within fault zones which may enhance recharge or discharge, particularly where there are inclined or low-angle conduit faults within or between those zones.
- Enhanced vertical groundwater movement through units assumed to be regional aquitards.
- Anisotropy. Faults or joints that have a dominant orientation can impart a preferred flow direction on intersected groundwater systems.

If the faults acted as barriers, the potential regional effects of faulting would include:

- Limited flow within fault zones which may impede regional recharge, discharge or flow.
- Anisotropy. Faults that have a dominant orientation but are clogged with low permeability clays can create a barrier to preferred flow directions within dislocated groundwater systems.
- Compartmentalisation of the regional flow (differences in groundwater level and/or flow direction between fault-bounded blocks).
- Hydraulic sheltering; where quasi-stagnant zones of ‘no-flow’ are formed.

In relation to CSG development in the Gloucester Basin, the hydraulic characteristics of faults are relevant to modelling the extent of groundwater depressurisation as a result of CSG extraction and potential environmental impacts. Understanding the nature of fault zones in the Gloucester Basin and their potential behaviour under development conditions requires a multi-faceted approach including literature review, field investigations, water monitoring (water levels, water quality and isotopes) and numerical modelling. This section presents and discusses evidence relating to the hydraulic behaviour of faults within the Gloucester Basin including:

- Literature review of fault zone hydrogeology and fault seal mechanisms.
- A summary of field investigations carried out by AGL to assess fault characteristics.
- Numerical modelling of various fault permeability scenarios.

8.2 Hydrogeological characteristics of fault zones

The hydrogeology of fault zones has received much attention in the scientific literature, particularly in the context of petroleum and coal seam gas extraction (e.g. Yielding et al., 1997) and auriferous mineral exploration (e.g. Eisenlohr et al., 1989). In the petroleum industry, understanding the hydraulic characteristics of fault zones is important in predicting the role of faults in providing pathways and traps for oil and gas resources, and in predicting reservoir characteristics during resource extraction. Faulting at a number of scales is important in focussing fluid flow in the crust and controlling the distribution and grade of ore mineral deposits (e.g. Groves, 1993). The following discussion draws on recent review papers relating to the hydrogeological characteristics of faults.

8.2.1 Fault structure

Faults are divided into four broad categories, depending on their orientation and sense of movement:

- Normal faults: high-angle (>45°) faults where the overlying block ('hanging-wall') moves downwards relative to the underlying ('foot-wall') block. These faults are common in extensional settings.
- Reverse faults: high-angle (>45°) faults where the hanging-wall block moves upward relative to the foot-wall. This style of faulting is indicative of compressional settings and shortening of the crust.
- Thrust faults: low-angle (<45°) reverse faults where the hanging-wall block is thrust over the foot-wall block. Low-angle thrusts often follow existing bedding planes along part of their length and are difficult to locate in the field (and in core), except where stratigraphic repetitions can be identified.
- Strike-slip fault: faults where the principal displacement is parallel to the strike of the fault plane. The fault plane is usually vertical or nearly so.

All four faulting styles are represented in the Gloucester Basin, although thrust and reverse faulting is most characteristic of the eastern part of the Basin and the Stage 1 area.

Fault zones are described as consisting of a fault core (FC) which is surrounded by a damage zone (DZ), as shown in Figure 8.1 (Caine et al., 1996). The fault core is the zone of focussed and intense strain. It accommodates most of the displacement across the fault zone and is characterised by planar zones of finer-grained material. The damage zone contains secondary structures such as fractures and minor faults that can extend into the adjacent rock mass on both sides of the fault core and accommodate the remainder of the movement across the fault. Faults can contain multiple fault cores defined by fine-grained material that entrain blocks and lenses of fractured rock and are surrounded by a complex overlapping fracture zone.

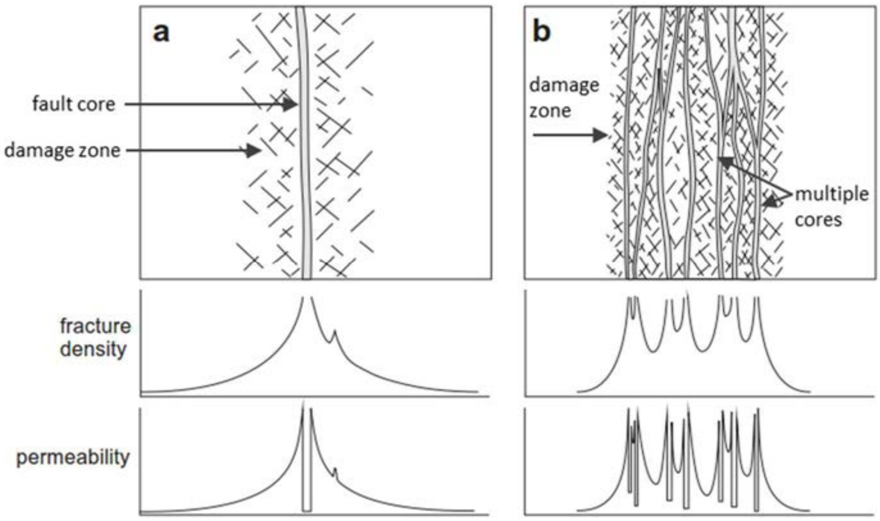


Figure 8.1 Physical properties of fault zones related to their structural elements (after Faulkner et al., 2010); a) a single fault core and b) multiple fault cores.

The permeability structure of faults is related to the internal structure and the rock type. In consolidated sedimentary rocks the damage zone will represent a zone of enhanced permeability due to preferred flow along interconnected fractures. The permeability is proportional to the (cube of) fracture density (Snow, 1968) and will tend to increase towards the fault core(s). Superposition of damage zones in overlapping faults can result in locally high fracture densities. The finer grained material within the fault core will have a low permeability relative to the damage zone, and possibly also relative to the rock type.

The FC-DZ model of fault architecture implies that the fault core provides an across-fault barrier to fluid flow, whereas the damage zone provides an along/up-fault conduit. This dual “conduit-barrier” behaviour has been observed in faults elsewhere and may explain apparently contradictory information from some field investigations (Bense and Person, 2006). The complex fault architectures that arise from multiple fault cores can lead to extreme permeability heterogeneity and anisotropy (Faulkner et al. 2010) both across and along a fault zone.

The width of a fault zone varies in scale depending on the rock type, the depth and the fault throw. In general, the width of the fault zone and the proportion of the fault core to the damage zone increase with increasing fault throw. The amount of fine-grained material entrained within the fault core (and hence the permeability of the fault core) can be broadly related to the proportion of fine-grained sedimentary rocks in the adjacent rock type, and the throw of the fault. Fine-grained material within a fault core (often called fault gouge) may develop through entrainment of fine-grained material into the fault (clay smear), or cataclasis (grinding) of the rock type, among other mechanisms. These concepts have been used to assess the potential for fault zones to act as hydrogeological barriers or seals in sedimentary aquifers (e.g. Yielding et al., 1997; Bense and Person, 2006), and are described in more detail below with reference to the Gloucester Basin.

8.2.2 Fault seal mechanisms

Fault movement gives rise to processes that can both enhance the permeability and decrease the permeability of the fault zone (Bense et al., 2013).

Processes that enhance the permeability in consolidated rocks include fracturing and brecciation (the formation of angular fragments) in the damage zone.

Processes that reduce permeability and therefore may lead to the formation of a sealing fault include:

- Juxtaposition: Permeable or water-bearing horizons are juxtaposed and truncated against a low-permeability lithology such as shale.
- Clay smear: The entrainment and smearing of clay sediments along the fault core forming a low-permeability barrier to fluid flow. This is an important mechanism in unconsolidated aquifers, but can also occur in consolidated rocks as a result of weathering of fault gouge material.
- Cataclasis: The grinding of rock to produce zones of fine-grained material (fault gouge) due to the disaggregation of mineral grains, or the total disintegration and alteration of weaker minerals such as feldspar. This process has more relevance to consolidated rocks than unconsolidated sediments.
- Mineralisation and diagenesis: Dissolution and precipitation of minerals such as silica, iron oxide or calcite within pore spaces and along open fracture planes. Alteration of minerals within the fault zone which may lead to reduced pore-space and permeability. Alignment of clay and mica minerals can result in distinct fault plane anisotropy in permeability.
- Regional stress field: The aperture of fractures and therefore the permeability of fracture networks is highly sensitive to the principal stress direction and magnitude. Faults and fractures oriented perpendicular to the principal axis of regional stress are likely to have smaller apertures and lower permeability (Liu et al., 2013). Increasing lithostatic pressure with depth also leads to closing of fracture apertures and a decrease in permeability (as seen in drill stem tests – see Section 7.2).

To assess the hydraulic characteristics of a fault requires the ability to relate these processes to measurable characteristics of the geology and fault displacement (Yielding et al., 1997). This is a highly active and developing area of research in the petroleum industry. Fault seal analysis involves techniques such as fault gouge (or clay-smear) analysis and structural-stratigraphic analysis (fault surface projection) are routinely applied in the context of conventional petroleum reservoirs (e.g. Manzocchi et al., 2010).

8.2.3 Application to the Gloucester Basin

The geology of the Gloucester Basin and the nature of the gas resource differ markedly from those of conventional petroleum reservoirs for which fault seal analysis was developed; for example:

- The host stratigraphy is dominated by consolidated siltstone, mudstone and sandstone that are all of very low permeability (10^{-6} to 10^{-4} m/d from core analysis) and the concept of a seal relative to these units has less relevance. It is assumed that the fault structures of most interest in regard to potential conduits for groundwater and gas are those that formed, or were reactivated, post-lithification.
- The gas resource is tightly bound to the target coal seam and is not reliant on faults and permeable strata for migration, sealing and entrapment (c.f. conventional oil and gas).
- Faults are avoided in CSG exploration because of the potential for the degradation of the gas resource.

Therefore, detailed fault seal analysis may not be applicable in the Gloucester Basin, and is beyond the scope of this report. Nevertheless, the concepts have been broadly applied to provide a (qualitative) indication of the likely fault behaviours.

The most effective way to assess the permeability in fractured rock terrain is using packer permeability tests or drill stem tests. The results of these rock-mass permeability tests can then be compared with smaller scale laboratory core permeability tests to determine the relative importance of fracture versus porous groundwater flow. Drill stem tests have been carried out on numerous exploration holes in the Gloucester Basin and in the Sydney Basin (Figure 7.2). These tests tend to focus on coal seams which are generally more permeable than the interburden. As such it is likely that DST permeability testing carried out to date has captured the variability in permeability resulting from fault related fracturing in the deeper coal measures.

8.2.3.1 Juxtaposition of water-bearing zones

Coal seams (at depth) represent weak water bearing zones relative to the low-permeability interburden which make up the vast majority of the stratigraphic thickness. Individual productive coal seams range from < 0.5 m to 3 m in thickness, and the total thickness of coal represents approximately 6% of the stratigraphic thickness or less (see Table 8.1, below). Therefore, a small amount of movement on a fault (more than a few metres) is likely to truncate the coal seams against the low-permeability interburden. It is expected that on the basis of juxtaposition alone most faults will represent transverse barriers to flow and depressurisation along coal seams. In fact, this assumption is included in AGL reservoir models.

8.2.3.2 Potential for fault-gouge sealing

Yielding et al. (1996) reviewed arithmetic methods for estimating the amount of fine-grained material that gets entrained into a fault, and assessed their ability to predict sealing characteristics of faults based on pressure observations in gas wells. Among a number of methods, the shale gouge ratio (SGR) was found to be both easily applied and a reliable indicator of fault sealing potential. The SGR is defined as follows:

$$SGR = \frac{\sum(shale\ bed\ thickness)}{throw\ of\ fault}$$

In essence the SGR is the proportion of shale in a column of rock that has moved past a fixed location on the foot-wall block. The value will vary over a fault plane depending on the throw and angle of the fault and the stratigraphy of the column that has passed any given point. Yielding et al. (1996) point out that in this analysis, clay material can be derived from both coal beds and the fine-grained clastic sediments. Comparison with field measurements indicated a threshold value between 15% and 20%, above which the fault would likely act as a seal (in the context of oil/gas migration and a petroleum reservoir).

A summary of the stratigraphic composition in Waukivory 1 corehole (northern Gloucester Basin as shown in Figure 4.5) is shown in Table 8.1. Approximately 12% of the stratigraphic thickness is composed of coal, mudstone and shale. Taking into consideration siltstone, the total percentage of fine-grained rocks is approximately 40%. On the basis of the total stratigraphic thickness intersected by Waukivory 1, this would suggest that most faults would be close to or exceed the threshold at which they would tend to form fault-core seals.

Table 8.1 Summary statistics from the geology log of Waukivory 1

Lithology	Median lithology thickness (m)	Total thickness (m)	Percentage of stratigraphic thickness	Cumulative percentage (with increasing grainsize)
Coal	0.41	49.8	6.3%	6.3%
Mudstone	0.13	21.8	2.8%	9.1%
Shale	0.21	22.5	2.9%	**11.9%**
Siltstone	0.35	222.6	28.2%	**40.2%**
Sandstone	1.01	431.9	54.8%	95.0%
Conglomerate	1.05	14.6	1.8%	96.8%
Tuff	3.01	24.9	3.2%	100.0%

8.2.3.3 Fault damage zones

The key mechanism for enhancing permeability in consolidated rocks is fracturing and brecciation in fault damage zones. Core from exploration hole Waukivory 1 was used to assess fracture density and indicators of fault movement compared with faults that are inferred to intersect the hole from seismic interpretation.

Figure 8.2 is a plot of fracture density against depth below the surface from inspection of core photographs for Waukivory 1 (using a 5 metre moving average). A histogram of the number of slickensides noted in the detailed geology log per 10 m interval is overlain. Slickensides are polished and striated surfaces that form along a rock surface as a result of friction along a fault plane, and are therefore an indication of fault movement. Two major thrusts are apparent in the Waukivory area from seismic reflection survey data, referred to as the “upper” and the “lower” thrusts. Seismic cross sections show the upper thrust intersecting Waukivory 1 at about 250 m to 260 m depth (shown in green in Figure 8.2), whereas the lower thrust passes below and is not intersected by Waukivory 1. The remainder of Waukivory 1 appears to intersect a relatively coherent stratigraphy with no obvious faults that can be resolved in the seismic image.

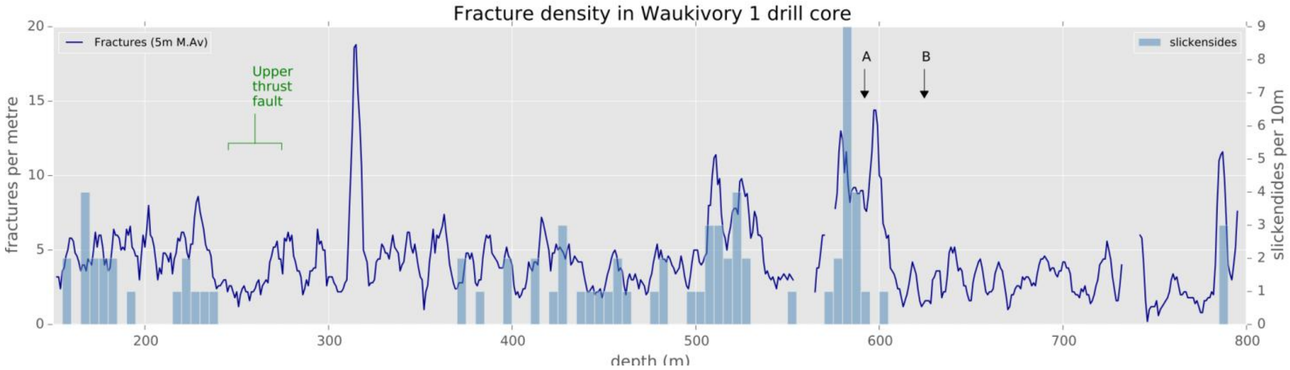


Figure 8.2 Plot of fracture density and slickenside observations against depth in Waukivory 1. Markers A and B refer to the locations of core shown in Figure 8.3

Figure 8.2 shows that the fracture density varies down the hole from 2 per m to >15 per with distinct intervals of high fracture density at, for example, ~220 m, ~315 m, 510 – 530 m, 580 – 600 m, and ~780 m. Examples of highly fractured rock (including slickensides) and coherent sandstone are shown in Figure 8.3. The highest densities of slickenside observations coincide with zones of high fracture density suggesting that those zones accommodated some fault movement post-consolidation and likely represent minor fault zones that are not resolved in the seismic survey. Importantly, the inferred intersection of the upper thrust fault does not closely correspond with any distinct peak in fracture density.

From this it can be inferred that the deeper coal measures contain fracture zones that are associated with fault movement. However, the density and width of the fracture zones do not necessarily correlate with large-offset faults that are resolvable in seismic reflection images. This has important implications for modelling of groundwater flow and drawdown impacts:

1. Seismic interpretation and surface mapping can delineate faults and thrusts that offset the stratigraphic units, but are not necessarily good predictors of structural controls on groundwater flow in fractured rock terrains.
2. Adding complex faulting patterns derived from mapping or seismic surveys to a regional numerical model may impose significant structural errors to the model, similar to adding surface water features that are in fact not present.

Figure 8.3 Photographs of drill core from Waukivory 1 showing (A) a high fracture density and slickensides associated within bedded siltstone and mudstone, and (B) relatively fractured sandstone. The width of the core trays is 1 m.

8.2.3.4 Regional stress

In fractured or faulted rocks, the permeability of fracture networks can be influenced by the regional stress regime (e.g. Morin and Savage, 2003), whereby fractures oriented parallel to the principal stress direction may dilate (increasing the permeability) whereas fractures oriented perpendicular to the principal stress direction are more likely to be closed (decreasing the permeability). The assumed east-west principal stress direction in the Gloucester Basin would tend to result in closed fractures within the dominant meridional (N-S) faults and shear zones in the area.

8.2.3.5 Faults as barrier-conduit systems

The above observations have the following implications for the hydrogeological role of faulting in the Gloucester Basin:

1. Faults with a displacement of ~3 m or more are likely to represent barriers to horizontal groundwater flow due to juxtaposition of strata and truncation of water bearing zones (coal seams) against relatively impermeable interburden units. Cataclasis and entrainment of fine-grained material in fault cores will add to the barrier effect where the stratigraphy has a high proportion of coal and shale. As such depressurisation at depth will tend to be compartmentalised and restricted to within fault-bound blocks.
2. It is possible that fracturing associated with fault damage zones may form zones of enhanced permeability relative to the unfaulted rock mass. However, there is currently no evidence from field investigations of enhanced permeability in fault zones in the Gloucester Basin. The permeability structure of the damage zones will be highly heterogeneous and anisotropic, being higher in the plane of the fault and relatively low perpendicular to the fault plane. The permeability of the fractured rock will be highly sensitive to regional stress and lithostatic pressure, tending to be lower in the dominant N-S trending faults and decreasing with depth.

8.3 Stratford field investigation

A field based hydrogeological investigation was carried out to assess the hydraulic characteristics of a strike-slip fault within the Stage 1 GFDA on the Tiedman property (Parsons Brinckerhoff, 2013c). The investigation used field based studies and geophysical methods to identify and characterise the fault in the near surface environment. The Tiedman Test nested monitoring bores (TTMB locations) were installed as part of this investigation, with TTPB installed as the test pumping bore (Figure 5.1).

The target strike-slip fault on the Tiedman property is clearly identified in the seismic sections. In the upper 200 m, the main fault zone appears to splinter into a number of related structures over a zone up to 300 m to 400 m wide. The surface projection of the fault zone corresponds to a visible surface trace and a zone of anomalous electrical conductivity in the TEM geophysical survey.

The hydraulic characteristics of the fault zone were investigated by inducing drawdown in both the fault zone (using a 3-day pumping test) and the deeper coal seam water bearing zones (using a 29-day gas well flow test) and monitoring the effects on the shallow groundwater system.

Water level trends were used as the primary proof of any enhanced connectivity within the fault zone. Water samples were collected and analysed for groundwater quality, dissolved methane content, isotopic composition and age to place further constraints on groundwater processes.

8.3.1 3-day pumping test

The following notable results were obtained from the 3-day pumping test of TTPB within the upper section of the fault zone (to depths of 100m):

1. Six out of 10 nearby monitored bores registered some drawdown response in shallow aquifer zones, ranging from 0.5 m to 7.4 m. The magnitude and timing of drawdown at each monitoring location reflected variation in aquifer characteristics across the site.
2. Results of the pumping test indicate that the fault zone is a broad zone of enhanced hydraulic conductivity within the shallow rock aquifer. The fault zone does not form a barrier to flow in the shallow rock, and does not cause strong preferred longitudinal flow in the direction of the surface trace, but may form heterogeneous, weakly transmissive zones in the near surface, relative to unfractured shallow rock domains.
3. Distinct hydrochemistry and (slightly older) radiocarbon ages within the fault zone may indicate some vertical (upward) migration of slightly deeper groundwater under natural conditions. However, this appears to contrast with groundwater level data from multiple nested piezometers which indicate a generally downward hydraulic gradient at this site, consistent with recharge, not discharge. In addition, deep groundwater samples obtained from gas wells are depleted in stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) compared with groundwater in the shallow rock and within the fault zone. Therefore there is no clear indication as to whether the fault zone is a net recharge or net discharge feature based on the data from this pumping test.

8.3.2 29-day flow test

The following conclusions are drawn from the 29-day flow test of Stratford 4 gas well:

1. Depressurisation of deeper coal seams was carried out during the 29-day flow test on Stratford 4 (Stratford 4 is located 100m west of the edge of the fault zone on the Tiedman property). Observations of groundwater levels indicated no apparent groundwater drawdown in the majority of monitoring bores, while a few bores show a slight declining trend that appears to start in early October after completion of the flow test. An example is shown of the S4MB series monitoring bores (Figure 8.4), in which

groundwater declined anomalously in the deepest monitoring bore S4MB03 about 2 months after the end of the flow test. It is not possible from the existing data to determine unequivocally the cause of the observed groundwater decline. However, it appears to be more consistent with the regional decline in groundwater levels due to the very low rainfall conditions in late 2012, than due to a possible depressurisation effect.

2. The hydrographs for the S4MB bores were statistically assessed by applying a 6-month rolling correlation between each of the hydrographs (Figure 8.5). Anomalous groundwater behaviour should be apparent as a decrease in the correlation coefficient over the relevant period. Figure 8.5 shows that the hydrographs are usually highly correlated; poor correlation is seen during and after the 3-day pumping test and sampling events (as expected). Significantly, hydrographs remain well-correlated (Pearson's R >0.8) for more than 4 months after the end of the flow test, indicating that the decline in S4MB03 is correlated with similar but less pronounced declines in the other two bores during a dry period. The 6-month rolling correlation then deteriorates and becomes negative after March 2013 due to divergent trends in the three monitoring bores. This divergence is subtle and probably related to the differing responses to the large rainfall and flood event that occurred in early March 2013 at the three different depths of measurement. There is a differing lag time (over several months) between rainfall and recharge to the shallow rock and to the deeper coal seams which would explain the divergent trend.

3. Most hydrochemical parameters did not change significantly in shallow groundwater during or after the flow test. However, dissolved methane declined significantly in three monitoring bores within the fault zone during the flow test. The exact mechanism for this change is not yet understood, but it is clear that no increase in dissolved methane flux resulted from the flow test.

In summary, test pumping and isotopic analysis indicate that this strike-slip fault zone is a broad and heterogeneous zone of increased hydraulic conductivity within the shallow rock aquifer. However monitoring of groundwater levels and dissolved methane during the Stratford 4 gas flow test provided no evidence of enhanced connections between the deeper coal seams and shallow groundwater system.

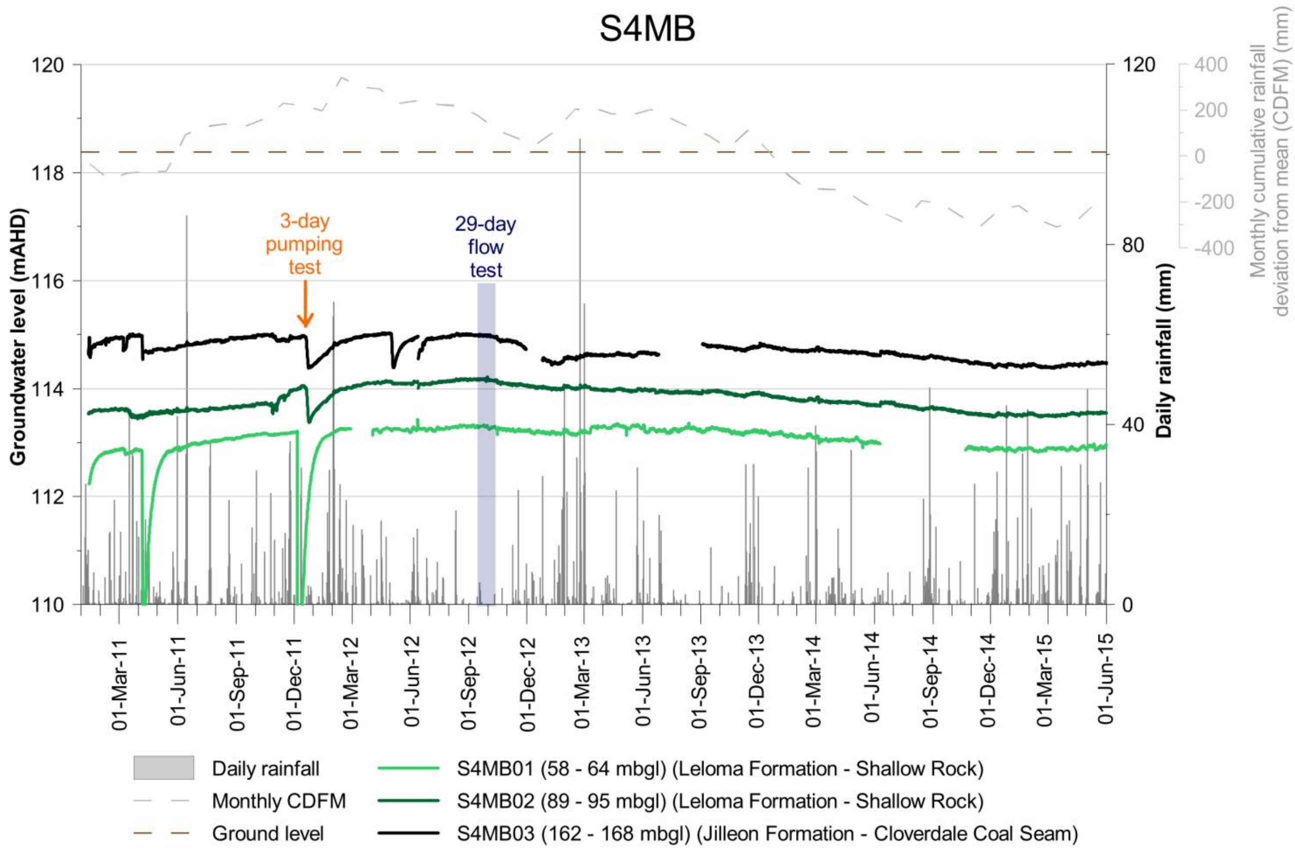


Figure 8.4 Groundwater levels and rainfall at the S4MB monitoring bores

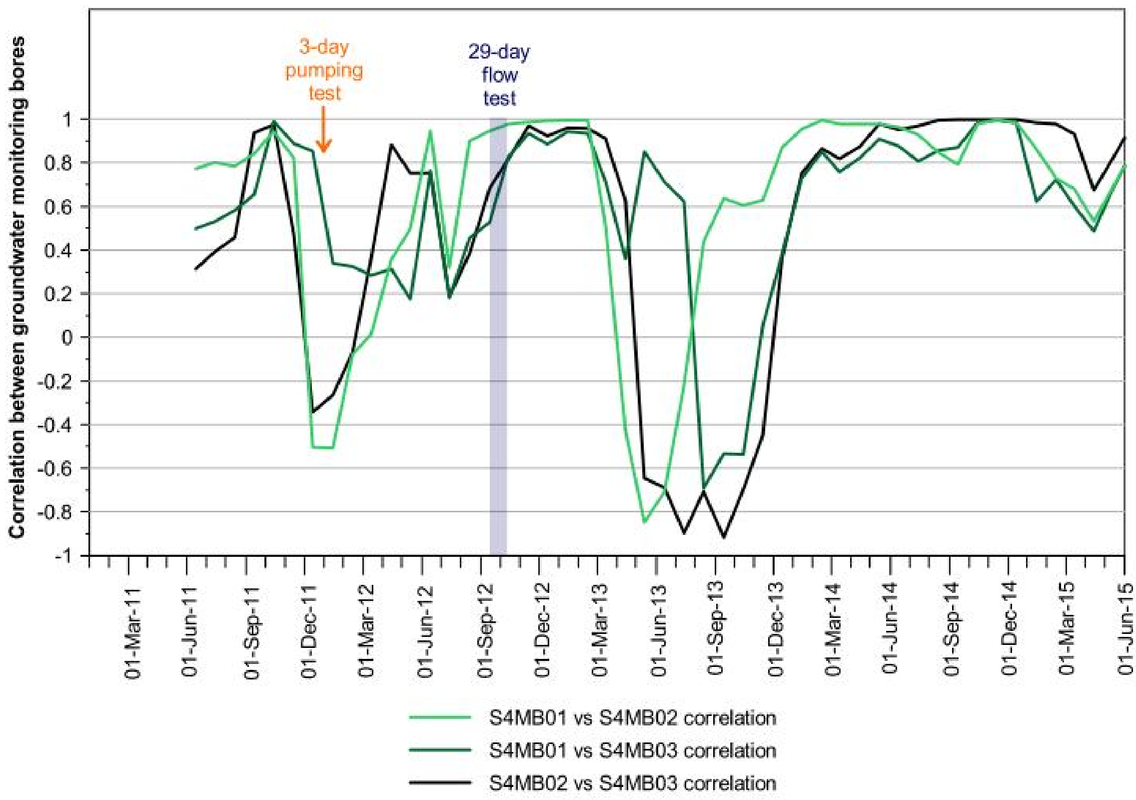


Figure 8.5 Rolling 6-month correlation between groundwater levels at the S4MB monitoring bores

8.4 Waukivory pilot investigation

8.4.1 Pilot testing

Pilot testing is an exploration activity that identifies potential gas resources by testing the composition, flow rate, and volume of gas in target coal seams. Pilot testing also assesses water production volumes (as the wells are depressurised to allow gas flow) and potential connectivity between shallow aquifers and the water bearing zones of the deep coal seams.

AGL received approval for the Waukivory Pilot Project from the NSW Office of Coal Seam Gas (OCSG) on 6 August 2014. The approval permits AGL to fracture stimulate and flow test four existing pilot wells (Waukivory 11 (WK11), Waukivory 12 (WK12), Waukivory 13 (WK13), and Waukivory 14 (WK14)). The pilot wells were installed between 2 October and 24 November 2012. The Waukivory pilot wells and groundwater and surface water monitoring locations are located in the northern part of the Stage 1 GFDA (Figure 8.6).

The Waukivory pilot is located in an area of thrust faulting which is characteristic of the eastern part of the basin and the Stage 1 GFDA, as shown in the Waukivory interpreted seismic section (Figure 4.5).

The Waukivory pilot includes the following water monitoring phases:

- Baseline sampling was undertaken to characterise the pre-Project groundwater and surface water conditions at the Waukivory site. The baseline sampling comprised four sampling events in March, June, September and October 2014 (prior to fracture stimulation).
- Fracture stimulation involves pumping a fluid under pressure through a zone of perforated steel well casing into the coal seam to open cracks or fractures, increasing the hydraulic conductivity and enabling the flow of water and gas (27 October 2014 to 26 November 2015). The fluid is typically a mixture of

sand, water and additives. The four pilot well have been perforated and fracture stimulated within target coal seams ranging from approximately 370 to 960 mbgl.

- Flowback water is the return to surface (by pumping) of fracture stimulation fluids before transition to natural formation water (groundwater), after which, water flowing from the well is termed produced water. Flowback water includes water and fluids extracted during the short period of pump commissioning (ongoing since 27 November 2014).
- Produced water is formation water which is co-produced with gas, and follows the removal of the fracture stimulation fluid (flowback) (not commenced). Pumping groundwater from a coal seam reduces the pressure and allows the gas and 'produced' groundwater to flow into the well and up to the surface. The flow rate of produced water typically decreases over time.

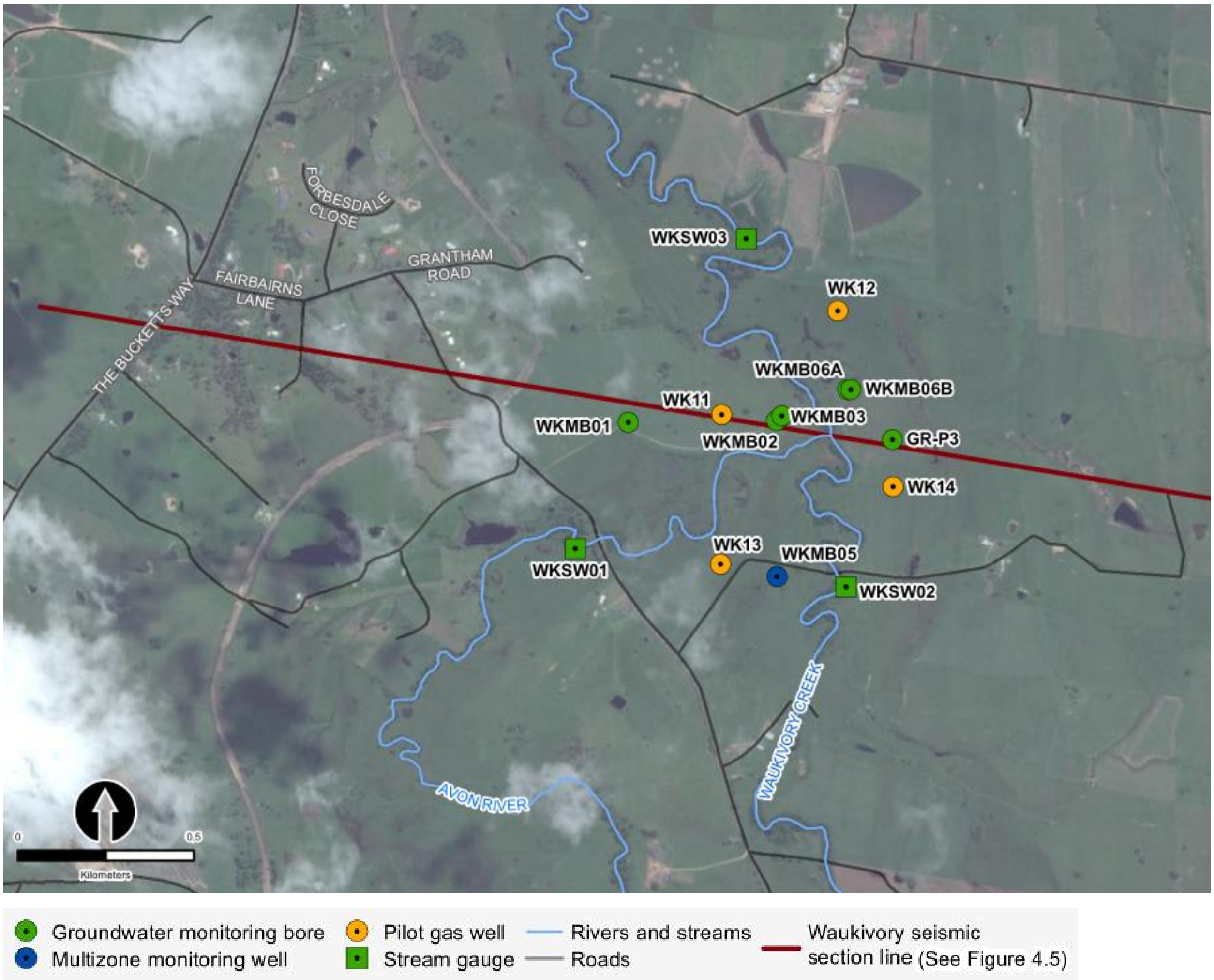


Figure 8.6 **Waukivory monitoring network**

8.4.2 Hydraulic conductivity

The Waukivory monitoring bores are installed in the alluvium (WKMB06A and GR-P3), shallow rock (WKMB01, WKMB02 and WKMB06B) and interburden (WKMB03). Monitoring bores WKMB03 and WKMB06B monitor groundwater levels in the same thrust fault zone.

A summary of the range of hydraulic conductivities for each hydrogeological unit based on hydraulic testing data from the Waukivory monitoring bores, compared to hydraulic testing data for all monitoring bores in the Gloucester Basin are presented in Table 8.2.

Hydraulic testing data at the Waukivory site falls within the range of hydraulic conductivities across the Gloucester Basin. Observations during drilling, and hydraulic testing on the monitoring bores screened in the fault zone ($2x10^{-4}$ m/d at WKMB03, and $5x10^{-3}$ m/d at WKMB06B) do not provide any evidence for enhanced hydraulic conductivity within the thrust fault zone.

Table 8.2 Hydraulic conductivity at Waukivory compared to the wider Gloucester Basin

Hydrogeological unit	Waukivory horizontal hydraulic conductivity range (m/d)[(a)]	Gloucester basin horizontal hydraulic conductivity range (m/d)[(b)]
Alluvial aquifers	20 - 75	0.3 – 300[(c)]
Shallow fractured rock aquifers (<150m)	$2x10^{-4}$ - $5x10^{-3}$	$1x10^{-6}$ – 10
Deep coal measure interburden confining unit	$2x10^{-4}$	$1x10^{-7}$ – 0.005
Deep coal seam water bearing zones	n/a	$1x10^{-6}$ – 2

(a) Horizontal hydraulic conductivity estimates from hydraulic testing on groundwater monitoring bores (Parsons Brinckerhoff 2011, 2014b, 2015i).

(b) Horizontal hydraulic conductivity estimates from hydraulic testing on groundwater monitoring bores (Parsons Brinckerhoff 2012a, 2013c, 2014b, 2014c, 2015c), drill stem tests on exploration bores (AGL, 2013) and comparative hydraulic conductivity data from the Gloucester Basin, Sydney Basin and Hunter Valley (Tammetta, 2009).

(c) The alluvium is highly heterogeneous. All but one slug test yielded a hydraulic conductivity less than 100 m/d. The 300 m/d value is considered anomalous.

8.4.3 Groundwater levels

Alluvium, shallow rock and interburden

Groundwater levels in the alluvial monitoring bores (WKMB06A and GR-P3), shallow rock monitoring bores (WKMB01, WKMB02 and WKMB06B) and interburden monitoring bore (WKMB03) are shown in Figure 8.7. Spikes depicting rapid groundwater level decline followed by recovery on the hydrographs are associated with water sampling events that have taken place since March 2014.

There is a rapid recovery of groundwater levels in response to sampling events at the alluvial monitoring bores, which is indicative of the typically high hydraulic conductivity of the alluvium compared with the coal measures and interburden. The shallow rock monitoring bores show a slower recovery response to sampling events, indicative of the lower hydraulic conductivity of the shallow rock. Groundwater levels at interburden monitoring bore WKMB03 (screened in the fault zone) show a distinctive delayed recovery response to sampling events, which is indicative of very low hydraulic conductivity within the interburden/fault zone.

Groundwater levels in the Waukivory monitoring bores show no response attributable to fracture stimulation or flowback pumping (Figure 8.7). Both WKMB03 and WKMB06B are screened across the thrust fault zone, and WKMB06A is screened within the alluvium above the thrust fault zone. Hydrographs from these three monitoring bores show no anomalous water level responses and therefore provide no evidence of connectivity between the fracture simulation zones and the shallow groundwater system via the thrust fault zone.

However it is interesting to note that the shallower fractured rock monitoring bores (WKMB01, WKMB02, and WKMB06B) all showed an apparent recharge response to the high rainfall event in early May 2015. Prior to this large rainfall recharge event, only WKMB02 had responded to significant rainfall events.

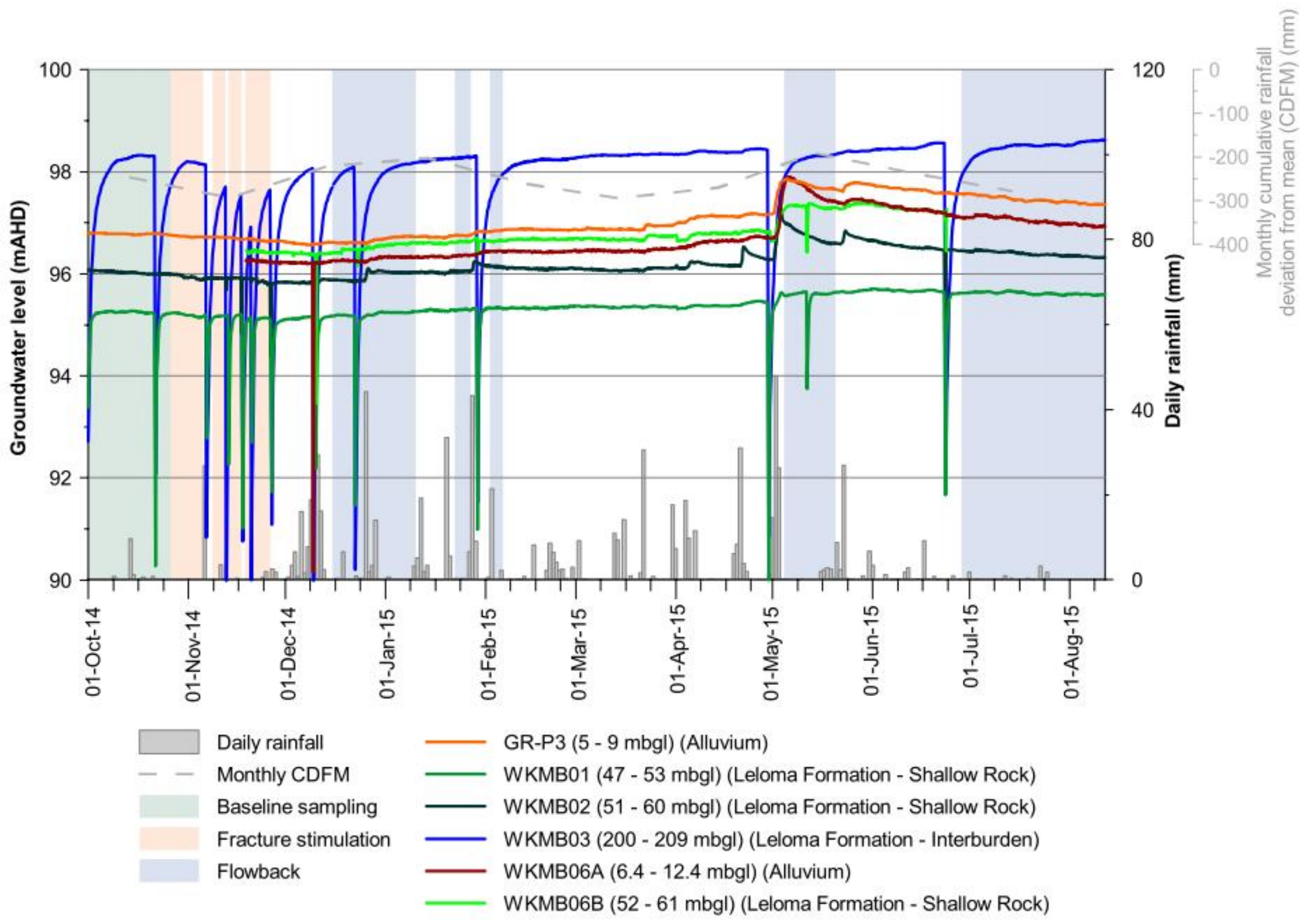


Figure 8.7 **Groundwater levels and rainfall at the Waukivory monitoring bores**

Deep groundwater

Deep groundwater is monitored by multi-zone monitoring well WKMB05 (Figure 8.8). WKMB05 monitors intervals in the deep coal seam water bearing zone and overlying aquitards, and is located 164 m to the east of pilot well WK13.

Piezometric levels at WKMB05 sensors 1 to 6 show an upward vertical gradient prior to any substantial flowback pumping in January 2015 (Figure 8.8). An upward trend in piezometric levels at WKMB05 sensor 1 and a downward trend in piezometric levels at sensor 2 from January 2015 to May 2015 have resulted in a reversal of this gradient. This trend may be related to the pumping and flowback activities at nearby WK13 leading to depressurisation of the Cloverdale coal seam whilst the pressure within the overlying aquitard is maintained due to the relatively low permeability of this unit attenuating vertical groundwater movement.

WKMB05 sensors 5 and 6 show piezometric levels of approximately 45 m and 70 m respectively above ground level (Figure 8.8). Piezometric pressures at these depths and in the centre of the basin are expected to be artesian (above ground elevation); although initial numerical modelling suggests that the piezometric pressures at the deepest sensors should be approximately 10 to 20 m above ground level. It is possible that sensors 5 and 6 have been influenced by the pressure effects of the fracture stimulation at WK13; however it may also be the case that some of the monitored horizons in WKMB05 have not yet fully equilibrated to formation pressure following installation (due to the very low permeability of the coal measures at depths of

700 mbgl). Further monitoring during the continuation of the Project will assess the vertical and temporal trends at WKMB05.

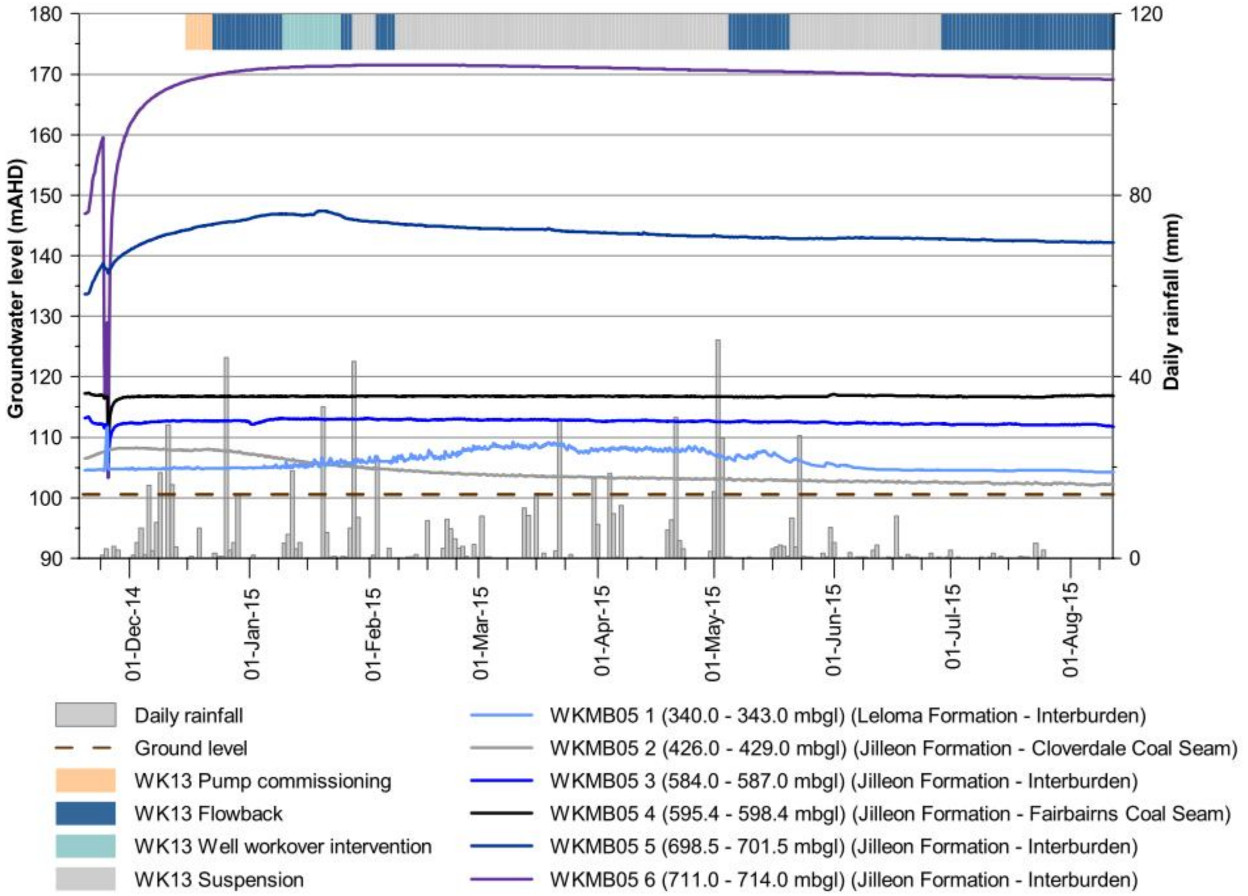


Figure 8.8 Groundwater levels and rainfall at multi-zone monitoring well WKMB05

8.4.4 Fracture stimulation fluid

Details of the chemical analysis of the fracture stimulation fluid are provided in the Waukivory Pilot Project Surface Water and Groundwater Monitoring Report to 31 December 2014 (Parsons Brinckerhoff, 2015d). Summary findings of chemical analysis of waters during the fracture stimulation period in November 2014 were as follows:

- The injected fracture stimulation fluid contained lower concentrations of total dissolved solids, major ions, and trace metals than the Waukivory groundwater and surface water monitoring sites (salinity (EC) of the fracture stimulation fluid ranged from 470 to 653 µS/cm).
- Monoethanolamine (MEA) was present in concentrations that are 2 to 3 orders of magnitude higher in the fracture stimulation fluid than in surface and groundwater. Boron (a constituent of monoethanolamine borate) concentrations of the fracture stimulation fluid ranged from 82.5 mg/L to 115.0 mg/L).
- Tetrakis (hydroxymethyl) phosphonium sulphate (THPS) was also present in the fracture stimulation fluid at concentrations 2 to 3 orders of magnitude higher than the surface and groundwater. Sulphate (a constituent of THPS) concentrations of the fracture stimulation fluid ranged from <10 mg/L to 63 mg/L.

8.4.5 Groundwater quality

Key groundwater quality trends at monitoring bores WKMB03 and WKMB06B screened in the thrust fault zone are shown in Figure 8.9. The exponentially weighted moving average (EWMA) does not show a trend outside of the 5th or 95th percentile for historical data for the key analytes of electrical conductivity (EC) or boron (as an indicator of MEA borate). This suggests that the water quality at monitoring bores WKMB03 and WKMB06B has not been affected by fracture stimulation or flowback pumping, and that there is no water quality evidence for enhanced connectivity through the thrust fault zone during the pilot testing.

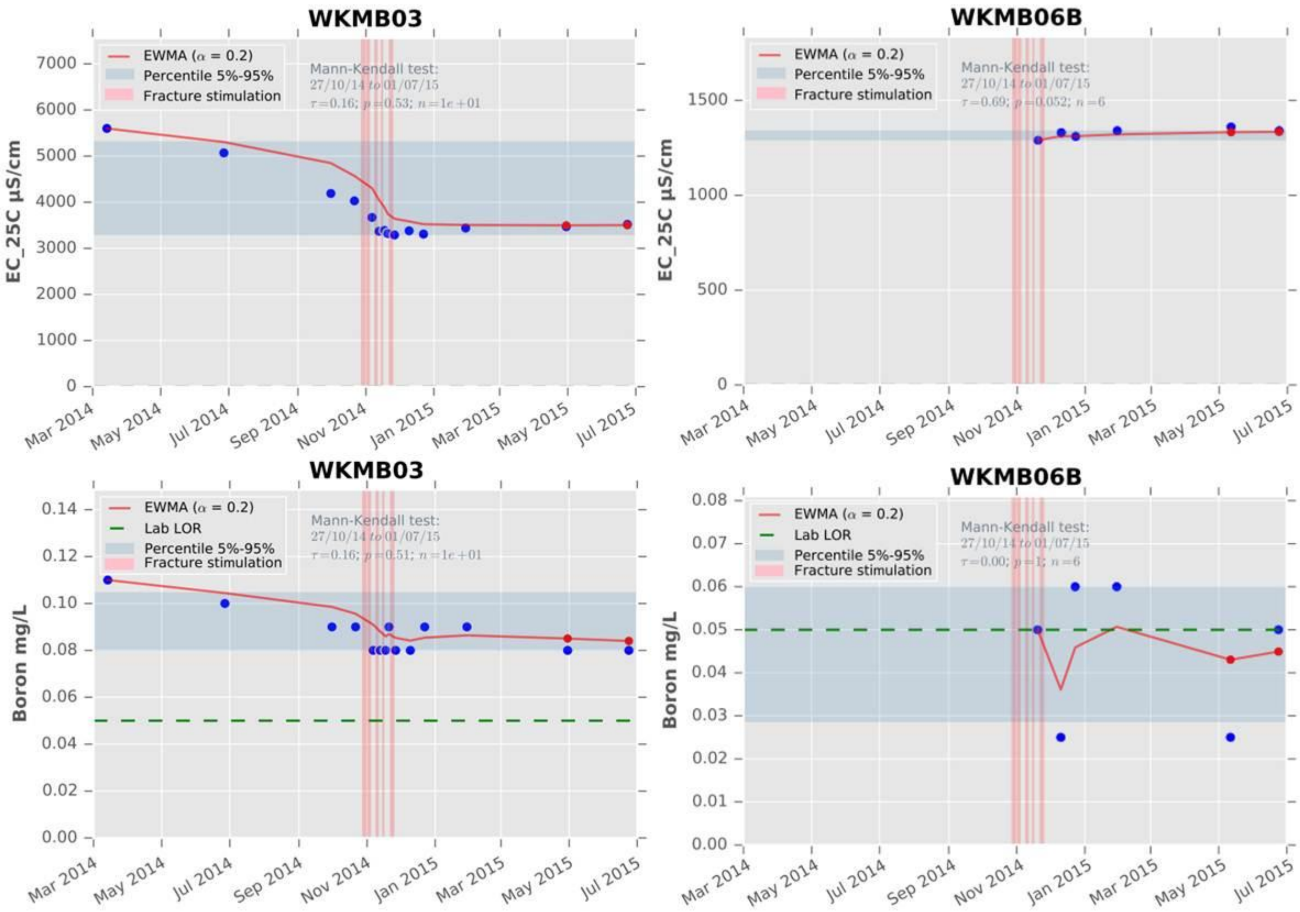


Figure 8.9 Key Waukivory groundwater quality trends

8.4.6 Conclusions

There is currently no water level or water quality evidence that the Waukivory alluvial, shallow rock or interburden monitoring bores have been influenced by fracture stimulation or flowback pumping activities associated with the Waukivory pilot testing. Local-scale numerical modelling undertaken for the Waukivory pilot testing REF (Parsons Brinckerhoff, 2013g) predicts that no pressure drawdown at the Waukivory monitoring bores (except WKMB05) would be observed within the first 12 months of pilot testing.

Hydraulic testing, water level analysis and water quality trend analysis at monitoring bores WKMB03 and WKMB06B, screened across the fault zone, show no evidence of naturally enhanced hydraulic conductivity in the thrust fault zone, and no evidence for enhanced connectivity as a result of the fracture stimulation and the initial flow testing. Further monitoring during the pilot testing program will assess groundwater level and quality trends.

8.5 Fault modelling

Local scale numerical modelling has commenced to assess the role of faults in influencing the impacts of CSG development. The objective of the modelling was to assess the extent of depressurisation under a number of fault behaviours scenarios ranging from faults as high permeability conduits to faults as groundwater barriers. The results of the modelling are summarised below; detailed results are in a separate draft report (Parsons Brinckerhoff, 2015a) and in the Waukivory pilot testing REF Appendices (Parsons Brinckerhoff, 2013g).

8.5.1 Fault scenarios

Numerical models were developed using FEFLOW of two cross sections within the Stage 1 GFDA for which the geology and groundwater conditions are well known. The cross-sectional models are located at the Stratford and Waukivory pilot testing sites, as shown in Figure 4.1. The models are based on interpreted seismic sections as shown in Figure 4.4 (Stratford) and Figure 4.5 (Waukivory). The models were constructed and parameterised using data and estimates from recent groundwater investigations and in accord with the current conceptual hydrogeological understanding of the Basin. FEFLOW is a single phase saturated/unsaturated groundwater flow and transport code and excludes the effects of dual-phase flow close to the production wells. Model predictions will therefore overestimate depressurisation close to the wells and be conservative with respect to potential groundwater impacts.

The potential role of faults in groundwater flow and in influencing depressurisation associated with CSG extraction was explored by running the models multiple times, varying the permeability of the faults each time to simulate faults as conduits and as barriers relative to the coal seams and interburden. Representative results from the Stratford cross-sectional model are presented in Figure 8.10, and the main conclusions are as follows:

- The overall extent of depressurisation due to CSG extraction is similar for each of the scenarios run, suggesting that faults may have insignificant influence on the regional extent of impacts.
- The shape of the depressurisation envelope is strongly influenced by the decrease in permeability with depth, but less sensitive to the anisotropy in permeability associated with dipping coal seams and other strata. It follows that production wells perforated at shallow depths will have a wider impact than wells perforated only in deeper seams.
- In the case of faults as conduits, pressure drawdown propagates preferentially along conductive fault zones, particularly at depths greater than approximately 400 m. The propagation of drawdown is only significant in cases where the fault passes very close (<50 m) to the perforated zone of a production well. More distant faults have significantly less influence on drawdown.
- Low permeability or barrier faults compartmentalise drawdown in the vicinity of production wells. They enhance drawdown on the side of the fault (or within the fault block) in which the production well operates, but impede the transmission of drawdown across the fault.
- The Stratford field investigation suggests that faults may be weak barriers at depth, but correspond to broad fracture zones with enhanced permeability near the ground surface. Simulations using this scenario suggest that faults will have little influence on groundwater drawdown at the surface, particularly outside of the gas field.
- Drawdown at the water table can be variable depending on the location and orientation of the fault with respect to the gas well. Barrier faults can result in locally higher drawdown at the water table adjacent to the fault and within fault bound blocks (within the gas field), whereas conduit faults have little effect on drawdown at the water table.

The influence of faults is therefore both localised and highly dependent on the nature and orientation of the faults. The uncertainty in relation to those attributes is such that the local effects, although understood in principle, can be simulated but the predictive capacity of the models is uncertain without calibration from longer term stress data.

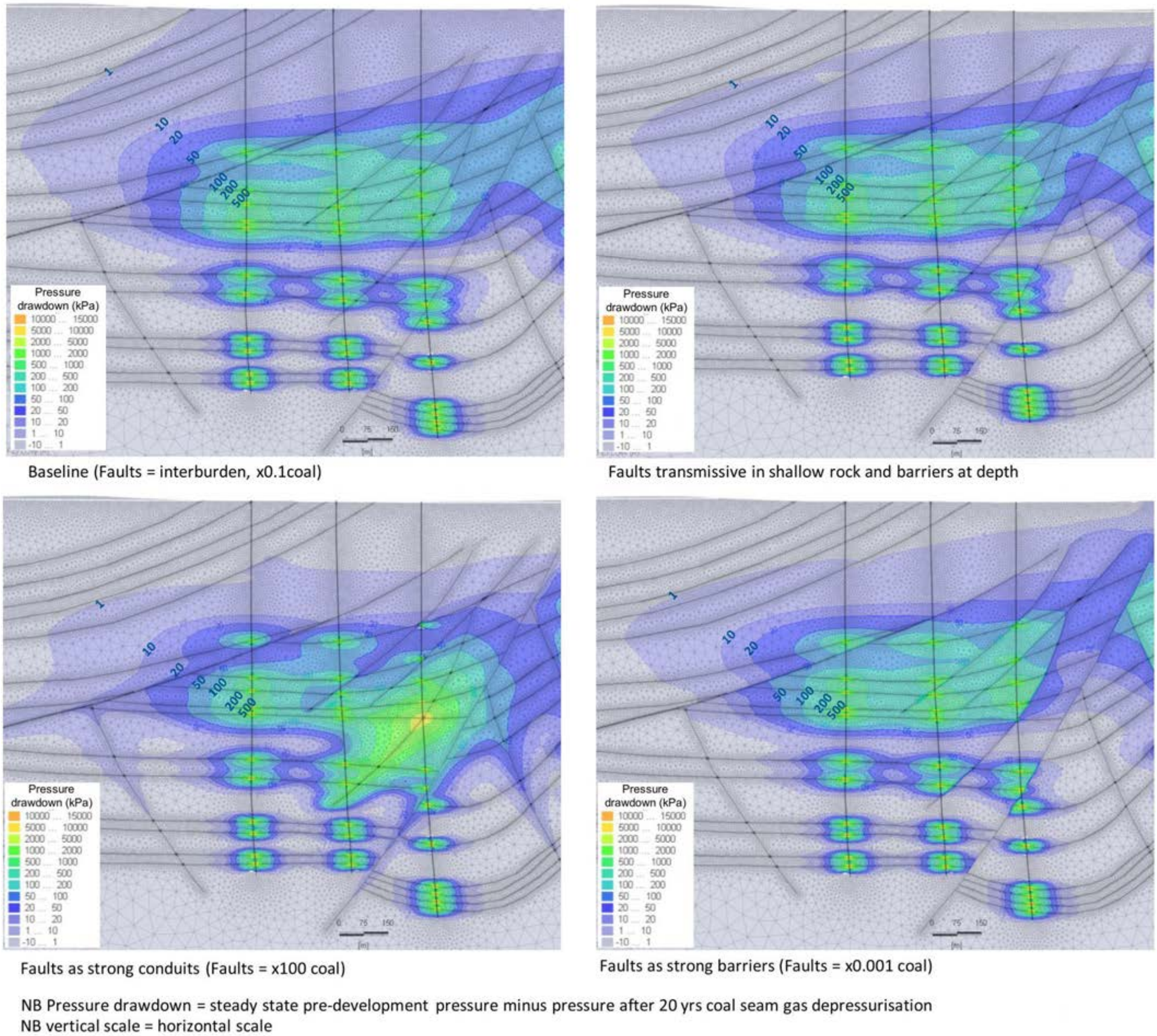


Figure 8.10 Modelled pressure drawdown (kPa) at Stratford after 20 years of coal seam gas depressurisation

8.5.2 Stratford 4 flow test

Numerical modelling was carried out to simulate the groundwater pressure drawdown associated with the Stratford 4 29-day flow test (see Section 8.3.2). Specifically, the aim was determine whether the anomalous decline in groundwater level noted in monitoring bore S4MB03 about one month after the conclusion of the test could be replicated, and if so, what are the implications for the rock-mass hydraulic characteristics. The two scenarios considered were:

1. **Field-based hydraulic conductivity distribution**: The hydraulic conductivity distribution is based on field data summarised in accordance with the conceptual model, with faults assigned the same hydraulic conductivity as the interburden.
2. **High hydraulic conductivity distribution**: The field-based hydraulic conductivity distribution is multiplied by 1000, with faults assigned the same hydraulic conductivity as the interburden. This

scenario was designed to identify what parameter values would be necessary (regardless of how unrealistic) to induce detectable drawdown at the closest piezometer during the flow test.

The model scenarios were run with a 29-day period of depressurisation in the coal seams perforated in the Stratford 4 test well. The simulated flow test was followed by 30 days of recovery (with no depressurisation). Time-varying recharge to simulate the low rainfall conditions in late 2012 was not included in the model. This is because the purpose of the modelling was to assess whether any decline in water levels is due to coal seam gas depressurisation. Simulated responses in monitoring bores were compared with observations from the field testing in 2012 which had a maximum observation depth of 170 m (S4MB03). Results are shown in Figure 8.11, and drawdown hydrographs are shown in Figure 8.12. The simulations indicate the following:

1. Field based hydraulic conductivity distribution
   - Using the field based hydraulic conductivity distribution, pressure drawdown associated with the Stratford 4 flow test is unlikely to extend to depths shallower than 500 mbgl, and would not cause any measurable drawdown in any nearby monitoring bores.
2. High hydraulic conductivity distribution
   - Using the high hydraulic conductivity distribution, groundwater level drawdown associated with the Stratford 4 flow test is modelled to be ~ 0.1 m at the deepest S4MB03 bore (screened at 160 mbgl) after 29 days. This high hydraulic conductivity distribution is unrealistic based on field data.
   - A maximum decrease in groundwater levels is modelled to be ~0.02 m at S5MB03, and ~ 0.1 m at TTMB03 with the high hydraulic conductivity distribution.

An actual decrease in groundwater levels of ~ 0.5 m was observed at S4MB03, commencing one month after the Stratford 4 flow test. This is most likely the result of very dry seasonal conditions rather than a pumping induced drawdown effect. Time-varying recharge to simulate the low rainfall conditions in late 2012 was not included in the model. This is because the purpose of the modelling was to assess whether any decline in water levels is due to coal seam gas depressurisation only. It is not possible to reproduce this magnitude of decline in groundwater levels, nor the time delay with either the field-based or high hydraulic conductivity distributions, in response to coal seam gas depressurisation at Stratford 4.

The predicted drawdowns in S4MB03 (~ 0.1 m), S5MB03 (~0.02 m) and TTMB03 (~ 0.1 m) due to the flow test are very small and would be difficult to detect in hydrographs. The observed fluctuations which are greater than these (worse case) drawdowns are most likely the result of natural seasonal conditions given successive dry months during and immediately after the flow test in September 2012.

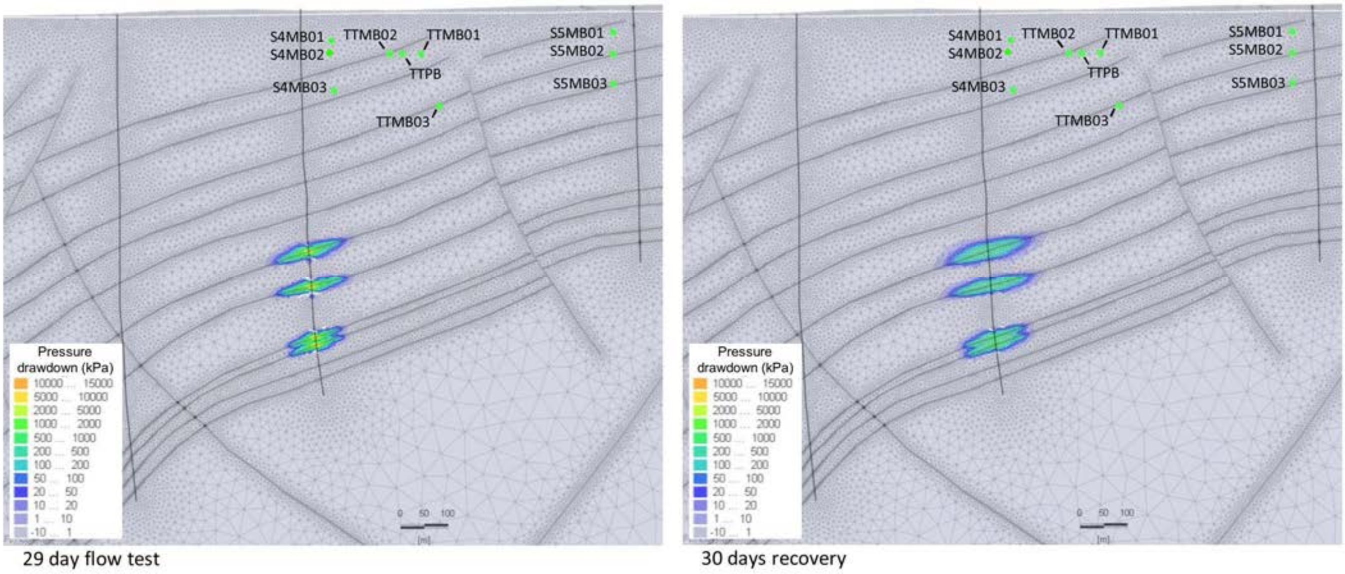


Figure 8.11 **Simulated pressure drawdown (kPa) at the end of the 29-day flow test at Stratford 4 for the two modelled scenarios**

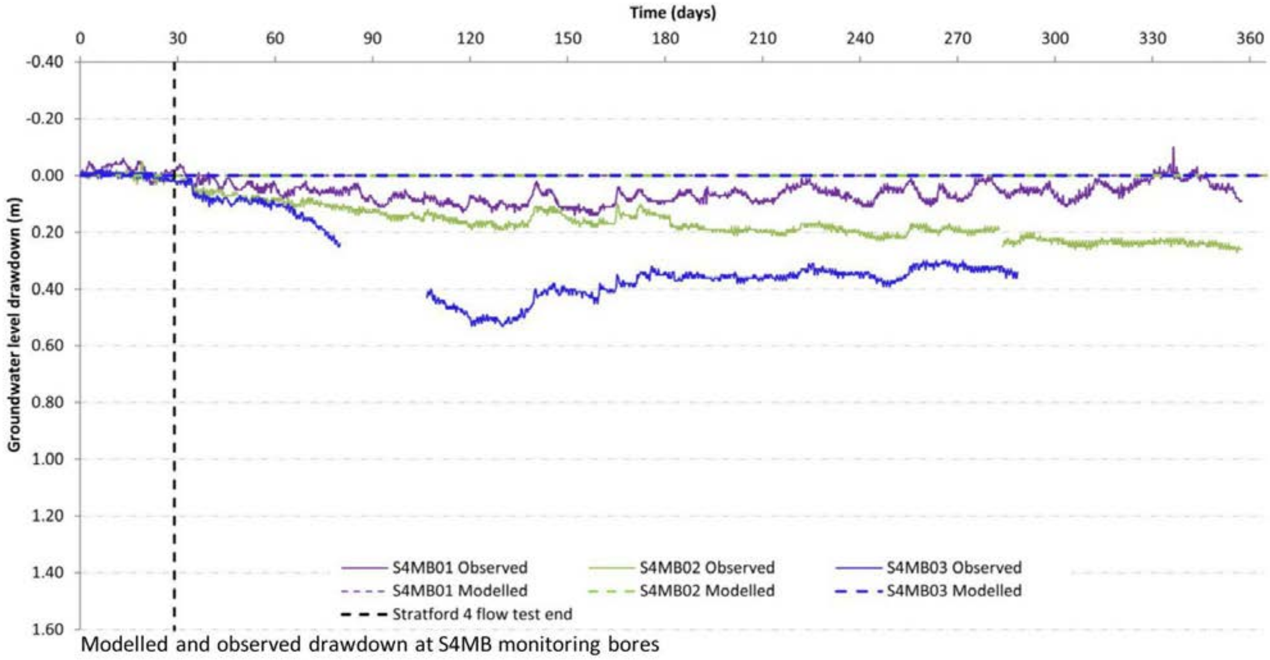


Figure 8.12 **Stratford 4 flow test drawdown hydrographs compared with modelled drawdown**

9. Basin-wide water and salt balance

This chapter presents a summary of a quantitative water balance and salt balance for the Gloucester Basin. It provides a basis for developing numerical models to assess those potential impacts in more detail. Detailed methodology and results are discussed in the water balances for the Gloucester Basin (Parsons Brinckerhoff, 2012c and 2013b).

9.1 Water balance

A water balance is an estimate of the storage and flow of groundwater and surface water in a defined area, during a given timeframe. Under natural long term conditions (or steady state conditions), the Gloucester Basin water balance is assumed to be in equilibrium, where inflows equal outflows and the change in storage is (approximately) zero. This and several other assumptions underpinned the development of the water balance. The water balance was developed by focussing on elements derived from data of high reliability such as rainfall and stream records. Other components were estimated using a simple numerical model of the Basin, or through applying the water balance equations.

Water balance diagrams for current development and future development (which includes CSG) are presented in Figure 9.1 and Figure 9.2 respectively. These diagrams are schematic water balances used to demonstrate fluxes in the Gloucester Basin's water cycle in an average rainfall year.

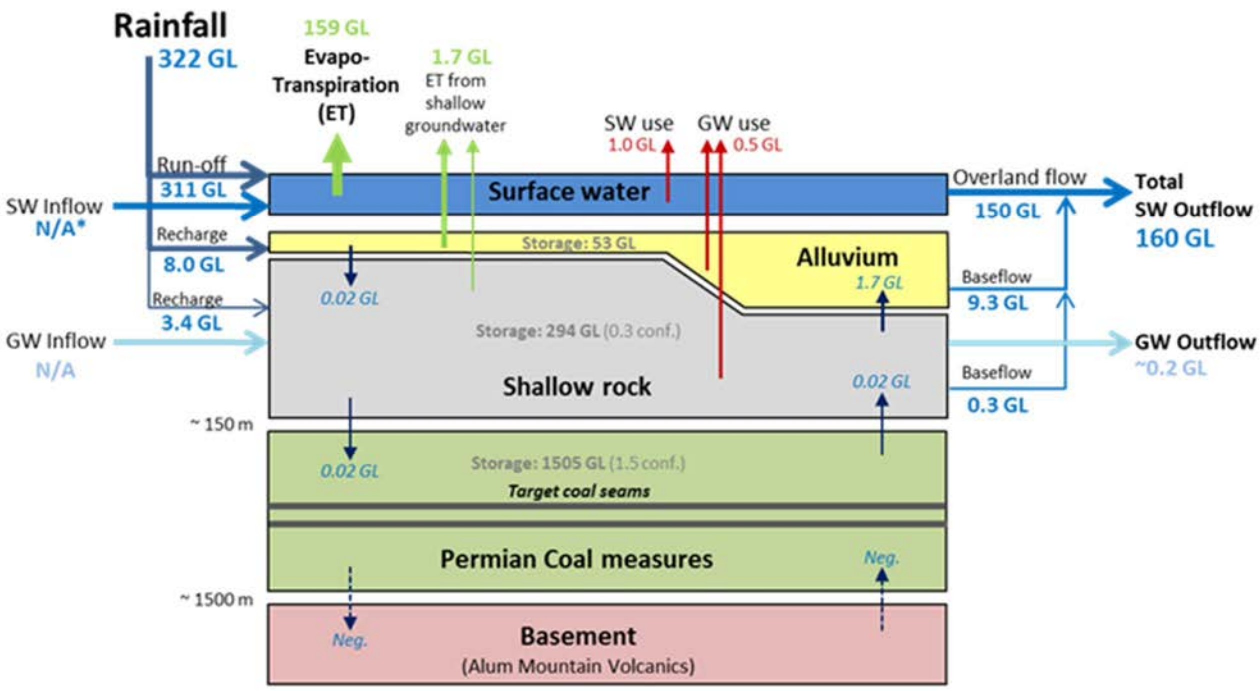


Figure 9.1 Annual water balance for the Gloucester Basin – current development

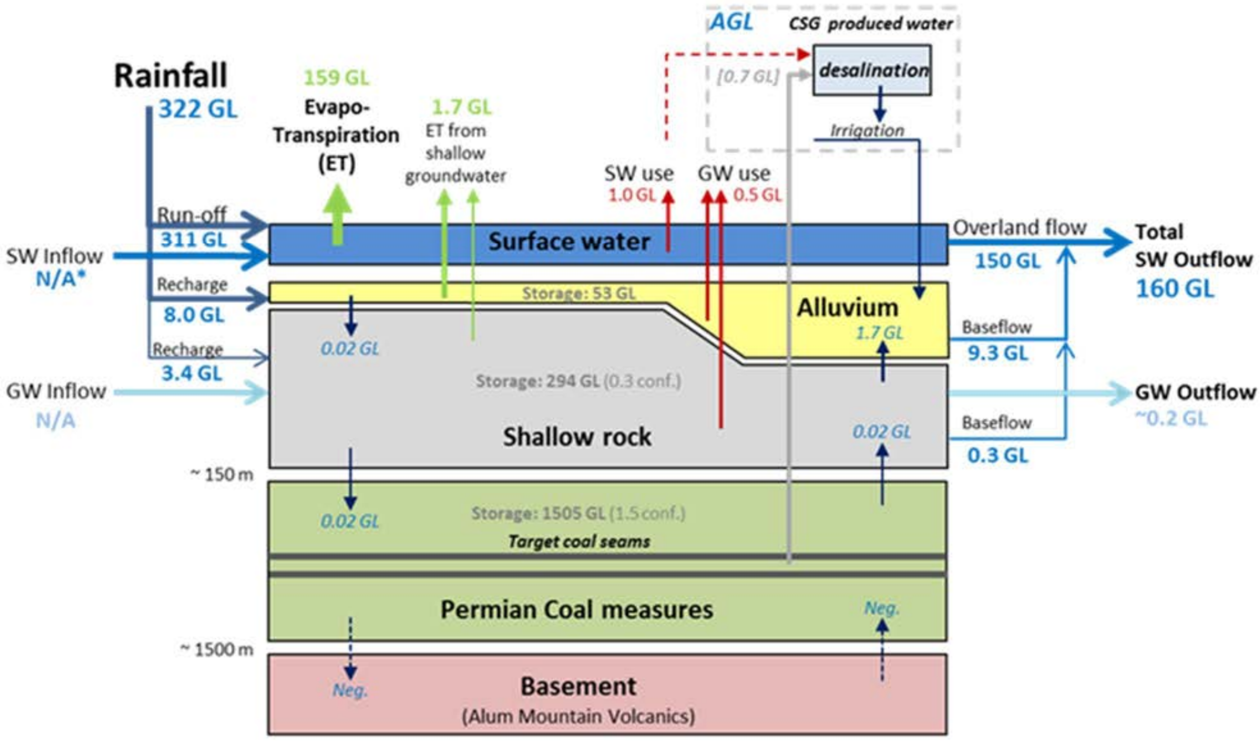


Figure 9.2 **Annual water balance for the Gloucester Basin – future development**

Of the ~322 gigalitres (GL) of rainfall that falls on the Gloucester Basin each year, approximately 150 GL (47 %) flows overland, bypassing the groundwater system, and is discharged via the Avon River and Wards River systems; a further 159 GL (49 %) is returned to the atmosphere via evapotranspiration (ET) or otherwise lost from the system. Surface water flows and ET losses from the catchment and the unsaturated zone therefore dominate the hydrological system, together accounting for 96% of rainfall (Figure 9.3).

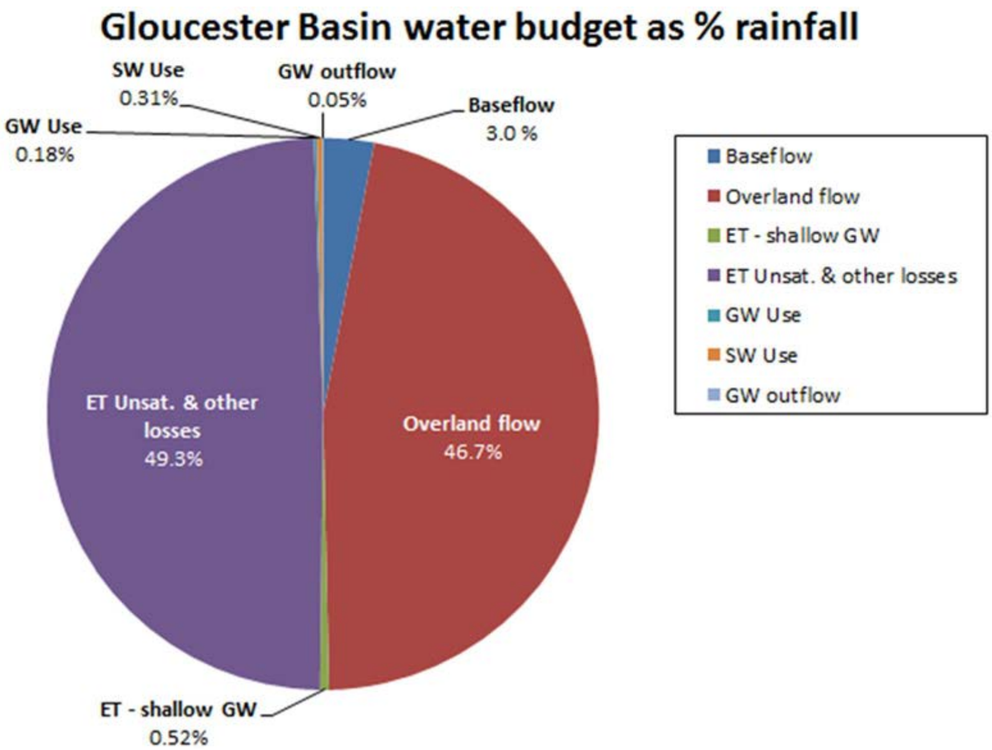


Figure 9.3 **Estimate of total outflow as a proportion of total rainfall (322 GL)**

The lower reaches of the Avon and Karuah Rivers flow all year round except in very dry conditions (the rivers flow 96% and 98% of the time respectively). Of the total flow in these systems, approximately 6% (Avon River) and 11% (Karuah River) is baseflow derived from groundwater discharge. Most of this is derived from the alluvial deposits with a relatively minor discharge directly from the shallow rock. Groundwater discharge therefore represents a small component of the total surface water balance.

On a Basin scale, approximately 3.5% of rainfall (~11 GL per year) infiltrates the unsaturated zone to recharge the water table. Recharge rates are spatially variably however, being highest in the more permeable alluvial deposits (4% to 13% of rainfall) and significantly lower in areas where the less permeable shallow fractured rock unit outcrops (~0.5% to 1% of rainfall).

There is substantial groundwater storage within the Basin. The main beneficial aquifer unit (shallow fractured rock) has an unconfined storage of approximately 294 GL. By comparison, the alluvial aquifer has less storage (approximately 53 GL). The deeper coal measures unit (comprising coal seams and low-permeability interburden) are large but tight groundwater systems, containing approximately 1505 GL of total groundwater storage, of which approximately 1.5 GL is held in elastic (confined) storage.

It is evident from the water balance, that most groundwater flow in the Basin occurs in the uppermost aquifer units; the alluvium and to a lesser extent, the shallow fractured rock where it is most permeable. The alluvial deposits have a through flow of 8 to 9 GL per year, which, considering a total storage of ~53 GL, implies short groundwater residence times, consistent with the relatively young isotopic ages obtained from alluvial groundwater monitoring program. The shallow rock aquifer is of lower permeability and therefore transmits less groundwater (in the order of 2 to 3 GL per year). Much of the discharge from the shallow rock is via the alluvium adjacent to streams. Evapotranspiration from the shallow water table and groundwater outflow from the basin are very small components of the water balance and account for less than 2 GL per year.

Simple numerical modelling (completed for the purpose of the water balance) indicates that vertical groundwater movement between the shallow fractured rock unit and the deeper coal measures is very low and amounts to less than 0.02 GL per year. Groundwater movement between shallow rock unit and the higher permeability alluvium is several orders of magnitude higher (up to 1.7 GL per year), driven mainly by the regional discharge to the rivers.

9.1.1 Development in the Basin context

The water balance study is not intended to provide detailed or quantitative assessment of the impacts of depressurisation associated with the proposed Stage 1 development. However, a comparison of the projected maximum groundwater extraction rates against key water balance parameters provides a useful perspective regarding the likely magnitude of impacts to the natural water balance.

The Stage 1 development is capped at a maximum dewatering volume of approximately 730 ML per annum. Dewatering volumes will be greatest in the initial years of the project and will diminish substantially with time because of the dewatering of the targeted coal seams and the low permeability strata overlying the targeted coal seams. Most groundwater abstraction will be from the coal measures and interburden at depths greater than 250 m. The maximum groundwater use of 730 ML (0.7 GL) per year represents approximately 6% of the estimated 11.4 GL that is recharged annually to the shallow groundwater systems. It is also a very small proportion (~0.2%) of the groundwater storage in the shallow fractured rock unit (~294 GL).

During operation, the produced water pumped from the deep confined coal measures will be initially derived from storage, and over the following years and decades will be derived from lateral flow through the deep coal seams and minor vertical flow through the overlying interburden. It is also expected that the upward flows from the coal measures to the shallow rock and the shallow rock to the alluvium will diminish during development and recovery of the GGP.

Downward hydraulic gradients will develop due to depressurisation, and any subsequent downward movement of groundwater will be limited by the very low permeability in the deeper coal measures and aquitards. Those downward fluxes are likely to be minor compared with the recharge rates in the alluvium and shallow rock and the unconfined storage available in those shallow systems.

To conclude, the water balance is dominated by surface water runoff and evapotranspiration, and most of the groundwater recharge and discharge is to/from the shallow alluvial and shallow rock aquifers. Therefore the initial water balance analysis implies that the proposed CSG pumping from deep coal seams will have a minimal effect on shallow groundwater systems and surface water flows.

9.2 Salt balance

A catchment salt balance is conceptually similar to a water balance in that the change in salt storage within the catchment is equal to the difference between the salt inputs to, and outputs from the catchment. Because of the high solubility of most salts (predominantly NaCl in rainfall and Na-Cl-HCO_3 in produced water), its movement is strongly associated with the movement of water. A salt balance can therefore be calculated by assigning salinities to key water fluxes from the water balance.

Over the long term and during relatively stable conditions, the salt balance of a catchment will be in equilibrium whereby the input of salt (through rainfall, dry deposition) equals the output of salt from the Basin (via stream flow, groundwater flow, and aeolian soil loss). Changes to the salt balance can occur due to changes in land-use, rainfall or surface water flow (diversions), as has been dramatically demonstrated by the widespread salinisation of many catchments in Australia due to land clearing for agriculture over the last two hundred years. Catchments return to an equilibrium state where salt input equals output over a very long period, ranging from decades to millennia, depending on the rainfall conditions (Walker, 2001; Walker et al., 1998). In addition, annual and longer term variations in rainfall and associated variation in surface runoff will lead to smaller scale fluctuations in the salt balance from year to year. For this reason, long term records (decades) of rainfall and stream salinity are necessary to characterise the equilibrium salt balance.

DPI Water has a relatively short (two year) record of combined flow and salinity for the Avon River (Station 208028), and this record corresponds to a period of unusually low rainfall and runoff. Therefore in this report the catchment salt balance is characterised in terms of the input side of the salt equation only. That is, the salt imported to the catchment via rainfall. This is compared with the salt that is expected to be extracted and exported from the catchment through managing the CSG produced water. Estimates of catchment salt balance and CSG salt production are shown in Table 9.1.

Table 9.1 Salt balance for the Gloucester Basin

Balance component	Gloucester Basin (including Alum Mtn Volcanics)	Stage 1 GFDA	CSG produced water – max volume (1) (Years 2 and 3)	CSG produced water – median volume (1) (Years 2 and 3)	CSG produced water – median volume (2) (Year 3+)
Area (km^2)	305	50	N/A	N/A	N/A
Average annual rainfall (mm)	1049(3)	1018(4)	N/A	N/A	N/A
Annual volume (total rain or produced water) (GL)	322	51	0.7	0.2	0.04
Salt concentration in rainfall and produced water (mg/L)	20(5)	20(5)	5336(6)	5336(6)	5336(6)
Salt total (tonnes)	6399	1018	3735	1067	213
Salt as % of annual Basin input	**100%**	**16%**	**58%**	**17%**	**3%**

(1) Produced water volumes are now expected to be much lower than the maximum cap of 2 ML/d and 0.7 GL/yr. Peak volumes of 0.9 ML/d with a median volume of 0.6 ML/d are predicted in year 3 with volumes less than 0.1 ML/d after year 5 (AGL, 2015c)

(2) Assumed that CSG water production will decrease to 20% of initial rate after year 3 and 10% after year 5.

(3) Average annual rainfall from all BoM stations within the Gloucester Basin (Table 3.1).

(4) Average annual rainfall from Gloucester Post Office BoM station 60015 and Craven BoM station 60042 (Table 3.1) within Stage 1 GFDA.

(5) Based on average TDS (mg/L) from rainfall samples collected at the AGL weather station in 2013 and 2014 (Parsons Brinckerhoff, 2014h).

(6) Based on average TDS (mg/L) from all produced water quality data to date (Parsons Brinckerhoff 2014e, 2015d, 2015e and 2015f).

Based on a salt concentration of 20 mg/L and rainfall of 1049 mm per year, it is estimated that average rainfall across the Gloucester Basin delivers 6399 tonnes of salt annually. Under equilibrium, a similar amount of salt is exported via stream flow (the Avon and Wards Rivers). However with land clearing for agriculture and grazing, a greater amount of salt is exported via stream flow and sediment loss.

Salt extracted from produced water in the initial years of production is estimated to represent approximately 17% of the average salt load in rainfall; or approximately the same volume of salt that falls on the Stage 1 area as rainfall in an average year. CSG produced water volumes are estimated to decrease significantly after the first couple of years of production to around 3% of the average salt load in rainfall. The exact water production profile will not be known until production commences, however rates are estimated to be less than 10% of the initial flow rates after Year 5. Salt will be removed from extracted water by the proposed desalination plant, crystallised, transported and landfilled outside of the Basin.

Removal of salt from the Basin due to CSG activities in the Stage 1 GFDA will result in a net reduction in salt accumulation in the northern part of the Basin. This reduction will ultimately manifest as a small decrease in the salt flux from the shallow fractured rock to the base of the alluvium, and ultimately to the Avon River system over future decades.

10. Conceptual model

This chapter presents the (updated) conceptual hydrogeological model for the whole of the Gloucester Basin with a strong focus on the groundwater systems underlying and adjacent to the Stage 1 GFDA. It is based on earlier models described in SRK (2010), Parsons Brinckerhoff (2012a), Parsons Brinckerhoff (2013a) and is updated based on more than four years of monitoring data, and the knowledge gained from several testing programs around a slip-strike fault and thrust faults.

A conceptual hydrogeological model is a summary, accompanied by a graphical representation, of the key processes considered to control groundwater levels and flow within a groundwater system. The conceptual model describes how water enters, exits, is stored, and moves within a hydrogeological system and how groundwater interacts with surface water systems and potentially dependent ecosystems. Ultimately the conceptual model informs the development of a numerical predictive groundwater model which is used to assess impacts on hydrologic systems from activities such as mining and groundwater extraction.

The conceptual model for groundwater systems across the Basin is based on the cumulative results from extensive groundwater investigations carried out by Parsons Brinckerhoff since 2010 and earlier studies by SRK (2010), URS (2007) and others. While our conceptual understanding is always evolving as new data is collected, there is now a strong scientific basis for the following conceptual framework. The current conceptual understanding of the groundwater systems in the central area of the Basin is depicted in Figure 10.1 and quantified in the water balance diagrams in Figures 9.1 and 9.2.

10.1 Gloucester Basin

The Gloucester Basin is a broad north-south elongated basin underlain by Permian sedimentary and volcanic rocks that have been folded and faulted into a synclinal (canoe-shaped) structure. The Permian geological sequence 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 geological and depositional history of the Basin is such that economic coal seams are well developed on the eastern side of the Basin, while coarse proximal fan deposits with relatively few coal seams prevail on the western side of the Basin. The CSG development in the Stage 1 GFDA is targeting the intermediate and deep coal seams in the Gloucester Coal Measures generally below depths of 250 m to around 1000 m.

The Basin is bounded to the west by the elevated topography of the Gloucester and Barrington Tops, and to the east by the Mograni Range. These topographic divides also correspond to outcrops of the largely impermeable Alum Mountain Volcanics which forms the hydrogeological basement to the Basin. By contrast, the coal measures and near surface rocks within the Basin are slightly more permeable, mainly due to sparse fracturing in near-surface rocks and cleating within coal seams which form weak water bearing horizons. In hydrogeological terms therefore, the Basin is conceptualised as an essentially closed groundwater system, with minor surface water and groundwater inflows from adjacent tributary catchments and minor groundwater outflow at the northern and southern ends of the Basin. All surface water and most discharging groundwater exits the Basin via the Avon and Gloucester Rivers to the north and the Wards River system to the south.

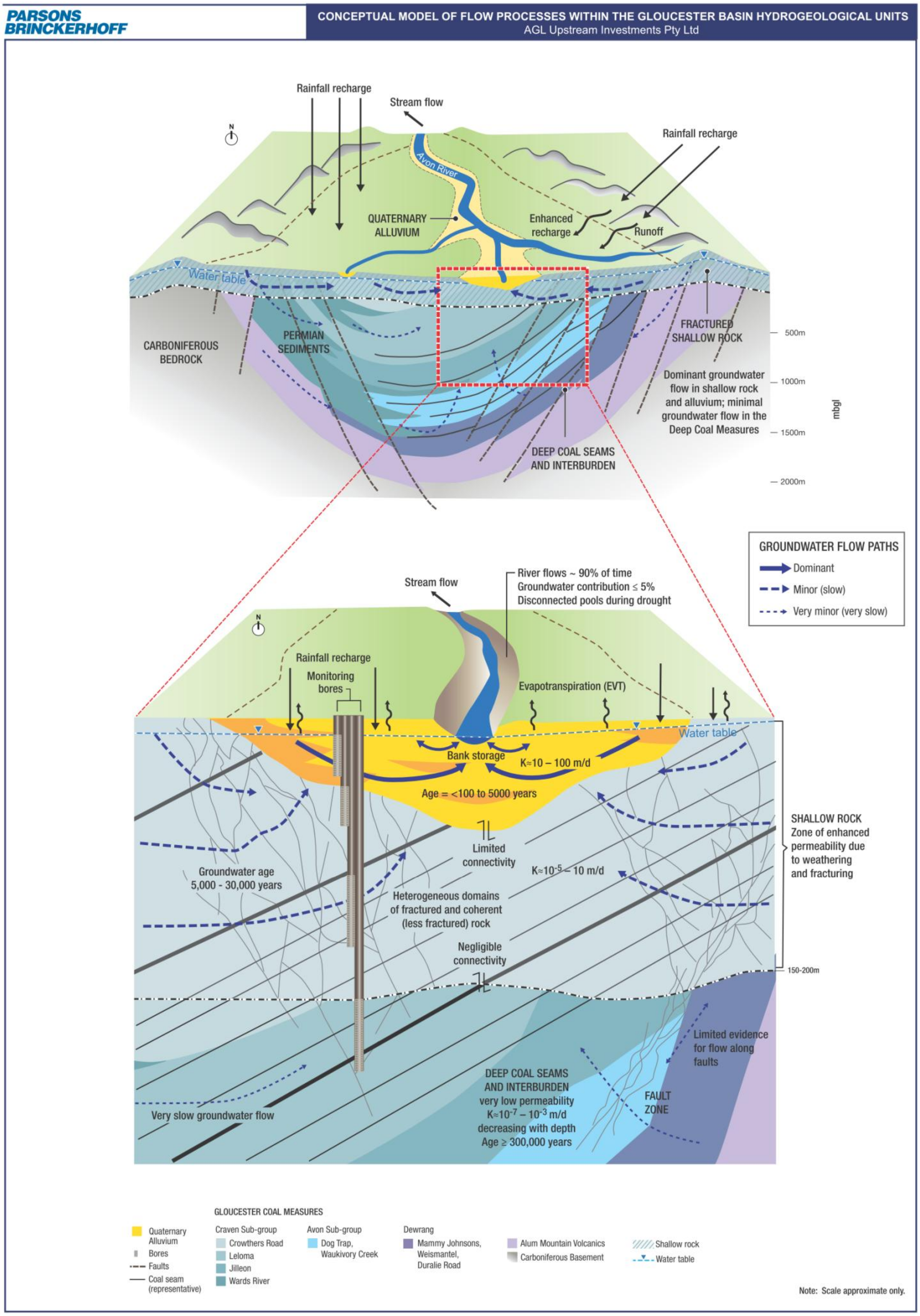


Figure 10.1 Conceptual model of flow processes within the Gloucester Basin hydrogeological units

In terms of groundwater flow, the Basin can be divided into two distinct groundwater flow systems which are largely controlled by the topography and surface drainage features: The northern Gloucester Basin in which groundwater predominantly flows to the north, and the southern Gloucester Basin in which groundwater generally flows in a southerly direction. The boundary between the two flow systems, under natural conditions, corresponds with the catchment divide between the Avon and Wards Rivers. Unlike the surface catchment divide however, the groundwater divide may move in response to drawdown related to groundwater abstraction, CSG depressurisation and/or mining. The Stage 1 GFDA is confined to the northern Gloucester Basin.

The permeability and groundwater flow characteristics of rocks within the Basin are controlled by several factors including lithology, depth and the degree of fracturing and faulting. In this sense hydrogeological units and flow systems do not always correspond with defined geological boundaries. Four main hydrogeological units influence groundwater flow within the Basin:

1. **Alluvial deposits** adjacent to major creeks and rivers comprising unconsolidated sand, gravel and clay. These systems are heterogeneous but generally permeable with rapid recharge, through-flow and discharge associated with interactions with streams, and to a lesser extent with the underlying less permeable shallow rock. Hydraulic conductivity measurements range from 0.3 to 300 m/d, averaging around 10 m/d.

2. **Shallow fractured rock** comprising variably weathered and fractured sedimentary rocks extending to approximately 150 m below the surface, across all sub-cropping Permian units. The shallow rock zone is highly heterogeneous with relatively impermeable domains separated by more permeable domains, but on the whole it is more permeable that the deeper coal measures. The areas of higher permeability are due to a higher density of fracturing associated with an irregular weathering profile and the near-surface expression of faulting. Groundwater flow within this zone is more strongly controlled by weathering and fracturing than the attitude of geological strata. Hydraulic conductivity of the shallow rock ranges from 10 m/d to $1x10^{-6}$ m/d at a depth of 150m, but is typically in the order of 10^{-3} to 10^{-4} m/d.

3. **Deep Coal Measures interburden**. Predominantly sandstone and siltstone units form the interburden to coal seams and are typically of very low permeability, forming aquitards and confining layers. Permeability of interburden decreases with depth such that, at the maximum depth of CSG production is likely to be in the order of 10^{-5} to 10^{-7} m/d, or less.

4. **Deep coal seams**. Coal seams tend to be slightly more permeable than interburden and commonly form weak water bearing zones. Permeability and storage are provided by small fractures and cleats in the coal. As with the interburden, drill-stem tests clearly show that the permeability of coal seams generally decreases with depth. At the maximum depth of CSG production, the permeability of coal seams is very low (10^{-4} to 10^{-6} m/d), but may be an order of magnitude higher than the interburden.

The only beneficial aquifers are contained within the alluvium to around 15m depth and the shallow fractured rock to around 75m depth. There are no beneficial aquifers in the deep coal seams or interburden rocks. Also recent property surveys have indicated predominant surface water use and no groundwater bores or use within the Stage 1 GFDA.

10.2 Groundwater recharge

Rainfall is the primary recharge source to the aquifers and water bearing zones within the Gloucester Basin. Minor recharge from streams may occur during periods of high rainfall/surface flow and flooding when there is the potential for the rivers to lose water, particularly in upper catchment areas. Direct recharge rates to the rock aquifers and water bearing zones are low based on water level responses, and water quality indicators such as chloride and age dating (Parsons Brinckerhoff, 2012c). Recharge to deeper rock layers through vertical groundwater movement from overlying hydrogeological units is possible but lateral flow appears to dominate. Observations of vertical head differences indicate that recharge is highest towards the margins of the Basin due to surface runoff from the adjacent elevated areas and rockier outcrop/thinner soils in these areas.

10.3 Groundwater flow

10.3.1 Lateral flow

The groundwater flow pattern is controlled by topography, and recharge and discharge locations. The regional groundwater flow in the northern part of the Basin is predominantly from south to north. The regional groundwater flow in the southern Basin is predominantly from north to south. At the margins of the Basin, groundwater will flow away from elevated areas of outcrop where recharge occurs and towards the centre of the Basin where discharge occurs as into the alluvial sediments then stream baseflow and evapotranspiration.

The largest groundwater flows (in terms of through-flow per year) are likely to occur within the shallow rock unit which forms a thick and relatively permeable mantle of weathered and fractured rock over the low permeability Permian Coal Measures and basement rocks. Groundwater flow is likely to be relatively rapid within the alluvial deposits that underlie the floodplains of the main drainage systems. However these deposits tend to be thin (i.e. 15 m or less) and of relatively limited storage volume (compared to the deeper hydrogeological units). In the underlying Permian rocks, age dating of the groundwater indicates very slow groundwater movement and very long residence times, consistent with the very low measured permeability of those rocks.

10.3.2 Vertical connectivity

Vertical head differences in groundwater head have been observed in sedimentary rock aquifers and water bearing zones within the Stage 1 GFDA, based on information from multiple piezometer installations. Although there is no systematic spatial pattern of upward and downward gradients across the Stage 1 GFDA, it is expected that downward gradients will prevail in topographically elevated areas towards the Basin margin (recharge areas) and upward gradients in topographically lower parts of the Basin, towards the drainage lines (discharge areas).

Connection between the shallow and deep groundwater systems will be limited by the permeability of the rock strata which is known to be very low. Isotopic dating indicates that groundwater in the deep coal seams is greater than 300,000 years old, shallow fractured rock is greater than 10,000 years old, on average, while groundwater within the alluvium and shallow rock domains is mostly modern (<200 years). This implies that recharge to the deeper hydrogeological units via vertical or lateral groundwater movement is very slow. This is further supported by bore hydrographs which show rapid groundwater responses to rainfall events in shallow alluvium and a few fractured rock locations, but negligible, delayed or subdued responses in deeper water bearing zones.

10.3.3 Role of faults

A large number of faults of varying orientations are known to occur within the Basin, many of which are not apparent at the surface or in drill logs. Faults have been divided into several types according to their orientation and past movement. On the eastern side of the Basin (and in the vicinity of the Stage 1 GFDA) the structure is dominated by west-dipping thrust faults and near-vertical sinistral strike-slip faults.

Faulting of sedimentary rocks can give rise to complex hydrogeological systems including compartmentalisation. In consolidated rocks, faults can act as complex barrier-conduit systems with low permeability core zones and broader fracture zones that are transmissive in the plane of the fault. Information from fault investigations suggests that in the near surface faults (within the shallow rock in the upper 150m) are represented by broad fractured zones with enhanced permeability and groundwater flow.

However in the deeper coal measures (greater than 150 m) the investigations show that faults across the Gloucester Basin are likely to be barriers to horizontal flow due to juxtaposition of water bearing units against low permeability interburden. The vertical permeability of fracture zones associated with faults decreases with depth and increasing lithostatic pressure causes fractures to close. The range in permeability in the deep coal measures (including fractured zones) is considered to be well characterised by drill stem tests carried out during exploration drilling.

Monitoring of shallow groundwater systems during flow testing of gas wells intersecting deep coal seams have not shown any indication of drawdown or connection via faulting over the timescale of the tests. Simulations of such tests using numerical models suggest that drawdown impacts within beneficial aquifers are likely to take decades to manifest (if ever) and are likely to be negligible in terms of drawdown at the water table. Faulting (even when assessed as being strong conduits) has little impact on regional groundwater flow, beneficial aquifers and the water table. This is due to the very low permeability of the coal measures and the contrast in storage characteristics between the deep confined units and the shallow unconfined systems.

The potential for longer term drawdown or vertical groundwater movement cannot be further assessed until production commences and long term monitoring data is collated and reviewed.

10.4 Groundwater discharge

Groundwater outflow predominantly occurs as discharge to gaining streams (baseflow) and, to a lesser extent, direct evapotranspiration losses from the water table where the groundwater is shallow (i.e. close to the creeks and towards the northern and southern Basin outflow points). Monitoring data suggests that most baseflow to the perennial streams is derived from groundwater discharge from the alluvium via relatively short flow paths. By contrast groundwater discharge from the shallow rock and underlying coal measures via longer flow paths is to the base of the alluvium and is expected to be a minor component of stream baseflow.

Groundwater and surface water have distinct hydrochemical and isotopic characteristics and define a number of compositional groups. Surface water tends to be low salinity relative to adjacent groundwater, even during periods of low flow. This provides evidence that streams are somewhat disconnected from the groundwater systems and that the baseflow that sustains the connected pools during periods of drought is derived from storage within the alluvium. However the increasing salinity of surface water during extended dry periods is symptomatic of the discharge from the shallow fractured rock to the alluvium and this component becoming a larger proportion of the flow.

Groundwater may also exit the Basin via aquifer through-flow in the alluvium and deeper hydrogeological units beneath the Avon and Wards Rivers, although this is assumed to be a minor component of the total outflow. For the purpose of this study, the Basin is assumed to be a closed groundwater system in that negligible groundwater enters from outside the Basin and most groundwater exits the Basin via stream baseflow or evapotranspiration from the shallow water table.

Groundwater use for mining and stock use are identified as consumptive groundwater uses from the Gloucester Basin. New CSG extractions will slightly increase the future consumptive uses. The cumulative impact of these consumptive uses is small based on the overall Basin water balance (see Section 9.1). The net effect is there will be slightly less saline water discharging to the alluvium and discharging to the streams as baseflow. Slightly increased rainfall recharge to the shallow alluvium is expected if there is any capacity in this shallow aquifer to accept more water. Overall there will be a negligible impact on total river flows but there may be slightly improved stream water quality (especially during low flow periods) in the long term.

10.5 Water and salt balance

Water and salt balances for the Gloucester Basin provide an indication of the main fluxes and storages of water and salt in the Basin. Approximately 322 GL of rain falls on the Gloucester Basin each year. Of that total, approximately 150 GL (47 %) flows overland, bypassing the groundwater system, and is discharged via the Avon River and Wards River systems; a further 159 GL (49 %) is returned to the atmosphere via evapotranspiration (ET) or otherwise lost from the system. Surface water flows and ET losses therefore dominate the hydrological system, together accounting for 96% of rainfall. Approximately 3.5% of rainfall (~11 GL per year) infiltrates the unsaturated zone to recharge the water table. Recharge rates are higher in the alluvial deposits (4% to 13% of rainfall) and significantly lower in areas where the less permeable shallow fractured rock unit outcrops (~0.5% to 1% of rainfall).

There is substantial groundwater storage within the Basin. The main unconfined aquifer unit (shallow fractured rock) has an unconfined storage of approximately 294 GL. By comparison, the alluvial aquifer has less storage (approximately 53 GL).

Most groundwater flow in the Basin occurs in the uppermost aquifer units; the alluvium and to a lesser extent, the shallow fractured rock where it is most permeable. The alluvial deposits have a through flow of 8 to 9 GL per year, with relatively short groundwater residence times. The shallow rock aquifer is of lower permeability and therefore transmits less groundwater (in the order of 2 to 3 GL per year). Much of the discharge from the shallow rock is via the alluvium adjacent to streams.

Based on a salt concentration of 20 mg/L and rainfall of 1049 mm per year, it is estimated that average rainfall across the Gloucester Basin delivers 6399 tonnes of salt. Under equilibrium, a similar amount of salt is exported via stream flow (the Avon and Wards Rivers). However with land clearing for agriculture and grazing, a greater amount of salt is exported via stream flow and sediment loss.

Salt extracted from produced water in the initial years of production is estimated to represent approximately 17% of the average salt load in rainfall; or approximately the same volume of salt that falls on the Stage 1 area as rainfall in an average year. CSG produced water volumes are estimated to decrease significantly after the first couple of years of production to around 3% of the average salt load in rainfall. The exact water production profile will not be known until production commences, however rates are estimated to be less than 10% of the initial flow rates after Year 5. Salt will be removed from extracted water by the proposed desalination plant, crystallised, transported and landfilled outside of the Basin.

Removal of salt from the Basin due to CSG activities in the Stage 1 GFDA will result in a net reduction in salt accumulation in the northern part of the Basin. This reduction will ultimately manifest as a small decrease in the salt flux from the shallow fractured rock to the base of the alluvium, and ultimately to the Avon River system over future decades.

10.6 CSG development and potential impacts

Production of CSG in the Stage 1 GFDA will involve depressurisation of target coal seams by pumping groundwater from wells perforated within the target (deep) coal seams. The wells are only perforated adjacent to the target coal seams and not against the interburden or overlying shallow strata. Under normal operation conditions the pump is placed below the deepest coal seam that is perforated and the hydraulic head in the well is lowered over time. Within the well the hydraulic head is eventually reduced to the pump intake but in the adjacent natural formation (due to low permeability) the hydrostatic heads are highly variable and are generally higher.

The current proposal is to develop the gas field in one phase with the drilling program 6 to 12 months in advance of the fracture stimulation program. The FDP for the 110 wells that comprise the Stage 1 development is in preparation and will be submitted with the numerical modelling.

Given the data and knowledge obtained from AGL's extensive water monitoring program and pilot testing programs, it is recommended that one phase of gas well development with monitoring throughout the construction/commissioning period and updating of the numerical model periodically will achieve the objective of avoiding and minimising adverse impacts to beneficial aquifers. Collectively monitoring and modelling studies to date have indicated:

- Negligible connectivity between shallow aquifers and deeper coal measure water bearing zones.
- Long timeframes for any groundwater impacts to be propagated laterally and vertically.
- No enhanced connectivity between deeper coal measures and shallow beneficial aquifers in faulted areas.

Based on this improved understanding of the different groundwater systems across the Gloucester Basin since 2010, no formal phased (hydrogeological) review of the field development program is recommended. A full assessment of the minimal impact considerations and the risks to beneficial aquifers, streams and groundwater dependent ecosystems has been provided in the CFDP (AGL, 2015b), and additional discussion is provided in Section 10.6.5.

The Stage 1 development is capped at a maximum dewatering volume of approximately 730 ML per annum. Dewatering volumes will be greatest in the initial years of the project and will diminish substantially with time. The actual water production profile will be defined by the commissioning rate for new wells. Dewatering volumes will diminish with time because of the dewatering of the targeted coal seams and the impedance of the low permeability strata overlying the targeted coal seams. Most groundwater will be derived from the deep coal measures at depths greater than 250 m. During operation, the produced water pumped from the deep confined coal measures will be initially derived from storage, and over the following years and decades will be derived from lateral flow through the deep coal seams and minor vertical flow through the overlying interburden.

Water table aquifers in the alluvium and in the uppermost fractured rock (based on the available investigation and modelling data) are expected to experience only minor drawdown. Registered bore users with water supply bores to 75 m are unlikely to experience any water level declines outside of the normal seasonal variations (note that property surveys have not identified any private groundwater users in the Stage 1 GFDA). Detailed numerical modelling will assist in confirming the extent of any drawdown within the shallow beneficial aquifers. In addition, groundwater monitoring and modelling will be in accordance with the approved Groundwater Monitoring and Modelling Plan (GMMP) which is an additional Part 3A consent condition (Condition 4.1).

10.6.1 Potential for drawdown

AGL has collected more than four years of baseline data (both water level and water quality) for the different groundwater systems across the Gloucester Basin. Some of this data relates to pumping tests and pilot testing programs. Climatic variations are seen in the water level data set as the result of wet and dry seasons. There are no data from these testing programs to suggest that shallow beneficial aquifers have been affected by the depressurisation of deep coal seams.

As gas production starts and the field is developed, the zone of depressurisation for the confined water bearing zones will increase and expand preferentially along zones of higher permeability (the coal seams). This (long term) depressurisation is depicted in the piezometric surface for the target coal seams in the Stage 1 area as shown in Figure 10.2. The zone of depressurisation will expand vertically into the adjacent interburden at a much slower rate due to its lower permeability. No zones of enhanced connectivity have been identified to date and therefore no or negligible impact on beneficial aquifers is expected. If a 'worse case' situation arose (i.e. if a zone of enhanced connectivity is identified), there could be minor vertical movement of groundwater, very localised drawdown of the water table and potentially a decrease in groundwater discharge to the alluvium. However based on all knowledge to date, a reduction in baseflows to the major streams as a result of the GGP within the Stage 1 area is unlikely.

The changes in vertical fluxes are expected to be small given the total extraction is capped at a maximum 2 ML/d (and based on the latest water production profiles will most likely be less than 1 ML/d) and will decrease after the initial years of production. Any drawdown is expected to be relatively minor given the small produced water volumes, the bulk of the water coming from storage within the coal seams and adjacent strata, and there being multiple (low permeability) aquitards between the deeper coal seams and shallow beneficial aquifers. The risk of stream baseflow losses is considered to be negligible because any slight drawdown in the alluvium and decrease in discharge from the bedrock is likely to be offset by the high rainfall recharge rates to the alluvial aquifers.

It is expected that natural groundwater recharge and the high storage characteristics of the shallow and deep groundwater systems will mitigate any vertical movement of shallow groundwater associated with CSG depressurisation. Preliminary numerical modelling suggests that the drawdown impacts to the water table and surface water systems are expected to be negligible. Nevertheless, these potential impacts will be closely monitored and further modelled using numerical methods. The modelling will allow some of the uncertainties relating to structure and hydraulic properties to be explored using sensitivity analyses and stochastic approaches. Modelling will quantify the possible range of drawdowns in both shallow and deeper groundwater systems.

10.6.2 Potential for gas migration

There is considered to be a negligible risk of gas migration to surface either updip along the targeted coal seams or vertically through the overburden strata because:

- Near surface coal seams are already largely degassed as a result of shallow groundwater circulation processes and natural biodegradation;
- Only coal seams deeper than 250 mbgl will be targeted and there are substantial overlying confining layers;
- Fracture stimulation and depressurisation is largely only within the target coal seams and the overlying aquitards are not compromised;
- Current local scale cross sectional models suggest negligible drawdown at the water table in updip areas;
- Wells will be constructed with multiple casings and pressure cemented in place to stop the vertical migration of groundwater and gas at the wellbore; and
- Baseline data of fugitive gas emissions to date suggests no increased gas levels in the vicinity of gas wells or coal seam outcrop areas.

To confirm whether gas migration is occurring longer term, the groundwater monitoring network will be assessed for dissolved methane trends, and fugitive gas emissions will be monitored at gas wells and at gas monitoring bores in the coal seam outcrop areas.

10.6.3 Potential for subsidence

Subsidence can be defined as the movement of the surface strata in response to the loss of underground support. A loss of underground support can come from hydrocarbon removal from a conventional oil and gas reservoir, groundwater extraction from an unconsolidated aquifer and associated strata from the creation of voids due to mining.

Unconsolidated materials, such as gravel, sand, silt and clay are most prone to subsidence from large scale groundwater extraction. For the Stage 1 GFDA, variations within expected seasonal ranges and occasional drawdown responses would not be sufficient to cause subsidence. In cases where groundwater extraction occurs in consolidated rocks, such as sandstone or shale, subsidence is rare, as these materials do not deform easily.

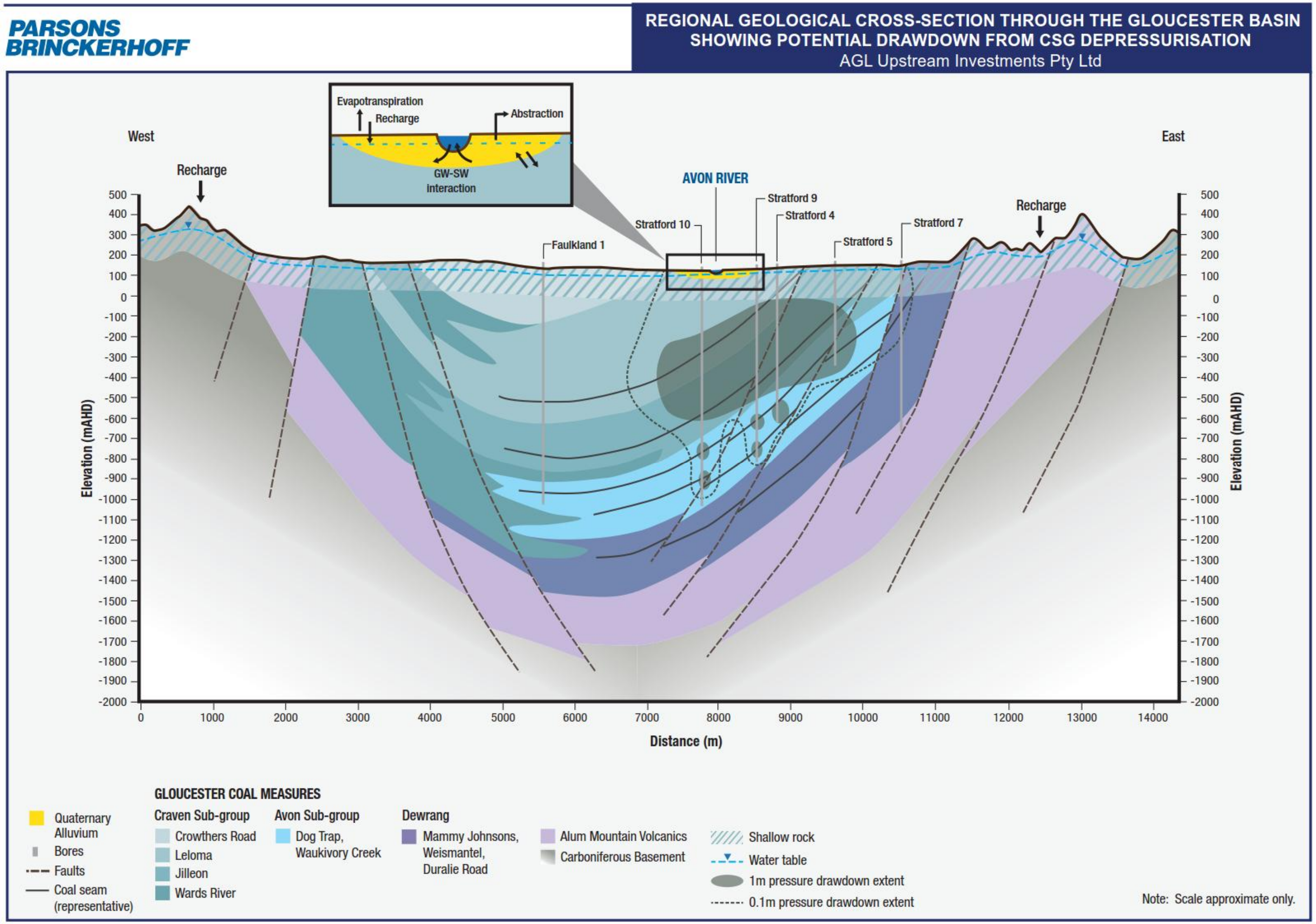


Figure 10.2 Regional geological cross-section through the Gloucester Basin showing potential drawdown from CSG depressurisation

Although some deformation of the target coal seams may occur, the deformation would be limited to the coal seams and would be dependent on the depressurisation of those seams over large areas. Currently it is expected that targeted coal seams will only be depressurised and not totally dewatered, thereby minimising the potential for any subsidence within the coal seams.

Consequently there is expected to be negligible subsidence as a result of CSG activities.

10.6.4 Gas well location and development

10.6.4.1 Surface considerations for wells

There is no groundwater use across the Stage 1 development area and none is expected in the future given the reliable surface water resources. Based on expected negligible drawdowns in shallow aquifers and negligible risk of gas migration, there is no one area of the Stage 1 GFDA that is considered to be more optimal than another area. In addition, coal seams greater than 250 mbgl will be targeted and all coal zones at all sites will be assessed for potential risk to natural fractures and faults in the vicinity of each proposed well.

The field development plan is still in development and will largely depend on the final access and cooperation agreements brokered with Yancoal, GRL and other private landowners. Land holder's preferences are the primary consideration for siting each of the gas production wells.

The current locational principles are:

- Establish a notional grid pattern based on geological considerations;
- Identify and assess environmental constraints within the envelope;
- Undertake environmental constraints mapping utilising GIS to spatially identify constraints and develop an overall site suitability model. The constraints analysis would be based on locational principles, described below:
  - Not within 200 m of existing residences (unless agreed to by the landowner/resident) or as required to meet project noise goals;
  - Minimum 40 m from a major watercourse or 20 m from a minor watercourse;
  - Avoidance of significant vegetation and riparian areas;
  - Avoidance of Indigenous and European heritage places or items;
  - Located adjacent to existing fence lines and access tracks where possible;
  - On relatively flat ground, where possible;
  - Consideration of visual effects and opportunistic use of natural screening such as vegetation; and
  - Land use and landowner preferences.

10.6.4.2 Subsurface considerations for wells

Subsurface the design of individual gas production wells will:

- Include conductor casing and pressure cemented surface casing to ensure that all shallow aquifers are cased off and not in connection with deeper coal seams;
- Ensure there is at least 150 m of competent cemented production casing above zones to be fracture stimulated;
- Avoid targeting shallow coal seams less than 250 m from surface; and

- Involve a risk assessment of any zones to be fracture stimulated in reference to natural fractures and faults in the vicinity of the well.

Numerical (predictive) modelling is required to provide further insight into the drawdown effects that result from the proposed 110 wells that will comprise the Stage 1 GFDA.

The Groundwater Monitoring and Modelling Plan (GMMP) for the Stage 1 development will include:

- Monitoring of shallow groundwater systems and surface water to identify, and if necessary, manage changes to the characteristics of these water resources.
- Monitoring of piezometric pressures in intermediate interburden and coal seam units to identify, and if necessary, manage depressurisation and drawdown effects.
- Monitoring of the potential for gas migration.
- Maintaining a focus on the existing monitoring networks in the vicinity of known faults at the Stratford and Waukivory locations.
- Tracking produced water volumes and chemistry to monitor any trends that may suggest enhanced recharge or vertical groundwater movement.

10.6.5 Phased well development

The current GGP development proposal includes the construction, operation and decommissioning of 110 coal seam gas wells and associated infrastructure, including gas and water gathering lines, within the Stage 1 GFDA. The CSG wellfield is proposed to be developed in one phase with progressive development of the proposed 110 wells. The drilling program is proposed to be 6 to 12 months in advance of the fracture stimulation program and completed over an expected 36 month period.

With the current understanding of shallow and deep groundwater systems, knowledge surrounding groundwater flow processes and surface water – groundwater interaction, it is recommended that a single phase gas well development (from a water management perspective) is appropriate. Justification for a single construction phase with milestone reviews is based on the following:

- There is sufficient groundwater and surface water monitoring data (both spatially and at depth) to assess:
  - Drought responses
  - Flood responses
  - CSG depressurisation responses.
- There are no identified zones of enhanced connectivity.
- There are multiple low permeability aquitards that separate beneficial aquifers from deep water bearing (coal) zones.
- No drawdowns in beneficial aquifers have been observed as a result of exploration activities.
- There is no private groundwater use within the Stage 1 area.
- Groundwater is a very small component of the water balance.
- Preliminary numerical modelling predictions suggest negligible impacts and only at long time periods (and not during the construction phase of the project).

Milestone reviews are described in the CFDP (AGL, 2015b).

11. Framework for numerical modelling

The conceptual hydrogeological model provides the framework for the development of a numerical groundwater model that will be used to assess the impacts of the proposed development on groundwater and connected surface water resources. This chapter provides a detailed framework for the numerical modelling which is the next phase of work to be completed in the groundwater investigation program.

The Australian Groundwater Modelling Guidelines (Barnett et al, 2012a) provides guiding principles and minimum standards for numerical groundwater models. A framework for numerical modelling for the Gloucester Gas Project based on those guidelines is provided below. The framework considers the following aspects:

- Model planning:
  - intended use
  - modelling objectives
  - confidence level.
- Conceptual framework:
  - model domain
  - hydrostratigraphy
  - aquifer properties
  - conceptual boundaries
  - stresses
  - physical processes.
- Model design:
  - modelling code.

11.1 Regulatory context

Condition 18 of the Commonwealth approval under the EPBC Act requires that a numerical model must be developed, based on the revised water balance model (Parsons Brinckerhoff, 2013b). The model is to be used to '*explore the pressure at which gas and water may be released and transmitted along faults*' (Condition 18), and to assist in a risk analysis in relation to impacts to potential habitats for the green and golden bell frog and giant barred frog (Condition 19). The following potential impacts are specified: the surface expression of methane gas; water pollution including salinity; water drawdown; and any impacts on surface water.

Condition 3.10 of the Part 3A approval requires the development of a FDP that is then used as the basis of the numerical modelling and the predictive scenarios required under Condition 4.2. AGL is proposing one construction phase for its Stage 1 development.

Condition 4.2 of Part 3A approval requires that a numerical model be developed of the Stage 1 GFDA based on the conceptual model already developed. The model '*is to be used as a predictive, adaptive management and verification tool*' to guide ongoing operations. This includes identifying any impact from the initial development and subsequent development stages.

In addition, numerical modelling should satisfy requirements of the NSW AI Policy. Under the policy, numerical modelling should be of sufficient scope and complexity to identify and assess potential impacts to groundwater, connected surface water systems, groundwater dependent ecosystems, and sites of cultural significance and water users. Criteria of minimal harm to receptors are assessed against three attributes: water table; water pressure; and water quality. The model should allow water use and induced losses from connected groundwater and surface water sources to be quantified for the purpose of wellfield licensing and ongoing water management.

A model designed to assess regional impacts and risks associated with CSG development would not be suitable (in terms of resolution) for assessing the local scale effects of faults on depressurisation and gas migration close to the gas production wells. For this reason, numerical modelling for the Stage 1 GFDA is to be carried out at two scales:

- Local scale cross-sectional modelling to address Condition 18 of the Commonwealth approval and to inform model construction and calibration of the numerical model/s required under Condition 4.2 of the Part 3A approval. Currently local scale (cross-sectional) models have been built for the historical Stratford pilot testing program, the current Waukivory pilot testing program, and the proposed Wards River pilot testing program.
- Regional scale impacts modelling to address Condition 4.2 of the Part 3A approval and satisfy requirements of the NSW Aquifer Interference Policy. The regional numerical model for the whole of the Gloucester Basin is in early development.

11.2 Local-scale modelling

11.2.1 Model planning

Intended use

The local scale cross-sectional modelling is intended to fulfil Condition 18 of the Commonwealth approval and inform Condition 4.2 of the Part 3A approval.

Modelling objectives

The objectives of the local-scale modelling are to:

- Develop a numerical model to simulate coal seam depressurisation and complex elements of geological structure along cross sections within the Gloucester Basin
- Base the model structure and parameterisation on field data and concepts derived from hydrogeological investigations, as summarised in this Conceptual Model report, and the Water Balance report (Parsons Brinckerhoff, 2013b)
- Use the model to assess the role of faults in transmitting changes in hydraulic pressure to the near surface groundwater systems
- Assess the potential role that faults play in the movement of groundwater and the release and transport of gas
- Use the model to simulate groundwater depressurisation associated with gas well flow testing programs.

- Update these models with the available field data so as to assist in the upscaling of parameters for the regional model.

The results of the local-scale modelling will also be used to determine whether major faults are important features that should be included in the regional scale numerical model.

Confidence level

The Australian Groundwater modelling guidelines recommends that the overall reliability, complexity and confidence level of the model(s) should be assessed and agreed prior to construction of the model, and if possible re-assessed at a later stage in the modelling project. The confidence level classification comprises three classes; Class 1, Class 2 and Class 3, in order of increasing confidence level. The level of confidence typically depends on the available data, calibration procedures, consistency between the calibration conditions and predictive analysis scenario, and the level or severity of stresses being simulated. A table of quantifiable indicators with which to assess a model's confidence level based on those attributes is included in the Modelling Guidelines.

The confidence level classification is often constrained by the available data, budget and/or time. Typically in impact assessments for mining or CSG projects, the paucity of time series and spatial data for calibration compared with the proposed development timeframe is such that a class 2 confidence level is the highest feasible. Class 1 models, in which data are not sufficient for calibration, are nonetheless often useful to provide initial assessments or to demonstrate processes and relationships based on the conceptual model and reasonable parameter estimates.

Comparison of available data and the modelling objectives indicates that the existing and any proposed local scale models would be Class 1 models, and Class 2 models if calibrated with transient water level/pressure data.

11.2.2 Conceptual framework

The setup and parameterisation of the local-scale fault models is closely based on the conceptual understanding of the hydrogeology and water balance of the Gloucester Basin as outlined in this report and the Water Balance report (Parsons Brinckerhoff, 2013b).

In keeping with the key objectives of the local scale modelling, three separate models have been set up to represent east-west cross sections through the Gloucester Basin:

- Stratford Section. A 5 km section that passes through (or close to) the locations of the Stratford 4, 5A, 9 and 10 gas exploration wells. The cross section passes through the site of the fault investigation (Parsons Brinckerhoff, 2013c) on the Tiedman property.
- Waukivory Section. A 5 km section that passes through (or close to) the locations of the Waukivory 1, 11 and 14 gas exploration wells, and the site of the Waukivory fault investigation.
- Wards River Section. A 5km section that passes through the location of the proposed Wards River pilot testing program.

The lateral extent of the cross sectional models far exceeds the investigation areas so that the model boundaries would have negligible influence on model predictions. Furthermore, the vertical extent of the model is to a depth of 2000 m, which is below the base of the Permian sediments which are estimated to extend to a depth of 1500 – 1700 m.

The geological structure of each section was interpreted from a combination of 3D seismic data, gas exploration well logs and groundwater bore logs. Where the cross section extended beyond the area of the 3D and 2D seismic surveys, the geological structure was extrapolated on the basis of exploration logs and adjacent seismic information. The geological interpretations were verified with AGL geologists and geophysicists.

Each cross section model was constructed as a vertical 3D block with a nominal width of 250 m. The cross section width allows radial flow to each gas well and interference with adjacent rows of gas wells to be approximated, taking advantage of symmetries within the proposed gas production field (rows of wells are nominally 500 m apart) and the principle of superposition of well drawdown (Fetter, 2001). Cumulative drawdown and interference associated with the wider gas field will be assessed more rigorously in the regional 3D numerical model.

11.2.3 Model design

The local-scale numerical models were developed using FEFLOW; a finite element single phase saturated/unsaturated groundwater flow and transport code. Model parameters were modified to account for the effects of dual-phase flow close to the production wells and to ensure that modelled water production rates are consistent with observed production rates.

11.2.4 Application to regional modelling

The local scale cross-sectional models are intended to be used iteratively in conjunction with the regional model to continue to improve the conceptual hydrogeological understanding and hence the confidence in the local and regional models. The local-scale models have been constructed first to assist with understanding parameterisation, geological complexity and the role of individual geological structures. For example, the results of the local-scale modelling will provide an indication as to whether individual faults should be included in the regional scale models or represented as part of the up-scaled parameterisation.

The results of field investigations, such as the ongoing Waukivory pilot test, will be used to assist with calibration of the local scale models, and any improvements to understanding of model parameterisation will then be applied to the regional scale model. Likewise, as the gas field becomes operational, the local scale models can be used as a management tool to investigate any responses that may be identified in the monitoring data that cannot be explained by the regional model.

11.3 Regional modelling

11.3.1 Model planning

Intended use

The regional numerical groundwater model is intended to fulfil condition 4.2 of the Part 3A approval and satisfy requirements of the NSW Aquifer Interference Policy.

Modelling objectives

The regional model should enable AGL to:

- Simulate the main features of the Basin water balance, groundwater systems and contributions to surface water systems.
- Assess impacts to groundwater and connected surface water resources as a result of the coal seam depressurisation related to the proposed development. The model should allow assessment of:
  - depressurisation of coal measures at depth
  - changes to the water table

  - changes to groundwater contributions to surface water flows
  - changes to the Basin-scale water balance and water fluxes to and from each water source (for licencing purposes).
- Identify potential impacts to water users, dependent ecosystems and/or sites of cultural significance.
- Provide an adaptive management tool in relation to groundwater impacts, for ongoing operations.
- Assess cumulative impact of open cut coal mining in terms of the minimum harm considerations of the Aquifer Interference Policy.

Confidence level

Comparison of available data and the modelling objectives indicates that a Basin-scale model of the Gloucester Basin designed to assess regional impacts from CSG would fall into the Class 2 category.

11.3.2 Conceptual framework

Conceptualisation is a process that provides the basis for model design and communicates how the system works to a wide range of audiences (Barnett et al, 2012a). A conceptual hydrogeological model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrogeological conditions, and description of existing and possible future stresses.

An updated conceptual model for the Gloucester Basin has been developed from multiple groundwater investigations, including high quality baseline hydrological and hydrogeological data, and is presented in Chapter 10 of this report. The following subsections highlight key aspects of the conceptual framework and implications for regional numerical model development.

Model domain

The hydrogeological model domain should be large enough to cover the location of the key stresses on the groundwater system (both current and future) and the area influenced or impacted by those stresses. It should also be large enough to adequately capture the processes controlling groundwater behaviour in the study area (Barnett et al, 2012a).

The Gloucester Basin has been conceptualised as an essentially closed groundwater system, bounded to the east and west by topographic divides and with outflows via surface water flows to the north (Avon River) and south (Wards River). In reality no system is entirely closed and in the case of the Gloucester Basin there are some surface water inputs and outputs to the Basin from catchments that extend beyond the Basin, and possibly some lateral groundwater flow (e.g. springs) from shallow rock domains that extend outside of the Basin.

For the purposes of numerical modelling the outer outcrop limit of the impermeable Alum Mountain Volcanics is considered to be an appropriate model boundary, beyond which groundwater impacts are unlikely to propagate.

Hydrostratigraphy

Four broad hydrogeological units have been identified within the Gloucester Basin: the alluvial aquifers along major creek lines, shallow fractured rock aquifers, and; a thick succession of low permeability coal measures comprising interbedded coal seams and interburden units of very low permeability. These hydrogeological units overlie the impermeable Alum Mountain Volcanics.

These hydrogeological units should be represented as separate layers within the numerical model. Multiple layers within the interburden and coal seam units will be required to represent the alternating sequence of low permeability coal seam water bearing zones, and very low permeability interburden units. The geometry of model layers representing geological units and coal seams should be based on all available geological information, including exploration drill hole data, available geological models and seismic surveys. In particular, the model will need to have specific layers for those coal seams that are to be stressed by open cut coal mines to enable focussed cumulative impact assessment of other existing/approved projects. Coal plies associated with a particular seam can be lumped into a single model layer which honours the floor elevation rather than the roof.

Model layering should be assigned to allow realistic estimates of time delays associated with pressure changes across aquitards.

Throughout the Gloucester Basin there are numerous faults of various types and orientation which may have some local influence on groundwater flow. In addition there are likely to be structures outside of the immediate area of investigations that are either unknown or for which there is limited detailed information. The results of the local-scale modelling will provide an indication as to whether individual faults should be included in the regional scale models or represented as part of the up-scaled parameterisation.

Aquifer properties

A summary of hydraulic property estimates for each hydrogeological unit is presented in this report. This information and other available estimates will be considered when assigning initial parameter estimates in the model. Hydraulic conductivity values presented in this report are considered representative based on literature review and field investigations across the Gloucester Basin. The following will be taken into account in the regional numerical modelling:

- Due to the high variability in hydraulic conductivity in the alluvium and shallow rock, and the large number of monitoring bores screened in these hydrogeological units, detailed calibration of the regional numerical model will be undertaken for these model layers. The alluvium will be represented as one model layer, and the shallow rock will be represented as two model layers (to 60 mbgl and 150 mbgl) in the regional model. Spatially variable grids of hydraulic conductivity will be developed for these hydrogeological units. This approach will enable both horizontal variability in hydraulic properties, and vertical head differences observed within the alluvium and shallow rock monitoring bores, to be represented.
- There is a clear relationship of decreasing hydraulic conductivity with depth in the coal seams and interburden, typical of fractured rock terrains. This depth dependence will be represented in the numerical model. The coal seams and interburden of the deep coal measures will be represented by several layers in the regional numerical model. Due to the steeply dipping geology of the coal measures, and therefore the model layers, it will not be appropriate to use a single value of hydraulic conductivity for each model layer. A depth dependent function will be used to develop spatially variable grids of hydraulic conductivity for each of the coal seam and interburden layers based on the depths of the model cells. This depth dependent function will initially be based on the relationships shown in Section 7.2, and will then be tested and varied throughout the model calibration process.
- Field testing shows that each of the hydrogeological units has distinct hydraulic characteristics, but each is quite heterogeneous with a wide range in measured values. Therefore sensitivity analysis will be undertaken, and uncertainty in parameters will be taken into account and quantified with regard to any model predictions.

Conceptual boundaries

The main conceptual boundaries relevant to numerical modelling are as follows:

- The Gloucester Basin groundwater systems: The outer boundary of the groundwater systems relevant to the model is the base of the synclinal trough of the Permian Coal Measures. These coal measures are essentially enclosed and bounded by the impermeable Alum Mountain Volcanics within which groundwater flow is likely to be negligible (except within the shallow fractured rock).

- Recharge boundaries: Recharge occurs via distributed rainfall recharge through the unsaturated zone to the water table, river recharge in losing sections of streams and during flood events, and groundwater movement from adjacent aquifers.
- Rivers and streams are the main natural discharge features within the Basin. However they can also act as recharge features depending on the river stage relative to the adjacent groundwater levels. These factors can vary both spatially and temporally across the Basin.
- Evapotranspiration from the shallow water table (<5 m bgl) is also a mechanism for groundwater discharge.

The numerical model boundary conditions should be consistent with the conceptual model boundaries and their controls on groundwater flow in the Basin. It is noted that most numerical modelling codes have capabilities to effectively simulate these boundaries.

Stresses

The non-natural stresses on the groundwater system in the Gloucester Basin include the following:

- Abstraction for stock and domestic use (none known within the Stage 1 GFDA).
- Mine pit inflows.
- Depressurisation as a result of CSG activities.

These stresses will be represented by appropriate boundary conditions in the numerical model. Possible candidate boundary conditions in MODFLOW include DRN, WEL and modified EVT. Mine pit inflows due to open cut mining and depressurisation as a result of CSG activities will vary over time depending on the stage in development. Time varying boundary conditions will therefore be used in the numerical flow model.

Physical processes

Groundwater flow processes identified in the conceptual model will be accurately represented in the numerical model. These include the following:

- Recharge, evapotranspiration and groundwater discharge to (or recharge from) streams are fundamental processes in the Basin water cycle and should be realistically represented in the numerical model. Boundary conditions have been developed in the MODFLOW family of codes to represent recharge (e.g. RCH), evapotranspiration (EVT) and stream interaction (DRN, STR, SFR and RIV packages).
- The equilibrium condition of the aquifer prior to development. On a regional scale and over long timescales, the groundwater system approaches a quasi-steady state. On smaller timescales (months) however, groundwater systems are constantly adjusting to seasonal variations and rainfall patterns – a condition referred to as a ‘dynamic equilibrium’. In order to ensure that the model can adequately simulate these natural variations, key model parameters will be calibrated in transient mode using baseline observations. The selection of a relative stable period that approximates equilibrium will be guided by a residual rainfall mass curve.
- Vertical hydraulic gradients. There are vertical head differences and the potential for flow at some multi-piezometer sites. These data will be included in the calibration to simulate vertical head differences where they are significant.
- Groundwater density effects. Due to the generally low to moderate salinity of groundwater in the Basin, density effects can be assumed to be insignificant in terms of regional groundwater flow and drawdown impact assessment.

- Fracture stimulation. To simulate the enhanced permeability of coal seams in the near vicinity of each gas well that is fracture stimulated, an order of magnitude increase in permeability will be included in the model at gas production well locations for the initial three months of depressurisation.
- Dual phase effects. These effects are important once gas starts to desorb from the targeted coal seams, particularly in the vicinity of the gas production wells where methane is transported as a separate gas phase within groundwater, or becomes the dominant phase over water. This effect will be represented by an exponential decrease in permeability.

11.3.3 Model design

The design stage of modelling involves describing how the modeller(s) intend to represent the conceptual model in a quantitative (mathematics-based) framework. Barnett et al (2012a) outlines a number of well-established principles relating to model design and construction including model extent, structure, spatial and temporal discretisation and boundary conditions. The numerical model will be developed on the basis of those principles. Many of those design decisions will be made prior to the model construction phase, in light of the available data.

Model code

Of particular importance prior to embarking on model design is the choice of modelling code. Model code relates to the mathematical approach adopted in the software code for modelling. For example, common approaches are finite elements (FE), finite difference (FD), or finite volume (FV). A recently developed variant of MODFLOW (USG) allows the use of unstructured grids and uses a Control Volume Finite Difference approach (CVFD). Some codes are designed to simulate porous flow of a single phase (water), while others extend to multiple phases (water/gas/oil).

Barnett et al (2012a) suggest that multi-phase effects may be important for modelling of CSG depressurisation, particularly in the vicinity of the gas field, and recommend the use of specialised petroleum reservoir software such as ECLIPSE. There is currently no consensus regarding the most appropriate code to use for predicting regional (far-field) groundwater drawdown impacts, although it is expected that single-phase models will tend to over-estimate depressurisation where two phase flow occurs (i.e. will be conservative with respect to impacts on water). A guideline report that specifically addresses modelling of impacts related to CSG has been published by the Commonwealth's Independent Expert Scientific Committee (IESC 2014).

For the purpose of modelling regional impacts on groundwater due to depressurisation of coal seams, it is considered that a single-phase saturated groundwater flow code will be suitable. All four numerical methods (FE, FD, FV and CVFD) would be capable of modelling the Basin-scale groundwater flow and impacts. It is noted that the recently developed MODFLOW USG is increasingly being used by industry and incorporates some packages (such as bubble point pressure) that are advantageous for modelling groundwater impacts from CSG development.

12. Conclusion

This updated conceptual hydrogeological model has been prepared for the whole Gloucester Basin with a focus on the groundwater systems underlying and adjacent to the Stage 1 GFDA.

Four main hydrogeological units influence groundwater flow within the Basin:

- Thin alluvial deposits (to maximum 15m depth) adjacent to major creeks and rivers that comprise unconsolidated sand, gravel and clay.
- Shallow fractured rock comprising variably weathered and fractured sedimentary rocks extending to approximately 150 m below the surface.
- Deep coal measures interburden comprising consolidated sandstone and siltstone units that are very low permeability.
- Deep coal seams that are slightly more permeable than the interburden and commonly form weak water bearing zones.

The only beneficial aquifers are contained within the alluvium and the shallow fractured rock to around 75m depth. There are no beneficial aquifers in the deep coal seams or interburden rocks. Both the yields from the alluvial aquifer and the fractured rock aquifers are too low, and the total dissolved solids (TDS) of the groundwater are too high to classify the shallow aquifers of the Gloucester Basin as a highly productive groundwater source. Only ‘less productive groundwater sources’ exist across the Stage 1 GFDA.

Rainfall is the primary recharge source to the aquifers and water bearing zones within the Gloucester Basin. Minor recharge from streams may occur during periods of high rainfall/surface flow and flooding when there is the potential for the rivers to lose water, particularly in upper catchment areas.

Groundwater outflow predominantly occurs as discharge to gaining streams (baseflow) and, to a lesser extent, direct evapotranspiration losses from the water table where the groundwater is shallow (i.e. close to the creeks and towards the northern and southern Basin outflow points). The sensitive receptors for deep groundwater discharge are the beneficial aquifers and the baseflows to the Avon River. Monitoring data suggests that most baseflow to the perennial streams is derived from groundwater discharge from the alluvium via relatively short flow paths. By contrast groundwater discharge from the shallow rock and underlying coal measures via longer flow paths is to the base of the alluvium and known to be a minor component of stream baseflow.

Regional groundwater flow is controlled by gravitational flow from elevated areas where groundwater is recharged, to low-lying areas where groundwater discharges to streams and to the atmosphere via evapotranspiration. The Basin can be divided into two distinct groundwater flow systems: the northern Gloucester Basin in which groundwater predominantly flows to the north, and the southern Gloucester Basin in which groundwater generally flows in a southerly direction. The Stage 1 GFDA is wholly located within the northern Gloucester Basin area. The boundary between the two flow systems, under natural conditions, corresponds with the catchment divide between the Avon and Wards Rivers.

A large number of faults of varying orientations are known to occur within the Basin, many of which are not apparent at the surface or in drill logs. Information from ongoing fault investigations suggests that in the near surface (shallow rock) faults are represented by broad fractured zones with enhanced permeability and groundwater flow. However in the deeper coal measures (>150 mbgl) faults are likely to be barriers to horizontal flow due to low permeabilities and the juxtaposition of water bearing units against low permeability interburden. The range in permeability in the deep coal measures (including fractured zones) is well characterised by permeability testing carried out during exploration drilling and testing programs.

Assessment of the geological and hydrogeological data collected since 2010, together with the numerical modelling completed to date has confirmed there are negligible risks associated with the minimal impact criteria under the NSW Aquifer Interference (AI) Policy.

The current level of knowledge about the hydrogeology of the Gloucester Basin which includes more than four years of data, local numerical modelling and several flow/pilot tests, as well as the proposed construction methodology and risk mitigation measures, supports a single phase development approach, thereby avoiding and minimising impacts to groundwater resources.

In regard to the specific Part 3A Approval, Condition 3.9 sub-clauses, the updated conceptual model concludes that:

- The potential for drawdown within the shallow beneficial aquifers is expected to be negligible based on no identified zones of enhanced connectivity, no observed drawdowns associated with exploration program activities to date, and the predictions from preliminary numerical modelling. Also there are no existing registered bore users within the Stage 1 GFDA that could be affected.
- There are no recommendations for optimal areas within the Stage 1 GFDA for gas well locations based on the current understanding of shallow and deep groundwater systems, and our improved knowledge surrounding groundwater flow processes and surface water – groundwater interaction.
- Given our current understanding and no consumptive use of groundwater within the Stage 1 GFDA, no phasing of gas development (with gaps between program activities) is considered warranted nor recommended.

Continuous monitoring systems are now in place, DPI Water is establishing its own independent groundwater monitoring network, and AGL's numerical models will be periodically updated to reflect groundwater levels/pressures (and to address any connectivity issues) as the field develops.

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Appendix A

Approval conditions

Project Approval

Section 75J of the *Environmental Planning and Assessment Act 1979*

The Planning Assessment Commission of New South Wales (the Commission) having considered all relevant matters prescribed under Section 75I(2) of the *Environmental Planning and Assessment Act 1979* (the Act), grant project approval pursuant to Section 75J of the Act to the Proposal referred to in Schedule 1, subject to the conditions in Schedule 2.

These conditions are required to:
- prevent, minimise, and/or offset adverse environmental impacts;
- set standards and performance measures for acceptable environmental performance;
- require regular monitoring and reporting; and
- provide for the ongoing environmental management of the project.

Member of the Commission	**Member of the Commission**

Sydney — 22 February 2011 — File No: 10/02017

SCHEDULE 1

Application No:	08_0154
Proponent:	AGL Upstream Infrastructure Investments Pty Ltd and its successors and assigns.
Approval Authority:	Planning Assessment Commission.
Land:	Land required for the development of the proposal, otherwise referred to as the Site.
Proposal:	Stage 1 project comprising the pre-construction, construction, commissioning, operation, decommissioning and rehabilitation of the: • *Stage 1 Gas Field Development Area* - 110 gas wells and associated infrastructure including gas and water gathering lines, within an approximately 50 km^2 section of the overall 210 km^2 gas field development area, between the townships of Gloucester and just south of Stratford in the Gloucester local Government area; • *Central Processing Facility* - a facility for the compression and processing of the extracted gas, and associated

infrastructure (including extracted and treated water storage ponds, salt evaporation ponds, water treatment plant, options for treated water disposal (excluding groundwater re-injection) and an up to 15 megawatt gas-fired electricity generating facility) at one of two locations in the Gloucester Shire local Government area: site 1 (within the property owned by the Proponent known as the "Tiedeman" property) or site 7 (land currently owned by Gloucester Coal, adjacent to a rail loop which currently services the Stratford Colliery);

- *Gas Transmission Pipeline* - an approximately 95-100 kilometre length pipeline between the central processing facility and receiving station located at Tomago (located within an overall assessment corridor of 100 metres width), traversing the Gloucester Shire, Great Lakes Shire, Dungog Shire, Port Stephens, Maitland City and Newcastle City local Government areas;
- *Tomago Receiving Station* - a gas receiving station at Tomago to deliver the transported gas to the existing Newcastle-Sydney gas supply pipeline; and
- associated ancillary infrastructure such as access roads, temporary construction facilities and construction personnel camps.

Major Project: The proposal was declared a Major Project under section 75B(1)(a) of the *Environmental Planning and Assessment Act 1979*, because it is development of a kind described in clauses 6 and 26A of Schedule 1 of *State Environmental Planning Policy (Major Development) 2005.*

KEY TO CONDITIONS

SCHEDULE 2

Act, the	*Environmental Planning and Assessment Act, 1979*
Conditions of Approval	The Minister's conditions of approval for the project.
Construction	All pre-operation activities associated with the project other than pre-construction and commissioning.
Councils	Gloucester Shire, Great Lakes Shire, Dungog Shire, Port Stephens, Maitland City and Newcastle City
Department	Department of Planning and Environment
DoE	Commonwealth Department of the Environment
Secretary's approval/ agreement or satisfaction	A written approval from the Secretary (or delegate).
DPI	Department of Primary Industries
DRE	Division of Resources and Energy (within NSW Trade & Investment)
Dust	Any solid material that may become suspended in air or deposited.
EA (Mod 1)	The Environmental Assessment *Minor Pipeline Corridor Realignments - Modification to the Gloucester Gas Project*, prepared by EMGA Mitchell McLennan Pty Limited, and dated 15 November 2013, and associated response to submissions dated 18 February 2014 and supplementary information dated 5 June 2014 and 22 August 2014.
Environmental Assessment	Gloucester Gas Project Environmental *Assessment,* dated November 2009 and prepared by AECOM
EPA	Environment Protection Authority
Hunter LLS	Hunter Local Land Services
NOW	NSW Office of Water
OCSG	Office of Coal Seam Gas
OEH	Office of Environment and Heritage
Operation	Operation comprises the following, however does not include commissioning activities: • for the Stage 1 Gas Field Development Area – when wells commence gas extraction; • for the Central Processing Facility - when gas commences to be processed at the facility; and • for the Pipeline and Tomago Receiving Station – when gas commences to be transported via the pipeline.
Publicly Available	Available for inspection by a member of the general public (for example available on an internet site or at a display centre).
Pre-construction	Activities including survey, acquisitions, fencing, investigative drilling or excavation, building/road dilapidation surveys or other activities determined by the Environmental Representative to have minimal environmental impact such as minor access roads, minor adjustments to services / utilities, or minor clearing (except where threatened species, populations or ecological communities would be affected).
Reasonable and Feasible	Consideration of best practice taking into account the benefit of proposed measures and their technological and associated operational application in the NSW and Australian context. **Feasible** relates to engineering considerations and what is practical to build. **Reasonable** relates to the application of judgement in arriving at a decision, taking into account: mitigation benefits, cost of mitigation versus benefits provided, community views and nature and extent of potential improvements.
RMS	NSW Roads and Maritime Services
Secretary	Secretary of the Department, or nominee

Site	Land required for the development of the project.
Statement of Commitments	Statement of Commitments contained in the Environmental Assessment
Statement of Commitments (Mod 1)	Statement of Commitments contained in *Minor Pipeline Corridor Realignments - Modification to the Gloucester Gas Project*, dated 15 November 2013, prepared by EMGA Mitchell McLennan Pty Limited
Submissions Report	*Gloucester Gas Project Submissions Report*, dated May 2010, and prepared by AECOM

1. ADMINISTRATIVE CONDITIONS

Terms of Approval

1.1 The Proponent shall carry out the project generally in accordance with the:

a) Major Project Application 08_0154;

b) *Gloucester Gas Project Environmental Assessment,* dated November 2009 and prepared by AECOM;

c) *Gloucester Gas Project Submissions Report*, dated May 2010, and prepared by AECOM;

d) *Gloucester Basin Stage 1 Gas Field Development Project Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model,* dated July 2010, and prepared by SRK Consulting;

e) additional information on offset site(s) and pre-construction surveys submitted to the Department by email on 10 August 2010 and 31 August 2010, respectively;

f) draft management plans on acid sulphate soil and the threatened species *Grevillea Parviflora sub. Species parviflora*, submitted to the Department by email on 12 October 2010;

g) the concept plan approval granted with respect to the Gloucester Gas Project (08_0154);

h) Statement of Commitments;

i) EA (Mod 1);

j) Statement of Commitments (Mod 1); and

k) the conditions of this approval.

1.2 In the event of an inconsistency between:

a) the conditions of this approval and any document listed from condition 1.1a) to 1.1j) inclusive, the conditions of this approval shall prevail to the extent of the inconsistency; and

b) any document listed from condition 1.1a) to 1.1j) inclusive, the most recent document shall prevail to the extent of the inconsistency.

1.3 The Proponent shall comply with any reasonable requirement(s) of the Secretary arising from the Department's assessment of:

a) any reports, plans or correspondence that are submitted in accordance with this approval; and

b) the implementation of any actions or measures contained in these reports, plans or correspondence.

1.3A The Applicant must ensure that all wells:

a) must be designed, constructed, maintained and abandoned in accordance with the *Code of Practice for Coal Seam Gas – Well Integrity* (DRE 2012) or its latest version; and

b) where hydraulic fracturing is proposed, are operated in accordance with the Code of *Practice for Coal Seam Gas – Fracture Stimulation* (DRE 2012) or its latest version.

Limits of Approval

1.4 This project approval shall lapse five years after the date on which it is granted, unless the Proponent has demonstrated to the satisfaction of the Secretary prior to this time that orders have been placed for key plant/ elements essential and fundamental for the development of at least two project components (gas extraction, central processing facility, pipeline and/or Tomago Receiving Station).

1.5 To avoid any doubt, this approval only allows for the development of a single central processing facility at either site 1 or site 7.

1.6 To avoid any doubt, this approval does not authorise the following activities or works unless the subject of additional assessment and approval as part of a modification application under section 75W of the Act:

a) construction or operation of a transmission line connection between the central processing facility (15 megawatt gas-fired electricity generating facility) and existing electricity grid; and
b) direct re-injection of groundwater produced during gas well development, back into groundwater aquifers as a water disposal option.

Statutory Requirements

1.7 The Proponent shall ensure that all necessary licences, permits and approvals required for the development of the project are obtained and maintained as required throughout the life of the project. No condition of this approval removes the obligation for the Proponent to obtain, renew or comply with such necessary licences, permits or approvals.

1.8 The Proponent may elect to construct the project in discrete work packages or stages. Where that occurs, these conditions of approval need only be complied with to the extent that they are relevant to that discrete work package or stage.

2. PROJECT DESIGN REQUIREMENTS

2.1 The Proponent shall in consultation with OCSG and NOW ensure that gas wells within the Stage 1 Gas Field Development Area are located consistent with the locational principles identified in Statement of Commitment 3 (concept area) of the Environmental Assessment, with consideration to flood prone land and with consideration to minimising the risk of groundwater impacts consistent with the requirements of condition 3.10. Prior to the commencement of construction of the Stage 1 Gas Field Development Area, the Proponent shall submit to OCSG location sheets identifying the final location of wells including associated infrastructure such as gas/water gathering lines and access roads. Where gas development is phased, the Proponent shall submit the above information (with appropriate updates) to OCSG prior to the commencement of each phase.

Nothing in this condition precludes the Proponent from submitting the above required information as part of the Field Development Plan referred to in condition 3.10.

2.2 The Proponent shall finalise the route alignment of the gas transmission pipeline within the 100 metre assessment corridor identified in the Environmental Assessment, in consultation with affected landowners, with the aim of maximising the length of route within existing disturbed areas (including existing infrastructure easements) and minimising conflict with private properties and landuse. Where the route is proposed to traverse existing infrastructure easements, the Proponent shall ensure that the pipeline route is located in consultation with the owners of existing infrastructure within the easement with the aim of minimising conflict with the ongoing operation and future upgrade/ maintenance requirements of that infrastructure. Prior to the commencement of construction of the gas transmission pipeline, the Proponent shall submit to the Department route alignment sheets identifying the final location of the pipeline.

2.3 The Proponent shall ensure that the final design of the gas transmission pipeline makes provisions for all reasonable requirements of the Mine Subsidence Board, where the gas pipeline route traverses a Mine Subsidence District.

2.4 The Proponent shall ensure that engineering measures are incorporated into the design of the central processing facility so that the associated flare plant is shielded (visually and in relation to noise emissions) from nearest sensitive receptors, as far as reasonable and feasible. The Proponent shall also ensure that gas wells are designed so as to ensure that associated flaring is visually shielded from nearest sensitive receptors as far as reasonable and feasible. The Proponent shall submit details of engineering measures incorporated into the design of the flare plant and gas wells for the approval of the Director-General, prior to the commencement of construction.

3. SPECIFIC ENVIRONMENTAL CONDITIONS

Surface Water Quality

3.1 Except as may be expressly provided by an Environment Protection Licence for the project, the Proponent shall comply with section 120 of the *Protection of the Environment Operations Act 1997* which prohibits the pollution of waters.

3.2 Soil and water management measures consistent with Landcom's *Managing Urban Stormwater: Soils and Conservation* shall be employed during the construction of the project for erosion and sediment control.

Watercourse Crossings

3.3 All pipeline crossings of the Karuah River, Williams River, Hunter River, Deadmans Creek and any wetlands listed under *State Environmental Planning Policy No 14 – Coastal Wetlands* shall be undertaken using horizontal directional drilling techniques.

3.4 Unless otherwise agreed to by the Secretary, the Proponent shall ensure that any disturbance to watercourses and/or associated riparian vegetation is rehabilitated to a standard equal to or better than the existing condition in consultation with the NOW, Hunter LLS and DPI (Fisheries). Measures to facilitate the long-term rehabilitation of the site (including land stabilisation and re-vegetation) shall be implemented within six months of the cessation of construction activities at the relevant area.

Unless otherwise agreed to by the Secretary, the Proponent shall monitor and maintain the condition of the rehabilitated area until such time that the area (including re-vegetated areas) has been verified by an independent and suitably qualified expert (whose appointment has been agreed to by the Secretary) as being well established, in good health and self sustaining and rehabilitated to the standard required by this condition.

Groundwater Management

3.5 The Proponent shall implement all reasonable and feasible measures to ensure that gas wells are constructed, operated and decommissioned to avoid and minimise gas migration risks and adverse impacts to beneficial aquifers including associated groundwater users, surface waters and groundwater dependent ecosystems.

3.6 Unless otherwise agreed to by the Secretary, prior to the commencement of construction of the Stage 1 Gas Field Development Area, the Proponent shall identify and plug with cement any abandoned or old gas exploration wells that have not already been plugged and are located within a 500 metre radius of finalised gas well locations to minimise the risk of gas migration via these wells, to the satisfaction of the OCSG. Where casing has been installed in any of the abandoned or old exploration wells, and the extent of cementing to support the casing is unclear or unknown, the bore annulus must be sealed to prevent waters intermixing.

3.7 The Proponent shall ensure that no fraccing fluids containing Benzene, Toluene, Ethylbenzene and Xylene (BTEX) chemicals are used in gas field development.

Baseline Monitoring and Updated Hydrogeological Model

3.8 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.

3.9 The updated conceptual hydrogeological model referred to in condition 3.88 shall be submitted for the Secretary's approval, prior to the commencement of construction and shall include:

a) updated assessment of the potential for drawdown and displacement of shallow rock and alluvial beneficial aquifers, considering impacts to nearby registered bore users, based on detailed baseline data gathered from condition 3.8 a) to c);
b) optimal areas for gas well location within the Stage 1 Gas Field Development Area based on minimising the risk of gas migration and of interaction with beneficial aquifers and the outcomes of the updated assessment;
c) recommendations for phased gas well development including identifying the maximum number of gas wells that would be developed during the first phase of development and associated operational groundwater monitoring strategy consistent with the requirements of condition 4.1; and
d) include an independent peer review by an appropriately experienced and qualified hydrogeologist (who is approved by the Secretary for the purposes of this condition) on the robustness and technical veracity of the model.

In submitting the updated conceptual hydrogeological model for the Secretary's approval, the Proponent shall provide written evidence of consultation with NOW on the robustness and technical veracity of the model (including well location areas and phasing program) identifying the issues raised by NOW and how these have been addressed by the Proponent.

Field Development Plan Implementation during Operation

3.10 Unless otherwise agreed to by the Secretary, the Proponent shall ensure that gas wells within the Stage 1 Gas Field Development Area are developed in a phased manner to avoid and minimise adverse impacts to beneficial aquifers consistent with the requirements of condition 3.5. Prior to the commencement of construction of the Stage 1 Gas Field Development Area, the Proponent shall in consultation with NOW develop and submit to the Secretary for approval a **Field Development Plan**, which includes a phasing program for the development of gas wells and details of the final location of gas wells and associated infrastructure such as gas/water gathering lines and access roads for at least the first phase of gas well development identified in the Field Development Plan. As gas field development progresses, the Proponent shall in consultation with NOW update the Field Development Plan with phasing and location details of gas wells and associated infrastructure for subsequent phases, and submit the plan to the Secretary for approval prior to the commencement of each phase.

The Proponent shall ensure that the Field Development Plan includes a program that:

a) for the first phase of gas well development, is consistent with the recommendations of condition 3.9c); and
b) for all subsequent phases of gas well development, is prepared in consultation with NOW, and:
    i. is consistent with the outcomes of the groundwater monitoring program and associated numerical hydro-geological model implemented in accordance with condition 4.1 and 4.2;
    ii. demonstrates satisfactory management of groundwater risks in accordance with condition 3.5; and
    iii. is in accordance with any requirements of the Secretary following review of groundwater monitoring results in accordance with conditions 4.1 and 4.2,

to the satisfaction of the Secretary.

Rate of Groundwater Extraction

3.11 Prior to the commencement of any groundwater extraction associated with the project, the Proponent shall ensure that all relevant Water Licence(s) have been obtained from NOW for groundwater extraction at the volumetric rate of two mega litres per day (averaged over a 12 month period). Except as may be expressly provided by a Water Licence for the project, the Proponent shall ensure that the volumetric rate of groundwater extraction for the project is no greater than two mega litres per day (averaged over a 12 month period).

Extracted Water Management

3.12 Unless otherwise agreed to by the Secretary, prior to the commencement of construction of the project, the Proponent shall develop an **Extracted Water Management Strategy** in consultation with OCSG, NOW, Hunter LLS, EPA and relevant Councils and to the satisfaction of the Secretary, which:

a) identifies the final suite of water disposal and re-use option(s) that would be implemented to manage groundwater extracted from the gas production wells;
b) identifies the water quality required to achieve the disposal/ re-use option(s) identified in a) above including the procedure for monitoring of treated water to ensure that required water quality criteria are achieved;
c) if discharge to surface waters is proposed – identifies details of all practical measures investigated to prevent, control, abate or mitigate that discharge; details of the receiving environment including water quality and flow conditions; proposed discharge rate and frequency; and details of all practical measures investigated to protect the environment from harm as a result of that discharge including demonstration that any discharge would satisfy the requirements of condition 3.1;
d) if re-use for irrigation is proposed – demonstrates that there is demand for the volumes of water to be generated, details of all practical measures investigated to protect the environment from harm including details of optimal application rates to prevent over-irrigation and associated salinity issues or groundwater contamination, and demonstration that any discharge would satisfy the requirements of condition 3.1;
e) if extracted water is proposed to be made available to the market – demonstrates that suitable buyers of the water have been secured and where the water is proposed to supplement drinking water supplies, demonstration that the water quality is suitable for drinking water supplies;
f) identifies the final option for the management of the salt volumes produced from the extracted water treatment process;
g) includes a contingency strategy for the management of extracted water should the volumetric rate of groundwater extraction be greater than two mega litres per day (consistent with the requirements of condition 3.11), including analysis of associated risks to groundwater users and/ or surface waters and groundwater dependent ecosystems;
h) provides an assessment of the need for control measures to be implemented at the extracted water and brine evaporation ponds to minimise wildlife (including bird) access to these ponds, with consideration to the water quality and associated risks to wildlife likely to be posed by these storage ponds; and
i) provide for the development of site specific water quality criteria in accordance with the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000* (ANZECC 2000 Guidelines), as necessary, in consultation with DECCW, for the purposes of conditions b), c), d) and e) above.

3.13 The Proponent shall ensure that any water storage ponds developed at the central processing facility or on the Tiedeman property as part of the project (including extracted water, treated water and brine evaporation ponds) are appropriately lined to ensure no leaching of stored waters and designed consistent with a 1 in 100 year flood design standard.

Noise Impacts

Construction Hours

3.14 With the exception of construction of the pipeline, the Proponent shall only undertake construction activities associated with the project that would generate an audible noise at any sensitive receptor during the following hours:

a) 7:00 am to 6:00 pm, Mondays to Fridays, inclusive;
b) 8:00 am to 1:00 pm on Saturdays; and
c) at no time on Sundays or public holidays.

This condition does not apply in the event of a direction from police or other relevant authority for safety reasons or emergency work to avoid the loss of lives, property and/or to prevent environmental harm.

Construction works associated with the gas pipeline that would generate audible noise at any sensitive receptor shall only be undertaken during the following hours: 7.00 am to 6.00 pm Monday to Saturday and 8.00 am to 6.00 pm Sundays or public holidays for a maximum period of 28 days at a time, separated by a minimum respite period of nine days.

3.15 Blasting associated with the construction of the project shall only be undertaken during the following hours:

a) 9:00 am to 5:00 pm, Mondays to Fridays, inclusive;
b) 9:00 am to 1:00 pm on Saturdays; and
c) at no time on Sundays or public holidays.

3.16 The hours of construction activities specified under conditions 3.14 and 3.15 of this approval may be varied with the prior written approval of the Secretary. Any request to alter the hours of construction specified under condition 3.14 and 3.15 shall be:

a) considered on a case-by-case basis;
b) accompanied by details of the nature and need for activities to be conducted during the varied construction hours including alternatives considered;
c) accompanied by details of the likely noise levels at nearest sensitive receptors with and without mitigation;
d) accompanied by details of all reasonable and feasible measures identified to minimise noise impact at nearest sensitive receptors;
e) accompanied by details of consultation and notification undertaken with surrounding receptors (including, in respect to proposed gas drilling works on a 24 hour basis – written agreement from affected landowners, where relevant construction noise goals are not expected to be achieved); and
f) accompanied by written evidence demonstrating consultation with the EPA in relation to the proposed variation in construction times (including consideration of any comments made by the EPA).

Construction Noise

3.17 The Proponent shall implement all reasonable and feasible measures to minimise noise generation from the construction of the project consistent with the requirements of the *Interim Construction Noise Guideline* (DECC, July 2009) including noise generated by heavy vehicle haulage and other construction traffic associated with the project.

Construction Blasting

3.18 The Proponent shall ensure that air blast overpressure generated by blasting associated with the project does not exceed the criteria specified in Table 1 when measured at the most-affected residential or sensitive receiver.

Table 1 – Airblast Overpressure Criteria

Air blast Overpressure (dB(Lin Peak))	Allowable Exceedance
115	5% of total number of blasts over a 12 month period
120	Never

3.19 The Proponent shall ensure that the ground vibration generated by blasting associated with the project does not exceed the criteria specified in Table 2 when measured at the most-affected residential or sensitive receiver.

Table 2 – Peak Particle Velocity Criteria

Peak Particle Velocity Criteria (mms^{-1})	Allowable Exceedance
5	5% of total number of blasts over a 12 month period
10	Never

3.20 Prior to each blasting event, the Proponent shall notify the relevant local council and potentially-affected landowners, including details of time and location of the blasting event and providing a contact point for inquiries and complaints.

Vibration Impacts

3.21 The Proponent shall ensure that the vibration resulting from construction and operation of the project does not exceed the preferred values vibration (for low probability of adverse comment) presented in *Assessing Vibration: A Technical Guideline* (DECC, February 2006), at any surrounding sensitive receptor.

Operational Noise

3.22 The Proponent shall design, construct, operate and maintain the project to ensure that the noise contributions from the project do not lead to an exceedence of the noise limits specified in Table 3 (at the locations and during the periods indicated) for the operation of the project unless subject to a negotiated noise agreement established consistent with Section 8.3 of the *New South Wales Industrial Noise Policy* (EPA, 2000). The noise limits apply under wind speeds up to 3 ms^{-1} (measured at 10 metres above ground level), or under temperature inversion conditions of up to 3 ºC/ 100 metres and wind speeds of up to 2m/s at 10 metres above the ground.

This condition only applies to the project operating under normal operating conditions and does not apply to:

a) start-up, shut-down or emergency situations (emergency situations being defined as situations where there is the potential for the loss of lives, property and/ or environmental harm); or

b) the re-drilling and/ or re-fraccing activities of previously operational wells or gas well maintenance activities, which are specifically agreed to by the Secretary in writing, on a case by case basis, and which are undertaken in accordance with an approved noise management protocol prepared in accordance with the requirements of condition 7.4e)(iii).

Table 3 - Operational Noise Limits

Project Component	Location	Project Specific Noise Limit (all time periods)	
		dB(A) $L_{Aeq(15\ minute)}$	dB(A) $L_{A1\ (1\ minute)}$
Gas Wells	Nearest Sensitive Receptor	35	45
Central Processing Facility (Site 1)	P7	36	46
	P8	36	46
	P9	35	45
	P10	36	46
	P11	36	46
	P12	36	46
	P13	36	46
Central Processing Facility (Site 7)	P1	36	46
	P2	42	52
	P3	37	47
	P4	35	45
	P5	35	45
	P6	35	45

Tomago Receiving Station	P18/R37	49	59
	P19/R38	49	59
	P20/R39	42	52
	P21/R41	51	61

3.23 For the purpose of assessment of noise contributions specified under condition 3.22 of this approval, noise from the project shall be:

a) measured at the most affected point within the residential boundary or at the most affected point within 30 metres of the dwelling where the dwelling is more than 30 metres from the boundary to determine compliance with the $L_{Aeq(15\ minute)}$ noise limits;

b) measured at 1 metre from the dwelling façade to determine compliance with the $L_{A1\ (1\ minute)}$ noise limits; and

c) subject to the modification factors provided in Section 4 of the *New South Wales Industrial Noise Policy* (EPA, 2000).

Notwithstanding the above, should direct measurement of noise from the project be impractical, the Proponent may employ an alternative noise assessment method deemed acceptable by the EPA (refer to Section 11 of the *New South Wales Industrial Noise Policy* (EPA, 2000)). Details of such an alternative noise assessment method accepted by the EPA shall be submitted to the Secretary prior to the implementation of the assessment method.

Detailed Design Noise Report

3.24 Unless otherwise agreed to by the Secretary, at least 3 months prior to the commissioning of the central processing facility and Tomago Receiving Station, the Proponent shall in consultation with EPA prepare and submit a **Detailed Design Noise Report** for the Secretary's approval to confirm the predicted noise levels associated with the central processing facility and Tomago Receiving Station considering all reasonable and feasible at-source control measures (based on detailed design) at the sensitive receptors identified in Table 3.

Acquisition Rights

3.25 Unless otherwise agreed to by the Secretary, where the **Detailed Design Noise Report** required to be prepared under condition 3.24 predicts exceedences of greater than 5 dB(A) of project specific noise limits at any sensitive receptor identified in Table 3 for either the operation of the central processing facility or the operation of the Tomago Receiving Station, the relevant receptors shall be subject to acquisition rights in accordance with condition 3.26 unless a negotiated agreement is in place with respect to that receptor in accordance with condition 3.22. The Proponent shall ensure that any receptor subject to acquisition rights is notified of his/her rights as outlined in condition 3.26 within one month of the Department's approval of the Detailed Design Noise Report.

3.26 Within three months of receiving a written request from a landowner with acquisition rights under condition 3.25 of this approval, the Proponent shall make a binding written offer to the landowner based on:

a) the market value of the landowner's interest in the property at the date of this written request, as if the property was unaffected by the project:

b) the reasonable costs associated with;

  i) property relocation;

  ii) obtaining legal advice and expert advice for determining the acquisition price of the land, and the terms upon which it is acquired; and

c) reasonable compensation for any disturbance caused by the land acquisition process.

However, if at the end of this period, the Proponent and landowner cannot agree on the acquisition price of the land, and/or the terms upon which the land is to be acquired, then either party may refer the matter to the Secretary for resolution.

Upon receiving such a request, the Secretary shall request the President of the NSW Division of the Australian Property Institute to appoint a qualified independent valuer or Fellow of the Institute, to:

a) consider submissions from both parties;
b) determine a fair and reasonable acquisition price for the land, and/or terms upon which the land is to be acquired having regard to the matters in a), b) and c) above; and
c) prepare a detailed report setting out the reasons for any determination and provide a copy of the report to both parties.

Within 14 days of receiving the independent valuer's determination, the Proponent shall make a written offer to purchase the land at a price not less than the independent valuer's determination.

If the landowner refuses to accept the Proponent's binding written offer within six months of the date of the Proponent's offer, the Proponent's obligations to acquire the land shall cease, unless the Secretary determines otherwise.

The Proponent shall bear the reasonable costs of any valuation or survey assessment requested by the independent valuer or the Secretary and the reasonable costs of determination referred to above.

Any receptor, for which acquisition rights have ceased in accordance with the requirement of this condition, would nevertheless be eligible to receive at-receptor acoustic treatments in accordance with condition 3.27.

At-Receptor Acoustic Treatment

3.27 Unless otherwise agreed to by the Secretary, where the **Detailed Design Noise Report** required to be prepared under condition 3.24, predicts exceedences of project specific noise criteria of no greater than 5 dB(A) at any sensitive receptor identified in Table 3 for either the operational of the central processing facility or the operational of the Tomago Receiving Station, the relevant receptors shall be eligible to receive at-receptor acoustic treatments, at the Proponent's expense, to minimise noise impacts at the receptors as far as reasonable and feasible, unless operational noise monitoring undertaken in accordance with condition 4.3 confirms that project specific noise limits would be achieved at these receptors. All receptors eligible for at-receptor mitigation measures in accordance with the requirements of this condition shall be informed of their rights following the confirmation of noise levels at these receptors as part of the Noise Verification Report required to be prepared under condition 4.3, within one month of the Secretary's approval of that Noise Verification Report.

Air Quality Impacts

Dust Generation

3.28 The Proponent shall employ all reasonable and feasible measures (including temporary cessation of relevant works, as appropriate) to ensure that the project is constructed in a manner that minimises dust emissions from the site, including wind-blown and traffic-generated dust. All activities on the site shall be undertaken with the objective of preventing visible emissions of dust from the site, as far as practicable.

Odour

3.29 The Proponent shall not permit any offensive odour, as defined under section 129 of the *Protection of the Environment Operations Act 1997*, to be emitted from the site which impacts on any sensitive surrounding receptor.

Monitoring and Discharge Points

3.30 For the purposes of this approval, air monitoring/ air discharge points shall be identified as provided in Table 4 below.

Table 4 - Identification of Air Monitoring and Discharge Points

Monitoring / Discharge Point Identifier	Monitoring/ Discharge Point Location
1	Water Bath Heater, Tomago Receiving Station
2	Internal Combustion Engine, Power Generation Facility, Central Processing Facility
3	Reciprocating Multistage Compressor, Gas Compression Plant, Central Processing Facility
4	Alternator, Central Processing Facility
5	Triethylene Glycol Regeneration Skid, Central Processing Facility
6	Triethylene Glycol Boiler, Central Processing Facility

Discharge Limits

3.31 The Proponent shall design, construct, operate and maintain the project to ensure that for each discharge point, identified in condition 3.30, the concentration of each pollutant listed in Table 5 is not exceeded during the operation of the project. This condition only applies to the project operating under normal operating conditions and does not apply during start-up, shut-down or emergency situations.

Table 5 - Maximum Allowable Discharge Concentration Limits (Air)

Discharge Point	Pollutant	Units of Measure	100 Percentile limit (mgm^{-3})	Averaging Period	Reference conditions
1 (TRS)	Oxides of Nitrogen	mg/m^3	350	1 hour	dry, 273 K, 101.3 kPa, and 3% O_2
	Volatile Organic compounds or carbon monoxide	mg/m^3	40 (VOCs or 125 (CO)	Rolling 1-hour	dry, 273 K, 101.3 kPa, and 3% O_2
2	Oxides of Nitrogen	mg/m^3	450	1 hour	dry, 273 K, 101.3 kPa, and 3% O_2
	Formaldehyde	mg/m^3	6	1 hour	dry, 273 K, 101.3 kPa, and 3% O_2
	Volatile Organic compounds or carbon monoxide	mg/m^3	40 (VOCs or 125 (CO)	Rolling 1-hour	dry, 273 K, 101.3 kPa, and 3% O_2
3	Oxides of Nitrogen	mg/m^3	250	1 hour	dry, 273 K, 101.3 kPa, and 13% O_2
	Formaldehyde	mg/m^3	10	1 hour	dry, 273 K, 101.3 kPa, and 13% O_2
	Volatile Organic compounds or carbon monoxide	mg/m^3	40 (VOCs or 125 (CO)	Rolling 1-hour	dry, 273 K, 101.3 kPa, and 13% O_2
4	Oxides of Nitrogen	mg/m^3	60	1 hour	dry, 273 K, 101.3 kPa, and 13% O_2
	Formaldehyde	mg/m^3	10	1 hour	dry, 273 K, 101.3 kPa, and 13% O_2
	Volatile Organic compounds or carbon monoxide	mg/m^3	40 (VOCs or 125 (CO)	Rolling 1-hour	dry, 273 K, 101.3 kPa, and 13% O_2
5	Oxides of Nitrogen	mg/m^3	35	1 hour	dry, 273 K, 101.3 kPa, and 3% O_2
	Formaldehyde	mg/m^3	5	Rolling 1-hour	dry, 273 K, 101.3 kPa, and 3% O_2
6	Oxides of Nitrogen	mg/m^3	60	1 hour	dry, 273 K, 101.3 kPa, and 3% O_2
	Formaldehyde	mg/m^3	5	Rolling 1-hour	dry, 273 K, 101.3 kPa, and 3% O_2

Gas Flare Management

3.32 In relation to gas wells under flare during the commissioning of the Stage 1 Gas Field Development Area, the Proponent shall ensure that a separation distance of at least 500 metres is maintained for flaring wells positioned in a straight line (maximum of five wells simultaneously flaring) and 800 metres for flaring wells positioned in a triangular grid (maximum of four wells simultaneously flaring). If additional wells are to be flared simultaneously a four kilometre separation distance shall be maintained between flaring well clusters.

3.33 The Proponent shall ensure that records of gas venting from the central processing facility, either through flare or directly to the atmosphere shall be recorded and reported to the Secretary and EPA on an annual basis

Biodiversity Offset

3.34 Unless otherwise agreed to by the Secretary, prior to the commencement of construction of the project, the Proponent shall in consultation with OEH and DoE finalise and secure in perpetuity (through appropriate legal mechanisms), a compensatory habitat package, which offsets the biodiversity impacts of the project as specified below to the satisfaction of the Secretary. Unless otherwise agreed to by the Secretary, the package shall be finalised following:

a) targeted surveys of the gas transmission pipeline corridor to confirm the project's impacts on the following listed flora species, based on survey methodology determined in consultation with OEH: *Asperula conferta* (Trailing Woodruff), *Galium australe* (Tangled Bedstraw), *Callistemon linearifolius* (Nettled Bottle Brush), *Cryptostylis hunteriana* (Leafless Tongue Orchid), *Cynanchum elegans* (White-flaxed Wax Plant), *Grevillea Parviflora sub. Species parviflora* (Small-flower Grevillea), *Persicaria elatior* (Tall Knotweed), *Pomaderris queenslandica* (Scant Pomaderris), *Rhizanthella slateri* (Eastern Australian Underground Orchid) and *Tetratheca juncea* (Black-eyed Susan);

b) survey of the offset site identified in the documents listed under condition 1.1e) in consultation with OEH and consistent with OEH's Biobanking Methodology to confirm the ecological values of the site(s);

c) based on b) above, demonstration that the offset site referred to in b) above, provides suitable offset (consistent with the principles of "maintain or improve") for the biodiversity impacts of the project on:

   i) *Grevillea Parviflora sub. Species parviflora*, any additional listed flora species identified to be impacted by the gas transmission pipeline corridor based on a) above, and the habitat of any listed flora species identified to have a medium to high potential of occurring within the remaining disturbance footprint of the project;

   ii) habitat of the Grey-crowned Babbler species and any other fauna species identified to have a medium to high potential of occurring within the disturbance footprint of the project;

   iii) the Hunter Lowland Redgum Forest in the Sydney Basin and New South Wales North Coast Bioregions endangered ecological community; and

   iv) important native vegetation and habitat values within the disturbance footprint of the project;

d) where the offset site referred to in b) above does not provide all required offset values as identified in c) above, the identification of additional offset measures and / or sites in consultation with OEH and DoE, to address residual offset requirements including survey of additional offset sites in accordance with b) above, where required; and

e) finalisation of the management measures required to maintain the biodiversity values of each offset option identified, in perpetuity in consultation with OEH and DoE.

In submitting the compensatory habitat package for the Secretary's approval, the Proponent shall clearly detail the consultation undertaken with OEH and DoE, including opportunity provided to review draft versions of the package (should this be required by the agencies) and identification of the issues raised by the agencies and how these have been addressed in the package.

Heritage Impacts

3.35 If during the course of construction the Proponent becomes aware of any previously unidentified Aboriginal object(s), all work likely to affect the object(s) shall cease immediately and the objects managed in accordance with the requirements of condition 7.2g)iv), in consultation with registered Aboriginal stakeholders.

3.36 The Proponent shall ensure that the Stage 1 Gas Field Development Area is developed such as to avoid impacts to AHIMS 38-1-0008 and AHIMS 38-1-0031 to the satisfaction of the Secretary.

3.37 The Proponent shall ensure that pipeline construction in the vicinity of AHIMS 28-1-0006 and AHIMS 38-4-0010 is restricted to the existing disturbed road alignment to ensure no disturbance or interference with these sites. The Proponent shall ensure that a qualified archaeologist and relevant Aboriginal stakeholders are on site at all times during construction works in the vicinity of these sites to monitor the construction works and ensure that appropriate buffer distances are maintained to these sites to avoid disturbance.

3.38 Should the Central Processing Facility or any temporary construction facilities be located within Site 1, the Proponent shall prior to the commencement of construction provide opportunity for representatives from the Forster Local Aboriginal Land Council to survey the site, re-locate and salvage the three isolated finds that have been previously identified on site (but which were unable to be relocated during studies undertaken as part of the Environmental Assessment).

3.39 If during the course of construction the Proponent becomes aware of any unexpected historical relic(s), all work likely to affect the relic(s) shall cease immediately in the vicinity of the relics and the Heritage Office notified in accordance with the *Heritage Act 1977*. Works shall not recommence until the Proponent receives written authorisation from the Heritage Office.

Visual Amenity Impacts

3.40 The Proponent shall minimise the use of reflective building elements and maximise the use of building materials and treatments which visually complement the surrounding landuse.

3.41 The Proponent shall ensure that all external lighting associated with the project is mounted, screened, and directed in such a manner so as not to create a nuisance to the surrounding environment, properties and roadway. The lighting shall be the minimum level of illumination necessary and shall comply with *AS 4282(INT) 1997 – Control of Obtrusive Effects of Outdoor Lighting.*

3.42 Unless otherwise agreed to by the Secretary, within six months of the completion of the construction of the central processing facility, the Proponent shall implement all reasonable and feasible landscaping measures within the central processing facility site to screen views of this facility from nearest sensitive receptors. The Proponent shall monitor and maintain the health of these landscape plantings for the life of the central processing facility, including replacing of any plantings which fail.

Traffic, Transport and Access Impacts

3.43 The Proponent shall ensure that any disturbance to public roads associated with the pipeline crossing or any road upgrades to accommodate the construction or operational traffic associated with the project is designed and constructed in consultation with and to meet the reasonable requirements of the relevant road authority (relevant Council or the RMS), to the satisfaction of the Secretary.

3.44 Prior to the commencement of construction of the project, the Proponent shall commission a suitably qualified expert to assess the condition of all public roads proposed to be traversed by construction traffic associated with the project (including over-mass or over-dimensional vehicles) in consultation with relevant Councils and the RMS, and identify any upgrade requirements to accommodate project traffic for the duration of construction (including culvert, bridge and drainage design; intersection treatments; vehicle turning requirements; and site access) considering final traffic volumes. The road dilapidation report shall be submitted to the Secretary prior to the commencement of construction clearly identifying recommendations made by the Council and the RMS and how these have been addressed.

The Proponent shall ensure that all upgrade measures identified in the report are implemented to meet the reasonable requirements of the relevant Council and the RMS, prior to the commencement of construction, to the satisfaction of the Secretary.

3.45 Prior to the commencement of operation of the project, the Proponent shall commission a suitably qualified expert to assess the condition of all public roads traversed by construction traffic associated with the project (including over-mass or over-dimensional vehicles) in consultation with Council and the RMS. Should the pre-operational dilapidation survey report identify any damage to roads attributable to construction traffic associated with the project, the Proponent shall repair the roads consistent with the recommendations of the pre-operational dilapidation survey report, within such time as agreed to with the relevant Council and the RMS and to meet the reasonable requirements of the relevant Council and the RMS. The pre-operation road dilapidation report shall be submitted to the Secretary prior to the commencement of operation, clearly identifying recommendations made by relevant Councils and the RMS and how these have been addressed, to the satisfaction of the Secretary.

Hazards and Risk

Technical Controls

3.46 The design, operation and technical controls for the well heads shall be consistent with the requirements of the Department's Guideline – *'Development in the Vicinity of Operating Coal Seam Methane Wells'* to the satisfaction of the Secretary.

Pre-Construction

3.47 The Proponent shall prepare and implement the following hazards and safety studies to the satisfaction of the Secretary:

a) a **Fire Safety Study** covering the relevant aspects of the Department's *'Hazardous Industry Planning Advisory Paper No. 2, 'Fire Safety Study Guidelines'*. The study shall meet the requirements of the NSW Fire Brigades. For the Central Processing Facility, the study shall also consider the New South Wales Government's *'Best Practice Guidelines for Contaminated Water Retention and Treatment Systems'*;
b) a **Hazard and Operability Study** for the Central Processing Facilities, including any abnormal operating modes such as flare and blowdown operations, chaired by a qualified person, independent of the project. The study shall be consistent with the Department of Planning's '*Hazardous Industry Planning Advisory Paper No. 8, 'HAZOP Guidelines*';
c) a **Final Hazard Analysis** consistent with the Department's Hazardous Industry Planning Advisory Paper No. 6, *'Guidelines for Hazard Analysis'*. The final design shall apply appropriate risk mitigation measures for the Export Sales Pipeline (ESP) in locations where the pipeline risk transects exceed the Department's risk criteria. Further, the final design shall consider all recommendations in Table A1.1 to A1.5 of the Preliminary Hazard Analysis presented in the Environmental Assessment and *Appendix 5 Addendum to the GGP Preliminary Hazard Analysis* prepared by Planager Pty Ltd dated 4 November 2013; and
d) a **Construction Safety Study**, consistent with the Department's Hazardous Industry Planning Advisory Paper No. 7, *'Construction Safety Study Guidelines'*. The study should consider the bush fire risk during construction of the project.

The hazards and safety studies shall be submitted to the Secretary for approval no later than 2 months prior to the proposed commencement of construction of the project (or a relevant stage of the project), or within such further period as the Secretary may agree. Except for construction of preliminary works that are outside the scope of the hazard and safety studies, construction of the project (or a relevant stage of the project), shall not commence until these documents are approved by the Secretary.

Pre-commissioning

3.48 The Proponent shall prepare and implement the following plan and system to the satisfaction of the Secretary:

a) a comprehensive **Emergency Response Plan** detailing emergency procedures for the Central Processing Facility. The plan shall include detailed procedures for the safety of all people outside of the project who may be at risk from the project. The plan shall be consistent with the Department's Hazardous Industry Planning Advisory Paper No. 1, *'Industry Emergency Planning Guidelines'*; and
b) a document setting out a comprehensive **Safety Management System** for the Central Processing Facility, covering all on-site operations. The document shall clearly specify all safety related procedures, responsibilities and policies, along with details of mechanisms for ensuring adherence to the procedures. The Safety Management System shall be consistent with the Department's Hazardous Industry Planning Advisory Paper No. 9, *'Safety Management'*.

Documents describing the plan and system shall be submitted to the Secretary for approval no later than 2 months prior to the proposed commencement of commissioning of the project, or within such further period as the Secretary may agree. Commissioning of the project shall not commence until these documents are approved by the Secretary.

Pre-Operation

3.49 At least one month prior to the commencement of operation of the project, the Proponent shall submit to the Secretary, a report detailing compliance with conditions 3.47 and 3.48, including:
a) dates of study/plan/system completion;
b) actions taken or proposed, to implement recommendations made in the studies/plans/systems; and
c) responses to each requirement imposed by the Secretary following its review of the studies/ reports.

Post Operation

3.50 Three months after the commencement of operation of the project, the Proponent shall submit to the Director General, a report verifying that:
a) the Emergency Response Plan required under condition 3.48a) is effectively in place and that at least one emergency exercise has been conducted; and
b) the Safety Management System required under condition 3.48b) has been fully implemented and that records required by the system are being kept.

3.50A Prior to the construction of the Tomago Receiving Station, the Proponent shall ensure that the following hazard studies, prepared under the approval for the Newcastle Gas Storage Project (MP 10_0133), are updated to account for the presence of the Station:
a) Fire Safety Study;
b) Hazard and Operability Study;
c) Final Hazard Analysis;
d) Emergency Plan; and
e) Safety Management System,
to the satisfaction of the Secretary.

Waste Generation and Management

3.51 The Proponent shall not cause, permit or allow any waste generated outside the site to be received at the site for storage, treatment, processing, reprocessing, or disposal on the site, except as expressly permitted by a licence under the *Protection of the Environment Operations Act 1997*, if such a licence is required in relation to that waste.

3.52 Except in the case of water or salt waste managed in accordance with condition 3.12, the Proponent shall maximise the reuse and/or recycling of waste materials generated on site as far as practicable, to minimise the need for treatment or disposal of those materials off site to the satisfaction of the Secretary.

3.53 The Proponent shall ensure that all liquid and/or non-liquid waste generated on the site is assessed and classified in accordance with *Waste Classification Guidelines* (DECC, 2008), or any future guideline that may supersede that document and where removed from the site is only directed to a waste management facility lawfully permitted to accept the materials to the satisfaction of the Secretary.

Temporary Construction Facilities

3.54 Prior to the commencement of construction of the Project, the Proponent shall prepare a **Temporary Construction Facilities Management Strategy** in consultation with EPA and relevant Councils to the satisfaction for the Secretary detailing:

a) the final location of all temporary construction facilities including construction camps, demonstrating that the facilities have been located consistent with the location principles identified in Statement of Commitment 4 (project area) of the Environmental Assessment; within the assessed footprint of the project; and to ensure that the facilities would not result in any increased impacts (including biodiversity, heritage items and noise) as assessed in the Environmental Assessment and Submissions Report;
b) the scale and dimension of facilities including duration of establishment;
c) utility and service requirements (such as sewage, water supply and electricity) required to operate the facilities for the duration of construction including demonstration that all relevant approvals for these services and connections have been obtained;
d) management measures that would be implemented on site including behavioural protocols to ensure that the facilities do not pose a disturbance to surrounding receptors including noise, air quality, visual (and lighting), and traffic impacts;
e) protocols that would be put in place to control or avoid any unintended social impacts (such as anti-social behaviour), particularly from the construction camps; and
f) detailed decommissioning and rehabilitation requirements at the cessation of the construction period.

Rehabilitation

3.55 The Proponent shall ensure that all surface areas of the project footprint which are disturbed during the construction but which are not required for the ongoing operation of the project (including temporary construction facility sites, construction access roads, relevant areas of the pipeline construction corridor and buried gas and water gathering lines) are rehabilitated consistent with existing landuse in consultation with affected landowners, to a standard better than or equal to existing. In relation to areas which were vegetated prior to disturbance, this shall comprise a program of revegetation to a standard equal to or better than the existing condition (where this does not conflict with the ongoing operation of the gas transmission pipeline) to the satisfaction of the Secretary.

Measures to facilitate the long-term rehabilitation of applicable surface areas (including land stabilisation and re-vegetation measures) shall be implemented within six months of the cessation of construction activities to the satisfaction of the Secretary, at the relevant area unless an alternative timeframe is agreed to with the landowners. Unless otherwise agreed to by the Secretary, the Proponent shall monitor and maintain the condition of the rehabilitated areas to the satisfaction of the Secretary until such time that the areas (including re-vegetated areas) have been verified by an independent and suitably qualified expert (whose appointment has been agreed to by the Secretary) as being well established, in good health and self sustaining and rehabilitated to the standard required by this condition.

3.56 The Proponent shall ensure that all gas wells are decommissioned and rehabilitated at the cessation of operation in accordance with the requirements of and to the satisfaction of OCSG. Unless otherwise agreed to by OCSG, the Proponent shall ensure that the decommissioning and rehabilitation of gas wells are independently verified within three-months of the decommissioning of the well, to the satisfaction of OCSG.

4. ENVIRONMENTAL MONITORING AND AUDITING

Ground Water Monitoring

4.1 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 Secretary, 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 (based on risk assessment) 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 (based on risk assessment) 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 Secretary'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 Secretary, 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 Prior to the commencement of construction of the Stage 1 Gas Field Development Area, the Proponent shall in consultation with NOW develop a **Numerical Hydrogeological Model** of the Stage 1 Gas Field Development Area building on the detailed conceptual hydrogeological model developed in accordance with conditions 3.8 and 3.9 to the satisfaction of the Secretary. The Model shall be used as a predictive, adaptive management and verification tool to guide the ongoing operation and implementation of gas wells as part of the Field Development Plan including feeding into recommendations on the phasing of gas wells in accordance with condition 3.10 (this includes identifying any impacts of the project from the previous phase of gas well development and the mitigation and contingency measure employed to control any impacts including their effectiveness and the recommended number and location of gas well to be developed in the next phase). The Model shall also feed into recommendations on updates to the Groundwater Monitoring program in accordance condition 4.1.

Noise Monitoring

4.3 Within 90 days of the commencement of operation of the project or as otherwise agreed by the Secretary, and during a period in which the project is operating under normal operating conditions, the Proponent shall undertake a program to confirm the noise emission performance of the project. The program shall meet the requirements of the EPA, and shall include, but not necessarily be limited to:

a) noise monitoring, consistent with the guidelines provided in the *New South Wales Industrial Noise Policy* (EPA, 2000), to assess compliance with condition 3.22 of this approval;
b) methodologies, locations and frequencies for noise monitoring;
c) identification of monitoring sites at which pre- and post-project noise levels can be ascertained; and
d) details of any entries in the Complaints Register (condition 6.3 of this approval) relating to noise impacts.

Unless otherwise agreed to by the Secretary, a report providing the results of the program shall be submitted to the Secretary and the EPA within 28 days of completion of the testing required under a).

4.4 In the event that the program undertaken to satisfy condition 4.3 of the approval indicates that the operation of the project, under normal operating conditions, will lead to greater noise impacts than permitted under condition 3.22 of this approval, then the Proponent shall provide details of remedial measures to be implemented to reduce noise impacts to levels required by that condition, including (but not necessarily limited to) at-receptor acoustic screening as required under condition 3.27. At-receptor acoustic screening shall only be considered where other at-source methods of acoustic amelioration are found to not be reasonable or feasible. A report providing details of the remedial measures and a timetable for implementation shall be submitted to the Secretary for approval within such period as the Secretary may require, and be accompanied by evidence that the EPA is satisfied that the remedial measures are acceptable.

Following review of the report, the Secretary may require additional noise monitoring to confirm the performance of the implemented remediation measures. Where such additional noise monitoring indicates exceedences of project specific noise criteria specified in condition 3.22 of this approval at any sensitive receptor identified in Table 3 after the implementation of all reasonable and feasible remedial measures, these receptors (unless otherwise agreed to by the Secretary) shall be subject to noise agreements within such time period as agreed to by the Secretary or in the case that exceedences greater than 5dB(A) are indicated, subject to acquisition criteria in accordance with condition 3.26 (except in the case where a noise agreement is in place).

Air Quality Monitoring

4.5 The Proponent shall determine the pollutant concentrations and emission parameters specified in Table 6 below, at each of the discharge points (established in strict accordance with the requirements of test method TM-1 as specified in *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales* (EPA, 2001)). Monitoring shall be undertaken during operation of the project, at the frequency indicated in the Table, unless otherwise agreed by the EPA.

Table 6 – Periodic Pollutant and Parameter Monitoring (Air)

Discharge Point	Pollutant/ Parameter	Units of Measure	Method	Frequency
1 (TRS)	Oxides of Nitrogen	mgm^{-3}	TM-11	Post commissioning

	Carbon Monoxide or Volatile Organic Compounds	mgm^{-3}	TM 34 or TM 32	and annually thereafter
	Velocity	m/s	TM-2	
	Volumetric flow rate	m^3/s	TM-2	
	Temperature	^oC	TM-2	
	Moisture	%	TM-22	
	Dry gas density	kgm^3	TM-23	
	Molecular weight of stack gases	g/gmol	TM-23	
	Oxygen	%	TM-25	
	Carbon dioxide	%	TM-24	
	Selection of Sampling Positions	-	TM-1	-
2	Oxides of Nitrogen	mgm^{-3}	TM-11	Post commissioning and annually thereafter
	Formaldehyde	mgm^{-3}	US EPA Method 323, upon confirmation by EPA in accordance with condition 0.	
	Carbon Monoxide or Volatile Organic Compounds	mgm^{-3}	TM 34 or TM 32	
	Velocity	m/s	TM-2	
	Volumetric flow rate	m^3/s	TM-2	
	Temperature	^oC	TM-2	
	Moisture	%	TM-22	
	Molecular weight of stack gases	g/gmol	TM-23	
	Oxygen	%	TM-25	
	Carbon dioxide	%	TM-24	
	Oxides of Nitrogen	mgm^{-3}	CEM-2	Continuous
	Temperature	^oC	TM-2	
	Moisture	%	TM-22	
	Volumetric flow rate	m^3/s	CEM-6	
	Oxygen	%	CEM-3	
	Selection of Sampling Positions	-	TM-1	-
3, 4, 5 and 6	Oxides of Nitrogen	mgm^{-3}	TM-11	Post commissioning and annually thereafter
	Formaldehyde	mgm^{-3}	US EPA Method 323, upon confirmation by EPA in accordance with condition 0.	
	Carbon Monoxide or Volatile Organic Compounds	mgm^{-3}	TM 34 or TM 32	
	Velocity	m/s	TM-2	
	Volumetric flow rate	m^3/s	TM-2	
	Temperature	^oC	TM-2	
	Selection of Sampling Positions	-	TM-1	-

4.6 Unless otherwise agreed to by the Secretary, prior to the commencement of construction, the Proponent shall confirm the methodology for the monitoring of formaldehyde from discharge points 2, 3, 4 and 5 in Table 6 to the satisfaction of EPA. The monitoring methodology agreed to by EPA shall apply to discharge points 2, 3, 4 and 5 for the purposes of condition 4.5.

Air Quality Performance Verification

4.7 Unless otherwise agreed to by EPA, the Proponent shall in consultation with EPA, prior to the commencement of construction, establish a meteorological station(s) at a representative location(s) to collect meteorological information representative of the Gloucester Valley, to enable air quality performance verification for the central processing facility in accordance with condition 4.8. At least one year's data must be collected for the purpose of undertaking the air quality performance verification required under condition 4.8 for the central processing facility.

4.8 Within 90 days of the commencement of operation of the project or as otherwise agreed by the Secretary, and during a period in which the project is operating under normal operating conditions, the Proponent shall undertake a program to confirm the air emission performance of the project to the satisfaction of the Secretary. The program shall include, but not necessarily be limited to:

a) point source emission sampling and analysis subject to the requirements listed under condition 4.5 to determine compliance with the discharge concentration limits identified in condition 3.31;
b) a comprehensive air quality impact assessment in accordance with the methods outlined in *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* (DECC, 2005), using actual air emission data collected under condition 4.5 to determine performance against the ground-level concentrations for air pollutants predicted for the project; and
c) details of any entries in the Complaints Register (condition 6.3 of this approval) relating to air quality impacts.

A report providing the results of the program shall be submitted to the Secretary and EPA within 28 days of completion of the testing required under a).

4.9 In the event that the program undertaken to satisfy condition 4.8 of this approval indicates that the operation of the project, under normal operating conditions, will lead to:

a) greater point source emissions than the discharge concentration limits identified in condition 3.31; or
b) greater ground-level concentrations of air pollutants than that predicted for the project in the documents listed under condition 1.1 of this approval;

then the Proponent shall provide details of remedial measures to be implemented to reduce point source emissions to no greater than the discharge concentration limits identified in condition 3.31 and to reduce ground-level concentrations of air pollutants to no greater than that predicted for the project in the documents listed under condition 1.1 of this approval and under no circumstance greater than the limits detailed in the *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* (DECC, 2005). Details of the remedial measures and a timetable for implementation shall be submitted to the Secretary for approval within such period as the Secretary may require, and be accompanied by evidence that the EPA is satisfied that the remedial measures are acceptable.

Hazard Audit

4.10 Twelve months after the commencement of operations of the project and every three years thereafter, or at such intervals as the Secretary may agree, the Proponent shall carry out a comprehensive Hazard Audit of the project and submit the audit report to the Secretary within one month of the audit report being completed. The audits shall be carried out by a qualified person or team, independent of the project and shall be consistent with the Department's Hazardous Industry Planning Advisory Paper No. 5, *'Hazard Audit Guidelines'*.

5. COMPLIANCE MONITORING AND TRACKING

5.1 The Proponent shall develop and implement a **Compliance Tracking Program** to track compliance with the requirements of this approval. The Program shall be submitted to the Secretary prior to the commencement of construction. The Program shall relate to both construction and operational stages of the project and shall include, but not necessarily be limited to:

a) provisions for periodic review of the compliance status of the project against the requirements of this approval, Statement of Commitments and relevant environmental approvals, licences or permits required and obtained in relation to the project;
b) provisions for periodic reporting of compliance status against the requirements of this approval and Statement of Commitments to the Secretary including at least one month prior to the commencement of construction and operation of the project;

c) a program for independent environmental auditing in accordance with *AS/NZ ISO 19011:2003 - Guidelines for Quality and/or Environmental Management Systems Auditing*; and

d) mechanisms for rectifying any non-compliance identified during environmental auditing or review of compliance.

6. COMMUNITY INFORMATION, CONSULTATION AND INVOLVEMENT

6.1 Subject to confidentiality, the Proponent shall make all relevant documents required under this approval available for public inspection on request.

Complaints Procedure

6.2 Prior to the commencement of construction of the project, the Proponent shall ensure that the following are available for community complaints for the life of the project (including construction and operation):

a) a telephone number on which complaints about construction and operational activities at the site may be registered;

b) a postal address to which written complaints may be sent; and

c) an email address to which electronic complaints may be transmitted.

The telephone number, postal address and email address shall be published in a newspaper circulating in the local area prior to the commencement of construction of the project. The above details shall also be provided on the website required by condition 6.4 of this approval.

6.3 The Proponent shall record details of all complaints received through the means listed under condition 6.2 of this approval in an up-to-date Complaints Register. The Register shall record, but not necessarily be limited to:

a) the date and time, where relevant, of the complaint;

b) the means by which the complaint was made (telephone, mail or email);

c) any personal details of the complainant that were provided, or if no details were provided, a note to that effect;

d) the nature of the complaint;

e) any action(s) taken by the Proponent in relation to the complaint, including any follow-up contact with the complainant and the timing for implementing action; and

f) if no action was taken by the Proponent in relation to the complaint, the reason(s) why no action was taken.

The Complaints Register shall be made available for inspection by the Secretary upon request.

The Complaints Register for the project may be incorporated into an existing complaints handling system managed by the Proponent if it is demonstrated to meet the requirements of condition 5.3.

Provision of Electronic Information

6.4 Prior to the commencement of construction of the project, the Proponent shall establish a dedicated website or maintain dedicated pages within its existing website for the provision of electronic information associated with the project subject to confidentiality. The Proponent shall publish and maintain up-to-date information on this website or dedicated pages including, but not necessarily limited to:

a) information on the statutory context and current implementation status of the project;

b) the documents referred to under condition 1.1 of this approval;

c) a copy of this approval and any future modification to this approval;

d) a copy of each relevant environmental approval, licence or permit required and obtained in relation to the project;

e) all plans, monitoring programs and strategies required under this project approval; and

f) details of the outcomes of compliance reviews and audits of the project.

Community and Stakeholder Engagement Plan

6.5 The Proponent shall prepare a **Community and Stakeholder Engagement Plan** which outlines measures for disseminating information on the development status of the project and methods for actively engaging with surrounding landowners, members of the community and affected stakeholders regarding issues that would be of interest/ concern to them during the detailed design, construction and operation of the project. This may include distribution of community newsletters, stakeholder meetings, community consultative committees and opportunities for site visits. The Plan shall include but not be limited to:

a) procedures to finalise the detailed design of the project including gas well locations and gas transmission pipeline route in consultation with landowners;

b) measure and procedures to work consultatively with landowners during construction and operational activities so as to minimise intrusion and disruption to existing landuse including agricultural activities;

c) measure and procedures to consult with affected stakeholders (including the owners of existing infrastructure within the proposed pipeline easement, mineral titleholders and quarry and mining operators) to minimise design, construction or operational impacts on existing infrastructure and future development potential and to manage cumulative impacts from neighbouring development;

d) procedures to inform the local community of planned construction activities including construction traffic routes, potential traffic disruptions, high noise generating activities and works outside of normal construction hours; and

e) dispute resolution processes in case of disagreement between parties including provision for an independent arbitrator.

The Community and Stakeholder Engagement Plan shall be submitted for the approval of the Secretary prior to the commencement of the detailed design stage of the project covering at least the community engagement and consultation measures to be implemented during the detailed design phase. An updated plan shall be subsequently submitted for the approval of the Secretary, prior to the commencement of the construction stage and prior to the commencement of the operational stage of the project covering the community engagement and consultation measures to be undertaken in these respective stages of the project.

7. ENVIRONMENTAL MONITORING AND MANAGEMENT

Environmental Representative

7.1 Prior to the commencement of any construction activities, or as otherwise agreed by the Secretary, the Proponent shall nominate for the approval of the Secretary a suitably qualified and experienced Environmental Representative(s) independent of the design, construction and operation personnel. The Proponent shall engage the Environmental Representative(s) during any construction activities. The Environmental Representative(s) shall:

a) oversee the implementation of all environmental management plans and monitoring programs required under this approval, and advise the Proponent upon the achievement of these plans/programs;

b) consider and advise the Proponent on its compliance obligations against all matters specified in the conditions of this approval and the Statement of Commitments as referred to under condition 1.1c) of this approval, and any other relevant environmental approval, licence or permit required and obtained in relation to the project; and

c) have the authority and independence to recommend to the Proponent reasonable steps to be taken to avoid or minimise unintended or adverse environmental impacts, and, failing the effectiveness of such steps, to recommend to the Proponent that relevant activities are to be ceased as soon as reasonably practicable if there is a significant risk that an adverse impact on the environment will be likely to occur.

Construction Environmental Management Plan

7.2 The Proponent shall prepare and implement a **Construction Environmental Management Plan** (CEMP) prior to the commencement of construction of the project to outline environmental management practices and procedures to be followed during construction of the project. The CEMP shall be consistent with *Guideline for the Preparation of Environmental Management Plans* (DIPNR, 2004) and shall include, but not necessarily be limited to:

a) a description of all activities to be undertaken on the site during construction including an indication of stages of construction, where relevant;
b) identification of the potential for cumulative impacts with other construction activities or existing development (including mining) in the vicinity and how such impacts would be managed;
c) identification of the location of temporary construction sites, details of construction material sourcing (including gravel and water requirements);
d) a description of the statutory obligations that the Proponent is required to fulfil prior to and during construction including all relevant approvals, licences and permits required and applicable key legislation and policies;
e) evidence of consultation with relevant public authorities including all applicable Councils, identifying how issues raised by these public authorities have been addressed in the plan;
f) a description of the roles and responsibilities for all relevant employees and contractors involved in the construction of the project including relevant training and induction provisions for ensuring that all employees, contractors and sub-contractors are aware of their environmental and compliance obligations under these conditions of approval;
g) an environmental risk analysis to identify the key environmental performance issues associated with the construction phase and details of how environmental performance would be monitored and managed to meet acceptable outcomes including what actions will be taken to address identified potential adverse environmental impacts. In particular, the following environmental performance issues shall be addressed in the Plan:
    i) measures to monitor and manage **dust emissions** including dust generated by traffic on unsealed public roads and unsealed internal access tracks;
    ii) measures to monitor and manage **noise, vibration and blasting** impacts with consideration to cumulative impacts from surrounding development including: identification of nearest sensitive receptors and relevant construction noise and vibration goals applicable, identification of all reasonable and feasible measures proposed to be implemented to minimise construction noise and vibration impacts (including construction traffic noise impacts), measures for notifying surrounding receptors of noisy activities or works outside of standard hours, measures for monitoring compliance and responding to complaints and contingency strategy in the case that project related vibration or blasting results in damage to buildings or structures;
    iii) measures to monitor and manage **traffic impacts** in consultation with relevant road authorities (Council and RMS, as relevant) including: identification of construction traffic routes and traffic volumes along each route with considering to minimising traffic on local/ residential streets, potential traffic disruptions considering road safety and level of service, specific measures for minimising traffic impacts and mechanisms to monitor road condition during construction and remediate any damage attributable to the project (should such remediation be required prior to the requirements of condition 3.455 taking effect);
    iv) measures to monitor and manage **Aboriginal heritage impacts** in consultation with registered stakeholders and OEH including:
        i. details of management measures to be carried out in relation to already recorded sites and potential Aboriginal deposits (including further archaeological investigations and/ or salvage measures);
        ii. procedures for dealing with previously unidentified Aboriginal objects excluding human remains (including halting of works in the vicinity, assessment of the significance of the item(s) and determination of appropriate mitigation measures including when works can re-commence by a qualified archaeologist in consultation with registered Aboriginal stakeholders, assessment of the consistency of any new Aboriginal heritage

impacts against the approved impacts of the project, and registering of the new site in the OEH AHIMS register);

iii. procedures for dealing with human remains (including halting of works in the vicinity and notification of the NSW Police, OEH and registered Aboriginal stakeholders and not-recommending any works in the area unless authorised by OEH and/ or the NSW Police); and

iv. Aboriginal cultural heritage induction processes for construction personnel and procedures for ongoing Aboriginal consultation and involvement; and

ii) emergency management measures including measures to control bushfires; and

h) procedures for the periodic review and update of the Construction Environmental Management Plan as necessary.

The Plan shall be submitted for the approval of the Secretary no later than one month prior to the commencement of Construction of the project or within such period as otherwise agreed by the Secretary. Construction shall not commence until written approval has been received from the Secretary.

7.3 As part of the Construction Environmental Management Plan for the project, required under condition 7.2 of this approval, the Proponent shall prepare and implement the following:

a) a **Flora and Fauna Management Plan** to manage the construction impacts of the project on flora and fauna. The Flora and Fauna Management Plan shall be prepared in consultation with the OEH and the Hunter LLS and shall include, but not necessarily be limited to:

(i) detailed constraint mapping of the final project area clearly identifying sensitive vegetation/habitat areas to be avoided and/or areas where site-specific management measures are required;

(ii) measures for minimising and managing impacts to native vegetation and important habitat features including but not necessarily limited to: pre-clearance surveys by a qualified ecologist to identify sensitive vegetation areas or habitat features (such as hollow bearing trees and surface rock) and weed and pest management (including phytophthora management);

(iii) measures to minimise disturbance of riparian and instream habitat including pre-construction surveys of each water crossing to identify habitat sensitivity (in particular habitat suitability for sensitive frog species) and measures to be undertaken to avoid and minimise impacts to riparian and instream habitat, including for sensitive frog species;

(iv) small-flower Grevillea Management strategy in consultation with the OEH and DoE to manage impacts to the population identified within the pipeline corridor including pre-construction baseline surveys to identify the distribution and extent of the species and construction methodology to minimise construction widths and disturbance as far as practicable;

(v) construction practices to avoid direct interaction/ injury to fauna including but not necessarily limited to:

i. timing of construction so as to take into account sensitive life cycle stages for sensitive species;

ii. pre-construction surveys for the presence of sensitive fauna by a qualified ecologist and protocols for the safe capture and release of fauna to adjacent habitat where fauna are identified to be in danger of injury or harm from construction; and

iii. measures to minimise the potential for fauna to get trapped in trenches during construction and measures for monitoring and rescuing any species should they become trapped including ensuring that monitoring and rescue measures are undertaken by a qualified ecologist; and

(vi) measures for progressive rehabilitation during construction including identification of performance indicators and completion criteria for revegetation works and measures for the monitoring and maintenance of revegetation works consistent with the requirements of condition 3.555;

b) a **Watercourse Crossing Management Strategy** prepared in consultation with NOW and DPI (Fisheries) to manage the construction impacts of pipeline waterway crossings including:
   (i) baseline surveys of each water crossing to identify habitat sensitivity and water course integrity;
   (ii) design details of each water course crossing;
   (iii) site specific mitigation measures to be implemented to minimise disturbance during construction; and
   (iv) rehabilitation requirements to stabilise bank structure and rehabilitate affected riparian vegetation including performance and completion criteria (based on base line surveys) and monitoring requirements; and

c) a **Soil and Water Management Plan** prepared in consultation with NOW and DPI (Fisheries) to manage the water quality impacts during construction. The plan shall detail:
   (i) pre-construction investigations including: soil testing to determine the likely potential for uncovering acid sulphate soils, investigation of the risk of groundwater interception (particularly, shallow perched groundwater tables) during pipeline trenching or horizontal directional drilling, and identification of any sites of potentially contaminated soils which require remediation prior to the commencement of construction (such as previous industrial land use or intensive agricultural activity);
   (ii) base-line water quality monitoring (both up stream and down stream of the construction sites) and where required pre-construction monitoring of groundwater quality (particularly where there is a high risk of groundwater interception coupled with potential acid sulphate soils);
   (iii) a management strategy to control acid sulphate soil impacts at any identified acid sulphate soil areas and should they be uncovered during construction (including measures for testing, treatment, and disposal; protection and treatment of groundwater; and contingency measures in the case of an incident);
   (iv) site specific erosion and sediment control plans (detailing measures to control and protect waterways from runoff, control measures in the case of groundwater interception, measures to minimise the extent and duration of soil disturbance, measures for ground stabilisation including progressive rehabilitation, and contingency measures in the case of an incident);
   (v) strategy for contaminated soil management should any such areas be uncovered during construction (including measures for pre-construction testing, treatment, and disposal; measures for surface groundwater protection; and contingency measures in the case of an incident); and
   (vi) a water quality monitoring strategy to monitor down stream impacts to water quality during the construction phase, including a program for monitoring groundwater quality (where required) and trigger and hold points for compliance actions should adverse water quality be detected.

Operation Environmental Management Plan

7.4 The Proponent shall prepare and implement an **Operation Environmental Management Plan** to detail an environmental management framework, practices and procedures to be followed during operation of the project. The Plan shall be consistent with *Guideline for the Preparation of Environmental Management Plans* (DIPNR 2004) and shall include, but not necessarily be limited to:

a) a description of key operational and maintenance activities associated with the project;
b) identification of all statutory and other obligations that the Proponent is required to fulfil in relation to operation of the project, including any approvals, licences, approvals and consultations;
c) a description of the roles and responsibilities for all relevant employees and contractors involved in the operation of the project including relevant training and induction provisions for ensuring that all employees, contractors and sub-contractors are aware of their environmental and compliance obligations under these conditions of approval;
d) overall environmental policies and principles to be applied to the operation of the project;

e) an environmental risk analysis to identify the key environmental performance issues associated with the operation phase and details of how environmental performance would be monitored and managed to meet acceptable outcomes including what actions will be taken to address identified potential adverse environmental impacts. In particular, the following environmental performance issues shall be addressed in the Plan:
   (i) measures to monitor and manage groundwater impacts including residual impacts following decommissioning of gas wells in accordance with conditions 4.1and 4.2;
   (ii) measures to monitor and manage flood risks including risks of equipment damage or disconnection during flood events and measures for clean up and restoration;
   (iii) measures to monitor and manage noise emissions including measures for regular performance monitoring of noise generated by the project (in addition to measures identified in conditions 4.3) and 4.4), measures to proactively respond to and deal with noise complaints and procedure for the development of a case-specific noise management protocol in consultation with EPA to manage short-term noise amenity impacts at surrounding receptors in the case of works identified in condition 3.222b);
   (iv) measures to monitor and manage air quality impacts in accordance with the requirements of this approval;
   (v) measures to monitor and manage landscape plantings and revegetation measures;
   (vi) measures to monitor and manage operational traffic impacts particularly during maintenance events where operational traffic volumes associated with the project may increase and procedures for restoring any damage attributable to the project during the operation phase;
   (vii) hazard and safety and emergency management measures including measures to control bushfires; and
   (viii) rehabilitation and completion criteria for the decommissioning and rehabilitation of the project; and

f) procedures for the periodic review and update of the Operation Environmental Management Plan as necessary.

The Operation Environmental Management Plan shall be submitted for the approval of the Secretary no later than one month prior to the commencement of Operation of the project or within such period as otherwise agreed by the Secretary. Operation shall not commence until written approval has been received from the Secretary.

APPENDIX 1
STATEMENT OF COMMITMENTS

Issue	Commitments
General (applicable to all four project components)	
General	1. The Proponent shall undertake the activities subject of the Project application in accordance with the general descriptions and details provided in this EA, including the mitigation and management measures recommended by this EA. 2. The Proponent will gain all necessary approvals and permits supporting both construction and operation. 3. The Proponent will prepare and implement the following management plans for the Project: • A Construction Environmental Management Plan (CEMP); and • An Operations Environmental Management Plan (OEMP). 4. The Proponent will ensure that the location of compound sites and other ancillary facilities are selected generally in line with the following : • In existing disturbed areas wherever possible; • Avoiding vegetation and riparian areas where possible; • Minimum of 40 m from a major watercourse and 20 m from a minor watercourse; • Avoiding Indigenous and European heritage places or items • Utilising existing access tracks where practicable; • Avoiding impacts on existing infrastructure • On relatively flat ground where possible; • Considering visual effects and opportunistic use of natural screening such as vegetation; • In consultation with landowners.
Further Studies	5. The Proponent shall prepare and implement the following studies, to the satisfaction of the Director General prior to the commencement of construction: • A Hazard and Operability Study; • A Final Hazard Analysis (update of the PHA); • A Fire Safety Study; • An Emergency Response Plan; • A Construction Safety Study. 6. The Proponent shall prepare/undertake the following to the satisfaction of the Director General prior to the commencement of operation of the Project: • A Safety Management System; • An Independent Hazard Audit.

Issue	Commitments
	7. The Proponent shall prepare a Petroleum Production Operations Plan in accordance with DPI requirements.
Air Quality	8. An Air Quality Management Plan (AQMP) will be prepared for inclusion in the CEMP. The Proponent will ensure that the AQMP outlines all activities required to minimise dust and vehicle emissions during the construction of the Stage 1 GFDA, CPF, pipeline and HDS. 9. The Proponent will ensure that the OEMP includes measures regarding monitoring, assessing and if required rectifying any air quality issues associated with the operation of the Stage 1 GFDA, CPF, pipeline and HDS.
Ecology	10. The Proponent shall ensure that all practicable measures are implemented to minimise the potential impacts on flora and fauna. 11. The Proponent shall manage the potential ecological impacts of the construction of the proposed project in accordance with the Flora and Fauna Management Plan which is to form part of the CEMP for the Project, as detailed in **Chapter 25** of this EA. 12. The Proponent shall manage the potential ecological impacts of the operation of the proposed project in accordance with the OEMP for the Project as detailed in **Chapter 25** of this EA. 13. Rehabilitation shall be undertaken in areas disturbed by the Project in accordance with a Landscape and Rehabilitation Management Plan (LRMP) as detailed in **Chapter 5, 10, 12** and **22** of this EA to ensure that the site is restored to existing or better conditions.
Land Use	14. The Proponent will ensure that ongoing consultation is undertaken with affected landowners throughout the detailed design phase of the Project and prior to and during the construction and operation phases of the Project. 15. The Proponent will adopt locational principles for siting of the construction workforce camps within the Stage 1 GFDA and proximate to the pipeline. 16. The Proponent will prepare and implement a Construction Workforce Management Plan as part of the CEMP to manage potential impacts associated with the construction workforce camps. 17. The Proponent will implement acoustic attenuation and mitigation where necessary as recommended by the Project noise assessment to ensure impacts upon surrounding land uses (particularly residential land) are minimised. 18. The Proponent will provide landscape screening as recommended in the visual assessment to ensure visual impacts are minimised. 19. The Proponent will negotiate access arrangements during construction and operation with relevant landholders and stakeholders in advance of commencement of works. 20. The Proponent will undertake rehabilitation as soon as practical upon completion of construction works to allow normal farming practices to resume. 21. The Proponent will ensure that access to properties and farming land is maintained during works. Should the works require closure of access, a detailed consultation program would be undertaken with affected

Issue	Commitments
	stakeholders and landholders. 22. The Proponent will ensure that upon completion of construction activities, disturbed areas (excluding the Stage 1 GFDA) would be rehabilitated to restore the areas to their original land use. 23. The Proponent will ensure that upon completion of the Project, the entire site would be rehabilitated, including restoration of the area to its original land use.
Water	24. The Proponent shall implement all practicable measures to minimise soil erosion and discharge of sediments from the various project sites. 25. The Proponent shall prepare and implement the following management plans as part of the CEMP for the Project prior to commencement of construction, as detailed in **Chapter 25**: • Construction Soil and Water Management Plan; • Erosion and Sediment Control Plan; • Acid Sulfate Soils Management Plan; • Emergency Response Plan. 26. The Proponent shall prepare and implement the following management plans as part of the OEMP for the Project, as detailed in **Chapter 25**: • Soil and Water Management Plan; • Emergency Response Plan.
Groundwater	27. The Proponent shall prepare and implement a Groundwater Management Plan (GWMP), as detailed in **Chapter 25.**
Noise	28. A Noise Management Plan (NMP) would be prepared as part of the CEMP to address construction noise and vibration, and methods to minimise impacts. 29. A NMP would also be prepared as part of the OEMP to address operation noise and vibration, particularly related to operation of the CPF and HDS and post-commissioning noise monitoring.
Hazard and Risk	30. The Proponent shall prepare and implement the following for the Project prior to commencement of construction, as detailed in **Chapter 15**: • Hazard and Operability Study; • Final Hazard Analysis (comprising an update of the PHA); • Fire Safety Study; • Emergency Response Plan. • A Construction Safety Study. 31. The Proponent shall undertake the following for the Project prior to commencement of operations, as detailed in **Chapter 15**: • Development of a Safety Management System • An Independent Hazard Audit. 32. The Proponent shall undertake the following specific mitigation measures in respect of the Stage 1 GFDA, CPF and HDS:

Issue	Commitments
	• Designed and operated in accordance with the relevant Australian Standards; • Security fencing would be installed around infrastructure as appropriate, including installation of a security fence around the HDS outside the hazardous area classified by AS 2430 to minimise risk of ignition sources; • Vehicle barriers would be installed around infrastructure where appropriate; • A regular program of maintenance/inspection of infrastructure would be adopted in accordance with the Proponent's standard procedure; • Gravel or hardstand area to be constructed inside the fenced site around gas filled equipment to minimise risk of grass fires; • Lightning protection to be fitted as appropriate; • Adoption of the Proponent's standard operating procedures in respect of the proposed facilities; • Monitoring of pressure via SCADA system. • Use of remotely operated ESD valves; • Ignition control as per AS2430 Hazardous Area requirements; • Appropriate separation distances to be maintained between release points and site boundary in accordance with the consequence impact distances reported in the PHA report; • Disused wells and coal holes encountered throughout the Stage 1 GFDA would be cemented to minimise the likelihood of gas migration.
Traffic and Transportation	33. The Proponent shall ensure that construction and operational traffic is managed in accordance with a Traffic Management Plan prepared and implemented as part of the CEMP and OEMP for the Project.
Geology and Soils	34. The Proponent shall prepare and implement the following management plans as part of the CEMP for the Project prior to commencement of construction, as detailed in **Chapter 25**: • Construction Soil and Water Management Plan; • Acid Sulfate Soils Management Plan.
Visual	35. The Proponent shall ensure that directional lighting is employed during construction, to minimise light spill from construction footprints, particularly for night time drilling. 36. The Proponent shall prepare and implement a Landscape and Rehabilitation Management Plan as part of the OEMP for the Project, to minimise potential visual impacts during operations.
Heritage	37. The Proponent shall prepare and implement a Heritage Management Plan as part of the CEMP for the Project, to minimise potential impacts on Aboriginal and/or historic heritage during operations.

Issue	Commitments
Socio Economic	38. The Proponent shall prepare and implant a site specific Construction Workforce Management Plan (CWMP) as part of the CEMP for the Project.
Rehabilitation	39. The Proponent shall prepare a Landscape and Rehabilitation Management Plan as part of the CEMP for the Project, as detailed in **Chapter 25.**
Waste	40. The Proponent shall prepare and implement a Waste Management Plan as part of the CEMP for the Project.
Stage 1 GFDA	
Air Quality	41. The Proponent will ensure that the Construction AQMP outlines activities required to minimise potential impacts to air quality from: • Flaring of wells during commissioning. • Dust and vehicle emissions during the construction of the Stage 1 GFDA. 42. The Proponent will ensure that the OEMP includes measures aimed at monitoring, assessing and if required rectifying any air quality issues associated with the operation of the Stage 1 GFDA.
Ecology	43. The Proponent shall implement the following measures to minimise clearing of native vegetation required for construction of the Stage 1 GFDA: • Place disturbance footprints of gas wells outside remnant vegetation patches (about 6% of GFDA) and at least 40 m from major watercourses. • Design gas gathering system to avoid large remnant vegetation patches and to cross watercourses at sites with no or limited native vegetation, wherever possible, based on further survey work.
Land Use	44. The Proponent shall adopt an environmental envelope approach to allow for the movement of proposed well locations within designated limits, in order to be able to address and accommodate constraints as they arise. 45. The Proponent will decommission each well upon expiration of the life of the well. Land comprising the Stage 1 GFDA will be rehabilitated and returned to its previous use.
Noise & Vibration	46. The proponent shall conduct construction activities that are generally between the following hours of 7.00 am to 6.00 pm Monday to Saturday. Where it is demonstrated that construction noise goals can be achieved construction would be undertaken outside these hours. 47. Fraccing to be undertaken only during daytime hours, subject to geological conditions. Secondary noise controls such as portable acoustic screens would be utilised for fraccing activities. 48. Activities associated with the construction of access tracks and the clearing of vegetation would be undertaken during daytime hours only.
Heritage	49. The Proponent shall prepare and implement a Heritage Management Plan as part of the CEMP for the Project, to minimise potential impacts on Aboriginal and/or historic heritage during operations.
CPF	
Air Quality	50. The Proponent will ensure that the AQMP outlines activities required to minimise potential impacts to air quality from dust and vehicle emissions

Issue	Commitments
	during the construction of the CPF. 51. The Proponent will ensure that the OEMP includes measures aimed at monitoring, assessing and if required rectifying any air quality issues associated with the operation of the CPF. .
Ecology	52. Place disturbance footprints of the CPF outside remnant vegetation patches and at least 40 m from major watercourses.
Land Use	53. The Proponent will decommission the CPF plant upon completion of the Project. CPF Site 1 will be redeveloped with a land use compatible with the land use zoning at the time of decommissioning.
Noise and Vibration	54. The proponent shall conduct construction activities that are generally between the following hours of 7.00 am to 6.00 pm Monday to Saturday. Where it is demonstrated that construction noise goals can be achieved construction would be undertaken outside these hours. 55. The Proponent shall undertake a program of noise monitoring once the CPF is operational in order to validate the design and mitigation measures applied to the facility. If required, further mitigation may be recommended following the monitoring program to ensure that operational noise is maintained in accordance with the relevant project noise goals. 56. The Proponent shall undertake the following design measures for the CPF plant to ensure that operational noise levels are maintained within the relevant project noise goals: 57. Following final plant selection and detailed design, the Proponent shall commission a further detailed operational noise assessment of the CPF plant to establish and confirm expected operational noise levels and inform detailed design of noise mitigation for the plant.
Hazard and Risk	58. The PHA should be updated when final design details are known, particularly for the operation of the flare. 59. Once final design details are known, a HAZOP of the design will be undertaken, particularly to assess abnormal operating modes such as flare and blowdown operations.
Pipeline	
General	60. The Proponent shall ensure that the pipeline is provided with marker tape at all sections of pipeline located within 35 m of residential development (as measured from the pipeline centreline). 61. Pipeline works, including construction, operation and decommissioning, would be undertaken in accordance with the recommendations in The Australian Pipeline Industry Association Limited – *Code of Environmental Practice – Onshore Pipeline (2005)* and AS 2885.
Air Quality	62. The Proponent will ensure that the Construction AQMP outlines activities required to minimise potential impacts to air quality from dust and vehicle emissions during the construction of the pipeline. 63. The Proponent will ensure that the OEMP includes measures aimed at monitoring, assessing and if required rectifying any air quality issues associated with the operation of the pipeline. .
Ecology	64. The Proponent shall implement all practicable measures to minimise potential impacts to flora and fauna from the construction of the pipeline in accordance with the Flora and Fauna Management Plan which is to form

Issue	Commitments
	part of the CEMP for the Project, as detailed in **Chapter 25** of this EA.
Land Use	65. The Proponent will ensure that where possible, the pipeline route remains within existing infrastructure easements. 66. The Proponent will ensure that the proposed pipeline is buried underground in accordance with AS2885 and protected by easements. The Proponent will ensure that future landowners and other stakeholders are aware of the location of the pipeline and any restrictions on the use of land within the easement. 67. Upon expiration of the life of the Project, the Proponent will abandon the pipeline in accordance with the regulator's guidelines. The easement will be extinguished from the title and the above ground infrastructure removed.
Noise and Vibration	68. Construction works would typically occur between 7.00am to 6.00pm, seven days per week with the exception of HDD which may need to be continued beyond typical construction hours in order to ensure the integrity and safety of the process. Blasting would typically occur between 9.00am to 5.00pm Monday to Friday, 9.00am to 1.00pm Saturday and no blasting on Sundays, if blasting is required. 69. The Proponent shall ensure that advanced notification of commencement of construction works is provided to potentially affected landowners indicating the length of time during which impacts may be experienced, the nature of potential impacts and a contact number for complaints to be recorded and responded to. 70. The Proponent shall ensure that works requiring the use of rock hammers do not occur within 20 m of a residence. 71. The Proponent shall ensure that works requiring blasting do not occur within 200 m of a residence.
Hazard and Risk	The Proponent shall undertake the following specific mitigation measures in respect of the pipeline: 72. The pipeline is to be provided with marker tape at all sections that would be located within a 35 m distance of residential development (as measured from the pipeline centreline) and or additional depth of cover in these areas. 73. Appropriate safety measures to be designed and adopted for sections of the pipeline which are in close proximity to 132 and 330 kV power lines to ensure the safety of personnel and equipment. These measures may include: • Selective earthing at certain positions along the pipeline; • Installation of zinc ribbon in the pipeline trench; • Installation of inline isolation in the pipeline; • Restriction of access to the pipeline and its facilities; • Use of equi-potential grids or other similar safety equipment during maintenance of the pipeline; and • Use of lockable test points for the cathodic protection system. 74. Preparation of a Construction Safety Study in respect of the pipeline. This

Issue	Commitments
	study should address general construction safety requirements as well as specific locational hazards such as AC induction. 75. Pipeline to be designed and operated in accordance with AS 2885-2007. Pipeline design to meet the requirements for T1 locations, being rural areas developed for residential, commercial or industrial use, where allotments are less than 1 hectare in area and buildings do not exceed four floors. 76. Regular maintenance/inspection of pipeline in accordance with the Proponent's standard procedures. 77. Relieving of stress where ground movement stresses pipework. 78. Installation of marker signs and marker tape along the length of the pipeline to alert people to the presence and location of the pipeline. Signage to include details of 'One-Call'/'Dial before-you-dig' services. 79. External surfaces of pipeline to be coated to protect against corrosion. Testing of the integrity of the coating ('Holiday' detection) to be carried out prior to burial of the pipeline. 80. Use of sacrificial anode cathodic protection system to provide further protection against corrosion. 81. Gas quality to be such that corrosion enhancing components are minimised. 82. Intelligent pigging of the pipeline to be carried out to assess pipeline condition every 5-10 years. 83. Regular patrolling of pipeline by the Proponent to assess for damage or activities which have the potential to cause damage to the pipeline. Patrols would also facilitate detection of ground movement or land subsidence. Where significant ground movement is detected and stresses are determined to be high, the ground around the pipeline/gathering line would be dug up to relieve stresses. 84. Pipeline design to make provision for current subsidence parameters for the location (as provided by the Mine Subsidence Board), where required. 85. Liaison with Mine Subsidence Board to determine the location and details of likely future mining activity in the vicinity of the pipeline.

APPENDIX 2
STATEMENT OF COMMITMENTS (MOD 1)

Environmental attribute	Recommendation/management	Relevant Project approval condition
Ecology		
Seaham	Surrounding remnant vegetation • Implement sedimentation and erosion controls • Undertake follow up weed control	3.2, 7.3(a), 7.3(c)
	Waterways • Implement sediment and erosion controls before trenching of watercourses (ID to 138 to 141)	3.2, 7.3(c)
Brandy Hill	Native vegetation in alignment • Limit clearing in areas of remnant and regrowth vegetation • Implement sedimentation and erosion controls • Undertake follow up weed control	3.2, 7.3(a), 7.3(c)
	Swamp Oak Floodplain Forest (EEC) – Mapped as 'Marginal" habitat for Koala under the Port Stephens Council CKPoM. • Minimise ROW to 15 m width • Implement and regularly check sediment and erosion controls	3.2
	Hunter Lowland Redgum Forest (EEC) • Minimise ROW to 15 m width • Implement and regularly check sediment and erosion controls	3.2, 7.3(a), 7.3(c)
	Adjacent Barties Creek (constructed irrigation channel) • Implement and regularly check sediment and erosion controls	3.2, 7.3(c)
Tomago	Swamp Oak Floodplain Forest (EEC) • Minimise ROW to 15 m width • Implement and regularly check sediment and erosion controls	3.2, 7.3(a), 7.3(c)
	Tributary of Francis Greenway Creek • Implement sediment and erosion controls before trenching	3.2, 7.3(c)

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Environmental attribute	Recommendation/management	Relevant Project approval condition
	Hunter River • Underboring or HDD will be set back from the riparian areas to avoid the fringing Mangrove Forest and patch of Swamp Oak Forest (EEC) at KP 91 (Rev F)	7.3(c)
Aboriginal cultural heritage		
All sections	Disturbance of previously unidentified Aboriginal objects • AGL will cease work in the immediate vicinity if during the course of construction, they become aware of any previously unidentified Aboriginal objects	3.35 and 7.2(iv)
	Management of construction activities and consultation with RAPs • AGL will implement measures to manage potential impacts and consult with the RAPs during construction of the proposed pipeline corridor realignments	
Noise		
All sections and the TRS	Construction noise management to minimise impacts to nearby receptors • Construction activities of the modified pipeline and the TRS will be managed and impacts to surrounding nearby receptors minimised.	3.14, 3.15, 3.17, 7.2(g)
	Blasting management to minimise impacts to nearby receptors • Blasting activities of the modified pipeline and the TRS will be managed and impacts to surrounding nearby receptors minimised.	3.18, 3.20, 3.21
	Management of complaints during construction and operation • Complaints from the community regarding construction and operational activities of the modified pipeline and the TRS will be managed and handled appropriately.	6.2, 6.3
TRS	Operational noise management to minimise impacts to nearby receptors • Operational noise of the TRS will be managed and impacts to surrounding nearby receptors minimised.	3.24, 7.4(e)iii
Hazard and risk		
Seaham	MLV final location • AGL will prepare a FHA which will provide a quantitative evaluation of the risk	3.47(c)
Tomago	The placement of the pipeline in proximity to an existing high pressure pipeline in the cleared easement to the TRS • AGL will prepare a FHA which provide a quantitative evaluation of the risk	3.47(c)
	The potential for excess dosing at the odourant facility either within the TRS or within the NGSF • AGL will prepare a HAZOP study which will include analysis and mitigation for the final location of the odourant facility	3.47(b)
Soils		
All sections	Encountering ASS during construction activities • The existing draft ASSMP will be finalised to incorporate the modified pipeline corridor alignment	1.1(f), 7.3(c)i and iii

Environmental attribute	Recommendation/management	Relevant Project approval condition
Surface water		
All sections	Watercourse crossings • The revised watercourse crossings due to the proposed modification will be included within the Watercourse Crossing Management Strategy Ground disturbance • Construction activities will manage soil and erosion to minimise effects to surface water quality, both in the immediate area and downstream	3.4, 7.3(b)
Groundwater		
All sections	Groundwater interception with ASS during trenching • The modified sections will require pre-construction investigations to be undertaken in relevant areas to determine ASS and implementation of appropriate management strategies	7.3(c)i
Air quality		
Tomago	TRS discharges to air due to dual water bath heaters • A discharge monitoring point will be established at the TRS and monitor relevant emissions similar to the requirements of the HDS stated in the Project approval	3.30, 3.31 and 4.5
Socio-economic		
All sections	Community stakeholder engagement • The Community and Stakeholder Engagement Plan will be updated to incorporate the modified pipeline corridor alignment	6.5
Visual		
Tomago	Building materials • AGL will consider the use of building materials and treatments for the TRS which visually complement the surrounding land uses	3.40

Australian Government

Department of Sustainability, Environment, Water, Population and Communities

Approval

Gloucester Coal Seam Methane Gas Project, Gloucester region, New South Wales (EPBC 2008/4432)

This decision is made under sections 130(1) and 133 of the *Environment Protection and Biodiversity Conservation Act 1999*.

proposed action

person to whom the approval is granted	AGL Upstream Infrastructure Investments Pty Ltd
proponent's ACN	092 684 010
proposed action	To construct, operate and decommission: • not more than 110 coal seam gas wells and associated infrastructure including gas and water gathering lines; • a central processing facility (at one of two proposed alternative sites); • a gas receiving station at Hexham; and • a pipeline from the central processing facility to the Hexham receiving station; as described in the referral received on 29 August 2008 and subsequently varied on 1 May 2012 (referral EPBC 2008/4432).

approval decision

controlling provision	decision
wetlands of international importance (sections 16 & 17B)	approve
listed threatened species and communities (sections 18 & 18A)	approve

conditions of approval

This approval is subject to the conditions specified below.

expiry date of approval

This approval has effect until 30 November 2062.

decision-maker	
name and position	The Hon Tony Burke MP Minister for Sustainability, Environment, Water, Population and Communities
signature	Tony Burke
date of decision	11 February 2013

Conditions attached to the approval

Scope of proposal

1. The person taking the action must ensure that the action is undertaken in accordance with the ***finalised assessment documentation*** and entirely within the Stage 1 Gas Field Development Area and Pipeline Corridor as identified in Attachments 1 and 2 to the conditions of this approval.

2. The following ***disturbance limits*** apply to the action:
   - 1000 individuals (loss or damage) in the case of small-flower grevillea (*Grevillea parviflora* subsp. *parviflora*).

Pre-clearance surveys

3. At least three months prior to ***clearance of native vegetation*** within a defined area, a suitably qualified person with prior written approval of ***the department*** must undertake pre-clearance surveys for ***listed threatened species*** (including their habitat) ***and communities*** within that defined area. Surveys must be undertaken in accordance with current relevant survey guidelines published by ***the department***, or best practice if no guidelines are available.

   Alternatively, recent surveys undertaken prior to this approval may satisfy this condition if ***the department*** agrees in writing that they are adequate.

4. Reports must be prepared in relation to any surveys (including but not limited to pre-clearance surveys) by a suitably qualified person with prior written approval of ***the department***, and must include information on:

   a) survey methodology (including reasons for any deviation from relevant survey guidelines if any have been published by ***the department***) and habitat definitions / threshholds used;

   b) results;

   c) analysis of significant findings (including quality, size and location of any habitat identified); and

   d) personnel involved and their qualifications.

   Survey reports must be published by the person taking the action on their website for the duration of this approval within three (3) months of completion of the corresponding survey, and be provided to ***the department*** on request.

Alternatively, recent reports prepared prior to this approval may satisfy this condition if ***the department*** agrees in writing that they are adequate.

Species management plans

5. If a ***listed threatened species*** (or species habitat) ***or community*** (other than small-flower grevillea, green and golden bell frog or giant barred frog) is encountered during a pre-clearance survey (or at any other time), prior to any further ***clearance of native vegetation*** which has been identified as supporting a ***listed threatened species*** (or species habitat) ***or community***, the person taking the action must provide ***the minister*** with the survey report prepared under Condition 4. ***The minister*** may direct the person taking the action to prepare a management plan for the ***listed threatened species*** (or species habitat) ***or community***. The plan must be prepared by a suitably qualified person with prior written approval of ***the department*** and must include:

   a) discussion of distribution and current legal status;

   b) discussion of key ecological features of the species or community;

   c) discussion of the biology and reproductive needs of the species (if a species);

   d) discussion and working definition(s) of "habitat" (if a species), considering:

      i. habitat function (for example distinguishing where relevant between breeding habitat and foraging habitat); and

      ii. habitat quality (with reference to both key features and landscape context);

   e) results of targeted surveys, including quantification of occurrence or habitat extent and a map of the location of the species or community occurrence on the site of the action (or its area of influence);

   f) description of measures that will be employed to avoid or mitigate impacts on the species or community;

   g) quantification of any unavoidable impact (expressed as an area in hectares in the case of a community or fauna habitat or number of individuals); and

   h) a detailed description of measures to ***offset*** that impact (including in relation to direct ***offsets***, size, location, ecological attributes and mechanisms for legal ensuring enduring protection).

   Clearance of native vegetation which has been identified as supporting a ***listed threatened species*** (or species habitat) ***or community*** may only recommence on the written authorisation of ***the minister*** or the approval by ***the minister*** of a species management plan.

   Each approved species management plan must be published by the person taking the action on their website, for the duration of this approval, within twenty (20) business days of its approval by ***the minister***, and must be implemented.

Green and golden bell frog management

6. A suitably qualified person with prior written approval of ***the department*** must undertake targeted surveys for the green and golden bell frog (*Litoria aurea*) in all potential habitat within twenty (20) metres of the entire pipeline route and within twenty (20) metres of any proposed infrastructure. Surveys must be undertaken in accordance with current relevant survey guidelines published by ***the department***, or best practice if no guidelines are available.

Alternatively, recent surveys undertaken prior to this approval may satisfy this condition if ***the department*** agrees in writing that they are adequate.

7. A green and golden bell frog management plan must be prepared for each ***component of the action*** by a suitably qualified person with prior written approval of ***the department***. The plan must include:

   a) discussion of distribution and current legal status;

   b) discussion of key ecological,biological and reproductive needs;

   c) discussion and working definition(s) of habitat for the species, considering:

      i. habitat function (for example distinguishing where relevant between breeding habitat and foraging habitat); and

      ii. habitat quality (with reference to both key features and landscape context);

   d) results of targeted surveys, including quantification of occurrence and habitat extent and a map of the location of occurrence on the site of the action (and its area of influence);

   e) description of measures that will be employed to avoid or mitigate impacts;

   f) quantification of any unavoidable impact (expressed in terms of habitat and individuals) with a detailed description of measures to ***offset*** that impact (including in relation to direct ***offsets***, size, location, ecological attributes and mechanisms for legal ensuring enduring protection);

   g) measures for the monitoring (using at least eight (8) reference sites), and remediation as required, of impacts of the operation of the gas field on sites of potential habitat, including:

      i. surface expression of methane gas;

      ii. water pollution including salinity;

      iii. water drawdown; and

      iv. any impacts on surface water; and

   h) a list of personnel involved in survey and management activities and their qualifications.

   The plan must be approved by ***the minister*** prior to ***commencement*** of the relevant ***component of the action***, and the approved plan must be implemented.

   Note: Plans prepared under Conditions 7 and 10 may be combined.

8. Within three (3) months of completion of the risk analysis described in Condition 19, the person taking the action must update the management plan described in Condition 7 to incorporate:

   a) results of the risk analysis;

   b) additional surveys (undertaken by a suitably qualified person with prior approval of the department, in accordance with current relevant survey guidelines published by ***the department***, or best practice if no guidelines are available) wherever either of the hydrogeological models described in Conditions 16 and 18 predict impacts on surface water;

   c) if necessary, a description of revised measures that will be employed to avoid or mitigate impacts on the species or community; and

   d) if necessary, revised quantification of any unavoidable impact (expressed as an area in hectares or number of individuals) with a description of measures to ***offset*** that impact.

The updated plan must be approved by ***the minister*** prior to the commissioning of the approved central processing facility, and once approved must be implemented.

Giant barred frog management

9. A suitably qualified person with prior written approval of ***the department*** must undertake targeted surveys for giant barred frog (*Mixophyes iterates*) in all potential habitat within twenty (20) metres of the entire pipeline route and within twenty (20) metres of any proposed infrastructure. Surveys must be undertaken in accordance with current relevant survey guidelines published by ***the department***, or best practice if no guidelines are available.

   Alternatively, recent surveys undertaken prior to this approval may satisfy this condition if ***the department*** agrees in writing that they are adequate.

10. A giant barred frog management plan must be prepared for each ***component of the action*** by a suitably qualified person with prior written approval of ***the department***. The plan must include:

    a) discussion of distribution and current legal status;

    b) discussion of key ecological biological and reproductive needs;

    c) discussion and working definition(s) of habitat for the species, considering:

       i. habitat function (for example distinguishing where relevant between breeding habitat and foraging habitat); and

       ii. habitat quality (with reference to both key features and landscape context);

    d) results of targeted surveys, including quantification of occurrence and habitat extent and a map of the location of occurrence on the site of the action (and its area of influence);

    e) description of measures that will be employed to avoid or mitigate impacts;

    f) quantification of any unavoidable impact (expressed in terms of habitat and individuals) with a detailed description of measures to ***offset*** that impact (including in relation to direct ***offsets***, size, location, ecological attributes and mechanisms for legal ensuring enduring protection);

    g) measures for the monitoring (using at least eight (8) reference sites), and remediation as required, of impacts of the operation of the gas field on sites of potential habitat, including:

       i. surface expression of methane gas;

       ii. water pollution including salinity;

       iii. water drawdown; and

       iv. any impacts on surface water; and

    h) a list of personnel involved in survey and management activities and their qualifications.

    The plan must be approved by ***the minister*** prior to ***commencement*** of the relevant ***component of the action***, and the approved plan must be implemented.

    Note: Plans prepared under Conditions 7 and 10 may be combined.

11. Within three (3) months of completion of the risk analysis described in Condition 19, the person taking the action must update the management plan described in Condition 10 to incorporate:

a) results of the risk analysis;

b) additional surveys (undertaken by a suitably qualified person with prior approval of the department, in accordance with current relevant survey guidelines published by ***the department***, or best practice if no guidelines are available) wherever either of the hydrogeological models described in Conditions 16 and 18 predict impacts on surface water;

c) if necessary, a description of revised measures that will be employed to avoid or mitigate impacts on the species or community; and

d) if necessary, revised quantification of any unavoidable impact (expressed as an area in hectares or number of individuals) with a description of measures to ***offset*** that impact.

The updated plan must be approved by ***the minister*** prior to the commissioning of the approved central processing facility, and once approved must be implemented.

Small-flower grevillea management

12. The person taking the action must prepare a plan for the management of small-flower grevillea on each ***component of the action***. The plan must include:

a) discussion of preferred habitat of the species, known distribution and current legal status;

b) discussion of key ecological features of the species;

c) discussion of the biology and reproductive needs of the species;

d) a map and ***shapefiles*** of the location of the species at the site of the action;

e) a description of measures that will be employed to avoid or mitigate impacts on the species at the site of the action, specifically addressing the following;

   i. access, signage and fencing;

   ii. fire management;

   iii. browsing management;

   iv. weed and pathogen management;

   v. post construction rehabilitation;

   vi. measures for monitoring and reporting on the health of the population including in particular, survival and recruitment;

   vii. performance measures and response actions (if performance measures are not met); and

f) a list of personnel involved in survey and management activities and their qualifications: and

g) an assessment of offset requirements consistent with the *Environment Protection and Biodiversity Conservation Act 1999 Biodiversity Offsets Policy* (October 2012).

The plan must be approved by ***the minister*** prior to the removal of any small-flower grevillea plants, and the approved plan must be implemented.

Note: Plans prepared under Conditions 12 and 14 may be combined.

13. The person taking the action must secure enduring protection of, and actively manage, habitat suitable for the conservation of small-flower grevillea (the offset site) in accordance with the plans referred to in Conditions 12 and 14.

14. The person taking the action must prepare a plan for the management of small-flower grevillea at the offset site. The plan must include:

    a) discussion of preferred habitat of the species, known distribution and current legal status;
    b) discussion of key ecological features of the species;
    c) discussion of the biology and reproductive needs of the species;
    d) documentary evidence of enduring protection of the offset site;
    e) a map and ***shapefiles*** of the offset site;
    f) a description of measures that will be employed to establish and / or maintain a population, with reference to;
        i. access, signage and fencing;
        ii. fire management;
        iii. browsing management;
        iv. weed and pathogen management;
        v. post construction rehabilitation;
        vi. propagation methods (if relevant)
        vii. measures for monitoring and reporting on the health of the population including in particular, survival and recruitment; and
        viii. performance measures and response actions (if performance measures are not met); and
    g) a list of personnel involved in survey and management activities and their qualifications.

    The plan must be approved by ***the minister*** prior to the removal of any small-flower grevillea plants, and the approved plan must be implemented.

    Note: Plans prepared under Conditions 12 and 14 may be combined.

Conditions for the protection of water resources

15. The person taking the action must comply with Conditions 3.5 to 3.13 and 4.1 to 4.2 of the ***state approval conditions***.

    Note: It is noted that some of the requirements of ***state approval conditions*** are similar to requirements under the conditions of this approval. While no unnecessary duplication is intended, where requirements are similar, the conditions of this approval must be met in full.

16. The person taking the action must consult the department on the development of the conceptual hydrogeological model required under Conditions 3.8 and 3.9 of the ***state approval conditions***, and must provide a copy of the model to the department within twenty (20) business days of its finalisation.

17. The person taking the action must revise the water balance model to:

a) take into account the following inputs:

i. field-based investigation of the spatial distribution of strata and structures within the project area and the role of faulting and its influence on migration of groundwater and/or gas into surface water systems;

ii. investigation of the age, depth and location of groundwater including proximity to known faults and fractures;

iii. a baseline investigation of gas occurrence in surface and groundwater;

iv. results from pilot testing of the Stratford and Waukivory pilot wells;

v. baseline data associated with Phase 1 and Phase 2 studies;

vi. information on the assessment of a representative site for fault testing; and

b) extend to 1000 metres below ground level;

c) ensure that all hydrological inputs and outputs are accounted for (sum to zero); and

d) include a list of information sources and statements on confidence, accuracy and precision.

A report on the revised water balance model, including the inputs described in a) above, must be approved by ***the minister*** prior to the finalisation of the numerical hydrogeological model (refer to Condition 18).

18. The person taking the action must provide ***the minister*** with a numerical hydrogeological model that explores the pressure at which gas and water may be released and transmitted along faults. The model must be based on the water balance model described in Condition 17 and informed by monitoring data, for example as collected in accordance with Condition 4.1 of the ***state approval conditions***.

The model must be approved by ***the minister*** prior to the commissioning of the approved central processing facility.

Note: It is expected that ***the minister*** will require the model to be peer-reviewed prior to approval.

19. Within three (3) months of the approval of the numerical hydrogeological model described in Condition 18, or the conceptual hydrogeological model required under Conditions 3.8 and 3.9 of the ***state approval conditions*** (whichever is the later), the person taking the action must use the models to complete a risk analysis in relation to the following potential impacts on the green and golden bell frog and giant barred frog, and their potential habitats:

a) surface expression of methane gas;

b) water pollution including salinity;

c) water drawdown; and

d) any impacts on surface water.

20. Prior to undertaking any hydraulic fracturing, the person taking the action must provide ***the minister*** with the following details on any hydraulic fracturing agents or other reinjected fluids likely to be used under this approval:

a) estimated number and location (mapped, and expressed in latitude, longitude and depth) of wells where the agent or fluid may be used;

b) Chemical Abstracts Service Number;

c) typical load;

d) typical concentration; and

e) toxicity as total effluent toxicity and ecotoxicity, based on methods outlined in the ***National Water Quality Management Strategy***.

This information must be updated prior to the first use of any new any hydraulic fracturing agents or other reinjected fluids.

No agents or fluids may be used without the prior written approval of ***the minister***.

21. The person taking the action must provide ***the department*** with a copy of the extracted water management strategy (also known as produced water management strategy) required under ***state approval conditions***. If the strategy is not to the satisfaction of ***the minister*** (and in particular if it does not consider the feasibility and likely effectiveness of reinjection of extracted water), he may require a supplement to be developed, which must be approved by ***the minister*** prior to ***commencement*** of the action, and must be implemented.

22. The person taking the action must ensure that no more than 2 megalitres per day (averaged over a twelve month period) of groundwater is extracted. In addition, the person taking the action may only extract sufficient groundwater as is required to undertake the action in accordance with the conditions of this approval.

23. The person taking the action must ensure that any water storage ponds associated with the action are appropriately lined to ensure no leaching of stored waters and designed consistent with a 1 in 100 year flood design standard.

24. The person taking the action must prepare an acid sulphate soils management plan (or plans, based on ***components of the action***) to predict, detect, map and manage acid sulphate soils along the entire pipeline route, on and adjacent to the sites of any proposed infrastructure. The plan must be approved by ***the minister*** prior to ***commencement*** of the relevant ***component of the action***, and must be implemented. The person taking the action must ensure that the plan is updated (at least quarterly) as field work progresses and site specific information becomes available. The plan must also ensure an appropriate regime for reporting water quality monitoring results to the New South Wales Government.

25. The person taking the action must provide ***the department*** with a copy of the watercourse crossing management strategy required by ***state approval conditions***. If the strategy is not to the satisfaction of ***the minister***, he may require a supplement to be developed, which must be approved by ***the minister*** prior to ***commencement*** of the action, and must be implemented. In particular, it is expected that the strategy should include:

a) baseline surveys of each crossing to identify any habitat for ***listed threatened species and communities***; and

b) design details of each watercourse crossing to avoid and mitigate impacts on ***wetlands of international importance*** and ***listed threatened species and communities***.

Standard and administrative conditions

26. Within twenty (20) business days after the ***commencement*** of the action, the person taking the action must advise ***the department*** in writing of the actual date of ***commencement***.

27. If, at any time after five (5) years from the date of this approval, the person taking the action has not ***substantially commenced*** the action, then the person taking the action must not ***substantially commence*** the action without the written agreement of ***the minister***.

28. Unless otherwise agreed to in writing by ***the minister***, the person taking the action must publish all ***management documents*** referred to in the conditions of this approval on their website, within twenty (20) business days of being approved. A ***management document*** must be published in a specified location or format and / or with specified accompanying text, if requested by ***the minister***.

29. If the person taking the action wishes to carry out any activity otherwise than in accordance with a relevant ***management document***, the person taking the action must submit to ***the department*** for ***the minister***'s written approval a revised version of that ***management document***. The varied activity shall not commence until ***the minister*** has approved the varied ***management document*** in writing. ***The minister*** will not approve a varied ***management document*** unless the revised ***management document*** would result in an equivalent or improved environmental outcome over time. If ***the minister*** approves the revised ***management document***, that ***management document*** must be implemented in place of the ***management document*** originally approved.

30. If ***the minister*** believes that it is necessary or convenient for the better protection of wetlands of international importance, or listed threatened species and communities, to do so, ***the minister*** may request that the person taking the action make specified revisions to a ***management document*** specified in the conditions of this approval and submit the revised ***management document*** for ***the minister***'s written approval. The person taking the action must comply with any such request. The revised approved ***management document*** must be implemented. Unless ***the minister*** has approved the revised ***management document***, then the person taking the action must continue to implement the ***management document*** originally approved, as specified in the conditions of this approval.

31. The person taking the action must maintain accurate records substantiating all activities associated with or relevant to the conditions of this approval, including measures taken to implement ***management documents*** required by this approval, and make them available upon request to ***the department***. Such records may be subject to audit by ***the department*** or an independent auditor in accordance with section 458 of the EPBC Act, or used to verify compliance with the conditions of this approval. Summaries of audits will be posted on ***the department***'s website. The results of audits may also be publicised through the general media.

32. ***The person taking the action*** must:
    a) report any non-compliance with these conditions or a ***management document*** to ***the department*** within five (5) business days of the date of the incident;
    b) discuss with ***the department*** how the matter may be brought into compliance within a reasonable timeframe; and
    c) comply with any consequent written direction from ***the minister*** regarding the matter.

33. By 30 November of each year after the ***commencement*** of the action, the person taking the action must publish an annual report on their website addressing compliance (including any non-compliance) with the conditions of this approval, including any ***management documents***, since the previous compliance report. The report must specifically include the following:
    a) a reconciliation statement comparing impacts on small-flower grevillea against the ***disturbance limit*** for the species;
    b) a summary of well activity for the past year, including:
        i. number and spatial distribution of extant wells (mapped and also expressed in latitude, longitude and depth);
        ii. identification of which wells are new, continuing, inactive and exhausted since the previous compliance report;
        iii. information on how many times each well has been hydraulically fractured;
        iv. information on all hydraulic fracturing agents and other reinjected fluids as per Condition 20;
        v. information on volumes of gas and water produced by each well; and
        vi. identification of which wells have been implicated in incidents of non-compliance.
    c) a forecast of well activity (including hydraulic fracturing) for the coming year.

34. Upon the direction of ***the minister***, the person taking the action must ensure that an independent audit of compliance with the conditions of this approval is conducted (at the expense of the person taking the action) and a report submitted to ***the department***. The independent auditor and audit criteria must be approved by ***the minister*** prior to the commencement of the audit. The audit report must address the criteria to the satisfaction of ***the minister***.

35. The person taking the action must provide all data and related information from ecological surveys relevant to this approval or otherwise to ***matters of national environmental significance***, if requested by ***the department***.

36. The person taking the action must provide ***the department*** with a copy of any management document required under a state government approval, if requested by ***the minister***.

Definitions applying to the conditions

Clearance of native vegetation means the complete or partial removal, by any means, of plants native to the site of the action. Note that native vegetation can include grasslands.

Commencement of the action (except in the sense of ***substantial commencement***), includes the construction of any infrastructure associated with the proposed action, excluding geotechnical and survey works, signage, fencing, unsealed roads not requiring ***clearance of native vegetation***.

Completion of the action includes all rehabilitation and remediation works planned or required under these or any other conditions on approval, noting that this approval expires on 30 November 2062.

The ***components of the action*** are:

- areas of the Stage 1 Gas Field as defined by the proponent
- the central processing facility (at either of the proposed locations)
- areas of the pipeline route as defined by the proponent

A ***disturbance limit*** is the maximum impact (expressed as an area or a number of individuals) on wetlands of international importance or listed threatened species and communities that may occur as a direct consequence of the action before specified consequences are triggered. Disturbance limits do not apply to indirect impacts such as impacts of the action on water resources that may affect protected matters.

Management documents are any plans, strategies, reports or other documents required by the conditions of this approval that direct or report on management arrangements for the proposal. To avoid any doubt, multiple management documents (including those required under a state approval) may be combined, provided that the person taking the action, when submitting the documents, explains how they have been arranged.

Matters of national environmental significance are as defined in the EPBC Act, and include ***wetlands of international importance***, and ***listed threatened species and / or communities***.

National Water Quality Management Strategy is the policies, processes and guidelines in effect at the time of approval that together comprises the National Water Quality Management Strategy.

Offset means "compensate for", and is interpreted in light of the *Environment Assessment and Biodiversity Conservation Act 1999 Environmental Offsets Policy*, October 2012 (or as updated).

Phase 1 refers to a completed desktop study, *Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model*. SRK Consulting, 2010.

Phase 2 refers to a detailed groundwater investigation initiated in November 2010, as described in information provided by the person taking the action 1 August 2011.

A ***shapefile*** is an ESRI Shapefile, containing .shp, .shx and .dbf files and other files capturing attributes including at least the EPBC reference number of the proposaland matters of national environmental significance present at the relevant site Attributes should also be captured in .xls format.

State approval conditions are those conditions imposed by the NSW Planning Assessment Commission on the Gloucester Coal Seam Gas Project under section 75J of the *Environmental Planning and Assessment Act 1979* and reflected in the corresponding project approval notice signed 22 February 2011.

Substantial commencement means the drilling of any wells subject to this approval, to a depth of at least 100 metres.

The department is the Australian Government department administering the ***EPBC Act***.

The ***EPBC Act*** is the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.*

The minister is the Australian Government minister administering the ***EPBC Act*** and includes delegates of ***the minister*** as established by a relevant legal instrument.

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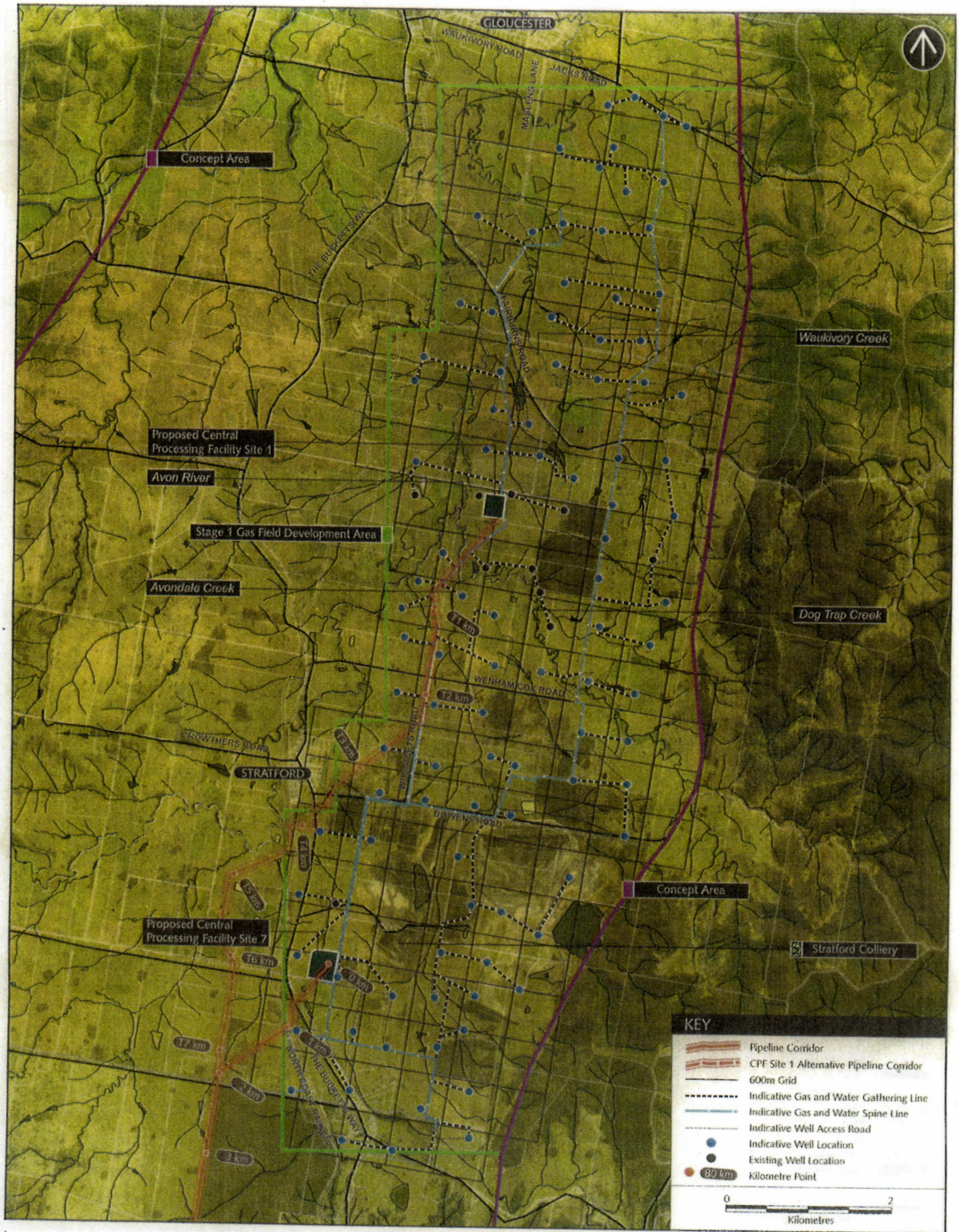
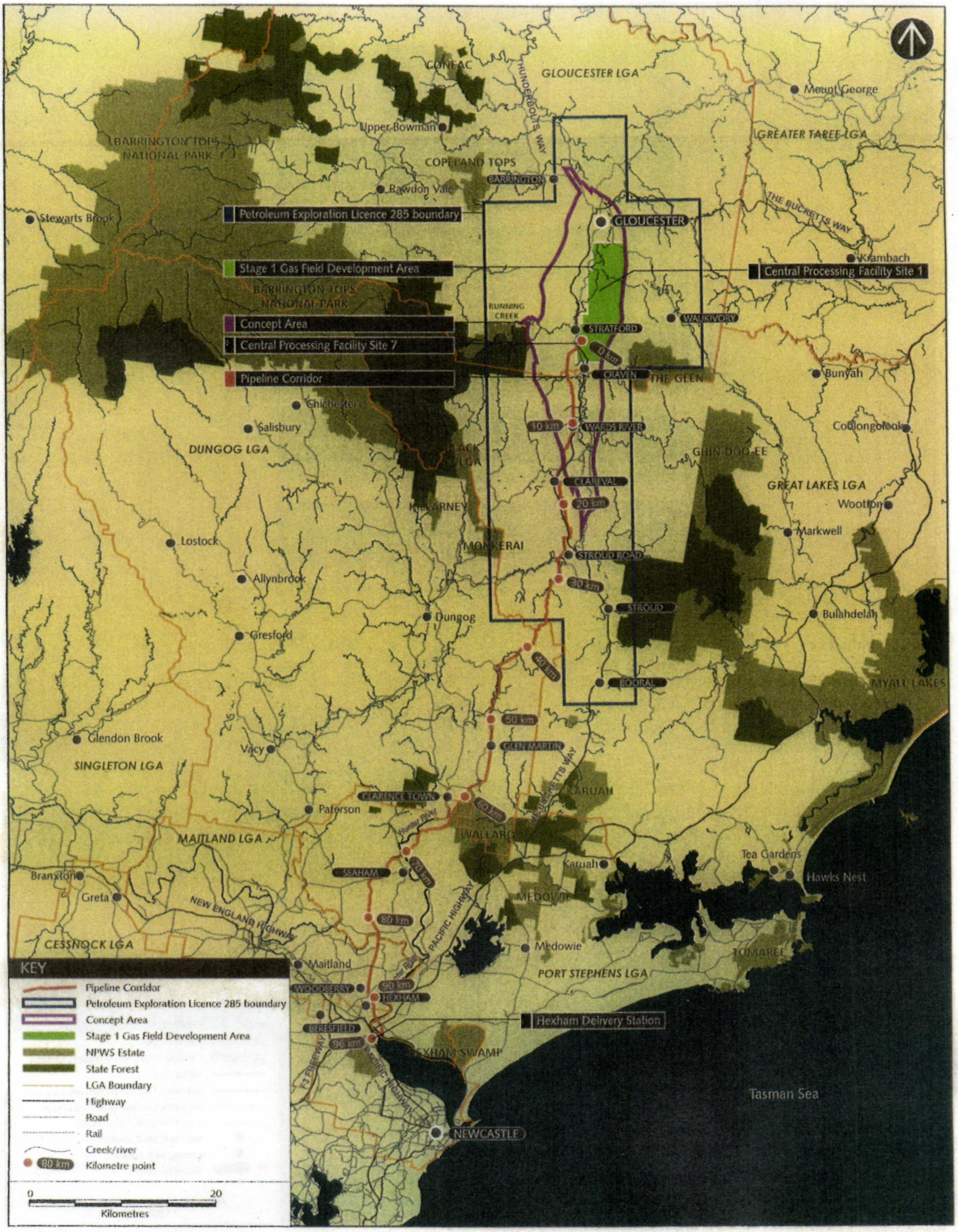


AECOM

GLOUCESTER GAS PROJECT - STAGE 1 GFDA

Attachment 1 – Stage 1 Gas Field Development Area



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GLOUCESTER GAS PROJECT LOCATION AND PEL 285 BOUNDARY

Attachment 2 – Pipeline Corridor

Appendix B

Peer reviews

Gloucester Coal Seam Gas Project

PEER REVIEW OF GROUNDWATER STUDIES – REPORT TO GLOUCESTER COMMUNITY CONSULTATIVE COMMITTEE

- FINAL
- 3 May 2012

Gloucester Coal Seam Gas Project

PEER REVIEW OF GROUNDWATER STUDIES – REPORT TO GLOUCESTER COMMUNITY CONSULTATIVE COMMITTEE

- FINAL
- 3 May 2012

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Contents

Executive Summary

This report presents the findings of an Independent Review of hydrogeological aspects of the Gloucester Gas Project. AGL is the holder of 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. AGL is proposing to build the Gloucester Gas Project (GGP), comprising several stages of development. Only Stage 1 has obtained planning approval at this time and this review is only concerned with the Stage 1 development (referred to as the Stage 1 GFDA).

The scope of the review is described in Section 2 of this report, but can be summarised as assessing the suitability of the conceptual model developed in three reports (URS, 2007; SRK, 2010 and PB, 2012) and assessment of the adequacy of the current monitoring infrastructure for measuring potential impacts under the Stage 1 GFDA development, including identification of any gaps in the monitoring network. This review has largely focused on the PB (2012) report, as it presents an updated conceptual model of the area, building on the URS (2007) and SRK (2010) studies.

This review concludes that the conceptualisation presented in the PB (2012) report is broadly considered to be appropriate, and the fundamentals of the conceptual model are reasonable. The PB (2012) study has largely gathered sufficient information to enable development of a suitable conceptual model (which will be supplemented by current/proposed investigation programs), however some further work is recommended as a result of this review. Similarly, some additional monitoring infrastructure is recommended.

In some instances it is considered that the PB (2012) study has drawn inaccurate conclusions from the data or omitted some work which would improve conceptual understanding. These generally fall into categories of: connectivity between deep and shallow systems, recharge and discharge processes, characterisation of vertical hydraulic conductivity and specific improvements that can be made to the conceptual model.

Regarding improvements to the conceptual model, the most important improvements relate to the spatial coverage of the model, definition of model boundaries and preliminary quantification of key processes (i.e. a water balance). It is apparent that not all available information has been used to develop the conceptual model, and incorporation of additional data will enhance the current conceptualisation. This review has highlighted the importance of not directly extrapolating conclusions regarding the developed hydrogeological system based on observations from the natural (i.e. unstressed or lightly stressed) condition.

None of the criticisms presented in this review are considered to be issues that cannot be readily addressed or the conceptual model revised to take account of the comments. The review has not identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective, however it is the role of the numerical modelling to assess the location and magnitude of impacts.

Recommendations for further work have been divided into field based activities and desk based activities, and then further divided into High and Moderate priority activities. The high priority field related recommendations include assessment of hydraulic behaviour of faults, rating of stream gauges to enable flow determination, installation of some new bores (including VWP), and investigation of the nature of stream-groundwater interaction over the recharge areas. The high priority 'desk-based' recommendations include development of a conceptual model of fault behaviour (after completion of relevant field programs), development of a natural and developed water balance (including definition of model boundaries) and additional analysis of hydraulic conductivity data, including assessment of vertical hydraulic conductivity. It is suggested that all of these recommendations can occur in parallel with the Waukivory Flow Testing Program and should not be delayed pending the results of that program.

It is important that this report is read in its entirety. Selective quoting of individual sections may result in an inaccurate understanding of the report's contents.

1. Introduction

This report presents the findings of an Independent Review of hydrogeological aspects of the Gloucester Gas Project, conducted by Dr Richard Evans. Based on the recommendation of the Gloucester Community Consultative Committee (GCCC), Dr Evans was appointed the Independent Peer Reviewer and commissioned by AGL on 21st February. The scope of the review is described in Section 2 of this report.

On 23rd February 2012, Dr Evans inspected the project area with representatives of the GCCC. This included inspection of the project area, some of the pilot wells and the produced water holding dams.

It is important that this report is read in its entirety. Selective quoting of individual sections may result in an inaccurate understanding of the report's contents.

2. Scope of Peer Review

The scope of this Peer Review is described below:

a. conduct independent technical review of the following reports:

- *Hydrogeological Review: Proposed Coal Seam Gas Exploration Areas, Gloucester-Stroud Basin*, NSW (URS, 2007);
- *Gloucester Basin Stage 1 Gas Field Development Project: Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model.* Report No AGL002_Glouceser Basin Hydrogeology Study_Rev 2 (SRK Consulting, 2010); and
- *Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area Gloucester Gas Project* 2162406A PR_5630 (Parsons Brinckerhoff, January 2012).

b. conduct independent technical review of underlying data which are:

- additional water quality data as included in Gloucester Gas Project: irrigation trial water monitoring - baseline results (PB letter dated February 2012);
- groundwater level data for the monitoring network, plotted hydrographs in excel spreadsheets;
- surface water level and salinity (EC) data for the monitoring network and plotted hydrographs and EC traces in excel spreadsheets, and
- the summary water quality data for all monitoring network sites in excel spreadsheets.

c. conduct a review of the installed monitoring networks; and

d. consider any other technical data and reports/papers referenced in the three groundwater reports as required,

for the purpose of providing an expert opinion on the following:

e. scope and methodologies adopted for the Reports and the investigations/baseline data;

f. whether the Reports are adequate for the purposes of assessing the hydrological catchment and the different groundwater systems, and for assessing impacts to surface water and groundwater resources, and the connectivity of aquifers as a result of deep coal seam dewatering; and

g. any recommendations to address any technical gaps identified relating to the matters set out in (a) above.

In addition to the above scope, the brief was expanded to include addition of "contextual comments on the issues relevant to extraction activity and completion methods (hydraulic fracturing and under reaming)" (as per email from John Ross to Richard Evans on 24th February 2012).

The scope is not considered to include issues related to hydraulic fracturing other than as described here (i.e. potential water quality issues related to hydraulic fracturing are not in scope). Also, possible groundwater issues associated with the proposed irrigation based water disposal system are not in scope.

3. Project Background

AGL is the holder of 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. AGL Upstream Gas Pty Limited (AGL) is proposing to build the Gloucester Gas Project (GGP), comprising several stages of development. Only Stage 1 has obtained planning approval at this time.

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 Gas Field Development Areas (GFDA) was granted on 22 February 2011 under Part 3A of the Environmental Planning and Assessment Act (1979).

The Stage 1 GFDA involves 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. This will involve 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). It is understood that approximately 110 CSG wells will be required within the Stage 1 GFDA (SRK, 2010). These are understood to be approximately evenly distributed across the area.

Further to the Environmental Assessment for the Gloucester Gas Project, the Submissions Report for the Gloucester Gas Project and the Approvals, AGL commissioned the following groundwater assessment and investigations:

1) URS (2007). *Hydrogeological Review: Proposed Coal Seam Gas Exploration Areas, Gloucester-Stroud Basin, NSW*;
2) SRK Consulting (2010). *Gloucester Basin Stage 1 Gas Field Development Project: Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model* Report No AGL002_Glouceser Basin Hydrogeology Study_Rev 2; and
3) Parsons Brinckerhoff (2012). *Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area Gloucester Gas Project* 2162406A PR_5630.

The role of the Peer Reviewer is to provide independent advice to the GCCC on scientific and technical matters relating to Coal Seam Gas (CSG) groundwater and surface water studies completed to date for the GGP, primarily the Stage 1 GFDA. This includes determining whether the AGL studies are 'fair and reasonable', and to provide an expert view to the community on the extent of these studies, the baseline data collected to date, their suitability for assessing impacts to water resources, any gaps identified in the baseline data, and the connectivity of aquifers as a result of deep coal seam dewatering. The main documents reviewed as part of this study are the three report listed above, in addition to raw water level and water quality monitoring data sets.

4. Overview Comments

This review has largely focused on assessment of the PB (2012) report, as it presents an updated conceptual model of the area, building on the URS (2007) and SRK (2010) studies. It therefore presents the most current conceptualisation upon which the impact assessment and numerical modelling will be based. (The URS and SRK reports have been reviewed and commented on where appropriate).

The primary objectives of the PB (2012) study are described as:

- 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 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.

  (PB, 2012: xxiv)

In general the conceptualisation as presented in the PB (2012) report is broadly considered to be appropriate. The fundamentals of the conceptual model are reasonable, including:

- The breakdown of the hydrogeology into four basic hydrostratigraphic units
- The principle of decreasing hydraulic conductivity with depth in the interburden confining units, and the relatively high hydraulic conductivity of the coal water bearing zones
- That the major discharge mechanism from the alluvium is as baseflow to rivers, and that the main discharge of the shallow rock aquifers is to the alluvium (although this is likely to be small compared to the water balance of the alluvial unit).
- In the natural state (within the Stage 1 GFDA), lateral flow process within units are dominant, with vertical processes being relatively small
- The likelihood of other groundwater dependent ecosystems (apart from baseflow) within the study area being significantly dependent on groundwater is considered to

be low (with the possible exception of springs, although more information is required to determine their significance and vulnerability to potential impact)

- That further work is necessary to understand the hydraulic significance of faults

Further, it is considered that the PB (2012) study has largely gathered sufficient information to enable development of a suitable conceptual model (which will be supplemented by current investigation programs), however some further work is recommended as a result of this review.

In some instances it is considered that the PB (2012) report has:

- drawn the wrong conclusion from the data, or,
- omitted some work/calculations which would improve conceptual understanding

These issues are dealt with in Chapter 5 – however it is emphasised that based on the data presented in the PB report, none of these represent criticisms that cannot be readily addressed or the conceptual model revised to take account of the comments. The review has not identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective - not that this was the scope of the review, as it is the role of the numerical modelling to assess the location and magnitude of impacts.

5. Specific Comments

5.1. Conceptual model

This section discusses issues relevant to the conceptual model including:

1. The limited geographic coverage of the conceptual model
2. Absence of a water balance
3. Model boundaries
4. Consideration of processes in the natural versus developed state
5. Potentiometric surface data
6. Recharge processes
7. Continuity of coal seams

5.1.1. Limited coverage of conceptual model

The conceptual model presented in PB (2012) is the conceptualisation on which the numerical model will be built for the Stage 1GFDA (and associated impact assessment):

> 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 build a database of information for the pending numerical model. (PB, 2012: xxv)

This being the case, it is apparent that the conceptual model is spatially and vertically limited in its ability to represent the Stage 1 GFDA area:

a. *Spatially limited* – Cross sections, block diagrams or other graphical aids are an important part of the conceptual model. The cross sections presented in PB (2012) are contained almost entirely within the Tiedman property, which represents a relatively small part of the Stage 1 GFDA. This in turn, is because the observation bores installation are mainly on the Tiedman property. There are bores located on the northern and southern boundaries of the Stage 1 GFDA (the RMB and WMB series bores), however these are not incorporated into the cross sections and further they are relatively shallow compared to the bores in the Tiedman area.

It may be argued that the seismic survey provides a geological model across the whole area, with the bores on the Tiedman property calibrating the seismic data. (*however the seismic surveys do not appear to cover the whole area, see page 26 & 27 of the PB report – the scale on the axis of these surveys seems to contradict the coverage indicated on the inset map of the survey*). It is agreed that the seismic model is an important dataset which contributes to development of the numerical model, however additional bores - particularly north and south of the Tiedman property - would provide better spatial coverage of the Stage 1 GFDA, add confidence to interpretation / calibration of the seismic survey and allow development of a cross section which would better cover the Stage 1 GFDA.

In an east-west direction, one would expect to see a cross section covering the full synclinal basin or at least an area greater than the Stage 1 region. This is because it is expected that the numerical model would cover an area significantly greater than the Stage 1 region.

Further, it can be important for a conceptual model to capture information outside of the numerical model boundary, in order to better define the boundary conditions of the numerical model.

b. *Vertically limited* – The conceptual model (including the cross sections) only describes/characterises the relatively shallow layers, down to approximately 300-350m. It is understood that the target coal seams will vary from site to site but are expected to range between 200 – 1000 metres below ground level. Given that a significant amount of extraction will occur much deeper than the exploration depths in the PB conceptualisation study, it is uncertain how the deep coal seams, and in the deep interburden, will be characterised within the numerical model. It is likely that potential impacts (on the shallow aquifers, creeks) will be most sensitive to the properties of the interburden material in the upper 200m, and in this sense it is appropriate that the conceptual model should focus on the upper 200m. However, the deeper units cannot be ignored in the conceptual model and some discussion on the behaviour and properties of units below this depth is warranted in the conceptual model report. This conceptualisation may not necessarily include detailed field investigation (however at least one site to monitor pressures in the target coal seams is recommended elsewhere in this report), and may be based on literature of properties of similar units elsewhere. . The current conceptual model lumps the interburden confining units in the range of 150m to 1000m into one category, however it is unlikely the permeability of this unit will be the same at 150m compared to 1000m, assuming uniform lithology which is probably not the case.

> The conceptual model provided in the SRK report (Figure 6-2, p41) is an appropriate cross section for conceptualisation in that it shows the full depth of the target coals layers. The PB conceptual model is helpful in that it focuses on the unit that will be critical in terms of potential surface impacts, however the model needs to be placed in the wider context of the target coal seams and the basin.
>
> Recognising that it is the upper 200m that is the most important part of the characterisation, the rigour of the characterisation of the upper 200m is discussed below.
>
> Two of the monitoring bores are screened deeper than 180m, three are screened between 150 to 200m and two are screened between 100 – 150m. Hence, most of the 22 monitoring bores are relatively shallow. Given that the PB conceptualisation is of the "interburden confining units" being from 150 – 1000 m depth and of relatively low hydraulic conductivity, (whereas the overlying shallow rock aquifers are more permeable), there is a fairly small sample size of the hydraulic conductivity of the "interburden confining units". The combination with the lack of spatial coverage further suggests that the units between the target coal seams and the upper ('shallow rock aquifers') have not been adequately characterised.

Further, the monitoring network is not only for calibration of the numerical model, but also for monitoring of impacts during the CSG production phase. In this respect the monitoring network also does not appear to be spatially or vertically comprehensive, and could not reasonably be considered to provide 'detailed spatial and depth coverage' (PB, 2012, xxv) of the Stage 1 GFDA.

It is acknowledged that the Waukivory Flow testing program will significantly add to the monitoring network towards the north of the study area. It is further recommended that a (deep) monitoring site be installed further north again (the rationale for this is discussed further in Section 5.4). In addition a site of nested vibrating wire piezometers is recommended (near the centre of the Stage 1 GFDA) in order to measure pressure / pressure changes at depth within the target coal seams. Correspondence from AGL post the draft IPR indicates that plans are underway that will address this data gap, utilising a reservoir corehole after testing and sampling is complete.

In addition, further correspondence from AGL post the draft IPR indicates that additional water level and hydraulic conductivity data beyond that presented in PB (2012) will be obtained from the following sources:

- AGL/LE coreholes and stratigraphic holes where intrinsic permeability tests have been undertaken, and ,
- GRL and GCL models, monitoring data and networks

It is possible that this data will address some (or all) of the data gaps described above, but without details of these activities it is not possible to provide any detailed comments.

5.1.2. Absence of a water balance

A water balance (or budget) is an important part of conceptual model development. The water balance is a quantification (estimation) of the inflows and outflows across the model domain boundaries, plus any internal consumptive uses. The Murray Darling Basin (MDB) Groundwater Modelling Guidelines are the closest document that exists to national guidelines for developing a groundwater model, including the conceptual model. (They are widely considered a standard for groundwater model development). Regarding a water balance, the MDB guidelines indicate that "the definition of a water budget and associated boundary conditions for the model domain are integral components of the conceptual model" and "The conceptual model should present in descriptive and quantitative terms the essential system features outlined in Table 2.4.1 (geological framework and boundaries), and the hydrological behaviour (natural and human-induced stresses), including a preliminary water balance" (Middlemis et al., 2000).

The conceptual model developed in the PB report (or SRK and URS studies) does not include a water balance. The advantage of developing a water balance in terms of the numerical model and associated impact prediction is that:

- It starts the process of defining and conceptualising the boundaries of the model area, which is a necessary step when developing a numerical model (discussed further in the following section).
- It will highlight aspects of the water balance where there is significant uncertainty, and can provide focus for where further information may need to be gathered. This uncertainty is not just in terms of the magnitude of fluxes but also in terms of processes and direction of flow and locations of discharge. For example, examination of the cross sections in the PB report provides no indication of where groundwater discharges (there is some discussion of this in the text, but not in the diagrams). It shows recharge and some flow paths but as currently presented there is only water entering the groundwater system.
- Quantifying components of the water balance (even if only approximately), begins to put into perspective the possible scale of the potential impacts compared to the natural water balance. The PB report implies that the hydrological impacts of the development will be small, but this is a difficult conclusion to assess when the water balance has not been quantified.

- It will highlight the assumed rate and timing of recharge after the end of the CSG development and thus allow the relative significance of long term changes in recharge and discharge to be placed in the context of natural recharge and discharge rates.

Development of a water balance for the area should include:

- Defining model boundaries and any fluxes across the boundaries,
- Estimating the various components of the water balance (internal and external), including recharge, discharge and change in storage .

The impact of temporal scales is also important - depending on the component of the water balance being assessed its importance will also change. It is suggested that pre development , maximum development and post development water balances be postulated.

5.1.3. Model boundaries

This point is closely related to the above discussion regarding a water balance. The conceptual model should define the boundaries of the numerical model, otherwise this step becomes wrapped up in the numerical modelling process. Good practice is to develop a robust conceptual model, inclusive of model boundaries, so that the whole conceptual model can be reviewed prior to development of the numerical model. As described in Section 5.1.2, the MDB Groundwater Modelling Guidelines consider definition of the model boundaries as a key part of the conceptual model and water balance. They further state that:

> The model domain covers the entire area of interest, including areas of potential future impact, although its size should be minimised to reduce computational effort. Model boundaries are the interface between the model calculation domain and the surrounding environment (Spitz and Moreno, 1996), and occur notably on the edges of the domain. Other ("internal") boundary conditions reflect influences from other environmental factors (such as rivers, wells, etc.) that are manifest inside the domain. The external boundaries of the model domain should take advantage of natural or physical groundwater boundaries (eg. aquifer extents, coastlines, rivers, lakes). Middlemis et al. (2000)

At the moment it is not clear what the boundaries of the numerical model will be. The conceptual model as presented in PB (2102) does not appear to cover the same extent that a numerical model would be required to cover. Defining the boundaries of the model (and associated boundary conditions) will address this issue.

5.1.4. Consideration of processes in the natural versus developed state

The conceptualisation reports (PB, URS, SRK) make conclusions like “there is no evidence of natural connectivity between shallow and deep groundwater systems” (PB 2012, xxviii). While that may or may not be true (that issue is discussed further in Section 5.2), the point here is that it is not only the natural state that requires consideration. Just because there may be a lack of connection in the natural (unstressed) condition, this does not mean there will be a lack of connection in the developed (stressed) conditions. The pressures changes induced during the CSG related extraction are significant compared to the natural gradients between the shallow and deep systems, and it cannot be implied that because there is no connection in an unstressed condition that there will be no connection in the stressed condition. (Typical head declines are 200m, with a maximum decline of approximately 400m).

There are fleeting references to this issue, e.g. in the chemistry section in PB (2012:111); ‘indicating limited connection between them under natural conditions’, but the concept is not discussed elsewhere in the report.

Discussion of this issue would normally be expected, but there are also a range of tools available (analytical models, simple numerical models) to conduct a preliminary quantitative assessment of changes under the stressed condition. These types of tools would be required to assist in development of the stressed state water balance. In turn these tools highlight the sensitivity of the various aspects of the water balance to identify where effort should be directed in terms of data gathering for the numerical model.

5.1.5. Potentiometric surface data

It is noted that the PB report only includes a potentiometric surface map for the alluvial aquifer. There is no potentiometric surface provided for the underlying three (conceptual) layers: shallow rock aquifers, interburden confining units and coal seam water bearing layers. While the PB report has collected some data in the shallow rock aquifers and interburden confining units, it is acknowledged that it may be difficult to construct a potentiometric surface given the limited number of points available.

There are apparently only two bores screened in the target coal seams (Bores S5MB03 and TCMB04 are screened in the Roseville Coal Seams), and these are only in the very upper of the target coal seams. It is suggested that, in the absence of a potentiometric surface for the target coal seams, the conceptual model should include an estimation of the starting heads in the coal seams (which is a necessary input to the numerical model). The VWPs within the coal seams recommended above will assist in this process.

5.1.6. Recharge Processes

The PB (2012) report could be enhanced by further discussion of the following issues related to recharge processes:

- The SRK (2010) report (p45) indicates that some recharge will also occur via vertical leakage (not just via outcropping areas at the margin of the basin). The vertical gradients at some nested bores suggest that this is the case. While this process may be very small compared to lateral recharge, it warrants some discussion (and ideally preliminary quantification).
- The SRK (2010) report (p45) suggests that faults may act as potential enhanced recharge zones. It is acknowledged that work is currently underway to assess the hydraulic conductivity of the fault zones, and hence at this point a conclusive answer is not possible, however a discussion of the potential role of faults in recharge processes would seem appropriate.
- The PB (2012) report does not discuss the potential for recharge of the interburden confining units or the coal seams via streams over the areas where these units outcrop or subcrop (in particular Waukivory Creek and Dog Trap Creek). It is not known if these are gaining, losing or losing-disconnected streams in these areas; discussion of the conceptual understanding of how these streams interact with groundwater would be useful. If they are losing streams, it may be that the rates of recharge are very low compared to rainfall recharge, but discussion of this process is desirable. The conceptual understanding of the streams (and how they are incorporated into the model) affects whether the streams may be impacted under the developed state (and the magnitude of impact).

5.1.7. Continuity of Coal Seams

The conceptualisation reports do not discuss the lateral continuity of the coal seams. The inference in the reports is that they are more or less laterally continuous (with the exception of fault zone truncation), but this is not specifically discussed or stated. Many of the CSG developments in other parts of Australia (e.g. Surat Basin) are characterised by target coal seams of limited lateral continuity, so continuity cannot be assumed and should be stated. How the coal seams are characterised is an important part of the conceptual model because it indicates the potential lateral transmission of pressures within coal seams.

5.2. Connectivity and potential shallow aquifer / surface impacts

The PB report makes the following statements regarding connection between the deep groundwater system and the shallow groundwater system / surface waters:

> "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" (PB 2012, xxviii).
>
> "The low permeability interburden units are locally saturated, but generally act as confining layers between and overlying coal seams. The layered aquitards of the interburden units create separate and distinct groundwater systems with no connection evident between the deeper coal water bearing zones and the shallow rock alluvial aquifers" (PB, 2012; para 4, p131)
>
> "The interburden confining units are effective confining units that separate shallow groundwater aquifers from deep coal seam water bearing zones" (PB, 2012; para 13, p134)

The following sub-sections address different aspects of these statements.

5.2.1. Assessment of Evidence for PB Conceptual Model of Hydraulic Isolation of Shallow and Deep Groundwater Systems

The following comments are made regarding these, and other similar statements within the PB (2012) report:

- The statements imply that because the interburden is 'low permeability' and are 'confining layers' that they form a layer that hydraulically separates the deep coal seams and the shallow aquifer system. However neither of these properties of the interburden makes the interburden a hydraulically separating layer. Only if the interburden is of zero hydraulic conductivity or an unsaturated zone exists within the interburden, would the interburden act as a hydraulically separating layer. (The PB or other reports do not appear to make either of these claims, however use of the phrase 'locally saturated' is discussed below).

  If the interburden is of low hydraulic conductivity (not zero hydraulic conductivity), the discussion around potential effects on upper aquifers and surface water should be framed around the timeframes and magnitude of interaction (e.g. over very long timeframes and very low rates of leakage) rather than no interaction. No evidence is presented to warrant the claim of hydraulic isolation of the units.

  It is acknowledged that PB do use the term "aquitard" to define the interburden, and therefore by definition imply the potential of this unit to leak. However, use of the term appears to contradict description of the unit elsewhere in the PB report, i.e. that they hydraulically separate layers above and below, implying no leakage.
- The term "locally saturated" is used in the PB report to describe the interburden (refer above quote) but the term is not defined. Hence what "locally saturated" means is unclear, but if it is a reference to the interburden containing perched groundwater systems, this should be explicitly stated. If this is the intended claim and it is true, it would have significant implications for the set-up of the numerical model. It would mean that by definition the

shallow groundwater system and deeper groundwater system are hydraulically isolated (and in terms of assessing potential surface water impacts, it would mean there is limited value in constructing / using a numerical model at all). A conceptual model of complete hydraulic separation between the deeper and shallow groundwater systems is certainly the hydrogeological exception rather than the norm . Hence if this term is suggesting that groundwater in the interburden is perched, this claim has far reaching consequences and firm evidence to support the assertion is required (e.g. some dry bores screened in the interburden, or evidence in certain types of geophysical surveys).

- In different locations throughout the report the following evidence is provided for the hydraulic separation of the deeper and shallow groundwater systems:
  - *The different chemistries of the groundwater at nested sites* – for example "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" (PB, 2012: 111). The terminology used by PB is accurate – the different chemistries indicate *limited* connection / limited movement of water between the shallow and deep systems - not 'no connection', as inferred in the above quotes. Where there is a head (i.e. pressure) difference between two layers and some permeability, there will be some leakage of water from the higher head unit to the lower head unit. The vertical leakage may be very small compared to the lateral recharge and hence the chemistries of the water will be very different. However the difference between low or limited leakage and no leakage is critically important for conceptualisation and set up of the model. In the chemistry section of the PB report, the chemistry differences are used to suggest low leakage (not quantified but considered likely to be true) but the conclusion reached in other parts of the report regarding isolation of the units cannot be made based on chemistry differences.

  - *Static nature of hydrographs* – "Initial monitoring in all three bores shows static water levels indicating strong confining layers above the water bearing zones" (PB, 2012: 82) – The link between static water levels and strong confining layers is not explained in the PB report. Presumably the inference is that the absence of any fluctuations or trends in the groundwater suggests that the hydraulic conductivity is so low that the units are not being recharged (or discharged) and hence is evidence of (effective) hydraulic isolation. Closer examination of the hydrographs, as discussed in the dot point below, suggests that they are not in fact static and hence this argument does not appear to be supported.

- *Absence of response to rainfall recharge* – "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". The hydrographs of these five bores (plus bores screened in the coal) are presented and discussed in the following section. The data seems to contradict the finding that there is no response to rainfall recharge observable in groundwater levels.

5.2.2. Assessment of Monitoring Bore Hydrographs

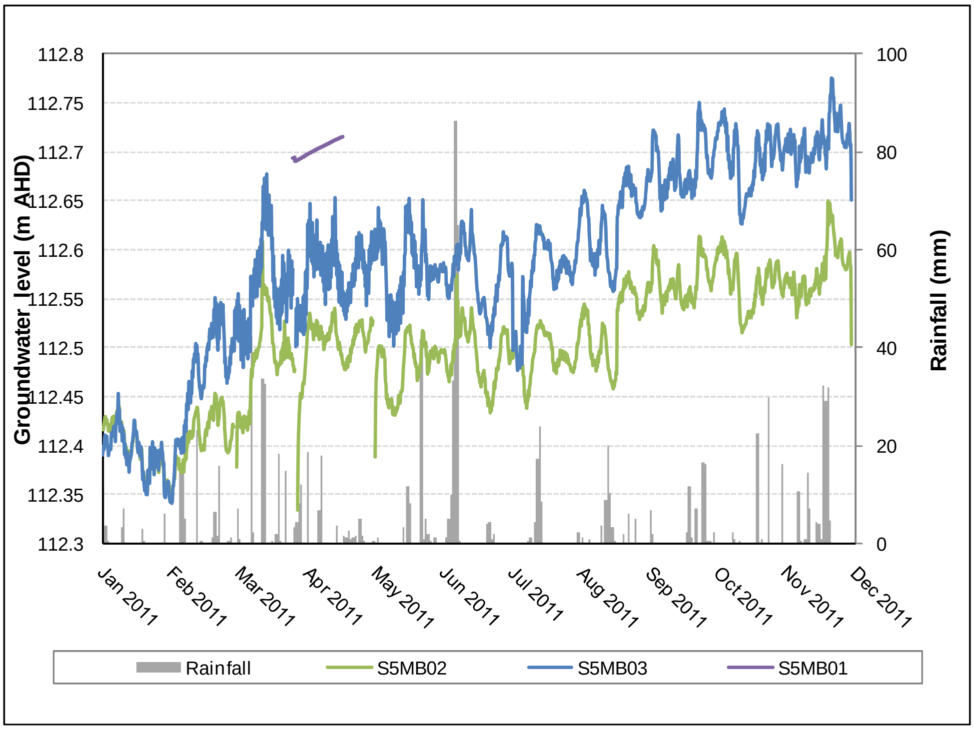
The groundwater level hydrographs of bores in the interburden units and the coal seams are discussed below:

S5MB02 (Sc. : 89 – 95m, Sandstone/siltstone) and **S5MB03** (Sc: 158-164m, Coal/shale) – The effect of the high rainfall in mid-June 2011 (195 mm between 13th and 16th June 2011, as measured at the Gloucester, Hiawatha, rainfall gauge) is apparent in these two bores. The rise in the hydrograph after the intense period of rainfall may not be coincidental. There is a delay of approximately one to two months before the hydrographs begin to rise, which may be the time for the pressure transmission of the recharge event to impact the point in the aquifer where the bores are screened. This suggests there is hydraulic continuity laterally within the units (and also possibly vertically), and that the hydraulic conductivity is not negligible. (The one to two month delay suggests this water level rise is not caused by a hydraulic loading effect).

Further, regardless of the link between the June 2011 rainfall and hydrograph response, there is a total rise in groundwater elevation of around 0.3m and 0.4m within the 12 month monitoring period (for S5MB02 and S5MB03 respectively), indicating recharge is occurring. There is also a very strong correlation in the micro-fluctuations between S5MB02 and S5MB03. This may be explained solely by barometric response, however an analysis of water levels with barometric effect removed is recommended to confirm that this is the case.

S5MB01 (Sc. :52 – 58m, Sandstone/siltstone) – not analysable for water level trends due to impact of slug test.

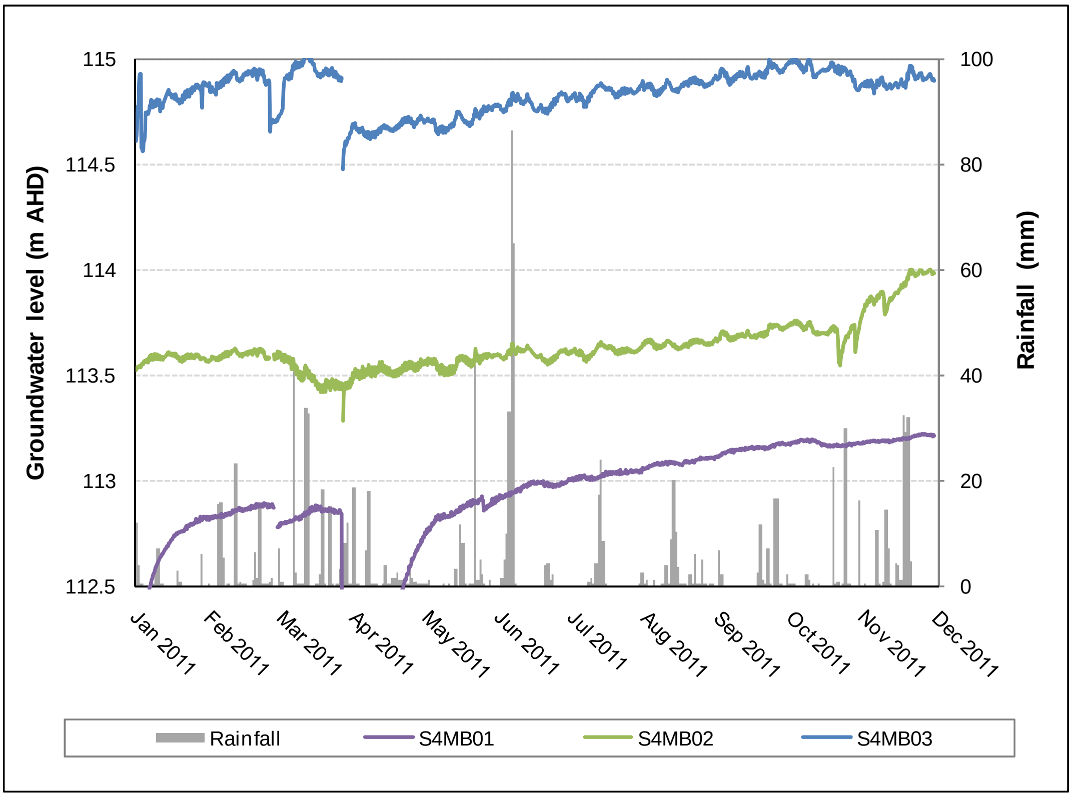
Figure 1 Groundwater levels and rainfall at S5MB nested site



S4MB01 (Sc. : 58 – 64m, Sandstone) – This bore does not show a clear response to the high rainfall in mid-June 2011 (e.g. as observed at the S5MB nested site), but (excluding the first month of data which may have been influenced by sampling/testing), does show an increase in water level of 0.5m over 2011.

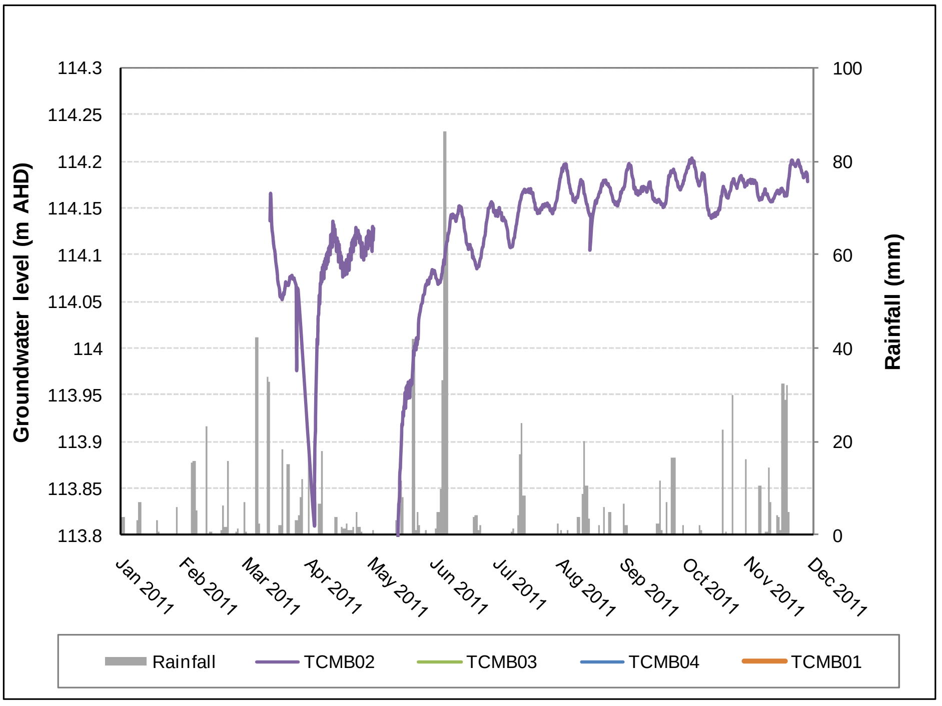
S4MB02 (Sc. : 89 – 95m, Sandstone/siltstone) – This bore shows a similar overall trend to S4MB01 (above) with an increase in water level of 0.5m over 2011. For this bore and S4MB01, the yearly increase in water level is the same as the deeper bore screened in the coal at this nested site (S4MB03, Sc: 162-168m) which is also 0.5m. Fluctuations at a small scale (e.g. weekly) do not always correspond across these three bores, but the annual increase in water level is similar. In contrast to the above statement (p80 in the PB report) this suggests that these units are responding to the effect of rainfall recharge, or else possibly recovery from flow testing in 2010. Either way, the results do not support a conceptual model of hydraulic isolation of interburden layers.

- **Figure 2 Groundwater levels and rainfall at S4MB nested site**



TCMB02 (Sc.: 175 – 181m, Sandstone) – This bore exhibits a rise in water levels of around 0.15m within the monitoring period (ignoring the impact of the hydraulic testing and sampling on the bore), as shown in Figure 3.

Figure 3 Groundwater levels and rainfall at TCMB02

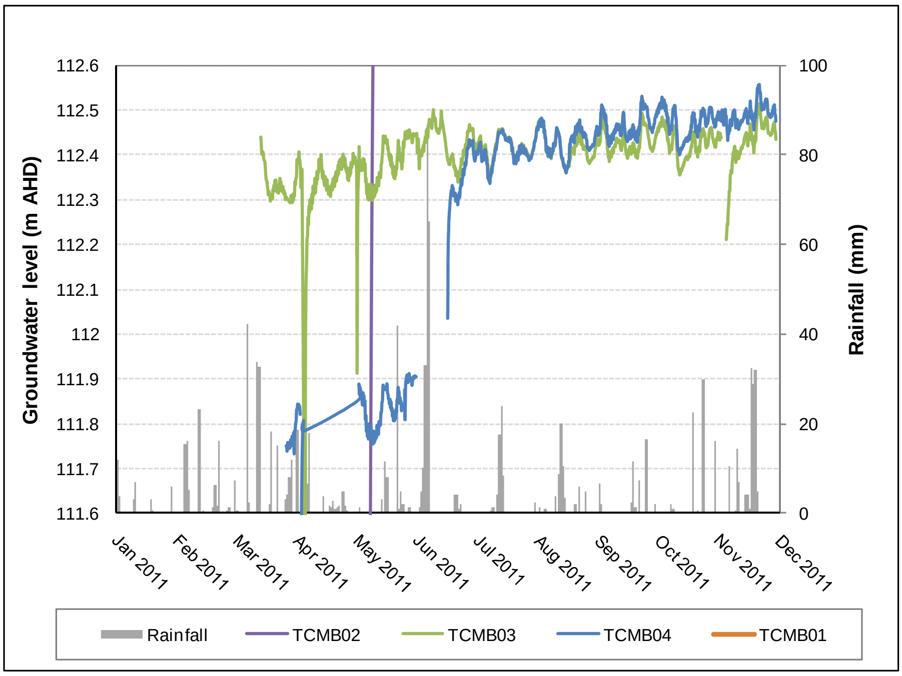


The above section discussed bores screened in the interburden. The section below discusses bores screened in the coal seams.

TCMB03 – (Sc.: 260 – 266m, Coal and Sandstone) – The PB report states that this bore shows “negligible seasonal variation and no response to rainfall recharge” (PB, 2012: 80). Figure 4 shows that there has been a water level rise of around 0.2m within the monitoring period. This suggests the bore is responding to recharge.

TCMB04 – (Sc.: 327 – 333m, Coal and Sandstone) – The PB report states that this bore shows “negligible seasonal variation and no response to rainfall recharge” (PB, 2012: 80). Figure 4 shows that there has been a water level rise of around 0.75m within the monitoring period. However, correspondence from AGL post the draft IPR indicates that the early data in this bore is not representative due to the bore being ‘shut in’ to monitor gas build up. The bore was vented in June 2011, which has resulted in the step change apparent in the hydrograph at this time. Examining only the data after June 2011, there has been a water level rise of around 0.45m in this bore. If the steep rise in the data in late June is assumed to be part of the bore re-equilibrating after the venting (and also assumed invalid), then there is a water level rise of around 20cm post-June 2011 in the bore. Regardless which interpretation is correct, it is apparent the bore is responding to recharge. This response is particularly significant given that this is the deepest of the monitoring bores, and screened in one of the target coal seams.

Figure 4 Groundwater levels and rainfall at TCMB03 and TCMB04



S4MB03 – (Sc.: 162 – 168m, Coal) – The PB report states that this bore shows "negligible seasonal variation and no response to rainfall recharge" (PB, 2012: 80). Figure 2 shows that there has been a water level rise of around 0.4m within the monitoring period. It might be argued that the rise in water level post-April 2011 is related to slow recovery from the sampling in early April, however this is unlikely based on the shape of the recovery (e.g. compared to the recovery from the slug test in March 2011), and is more likely a recharge response. Further, there is a 0.4m rise in water level observed between January and March is not impacted by either the slug testing or sampling.

In summary, the water levels of bores screened in the "Interburden units" and the "Coal seams" each indicate one or more of the following:

- A response (increase in water levels) to rainfall recharge associated with high rainfall in mid- June 2011(195 mm between 13th and 16th June 2011, as measured at the Gloucester, Hiawatha, rainfall gauge) , with a lag of up one to two months.
- An overall upward trend across the monitoring period, ranging between 0.15 to 0.75m. This corresponds with the fact that since early 2008 there has been a period of above average rainfall in the study area (refer rainfall residual mass curve: Figure 3-4 in PB, 2012) and groundwater levels are responding to recharge caused by this rainfall.
- In addition to the overlying upward trend, some bores show a fall and rise, possibly indicative of a seasonal trend.

These observations suggest that deeper confining units are responding to recharge relatively quickly, and are not hydraulically isolated units. The conceptual model should account for this variability. A potential alternate cause of the response in the hydrographs is that of hydraulic loading (i.e. an increase in total weight overlying the screened interval), however this is considered an unlikely cause, in part due to the time lag observed in the response in some bores.

5.2.3. Potential Impacts on Surface Water Features in Recharge Areas

The PB assessment appears to mainly consider potential impacts caused by vertical transmission of pressure and associated decline in water levels in the shallow rock units / alluvial aquifers in the valley floor. A potential mechanism for impact on water levels which seems to have been overlooked is lateral transmission of pressures back along the coal seams (and interburden) and into the areas where these units outcrop/sub-crop in the hills east of the site. (It is acknowledged that the PB report recognises the importance of lateral recharge where the units outcrop/sub-crop, e.g. PB, 2012:131, – the point here however is that the implication of this for potential impacts under the developed case does not seem to be discussed in the report).

Depending on the nature of the connection with the streams (in particular Waukivory Creek and Dog Trap Creek but also other unnamed smaller streams) in the outcrop/sub-crop areas, there may be an impact on stream flow in these creeks, as either the baseflow sustaining a gaining stream is reduced, or losses from the streams are increased due to lowering of groundwater levels. The impact is likely to occur more quickly than vertical impacts to the valley floor, as the change in pressure will be transmitted along units rather than across units (i.e. K_h is typically about one order of magnitude greater than K_v).

A first step towards assessing potential impacts to these creeks is to understand the nature of the connection (if any) between groundwater and the creeks where they overlie the recharge areas.

5.3. Characterisation of Vertical Hydraulic Conductivities

The vertical hydraulic conductivity (K_v) of the layers overlying the target coal seams is often the most important parameter influencing the prediction of impacts (including magnitude and timing) on upper aquifers and surface water. Characterising K_v is therefore a very important part of conceptual model development.

5.3.1. Vertical and horizontal conductivity

The PB (2012) report currently does not address in any detail the distinction between vertical (K_v) and horizontal hydraulic conductivity (K_h). The only time this differentiation is made is in the section reporting on laboratory permeability tests, where both horizontal and vertical permeabilities were reported. Generally slug testing and packer testing are methods that predominantly determine the K_h value of the unit tested, however this is not discussed in the report. It is therefore uncertain how the hydraulic conductivity values produced will be used to determine K_v values for the numerical model. Given the likely sensitivity of model outcomes to K_v it is considered important that this process / method is clearly described.

Of the four laboratory test results where both K_v and K_h were tested, three of the four indicated K_v and K_h were the same, and one test indicated K_v was higher than K_h (PB, 2012: 75-76). In general, empirical data suggest that it is typical for K_v values to be at least one order of magnitude smaller than K_h (due to the nature of sediement deposition and diagenesis). The fact that these results are contrary to this "rule of thumb" is therefore significant and warrants further discussion / investigation, e.g. if it is proposed that the numerical model adopt K_v values of 10% x K_h then an explanation of why the laboratory data, suggesting K_v is approximately equal to K_h, was discounted will be necessary.

5.3.2. Evaluation of collected conductivity data

In addition to the issue of vertical and horizontal hydraulic conductivity (described above), the PB (2012) report would benefit from further evaluation of the hydraulic conductivity data collected, in the following areas:

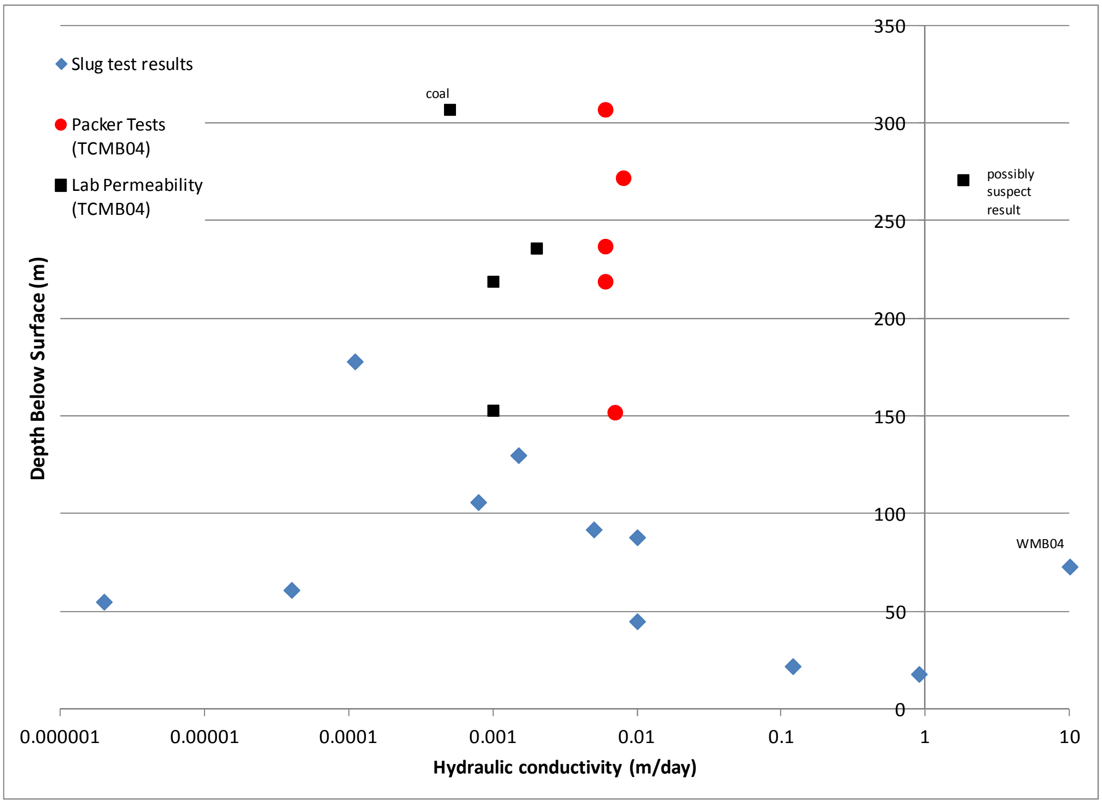
- Monitoring site TCMB04 was tested for hydraulic conductivity using packer tests, laboratory tests and slug tests. A discussion of the results derived from these various methods, including which is considered most reliable, would be helpful. Figure 5 presents hydraulic conductivity results for the shallow rock and interburden units from the PB (2012) field program. A general trend of decreasing hydraulic conductivity with depth can be seen in the slug test data, with a few anomalies. [The result at WMB04 in particular warrants further discussion – the text suggests that this high value results from 'the likely contribution of secondary permeability in the form of localised bedding plane fracture flow' (PB, 2012:70). This may be the case, but even if this result is returned infrequently for some bores, the implication for overall rock mass permeability will be significant].

At the nested site where the three slug tests were undertaken (TCB02, 03 and 04), the alternate method (packer tests and core permeability in the laboratory) at the same depth returned a significantly higher hydraulic conductivity, ranging between 30 to 900 times higher. (A comparison with the exact depth was not possible, but was interpolated between the lab and packer tests). If the packer tests and laboratory tests are more accurate, does this mean the remainder of the bores which have only been slug tested (19 tests) are an underestimate of actual hydraulic conductivity?

The literature generally indicates that laboratory permeability tests tend to underestimate actual regional hydraulic conductivity (e.g. Hart, 2006) compared to insitu tests because they do not measure secondary permeability (i.e. fracture flows). If this is the case at this site, this compounds the issue described above as the lab tests indicate higher permeabilities than the packer tests.

A further observation from Figure 5 is that the packer and laboratory tests do not indicate a trend of decreasing hydraulic conductivity with depth. Again, some explanation of why this may be the case is required, as the current conceptual model appears to be based on the slug test results but ignores the packer and laboratory tests.

- **Figure 5 Hydraulic conductivity results for shallow rock and interburden from PB (2012) field program**



- The results for each of the four conceptual model layers are simply presented in the PB (2012) report as a range for each of the four categories (refer Table 6-4 in PB, 2012):
  - Alluvial aquifers: 0.3 – 500 m/day
  - Shallow rock units: 0.01 – 20 m/day
  - Coal seam water bearing zones: 0.002 – 0.03 m /day
  - Interburden confining units: 4 x 10^{-5} – 0.006 m/day

  The range in these categories is quite large. The numerical model would normally only use one number for each layer, hence it would be helpful to include a discussion on what is considered the representative value for each layer as the initial input values to the model. While the values will be refined during model calibration, it is important to know how to depart from the initial estimates. (Sensitivity testing or Monte Carlo analysis could be used to asses results across a wide range of values, however ultimately a decision will still need to be made regarding which of the multiple results is considered most representative). Presentation of average and median values may be helpful in this assessment.

5.3.3. Comparison with other areas

The implication in the PB (2012) report is that the interburden confining units are of very low hydraulic conductivity, e.g. refer to the quotes at the start of Section 5.2 (in this report) which imply the hydraulic conductivity is sufficiently low to create hydraulic separation. In reality the values appear typical of hydraulic conductivity for the given rock type. In the author's experience, typical average values of vertical hydraulic conductivity of coal measure siltstones and claystones in deep sedimentary basins are around 10^{-4} to 10^{-5} m/day.

5.3.4. How representative are the results?

The hydraulic conductivity for the vast majority of bores has been determined using slug tests. These are a valid method for testing hydraulic conductivity, but intrinsically only test the hydraulic conductivity very close to the bore screen (typically in the order of tens of centimetres only). Similarly, laboratory permeability tests of core material are also (very) local scale, only testing the rock material extracted. Packer tests test the material in a slightly larger radius away from the bore (e.g. metres), but are still a relatively local test of relatively short duration.

All of these methods are a local scale test which generally does not indicate the broader hydraulic conductivity of the unit tested. This is particularly important in fractured rock aquifers, where the overall rock mass hydraulic conductivity is strongly controlled by the fractures – and these are more likely to be missed than intercepted by an observation bore. Hence these methods in fractured rock aquifers will tend to underestimate hydraulic conductivity compared to methods which assess the hydraulic conductivity across a much larger area by stressing the aquifer over a longer time period (allowing for a larger spread of drawdown in the tested unit), such as aquifer pumping tests or monitoring during flow testing. Longer terms tests will therefore generally provide more reliable hydraulic conductivity data.

It is unfortunate that the flow testing conducted between 2006 and 2009 did not include any monitoring bores in the target coals seams or interburden, or measure recovery rates in the production wells. (Documentation of the Stratford Flow Testing program is contained in the AGL Summary Report, 25 January 2012). Either of these data sets could have been used to determine vertical hydraulic conductivities in the interburden with higher levels of confidence than from slug tests. It is recommended that the upcoming flow test program should be used to determine vertical hydraulic conductivities, and these results compared with the slug testing results in PB (2012).

5.3.5. Use of other data to support the data set

The PB (2012) report has not made use of other potentially relevant data sets in characterising the hydraulic conductivity of the interburden and coal seams. For example, the URS (2007) report (in Section 4.4.1) describes hydraulic conductivities from two previous investigations in the area; Resource Strategies (2001) and Woodward-Clyde (1996). A discussion of the applicability of these hydraulic conductivity numbers to the Stage 1 GFDA site would enhance the data set collected by PB (2012). The Resource Strategies (2001) report is of interest as it describes permeabilities around the Bowens Rd North mine (i.e. within the Stage 1 GFDA). The Woodward-Clyde (1996) report was for the Duralie mine EIS; while the site is approximately 10km south of the Stage 1 GFDA, and the interburden is of a different (lower) stratigraphy, the result should not necessarily be dismissed as irrelevant. Woodward-Clyde (1996) report hydraulic conductivity values of between 0.04 and 3 m/day for the interbedded siltstones and sandstones assessed for the Duralie mine EIS. Evaluation of the relevance of this data to the Stage 1 GFDA site would be helpful (depths of the bores may limit relevance to the interburden confining units in the Stage 1 GFDA).

The SRK (2010) report also includes additional information on hydraulic conductivity in the area. Table 4-1 in SRK (2010) presents:

- Hydraulic conductivity data for coal seams in the area based on 28 tests in coal intervals by Pacific Power in 1999. Based on this data the SRK (2010) report develops a conceptual framework of permeabilities in the coal seams for different depths. This is a much larger sample size that the slug tests conducted in the coal seams in PB (2012), including to significantly greater depths. It would be useful for the conceptual model to draw upon this data.
- Hydraulic conductivity data from Duralie Extention Project Groundwater Assessment report (after Golder Associates 1982 and DCPL 1996 and 2009). This is apparently information additional to the original Duralie project referred to in Woodward-Clyde (1996). Again, while the site is some 10km from the Stage 1 GFDA and the stratigraphic units are different (sandstones of the Dewrang Group: Mammy Johnsons Formation , Weismantel Formation and Duralie Road) an evaluation is necessary to determine the relevance of the data to this area (e.g. the SRK conceptual model of the area adopted values from that study as applicable to the upper 150m profile for the Stage 1 GFDA). The relevance would need to consider the lithological similarity between the interburden at the two sites, structural similarities (e.g. degree of faulting) and the method of test data collection (e.g. SRK, 2010 indicates that some of this data was collected from pumping tests – normally hydraulic conductivity values from pumping tests are more reliable than from slug tests).

- Regional hydraulic conductivity data for the Hunter Valley and Sydney Basin lithologies (coal seams, sandstones, sills and interburden) – these may be of limited relevance to the site, but may help to place the test results into a regional context.

5.3.6. Abandonment of exploration bores

There is no detail provided in the reports on the method of abandonment of exploration bores in the area. If these bores are not decommissioned properly, they represent a (potentially) significant risk of inter-aquifer connection and enhanced vertical hydraulic conductivity of the rock mass. It is recommended that the method of abandonment of exploration bores be identified and that they are sealed / grouted appropriately, if this has not already occurred.

5.4. Characterisation of discharge processes and groundwater dependent ecosystems

5.4.1. Discharge processes

The conceptual understanding of regional discharge processes in the study area is summarised in the extracxts below:

> "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". (PB, 2012: 30)

> "Groundwater baseflows (and even discharge from deeper aquifers/water bearing zones) are suspected in the northern catchment area around Gloucester" (SRK, 2010: 39) and "Discharge from all the hydrogeological units occurs by seepage to springs, rivers and streams. As the Gloucester Basin is a closed basin, most groundwater is expected to discharge in the lower catchments areas of the Avon River and Gloucester River in the vicinity of Gloucester" (SRK, 2010:45)

The nested monitoring bores on/in vicinity of the Tiedman property indicate gradients of varying direction between the deeper and shallow aquifers. The S4MB site has an upward head gradient (of approximately 2m) between the deepest unit screened (162-168m in the Cloverdale Coal Seam) and the shallowest unit screened (58-64m in the Leloma Formation). There are however two sites with a downward gradient: S5MB and TCMB, with a head of approximately 3m and 2m respectively between the shallow and deepest monitoring bore. (At the TCMB site however the shallowest bore is screened from 175-181m, hence the comparison is not exactly the same as for the S4MB and S5MB sites which both have shallower bores. A new shallow monitoring bore has been constructed at the TCMB site, completed in November 2010, and screened from 87 – 93m. It was not included in the PB report as drilling/testing had not been completed in time to incorporate the data into the study. The screened depth of the bore will allow a comparison of vertical gradients between the deeper and shallow aquifers at this site, similar to that described above at other nested sites).

On the basis of these three nested sites, the interaction between the upper and shallow units within the vicinity of the Tiedman property is complex and varying in direction of flux over relatively short distances. It is however agreed with the conceptual process outlined above from PB and SRK that further down catchment (in the vicinity of Gloucester), all units will discharge, implying upward gradients from deep to shallow aquifers in that area. A nested monitoring site in the Gloucester area is therefore recommended, firstly to confirm this conceptual understanding which will add confidence in the numerical model and secondly to monitor potential (pressure) impacts on that area during the Stage 1 GFDA development.)

The above descriptions outline regional discharge processes - PB (2012) further describes discharge for each of their four conceptual hydrostrigraphic units:

Alluvial aquifers

> "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…. 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" (PB, 2012:128)

Shallow rock units

> 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.
>
> (PB, 2012: 130-131)

Interburden confining units

> 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. (PB, 2012: 131)

Coal seam water bearing zones

> 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. (PB, 2012: 131)

These conceptual processes generally appear sound, with the exception of the description for the interburden units. A discharge process for this unit is not described. It is inferred that this water does not discharge anywhere, because it is contained in isolated and distinct groundwater systems. However this does not agree with some of the key data – for example the age of the groundwater in the interburden is generally similar to that of the water in adjacent coals seams, implying that it is moving laterally (i.e. to somewhere) at a similar rate to water in the coal seams. Further the water level data indicates there is a gradient between the interburden and adjacent units (and the hydraulic testing shows it has some permeability) – hence in addition to any lateral movement there must be some vertical leakage.

Based on available data, an alternate conceptual model for the interburden is one of spatial variability within the Stage 1 GFDA, with some discharge upwards to shallow rock areas and some downward to underlying deeper coal seams and interburden. Further down catchment it is expected that discharge will be more consistently upward from the interburden, and into the shallow rock (and ultimately to the alluvial aquifers). Also, if faults 'are suspected conduits' for upward flow from the coal seams, the potential for faults to act as conduits / preferred pathways within the interburden should also be allowed for (refer Section 5.6 for further discussion).

5.4.2. Groundwater Dependent Ecosystems

Based on the conceptual model of discharge in the above section, there is potential for the following groundwater dependent ecosystems (GDEs) within the study area (discussion of stygofauna is not considered important here):

Baseflow GDEs –Baseflow is recognised in the PB report as the key discharge mechanism from the alluvial aquifers. The following comments are made:

- "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" (PB, 2012:31). Firstly, visual inspection of a stream/river is not a definitive means of assessing the size of the baseflow. For example, the discharge could be occurring below the surface of the water, so a seepage face above the river level is not a reliable means of assessing baseflow contribution. Secondly, baseflow contribution can be temporally variable (within and across years), so a once off visual inspection is not a reliable means of assessing baseflow contribution. Finally, even though baseflow contribution may be small it can still be important . For example, baseflow may only sustain a river for one or two months of the year or even less frequently (e.g. during a drought), but it may sustain ecological communities through these periods of low flow. Rather than assuming that baseflow contributions are small, a baseflow analysis is recommended to assess the contribution and timing of baseflow to the river. (This will require rating of (at least one of) the stream gauges, which are currently only able to measure stream flow).

- "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" (PB, 2012:31) – Figure 8-6 in the PB report (2012) presents EC levels at the three gauging stations. EC levels during periods of baseflow range between approximately 300 to 600 µS/cm. This is not brackish or saline and certainly capable of sustaining ecosystems. (It is acknowledged that 2011 was a year of average to above average rainfall in the catchment, and that there were not very long periods without rainfall. Nevertheless, examination of available data suggests that there were sufficiently long periods post-runoff events where baseflow appears to be a very significant contribution to stream flow. In years of lower rainfall this may become proportionally more significant and during low flow conditions streamflow salinity will increase beyond that observed in 2011). The PB report describes EC in the alluvial aquifers as ranging from 390 -5800 µS/cm (with an average of 3000 µS/cm). The difference between the salinity observed in the baseflow in the stream compared to the salinity measured in the alluvial aquifers suggests one or more of the following:
    - The salinity of the alluvial aquifers may not have been adequately characterised by the PB investigation
    - The part of the alluvial aquifers contributing most significantly to baseflow have not be adequately characterised by the PB investigation (e.g. high hydraulic conductivity zones of lower EC within the alluvial material may be contributing most of the baseflow)
    - The baseflow observed in the river is not predominantly *groundwater* baseflow but another type of baseflow (e.g. bank storage, interflow etc). This is potentially an important aspect requiring additional investigation, because if the baseflow is mainly not from groundwater, then the potential impacts on baseflow from the Stage 1 GFDA will be minor to negligible.
- The following statement in the PB report: "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)" (PB,

2012; para 3, p132) does not concur with preliminary assessment of stream level data and stream EC data provided in the PB report. The stream level and EC datasuggest that during 2011, streamflow was maintained for considerable lengths of the year by flow that is not associated with rainfall runoff (i.e. baseflow) and hence is an important process sustaining stream flows. (If flow data was available, instead of only level data, conclusions could be drawn with more certainty). Further, even though baseflow contribution may be volumetrically small (and surface flows may "dominate" from a total flow perspective), the baseflow can nevertheless be quite significant. Hence the AH Ecology conclusion does not seem to concur with other data and statements in the PB (2012) report. Finally, the statement seems to unreasonably extrapolate from commenting on streamflow to the potential for other types of GDEs (springs, terrestrial vegetation etc).

- The conceptual model describes groundwater baseflow north of the study area (in the vicinity of Gloucester) as a likely discharge location for most of the hydrostratigraphic units in the study area. Hence a stream gauge (including EC monitoring) would be useful in this area.

Springs – There is two references to springs in the PB report, the first is replicated at the start of Section 5.4.1 (in this report) and the second is below:

> 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. (PB, 2012: 10)

The number and location of springs in the Alum Mountain Volcanic Formation is not discussed in the report, or the importance of the springs from an ecological or consumptive use perspective. Further information on the springs would be helpful to assess their importance relative to the proposed development. (It is noted however that spring identification and analysis was not part of the PB scope).

The presence of springs in the Alum Mountain Volcanics also somewhat conflicts with another statement in the PB report: "the Gloucester Basin is a closed feature bound by impermeable volcanic rocks" (PB, 2012: 30). The fact that there are springs in this formation implies the unit is not impermeable. This raises the issue of how the bedrock in the numerical model is to be conceptualised.

The URS study refers to the possible presences of "springs/seeps where the aquifer is truncated by a fault which extends to the surface" (URS, 2007: 13). It proceeds to describe a swampy area in the north-west corner of the Bowens Road mine which "could be attributed to an east west aligned fault forcing groundwater to the surface" (URS, 2007: 14). This is not discussed any further in the

PB report – based on the additional seismic data collected post-2007, it may be possible to assess whether the area referred to is caused by a fault related spring.

Terrestrial vegetation - Wherever there is shallow groundwater, there is the potential for groundwater dependent terrestrial vegetation. This would be most likely for riparian vegetation. A depth to watertable map overlain with vegetation would assist in determining areas of potential groundwater dependent vegetation. It is however agreed with the PB (2012) conclusion that this is unlikely to be a relationship of high dependence, given the (generally) brackish nature of the alluvial groundwater and relatively consistent nature of rainfall within the area.

5.5. Approach to development of monitoring infrastructure

The approach and rationale behind development of the monitoring infrastructure (bores and stream gauges) is not clearly described in the PB (2012) report. For example, a logical approach to developing a monitoring network would be to adopt a risk based strategy which starts with the position of "what are the possible impacts from the Stage 1 GFDA development?" This would include consideration of a wide range of potential processes and pathways for impact (some of which would be dismissed as improbable to the point of impossible), the consequences of possible impacts and then design of a monitoring network around those potential risks.

There is essentially no discussion in the PB report of what the Stage 1 GFDA development will be (e.g. in terms of numbers of bores, locations, depths, construction information, estimated extracted volumes etc), and hence the logic and adequacy of the proposed monitoring program is difficult to assess. (It is acknowledged however that details of the Stage 1 GFDA and production well layout are provided in the Environmental Assessment (AECOM, 2009), which is a publically available document).

This thinking may have already been undertaken as background to the PB (2012) report, but it would be helpful to see this documented. For example, description of this thinking may help to explain the rationale behind:

- why the bore monitoring infrastructure is located in a relatively small part of the Stage 1 GFDA area.
- the selected screen depths of the bores
- the absence of monitoring bores screened in the target coal seams
- how the monitoring system would provide early warning of possible impacts (as opposed to simply indicating that an impact has occurred)

An additional consideration is the use of preliminary modelling to assist in the design of the monitoring network (e.g. use of analytical models or a very simplified numerical model to assess timing / magnitude of potential impacts). While this modelling may be relatively simple (and hence have a reasonable degree of uncertainty), it would nevertheless assist in identifying the range of potential impacts and timing of impacts, which would in turn assist in design of the monitoring network. Essentially there needs to be a feedback loop between the process of modelling impacts and design of the monitoring network. It is likely for example, that the numerical modelling stage will identify with more clarity than currently understood, the most pertinent risks resulting from the Stage 1 GFDA development and this may required installation of new monitoring infrastructure.

5.6. Characterisation of fault zones

A summary of the key points regarding faults in the area are listed below, and then further expanded below:

1. Fault zones are potentially important influences on groundwater hydraulics, but at present not enough is known about the faults to conclude whether they are flow enhancing or flow impeding (or variable).
2. There is an investigation program underway to improve understanding of the faults
3. Siting production bores away from faults in an important, but not necessarily sufficient control, to prevent minimise the impact of faults as potential preferred pathways

5.6.1. Faults zones are potentially important

Fault zones are potentially important influences on groundwater hydraulics. In the author's opinion it is common for faults in fine grained rocks to produce a clayey, low hydraulic conductivity material that will impede groundwater flow. However, depending on the nature of the faulting and the rock material, faults can cause significant fracturing such that the hydraulic conductivity is enhanced. At present there is insufficient evidence to conclude how faults are behaving in the area. The following comments have been made regarding faults in the three main reports to date:

URS (2007) report

- "the significant faulting known to exist within the Gloucester-Stroud Basin is likely to have resulted in the development of secondary permeability and localised increases in aquifer hydraulic conductivities (Woodward-Clyde, September 1996, in URS, 2007:12)
- URS (2007:12) suggested that "the confining units may be 'leaky', particularly given the likely presence of fracturing/faulting", based on results from the Duralie EIS report.

- Groundwater may occur “as springs/seeps where the aquifer is truncated by a fault which extends to the ground surface” URS (2007:13)
- Groundwater is likely to “flow vertically between aquifers, facilitated by the presence of fractures/faults, leaking confining layers and differences in potentiometric head” URS (2007:13)
- “Faulting in the basin was suggested to have compartmentalised groundwater flow” URS (2007:13), commenting on conclusions from Resource Strategies (2001)
- “A swampy area in the north-west corner of the Bowens Road mine could be attributed to an east west aligned fault forcing groundwater to the surface” (URS, 2007: 14)
- “The source of this existing (high) permeability may be local faulting, including a fault which was intersected during the drilling of an in-seam horizontal hole at LMG02” (URS, 2007: 15)
- The URS report concluded that “the conductivity of the coal seams and interbedded rocks genenerally low to moderate…..however (is) 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” (URS, 2007: 17).

SRK (2010) report

- Faults are “variously interpreted as fully or partially penetrating through the full geological sequence (SRK, 2010:12)
- Normal and reverse faults are characteristic of the area. Seismic interpretation of the area around Stratford shows high angle faulting at the basin edge and low angle sub-parallel faulting towards the basin centre (SRK, 2010:12)
- “A normal fault intersected at 325m in the Bowens Road coal seam by cored well SGSD3 (Pacific Power, 1999) increased the hydraulic conductivity of the coal seam by one order of magnitude (~ 5.8 x 10^{-2} m/day)” (SRK, 2010:24)
- “Upward leakage may occur through fault zones” (SRK, 2010:24)

PB (2012) report

- “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” (PB, 2012:25)

- "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" (PB, 2012:68)
- "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" (PB, 2012:38) These sites are S4MB and S5MB.
- "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". (PB, 2012:86) (The proposed works are described later in this section)
- "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" (PB, 2012:112)
- Referring to the coal seam water bearing zones: "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" (PB, 2012:131)
- Summarising on the significance of fault zones, the PB study concludes:

> 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. (PB, 2012:132)

To summarise the above knowledge regarding the effect of fault zones, the studies all agree that fault zones are potentially important, but there is insufficient evidence within the study areas to conclude that faults are zones of enhanced hydraulic conductivity. However the URS (2007) and SRK (2010) studies favour the theory that they are more likely to be areas of enhanced hydraulic conductivity. This is supported by the evidence of increased hydraulic conductivity (by approximately one order of magnitude) in a bore in the Bowen Road coal seam. This was in the coal seam not the interburden.

The only new evidence related to the hydraulic properties of the faults that appears to be collected in the PB study (so excluding the seismic data which is new but not directly helpful regarding hydraulics) is the chemistry, age and isotope date collected in two bores drilled either side of a high-angle oblique fault (S4MB and S5MB). However the conclusion regarding faults seem mixed. On the one hand it is concluded that “faults do not affect the natural groundwater flow characteristics of shallow rock aquifers, interburden confining units or coal seam water bearing zones” and yet in another part of the report it is stated that “Groundwater chemistry, stable isotope composition and age is distinctly different on either side of the high-angle oblique fault running through the Tiedman property”. The two statements appear contradictory. And further it is suggested that these bores possibly suggest that “near surface faults are enhanced recharge areas”.

Hence there is a somewhat confused picture presented regarding the effect and importance of faults. The overall conclusion is agreed with however, that further studies are required to understand their significance and behaviour.

5.6.2. Fault investigation

It is understood that there are two investigations proposed / underway to improve understanding of the faults within the Stage 1 GFDA:

i. The program outlined in Section 7.3 of PB (2012), involving investigation of the fault between S4MB and S5MB.

ii. The Waukivory Flow Testing Program, as described in EMGA Mitchell McLennan (2011) and supplementary information provided by email from AGL (email from John Ross to Rick Evans on 13 March 2012).

Fault in the vicinity of S4MB and S5MB

The investigation of the fault in the vicinity of S4MB and S5MB is described in PB (2012) and involves:

- A 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).

"The 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" (PB, 2012:87)

It is understood that this investigation program has already commenced. The program outlined in Section 7.3 of PB (2012), involving investigation of the fault between S4MB and S5MB appears suitable for assessing the hydraulic characteristics of the fault, however the following is suggested:

- If the fault zone is narrow and the production bore screen cannot target the fault zone with confidence, consideration should be given to an alternate approach of siting the production bore on one side of the fault, with comparison of drawdown in observation bores either side of the fault.
- Contingency for a longer pumping period than 72 hours should be allowed for, to provide sufficient time for a drawdown response in all relevant bores.
- The program should also be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units – this will not require any additional bores, but a longer pumping period is likely to benefit this objective.

Fault in the vicinity of the Waukivory Flow Testing Program

The Waukivory Flow Testing Program is described in EMGA Mitchell McLennan (March, 2011) and supplementary information provided by email from AGL (email from John Ross to Rick Evans on 13 March 2012).

The proposed Waukivory program involves five monitoring bores to be constructed in the near vicinity of the gas wells that will comprise the Waukivory pilot. These are all located west of the Avon River and are dedicated AGL monitoring bores for this pilot (and will also be incorporated into the broader monitoring network for the Gloucester Gas Project and the Stage 1 GFDA). In addition there will be three alluvial monitoring bores owned and monitored by Gloucester Resources east of the Avon River (within the Avon River alluvium) that will be additional (nearby) monitoring bores for this study. There are also remote AGL monitoring bores (to distances of 3kms) that will used to assess any wider water level impacts.

The AGL proposal is to monitor the watertable aquifer at two sites (WKMB01 and WKMB02); the deep Roseville coal seam (the shallowest coal seam likely to be the target of CSG testing) at one site (WKMB04); and the thrust fault at two sites (WKMB03 and WKMB05). The rationale for the observation network and program is to:

- Monitor shallow and deep groundwater conditions pre-flow testing and any CSG drilling and development
- Monitor the beneficial aquifers in the vicinity of the pilot (alluvium and shallow rock)
- Determine if the thrust fault is a conduit or impediment for groundwater flow
- Determine any differences in fault permeability at depth (immediately above the targeted coal seams) and at shallow intervals (adjacent to the Avon River)
- Determine if vertical leakage from shallow aquifers is likely to occur in the vicinity of the depressurised gas wells
- Enhance the conceptual model and determine whether significant fault features should be included in future numerical modelling
- Determine whether shallow aquifers and deeper water bearing zones are isolated or connected when deep coal seams are depressurised in areas of faulting

The monitoring program will comprise the following (at each of the AGL sites) during each of the following phases:

Baseline for a period of at least 3 months (ie pre fracture stimulation and flow testing)

- Permeability testing (slug testing)
- Water levels
- Water quality

Fracture Stimulation for the days and weeks of the fracture stimulation program

- Water level variations
- Water quality variations

Flow testing for periods of around 6 months

- Produced water profile
- Water level variations
- Water quality variations

The above information was provided from AGL (email from John Ross to Rick Evans on 13 March 2012) and the information supplements the detail provided in the Draft Groundwater Management Plan for the Waukivory Flow Testing Program dated 8 March 2012.

The program appears suitable for assessing the hydraulic characteristics of the fault, however it is suggested that consideration be given to installing one observation bore in the interburden, in relatively close proximity to test well WK-11 (e.g. 20-50m, or as close as safely possible) and screened approximately 20-30m above the fault. These two characteristics of the observation bore (i.e. vertically closer to the fault and laterally closer to the test well), will mean greater likelihood of water levels in the bore responding over the six month pumping period and minimise the possibility of obtaining a non-conclusive result from the test program. As per the fault testing program at S4MB and S5MB,the program should also be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units.

5.6.3. Siting CSG wells away from faults

Siting CSG wells away from faults (PB, 2102: 132) is an important, but not necessarily sufficient control, to prevent the impact of faults acting as potential preferred pathways. It is important that the results of the characterisation of the faults (i.e. conceptualisation of fault behaviour) derived from the above two programs is brought into the conceptual model, so that the effect of faults can be accounted for (if required) in the development of the numerical model.

5.7. Overview of possible risks associated with hydraulic fracturing and under-reaming

5.7.1. Hydraulic fracturing

This review provides some general contextual comments on the potential risks associated with hydraulic fracturing in the Gloucester Valley. The review focuses on the risks associated with hydraulic changes to aquifer behaviour and does not consider any potential issues resulting from the use of chemical hydraulic fracturing fluids.

The fracturing process

Hydraulic fracturing is the process of inducing fractures in coal measure sequences to enhance permeability and gas yields. Advances in hydraulic fracturing technology allow the opportunity to produce gas from rock formations that previously would have been too difficult and expensive to consider.

Hydraulic fracturing occurs after a well is drilled, cased and cemented by pumping water, often containing a suspended proppant, such as sand, down into a wellbore in order to increase productivity of a well. The pressure applied cracks the rocks and the proppant lodges in the cracks keeping the fracture open. The newly created fracture enables natural gas and formation water to flow to the CSG well.

The hydraulic fracturing operation typically takes place only once at the beginning of the well operation. Most wells then produce for years without requiring any further fracturing.

Assessment of potential risks

The practice of hydraulic fracturing, or fraccing, to increase gas output, has the potential to induce connection and cross-contamination between aquifers, with impacts on groundwater quality (National Water Commission, 2011). There are two possible mechanisms for this process:

- Poor well construction practices allowing pathways to develop in and around the well casing causing interaction with overlying aquifers/aquitards;
- Vertical fracture propagation in the target formation creating preferred pathways to overlying or underlying aquifers/aquitards.

Both of these mechanisms will result in an increased vertical hydraulic conductivity, which, particularly if extending into the 'shallow rock aquifers' and 'interburden confining units' in the upper 200m will increase downwards leakage from these units. The risk of these two mechanisms actually occurring is discussed below.

Potential for pathways to develop in and around the well casing

Development of pathways in and around the well casing can be avoided through appropriate well construction. Ensuring there is an impermeable grout or cement barrier around the well casing separating the target coal seams from the overlying aquifers will prevent inter-aquifer contamination. AGL state that the hydraulic fracturing in CSG production wells in the Gloucester Basin will consist of perforating pressure cemented casing over relatively small coal intervals (AGL email 16th March 2012). Thus the individual coal seams will be effectively hydraulically isolated from each other around the well annulus due to the cement seal.

The NSW Department of Trade Investment Resources and Energy require that all exploratory and production wells be constructed to hydraulically isolate the target formation from overlying aquifers. AGL are required to follow these conditions as a condition of their licence. Provided these requirements are followed, the potential for inter-aquifer leakage via the drill hole is eliminated. Also AGL will be undertaking hydraulic testing of the pressure cemented seals around the well annulus prior to any hydraulic fracturing or development work (AGL email dated 16th March 2012).

Potential for pathways to develop within overlying/underlying strata

Analysis of the depth of induced fractures compared to depth to overlying aquifers can provide some indication of the risk of inducing inter-aquifer connectivity through hydraulic fracturing. The liberation of coal seam gas can only occur when coal seams under significant hydraulic pressure are depressurised. Coal seam gas is trapped in pores inside the coal, held in place by the water pressure. The depressurisation through pumping of natural groundwater causes the coal seams to release the methane dominated gases. The pressures required to 'seal' the gas insitu are high, meaning reasonable depths are required before these natural hydrostatic pressures are obtained. In the Gloucester Valley, the coal seams where the liberation of coal seam gas is possible are hundreds of metres deep. For instance, the depth of the four proposed exploration CSG wells in the Waukivory Flow Testing Program is likely to be up to 1,000m (EMGA/ Mitchell Mclennan, March 2011). Given that the propagation of induced fractures through the hydraulic fracturing process is typically tens of metres (mostly horizontal) and the thickness of material between the target coal seam and the only usable aquifer close to the surface is hundreds of metres, the risk of creating a preferred pathway to the surface alluvial aquifers is considered to be very small.

The only potential process where hydraulic fracturing could result in the interconnection of the target coal seams and watertable is if the fracturing were to intersect a fault or fracture zone and where there was preferential flow along the fault or fracture zone. There are known faults in the Gloucester Basin so there is potential for this process to occur. AGL propose to investigate this process in the Waukivory Flow Testing program by monitoring a series of eight designated monitoring bores either side of a known thrust fault for a period before and after hydraulic fracturing of the four proposed exploration wells (AGL email dated 13th March 2012). The conclusions drawn from analysis of the monitoring results for the Waukivory pilot program will be an important indicator of the possible impact of hydraulic fracturing.

It is also important to recognise that it is not in AGL's interest for the hydraulic fracturing process to result in fractures to any formations other than the target coal seams. If the fractures do result in interconnection of overlying aquifers, then the coal seam gas can permeate into these aquifers rather than being drawn into the well. AGL will be undertaking diagnostic monitoring of fracture development to ensure the fracture propagation remains within the target coal seam. The use of tools such as micro-seismic, tilt meters and dipole sonic logs provide important information on the orientation and length of induced hydraulic fractures.

5.7.2. Under-reaming

Under-reaming is the process of enlarging the diameter of the hole beneath the end of the cemented casing. Under-reaming is a useful process to increase the surface area of the hole thus increasing gas liberation from the intersected coal seams. The technique is useful in particularly permeable coal seams where increased surface area of the hole can result in increased flow of liberated gas without the need for hydraulic fracturing.

All intervals that are under reamed are open and hence there will be hydraulic connection of coal seams and aquitards within this interval. This is in contrast to the hydraulic fracturing process where the casing is only perforated at specific coal intervals with the cement around the hole annulus remaining intact, thus isolating individual coal seams. The potential hydraulic linking of individual coal seams in the under-reaming process can cause migration of water between coal seams. However, in the case of the Gloucestor Basin, the groundwater chemistry of individual coal seams is reasonably similar (albeit slightly increasing in EC at depth) and there are no known good groundwater quality and/or high yielding aquifers within the target coal seam formations so the risk is considered to be negligible.

5.8. Seepage Monitoring

The PB (2012) report describes seepage monitoring bores around the Tiedman South dam (TMB04 and TMB05). The two monitoring bores are considered sufficient to assess potential seepage impacts from the dam. (A more distant down-gradient bore is not considered necessary; this could be installed in the event that any seepage was detected in TMB05, the down-gradient bore). It is not known if there are water level data loggers in these two bores; if there are none present this is recommended as an additional indicator of potential seepage (i.e. in addition to water quality monitoring).

The Stratford 1 and Stratford 3 dams do not have any nearby observation bores for detecting seepage assessment. If construction techniques or liners in Stratford 1 and Stratford 3 dams were the same as for the Tiedman dams, then the Tiedman monitoring is considered a sufficient indicator of the performance of all the dams. If different construction techniques or liners have been used in the Stratford dams, then (depending on those construction techniques / liners) consideration should be given to installing a monitoring bore down-gradient of one of the dams.

6. Conclusion

In general the conceptualisation presented in the PB (2012) report is broadly considered to be appropriate, and the fundamentals of the conceptual model are reasonable. The PB (2012) study has largely gathered sufficient information to enable development of a suitable conceptual model (which will be supplemented by current/proposed investigation programs), however some further work is recommended as a result of this review. Similarly, some additional monitoring infrastructure is recommended.

In some instances it is considered that the PB (2012) study has drawn inaccurate conclusions from the data or omitted some work which would improve conceptual understanding. These generally fall into categories of: connectivity between deep and shallow systems, recharge and discharge processes, characterisation of vertical hydraulic conductivity and specific improvements that can be made to the conceptual model. Regarding the latter, the most important improvements relate to the spatial coverage of the conceptual model, definition of model boundaries and preliminary quantification of key processes (i.e. a water balance). It is apparent that not all available information has been used to develop the conceptual model, and incorporation of additional data will enhance the current conceptualisation. This review has highlighted the importance of not directly extrapolating conclusions regarding the developed hydrogeological system based on observations from the natural (i.e. unstressed or lightly stressed) condition.

There is currently insufficient information available to characterise the hydraulic behaviour of faults within the project area. Given the potential importance of faults to groundwater movement, the two proposed field programs are important activities to fill this knowledge gap.

None of the criticisms presented in this review are considered to be issues that cannot be readily addressed or the conceptual model revised to take account of the comments. The review has not identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective, however it is the role of the numerical modelling to assess the location and magnitude of impacts.

7. Recommendations for Further Work

This section presents recommendations for further work. It is divided into field based activities and desk based activities, and then further divided into High and Moderate priority activities.

It is suggested that all of these recommendations can occur in parallel with the Waukivory Flow Testing Program and should not be delayed pending the results of that program.

7.1. Field work

7.1.1. High Priority

It is recommended that:

1) The currently planned investigations be undertaken to assess the hydraulic significance of faults in the study area. It is understood that there are two proposed programs to assess faults in the area:

    i. Regarding the investigation program outlined in Section 7.3 of PB (2012), involving investigation of the fault between S4MB and S5MB; this program appears suitable for assessing fault characteristics, however the following is suggested:

    - If the fault zone is narrow and the screen cannot be targeted with confidence, consideration should be given to an alternate approach of siting the pumping test production bore on one side of the fault, with comparison of drawdown in observation bores either side of the fault.
    - Contingency for a longer pumping period than 72 hours should be considered, to provide sufficient time for a drawdown response in all relevant bores.
    - The program should also be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units – this will not require any additional bores, but a longer pumping period is likely to benefit this objective.

    ii. Regarding the Waukivory Flow Testing Program, as described in the AGL report (8 March 2012) and supplementary information provided by email from AGL (email from John Ross to Rick Evans on 13 March 2012). This program appears suitable for assessing fault characteristics, however it is suggested that consideration be given to installing one observation bore in the interburden, in relatively close proximity to test well WK-11 (e.g. 20-50m, or as close as safely possible) and screened approximately 20-30m above the fault, to minimise the possibility of obtaining a non-conclusive result from the test program. The program at S4MB and S5MB should be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units. The Waukivory Flow Testing Program is an important part of the overall hydrogeological investigation and should proceed.

2) That at least one of the three existing stream gauges is rated to enable determination of flows. This will allow determination of baseflow contribution to the Avon River (refer Section 7.2).
3) To provide better spatial coverage across the Stage 1 GFDA, and to provide an indication of potential impacts in the area where the target coal seams (and interburden) are most likely to be discharging to the shallow rock/alluvial sediments, an additional nested monitoring site be installed (two bores are suggested) in the vicinity of the township of Gloucester.
4) Field work be undertaken to investigate the relationship between groundwater and Waukivory Creek and Dog Trap Creek, where these creeks run over the recharge areas of the coal seams (This is likely to involve at least one shallow observation bore at each creek in these areas). Depending on the relationship identified, gauging of one or both creeks may be required.
5) At least one VWP (nested site) should be installed in the target coal seams and interburden in order to determine pressure changes at depth as a result of the CSG extraction. The most logical location for this site would be around the central observation (nested) bore sites (e.g. on the Tiedman property), so that deeper pressure changes can be compared to the adjacent shallow pressures. Correspondence from AGL post the draft IPR indicates that up to two deep VWPs are planned on the Tiedman property (or more likely Farley property immediately to the north of the Tiedman property). The VWPs will utilise reservoir coreholes after sampling and investigation is complete. The REF for these works is currently with DTIRIS for approval (EMGA Mitchell McLennan, November 2011). It is noted that the REF states that the depths for the VWPs have not yet been determined, but assuming they target the deep coal seams and interburden, these works would address this recommendation.
6) At least one shallow monitoring site in the coal seam outcrop areas (with multiple monitoring levels) be installed to investigate the potential of up dip gas migration, as per SRK (2010) recommendation no. 11. This refers to the installation of gas monitoring bores further east than the current gas observation bores, in the coal seam outcrop/subcrop areas targeting seams underlying the Roseville coal seam. It is possible that a nil response might be observed in these bores, but the need to prove this is considered important.
7) The method of abandonment of exploration bores should be identified. The bores should be sealed / grouted appropriately, if this has not already occurred.

7.1.2. Moderate Priority

It is recommended that:

8) An investigation of the sources of baseflow to the Avon river be conducted. This is potentially significant, as it will indicate the importance of groundwater contribution to baseflow. (Currently there is a discrepancy between the salinity of the baseflow recorded in the river and the alluvial groundwater salinity).
9) Water level data loggers should be included in TMB04 and TMB05 (if they are not already).
10) If different construction techniques or liners have been used in the Stratford holding dams then, depending on those construction techniques / liners, consideration should be given to installing a monitoring bore down-gradient of one of the dams. Correspondence from AGL post the draft IPR indicates that the Stratford holding dams are to be decommissioned shortly; assuming this occurs, this recommendation will be redundant.
11) All of the private bores surveyed and dipped in the SRK (2010) study (p30-33) be re-dipped and incorporated into either the alluvial or shallow aquifer potentiometric surface
12) Surveying of springs in the project area be undertaken (including location, flow, use, ecological value).

7.2. Desk-based study / analysis

7.2.1. High Priority

It is recommended that:

13) Based on the two proposed field programs for investigating faults (refer Recommendation 1 above), a conceptual model of the hydraulic behaviour of the faults should be developed. If the field programs are inconclusive regarding hydraulic fault behaviour, further field investigations may be required. If the field investigations indicate the faults are significant preferred pathways, then geophysical mapping of faults in the shallow subsurface may be required to allow for inclusion of faults in the numerical model (as the current seismic surveys have very poor resolution in the upper 100-200m).
14) The conceptual model should account for major structural changes related to the faults. For example, the conceptual cross sections in PB (2012) do not appear to show some of the major fault-related displacements of units. While the conceptual model is necessarily a simplification of reality, major displacements should be included in the conceptual and numerical model.
15) The proposed numerical model boundaries should be defined, and the conceptual model expanded to include this area. The boundaries of the conceptual model should be expanded in

an east-west direction to include the full synclinal trough. They should also be expanded in a north-south direction to include the area around Gloucester (where the current conceptual model suggested target coal seams and interburden may be discharging).

16) A water balance be conducted (using the above boundaries). This should include a water balance for the natural and the developed case.

17) To provide better spatial coverage across the Stage 1 GFDA, additional bore data should be incorporated into the conceptual model to improve spatial coverage away from the central area where the PB (2012) investigation was focused. For example, it appears that there are a number of bores described in SRK (2010) report which would improve spatial coverage within the Stage 1 GFDA, such as:
    a. Some of the existing gas production wells e.g. Craven 6, Faukland 3 and Waukivory 3 provide lithological information away from the centre of the Stage 1 GFDA,
    b. Previous exploration bores drilled by Lucas Energy
    c. Some of the deeper monitoring bores associated with the Gloucester coal mine
    d. Some of the DNR bores (e.g. as shown in Figure 5-1 in SRK, 2010 - these may be shallow and not useful, however this should be investigated)

    Many of these will not contain water level data (and most will not be suitable to form part of the monitoring network) but they will be useful for developing the hydrostratigraphy in the conceptual model.

18) Additional analysis of the existing hydraulic conductivity data be undertaken. This should include:
    i. estimation of the vertical hydraulic conductivity of the units, recognising that the data currently collected is predominantly horizontal hydraulic conductivity.
    ii. consideration of the difference between the slug test data and the packer test and laboratory data, and a conclusion reached as to which is considered more reliable.
    iii. consideration of reasons for the absence of a trend in hydraulic conductivity and depth for the packer and lab test data.
    iv. representative values for the four hydrostratigraphic units should be proposed (recognising that this may change during model calibration). Upper and lower bounds that will be permitted within the model should also be described.

19) Further evaluation of the relevance of hydraulic conductivity data collected in or close to the Stage 1 GFDA area be undertaken, and incorporated into the numerical model as appropriate.

20) Baseflow separation be undertaken for the Avon River downstream of Waukivory Creek gauge (GS208028). If there is an additional gauge within a reasonable distance downstream of

GS208028 (e.g. within approximately 10-15km), baseflow separation should also be undertaken on that gauge.

21) Once the new stream gauge(s) have been rated, baseflow separation be undertaken on the gauge(s). (This should consideration of using the EC data to assist in calibration of the baseflow separation).
22) Once all of the above recommendations have been completed (1-21), the conceptual model should be updated and consolidated into one report.

7.2.2. Moderate Priority

It is recommended that:

23) An analysis of water levels with barometric effect removed be undertaken. This will allow a clearer evaluation of trends at nested sites.
24) Aspects of the conceptual model which are currently located partly in PB (2012) and partly in SRK (2010) be consolidated. For example, the stream gauge (GS208028) located near the northern boundary of the Stage 1 GFDA (a location highly relevant to the study) is referred to in the SRK (2010) report but not the PB (2012) report. Another example is the map of groundwater users presented in the SRK (2010) report but not in the PB (2012) report.

8. References

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Date: 26 June 2013

To: John Ross
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From: Dr Noel Merrick

Re: **Gloucester Gas Project - Groundwater Peer Review**

This report provides a Peer Review of the updated conceptual (hydrogeological) model under Condition 3.9 of the Part 3A approval (MP 08_0154) for the Gloucester Gas Project - Stage 1 GFDA. In a letter from the NSW Department of Planning & Infrastructure to AGL Energy Limited dated 5 March 2013, the Department noted that the Director-General had approved the appointment of Dr Noel Merrick as an appropriately experienced and qualified hydrogeologist for the undertaking of the review. Apart from over 40 years experience as a professional hydrogeologist, geophysicist and groundwater modeller, Dr Merrick has specific experience in the Gloucester Basin, having led the groundwater assessments for two recent open cut coal mine expansions (Duralie, Stratford).

Methodology

The peer review has been undertaken through examination of a written report, following a conceptualisation workshop and two meetings with the developers of the conceptual model.

The updated conceptual model has been documented in a report by Parsons Brinckerhoff (PB):

- Parsons Brinckerhoff, 2013, Hydrogeological Conceptual Model of the Gloucester Basin. Report No. 2162406A PR_7266 prepared for AGL Upstream Investments Pty Ltd. Revision A, Final Draft. Authors R. Rollins and S. Brown. Date 12 June 2013. 73p + 2 Appendices.

The terms of reference for the review are articulated in Conditions 3.8 and 3.9 of the Planning Assessment Commission (PAC) Project Approval (22 February 2011) and Condition 16 of the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) Approval (11 February 2013).

The methodology for the review is in accordance with the principles of the Australian Groundwater Modelling Guidelines issued by the National Water Commission (NWC) in June 2012 (Barnett *et al*., 2012[1]) and the Murray Darling Basin Commission Groundwater Flow Modelling Guideline (MDBC, 2001[2]).

Conditions

PAC Condition 3.8:

> *Prior to the commencement of construction of 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.*

PAC Condition 3.9:

> *The updated conceptual hydrogeological model referred to in condition 3.8 shall be submitted for the Director-General's approval, prior to the commencement of construction and shall include:*
> *a) updated assessment of the potential for drawdown and displacement of shallow rock and alluvial beneficial aquifers, considering impacts to nearby registered bore users, based on detailed baseline data gathered from condition 3.8 a) to c);*
> *b) optimal areas for gas well location within the Stage 1 Gas Field Development Area based on minimising the risk of gas migration and of interaction with beneficial aquifers and the outcomes of the updated assessment;*
> *c) recommendations for phased gas well development including indentifying the maximum number of gas wells that would be developed during the first phase of development and associated operational groundwater monitoring strategy consistent with the requirements of condition 4.1; and*
> *d) include an independent peer review by an appropriately experienced and qualified hydrogeologist (who is approved by the Director-General for the purposes of this condition) on the robustness and technical veracity of the model.*

SEWPaC Condition 16:

> *The person taking the action must consult the department on the development of the conceptual hydrogeological model required under Conditions 3.8 and 3.9 of the state approval conditions, and must provide a copy of the model to the department within twenty (20) business days of its finalisation.*

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[1] Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). Australian Groundwater Modelling Guidelines. Waterlines report 82, National Water Commission, Canberra.

[2] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: http://www.mdbc.gov.au/nrm/groundwater/groundwater_guides/

In addition to the regulatory conditions, the evolution of the Gloucester Basin conceptual model since 2010, as documented in three reports cited in PB (2013), was reviewed by Dr Richard Evans (Sinclair Knight Merz) on behalf of the Gloucester Community Consultative Committee. Consideration of his recommendations, as they pertain to an updated conceptual model, is noted in Table 2.3 of the PB (2013) report. Recommendations 13 and 14 sought inclusion in the conceptual model of the hydraulic behaviour of faults and major structural changes related to faults. Recommendation 22 sought consolidation of the conceptual model documentation into a single report.

Checklist

The NWC guide includes a checklist for the assessment of each stage of modelling, including the conceptualisation stage preceding the development of a numerical model. The completed checklist is offered at **Table 1**.

The comments in the checklist provide the foundation for this reviewer's certification of the *robustness and technical veracity of the model,* as required under PAC Condition 3.9(d).

In terms of the conditions:

- Seismic reflection surveys have been conducted and their outputs examined for the identification of fault locations and persistence [PAC Condition 3.8(a)];
- There has been a very extensive field program in accordance with the requirements of PAC Condition 3.8(b), including two field tests of potential effects of faulting on groundwater hydrology;
- There is now more than two years of baseline data in accordance with PAC Condition 3.8(c), with a network of more than 40 monitoring points covering representative lithologies down to a depth of about 350 m; hydraulic conductivity measurements extend to about 900 m depth;
- The report includes a generic discussion on drawdown propagation from CSG activity in accordance with Condition 3.9(a), in Section 6.5.1, with inclusion of a map of registered bores in Figure 5.20, but quantitative assessment is premature;
- There is some discussion on potential subsidence from CSG activity in accordance with Condition 3.9(a), in Section 6.5.2, but consideration of *displacement of shallow rock and alluvial beneficial aquifers* is premature;
- The requested *optimal areas for gas well location* in Condition 3.9(b) are premature, although operational logistics principles are addressed in Section 6.5.3;
- The requested *recommendations for phased gas well development* in Condition 3.9(c) are premature, although operational logistics principles are addressed in Section 6.5.3.

Specific Comments

Apart from the PB field investigation program from 2010 to 2012, the conceptual model is based on 14 prior studies. This reviewer is not aware of the omission of any significant study from examination, apart from the Rocky Hill Project investigations and the associated groundwater assessment which is not yet publicly available.

The geological map in Figure 4.5 (PB, 2013) shows the mapped area of "Quaternary Alluvium". It is likely that much of the mapped area is colluvium, following a detailed TEM survey conducted for the Stratford Extension groundwater assessment.

While Figure 5.1 (PB, 2013) shows the AGL monitoring network centred on AGL-owned properties, there are substantial networks to the south belonging to the Stratford Mine and Rocky Hill Project. Although no monitoring data are shown for these bores, the monitored sites are indicated in Figure 5.20 (PB, 2013).

In Section 5.2 (PB, 2013), an assessment is made of likely baseflow contributions to stream flow. There are many alternative algorithms for baseflow analysis and they can differ substantially in their estimates. It follows that the provided baseflow estimates have an associated uncertainty.

The pre-development regional groundwater level contours in Figure 5.9 are in broad agreement with the inferred levels determined by this reviewer in the Stratford Extension groundwater assessment.

The groundwater hydrographs in Figures 5.10 to 5.18 are compared with daily rainfall. To better illustrate cause-and-effect, the rainfall residual mass curve (in Figure 4.3) could have been overlaid to show that the observed trends are due to climate rather than any other candidate stress. Similarly, this practice would have helped to differentiate potential causative factors during the 29-day flow test (Section 5.3.3.4) and the 3-day pumping test (Section 5.5.2.1) experiments on a strike-slip fault.

Chapter 7 (PB, 2013) introduces the numerical model objectives, target confidence level, model domain, hydrostratigraphic upscaling, boundaries, and processes to be simulated. This reviewer concurs with the model plan as it stands. In particular, the plan is to simulate single-phase (water) rather than dual-phase (water and gas). Given the lack of availability of accessible and computationally efficient dual-phase software, and the focus on environmental impacts, this reviewer agrees with a single-phase approach as it is expected to be conservative in terms of impacts of relevance to the environment and the community.

Conclusion

The updated conceptual model has a very strong scientific basis. This reviewer attests to the *robustness and technical veracity of the model* [PAC Condition 3.9(d)].

The development of the conceptual model has highlighted an uncertainty in the hydraulic role of faults and has confirmed the very wide range in hydraulic properties of host lithologies within the Gloucester Basin.

Yours sincerely

Dr Noel Merrick

Table 1. Peer Review Checklist for the Gloucester Basin Conceptual Model

2. Conceptualisation	*Yes/No*	*Comment*
2.1 Has a literature review been completed, including examination of prior investigations?	Y	14 studies (Table 3.1)
2.2 Is the aquifer system adequately described?	Y	Section 5.3
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Y	Section 4.3
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Y	Entire basin; focus on faulting
2.2.3 aquifer geometry including layer elevations and thicknesses	Y	Provided as sections; detailed elevations and thicknesses deferred to numerical model
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	..	Confinement is discussed for natural and CSG conditions; premature to examine spatially and temporally
2.3 Have data on groundwater stresses been collected and analysed?	Y	
2.3.1 recharge from rainfall, irrigation, floods, lakes	..	Rainfall and residual mass
2.3.2 river or lake stage heights	Y	Stages at 4 gauges
2.3.3 groundwater usage (pumping, returns etc)	..	Mine inflow at Stratford mine; no stock & domestic, but estimate is made
2.3.4 evapotranspiration	Y	BoM map
2.3.5 other?	Y	Aquifer testing; GDE map
2.4 Have groundwater level observations been collected and analysed?	Y	
2.4.1 selection of representative bore hydrographs	Y	6 Sites in alluvium; nested hydrographs at 8 sites
2.4.2 comparison of hydrographs	Y	Alluvial sites compared. Vertical head differences compared at nested sites
2.4.3 effect of stresses on hydrographs	Y	Compared with stream stage and rain (not residual mass)
2.4.4 watertable maps/piezometric surfaces?	Y	One pre-development regional watertable map
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	N/A	
2.5 Have flow observations been collected and analysed?	Y	4 gauges; no flow duration curves or statistics; EC dynamics included
2.5.1 baseflow in rivers	Y	Baseflow separation analysis
2.5.2 discharge in springs	N/A	
2.5.3 location of diffuse discharge areas?	N/A	
2.6 Is the measurement error or data uncertainty reported?		
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	N	
2.6.2 spatial variability/heterogeneity of parameters	Y	Hydraulic conductivity variation with lithology and with depth; large ranges
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	N	
2.7 Have consistent data units and geometric datum been used?	Y	Metres; Days; ML; MGA; AHD
2.8 Is there a clear description of the conceptual model?	Y	

2.8.1 Is there a graphical representation of the conceptual model?	Y	Pre-development (Figure 6.1). During development (Figure 6.2).
2.8.2 Is the conceptual model based on all available, relevant data?	Y	Extensive analysis
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Y	Section 7.1. Objectives specified in PAC and SEWPaC conditions (for CSG impact assessment) - some unreasonable expectations of a numerical model in SEWPaC conditions. Nominated Class 2 confidence level for numerical model - this is appropriate
2.9.1 Are the relevant processes identified?	Y	Field investigations of potential faulting effects on groundwater hydrology.
2.9.2 Is justification provided for omission or simplification of processes?	Y	None omitted. Faulting will be tested.
2.10 Have alternative conceptual models been investigated?	Y	Faulting in or out

Gloucester Water Study Project – Independent Peer Review

GLOUCESTER SHIRE COUNCIL

VW07302

6 June 2014

JACOBS SKM

Contents

1. Introduction

This report presents the findings of an Independent Review of hydrogeological aspects of the Gloucester Gas Project, conducted by Dr Richard Evans. Based on the recommendation of the Gloucester Water Study Project Technical Steering Committee, Dr Evans was appointed the Independent Peer Reviewer and commissioned by Gloucester Shire Council on 23rd December 2013. The scope of the review is described in Section 2 of this report.

It is important that this report is read in its entirety. Selective quoting of individual sections may result in an inaccurate understanding of the report's contents.

2. Scope of Independent Review

The scope of the Independent Review covered by this report is to undertake an objective technical review of the following documents:

1. Parsons Brinckerhoff (2013a). *Hydrogeological Conceptual Model of the Gloucester Basin* 2162406A PR_7266, 28 June 2013.

2. Parsons Brinckerhoff (2013b). *Water Balance for the Gloucester Basin* 2162406A PR_7296, 12 July 2013.

3. Parsons Brinckerhoff (2013d). *2013 Gloucester Groundwater and Surface Water Monitoring – Annual Status Report.* 2162406E-RES-RPT-7423 Rev A, 11 October 2013.

The review is to take into consideration the following reports, guidelines and relevant documents, including but not limited to:

- Underlying data used in the creation of the above reports
- Any data in previous relevant AGL technical or monitoring reports, EIS's or associated technical studies released by mining companies
- Relevant groundwater modelling guidelines
- Recommendations from the 2012 Independent Peer Review commissioned by the Gloucester Community Consultative Committee (GCCC)
- Peer review of the Water Balance report undertaken by Heritage Computing, July 2013
- Peer review of hydrogeological conceptual model undertaken by Heritage Computing, June 2013

The review is to provide an opinion on the:

- Suitability of scope and methodologies used in the reports
- Adequacy and representativeness of data used in assessments in the reports
- Specifically in regard to the numerical model, whether the framework as described in the hydrogeological conceptual model is appropriate, and if any other aspects should be added to the numerical model.

The scope is not considered to include issues related to hydraulic fracturing. Also, possible groundwater issues associated with the proposed irrigation based water disposal system are not in scope.

In addition to the three Parsons Brinckerhoff reports which are the focus of this review and the two Heritage Computing peer reviews referred to above, this assessment has also examined the following reports (to varying levels of detail, as deemed appropriate for review of the three primary reports):

1. Parsons Brinckerhoff (2013c). *Hydrogeological Investigation of a Strike-slip fault in the Northern Gloucester Basin*. 2192406B PR_5741, 9 August 2013.

2. Heritage Computing (2012). *A Hydrogeological Assessment in Support of the Stratford Coal Project Environmental Impact Statement,* by Dr NP Merrick and Dr M Alkhatib. Report HC2012/2 (Forming Appendix A – Groundwater Assessment, of the Stratford Extension Project, Environmental Impact Statement.

3. Parsons Brinckerhoff (2014). *2013 Flow Testing of Craven 06 and Waukivory 03 Gas Wells.* 2162406C-WAT-RPT-7642 Rev B, 13 February 2014.

3. Project Background

AGL Upstream Infrastructure Investments Pty Ltd (AGL) is proposing to build the Gloucester Gas Project (GGP) which comprises several stages of development facilitating the extraction of coal seam gas (CSG) from the Gloucester Basin. Concept Plan and Project Approval (Part 3A Approval) for the Stage 1 Gas Field Development Area (GFDA) was granted on 22 February 2011 under Part 3A of the Environmental Planning and Assessment Act (1979) (EP&A Act). In addition the project received approval under the Environment Protection and Biodiversity Conservation Act (1999) (EPBC Act) (EPBC Approval) on 11 February 2013.

AGL also holds Petroleum Exploration Licence (PEL) 285, under the Petroleum (Onshore) Act 1991, covering the whole of the Gloucester Basin, approximately 100 km north of Newcastle, NSW. AGL has also applied for a Petroleum Production Lease (PPL) for the area subject of the planning approvals.

The GGP will involve the dewatering of deep groundwater 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 1,000 metres below ground level (m bgl). The current GGP includes the construction, operation and decommissioning of not more than 110 coal seam gas wells and associated infrastructure, including gas and water gathering lines, within the Stage 1 GFDA.

The field based groundwater studies commenced in 2010 with a comprehensive groundwater investigation, the Phase 2 Groundwater Investigations, which was completed in 2011 (Parsons Brinckerhoff, 2012a). This investigation confirmed the desktop based hydrogeological conceptual model for the Stage 1 GFDA (SRK 2010). The investigation established a dedicated water monitoring network, and enabled the collection of baseline water level, water quality and hydraulic conductivity data for each of the hydrogeological units represented across the different groundwater systems and the surface water systems.

Part 3A Approval (condition 3.8 and 3.9) and EPBC Approval (condition 16) require that the conceptual hydrogeological model developed during the assessment stage of the project is updated based on additional baseline data gathered. The collection and interpretation of groundwater and surface water level and quality data enhances and verifies the understanding of the conceptual (hydrogeological) model, and is the primary scientific data to determine whether there are any impacts resulting from CSG activities on groundwater and surface water systems.

In 2012, the following reports were reviewed by this author, as part of the GCCC Independent Peer review process:

1) URS (2007). *Hydrogeological Review: Proposed Coal Seam Gas Exploration Areas, Gloucester-Stroud Basin*, NSW;

2) SRK Consulting (2010). *Gloucester Basin Stage 1 Gas Field Development Project: Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model* Report No AGL002_Glouceser Basin Hydrogeology Study_Rev 2; and

3) Parsons Brinckerhoff (2012a). *Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area Gloucester Gas Project* 2162406A PR_5630.

This commission involves reviewing further hydrogeological and hydrological work undertaken since that review, primarily the conceptual model and water balance assessments. Other documents reviewed as part of this study are outlined in Section 2 of this report.

The role of the Independent Reviewer is to provide independent advice to the Gloucester Shire Council on scientific and technical matters relating to Coal Seam Gas (CSG) groundwater and surface water studies completed to date for the GGP, primarily the Stage 1 GFDA. This includes determining whether the AGL studies are 'fair and reasonable', and to provide an expert view to the community on the extent of these studies, the baseline data collected to date, the veracity of the conceptual model and water balance studies, and their suitability for assessing impacts to water resources, including suitability as a foundation for the numerical model, any gaps identified in the baseline data and conceptual model, and the connectivity of aquifers as a result of deep coal seam depressurisation.

4. Overview Comments

In general, the conceptualisation and water balance as presented in the reviewed reports is considered to be appropriate. The fundamentals of the conceptual model and water balance are reasonable, including:

- The conceptual framework for the model, including model domain, hydrostratigraphy (including breakdown into four basic hydrostratigraphic units), conceptual boundaries and stresses are all generally appropriately conceptualised.
- The water balance is a reasonable representation of the main processes and water fluxes, and has in general been developed with suitable techniques and to a level of accuracy typical of a Basin-wide water balance
- The likelihood of other groundwater dependent ecosystems (apart from baseflow) within the study area being significantly dependent on groundwater is considered to be low
- That there is a sufficient baseline of data (groundwater and surface water) to enable transient calibration of the model
- That maximum annual extraction from the Stage 1 GFDA will be a relatively small component of the groundwater budget within the Gloucester Basin
- The principle of decreasing hydraulic conductivity with depth in the interburden confining units (although possibly not within the upper 150-200m), and the relatively higher hydraulic conductivity of the coal seams
- The assessment that baseflow to the rivers within the Gloucester Basin is a relatively small component of total flow, albeit with significant variations across the different catchments represented
- That the fault zone investigated represents an area of somewhat enhanced hydraulic conductivity in the Shallow Rock unit
- That in the natural state and in the central part of the basin, lateral flow process within units are dominant, with vertical processes being relatively small

In some instances it is considered that during development of the conceptual model and water balance some work has been omitted which would improve conceptual understanding and in places inappropriate methods have been used. These issues form the discussion presented in Chapters 5 and 6 of this report. However, it is emphasised that based on the data presented in the PB reports, none of these represent criticisms that cannot be readily addressed or the conceptual model revised to take account of the comments. They are normal hydrogeological issues which are considered and debated in most hydrogeological studies, and should not be interpreted to mean that the fundamental science is flawed. The fundamentals of the conceptual model and water balance provide a foundation on which the numerical model can be developed.

The review has not identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective - not that this was the scope of the review, as it is the role of the numerical modelling to assess the location and magnitude of impacts.

5. Specific Comments – Conceptual Model

This chapter presents review comments on the *Hydrogeological Conceptual Model of the Gloucester Basin* (PB, 2013a) report.

5.1 Surface water and baseflow

The following comments are made regarding the “Surface Water” chapter of the conceptual model report (Section 5.2):

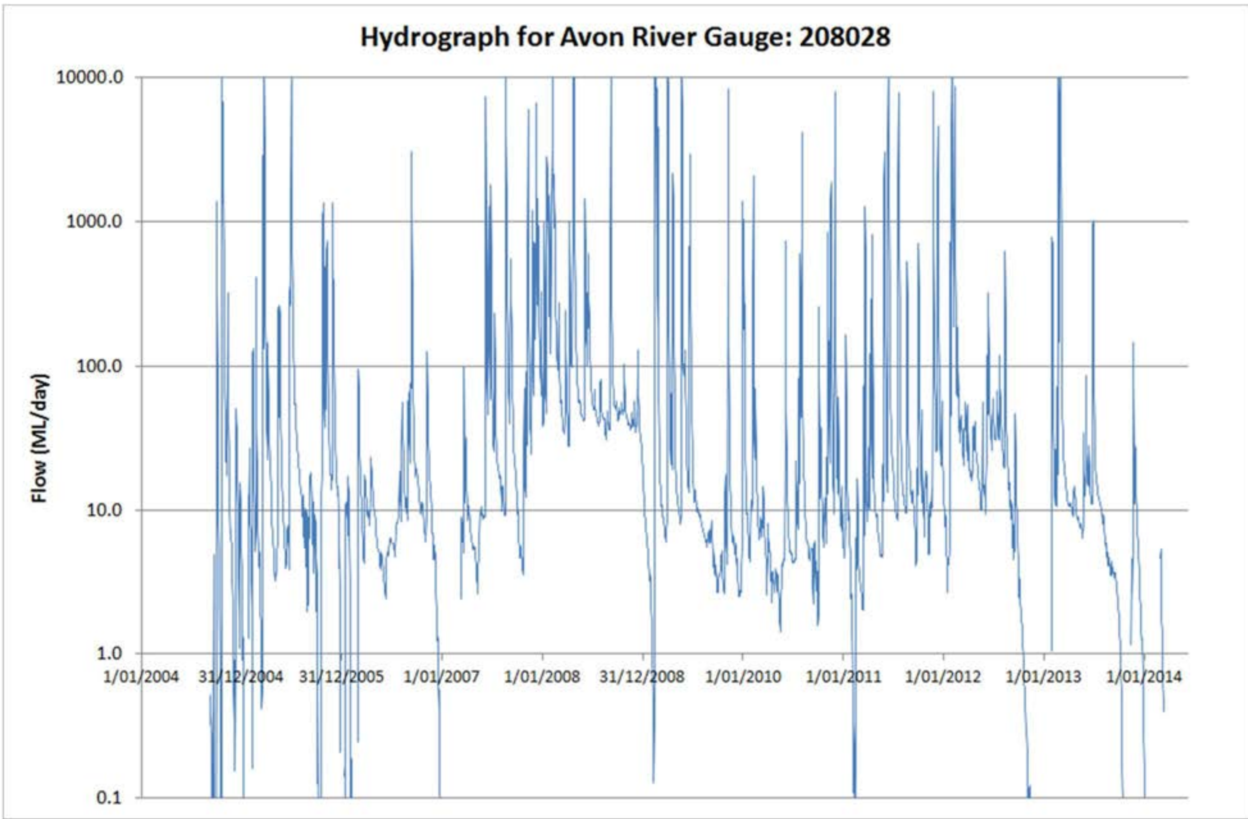
- It would be helpful to see the hydrographs plotted as flow, not just as reduced levels (p29). It is understood that there is no streamflow data available (only stream heights) from the AGL gauges at this time, as the rating curves are still being constructed. It is difficult to draw conclusions regarding processes and conceptualisation with level data alone. It is assumed that the rating curves and associated process of producing a flow record will be complete prior to the development and calibration of the numerical model.
- It would useful to know the minimum flow rating for the AGL gauges. Given the relatively low baseflow in the monitored rivers/creeks, a monitoring method that is sensitive at low flows is desirable. i.e. that the "cease to flow" value is relatively low.
- The report notes that: “Groundwater discharge (baseflow) is a small component of total stream flow. This discharge is expected to manifest as minor seepage over broad areas so there is no strong discharge expression in the landscape” (PB, 2013a, p33). This description of baseflow occurring across broad areas is difficult to understand – if the intent of this statement is to say that baseflow is conceptualised as being evenly distributed along the river, with no strongly localised baseflow evident, then alternate wording to clarify this meaning would be helpful.
- The conceptualisation of river recharge to groundwater as being a minor part of the water balance seems to deal mainly with the central areas of the Stage 1 GFDA (e.g. p31), rather than the flanks of the Basin, where this process may be important. The Heritage Computing numerical model (Heritage Computing, 2012) has river recharge as a significant part of groundwater recharge (as discussed later in this report).
- On page 61 of the Conceptual Model report there is reference to groundwater discharge to perennial streams within the Gloucester Basin. The report does not specifically state which streams but given the Avon River is the major water course within the Basin there is an inference that the Avon River is a perennial river. The Water Balance report (PB, 2012b) presents the stream flow hydrograph on the Avon River at NOW gauge 208028, and notes that the river flows 96% of the time (p35). ‘Periods of ‘no flow’ or very low flow, when the river is characterised by multiple disconnected pools, correspond to anomalously low rainfall, particularly in the months leading up to summer (PB, 2012b: p35). The hydrograph below presents flow for gauge 208028. Note the y-axis extends to flows of 0.1 ML/day (~ 1 L/s) but the stream flow data actually records flow down to 0.01 ML/day (~ 0.1 L/s). (For the purposes of highlighting the data of most interest, the full range of the streamflow data is not shown in the figure below). The hydrograph shows that between 2007 and late 2012, the Avon River only dropped below 0.1 ML/day on one occasion. However in 2005 and 2006 there were several occasions when this occurred. Exactly how accurate the gauge is at these very low flows (0.01 and 0.1 ML/day), may account for differences between the gauge data and observations by some community members that the Avon River ceases to flow in most years. Other causes of these differences may be the location within the catchment of the observations (i.e. generally there is less flow further up the catchment). Under very low flow conditions, it is possible that the river may flow in the alluvial sediments in the upper catchment (i.e. subsurface flow but no surface flow) but then discharge lower in along the catchment due to changing bed levels and/or increased baseflow contribution.

  Mackay et al. (2012) classifies streams according to the following categories:

  - **Perennial**: streams and rivers that consistently discharge water sourced from runoff and groundwater in all but extreme drought periods where groundwater availability is so low that connection to the main channel of the stream is lost.

- **Intermittent**: streams and rivers that have seasonally predictable flow that occurs between a few months to multiple years depending on climate conditions. These streams are placed in the middle of a continuum from ephemeral to permanent.
- **Ephemeral**: Streams and rivers that discharge water during and immediately after rainfall. These streams do not have significant baseflow, meaning that such streams are generally dry (apart from isolated waterholes) when not flowing.

Based on these definitions and the hydrograph data representing the Avon River at the location of gauge 208028, the river most closely fits within the definition of a perennial river. However, all three definitions lie on a continuum, and in that sense the river would fall between the Mackay et al. (2012) definition of perennial and intermittent (but closer to perennial).



5.2 GDEs

The Australian GDE Atlas records a stand of remnant native vegetation (within the Stage 1 GFDA area), that is mapped as having potential groundwater dependence, as noted in the PB (2013a) report. However the report proceeds to dismiss the potential for groundwater dependence on the basis that groundwater levels are more than 10m below surface. Three points are made regarding this conclusion:

1. It is not clear in the report which data is being used to conclude that the depth to watertable is more than 10 m below surface. There are no bores close to the remnant vegetation, with the exception of two gas monitoring wells which are in the centre of the vegetation (TGMB01 and TGMB02). Based on information received post the initial draft of this report, the two gas wells in question are 6m and 15.4m deep. They were both dry on completion in February 2011, and have been dry during all subsequent dipping, including the latest dipping event in February 2014 (J.Ross, pers. comm., 29 April 2014). These bores were not formally part of the GGP Water Monitoring network and hence water level information has not been reported in annual reports. Based on this new information, the PB conclusion regarding depth to watertable at the terrestrial vegetation site appears sound.

2. Trees can access groundwater deeper than 10m, and examples of trees accessing water to 20-40m below surface is not uncommon in the literature, including through rocky sub-soil profiles. For example, a recent Australian study showed eucalyptus species to be accessing groundwater from 30 to 35m below surface (Lintern et al, 2013). A literature review by Stone and Kalisz (1991) includes reference to eucalyptus species with roots penetrating to 45 and 60m below surface. This study also documents deep rooting depths (tens of metres) being achieved into rock for many tree species. Dell et al (1983) documents eucalyptus species with root depths to 40m. The study refers to eucalyptus utilising either natural fractures/fissures in the rock for root development or penetration through the rock/soil matrix (with fine roots) where necessary, i.e. deep rooting was possible in the absence of any significant rock/soil defects (through hard clays).The literature review of Canadell et al (1996) includes documentation of Eucalyptus species accessing water from 30 to 40m below surface. This includes a number of examples in which roots have found their way down to very deep layers, even in compact clay and rocky soils.

3. The PB (2013a) report notes that “Regional groundwater flow is controlled by gravitational flow from elevated areas where groundwater is recharged, to low-lying areas where groundwater discharges to streams and to the atmosphere via evapotranspiration” (p vi Exec Summary). This potentially conflicts with the claim that there are no GDEs in the area that rely on the subsurface presence of groundwater. The question is where and what form does the ET take in the Basin?

It is agreed that any potential impact on any terrestrial GDEs (if they exist), is likely to be relatively small. Based on the deeper of the dry gas monitoring wells, it is apparent that groundwater levels below the native vegetation identified in the National Atlas as potentially groundwater dependent are relatively deep. While deep groundwater does not necessarily mean there is no groundwater use by the vegetation, it does mean that the trees will have a high resilience to any changes in groundwater level through access to large storage of water in the unsaturated zone. Further, given the relatively high rainfall (and only moderate seasonality of rainfall) in the Basin, it is quite possible that the vegetation is not at all groundwater dependent, and that the unsaturated zone contains sufficient water to meet vegetation requirements when upper soil moisture stores are depleted.

5.3 Hydraulic properties

The following comments are made regarding aspects of the Conceptual Model (PB, 2013a) addressing hydraulic properties: p37-39 (Hydraulic Properties in Chapter 5 - Review of Hydrology and Hydrogeology) and p69 (Aquifer Properties, in Chapter 7 - Framework for Numerical Modelling).

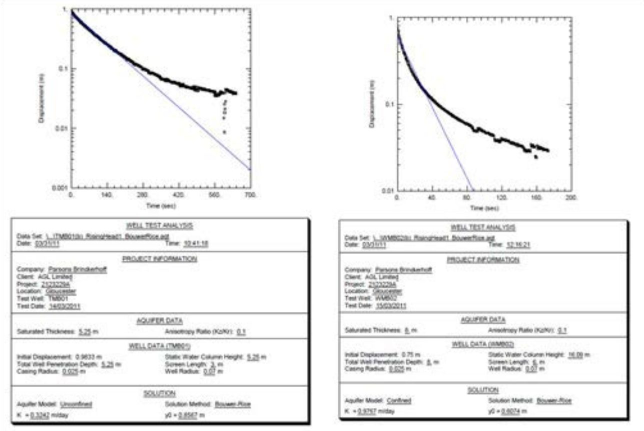
1. The broad range in hydraulic properties presented in Table 5-5 are so wide that they provide little guidance or indication as to what will be used in the numerical model. For example, for the key units of the shallow rock and interburden, there is a range of 7 and 3.5 orders of magnitude between the upper and lower range respectively. While this range is common for fractured rock permeabilities, the spectrum of these ranges represents the difference between relatively rapid vertical propagation of pressure versus extremely slow transmission of pressure. Therefore, ideally there would be a process of identifying a narrower range for use in the numerical model. While there is a degree to which hydraulic conductivity values are depth dependent, it would be helpful for the various ranges proposed for different depths to be presented and discussed. The PB (2013a) report indicates the following response to the wide range of hydraulic parameters: ‘Therefore uncertainty in parameters should be taken into account and quantified with regard to any model predictions’ (PB, 2013a, p69). This implies that the range in hydraulic data will be addressed via running multiple scenarios across the hydraulic conductivity range, which leaves the possibility of having a wide range of results (and associated impacts) but no indication or opinion on which result is the most representative.

   On page 59 of the Conceptual Model report, there is indication provided as to what is considered more representative for the Shallow Rock unit: “Hydraulic conductivity of the shallow rock ranges from 10 m/d to 1x10^{-6} m/d at a depth of 150m, but is typically in the order of 10^{-3} to 10^{-4} m/d" (PB, 2013a, p59). However, examination of the hydraulic conductivity data in Figure 5.8 (in PB, 2013a) does not support this statement; only three of the values are less than10^{-3} m/d and, based on visual inspection, the median value appears to be between 10^{-2} m/d and 10^{-3} m/d. (It may well be that there is a reason why the data collected is not considered indicative of the Shallow Rock unit, but it is expected that the case for this would be explained in the Conceptual Model report).

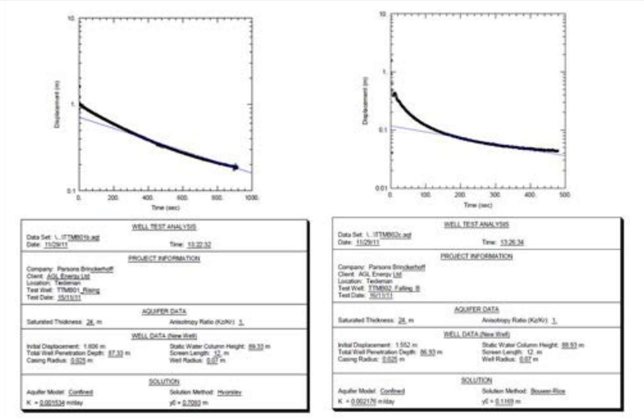
2. There is apparently no discussion in the report on vertical hydraulic conductivity, which is a key parameter effecting the time for upwards pressure transmission. All of the data collected provide a horizontal hydraulic conductivity, and not a vertical hydraulic conductivity. Therefore, a conceptual model should discuss and justify selection of a vertical hydraulic conductivity for the numerical model. (It is acknowledged that in some locations the tests may not be strictly measuring a true horizontal permeability, due to the steeply dipping strata, e.g. on the basin margins).

3. There are relatively few tests in the interburden, which is a key unit. Figure 5.8 (in PB, 2013a) suggests there are only 8 tests (and it is possible some of these are from the same hole and possibly the same depth, but using a different analysis method). There would not appear to be enough data to support a sliding scale of decreasing hydraulic conductivity with depth for this unit. For example, on page 59 of the conceptual model report: 'Permeability of interburden decreases with depth such that, at the maximum depth of CSG production is likely to be in the order of 10^{-5} to 10^{-7} m/d, or less'. However, examination of Figure 5-8 in the Conceptual Model report indicates that the maximum depth of testing in the Interburden is 309 metres. (Note: there appears to be a discrepancy for the interburden unit between Table 5-5 and Figure 5-8, as the range in Figure 5-8 is less than the range in Table 5-5).

4. The interpretation of slug tests (as reported in PB (2013a) is not entirely consistent with previous interpretations. While most of the curve fitting is appropriate, there are some potential minor variations. For example, there seems to be some difference in the approach to curve fitting between PB (2012a) and PB (2013a) as shown in the diagram below. In PB (2012a), in cases where there is a choice between fitting to early or late time data, the curve is fitted to the early time data, whereas in PB (2013a) the curve tends to be fitted to late time data. The PB (2012a) approach is preferred, as the curve is fitted to the greater amount of drawdown (even though fitted to a reduced period of time). In the example cases shown below, the PB (2013a) approach of fitting to later time data will result in a lower hydraulic conductivity value than if fitted to the early time data. In some cases the difference in hydraulic conductivity will be very small (e.g. bottom left hand side in figure below), while in other cases the difference will be large (e.g. bottom right hand side in figure below).



From PB, 2012



From PB, 2013

5. The vast majority of the hydraulic conductivity measurements for the Gloucester Basin are very local scale tests. In other words the amount of geological formation tested is relatively small. For example, the three common test types for hydraulic conductivity data in the Gloucester Basin are:

   a. Laboratory tests - which typically sample material in the range of centimetres,

   b. Slug tests - which will test material around the borehole at a radial distance of tens of centimetres up to a several metres, and,

   c. DSTs (drill stem tests) will typically not test more than five metres (maximum ten metres) from the bore.

   Hence the data set for the hydraulic properties of the formations is mostly derived from measurements at a very small scale compared to the thickness and horizontal extent of the formation. The only tests measuring formation properties at a scale greater than the local scale, are two observation bores in the 48 hour pumping test, and (based on visual inspection of Figure 5-8) these comprise less than 5% of the hydraulic conductivity data.

   There is a significant body of literature that indicates hydraulic conductivity increases with increasing scale of measurement [e.g. Keller et al. (1988), Van Der Kamp (2001) and Hart et al. (2006)]; this is primarily due to the presence of preferential flow paths at larger scales. Accordingly, most groundwater models that aim to address aquifer connectivity – via implementation of measured hydraulic conductivity data – will under-predict the magnitude of inter-aquifer leakage.

Hence direct application of a median or average hydraulic conductivity derived from the data presented in Table 5-5 or Figure 5-8, is likely to underestimate regional flow parameters as the presence of preferential flow paths, may not have been observed in the smaller scale measurements. It is expected that this issue would be addressed in the Conceptual Model report, including how these results might be up-scaled for the regional numerical model.

Further, there is evidence of this scale effect of hydraulic conductivity within the existing data set. Comparison of the slug test results in two observation bores where pumping test results are also available indicates that the hydraulic conductivity is approximately 10 to 40 times greater for the pumping test results compared to the slug test results. Further comment on this matter, as well as additional assessment of the two day pumping test is presented in the section below.

6. There is a significant amount of hydraulic conductivity data presented in the Heritage Computing (2012) report (on the Stratford Coal Mine expansion groundwater assessment) that does not appear to be used in consideration of appropriate hydraulic properties for the study area. That data is highly relevant in that most of it lies within the proposed numerical model boundary. Further, it also contains vertical hydraulic conductivity data sets which would be a valuable addition to the existing data set. The report notes that the core permeability results 'can be regarded as lower limits for use in model calibration, as cores will not capture the bulk fractured characteristics of a formation' Heritage Computing (2012: p A-29). This underscores the issue raised in dot point 6 (above). Based on the same principle, the slug test results in the Heritage Computing (2012) report should also be considered lower limits for use in the model.

5.3.1 TTPB Aquifer Pumping Test

The following comments are made regarding the 72 hour aquifer pumping test at TTBB (conducted over the period 20 December 2011 – 23 December 2011):

1. The most important conclusion from the pumping test results is that the derived hydraulic conductivity results were "somewhat higher than the results of the slug testing" (p43, PB, 2013c). A comparison is presented in the table below for the two observation bores where slug tests were undertaken, which shows that hydraulic conductivity is approximately 10 to 40 times greater for the same bore, when using the pumping test results compared to the slug test results. As PB notes, this is 'not uncommon in fractured rock environments (Cook, 2003)'. In fact, the phenomenon of local scale tests (e.g. lab tests of core, packer tests, slug tests and DSTs) producing lower K values than large scale tests which sample more of the aquifer/formation (e.g. pumping tests, regional aquifer calibration) is documented in many studies (example references from the literature have been provided earlier in this report).

   The implications for the conceptual model of the Gloucester Basin are significant, as the overwhelming majority of the hydraulic conductivity data currently supporting the conceptual model are from local scale tests. This comparison from the TTPB pumping test site indicates that direct translation of these values into a numerical model may not be appropriate. Potentially some adjustment of the local scale tests may be required prior to use in the numerical model.

Table 5.1 : Comparison of slug test and pumping test hydraulic conductivity results at the TTPB pumping test site

Bore	Slug Test K (m/day) [1]	Pumping Test K (m/day) [2]	Pumping Test K / Slug Test K
TTMB01	0.0024	0.1	42
TTMB02	0.0025	0.02	8

1. p34, PB (2013)
2. p43, PB (2013)

2. The use of Cooper Jacob as the only method of analysis of the test data potentially limits the amount of information that can be gained from the test. For example, methods that allow for partial penetration can yield information on the Kv of the aquifer (discussed further below). Further, application of curve fitting methods like Theis, are useful not only for determining aquifer parameters, but deviations from the Theis curve importantly yield important information regarding processes occurring within the aquifer system.

3. The use of the Cooper Jacob method, when one of the assumptions of the method is not met - that the pumping well is fully penetrating - introduces potential errors to the analysis. The pumping well is screened over 12 metres, and yet the analysis of the test assumes an aquifer thickness of 150 metres. Partial penetration of the pumping well induces vertical flow components in the vicinity of the well, which means that the general assumption that the well receives water from horizontal flow is not valid. This in turn leads to higher flow velocities in the immediate vicinity of the well, leading to an extra loss of head. This effect is strongest at the well face, and decreases with increasing distance from the well. Kruseman and DeRidder (1994) indicate that this effect is negligible if measured at a distance that is 1.5 to 2 times greater than the saturated thickness of the aquifer, depending on the amount of penetration. They further indicate that if the aquifer has anisotropy on the vertical plane, the effect is negligible at distances $r > 2D(Kh/Kv)^{0.5}$. Hence standard methods of analysis are not appropriate for $r < 2D(Kh/Kv)^{0.5}$ unless allowance is made for partial penetration. Assuming a Kh/Kv ratio of 100, and an aquifer thickness of 100m, means that observations within 2000m of the production bore should be corrected for partial penetration effects. For a Kh/Kv ratio of 10, this reduces to 600m of the production bore. Nevertheless, all the observation bores which responded to the test are within this 600m range, and therefore a method which corrects for partial penetration effects should be applied.

4. The analysis of the data to derive aquifer parameters is limited to only the pumping bore and the two observation bores closest to the pumping well, on the grounds that the parameter u is less than 0.05 (or at most 0.1) only for these two bores. Firstly, a review of the data indicates that the u parameter could be around 0.1 or less for more distant bores (the S4MB or TCMB series), depending on the aquifer parameters at the site. Therefore calculation of values for these bores is worthwhile (noting some potential error if u is above 0.05 to 1). Secondly, and more importantly, a significantly larger number of bores could have been used if another method beyond Cooper Jacob was employed where there is no restriction on bores to be used based on the u value.

5. The aquifer thickness used to determine a K value from the transmissivity should be reviewed. There is an argument that a thinner aquifer thickness may be more appropriate (e.g. around 100m), based on bores screened above and below the pumping bore which did not respond during the test. This would somewhat increase the K values obtained from the report.

5.4 Groundwater level trends

Generally, this review agrees with the comments in the Conceptual Model report regarding groundwater level trends. Two additional comments are made regarding this section of the report:

1. There are three sites where deeper bores respond is a similar manner to shallower bores:

    a. S4MB03 is screened between 162 – 168 metres below ground level (in the Jilleon – Cloverdale Coal). The water levels in this bore respond essentially as quickly as the shallower bore to recharge events. (The size of the response also appears larger than some shallower bores, but this is likely due to differences in storage properties). It is the timing of the response which tends to indicate either a high level of vertical connection with deeper layers or a high level of connection laterally to areas where this unit outcrops / subcrops.

b. BMB02 is screened from 124 to 136 metres below ground level (in Leloma-Shallow Rock) and BMB01 is screened 15 to 29 metres below ground level (also in Leloma-Shallow Rock). The groundwater hydrographs for these bores essentially move in identical manner to each other, indicating a high level of vertical connection across the 100m of rock separating the two screens.

c. WKMB03 is screened from 200 to 208 metres below ground level (in Leloma-Deards Coal). The bore displays some highly anomalous behaviour, which may in part be due to stabilisation of levels after drilling, sampling and hydraulic testing. However, from around early to mid-December 2012 (assuming these early influences on the water levels are largely finished at this time) the bore hydrograph appears to show a relatively rapid response to recharge. Information received from AGL post the initial draft of this report indicates that the data plot for WKMB03 is likely based on a faulty data logger and as such is now considered spurious. The logger has been replaced, and the plot will not be reproduced in subsequent reports (J. Ross, pers. comm. 29 April 2014).

It is recognised that two of the three sites fall into the “Shallow Rock” classification, but they are noteworthy because the deeper bores at these nested sites are screened close to the “Interburden” unit (and noting that the distinction between these two categories in the real world is very blurred). The implication of this is that at some locations the vertical hydraulic conductivity of the shallow rock may be relatively high.

2. At two nested bore sites there is very little head difference between bores which are screened a significant vertical distance apart. In a tight aquitard, this is unlikely to occur – aquitards are generally characterised by heads that change with depth, whereas aquifers tend to have relatively much similar heads across the vertical extent of unit. At the following nested sites, very similar heads are noted between:

    a. TCMB01 (screened 87-93 m bgl, in Leloma-Shallow Rock) and TCMB02 (screened 175-181 m bgl, in Leloma-Interburden) have only a 10-15cm difference in head, and,

    b. BMB01 (screened 15-29 m bgl, in Leloma-Shallow Rock) and BMB02 (screened 124-136 m bgl, in Leloma-Shallow Rock) have practically no difference in head.

    The implication is that at these sites, the vertical hydraulic conductivity between the screened intervals, is not particularly low (i.e. there is reasonable vertical hydraulic connection across these intervals).

5.5 Stratford 4 flow testing

The Stratford 4 flow testing occurred over the period 11 September 2012 – 9 October 2012. Summary comments are contained in Section 5.3.3.4 (p48) of PB (2013a). The comments below are based on the more detailed reporting presented in PB (2013c), *Hydrogeological Investigation of Strike-slip fault in the Northern Gloucester Basin*.

There is some evidence to suggest that bores in the “Shallow Rock” close to Stratford 4 responded to the flow test, as the shallowest bores close to the site (the S4MB and TTMB series), declined around 15-20cm in the period up to 3 months after the test, whereas bores more distant such as the S5MB and TCMB series showed no change during the same period. However, the PB (2013c) conclusion that this cannot be definitively linked to the Stratford 4 testing is probably reasonable, as other shallow bores more distant again from Stratford 4 (i.e. than the S5MB and TCMB series) dropped a similar degree to the S4MB and TTMB bores.

However, a possible oversight in the PB (2013c) analysis is that there appears to be some evidence that the intermediate depth bore S4MB03 (screened between 162 – 168 metres in the Jilleon – Cloverdale Coal, and 73 metres from Stratford 4) did respond to the flow testing. This bore drops around 0.4m between the start of the test, and the end of January 2013. Most of this decline occurs from approximately mid-November (around one month after end of flow testing) to mid-December.

Two of the arguments made by PB (2013c) against any impact from the flow testing being observable in any the observation bore data are actually arguments for S4MB03 responding to the test pumping (refer dot point 2 and 3 on page 64 and 65 respectively in PB, 2013c):

1. S4MB03 is the closest of the coal monitoring bores to Stratford 4 (73m). The next closest coal bores are:

    - TCMB03 (510m distant), screened between 260-266m bgl in the Cloverdale Seam. This bore remained stable over the period S4MB03 declined.

    - TCMB04 (505m distant), screened between 327-333m bgl in the Roseville Seam. This bore remained stable over the period S4MB03 declined.

    - S5MB03 (656m distant) screened between 158-164m bgl in the Roseville Seam. This bore also remained stable over the period S4MB03 declined.

    Other bores screened at intermediate depth (similar to S4MB03), but screened in "Interburden" also had stable water levels during and in the months after the test (e.g. TCMB02 and TTMB03). The timing and magnitude of the decline in S4MB03, in contrast to these other bores which did not response, suggests that the water level response may be due to the flow testing.

    The one exception to this is WKMB03 (screened 200 – 208m in the Leloma – Deards Coal), around 3000 metres north of Stratford 4. This bore shows a decline of around 0.7m in the months immediately after the test. However the decline in this bore is highly anomalous and the trend cannot be explained by either the test or climatic behaviour and hence does not assist in any way in this analysis. [PB (2013d, p31) indicates that the logger in this bore failed and hence prior readings from the logger cannot be considered reliable].

    The question may be posed as to why the deeper bores, closer to the screened interval of Stratford 4 did not respond instead of, or prior to, S4MB03. (The Stratford 4 well span coal seams between 515 – 739 m bgl). As PB (2013) state: "It would be expected that depressurisation of the deeper coal seams would impact on the deeper screened monitoring bores before the shallower bores" (p64). The suggested answer is that the drawdown cone associated with the Stratford 4 test (within the targeted coals seams) was relatively steep and localised. This means for example that while TCMB04 is screened 327 – 333 metres below surface and therefore much closer vertically to the Stratford 4 well than S4MB03, at the 505m lateral distance TCMB04 is located, there was insufficient drawdown in the deep coal layers to induce a significant vertical gradient to cause drawdown in overlying layers.

2. The shape of the decline in S4MB03 is very different to the general gradual decline seen in the shallower bores (likely due to seasonal decline related to declining recharge). S4MB03 shows a relatively sharp change (decline) in drawdown about one month after the test, possibly indicative of a delayed pressure response due to delayed transmission time through the overlying layers.

If the conclusion that S4MB03 did respond to the test pumping is correct this would probably mean that the vertical hydraulic conductivity of the interburden is higher than currently conceptualised. It is curious why the apparent drawdown at S4MB03 was not analysed either analytically or numerically, in order to estimate a Kv based on the response in S4MB03. Such a value would be worth more than other Kv data collected to date, because it is representative of a large vertical section of rock mass instead of the very local data collected in slug tests, DSTs etc. (The problem with local scale hydraulic tests, as described earlier in this report, is that they are usually not representative of the hydraulic conductivity of the regional rock mass).

If the suggestion in the PB report is accepted - that the water level response in the shallow bores is more likely to be due climatic factors rather than the flow testing - then that result can still be used to constrain Kv numbers for the intervening rock, i.e. a null result can also be used to provide an upper limit to Kv for the area.

5.6 Craven 06 and Waukivory 03 flow testing

In 2013, Craven 06 and Waukivory 03 were flow tested over an 8 month and 6 month period respectively. The chemistry and isotopic results from these tests have been reported in considerable detail; however there is no presentation, analysis or discussion of hydraulic data associated with these tests. Given the long duration of these tests they potentially represent the best source of hydraulic conductivity data (and calibration data sets) for the numerical model. It is presumed that this will occur prior to development and calibration of the numerical model.

At Craven 06, while there are no AGL monitoring bores in close proximity, there are a number of Stratford mine observation bores nearby, including a nested vibrating wire piezometer around one kilometre north east of the site (the lowest piezometer in the nested site is set at 148m). The possibility of assessing data from those bores during the flow testing period should be explored.

At Waukivory 03, such an analysis may not be possible, as there are no monitoring bores in close proximity. The WMB series of monitoring bores are more than 2km south of the site.

5.7 Influence of faulting

The following comments are made regarding the conceptualisation and influence of faults within the Basin. The first few issues relate to the fault investigation on the Tiedman property and later points deal with broader issues relating to faulting:

- As per the conclusions in PB (2013c), it is agreed that the fault zone investigated on the Tiedman property appears to represent a broad zone of enhanced hydraulic conductivity within the shallow rock aquifer. It is assumed that this conceptualisation will be brought into the numerical model for the same type of faults.
- PB (2013c) notes that “Distinct hydrochemistry and (older) radiocarbon ages within the fault zone suggest that the fault forms a weak conduit that enhances discharge of deeper groundwater under natural conditions. However, the results of stable isotope analyses suggest that this connection is not strong and/or does not penetrate to the deeper coal seams which are significantly more depleted in terms of groundwater §18O and §2H” (page xv). This is potentially an important conclusion; the implication of this statement is that there is a zone of enhanced permeability to depth associated with the fault – however the conclusion appears to contradict other parts of the report (e.g. see the dot point below). The second sentence in the above quote implies that the zone of enhanced connection extends only to the upper coal seams and not to deeper coal seams – this is nevertheless still an important conclusion given that the target drawdown within gas production wells will be at least to the top of these upper coals seams. Further, in terms of the reference to the conduit existing under natural conditions, the ‘conduit’ will equally be present under developed conditions, albeit given the change in hydraulic gradients, fluxes will be downwards instead of upwards.
- The conclusion that “monitoring of groundwater levels and dissolved methane during the Stratford 4 gas flow test provide no clear evidence of enhanced connections between the deeper coal seams and shallow groundwater system” (PB, 2013c, p xvi) is not a particularly meaningful conclusion, unless some analysis is presented to show under what conditions (especially vertical K) an impact would have been observed in the test timeframe, i.e. even if the fault does represent a zone of enhanced connection between the deeper coal seams and the shallow groundwater system, would a 29 day test be sufficient to observe that this is the case? (e.g. to observed drawdown in the shallow bores).

Section 6.3.3 indicates that this type of assessment has been undertaken: “Simulations of such tests using numerical models suggest that drawdown impacts at the surface are likely to take many years to manifest and are likely to be minor in terms of drawdown at the water table” (PB, 2013a, p61). However there is no further presentation or discussion of the results, such as what permeabilities were used in these simulations, which bores and depths were used etc. This data could be used to constrain the vertical hydraulic conductivity of the interburden.

- The interpretation of the significant decline in the dissolved methane concentration in the fault zone associated with the flow test is unclear. It could be interpreted to imply some level of hydraulic response between the fault zone and the pumping wells.
- PB (2013a) recognises the high importance of the Waukivory Fracture Stimulation and Flow Testing program: “This is an equally (if not more important) fault investigation program than the Tiedman study as the thrust fault in this area is typical of many such features across the eastern portion of the basin (Figure 4.6)” (PB, 2013a, p 57). Hence there is a current gap in the conceptual understanding of the hydraulic behaviour of thrust faults in the area. This in turn raises the question of the timing of the Waukivory investigation and whether it will be complete in order to contribute to the conceptual and numerical model and associated impact assessment.
- Regarding fault zones at depth, the conceptual model report notes that: ‘… there is evidence that at depth, these fault zones decrease in permeability due to increasing clay content and increasing lithostatic pressure which causes fractures to close and may even form barriers to flow where water bearing zones are truncated or offset’ (PB, 2013a: p60). The evidence for this statement is not clearly presented in the reports. The lack of response in shallow bores from the Stratford 4 flow test is not considered strong evidence for this, as the duration of the test was insufficient to properly assess this issue. PB (2013b) notes that at the WKMB03 site (which targets the trust fault and was 208m deep), there were very clayey returns in the cuttings, there were no increases in water volumes with depth, and the slug testing suggested a hydraulic conductivity of $2x10^{-4}$ m/d. At face value this lends support to the above claim regarding faults zones at depth; ideally this would be supported by more than one bore and multiple lines of evidence.

5.8 Vertical connectivity and operational issues

The following comments are made regarding the sections in the Conceptual Model report dealing with Vertical Connectivity (Section 6.3.2, p60) and Potential Operational Issues (Section 6.5, p61):

- “Connection between the shallow and deep systems will be limited by the permeability of the rock strata which is known to be very low” (PB, 2013a: p60). As discussed earlier, there is fairly limited hydraulic data for the Interburden unit on which to base this comment. The permeability data that is available would probably be better described as low, rather than very low.
- Page 61 of the Conceptual model report discusses the level of drawdown that will be targeted during CSG operation. The water level in the CSG wells will be drawdown to the (top of) the pump which is situated below the lowest coal seam. The report notes that ‘in the adjacent natural formations (due to low permeability formations and poor well efficiency through the casing perforations) the hydrostatic heads are highly variable and are substantially higher’ (PB, 2013a: p60). It is important in the numerical modelling to estimate what the water level in the formations immediately adjacent the CSG wells will be, because this will be the drawdown in the potentiometric surface that is used in the model. This is an important input to the numerical model which is only very briefly mentioned, and not quantified, in these reports. The numerical model and associated reporting needs to be specific regarding the pressure reduction target that will be used in operations, and that this is applied in the numerical model. Based on the author’s experience, pressure reduction targets (to achieve desired gas yields) can vary widely, even when areas of CSG development are adjacent one another.
- While the comments in Section 6.5.1 ‘Potential for Drawdown’ in the conceptual model report regarding the anticipated very low impact on the watertable, streamflow etc, may well prove to be correct once the numerical modelling is conducted, they are potentially somewhat premature. If one accepts the assumption

behind the comments – that the regional vertical hydraulic conductivity of the interburden is low to very low – then the processes described in that section are generally sound. The exception is two phrases which refer to any losses to stream baseflow 'being offset by the high rainfall recharge rates to the alluvial aquifers' (p62) and 'natural groundwater recharge…will mitigate any vertical leakage associated with CSG depressurisation' (p62). Both of these comments imply that there will be an increase in aquifer recharge in response to drawdown related to CSG operations, but this is not explained, justified or discussed elsewhere in the reports. Possibly the comments simply mean that the reduction in baseflow would be very small compared to rainfall recharge, and the implication of increased recharge was not actually intended.

It is also important to note here that the modelling scenario conducted by Heritage Computing (2012) of the Stratford Coal mine combined with CSG production, indicated substantial drawdown in the watertable. The coal mine impact alone was relatively minor (i.e. the CSG production impact was significant). 'CSG activity would cause pronounced drawdown in the watertable between the Project and Stratford' (Heritage Computing, 2012; p A-57). The Heritage Computing report describes its assessment of cumulative impacts as being a 'conservative assessment' (p A-57), however it is unclear if this means that it is likely to have under- or over-predicted the impact of CSG production.

Regardless, the Heritage Computing (2012) numerical model results are in contrast to the predictions in the Conceptual Model report. It will be important for the differences in results between the two models to be critically reviewed, including differences in conceptualisation, parameters used and other assumptions that leads to the difference in predicted outcomes. It is possible that some of the difference relates to the fact that the Stratford model is less well conceptualised at depth, given that its focus is on relatively shallow processes at the depth of the open coal pits.

It is noted that the deepest observation bore is approximately 350m deep. It would be useful to compare this relatively shallow pressure data with the pressure response data from the CSG extraction wells, if any data is available.

5.9 Framework for numerical modelling

The following comments are made regarding the Framework for Numerical Modelling (Chapter 7 in the Conceptual Model report):

- The conclusion reached in Chapter 7 regarding use of a dual or single phase model is agreed with – that a single-phase saturated groundwater flow model is appropriate for the modelling assessment. A single phase model is better suited to the purpose of assessing regional impacts due to depressurisation of the coal seams. There appears to be slight contradiction within Chapter 7 however:
    - 'Groundwater flow processes identified in the conceptual model should be accurately represented in the numerical model. These include the following: ... Dual phase effects are likely to be important, particularly in the vicinity of the production wells where methane is transported as a separate gas phase within groundwater, or may be the dominant phase over water' (p70). This statement implies that dual phase effects should be able to be simulated in the model, which possibly contradicts the conclusion that a single phase model will used. However, the statement could be interpreted to mean that a single phase model should attempt to account for dual phase effects near the production bore (e.g. by using near well changes in hydraulic conductivity).
    - 'Condition 18 of the Federal approval under the EPBC Act requires that a numerical model must be developed ….. The model is to be used to 'explore the pressure at which gas and water may be released and transmitted along faults' (Condition 18), and to assist in a risk analysis in relation to impacts to potential habitats for the green and golden bell frog and giant barred frog (Condition 19). The following potential impacts are specified: the surface expression of methane gas; water pollution including salinity; water drawdown; and any impacts on surface water.' It is apparent that a model cannot (directly) address all these points, and clarification of which and how of these issues will be addressed by the model would be helpful.
- Regarding including the effects of faulting in the numerical model:

- It is proposed that faults are incorporated following an approach of 'adopting one or more separate local-scale models to assess the role of known and mapped faults in depressurisation and groundwater flow. These separate models could be of more limited extent or be 2D cross sections. The results of the limited scale modelling would provide an indication as to whether individual faults should be included in the regional scale models or represented as part of the up-scaled parameterisation' (p69). This is considered to be a valid approach, however it raises two questions – one is whether the testing program of the faults will be suitable to calibrate these local models (in particular with respect to the hydraulic conductivity of the Interburden), and secondly related to the timing of development of these local models with respect to development of the numerical model, i.e. will they be completed prior to the regional model, such that the decision point referred to can be reviewed? However, based on information received post the initial draft of this report, it is understood that local scale models will be completed in advance of the regional model and that these will form a decision point regarding whether to, and how to, include faulting in the regional model (J. Ross, pers. comm. 29 April 2014).
- Chapter 7 concludes that 'It would therefore be impractical and erroneous to include only the known faults as individual elements in a regional scale model' (p69). This statement is somewhat confusing, because in the following paragraph the report identifies that inclusion of individual faults is one of the options for accounting for the effect of faults, and secondly, only known faults can be included in the model.

- Regarding model calibration the report notes: 'In order to ensure that the model can adequately simulate these natural variations, key model parameters should be calibrated in transient mode using baseline observations. The selection of a relative stable period that approximates equilibrium should be guided by a residual rainfall mass curve' (p70). Normal transient calibration would involve use of the whole period of record, including the peaks and troughs of natural variations. Hence reference to selection of a stable baseline period for this purpose does not seem appropriate. Further, the baseline data for calibration is relatively short (in the order of 2 years), and to shorten this further would not be desirable.
- It is anticipated that all key data used in the Stratford mine extension model (Heritage Computing, 2012), such as groundwater levels (for calibration), mine pit dewatering and hydraulic data, will be used in the AGL numerical model. This is not discussed in the 'Framework for Numerical Modelling' (Chapter 7 in the Conceptual Model report), but it is assumed that this will occur - to exclude the data behind that model would leave significant gaps in the model (spatially and in terms of hydraulic data, stresses on the system from mine dewatering etc).

6. Specific Comments – Water Balance

This section focuses on Chapter 4 and 5 of the Water Balance for the Gloucester Basin (12th July 2013b, PB). Chapter 3 of the Water Balance report is a review of the geology and hydrogeology of the Gloucester Basin, and this is essentially duplicated in the Conceptual Model report (PB, 2013a) and hence review of that part of the report is covered in Section 5 of this report. (Chapters 1 and 2 of the Water Balance report are introductory and not technical in their content). The water balance is a pre-development case and is a preliminary assessment given that numerical modelling was not initiated in mid-2013 (i.e. at the time of the water balance report).

6.1 Area of the water balance

The water balance is for the “Gloucester Basin”, however the exact area of the basin is not clear. In Figure 3.1 of PB (2013b) two boundaries are shown – one is the Alum Mountain Volcanics boundary and the other the Permian Coal Measures boundary. The text implies that the boundary for the water balance is the latter of these two boundaries, but this is not certain. For much of the area, the difference is not very important. The exception is the far south, where the boundaries diverge significantly, and there is also a large amount of low lying land. Whether this is inside or outside the water balance boundary is important in terms of baseflow calculations later in the report.

Further, the relationship of the water balance boundary to the proposed numerical model boundary is not clear (i.e. the final numerical model to be used in the impact assessment). Presumably these are the same area, but it would be useful for this to be clarified.

6.2 Timeframe of the water balance

“A water balance involves estimation of the storage and flow of water in a defined area, during a given timeframe” (PB, 2013b, p28). However, the water balance does not appear to have been conducted over a set timeframe: “For this assessment, average rainfall data has been used together with more recent data sets regarding stream baseflow and groundwater recharge” (PB, 2013b, p31).

It is difficult to interpret from the report exactly, but the water balance appears to include:

- average rainfall from rain gauges with long records (e.g. 100 + years of data),
- stream flow and baseflow for various durations of each of the gauges used (ranging from approximately 10 years through to 40 years),
- various timeframes for the recharge estimates depend on the method applied, and,
- the timeframes for components associated with the numerical model (ET, inter-aquifer flow and groundwater outflow) are not stated.

The inconsistent timeframes used is not ideal practice in developing a water balance. For components with a high level of uncertainty, the significance of the impact on the water balance will likely be small compared to this uncertainty, however for other components which can be estimated relatively well, defining a timeframe is important (as shown later in this review, for example, for the Baseflow component).

6.3 Method and conceptual framework for the water balance

The following issues were identified relating to the method and conceptual framework for the water balance:

- Figure 4.2 in PB (2013b) presents a schematic of the water balance. This schematic is a useful depiction of the main components of the water balance. One shortcoming however is that where the coal measures outcrop / subcrop on the Basin margins is not included in the diagram. This means that the potential for more direct interaction between the coal measures and alluvium and/or surface water is not captured in this framework. (Creeks on the basin margins may be both losing and gaining in different locations along the water course). While this may be a relatively small component of the overall water balance, groundwater interaction with these creeks may be important locally.

- The method of closing the water balance by solving for the remaining variables (in this case unsaturated zone ET) is not ideal. While it is acknowledged that this is a difficult parameter to estimate, calculation via some other method is still worthwhile (even if this results in a less than perfectly balanced water budget), in order to provide an external check on the overall water balance. Otherwise the water balance is artificially closed.
- There is value in the total water balance that has been undertaken, but it would be further beneficial in condensing this down to a groundwater balance. Considerable effort has been expended calculating parameters which are ultimately of limited value in the numerical model, and the review would be better focused on a groundwater balance. Commenting on potential CSG impacts on the overall water balance numbers is in most cases not a meaningful comparison, and a comparison with the groundwater balance is preferred.
- Finally, while the water balance is rightly conducted for the whole Gloucester Basin, comparison of potential volumes of water extracted during CSG operations should be accompanied with the caveat or explanation that the CSG volumetric impact may be felt disproportionately locally. This is discussed further later in this section.

6.4 Recharge estimation

Both the watertable fluctuation method and the chloride mass balance method are reasonable and widely used approaches for estimating recharge, but as noted in the PB (2013b) report they are potentially subject to a reasonable amount of uncertainty, e.g. in the watertable fluctuation method due to reliance on estimation of the specific yield (without hard data), and then in converting a particular event to long term average percent of rainfall. For the chloride mass balance the high variability in chloride concentrations in groundwater introduces significant variability in the results.

The baseflow method as a means of determining recharge is not preferred as it involved estimating and then subtracting other groundwater discharge components, so it is not a direct measure of recharge, and then its accuracy becomes dependent on the accuracy of groundwater ET and groundwater outflow.

Where there is limited recharge data available locally and a reasonable amount of uncertainty (as is the case here), it is common practice to cite and use results from recharge studies in similar environments. This would be a helpful addition to the current recharge work. Notwithstanding, the recharge numbers quoted appear reasonable given the geology and climate.

However, it is well accepted that in most environments, estimating recharge as a linear proportion of rainfall is not the best method – recharge is better represented by a threshold response, whereby once a certain amount of rainfall has been received (onto a relatively dry catchment) then recharge commences (and can then be approximated by a linear relationship with rainfall). Consideration of this type of recharge estimation in the numerical model report should be considered.

One important difference between the numerical model developed for assessing the Stratford Extension Project (Heritage Computing, 2012), which covers a sub-set of the PB (2013b) model, and the PB (2013b) recharge estimates is that the Heritage Computing (2012) model has about half of its recharge derived from losses from streams and creeks, whereas the PB (2013b) model has no recharge from this source. Consideration needs to be given to adding recharge from streams and creeks on the flanks of the Basin to the numerical model.

The 11.4 GL/yr of recharge presented in the PB water balance represents an average recharge rate of around 14 mm/year (over the water balance area of 306 square kilometres). By way of comparison, the Heritage Computing (2012) total recharge (at the end of transient model calibration) is around 42 mm/yr – this is comprised of 19 mm/year of rainfall recharge and 23 mm/year of recharge from creeks and streams. (These numbers are based on the values provided in Table A-16 of Heritage Computing, 2012, and using the active model area of 179 square kilometres). Hence while rainfall recharge is similar to the PB water balance average rate, the recharge from creeks and streams means that there is a reasonable discrepancy in the total recharge rate.

6.5 Baseflow analysis

6.5.1 Baseflow method and timeframes

The baseflow method used in the water balance was determined "by integrating flows below a line that links the hydrograph recession lows (approximated by a moving monthly minimum flow)" PB (2013b, p35). This is not a best practice method for estimating baseflow, as it neglects the fact that baseflow generally increases under conditions of increasing runoff (e.g. due to higher groundwater levels due to increased recharge). As noted in the PB report "this method is likely to underestimate the baseflow slightly" (p35).

A comparison of the PB (2013c) baseflow estimates was made with a more recognised method of baseflow estimation. The method used applies the Lyne and Hollick (1979) filter to the runoff record, and the analysis was conducted using the software 'Basejumper' (SKM, 2012). The results of this comparison are presented in Table 6.1. As well as comparing methods of baseflow determination, the table compares the effect of selecting different periods of analysis. (Note that not all gauges have been analysed, as the purpose of this review was only to check the methods applied, and not to analyse all data).

The important conclusions from this comparison are:

1. The baseflow assessment conducted in PB (2013b) underestimates baseflow [compared to the Basejumper method, which uses the Lyne and Hollick (1979) filter] by between 3% and 26% for an alpha parameter of 0.98, with the difference varying between the four gauges where a comparison was conducted. The difference using an alpha parameter of 0.925 is between 29% and 47% across the four gauges. While for one gauge the difference between the PB and Basejumper baseflow is small, it is significant for the other three gauges. Given that baseflow is an important component of the groundwater balance, and one where there is data to enable assessment, it is recommended that a more recognised method of analysis is used.

2. The BFI changes slightly depending on the period of record used in the analysis.

3. The magnitude of average annual baseflow changes markedly depending on the period of record (and much more so than the BFI). In the case of the Karuah River at Booral, the baseflow over the period 2004 to 2013 is more than double the baseflow over the entire period of gauge record (1968 – 2013). Hence mixing of these numbers in a water balance (as appears to have occurred in this assessment) is not appropriate, and distortions can occur when different periods of analysis are used. The preferred method is to select a fixed period of assessment and factor the baseflow numbers around that (e.g. by establishing correlations between gauges, or by only using part of a gauge record etc).

   Hence while the baseflow analysis method has underestimated baseflow, for stream gauges with only approximately 10 years of record, baseflow has been overestimated compared to the long term average. In this case, the period of data selected appears to be a more significant factor than the baseflow separation method.

Table 6.1 : Comparison of PB (2013c) baseflow estimates with alternate method of baseflow analysis

From PB (2013b) Water Balance Report, Table 4.4 (2013)					**Analysis Conducted in this review (Basejumper; SKM, 2012)**			
Stream, Gauging Station (catchment area, km²)	Flow Record	Baseflow, GL/yr (Total Flow in brackets, GL/yr)	BFI	Baseflow as % of Rain	Entire Period of Record BFI (Baseflow in brackets, GL/yr)		2004 – 2013 BFI (Baseflow in brackets, GL/yr)	
					α = 0.925	α = 0.98	α = 0.925	α = 0.98
Avon River D/S Waukivory Creek (255 km²)	01/01/2004 – present	6.9 (118)	6%	2.9%	10% (9.7)	7% (7.1)	10% (9.7)	7% (7.1)
Mammy Johnsons River at Pikes Crossing (156 km²)	01/01/1967 – present	4.0 (56)	7%	2.4%	14% (7.6)	10% (5.4)	Not assessed	Not assessed
Karuah River at Booral (974 km²)	01/01/1968 – present	30.2 (275)	11%	3.0%	20% (55)	15% (41)	18% (118)	15% (94)
Karuah River at Dam Site (300 km²)	01/01/1979 – present	15.5 (98)	16%	4.9%	Not assessed	Not assessed	Not assessed	Not assessed
From PB Conceptual Model report (2013)								
Gloucester River at Gloucester (253 km²)	01/01/2003 - present	23.3 (82.5)	28%	-	39% (33)	32% (27)	Not assessed	Not assessed

6.5.2 Avon River baseflow

The issue of why baseflow and the BFI in the Avon River is so low (BFI of approximately 7%) is an issue that deserves further consideration. In particular, when compared to the adjoining Gloucester catchment (with a BFI of approximately 32%), the baseflow in the Avon River appears anomalously low. The catchments share similar rainfall and the Avon catchment appears to have more alluvium than the Gloucester catchment (e.g. based on visual inspection of Figure 4.5 in PB, 2013a). However, it has been postulated that the alluvial boundaries (as mapped by Roberts, 1991 and as reproduced in Figure 4-5) in the Conceptual Model report, have been incorrectly mapped. It is suggested that the extent of the alluvium is significantly thinner than as mapped in Roberts (1991); (J. Ross, pers. comm. 29 April 2014).

A possible explanation is land use change within the Avon River catchment (or relative land use change between the two catchments). Another contributing factor could be the Stratford Coal mine. The mine involves pit dewatering and is located relatively close to the Avon River, hence some impact on baseflow is likely. This mine has been in operation since 1995, so unfortunately the gauged data on the Avon River (commencing in 2004) cannot be used to directly examine possible impacts from the mine on baseflow. Heritage Computing

(2012) estimates an average of 1 ML/day of groundwater inflows associated with the mine expansion, planned for commencement in around 2014. The groundwater inflows into existing pits is not known (early reports into groundwater investigations prior to the Stratford mine have not been reviewed as part of this assessment, and estimates may be contained in those reports). Nevertheless, some impact is likely and therefore use of the Avon River baseflow as a baseline figure may not be appropriate in the numerical model.

6.6 Use of simple numerical model in the water balance

Three components of the water balance are estimated using a simple numerical model: groundwater ET, groundwater outflow and inter-aquifer flows. Part of the purpose of the water balance is a check on the outputs of the numerical modelling which will be conducted at a later stage. When this is one of the objectives of a water balance, it is not helpful to also use a numerical model to determine significant components of the water balance. Some basic methods, such as use of analytical calculations could be employed to estimate the groundwater outflow from the basin and similarly for estimating vertical fluxes.

In terms of ET, development of a depth to watertable map (using bore water levels and a DTM), and use of ET functions in a GIS framework could be used to derive estimates of groundwater ET. There are other more sophisticated methods for estimating groundwater ET also available, such as use of remote sensing data during dry periods (where non-groundwater ET is minimal), e.g. using SEBAL (Bastiaanssen et al. 1998a, Bastiaanssen et al. 1998b and Bastiaanssen et al. 2005),. PB (2013b) notes that the numerical model is not designed 'to predict absolute groundwater levels or groundwater level impacts' (p39). However, absolute groundwater levels are very important in determining groundwater ET.

The issue with using the numerical model for estimating components of the water balance is that it relies on the assumptions behind the conceptual model, which are only now being tested and reviewed (e.g. recharge estimates, hydraulic conductivity numbers etc). Therefore if these estimates are inaccurate, this will flow through to effect the other parameters being estimated.

The numerical model developed for assessing the Stratford Extension Project (Heritage Computing, 2012), which covers a sub-set of the PB (2013b) model (approximately covering half of the PB model area), estimated that around 20% of recharge was discharged as baseflow with around 80% discharged as groundwater ET. This is in contrast to the PB model estimate which calculated around 80% discharge to streamflow and 20% to groundwater ET. There are also other significant differences between the two models (which are discussed elsewhere in this report); this highlights the fact that it is useful to have external checks on key components of the water balance, to assess the veracity of differing model outputs. It is acknowledged however that the level of effort applied to the two models was very different, due to their different end purposes.

6.7 Aquifer storage

There is some discussion in the PB water balance report regarding storage. For the natural condition, using long term averages, the water balance assumes a state of quasi equilibrium (as stated in the PB report). In an equilibrium condition, over the long term, storage become largely irrelevant, as flow in is equal to flow out. Comparing the volumes in storage to the volumes to be extracted (e.g. bottom of page 44, PB, 2013b) is not a helpful comparison and is potentially misleading. This is because the impacts of groundwater extraction on a groundwater system can be significant, regardless of the magnitude of volumes in storage. It is comparison with the impact on discharge rates that is important, not storage volumes.

This is not to discount the fact that analysis of a dynamic situation, e.g. when a stress (like groundwater extraction) is imposed on the groundwater system, storage can form an important buffering to those stresses. In other words, the storage may cause the impact of extraction (at various points of discharge) to be delayed and spread out over time. However, eventually the extracted volume will be represented by an equivalent reduction in discharge volume somewhere in the groundwater system. Discussion in the PB water balance report around storage volumes and in particular comparison to expected extraction volumes should be accompanied by a discussion of this nature.

For example, the PB (2012b) report estimates that there is 53 GL of storage in the alluvial aquifer within the Gloucester Basin (p42) and therefore with an average baseflow of around 8 GL/yr, average residence times of groundwater in the alluvial aquifer are relatively short at around 6-7 years (p41). However it is elsewhere noted that "low rainfall conditions lasting more than a month or two leads to rapid depletion of storage in the alluvium, and when ET is high, a rapid decline in stream baseflow and ultimately to no-flow conditions" (PB, 2012b, p43). This appears to contrast with the elsewhere stated 6-7 years storage time in the alluvial aquifer. What is actually meant in this latter quote is that storage levels in the alluvial aquifer drop to a level where the discharge rate is insufficient to maintain flow in the creek. This highlights the fact that it is not storage in the aquifer that is relevant, but for many ecological receptors, it is the upper portion of that storage that is of importance.

6.8 Dry water balance

The section discussing the water balance under dry conditions (p43-44) is a valuable addition to the water balance assessment, because it is under these conditions that potential stresses on environmental (or other) receptors can be greatest. Two comments are made regarding this section of the report:

1. While there is some quantitative analysis, a clearer breakdown of the groundwater balance under dry conditions would be useful (e.g. the split of discharge into baseflow and ET components).

2. The analysis presents a prolonged dry period - the length of time does not appear to be specified, but the implication is that it is at least 10 years. What is also important is the seasonal change in the groundwater balance. In particular, in an average year, what is the baseflow component at the end of the drier months? (July to September). This is important because this number is likely to be significantly smaller than the average annual baseflow, and therefore is potentially a more relevant figure to be used in considering the impacts of changes in baseflow and possible associated ecological impacts.

6.9 CSG development impact on water balance

This is an important section of the PB (2013b) report (p44-45). It is in many ways at the crux of the assessment, as it examines the significance of extracted volumes in the context of water balance volumes. There are several comments to be made regarding this section of the report:

1. There is an important spatial discussion missing in this section. The comparison is with potential impacts on groundwater discharge volumes for the whole Gloucester Basin. While it is likely there will be some impact across the Basin, the greatest concentration of impact will be over the Stage 1 GFDA area (and hence greatest in the northern part of the Basin, and the Avon catchment). It is recognised that the spatial distribution of this impact cannot be known prior to the numerical modelling, but this point should be acknowledged / discussed in the report.

2. The baseflow volume in the Avon River appears to be overestimated in that it is based on a period of above average streamflow (refer Section 6.5.1 of this report). This means that the proportional comparison of CSG volumes to baseflow is larger than presented in the report.

3. Comparison with discharge rates (streamflow and baseflow) should not just be against average groundwater discharge rates (or even average rates from consecutive dry years) but also against seasonally low groundwater discharge rates (i.e. baseflow at the end of the drier months of July to September).

4. The comparison of likely CSG extraction volumes to aquifer storage is not a helpful comparison, for reasons described in Section 6.7 of this report.

5. The Heritage Computing (2012) numerical modelling predicts substantial impact on the watertable resulting from CSG extraction in the Gloucester Basin. It is expected that this would be discussed in either the water balance report or the conceptual model report, e.g. what are the differences in conceptualisation that have led to this different outcome?

7. Specific Comments – 2013 Gloucester Groundwater and Surface Water Monitoring - Annual Status Report

The *2013 Gloucester Groundwater and Surface Water Monitoring - Annual Status Report* (PB, 2013d) clearly and suitably summarises the hydrological and hydrogeological monitoring for 2013. The following comments are made on this report (some of these overlap with issues raised earlier in this report):

- It would be useful to see the flow gauging presented as flow, in addition to elevation.
- The 'cease to flow' levels for each of the streams gauges should be stated (i.e. the sensitivity of the gauges to low flow identified)
- It would be useful to include stream flow data from the NOW stream gauges in the annual status monitoring reports. (It is noted that the Avon River NOW gauge 208028 is included in the Water Balance report). Once existing gauges have levels converted to flow this would provide, for example, a picture of change in flow along the Avon River. It is acknowledged that the focus of this annual reporting is on AGL's monitoring network, however in some cases the most beneficial review of that data may be achieved by incorporation of other relevant data sets.
- The reference point for the barometric correction of water should be identified (presumably the correction has been around mean barometric levels?)
- Generally the assessment of groundwater level trends is sound. The possible link between the water level trend in S4MB03 and the Stratford 4 flow testing is one issue however that should be investigated further (as discussed earlier in this report).
- As the groundwater monitoring network is relatively highly concentrated within the central part of the Stage 1 GFDA area (whereas CSG wells and potential impacts may spread significantly wider), consideration should be given to including some of the Stratford coal mine and Rocky Hill monitoring bores as baseline data sets, including presentation of these in future monitoring reports. This is assuming the data is readily available. As noted above, it is acknowledged that the focus of the annual reporting is on AGL's monitoring network, however these bores would add significantly to the calibration (and/or validation) data set for the numerical model, and hence a review of this monitoring data seems appropriate. Indeed, that three projects in such close proximity to one another, with likely overlapping impacts would not cooperate in terms of data sharing would be unfortunate and inefficient.

8. Conclusion

In general, the conceptualisation and water balance as presented in the reviewed reports is considered to be appropriate. The fundamentals of the conceptual model and water balance are reasonable, including:

- The conceptual framework for the model, including model domain, hydrostratigraphy (including breakdown into four basic hydrostratigraphic units), conceptual boundaries and stresses are all generally appropriately conceptualised.
- The water balance is a reasonable representation of the main processes and water fluxes, and has in general been developed with suitable techniques and to a level of accuracy typical of a Basin-wide water balance
- The likelihood of other groundwater dependent ecosystems (apart from baseflow) within the study area being significantly dependent on groundwater is considered to be low
- That there is a sufficient baseline of data (groundwater and surface water) to enable transient calibration of the model
- That maximum annual extraction from the Stage 1 GFDA will be a relatively small component of the groundwater budget within the Gloucester Basin
- The principle of decreasing hydraulic conductivity with depth in the interburden confining units (although possibly not within the upper 150-200m), and the relatively higher hydraulic conductivity of the coal water bearing zones
- The assessment that baseflow to the rivers within the Gloucester Basin is a relatively small component of total flow, albeit with significant variations across the different catchments represented
- That the fault zone investigated represents an area of somewhat enhanced hydraulic conductivity in the Shallow Rock unit
- That in the natural state, lateral flow process within units are dominant, with vertical processes being relatively small

In some instances it is considered that during development of the conceptual model and water balance some work has been omitted which would improve conceptual understanding and in places inappropriate methods have been used. However, it is emphasised that based on the data presented in the PB reports, none of these represent criticisms that cannot be readily addressed or the conceptual model revised to take account of the comments. They are normal hydrogeological issues which are considered and debated in most hydrogeological studies, and should not be interpreted to mean that the fundamental science is flawed. The fundamentals of the conceptual model and water balance provide a foundation on which the numerical model can be developed.

The review has not identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective - not that this was the scope of the review, as it is the role of the numerical modelling to assess the location and magnitude of impacts.

Bearing in mind the above overarching comments, a summary of the issues identified in this review are outlined below:

Groundwater Dependent Ecosystems – The impact on potential terrestrial GDEs is likely to be relatively small, and it is apparent that groundwater beneath the native vegetation identified in the National GDE Atlas is relatively deep (10 – 15 metres). While deep groundwater does not necessarily mean there is no groundwater use by the vegetation, it does mean that the trees will have a higher resilience to any changes in groundwater level through access to large stores of water in the unsaturated zone. Further, given the relatively high rainfall in the Basin, it is quite possible that the vegetation is not at all groundwater dependent.

Hydraulic properties – The aquifer hydraulic properties adopted in the numerical model are very influential on the rate at which impacts are propagated from the targeted coal seams to overlying layers, including the amount of drawdown which might occur in the watertable aquifer. The following comments are made regarding aquifer hydraulic properties:

- The broad range in hydraulic properties presented in the reports is too wide to provide suitable guidance or indication as to what will be used in the numerical model. The spectrum of these ranges likely represents the difference between relatively rapid vertical propagation of pressure versus extremely slow transmission of pressure. Clarification on the proposed numbers within this range for use in the numerical model is required.
- A proposed approach for estimating a vertical hydraulic conductivity should be discussed (given that collected hydraulic data provides horizontal hydraulic conductivity).
- The vast majority of hydraulic conductivity measurements for the Gloucester Basin are local scale tests. Given that hydraulic conductivity is known to increase with increasing scale of measurement (and this effect is apparent in the Gloucester Basin data when comparing pumping test and slug test results), there should be a discussion on how hydraulic conductivity data might be adjusted upwards for use in the regional numerical model.
- Further analysis of the TTPB pumping test (20-23 December 2012) is recommended to examine the potential for obtaining additional data from the test, including aquifer hydraulic conductivity data from other observation bores.
- At the majority of nested bore sites, groundwater levels and trends imply at least a reasonable level of hydraulic separation between the Shallow Rock and the Interburden / Coal Measures. At a small number of nested sites, groundwater levels in the Shallow Rock bore either move in parallel with a bore in the Interburden / Coal Measures and/or the groundwater levels between the two units are very similar. This implies that at some locations there is only limited hydraulic separation between these units. (Note that these observations are for nested sites where the deeper bores in the Interburden / Coal Measures is screened less than 200m below groundwater level).

Stratford 4 flow testing – There is a possibility that the intermediate depth bore S4MB03 did respond to the Stratford 4 flow testing. This bore drops around 0.4m between the start of the test, and the end of January 2013. If S4MB03 did respond to the test pumping, the implications are that the vertical hydraulic conductivity of the interburden is higher than currently conceptualised. It is recommended that this issue be investigated further and the apparent drawdown at S4MB03 be analysed in order to estimate a Kv. Such a result would be valuable because it is representative of a large vertical section of rock mass instead of the local data collected in slug tests, DSTs etc. Even if it is assumed that S4MB03 did not respond to the flow testing), then the result can be used to constrain the vertical hydraulic conductivity of the intervening rock.

Craven 06 and Waukivory 03 flow testing - In 2013, Craven 06 and Waukivory 03 were flow tested over an 8 month and 6 month period respectively. The chemistry and isotopic results from these tests have been reported in considerable detail; however there is no presentation, analysis or discussion of hydraulic data associated with these tests. Given the long duration of these tests they potentially represent the best source of hydraulic conductivity data (and calibration data sets) for the numerical model. The possibility of using data from the Stratford coal mine observation bores in proximity to Craven 06 should be explored. The nearest observation bores to Waukivory 03 may be too distant to allow meaningful analysis.

Time frame of the water balance – the water balance does not appear to have been conducted over a constant timeframe. The effect of this is most important in the stream flow and baseflow estimates, which are sensitive to the period of record used.

Water balance method and conceptual framework – The exclusion of interaction between the coal measures and surface water at the margins of the Basin and the method used to close the water balance, have been identified as shortcomings in the water balance, although they are second order issues which don't impact the fundamentals of the water balance.

Comparing the CSG volumetric impact with water balance numbers for the whole Gloucester Basin is potentially misleading, as impacts may be felt disproportionately locally within the Basin. Further, care needs to be applied in how storage numbers are used in discussions relating to the water balance – large aquifer / rock mass storage does not necessarily imply a low risk of impact.

Groundwater recharge – The methods used for estimating recharge are reasonable and widely used approaches for estimating recharge but are potentially subject to a considerable amount of uncertainty. Where there is limited recharge data available locally and a reasonable amount of uncertainty (as is the case here), it would be useful to compare the results from recharge studies in similar environments. Notwithstanding, the recharge numbers quoted appear acceptable given the geology and climate. Further, the recharge numbers represent a starting point in the numerical model, and are likely to be modified during model calibration. Consideration needs to be given to adding recharge from streams and creeks on the flanks of the Basin to the numerical model.

Baseflow analysis – Important conclusions regarding the baseflow analysis are:

- The baseflow assessment underestimates baseflow compared to other more recognised method (by between 3% and 26%).
- The BFI changes slightly depending on the period of record used in the analysis.
- The magnitude of average annual baseflow changes markedly depending on the period of record. Mixing of these numbers in a water balance is not appropriate, and distortions can occur when different periods of analysis are used.
- While the baseflow analysis method underestimates baseflow, for stream gauges with only approximately 10 years of record, the variable timeframe means that baseflow is overestimated (compared to the long term average). In other words, the period of analysis is a more significant factor than the baseflow separation method, so that the overall effect is for baseflow to be overestimated for gauges with a short record (where, in this case, the period of analysis represents a wetter than average time interval; 2004 to 2013).
- The issue of why baseflow in the Avon River is so low (BFI approximately 7%), particularly compared to the adjoining Gloucester Basin (BFI around 32%) is an issue worth further discussion.

CSG development impact on water balance – Important conclusions regarding potential impact on the water balance are:

- Comparison with potential impacts on groundwater discharge volumes for the whole Gloucester Basin should recognise that the greatest concentration of impact will likely be over the Stage 1 GFDA area.
- The baseflow volume in the Avon River appears to be overestimated in that it is based on a period of above average streamflow. This means that proportional comparison of CSG volumes to baseflow is larger than presented in the water balance report.
- Comparison with streamflow and baseflow should not just be against average flow but also against seasonally low groundwater discharge rates, including baseflow at the end of the drier months (approximately July to September).
- The comparison of likely CSG extraction volumes to aquifer storage is potentially misleading.
- The Heritage Computing (2012) numerical modelling predicts substantial impact on the watertable resulting from CSG extraction in the Gloucester Basin. This should be discussed in either the water

balance report or the conceptual model report, e.g. what are the differences in conceptualisation that have led to this different outcome?

Faults – Key conclusions regarding faults include:

- o It is agreed that the fault zone investigated on the Tiedman property appears to represent a broad zone of enhanced hydraulic conductivity within the shallow rock aquifer. It is assumed that this conceptualisation will be brought into the numerical model for the same type of faults.
- o There is a current gap in the conceptual understanding of the hydraulic behaviour of thrust faults in the area. It is assumed that the Waukivory Fracture Stimulation and Flow Testing program will be complete in time to contribute to the conceptual and numerical model and associated impact assessment.
- o The evidence for the decrease in permeability in fault zones with depth is not clearly presented.

- **Vertical connectivity and operational issues** – Key conclusions regarding vertical connectivity and operational issues include:
  - o There is fairly limited number of hydraulic tests for the Interburden unit.
  - o The numerical model and associated reporting needs to be specific regarding the pressure reduction target that will be used in operations, and that this is applied in the numerical model.
  - o Comments implying that there will be an increase in aquifer recharge in response to drawdown related to CSG operations, should be clarified.
  - o The Heritage Computing (2012) numerical model results are in contrast to the forecasts in the Conceptual Model report. It will be important for the differences in results between the two models to be critically reviewed, including differences in conceptualisation, parameters used and other assumptions that leads to the difference in predicted outcomes.

- **Framework for numerical modelling** – Important conclusions regarding the framework for the numerical model are:
  - o The conclusion reached in Chapter 7 of the Conceptual Model report regarding use of a dual or single phase model is agreed with - that a single-phase saturated groundwater flow model is appropriate for the modelling assessment.
  - o The proposed approach for incorporating faults (using more separate local-scale models and incorporating the results into the regional model, as required) is valid, however the testing program of the faults needs to be able to calibrate these local models (in particular with respect to the hydraulic conductivity of the Interburden)
  - o Reference to selection of a stable baseline period for transient model calibration does not seem appropriate. The whole record should be used, particularly given that it is relatively short, otherwise further justification of the proposed approach is required.
  - o It is anticipated that all key data used in the Stratford mine extension model will be used in the AGL numerical model

9. Recommendations for Further Work

This review recommends that:

1. The baseflow analysis be re-done using a more recognised method, and using a consistent timeframe across gauges.
2. Further analysis of the TTPB pumping test (20-23 December 2012) be conducted to examine the potential for obtaining additional data from the test, including aquifer hydraulic conductivity data from additional observation bores.
3. That the possible drawdown at S4MB03 in response to Stratford 4 flow testing be analysed in order to estimate a Kv for the rock mass. Even if a null response is assumed, the analysis can be used to constrain the vertical hydraulic conductivity.
4. Streamflow hydrographs for the AGL gauges are plotted as flow, not just as reduced levels. The cease to flow values for the gauges should be stated.
5. The results of the Waukivory Fracture Stimulation and Flow Testing Program be used to inform conceptual understanding of the hydraulic behaviour of thrust faults in the area.
6. Consideration be given to adding recharge from streams and creeks on the flanks of the Basin to the numerical model.
7. All key data used in the Stratford mine extension numerical model (Heritage Computing, 2012), such as groundwater levels, mine pit dewatering rates and hydraulic data, be used in the AGL numerical model.
8. The horizontal and vertical hydraulic conductivity values proposed for use in the numerical model be stated, including preferred values and range that will be permitted in calibration. This should include discussion of the selection process, including (if and) how the values will be up-scaled to represent regional hydraulic values, given the local scale of current data sets.
9. The Craven 06 and Waukivory 03 flow testing be hydraulically analysed, including assessment of whether regional scale hydraulic conductivity values can be obtained.
10. That the assumed water level in the formations immediately adjacent the CSG wells be estimated and clearly reported, i.e. the numerical model needs to be specific regarding the pressure reduction target that will be used in operations.
11. Any difference between AGL numerical model results and the Heritage Computing (2012) numerical model results should be reviewed, including differences in conceptualisation, parameters used and other assumptions that leads to the difference in predicted outcomes. (This refers to models under construction, not the simple model used in the water balance).
12. Results of any modelled stream flow reduction should be compared to baseflow at the end of both extended dry periods (i.e. across a number of years) as well the baseflow at the end of the drier months (e.g. July to September).

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Important note about your report

The sole purpose of this report and the associated services performed by Jacobs SKM is to review particular technical studies relating to the Gloucester Gas Project, in line with the scope outlined in Section 2 of this report, and in accordance with the scope of services set out in the contract between Jacobs SKM and the Client. That scope of services, as described in this report, was developed with the Client.

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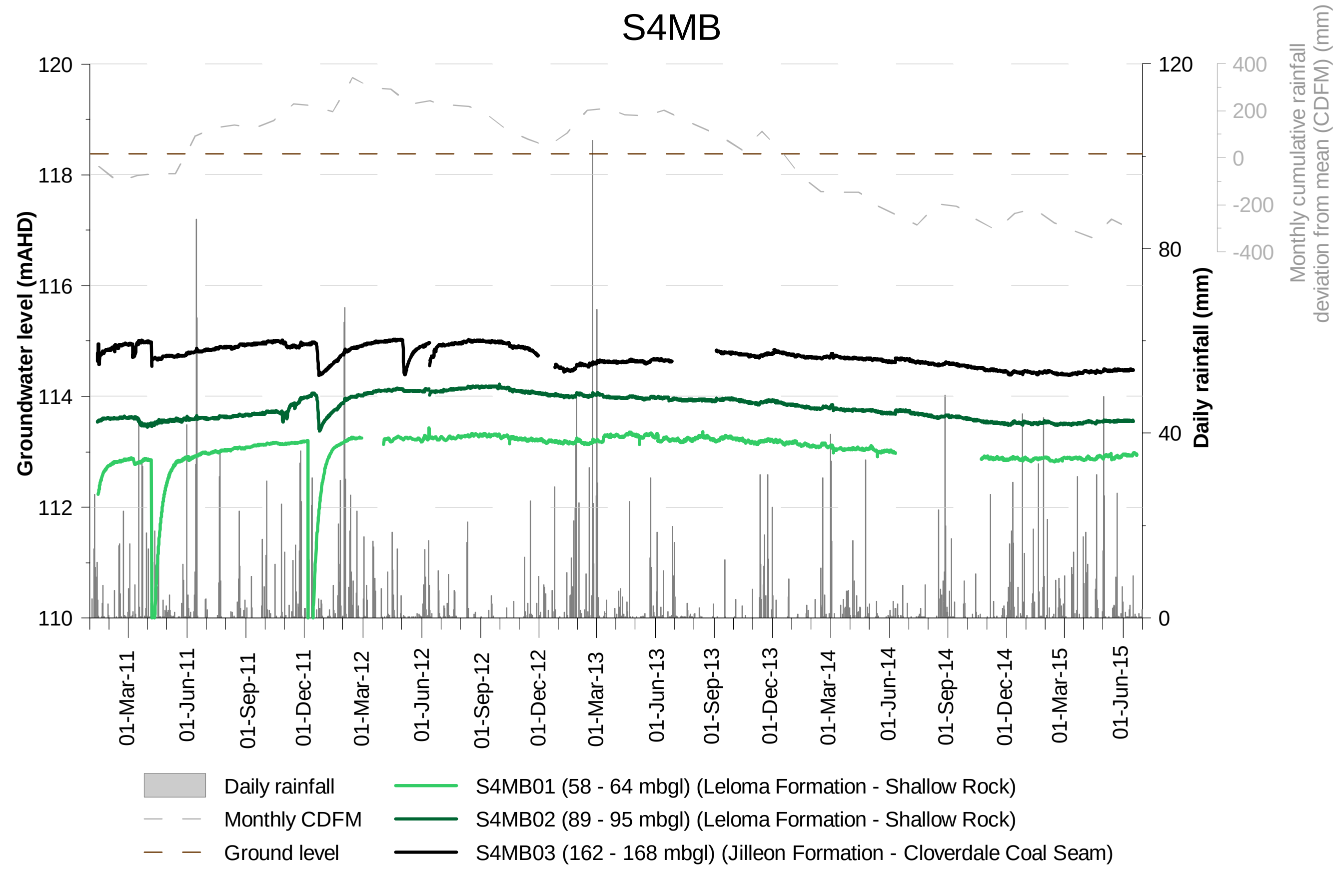
Appendix C

Groundwater and surface water hydrographs



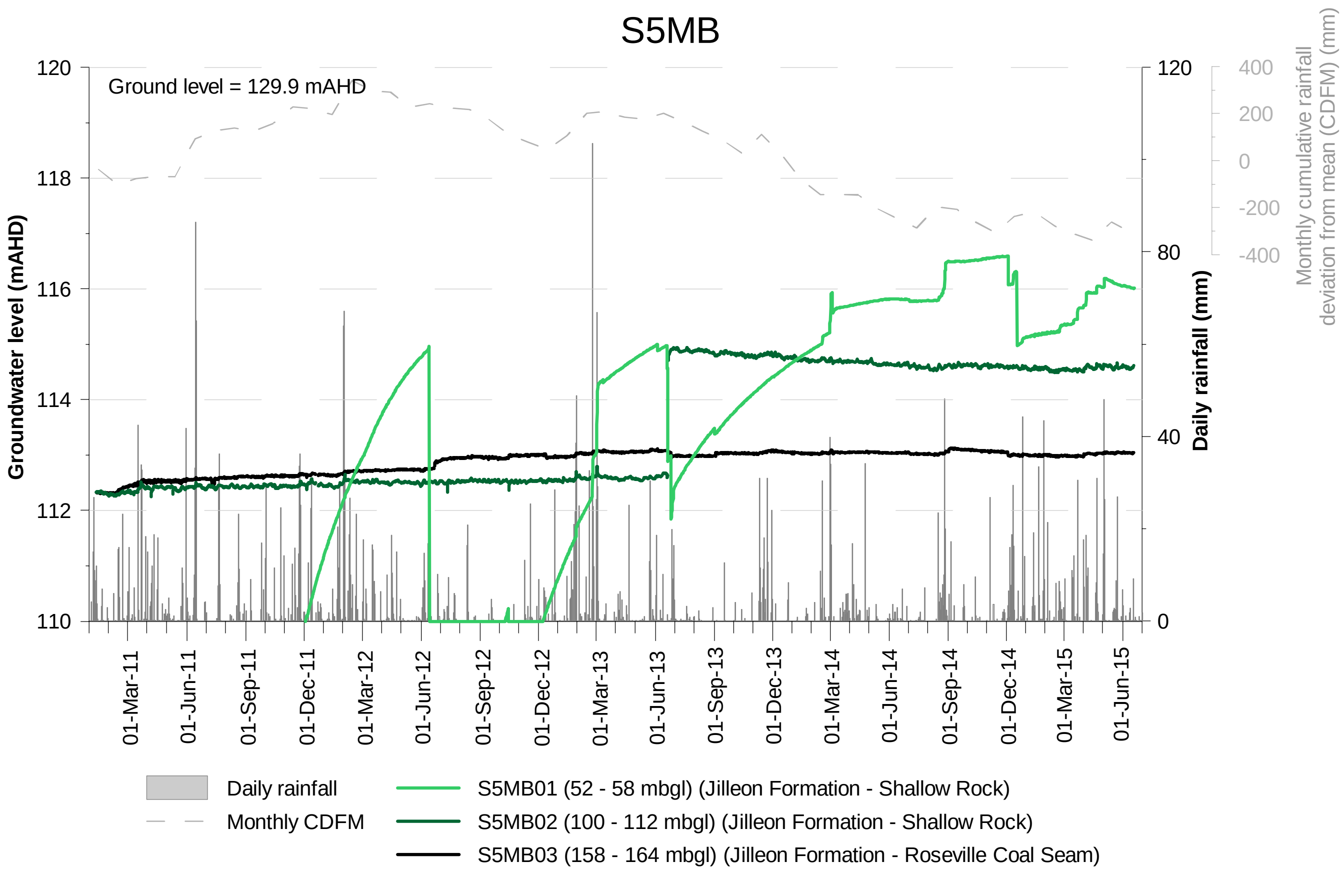
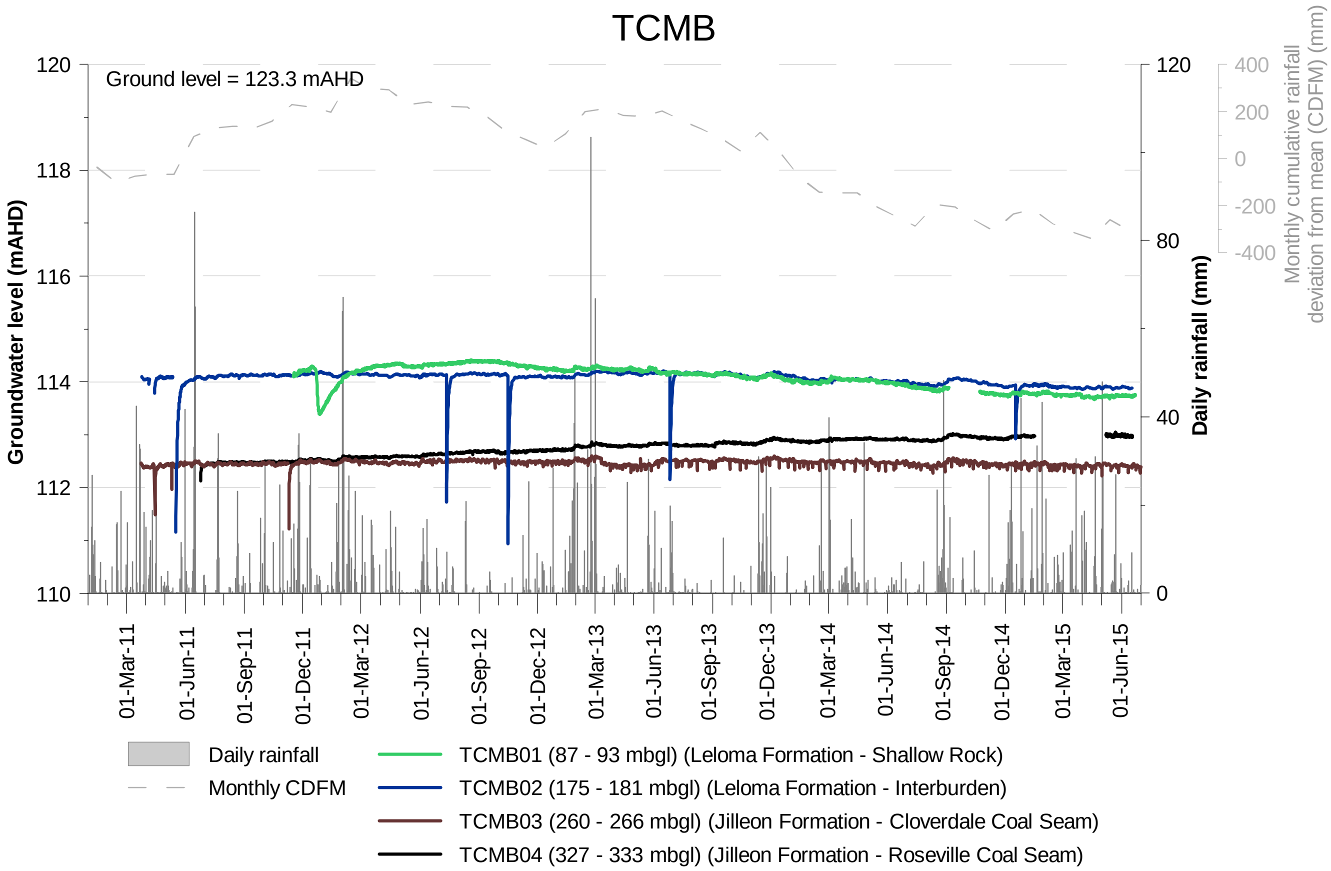


Figure 1: S4 and S5 monitoring bores



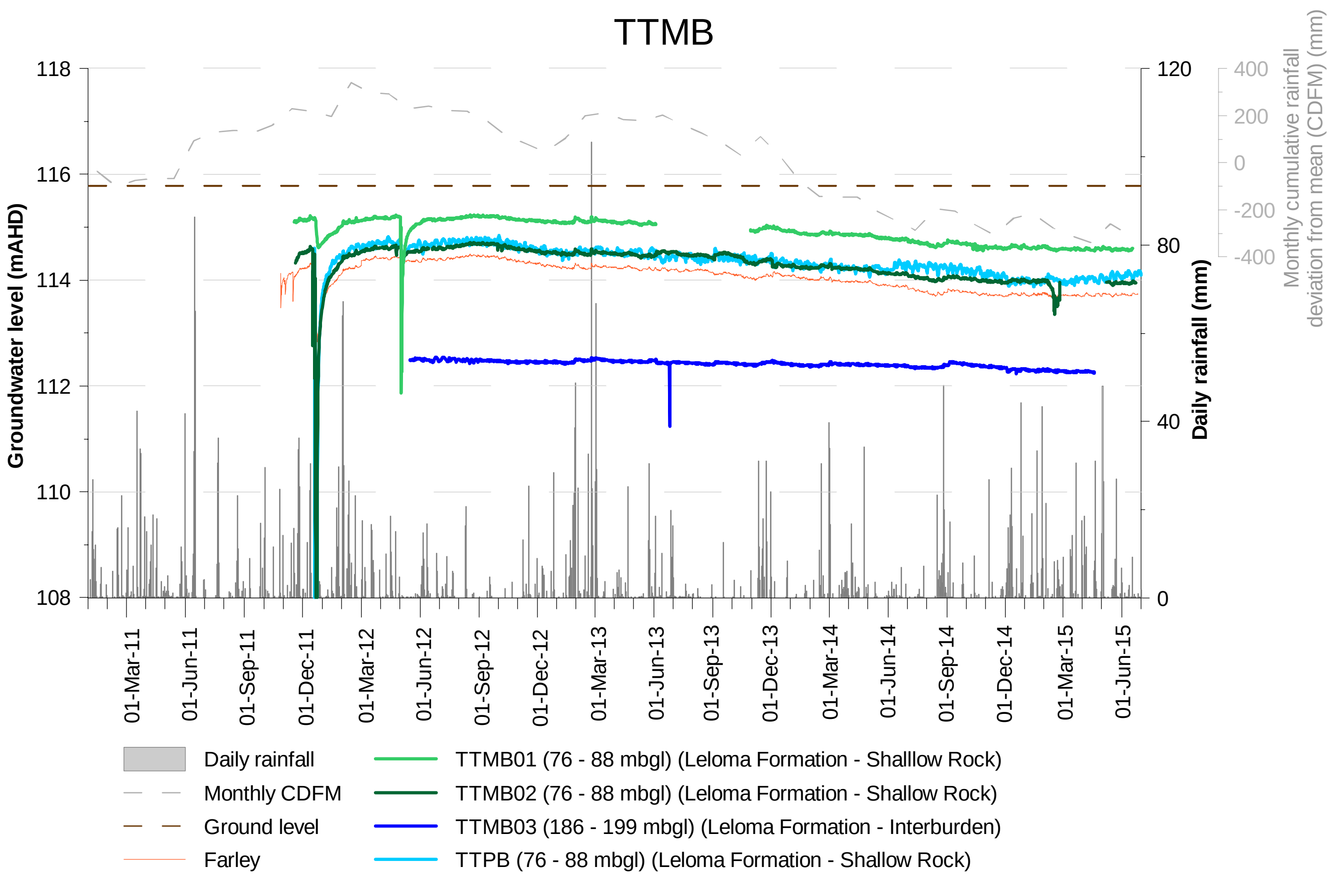
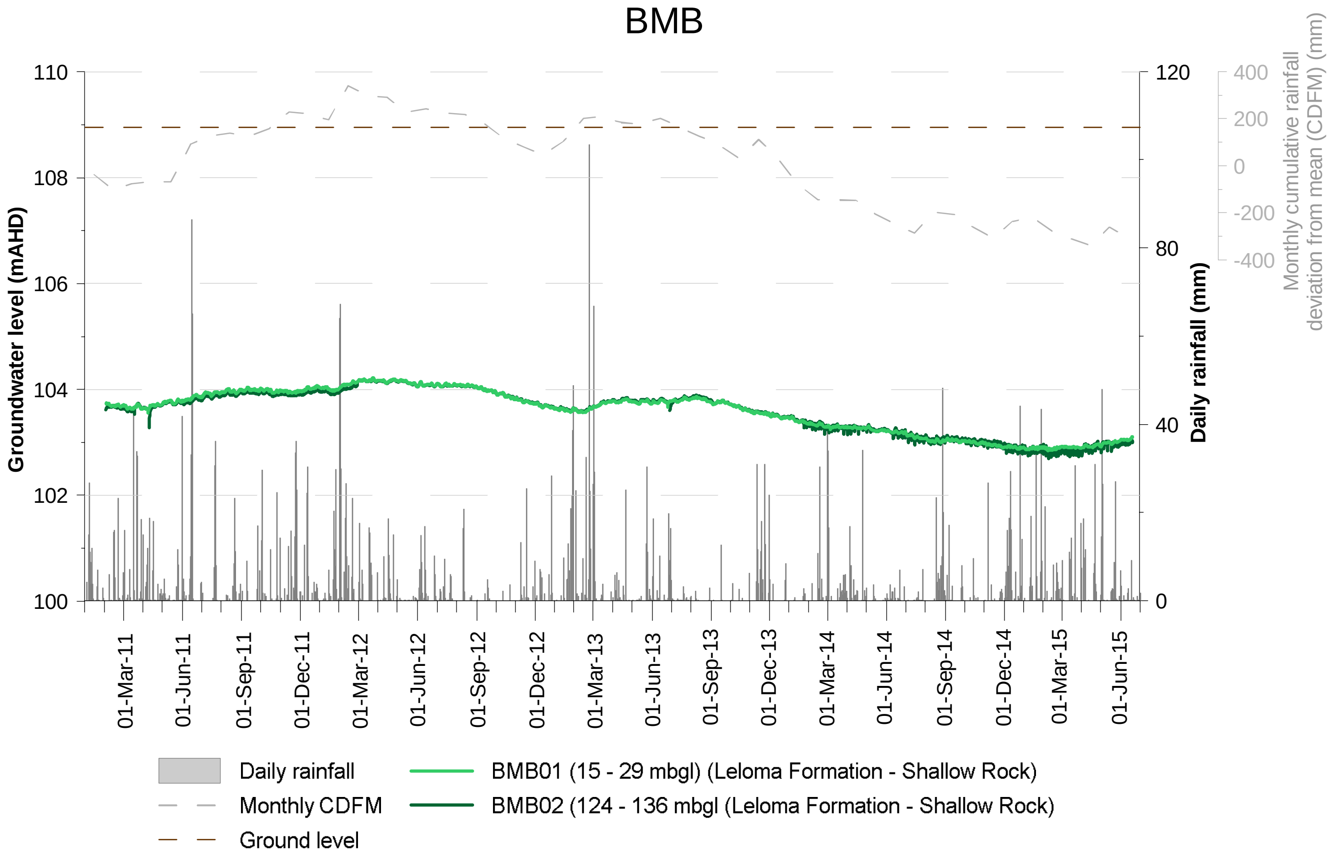


Figure 2: TCMB and TTMB monitoring bores



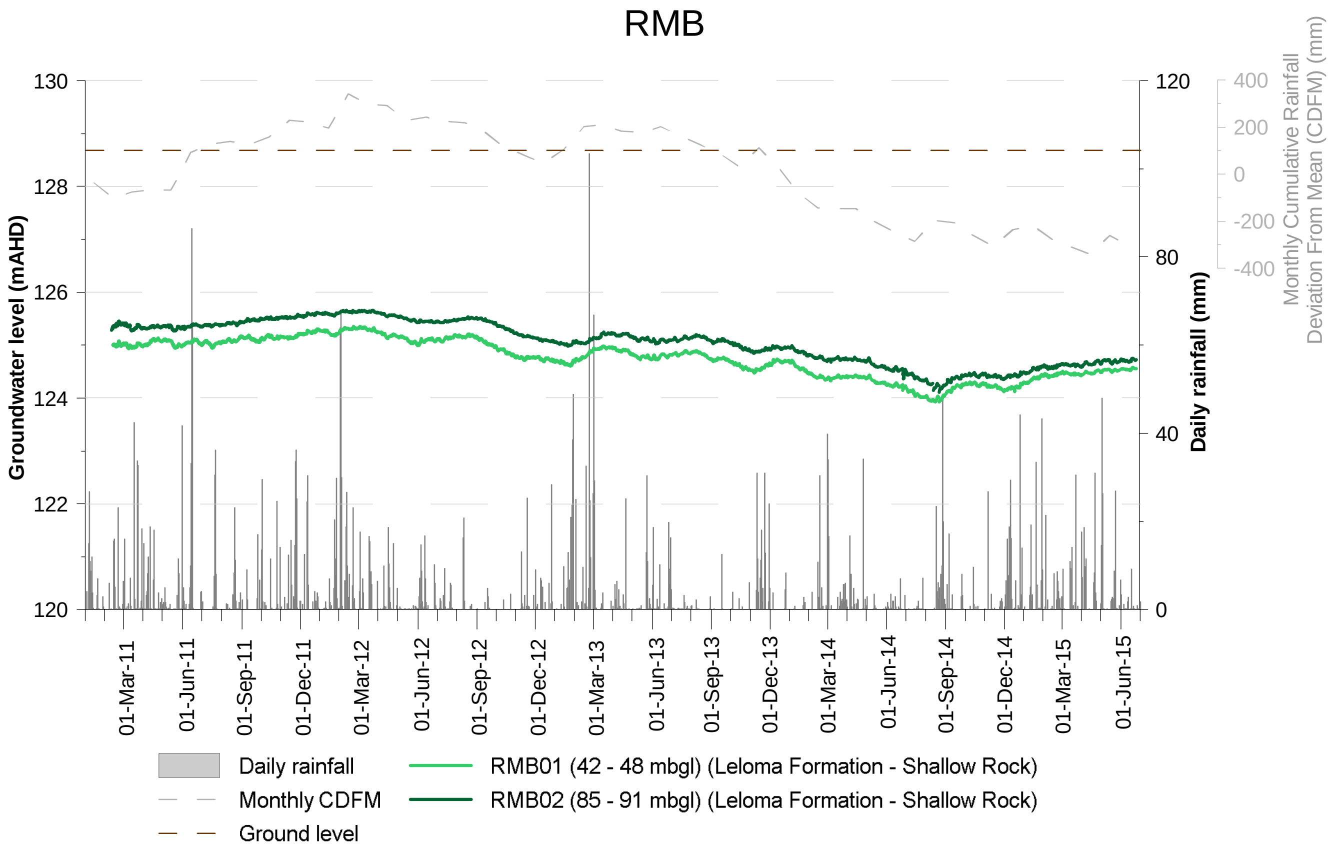
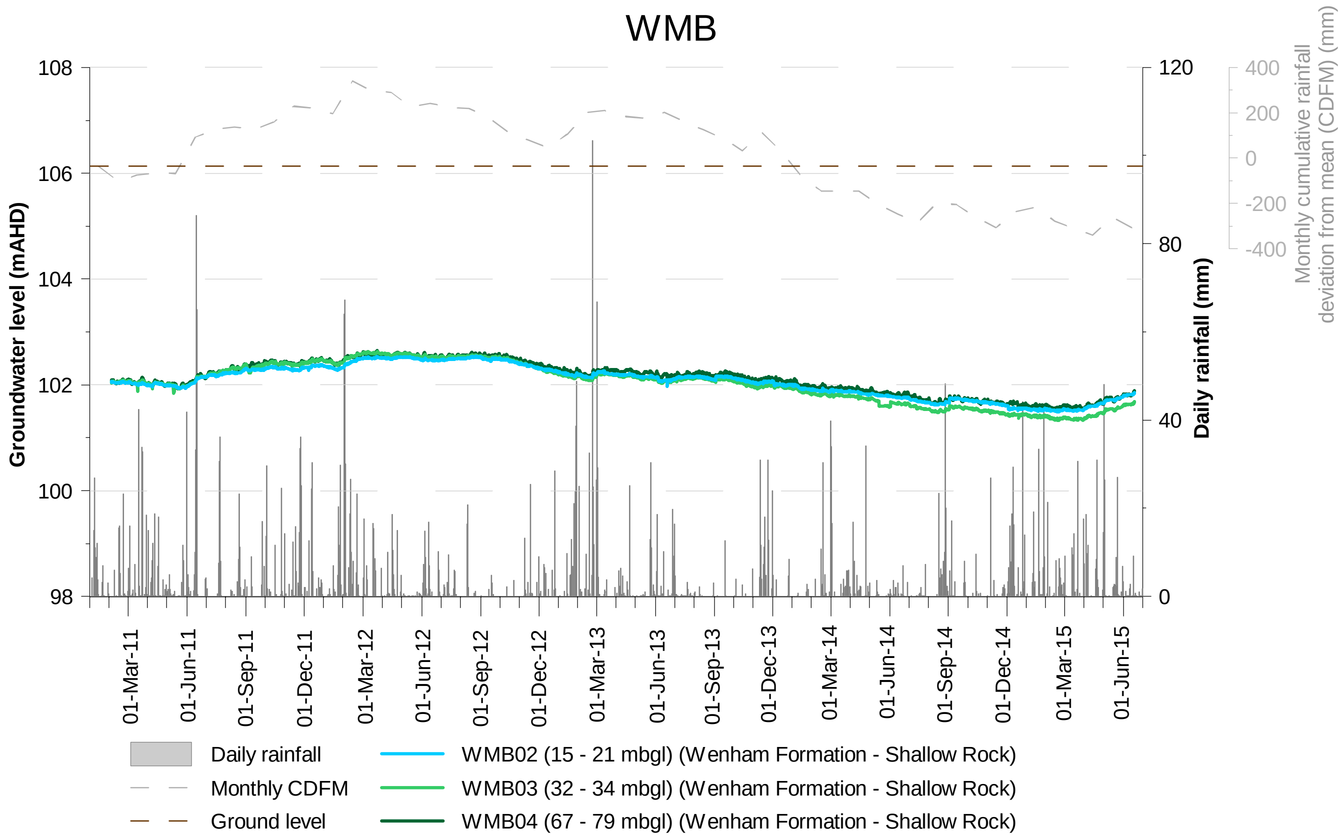


Figure 3: BMB and RMB monitoring bores



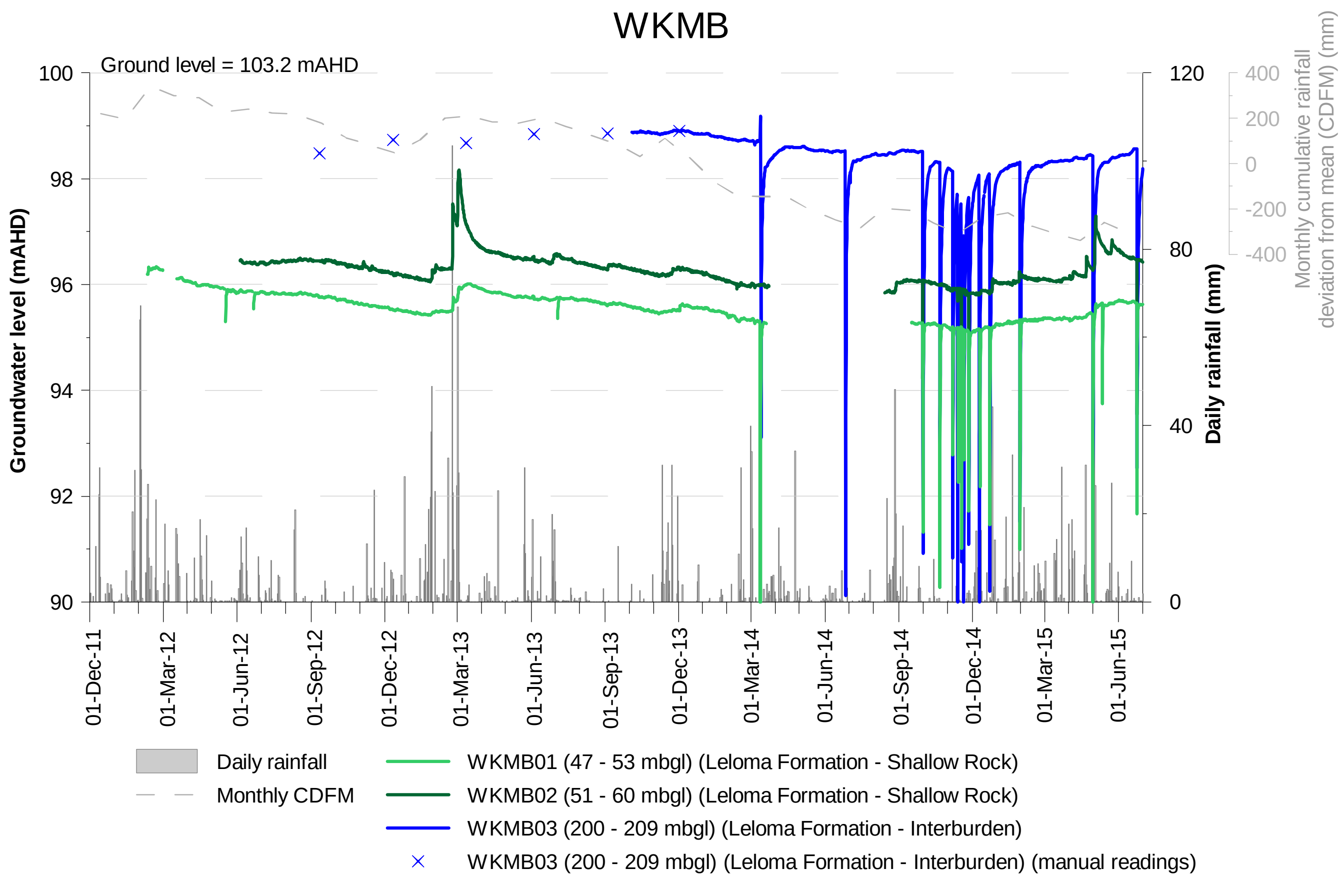
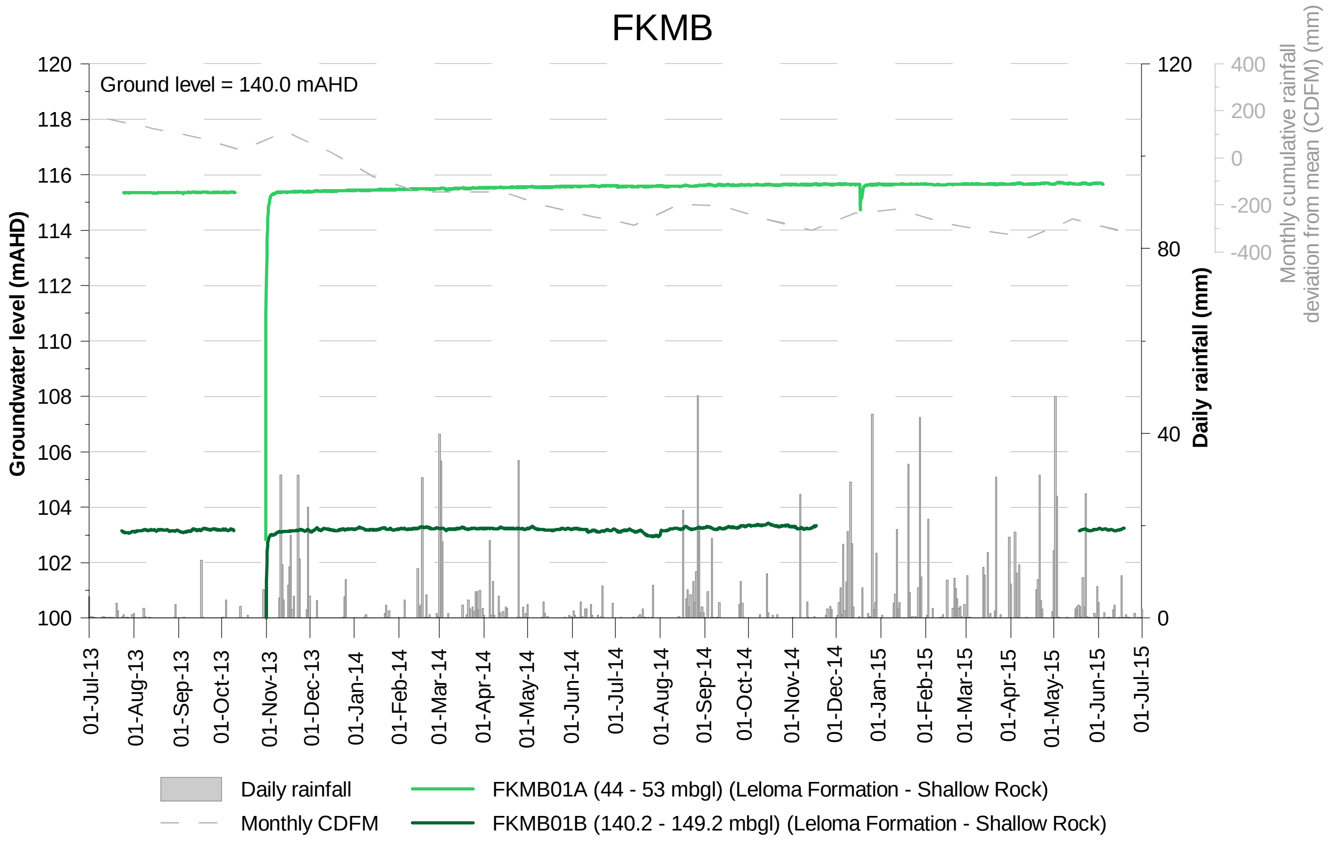


Figure 4: WMB and WKMB monitoring bores



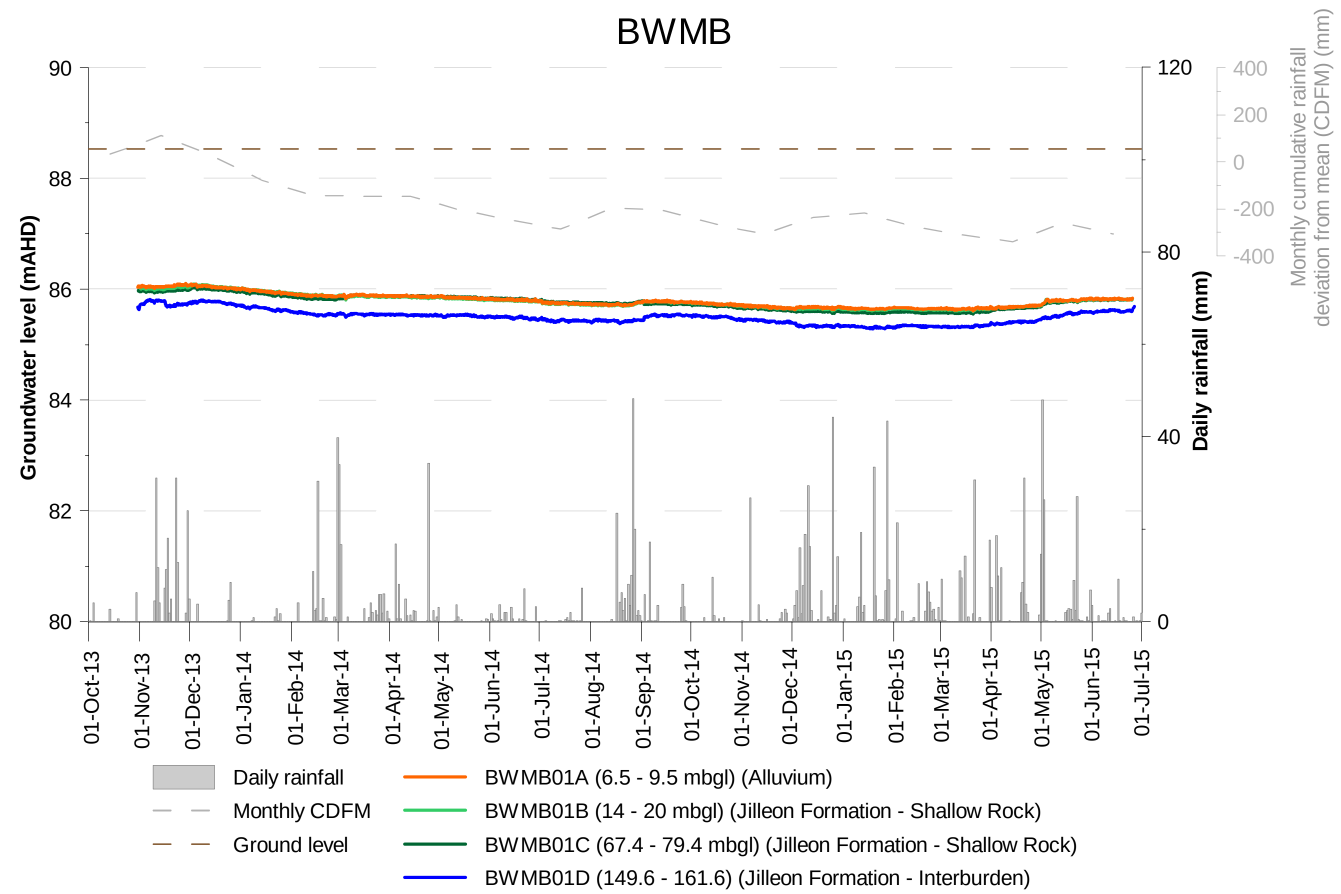
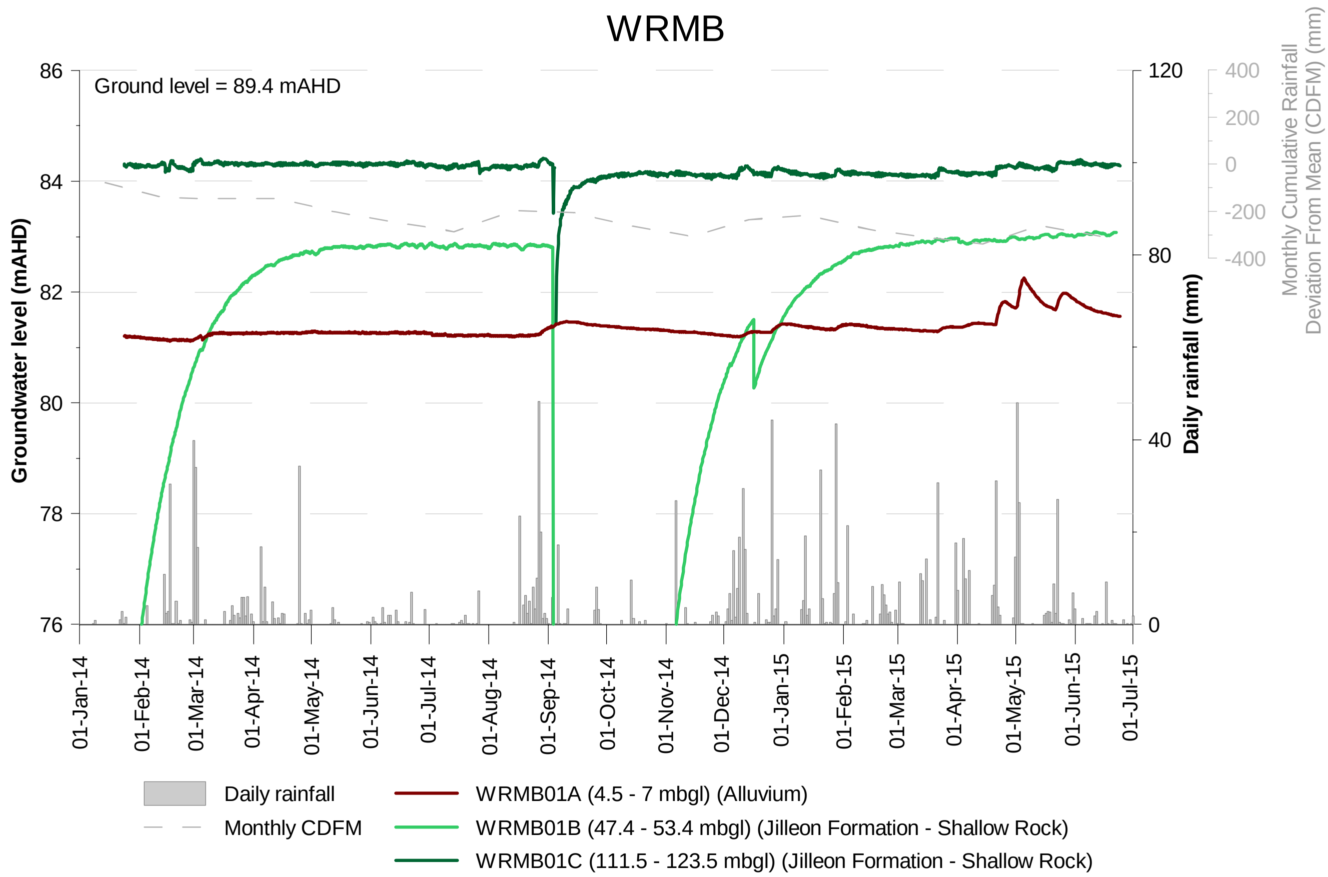


Figure 5: FKMB and BWMB monitoring bores



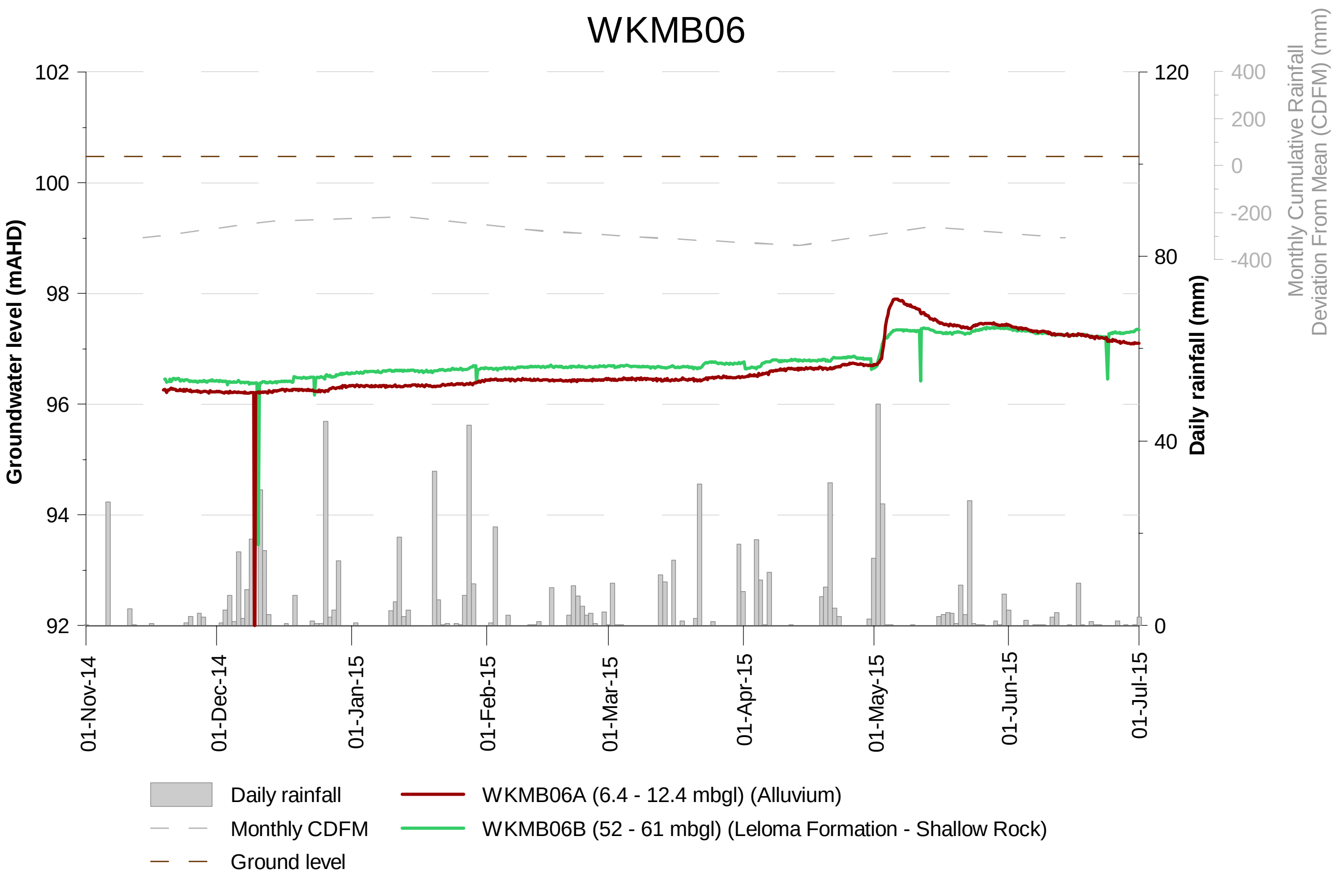
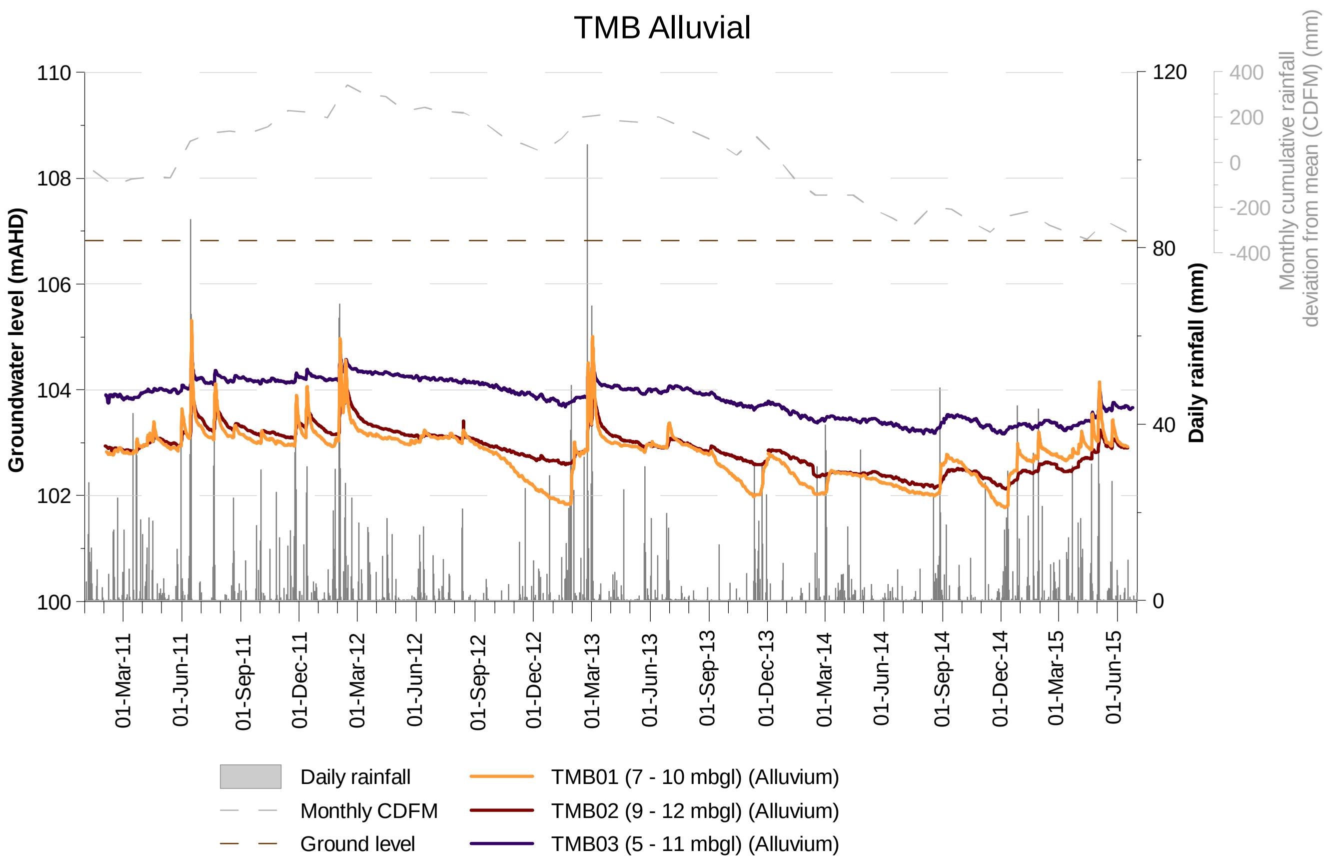


Figure 6: WRMB and WKMB06 monitoring bores



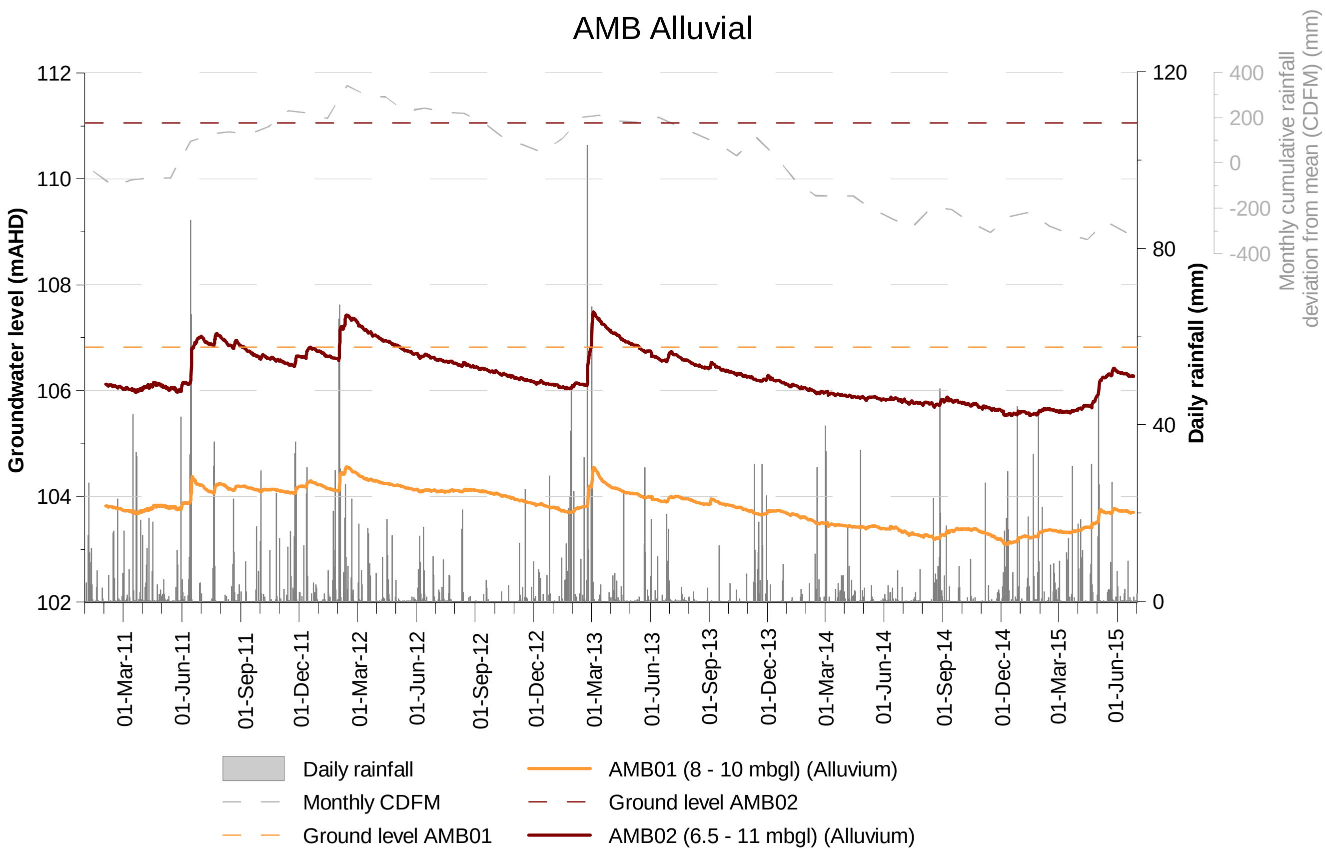


Figure 7: TMB and AMB Alluvial monitoring bores

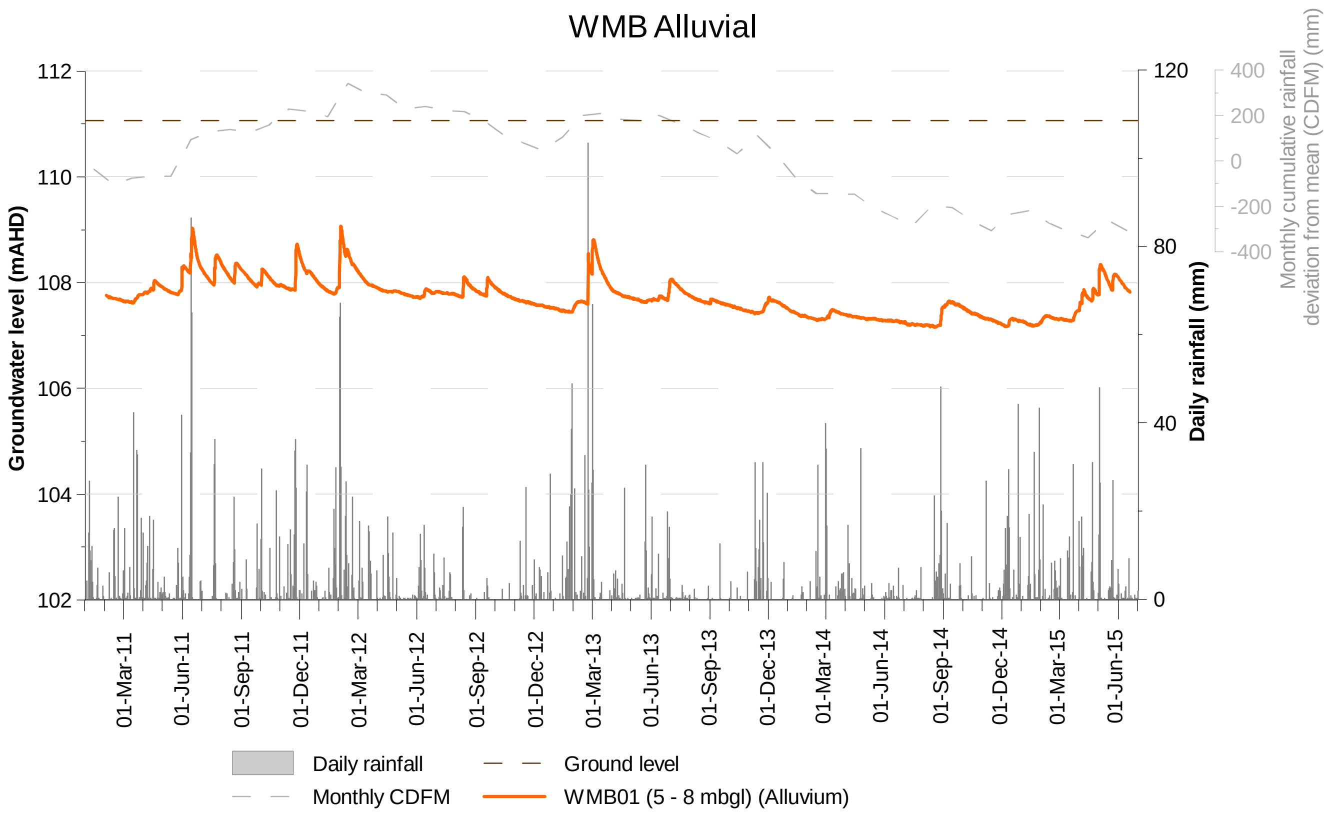
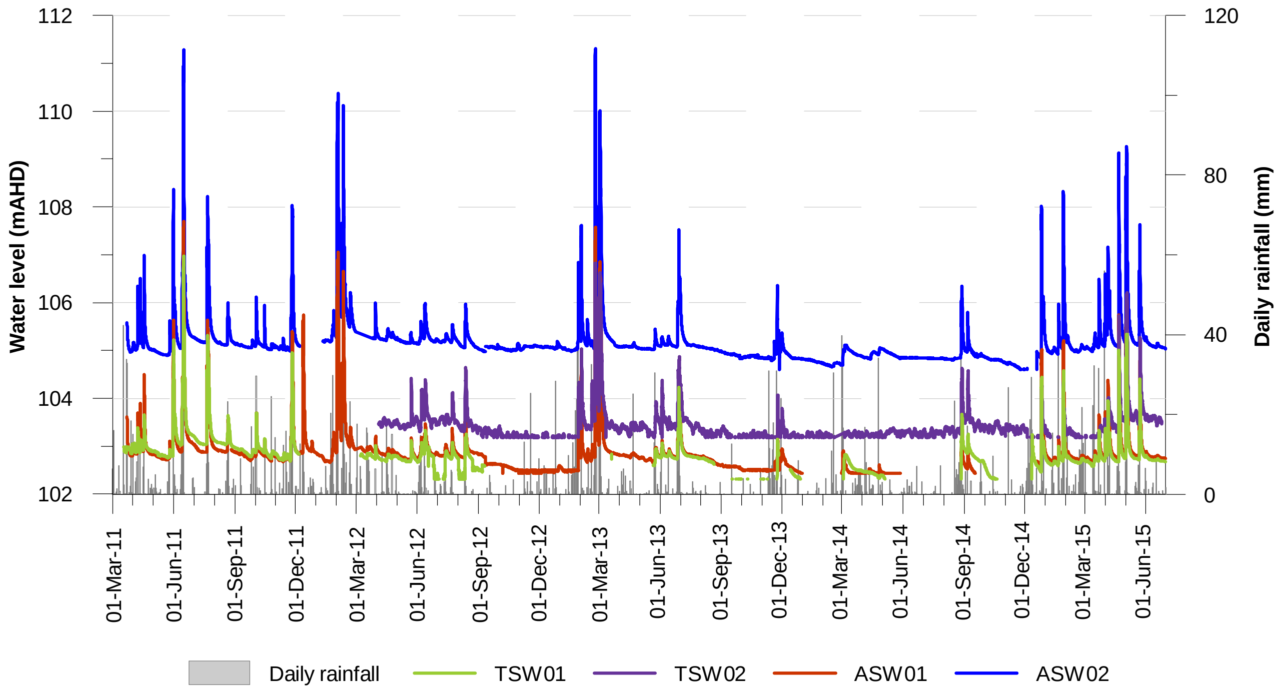


Figure 8: WMB Alluvial monitoring bore



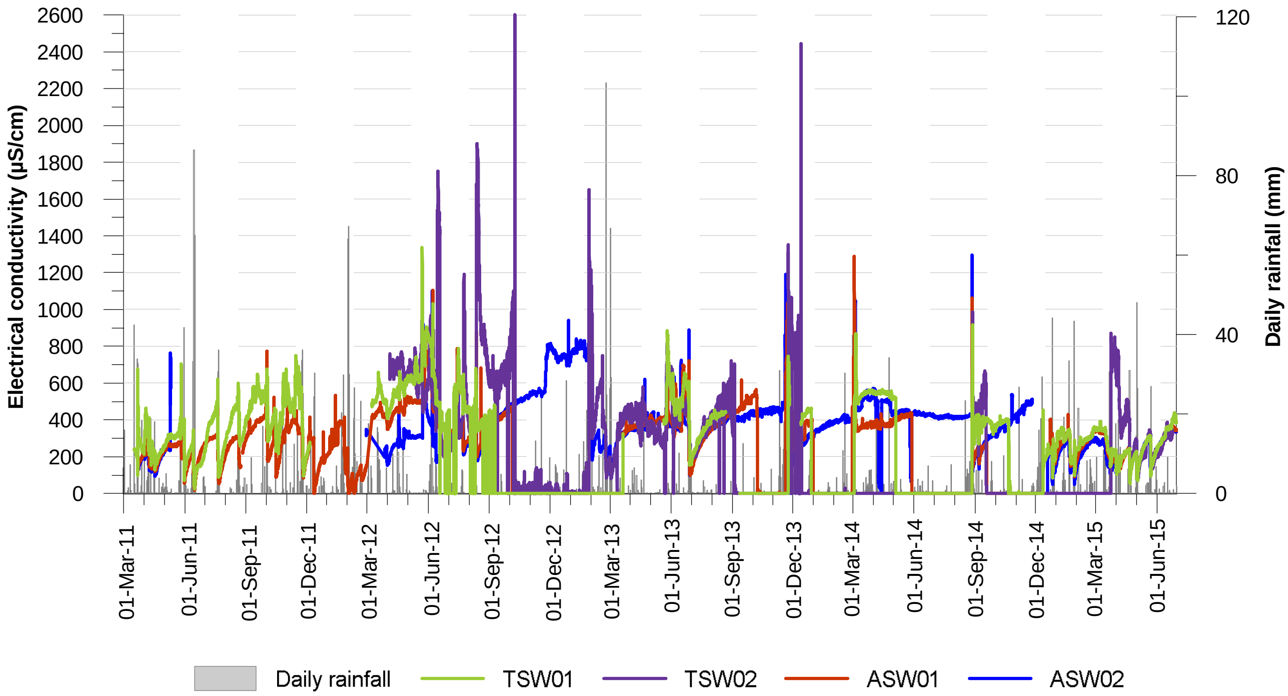
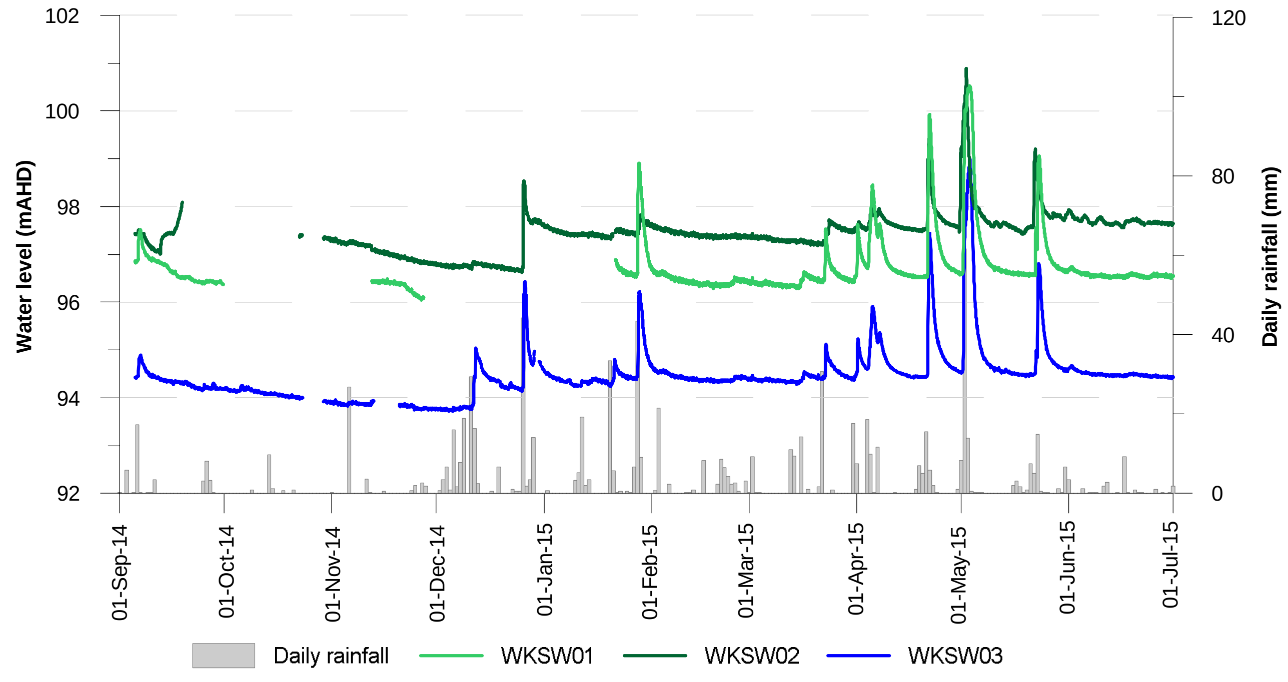


Figure 9: TSW01, TSW02, ASW01 and ASW02 surface water levels and electrical conductivity



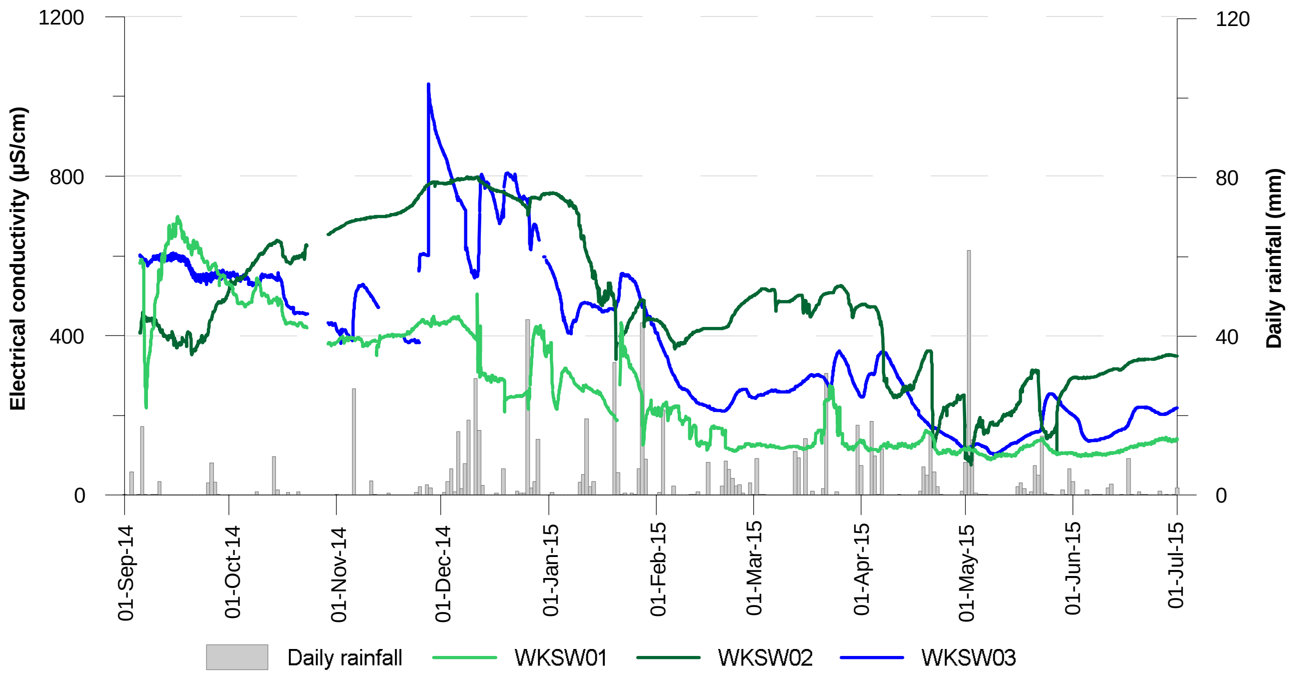
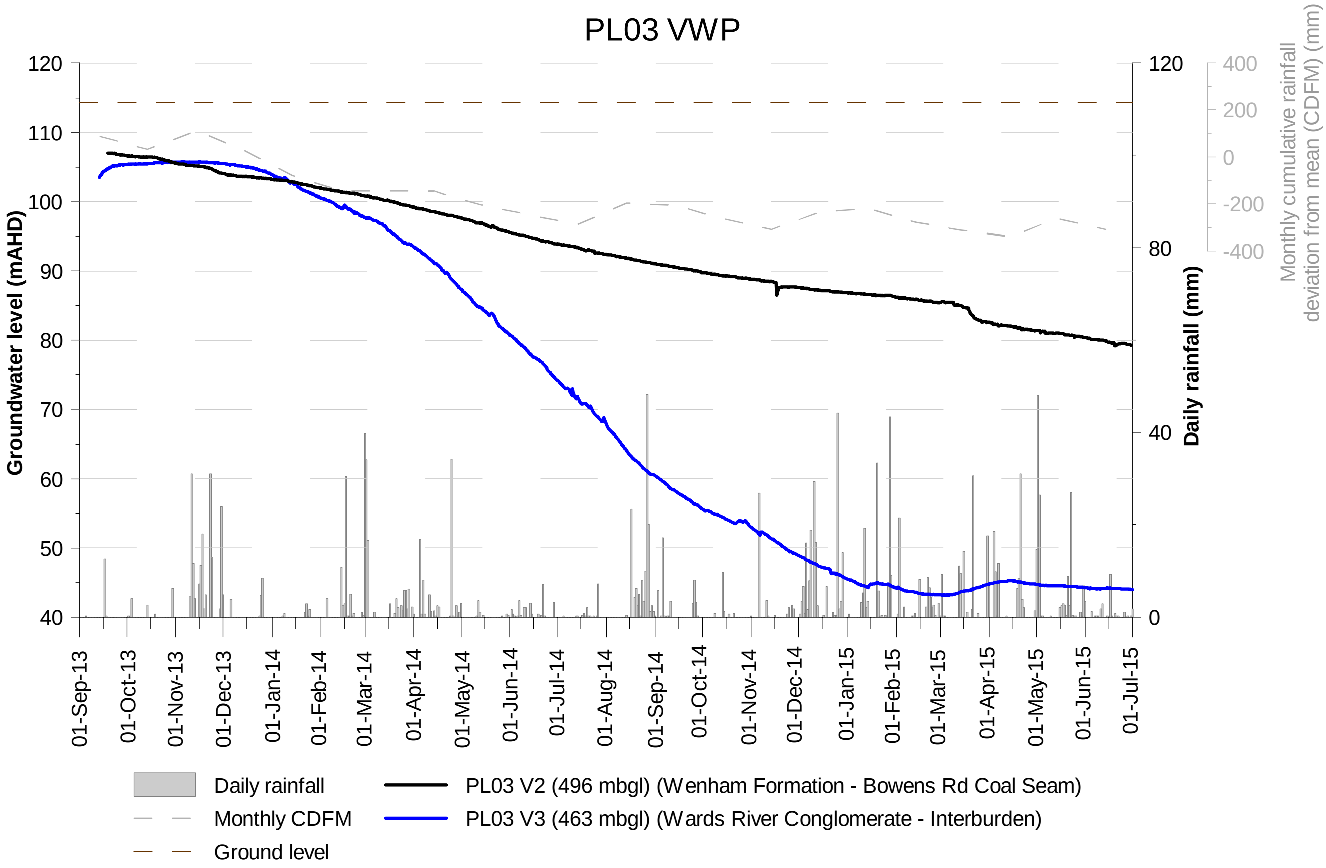


Figure 10: WKSW01, WKSW02 and WKSW03 surface water levels and electrical conductivity



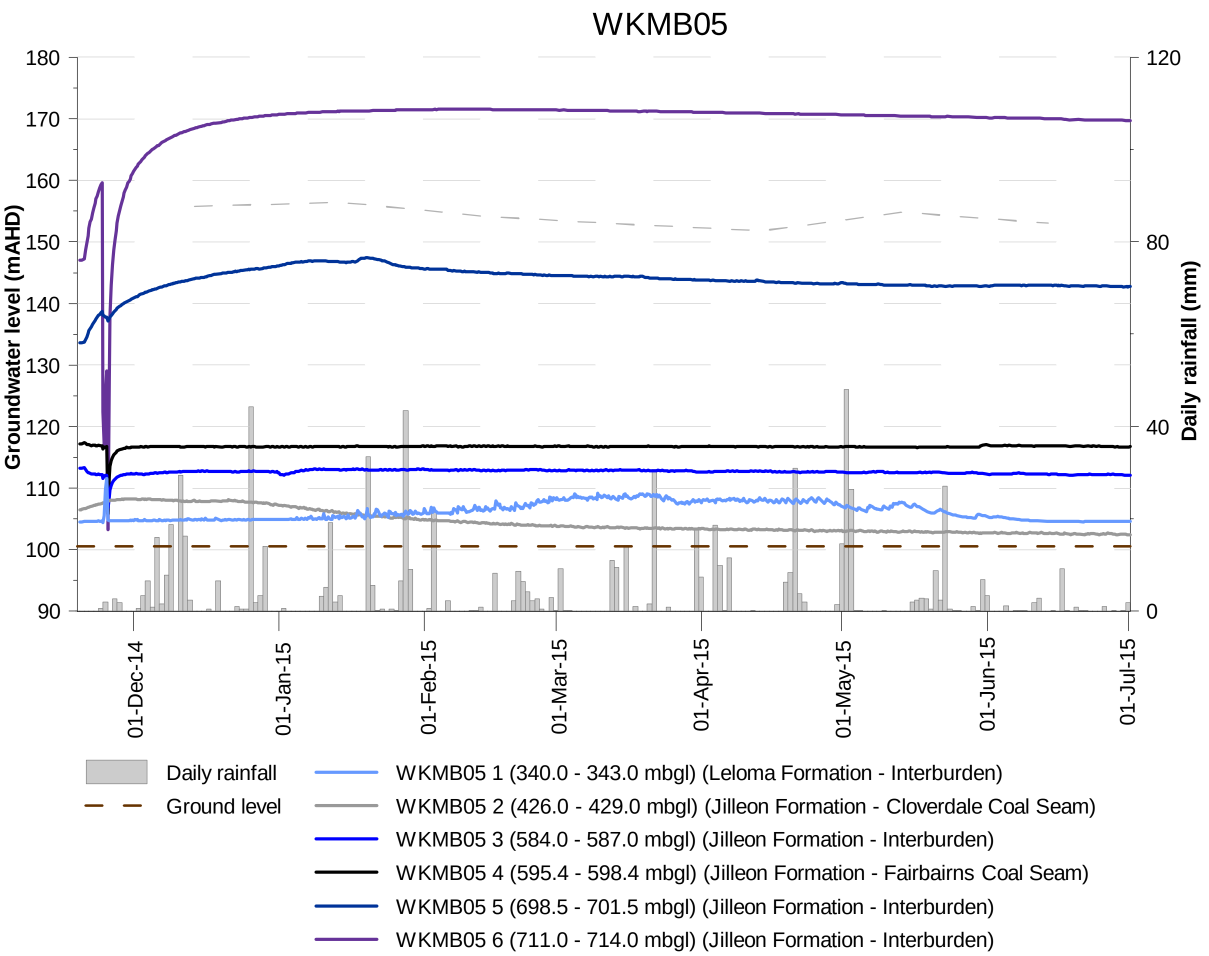
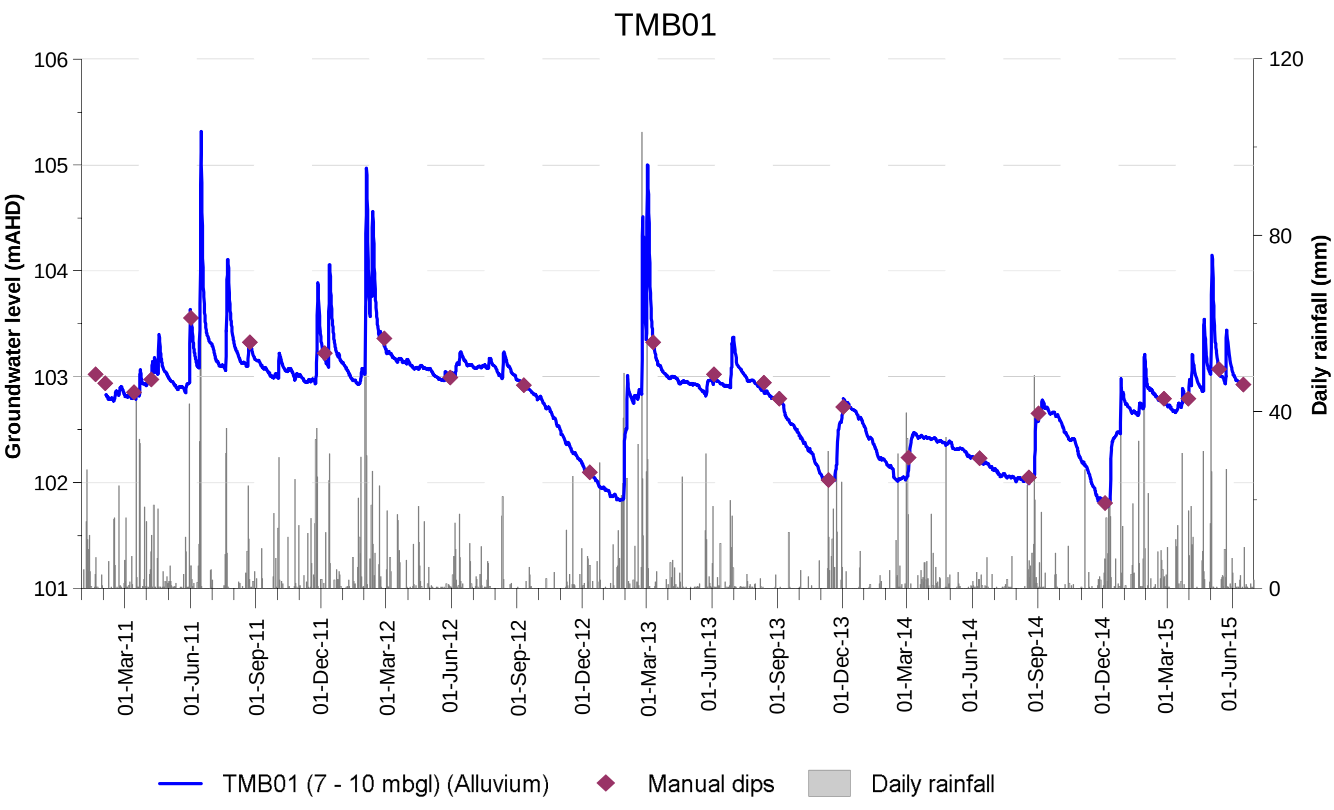


Figure 11: PL03 vibrating wire piezometer and WKMB05 multizone monitoring well



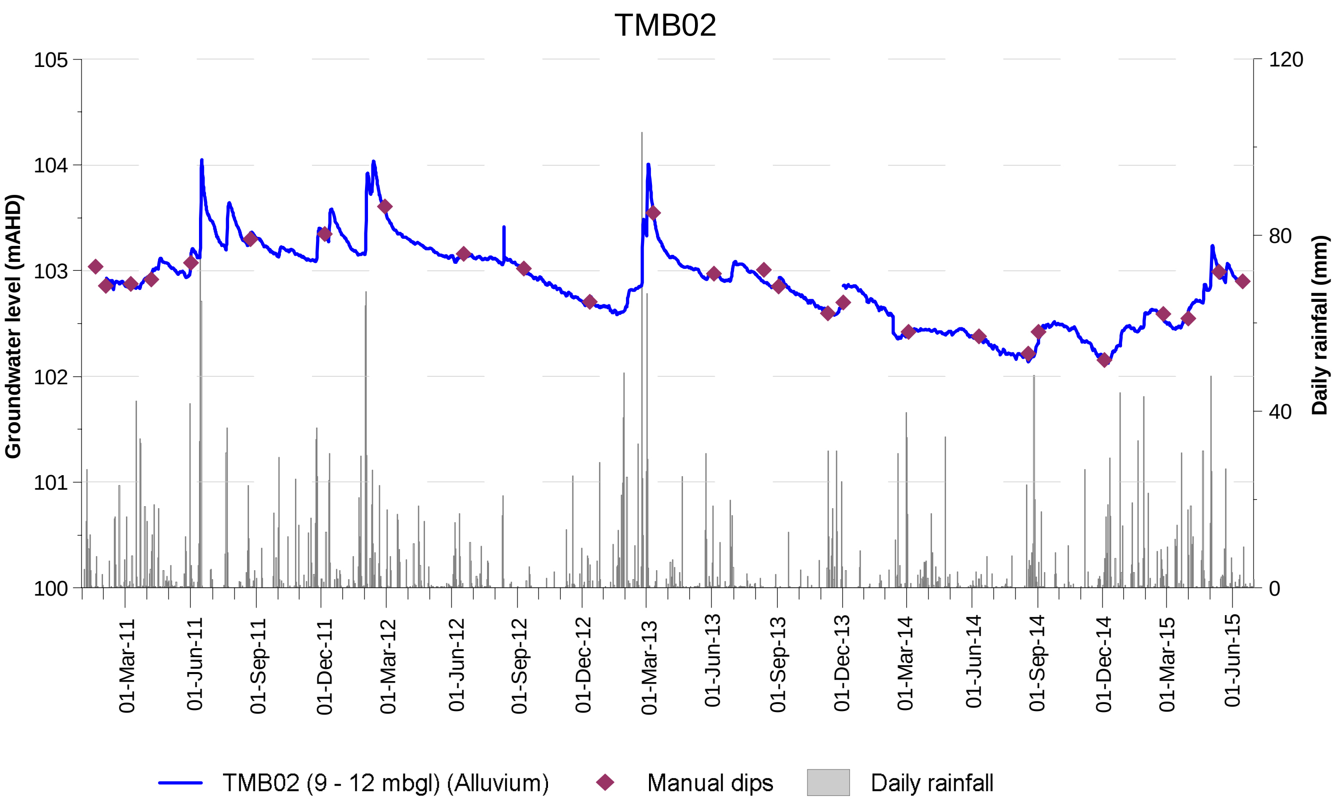
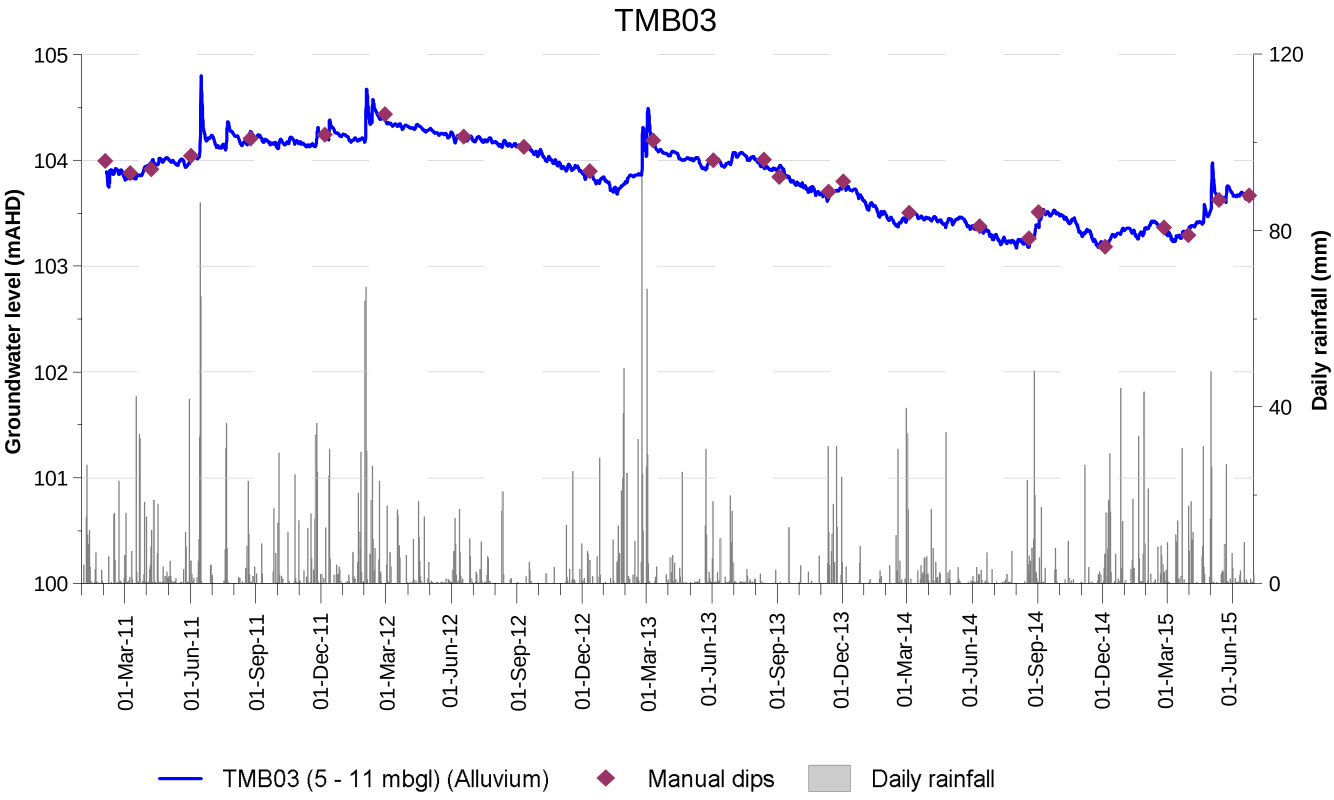


Figure A.1: TMB01 and TMB02 monitoring bores



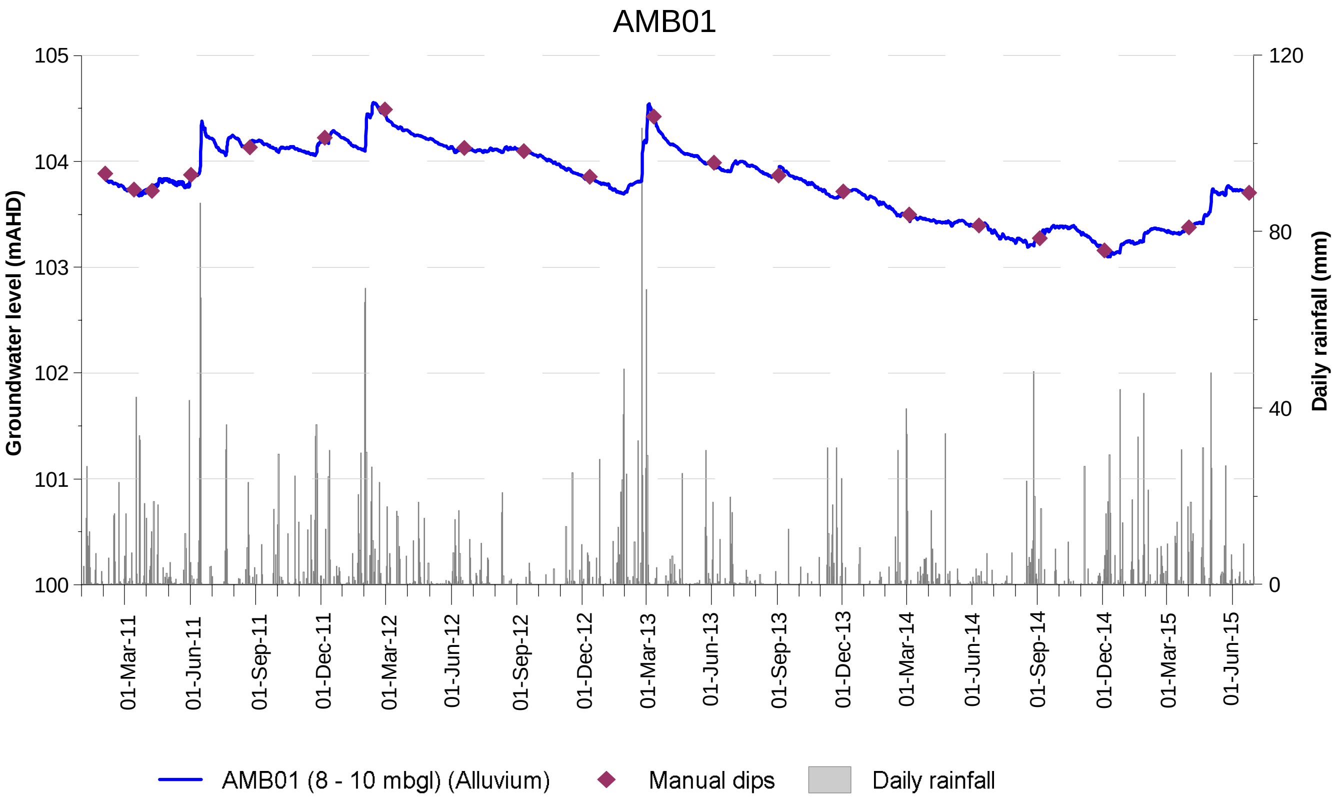
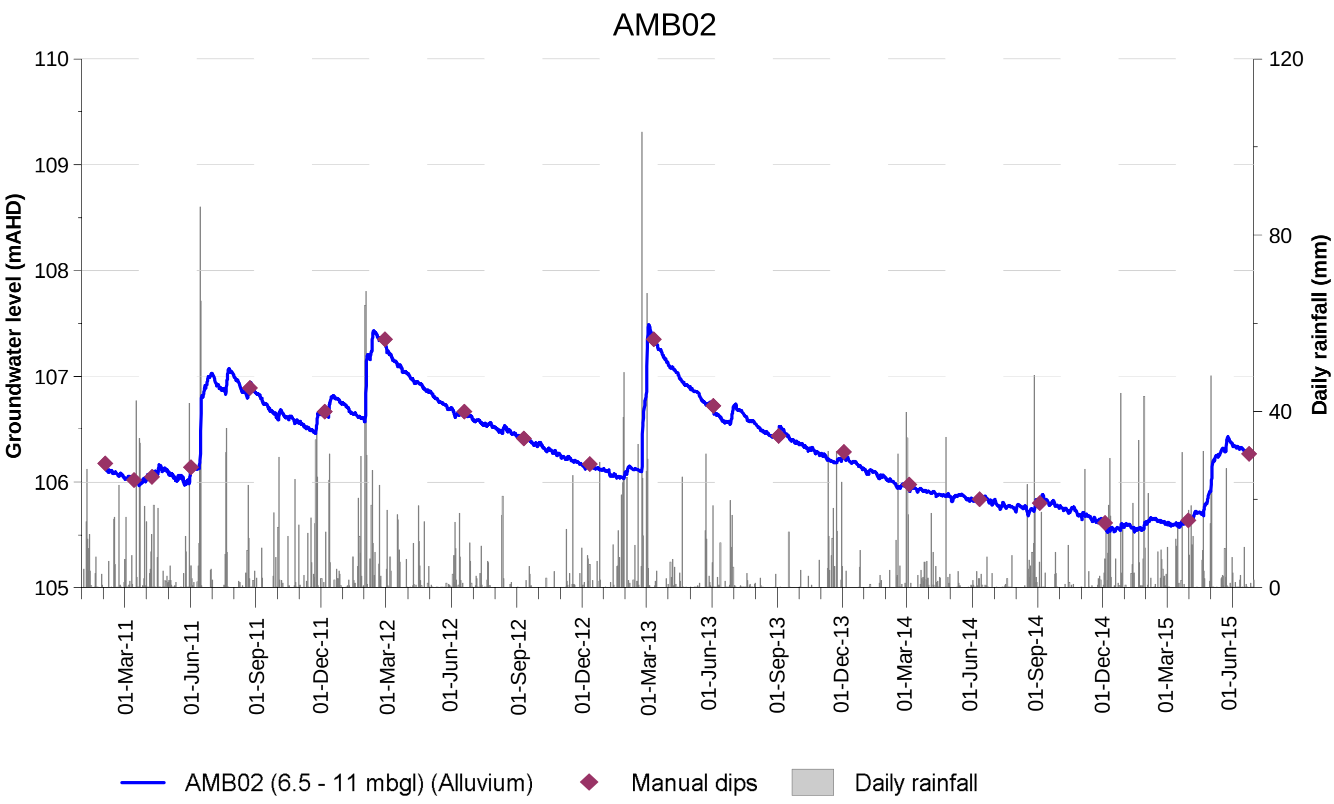


Figure A.2: TMB03 and AMB01 monitoring bores



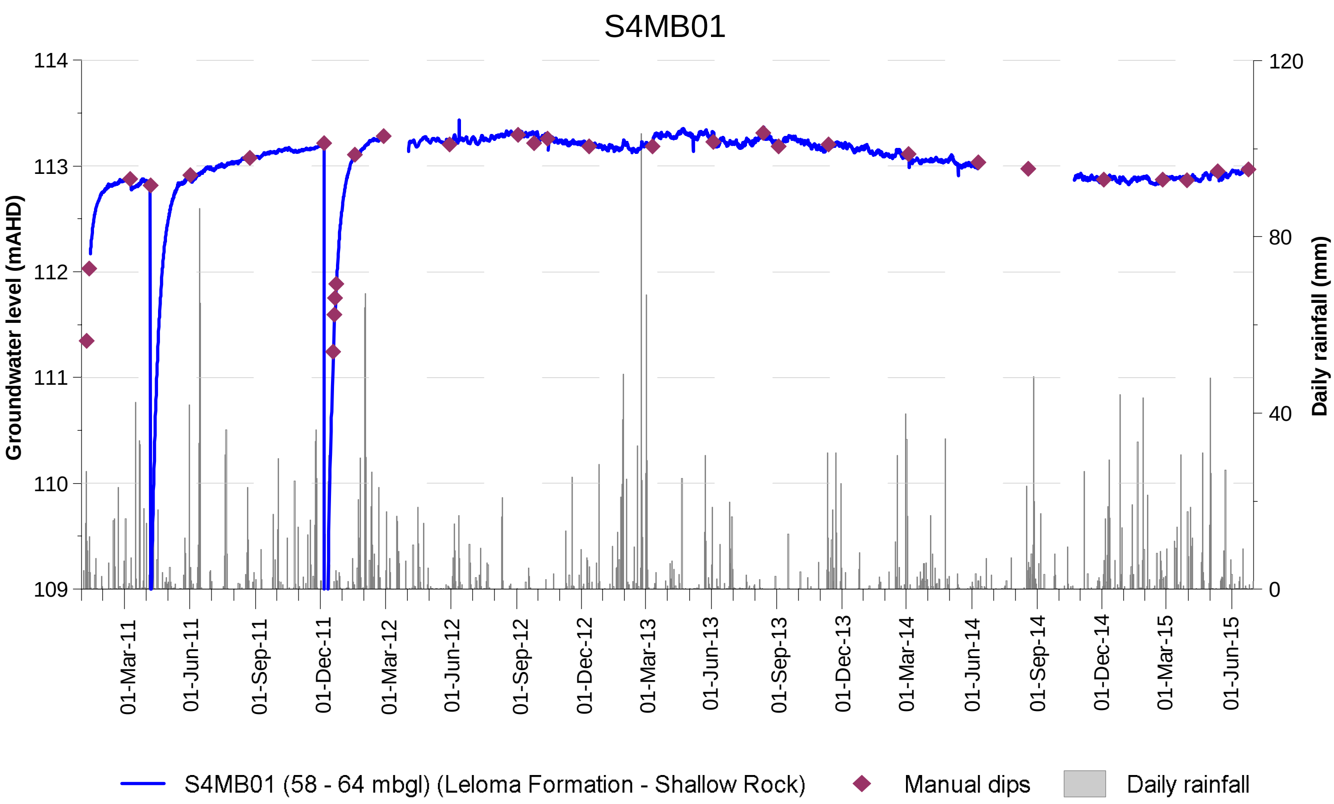
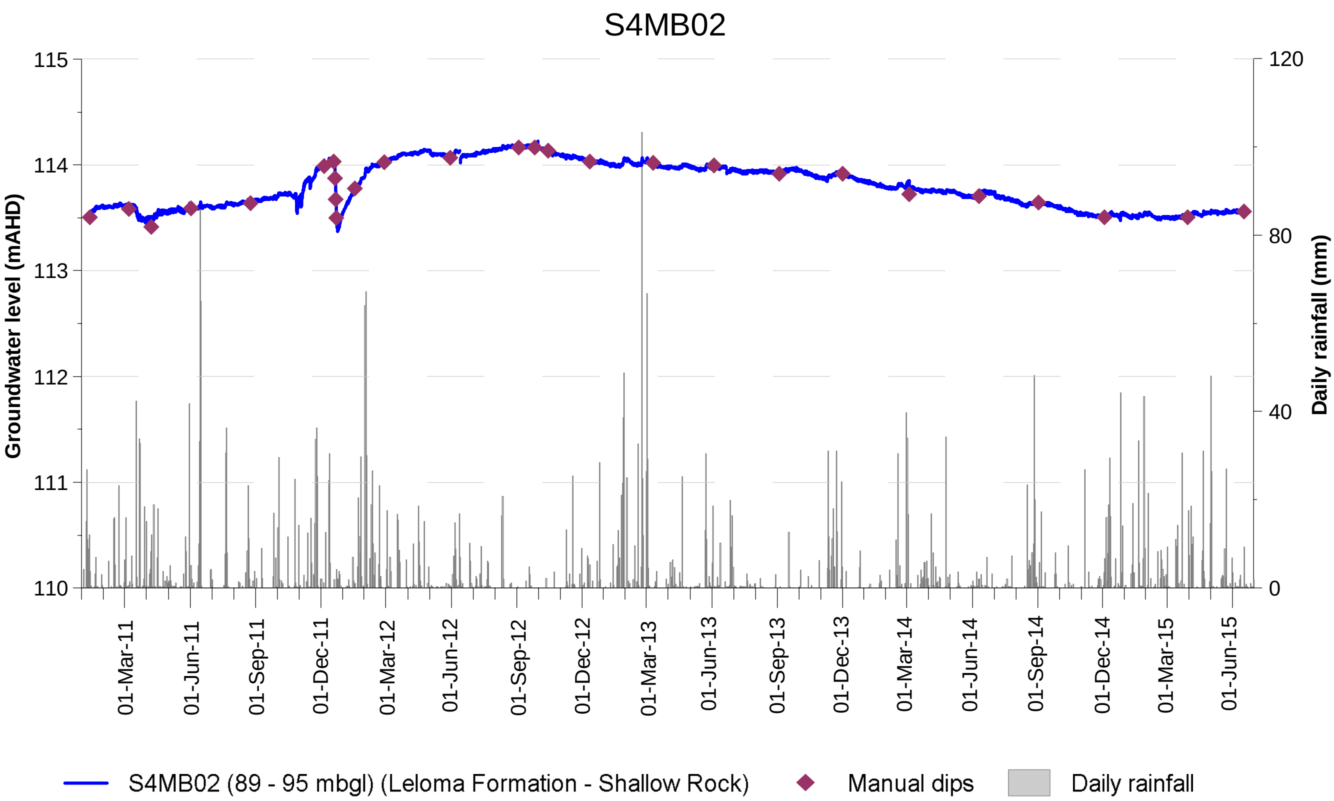


Figure A.3: AMB02 and S4MB01 monitoring bores



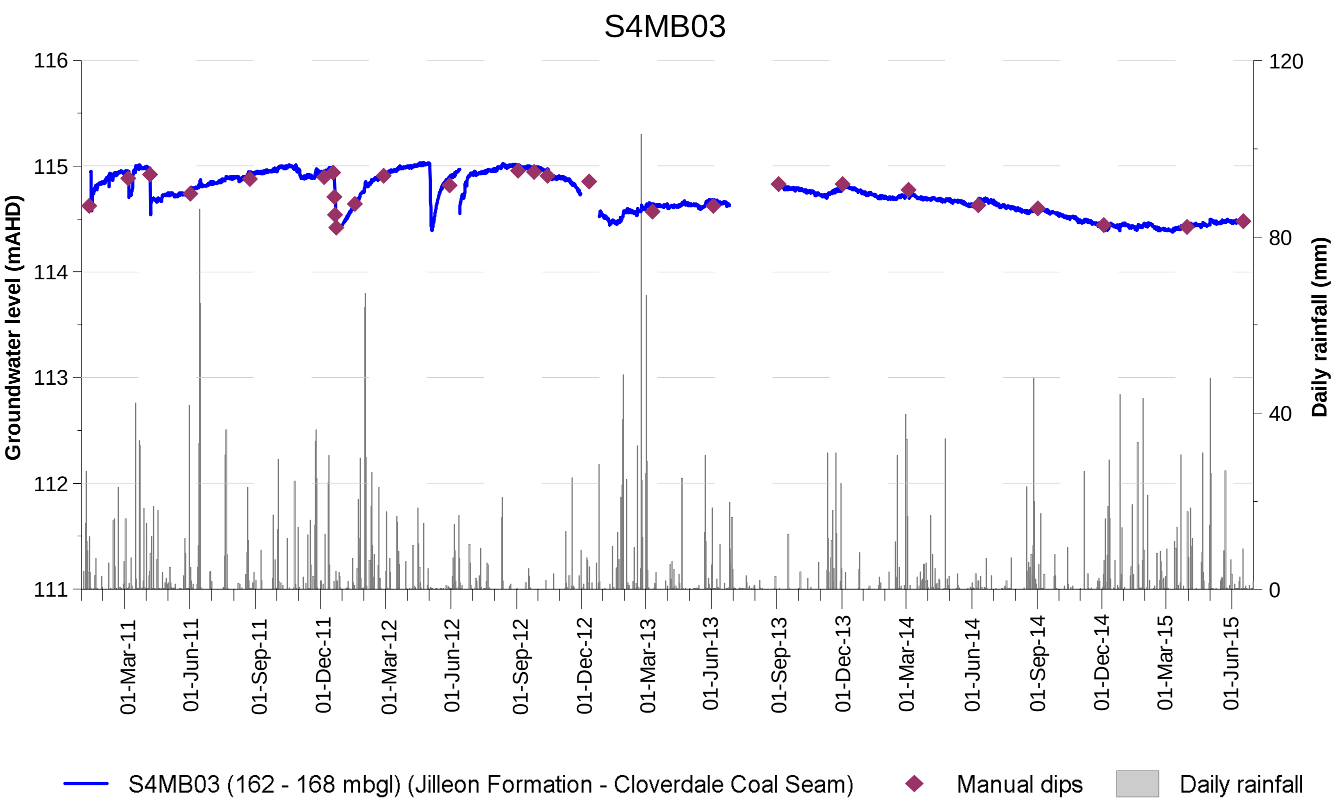
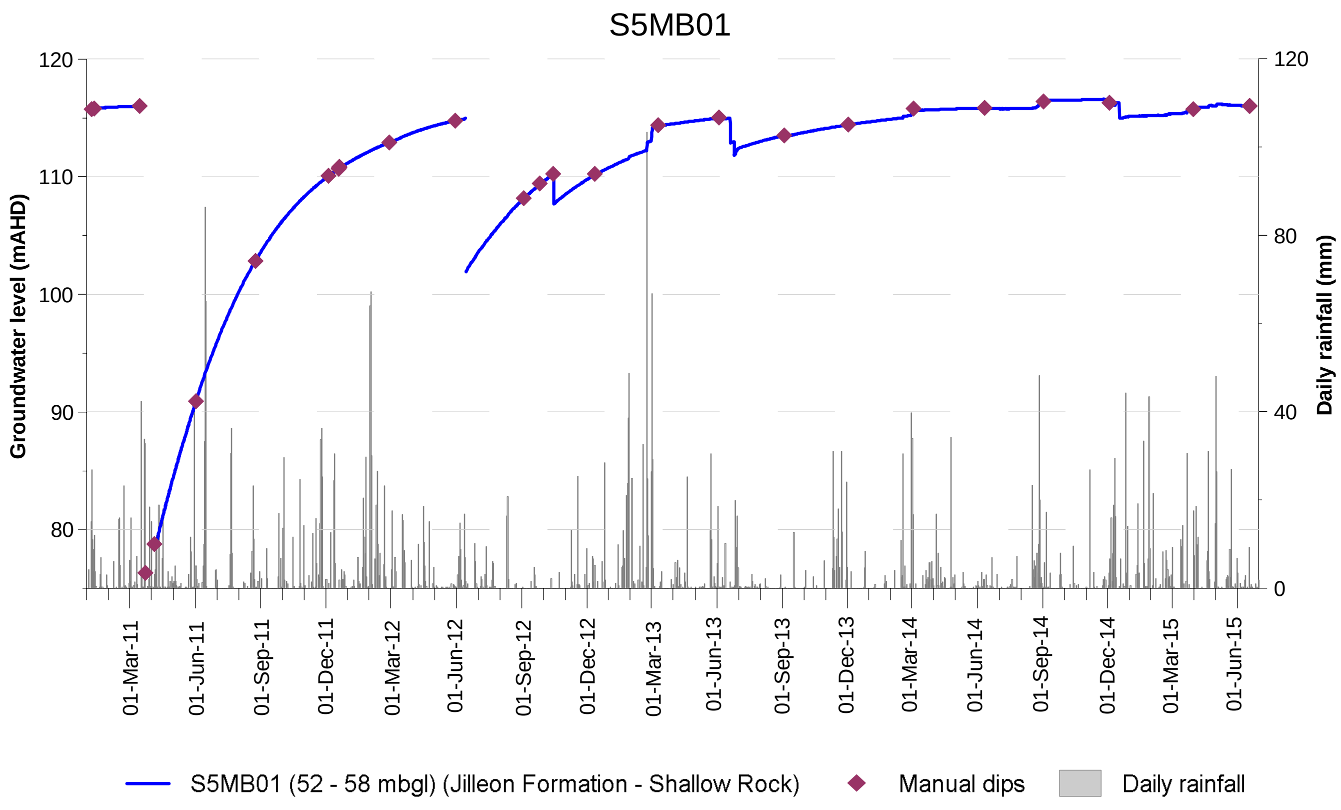


Figure A.4: S4MB02 and S4MB03 monitoring bores



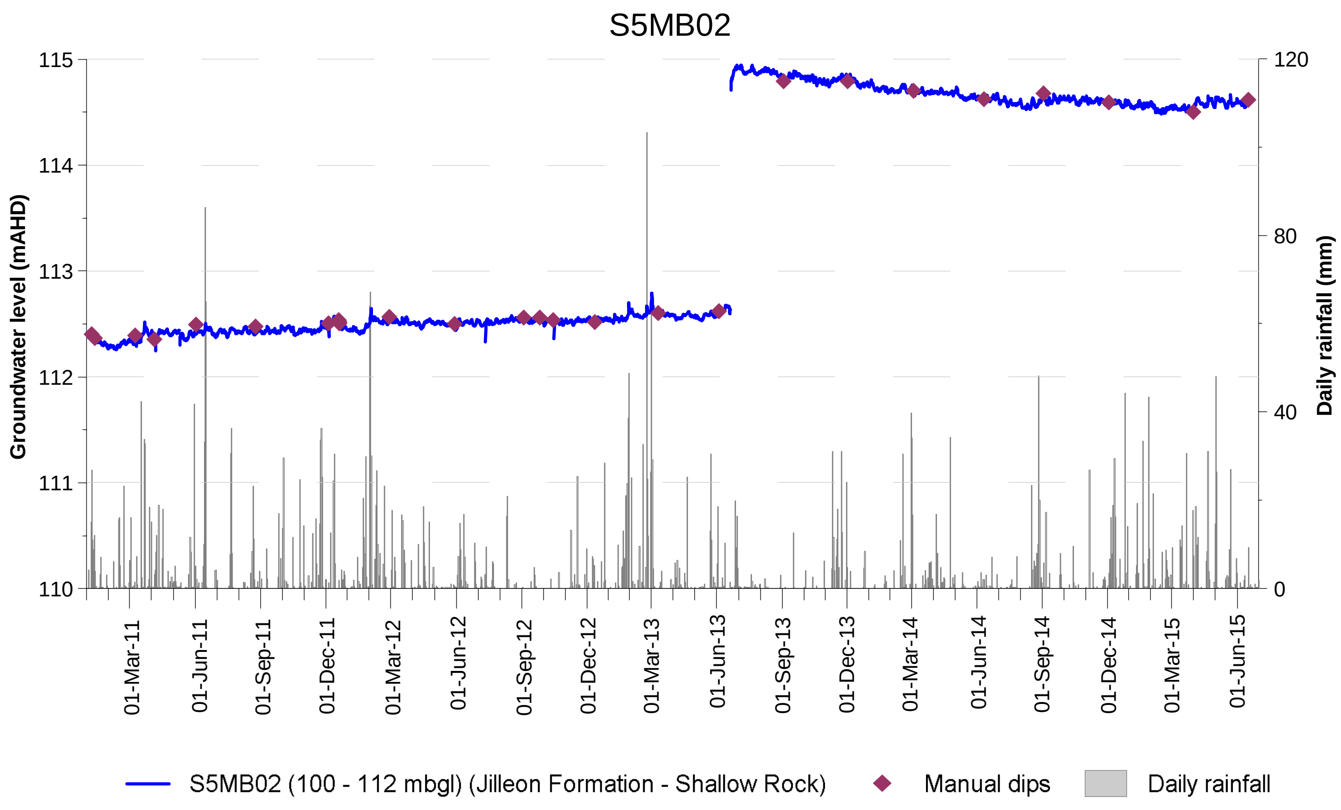
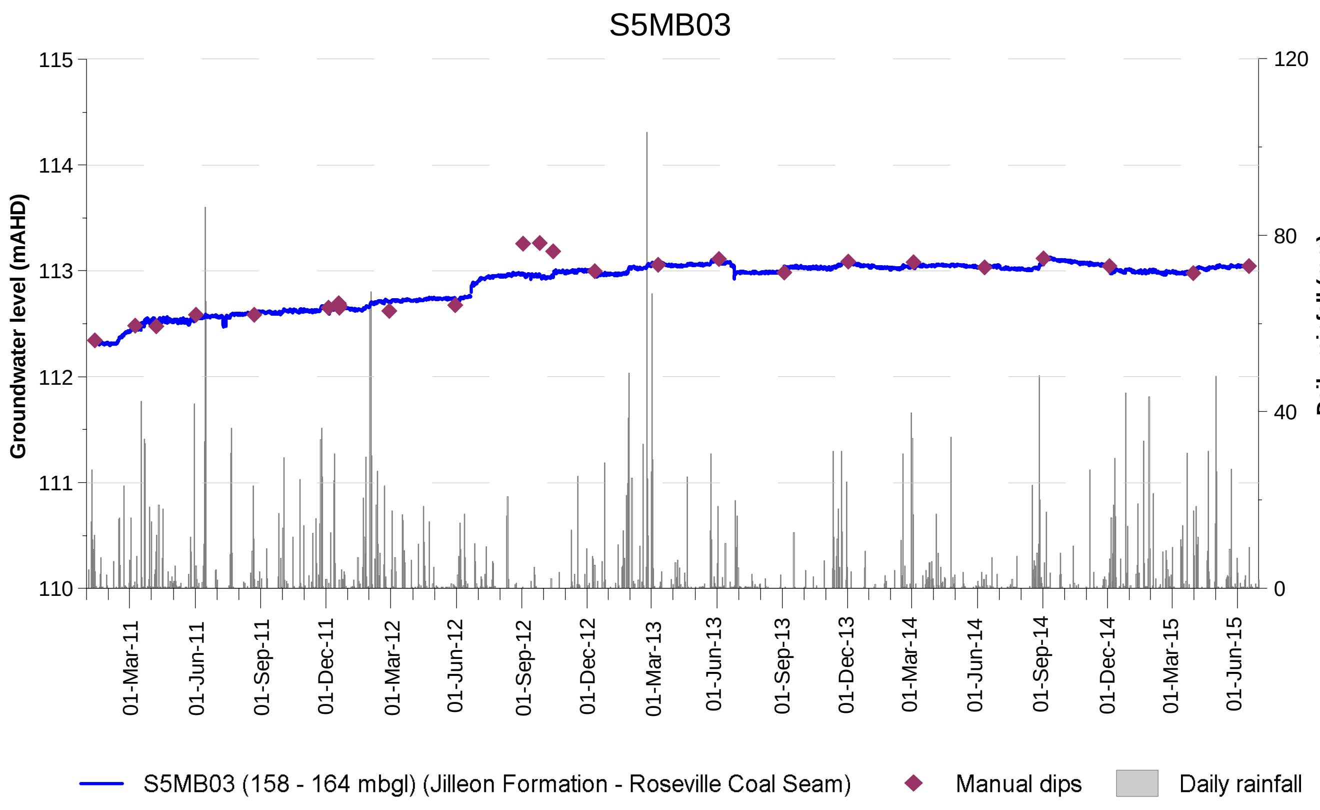


Figure A.5: S5MB01 and S5MB02 monitoring bores



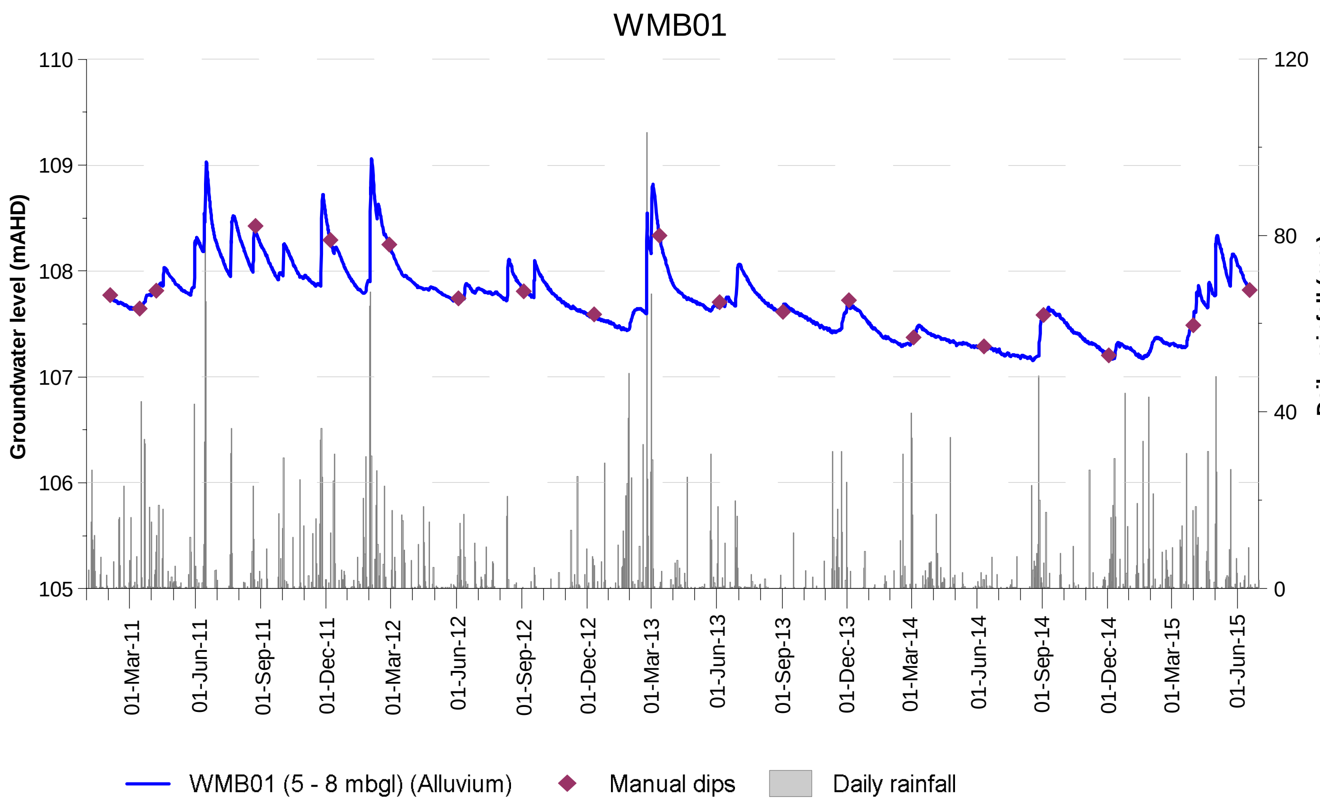
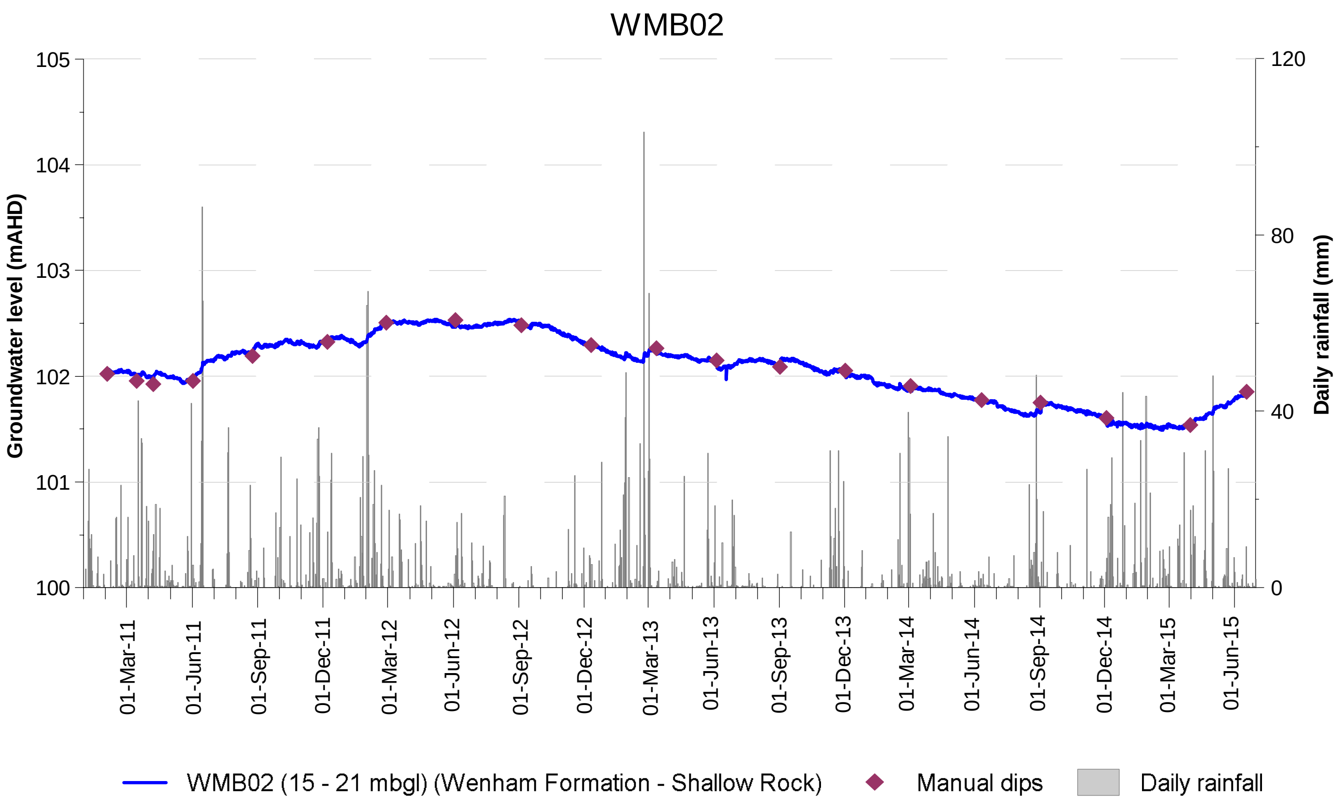


Figure A.6: S5MB03 and WMB01 monitoring bores



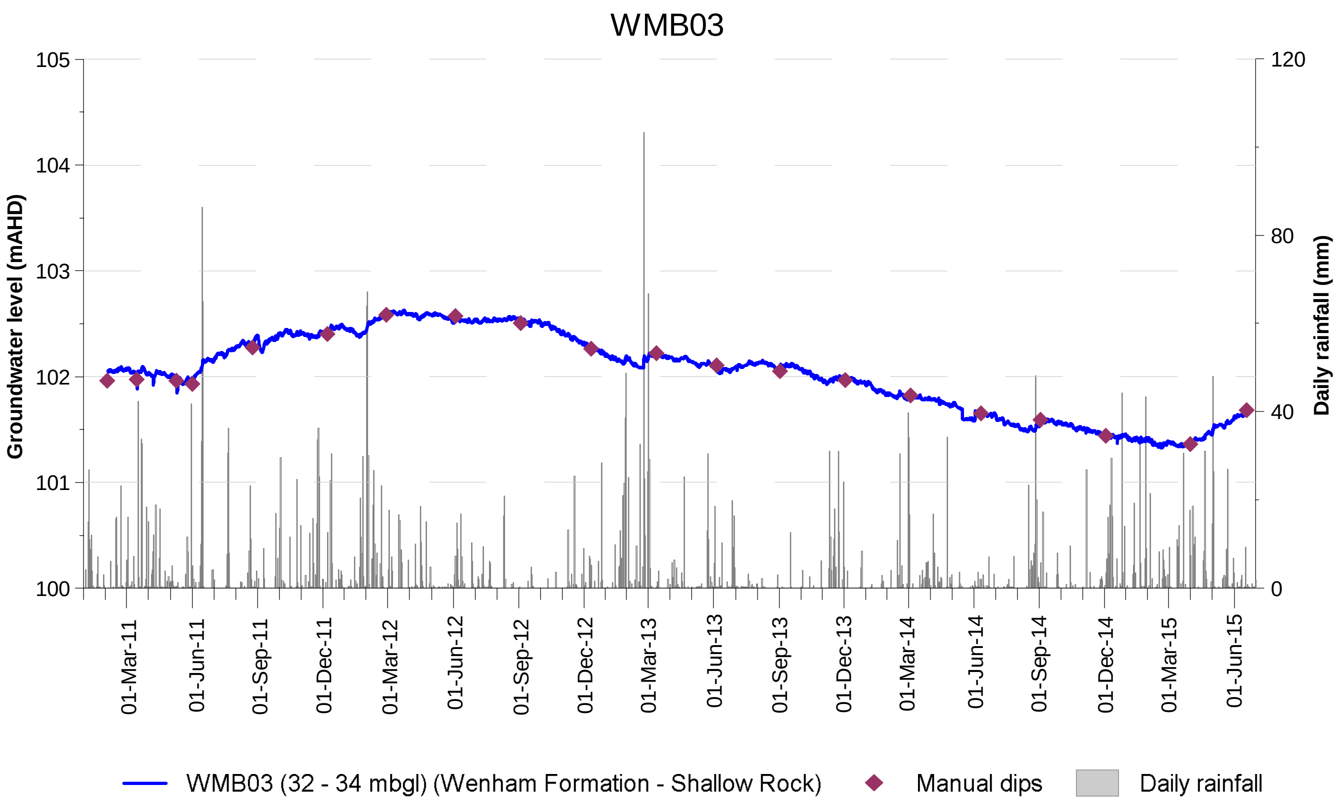
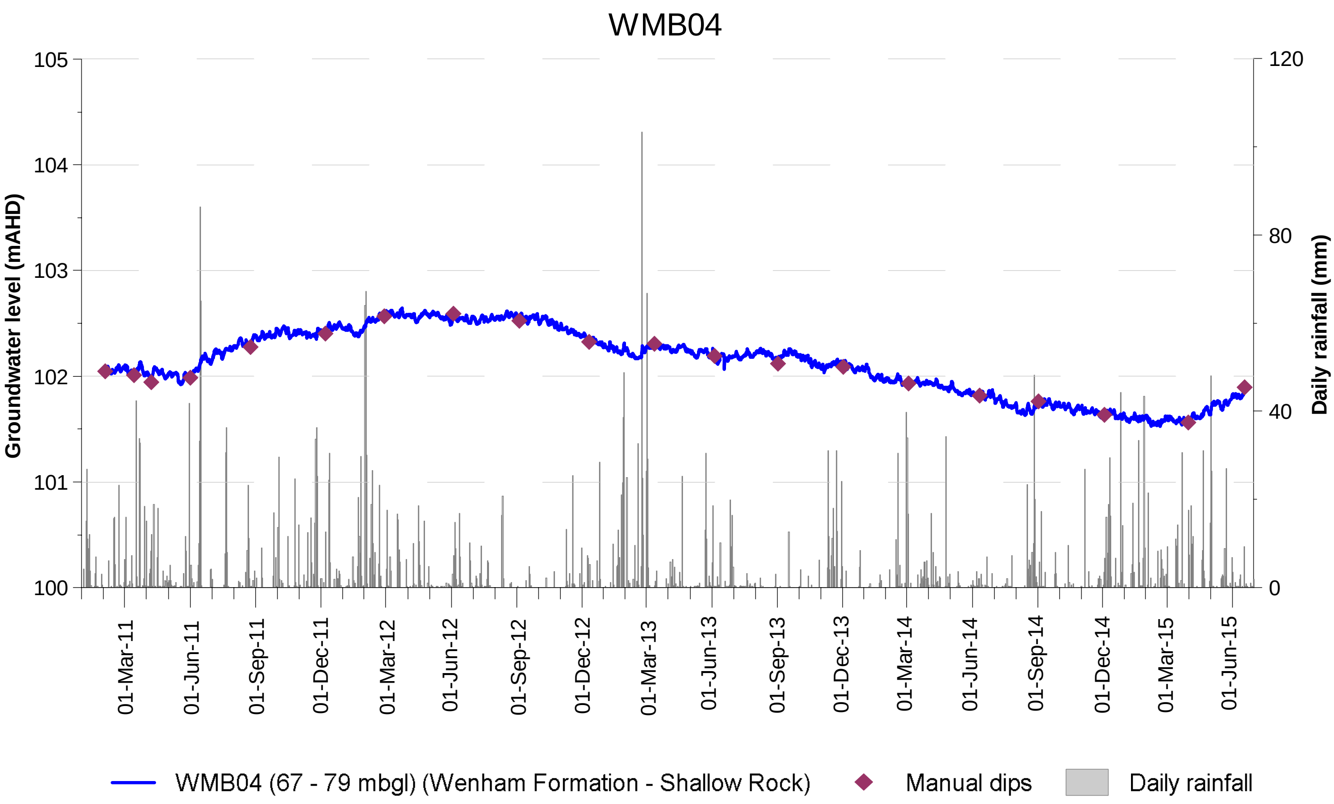


Figure A.7: WMB02 and WMB03 monitoring bores



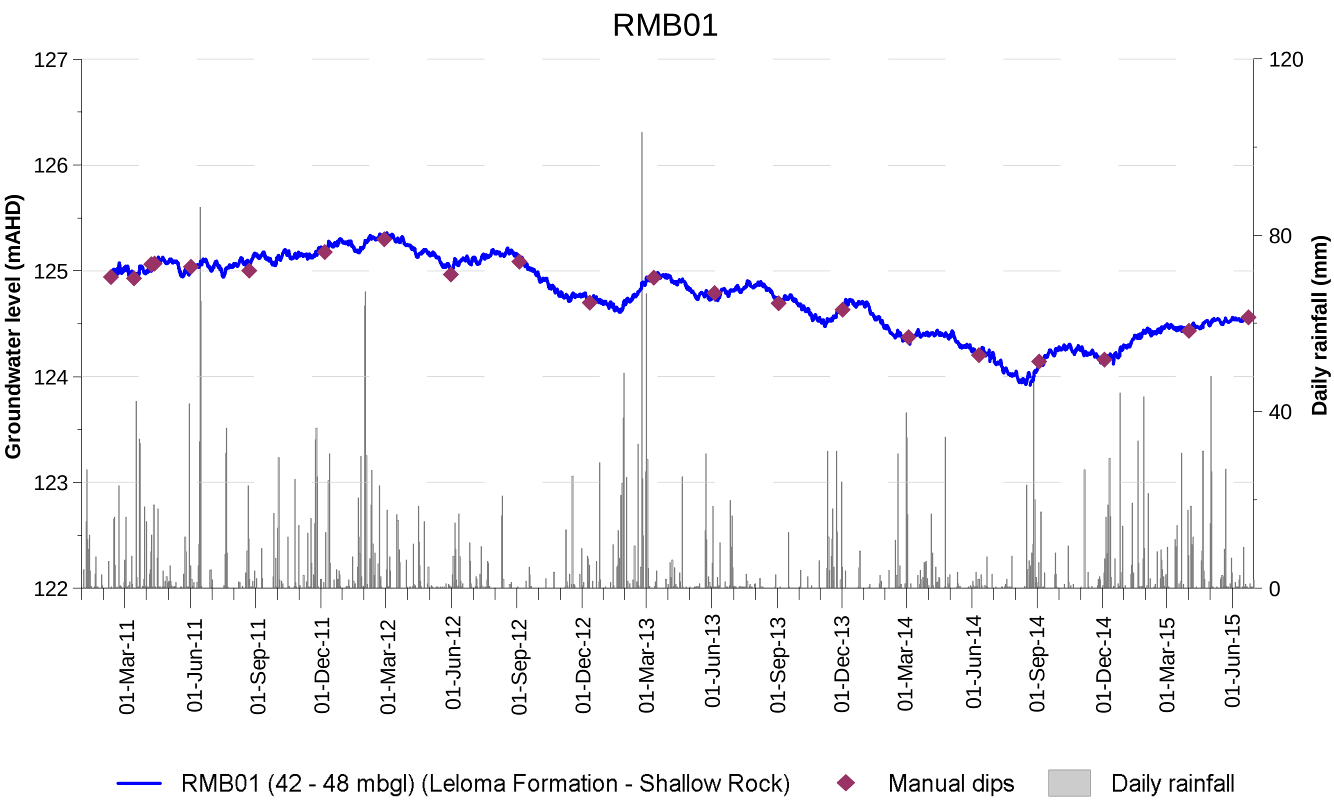
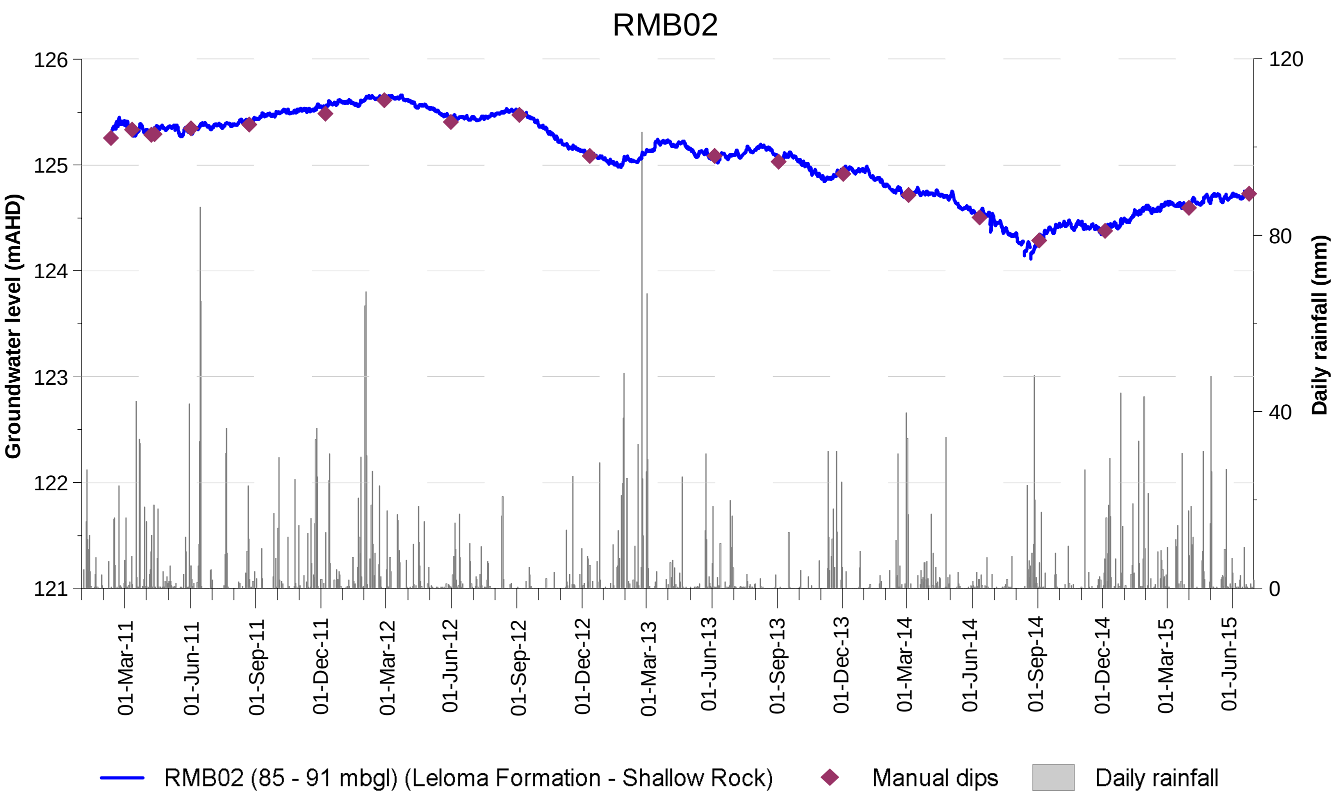


Figure A.8: WMB04 and RMB01 monitoring bores



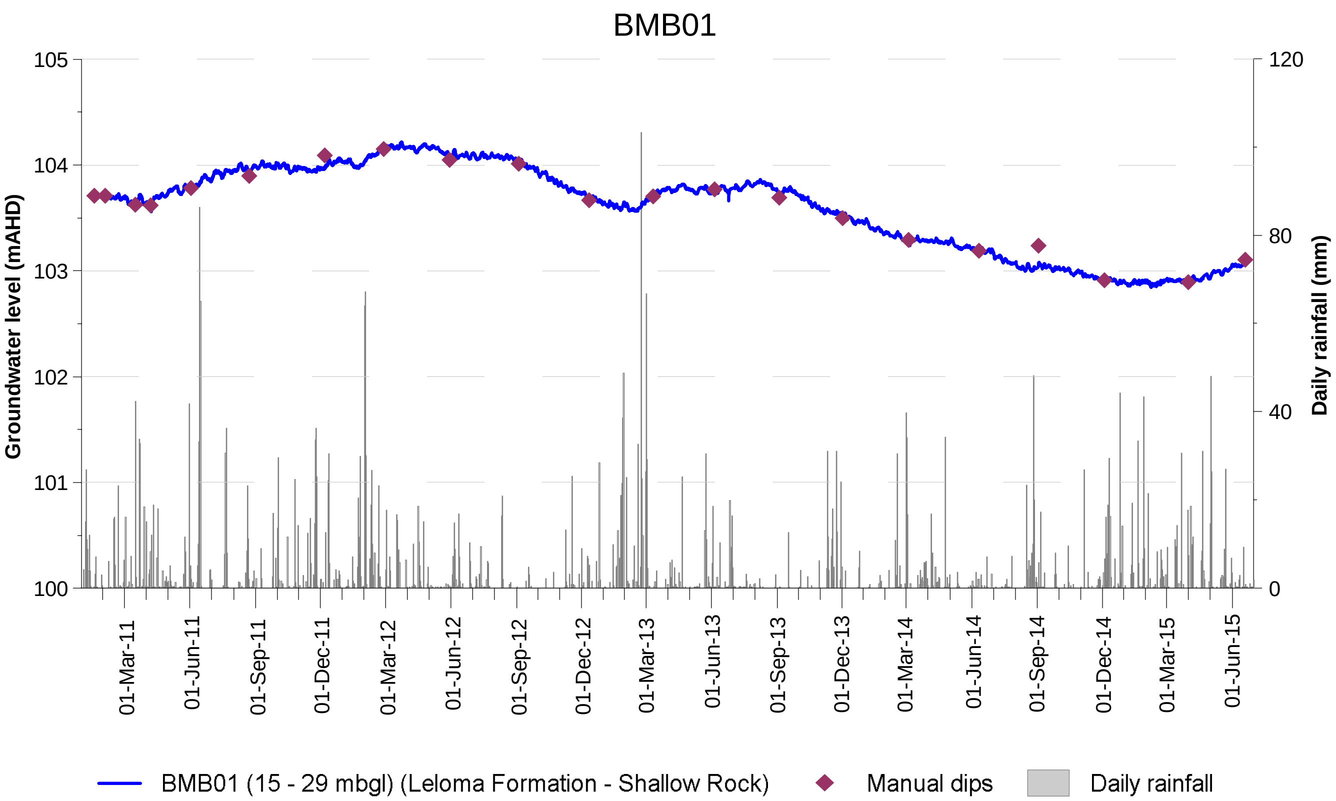
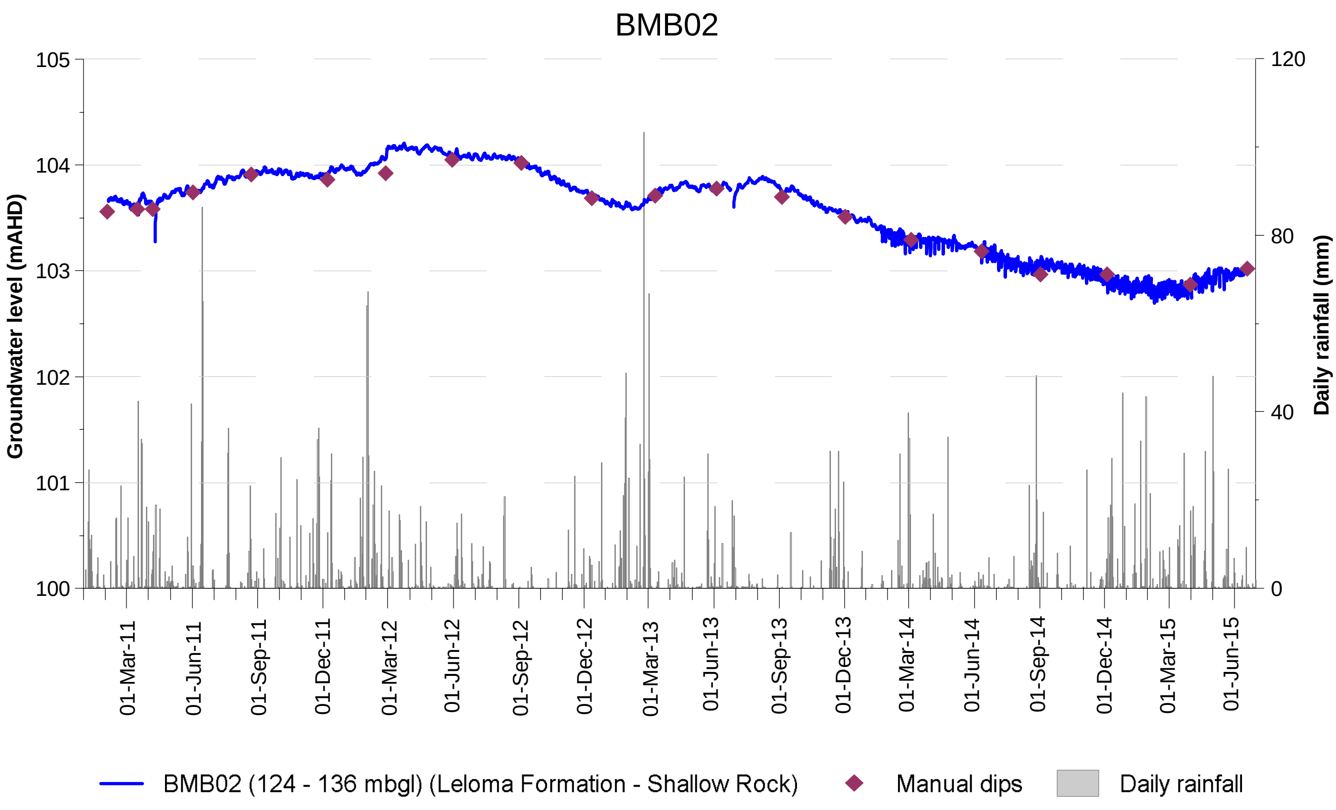


Figure A.9: RMB02 and BMB01 monitoring bores



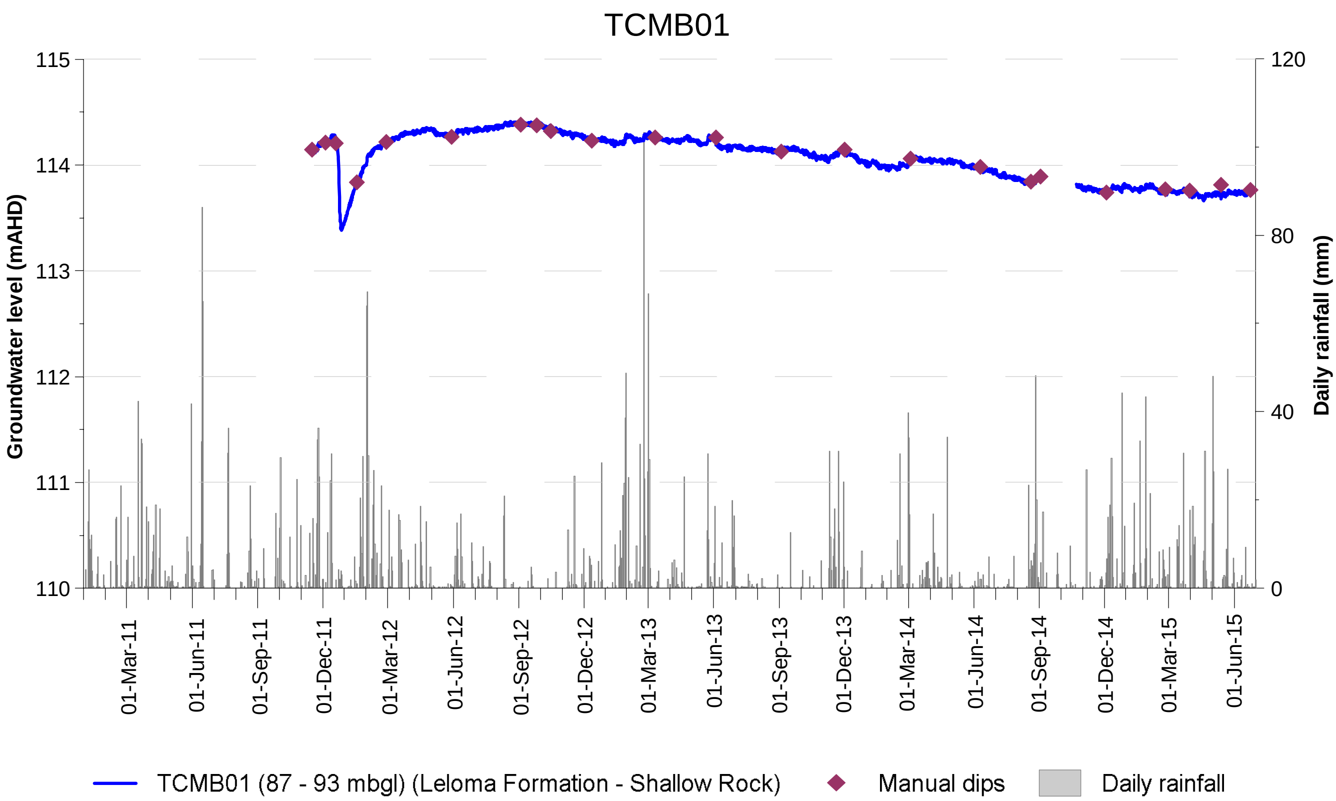
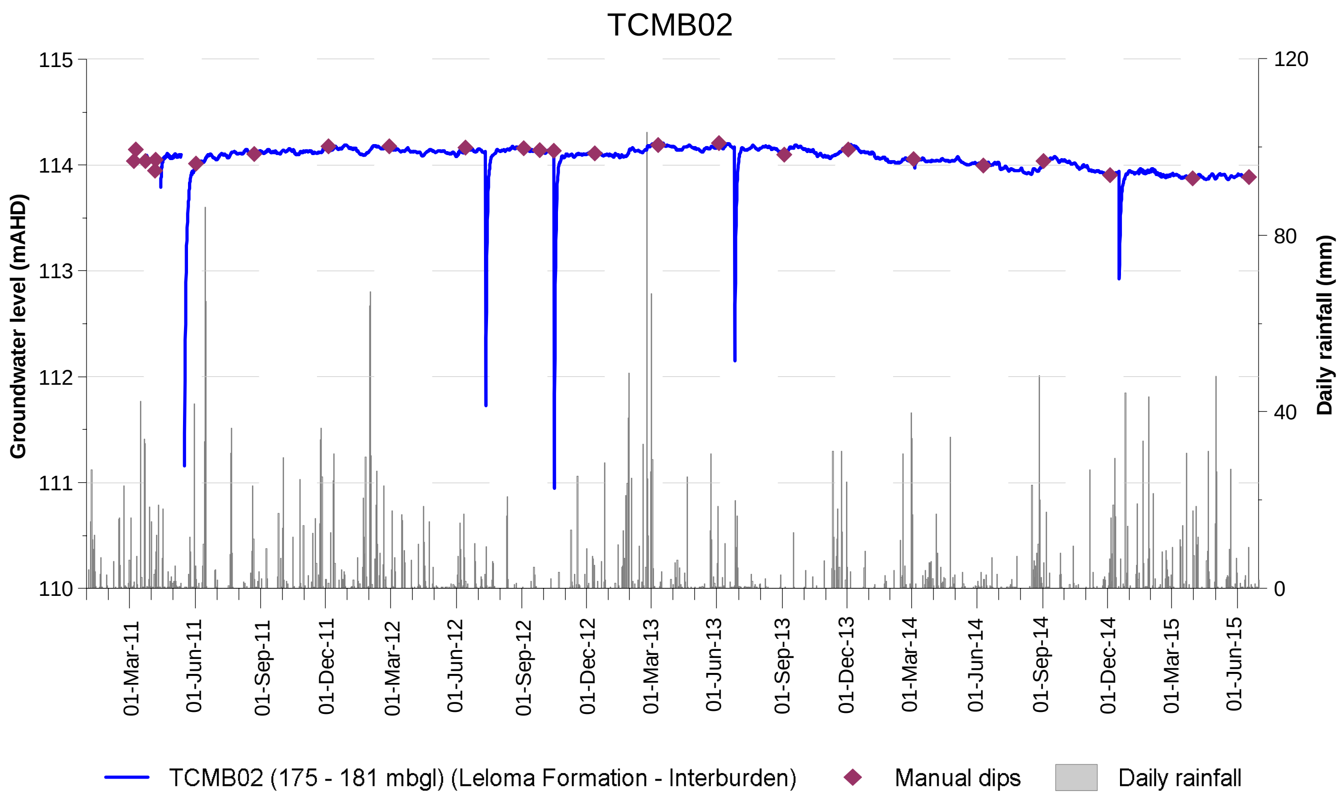


Figure A.10: BMB02 and TCMB01 monitoring bores



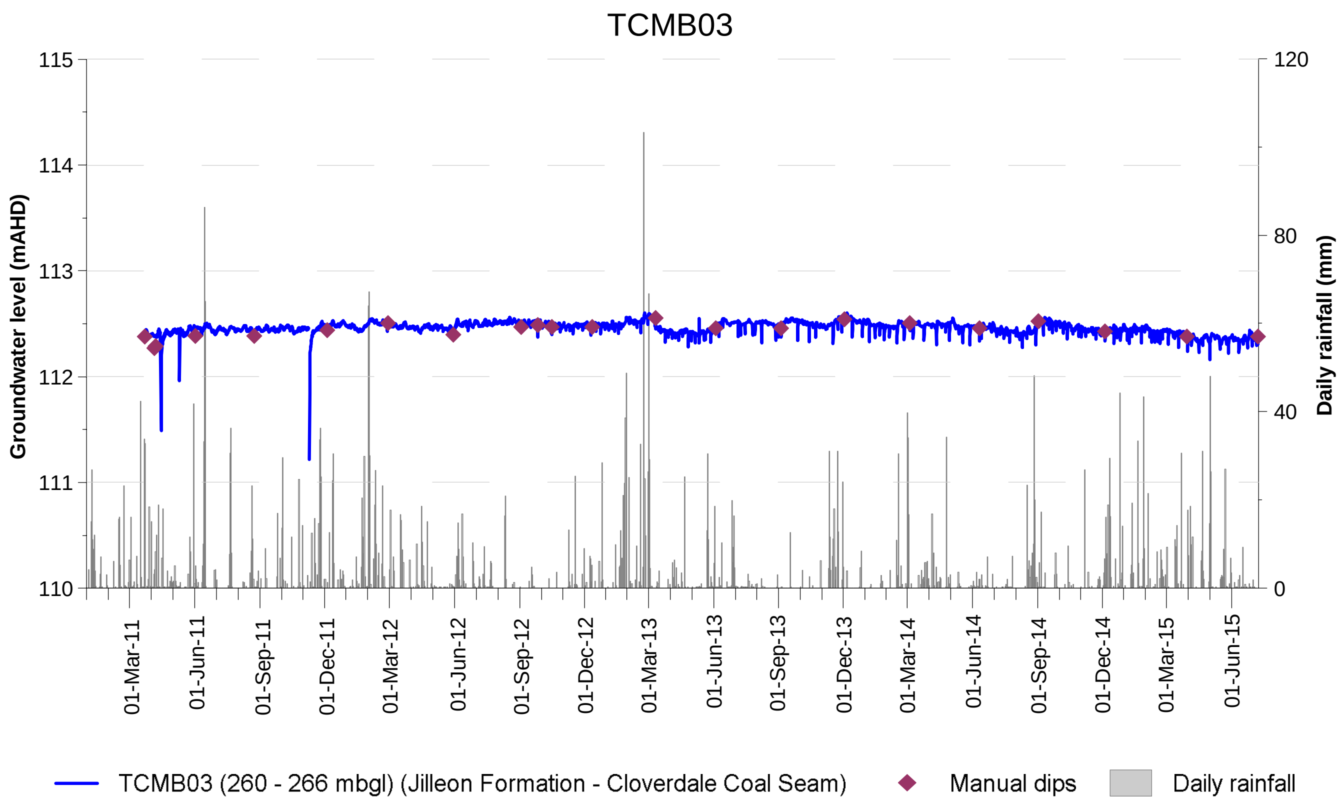
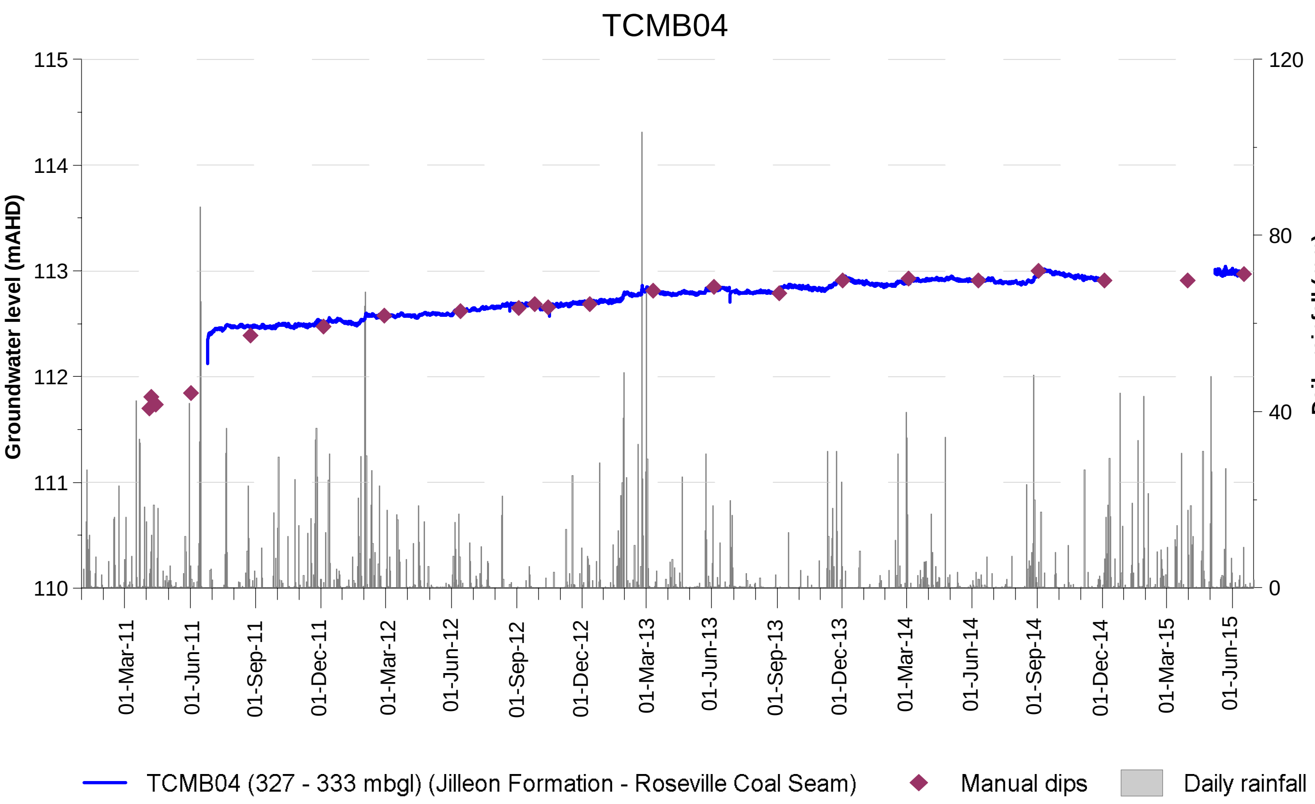


Figure A.11: TCMB02 and TCMB03 monitoring bores



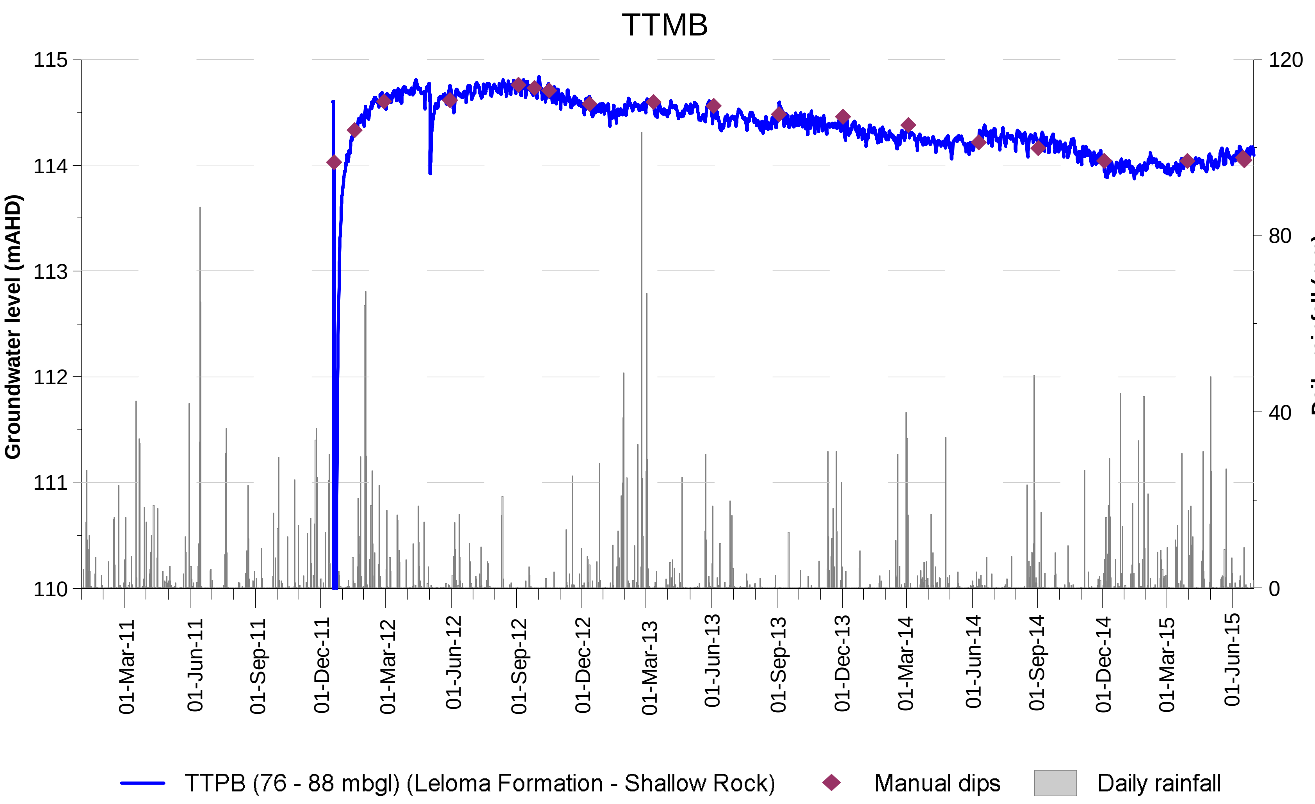
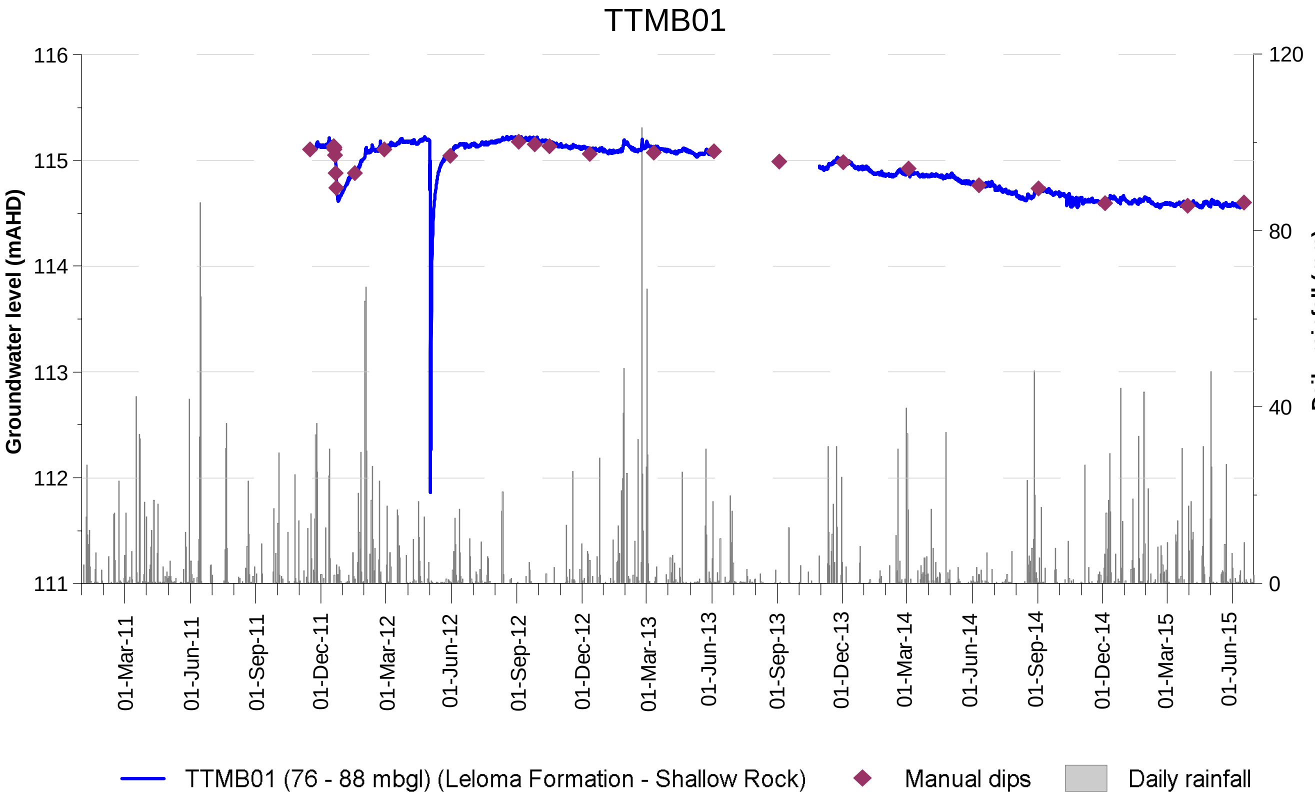


Figure A.12: TCMB04 and TTMB monitoring bores



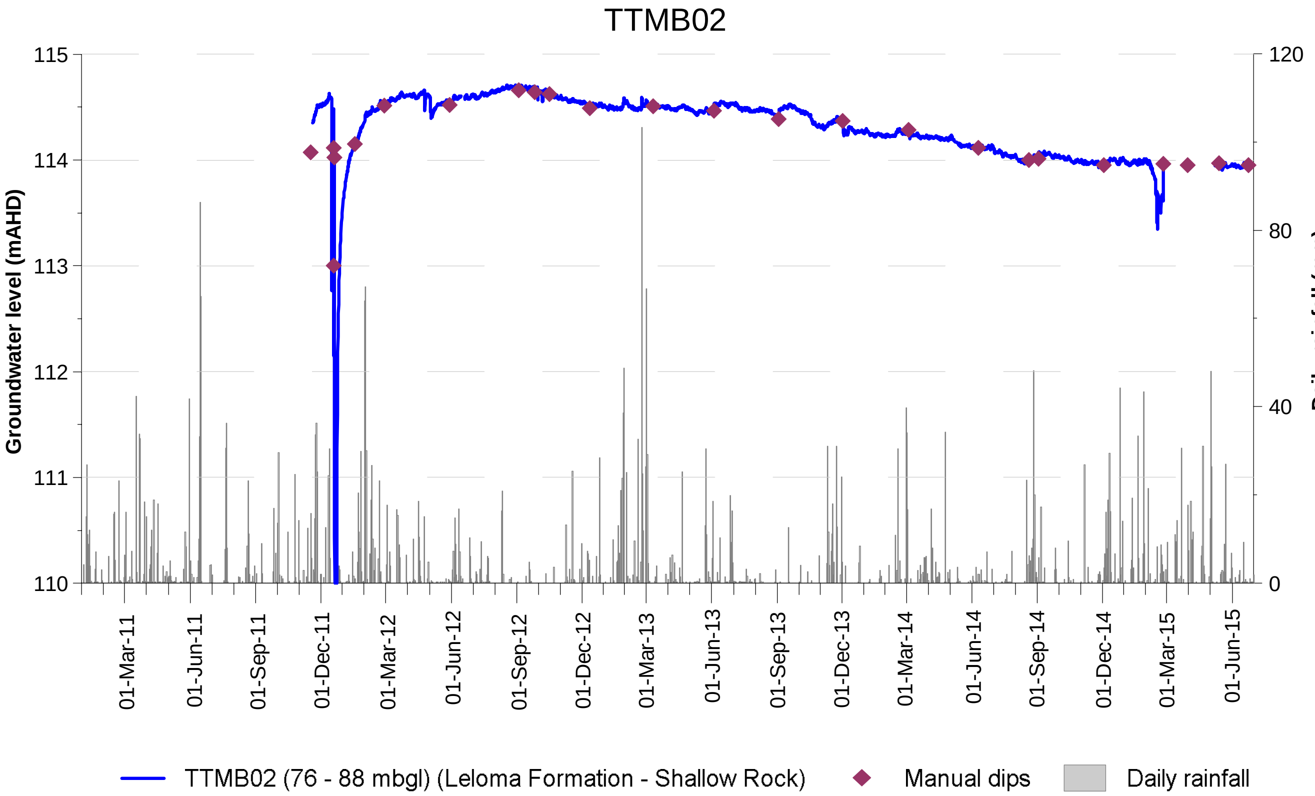
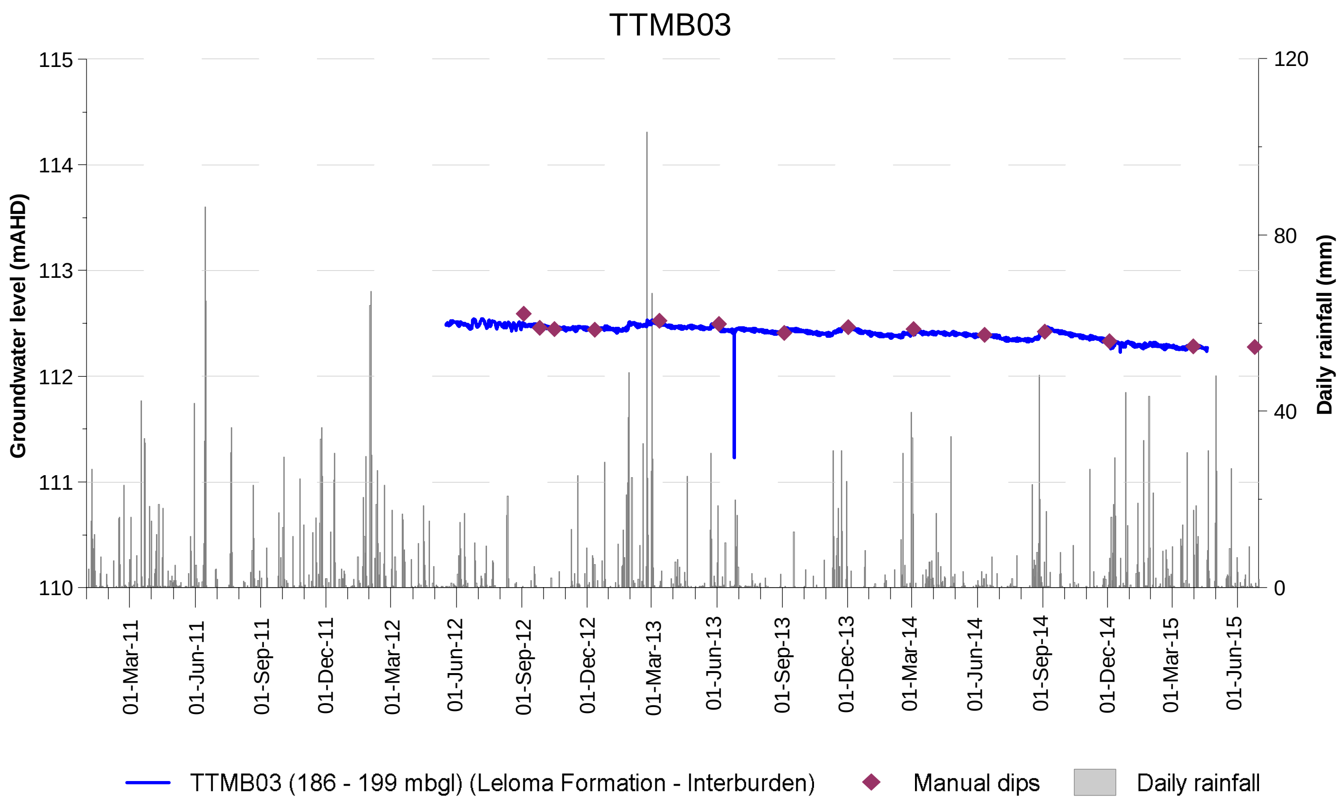


Figure A.13: TTMB01 and TTMB02 monitoring bores



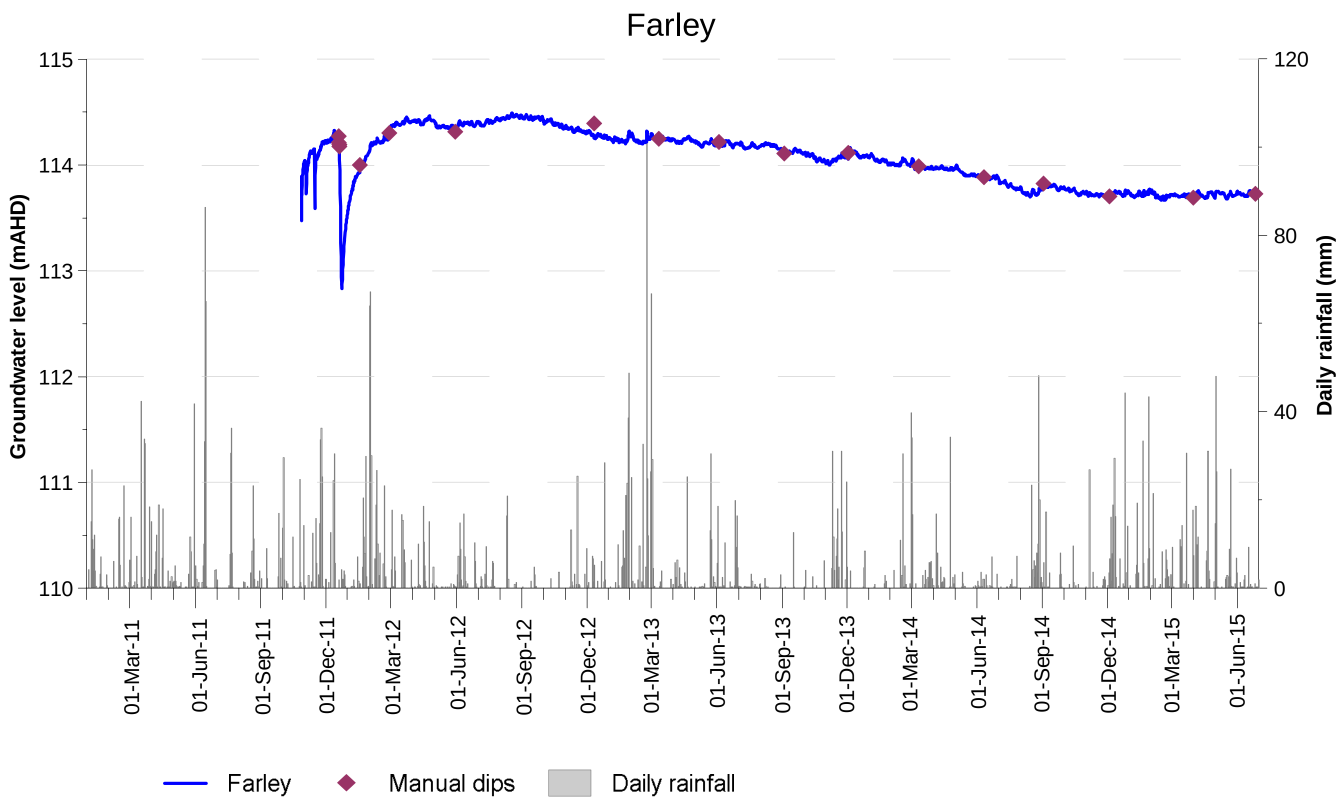
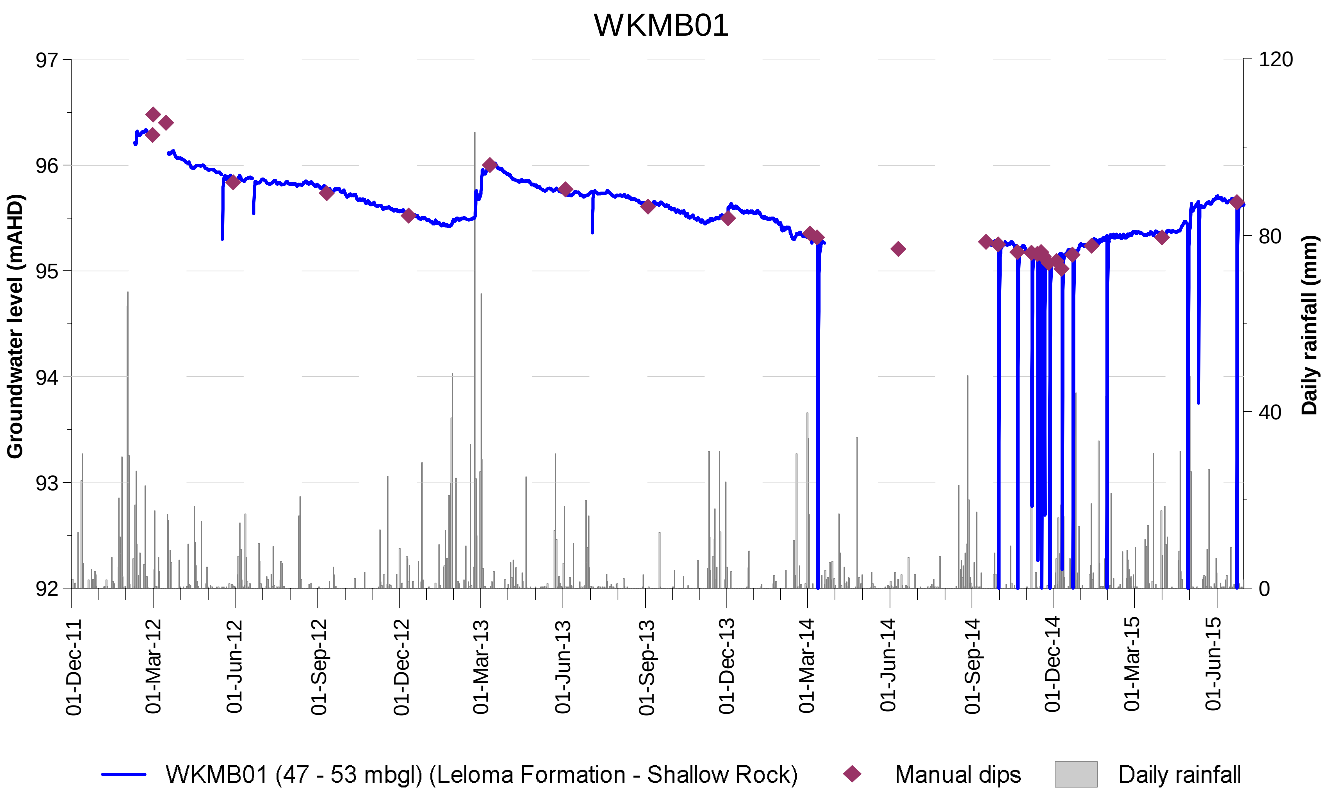


Figure A.14: TTMB03 and Farley monitoring bores



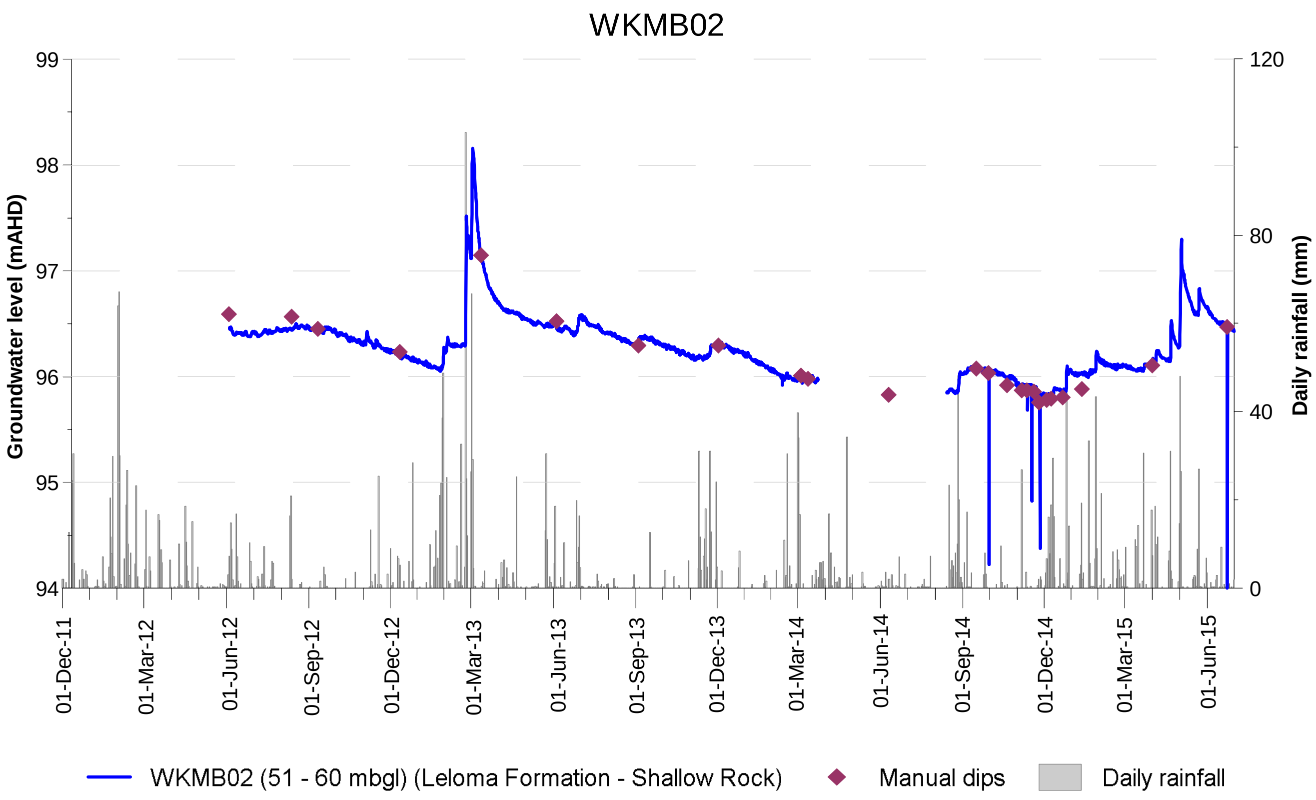


Figure A.15: WKMB01 and WKMB02 monitoring bores

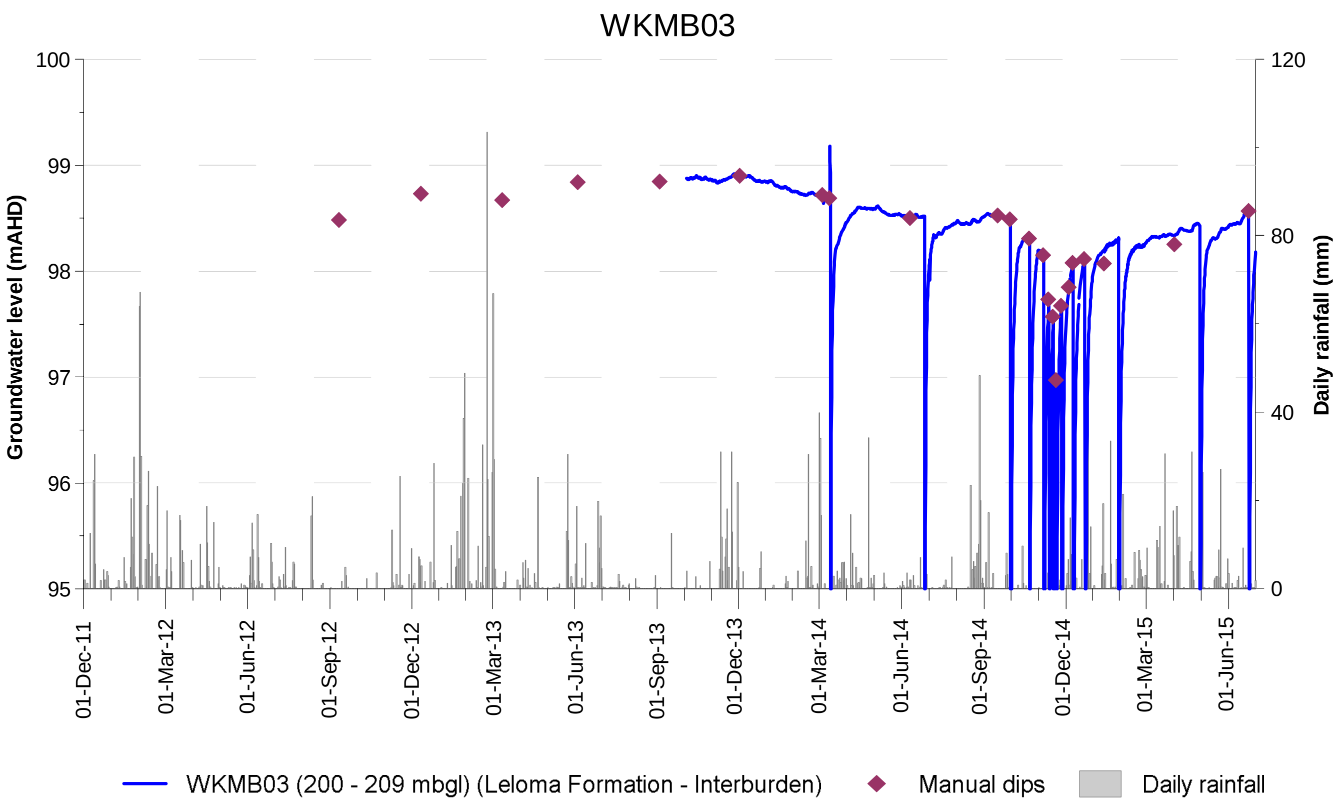
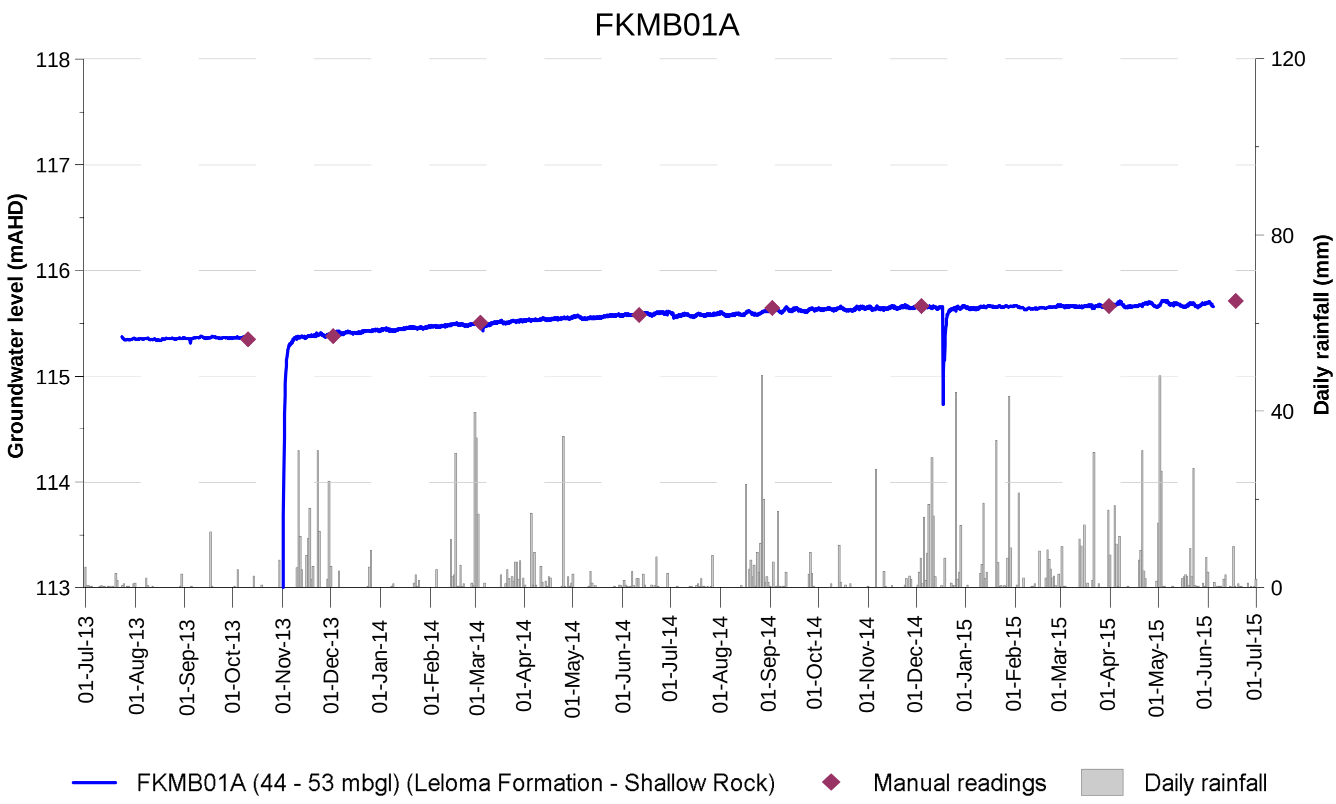


Figure A.16: WKMB03 monitoring bore



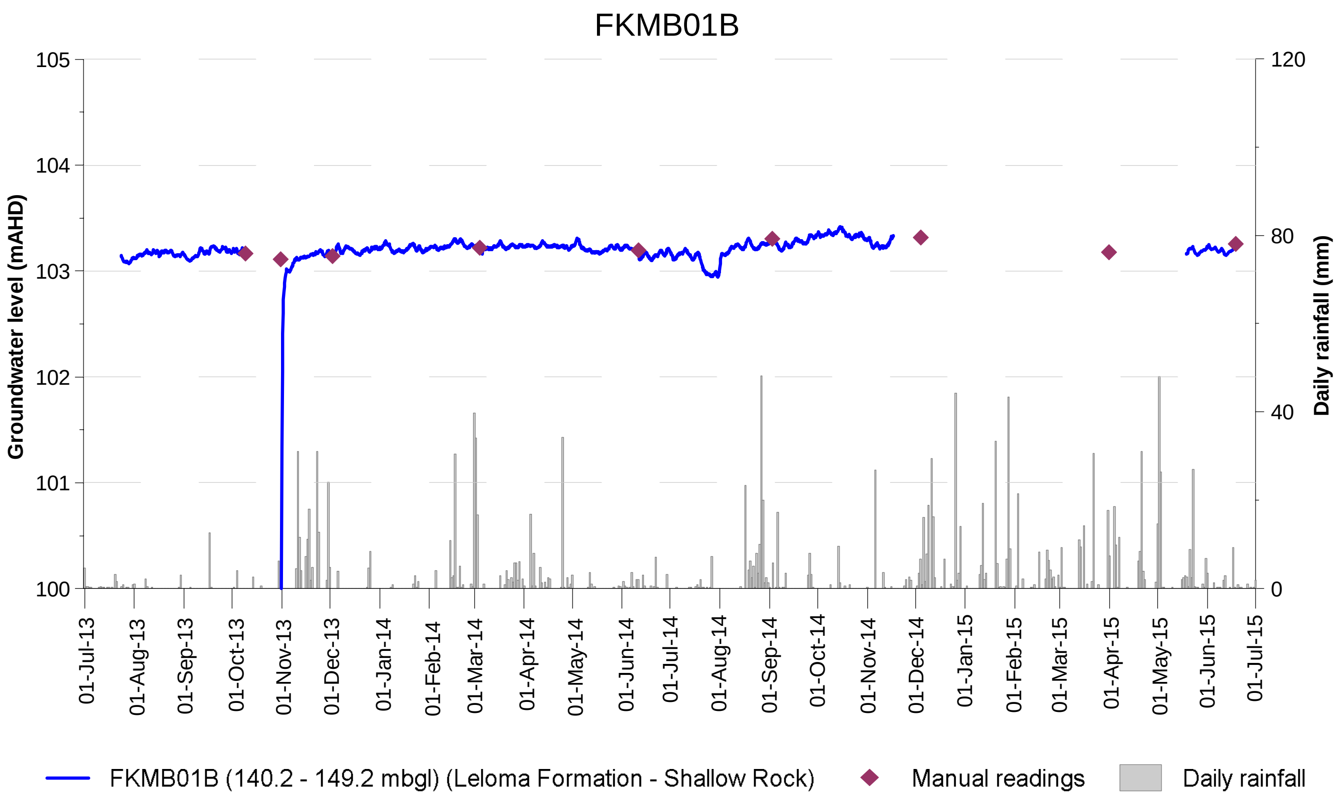
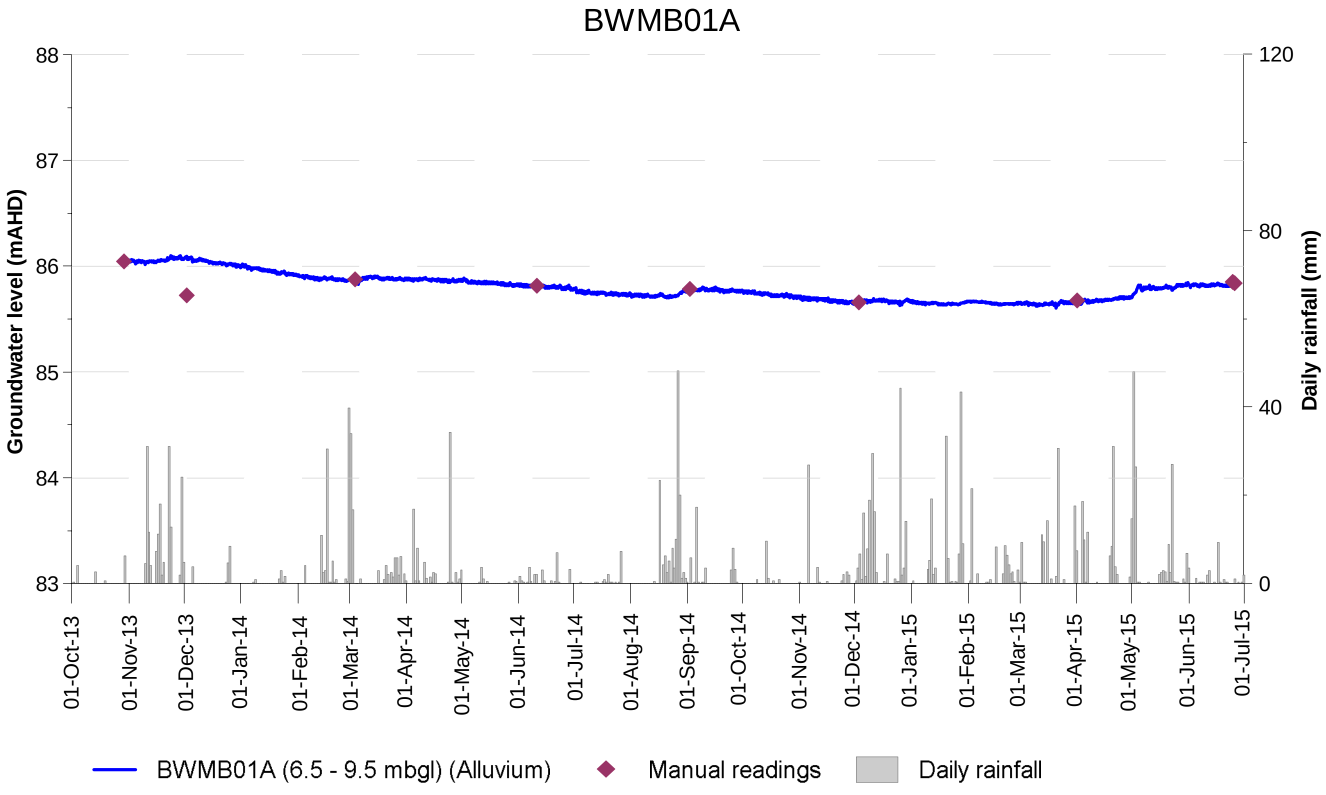


Figure A.17: FKMB01A and FKMB01B monitoring bores



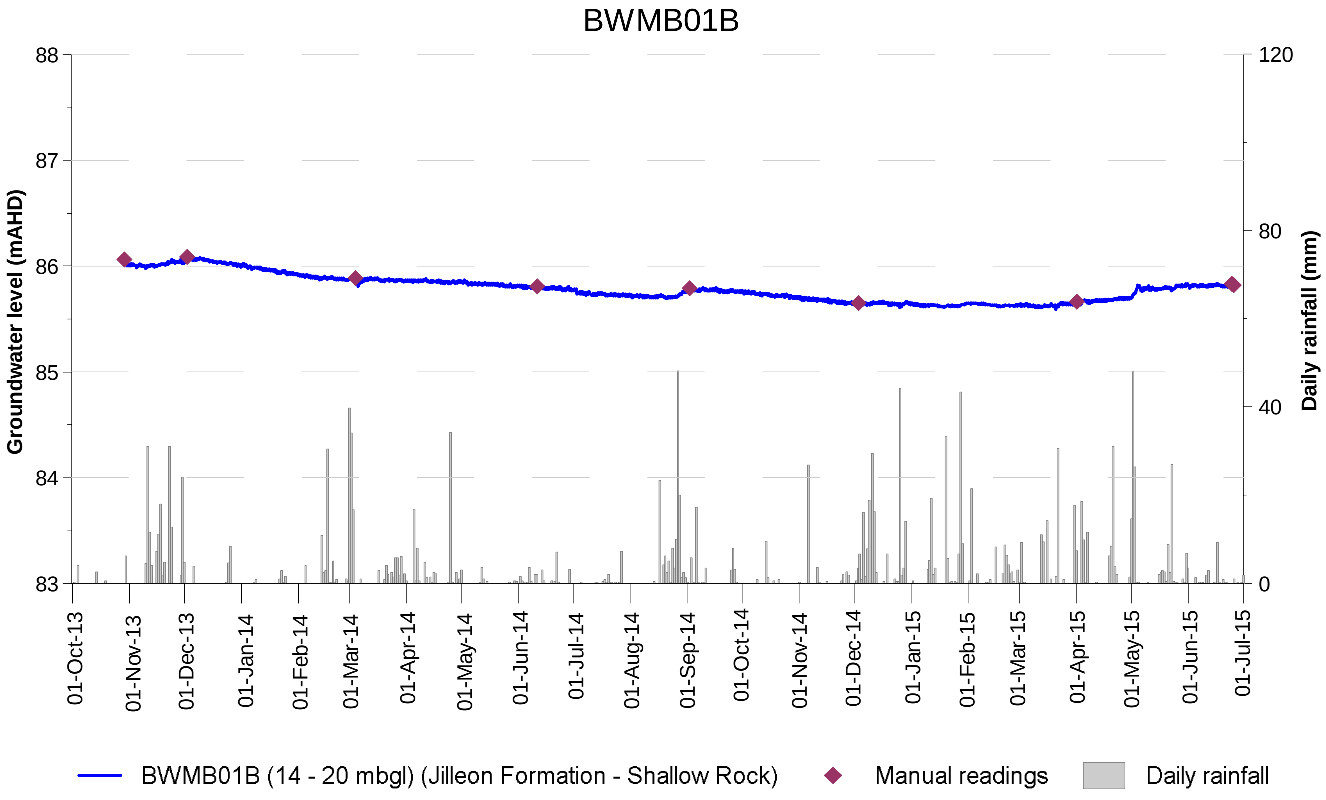
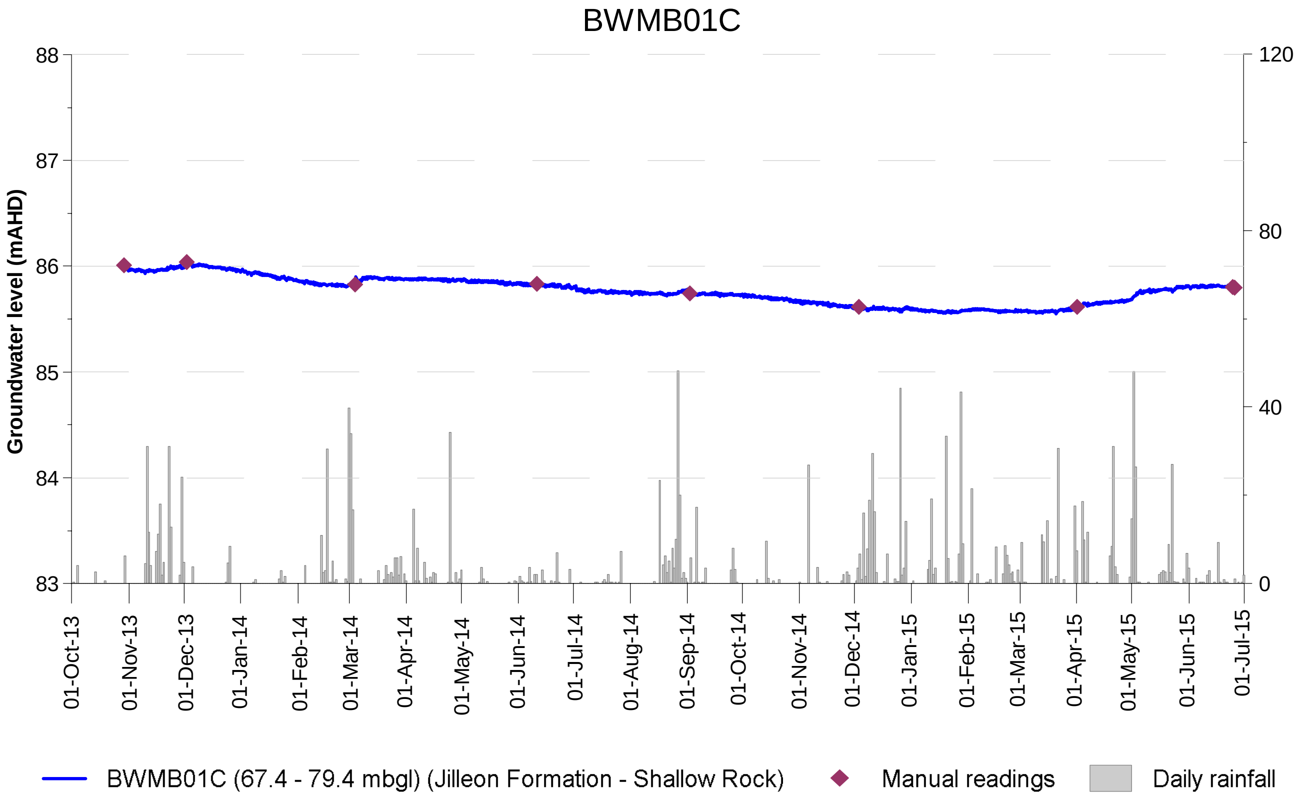


Figure A.18: BWMB01A and BWMB01B monitoring bores



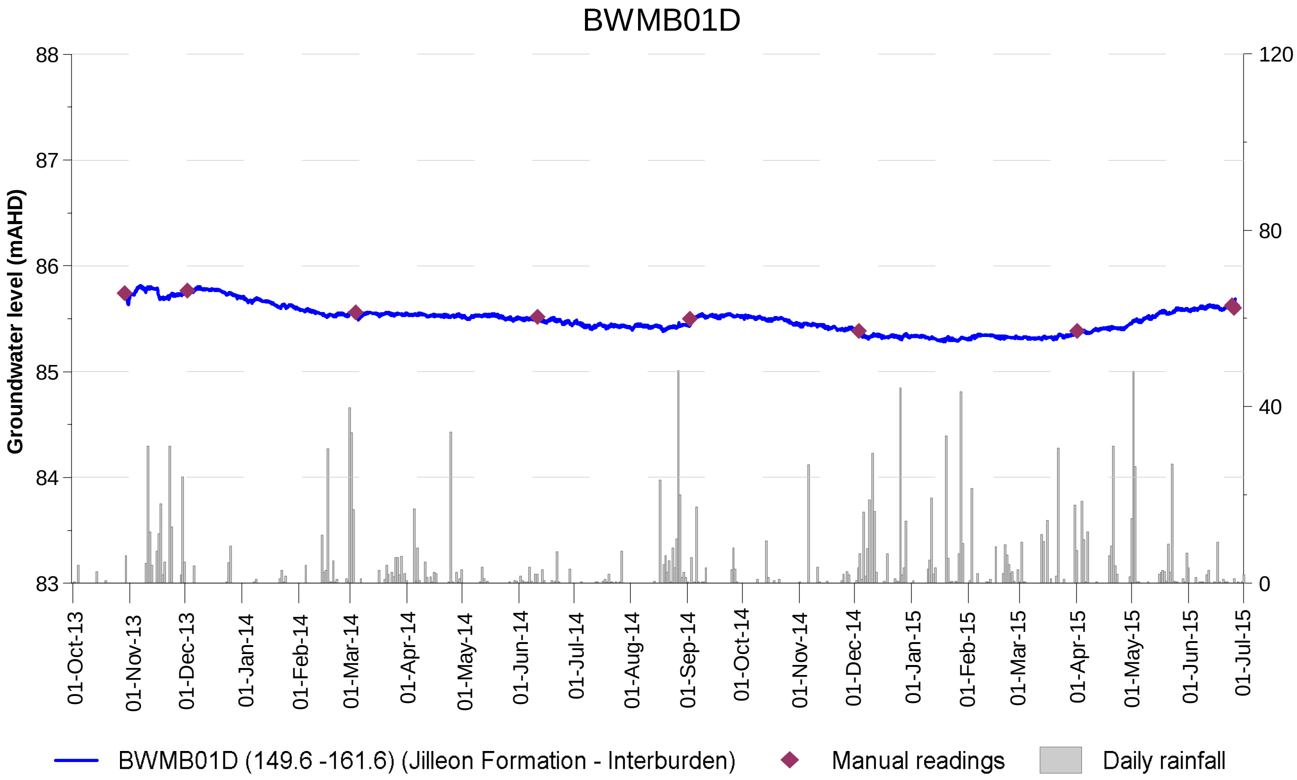
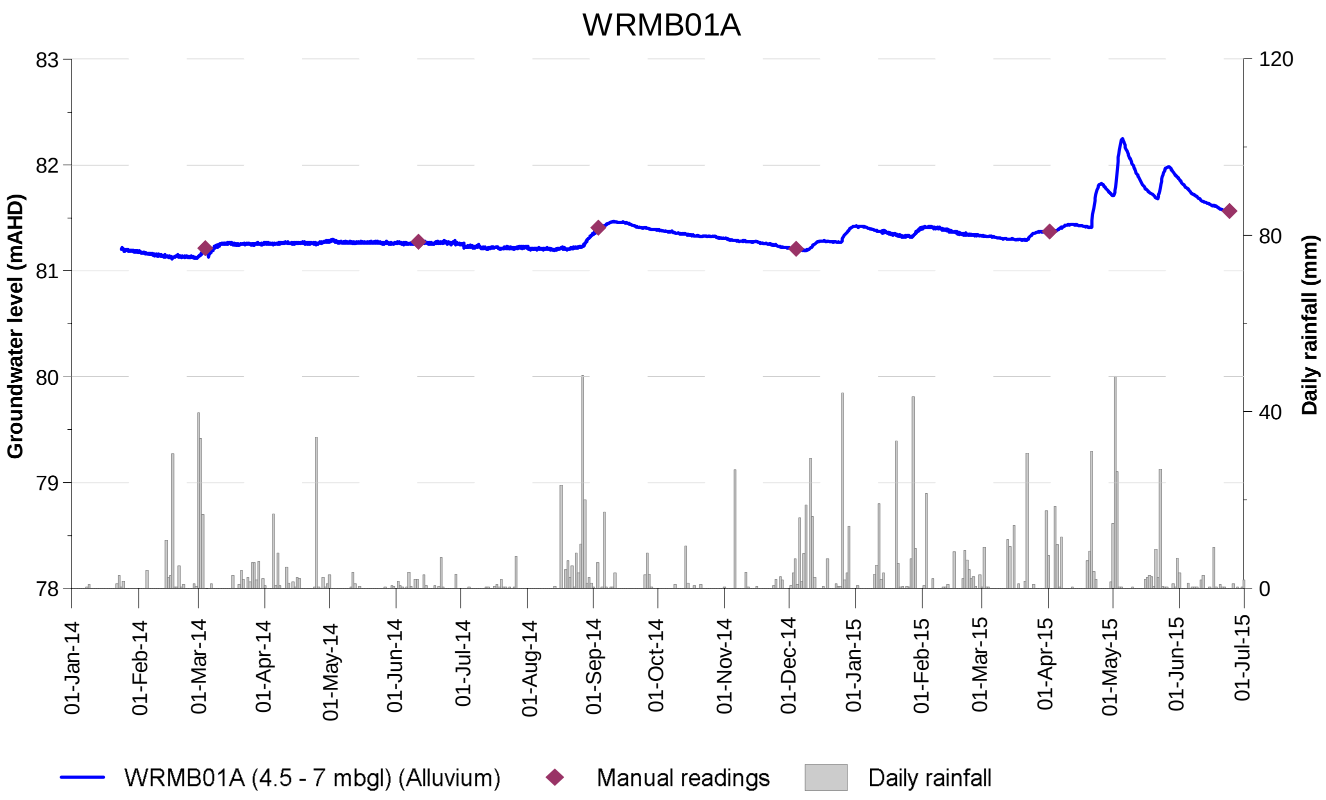


Figure A.19: BWMB01C and BWMB01D monitoring bores



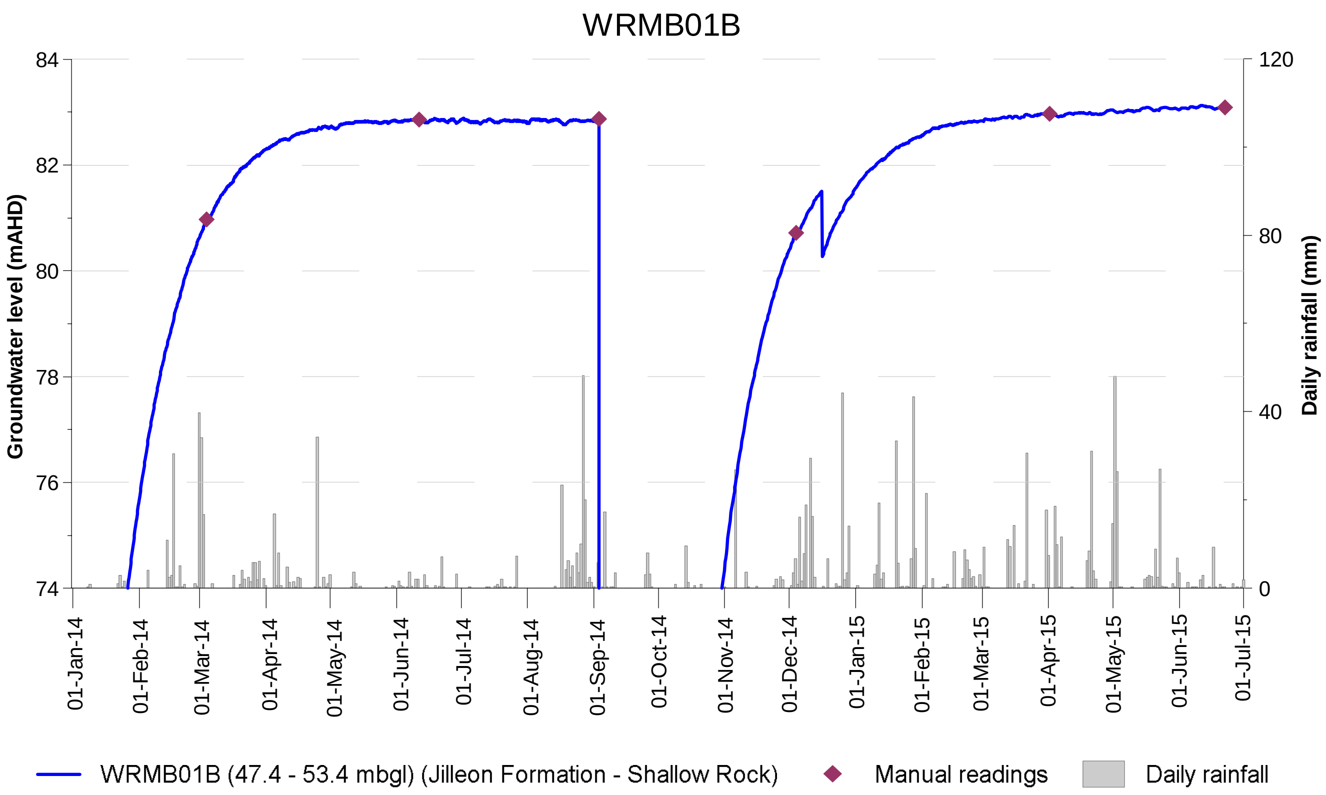


Figure A.20: WRMB01A and WRMB01B monitoring bores

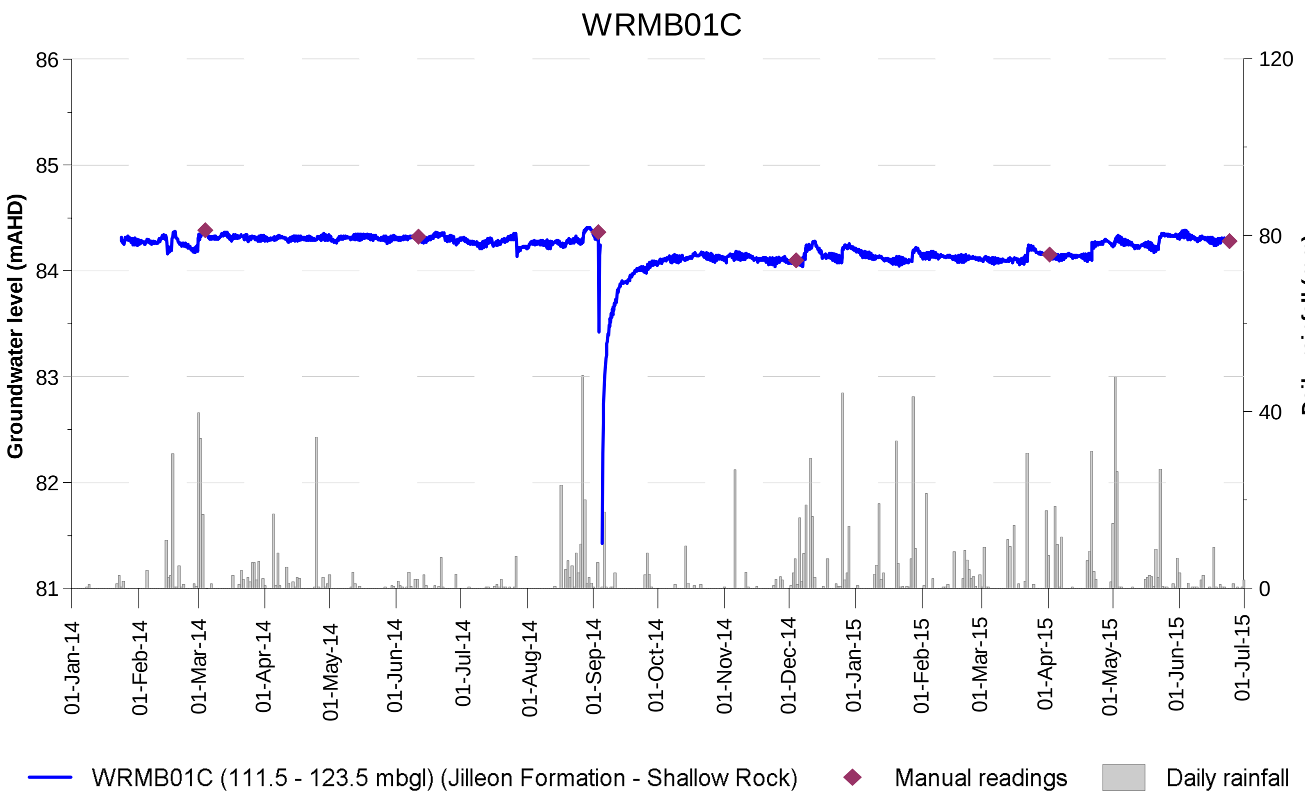
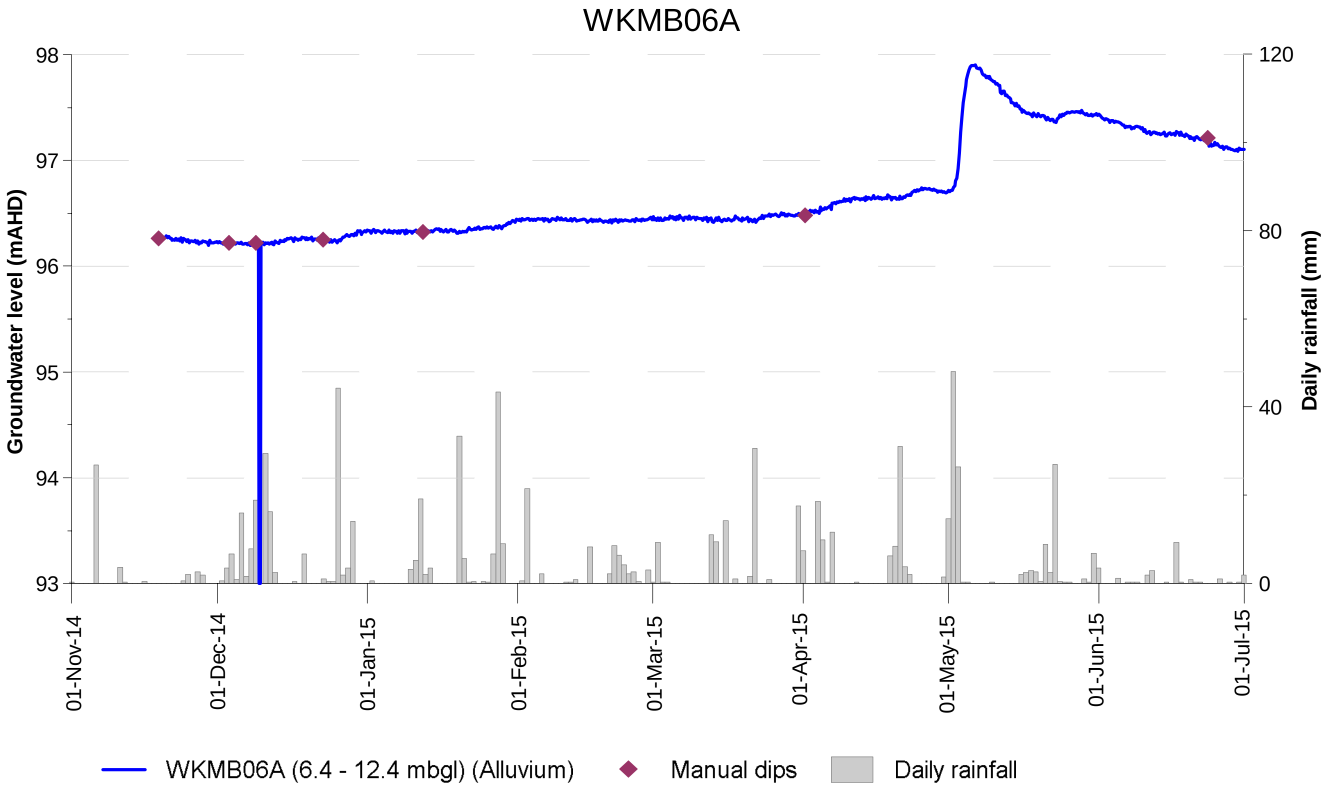


Figure A.21: WRMB01C monitoring bore



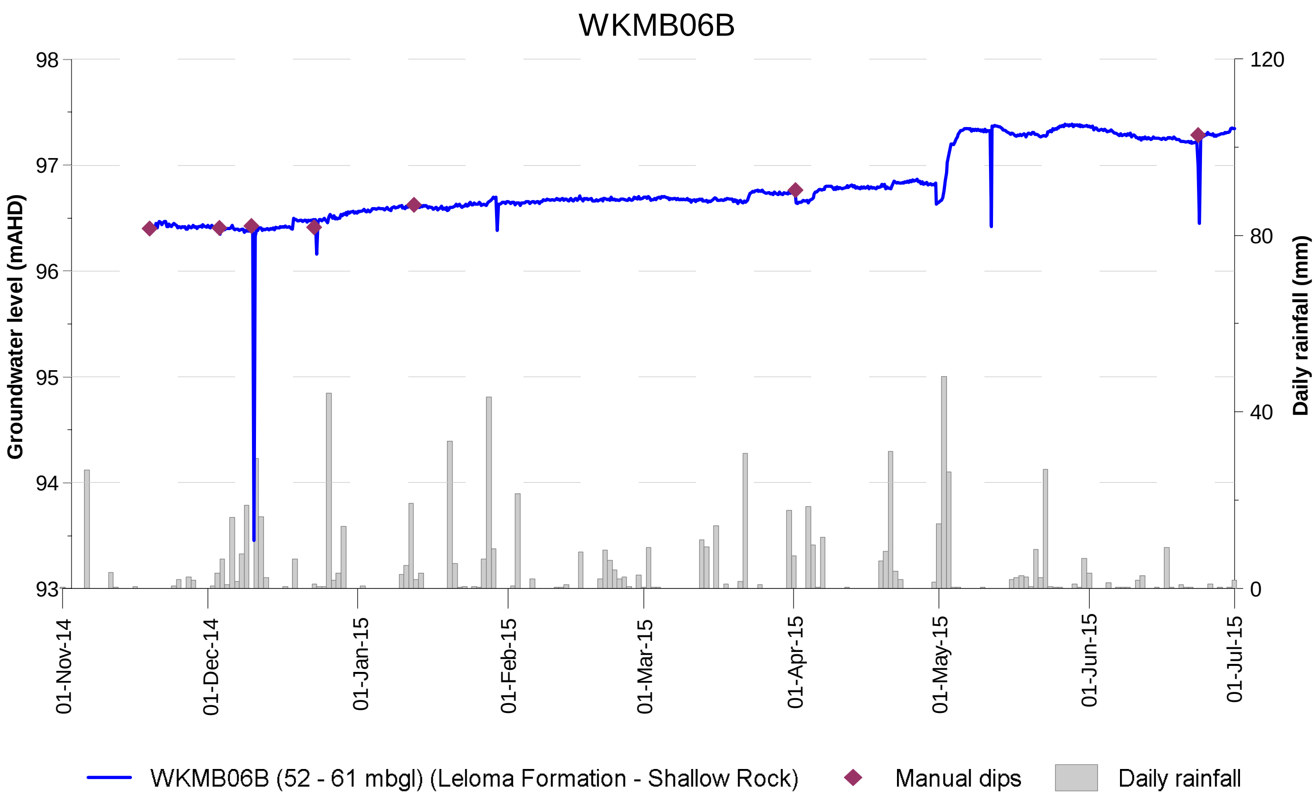
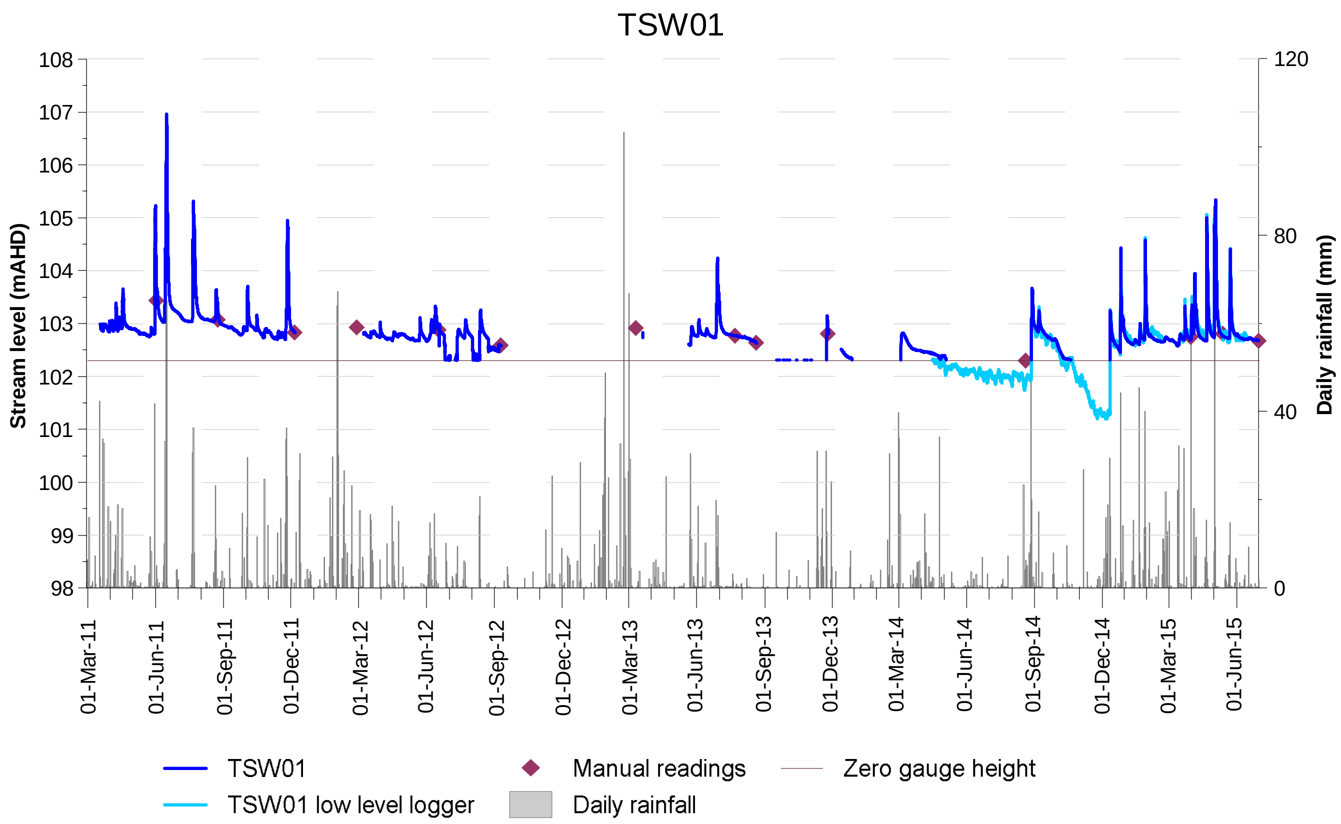


Figure A.22: WKMB06A and WKMB06B monitoring bores



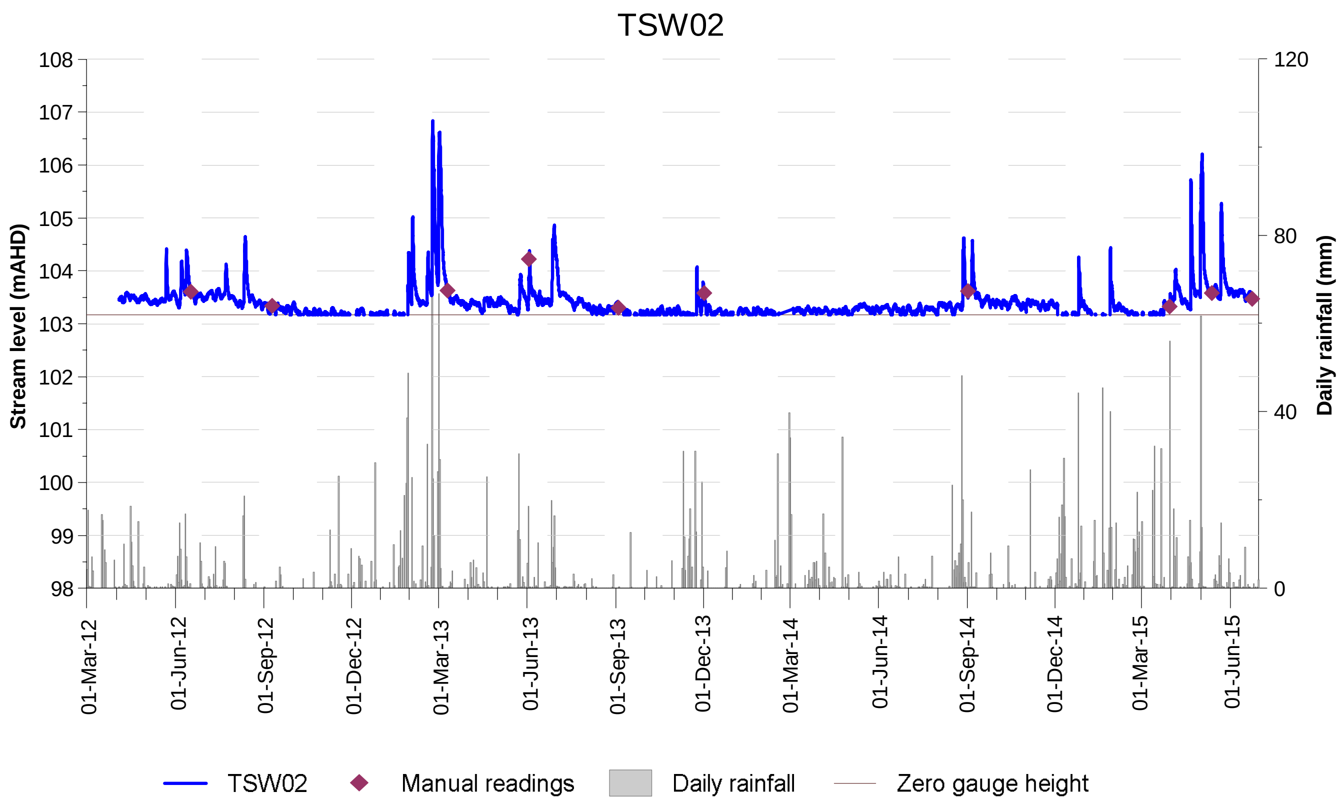
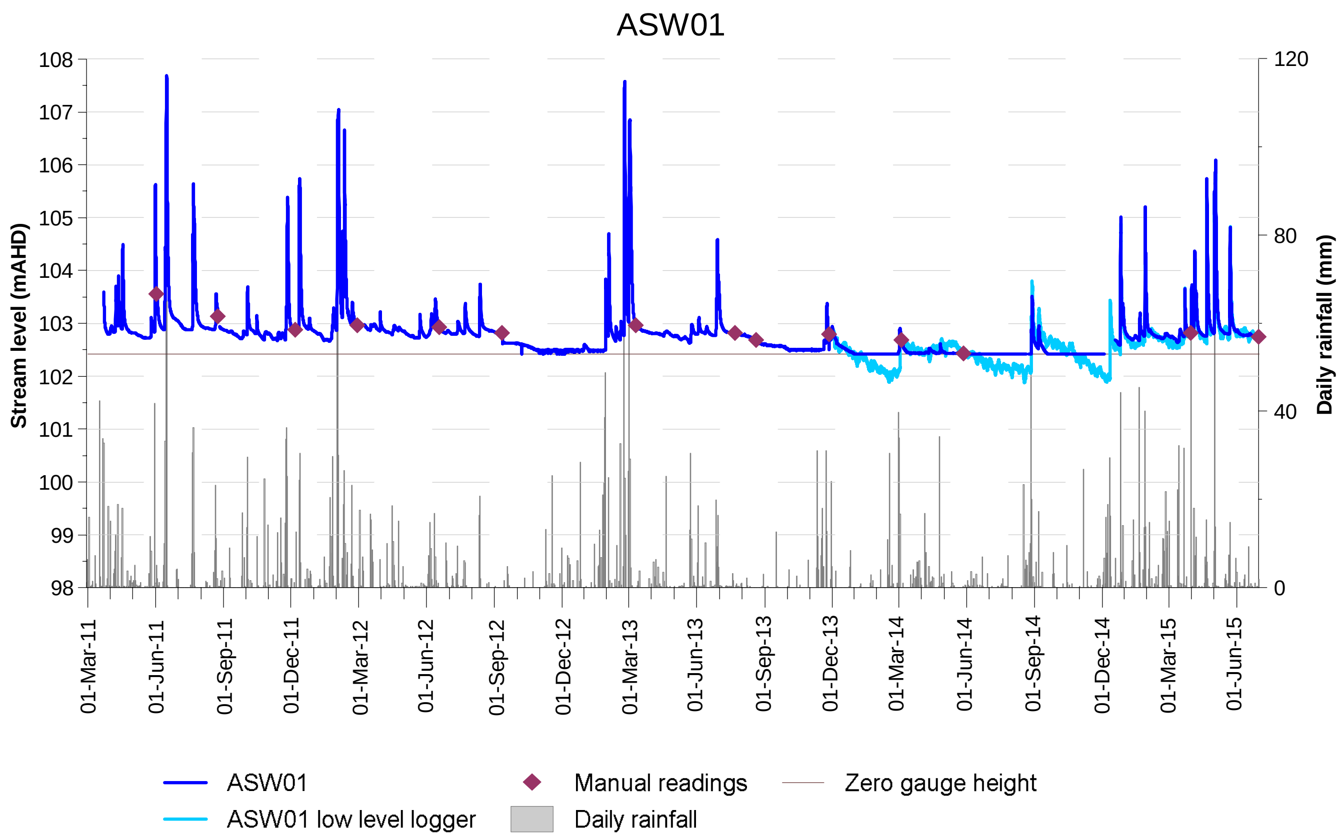


Figure A.23: TSW01 and TSW02 stream levels



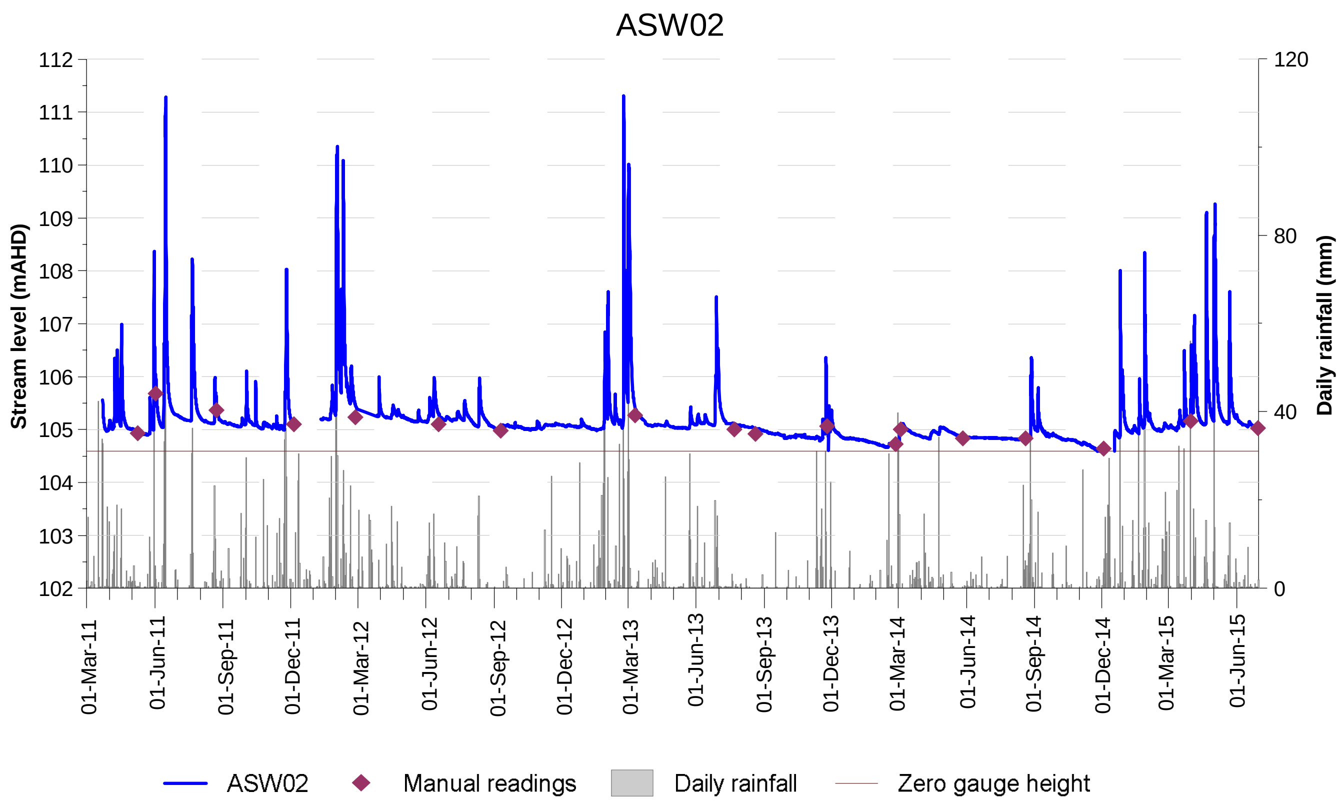
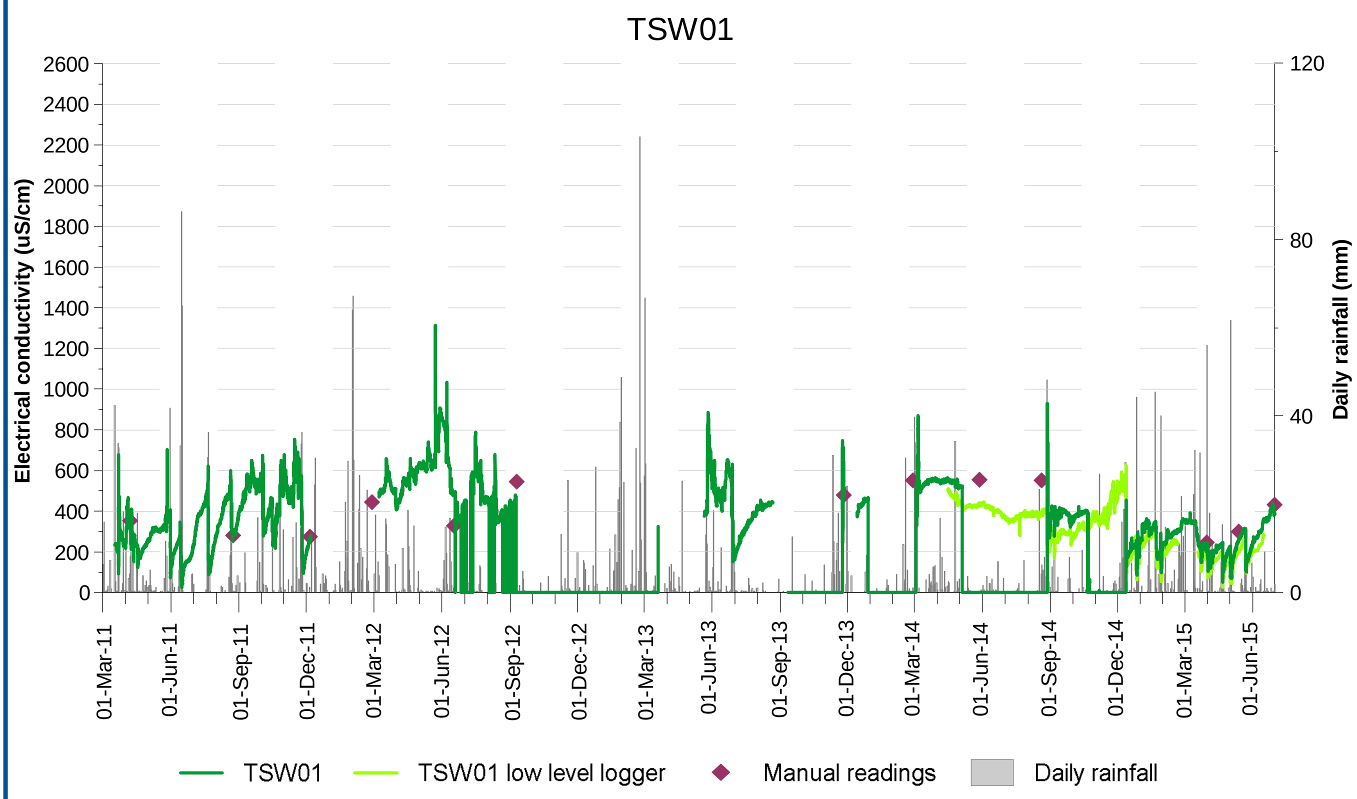


Figure A.24: ASW01 and ASW02 stream levels



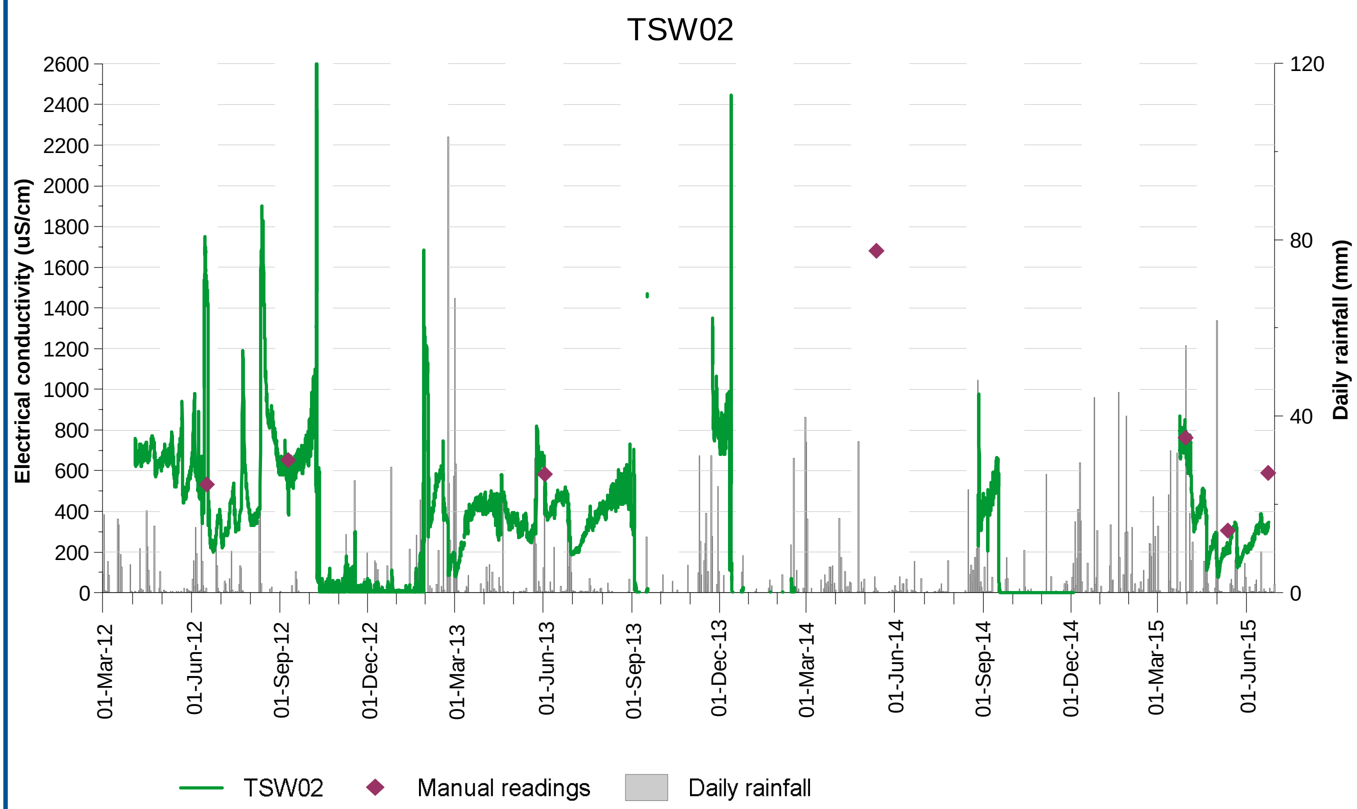
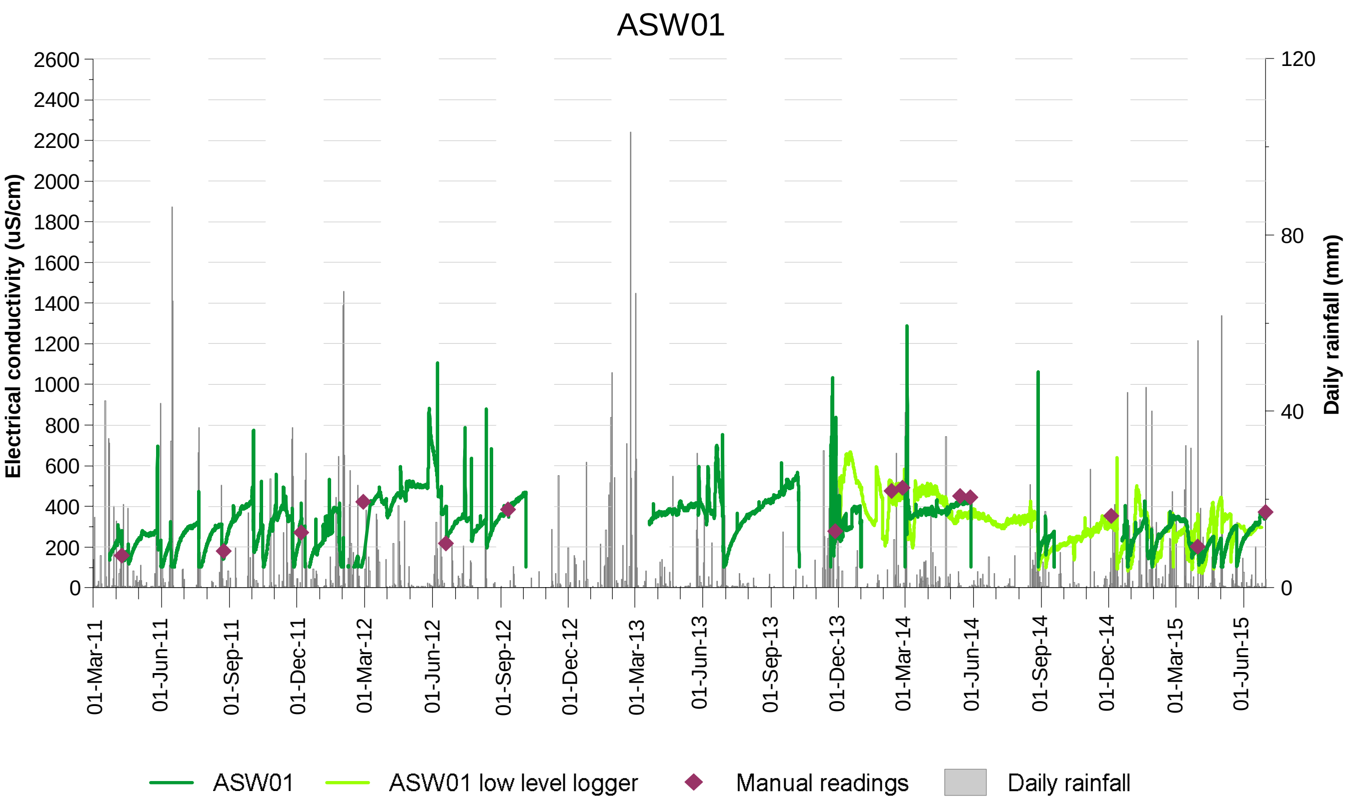


Figure A.25: TSW01 and TSW02 electrical conductivity



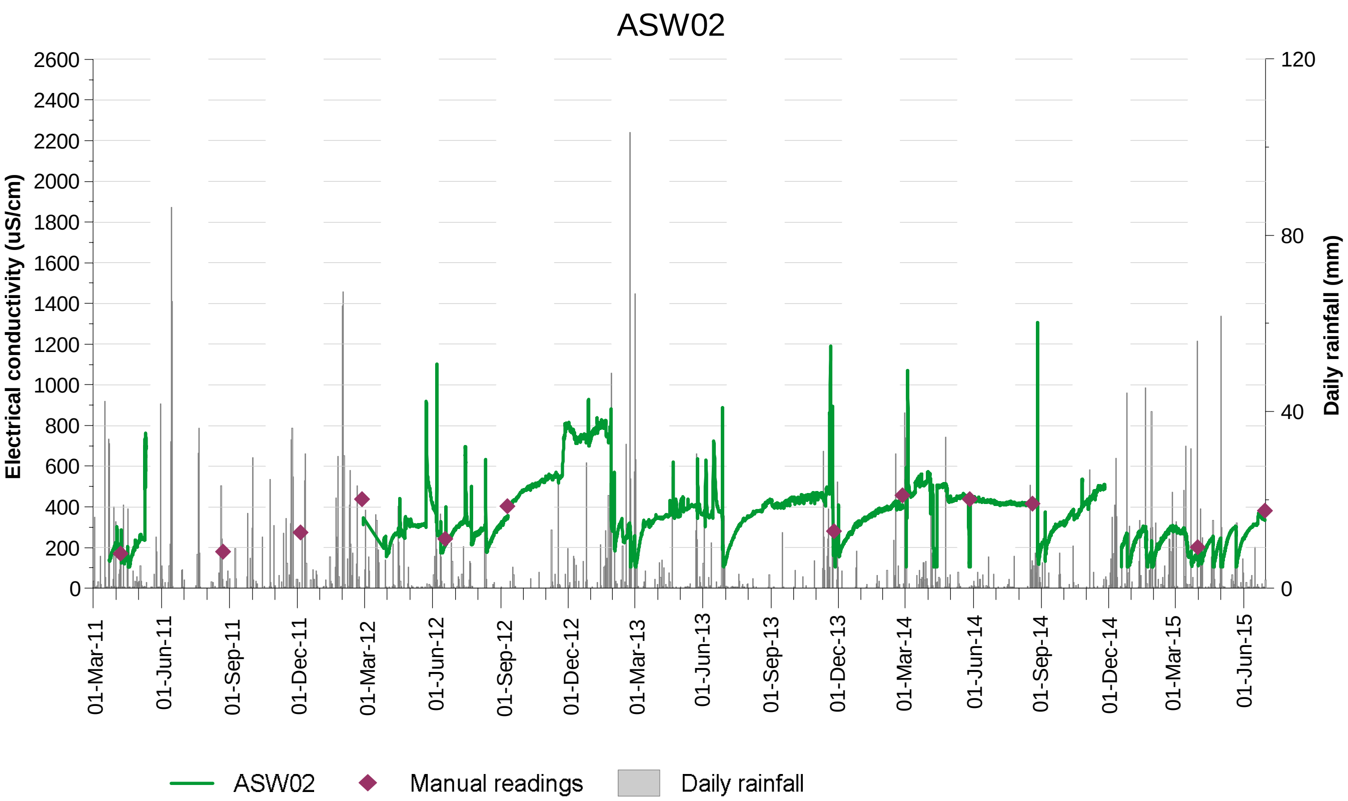
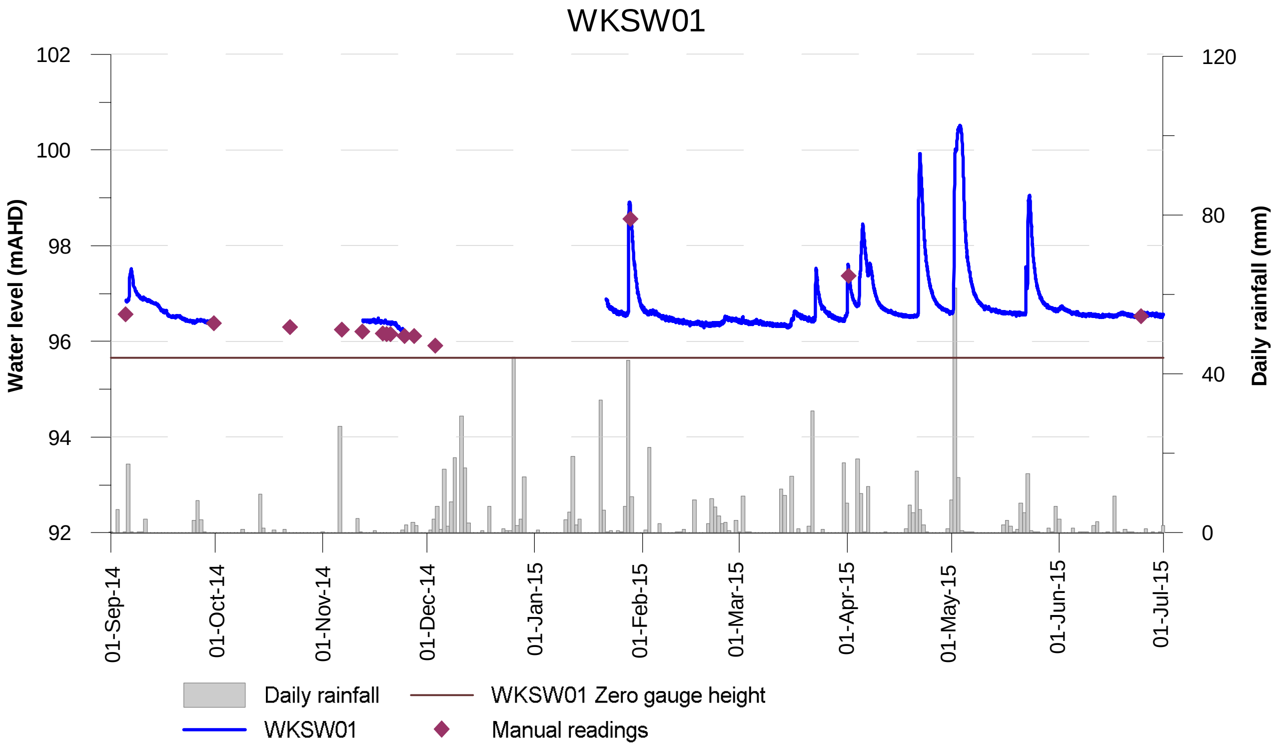


Figure A.26: ASW01 and ASW02 electrical conductivity



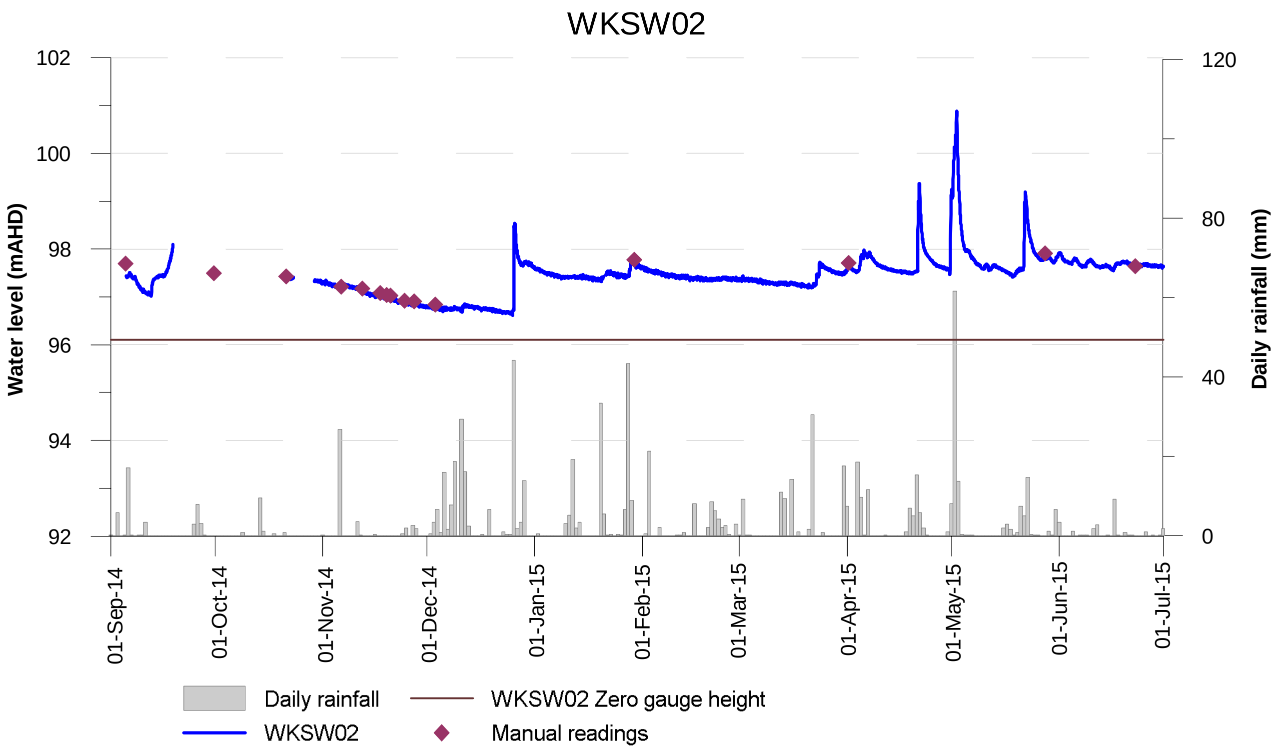


Figure A.27: WKSW01 and WKSW02 stream levels

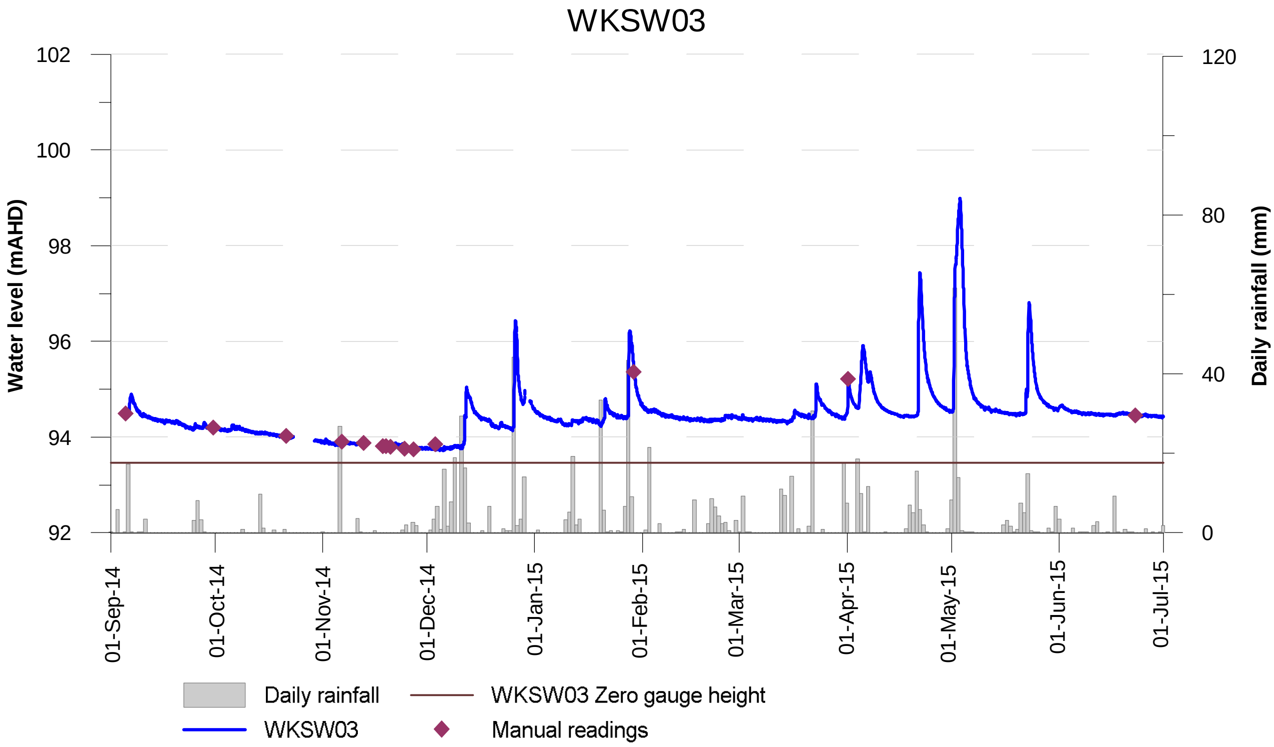
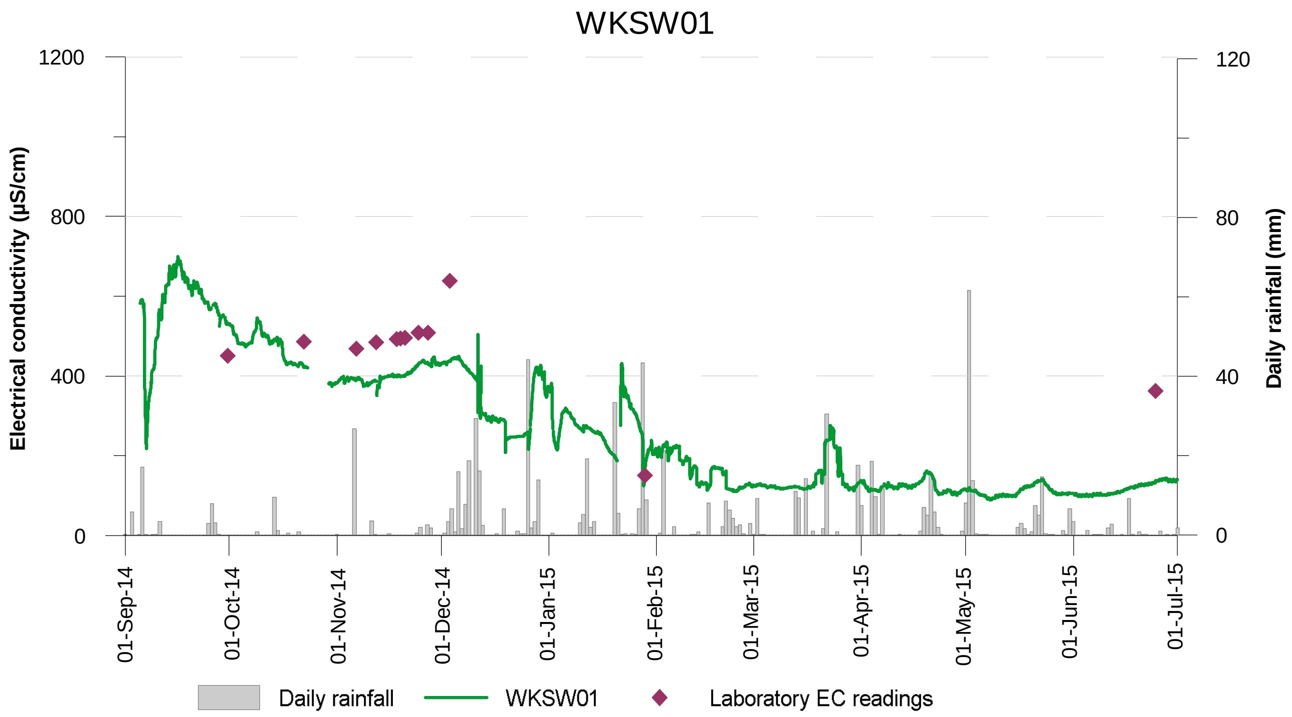


Figure A.28: WKSW03 stream levels



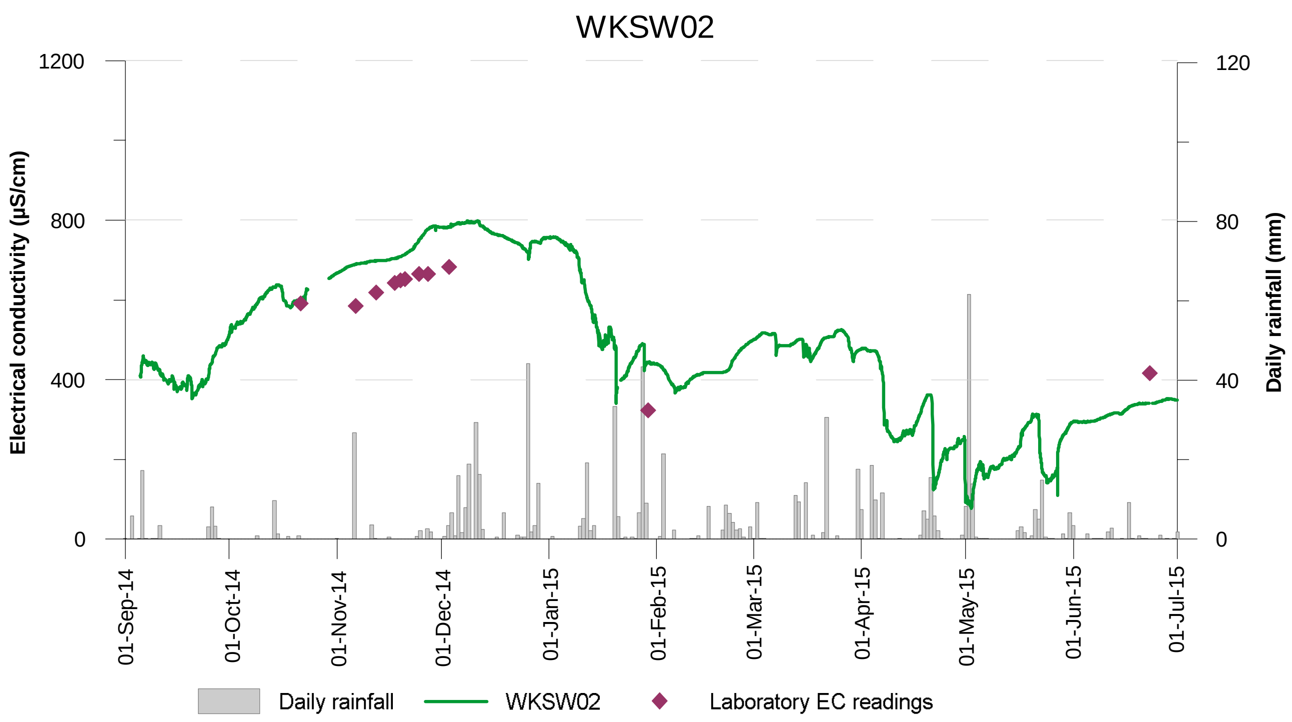


Figure A.29: WKSW01 and WKSW02 electrical conductivity

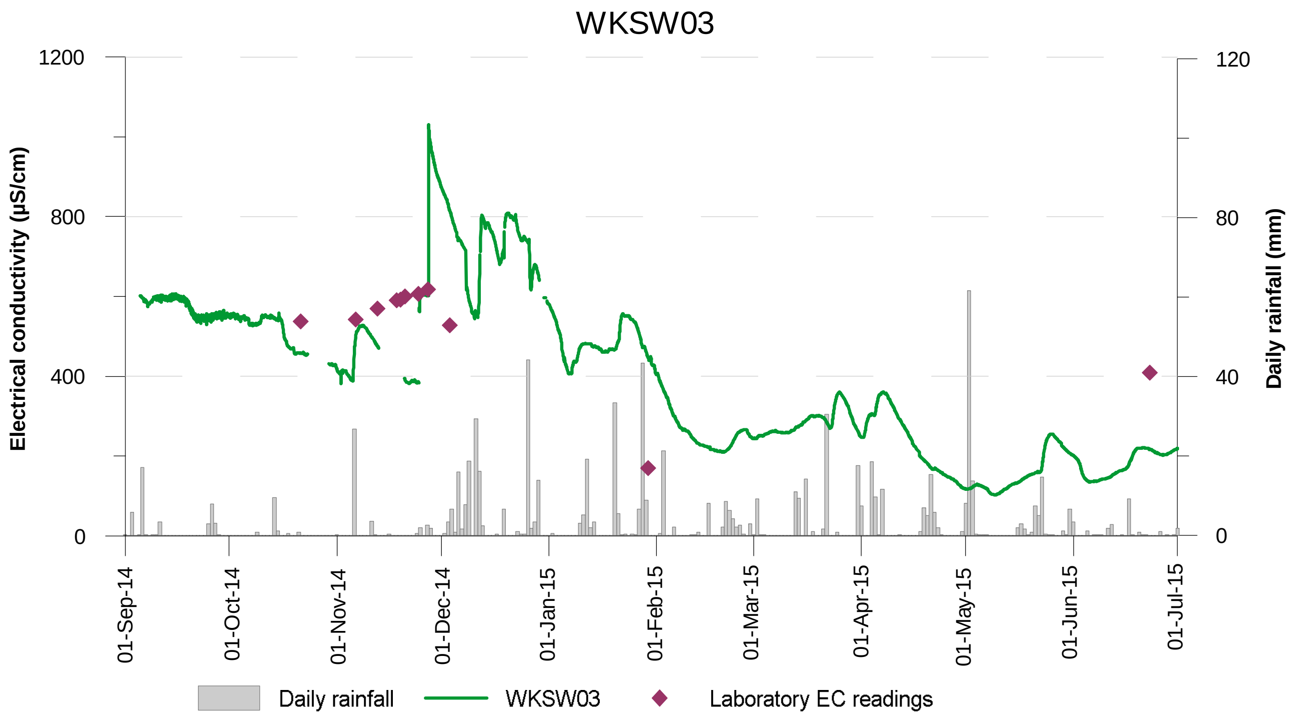
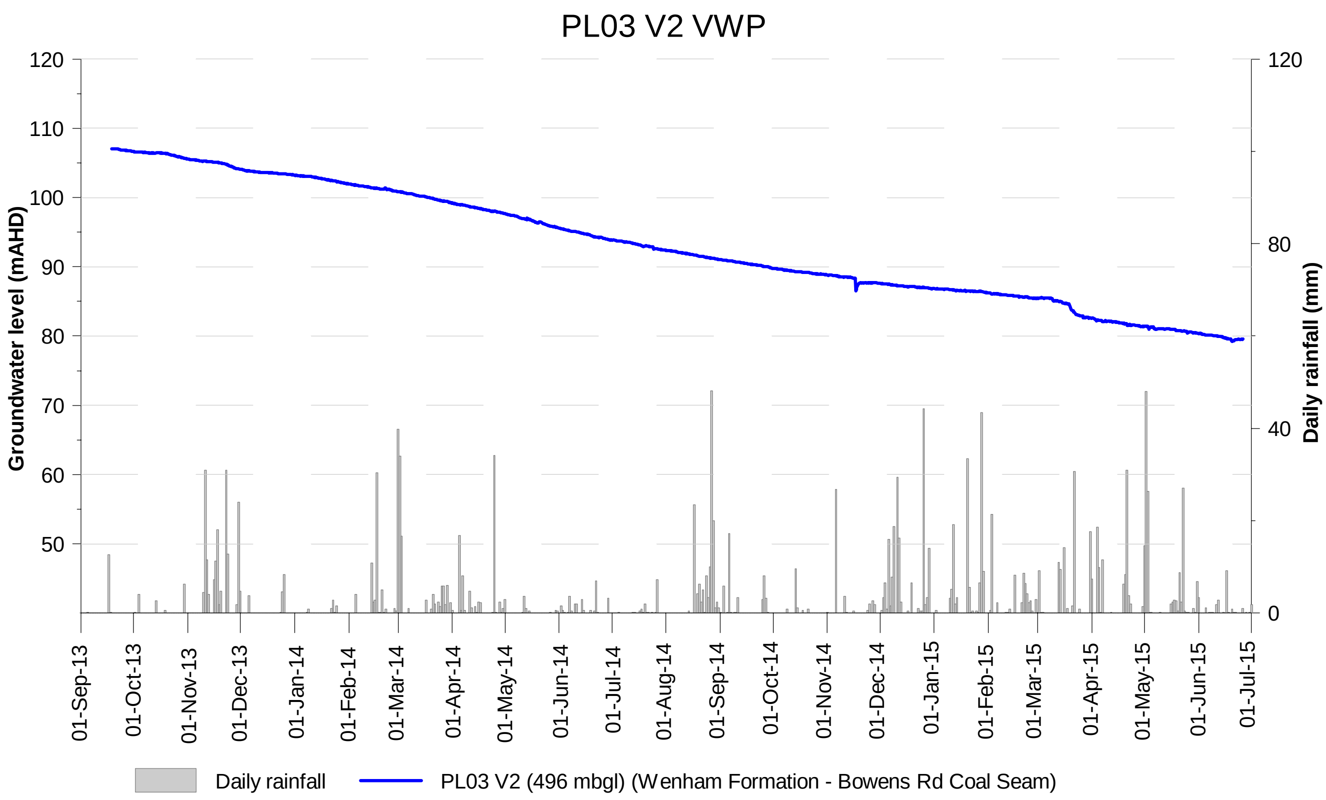


Figure A.30: WKSW03 electrical conductivity



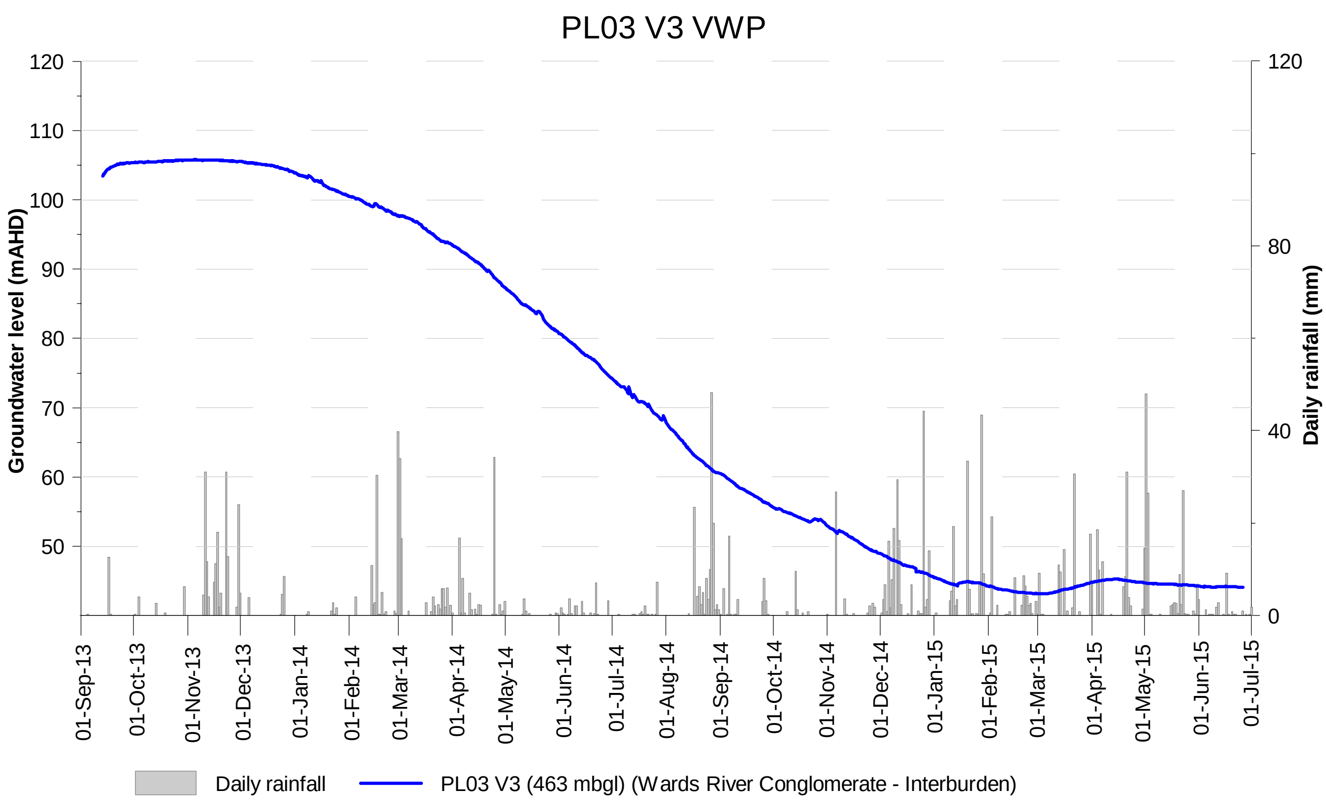
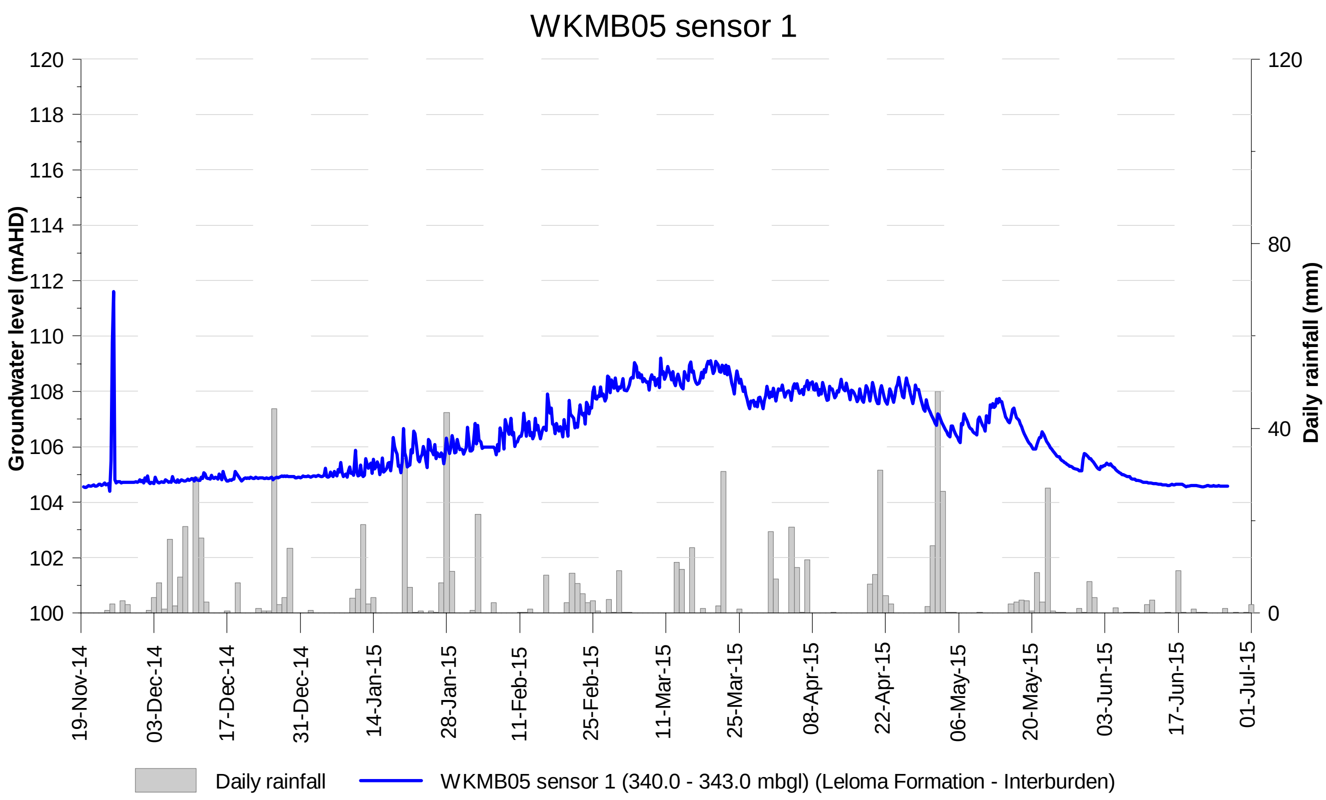


Figure A.31: PL03 VWP



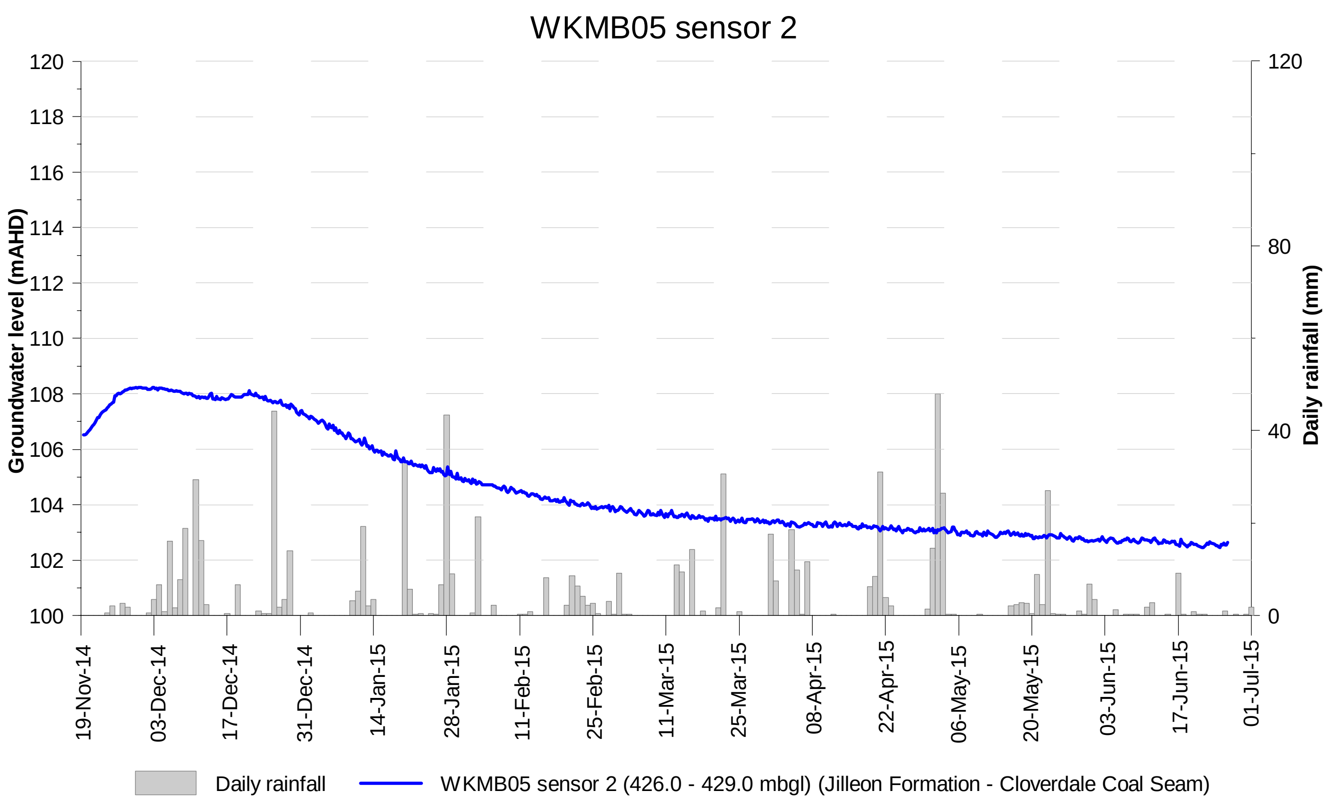
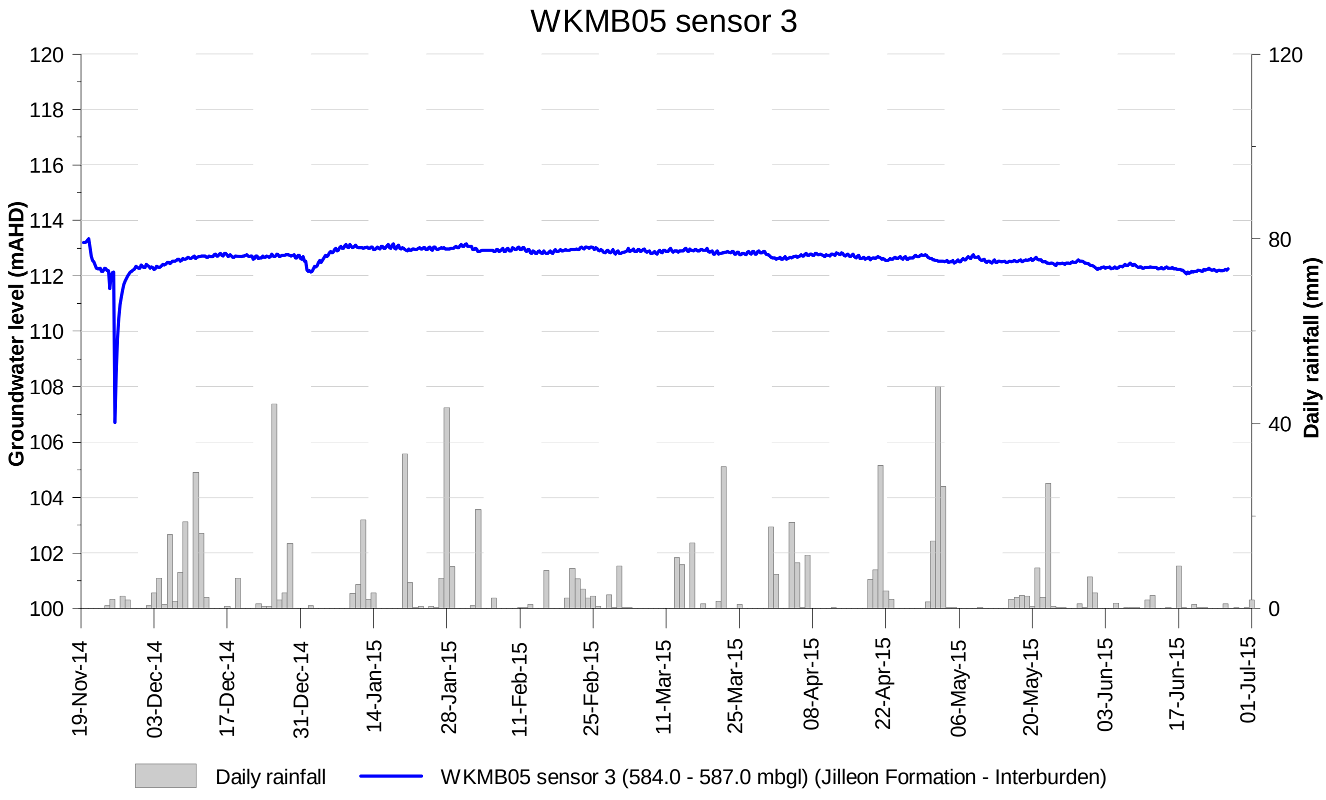


Figure A.32: WKMB05 sensors 1 and 2



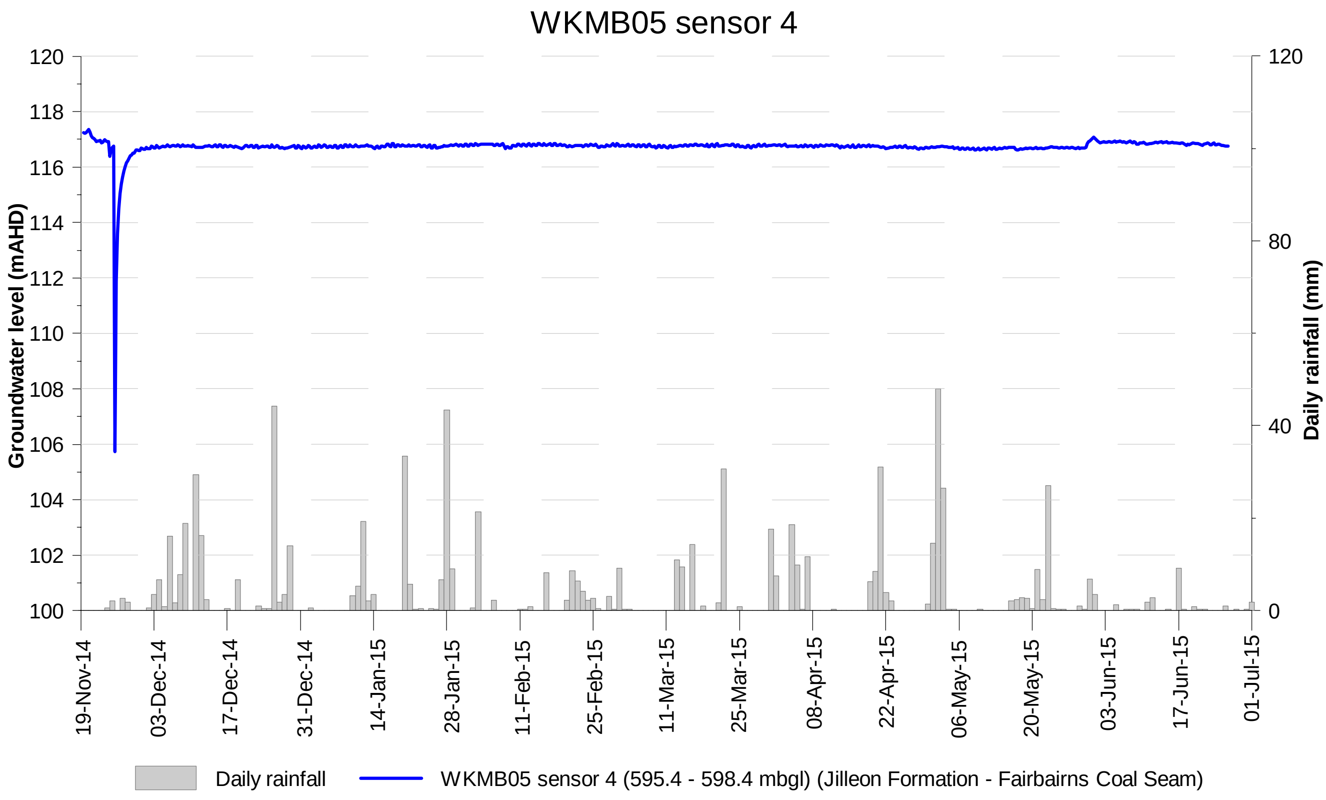
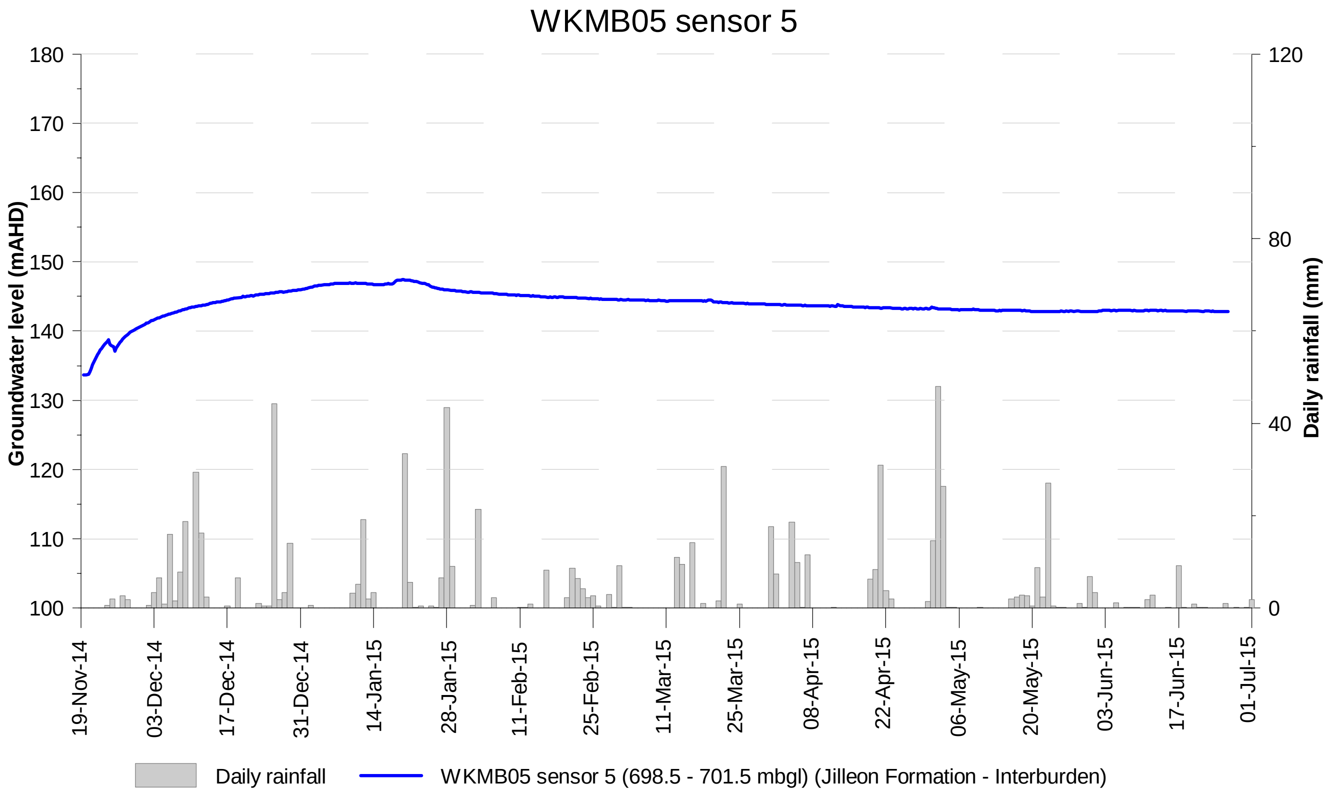


Figure A.33: WKMB05 sensors 3 and 4



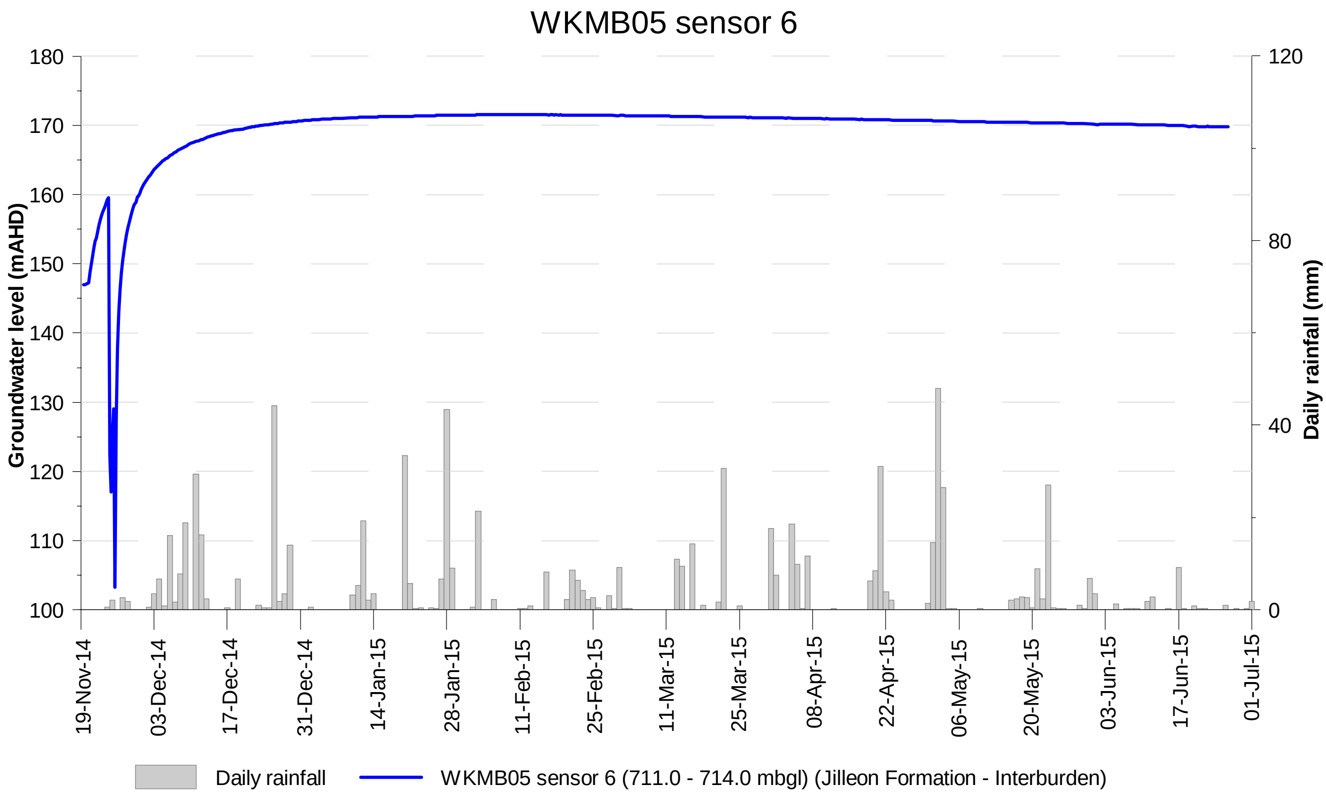


Figure A.34: WKMB05 sensors 5 and 6