AGL Upstream Investments Pty Ltd

# 2016 Groundwater and Surface Water Monitoring Status Report

# Gloucester Gas Project

7 September 2016

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. |
| 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, 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. |
| 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. |
| Beneficial aquifer | Aquifers found in the alluvium and Narrabeen Group sandstones less than 75 m from surface. |
| Bore | A structure drilled below the surface to obtain water from an aquifer or series of aquifers. |
| Claystone | A non-fissile rock of sedimentary origin composed primarily of clay-sized particles (less than 0.004 mm). |
| Coal | A sedimentary rock derived from the compaction and consolidation of vegetation or swamp deposits to form a fossilised carbonaceous rock. |
| Coal seam | A layer of coal within a sedimentary rock sequence. |
| Coal seam gas (CSG) | Coal seam gas is a form of natural gas (predominantly methane) that is extracted from coal seams. |
| Concentration | The amount or mass of a substance present in a given volume or mass of sample, usually expressed as milligram per litre (water sample) or micrograms per kilogram (sediment sample). |

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| 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. |
| Data logger | A digital recording instrument that is inserted in monitoring and pumping bores to record pressure measurements and water level variations. |
| Electrical conductivity (EC) | A measure of a fluid's ability to conduct an electrical current and is an estimation of the total ions dissolved. It is often used as a measure of water salinity. |
| 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. |
| Groundwater | The water contained in interconnected pores or fractures located below the water table in the saturated zone. |
| Groundwater level | The water level measured in a bore; this may be at or close to the water table in unconfined aquifers, or represent the average piezometric level across the screened interval in confined aquifers. |
| 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). |
| Head gradient | The change in total hydraulic head with a change in distance in a given direction. |
| Head (hydraulic) | 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. |
| Hydrology | The study of the occurrence, distribution, and chemistry of all surface waters. |
| Lithology | The study of rocks and their depositional or formational environment on a large specimen or outcrop scale. |

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| 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. |
| Permeability | The ability of a material to permit water to move through it. |
| Permian | The last period of the Palaeozoic era that finished approximately 252 million years before present. |
| Piezometric pressure | See hydraulic head. |
| Quaternary | The most recent geological period extending from approximately 2.6 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. |
| Recovery | The difference between the observed water level during the recovery period after cessation of pumping and the water level measured immediately before pumping stopped. |
| Salinity | The concentration of dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS). |
| Sandstone | Sandstone is a sedimentary rock composed mainly of sand-sized minerals or rock grains (predominantly quartz). |
| Screen | A type of bore lining or casing of special construction, with apertures designed to permit the flow of water into a bore while preventing the entry of aquifer or filter pack material. |
| Sedimentary rock | These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest volumes of groundwater. |
| Shale | A laminated sedimentary rock in which the constituent particles are predominantly of clay size. |
| Siltstone | A fine-grained rock of sedimentary origin composed mainly of silt-sized particles (0.004 to 0.06 mm). |
| Stratigraphy | The depositional order of sedimentary rocks in layers. |
| Groundwater-surface water 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 |

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| | groundwater through streambeds when the elevation of the water table is lower than the water level in the stream. |
| Vibrating wire piezometer | An instrument consisting of a vibrating wire element connected to a sensitive diaphragm; designed to measure pore pressures in fully and partially saturated soils and rock in boreholes. |
| Water bearing zone | Geological strata that are saturated with groundwater but not of sufficient permeability to be called an aquifer. |
| Water quality | Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose. |
| Water quality data | Chemical, biological, and physical measurements or observations of the characteristics of surface and ground waters, atmospheric deposition, potable water, treated effluents, and waste water and of the immediate environment in which the water exists. |
| Water table | The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water. |
| Well | Pertaining to a gas exploration well or gas production well. |

# Abbreviations

| | |
|---|---|
| AGL | AGL Upstream Investments Pty Ltd |
| BoM | Bureau of Meteorology |
| CDFM | Cumulative deviation from mean |
| CSG | Coal seam gas |
| EC | Electrical Conductivity |
| GFDA | Gas Field Development Area |
| GGP | Gloucester Gas project |
| LTA | Long term average |
| MGA | Map Grid of Australia |
| PEL | Petroleum Exploration Licence |
| PPL | Petroleum Production Lease |
| VWP | Vibrating wire piezometer |

# Units

| | |
|---|---|
| m | metres |
| $m^3/s$ | cubic metres per second |
| mAHD | metres Australian Height Datum |
| mbgl | metres below ground level |
| mg/L | Milligrams per litre |
| m/d | metres per day |
| µS/cm | microSiemens per centimetre |
| mm | millimetres |

# Executive summary

On 4 February 2016, AGL Energy (AGL) announced that the Gloucester Gas Project (GGP) would not proceed to final investment stage. AGL will relinquish Petroleum Exploration Licence (PEL) 285 (Figure 1.1) to the NSW Government and has commenced a comprehensive decommissioning and rehabilitation program for well sites and other infrastructure in the Gloucester region.

A dedicated water monitoring network had been in place that has enabled the collection of baseline water level and water quality data for the different groundwater and surface water systems within the Gloucester Basin (Figure 1.2). There were more than 50 dedicated water monitoring locations and more than five years of baseline monitoring (water levels and water quality) across the Gloucester Basin.

The majority of the monitoring network was decommissioned in June 2016 in advance of rehabilitation works and AGL's relinquishment of PEL 285.

This report is the final annual groundwater and surface water monitoring status report for AGL's water monitoring network for the GGP in the Gloucester Basin. This report represents the period 1 July 2015 to 30 June 2016 (the monitoring period).

**Rainfall**

Total rainfall for the period July 2015 to June 2016 at the AGL weather station was 855 mm, which is comparable to the long term average annual rainfall (979 mm) at Gloucester Post Office.

During the current monitoring period, rainfall was above the monthly average in September and December 2015 and January and June 2016 and below the monthly average during all other months of the monitoring period.

**Groundwater**

Groundwater level trends in monitoring bores vary depending on the lithology and depth of the screened interval:

- **Alluvium:** Groundwater levels in monitoring bores screened in the alluvial deposits showed a rapid response to significant rainfall events. This was a threshold response, which varied between sites, where rainfall events of a certain magnitude were required to trigger a response in groundwater levels. Most alluvial monitoring bores show a seasonal response characterised by a decrease in groundwater levels during times of below average rainfall, before increasing in response to the summer rainfall.
- **Shallow rock**: Groundwater levels in shallow rock monitoring bores increased slightly over the monitoring period in response to rainfall since October 2015. There were no strong responses to individual rainfall events in the shallow rock bores during this monitoring period with the exception of WKMB02 and WKMB06B. This is indicative of an increased hydraulic connection to recharge areas compared to other shallow rock monitoring bores.
- **Interburden units**: Monitoring bores screened within the interburden units showed no significant change over the monitoring period, and groundwater levels did not respond to individual rainfall events.
- **Deep coal seams:** Groundwater levels in monitoring bores that were screened within the coal seams showed a gradual increase during the monitoring period. There are no strong responses to individual rainfall events.

Vertical gradients were noted at 13 of the 15 nested bore installations:

- Downward hydraulic gradients were noted at the TTMB, S5MB, TCMB, FKMB and BWMB nested bore sites.
- Upward hydraulic gradients were noted at the S4MB, RMB, WKMB, WRMB, PL03, WKMB05 and LMG01 nested bore sites.
- An upward vertical gradient is noted at WKMB06 during periods of low rainfall which can change to a downward gradient following high rainfall and flood events.

No vertical head gradients were noted at the BMB and WMB. Due to the very low permeability of the interburden units, vertical groundwater flow is likely to be extremely slow and negligible, despite the vertical gradients. Lateral flow within each of the geological units is concluded to be the dominant groundwater flow mechanism when there are no stresses on the shallow or deep groundwater systems at these locations.

**Surface water**

Water levels remained relatively consistent throughout the FY16 monitoring period as a result of steady rainfall throughout the year. All stream gauges on the Avon River and Dog Trap Creek showed rapid responses to large rainfall events and runoff, and relatively steep recession curves, such as those associated with the December 2015, January and June 2016 rain events.

Surface water salinity decreased following rainfall events as relatively fresh runoff is routed into streams. An initial increase in salinity was often seen in the initial runoff phase as readily dissolvable salts are flushed from the ground surface and shallow soils, followed by dilution as rainfall persists.

**Groundwater – surface water interaction**

Groundwater levels in the alluvium have typically been higher than adjacent stream levels since monitoring began (by one to two metres), indicating that the streams are discharge features for shallow groundwater in the Stage 1 GFDA (Figure 5.3). Only during relatively short periods of high stream levels and flow, associated with rainfall events and floods, that the shallow alluvial groundwater were recharged from the streams.

The conclusions of this report regarding surface and groundwater levels, groundwater-surface water interaction and salinity observations captured in the FY16 monitoring period are consistent with the hydrogeological/ hydrological conceptual model of the Gloucester Basin (Parsons Brinckerhoff 2015g).

**Long term impact of the GGP**

A review of the groundwater level observation data collected for the 2016 monitoring period, (as is similar in previous years) has shown no attributable impacts from GGP site activities (fracture stimulation or flowback) evident in the monitoring data. Short term decreases in water levels can be seen in monitoring bores completed in the shallow rock, interburden and deeper coal seams and are associated with sampling events from these bores. In each case, the water level returned to pre sampling conditions in all bores for all sampling events.

It is not yet clear if the piezometric level hydrograph traces in the deep groundwater monitoring locations show a response to the Waukivory Pilot Project activities. It is possible that they show delayed pressure effect responses from either fracture stimulation or the commencement of flowback. However, these effects are not obvious and may be due to the low permeability of the interburden adjacent to the coal seams.

Surface water levels and quality have shown seasonal fluctuations in response to climate and have not shown any response that could be attributable to GGP site activities.

# 1. Introduction

This report is the final annual groundwater and surface water monitoring status report for the AGL Upstream Investments Pty Ltd (AGL) water monitoring network for the Gloucester Gas Project (GGP) in the Gloucester Basin. This report represents the monitoring period 1 July 2015 to 30 June 2016.

## 1.1 Background

On 4 February 2016, AGL announced that the GGP would not proceed to final investment stage. AGL will relinquish Petroleum Exploration Licence (PEL) 285 (Figure 1.1) to the NSW Government and has commenced a comprehensive decommissioning and rehabilitation program for well sites and other infrastructure in the Gloucester region.

A dedicated water monitoring network had been in place that has enabled the collection of baseline water level and water quality data for the different groundwater and surface water systems within the Gloucester Basin (Figure 1.2). There were more than 50 dedicated water monitoring locations and more than five years of baseline monitoring (water levels and water quality) across the Gloucester Basin.

The majority of the monitoring network was decommissioned in June 2016 in advance of rehabilitation works and AGL's relinquishment of PEL 285.

## 1.2 Objectives

The objectives of this final groundwater and surface water monitoring program were to:

- Provide baseline information on groundwater levels and salinity (where measured by data loggers) and the seasonal trends in levels and salinity at surface water monitoring sites across the Gloucester Basin (with a primary focus on the Stage 1 Gas Field Development Area (GFDA)).
- Provide baseline information on stream levels, flow and salinity (where measured by data loggers) in surface water systems across the Gloucester Basin (with a primary focus on the Stage 1 GFDA).

## 1.3 Scope of works

This report presents groundwater and surface water monitoring data for the GGP monitoring network, with an emphasis on data obtained during the monitoring period.

The scope of works relating to the GGP monitoring network and reporting includes:

- 4-monthly groundwater and surface water level monitoring, including data logger downloads and field measurements for verification.
- Maintenance of the water monitoring network and data loggers.
- Analysis and interpretation of water levels and salinity data (where measured by data loggers) with reference to the hydrogeological conceptual model (Parsons Brinckerhoff 2015g).
- 4-monthly updates and compilation of an interpreted annual report (this report) on water level and salinity (where measured by data loggers) trends during the year.

Water sampling was carried out in relation to the following exploration programs during the monitoring period across the GGP monitoring network:

- The Waukivory Pilot Project (Parsons Brinckerhoff 2015a, 2015b, 2015c, 2015d, 2016a and 2016b).
- The Tiedman Irrigation Program (Parsons Brinckerhoff 2015e and 2015f).

Data obtained from these programs prior to July 2015 are reported elsewhere and are not included in this annual status report.

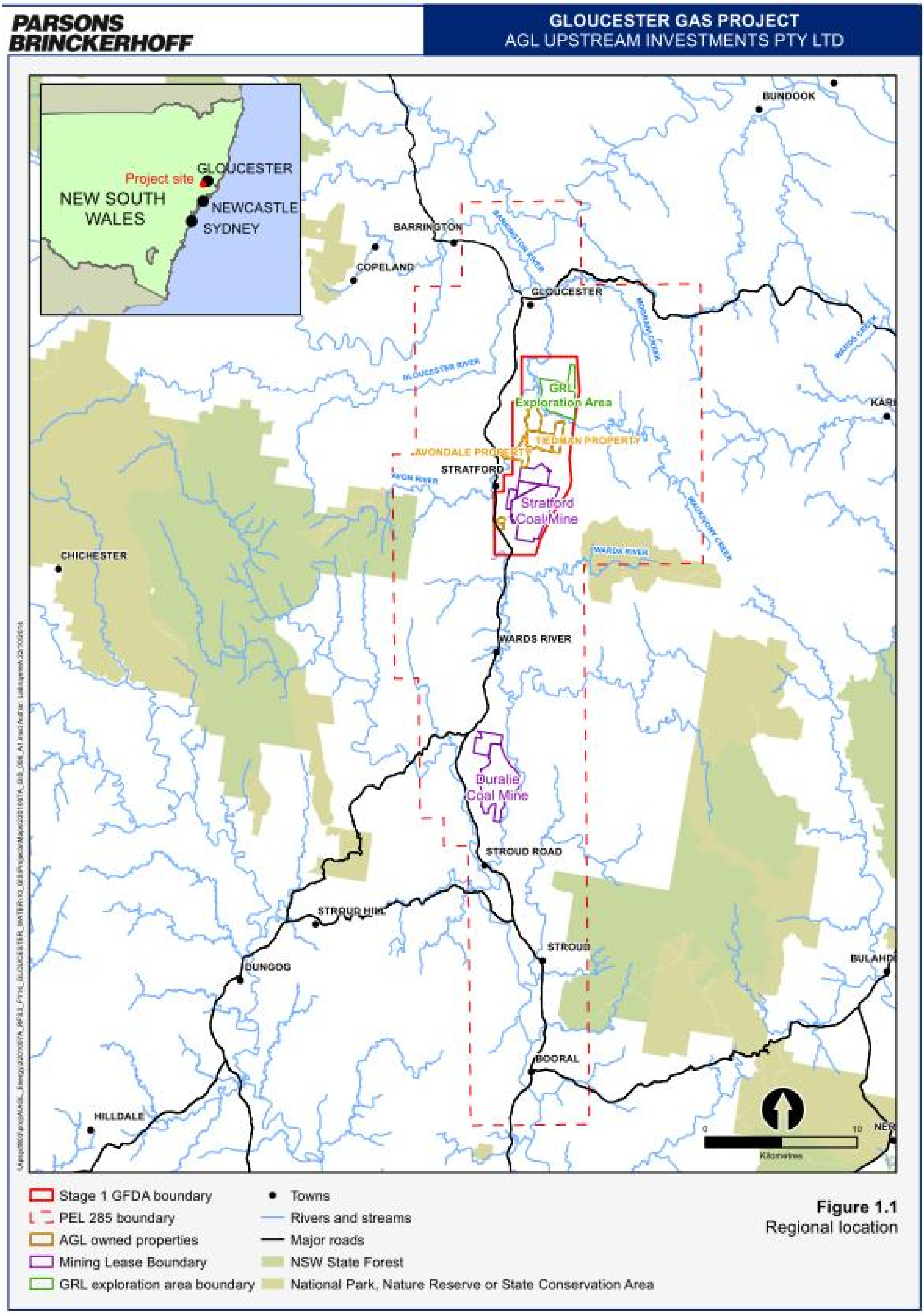


**Figure 1.1 Regional location**

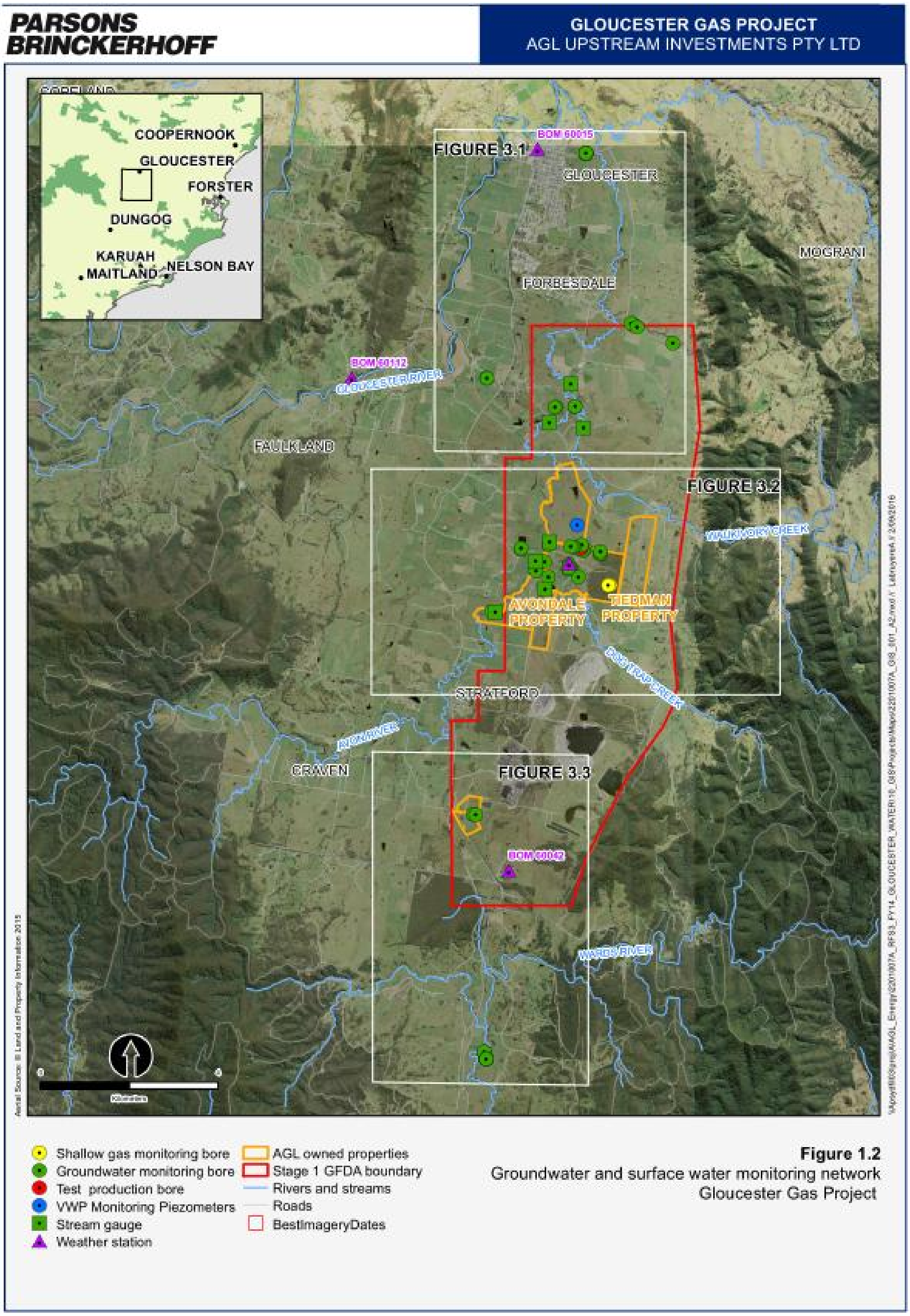


**Figure 1.2** **Groundwater and surface water monitoring network – Gloucester Gas Project**

# 2. Site characterisation

## 2.1 Rainfall

The Bureau of Meteorology (BoM) operates four weather stations within the Gloucester Basin and AGL operates one weather station on the Tiedman property (Figure 1.2). Average rainfall and the period of monitoring for the BoM stations are presented in Table 2.1.

**Table 2.1 BoM stations in the Gloucester Basin (BoM 2016)**

| BoM station number | Location name | Monitoring period | Long term average annual rainfall (mm)[a] |
|---|---|---|---|
| 60015 | Gloucester Post Office | 1888 to present | 978 |
| 60112 | Gloucester Hiawatha | 1976 to present | 1001 |
| 60042 | Craven (Longview) | 1961 to present | 1047 |
| 61071 | Stroud Post Office | 1889 to present | 1140 |

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

The long-term, annual cumulative deviation from mean (CDFM) rainfall for Gloucester Post Office weather station is plotted in Figure 2.1. 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 2.1) shows that over the last 60 years, short (2 to 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 from the AGL weather station for the period July 2011 (installation) to June 2016 are presented in Figure 2.2 and rainfall data for the current monitoring period is presented in Figure 2.3. During the current monitoring period, rainfall was above the monthly average in September and December 2015 and January and June 2016 and below the monthly average during all other months of the monitoring period.

Total rainfall for the period July 2015 to June 2016 at the AGL weather station was 855 mm, which is comparable to the long term average annual rainfall (978 mm) at Gloucester Post Office.

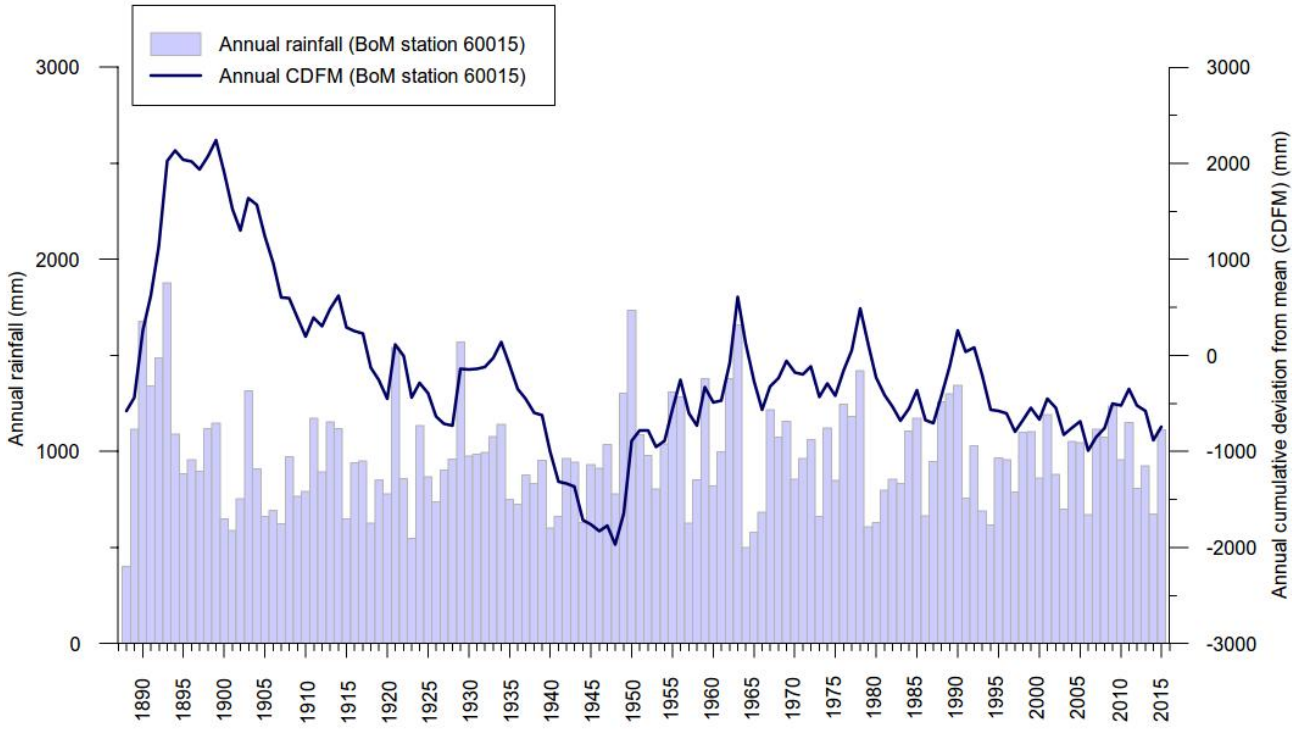


**Figure 2.1** **Long term annual rainfall and cumulative deviation from annual mean (CDFM) rainfall at Gloucester Post Office BoM station 060015 (BoM 2016)**

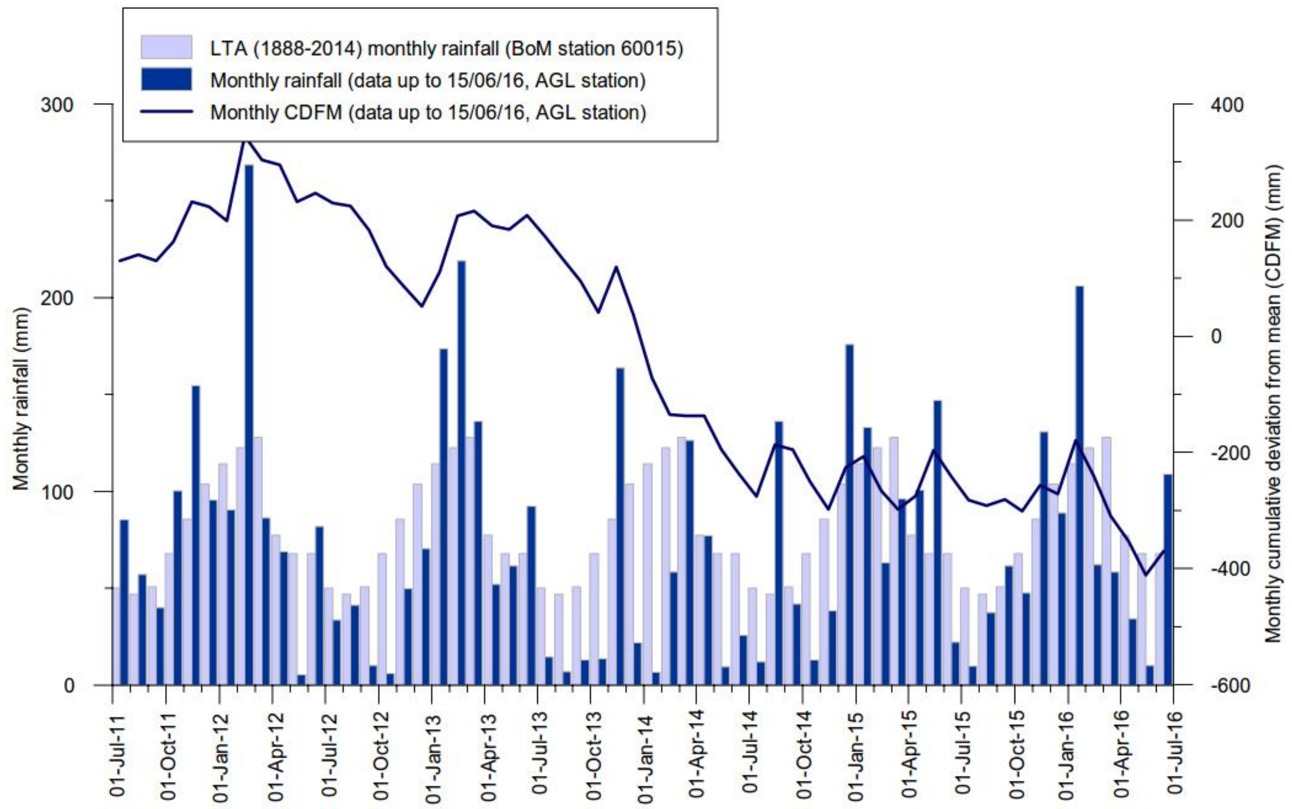


**Figure 2.2** **Monitoring period monthly rainfall, and cumulative deviation from the monthly mean (CDFM) rainfall at the AGL Gloucester station (AGL 2016)**

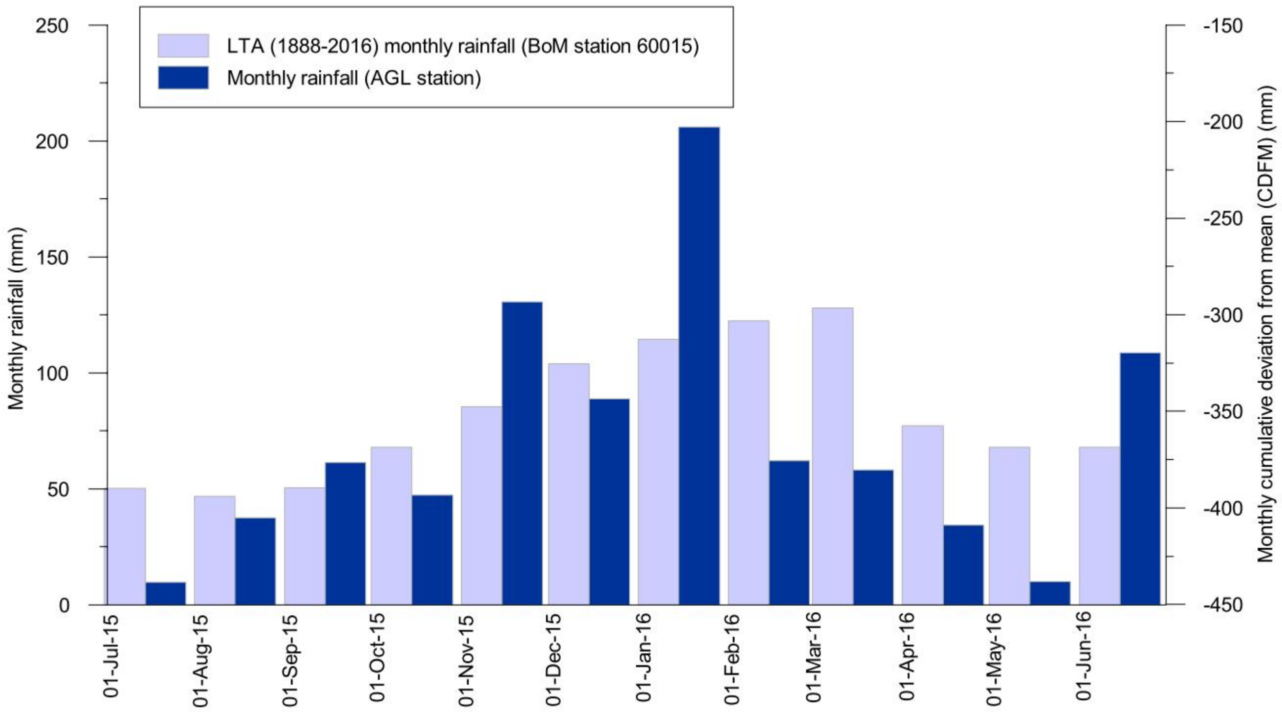


**Figure 2.3 Monthly rainfall and long term average (LTA) monthly rainfall for the monitoring period.**

## 2.2 Surface hydrology

The Gloucester Basin is a narrow, north-south trending, elongated basin approximately 40 km long and 10 km wide, extending from Gloucester in the north to Stroud in the south. The Gloucester Basin is located in the upper reaches of the Manning River and Karuah River coastal catchments. The area occupied by the Permian Coal Measures (about 217 $km^2$) is small in comparison to the size of these catchments.

Surface water flow in the Gloucester Basin is divided between the Wards River catchment (a sub-catchment of the Karuah River catchment) and the Avon River catchment (a sub-catchment of the Manning River catchment). In the north of the basin, within the Manning River catchment, the surface water flow direction is to the north. In the south of the basin, within the Karuah River catchment, the surface water flow direction is to the south.

Predominantly, surface water flow in the Stage 1 GFDA is within the Avon River catchment, and includes the tributaries of Dog Trap Creek and Waukivory Creek (Figure 1.2). The Avon River joins the Gloucester River in the north of the Gloucester Basin at Gloucester.

## 2.3 Geological setting

The Gloucester Basin 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 occurring towards the end of the Permian (Hughes 1984). 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 sedimentary deposits and regolith. The Quaternary sediments are variable 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.

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 2.2. A geological map of the basin is shown in Figure 2.4. The CSG development in the Stage 1 GFDA was targeting the intermediate and deep coal seams in the Gloucester Coal Measures generally below depths of 250 m to approximately 1,000 m.

**Table 2.2 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).

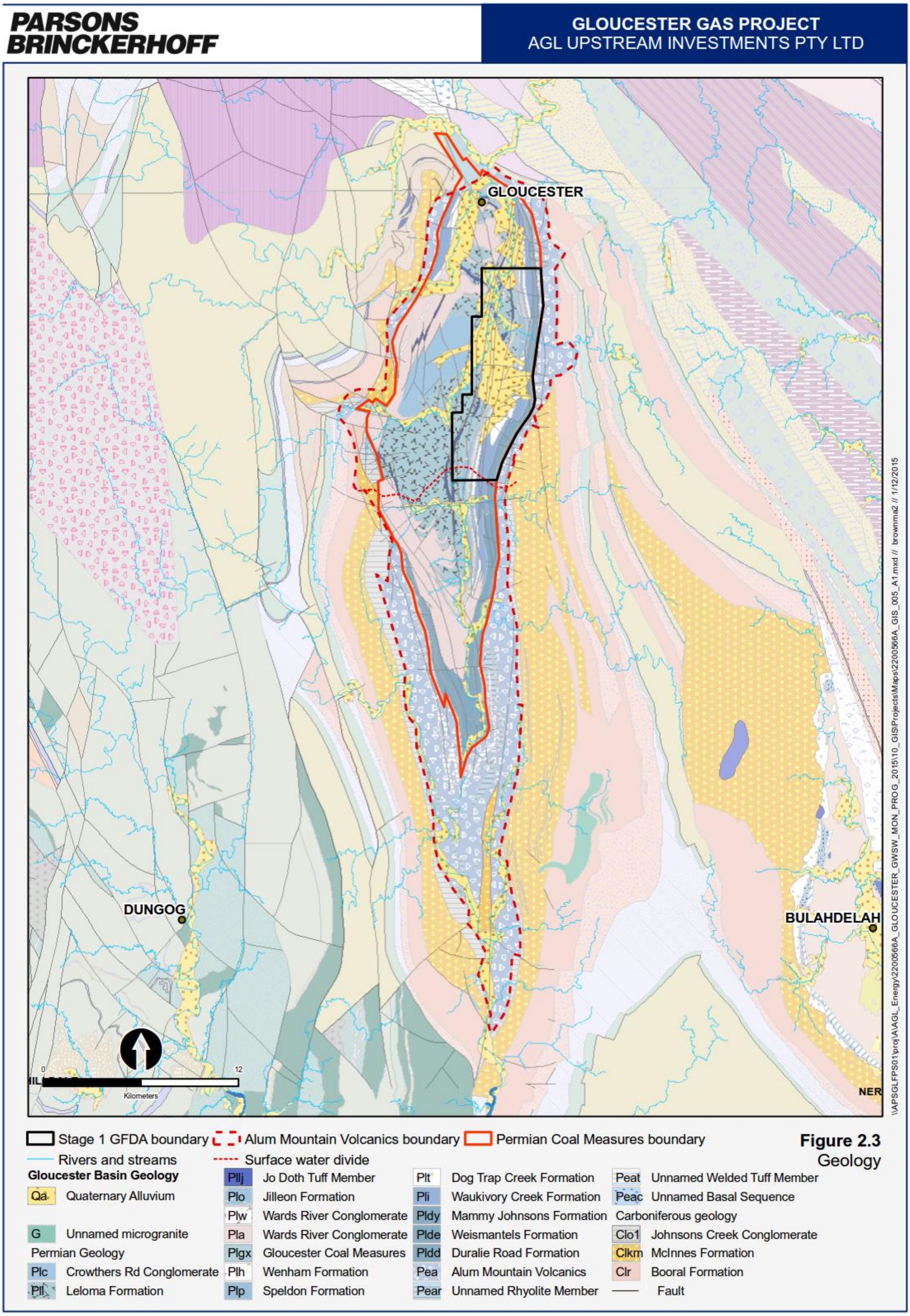


**Figure 2.4 Regional geology**

## 2.4 Hydrogeological setting

Four broad hydrogeological units have been identified within the Gloucester Basin (Table 2.3). The hydraulic conductivity and groundwater flow characteristics 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 2.3 Four hydrogeological units – Gloucester Basin**

| Unit | Aquifer type | Formation name | General lithology | Hydraulic characteristics |
|---|---|---|---|---|
| Alluvial aquifers | 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 Permian 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 ($10^{-4}$ to $10^{-6}$ 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.

# 3. Monitoring program

## 3.1 Monitoring network

AGL's groundwater and surface water monitoring locations are shown in Figure 3.1 (Bucketts Way, Waukivory and Faulkland locations), Figure 3.2 (Avondale, Bignell, Merridong, Pontilands and Tiedman locations), and Figure 3.3 (Rombo and Wards River locations). The decommissioning status of each monitoring location is outlined in Table 3.1 to Table 3.4.

### 3.1.1 Groundwater

The monitoring network comprised three types of groundwater monitoring installations:

1. Conventional monitoring bores targeting:
   a) The shallow alluvial sediments of the Avon River and its tributaries, and Wards River.
   b) The shallow fractured rock.
   c) The deep interburden and coal seams of the Gloucester Coal Measures.
2. VWP arrays installed to monitor piezometric pressure (pore pressure) in the deep interburden and a deep coal seam of the Gloucester Coal Measures (PL03 and LMG01).
3. A multizone monitoring well installed to monitor piezometric pressure in the deep interburden and deep coal seams of the Gloucester Coal Measures (WKMB05).

Monitoring bores were often installed in "nested" sites which comprise several bores targeting different depths and hydrogeological units at the one location. The construction details for the GGP groundwater monitoring bores are presented in Table 3.1, the details for the VWP array is presented in Table 3.2 and the details of the multizone monitoring well are presented in Table 3.3.

Prior to decommissioning there were 50 groundwater locations across the broader area of the Basin.

Seepage monitoring bores (TMB04 and TMB05) associated with water storage dams located on AGL's Tiedman property in the Stage 1 GFDA do not monitor regional groundwater therefore the monitoring results are not discussed in this report. Results of the analysis of the gas samples collected from shallow gas monitoring bores (TGMB01 and TGMB02) are presented in Section 4.2.

**Table 3.1 AGL Gloucester groundwater monitoring bores**

| Monitoring bore | Location | Total depth (mbgl) | Screened interval (mbgl) | Lithology | Formation | Hydro-geological unit | Decommissioning status |
|---|---|---|---|---|---|---|---|
| S4MB01 | Tiedman | 66 | 58.0 – 64.0 | Sandstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |
| S4MB02 | Tiedman | 97 | 89.0 – 95.0 | Sandstone/ siltstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |
| S4MB03 | Tiedman | 170 | 162.0 – 168.0 | Coal | Jilleon Formation – Cloverdale Coal Seam | Deep Coal Seam | Retain for future landowner |
| S5MB01 | Tiedman | 60 | 52.0 – 58.0 | Sandstone/ siltstone | Jilleon Formation | Shallow fractured rock | Retain for future landowner |
| S5MB02 | Tiedman | 114 | 100.0 – 112.0 | Siltstone | Jilleon Formation | Shallow fractured rock | Retain for future landowner |
| S5MB03 | Tiedman | 166 | 158.0 – 164.0 | Coal/shale | Jilleon Formation – Roseville Coal Seam | Deep Coal Seam | Retain for future landowner |
| TMB01 | Tiedman | 12 | 7.0 – 10.0 | Clay | Avon River Alluvium | Alluvial | Retain for future landowner |
| TMB02 | Tiedman | 15.5 | 9.0 – 12.0 | Mixed gravels | Avon River Alluvium | Alluvial | Retain for future landowner |
| TMB03 | Tiedman | 12.5 | 5.0 – 11.0 | Mixed gravels and sand | Avon River Alluvium | Alluvial | Retain for future landowner |
| TCMB01 | Tiedman | 90 | 87.0 – 93.0 | Sandstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |
| TCMB02 | Tiedman | 183 | 175.0 – 181.0 | Sandstone | Leloma Formation | Interburden | Retain for future landowner |
| TCMB04 | Tiedman | 334.7 | 327.3 – 333.3 | Coal | Jilleon Formation – Roseville Coal Seam | Deep Coal Seam | Retain for future landowner |
| TTPB | Tiedman | 90 | 76.0 – 88.0 | Sandstone/ siltstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |

| Monitoring bore | Location | Total depth (mbgl) | Screened interval (mbgl) | Lithology | Formation | Hydro-geological unit | Decommissioning status |
|---|---|---|---|---|---|---|---|
| TTMB01 | Tiedman | 90 | 76.0 – 88.0 | Sandstone/ siltstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |
| TTMB02 | Tiedman | 90 | 76.0 – 88.0 | Sandstone/ siltstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |
| TTMB03 | Tiedman | 198 | 186.0 – 199.0 | Sandstone/ siltstone | Leloma Formation | Interburden | Retain for future landowner |
| NS725R | Merridong | 50[a] | 14.0 - 32.0[a] | n/a | Avon sub-group | Shallow fractured rock | Retain for future landowner |
| NS726R | Merridong | 50[a] | 8.0 – 32.0[a] | n/a | Avon sub-group | Shallow fractured rock | Retain for future landowner |
| NS735R | Merridong | 50[a] | 8.0 – 32.0[a] | n/a | Jilleon Formation | Shallow fractured rock | Retain for future landowner |
| NS746R | Merridong | 50[a] | 14.0 – 32.0[a] | n/a | Jilleon Formation | Shallow fractured rock | Retain for future landowner |
| AMB01 | Avondale | 12.6 | 8.0 – 10.0 | Mixed gravels | Avon River Alluvium | Alluvial | Retain for future landowner |
| AMB02 | Avondale | 11.5 | 6.5 – 11.0 | Mixed gravels | Avon River Alluvium | Alluvial | Retain for future landowner |
| RMB01 | Rombo | 51 | 42.0 – 48.0 | Sandstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |
| RMB02 | Rombo | 93 | 85.0 – 91.0 | Sandstone | Leloma Formation | Shallow fractured rock | Retain for future landowner |
| TMB04 | Tiedman | 15 | 8.0 – 14.0 | Siltstone | Leloma formation | Seepage monitoring site | Retain for future landowner |
| TMB05 | Tiedman | 10 | 6.0 – 9.0 | Siltstone | Leloma Formation | Seepage monitoring site | Retain for future landowner |
| WMB01 | GRL – Waukivory | 8.5 | 5.0 – 8.0 | Mixed gravel/ sand | Avon River Alluvium | Alluvial | Retain for future landowner |

| Monitoring bore | Location | Total depth (mbgl) | Screened interval (mbgl) | Lithology | Formation | Hydro-geological unit | Decommissioning status |
|---|---|---|---|---|---|---|---|
| WMB03 | GRL – Waukivory | 36 | 32.0 – 34.0 | Coal | Wenham Formation – Bowens Road Coal Seam | Shallow fractured rock | Retain for future landowner |
| BWMB01A | Bucketts Way | 11.6 | 6.5 – 9.5 | Mixed gravels | Avon River Alluvium | Alluvial | Plug and Abandon |
| BWMB01B | Bucketts Way | 21 | 14.0 – 20.0 | Sandstone/ gravel | Jilleon Formation | Shallow fractured rock | Plug and Abandon |
| BWMB01C | Bucketts Way | 81.4 | 67.4 – 79.4 | Sandstone | Jilleon Formation | Shallow fractured rock | Plug and Abandon |
| BWMB01D | Bucketts Way | 162.6 | 149.6 – 161.6 | Sandstone/ siltstone | Jilleon Formation | Interburden | Plug and Abandon |
| FKMB01A | Faulklands | 54 | 44.0 – 53.0 | Sandstone | Leloma Formation | Shallow fractured rock | Plug and Abandon |
| FKMB01B | Faulklands | 150.2 | 140.2 – 149.2 | Sandstone | Leloma Formation | Shallow fractured rock | Plug and Abandon |
| TGMB01 | Tiedman | 6 | 3.0 – 6.0 | Weathered Rock | Jilleon Formation | Gas monitoring site | Plug and Abandon |
| TGMB02 | Tiedman | 15.4 | 12.3 – 15.3 | Weathered Rock/Coal | Jilleon Formation | Gas monitoring site | Plug and Abandon |
| TCMB03 | Tiedman | 268 | 260.0 – 266.0 | Coal and sandstone | Jilleon Formation – Cloverdale Coal Seam | Deep Coal Seam | Plug and Abandon |
| BMB01 | Bignell | 30 | 15.0 – 29.0 | Sandstone/ siltstone | Leloma Formation | Shallow fractured rock | Plug and Abandon |
| BMB02 | Bignell | 138 | 124.0 – 136.0 | Sandstone | Leloma Formation | Shallow fractured rock | Plug and Abandon |
| WMB02 | GRL – Waukivory | 23 | 15.0 – 21.0 | Sandstone | Wenham Formation | Shallow fractured rock | Plug and Abandon |
| WMB04 | GRL – Waukivory | 80.5 | 67.0 – 79.0 | Sandstone | Wenham Formation | Shallow fractured rock | Plug and Abandon |

| Monitoring bore | Location | Total depth (mbgl) | Screened interval (mbgl) | Lithology | Formation | Hydro-geological unit | Decommissioning status |
|---|---|---|---|---|---|---|---|
| WKMB01 | Waukivory Pilot | 54 | 47.0 – 53.0 | Sandstone | Leloma Formation | Shallow fractured rock | Plug and Abandon |
| WKMB02 | Waukivory Pilot | 61 | 51.0 – 60.0 | Sandstone/ siltstone | Leloma Formation | Shallow fractured rock | Plug and Abandon |
| WKMB03 | Waukivory Pilot | 210 | 200.0 – 209.0 | Sandstone | Leloma Formation | Interburden | Plug and Abandon |
| WKMB06A | Waukivory Pilot | 13.4 | 6.4 – 12.4 | Alluvium | Avon River Alluvium | Alluvial | Plug and Abandon |
| WKMB06B | Waukivory Pilot | 63 | 52.0 – 61.0 | Sandstone | Leloma Formation | Shallow fractured rock | Plug and Abandon |
| Farley[b] | Pontilands | ~60.0 | N/A | N/A | N/A | N/A | Plug and Abandon |
| WRMB01A | Wards River | 8.1 | 4.5 – 7.0 | Mixed gravels | Wards River Alluvium | Alluvial | Plug and Abandon |
| WRMB01B | Wards River | 56.4 | 48.4 – 54.4 | Sandstone | Jilleon Formation | Shallow fractured rock | Plug and Abandon |
| WRMB01C | Wards River | 126.5 | 111.5 – 123.5 | Sandstone | Jilleon Formation | Shallow fractured rock | Plug and Abandon |
| WRMB01D | Wards River | 199 | 178.0 – 184.0 | Sandstone | Jilleon Formation | Interburden | Plug and Abandon |

(a) Merridong monitoring bores are inclined by 60 degrees, total depth and screened interval is down hole depth and not true depth (mbgl).

(b) Although water levels are monitored in this bore, no trends are discussed in this report (the hydrograph trace is provided in Appendix A) as there are few details known about the construction of this old water (test) bore.

The groundwater monitoring bores highlighted in green above are subject to ongoing monitoring obligations associated with the Tiedman Irrigation Program (through Environment Protection Licence 20358 (EPA 2016)) and are therefore still operational at the time of writing.

**Table 3.2 Summary of AGL Gloucester vibrating wire piezometer construction details**

| VWP | Total depth (mbgl)[a] | Sensor ID | Sensor depth (mbgl) | Lithology | Formation | Hydrogeological unit | Decommissioning status |
|---|---|---|---|---|---|---|---|
| PL03[b] | 966.3 | 2 | 496 | Coal | Wenham Formation – Bowens Road Coal Seam | Deep coal seam | Retained for future landowner |
| | | 3 | 463 | Pebble conglomerate | Wards River Conglomerate | Interburden | |
| LMG01 | | 01 | 465 | Interbedded indurated sandstone/ siltstone and claystone | Waukivory Creek formation | Interburden | Retained for future landowner |
| | | 02 | 485 | Coal | Waukivory Creek - Avon Coal Seam | Deep coal seam | |

(a) mbgl – metres below ground level.

(b) PL03 Sensor ID #1 installed at a depth of 681 m is not operable.

**Table 3.3 Summary of AGL multizone monitoring well construction details**

| | Total depth (mbgl) | Sensor ID | Sensor depth (mbgl) | Lithology | Formation | Hydrogeological unit | Decommissioning status |
|---|---|---|---|---|---|---|---|
| WKMB05 | 1,100 | 1 | 340.0 – 343.0 | Siltstone/ sandstone | Leloma Formation | Interburden (aquitard) | Plugged and abandoned |
| | | 2 | 426.0 – 429.0 | Coal | Jilleon Formation – Cloverdale Coal Seam | Deep coal seam | |
| | | 3 | 584.0 – 587.0 | Siltstone/ sandstone | Jilleon Formation | Interburden (aquitard) | |
| | | 4 | 595.4 – 598.4 | Coal | Jilleon Formation – Fairbairns Coal Seam | Deep coal seam | |
| | | 5 | 698.5 – 701.5 | Siltstone/ sandstone | Jilleon Formation | Interburden (aquitard) | |
| | | 6 | 711.0 – 714.0 | Siltstone/ sandstone | Jilleon Formation | Interburden (fault zone) | |

mbgl – metres below ground level.

Each horizon is installed with a pressure transducer to measure the piezometric level.

### 3.1.2 Surface water

There were seven AGL stream gauges in the Gloucester Basin; five on the Avon River, one on Dog Trap Creek, and one on Waukivory Creek (Table 3.4). These were all located within the Stage 1 GFDA. The locations of the surface water monitoring sites are presented in Figures 3.1 to 3.3.

**Table 3.4 AGL Gloucester stream gauges**

| Stream gauge | Easting (MGA, m) | Northing (MGA, m) | Location | Stream | Decommissioning status |
|---|---|---|---|---|---|
| TSW01 | 401994 | 6449417 | Tiedman (downstream) | Avon River | Retained for future landowner |
| TSW02 | 401922 | 6448741 | Tiedman (tributary) | Dog Trap Creek | Retained for future landowner |
| ASW01 | 401711 | 6449092 | Avondale (downstream) | Avon River | Retained for future landowner |
| ASW02 | 400698 | 6447963 | Avondale (upstream) | Avon River | Retained for future landowner |
| WKSW01 | 402002 | 6452208 | Waukivory Pilot (upstream) | Avon River | Removed |
| WKSW02 | 402772 | 6452099 | Waukivory Pilot (tributary) | Waukivory Creek | Retained for future landowner |
| WKSW03 | 402488 | 6453088 | Waukivory Pilot (downstream) | Avon River | Removed |

MGA - Map Grid of Australia.

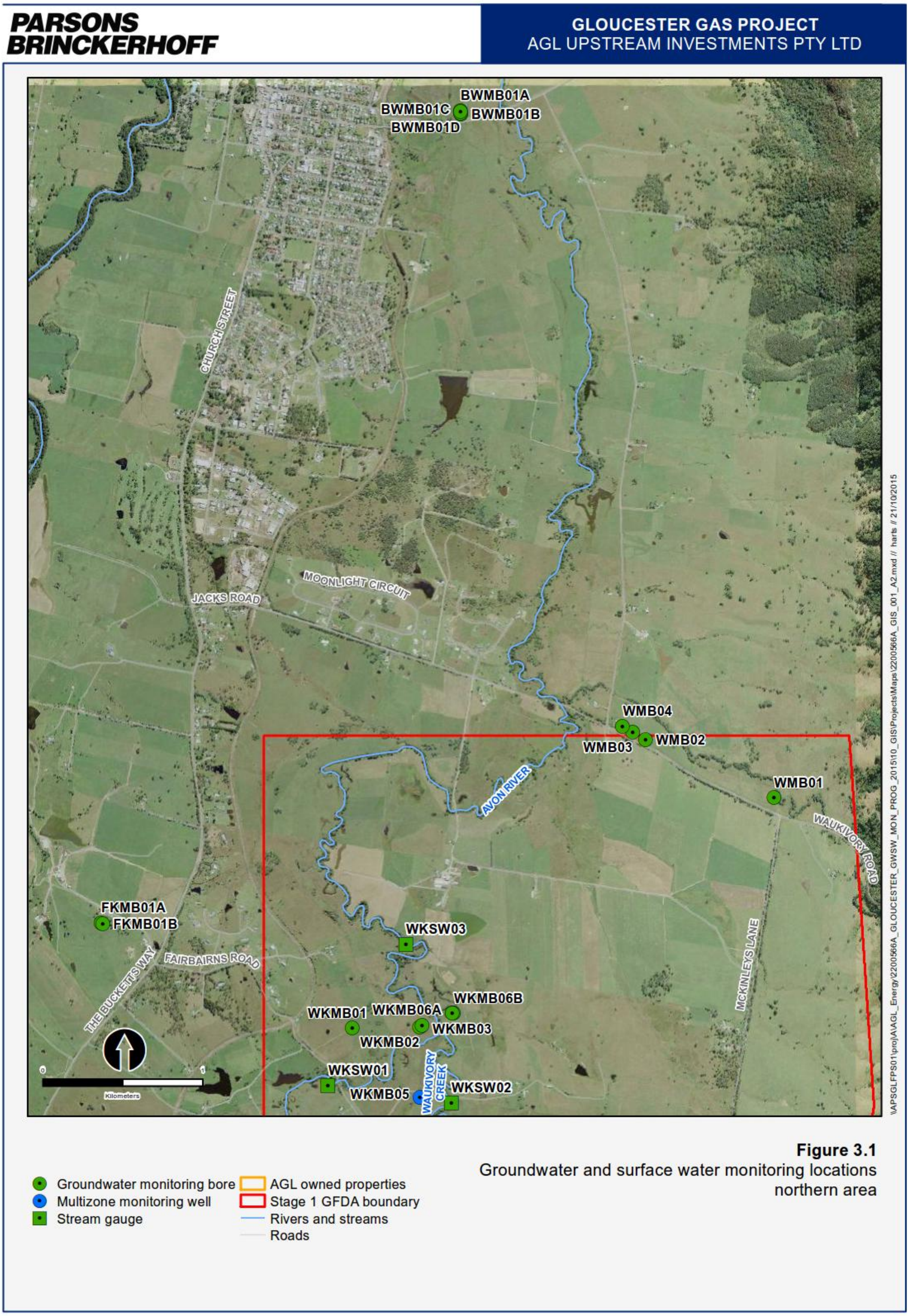


**Figure 3.1 Groundwater and surface water monitoring locations – northern area**

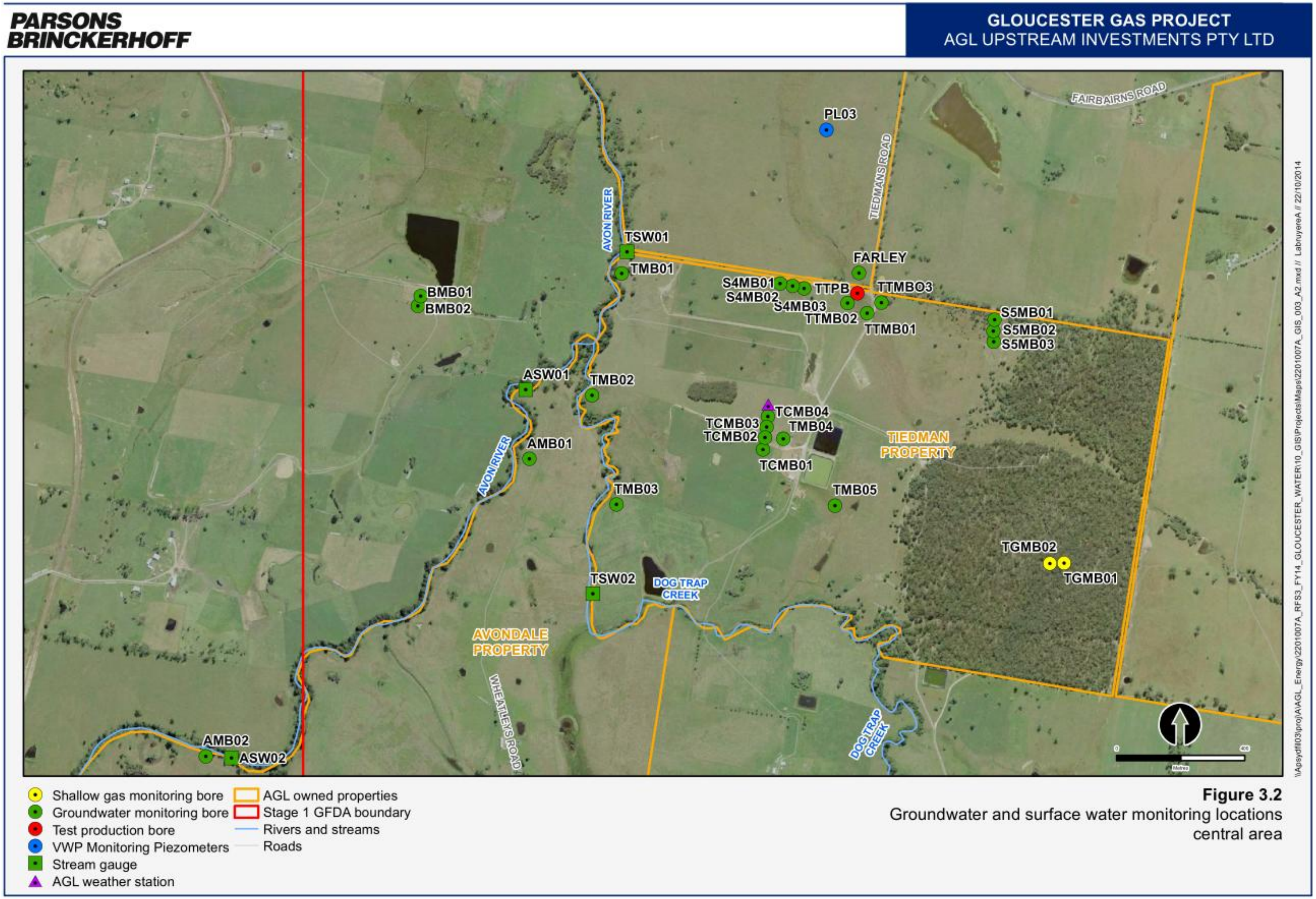


**Figure 3.2 Groundwater and surface water monitoring locations – central area**

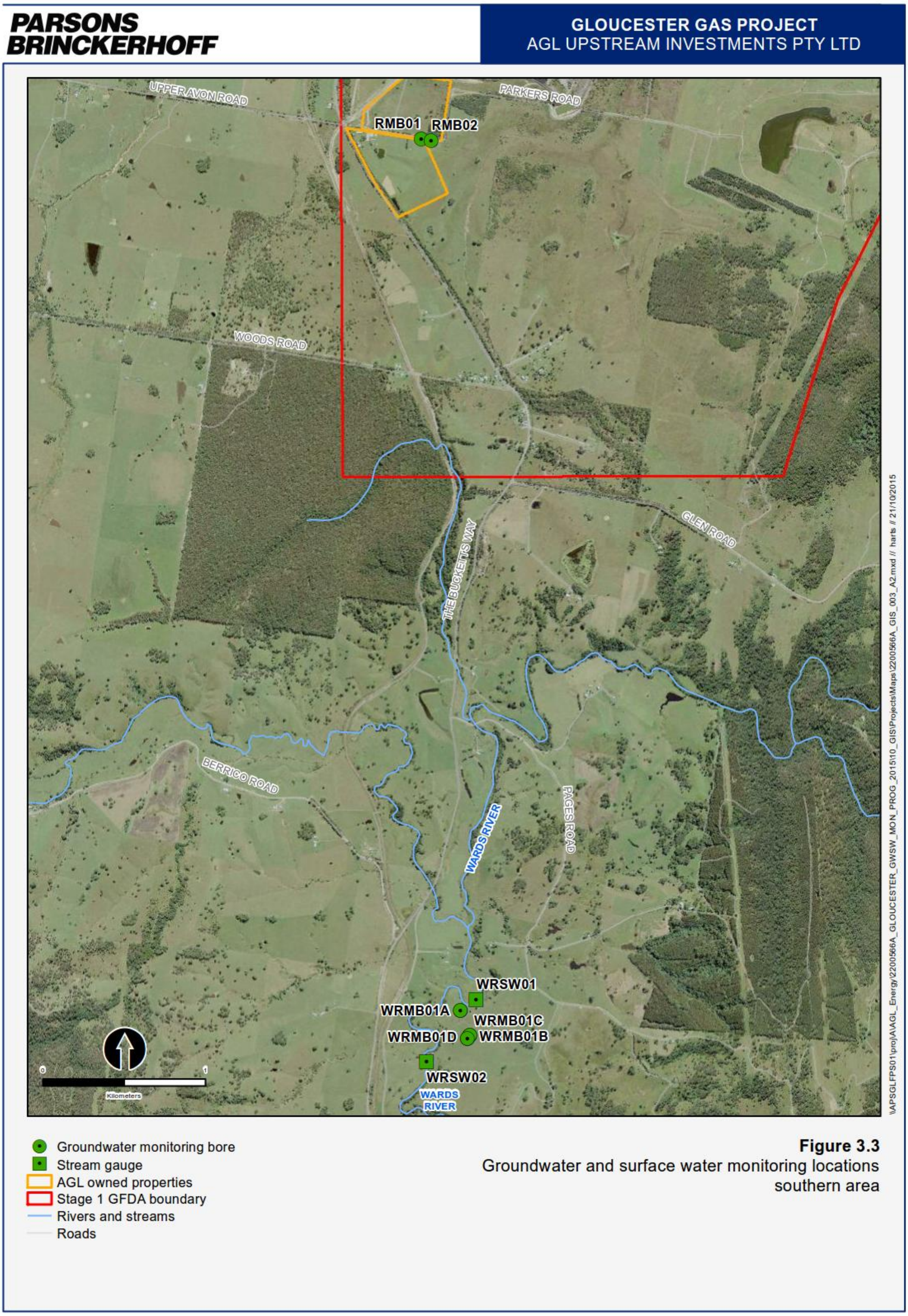


**Figure 3.3 Groundwater and surface water monitoring locations – southern area**

# 3.2 Water level monitoring

Groundwater level monitoring commenced in January 2011 (Figure 3.4) and surface water level monitoring commenced in March 2011 (Figure 3.5). The majority of the monitoring network has been in place since January 2011 (Parsons Brinckerhoff 2012). Following the decision to discontinue the GGP, with the exception of those locations highlighted in Table 3.1, AGL water monitoring has ceased and monitoring locations have been decommissioned or are being retained for future landowners (Table 3.4 to Table 3.4).

Data loggers were installed in each of the groundwater monitoring bores to monitor groundwater levels every six hours. To calibrate the level recorded by the data loggers, manual groundwater level measurements were recorded every four months using an electronic dip meter. Data loggers installed at the VWP sites and at the multizone monitoring well monitored piezometric pressure every six hours.

A barometric data logger installed at WKMB02 above the water table recorded changes in atmospheric pressure. Data from this logger were used to correct the effects of changing barometric pressure on groundwater levels. At the stream gauges, data loggers were installed to monitor water levels and salinity every 15 minutes. Water levels were verified by manual gauge board readings recorded every four months. Salinity (recorded as Electrical Conductivity (EC)) measurements were checked every four months using a hand-held water quality meter.

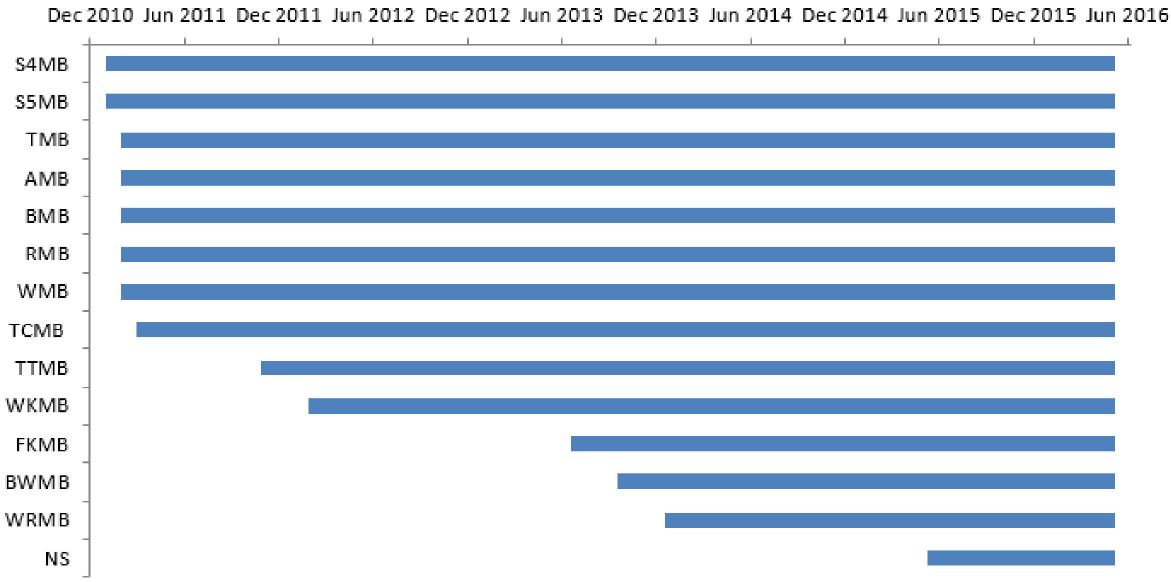


**Figure 3.4 Groundwater level data collection periods for each nested groundwater bore location**

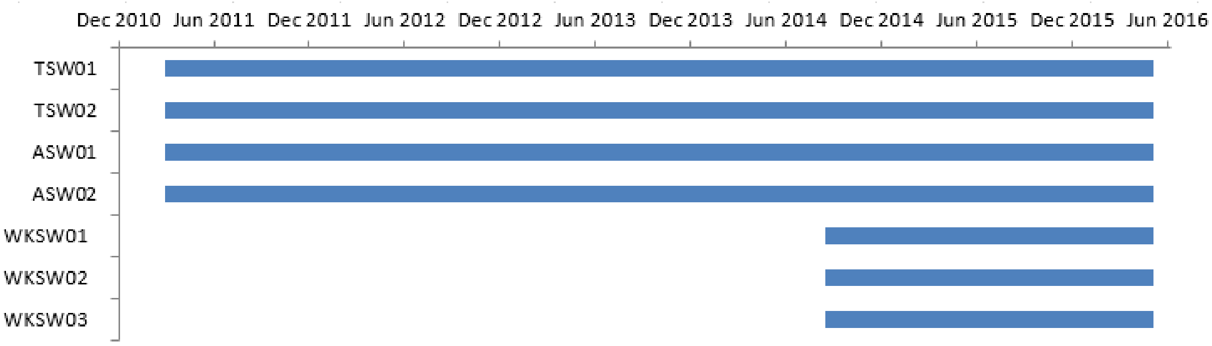


**Figure 3.5 Surface water level data collection periods for each monitoring location**

# 4. Groundwater monitoring

## 4.1 Groundwater levels

### 4.1.1 Temporal trends

Groundwater level trends in monitoring bores vary depending on the lithology and depth of the screened interval. Temporal trends are described for each hydrogeological unit in this section. Alluvial hydrographs are presented in Section 4.1.1.1. Trends for the shallow rock, coal seam and interburden hydrogeological units are presented in the nested monitoring bore hydrographs in Sections 4.1.1.2, 4.1.1.3 and 4.1.1.4, respectively. Individual hydrographs for each monitoring bore are shown in Appendix A. All monitoring bores were located in the Avon River catchment with the exception of the WRMB sites which were located in the Wards River catchment.

#### 4.1.1.1 Alluvium

Groundwater levels in most alluvial monitoring bores remained steady or slightly increased over the first months of the monitoring period, corresponding to the overall above average rainfall over this period, followed by an increase then gradual decline in groundwater levels over the remaining months of the year following the November/December 2015 and January 2016 rainfall.

Groundwater levels in monitoring bores screened in the alluvial deposits show a sharp response to significant rainfall events (Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.12 and Figure 4.15). This is a threshold response, with rainfall events of a certain magnitude required to trigger a response in groundwater levels. This response is variable between sites.

Over the course of the monitoring period groundwater levels at the TMB and WMB alluvial monitoring bores (Figure 4.1 and Figure 4.3) show an increase in response to the higher than average rainfall events in November 2015, December 2015, January 2016, June 2016. This increase is ~ 1.40 m at TMB01, ~ 0.6 m at TMB02, ~ 0.4 m at TMB03 and ~0.8 m at WMB01. The hydrographs for these sites show a relatively steep recession curve, with a return to antecedent groundwater levels over a period of one to two months. During dry periods when stream levels are known to be relatively low, a correlating decrease (ranging up to 1 m) in alluvial groundwater level at the TMB sites is observed. This response is most pronounced at TMB01 during late 2012/early 2013, late 2013, March 2014 and again in late 2014 (Figure 4.1).

During the year, groundwater levels at the AMB alluvial monitoring bores (Figure 4.2) typically show a smaller response (< 0.1 m) to most rainfall events. However, the groundwater level at AMB02 shows an increase of ~ 1.3 m in December 2015 and January 2016 in response to larger rainfall events. The hydrographs at these two sites show a flatter recession curve, with groundwater levels rising sharply following the January 2016 rainfall then steadily decreasing until June 2016.

BWMB01A (Figure 4.14) has shown no responses to individual rainfall events, although there is a very slight increase associated with large rainfall during December 2015 to January 2016.

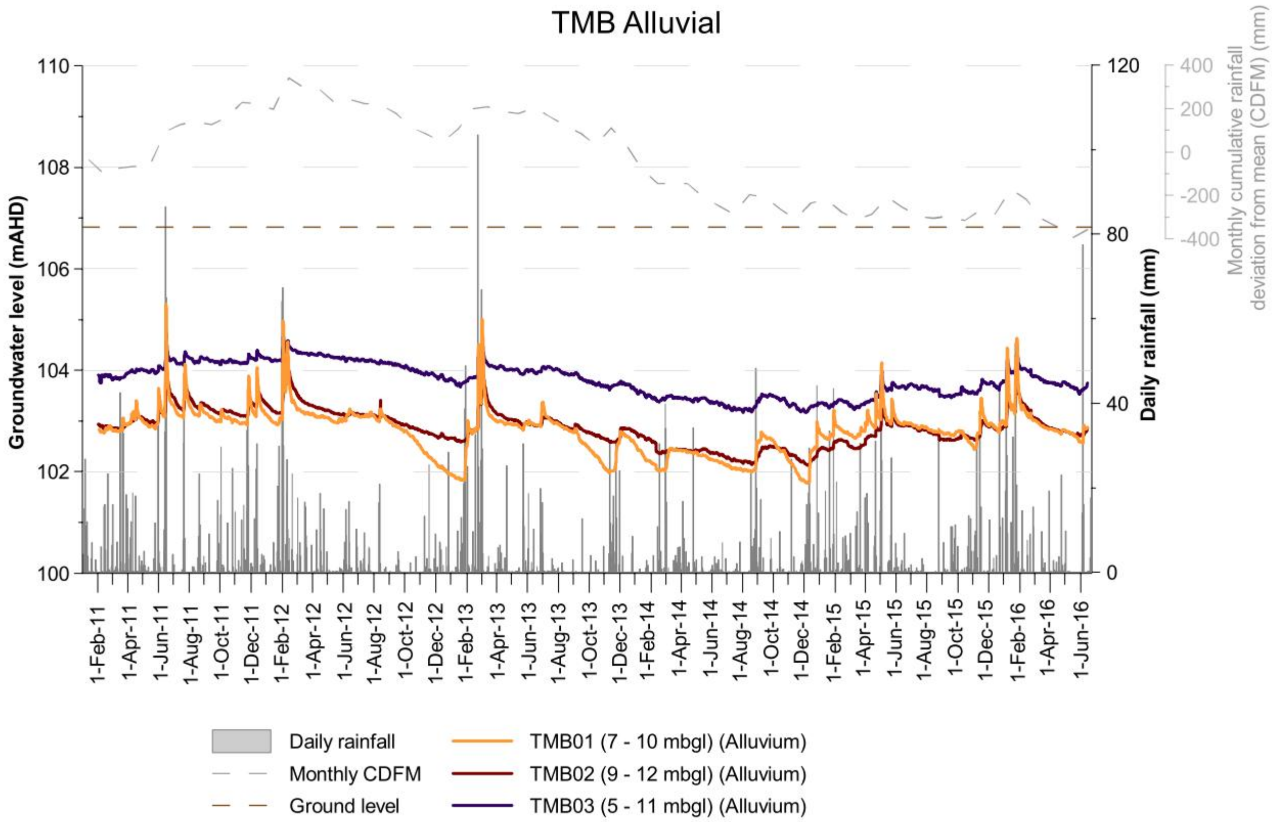


**Figure 4.1 Groundwater levels and rainfall in the TMB alluvial monitoring bores**

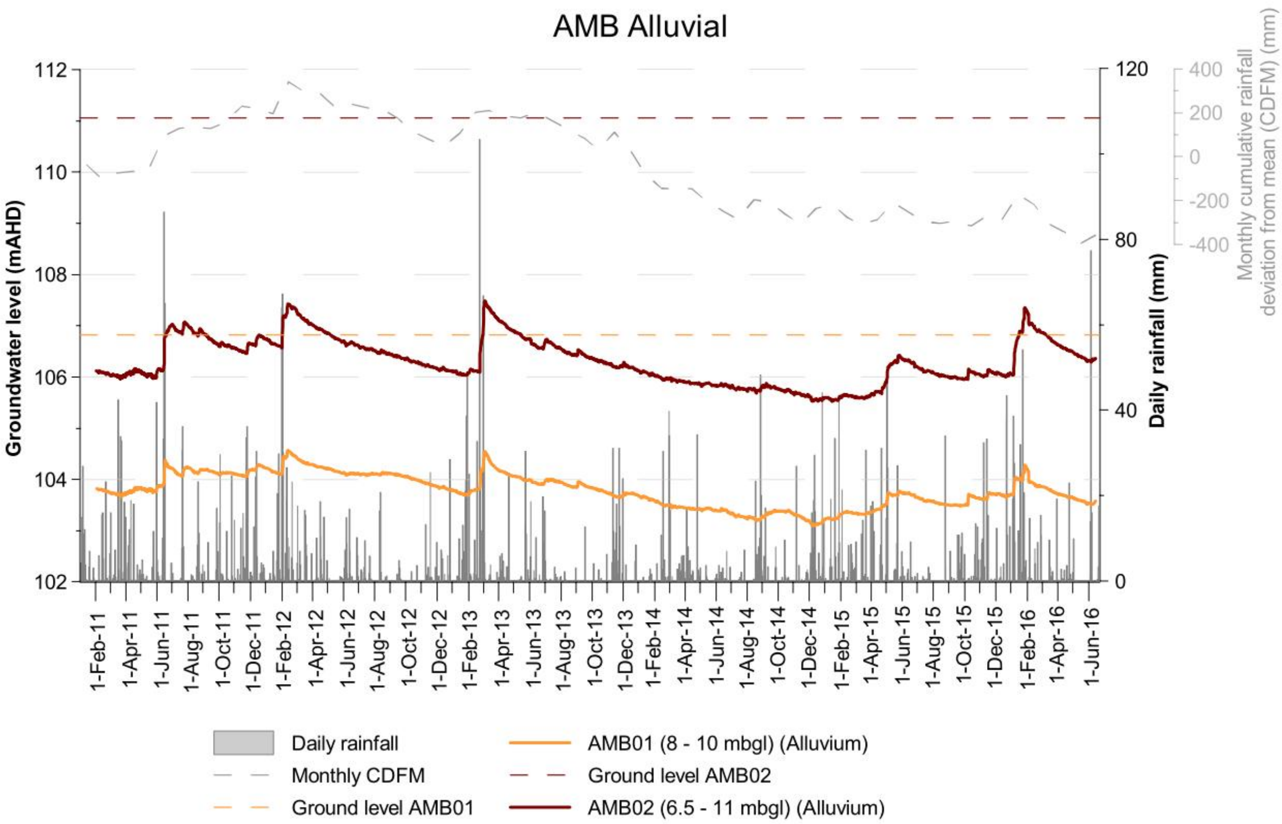


**Figure 4.2 Groundwater levels and rainfall at the AMB alluvial monitoring bores**

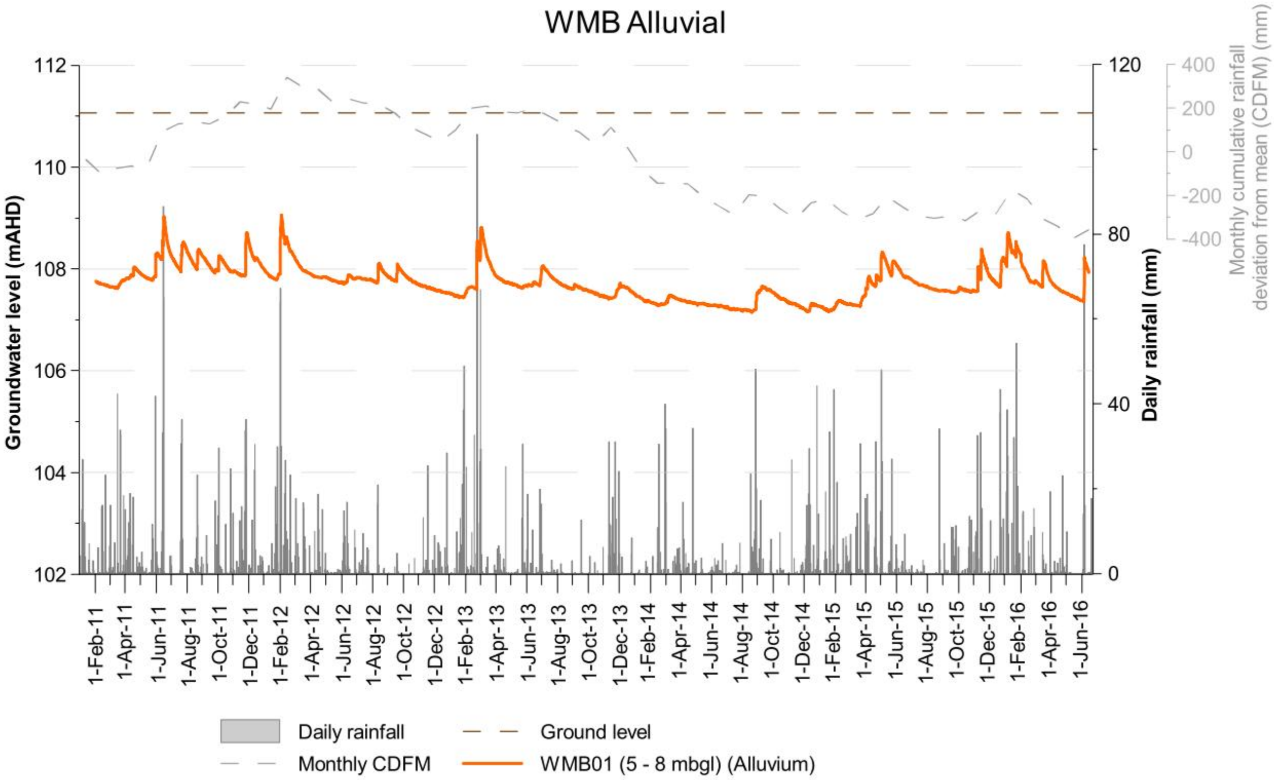


**Figure 4.3 Groundwater levels and rainfall at the WMB alluvial monitoring bore**

#### 4.1.1.2 Shallow rock

Monitoring bores screened within the shallow rock were present at all of the nested monitoring sites. Groundwater levels in the shallow rock typically showed 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 slowly to rainfall recharge over a broad area, assumed to be up-gradient of the monitoring locations. The groundwater level response is typically delayed approximately one to two months after periods of higher than average rainfall.

The shallow rock hydrographs at the S4MB (Figure 4.4), TCMB (Figure 4.6) and TTMB (Figure 4.7) sites show an overall slight increase in groundwater levels of (between 0.04 m and 0.1 m) between July 2015 and June 2016, as a delayed response to the above average rainfall conditions during the monitoring period.

At the BMB (Figure 4.8), RMB (Figure 4.9) and WMB (Figure 4.10) sites, groundwater levels in the shallow rock show a slightly greater response to long term rainfall recharge trends than compared to S4MB (Figure 4.4) and TCMB (Figure 4.6) bores. The greatest response is visible at the RMB site, which shows an increase in groundwater levels following the rainfall events from October 2015 to February 2016.

The data loggers at WKMB01 and WKMB02 failed in March 2014 and were replaced in September 2014 and August 2014, respectively, resulting in gaps in the data records. Groundwater levels in monitoring bores WKMB01 and WKMB02 (Figure 4.11) took roughly two days to recover from the frequent sampling events associated with the Waukivory Pilot Project (Parsons Brinckerhoff 2015c). This water level response to sampling is usually indicative of low conductivity conditions. Monitoring bores in the shallow rock at the WKMB02 (Figure 4.11) and WKMB06 (Figure 4.12) sites showed an overall increase in groundwater levels in response to rainfall events over the year. Water levels at WKMB01 did increase as a response to rainfall however due to logger malfunction it is not possible to determine the full range. The increase response from the December 2015/January 2016 rainfall is ~1.4 m at WKMB02 and ~1.2 m at WKMB06B.

There are no strong responses to individual rainfall events in the shallow rock monitoring bores, with the exception of WKMB02 in February 2013, and WKMB02 and WKMB06B in May 2015 and January 2016 (Figure 4.11 and Figure 4.12). The water levels in WKMB02 and WKMB06B show stronger responses to rainfall recharge in comparison to other shallow rock monitoring bores. The magnitude and lag time of the rainfall response depends on the degree of hydraulic connectivity between the screened formation and nearby recharge areas. This response indicates that WKMB02 and WKMB06B have an increased hydraulic connection to recharge areas than other shallow rock monitoring bores.

S5MB01 (Figure 4.5) shows a very slow recovery in response to the June 2013 sampling event (more than six months) and shows erratic groundwater level data since March 2014 and therefore does not provide useful information on baseline trends. S5MB02 screened in the shallow rock shows no overall change in groundwater level over the year from July 2015 to June 2016. The cause of the anomalous sharp increase in groundwater levels of ~ 2m at S5MB02 associated with the June 2013 water sampling event is not clear, although it may be associated with improved hydraulic connection after the water sampling event.

The shallow rock hydrographs at the FKMB (Figure 4.13) and BWMB (Figure 4.14) sites show no significant changes in groundwater levels within the shallow rock the since monitoring commenced.

The shallow rock hydrographs at the WRMB (Figure 4.15) site show minimal response to rainfall recharge over the monitoring year from July 2015 to June 2016. WRMB01B shows a delayed recovery following the July 2015 sampling event, which is indicative of very low hydraulic conductivity of the shallow rock at this monitoring location. From October 2015 the data logger at WRMB01B failed and the erroneous data has been omitted.

The shallow rock hydrographs at the Merridong site (NS725R, NS726R, NS735R and NS746S) (Figure 4.16) sites show no significant changes in groundwater levels within the shallow rock the since monitoring commenced.

#### 4.1.1.3 Interburden

The interburden monitoring bores TCMB02 (Figure 4.6), TTMB03 (Figure 4.7) and BWMB01D (Figure 4.14) show no overall change in groundwater levels over the monitoring year with the exception of a minimal response to the rainfall events in December 2015/January 2016. TCMB02 (Figure 4.6) and TTMB03 (Figure 4.7) took roughly two days to recover from sampling events associated with the Tiedman Irrigation Program, indicative of the low conductivity of the formation at these locations.

Groundwater levels at WKMB03 (Figure 4.11) show a distinctive delayed recovery response to sampling events, which is indicative of very low hydraulic conductivity within the interburden/fault zone. Increasing groundwater levels at WKMB03 from December 2014 to June 2016 are due to a delayed recovery response after the high frequency groundwater sampling events carried out as part of the Waukivory Pilot Project (Parsons Brinckerhoff 2015c, Parsons Brinckerhoff 2015d, Parsons Brinckerhoff 2016a and Parsons Brinckerhoff 2016b).

#### 4.1.1.4 Coal seams

The coal seam monitoring bore S4MB03 (Figure 4.4) shows a gradual increase in groundwater level of ~ 0.3 m between July 2015 and June 2016. The slight increase observed in February 2016 is most likely a delayed response to the period of rainfall during December 2015 and January 2016.

Coal seam monitoring bores S5MB03 (Figure 4.5) TCMB03 and TCMB04 (Figure 4.6) do not show an overall change in groundwater levels over the monitoring period with the exception of a minimal response to the rainfall events in late January 2016 in TCMB04. The dataloggers at S5MB03 and TCMB03 failed to connect and could not be downloaded causing the data gaps.

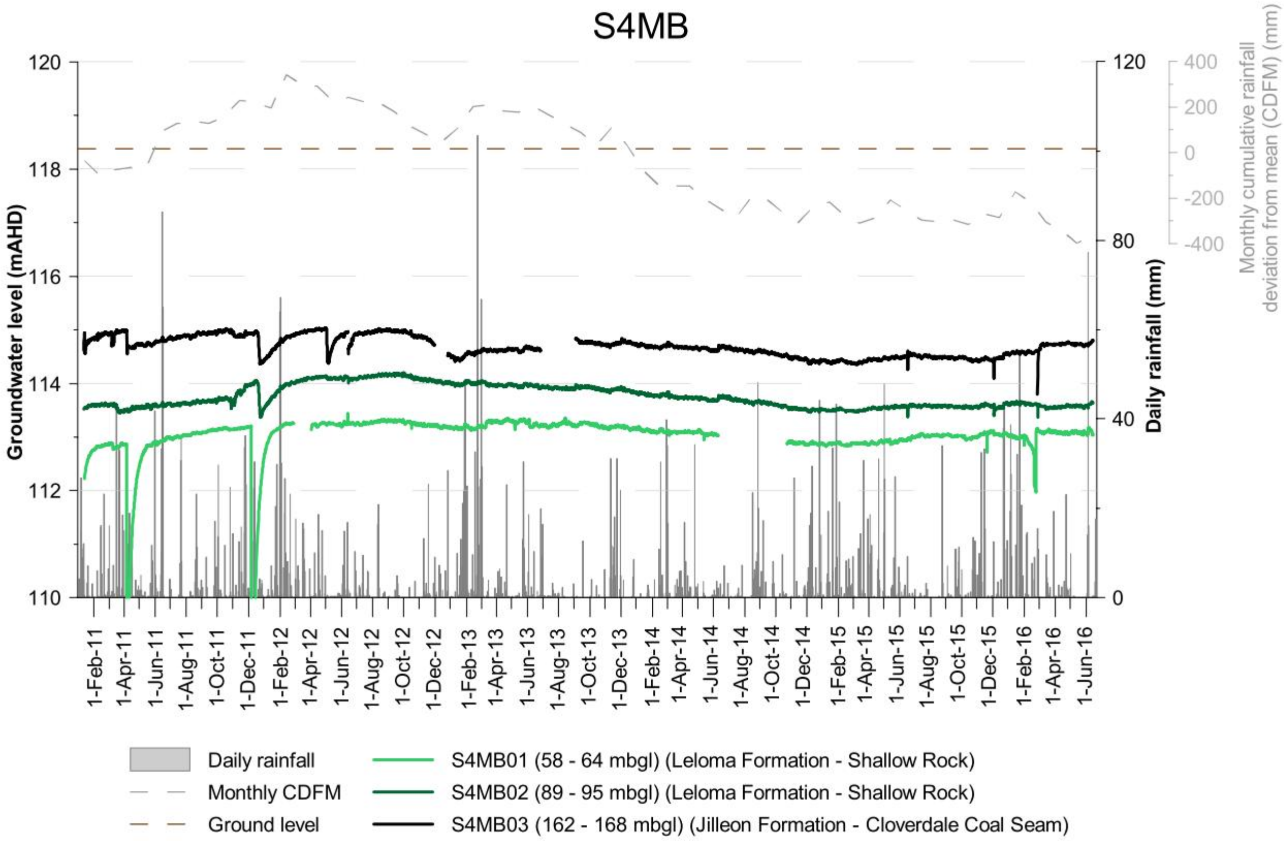


**Figure 4.4** **Groundwater levels and rainfall at the S4MB site**

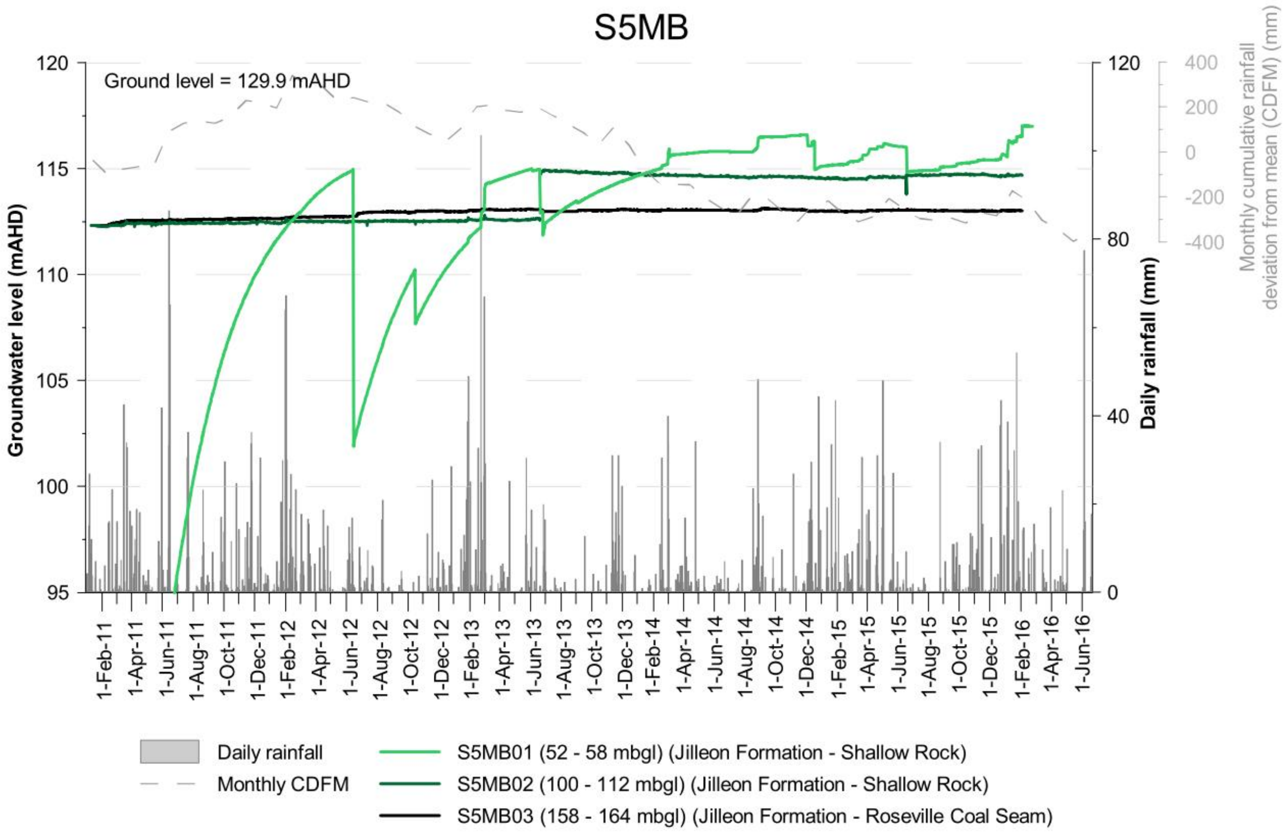


**Figure 4.5** **Groundwater levels and rainfall at the S5MB site**

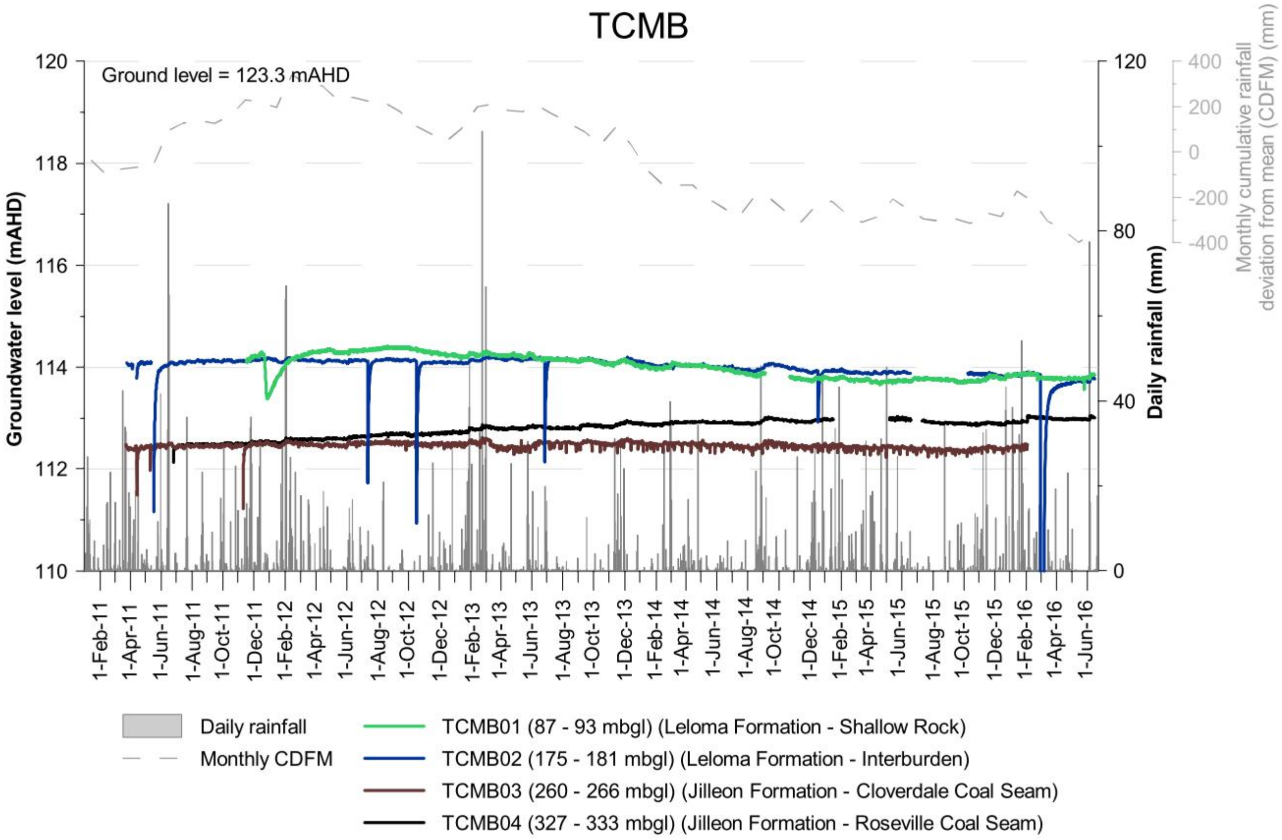


**Figure 4.6 Groundwater levels and rainfall at the TCMB site**

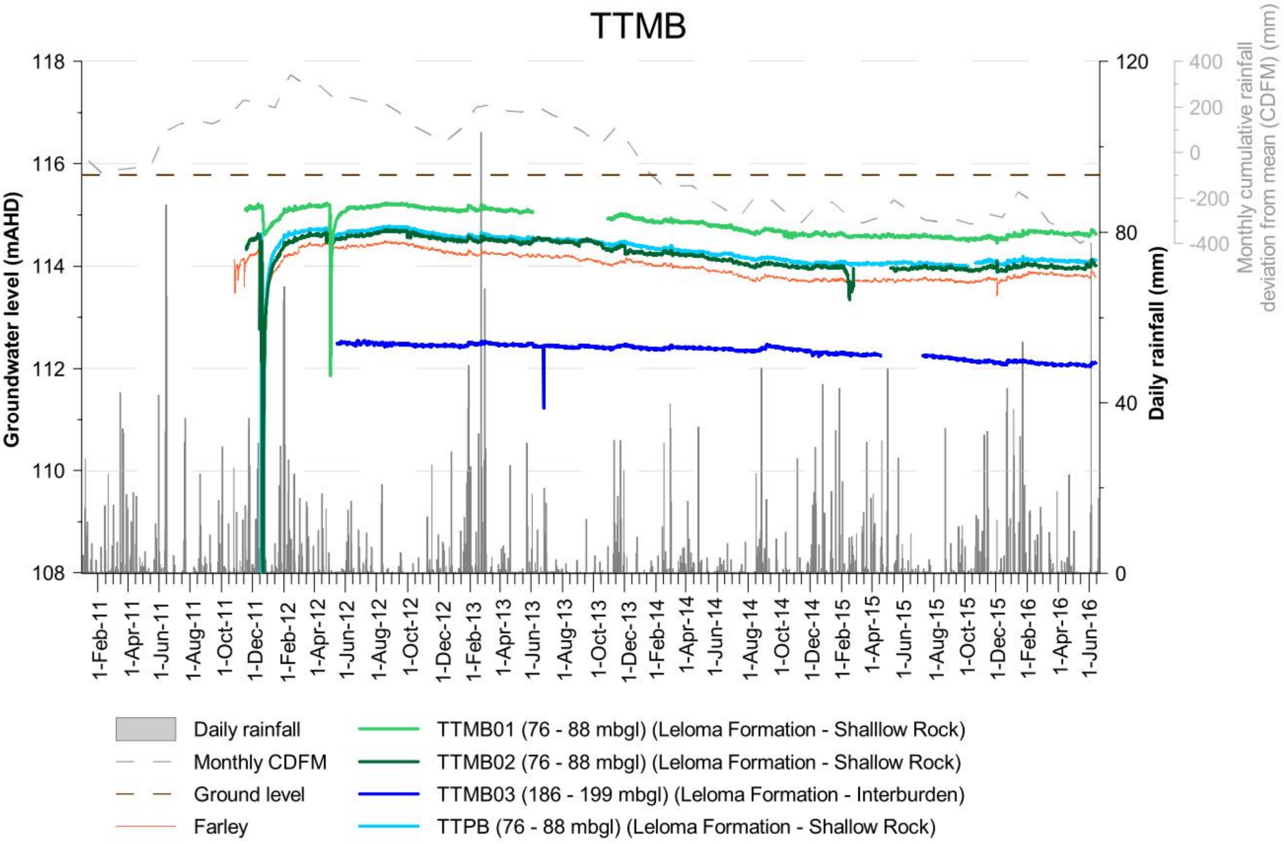


**Figure 4.7 Groundwater levels and rainfall at the TTMB site**

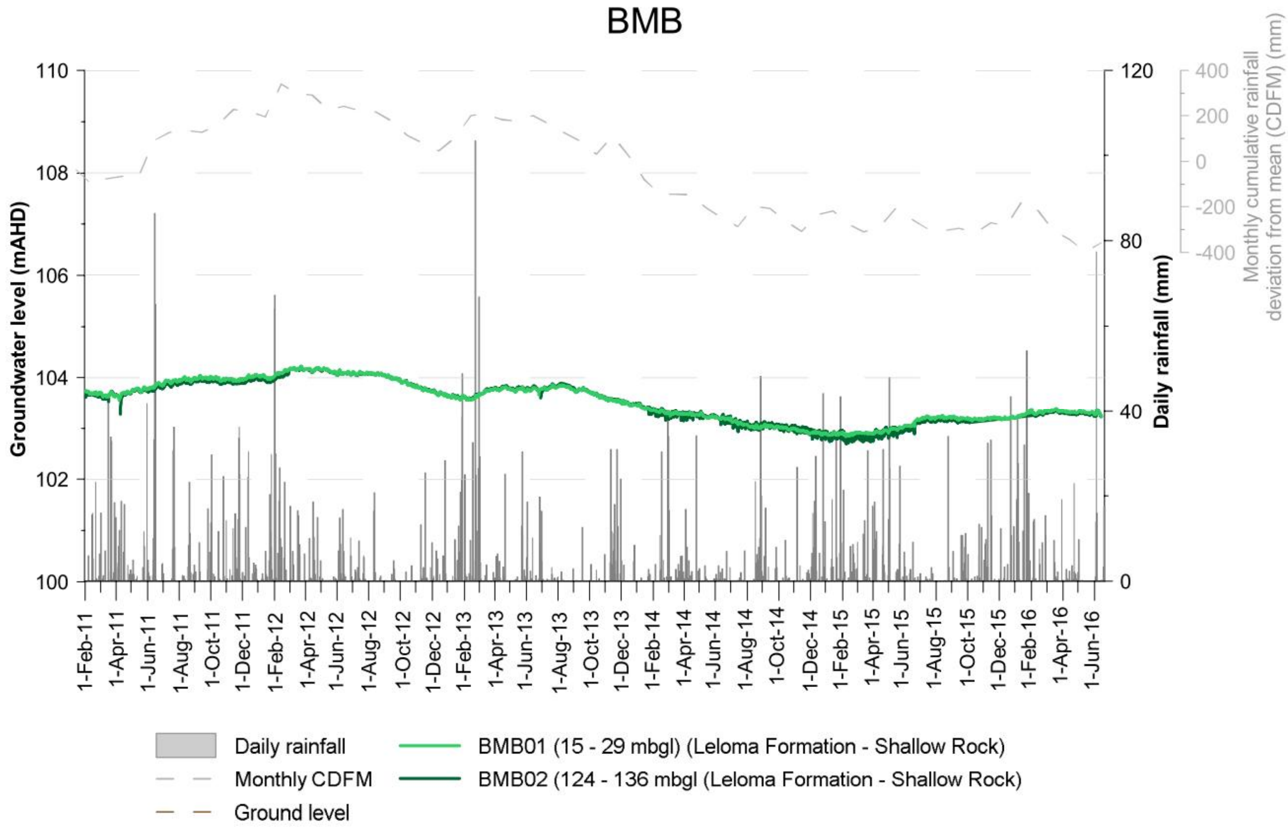


**Figure 4.8 Groundwater levels and rainfall at the BMB site**

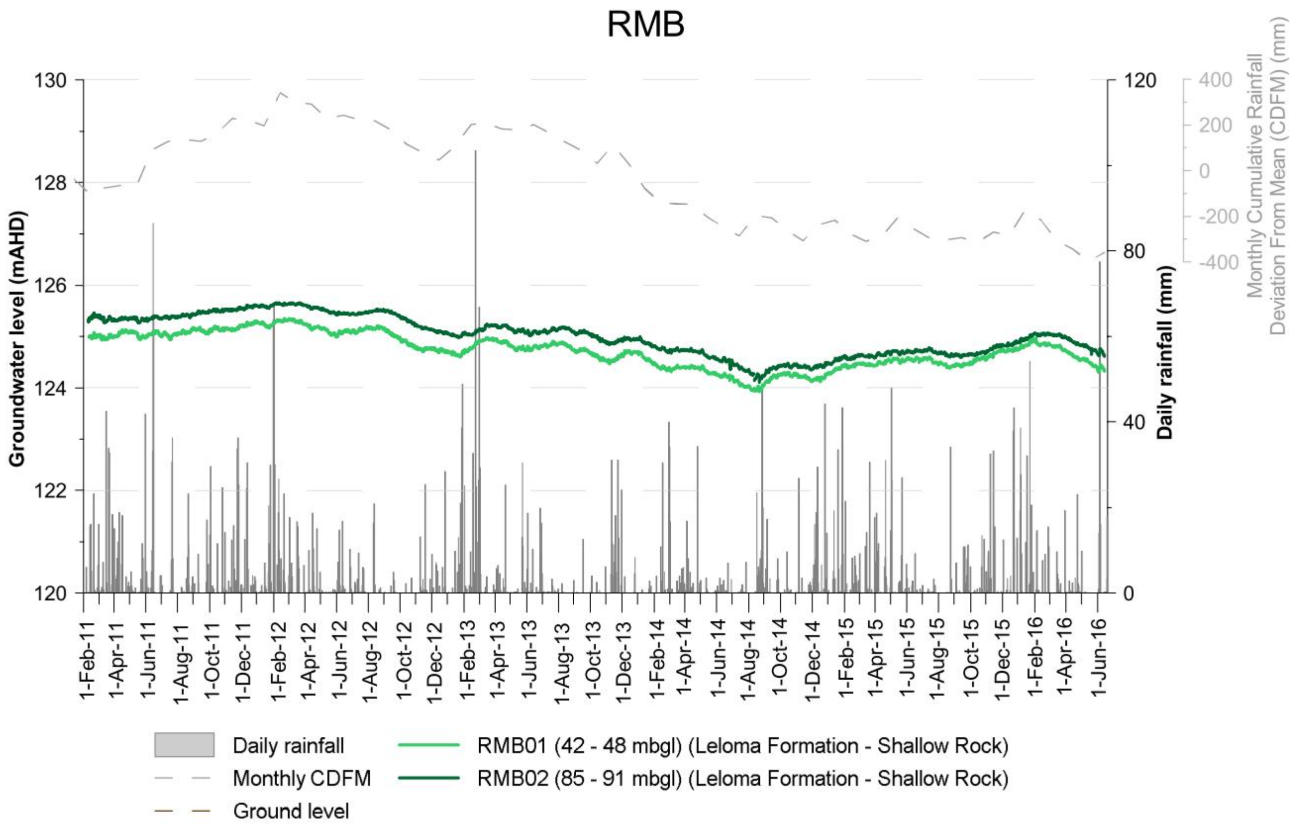


**Figure 4.9 Groundwater levels and rainfall at the RMB site**

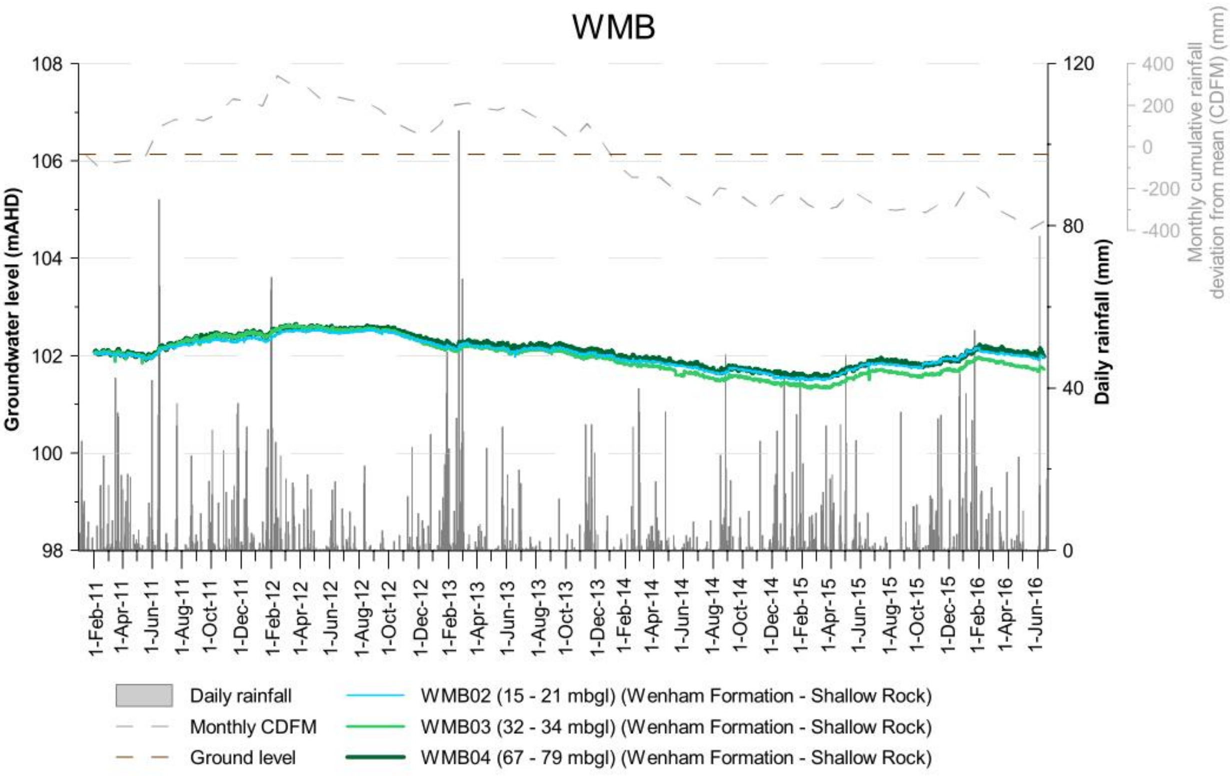


**Figure 4.10 Groundwater levels and rainfall at the WMB site**

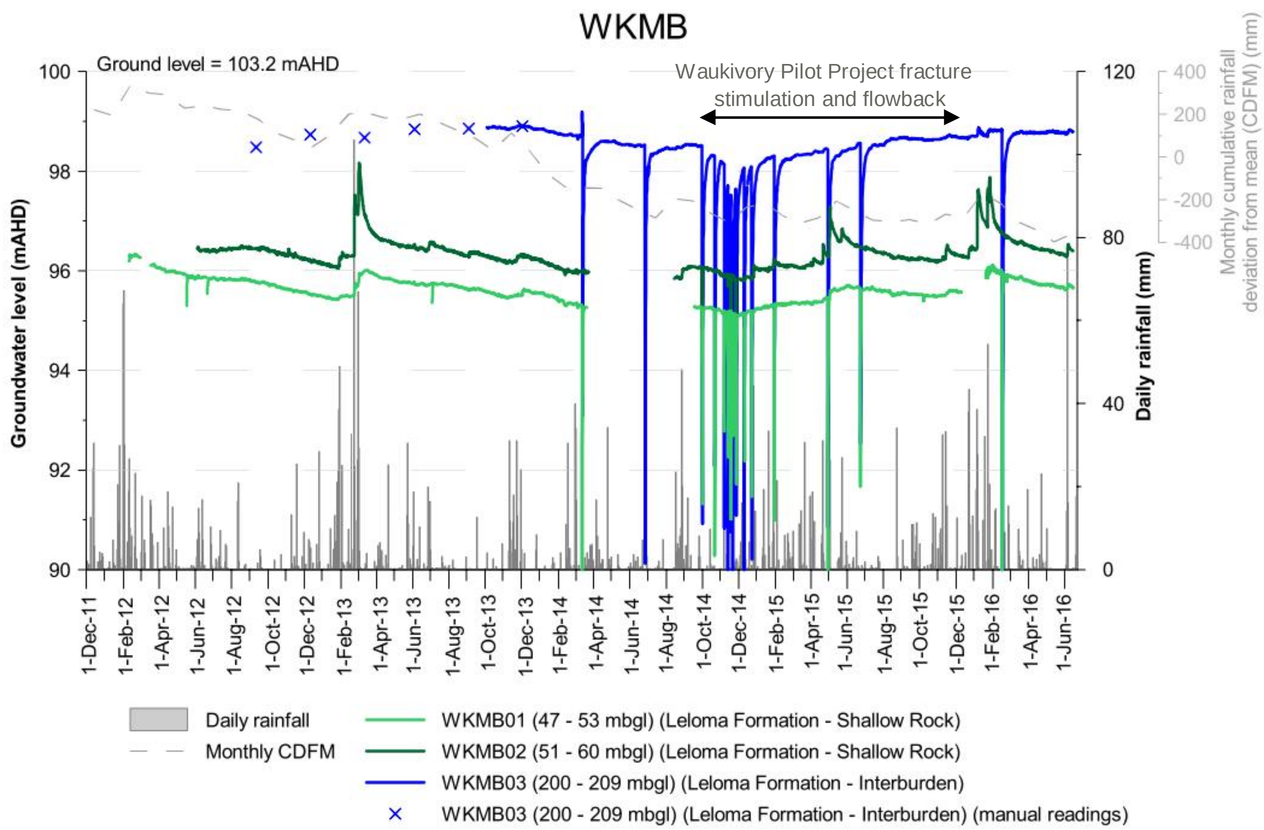


**Figure 4.11 Groundwater levels and rainfall at the WKMB site**

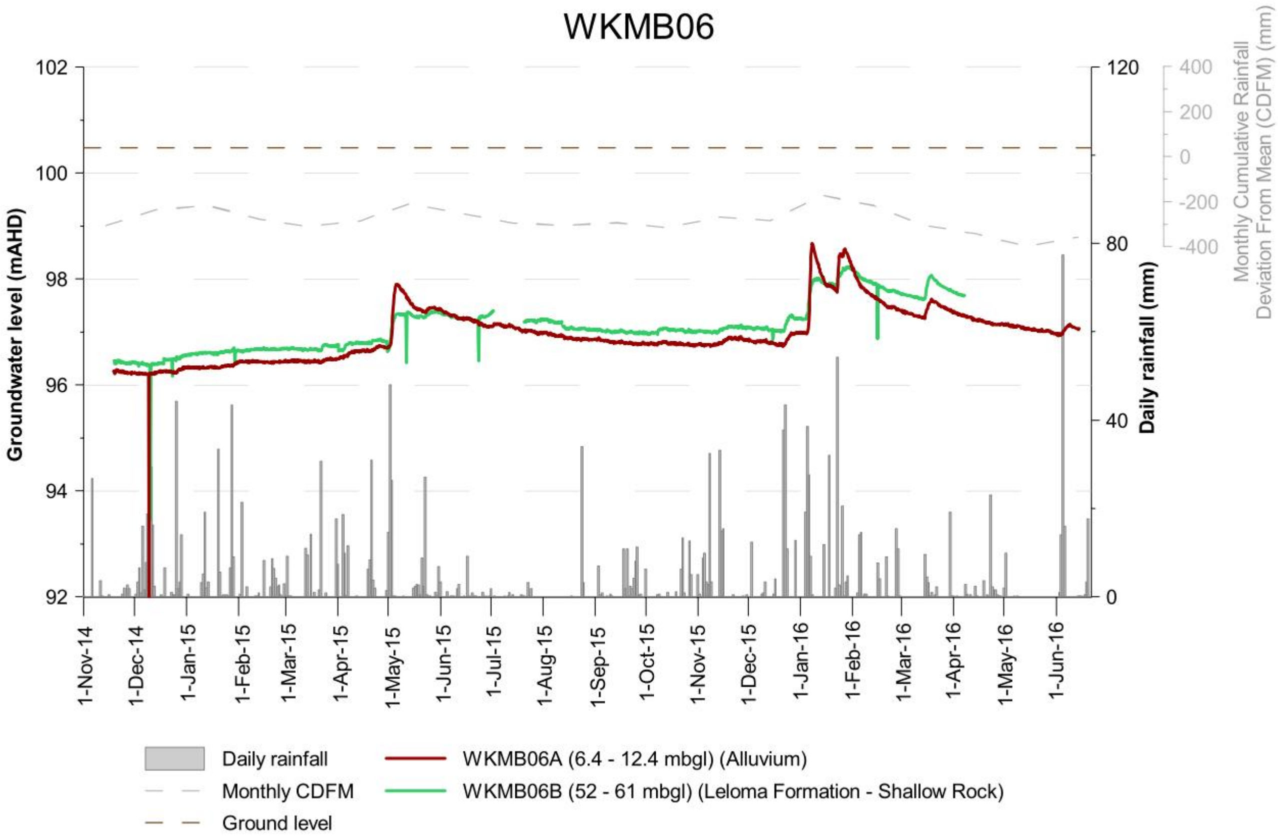


**Figure 4.12** **Groundwater levels and rainfall at the WRMB06 site**

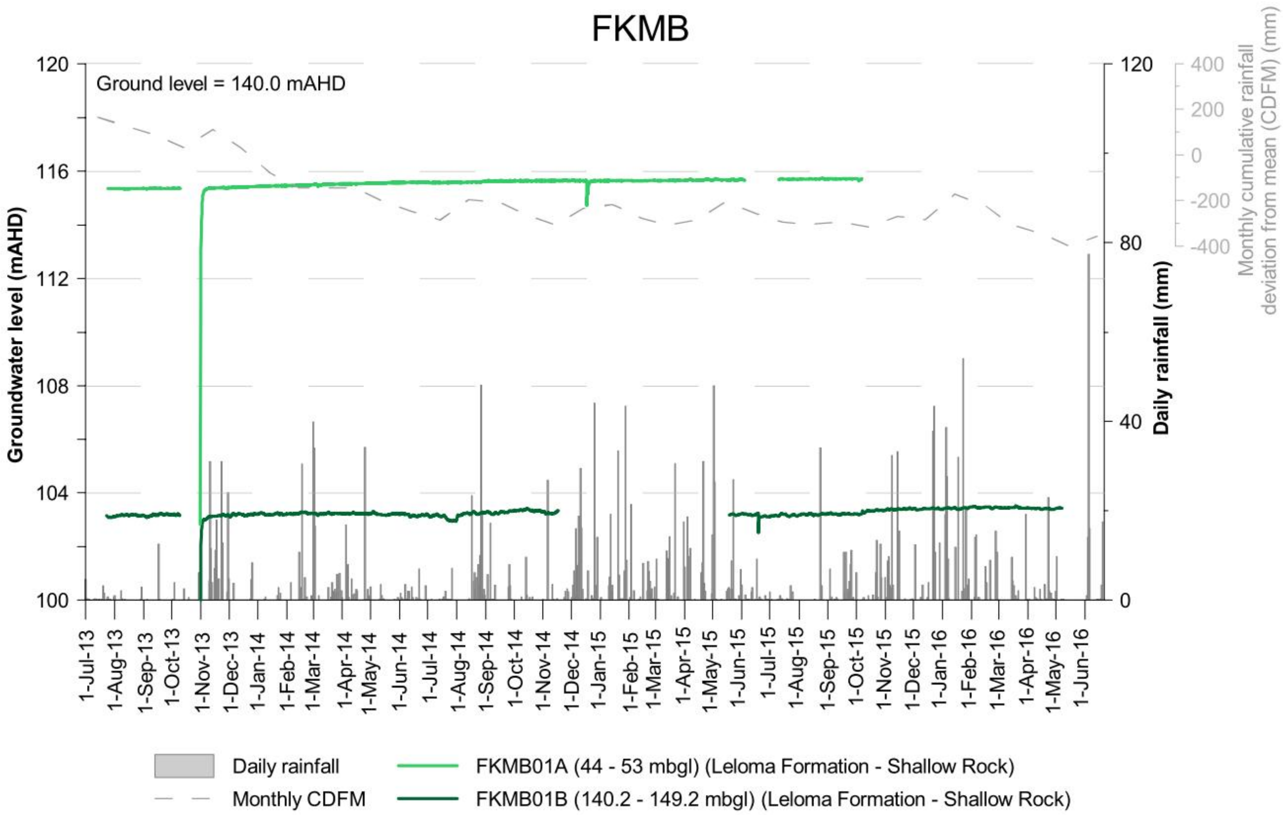


**Figure 4.13** **Groundwater levels and rainfall at the FKMB site**

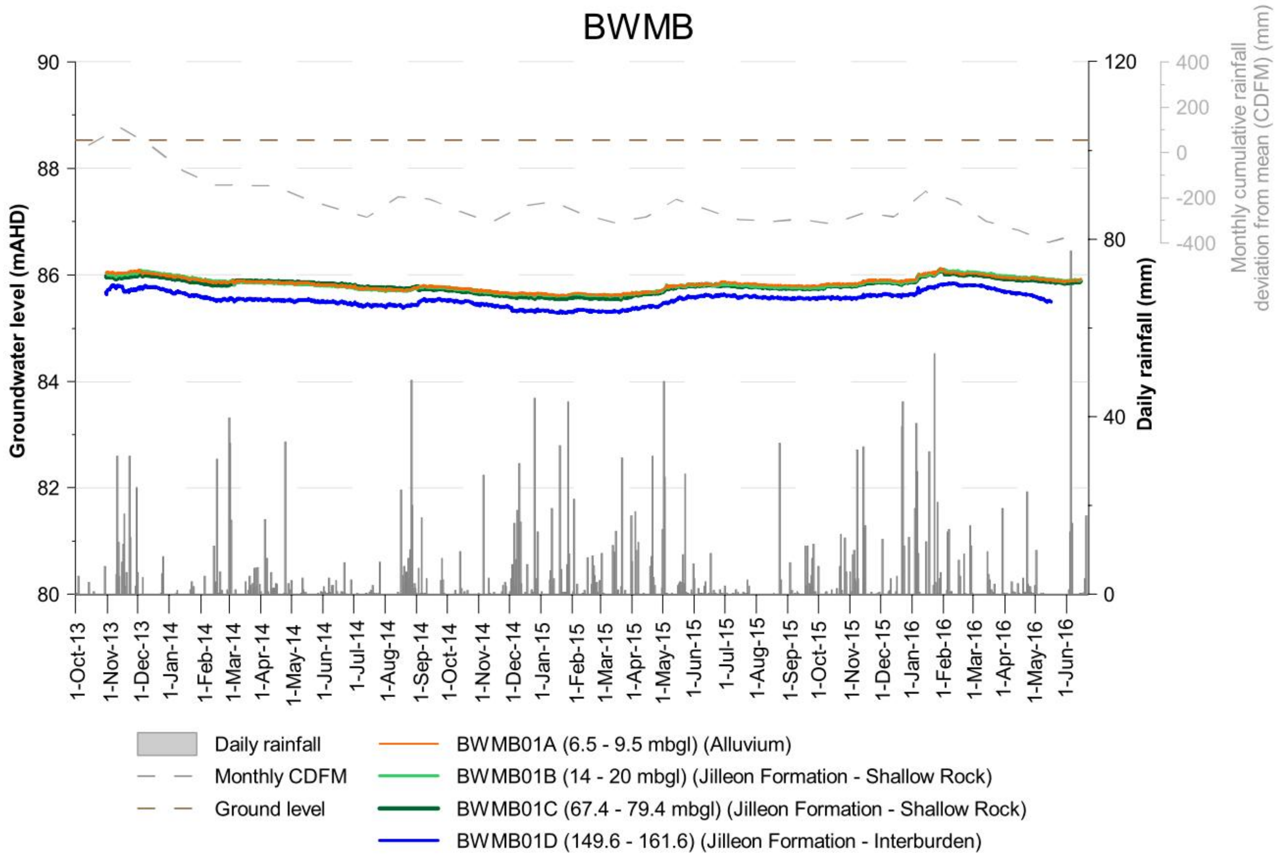


**Figure 4.14 Groundwater levels and rainfall at the BWMB site**

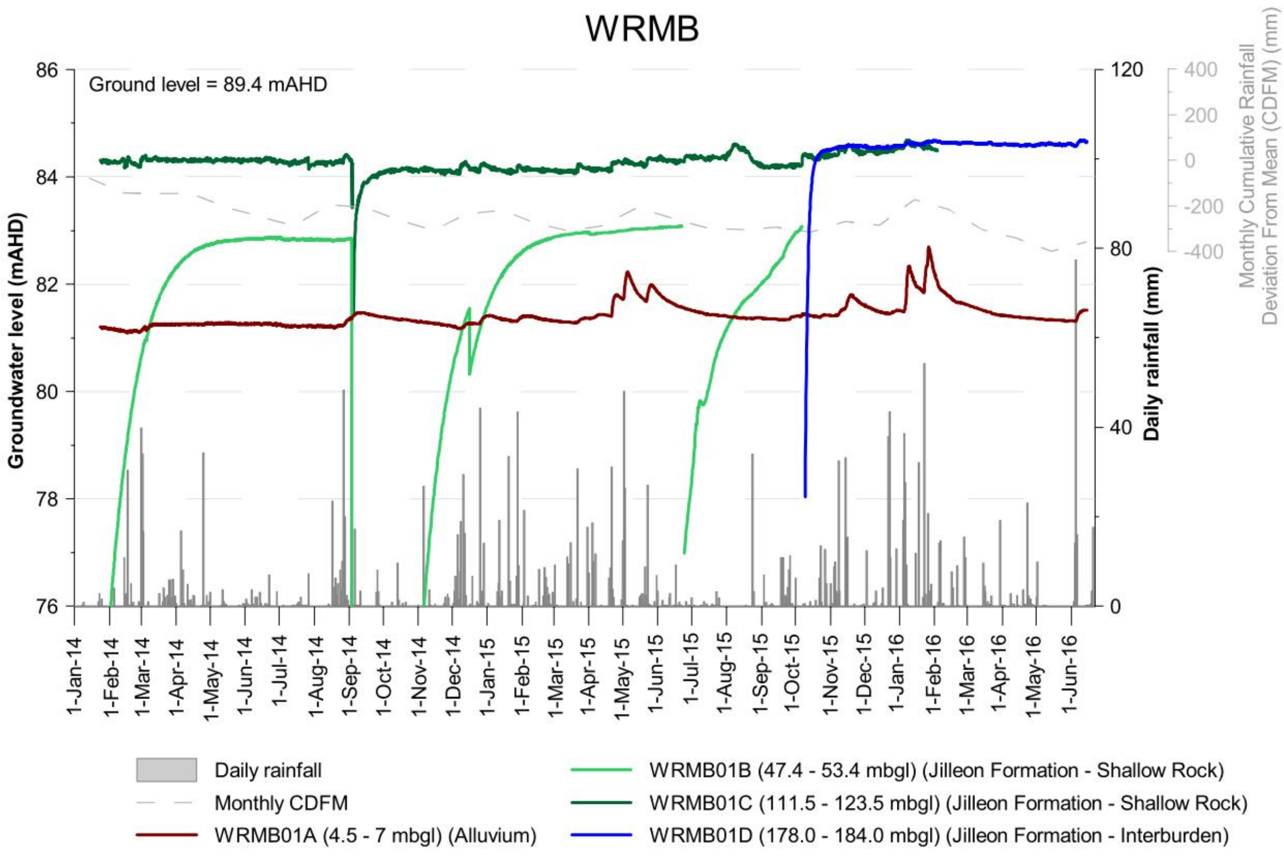


**Figure 4.15 Groundwater levels and rainfall at the WRMB site**

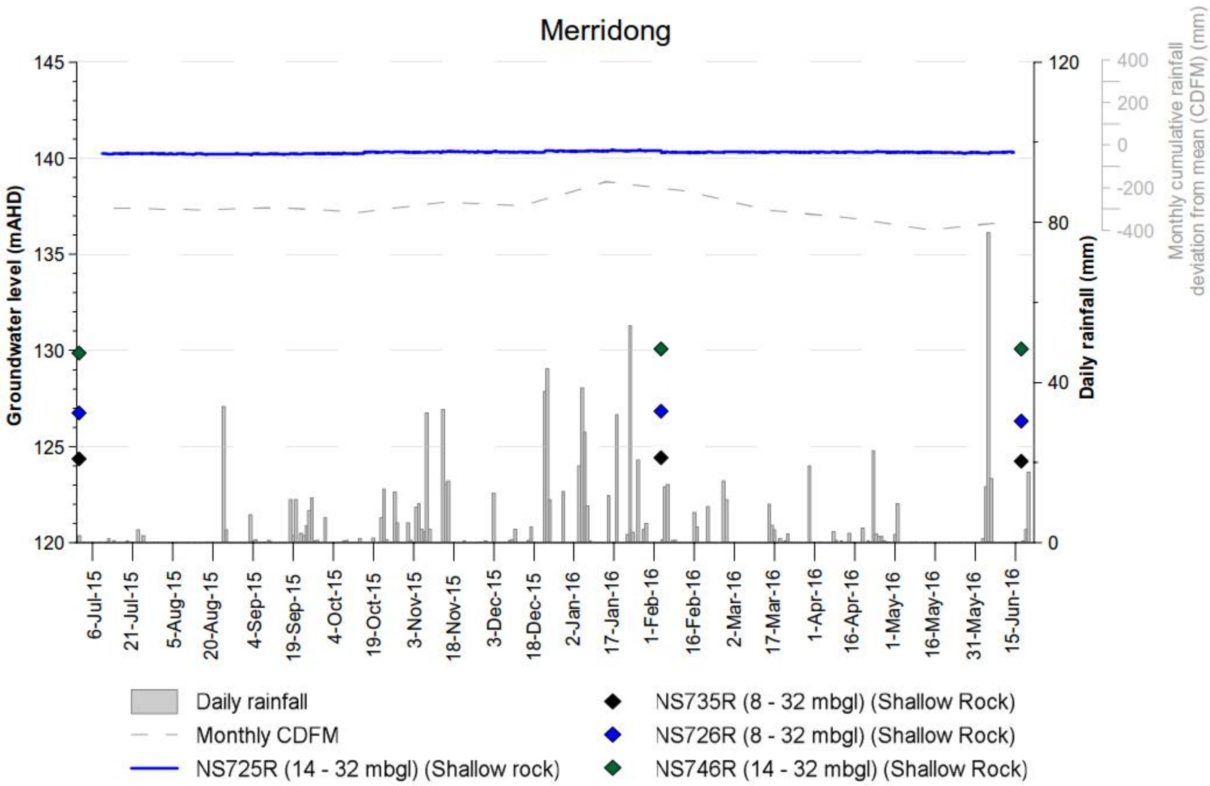


**Figure 4.16 Groundwater levels and rainfall at the Merridong site**

#### 4.1.1.5 Deep groundwater

Deep groundwater (formation depth >300 mbgl) was monitored by PL03 (VWP) (Figure 4.17), WKMB05 (multizone monitoring well) (Figure 4.18) and LMG01 (VWP) (Figure 4.19).

VWP PL03 was installed in September 2013. Interburden sensor 3 (463 mbgl) showed a decrease in piezometric pressure of about 60 m since installation. However, over the course of the last (July 2015 to June 2016) monitoring period piezometric pressure has increased by 3.3 m. Coal seam sensor 2 (496 mbgl) shows a steady decrease in piezometric pressure of about 20 m from installation until October 2015 with a slight increase in piezometric pressure from October 2015 to June 2016.

The declines in piezometric level reflect the long term readjustment of pore pressure in the surrounding rock since installation and do not represent natural trends. However, sensor 2 may possibly have equilibrated from around April 2015 and Sensor 3 from around October 2015 as piezometric pressures has been relatively stable since. Sensor 2 may have reached equilibrium in April 2015. The long recovery period is due to the very low permeability of the interburden and coal seams at the depth of the sensors. This phenomenon is widely observed in VWP installations and has been observed at VWPs installed at the AGL Hunter Gas Project. At that location, groundwater levels took over one year to equilibrate following installation (Parsons Brinckerhoff 2014a). These trends reflect pore pressures near the sensor adjusting and recovering towards hydrostatic pressures following the local disturbance associated with installation.

During the monitoring year, piezometric levels at PL03 sensor 2 increased (from October 2015) by about 1.5 m and at PL03 sensor 3 increased by about 3.3 m (Figure 4.17). At both sensors the rate of increase has reduced throughout the monitoring period.

Piezometric levels in WKMB05 for the period November 2014 (installation) to 22 June 2016 are shown in Figure 4.18. The rapid changes in the piezometric levels measured at all sensors on 25 November 2014 occurred during the commissioning of the packer system. All sensors in WKMB05 show slight declining trend in piezometric levels during the monitoring period, with the exception of sensor 4 which remains relatively steady.

It is not clear how, or if, the slight declining trends at WKMB05 relate to the Waukivory Pilot Project flowback activities, it is possible they represent delayed pressure responses, from either fracture stimulation or the commencement of flowback, due to the low permeability of the interburden.

Fluctuations in piezometric level (~300 m) in LMG01 most likely reflect the long term readjustment of pore pressure in the surrounding rock since installation and do not represent a natural trend.

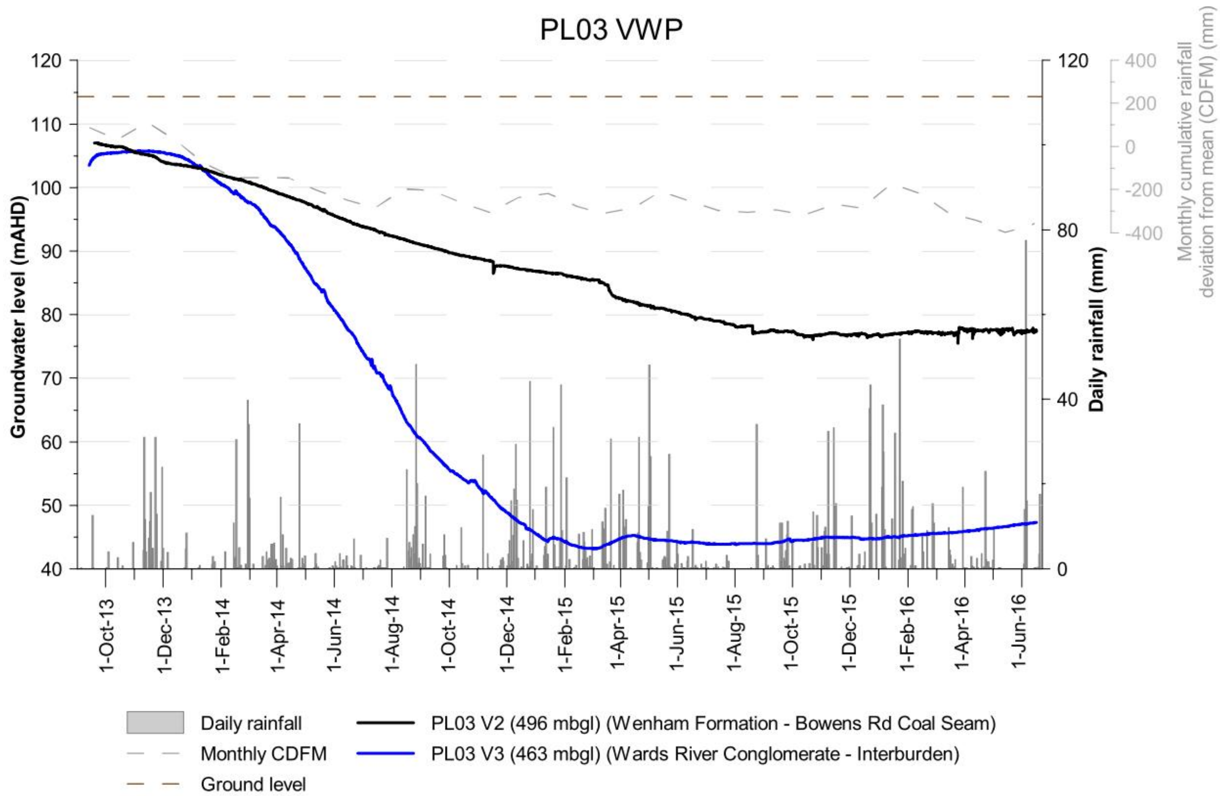


**Figure 4.17 Groundwater levels and rainfall at the PL03 VWP**

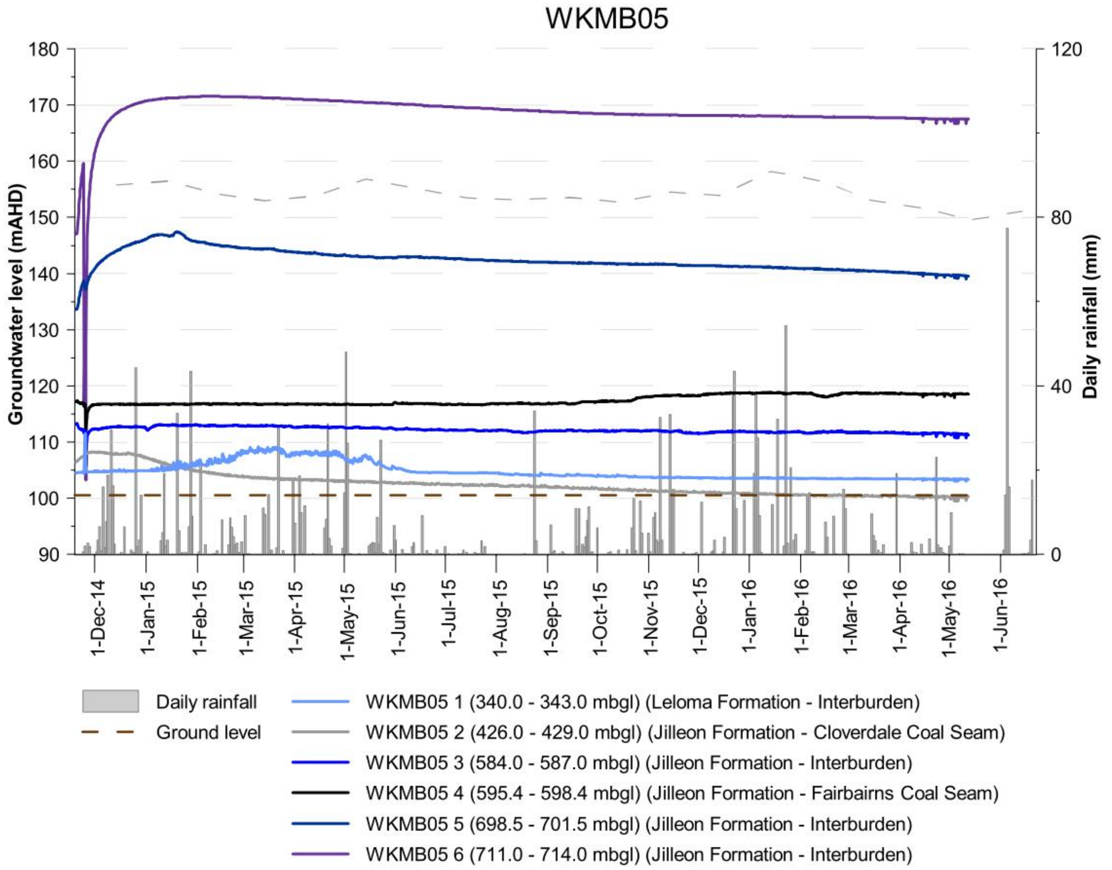


**Figure 4.18 Groundwater levels and rainfall at the WKMB05 multizone monitoring well**

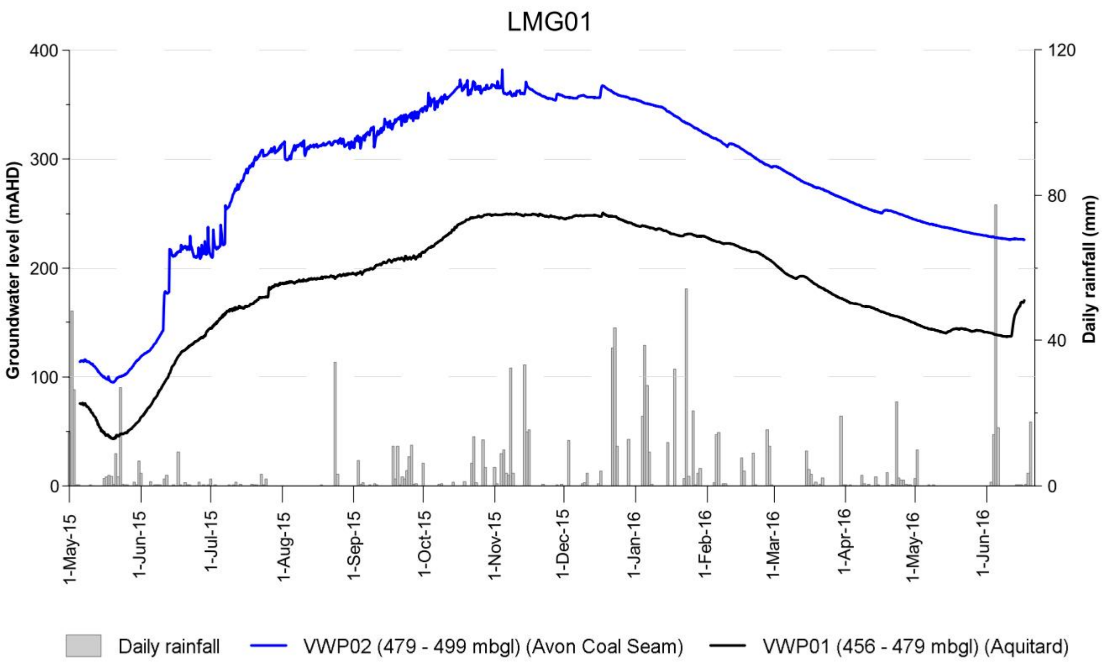


**Figure 4.19 Groundwater levels and rainfall at the LMG01 monitoring well**

### 4.1.2 Vertical gradients

Vertical gradients were noted at 13 out of 15 nested bore installations as shown in Table 4.1. Due to the very low permeability of the interburden units, vertical groundwater flow is likely to be slow or negligible, despite the vertical gradients. 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 (Parsons Brinckerhoff 2015g).

**Table 4.1 Vertical gradients at the nested monitoring bore installations**

| Monitoring site | Gradient | Comments |
|---|---|---|
| TTMB | Downward | ~ 2 m to ~ 2.5 m between the shallow rock and the deeper rock. |
| WMB | No gradient | Slight (<0.5 m) downward between the shallow and deeper monitoring bores in the shallow rock. |
| S4MB | Upward | ~ 1 m to ~ 2 m between the deeper coal seam and the shallow rock. |
| S5MB | Downward | ~ 2 m between the deeper coal seam at S5MB03 and the shallow rock at S5MB02 since July 2013 (a slightly upward gradient prior to July 2013).<br>The shallow rock monitoring bore at S5MB01 shows a very slow response to sampling and therefore may not be representative of water table trends. |
| TCMB | Downward | ~ 1 m to ~ 1.5 m between the shallow rock and deeper coal seams. |
| BMB | No gradient | No perceptible gradient. |
| 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 |
| WKMB06 | alternating | ~ 0.3 m between the shallow rock and alluvium<br>Reversal of vertical gradient during/following high rainfall events |
| 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. |
| WRMB | Upward | ~ 1.5 m between the deeper and shallow monitoring bore in the shallow rock<br>~3 m between WRMB01C and the alluvium |
| PL03 | Upward | ~35 m between the interburden and the Bowen Road Coal Seam |
| WKMB05 | Upward | Apparent and pronounced upward gradient between the deepest zones and the shallowest zones |
| LMG01 | Upward | Between ~10 m and ~20 m upward gradient between the Avon Coal Seam and the Aquitard. |

(a) Piezometric levels in LMG01 are most likely a reflection the long term readjustment of pore pressure in the surrounding rock since installation rather than natural trends and any observed vertical gradient should be revaluated as monitoring continues.

## 4.2 Shallow gas monitoring

Gas samples were collected using Isotech Isotubes® from the two shallow gas monitoring wells, TGMB01 and TGMB02 on the Tiedman property (Figure 3.2). TGMB01 was screened across the uppermost weathered rock (3 - 6 mbgl) and TGMB02 was installed close to the Roseville Coal Seam outcrop (from 12 – 15 mbgl). These were dry monitoring wells, above the water table. The results from the sampling event on 21 June 2016 are presented in Table 4.2.

**Table 4.2 Gas sampling composition**

| Analyte | TGMB01 (screened 3 – 4 mbgl) | | TGMB02 (screened 12 – 15 mbgl) | |
|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 |
| $O_2$ + Ar (ppm) | 211,000 | 216000 | 211,400 | 215900 |
| $CO_2$ (ppm) | 400 | 620 | 490 | 640 |
| $N_2$ (ppm) | 788,600 | 783400 | 788,100 | 783400 |
| $CH_4$ (ppm) | 4 | 4 | 4 | 15 |

Concentrations of oxygen ($O_2$), Argon (Ar) carbon dioxide ($CO_2$) and nitrogen ($N_2$) are typical of air. methane concentrations were negligible and were too low to perform any isotopic analysis of C or H isotopes. These results are comparable to gas sampling that was completed on 4 April 2015 as part of the 2015 groundwater sampling event (Parsons Brinckerhoff 2015h), however carbon dioxide concentrations were slightly higher than the 2015 results for both bores, while TGMB02 had slightly elevated levels of methane compared to 2015. Laboratory results from the gas sampling are included in Appendix B.

## 4.3 Groundwater salinity

Continuous salinity (as EC) data was recorded at six hour intervals at WKMB06A and WKMB06B. Figure 4.20 presents salinity during the 2016 monitoring period.

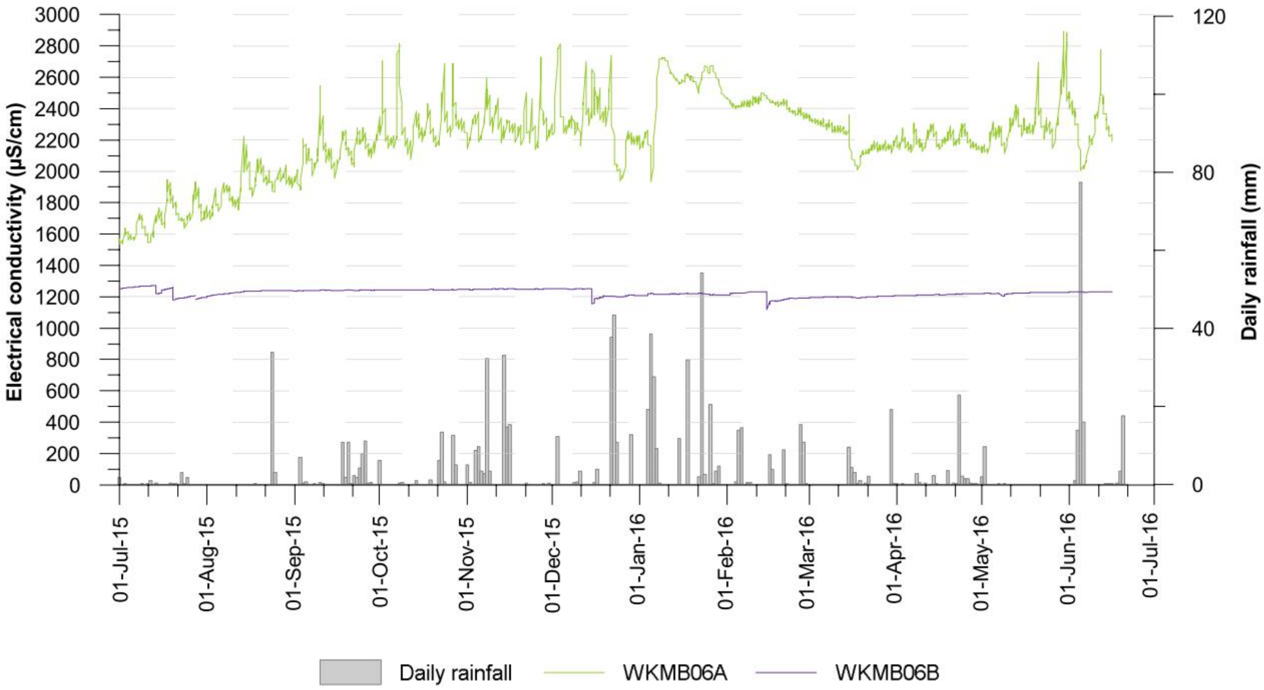


**Figure 4.20 EC of groundwater and rainfall at the WKMB06A and WKMB06b monitoring wells.**

An increase in salinity is observed at WKMB06A over the first half of the monitoring period that may be a response to a low rainfall and evaporative concentration effects in the alluvium. Subsequent salinity levels remain within an approximate range of 2,000 to 2,800 µS/cm. The salinity data for WKMB06B remains at approximately 1,200 µS/cm throughout the monitoring period.

# 5. Surface water monitoring

The details and location of the stream gauge installations for the GGP are provided in section 3.1.2, Figure 3.1 and Figure 3.2. Continuous water level and salinity (as EC) data was recorded at 15 minute intervals at selected surface water monitoring locations.

## 5.1 Surface water levels

The stream gauge monitoring network prior to decommissioning in June 2016 was located on the Avon River, Dog Trap Creek and Waukivory Creek (Section 3.1.2). During the decommissioning, stream gauges were removed from the Avon River stations WKSW01 and WKSW02 and one Avon River lower level sensor was removed from ASW02. One Avon River lower level sensor was washed away from station TSW01. All stream gauges across the monitoring network showed rapid responses to rainfall events (Figures 5.1 and 5.2) with peak discharge occurring within hours of the rainfall event. The hydrographs also show relatively steep recession curves, with stream levels declining to close to pre-existing levels within 2 weeks following rainfall events. This is representative of runoff high in the catchment, with limited storage capacity and baseflow contributions upstream of the GGP site. During the monitoring period, high rainfall events correlating with increased water levels occurred in November 2015, December 2015, January 2016 and June 2016.

There are data gaps for stations TSW01, ASW01 and ASW02. The reason for the data gaps for TSW01 and ASW01 were malfunctioning dataloggers, which were subsequently replaced. For ASW02 there was a logger malfunction that may possibly be associated with sensor damage during the January 2016 flood event (Ventia, 2016).

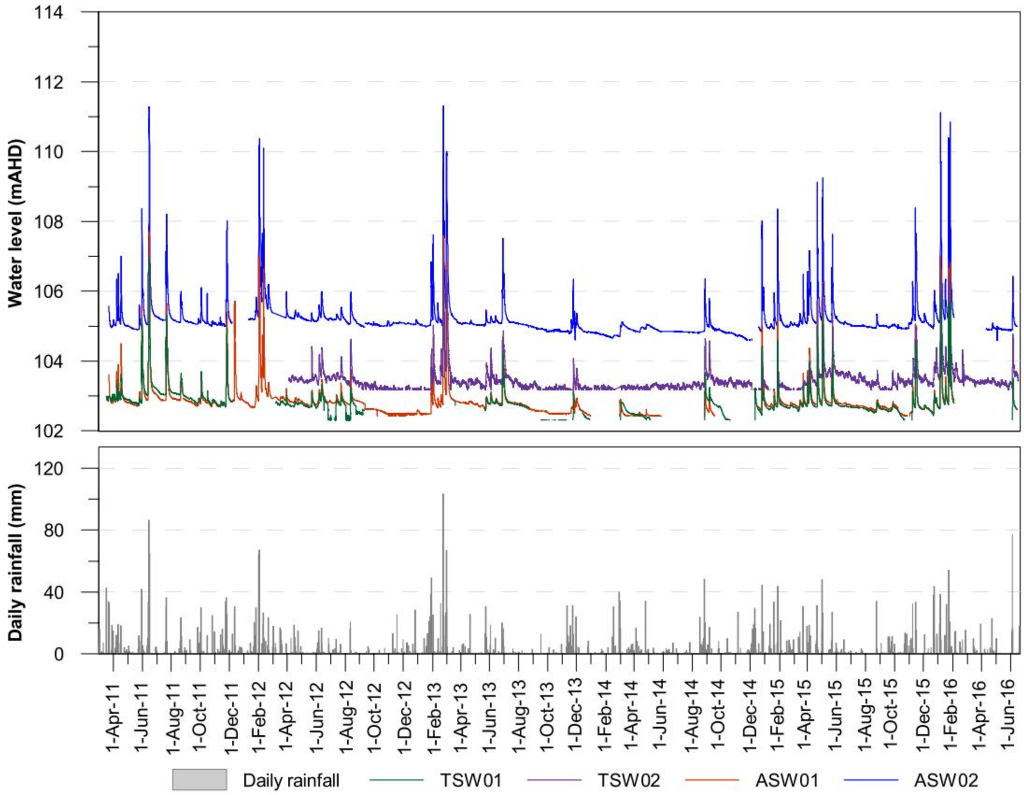


**Figure 5.1** **Avon River (ASW01, ASW02 and TSW01) and Dog Trap Creek (TSW02) stream level and rainfall**

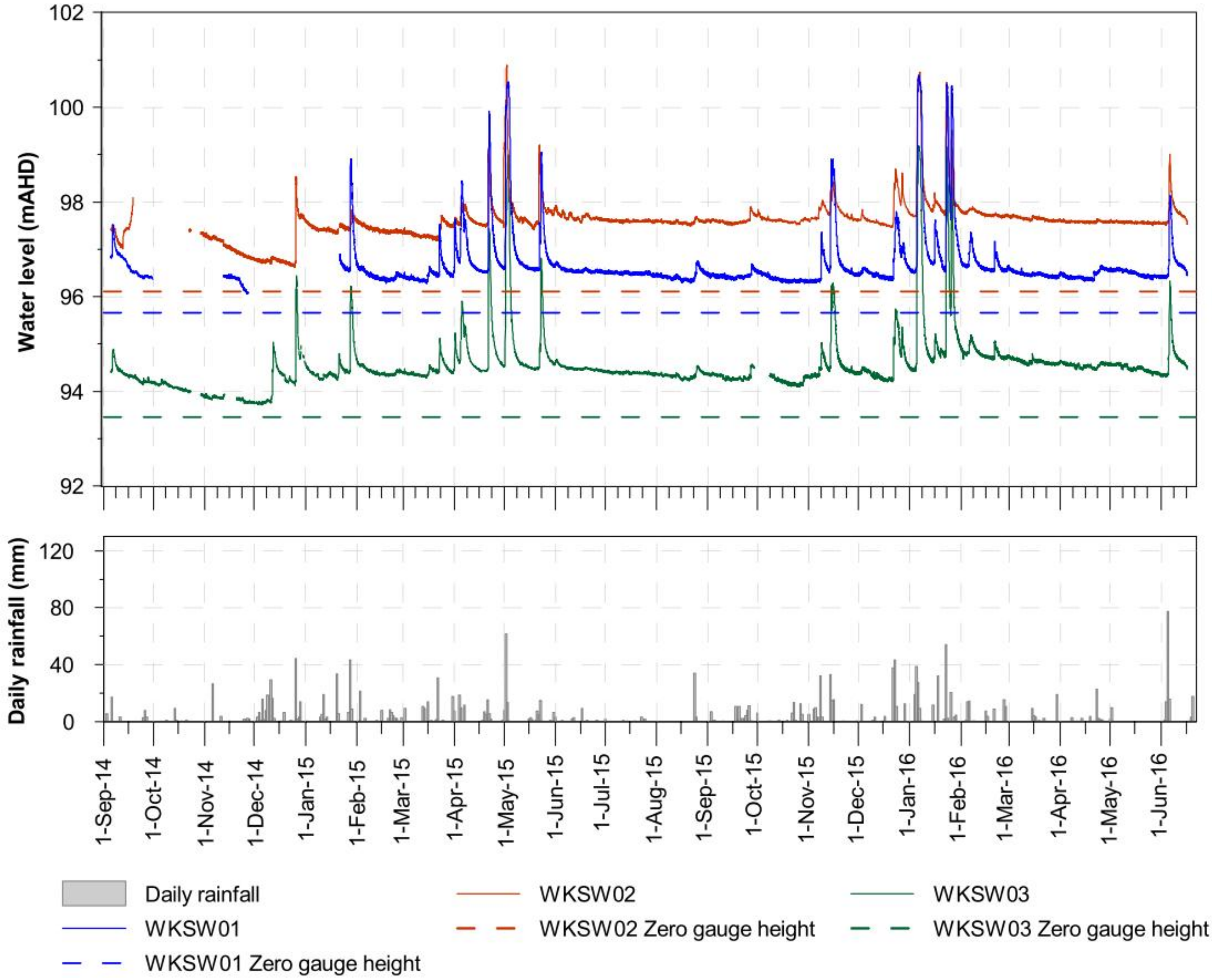


**Figure 5.2 Avon River (WKSW01 and WKSW03) and Waukivory Creek (WKSW02) stream level and rainfall**

## 5.1.1 Groundwater-surface water interaction

Groundwater levels for monitoring bores screened in the alluvium are plotted against water level data from the adjacent stream gauges for the Tiedman and Avondale properties on Figure 5.3. Alluvial water level data is compared to stream gauge data to determine the hydraulic gradient between the interconnected systems.

Groundwater levels in the alluvium were typically higher than adjacent stream levels (by one to two metres), indicating that the streams are discharge features for shallow groundwater in the Stage 1 GFDA (Figure 5.3). 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.

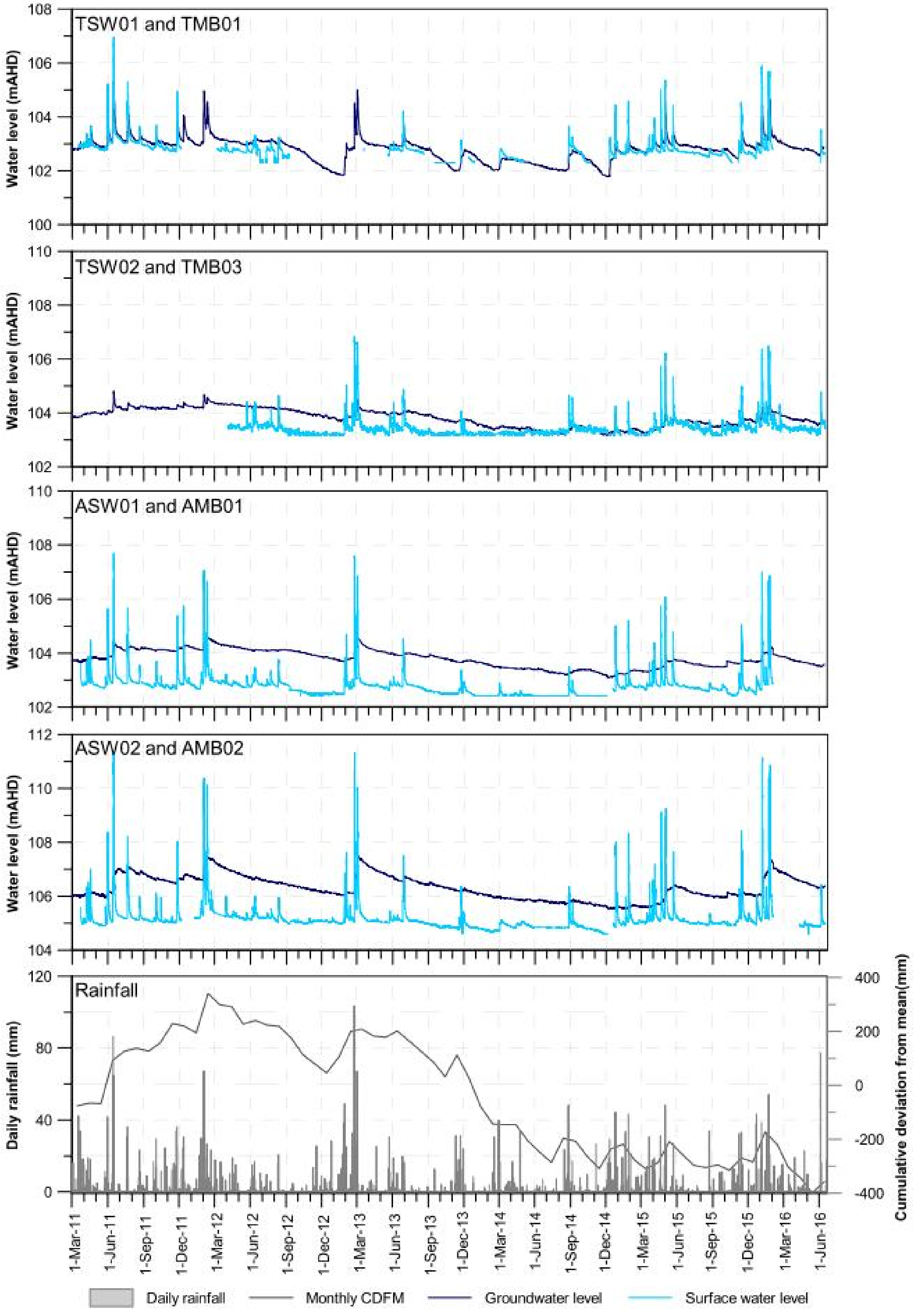


**Figure 5.3** **Surface water hydrographs and groundwater levels in the adjacent alluvium for the Avon River and Dog Trap Creek**

## 5.2 Surface water flows

Stream water levels have been converted to estimated stream flows using theoretical rating curves prepared for the 2014 Monitoring Status Report (Parsons Brinckerhoff 2014b). Estimated stream flows are provided in Figure 5.4. No calibrated rating curves are available for any of the stream gauge sites due to persistent low flows and very short periods of higher flows.

The theoretical rating curves estimate that The Avon River at ASW01 and Dog Trap Creek at TSW02 do not flow for approximately 94% and 98% of the time respectively (Parsons Brinckerhoff 2014b). During such times where flow is predicted to have ceased, the Avon River and Dog Trap Creek will be characterised by multiple disconnected pools as opposed to having dried out. The rating curve model incorporates a known level, above which flow occurs and below which, there is insufficient water to flow over the gauge. The Avon River at TSW01 has no flow for 30% of the time, and at ASW02 has no flow for 3% of the time.

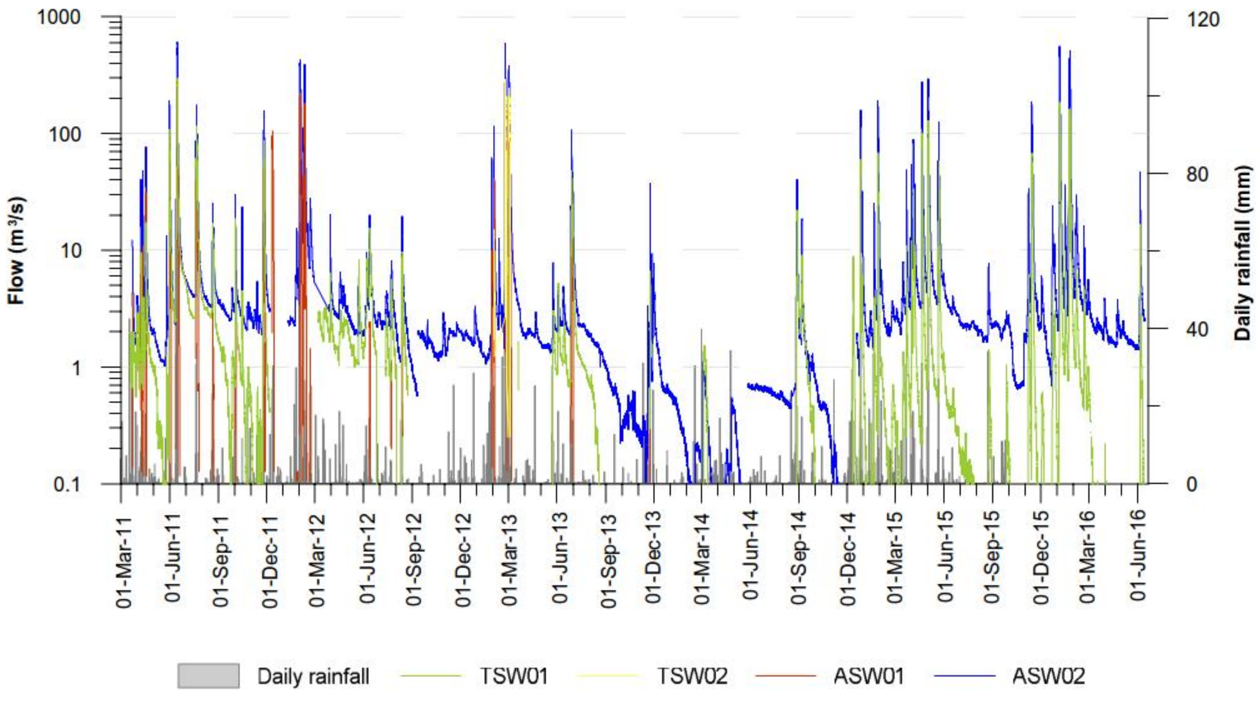


**Figure 5.4** **Avon River and Dog Trap Creek estimated flows and rainfall**

## 5.3 Surface water quality

The complete time series of water levels and EC since monitoring began at TSW01, TSW02, ASW01 and ASW02 are provided in Appendix A. The following figures present hydrographs and EC concentrations during the 2016 monitoring period at ASW01 and ASW02 (Figure 5.5), TSW01 and TSW02 (Figure 5.5), and WKSW01, WKSW02 and WKSW03 (Figure 5.6).

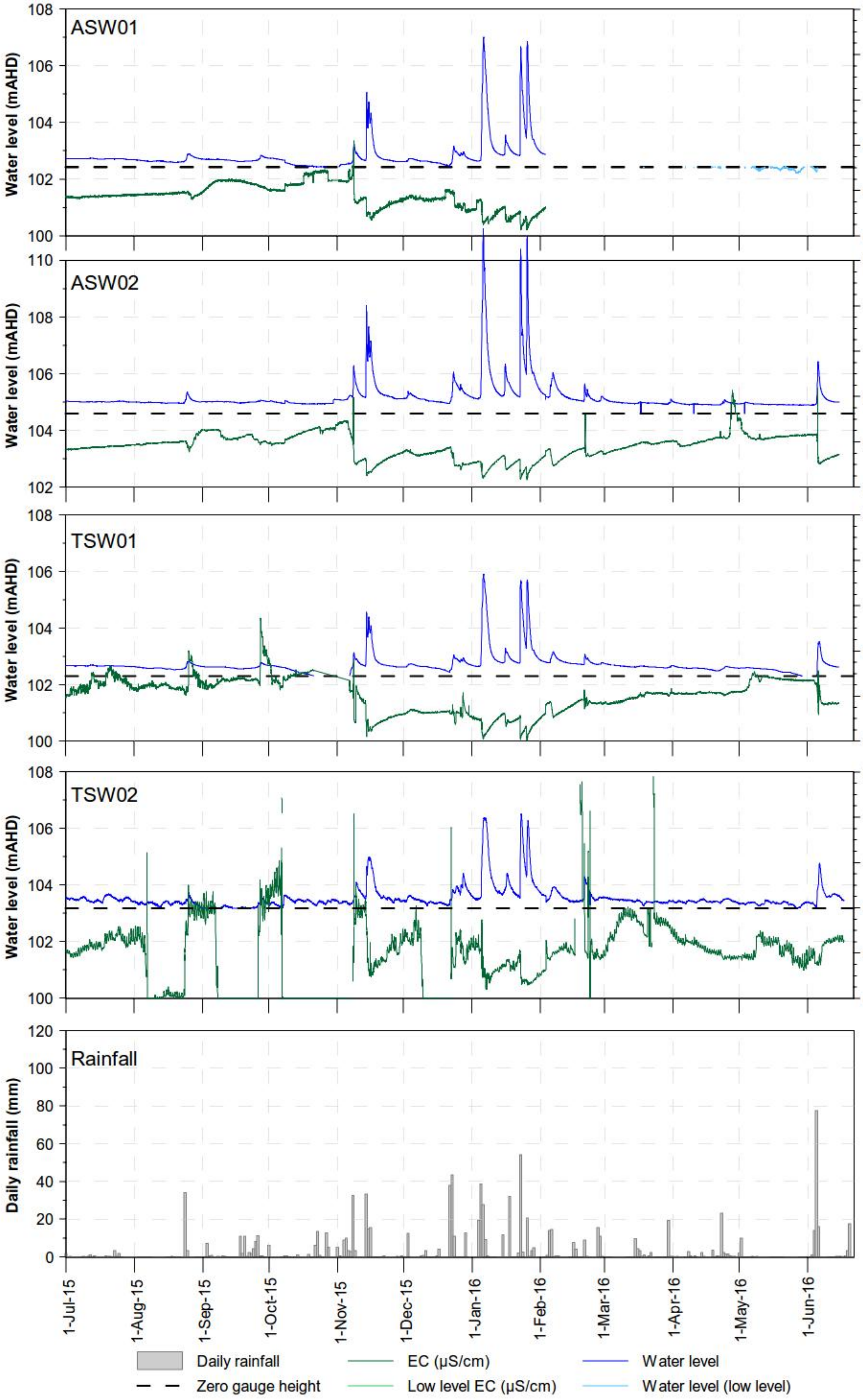


**Figure 5.5** **Water levels and EC (µS/cm) on the Avon River (ASW01, ASW02 and TSW01) and Dog Trap Creek (TSW02) during the 2016 monitoring period**

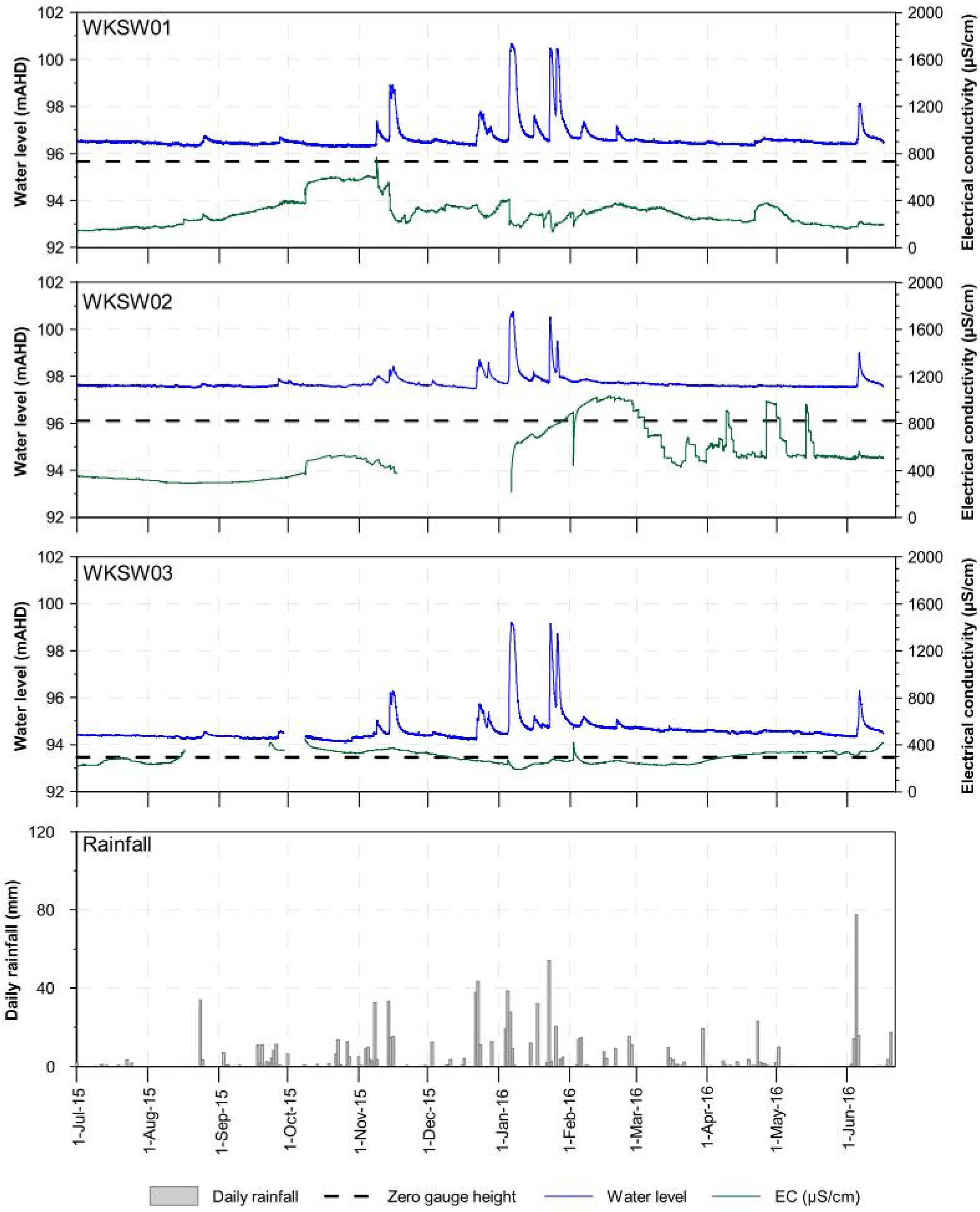


**Figure 5.6** **Water levels and EC (µS/cm) on the Avon River (WKSW01 and WKSW03) and Waukivory Creek (WKSW02) during the 2016 monitoring period**

Surface water levels showed a direct and immediate response to rainfall and runoff across all monitoring locations. Surface water salinity (measured as EC) is typically inversely related to levels and flow. Salinity decreased following rainfall events as relatively fresh runoff is routed into streams (Figures 5.5 and 5.6). An initial increase in EC was often seen in the initial runoff phase as readily dissolvable salts are flushed from the ground surface and shallow soils, followed by dilution as rainfall persists.

After the initial salinity spike and subsequent reduction in EC levels, EC then gradually increases as flow decreases and groundwater discharge from the alluvium starts to become a more dominant component of the baseflow. During the monitoring period, a gradual increase in EC is observed during low rainfall periods from February 2016 to May 2016. Low water levels are observed in the Avon River and Dog Trap Creek during these periods and an increase in EC may also be attributed to evaporative concentration of salts likely to be taking place in disconnected pools within the streams.

Table 5.1 presents statistics for each of the surface water sites where EC is measured. A percentile is the value below which a given percentage of observations fall. For example, the 5$^{th}$ percentile is the value below which 5% of observations are found. The 5$^{th}$ and 95$^{th}$ percentiles presented in Table 5.1 are used as a method of discounting outlying values.

Table 5.1 shows the range of EC data measured during the 2016 monitoring period. The maximum was found at TSW02 (3451 µS/cm) while the highest 95$^{th}$ percentile was found at WKSW02 (1000 µS/cm). This is attributed to the ephemeral characteristics of these tributaries and generally lower flows compared to the Avon River.

**Table 5.1 EC observations during the 2016 monitoring period**

| EC (µS/cm) | Location | 5$^{th}$ percentile | Median | 95$^{th}$ percentile | Maximum |
|---|---|---|---|---|---|
| **ASW01[a]** | Avon River | 156 | 356 | 542 | 839 |
| **ASW02** | Avon River | 185 | 373 | 515 | 867 |
| **TSW01[a]** | Avon River | 151 | 427 | 593 | 1091 |
| **TSW02** | Dog Trap Creek | 103 | 104 | 820 | 3451 |
| **WKSW01** | Avon River | 158 | 275 | 581 | 767 |
| **WKSW02** | Waukivory Creek | 296 | 515 | 1000 | 1035 |
| **WKSW03** | Avon River | 228 | 285 | 365 | 454 |

(a) ASW01 and TSW01 do not include low level logger data

# 6. Conclusions

The following conclusions are drawn from a review of the groundwater and surface water monitoring data for the 2016 monitoring period (1 July 2015 to 30 June 2016) from AGL's water monitoring network for the GGP in the Gloucester Basin.

**Rainfall**

Total rainfall for the period July 2015 to June 2016 at the AGL weather station was 855 mm, which is comparable to the long term average annual rainfall (979 mm) at Gloucester Post Office.

During the current monitoring period, rainfall was above the monthly average in September and December 2015 and January and June 2016 and below the monthly average during all other months of the monitoring period.

**Groundwater**

Groundwater level trends in monitoring bores vary depending on the lithology and depth of the screened interval:

- **Alluvium:** Groundwater levels in monitoring bores screened in the alluvial deposits showed a rapid response to significant rainfall events. This was a threshold response, which varied between sites, where rainfall events of a certain magnitude were required to trigger a response in groundwater levels. Most alluvial monitoring bores show a seasonal response characterised by a decrease in groundwater levels during times of below average rainfall, before increasing in response to the summer rainfall.
- **Shallow rock**: Groundwater levels in shallow rock monitoring bores increased slightly over the monitoring period in response to rainfall since October 2015. There were no strong responses to individual rainfall events in the shallow rock bores during this monitoring period with the exception of WKMB02 and WKMB06B. This is indicative of an increased hydraulic connection to recharge areas compared to other shallow rock monitoring bores.
- **Interburden units**: Monitoring bores screened within the interburden units showed no significant change over the monitoring period, and groundwater levels did not respond to individual rainfall events.
- **Deep coal seams:** Groundwater levels in monitoring bores that were screened within the coal seams showed a gradual increase during the monitoring period. There are no strong responses to individual rainfall events.

Vertical gradients were noted at 13 of the 15 nested bore installations:

- Downward hydraulic gradients were noted at the TTMB, S5MB, TCMB, FKMB and BWMB nested bore sites.
- Upward hydraulic gradients were noted at the S4MB, RMB, WKMB, WRMB, PL03, WKMB05 and LMG01 nested bore sites.
- An upward vertical gradient is noted at WKMB06 during periods of low rainfall which can change to a downward gradient following high rainfall and flood events.

No vertical head gradients were noted at the BMB and WMB. Due to the very low permeability of the interburden units, vertical groundwater flow is likely to be extremely slow and negligible, despite the vertical gradients. Lateral flow within each of the geological units is concluded to be the dominant groundwater flow mechanism when there are no stresses on the shallow or deep groundwater systems at these locations.

**Surface water**

Water levels remained relatively consistent throughout the FY16 monitoring period as a result of steady rainfall throughout the year. All stream gauges on the Avon River and Dog Trap Creek showed rapid responses to large rainfall events and runoff, and relatively steep recession curves, such as those associated with the December 2015, January and June 2016 rain events.

Surface water salinity decreased following rainfall events as relatively fresh runoff is routed into streams. An initial increase in salinity was often seen in the initial runoff phase as readily dissolvable salts are flushed from the ground surface and shallow soils, followed by dilution as rainfall persists.

**Groundwater – surface water interaction**

Groundwater levels in the alluvium have typically been higher than adjacent stream levels since monitoring began (by one to two metres), indicating that the streams are discharge features for shallow groundwater in the Stage 1 GFDA (Figure 5.3). Only during relatively short periods of high stream levels and flow, associated with rainfall events and floods, that the shallow alluvial groundwater were recharged from the streams.

The conclusions of this report regarding surface and groundwater levels, groundwater-surface water interaction and salinity observations captured in the FY16 monitoring period are consistent with the hydrogeological/ hydrological conceptual model of the Gloucester Basin (Parsons Brinckerhoff 2015g).

**Long term impact of the GGP**

A review of the groundwater level observation data collected for the 2016 monitoring period, (as is similar in previous years) has shown no attributable impacts from GGP site activities (fracture stimulation or flowback) evident in the monitoring data. Short term decreases in water levels can be seen in monitoring bores completed in the shallow rock, interburden and deeper coal seams and are associated with sampling events from these bores. In each case, the water level returned to pre sampling conditions in all bores for all sampling events.

It is not yet clear if the piezometric level hydrograph traces in the deep groundwater monitoring locations show a response to the Waukivory Pilot Project activities. It is possible that they show delayed pressure effect responses from either fracture stimulation or the commencement of flowback. However, these effects are not obvious and may be due to the low permeability of the interburden adjacent to the coal seams.

Surface water levels and quality have shown seasonal fluctuations in response to climate and have not shown any response that could be attributable to GGP site activities.

# 7. Statement of limitations

## 7.1 Scope of services

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

## 7.2 Reliance on data

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

## 7.3 Environmental conclusions

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

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

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

## 7.4 Report for benefit of client

assumes no responsibility and will not be liable to any other person or organisation for or in relation to any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report (including without limitation matters arising from any negligent act or omission of Parsons Brinckerhoff or for any loss or damage suffered by any other party relying upon the matters dealt with or conclusions expressed in the report). Parties other than the client should not rely upon the report or the accuracy or completeness of any conclusions and should make their own enquiries and obtain independent advice in relation to such matters.

## 7.5 Other limitations

Parsons Brinckerhoff will not be liable to update or revise the report to take into account any events or emergent circumstances or facts occurring or becoming apparent after the date of the report.

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

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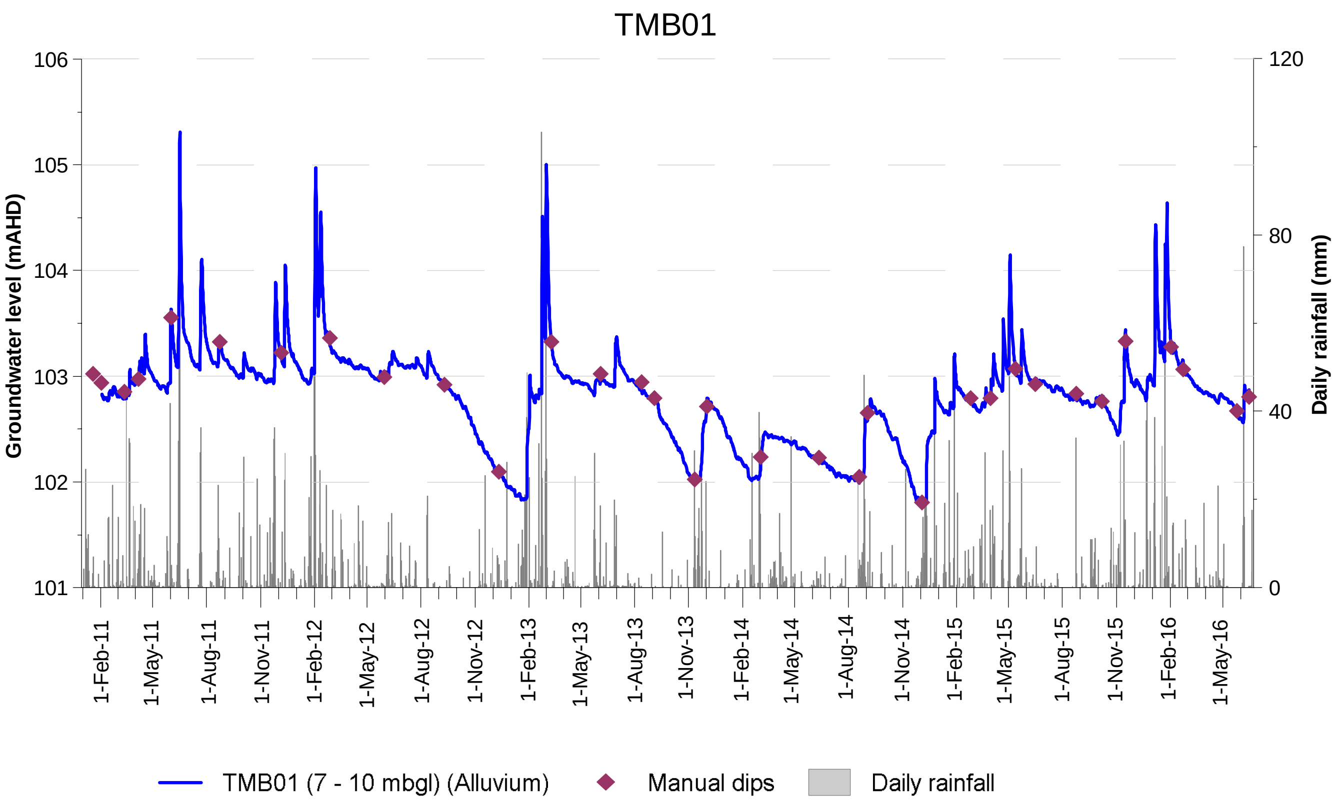
# Appendix A

Hydrographs



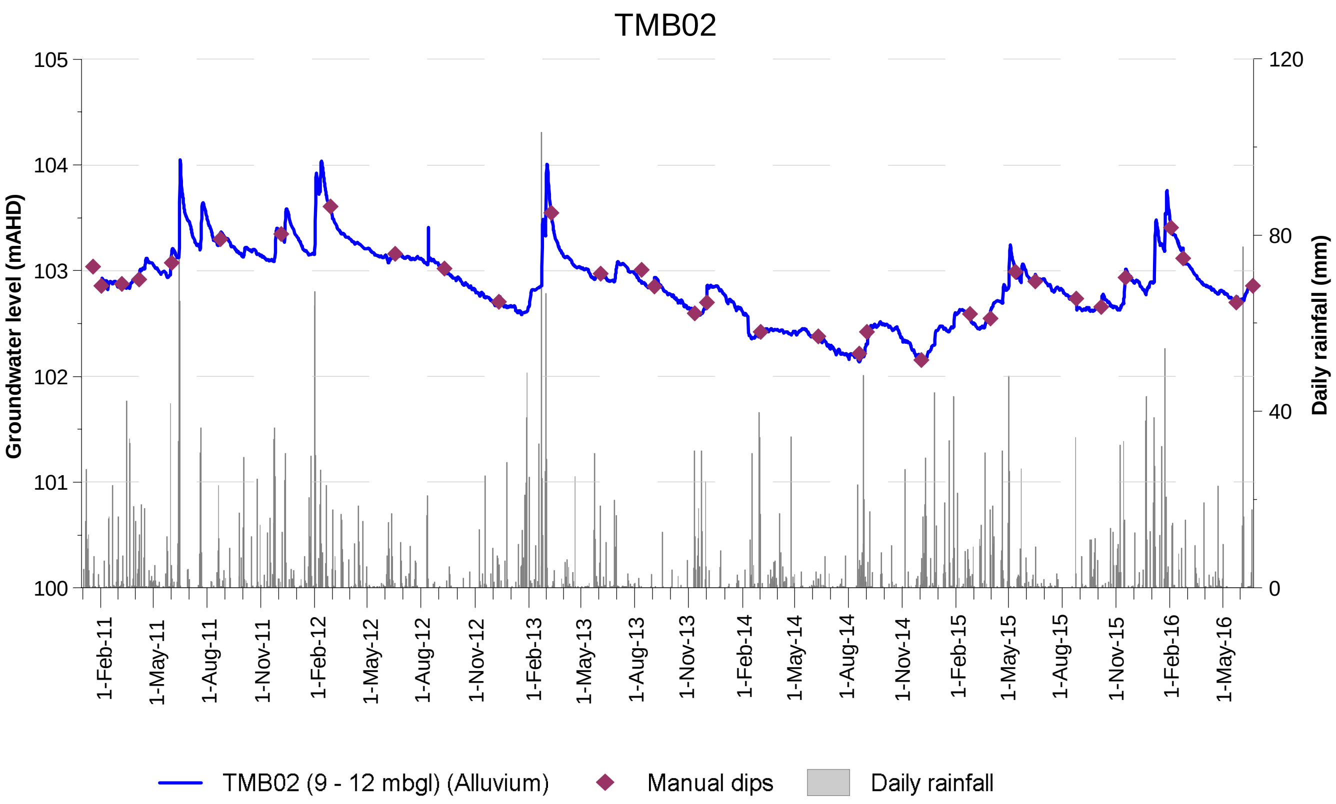
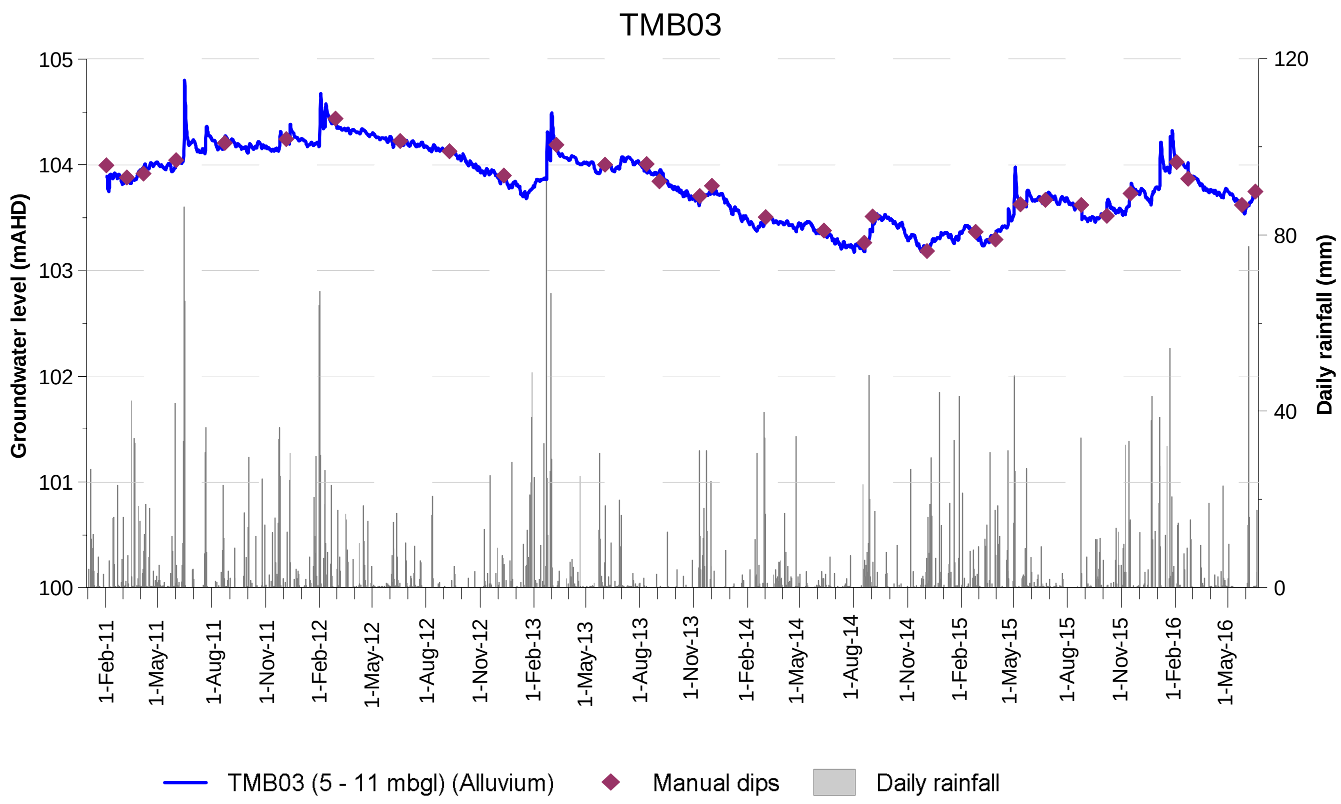




Figure A.1: TMB01 and TMB02 monitoring bores



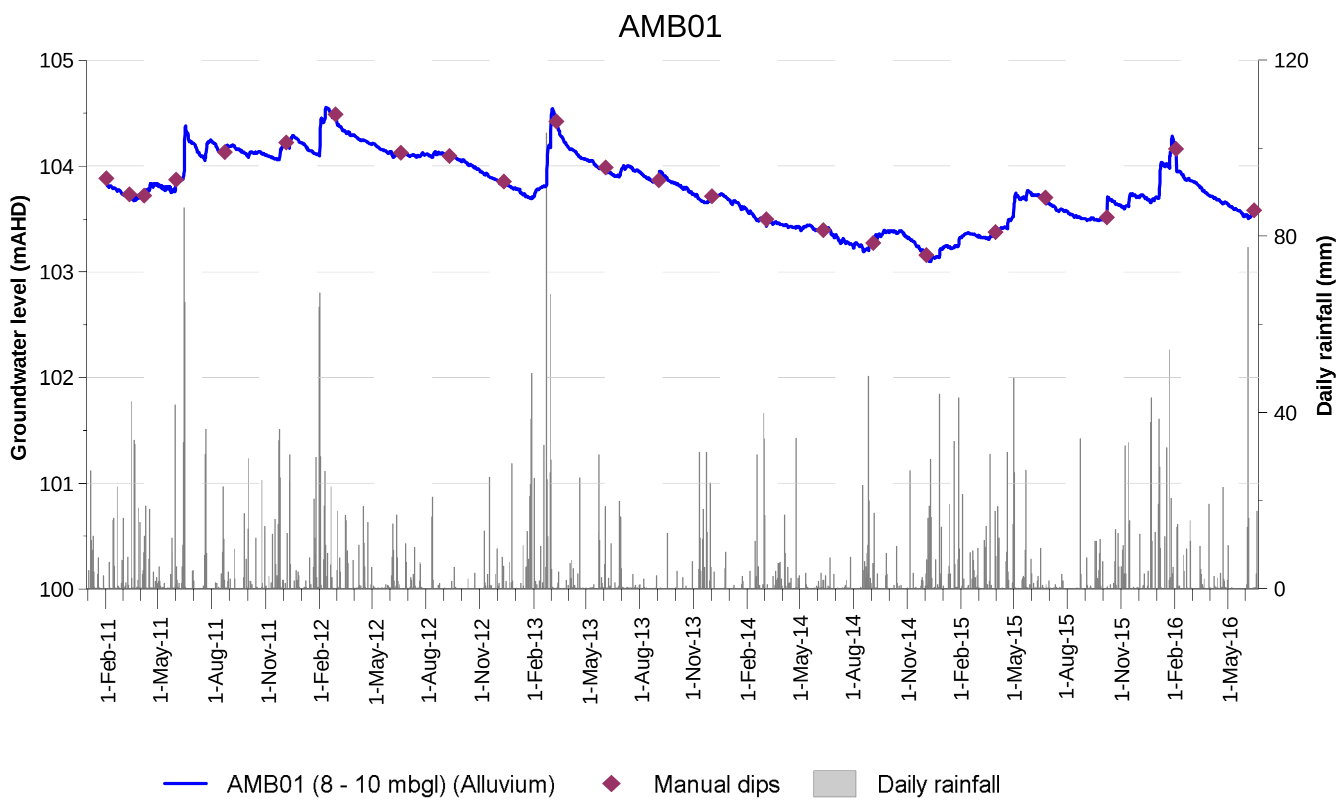
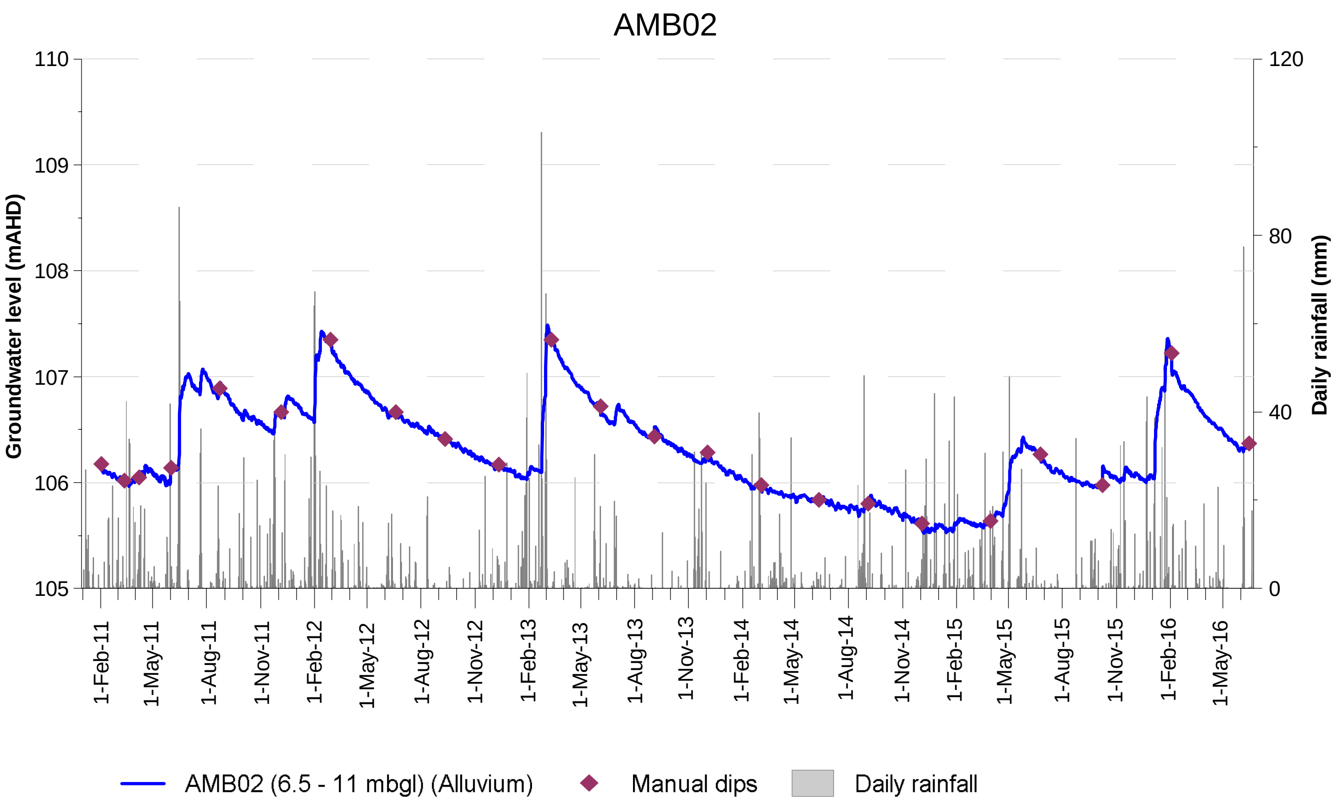




Figure A.2: TMB03 and AMB01 monitoring bores



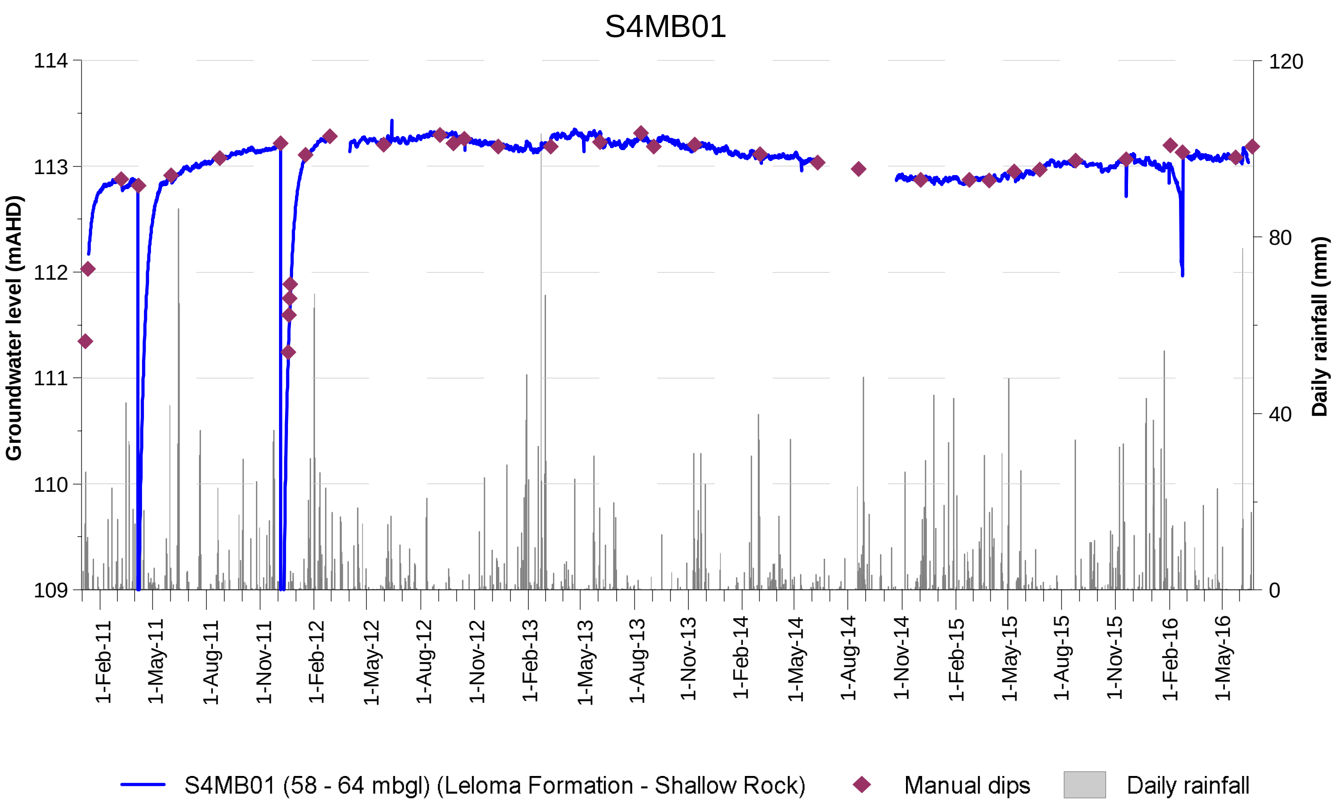
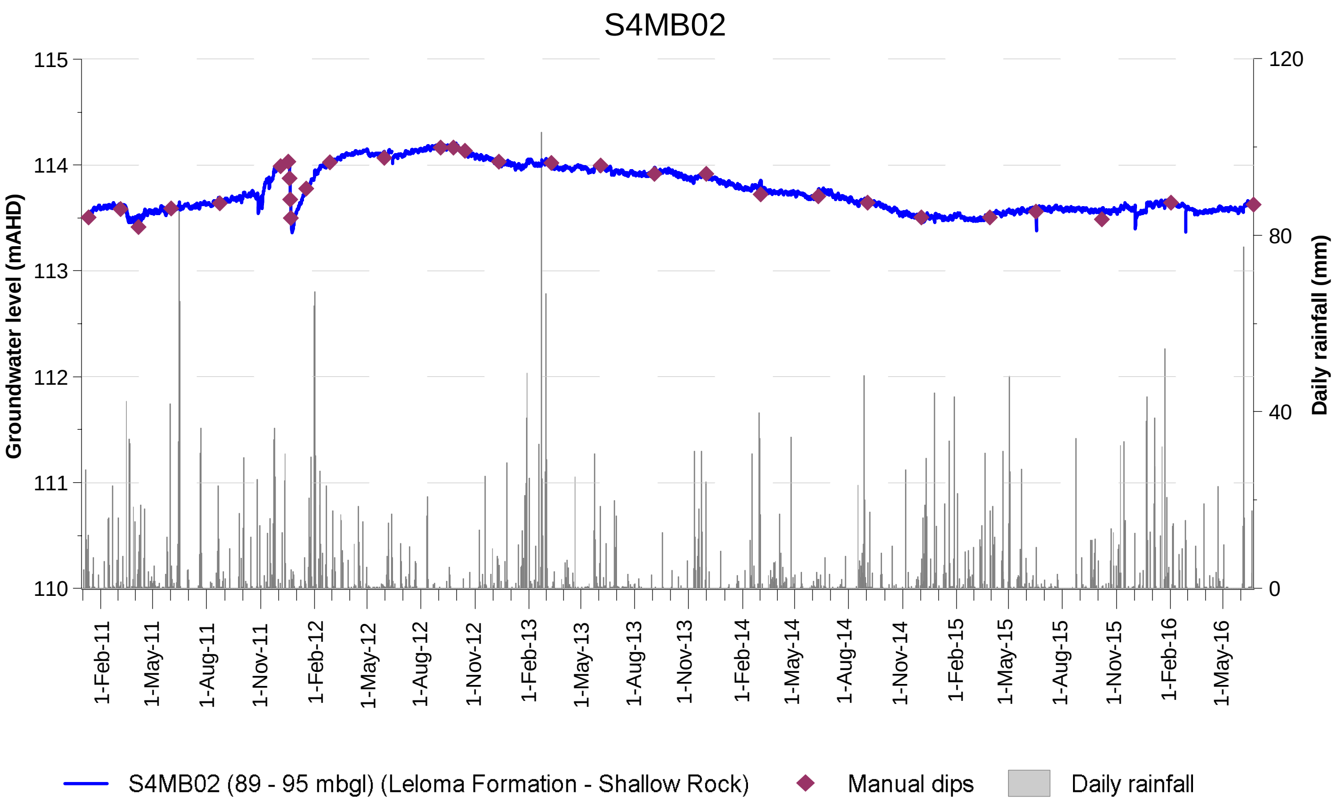




Figure A.3: AMB02 and S4MB01 monitoring bores



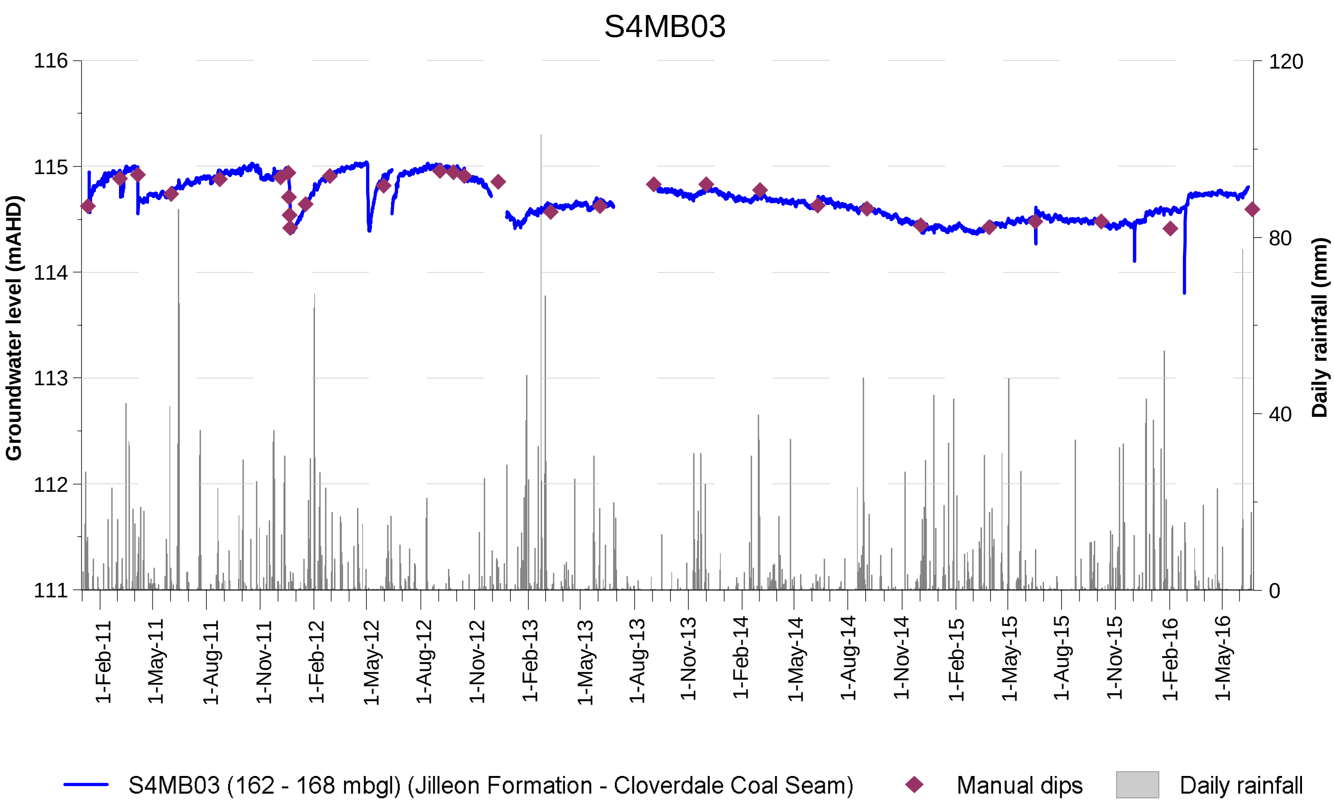
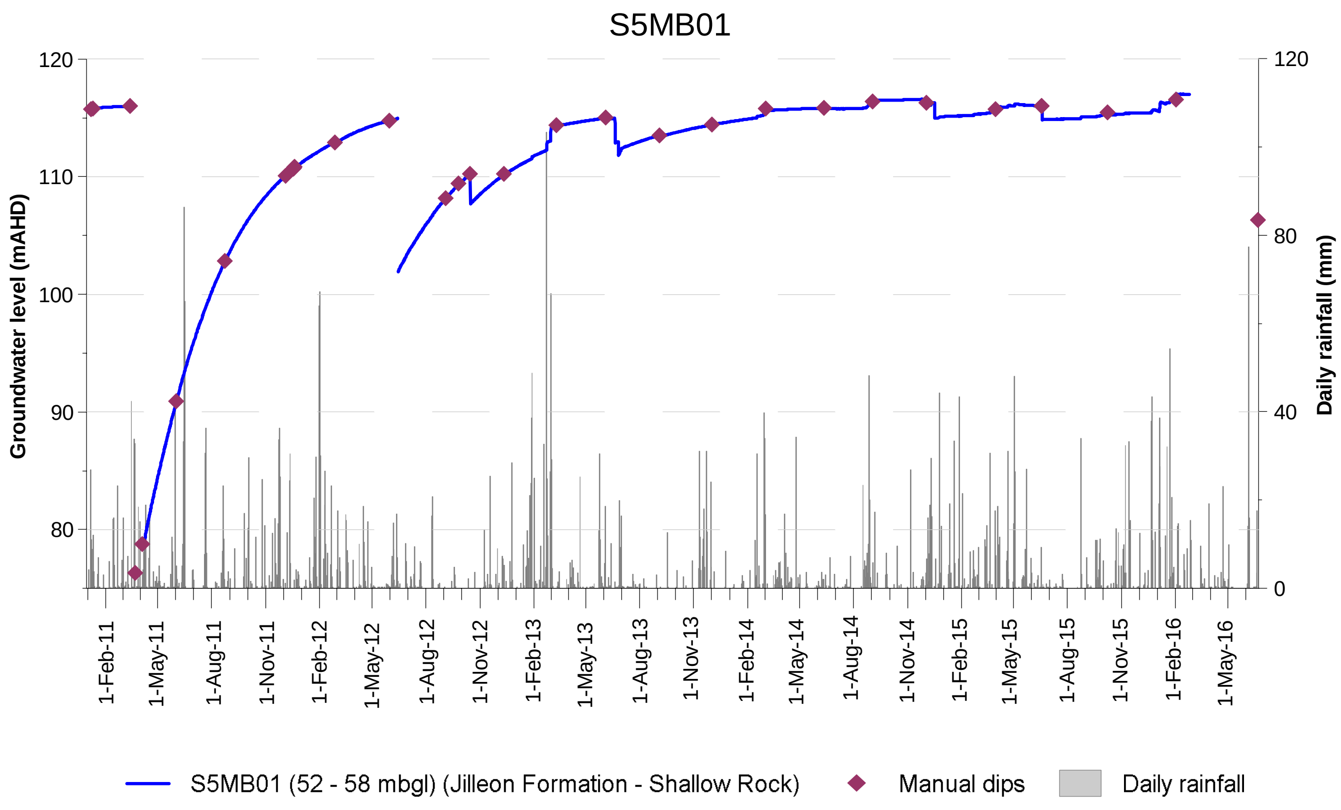




Figure A.4: S4MB02 and S4MB03 monitoring bores



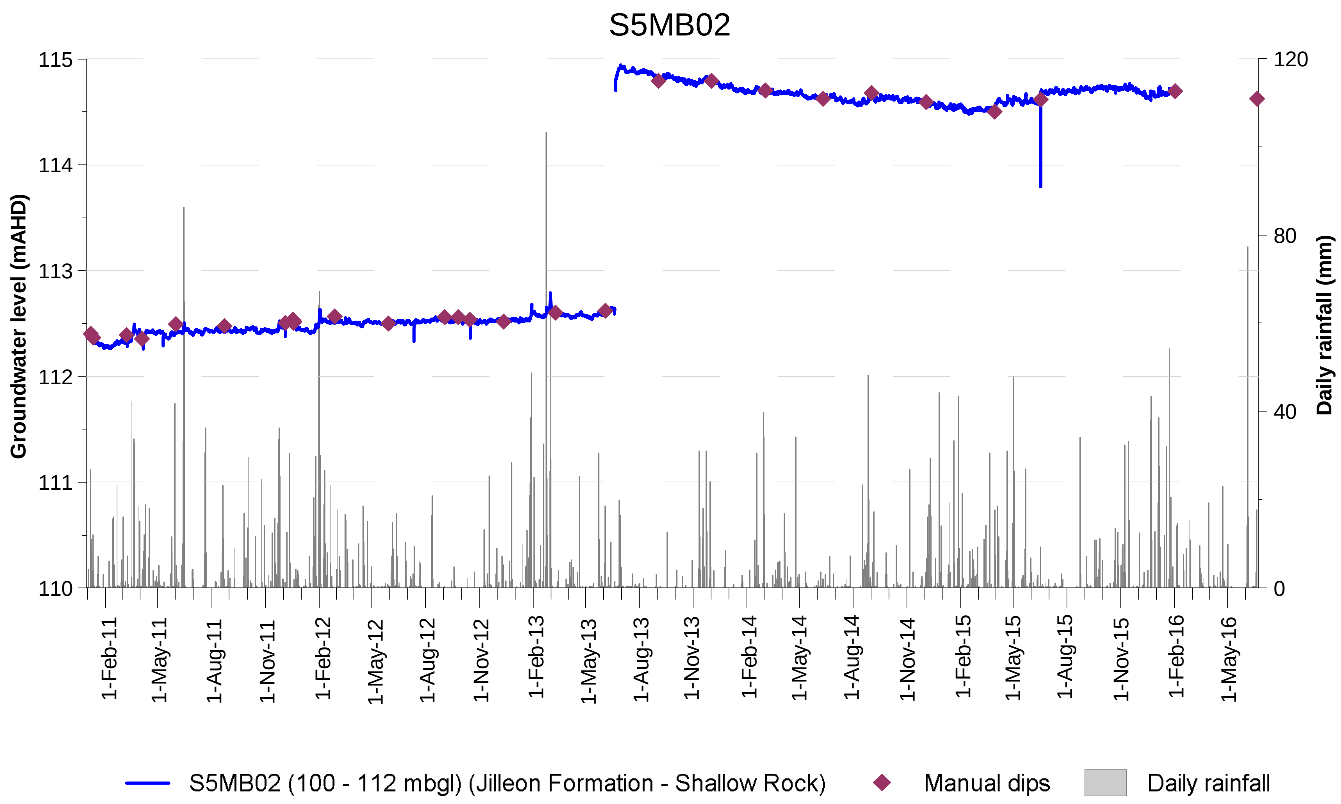
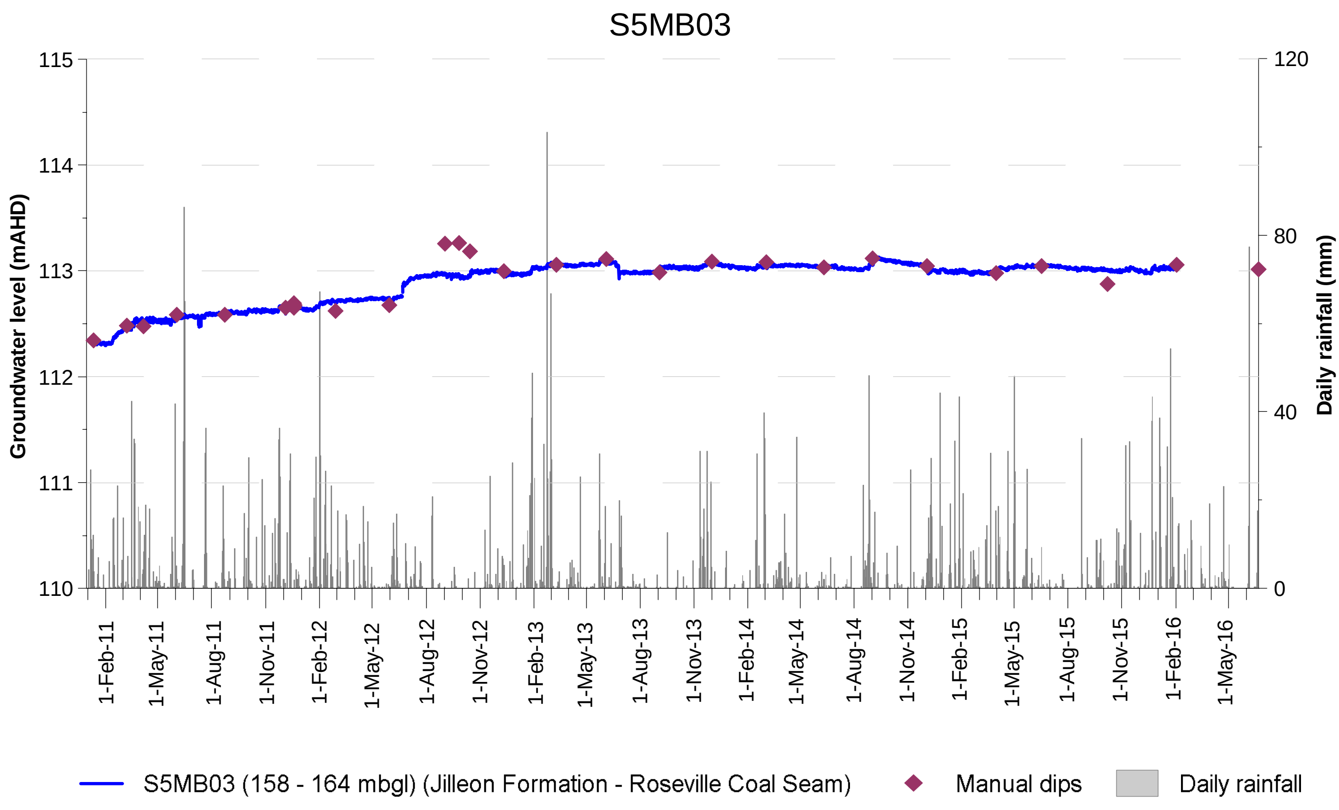
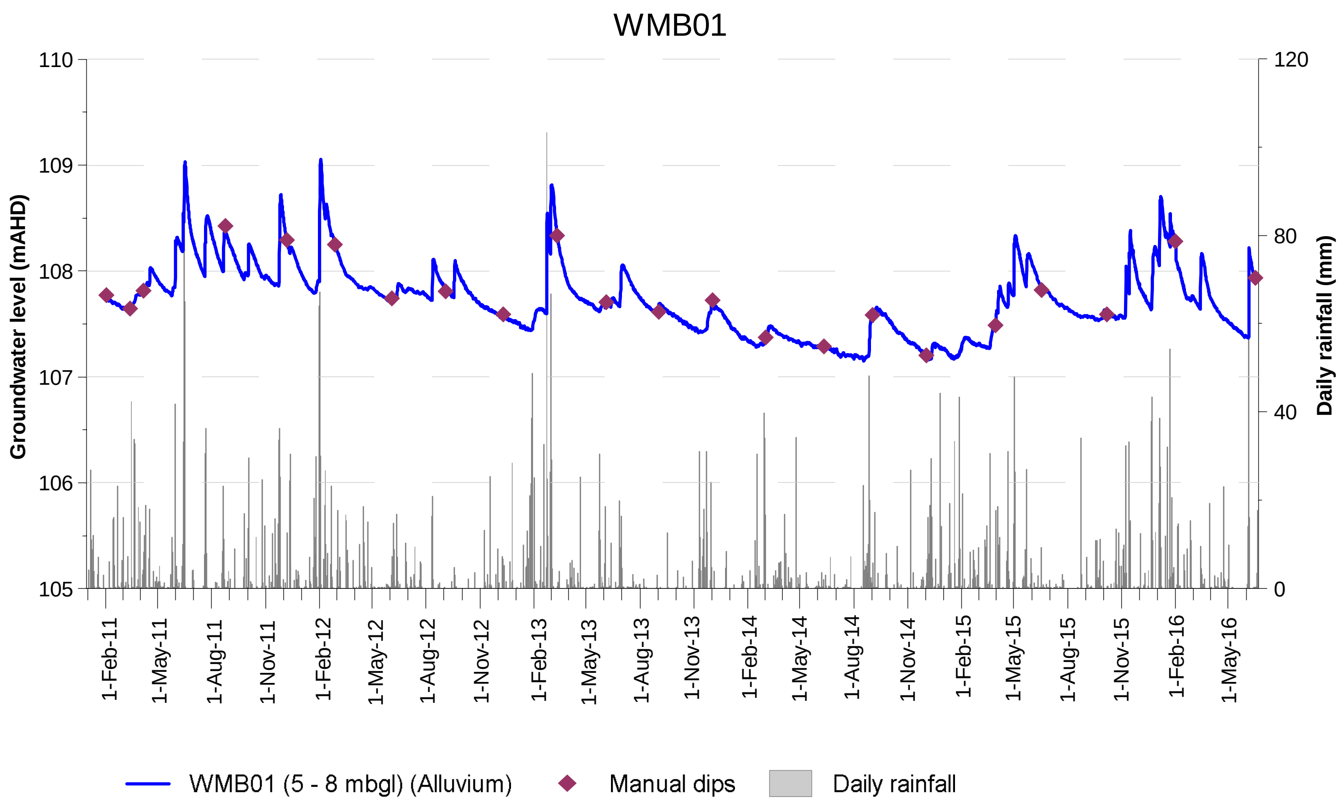




Figure A.5: S5MB01 and S5MB02 monitoring bores

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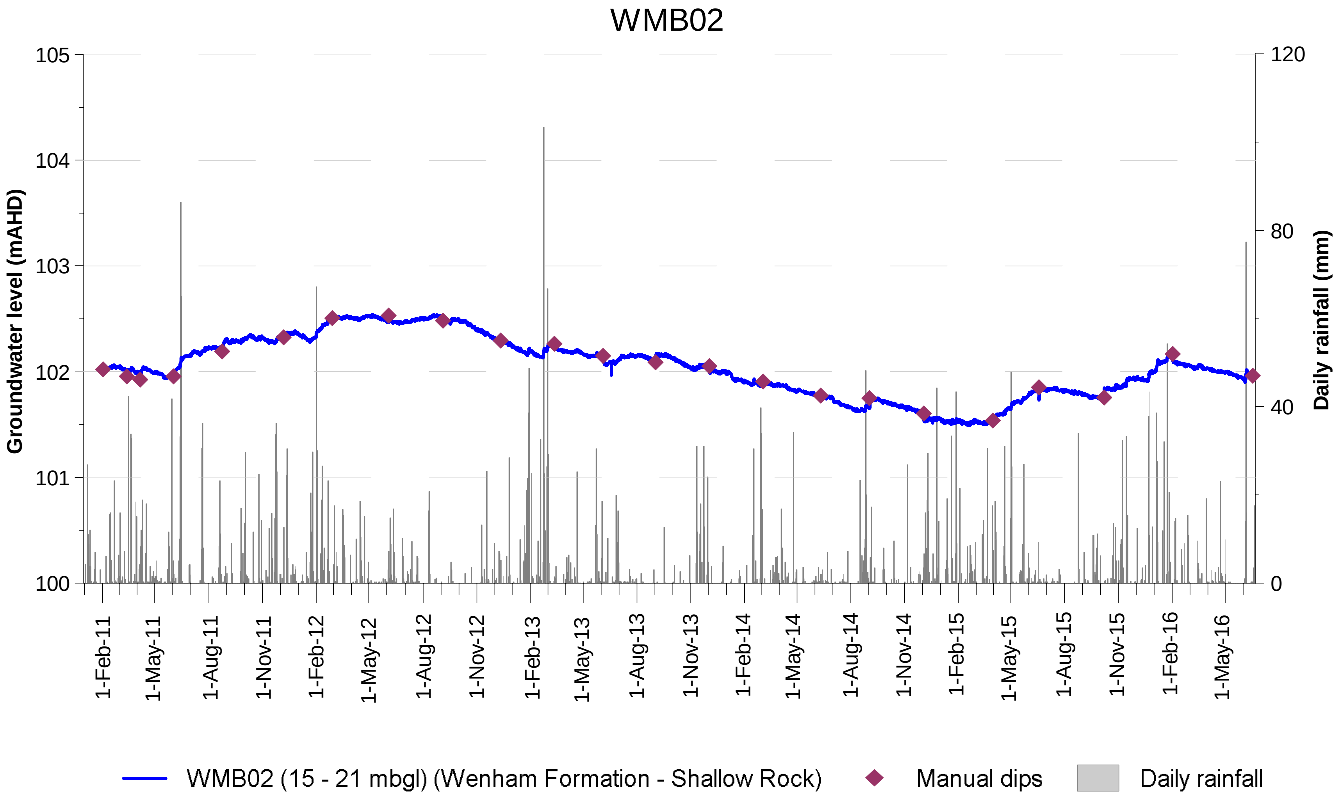


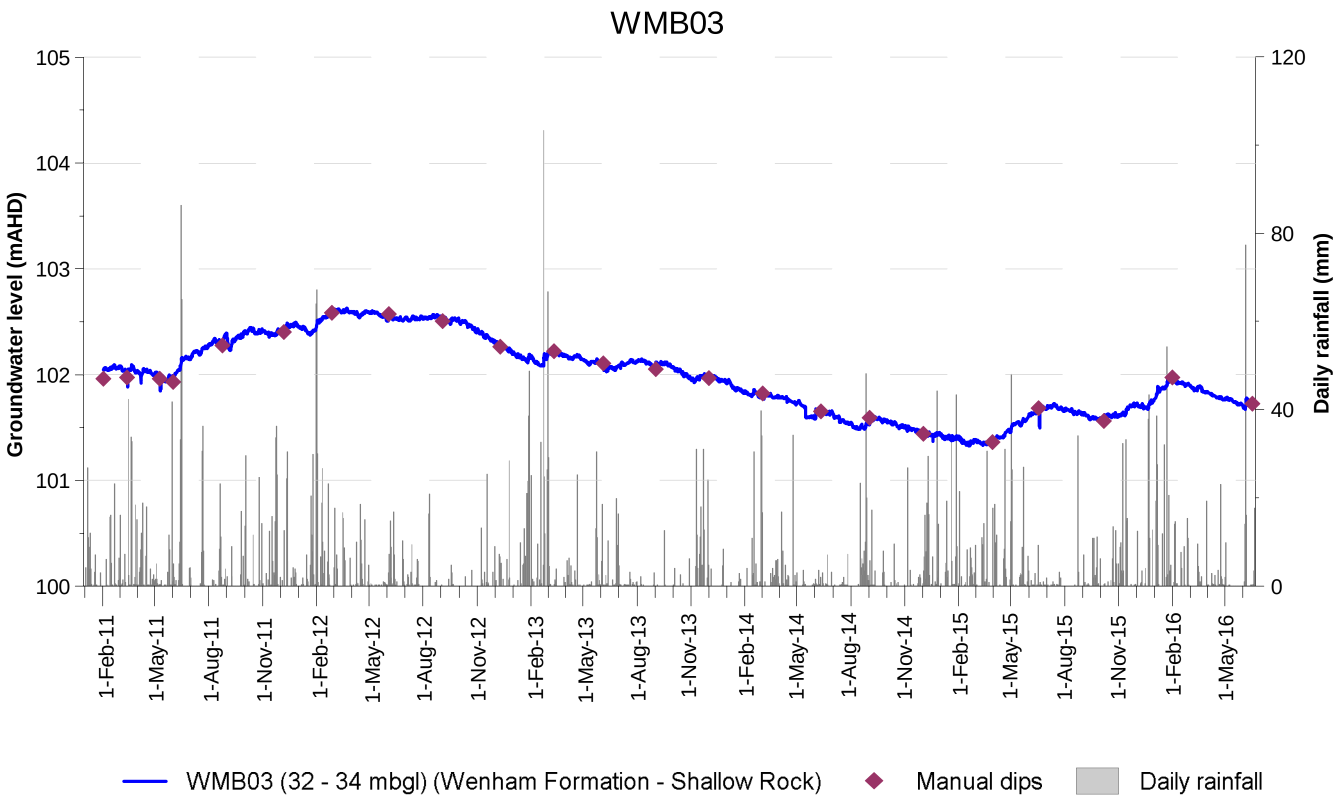
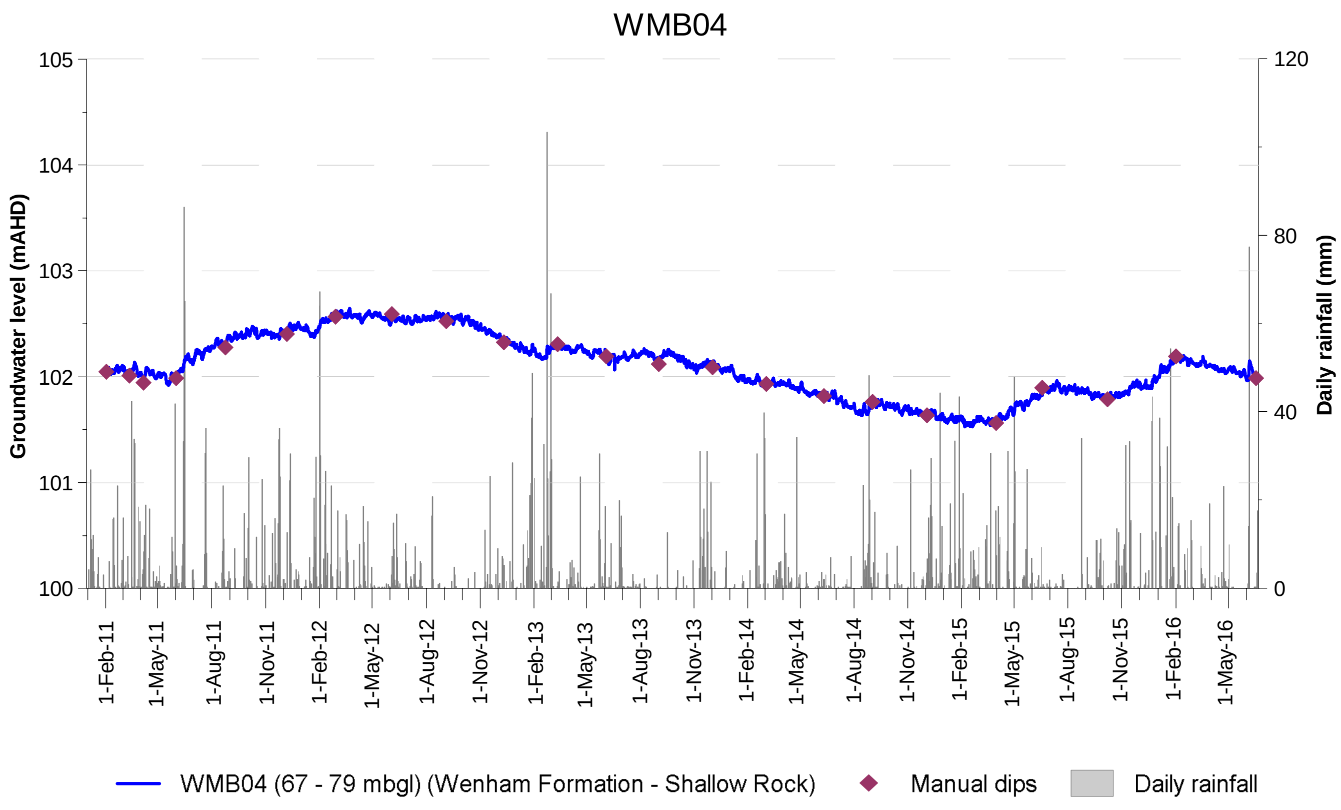




Figure A.7: WMB02 and WMB03 monitoring bores



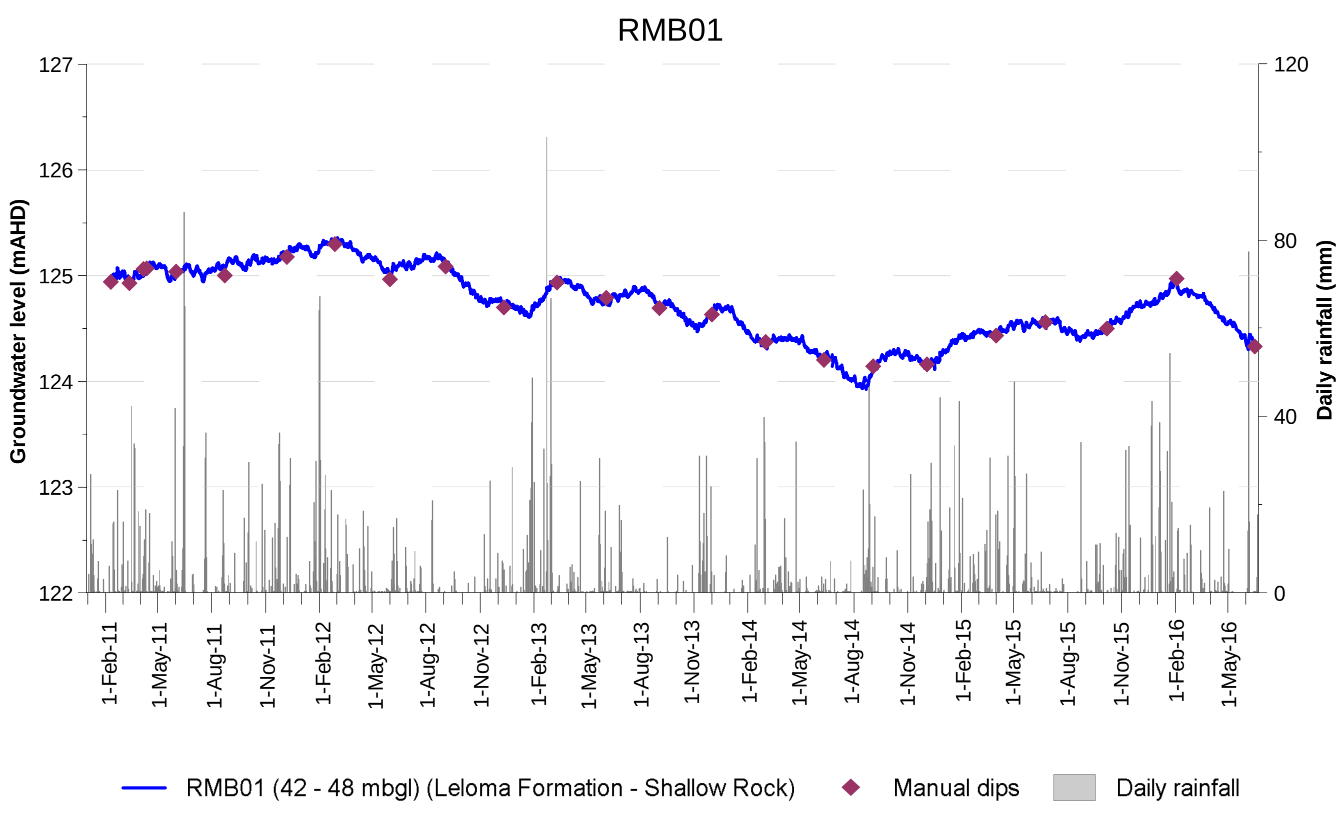
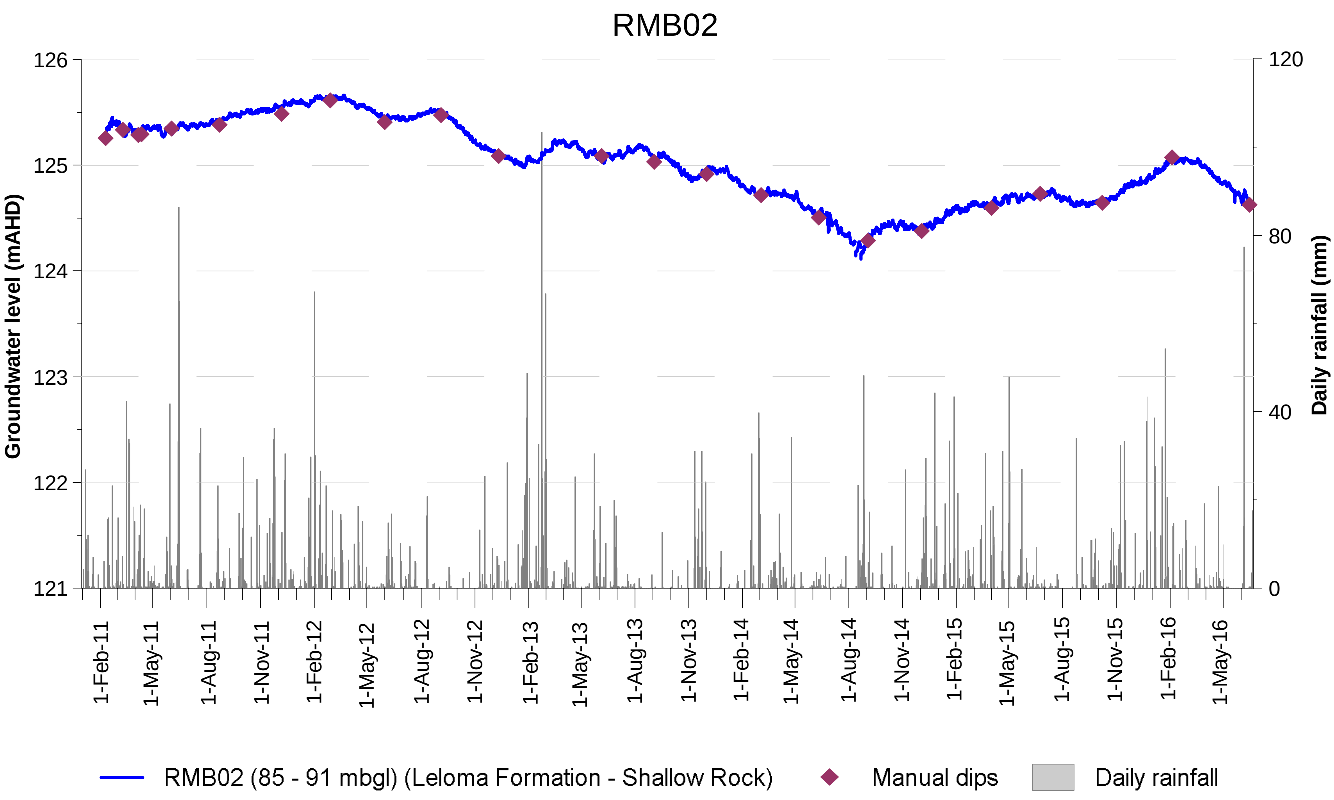




Figure A.8: WMB04 and RMB01 monitoring bores



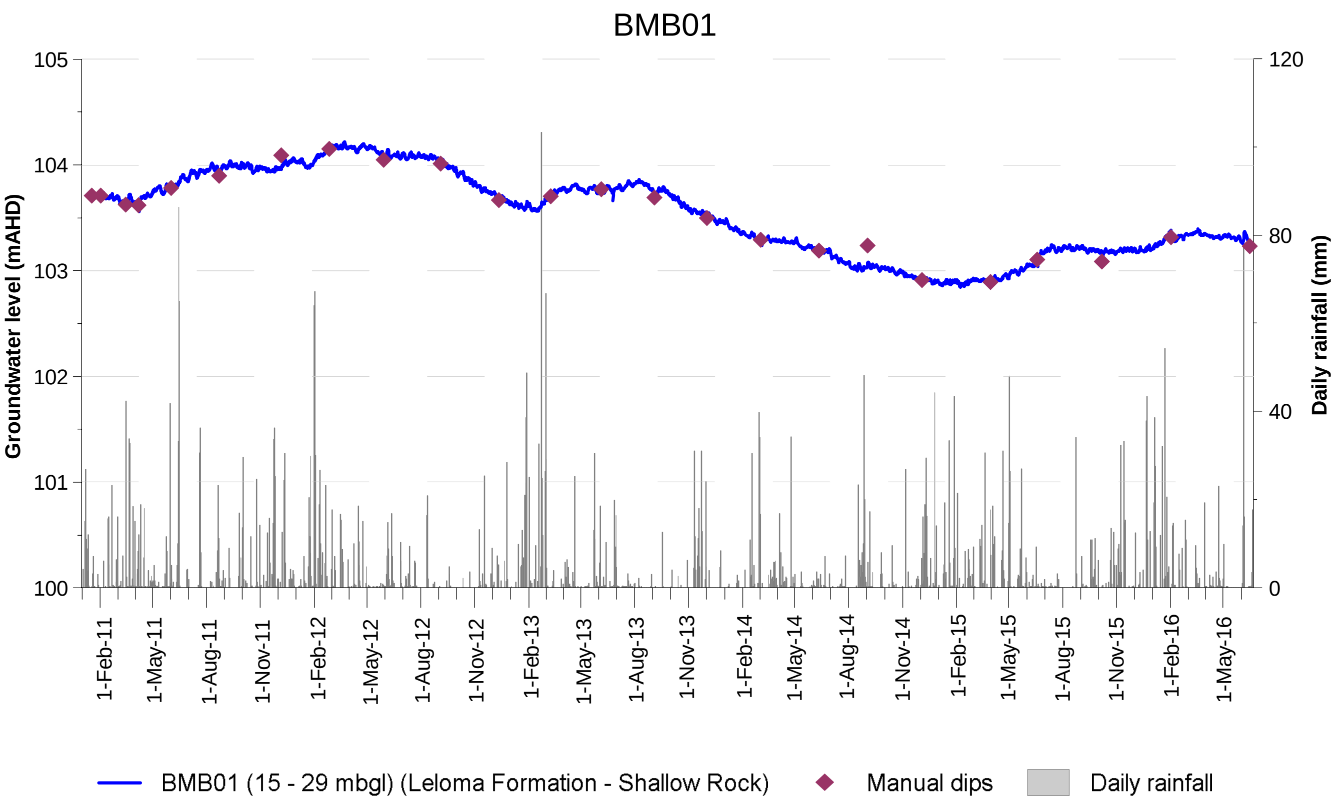
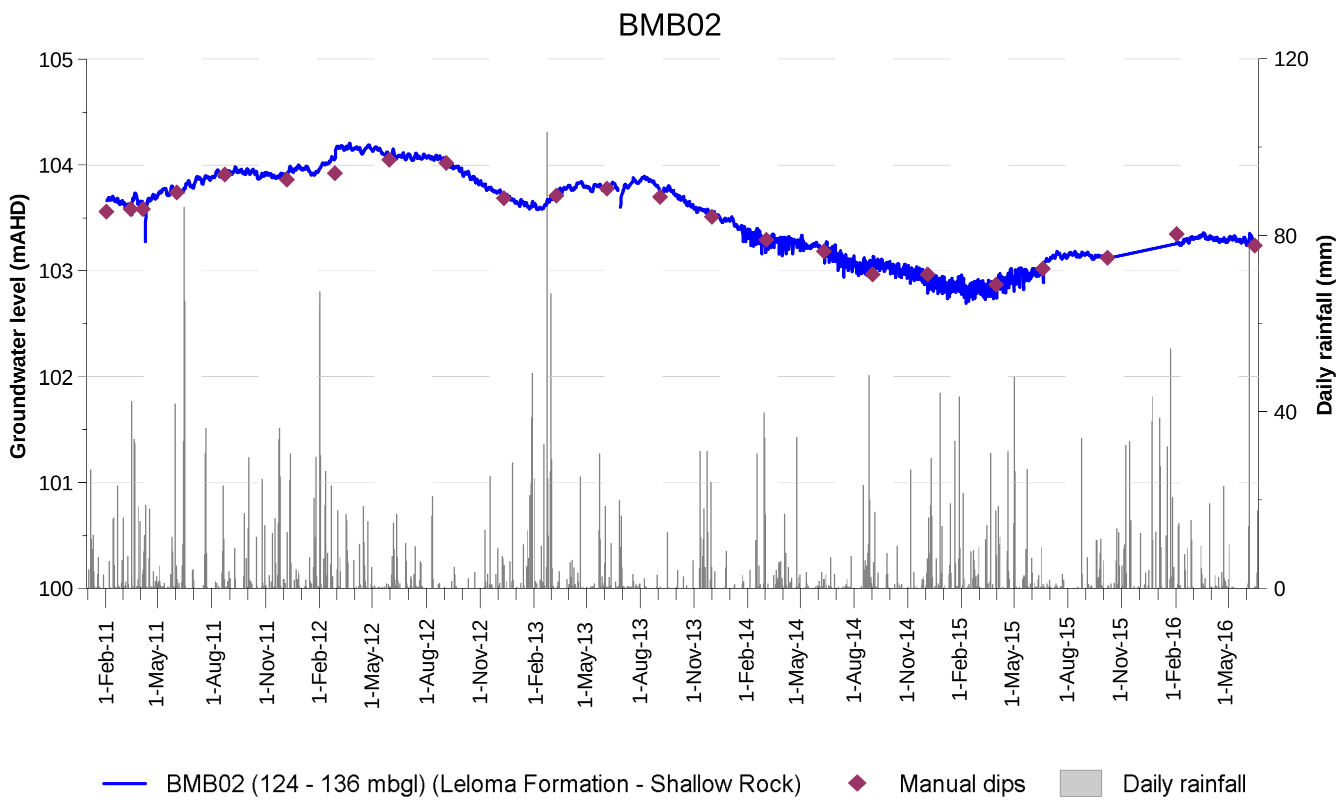




Figure A.9: RMB02 and BMB01 monitoring bores



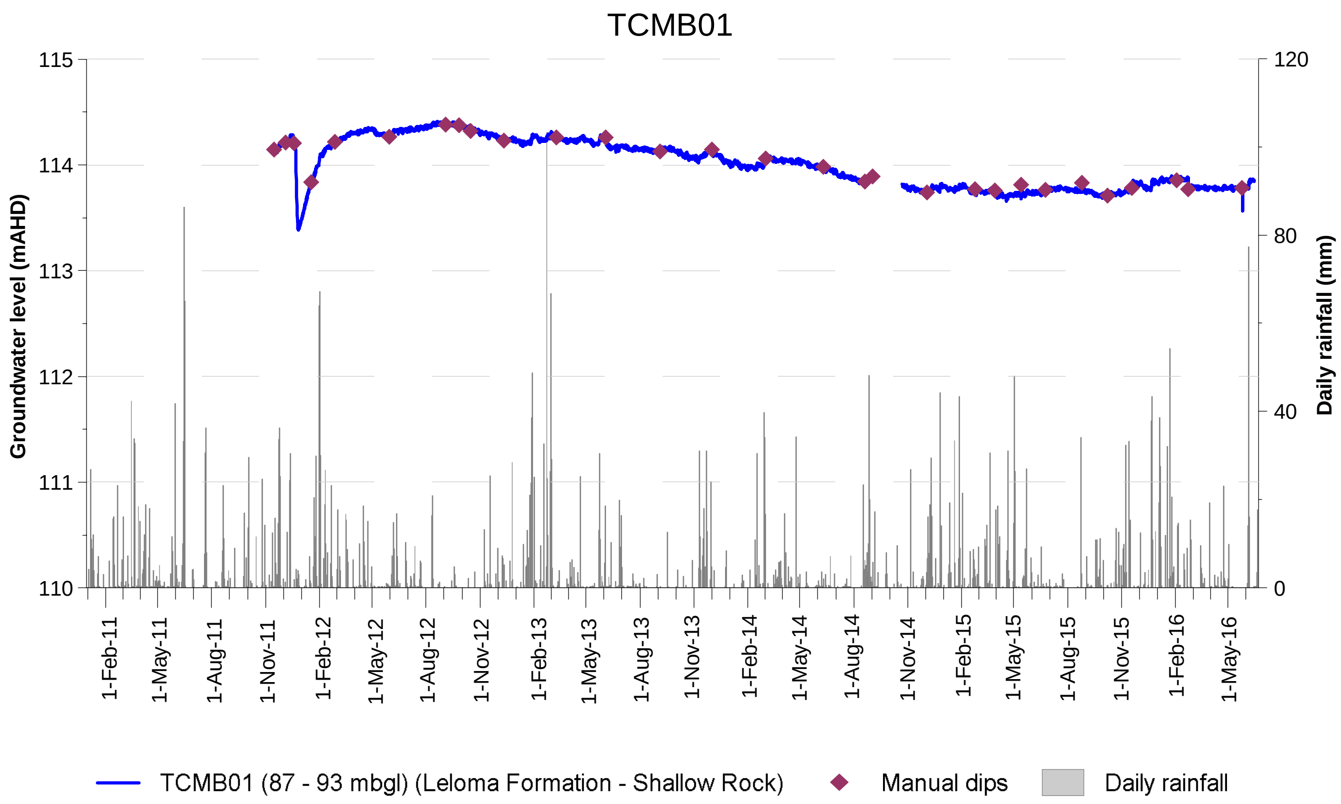
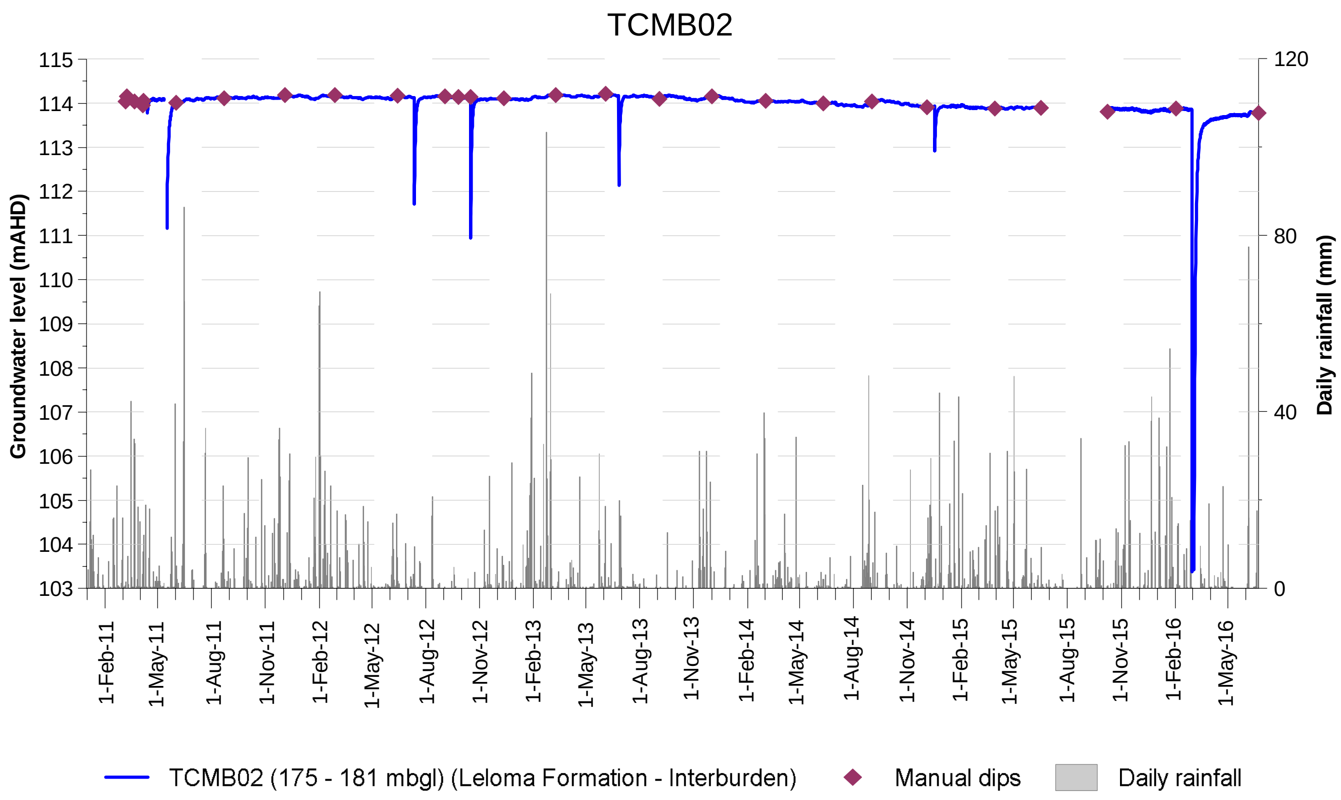




Figure A.10: BMB02 and TCMB01 monitoring bores



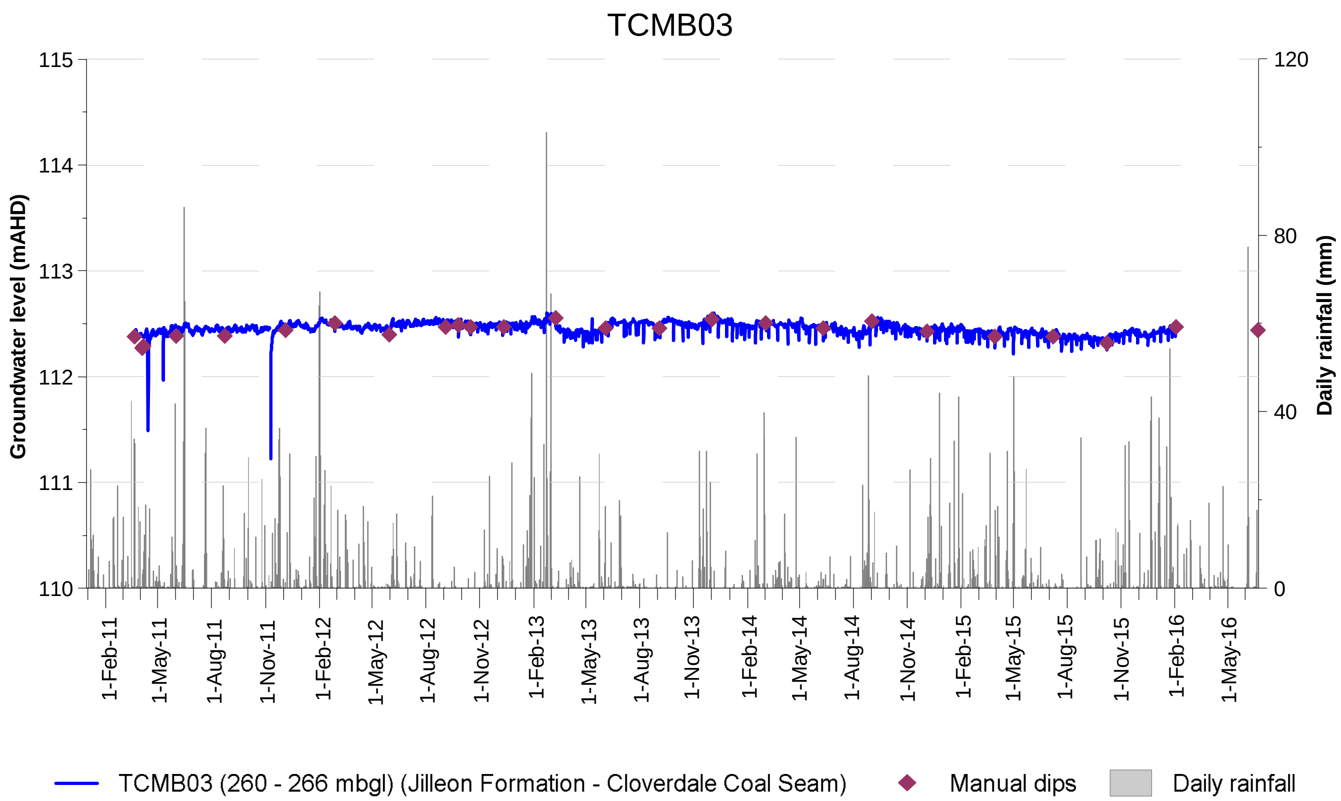
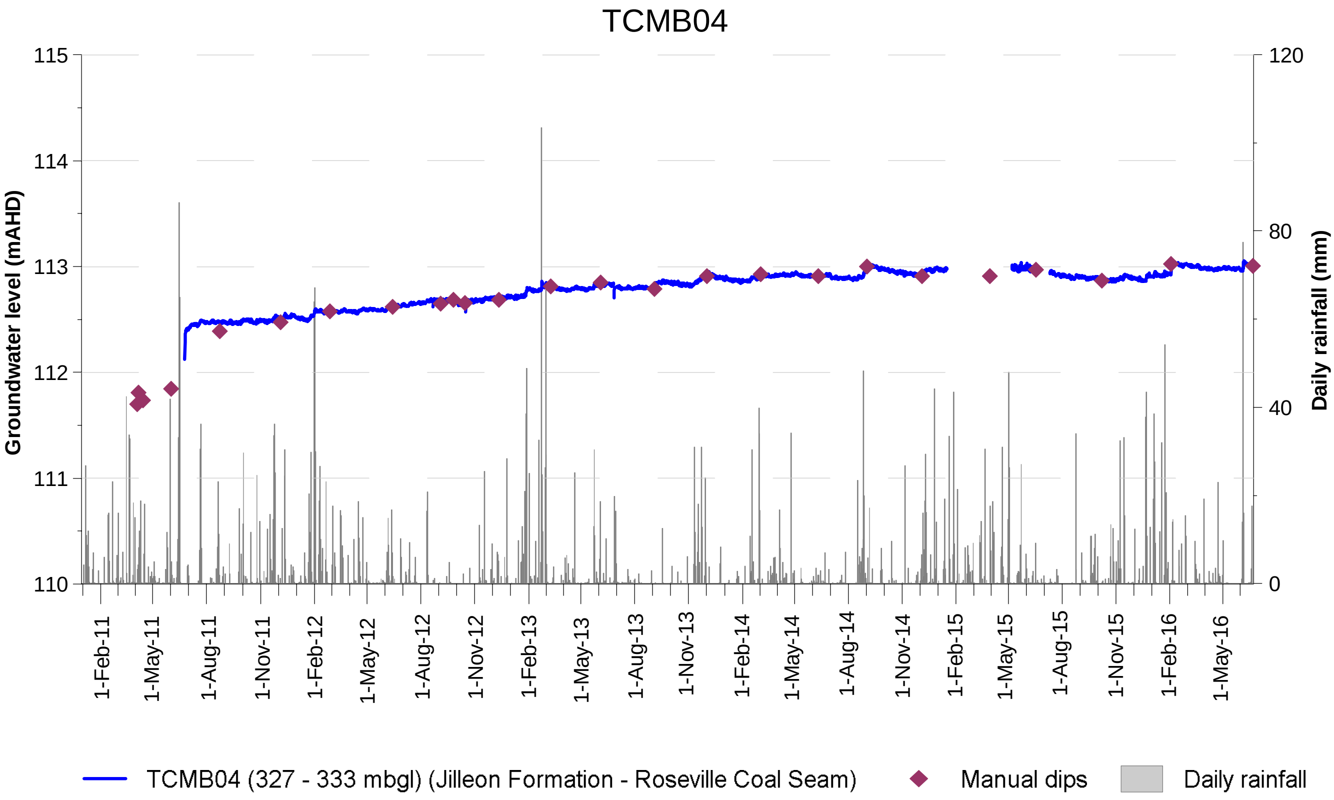




Figure A.11: TCMB02 and TCMB03 monitoring bores



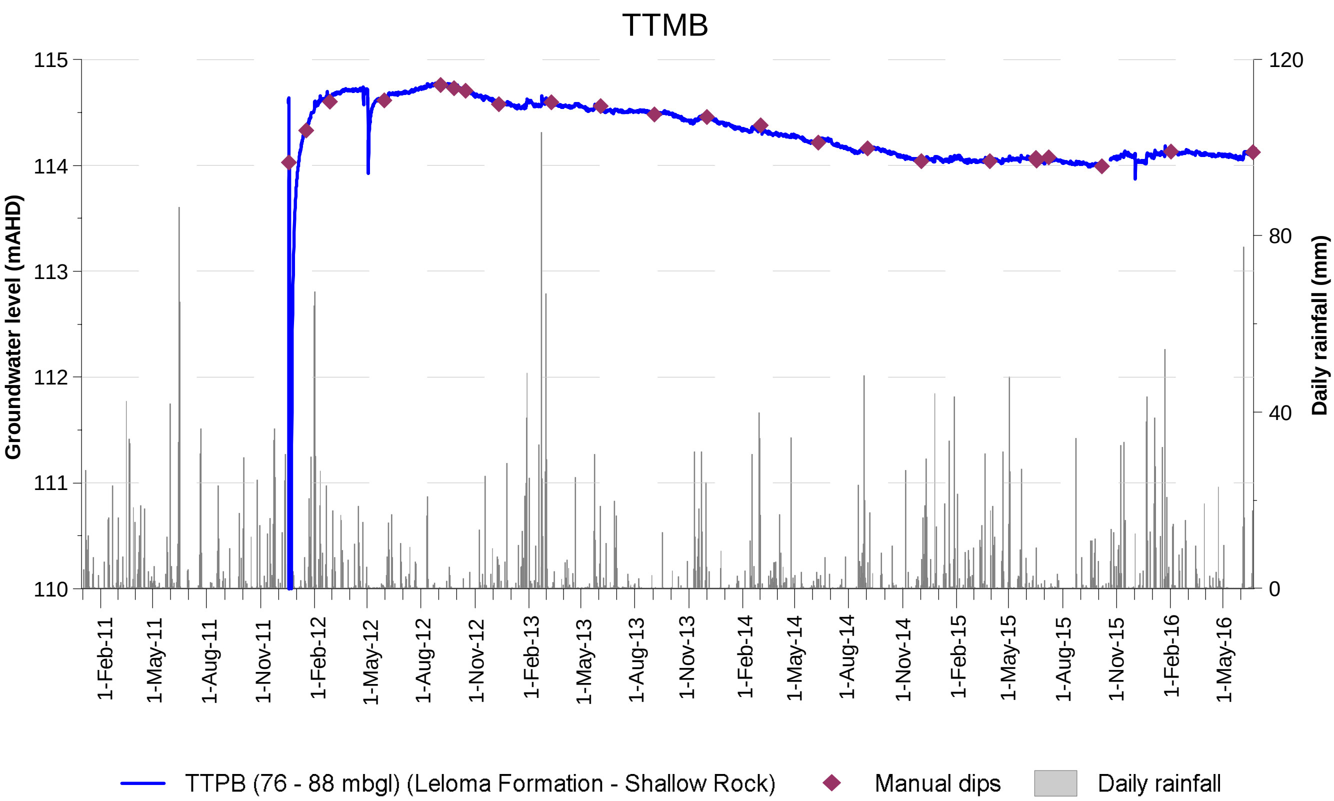
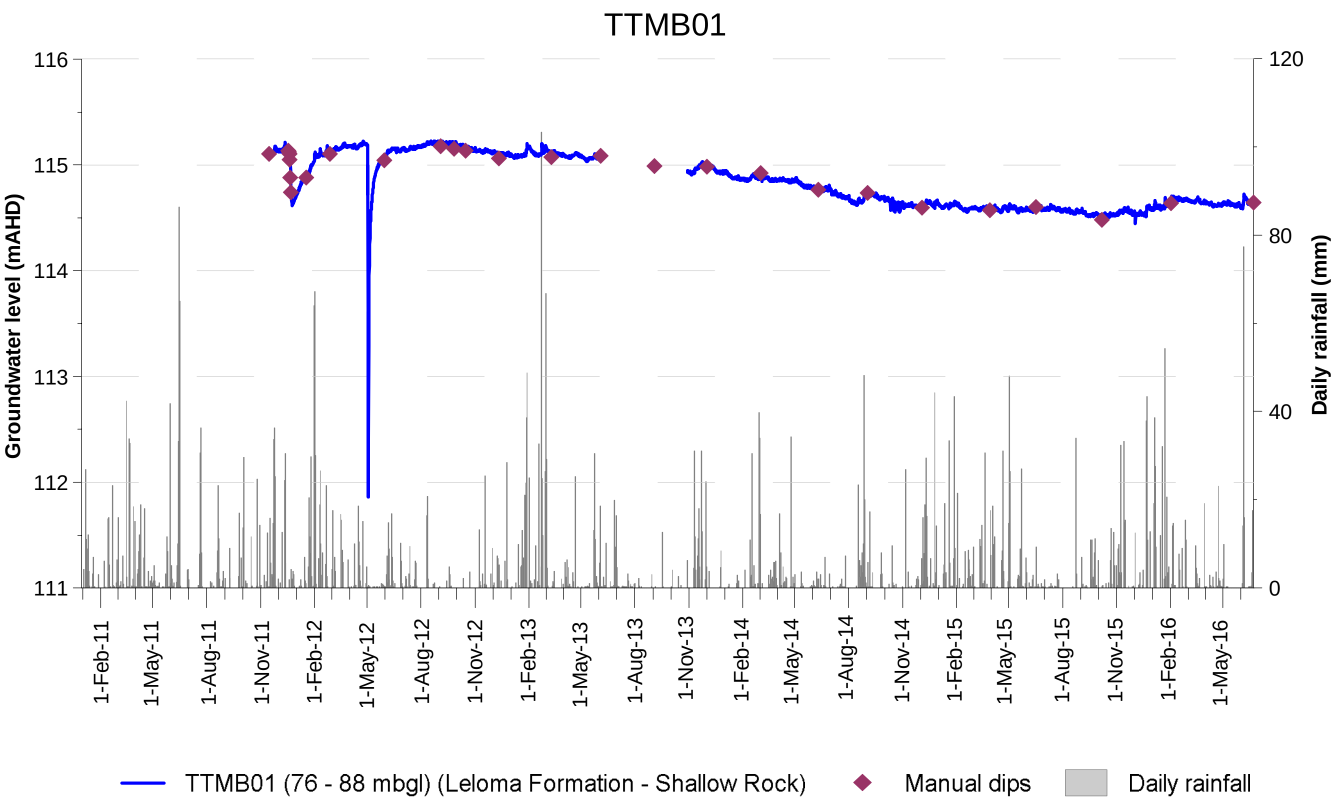




Figure A.12: TCMB04 and TTMB monitoring bores



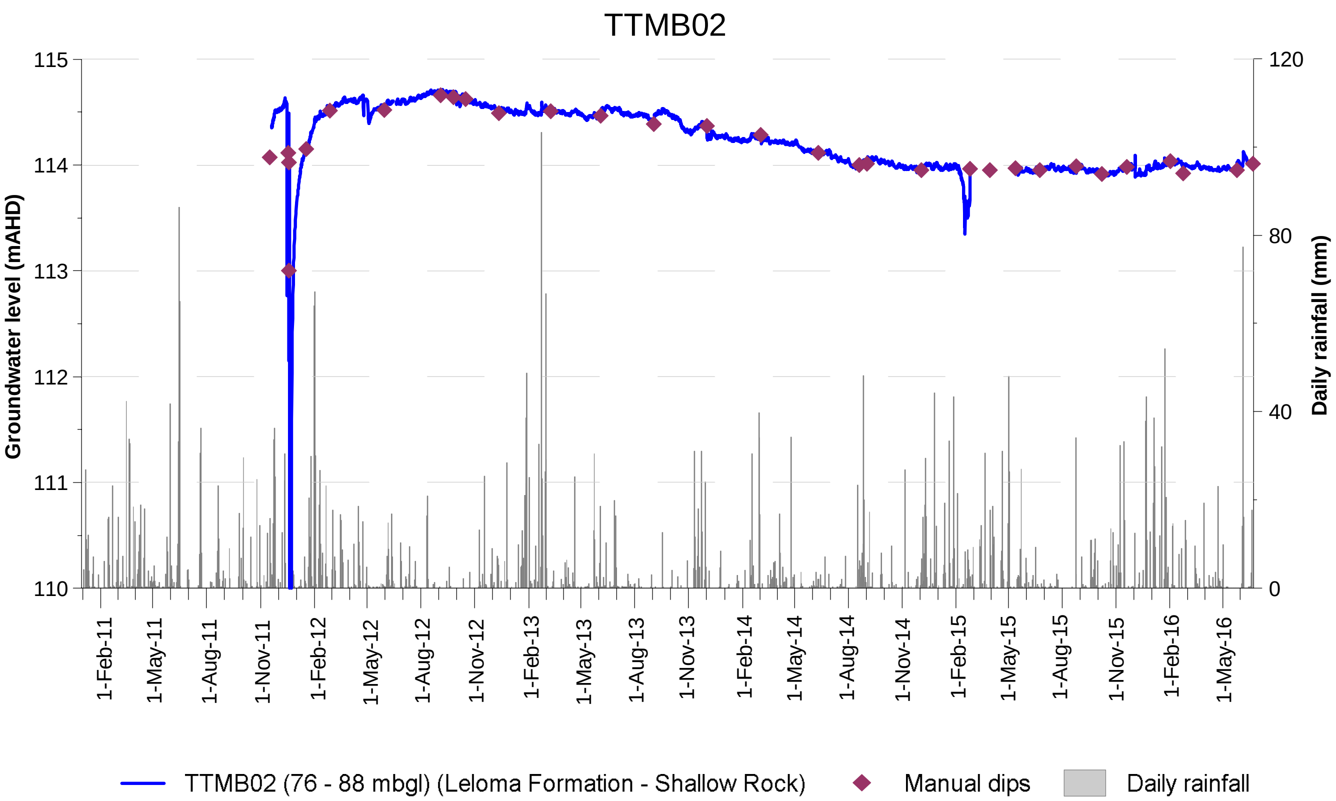
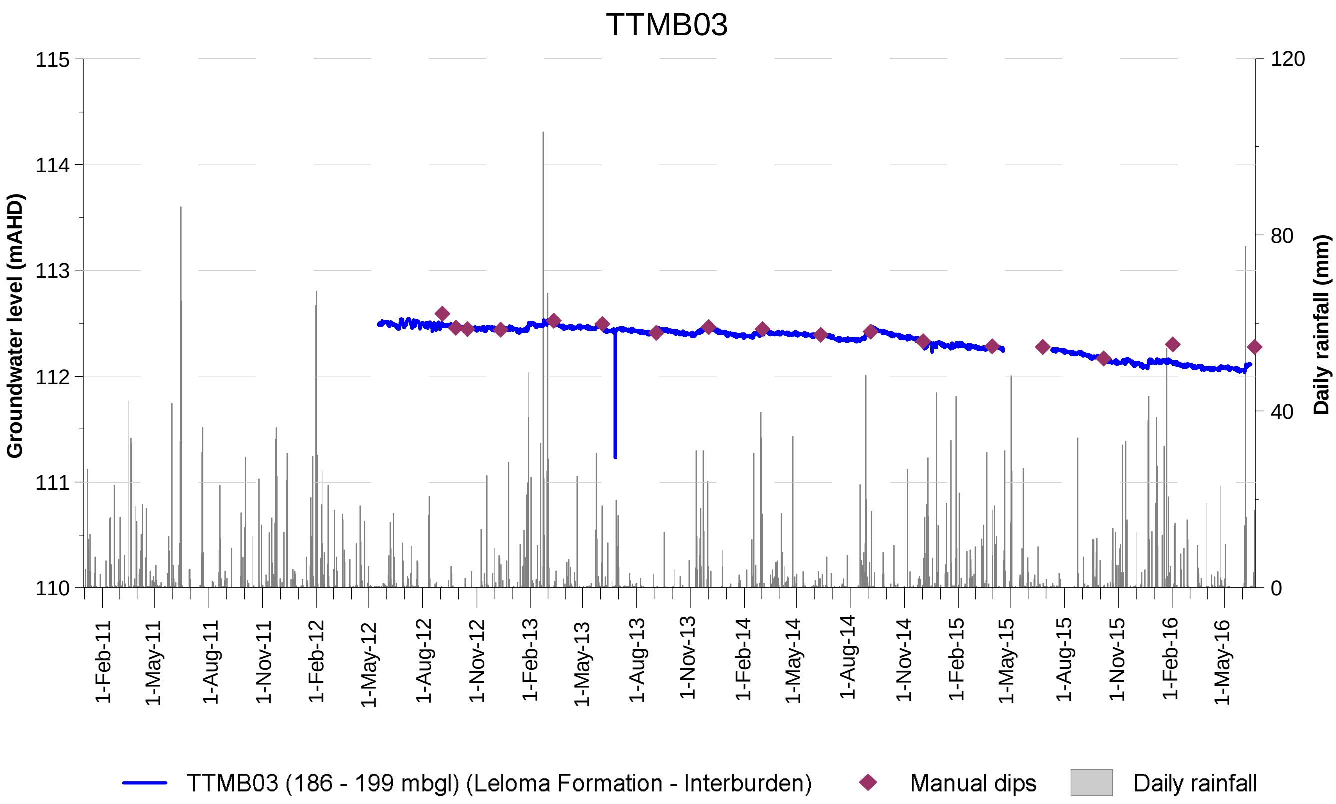




Figure A.13: TTMB01 and TTMB02 monitoring bores



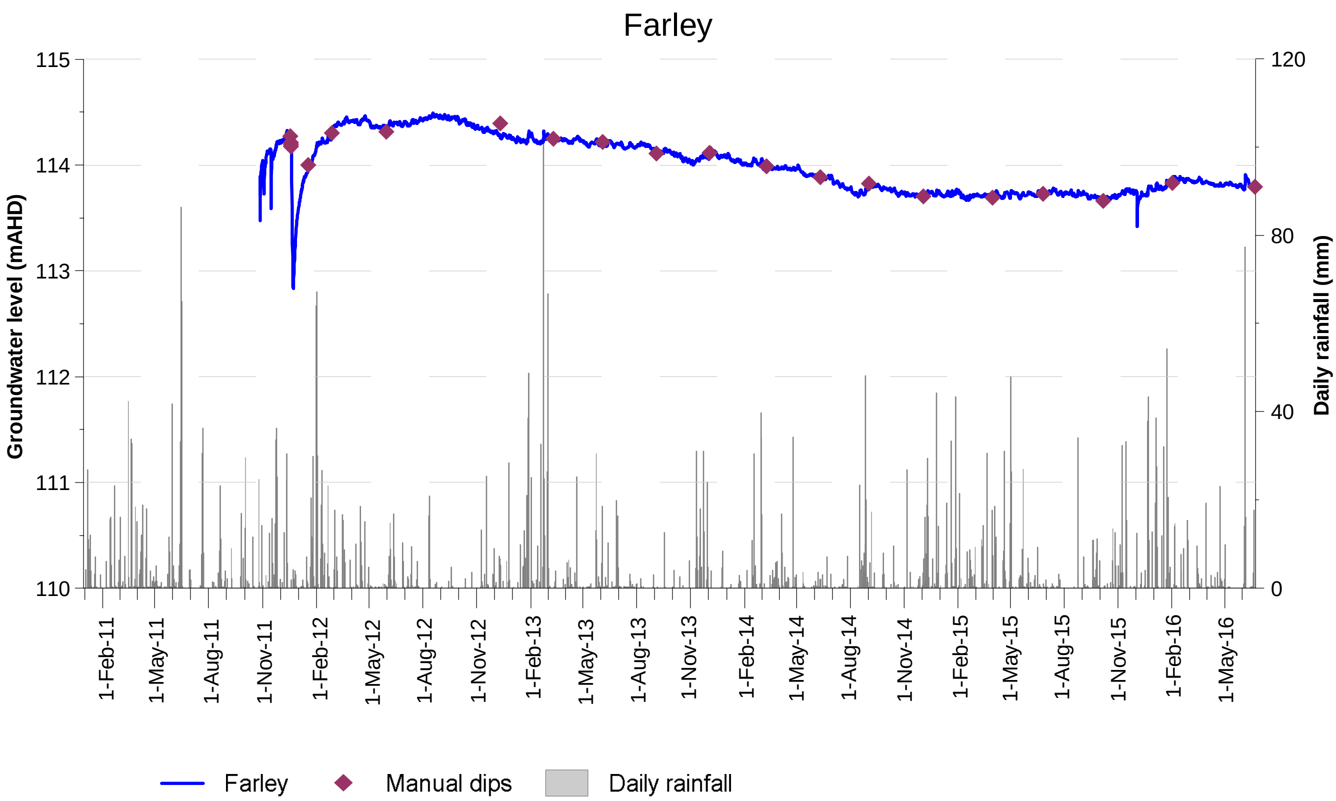
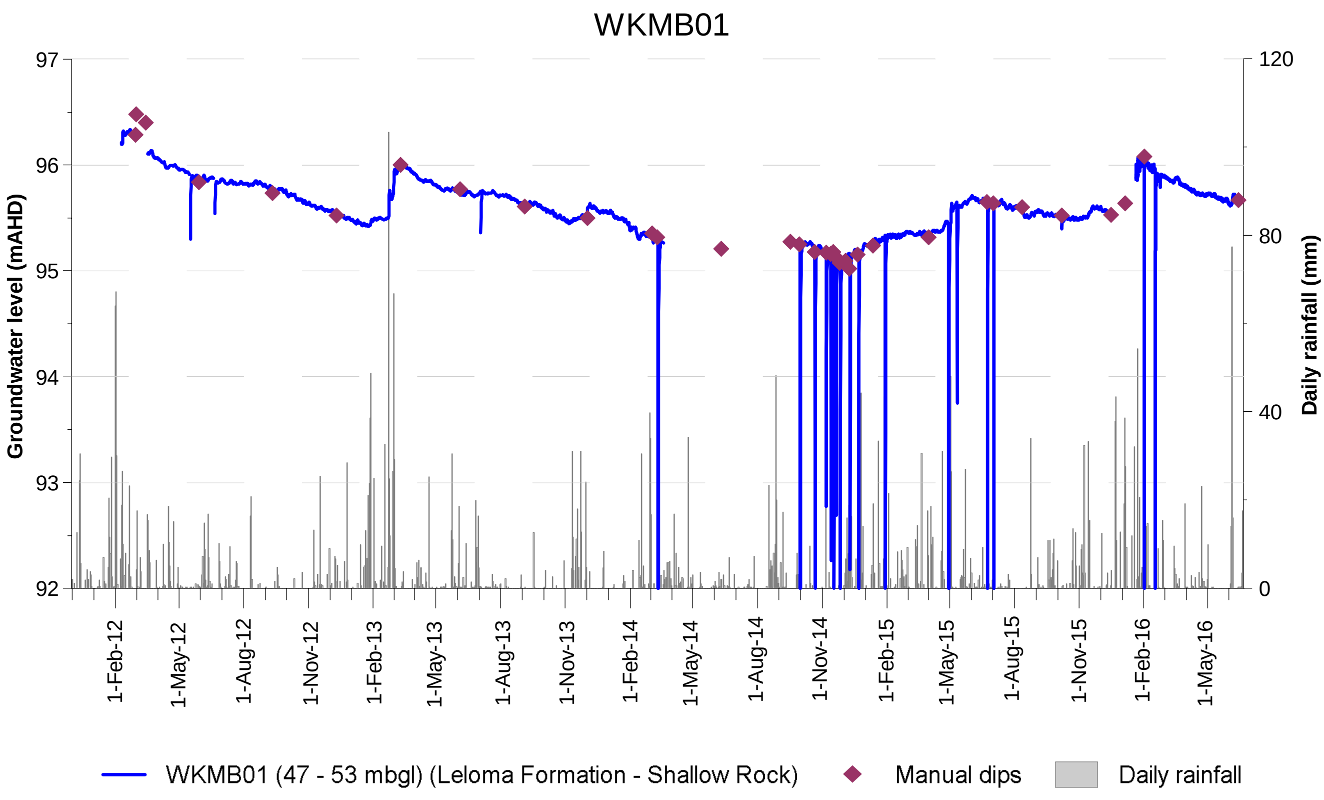




Figure A.14: TTMB03 and Farley monitoring bores



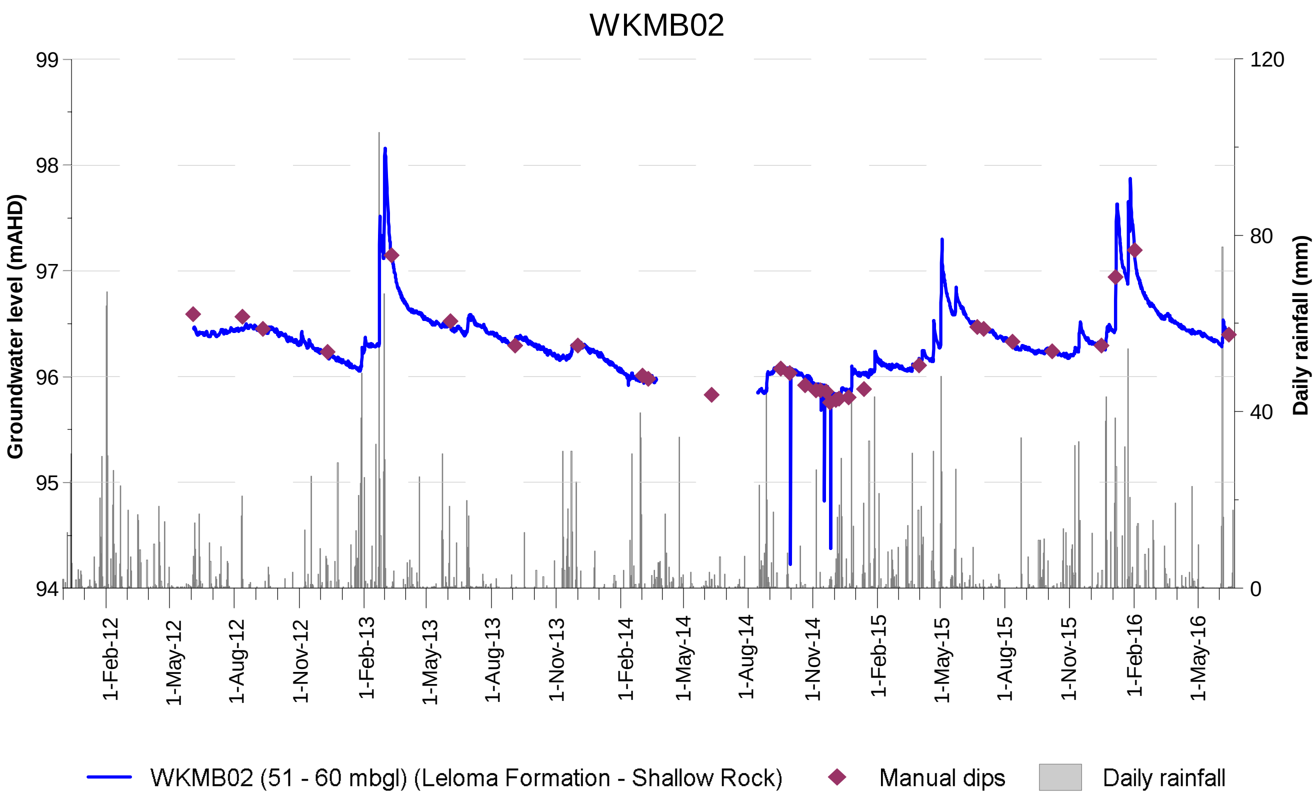




Figure A.15: WKMB01 and WKMB02 monitoring bores

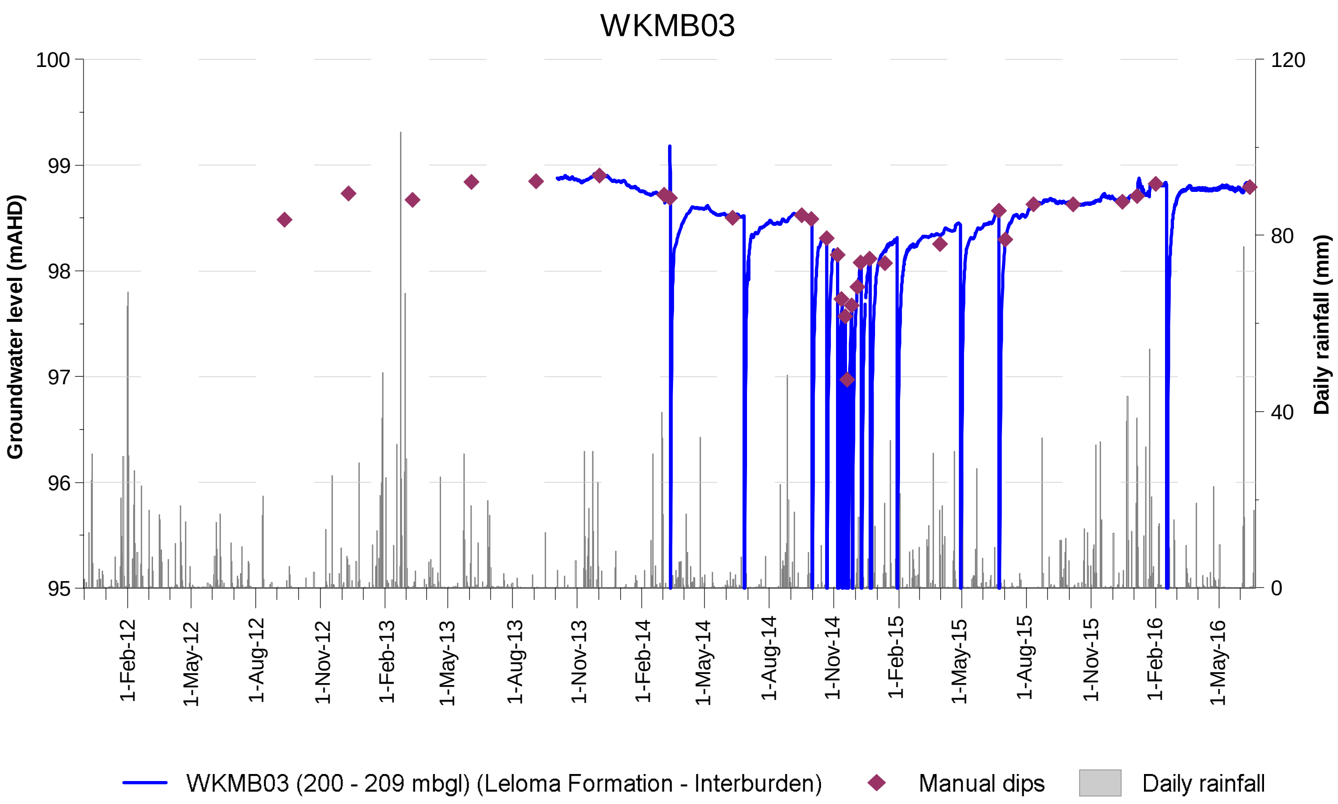
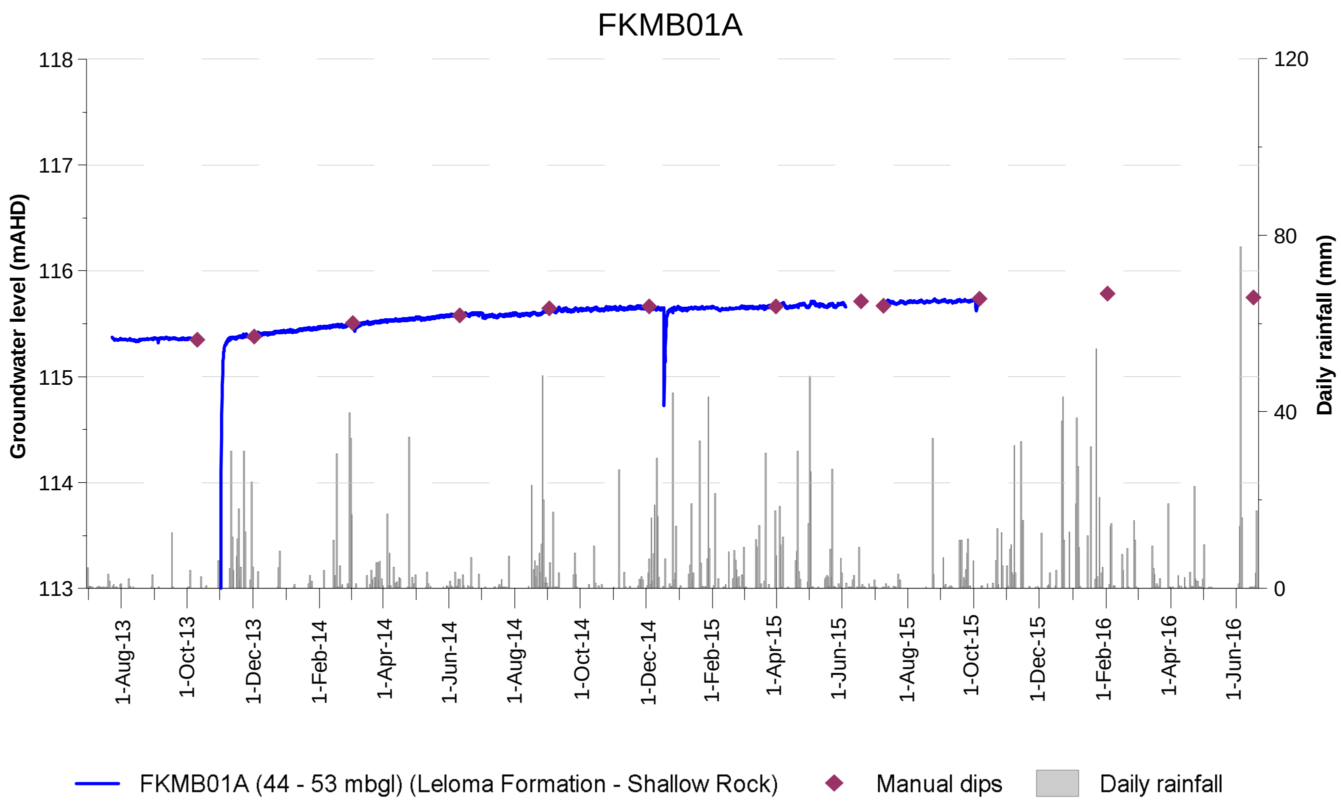



Figure A.16: WKMB03 monitoring bore



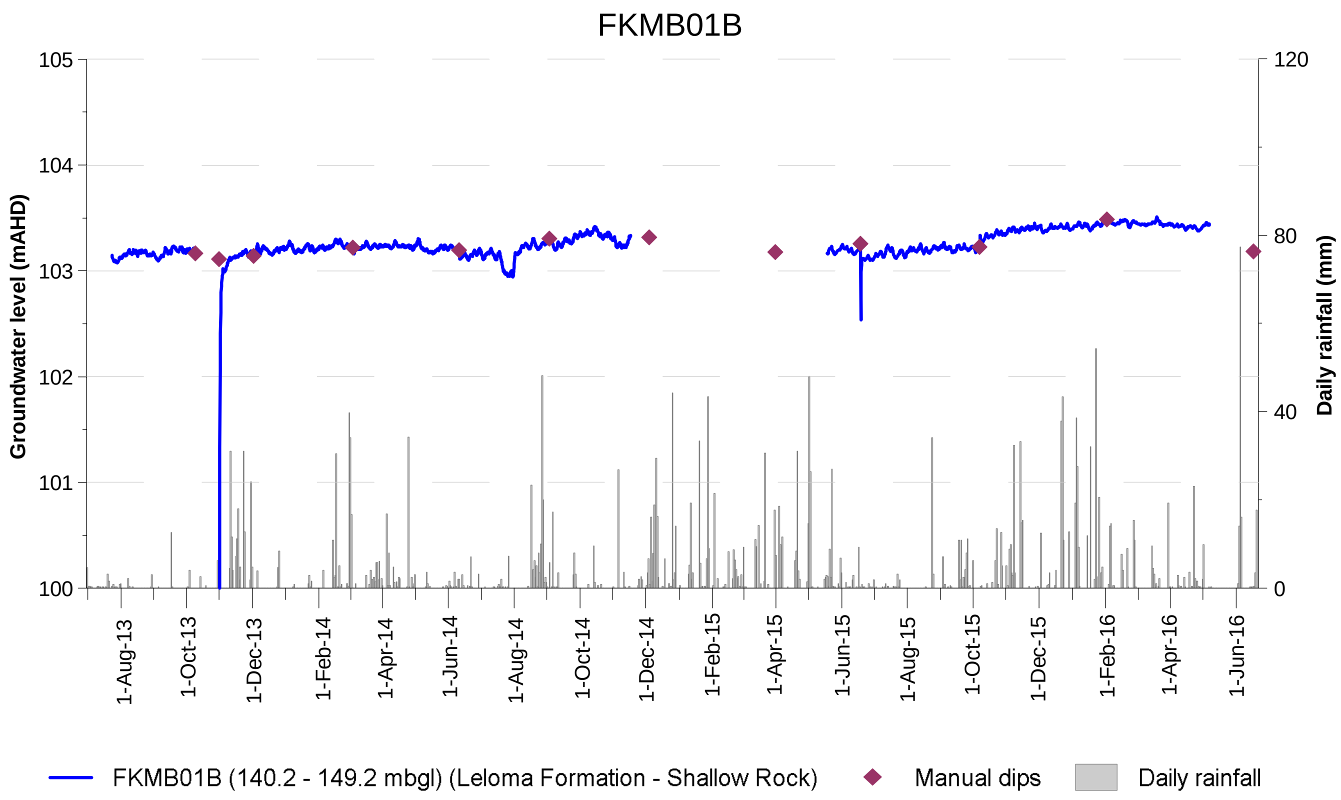
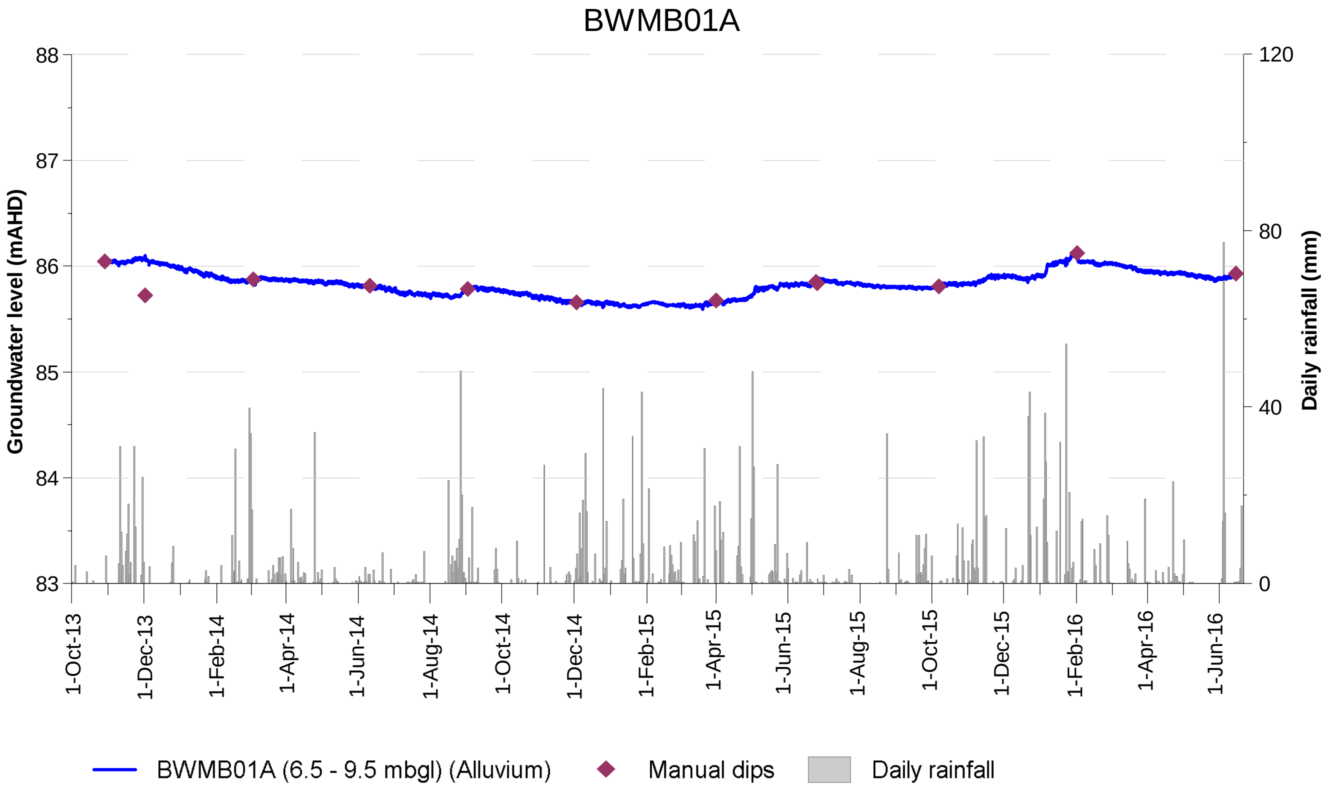




Figure A.17: FKMB01A and FKMB01B monitoring bores



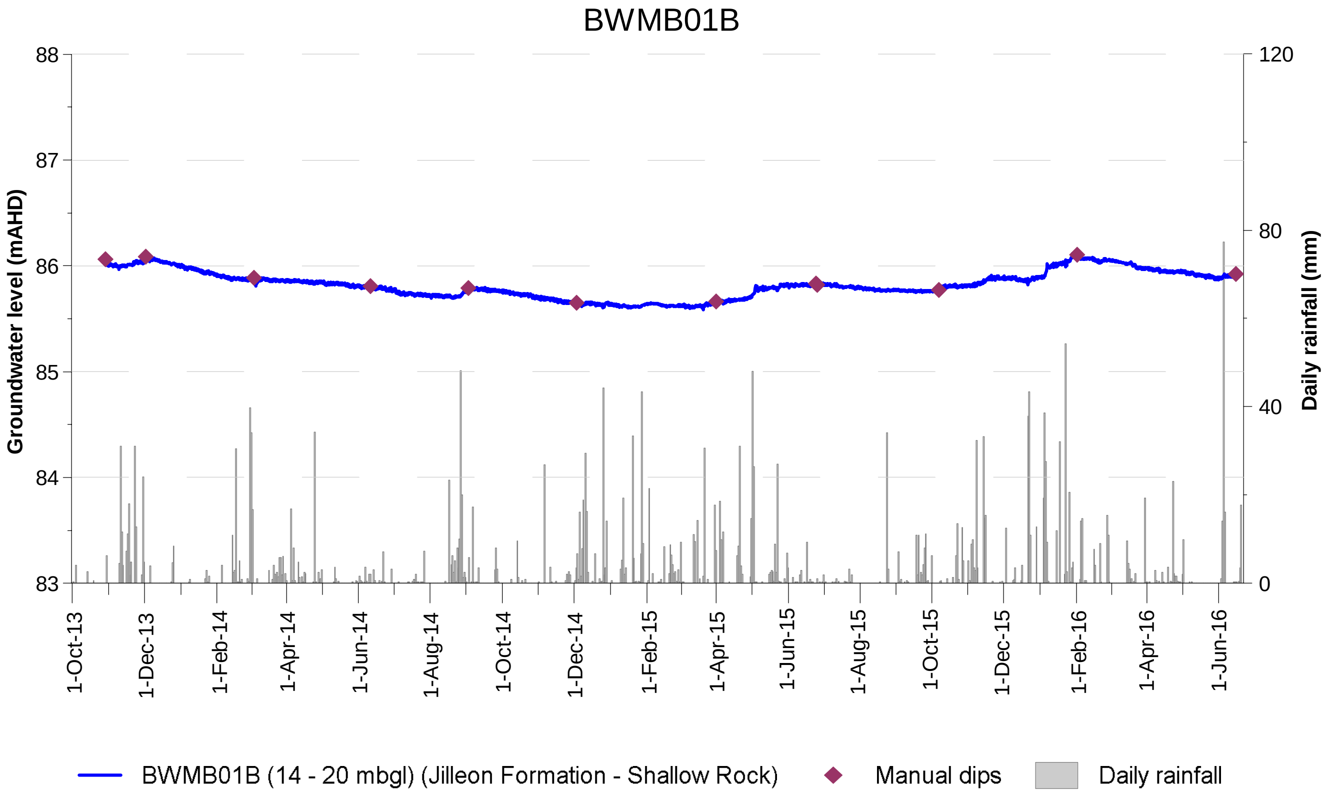
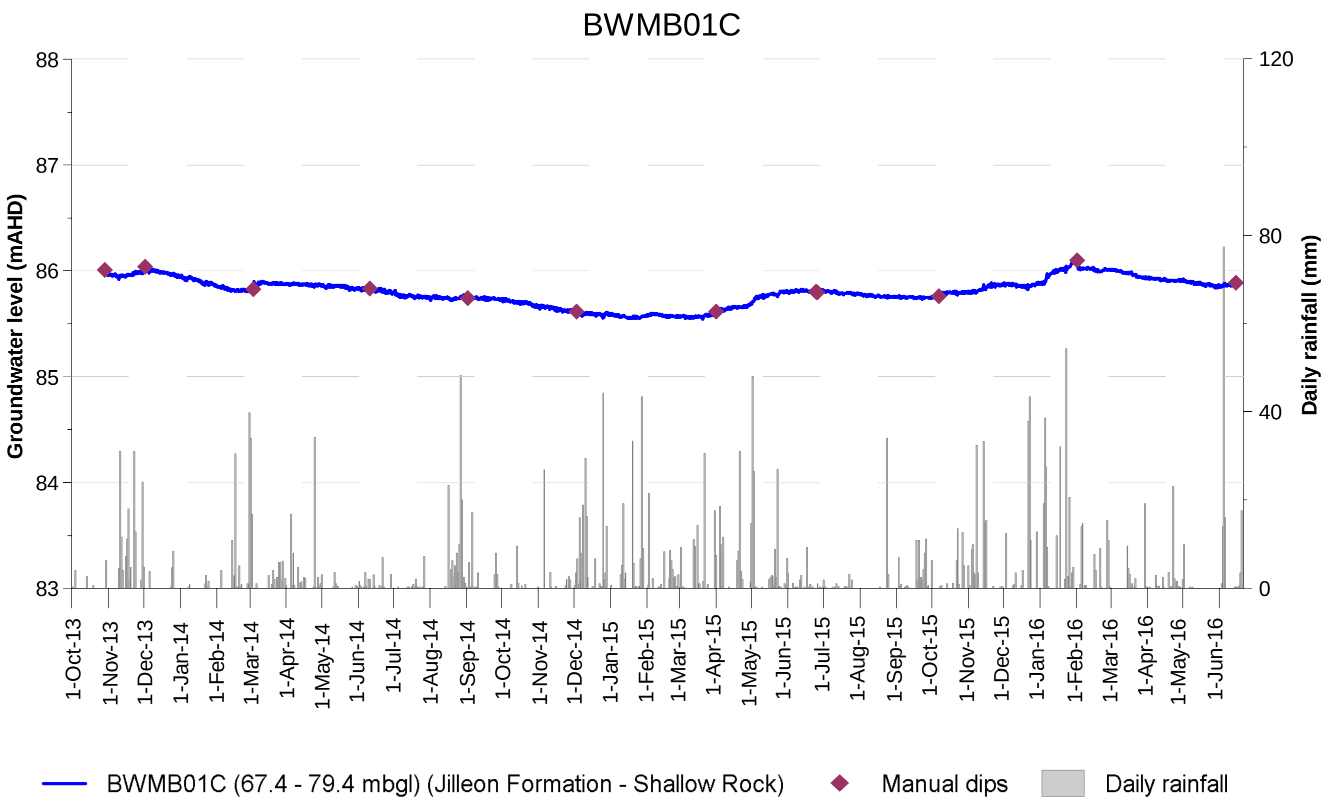
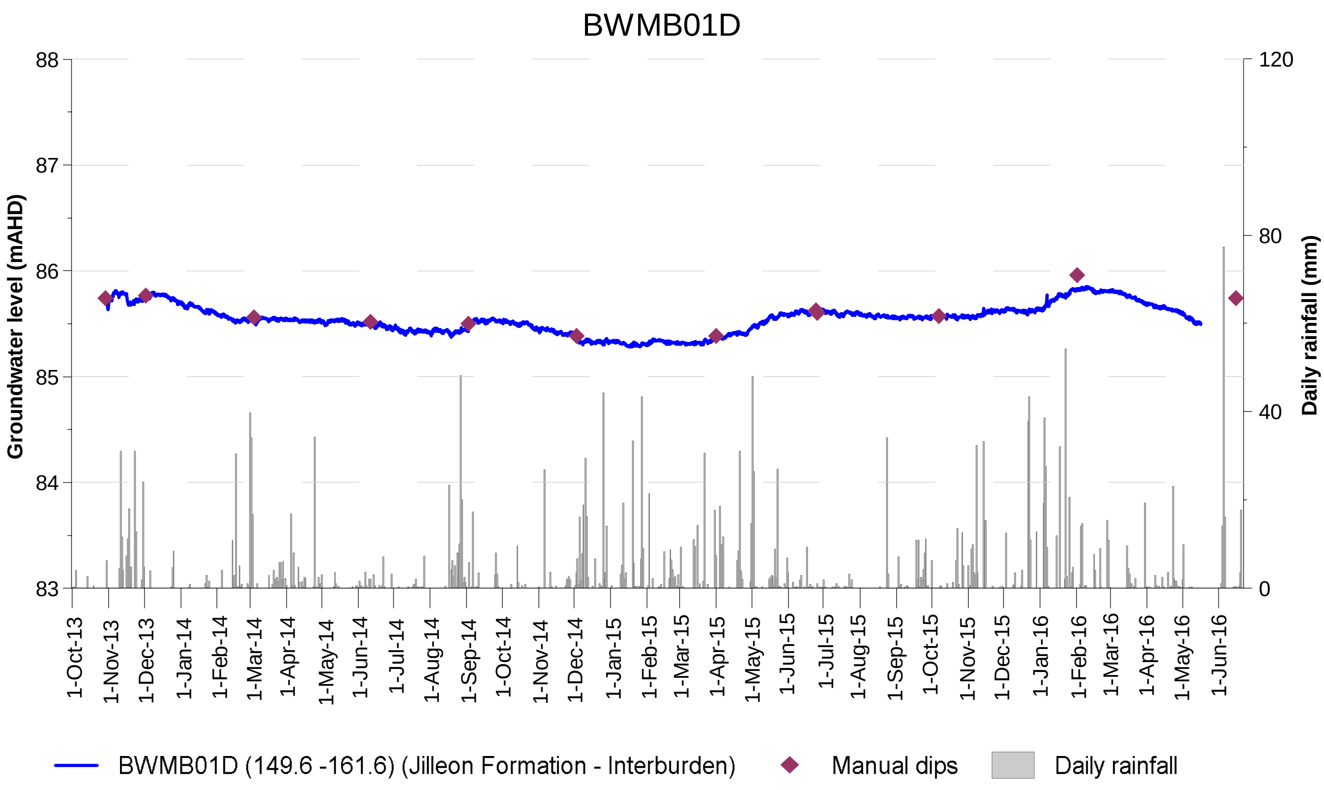




Figure A.18: BWMB01A and BWMB01B monitoring bores

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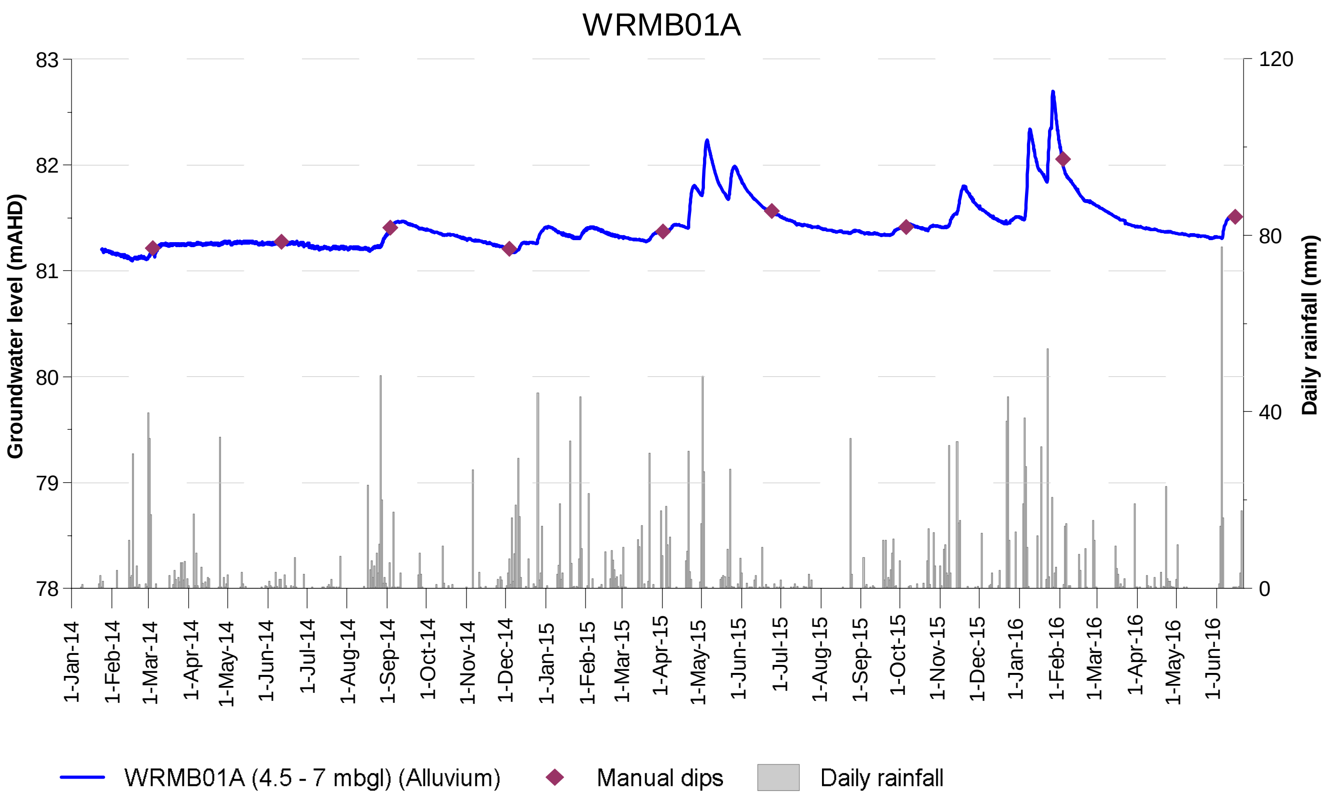


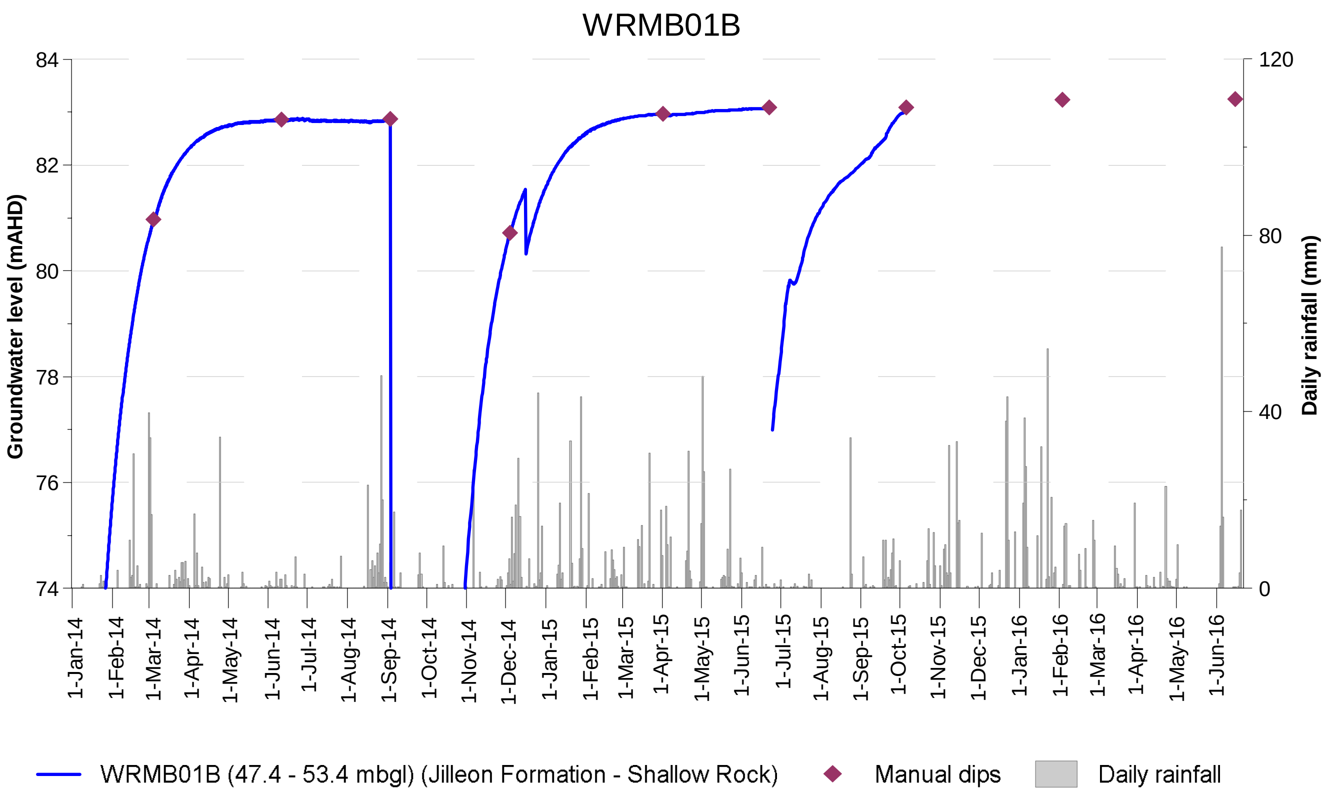
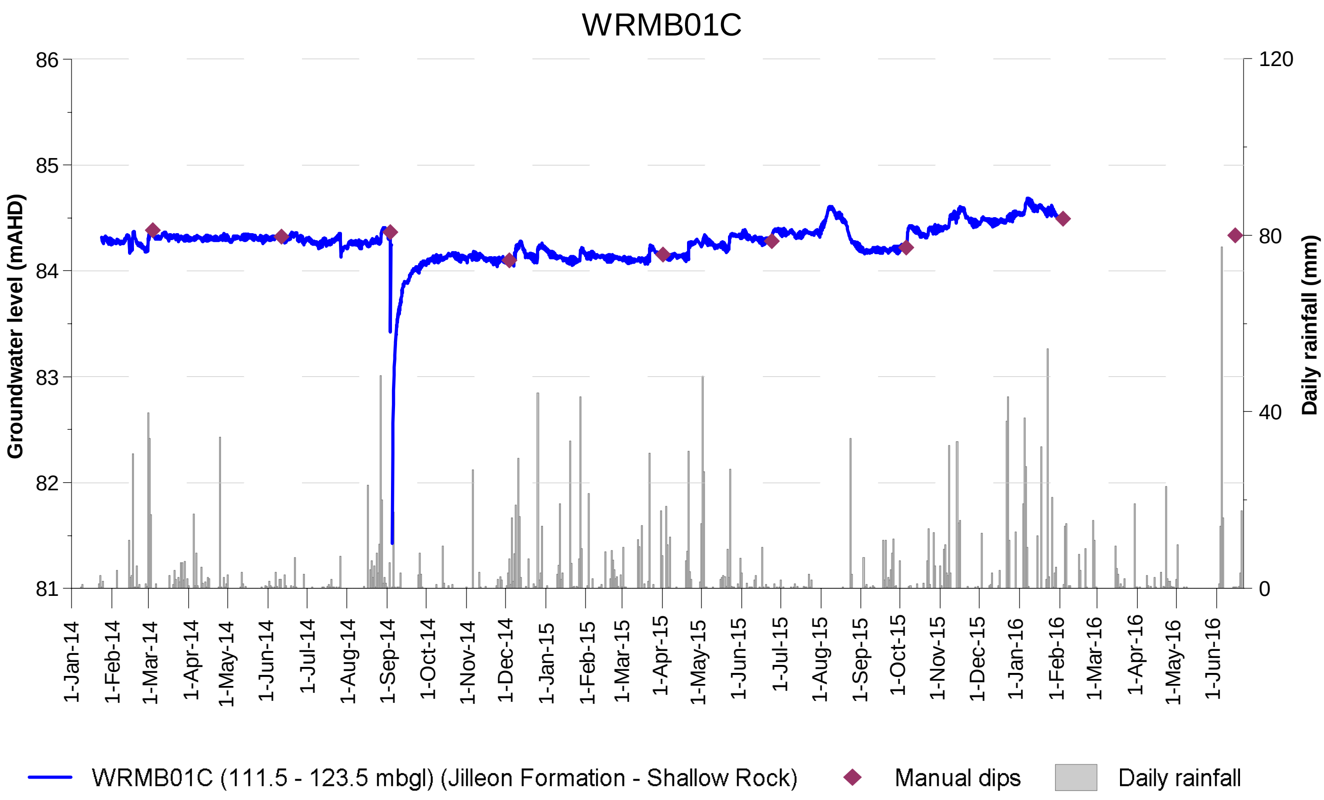




Figure A.20: WRMB01A and WRMB01B monitoring bores



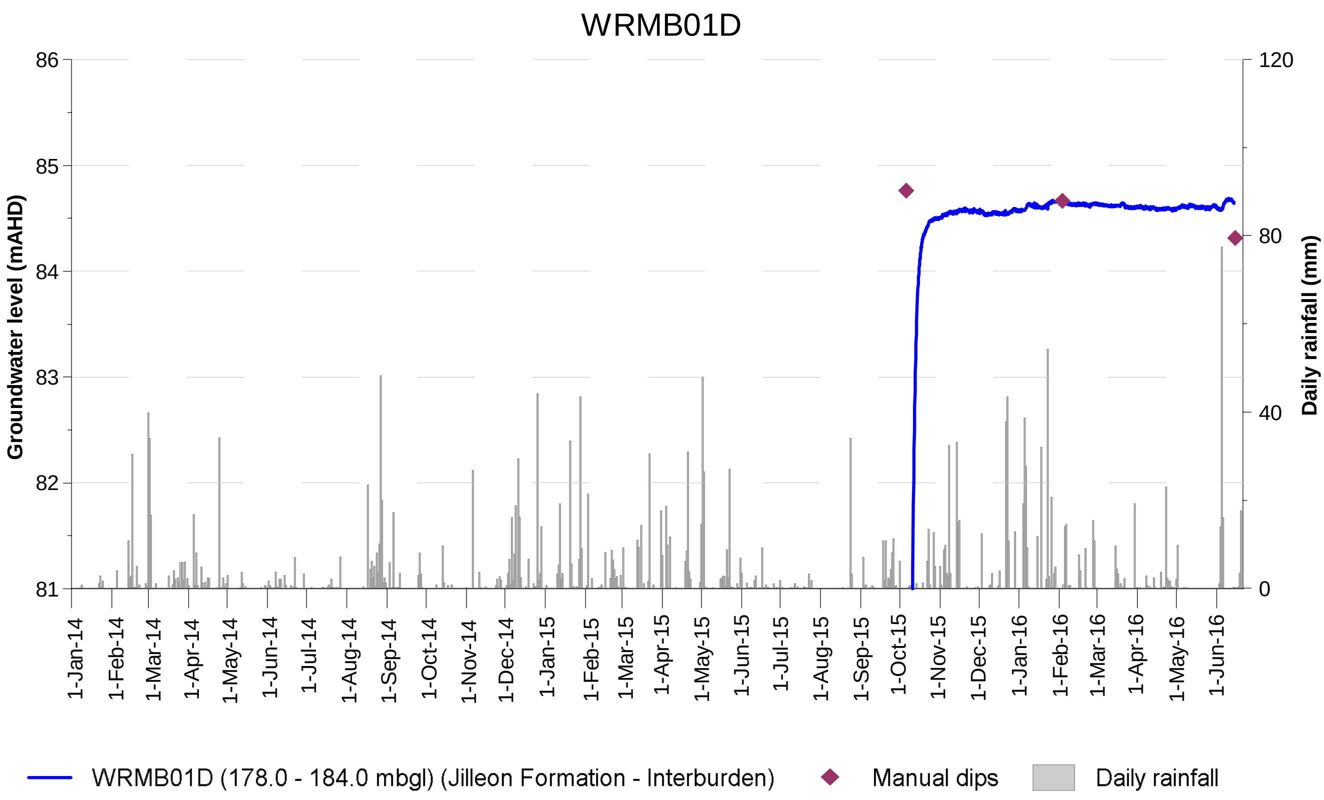
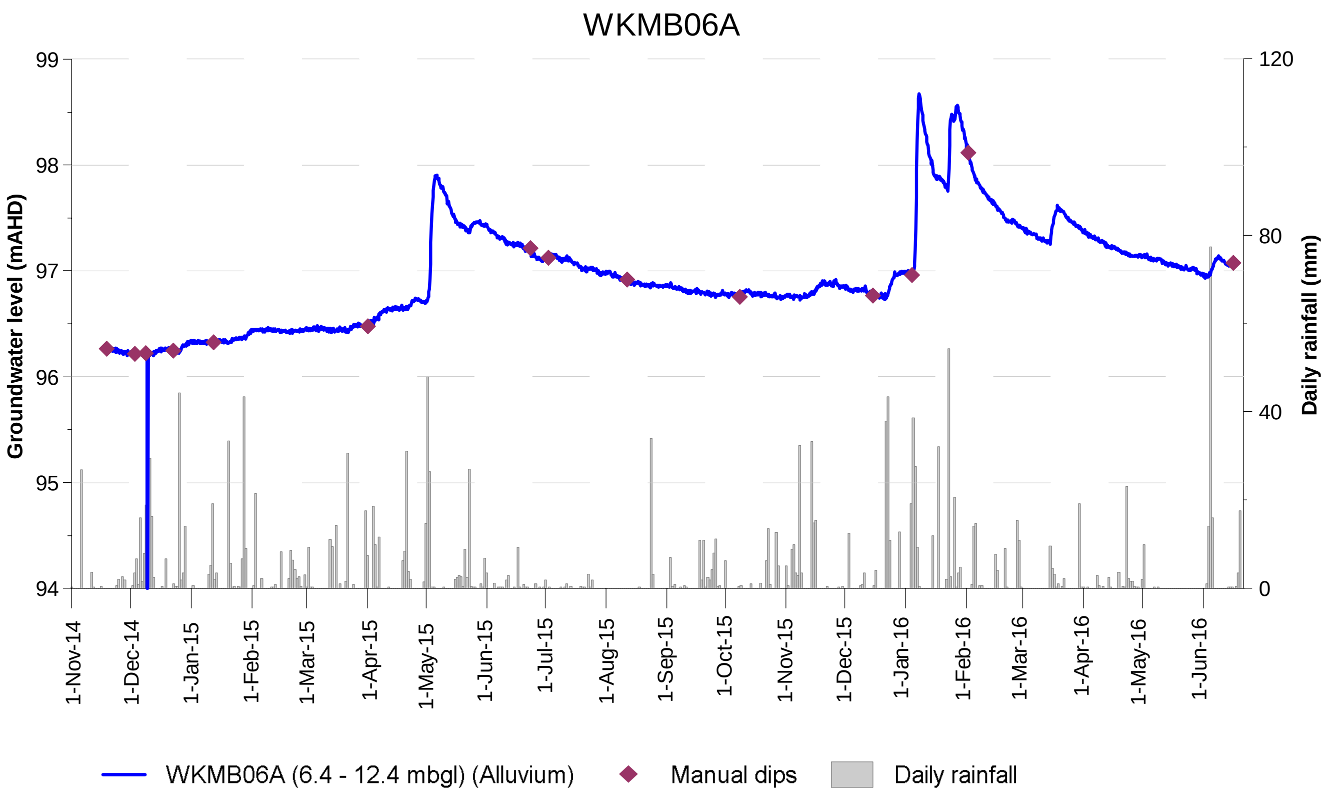




Figure A.21: WRMB01C and WRMB01D monitoring bores



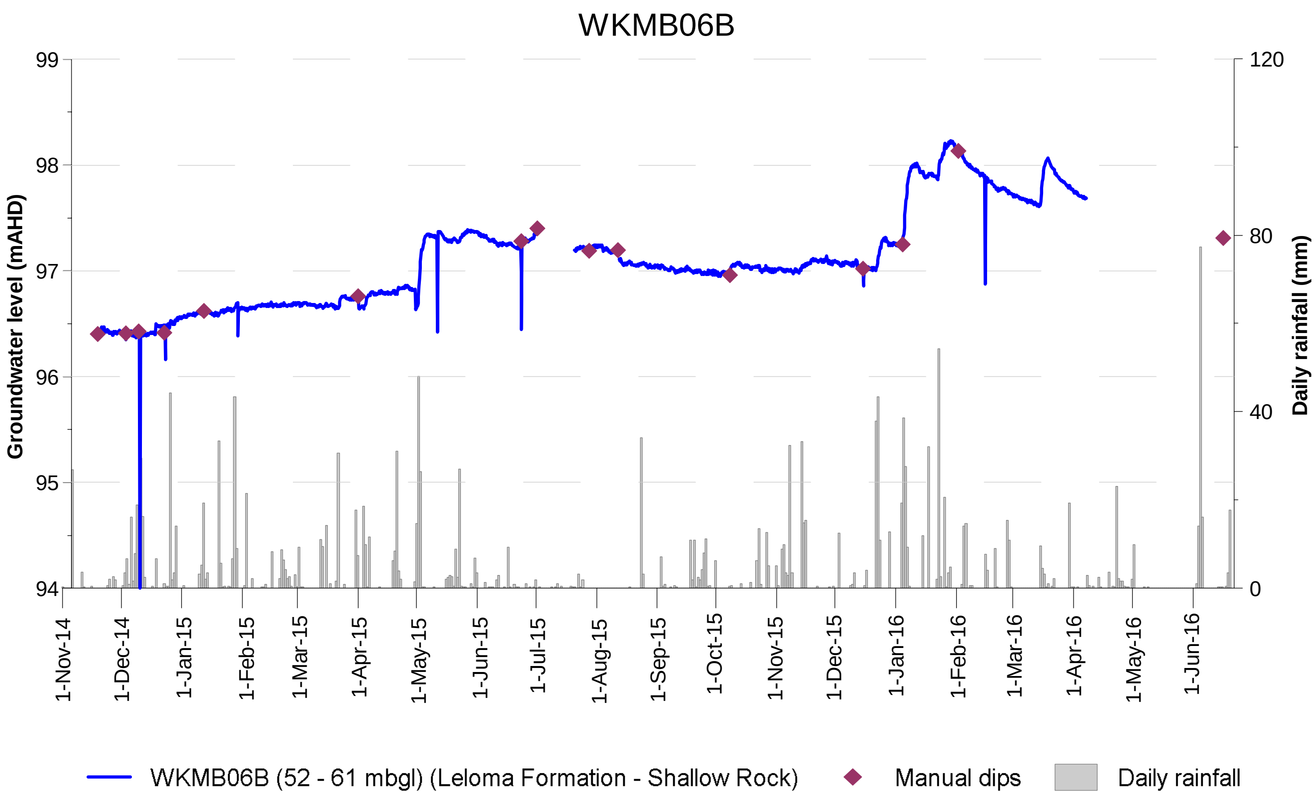
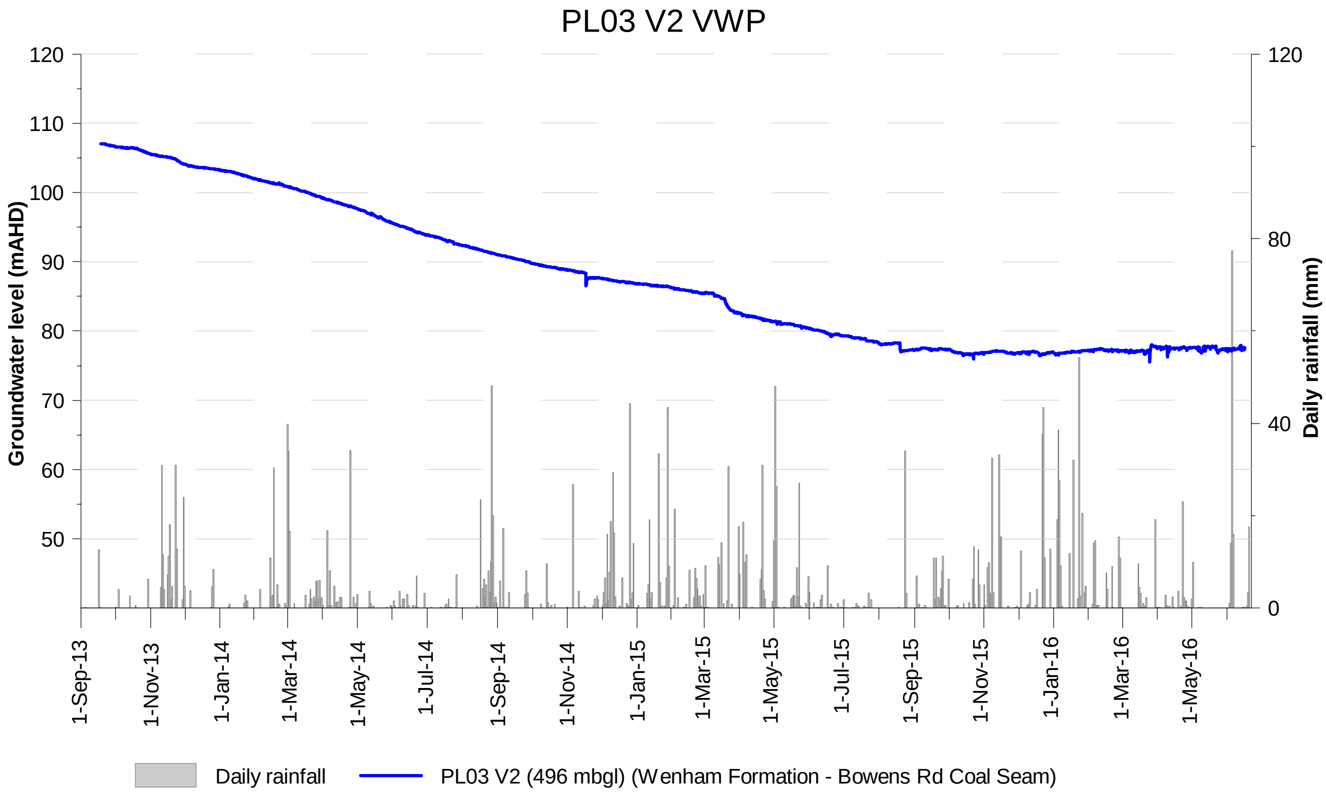
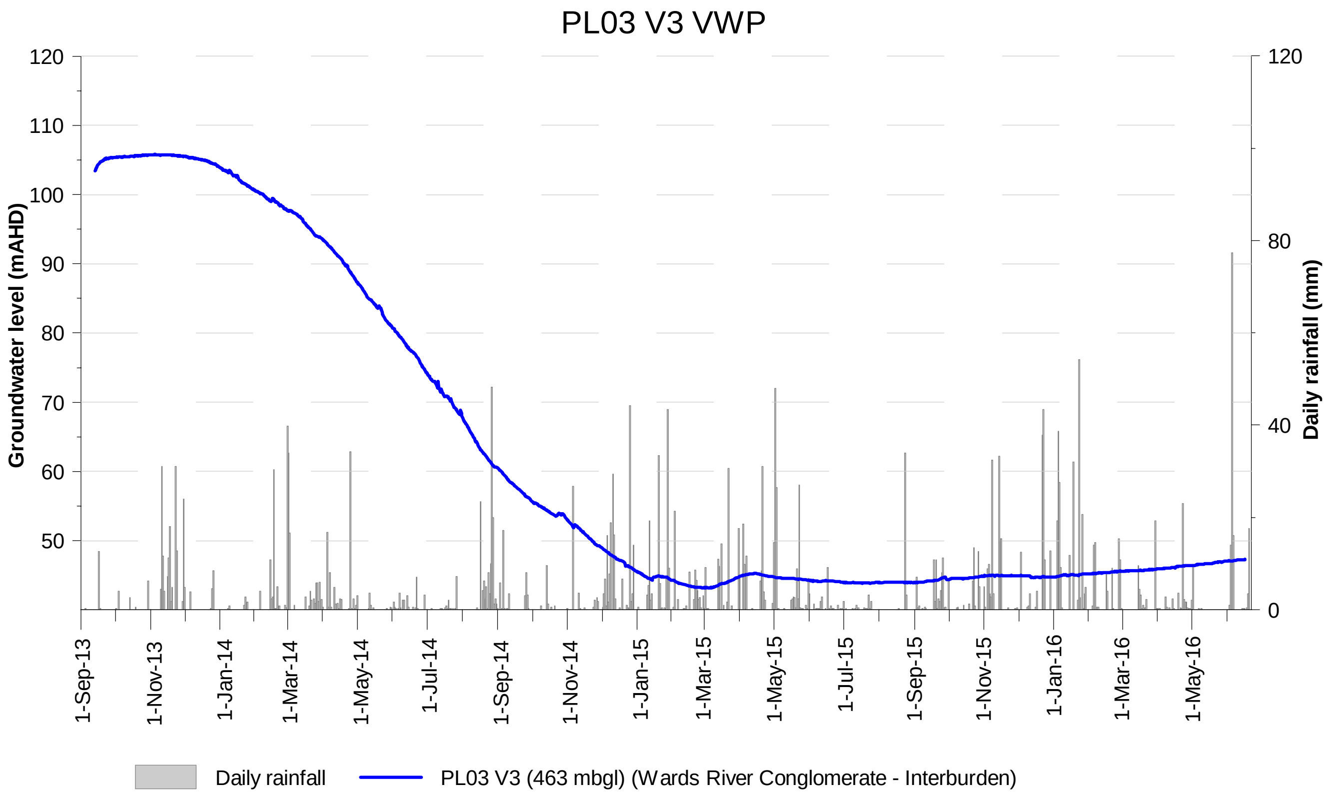




Figure A.22: WKMB06A and WKMB06B monitoring bores

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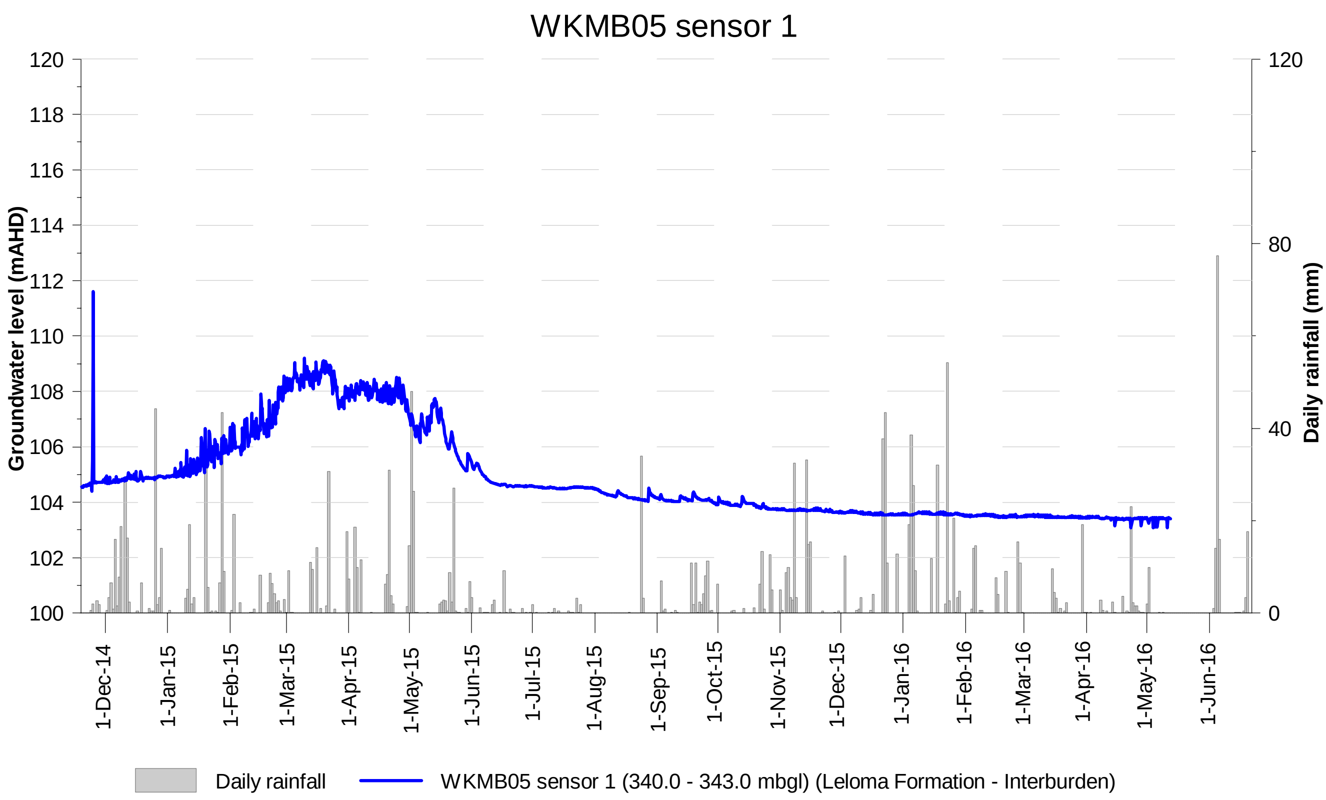


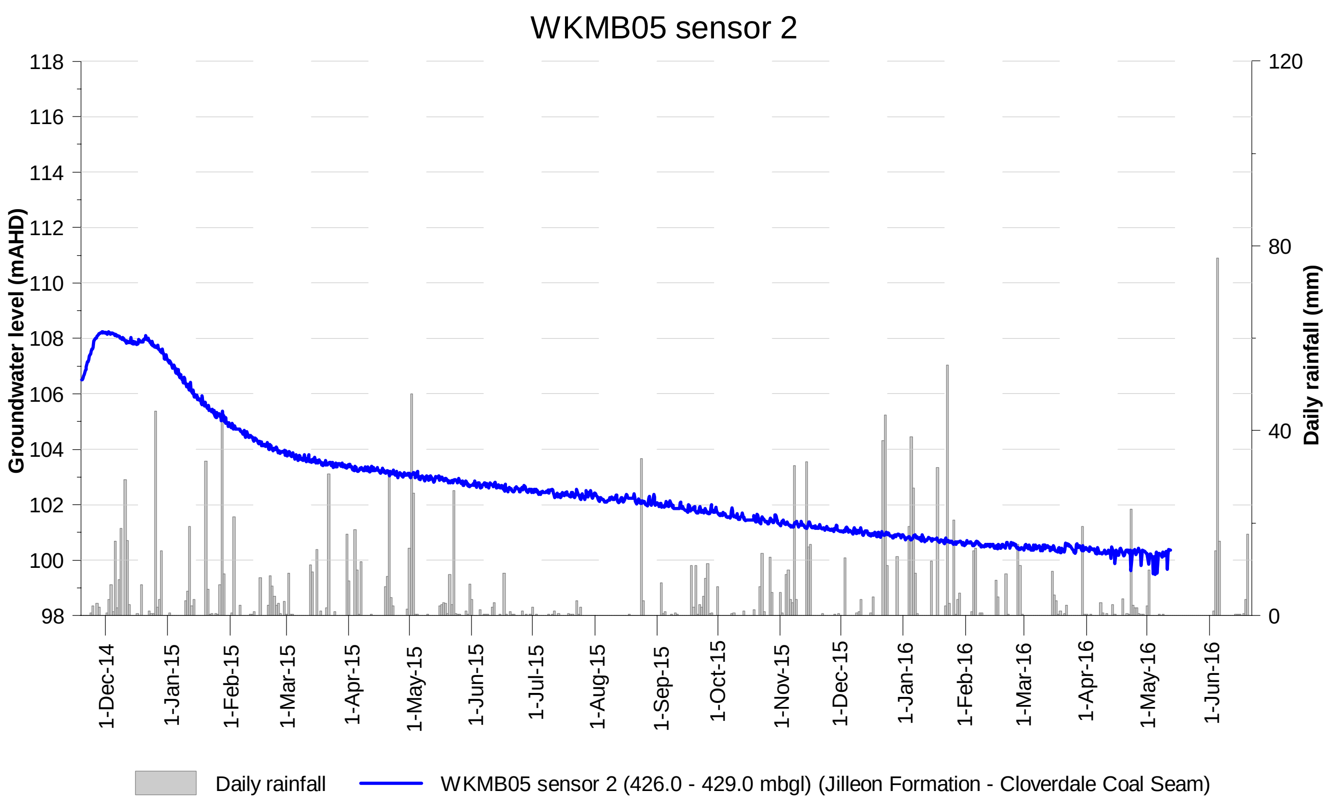


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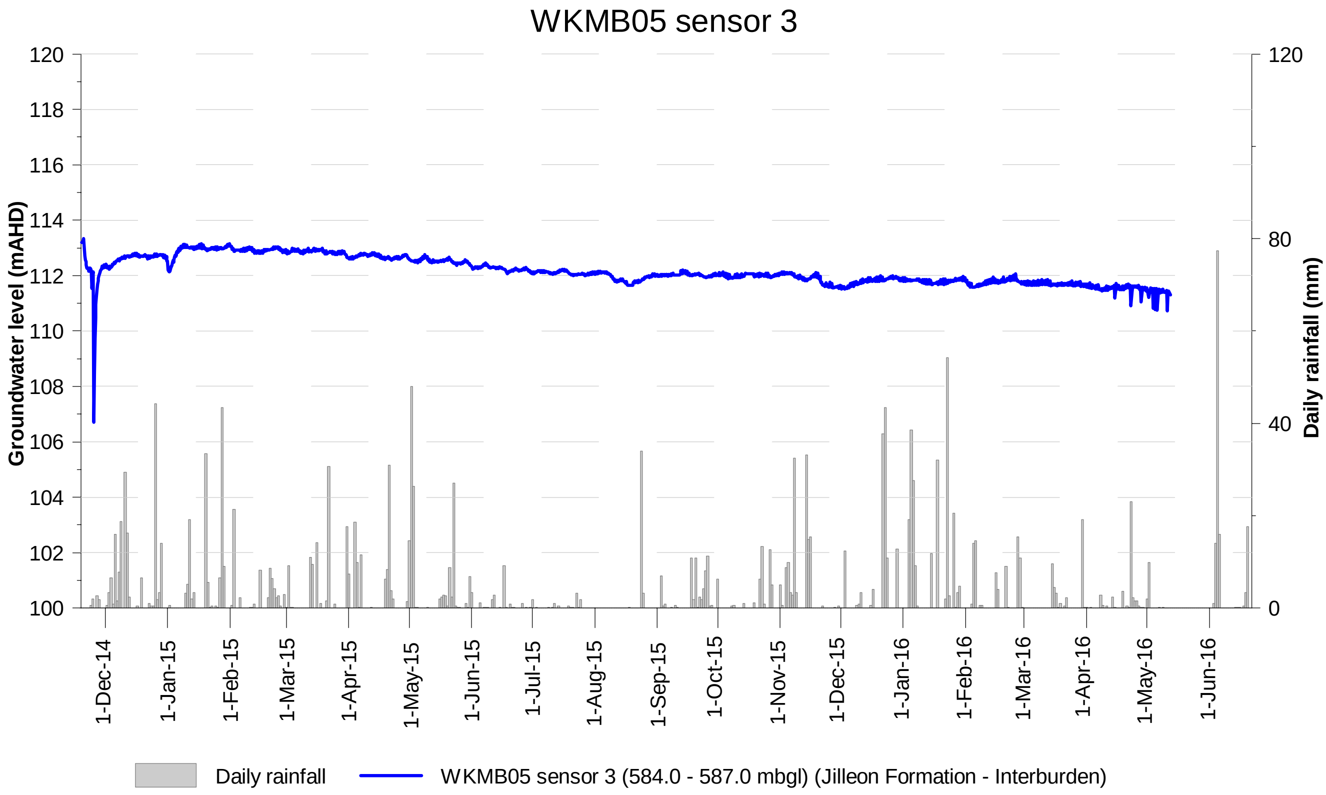


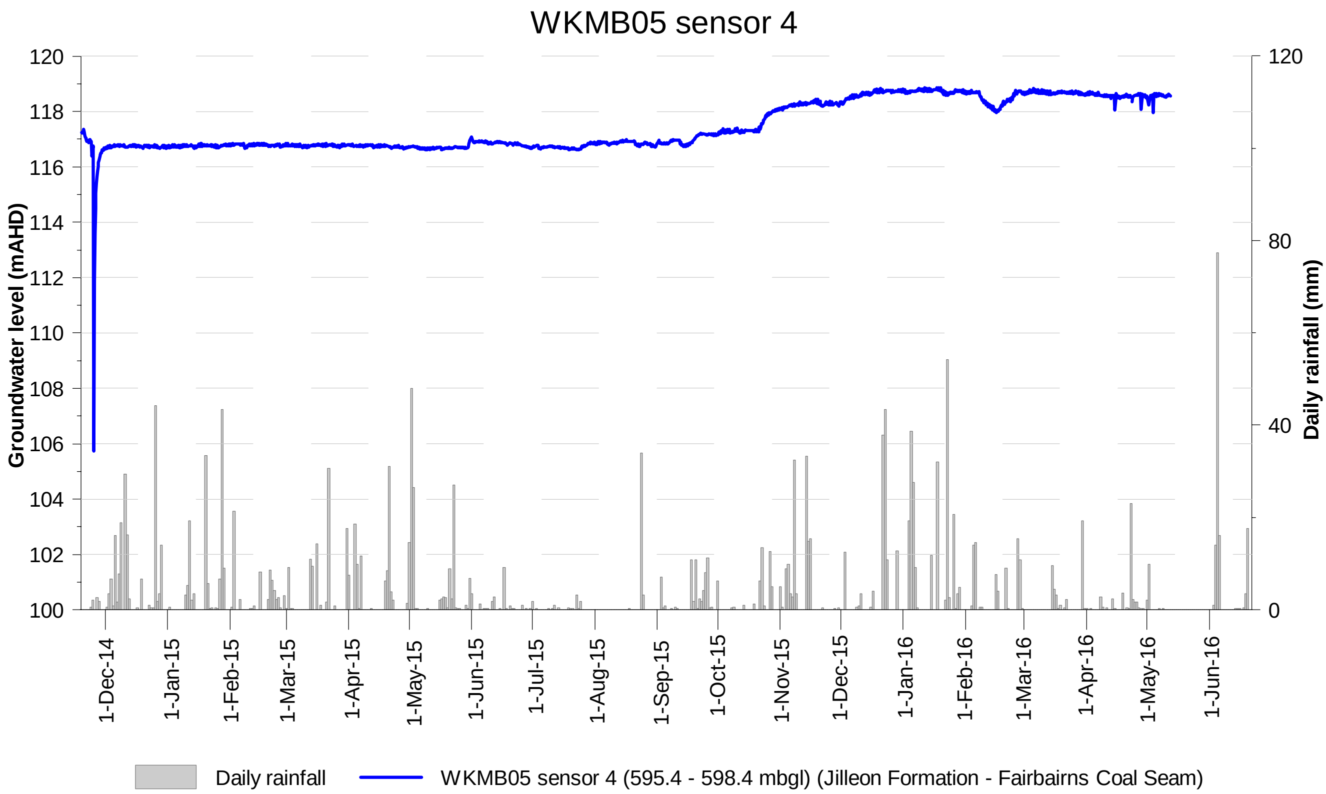
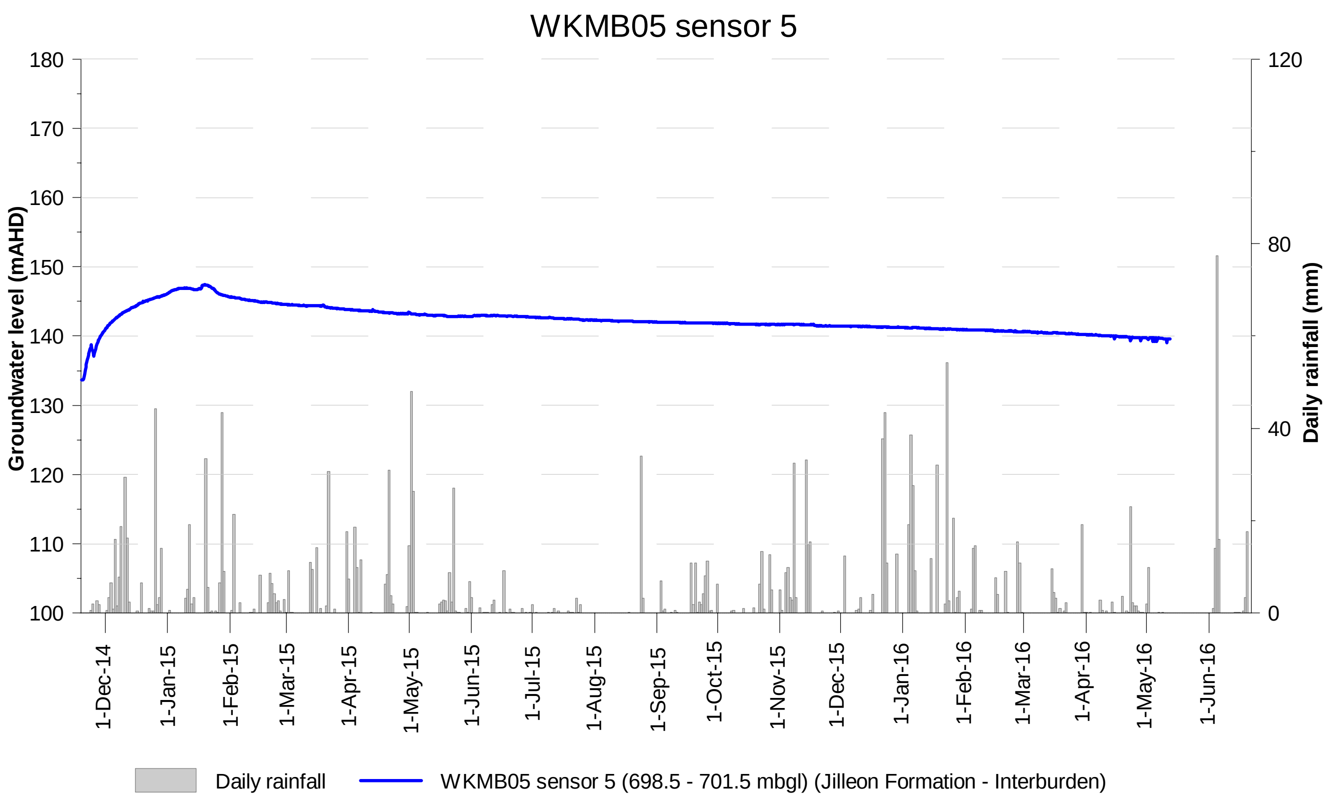




Figure A.33: WKMB05 sensors 3 and 4



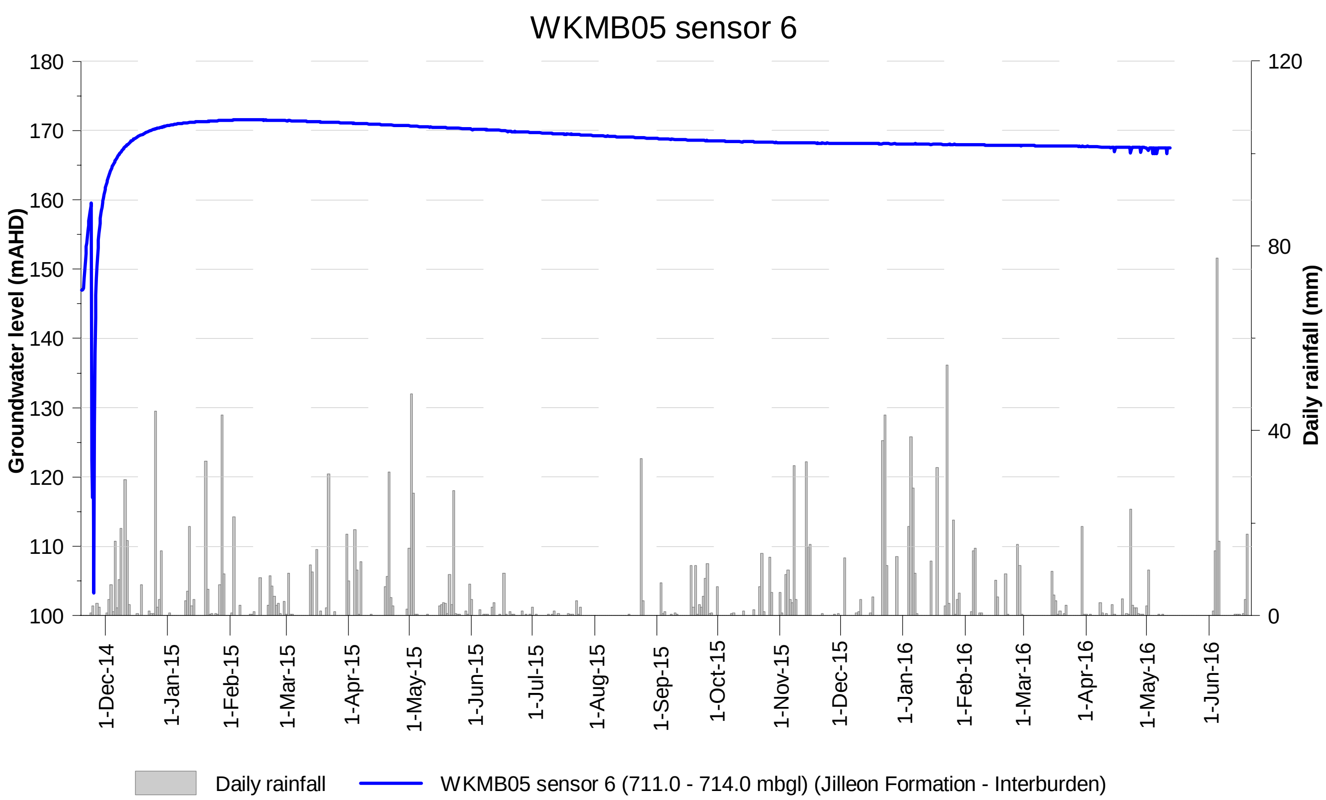




Figure A.34: WKMB05 sensors 5 and 6

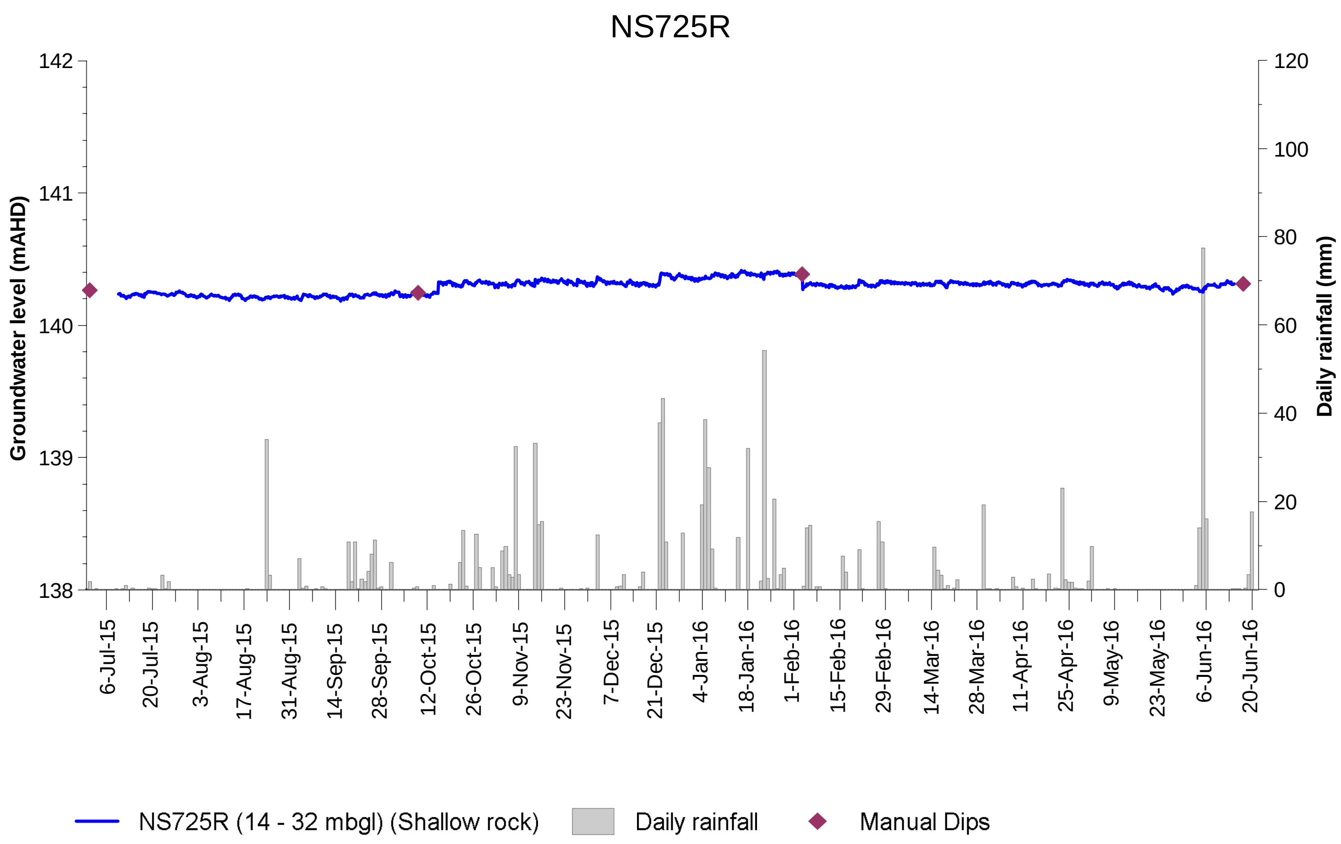



Figure A.35: NS725R monitoring bore

# Appendix B

Shallow gas monitoring laboratory results

Isotech Mudgas Data

Job 32850
Well Parsons
CoreTrac AP-76133
Containers IsoTube®(2)

| Isotech Lab No. | Weatherford Sample ID | Sample Name | GC Date | $H_2$ ppm | $O_2$ + Ar ppm | $CO_2$ ppm | $N_2$ ppm | CO ppm | $C_1$ ppm | $C_2$ ppm | $C_2H_4$ ppm | $C_3$ ppm | $C_3H_6$ ppm | $iC_4$ ppm | $nC_4$ ppm | $iC_5$ ppm | $nC_5$ ppm | $C_6$+ ppm | MS Date | $\delta^{13}C_1$ ‰ | $\delta^{13}C_2$ ‰ | $\delta^{13}C_3$ ‰ | $\delta^{13}iC_4$ ‰ | $\delta^{13}nC_4$ ‰ | $\delta^{13}iC_5$ ‰ | $\delta^{13}nC_5$ ‰ | $\delta DC_1$ ‰ | $\delta DC_2$ ‰ | $\delta DC_3$ ‰ | $\delta^{13}CO_2$ ‰ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 578312 | 6122583025 | 1_GC | 8/30/2016 | nd | 216000 | 620 | 783400 | nd | 4 | nd | nd | nd | nd | nd | nd | nd | nd | nd | | | | | | | | | | | | | |
| 578313 | 6122583027 | 2_GC | 8/30/2016 | nd | 215900 | 640 | 783400 | nd | 15 | nd | nd | nd | nd | nd | nd | nd | nd | nd | | | | | | | | | | | | | |

nd = not detected, na = not analyzed

red = components that can likely be obtained without cryogenic enrichment

**Bold = dD isotopes may be attempted**

**blue = components that would require cryogenic enrichment**