AGL Upstream Investments Pty Ltd

2014 Groundwater and Surface Water Monitoring Status Report

Gloucester Gas Project

20 November 2014

PARSONS BRINCKERHOFF

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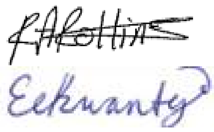
Prepared by:	Becky Rollins, Ellen Kwantes	Date: 20/11/2014	Signature:	
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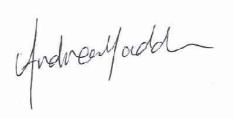
Approved by:	Andrea Madden	Date: 20/11/2014	Signature:	

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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.
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.
Baseline sampling	A period of regular water quality and water level measurements that are carried out over a period long enough to determine the variability in groundwater conditions.
Bore	A structure drilled below the surface to obtain water from an aquifer or series of aquifers.
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.
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.
Datalogger	A digital recording instrument that is inserted in monitoring and pumping bores to record pressure measurements and water level variations.
Drawdown	A lowering of the water table in an unconfined aquifer or the pressure surface of a confined aquifer caused by pumping of groundwater from bores and wells.
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).
Hydraulic gradient	The change in total hydraulic head with a change in distance in a given direction.
Hydraulic head	A specific measurement of water pressure above a datum. It is usually measured as a water surface elevation, expressed in units of length. In an aquifer, it can be calculated from the depth to water in a monitoring bore. The hydraulic head can be used to determine a hydraulic gradient between two or more points.
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.
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.
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.
Percentile	The value below which a given percentage of observations fall. For example, the 5^{th} percentile is the value below which five percent of observations are found.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Permian	The last period of the Palaeozoic era that finished approximately 252 million years before present.
pH	Potential of Hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).

Piezometric pressure	See hydraulic head
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).
Salinity classification	Fresh water quality – water with a salinity <800 µS/cm. Marginal water quality – water that is more saline than freshwater and generally waters between 800 and 1,600 µS/cm. Brackish quality – water that is more saline than freshwater and generally waters between 1,600 and 4,800 µS/cm. Slightly saline quality – water that is more saline than brackish water and generally waters with a salinity between 4,800 and 10,000 µS/cm. Moderately saline quality – water that is more saline than brackish water and generally waters between 10,000 and 20,000 µS/cm. Saline quality – water that is almost as saline as seawater and generally waters with a salinity greater than 20,000 µS/cm. Seawater quality – water that is generally around 55,000 µS/cm.
Sandstone	Sandstone is a sedimentary rock composed mainly of sand-sized minerals or rock grains (predominantly quartz).
Screen	A type of bore lining or casing of special construction, with apertures designed to permit the flow of water into a bore while preventing the entry of aquifer or filter pack material.
Sedimentary rock aquifer	These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest volumes of groundwater.
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.
Surface water-groundwater	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

interaction	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 remotely measure pore pressures in fully and partially saturated soils 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
m/d	metres per day
µS/cm	microSiemens per centimetre
mm	millimetres

Executive Summary

AGL Upstream Investments Pty Ltd (AGL) is proposing to build the Gloucester Gas Project (GGP) which comprises several stages of development facilitating the extraction of coal seam gas from the Gloucester Basin. Part 3A Approval and EPBC Approval has been granted for the Stage 1 Gas Field Development Area.

A comprehensive surface water and groundwater monitoring network comprising nested monitoring bores and stream gauges was established during the Phase 2 Groundwater Investigations (Parsons Brinckerhoff, 2012). Subsequent and ongoing site investigations have continued to expand this network since January 2011. This annual monitoring report provides a review of the groundwater and surface water monitoring data for the period July 2013 to June 2014.

The total rainfall for the period July 2013 to June 2014 at Gloucester Post Office was 568 mm, which is close to the lowest annual rainfall on record and reflects very dry conditions that had not been experienced in the valley for decades. Very low rainfall and water levels in the Avon River and Dog Trap Creek over the monitoring period resulted in 'no flow' or 'very low flow', where the rivers are characterised by multiple disconnected pools. All stream gauges on the Avon River and Dog Trap Creek show rapid responses to large rainfall events, such as in November 2013, and relatively steep recession curves.

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 show a rapid response to significant rainfall events. 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. Most alluvial monitoring bores show a decrease in groundwater levels over the monitoring period from July 2013 to June 2014, in response to lower than average rainfall over this period.
- **Shallow rock**: Groundwater levels in shallow rock monitoring bores have decreased slightly over the monitoring period in response to the below average rainfall. There are no strong responses to individual rainfall events in the shallow rock bores during this monitoring period.
- **Interburden units**: Monitoring bores screened within the interburden units show no significant change over the monitoring period, and groundwater levels do not respond to individual rainfall events.
- **Deep coal seams**: Groundwater levels in monitoring bores that are screened within the coal seams show varied but typically small changes in groundwater level over the monitoring period. There are no strong responses to individual rainfall events.

The conclusions of this report are consistent with the experienced climatic conditions and hydrogeological conceptual model of the Gloucester Basin (Parsons Brinckerhoff 2013a).

1. Introduction

This report is the annual groundwater and surface water monitoring status report for AGL Upstream Investments Pty Ltd (AGL) water monitoring network across the Gloucester Basin. The report is for the 2013/14 water year.

1.1 Background

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

AGL holds Petroleum Exploration Licence (PEL) 285, under the *Petroleum (Onshore) Act 1991*, covering the whole of the Gloucester Basin, approximately 100 km north of Newcastle, NSW. AGL has applied for several Petroleum Production Leases (PPL) for the Stage 1 GFDA. The Stage 1 GFDA in relation to the PEL 285 boundary is shown in Figure 1.1. The Stage 1 GFDA with AGL owned properties and the water monitoring network is shown in Figure 1.2.

The GGP will involve the dewatering of deep groundwater and the extraction of gas from multiple coal seams within the Gloucester Coal Measures. Target coal seam depths will vary from site to site but are expected to range between 200 and 1000 metres below ground level (mbgl). The current GGP includes the construction, operation, and decommissioning of 110 coal seam gas wells and associated infrastructure, including gas and water gathering lines, within the Stage 1 GFDA.

Groundwater and surface water studies are required to define baseline conditions (pre-development) and to assess impacts (if any) on water resources and local ecosystems as the GGP is constructed and operated. A dedicated water monitoring network is in place which has enabled the collection of baseline water level, water quality and hydraulic conductivity data for the different groundwater systems and surface water receptors. There are now more than 50 dedicated water monitoring locations and more than 36 months of baseline monitoring (water levels and water quality) across the Gloucester Basin.

1.2 Objectives

The objectives of the continuing groundwater and surface water monitoring program are to:

- Provide baseline information on groundwater levels and groundwater quality and the seasonal trends in levels and quality at monitoring sites across the Gloucester Basin.
- Provide baseline information on stream levels, flow and water quality in surface water systems in the Gloucester Basin.

1.3 Scope of work

This report presents groundwater and surface water level data and surface water salinity data collected using automated dataloggers since monitoring began at each of the established sites up to 30 June 2014, with a focus on the data obtained during the past 12 months.

The scope of work program for 2013/14 was to:

- Conduct quarterly groundwater and surface water monitoring, which included checking and downloading dataloggers and taking manual field measurements for verification.
- Maintain the water monitoring network and the installed dataloggers.
- Analyse and interpret water levels with reference to the hydrogeological conceptual model.
- Provide quarterly updates and an interpreted annual report on water level and salinity trends during the year.

Note that there was no regional water quality sampling event scheduled for the monitoring network in 2013/14. This is a bi-annual program with the next sampling event scheduled for March 2015. However during the year, water sampling was carried out in relation to:

- The Tiedman Irrigation Program (Parsons Brinckerhoff 2013c, 2013d, 2014f and 2014g).
- Newly installed monitoring bores (Parsons Brinckerhoff 2014a, 2014b and 2014c).
- Baseline sampling requirements for the Waukivory Pilot Program (Parsons Brinckerhoff 2014d).

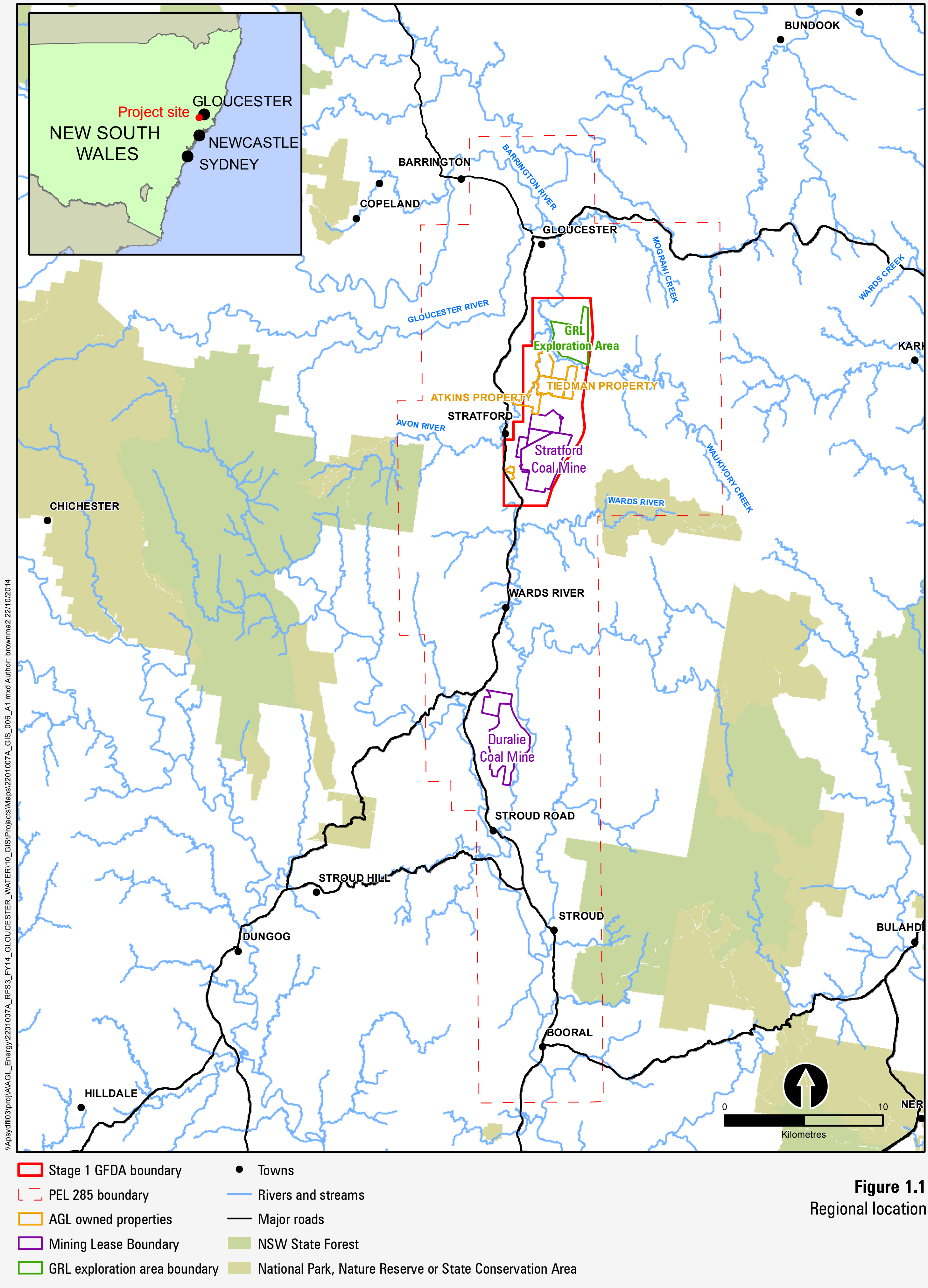
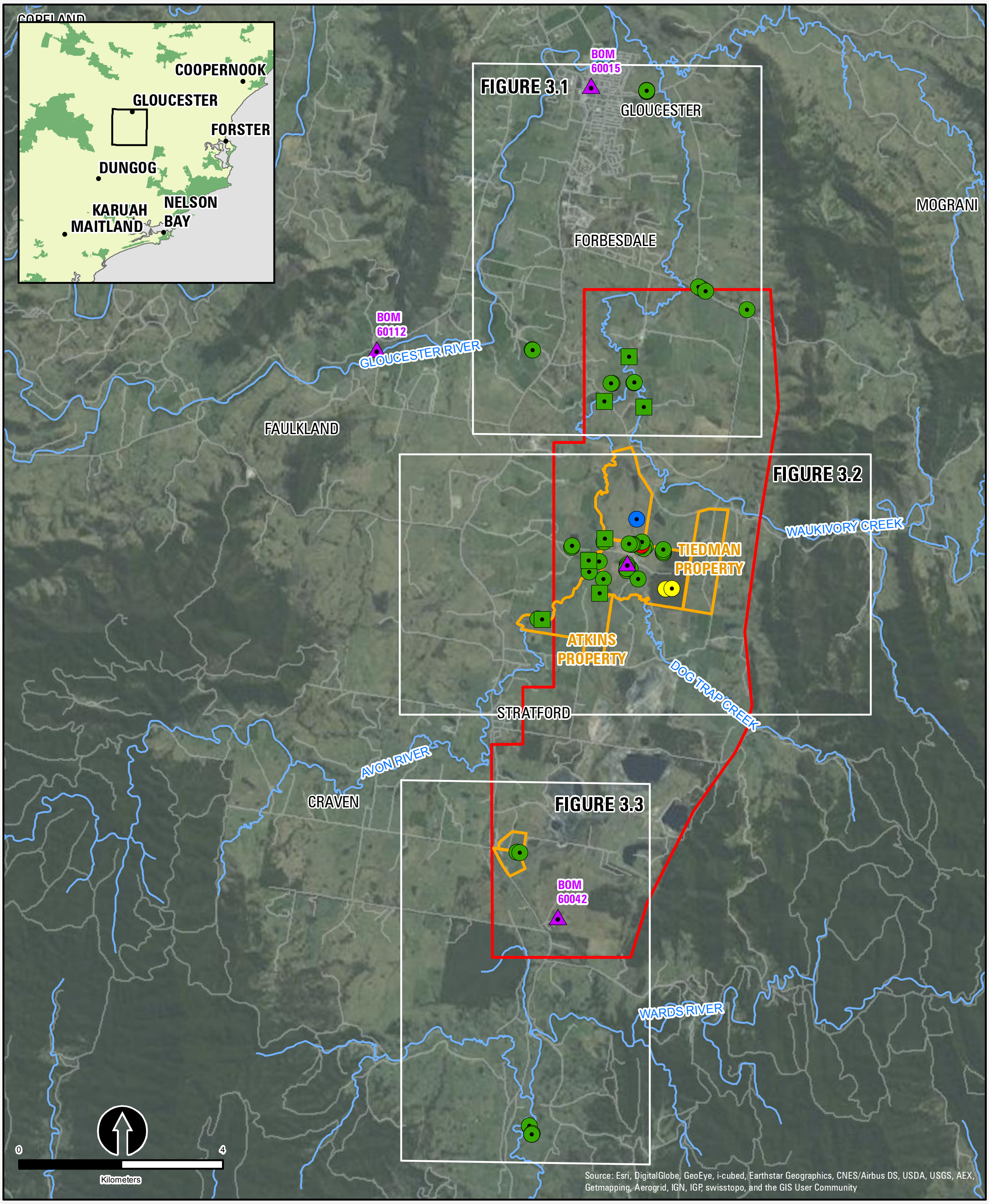


Figure 1.1
Regional location



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- Shallow gas monitoring bore
- Groundwater monitoring bore
- Test production bore
- VWP Monitoring Piezometers
- Stream gauge
- Weather station
- AGL owned properties
- Stage 1 GFDA boundary
- Rivers and streams
- Roads

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 is presented in Table 2.1.

Table 2.1 BoM stations in the Gloucester Basin (BoM 2014)

BoM station number	Location name	Monitoring period	Long term average annual rainfall (mm)[a]
60015	Gloucester Post Office	1888 to present	982
60112	Gloucester Hiawatha	1976 to present	981
60042	Craven (Longview)	1961 to present	1046
61071	Stroud Post Office	1889 to present	1147

(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 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 (2-3 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.

Rainfall data for the period January 2011 to June 2014 are presented in Figure 2.2. The AGL weather station commenced monitoring in June 2011; data prior to that was obtained from Gloucester Post Office. For most of this monitoring period (July 2013 - June 2014), rainfall was below the monthly average rainfall, as indicated by the downward sloping cumulative deviation curve, with only November 2013 recording higher than average rainfall.

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.

The rainfall for the period July 2013 to June 2014 at Gloucester Post Office was 568 mm, which is close to the lowest annual rainfall on record, and reflects very dry conditions that had not been experienced in the valley for decades.

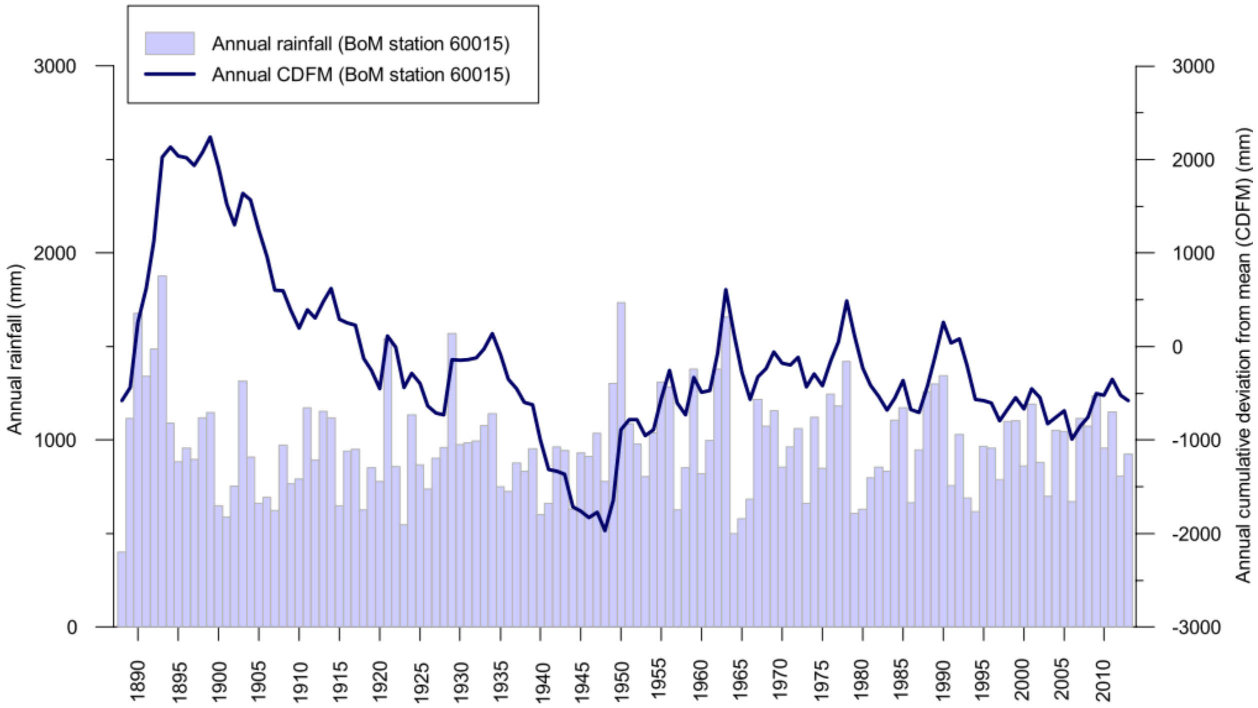

Figure 2.1 Long term annual rainfall and cumulative deviation from annual mean (CDFM) rainfall at Gloucester Post Office BoM station 060015 (BoM 2014)

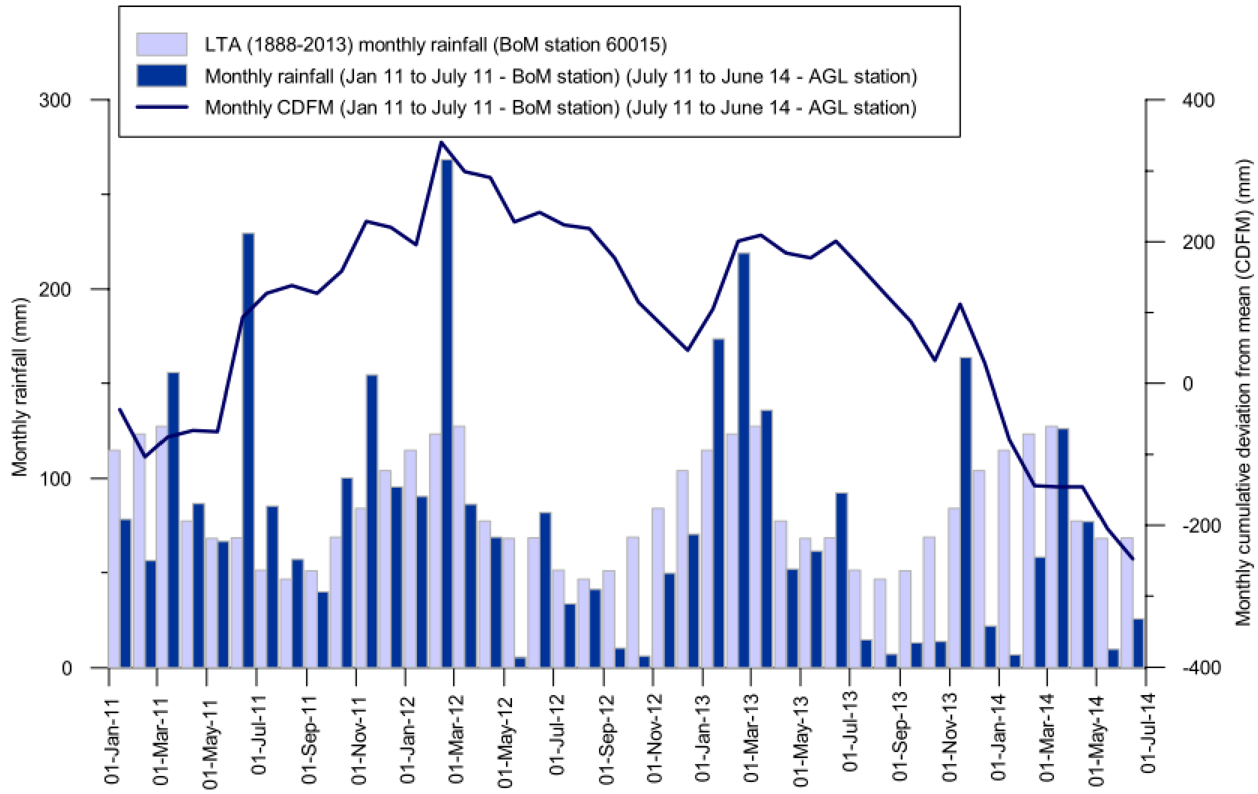

Figure 2.2 Monitoring period monthly rainfall, and cumulative deviation from the monthly mean (CDFM) rainfall at the AGL Gloucester station (AGL 2014)

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 high in 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.

There is a surface water divide between the Wards River catchment (part of the Karuah River catchment) and the Avon River catchment (part of the Manning River catchment). In the northern Manning River catchment, surface water flow is generally to the north. In the southern Karuah River catchment, surface water flow is generally to the south.

The Avon River flows to the north, and includes the tributaries of Dog Trap Creek and Waukivory Creek within the Stage 1 GFDA (Figure 1.2). The Gloucester River joins the Avon River at the north of the Gloucester Basin. Wards River flows to the south, and is outside of the Stage 1 GFDA (Figure 1.2).

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 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 non-uniform in thickness, and comprise unconsolidated alluvial sediments (sand, gravel, silt and clay) along the drainage channels and colluvial deposits across the rest of the plain sourced from the surrounding outcropping Permian deposits.

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 2.3. The CSG development in the Stage 1 GFDA is targeting the intermediate and deep coal seams in the Gloucester Coal Measures generally below depths of 200 m to around 1000 m.

Table 2.2 Stratigraphy of the Gloucester Basin

<table>
<tr><th>Period</th><th>Group</th><th>Sub-group</th><th>Formation</th><th>Approx. thickness (m)</th><th>Coal seam</th><th>Depositional environment</th><th>Tectonic events</th></tr>
<tr><td rowspan="24">Upper Permian</td><td rowspan="21">Gloucester Coal Measures</td><td rowspan="12">Craven</td><td>Crowthers Road Conglomerate</td><td>350</td><td></td><td rowspan="12">Marine regression, pro-gradation of alluvial fans</td><td rowspan="12">Uplift to west of Gloucester Basin</td></tr>
<tr><td rowspan="4">Leloma</td><td rowspan="4">585</td><td>Linden</td></tr>
<tr><td>JD</td></tr>
<tr><td>Bindaboo</td></tr>
<tr><td>Deards</td></tr>
<tr><td rowspan="3">Jilleon</td><td rowspan="3">175</td><td>Cloverdale</td></tr>
<tr><td>Roseville</td></tr>
<tr><td>Tereel/Fairbairns</td></tr>
<tr><td>Wards River Conglomerate</td><td>Variable</td><td></td></tr>
<tr><td rowspan="2">Wenham</td><td rowspan="2">23.9</td><td>Bowens Road</td></tr>
<tr><td>Bowens Road Lower</td></tr>
<tr style="display:none"></tr>
<tr><td colspan="2">Speldon Formation</td><td></td><td></td><td rowspan="9">Marine transgression but also some progradation of alluvial fans in the west related to uplift</td><td rowspan="9">Extension (normal fault development) and regional subsidence. Uplift to west of Basin</td></tr>
<tr><td rowspan="8">Avon</td><td>Dog Trap Creek</td><td>126</td><td>Glenview</td></tr>
<tr><td rowspan="7">Waukivory Creek</td><td rowspan="7">326</td><td>Avon</td></tr>
<tr><td>Triple</td></tr>
<tr><td>Rombo</td></tr>
<tr><td>Glen Road</td></tr>
<tr><td>Valley View</td></tr>
<tr><td>Parkers Road</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="3">Dewrang</td><td colspan="2">Mammy Johnsons</td><td>300</td><td>Mammy Johnsons</td><td rowspan="3">Marine transgression, regression and further marine transgression</td><td rowspan="3">Extension (normal fault development) and regional subsidence</td></tr>
<tr><td colspan="2">Weismantel</td><td>20</td><td>Weismantel</td></tr>
<tr><td colspan="2">Duralie Road</td><td>250</td><td></td></tr>
<tr><td rowspan="2">Lower Permian</td><td colspan="3" rowspan="2">Alum Mountain Volcanics</td><td rowspan="2"></td><td>Clareval</td><td rowspan="2">Arc-related rift</td><td rowspan="2">Rift?</td></tr>
<tr><td>Basal</td></tr>
</table>

Modified from AECOM (2009) and SRK (2005).

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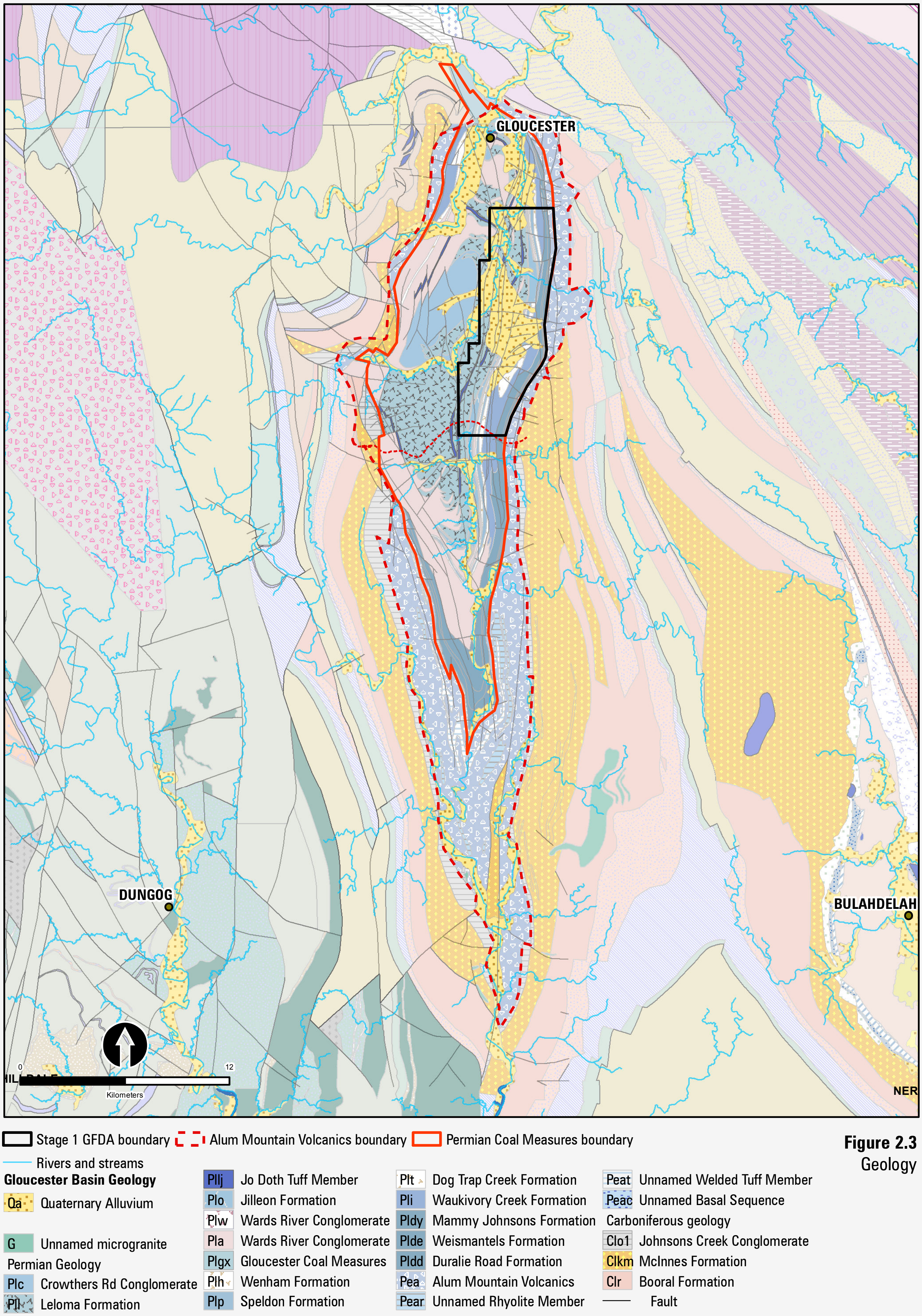

Figure 2.3
Geology

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2.4 Hydrogeological setting

Four broad hydrogeological units have been identified within the Gloucester Basin (Table 2.3).
The permeability and groundwater flow characteristics of rocks within the Gloucester Basin are controlled by several factors including lithology, depth and the degree of fracturing and faulting. In this sense hydrogeological units and flow systems do not always correspond with defined geological boundaries.

Table 2.3 Four hydrogeological units – Gloucester Basin

Unit	Aquifer type	Formation name	General lithology	Hydraulic characteristics
Alluvium	Semi-confined, clay capped, porous, granular	Quaternary alluvium	Clay/mixed gravels	Heterogeneous, highly variable permeability associated with varying lithology
Shallow Rock (<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
Interburden	Confined, fractured rock	Upper Permian Coal Measures	Interbedded indurated sandstone/siltstone and claystone	Low permeability associated with sparse fractures, permeability decreases with depth
Coal Seams	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 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 1×10^{-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**. Sandstone and siltstone units that form the interburden to coal seams are indurated and 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 interburden, drill-stem tests clearly show that the permeability of coal seams generally decreases with depth. At the maximum depth of CSG production, the permeability of coal seams is very low (10^{-4}–10^{-6} m/d), but may be an order of magnitude higher than the interburden.

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

3. Monitoring program

3.1 Monitoring network

AGL's groundwater and surface water monitoring locations are shown in Figure 3.1 (northern area), Figure 3.2 (central area), and Figure 3.3 (southern area). The monitoring network expanded in 2013/14 with nine new monitoring bores established at three new sites beyond the Stage 1 GFDA. The three surface water sites set up for the Waukivory Pilot Program were also established during the July 2013 to June 2014 monitoring period (although the dataloggers were not operational until September 2014).

3.1.1 Surface water

There are currently seven AGL stream gauges in the Gloucester Basin; five on the Avon River, one on Dog Trap Creek, and one on Waukivory Creek (Table 3.1).

Table 3.1 AGL Gloucester stream gauges

Stream gauge	Easting (MGA, m)	Northing (MGA, m)	Location	Stream
TSW01	401994	6449417	Tiedman (downstream)	Avon River
TSW02	401922	6448741	Tiedman (tributary)	Dog Trap Creek
ASW01	401711	6449092	Atkins (downstream)	Avon River
ASW02	400698	6447963	Atkins (upstream)	Avon River
WKSW01	402002	6452208	Waukivory Pilot (upstream)	Avon River
WKSW02	402772	6452099	Waukivory Pilot (tributary)	Waukivory Creek
WKSW03	402488	6453088	Waukivory Pilot (downstream)	Avon River

MGA - Map Grid of Australia.

3.1.2 Groundwater

The monitoring network comprises four types of groundwater monitoring installations:

1. Bores targeting the shallow alluvial sediments of the Avon River and its tributaries, and Wards River.
2. Bores targeting the shallow fractured rock.
3. Bores targeting the interburden and coal seams of the Gloucester Coal Measures.
4. A vibrating wire piezometer (VWP) array installed to monitor piezometric pressure (pore pressure) in the deep interburden and a deep coal seam of the Gloucester Coal Measures.

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

Perched groundwater/seepage monitoring bores (TMB04 and TMB05) and shallow gas monitoring bores (TGMB01 and TGMB02) also exist in the Stage 1 GFDA. However, as these sites do not monitor regional groundwater, monitoring results are not discussed in this report.

Table 3.2 AGL Gloucester groundwater monitoring bores

Monitoring bore	Location	Total depth (mbgl)	Screened interval (mbgl)	Lithology	Formation	Hydrogeolog-ical unit
S4MB01	Tiedman	66.0	58.0 – 64.0	Sandstone	Leloma Formation	Shallow rock
S4MB02	Tiedman	97.0	89.0 – 95.0	Sandstone/ siltstone	Leloma Formation	Shallow rock
S4MB03	Tiedman	170.0	162.0 – 168.0	Coal	Jilleon Formation – Cloverdale Coal Seam	Coal
S5MB01	Tiedman	60.0	52.0 – 58.0	Sandstone/ siltstone	Jilleon Formation	Shallow rock
S5MB02	Tiedman	114.0	100.0 – 112.0	Siltstone	Jilleon Formation	Shallow rock
S5MB03	Tiedman	166.0	158.0 – 164.0	Coal/shale	Jilleon Formation – Roseville Coal Seam	Coal
TMB01	Tiedman	12.0	7.0 – 10.0	Clay	Avon River Alluvium	Alluvial
TMB02	Tiedman	15.5	9.0 – 12.0	Mixed gravels	Avon River Alluvium	Alluvial
TMB03	Tiedman	12.5	5.0 – 11.0	Mixed gravels and sand	Avon River Alluvium	Alluvial
TCMB01	Tiedman	90.0	87.0 – 93.0	Sandstone	Leloma Formation	Shallow rock
TCMB02	Tiedman	183.0	175.0 – 181.0	Sandstone	Leloma Formation	Interburden
TCMB03	Tiedman	268.0	260.0 – 266.0	Coal and sandstone	Jilleon Formation – Cloverdale Coal Seam	Coal
TCMB04 (core hole)	Tiedman	334.7	327.3 – 333.3	Coal	Jilleon Formation – Roseville Coal Seam	Coal
AMB01	Atkins	12.6	8.0 – 10.0	Mixed gravels	Avon River Alluvium	Alluvial
AMB02	Atkins	11.5	6.5 – 11.0	Mixed gravels	Avon River Alluvium	Alluvial
BMB01	Bignell	30.0	15.0 – 29.0	Sandstone/ siltstone	Leloma Formation	Shallow rock
BMB02	Bignell	138.0	124.0 – 136.0	Sandstone	Leloma Formation	Shallow rock
WMB01	GRL – Waukivory	8.5	5.0 – 8.0	Mixed gravel/ sand	Avon River Alluvium	Alluvial
WMB02	GRL – Waukivory	23.0	15.0 – 21.0	Sandstone	Wenham Formation	Shallow rock
WMB03	GRL – Waukivory	36.0	32.0 – 34.0	Coal	Wenham Formation – Bowens Road Coal Seam	Shallow rock
WMB04	GRL – Waukivory	80.5	67.0 – 79.0	Sandstone	Wenham Formation	Shallow rock
RMB01	Rombo	51.0	42.0 – 48.0	Sandstone	Leloma Formation	Shallow rock

Monitoring bore	Location	Total depth (mbgl)	Screened interval (mbgl)	Lithology	Formation	Hydrogeolog-ical unit
RMB02	Rombo	93.0	85.0 – 91.0	Sandstone	Leloma Formation	Shallow rock
WKMB01	Waukivory Pilot	54.0	47.0 – 53.0	Sandstone	Leloma Formation	Shallow rock
WKMB02	Waukivory Pilot	61.0	51.0 – 60.0	Sandstone/ siltstone	Leloma Formation	Shallow rock
WKMB03	Waukivory Pilot	210.0	200.0 – 209.0	Sandstone	Leloma Formation	Interburden
Farley[a]	Pontilands	N/A	N/A	N/A	N/A	N/A
TTPB	Tiedman	90.0	76.0 – 88.0	Sandstone/ siltstone	Leloma Formation	Shallow rock
TTMB01	Tiedman	90.0	76.0 – 88.0	Sandstone/ siltstone	Leloma Formation	Shallow rock
TTMB02	Tiedman	90.0	76.0 – 88.0	Sandstone/ siltstone	Leloma Formation	Shallow rock
TTMB03	Tiedman	198.0	186.0 – 199.0	Sandstone/ siltstone	Leloma Formation	Interburden
FKMB01A	Faulklands	54.0	44.0 – 53.0	Sandstone	Leloma Formation	Shallow rock
FKMB01B	Faulklands	150.2	140.2 – 149.2	Sandstone	Leloma Formation	Shallow rock
BWMB01A	Bucketts Way	11.6	6.5 – 9.5	Mixed gravels	Avon River Alluvium	Alluvial
BWMB01B	Bucketts Way	21.0	14.0 – 20.0	Sandstone/ gravel	Jilleon Formation	Shallow rock
BWMB01C	Bucketts Way	81.4	67.4 – 79.4	Sandstone	Jilleon Formation	Shallow rock
BWMB01D	Bucketts Way	162.6	149.6 – 161.6	Sandstone/ siltstone	Jilleon Formation	Interburden
WRMB01A	Wards River	8.1	4.5 – 7.0	Mixed gravels	Wards River Alluvium	Alluvial
WRMB01B	Wards River	56.4	48.4 – 54.4	Sandstone	Jilleon Formation	Shallow rock
WRMB01C	Wards River	126.5	111.5 – 123.5	Sandstone	Jilleon Formation	Shallow rock
WRMB01D[b]	Wards River	199.0	178.0 – 184.0 (proposed)	Sandstone	Jilleon Formation	Interburden

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

(b) Monitoring bore capped and suspended pending completion; perforation of steel casing scheduled for early 2015 (Parsons Brinckerhoff, 2014c).

mbgl – metres below ground level.

Table 3.3 Summary of AGL Gloucester vibrating wire piezometer construction details

VWP	Total depth (mbgl)	Sensor ID	Sensor depth (mbgl)	Lithology	Formation	Hydrogeological unit
PL03	966.3	2	496	Coal	Wenham Formation – Bowens Road Coal Seam	Coal
		3	463	Pebble conglomerate	Wards River Conglomerate	Interburden

mbgl – metres below ground level.
Sensor ID #1 installed at a depth of 681 m is not operable.

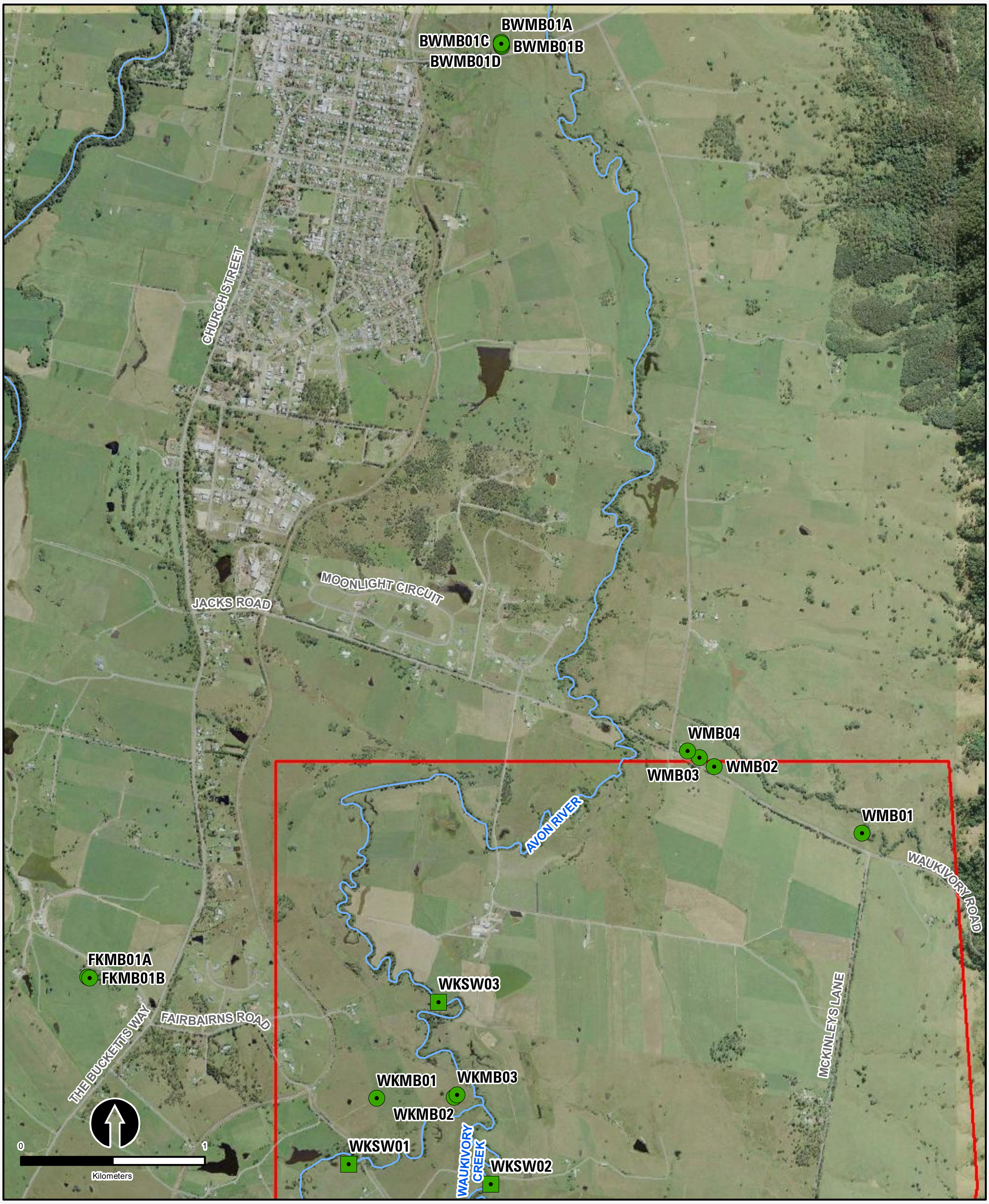

Figure 3.1
Groundwater and surface water monitoring locations northern area

Groundwater monitoring bore
Stream gauge
AGL owned properties
Stage 1 GFDA boundary
Rivers and streams
Roads

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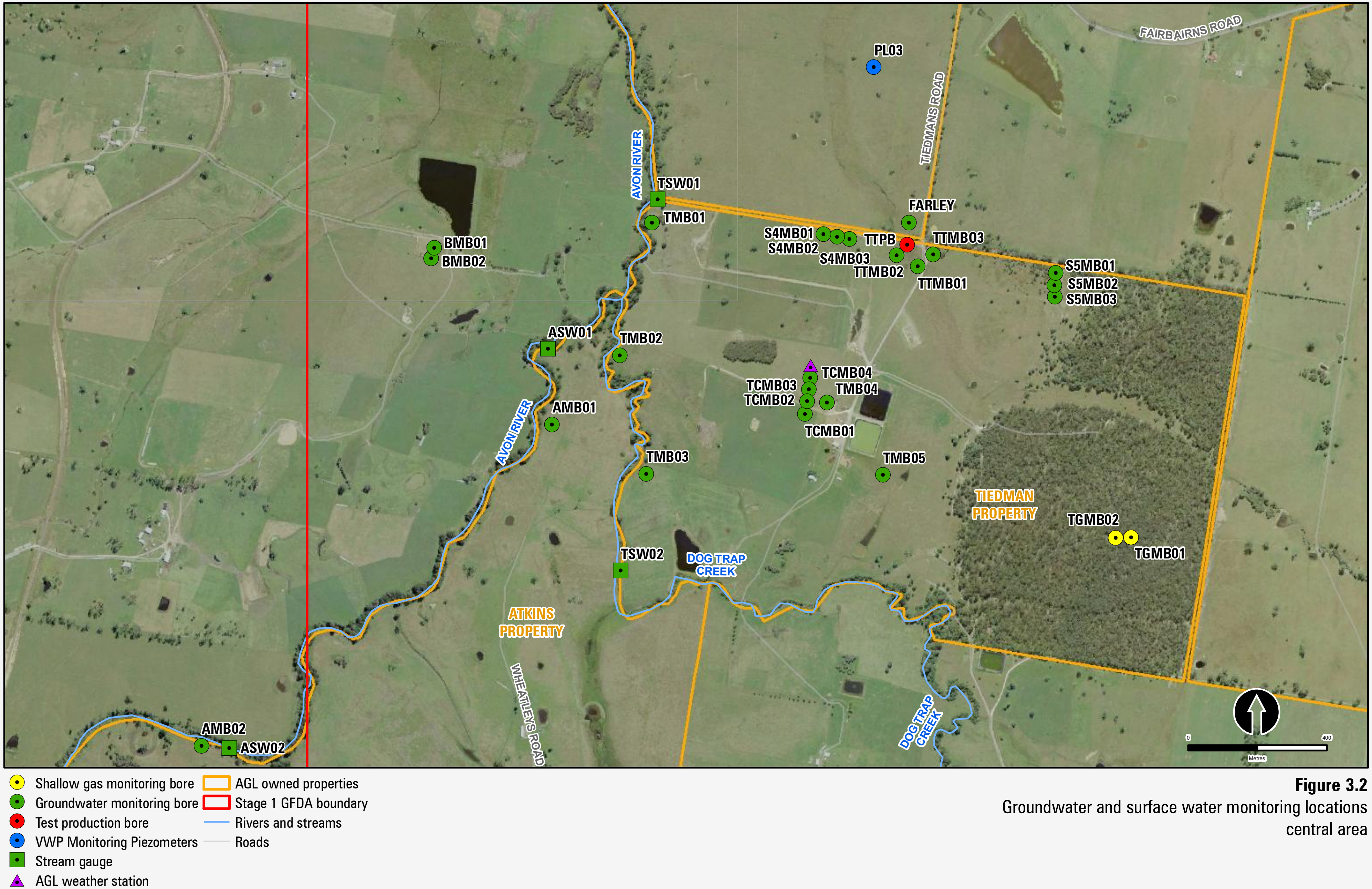

Figure 3.2
Groundwater and surface water monitoring locations central area

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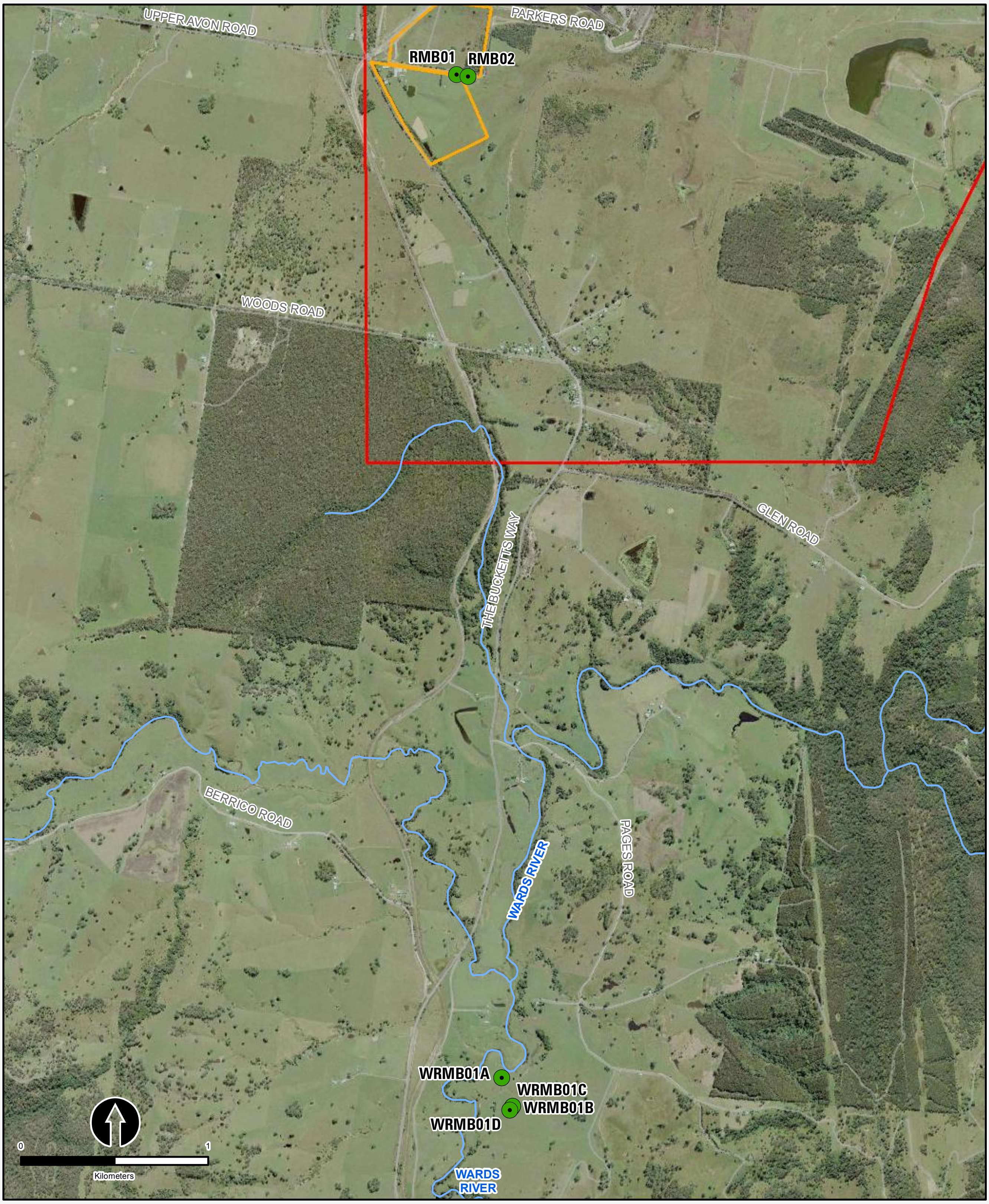

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- Groundwater monitoring bore
- AGL owned properties
- Stage 1 GFDA boundary
- Rivers and streams
- Roads

Figure 3.3
Groundwater and surface water monitoring locations southern area

3.2 Water level monitoring

Groundwater level monitoring commenced in January 2011 and surface water level monitoring commenced in March 2011. The majority of the monitoring network has been in place since January 2011, as described in Parsons Brinckerhoff (2012).

Dataloggers are installed in each of the groundwater monitoring bores to monitor groundwater levels every six hours. To calibrate the level recorded by the dataloggers, manual groundwater level measurements are recorded every three months using an electronic dip meter. The data collection period at each nested groundwater bore location is shown in Figure 3.4.

A barometric datalogger installed above the water table records changes in atmospheric pressure. This logger is installed in WKMB02. Data from this logger are used to correct for the effects of changing barometric pressure on groundwater levels.

Dataloggers installed at the vibrating wire piezometer (VWP) site monitor piezometric pressure every six hours.

At the stream gauges, dataloggers are installed to monitor water levels and salinity every 15 minutes. Water levels are verified by manual gauge board readings recorded every three months. Salinity (recorded as Electrical Conductivity (EC)) measurements are checked every three months using a hand-held water quality meter. The data collection period for each monitoring location is shown in Figure 3.5.

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

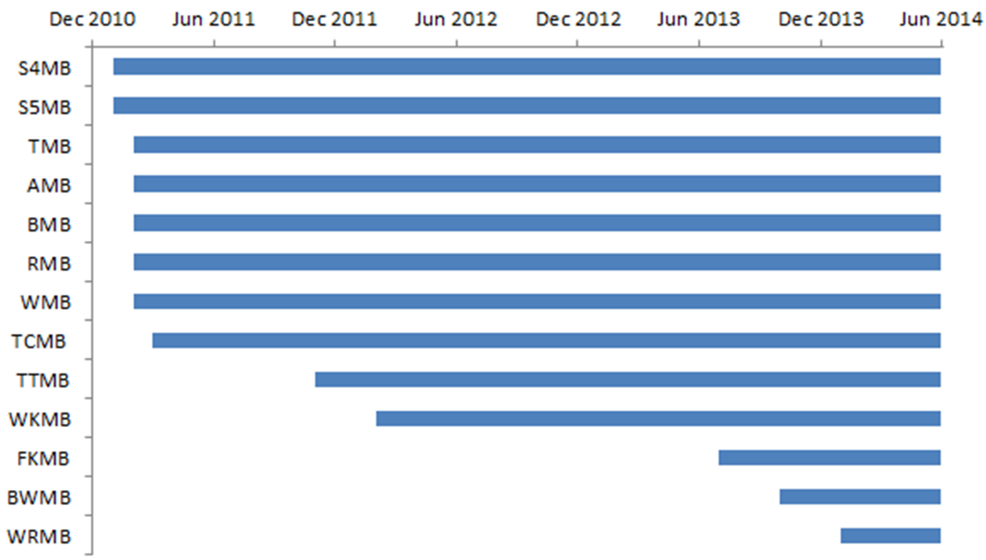
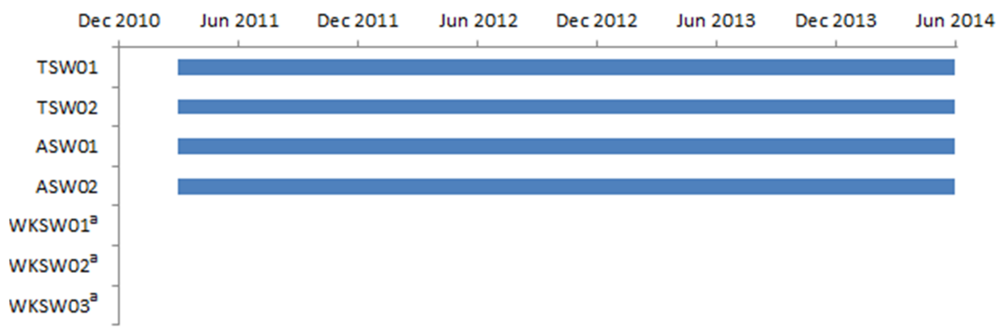


Figure 3.5 Surface water level data collection periods for each monitoring location



(a) Only operational for water quality monitoring during the 2013-2014 monitoring period; water level data collection commenced in September 2014.

3.3 Water quality monitoring

The frequency of water quality monitoring undertaken since the installation of the monitoring network in January 2011 is presented in Table 3.4. Groundwater and surface water quality results are presented in the Phase 2 groundwater investigations report (Parsons Brinckerhoff 2012), the 2013 annual monitoring report (Parsons Brinckerhoff 2013e) and the drilling completion reports for the WKMB (Parsons Brinckerhoff 2014a), FKMB and BWMB (Parsons Brinckerhoff 2014b) and WRMB (Parsons Brinckerhoff 2014c) monitoring sites.

A summary of water quality monitoring undertaken as part of the Tiedman Irrigation Program is given in Table 3.5; sampling locations are shown in Figure 3.6. Quarterly groundwater and surface water quality results from the S4MB and TMB bores, and selected surface water sites are presented in the Tiedman Irrigation Program 6-monthly reports (Parsons Brinckerhoff 2013c, 2013d, 2014f and 2014g).

A summary of the water quality monitoring undertaken as part of the Waukivory pilot baseline sampling is given in Table 3.6; sampling locations are shown in Figure 3.1. Groundwater and surface water quality results are presented in the Waukivory pilot baseline water monitoring report (Parsons Brinckerhoff 2014d).

Comprehensive groundwater and surface water quality sampling across the network was not undertaken during the latest monitoring period (July 2013 - June 2014). A regional event is proposed for March 2015.

Table 3.4 Water quality sampling frequency – all water monitoring locations

Monitoring site	April 2011	July – August 2012	June – July 2013	October 2013	September 2014
S4MB, S5MB, TMB, AMB, BMB, RMB, WMB	√[a]		√		
TCMB	√[a,b]		√[c]		
Surface water (TSW01, TSW02, ASW01, ASW02)	√[d]		√		
TTMB			√		
WKMB		√[a,e]	√[e]	√[a,f]	see Table 3.6
FKMB, BWMB				√[a]	
WRMB					√[a]
Reference report	Parsons Brinckerhoff (2012)	Parsons Brinckerhoff (2014a)	Parsons Brinckerhoff (2013e)	Parsons Brinckerhoff (2014a) Parsons Brinckerhoff (2014b)	Parsons Brinckerhoff (2014c)

(a) Sampling included isotope analysis.
(b) Excluding TCMB01.
(c) Excluding TCMB03.
(d) Excluding TSW02.
(e) WKMB01, WKMB02, WKMB03 only.
(f) WKMB04 only – bore plugged and abandoned November 2013 (Parsons Brinckerhoff 2014a).

Table 3.5 Water quality sampling frequency – Tiedman irrigation program

Monitoring site	October and December 2011	February, June and September 2012	May, August and November 2013	February and May 2014	August 2014
TMB, S4MB01	√[b]	√	√	√	√
Tiedman Dams (TND, TSD, TED)	√[c]	√[c]	√	√	√
Catch dams (CDE, CDW)			√[e]	√[f]	√
Surface water (TSW01, TSW02, ASW01, FSW01)	√[d]	√	√[d,e]	√[d,f]	√
Perched water (soil piezometers) SP1A/B to SP10A/B[a]			√	√	√
TCMB01					√
TTMB02					√
Reference report	Parsons Brinckerhoff (2013c)		Parsons Brinckerhoff (2013d and 2014f)	Parsons Brinckerhoff (2014g)	To be reported in January 2015

(a) Sampled only piezometer where sufficient water had accumulated to allow for a representative sample to be collected.
(b) Excluding TMB04 and TMB05.
(c) Excluding TED (dam not constructed until January 2013).
(d) Excluding FSW01.
(e) Including additional high rainfall sampling at the end of November 2013 (CDE, CDW, ASW01 and FSW01).
(f) Including additional high rainfall sampling at the beginning of March 2014 (CDE, CDW, ASW01 and FSW01).

Table 3.6 Water quality sampling program – Waukivory pilot baseline sampling

Monitoring site	March 2014	June 2014	September 2014	October 2014
WKMB	√[a]	√[a]	√	√
WKSW	√[a]	√[a]	√	√
Reference report	Parsons Brinckerhoff (2014d, in preparation)			

(a) Sampling included isotope analysis.

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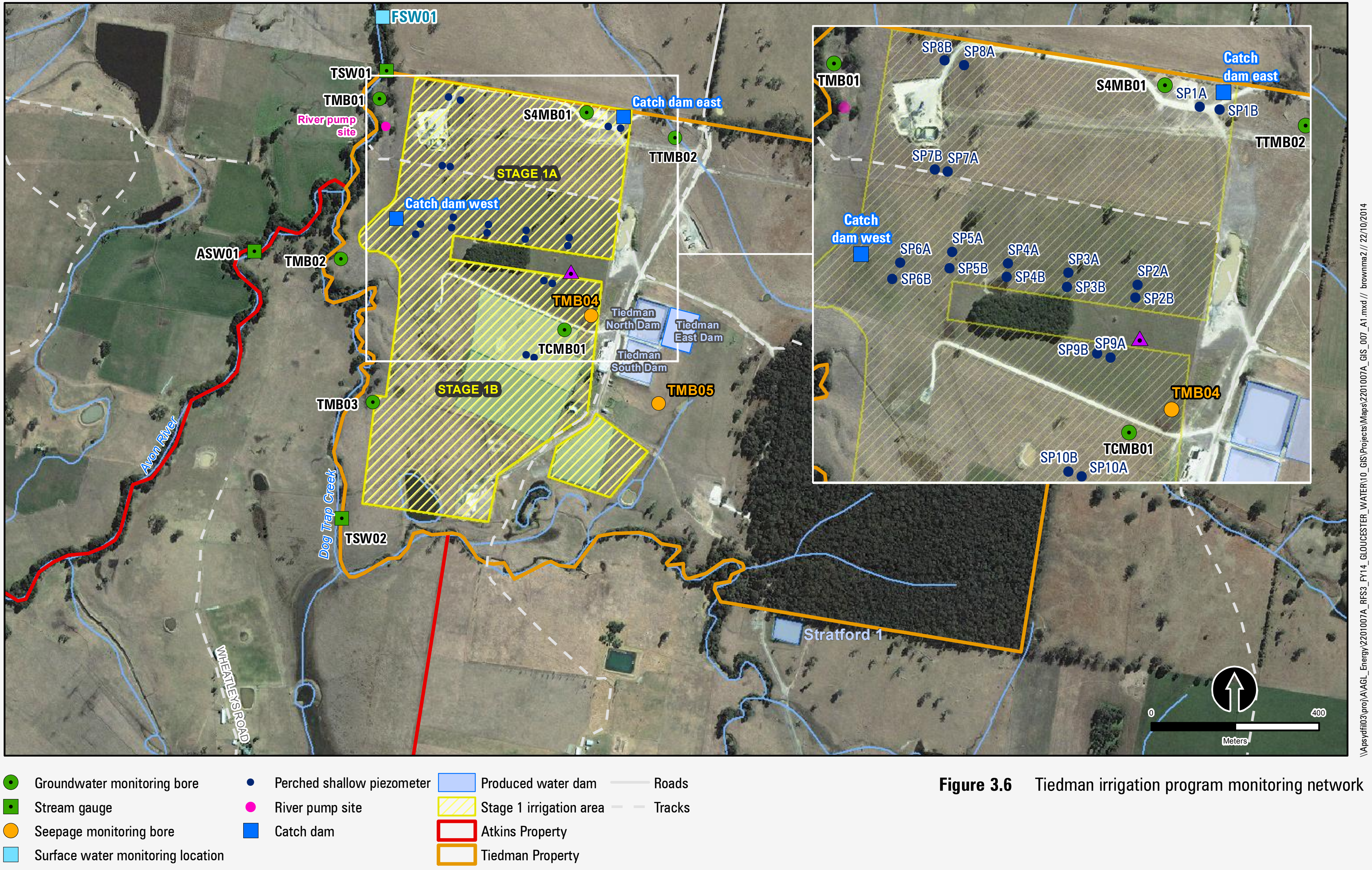

Figure 3.6 Tiedman irrigation program monitoring network

4. Surface water monitoring

4.1 Surface water levels

All stream gauges on the Avon River (TSW01, ASW01 and ASW02) and Dog Trap Creek (TSW02) show rapid responses to rainfall events (Figure 4.1). During the monitoring period (July 2013 to June 2014) the highest rainfall event and increase in water levels (1.7 m increase at ASW02) was in November 2013. The hydrographs also show relatively steep recession curves, with stream levels declining close to pre-existing levels over several weeks following rainfall events. The time taken to return to pre-existing levels depends on the size of the rainfall event.

Two periods of significantly below average rainfall occurred from July 2013 to October 2013 and from December 2013 to February 2014. This corresponds to periods of very low water levels in the Avon River and Dog Trap Creek. In September 2013, October 2013, January 2014, and February 2014, the water levels decreased to the zero gauge height at TSW01 (Avon River), ASW01 (Avon River), and TSW02 (Dog Trap Creek). Periods of very low rainfall and low water levels result in 'no flow' or 'very low flow', when the rivers are characterised by multiple disconnected pools.

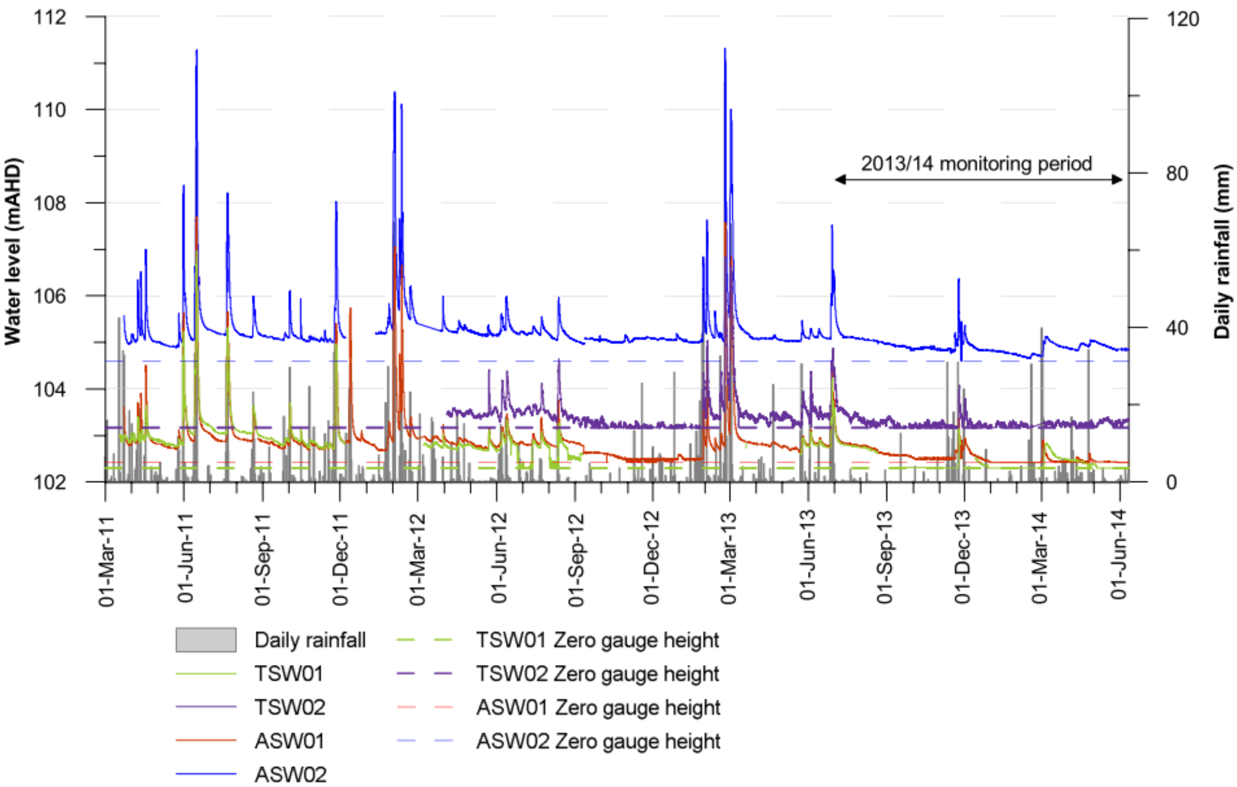

Figure 4.1 Avon River and Dog Trap Creek stream level and rainfall

4.2 Surface water flows

Stream water levels have been converted to estimated stream flows using theoretical rating curves, based on surveyed stream profiles and a number of assumptions regarding streambed characteristics (Figure 4.2). Flow duration curves have also been calculated (Figure 4.3). Theoretical modelling was undertaken using HEC-RAS software and flow parameters taken from a calibrated model of a locally gauged stream of similar profile and morphology.

Flows have not been calibrated to site flow measurements and therefore these interim calculated flow rates should be treated as indicative only and subject to uncertainty which is inherent in the assumptions used. There are clear discrepancies in the flows, for example higher flows are shown at ASW02 (upstream) than ASW01 (downstream), highlighting uncertainties associated with using unrated gauges. To improve the stream flow dataset, AGL is in the process of rating each of the stream gauging stations using site flow measurements under a range of conditions. Obtaining sufficient data to construct rating curves is proving difficult given that there have been long periods of very low or no flow over the last 12 to 18 months.

Theoretical flow duration curves for the stream gauges (Figure 4.3) show that the Avon River at ASW01 and Dog Trap Creek at TSW02 have no flow for 94% and 98% of the time respectively. Absence of flow does not reflect no water at a stream gauge. During periods of low rainfall, the Avon River and Dog Trap Creek are characterised by multiple disconnected pools. The Avon River at TSW01 has no flow for 30% of the time, and at ASW02 has no flow for 3% of the time.

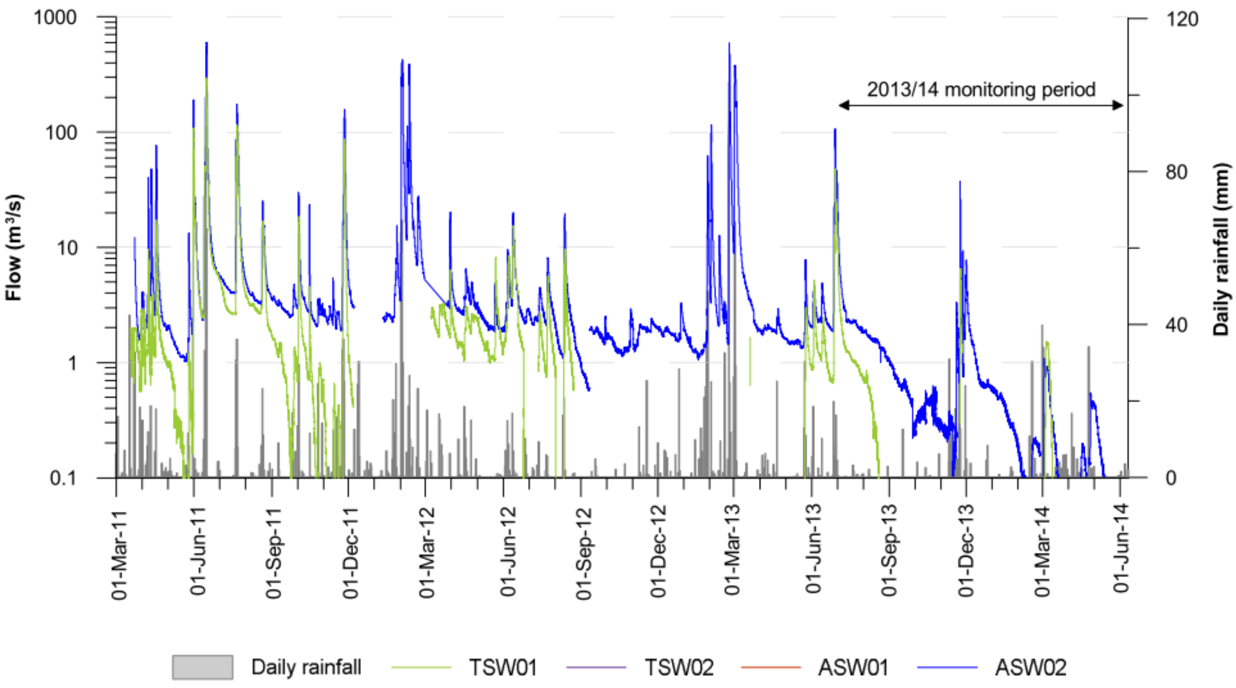

Figure 4.2 Avon River and Dog Trap Creek estimated flows and rainfall

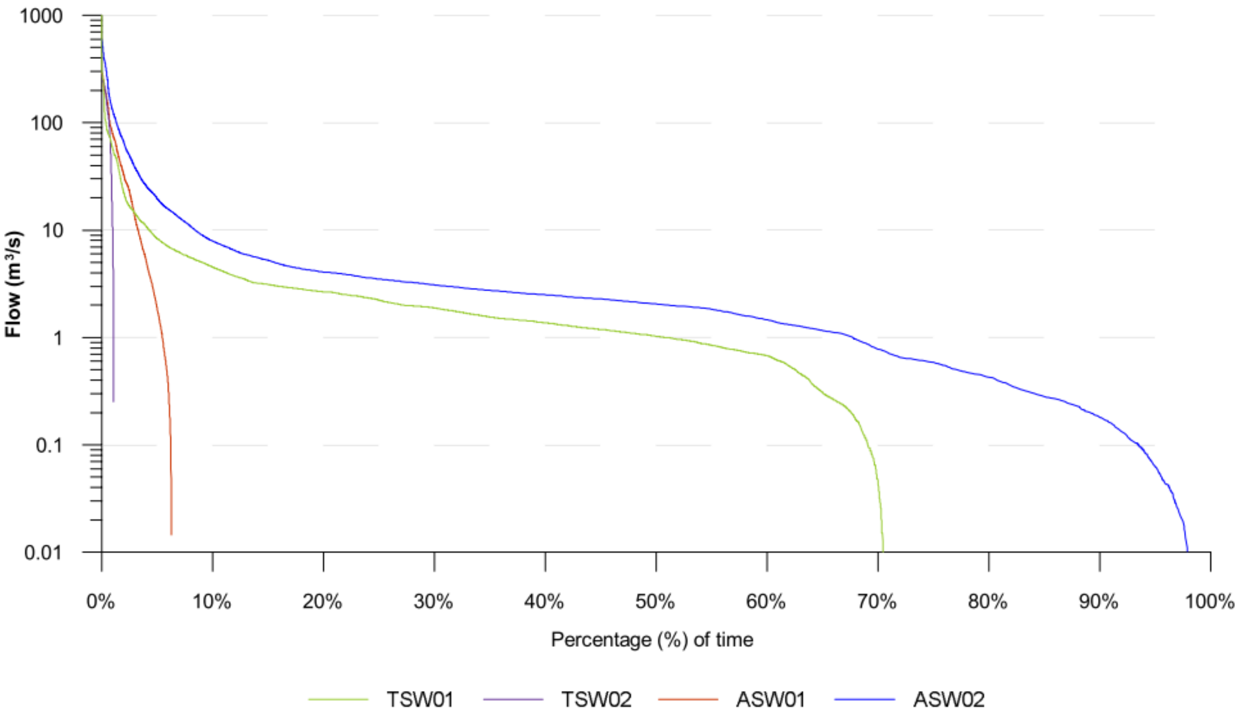

Figure 4.3 Estimated flow duration curves for the Avon River and Dog Trap Creek gauges

4.3 Surface water quality

Surface water salinity (measured as EC) is inversely related to rainfall and flow (Figure 4.4 and Figure 4.5). Salinity decreases after rainfall events as relatively fresh runoff is routed into streams. However, an initial increase in EC is often seen in the initial runoff phase as readily dissolvable salts are flushed from the ground surface and shallow soils. During the monitoring period, an increase in EC associated with high rainfall events and the initial runoff phase is observed in November 2013 and March 2014.

After the initial salinity spike and subsequent reduction in EC levels, EC then gradually increases as flow decreases, and as groundwater discharge starts to become a more dominant component of the baseflow. During the monitoring period (Figure 4.5), a gradual increase in EC is observed during low rainfall periods from July 2013 to October 2013, and from December 2013 to February 2014. 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 4.1 shows the range and average of the EC data at each of the surface water monitoring sites during the monitoring period. The highest 95th percentile (880 µS/cm) and maximum (2445 µS/cm) salinities are observed at Dog Trap Creek (TSW02). A percentile is the value below which a given percentage of observations fall. For example, the 5th percentile is the value below which 5% of observations are found. The 5th and 95th percentiles presented in Table 4.1 are used as a method of discounting outlying values.

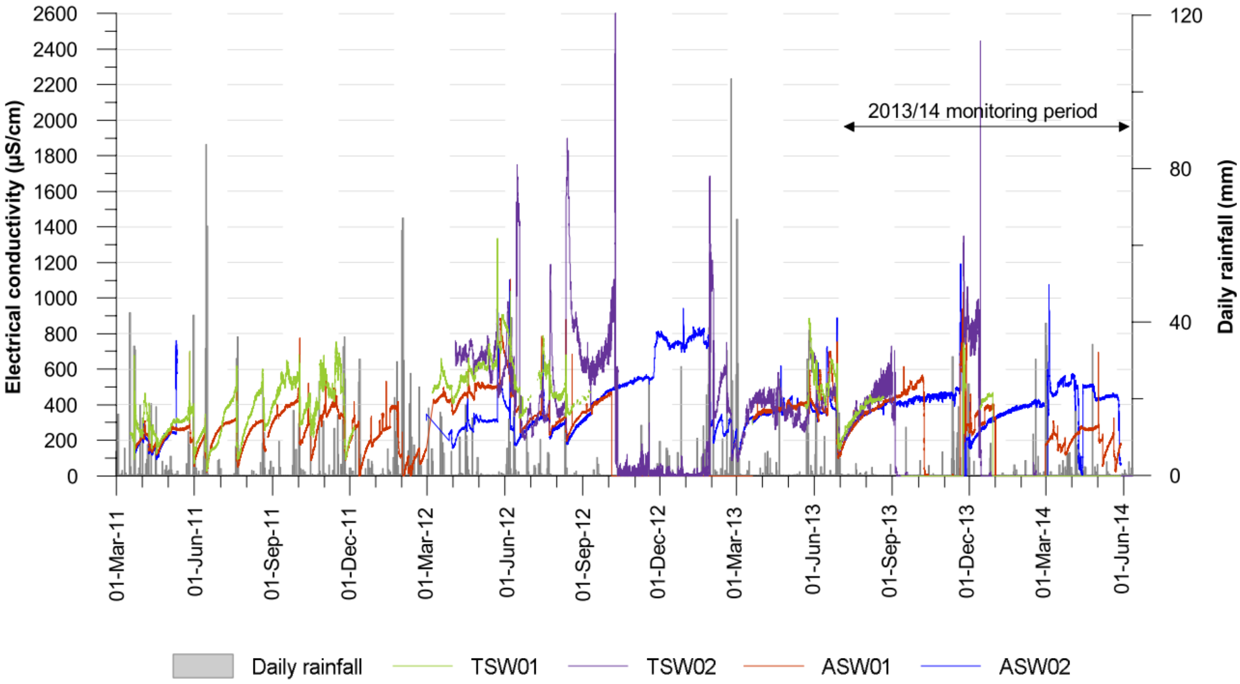

Figure 4.4 EC measurements and rainfall in the Avon River and Dog Trap Creek

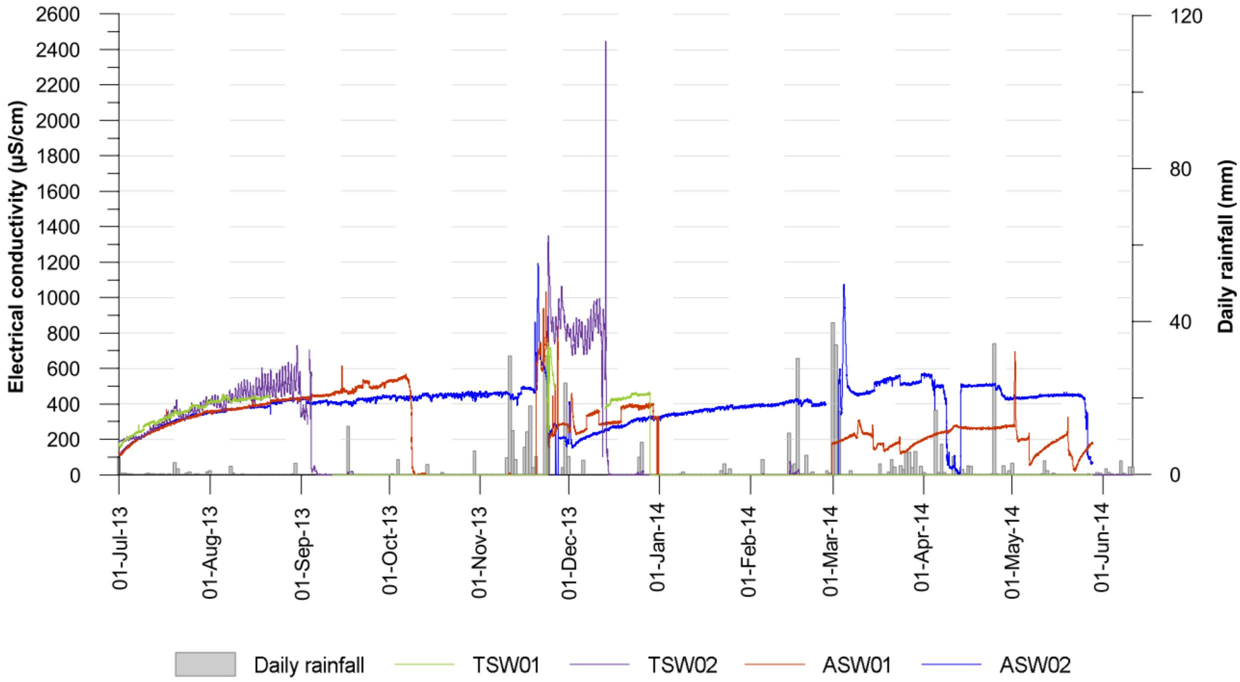

Figure 4.5 EC measurements and rainfall in the Avon River and Dog Trap Creek over the 2013/14 monitoring period only

Table 4.1 Maximum, minimum and average EC for surface water monitoring locations for the monitoring period (July 2013 to June 2014)

Location	River/creek	5th Percentile EC (µS/cm)	Median EC (µS/cm)	95th Percentile EC (µS/cm)	Maximum EC (µS/cm)
ASW01	Avon River	127	284	528	1032
AWS02	Avon River	207	424	536	1193
TWS01	Avon River	211	413	458	746
TWS02	Dog Trap Creek	20	415	880	2445

µS/cm– microSiemens per centimetre.

5. Groundwater monitoring

5.1 Groundwater – surface water interaction

Groundwater levels are typically higher than adjacent stream levels (by between one and two metres), indicating that the streams are discharge features for shallow groundwater in the Stage 1 GFDA (Figure 5.1). 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.

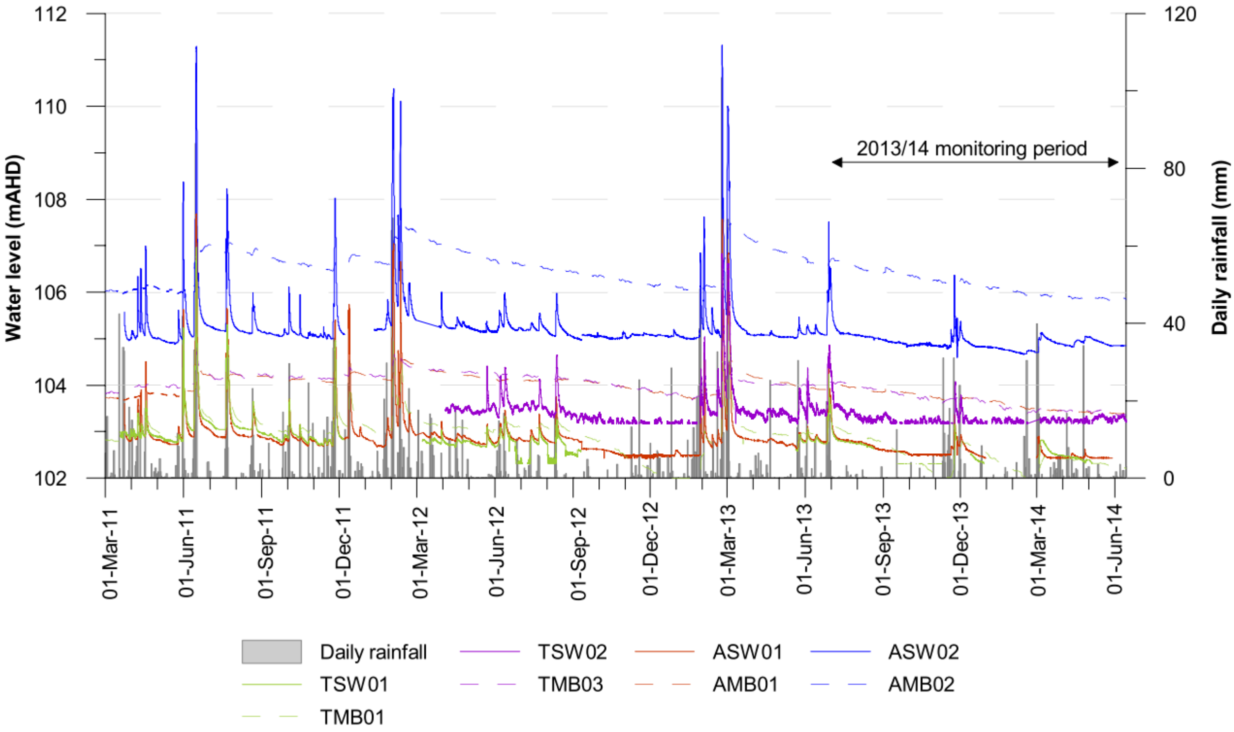

Figure 5.1 Surface water hydrographs for the Avon River and Dog Trap Creek (solid lines) and groundwater levels in the adjacent alluvium (dashed lines)

5.2 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 5.2.1. Trends for the shallow rock, coal seam and interburden hydrogeological units are presented in the nested monitoring bore hydrographs in Sections 5.22, 5.23 and 5.24. Individual hydrographs for each monitoring bore are shown in Appendix A. All monitoring bores are located in the (north flowing) Avon River catchment with the exception of the WRMB sites which are located in the (south flowing) Wards River catchment.

5.2.1 Alluvium

Groundwater levels in monitoring bores screened in the alluvial deposits show a sharp response to significant rainfall events (Figure 5.2, Figure 5.3, Figure 5.4 and Figure 5.5). 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.

During the monitoring period, groundwater levels at the TMB and WMB alluvial monitoring bores (Figure 5.2 and Figure 5.4) show an increase in response to the rainfall events in November 2013 and March 2014. This increase is ~ 0.5 m at TMB01, and ~ 0.2 m at TMB02, TMB03 and WMB01. The hydrographs at these sites show a relatively steep recession curve, with a return to near-previous groundwater levels over a period of one to two months. During extremely dry periods when there are very low stream levels, accelerated drainage of alluvial groundwater (from storage) is observed at the TMB01 site in late 2012/early 2013 and again in late 2013 and early 2014 (Figure 5.2).

During the July 2013 to June 2014 monitoring period, groundwater levels at the AMB alluvial monitoring bores (Figure 5.3) show a smaller response (< 0.1 m) to rainfall events. The hydrographs at these two sites show a flatter recession curve, with groundwater levels continuing to decrease since the large rainfall event in February 2013.

All alluvial monitoring bores show a decrease in groundwater levels over the monitoring period from July 2013 to June 2014, corresponding to the below average rainfall over this period. This decrease is approximately 0.8 m in all bores, with the exception of BWMB01A (downstream Avon River catchment) which commenced monitoring in October 2013 and WRMB01A (upstream Wards River catchment) which commenced monitoring in January 2014 (see Figure 5.5). These monitoring bores have not shown a change in groundwater level over this short period.

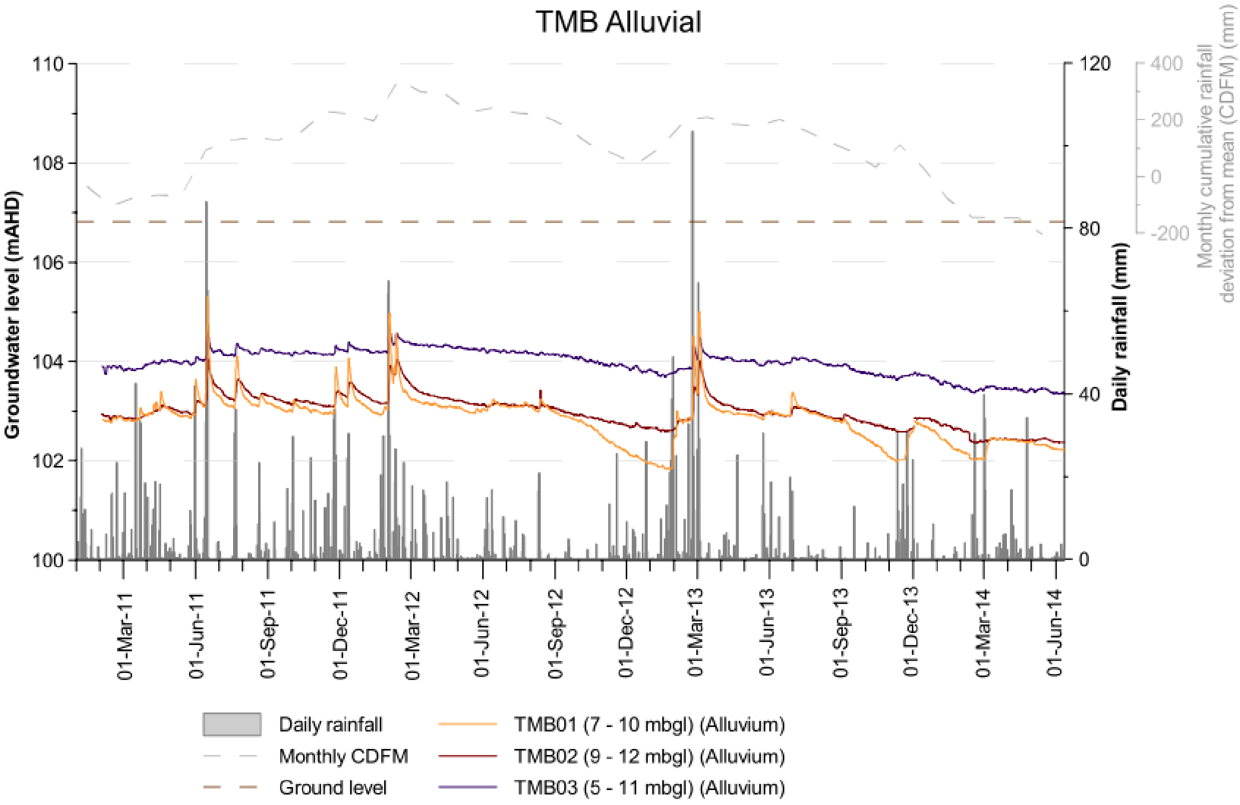

Figure 5.2 Groundwater levels and rainfall in the TMB alluvial monitoring bores

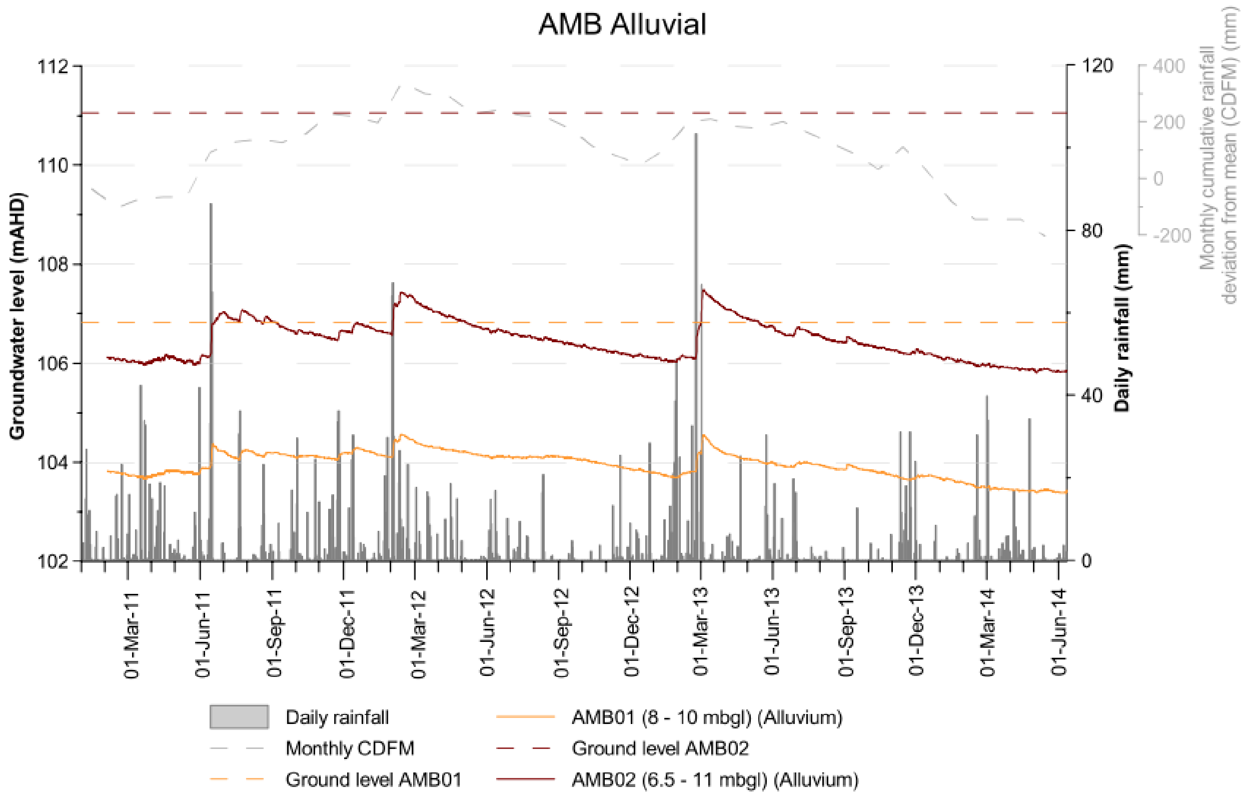

Figure 5.3 Groundwater levels and rainfall at the AMB alluvial monitoring bores

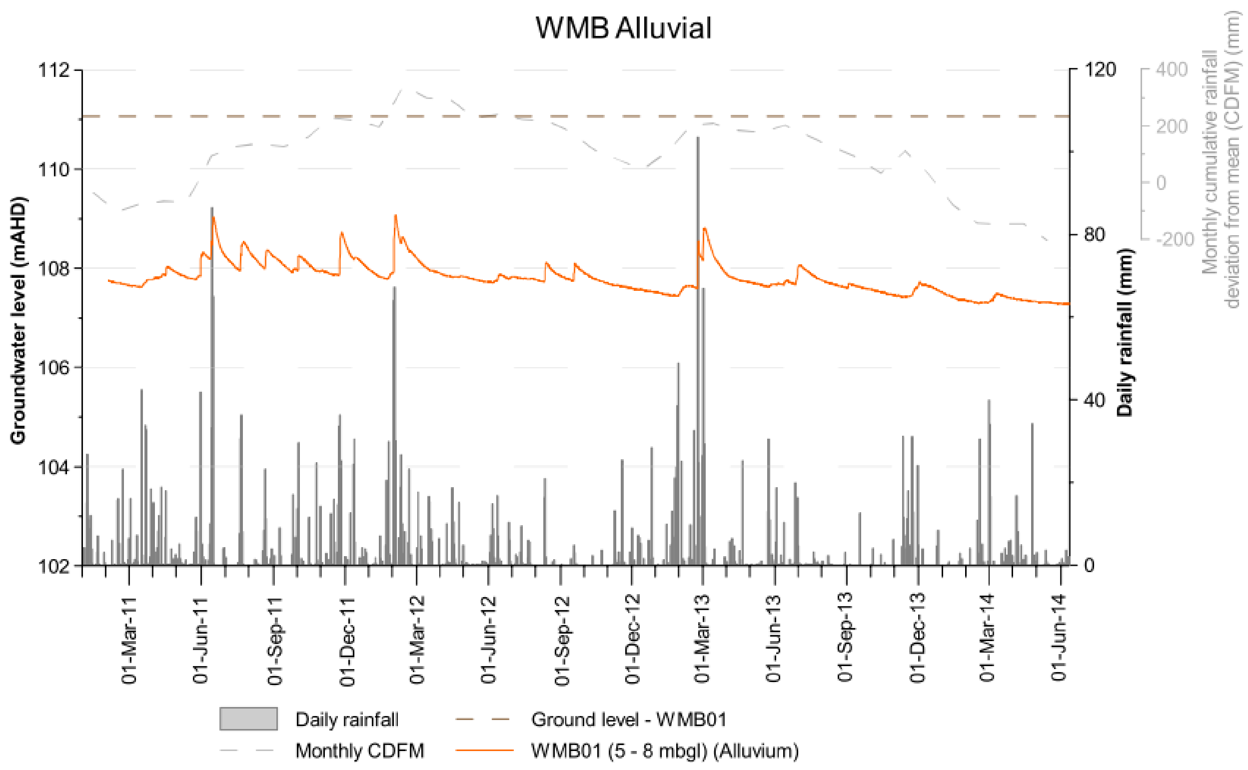

Figure 5.4 Groundwater levels and rainfall at the WMB alluvial monitoring bore

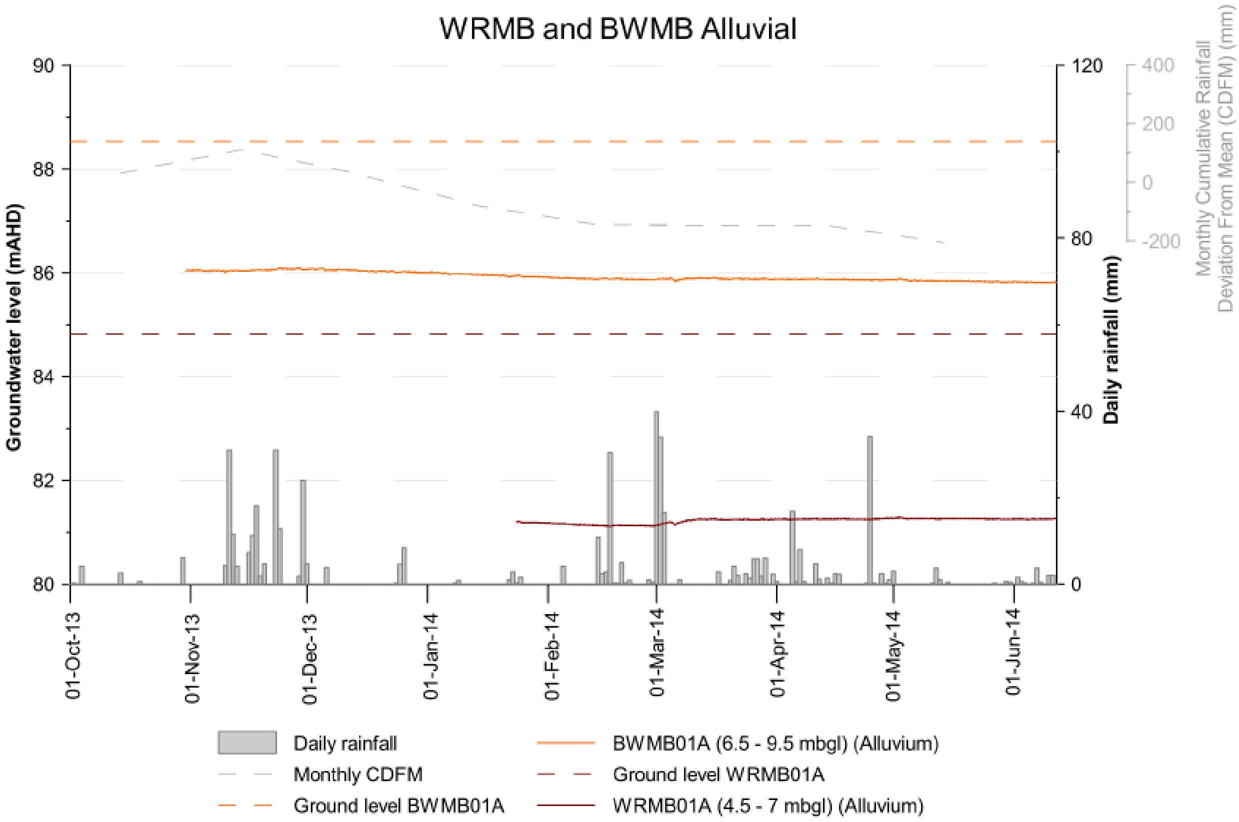

Figure 5.5 Groundwater levels and rainfall at the WRMB and BWMB alluvial monitoring bores

5.2.2 Shallow rock

Monitoring bores screened within the shallow rock are present at all of the nested monitoring sites. There are no strong responses to individual rainfall events in the shallow rock monitoring bores, with the exception of the WKMB site in February 2013, prior to this monitoring period. At this site there is a delayed response to periods of higher and lower rainfall, suggesting that groundwater levels are responding to local rainfall recharge (Figure 5.13).

The shallow rock hydrographs at the S4MB (Figure 5.6), TCMB (Figure 5.8), TTMB (Figure 5.9), and WMB (Figure 5.12) sites show a decrease in groundwater levels of ~ 0.2 m between July 2013 and June 2014. At these sites there are small water level changes due to rainfall recharge and very dry conditions over a broader area.

At the BMB (Figure 5.10) and RMB (Figure 5.11) sites groundwater levels in the shallow rock show a slightly greater decrease of ~ 0.5 m between July 2013 and June 2014, in response to the below average rainfall during the period.

S5MB01 (Figure 5.7) shows a very slow recovery in response to the June 2013 sampling event, and therefore does not provide useful information on baseline trends. This is due to the very low hydraulic conductivity at S5MB01 ($2x10^{-6}$ m/d, Parsons Brinckerhoff 2012). S5MB02 screened in the shallow rock shows a decrease in groundwater levels of ~ 0.2 m over the monitoring period. There is an anomalous sharp increase in groundwater levels of ~ 2m at S5MB02 associated with the June 2013 water sampling event. The cause of this anomaly is not clear; although it may be associated with improved hydraulic connection after the water sampling event.

The dataloggers at WKMB01 and WKMB02 failed in March 2014 and were replaced in September 2014 and August 2014 respectively. Monitoring bores in the shallow rock at the WKMB site (Figure 5.13) show an increase in groundwater levels of ~ 0.1 m in response to the high rainfall event in November 2013, however there is an overall decrease of ~ 0.5 m over the period the loggers were functioning.

Monitoring bores screened within the shallow rock at FKMB (Figure 5.14), BWMB (Figure 5.15) and WRMB (Figure 5.16) commenced monitoring in July 2013, October 2013, and January 2014 respectively. There have been no significant changes in groundwater levels at these sites since monitoring commenced, with the exception of WRMB01B, which is showing a slow recovery since installation due to the very low rock permeability.

5.2.3 Interburden units

The interburden monitoring bores TCMB02 (Figure 5.8), TTMB03 (Figure 5.9) and BWMB01D (Figure 5.15) show no overall change in groundwater levels over the monitoring period, and groundwater levels do not respond to rainfall events.

A new datalogger was installed at WKMB03 in October 2013. Groundwater levels at the WKMB03 interburden monitoring bore (Figure 5.13) show a decrease of ~ 0.3 m from October 2013 to June 2014. Sampling of the WKMB bores was carried out in March 2014 which disrupted the downward trend at the WKMB03 site.

5.2.4 Coal seams

The coal seam monitoring bore S4MB03 (Figure 5.6) shows a decrease in groundwater levels of ~ 0.2 m between July 2013 and June 2014.

Coal seam monitoring bores S5MB03 (Figure 5.7) and TCMB03 (Figure 5.8) do not show an overall change in groundwater levels over the monitoring period.

The coal seam monitoring bore TCMB04 (Figure 5.8) shows an increase in groundwater levels of ~ 0.2 m between July 2013 and June 2014. This bore is the deepest conventional monitoring bore in the monitoring network (screened from 327 to 333 mbgl) and may reflect a delayed response to a longer-term period of higher than average rainfall from 2006 to 2012.

Monitoring bores screened within the coal seams do not show a significant change in groundwater levels in response to rainfall events.

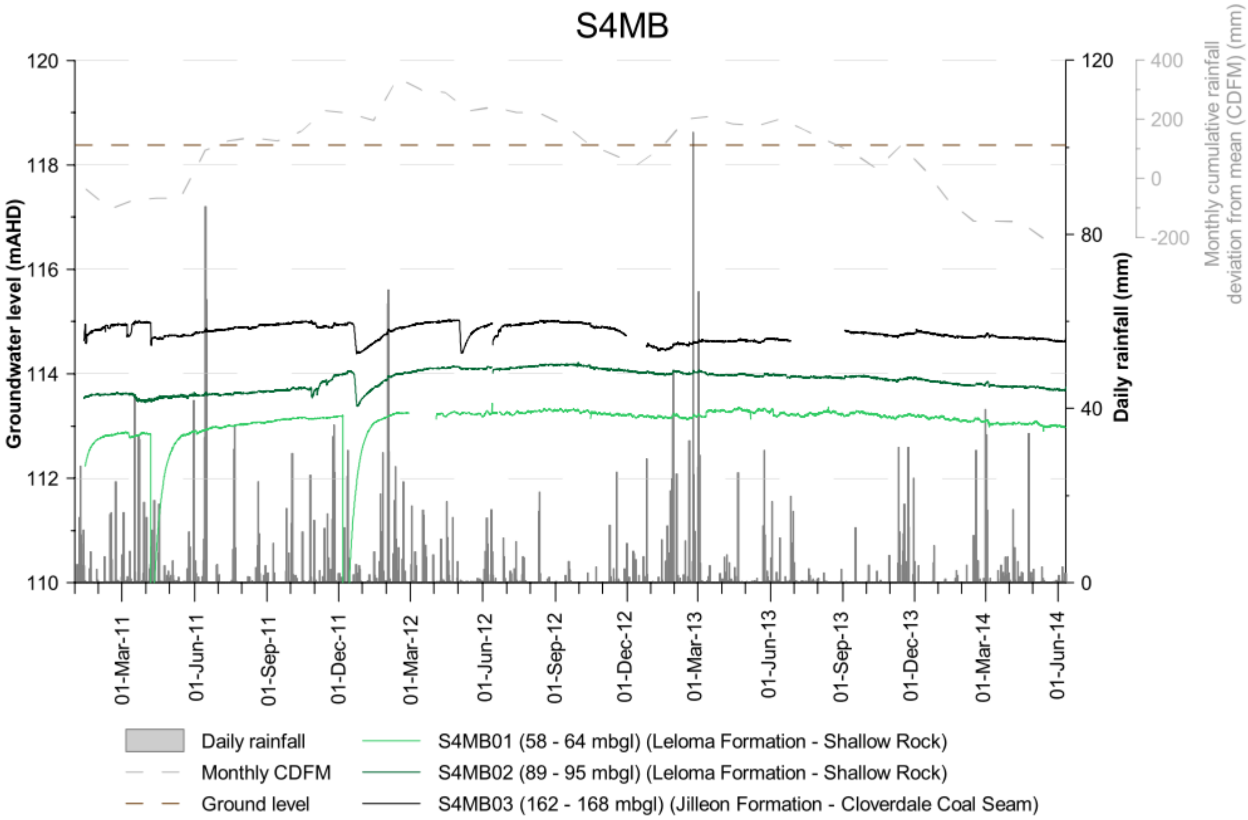

Figure 5.6 Groundwater levels and rainfall at the S4MB site

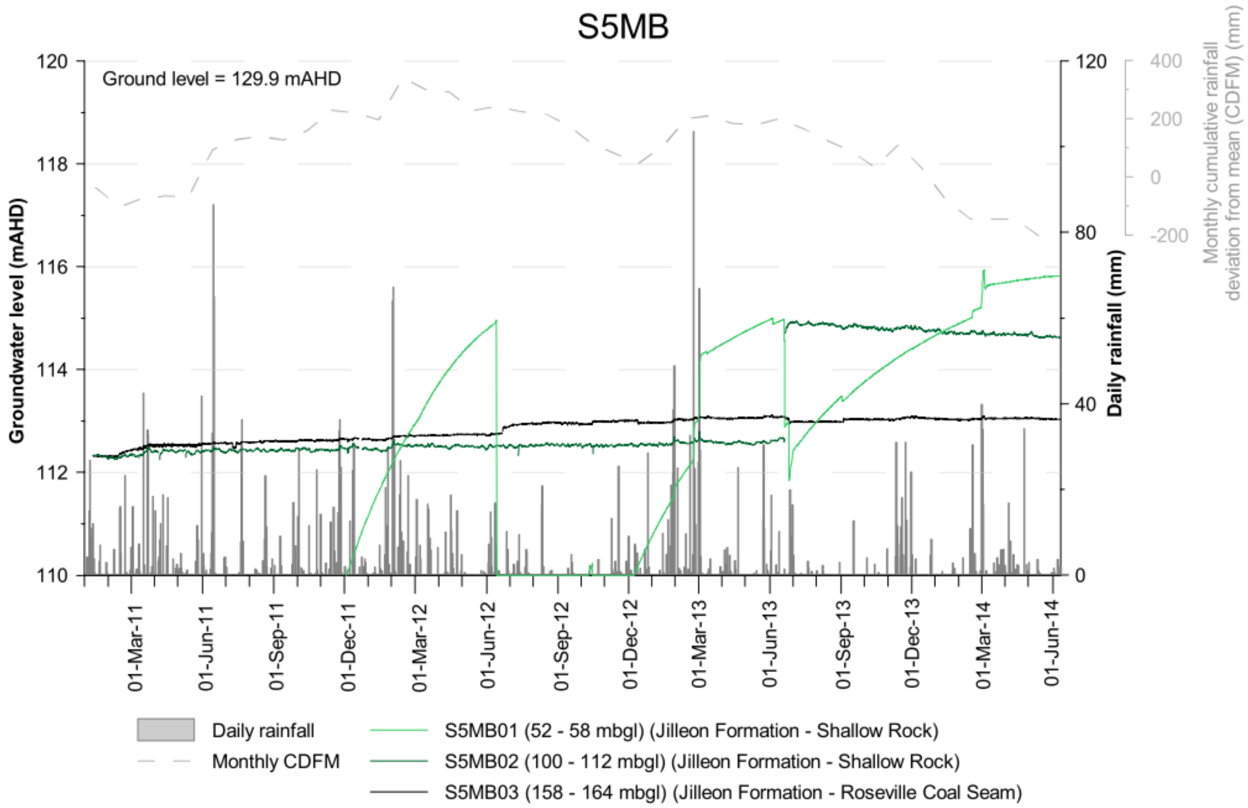

Figure 5.7 Groundwater levels and rainfall at the S5MB site

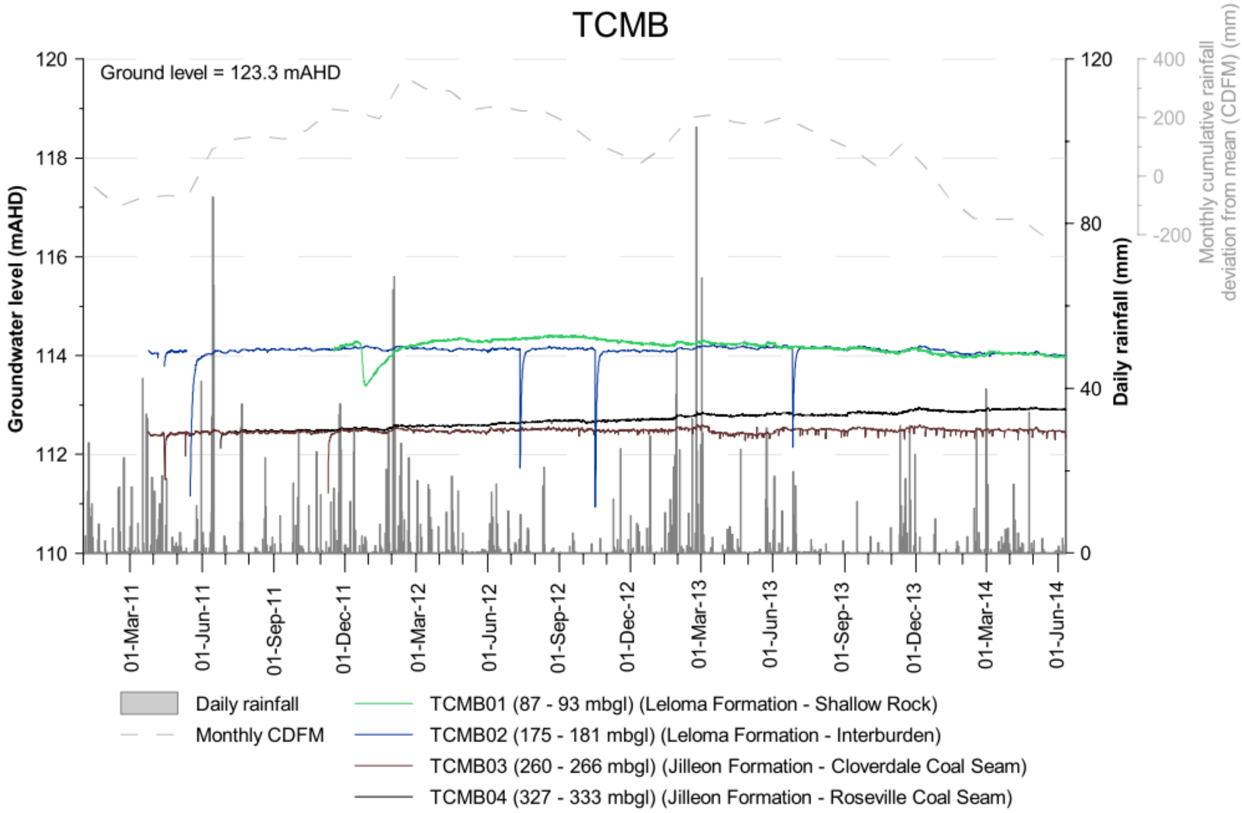

Figure 5.8 Groundwater levels and rainfall at the TCMB site

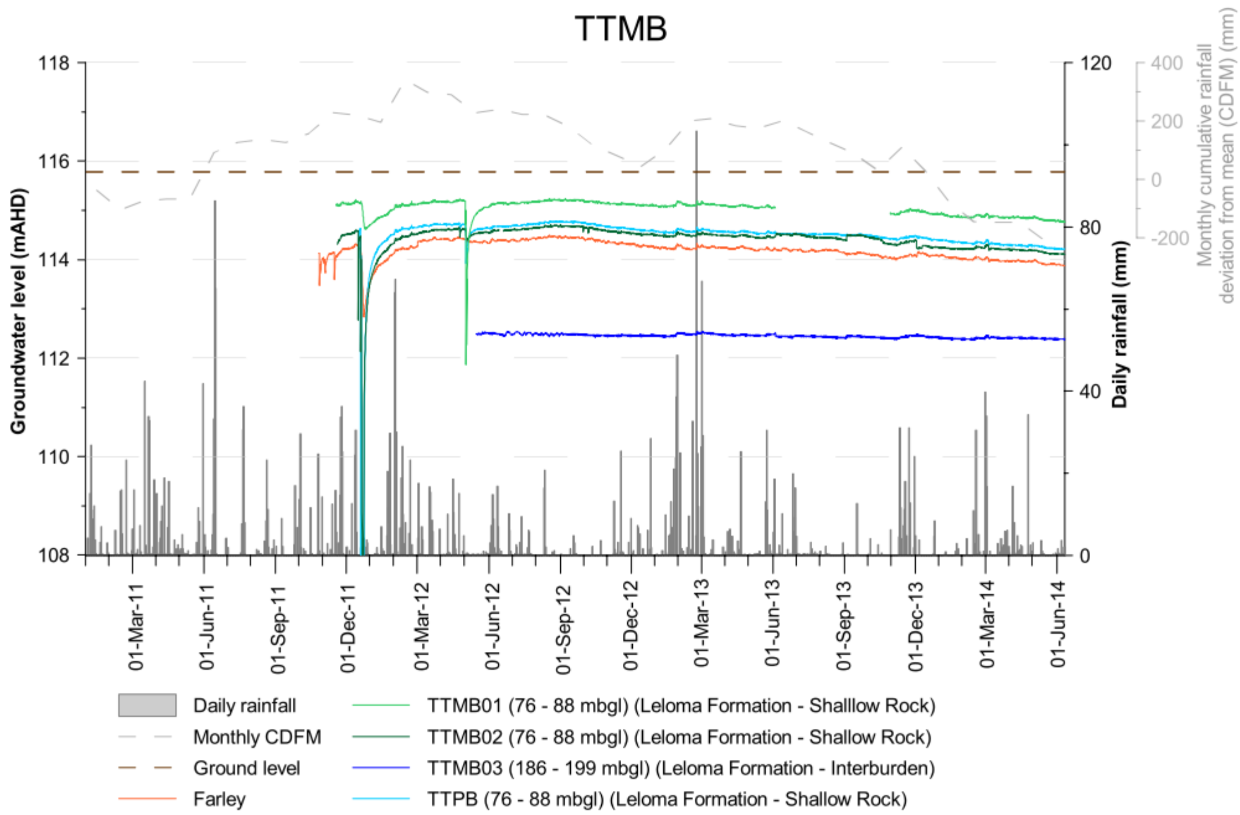

Figure 5.9 Groundwater levels and rainfall at the TTMB site

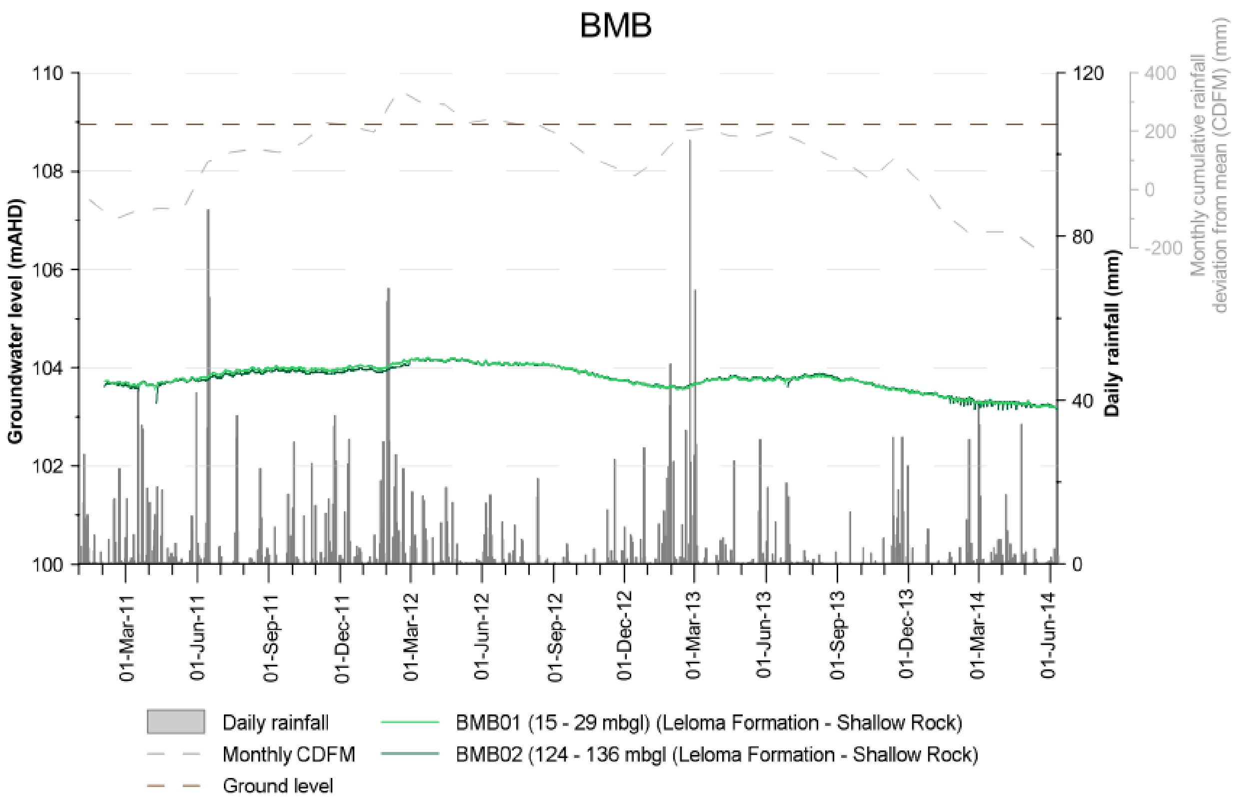

Figure 5.10 Groundwater levels and rainfall at the BMB site

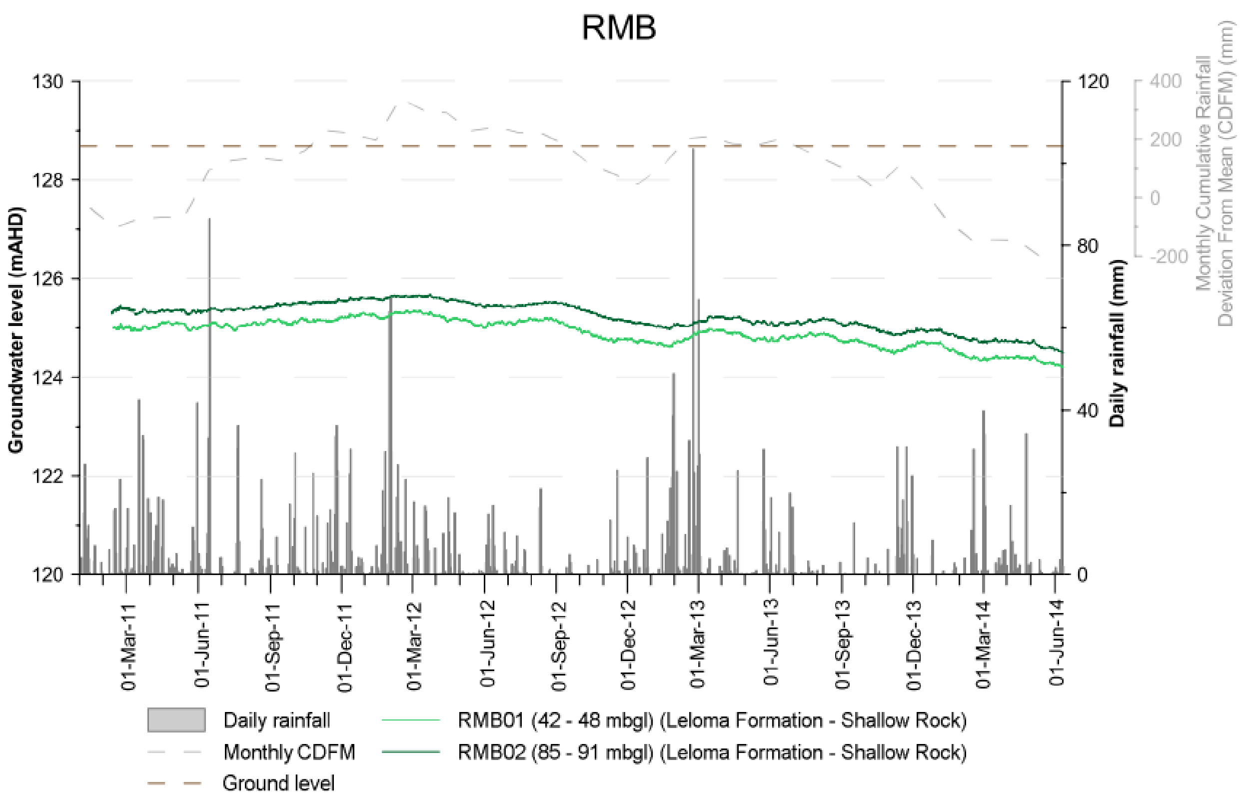

Figure 5.11 Groundwater levels and rainfall at the RMB site

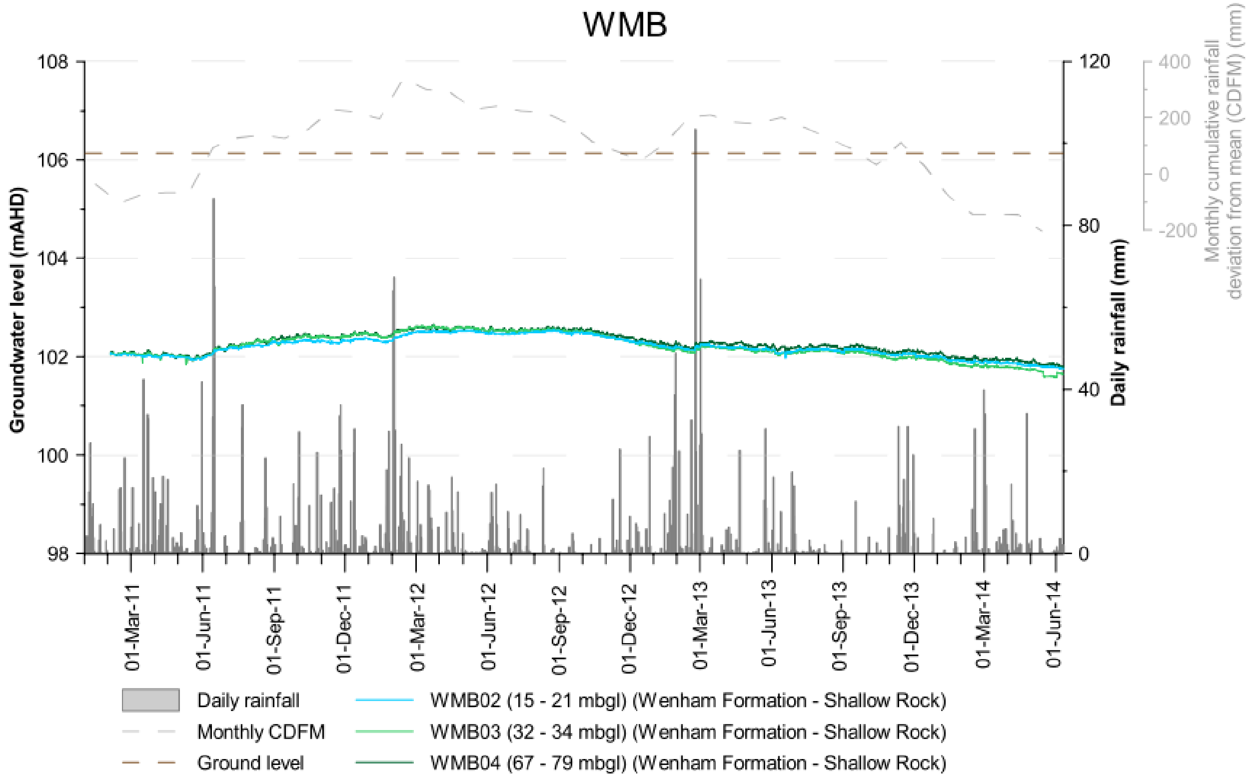

Figure 5.12 Groundwater levels and rainfall at the WMB site

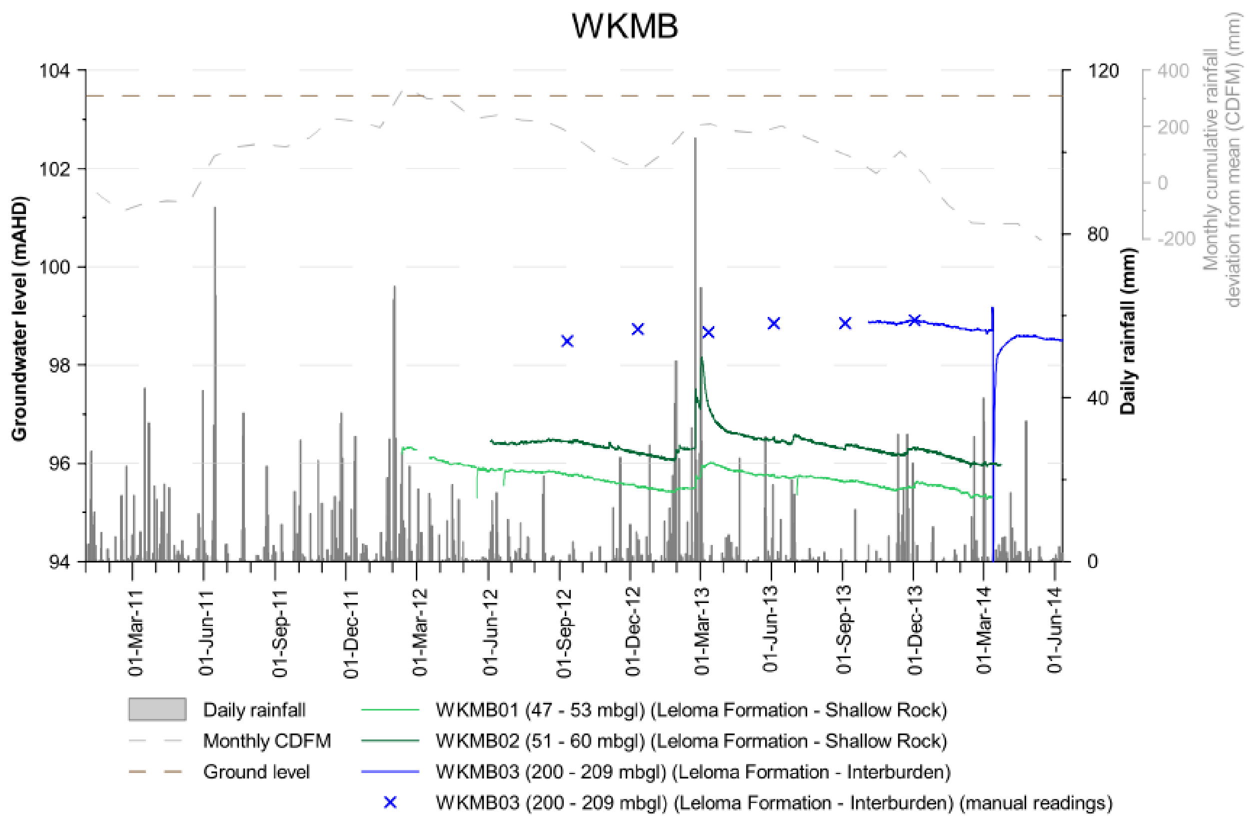

Figure 5.13 Groundwater levels and rainfall at the WKMB site

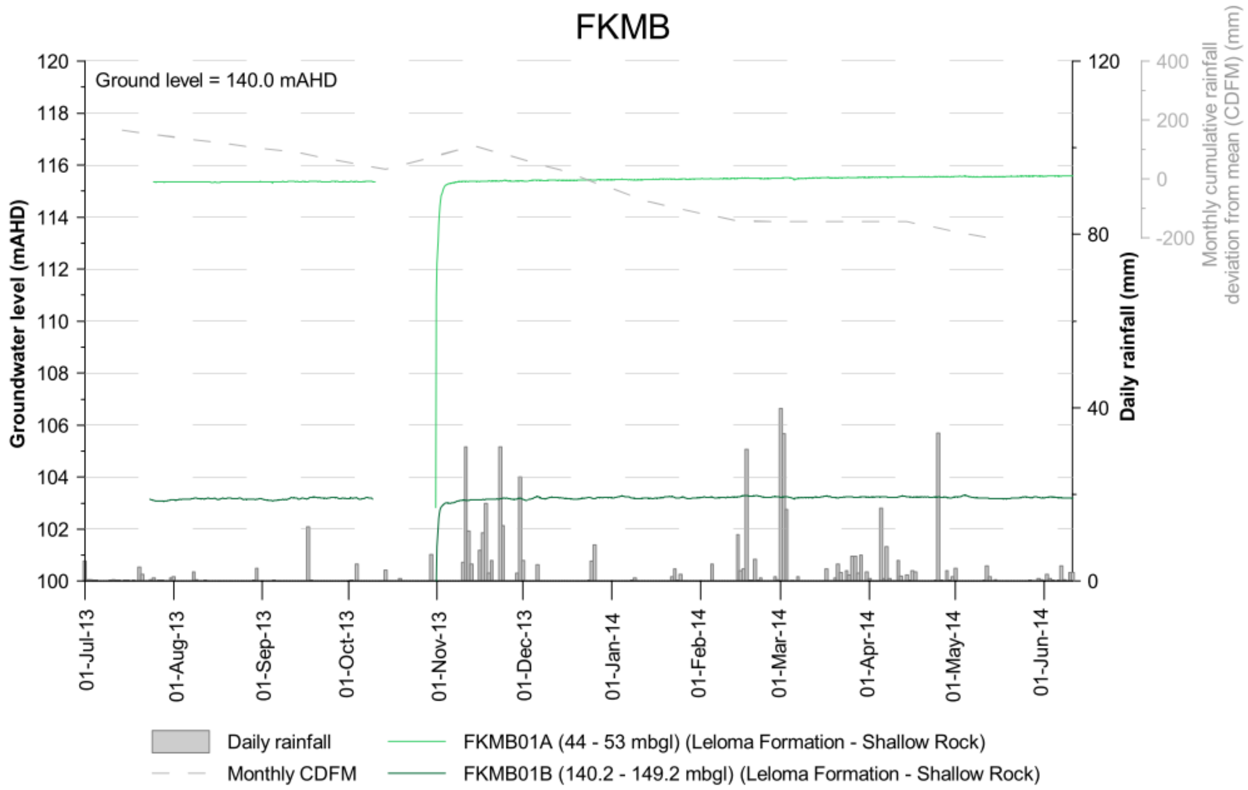

Figure 5.14 Groundwater levels and rainfall at the FKMB site

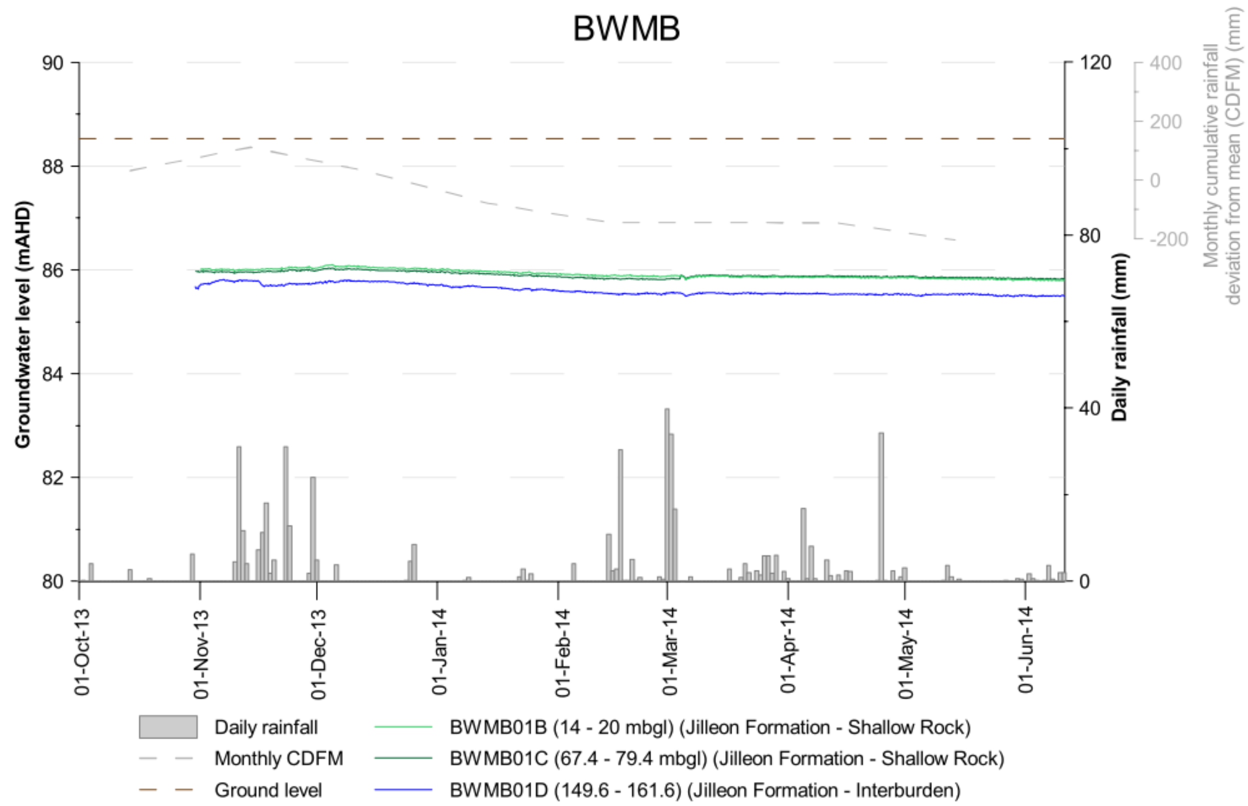

Figure 5.15 Groundwater levels and rainfall at the BWMB site

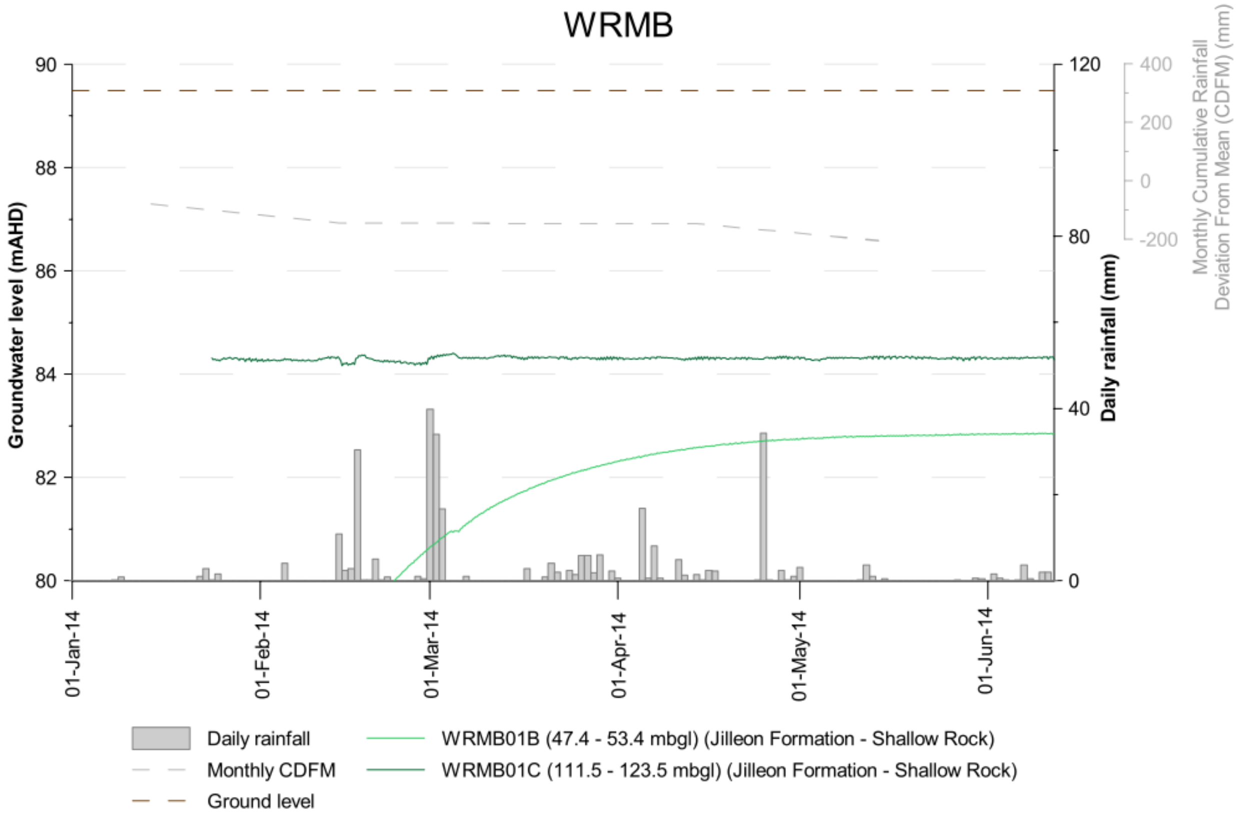

Figure 5.16 Groundwater levels and rainfall at the WRMB site

5.3 Vibrating wire piezometer (VWP)

Vibrating wire piezometer PL03 was installed in September 2013 (Figure 5.17). Interburden sensor V3 (463 mbgl) shows a decrease in groundwater pressures of ~ 27 m since installation. Coal seam sensor V2 (496 mbgl) shows a decrease in groundwater levels of ~ 12 m since installation. These declines in pressure are not considered to reflect natural trends and instead reflect the long term readjustment of pore pressures in the surrounding rock since installation. This long recovery is due to the very low permeability of the interburden and coal seams at the depth of the sensors. This phenomenon has also been observed in VWP's installed at the AGL Hunter site where groundwater levels took approximately one year to equilibrate following installation (Parsons Brinckerhoff 2014e).

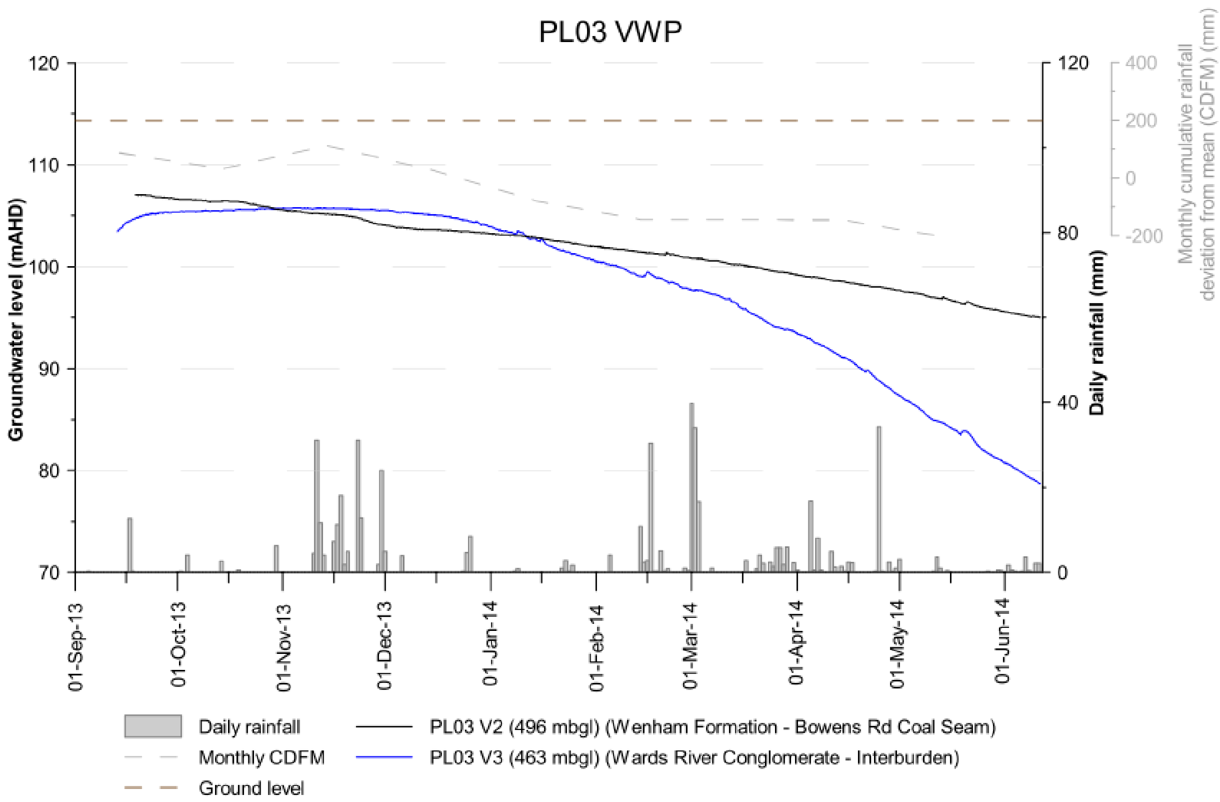

Figure 5.17 Groundwater levels and rainfall at the PL03 VWP

5.4 Vertical gradients

Vertical gradients were noted at nine of the eleven nested bore installations as shown in Table 5.1. Due to the very low permeability of the interburden units, vertical seepage is likely to be limited and slow, 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 2013a).

The complexity in groundwater elevations and apparent gradients, and the variability between some relatively close sites requires further assessment. Levels will be further assessed and calibrated as part of the current local-scale and basin-wide numerical modelling projects.

Table 5.1 Vertical gradients at the nested monitoring bore installations

Monitoring site	Gradient	Comments
TCMB	Downward	~ 1.5 m between the shallow rock and deeper coal seams
TTMB	Downward	~ 2 m to ~ 2.5 m between the shallow rock and the deeper rock
FKMB	Downward	~ 12.5 m between the shallower and the deeper monitoring bore in the shallow rock; this is the most significant gradient across the monitoring sites, however it is also the most elevated site
BWMB	Slight Downward	~ 0.5 m between the alluvium/shallow rock and the deep interburden
S4MB	Upward	~ 1 m to ~ 2 m between the deeper coal seam and the shallow rock
S5MB	Slight Upward Downward	~ 0.5 m between the deeper coal seam at S5MB03 and the shallow rock at S5MB02 until July 2013; ~ 2 m between the shallow rock at S5MB02 and the deeper coal seam at S5MB03 after July 2013 the shallow rock monitoring bore at S5MB01 shows a slow response to sampling and therefore may not be representative of water table trends
RMB	Slight Upward	~ 0.5 m between the deeper and the shallower monitoring bore in the shallow rock
WKMB	Upward	~ 2.5 m to ~ 3 m between the interburden and the shallow rock
WRMB	Upward	~ 1.5 m between the deeper and shallow monitoring bore in the shallow rock
BMB	No gradient	0 m
WMB	No gradient	0 m

6. Conclusions and recommendations

6.1 Conclusions

A comprehensive surface water and groundwater monitoring network comprising nested monitoring bores and stream gauges was established during the Phase 2 Groundwater Investigations (Parsons Brinckerhoff, 2012). Subsequent and ongoing site investigations have continued to expand this network since January 2011. The following conclusions are drawn from a review of the groundwater and surface water monitoring data for the period July 2013 to June 2014.

Surface water

The rainfall for the period July 2013 to June 2014 at Gloucester Post Office was 568 mm, which is close to the lowest annual rainfall on record and reflects very dry conditions that had not been experienced in the valley for decades. Very low rainfall and water levels in the Avon River and Dog Trap Creek over the monitoring period resulted in ‘no flow’ or very low flow, where the rivers are characterised by multiple disconnected pools. All stream gauges on the Avon River and Dog Trap Creek show rapid responses to large rainfall events, such as in November 2013, and relatively steep recession curves.

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 show a rapid response to significant rainfall events. This is a threshold response, with rainfall events of a certain magnitude required to trigger a response in groundwater levels. This is variable between sites. Most alluvial monitoring bores show a decrease in groundwater levels over the monitoring period from July 2013 to June 2014 in response to lower than average rainfall over this period.
- **Shallow rock**: Groundwater levels in shallow rock monitoring bores have decreased slightly over the monitoring period in response to the below average rainfall. There are no strong responses to individual rainfall events in the shallow rock bores during this monitoring period.
- **Interburden units**: Monitoring bores screened within the interburden units show no significant change over the monitoring period, and groundwater levels do not respond to individual rainfall events.
- **Deep coal seams:** Groundwater levels in monitoring bores that are screened within the coal seams show varied but typically small changes in groundwater level over the monitoring period. There are no strong responses to individual rainfall events.

During 2013/14, typically the groundwater level declines were:

- ~ 0.8 m in the alluvium
- ~ 0.5 m in the shallow fractured rock
- ~ 0.3 m in the interburden units
- ~ 0.2 m in the deep coal seams.

Vertical gradients are noted at nine of the eleven nested bore installations:

- Downward hydraulic gradients were noted at the TCMB, TTMB, FKMB and BWMB nested bore sites.
- Upward hydraulic gradients were noted at the S4MB, RMB, WKMB and WRMB nested bore sites.

No vertical head gradients were noted at the BMB and WMB nested bore sites. Levels at the S5MB site have swapped from an apparent upward to a downward gradient in the last 12 months.

Due to the very low permeability of the interburden units, vertical seepage is likely to be extremely slow, 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.

The conclusions of this report are consistent with the hydrogeological conceptual model of the Gloucester Basin (Parsons Brinckerhoff 2013a).

6.2 Recommendations

The following recommendations are made regarding the ongoing groundwater and surface water monitoring in the Gloucester Basin:

- Monitoring should continue at dedicated monitoring sites in accordance with the existing program, as outlined below:
  - continuous water level and salinity (EC) monitoring at the surface water monitoring sites
  - continuous water level monitoring at the groundwater monitoring sites
  - comprehensive water quality sampling at dedicated sites on a two-yearly cycle (i.e. next sampling event to be scheduled for mid-2015, and reported in the 2014/2015 annual status report).
- Quarterly datalogger downloads should continue for all sites and quarterly reports should continue to be issued presenting updated hydrographs and salinity traces (where applicable).
- Water level and salinity data for the newly installed surface water gauges at Waukivory should be included in the annual status report for 2014/2015.

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

The report has been prepared for the benefit of the client (and no other party). Parsons Brinckerhoff 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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- Parsons Brinckerhoff (2014c) *Drilling completion report - Wards River Groundwater Monitoring Bores*, Gloucester Gas Project, in preparation.
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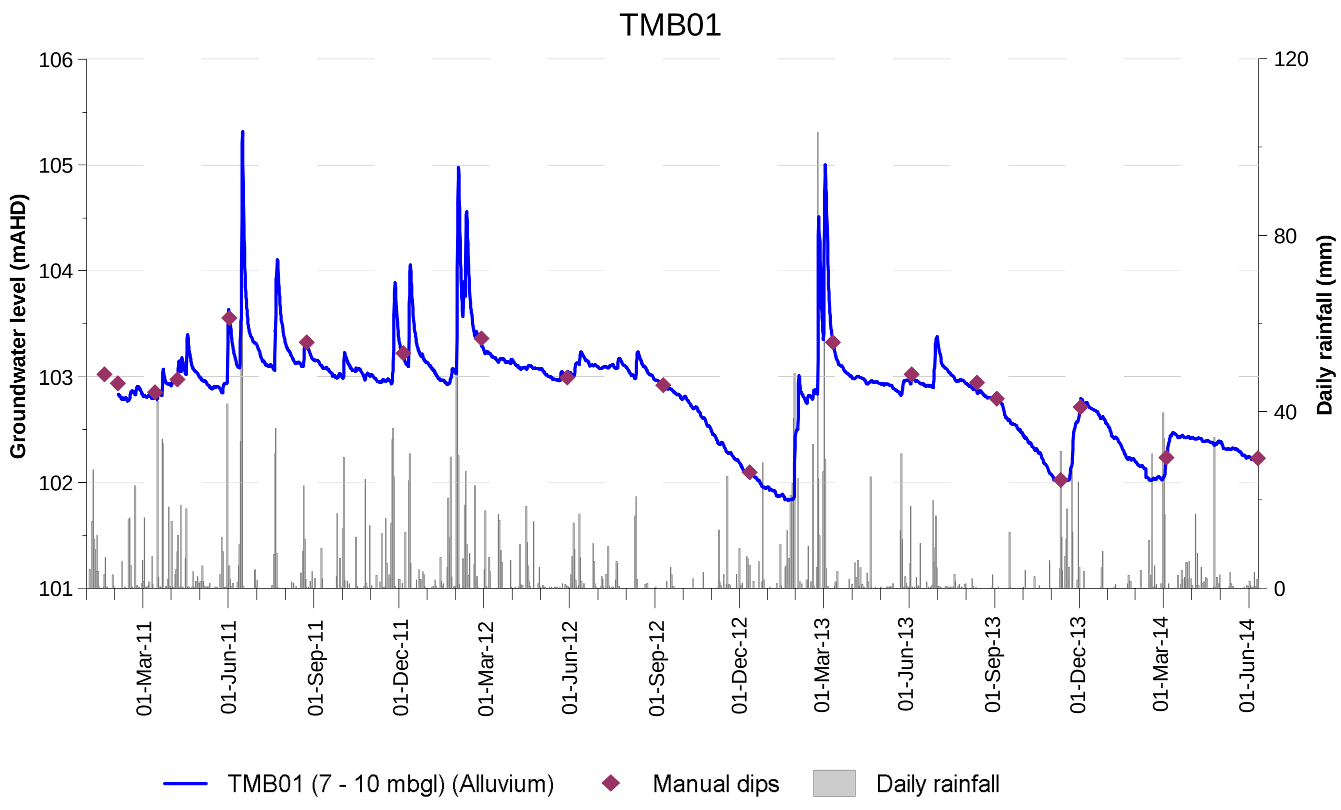
Appendix A

Groundwater and surface water hydrographs



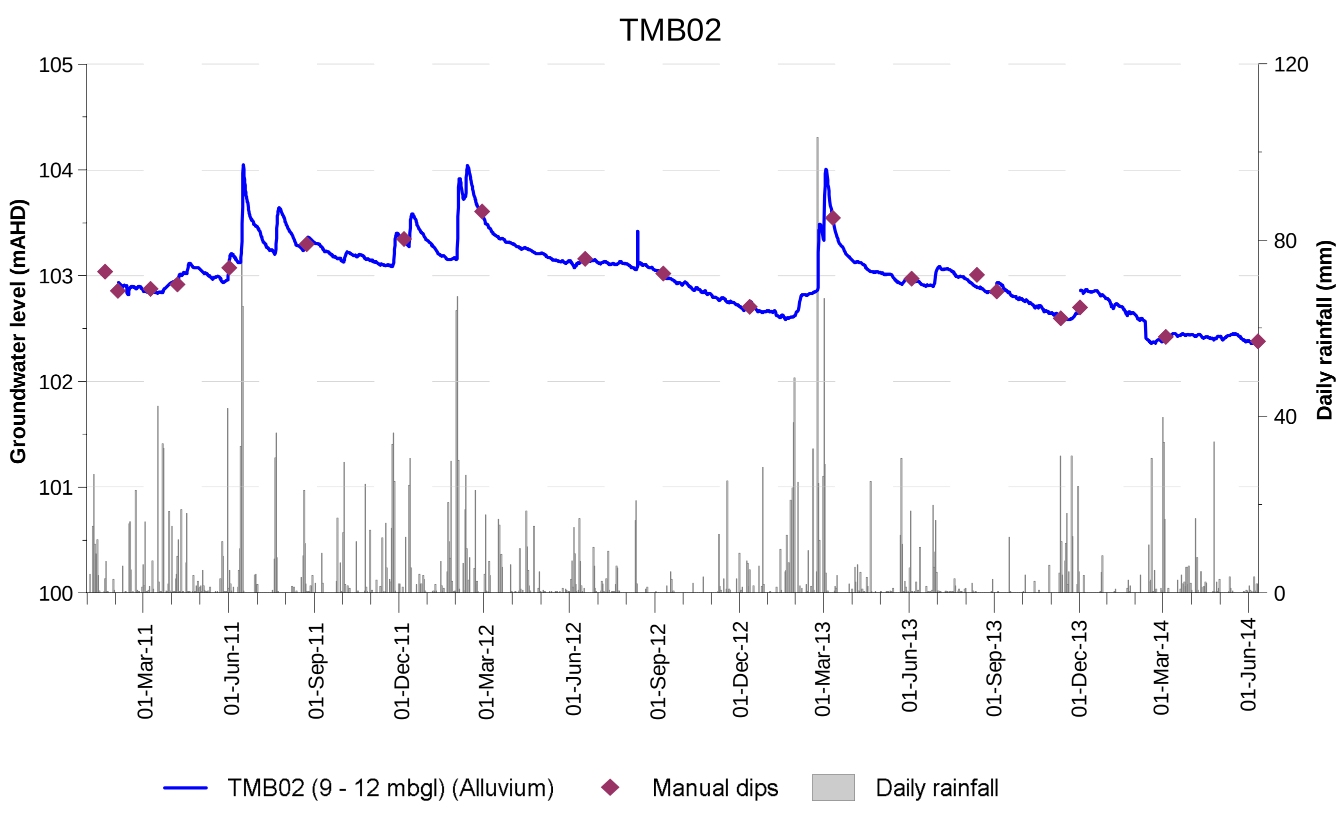
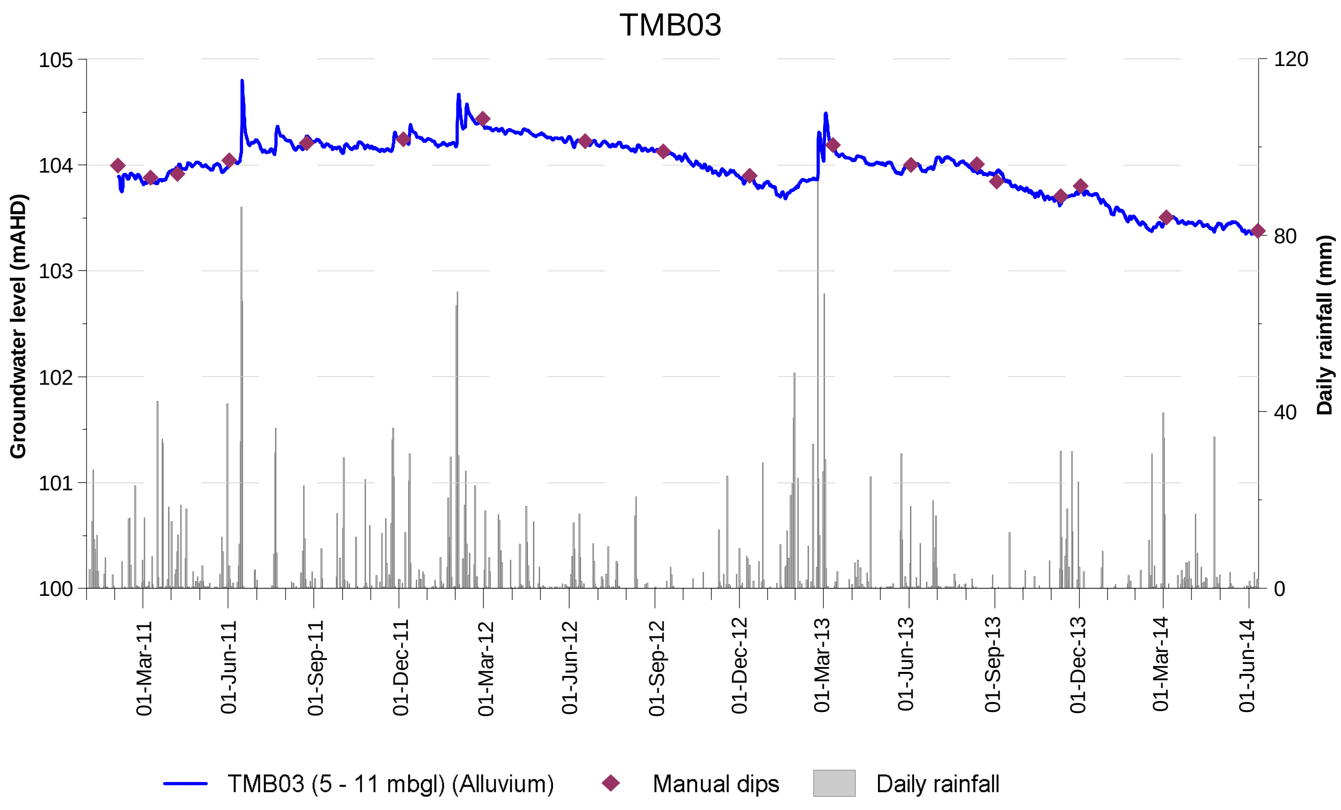


Figure A.1: TMB01 and TMB02 monitoring bores



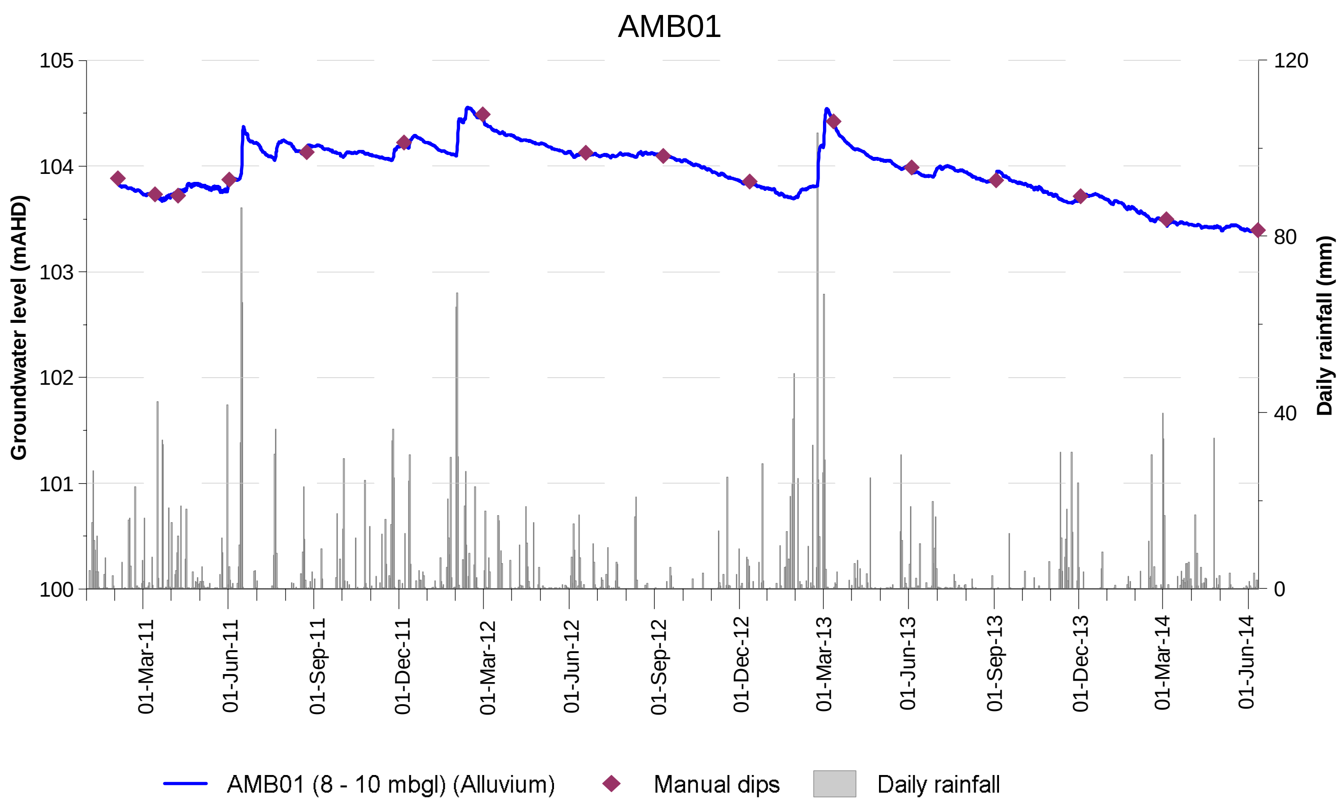
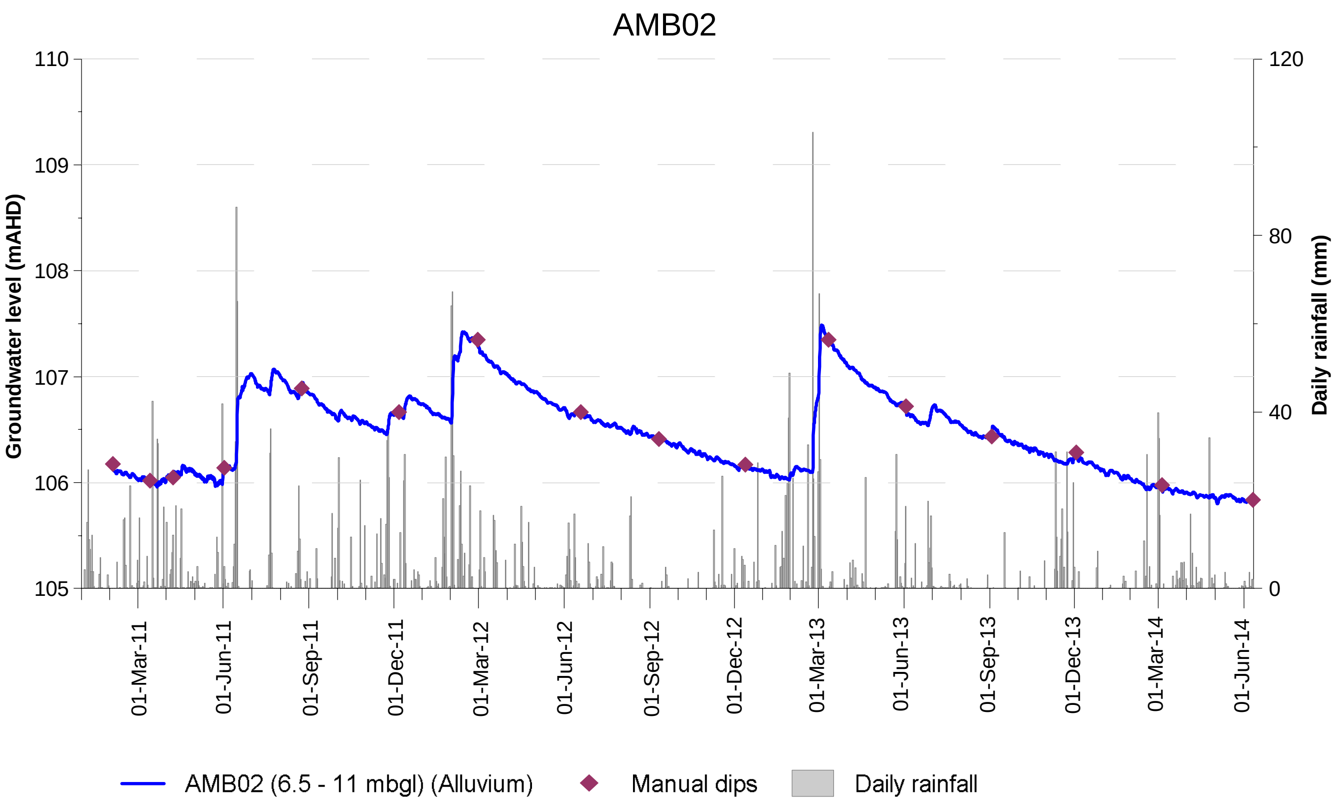


Figure A.2: TMB03 and AMB01 monitoring bores



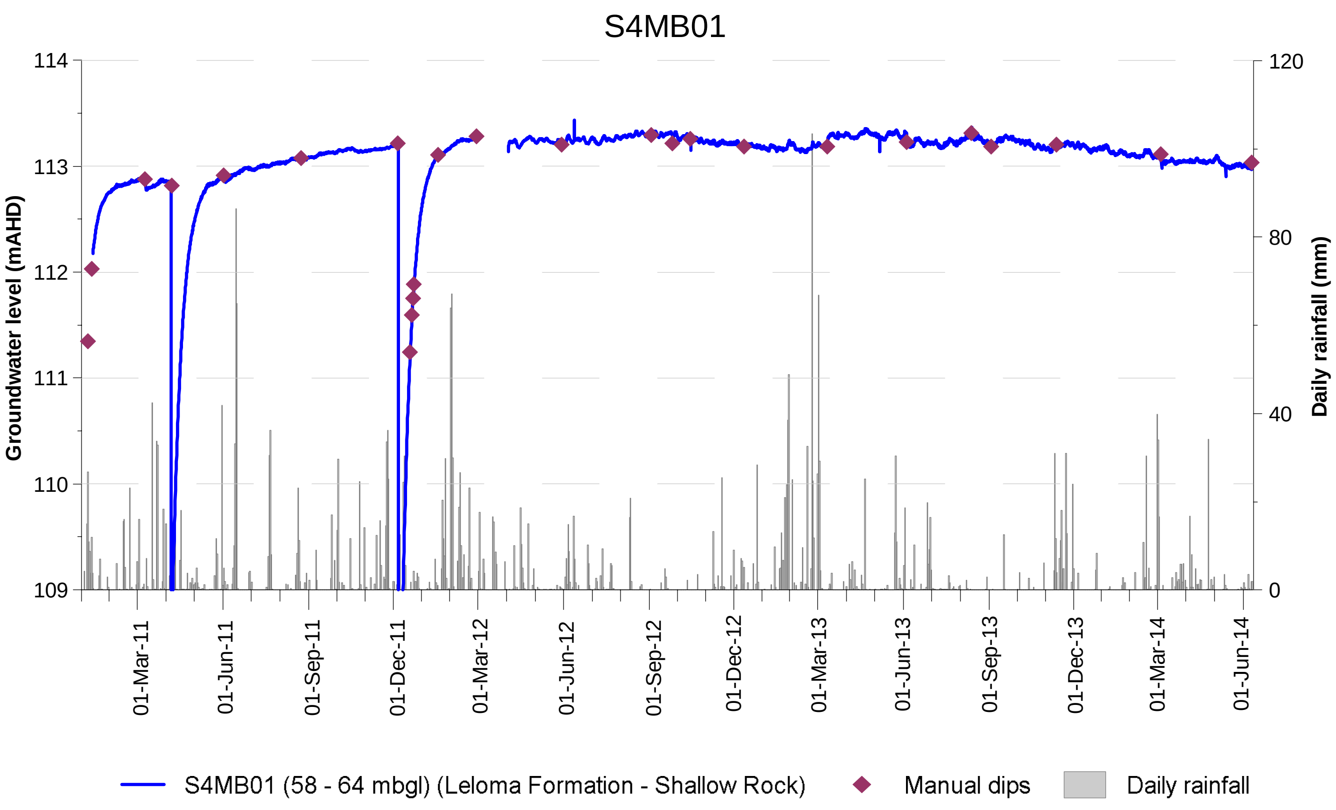
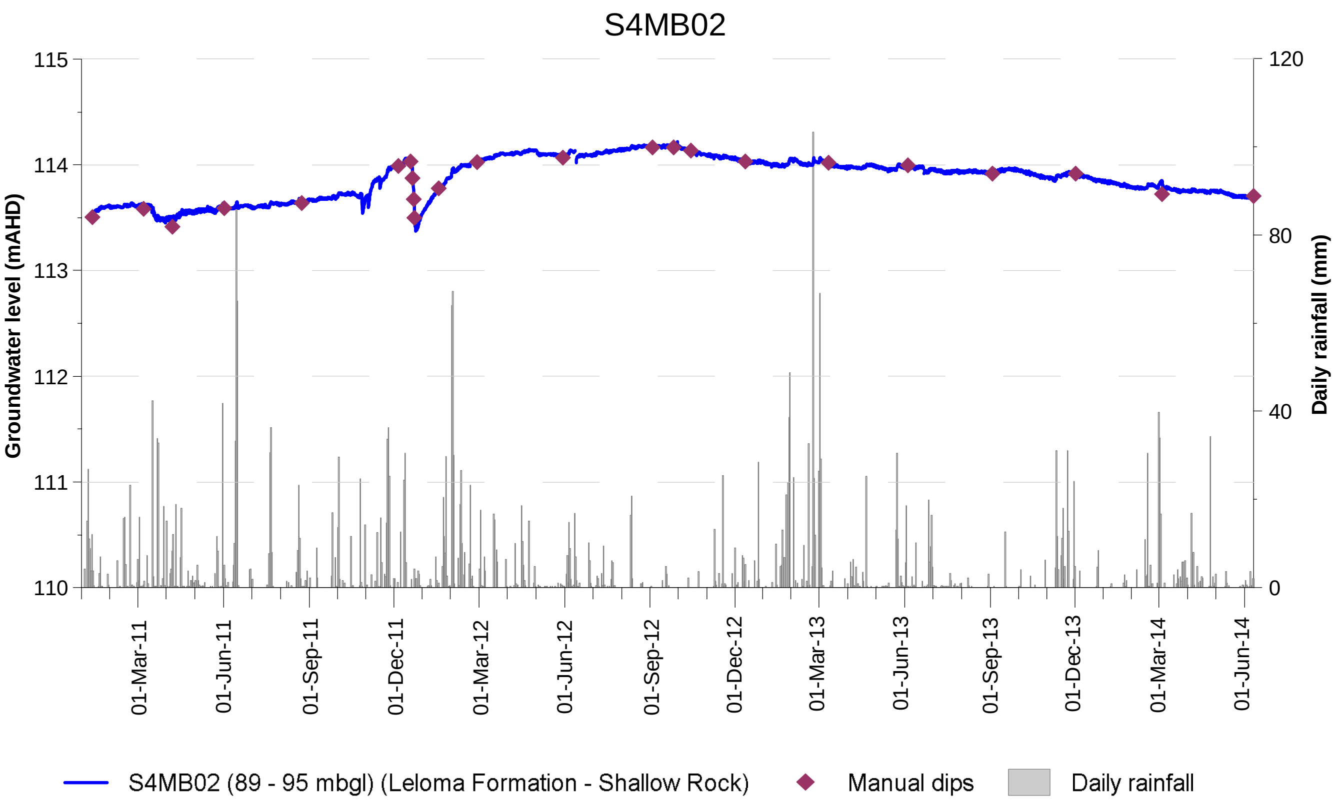


Figure A.3: AMB02 and S4MB01 monitoring bores



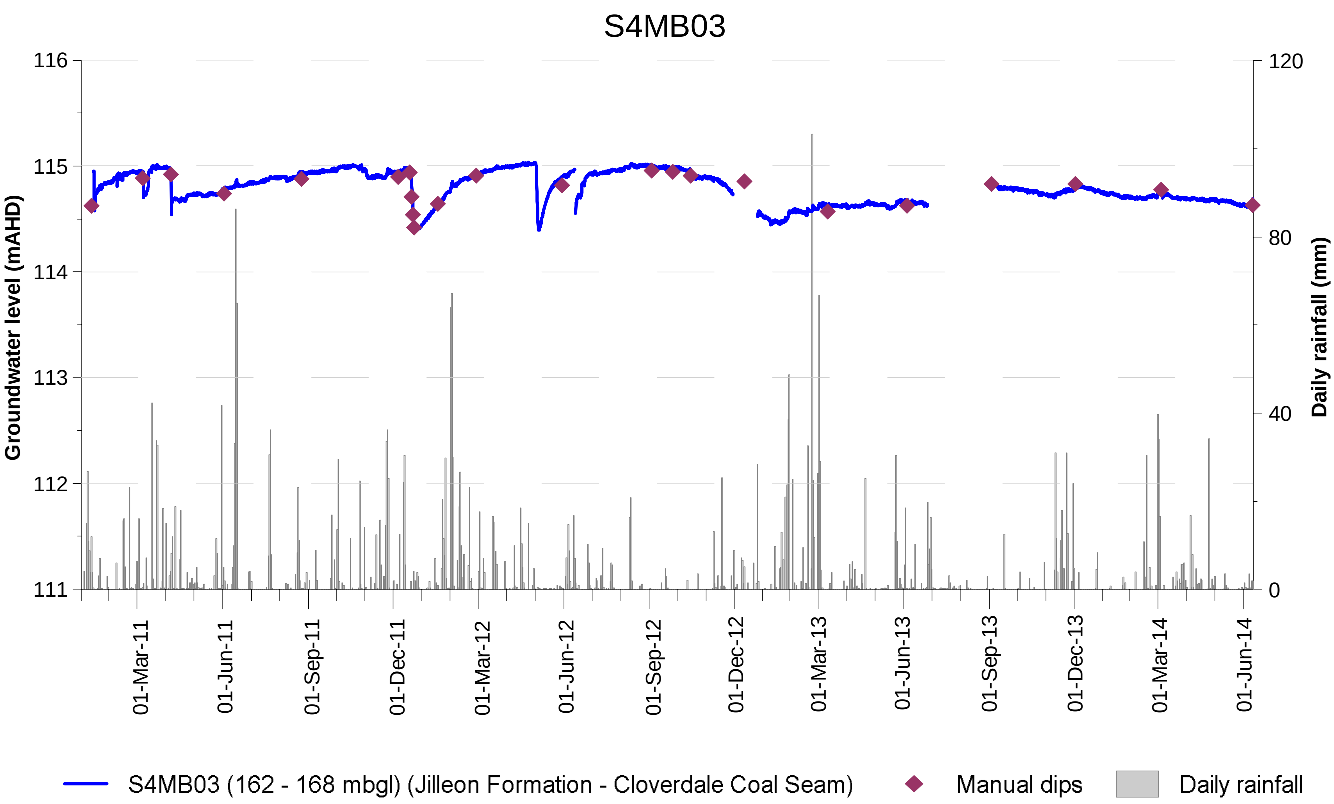
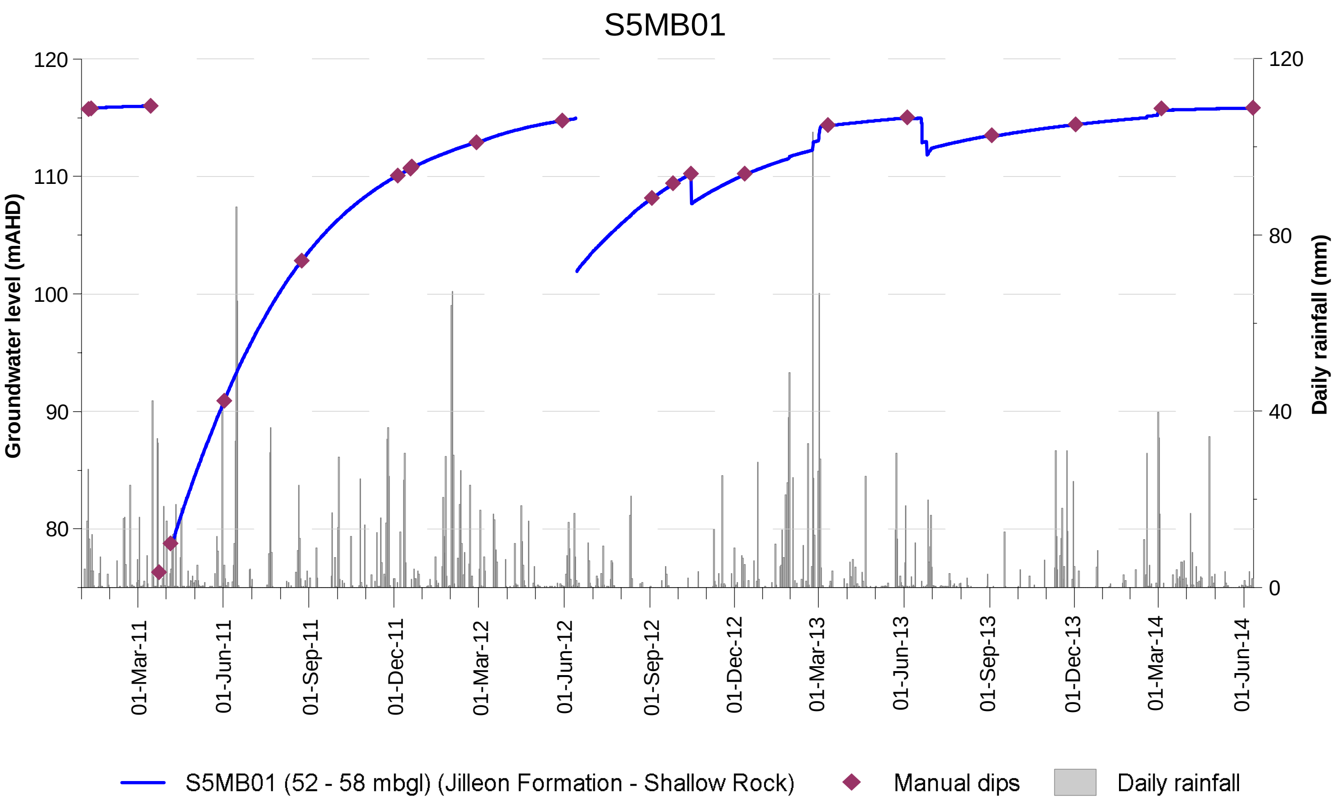


Figure A.4: S4MB02 and S4MB03 monitoring bores



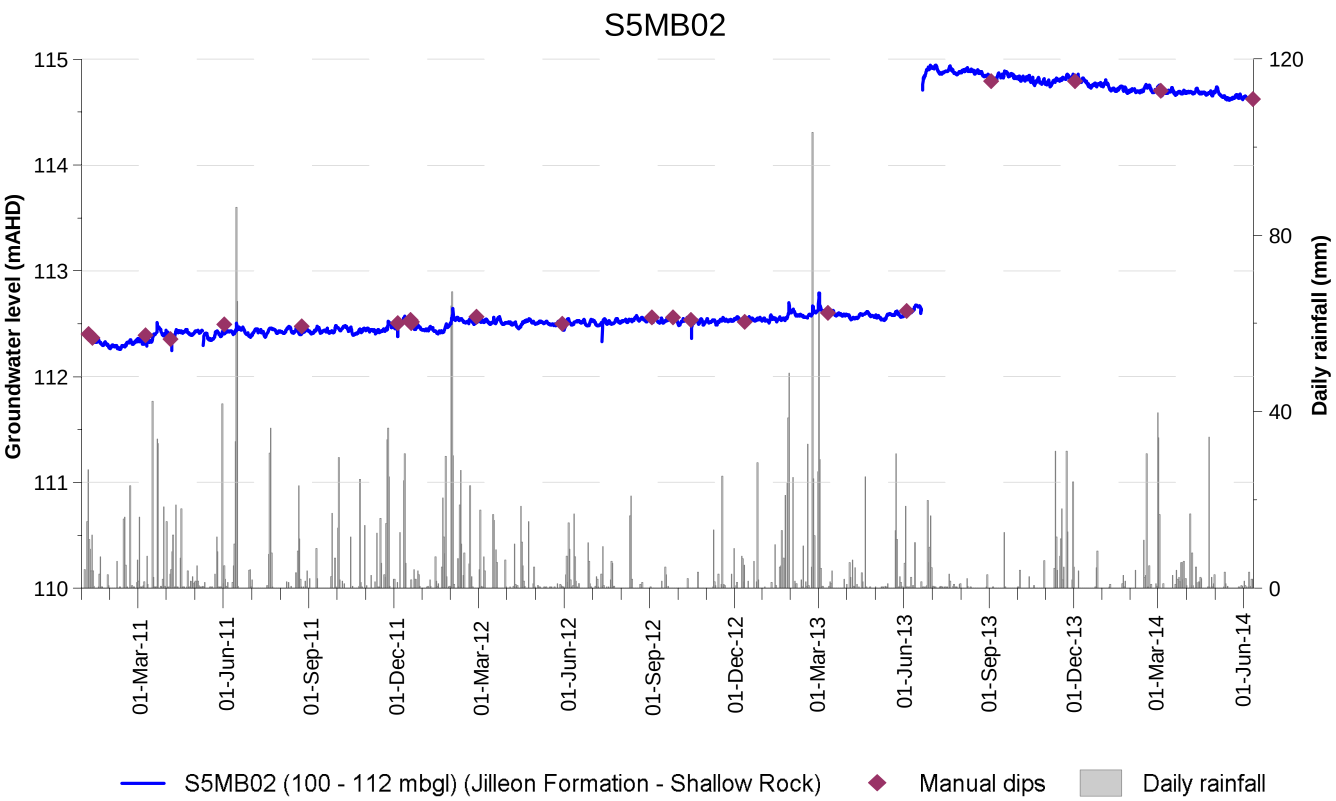
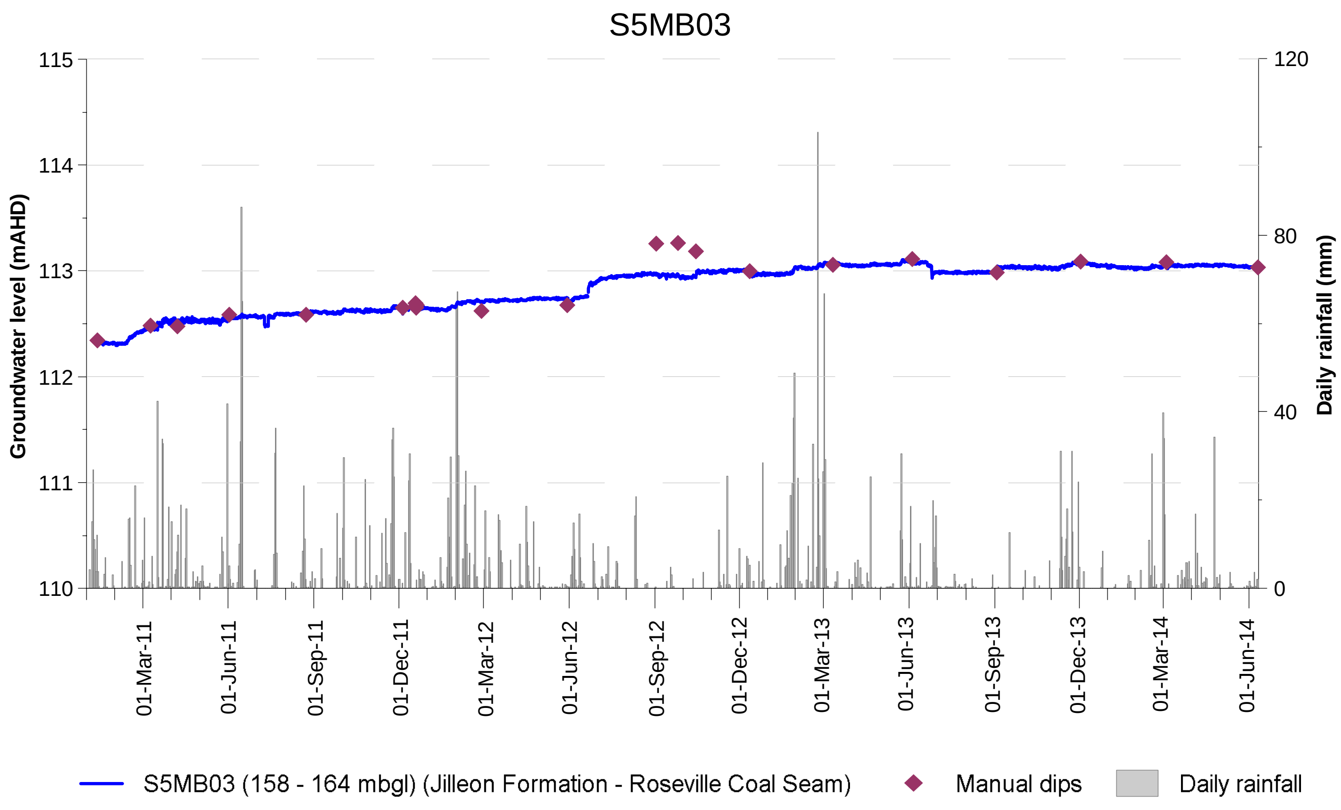


Figure A.5: S5MB01 and S5MB02 monitoring bores



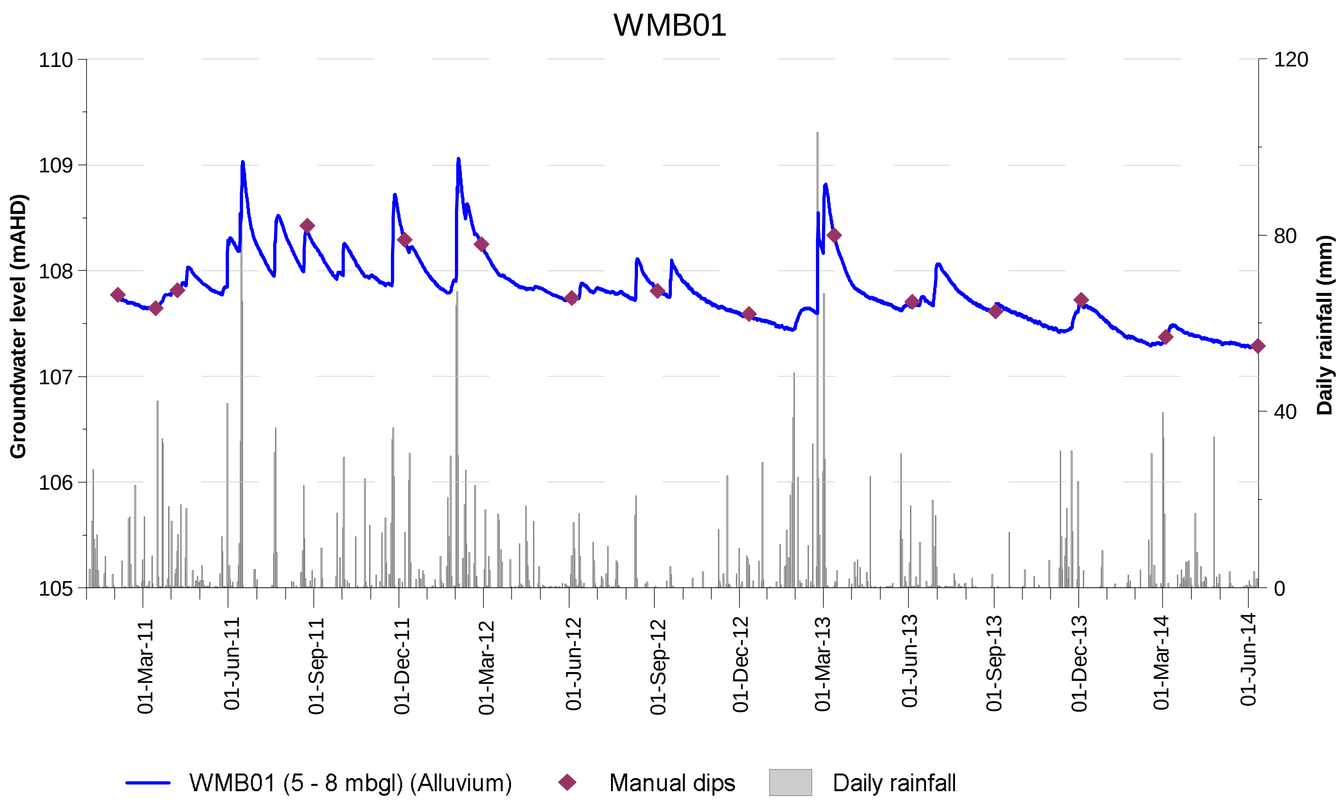
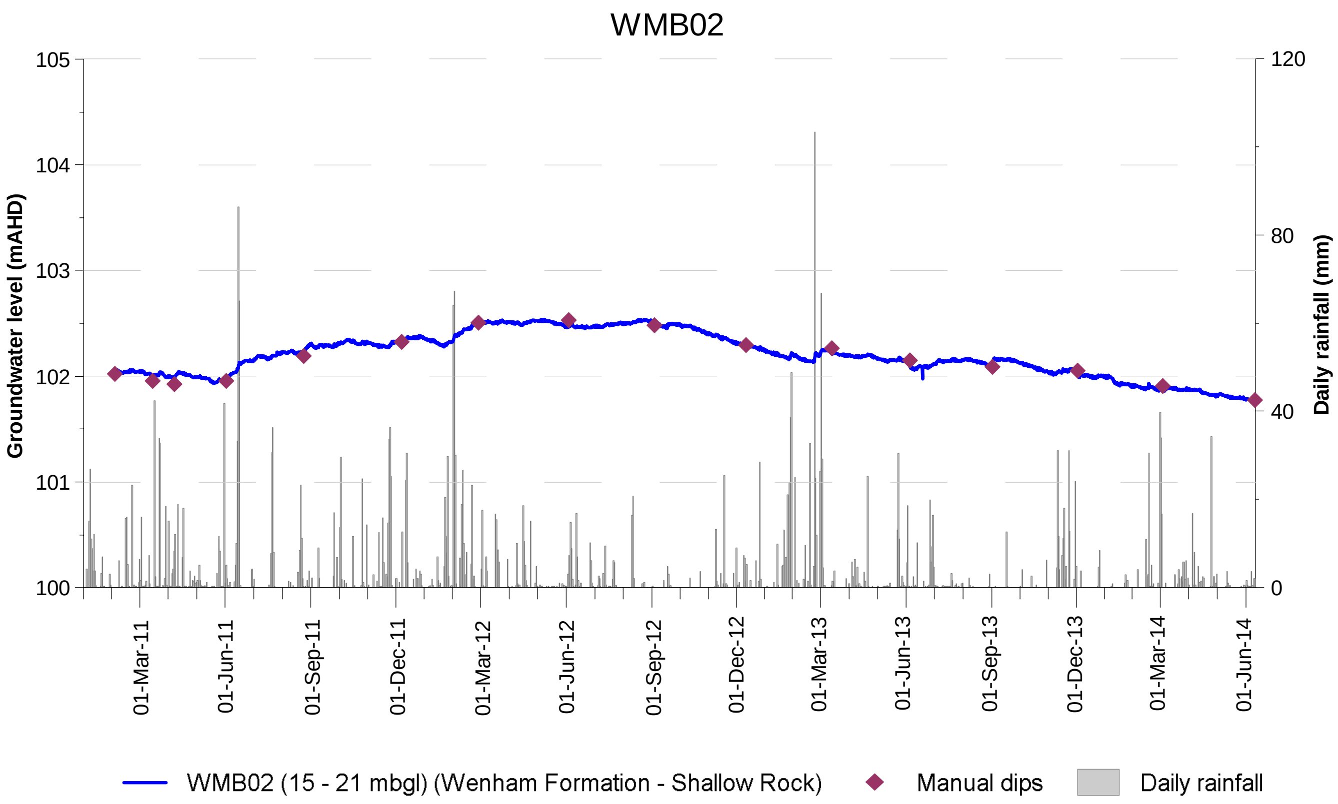


Figure A.6: S5MB03 and WMB01 monitoring bores



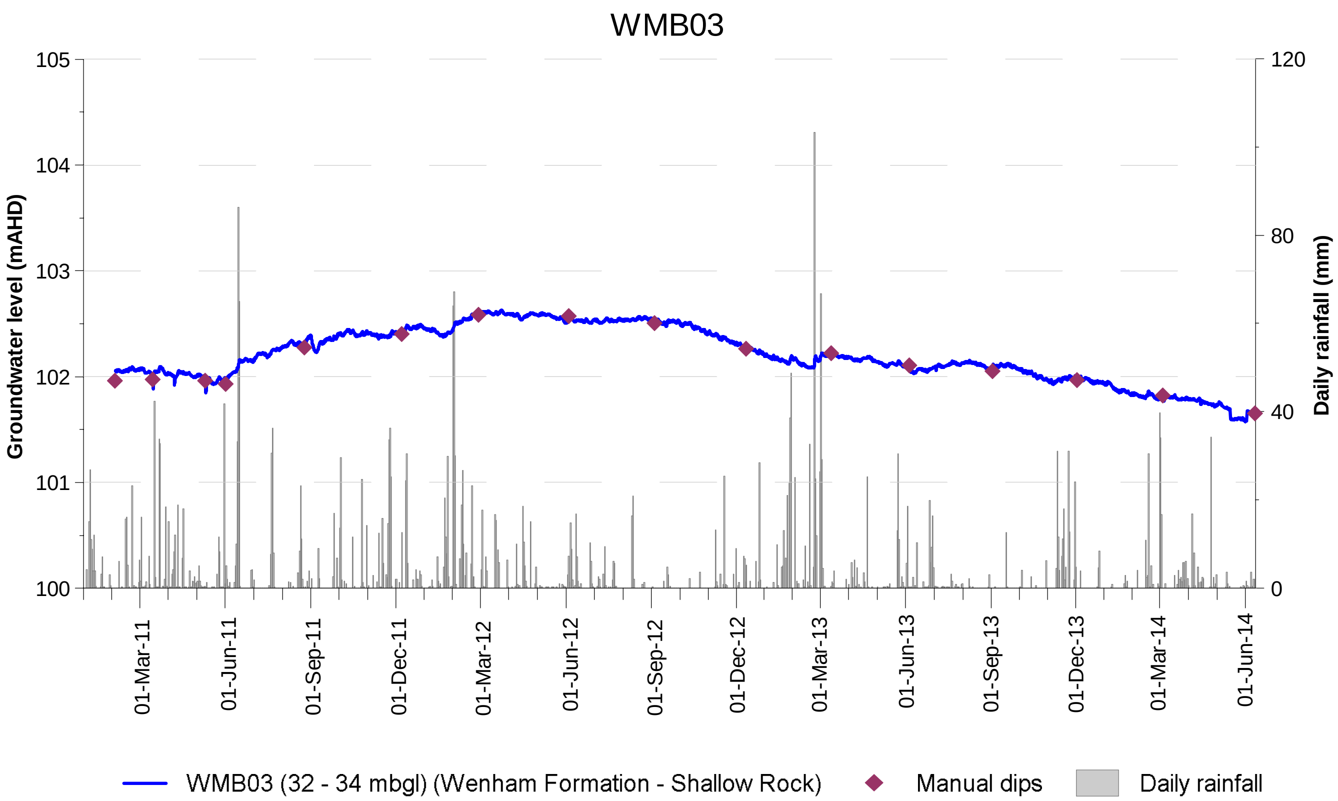
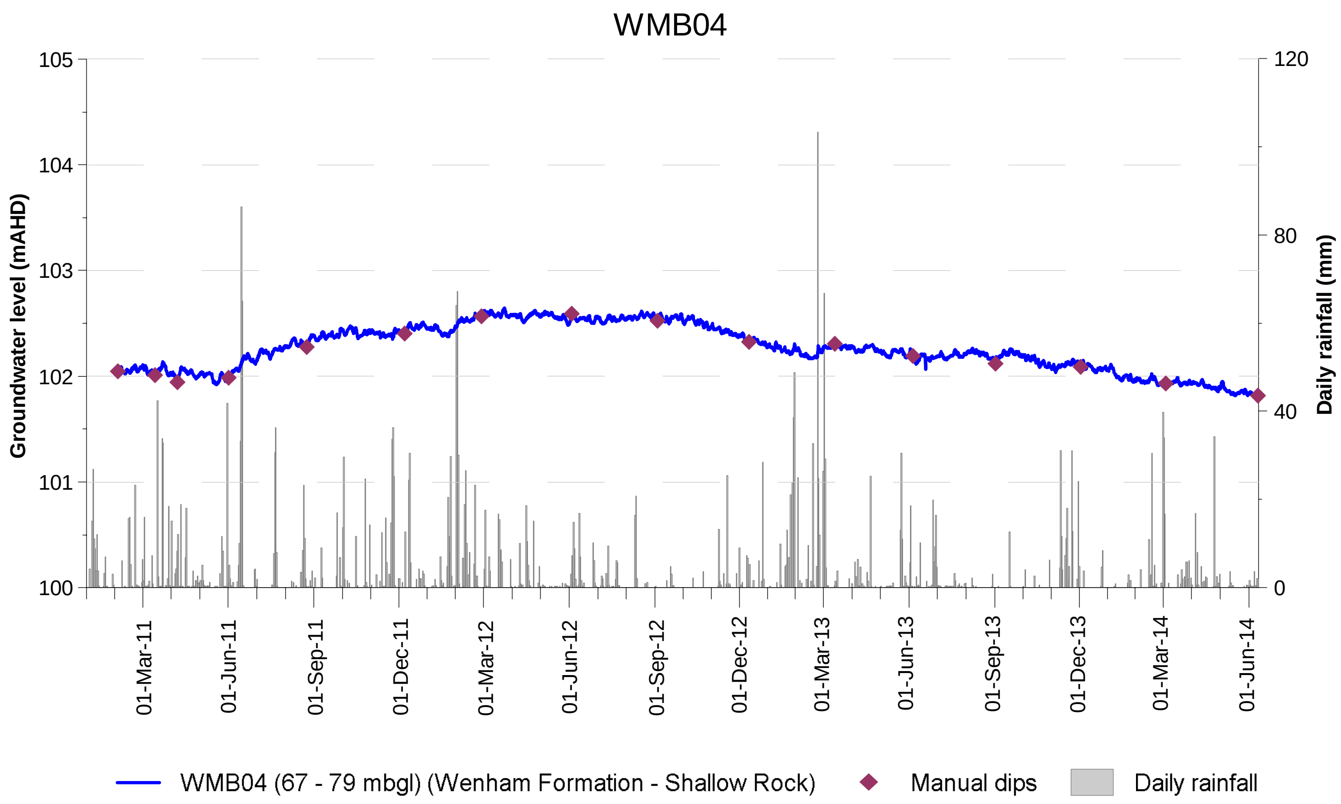


Figure A.7: WMB02 and WMB03 monitoring bores



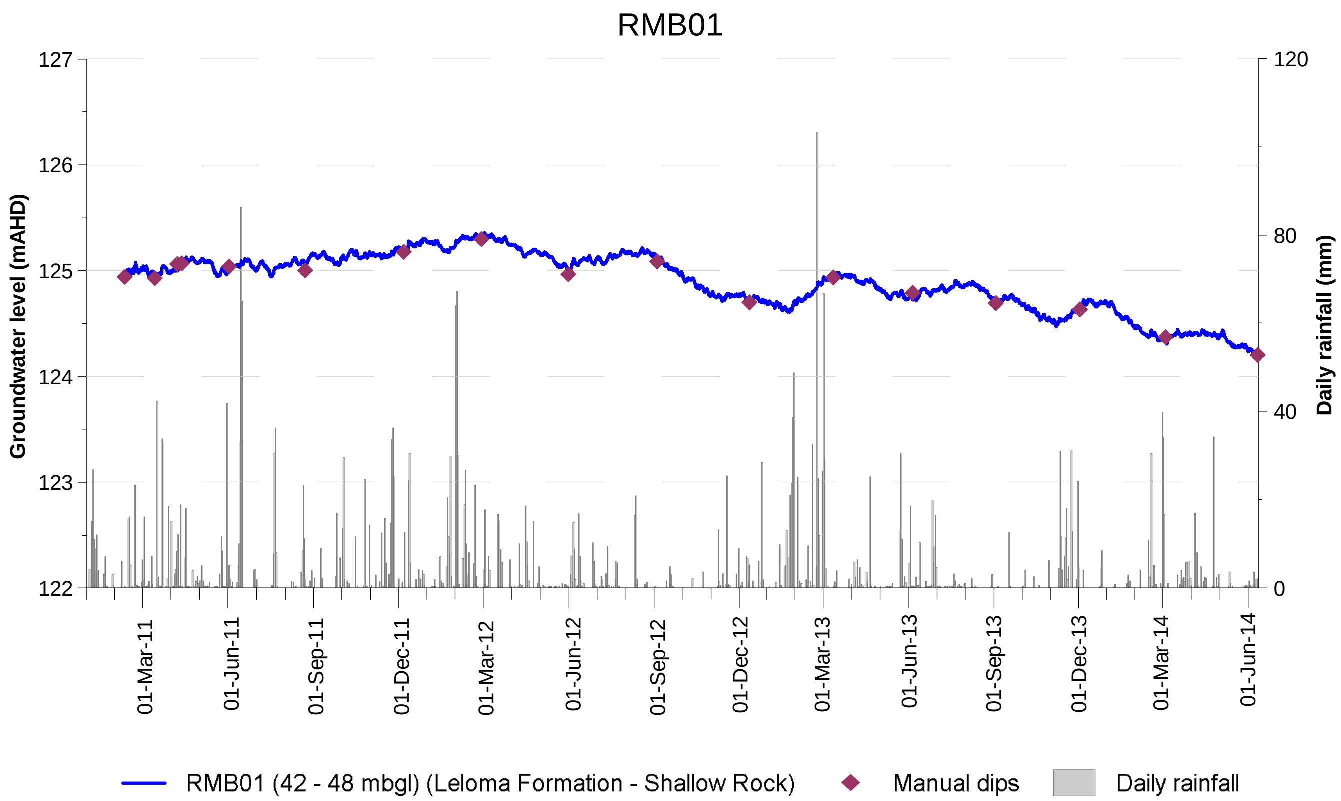
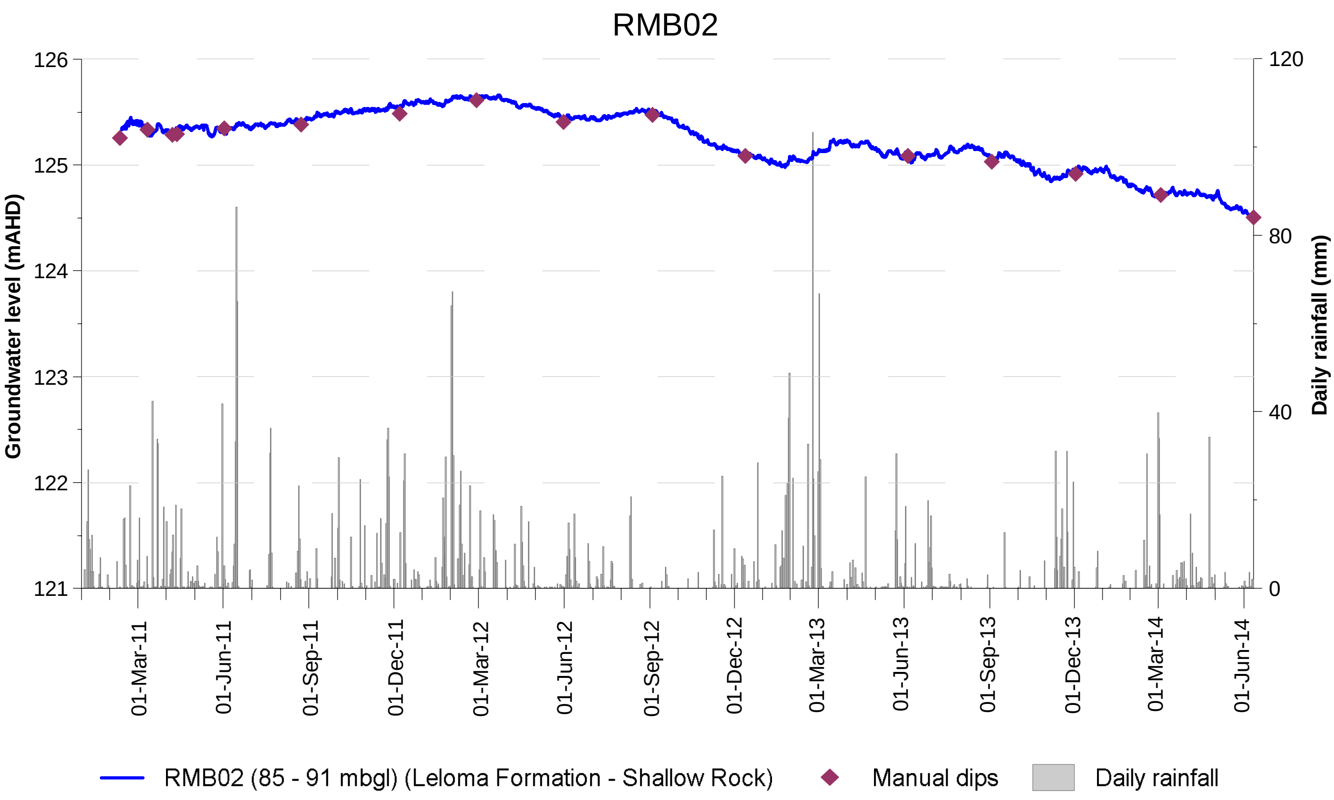


Figure A.8: WMB04 and RMB01 monitoring bores



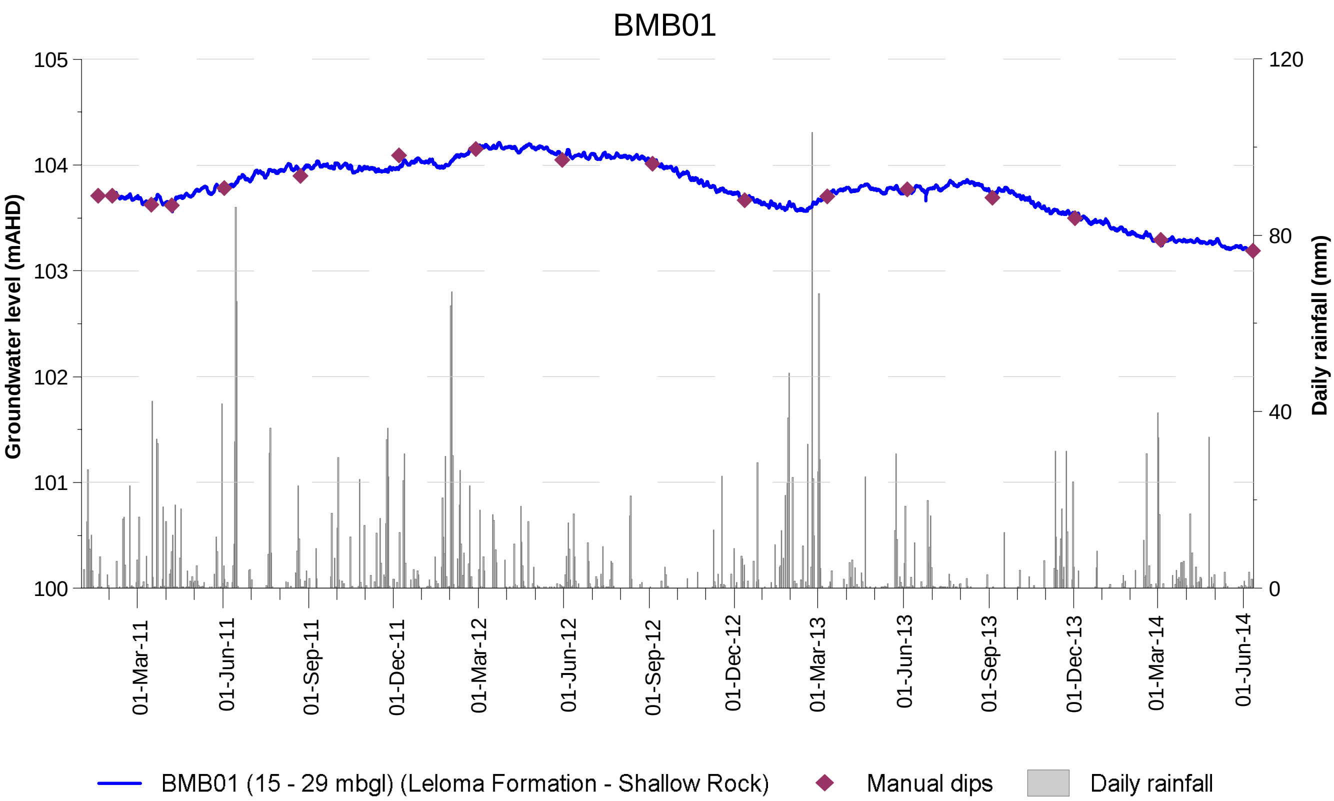
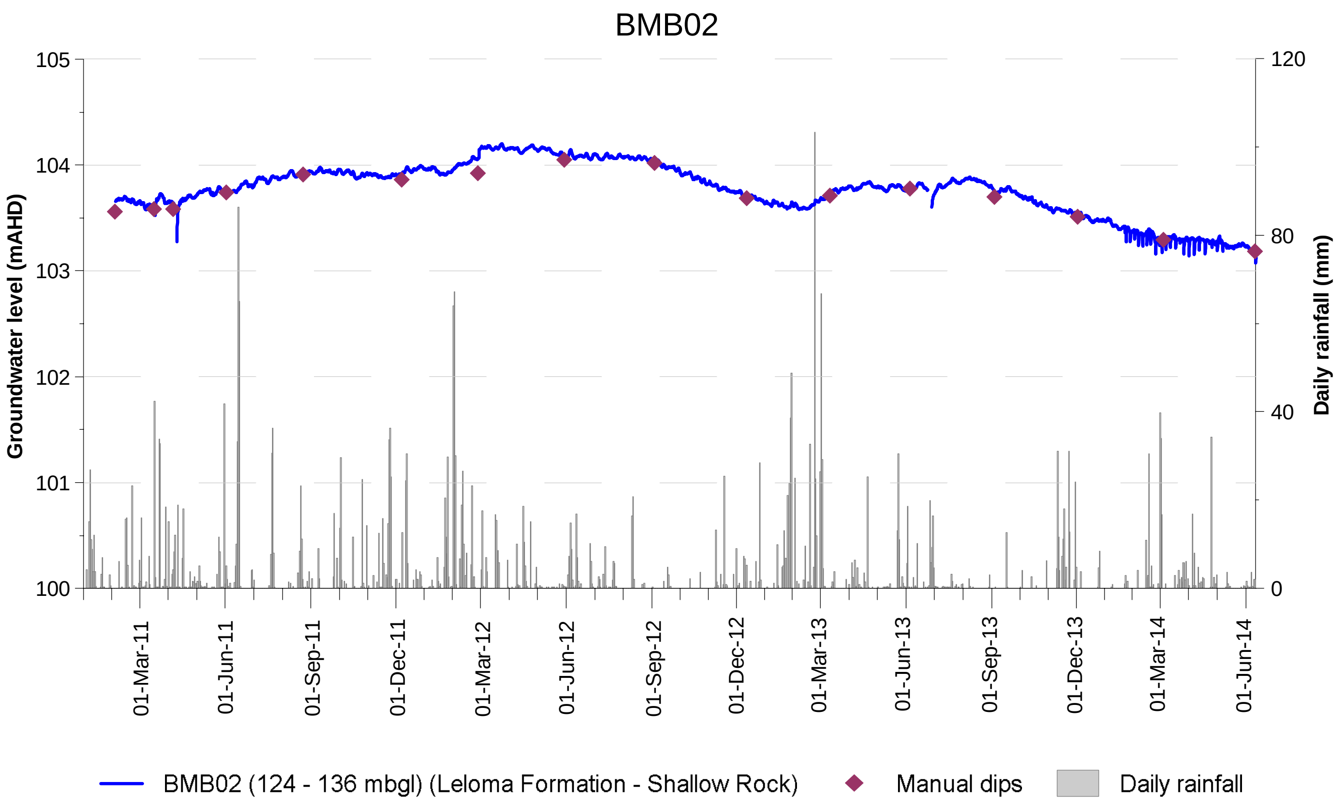


Figure A.9: RMB02 and BMB01 monitoring bores



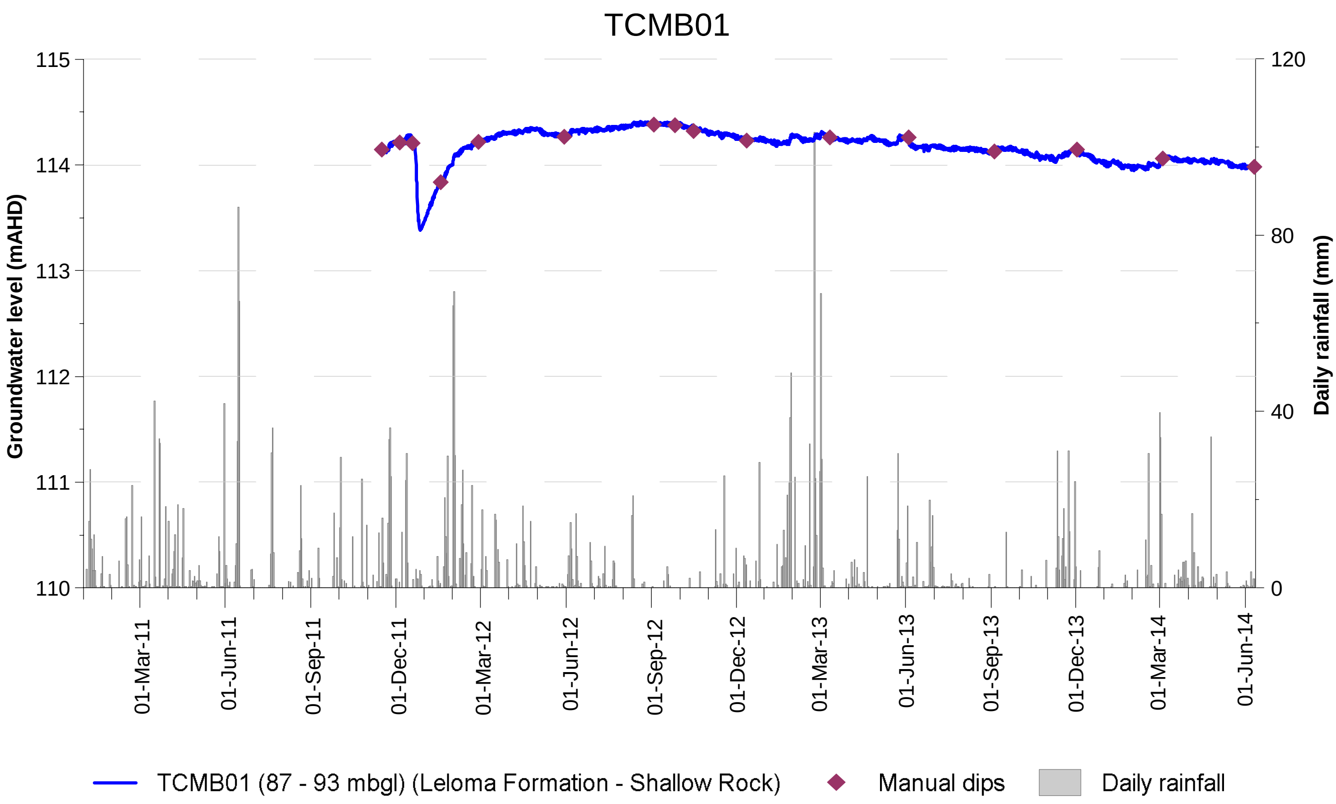
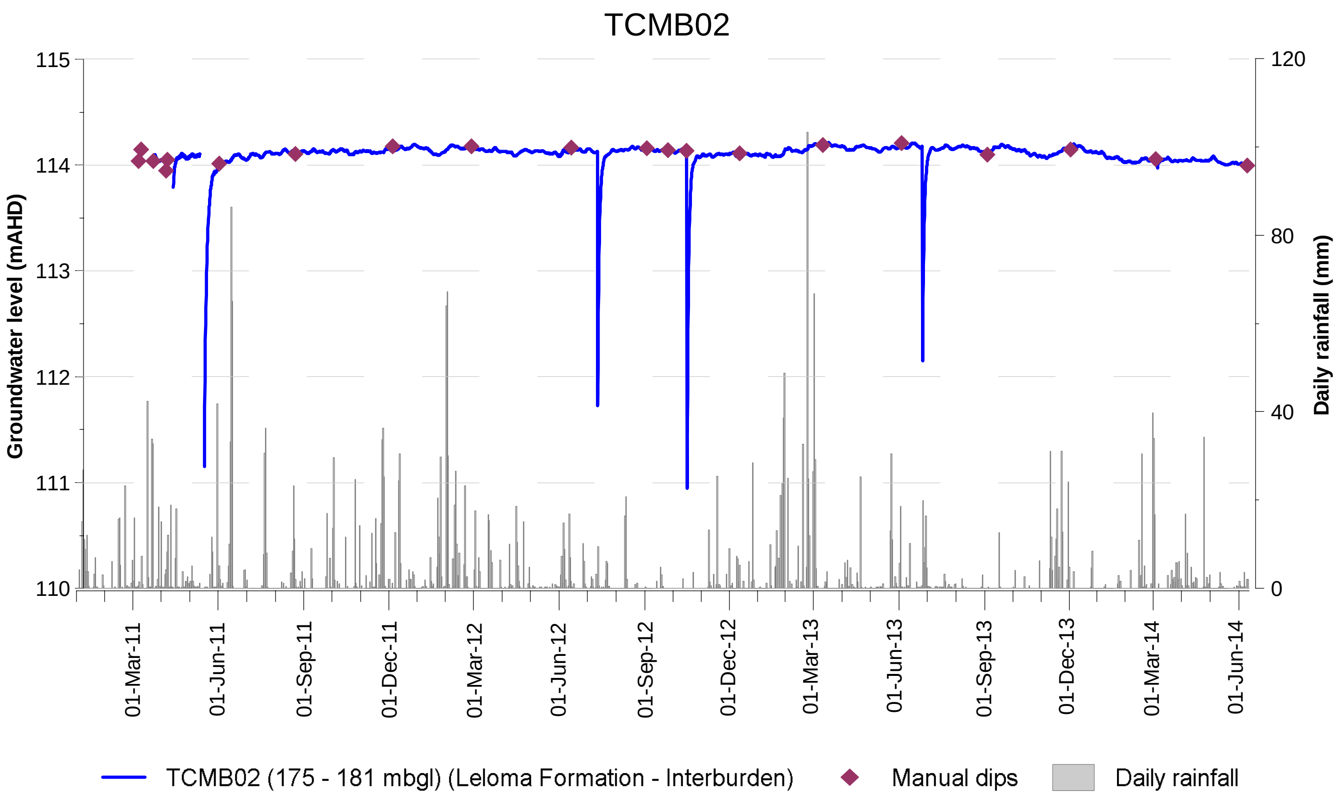


Figure A.10: BMB02 and TCMB01 monitoring bores



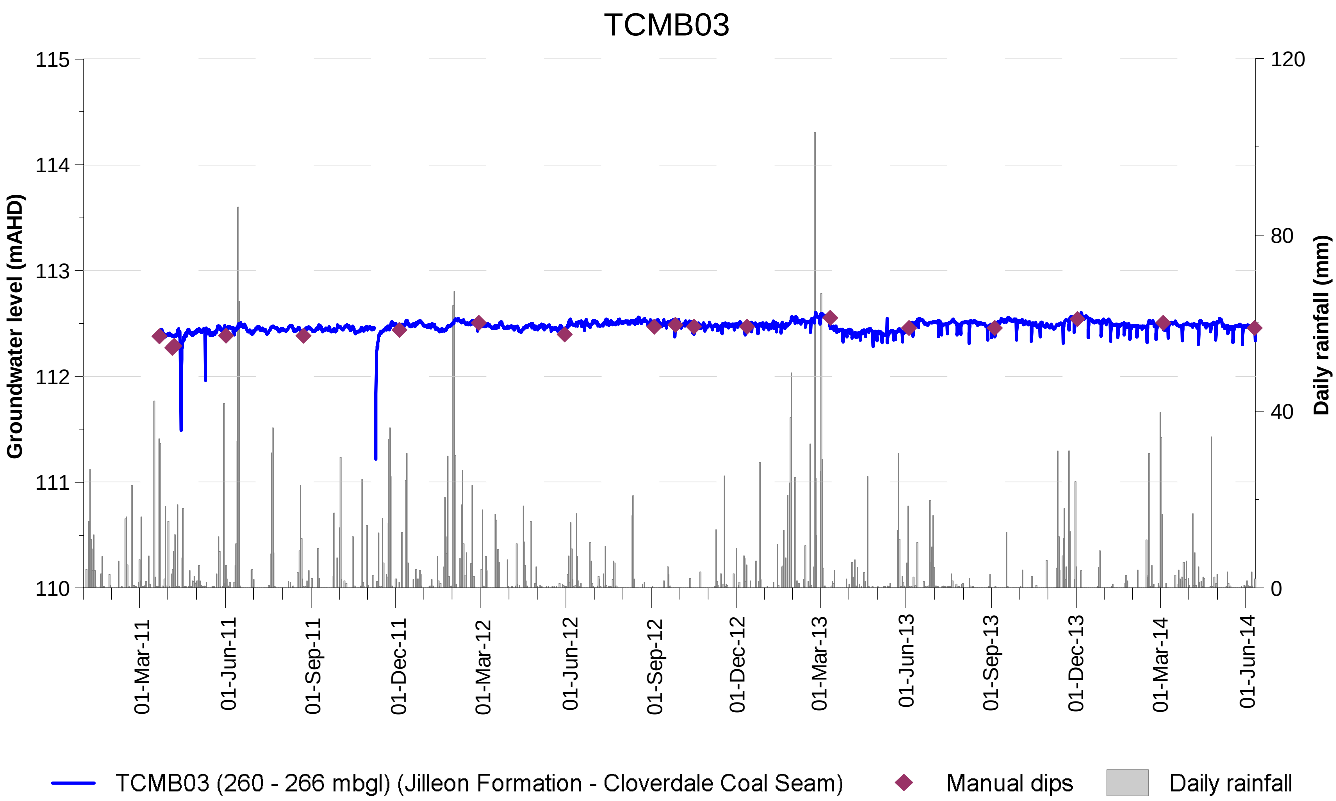
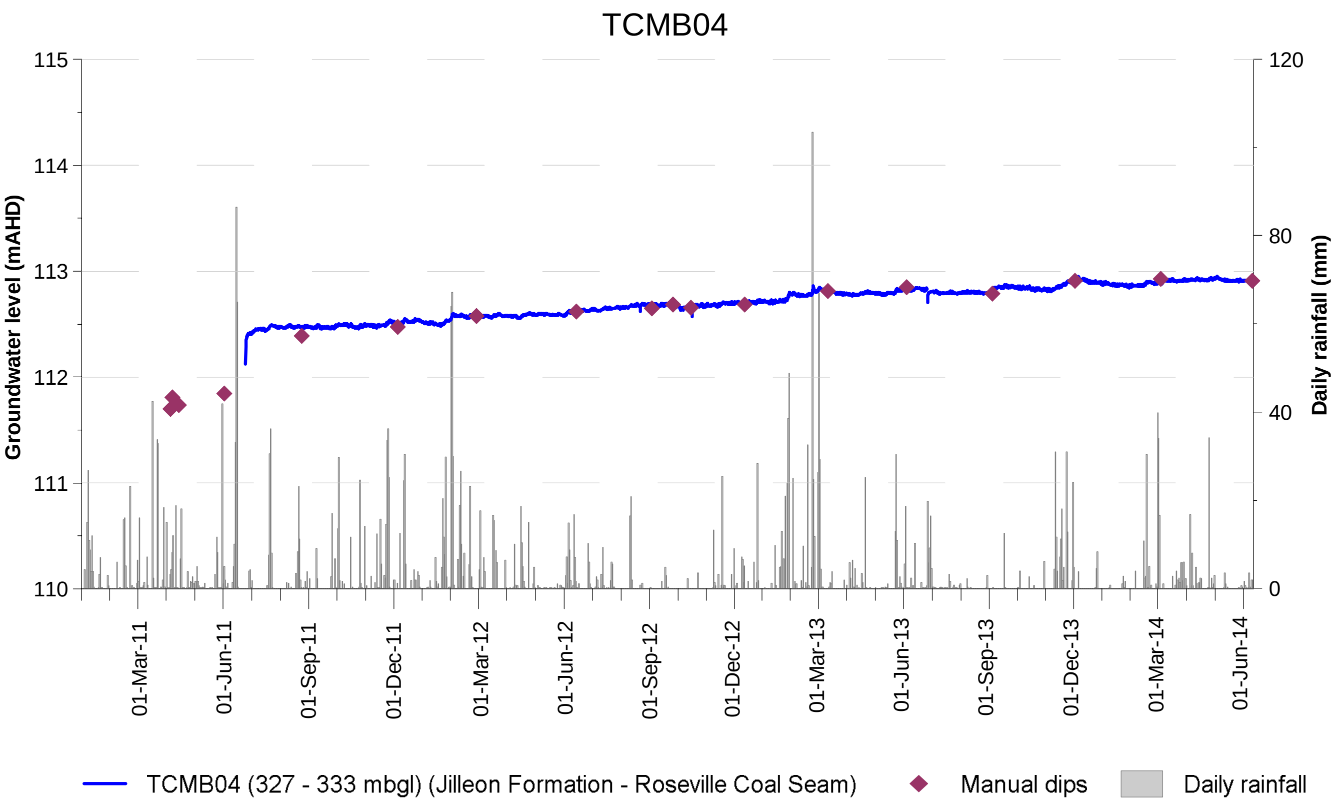


Figure A.11: TCMB02 and TCMB03 monitoring bores



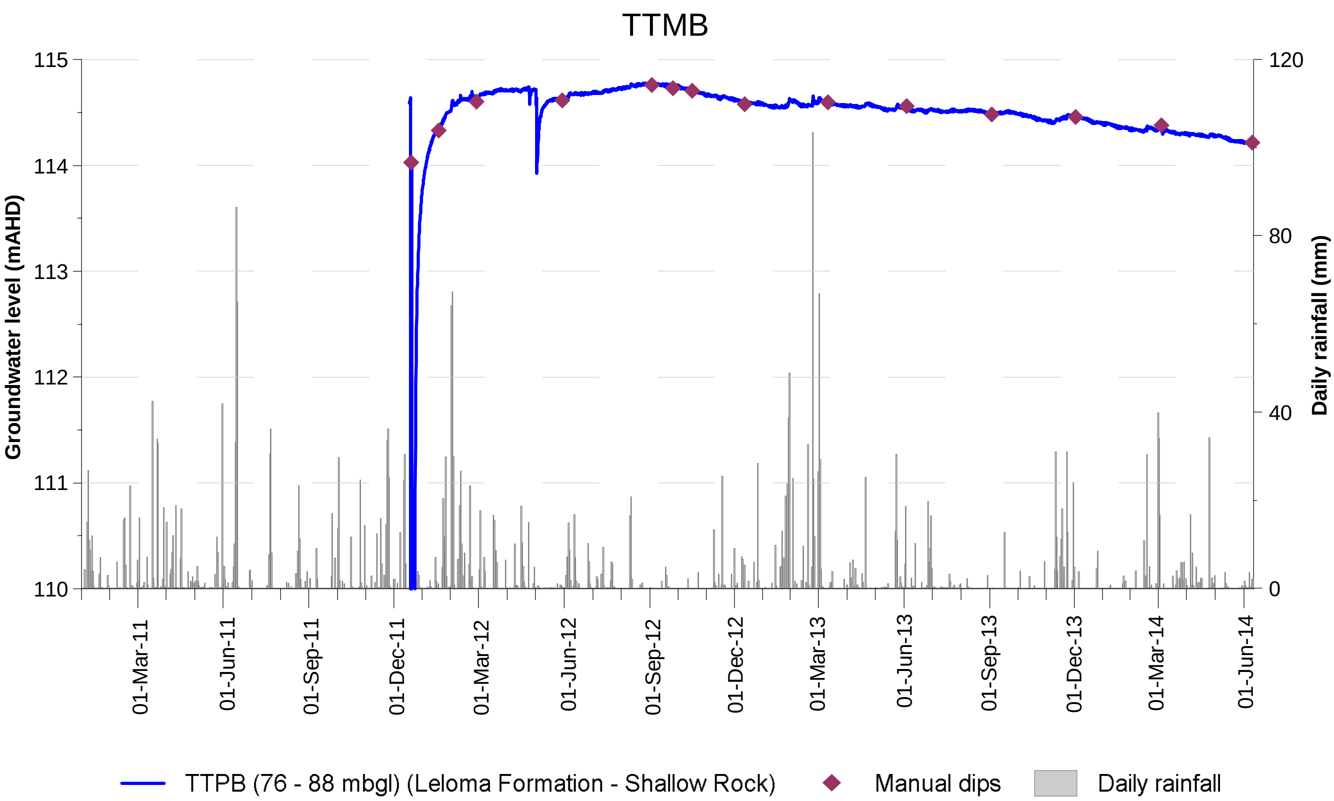
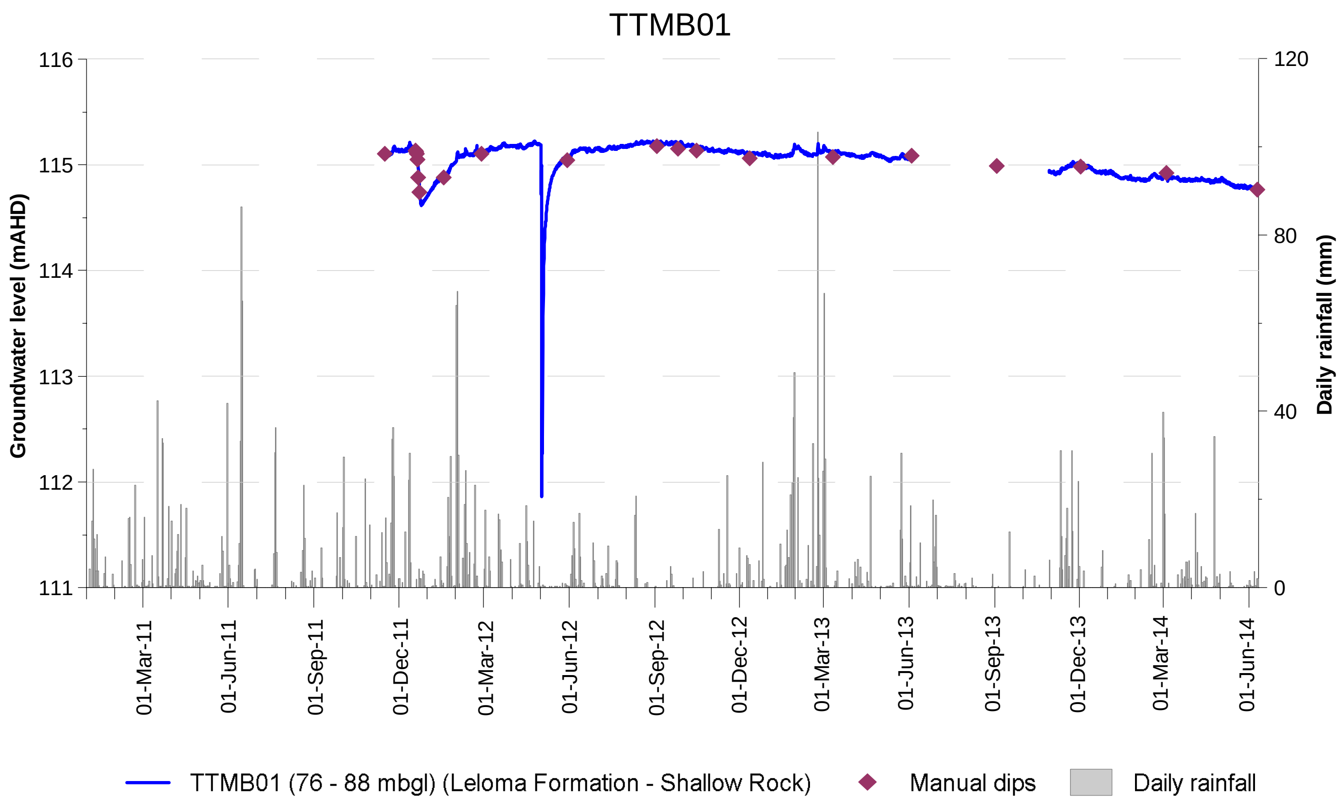


Figure A.12: TCMB04 and TTMB monitoring bores



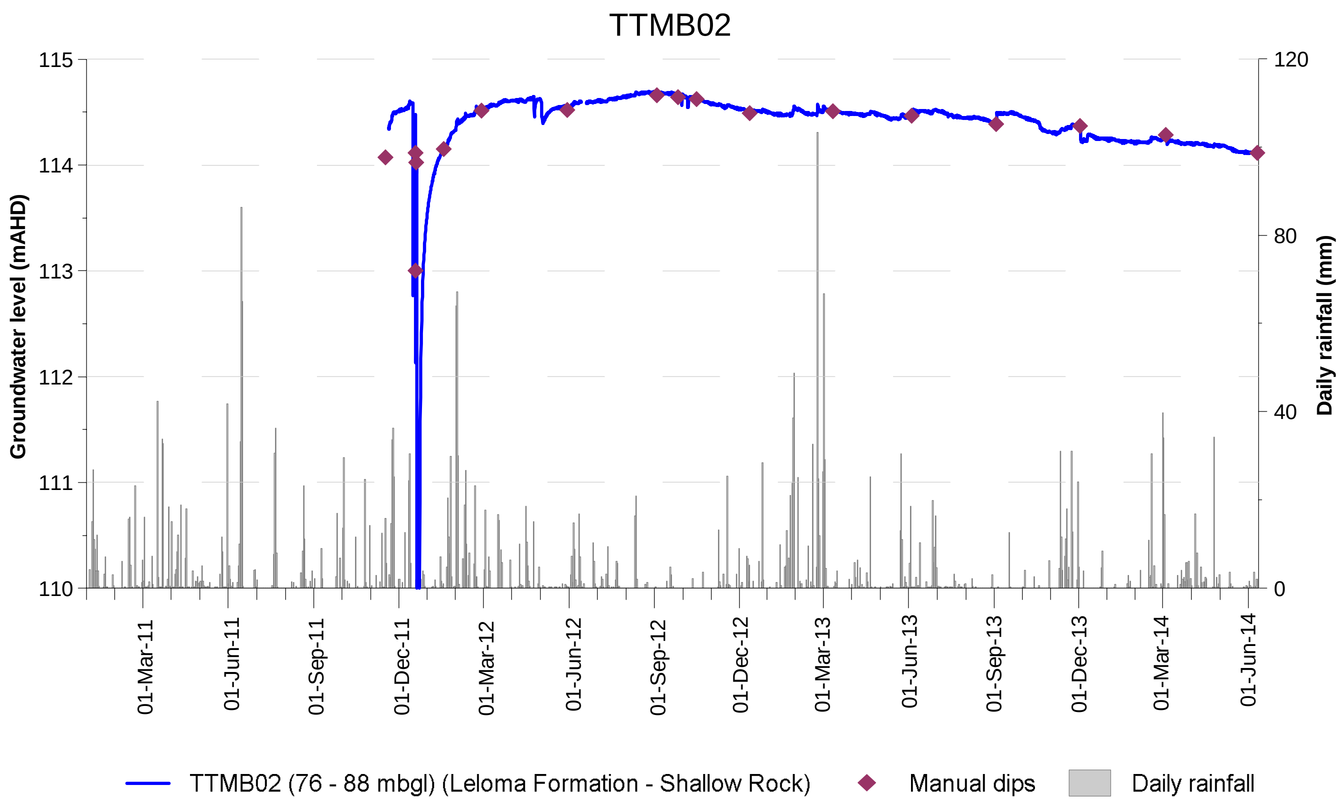
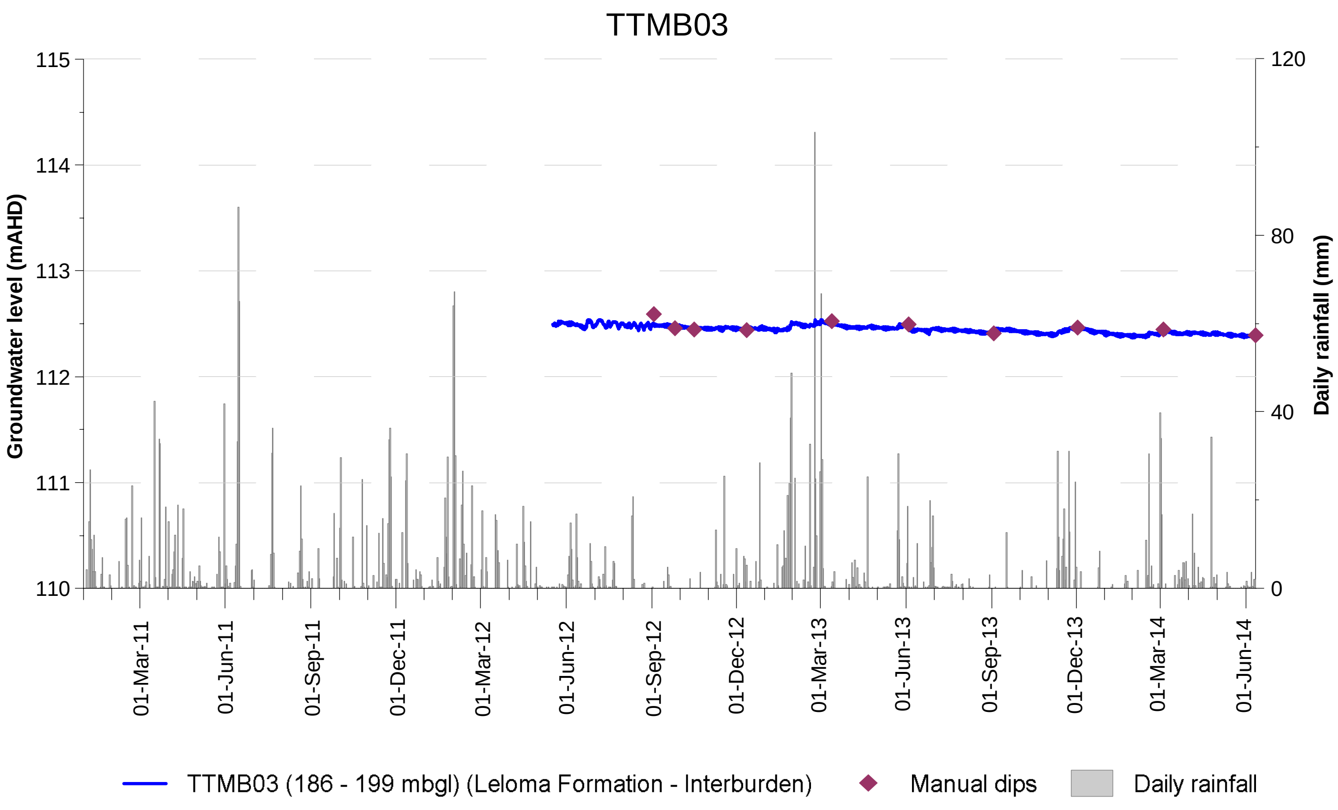


Figure A.13: TTMB01 and TTMB02 monitoring bores



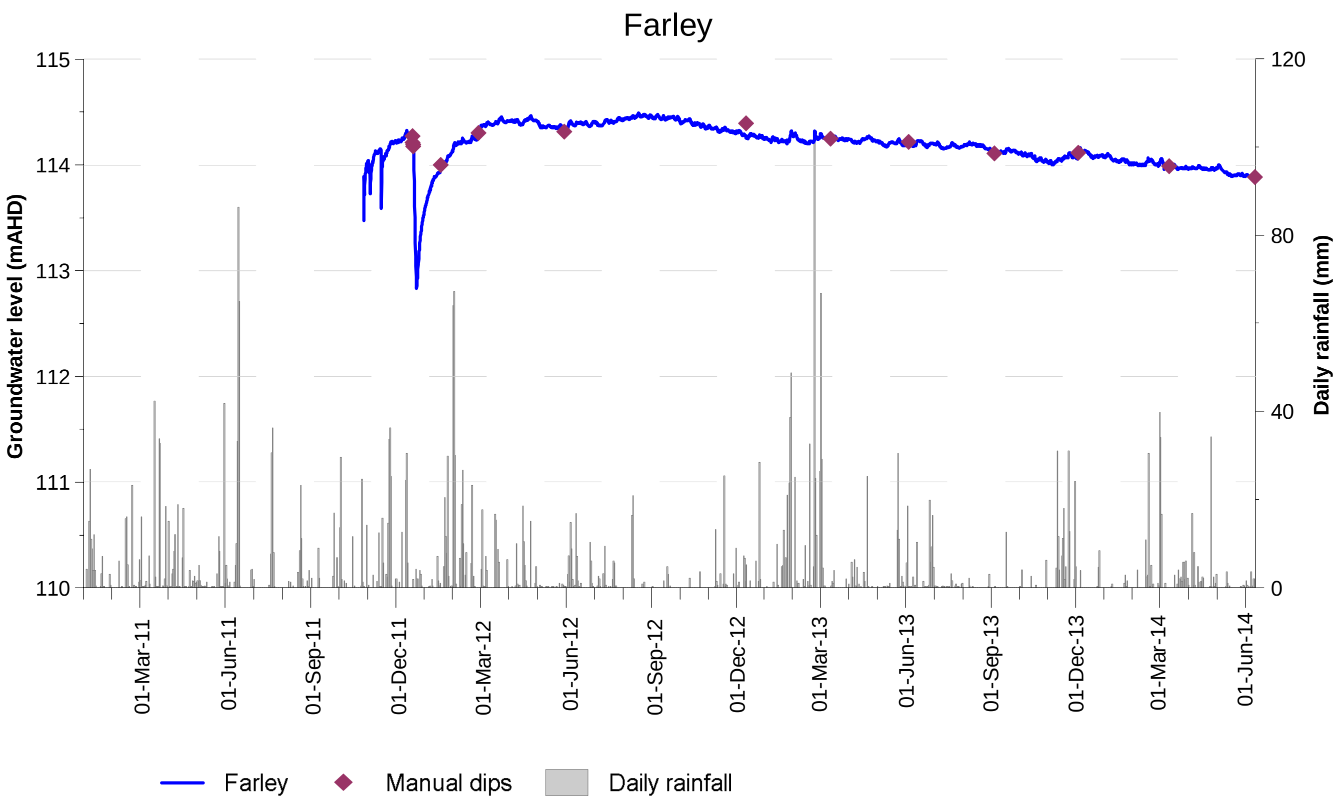
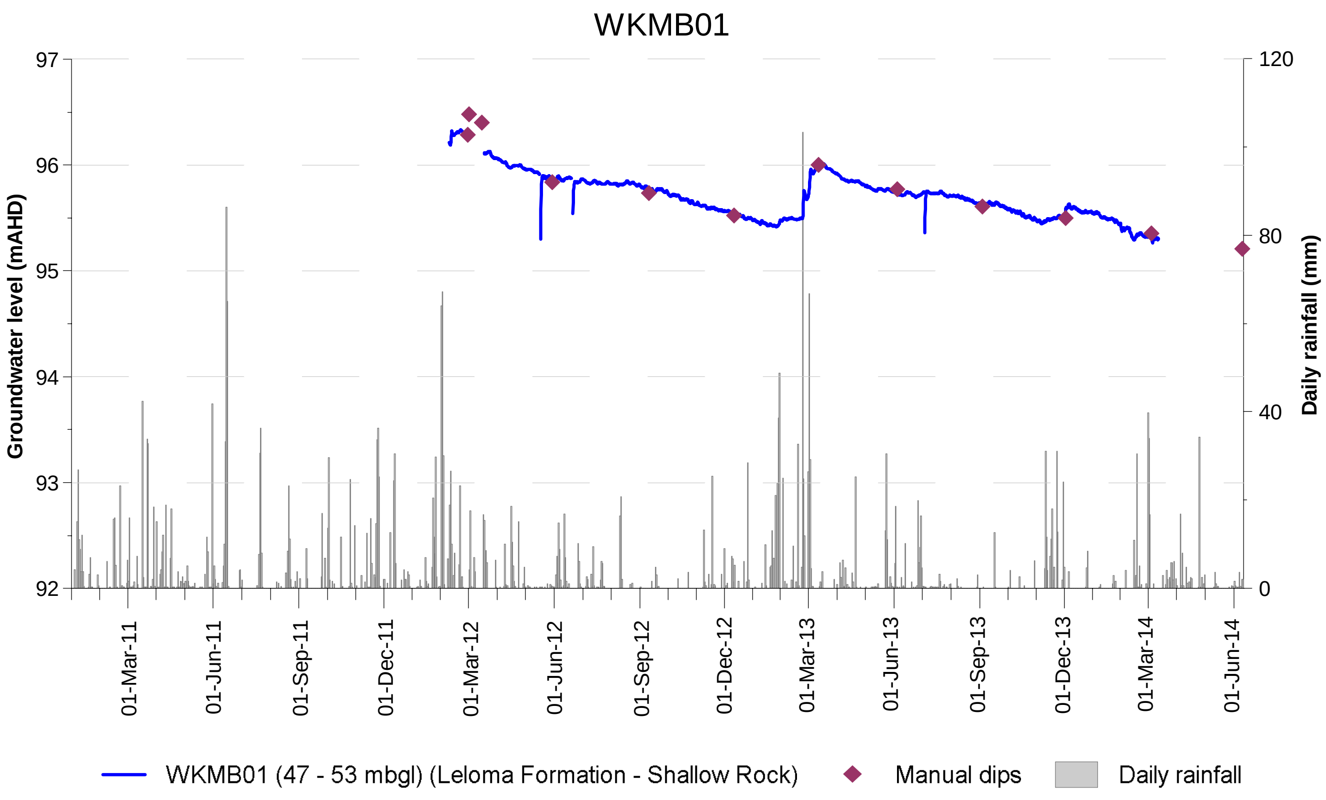


Figure A.14: TTMB03 and Farley monitoring bores



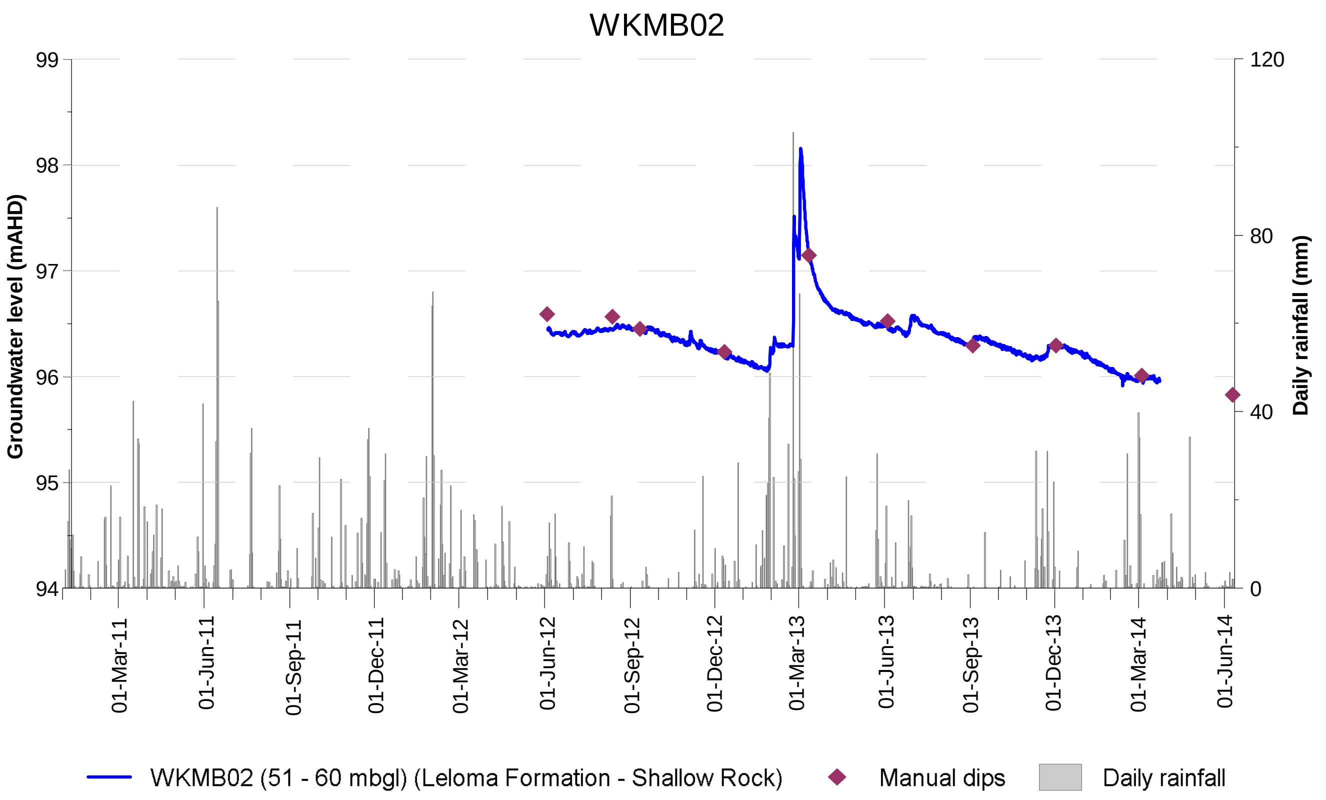


Figure A.15: WKMB01 and WKMB02 monitoring bores

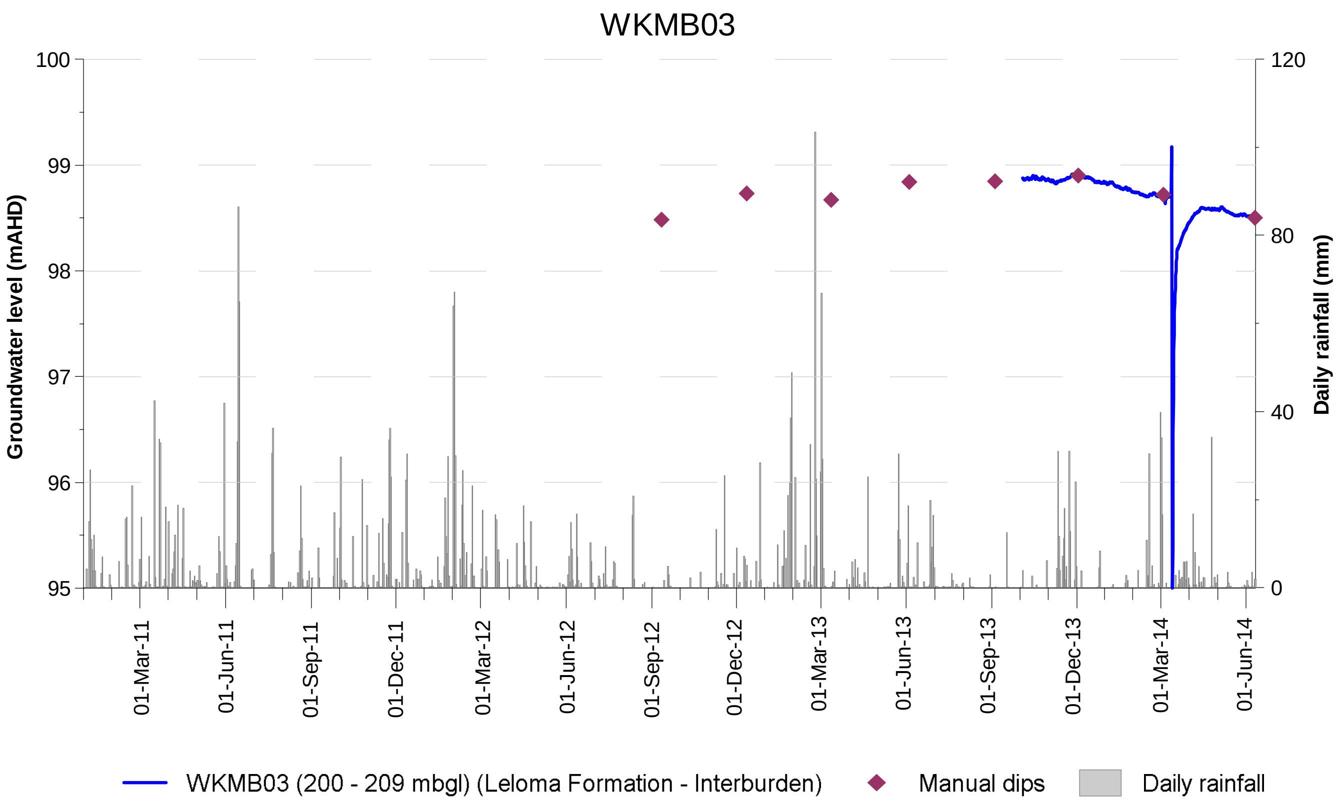
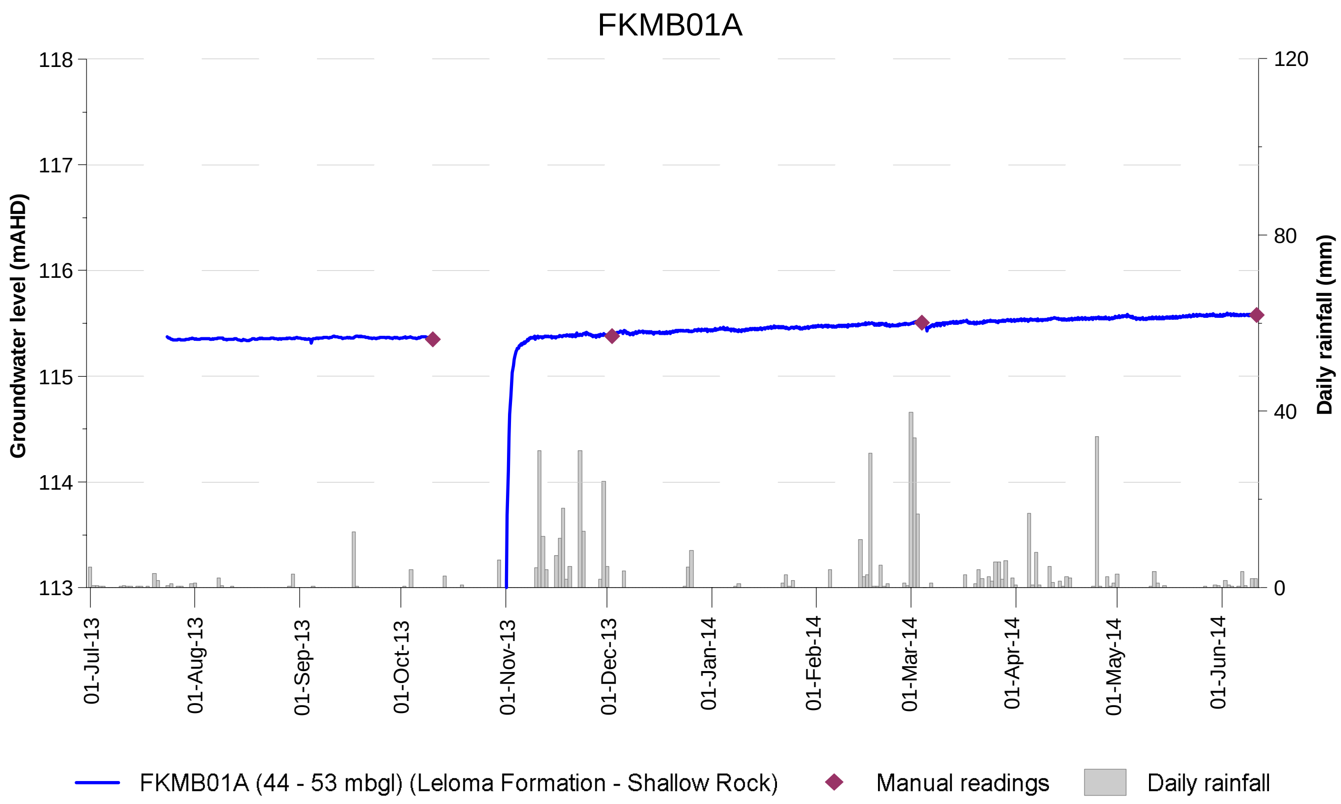


Figure A.16: WKMB03 monitoring bore



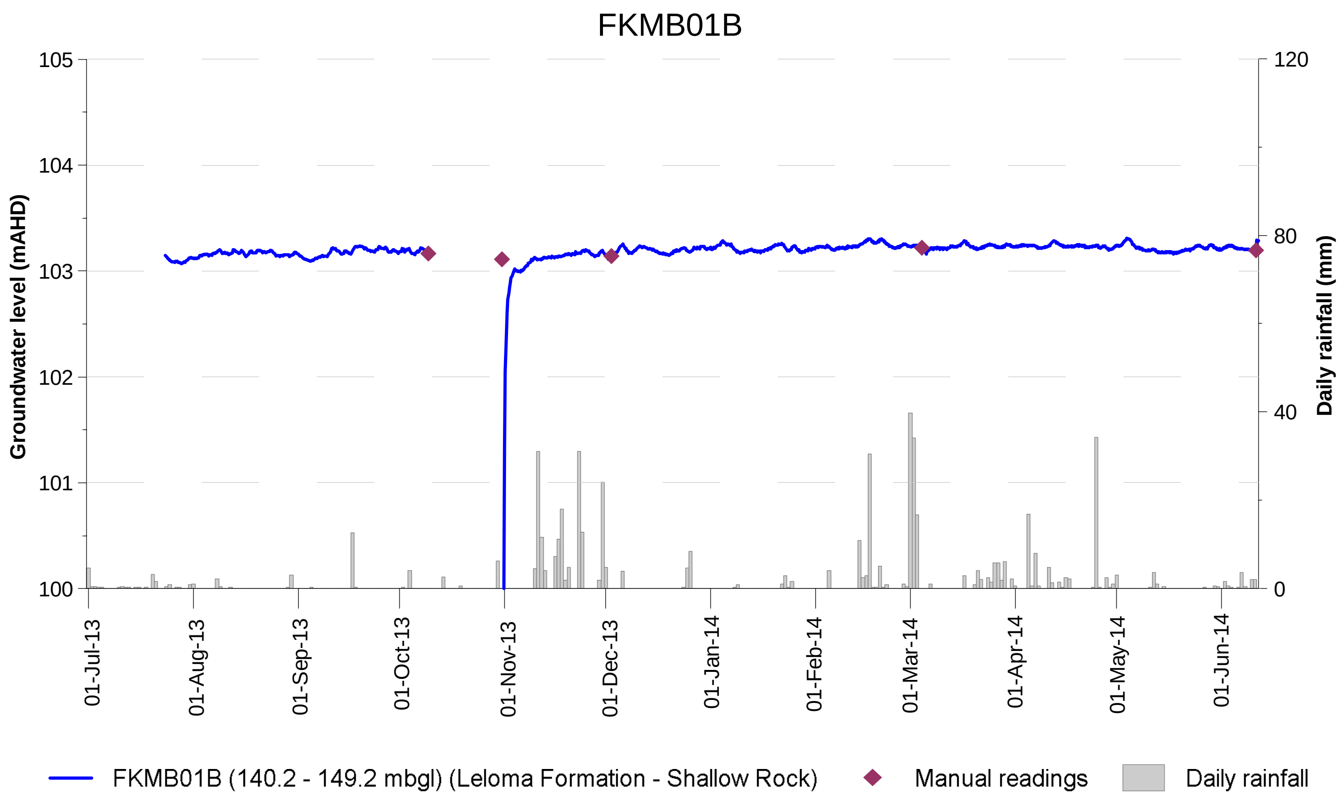
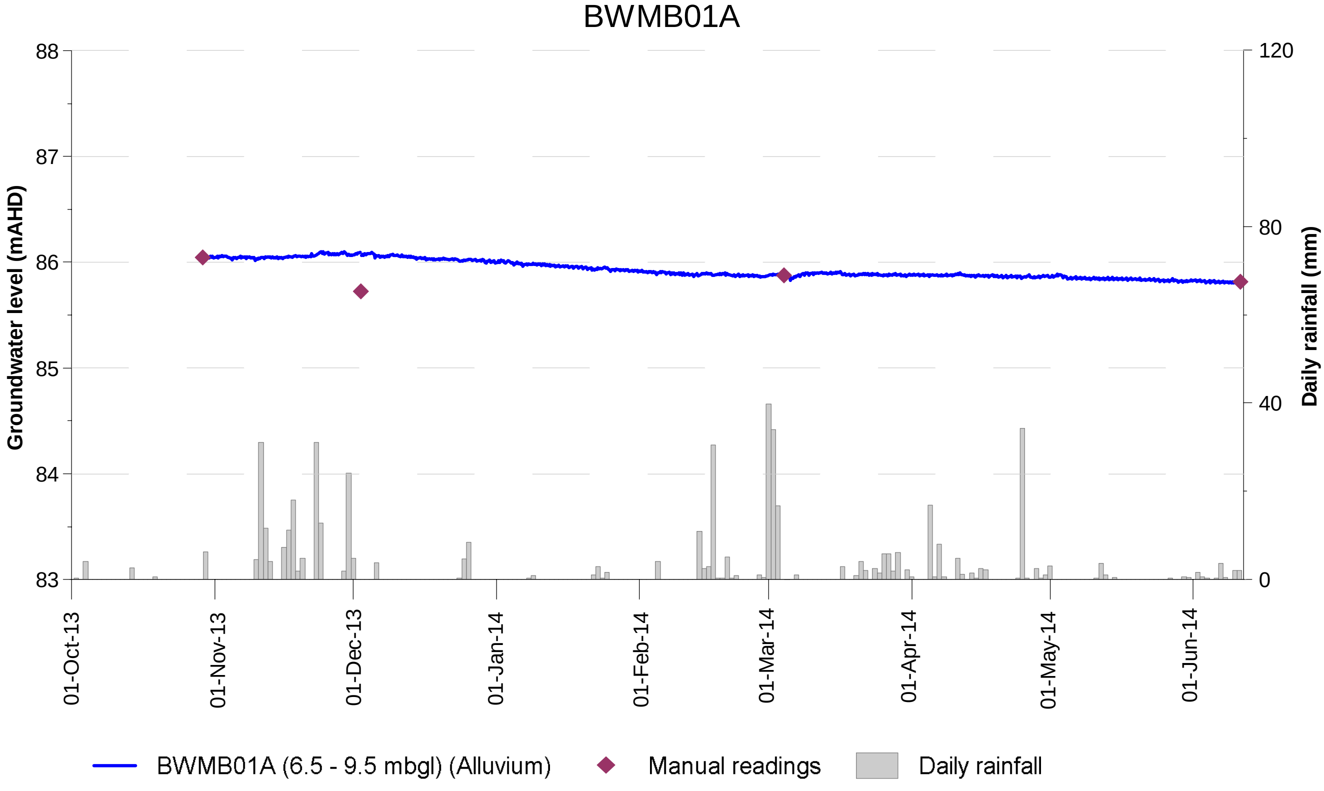


Figure A.17: FKMB01A and FKMB01B monitoring bores



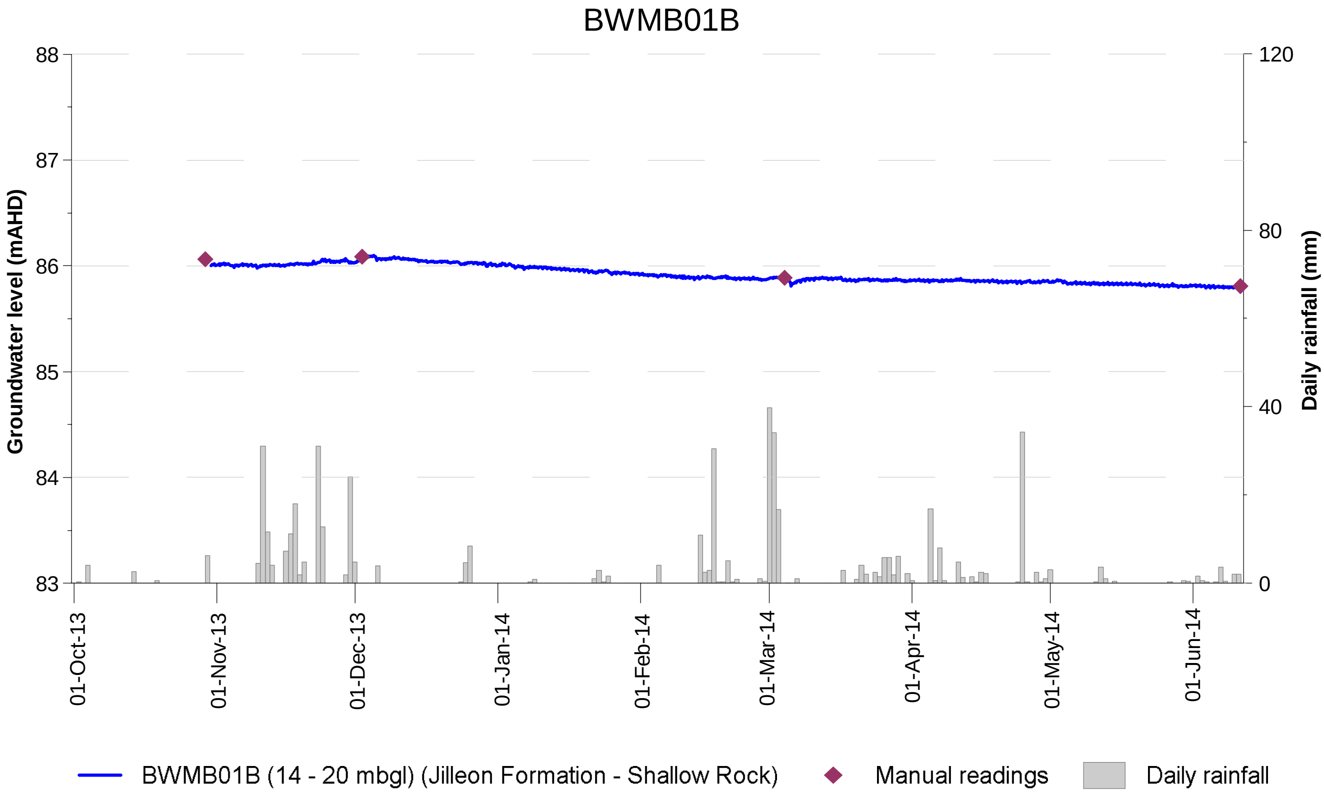
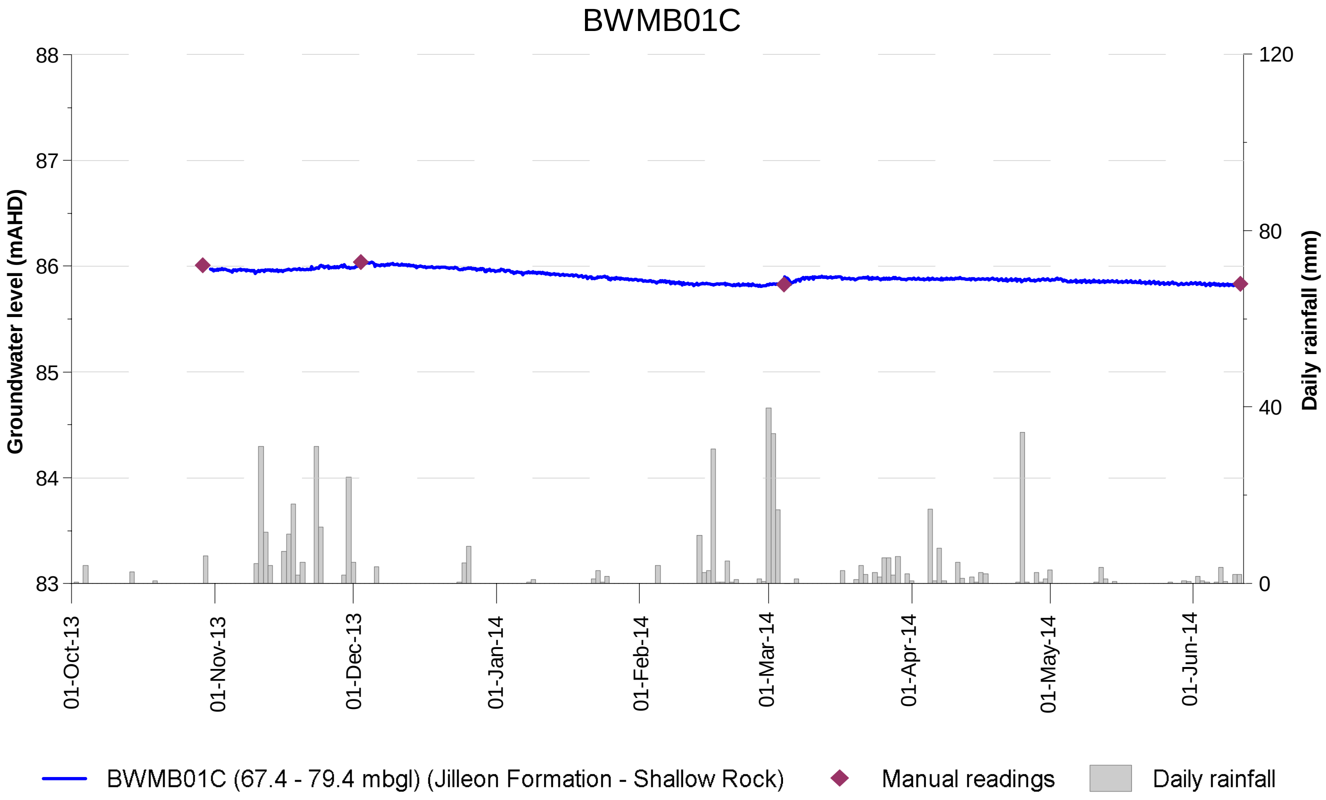


Figure A.18: BWMB01A and BWMB01B monitoring bores



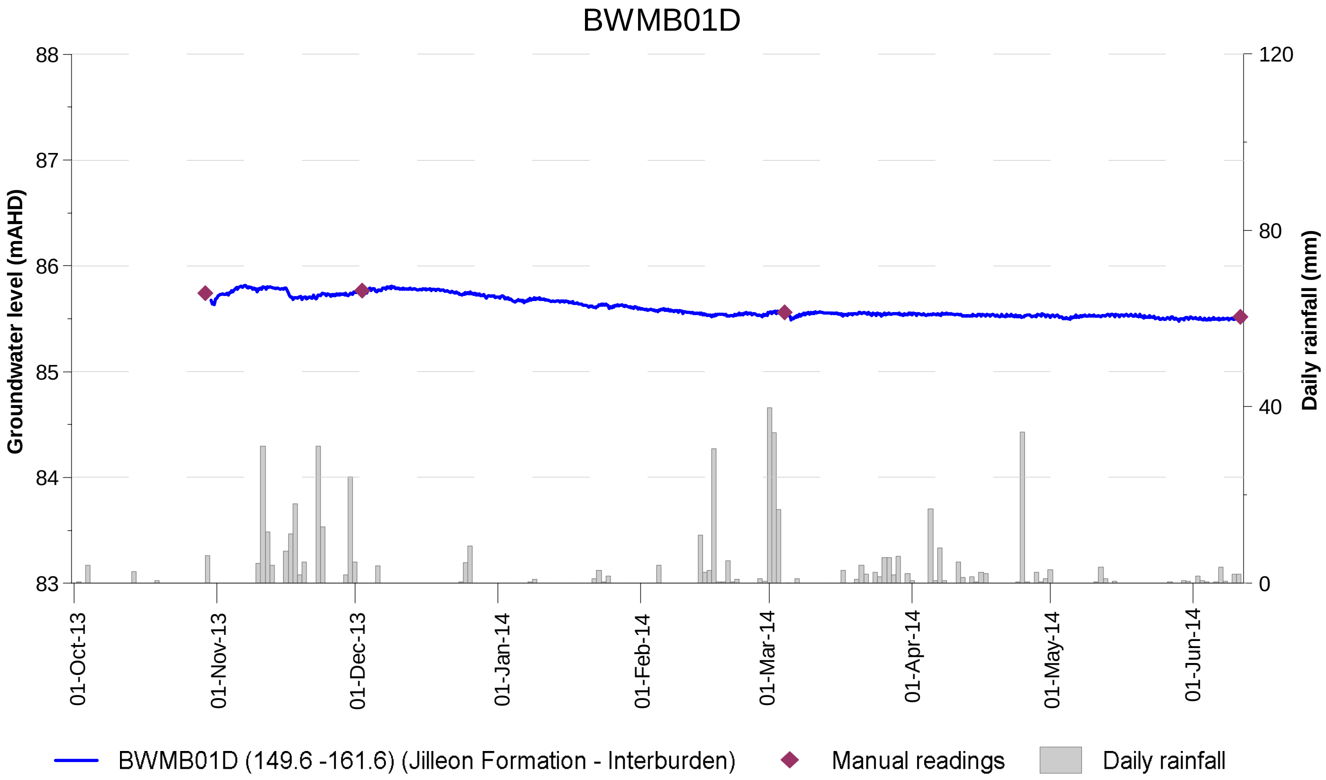
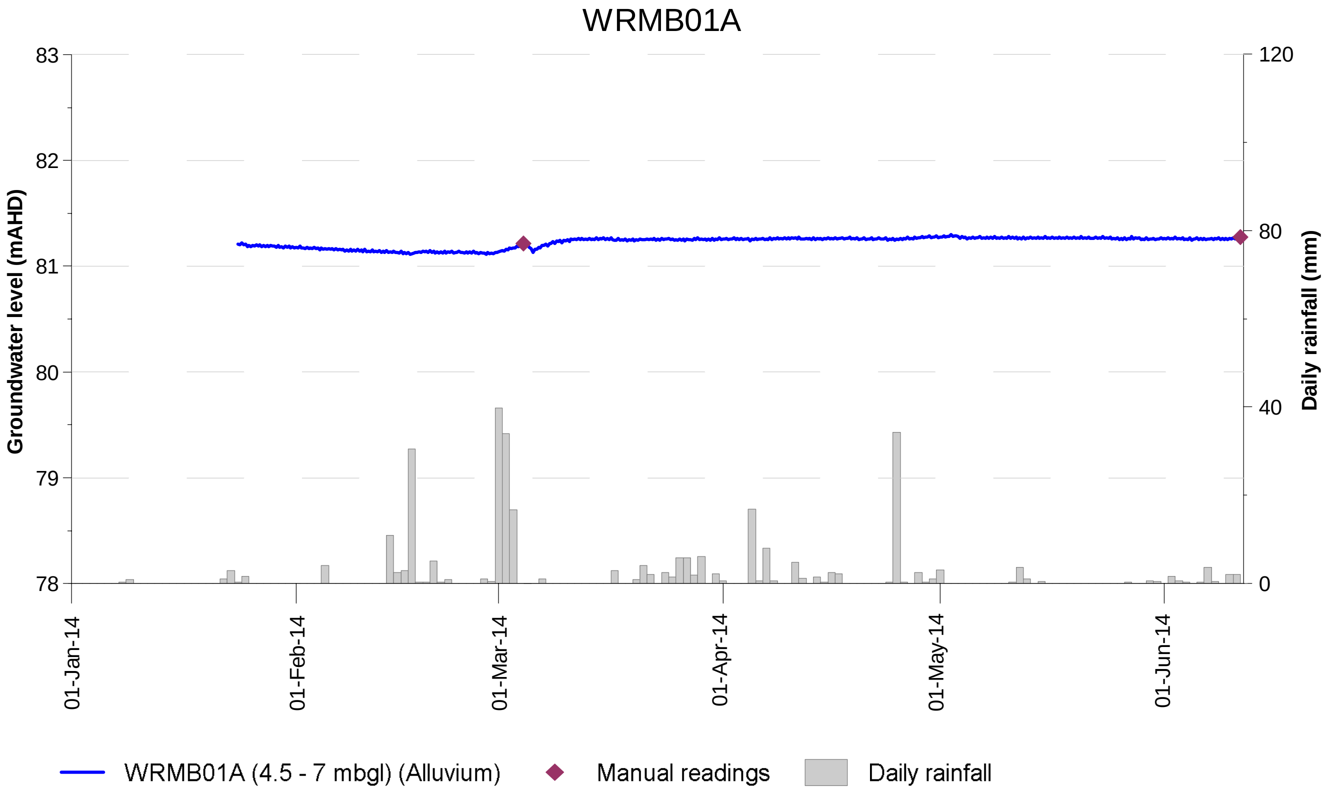


Figure A.19: BWMB01C and BWMB01D monitoring bores



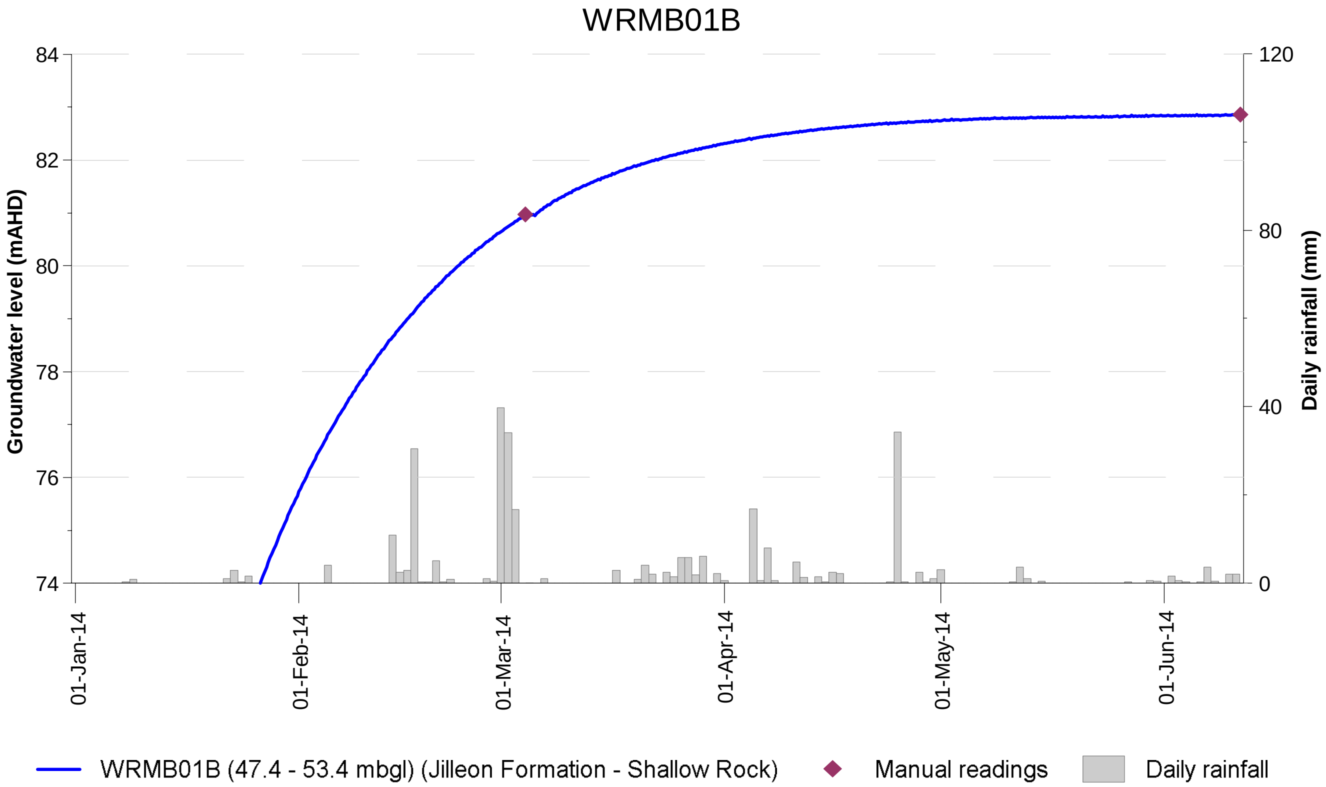


Figure A.20: WRMB01A and WRMB01B monitoring bores

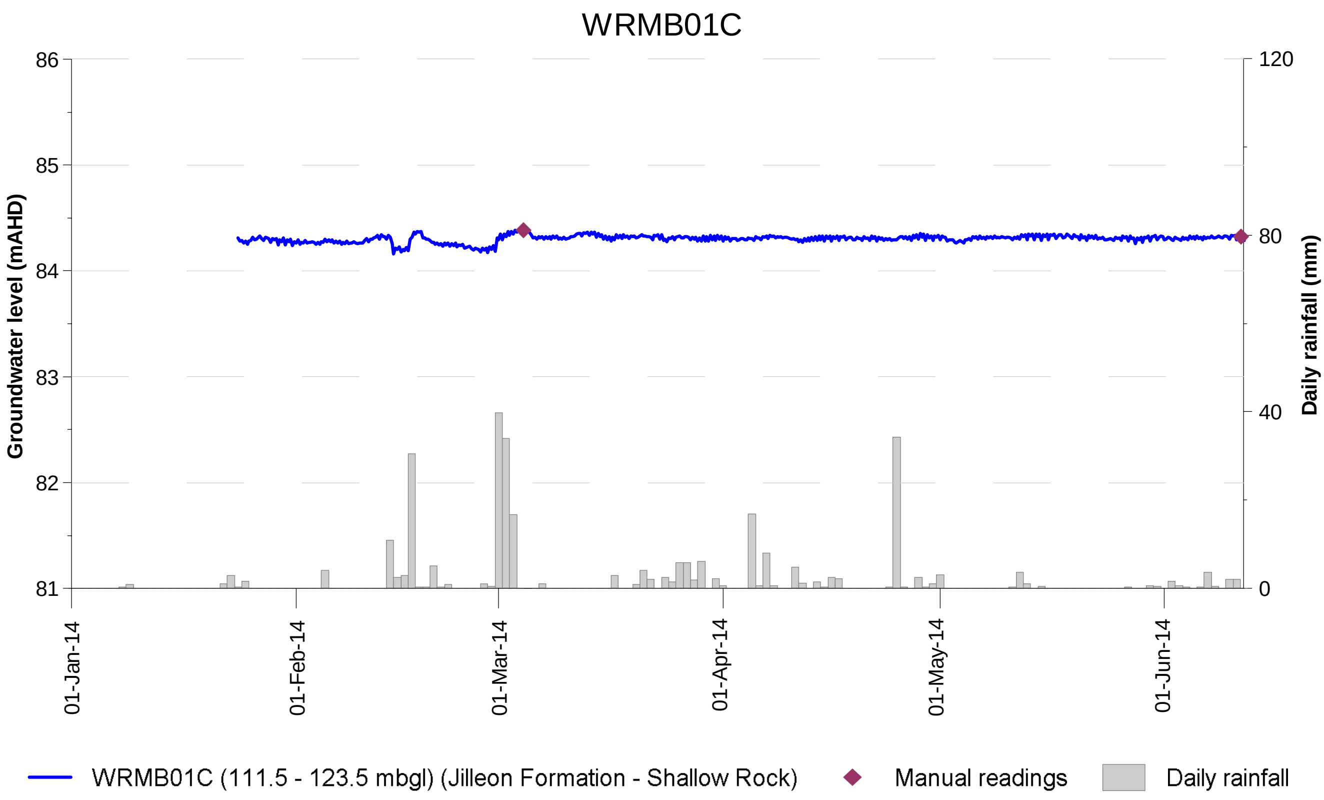
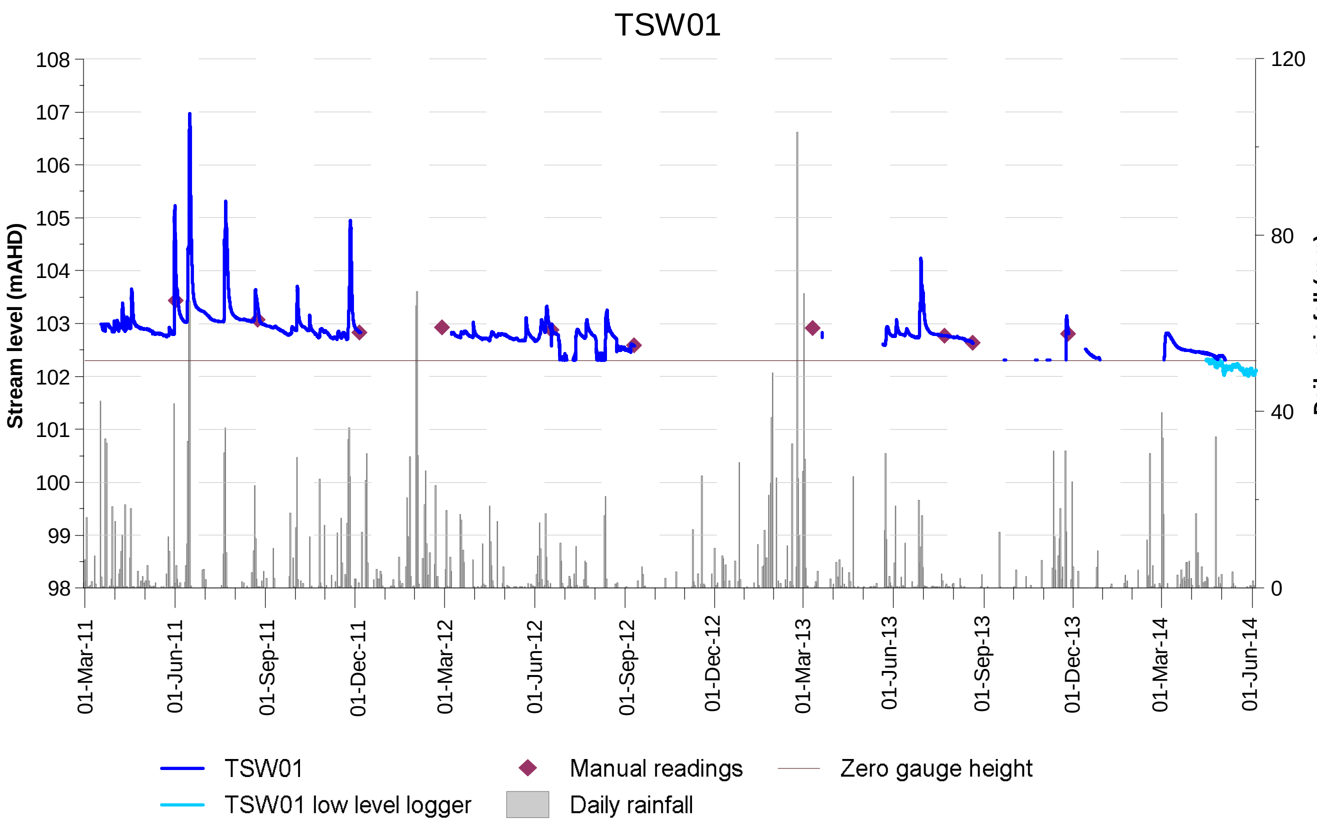


Figure A.21: WRMB01C monitoring bore



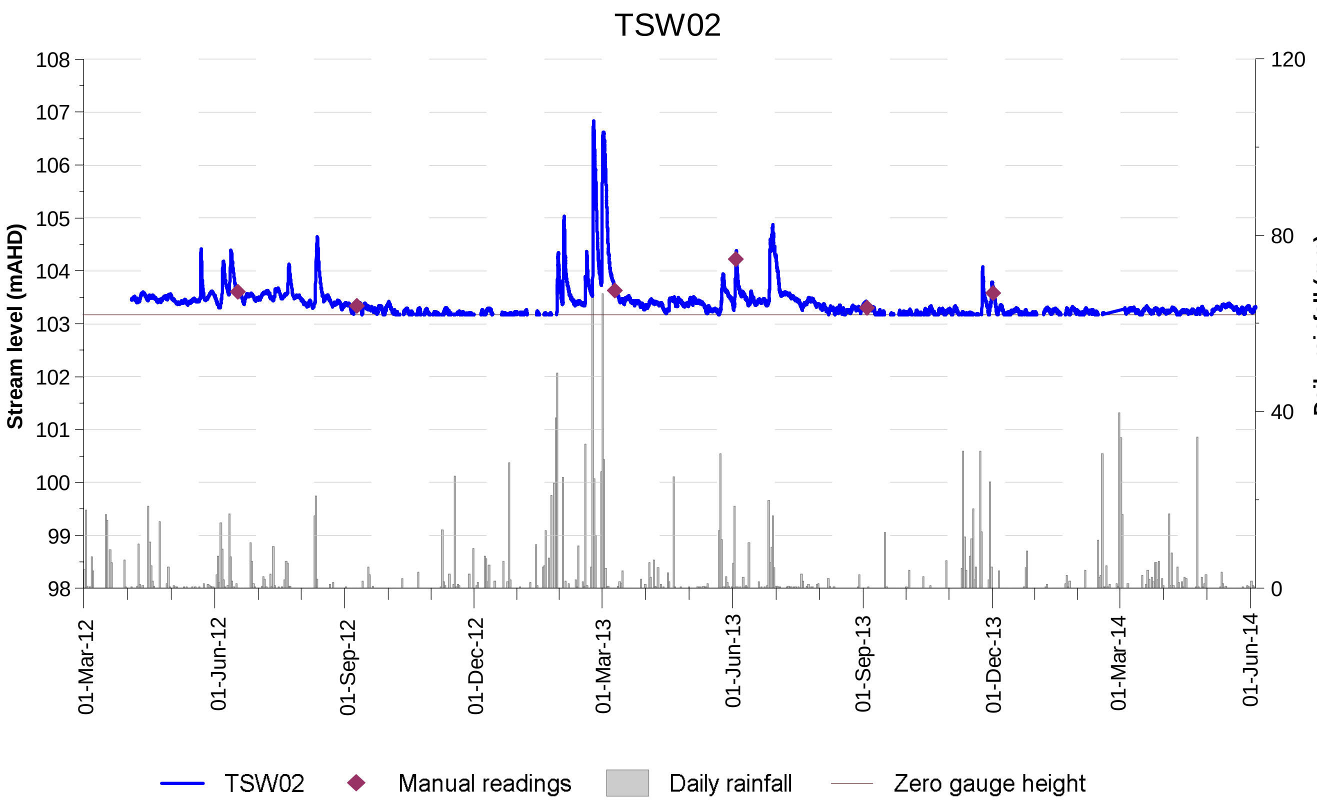
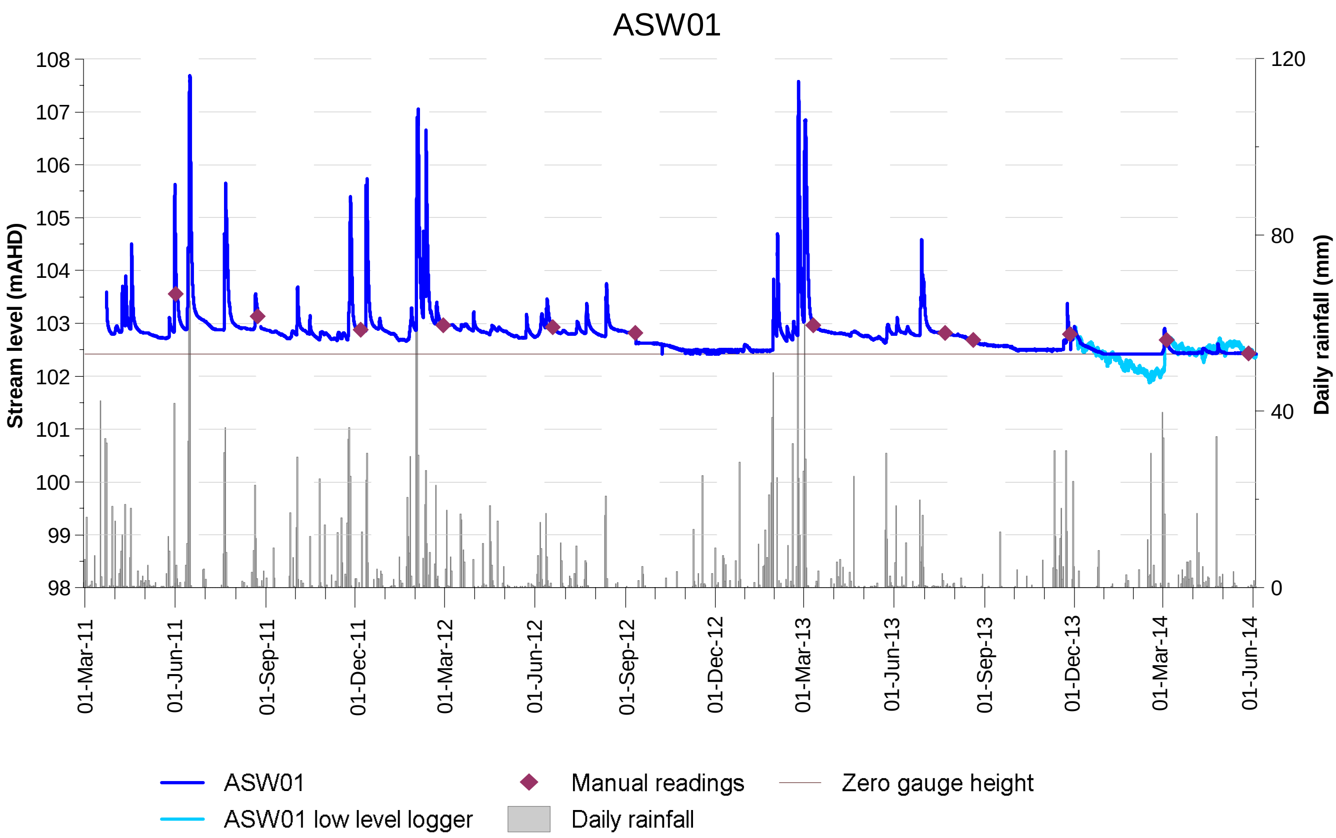


Figure A.22: TSW01 and TSW02 stream levels



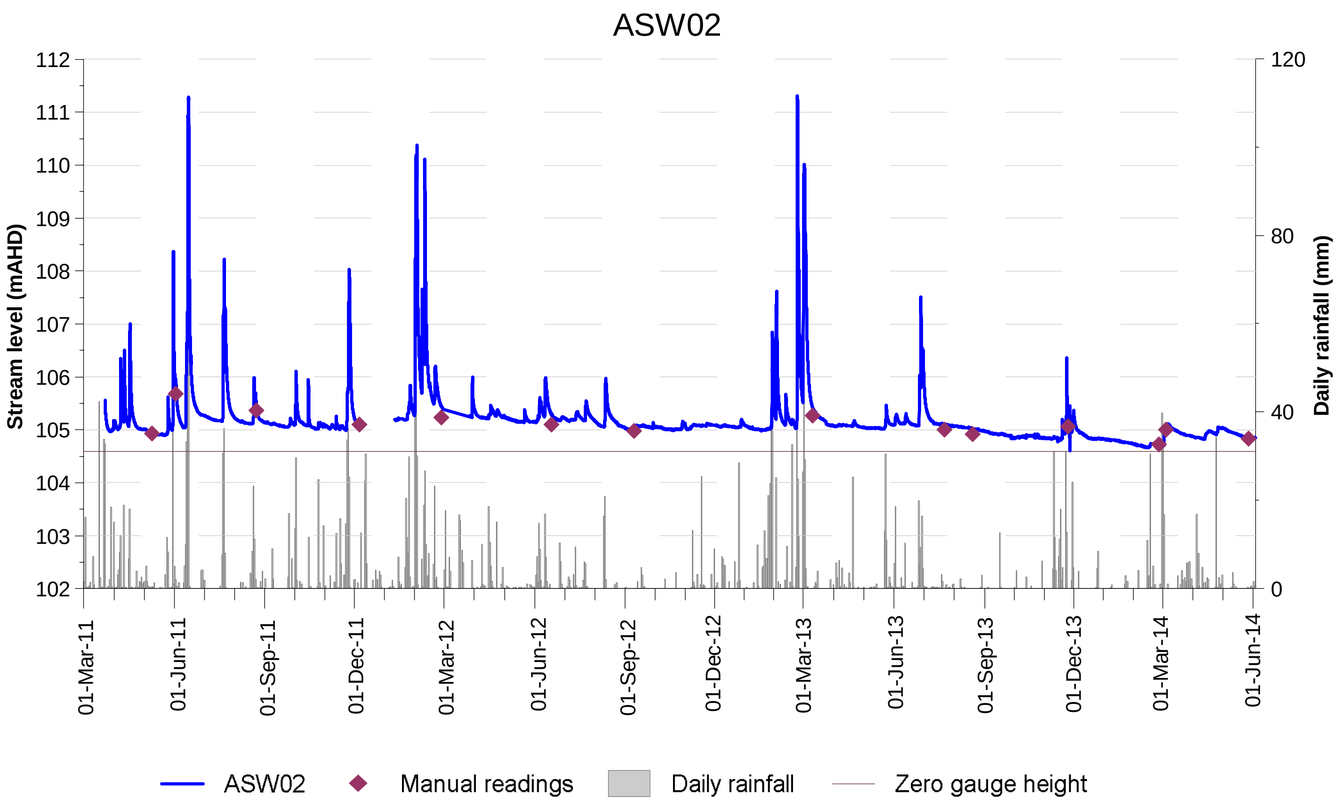
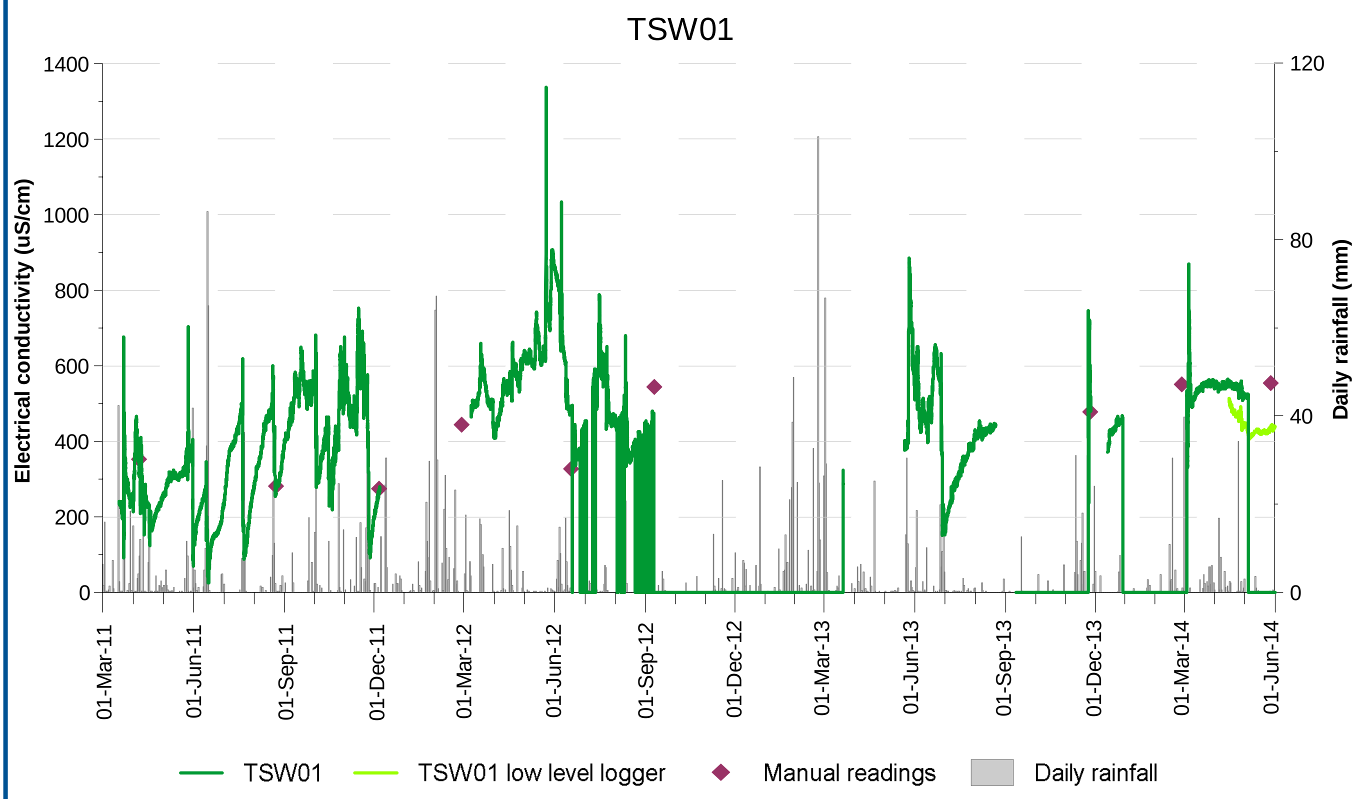


Figure A.23: ASW01 and ASW02 stream levels



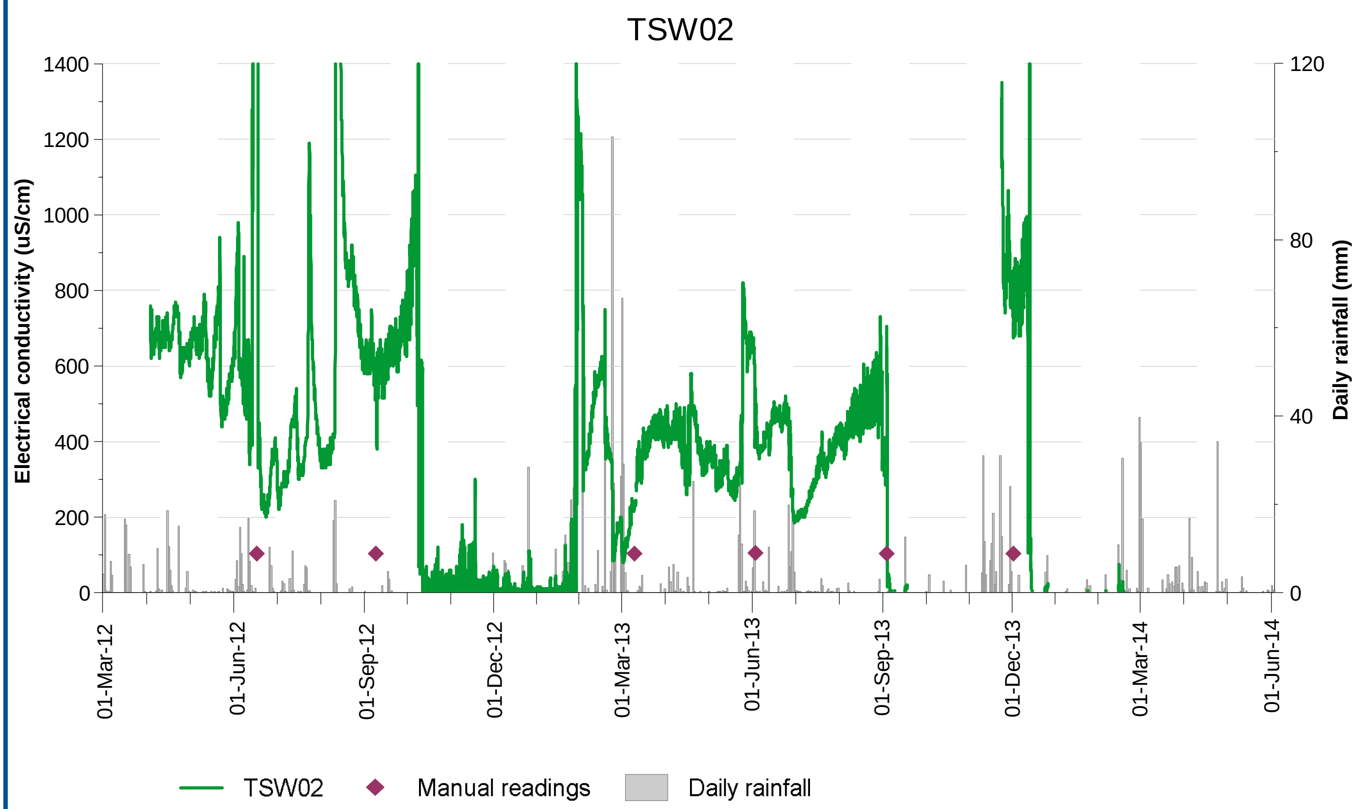
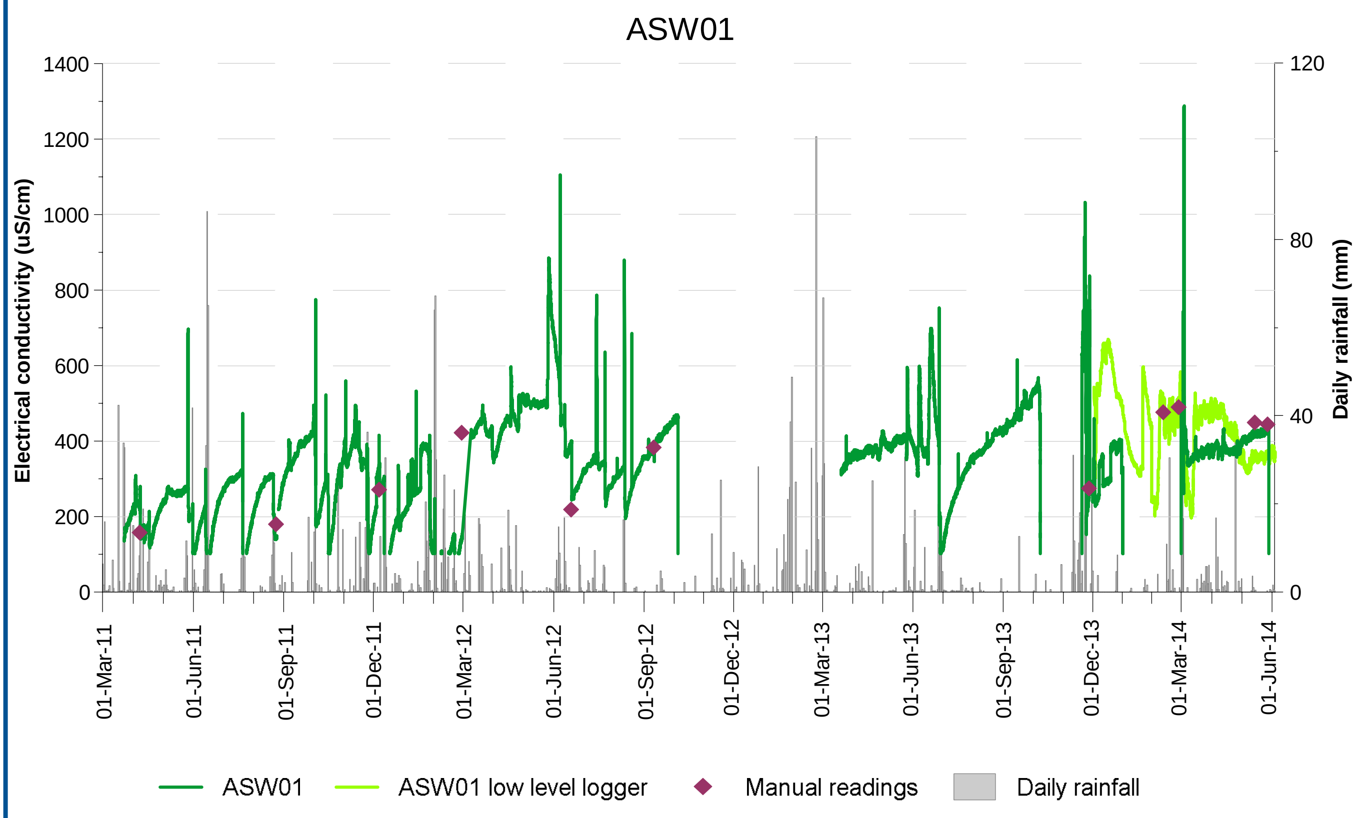


Figure A.24: TSW01 and TSW02 Electrical Conductivity



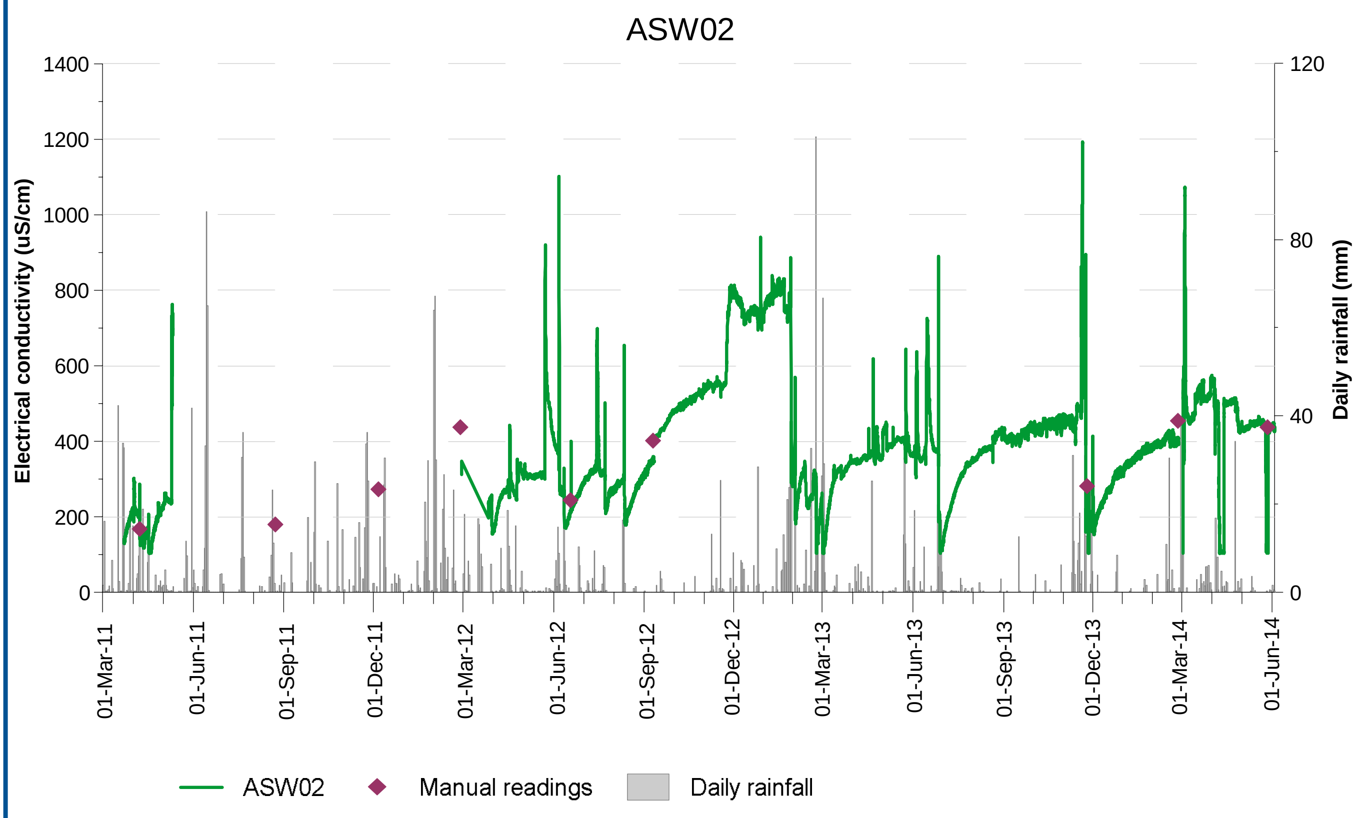
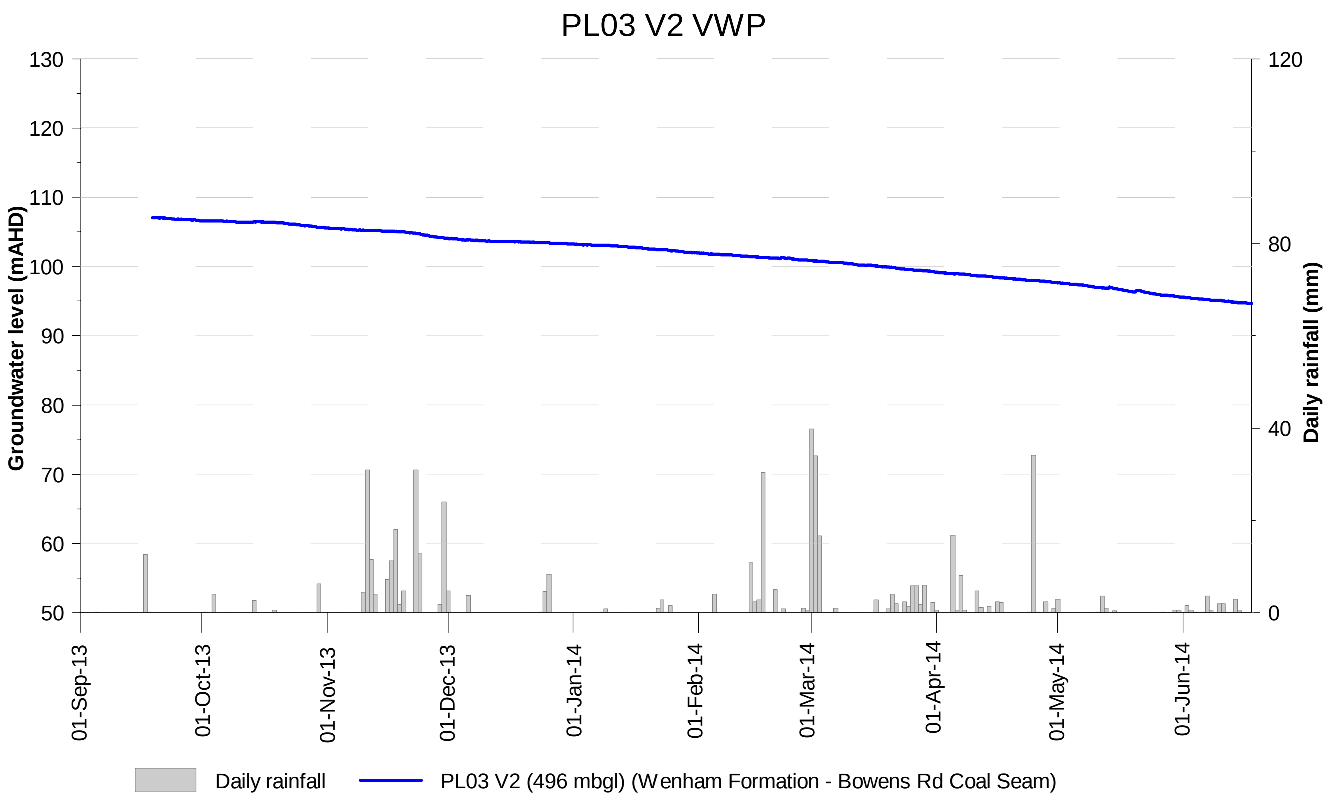


Figure A.25: ASW01 and ASW02 Electrical Conductivity



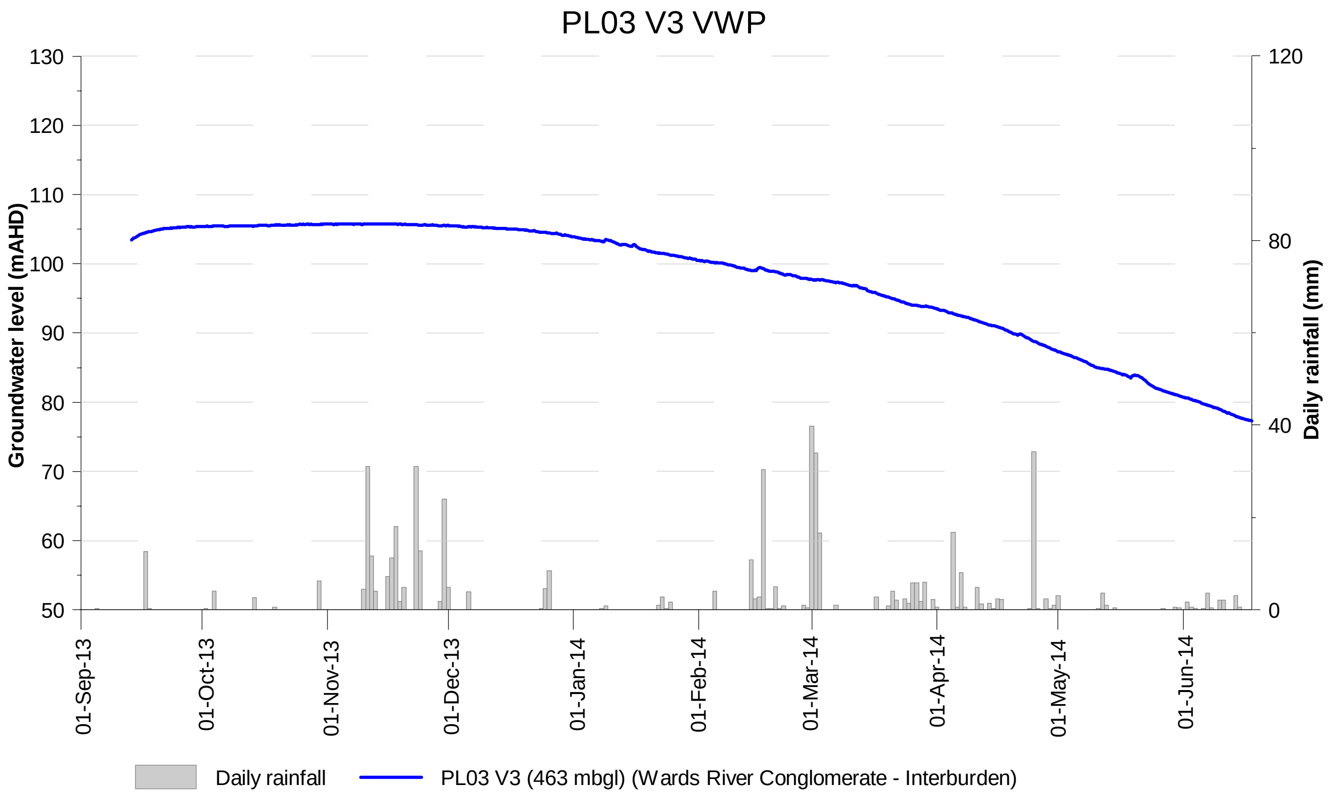


Figure A.26: PL03 VWP