Department of Planning and Environment

dpie.nsw.gov.au

Alstonville Basalt Plateau Groundwater Source

Groundwater Resource Description

September 2023

Acknowledgement of Country

The Department of Planning and Environment acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders past, present and emerging through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

Published by NSW Department of Planning and Environment

dpie.nsw.gov.au

Alstonville Basalt Plateau Groundwater Source

First published: September 2023

Department reference number: PUB23/290

Citation

[Kumar, P.B., Green, R.T., Turi, J. Alstonville Basalt Plateau Groundwater Resource Description, June 2022. NSW Department of Planning and Environment, Groundwater Management and Science.]

Executive summary

This report describes the status of the groundwater resources within the Alstonville Basalt Plateau Groundwater Source (Alstonville Basalt) located on the far north coast of New South Wales, approximately 700 km north of Sydney. The groundwater source covers an area of approximately 445 square kilometres.

The area receives an average annual rainfall of 1,800 mm/year. February to April are the wettest months, with each receiving 200 mm or more of rainfall.

Grazing, horticulture and urban development are the dominant land use types in the area, with increasing pressure from urban development.

The Alstonville Basalt consists of a sequence of Cenozoic basaltic flows and interbedded sediments of the Lismore Basalt. It is a multi-layered aquifer system that can be broadly divided into a shallow unconfined (<40 m) and a deep inter layered semi-confined to confined system with a highly variable base and with a maximum depth of approximately 170 - 220 m. The reported bore yields in the shallow and deep aquifers are similar and average 1.4 and 2.0 L/s respectively. Bore yields in the deep aquifer can be much higher with a reported maximum yield of 48 L/s.

The Alstonville Basalt is underlain by Silurian metasediments in the east (New England Fold Belt Coast Groundwater Source) and Mesozoic sandstones and coal measures (Clarence Moreton Basin Groundwater Source) in the central and western parts. The water sharing plan requires water supply works approvals (bores) in the Alstonville Basalt to be constructed such that they are only accessing one water source, and the others are sealed off.

Recharge to the shallow aquifer occurs primarily from rainfall infiltration. Inflow to the deeper aquifer system is mainly from vertical leakage from the shallow system and is influenced largely by the degree of vertical interconnection through jointing and fracturing. About 76% of the plateau area is dominated by free draining ferrosols soils. This results in a high proportion of infiltration from rainfall on the plateau.

Groundwater flow in the shallow aquifer system is influenced by surface topography, depth of weathering, degree and extent of rock fracturing. It provides significant baseflow to streams and creeks, discharges in the numerous springs and seepages, and is highly vulnerable to droughts, frequency of low rainfall events and shallow pumping. The deep aquifer also discharges as spring and baseflow particularly towards the base of the plateau in the more deeply incised parts of the aquifer.

The Alstonville Basalt is currently managed under the Water Sharing Plan (the Plan) for the North Coast Fractured and Porous Rock Groundwater Sources 2016 which commenced on 1 July 2016. Extraction in the groundwater source is managed to the long-term average annual extraction limit (LTAAEL) volume of 8,895 ML/year set by the Plan. At present there are 197 access licences with total shares of 7,082 ML. The Plan sets aside a volume of 2,014 ML for basic landholder rights (BLR) use. Local water utility licences (town water supply) equate to 14% of the LTAAEL.

There are 245 production and 830 BLR bores in the groundwater source. Extraction from production bores is mostly for irrigation. Groundwater take or use is not currently monitored.

Groundwater levels are monitored at 25 government monitoring bores (pipes) at 12 sites. At several of the sites there are 2 pipes monitoring different depths (aquifers). Most of these monitoring bores are equipped with continuous data loggers with 6 sites fully telemetered and data available in real time.

Groundwater level analysis show that levels within the shallow aquifer correlate strongly with rainfall, indicating it is the dominant recharge mechanism. Groundwater levels in the shallow aquifer have remained fairly stable for the duration of monitoring. Annual variations range 1 to 5 m and is mainly due to rainfall recharge events and groundwater pumping. However, there is little usage information available for detailed analysis.

Overall, the levels in the deep aquifer respond to pumping. The levels have been rising since mid-2000. There was a significant decline during late 1990s to early to mid-2000 (over 29 m) in monitoring bores located in the central and southern areas of the groundwater source. The levels have since recovered. This observed decline was due to pumping in the area for town water supply and other users indicating that large drawdowns are likely to result in these areas as groundwater pumping increases in future.

Water quality analysis from sampling in 2021 indicate groundwater in the shallow aquifer is fresh (median EC of 114.5 µS/cm) and ranges from mixed type to Na-Mg through Na-Cl to Na-HCO_3 water type. The salinity in the deep aquifer is still fresh, albeit slightly higher (median electrical conductivity of 485 µS/cm) with a water type ranging from Na-HCO_3 through Na-Cl and mixed dominant water type.

Preliminary age dating results indicate groundwater in the deep aquifer to be up to 30,000 years old. The shallow groundwater is believed to be very young (<50 years).

The NSW Government is implementing new metering requirements across the state. In western and coastal NSW, all works with groundwater access licenses (except bores less than 200 mm in diameter) will be required to have implemented metering on their equipment by December 2024.

Contents

Figures

Tables

1 Introduction

The Alstonville Basalt Plateau Groundwater Source (hereafter the Alstonville Basalt) is located on the far north coast of New South Wales, approximately 700 km north of Sydney (**Figure 1**).

It is centred around the township of Alstonville, extending from near Lismore in the west to the coast at Lennox Head, to around Bangalow in the north and almost to the Richmond River to the south. The groundwater source covers an area of approximately 445 square kilometres.

This report describes the location, climate and physical attributes of the fractured rock aquifer system and explains its geological and hydrogeological context, environmental assets, groundwater quality and management. It also presents the status of the groundwater resource covering groundwater rights, dealings (water trades) and groundwater behaviour.

The Alstonville Basalt is an area of spiritual and cultural importance to the Bundjalung nation, especially the Jali and Ngulingah Aboriginal people.

1.1 Description of groundwater source

The Alstonville Basalt includes all water contained in all volcanic rock sequences of Tertiary age (Cenozoic) below the surface of the ground within the boundary of the Plateau (**Figure 1**). It is bounded by the Wilsons River and Byron Creek to the northwest, the coastal plain to the east, and the Tuckean Swamp and Richmond River in the south.

The Alstonville Basalt is underlain by Silurian metasediments in the east (New England Fold Belt Coast Groundwater Source) and Mesozoic sandstones and coal measures (Clarence Moreton Basin Groundwater Source) in the central and western parts.

The elevation of the base of the Alstonville Basalt (in metres above mean sea level or mAHD) is shown on **Figure 2.** The contour map was prepared using elevation data from Geoscience Australia's *Elevation and Depth Digital Elevation Model* (ELVIS), and existing monitoring and private bore data for basement depth from bores constructed into the underlying New England Fold Belt Coast or Clarence Moreton Basin groundwater sources.

Figure 1 Location of the Alstonville Basalt Plateau Groundwater Source

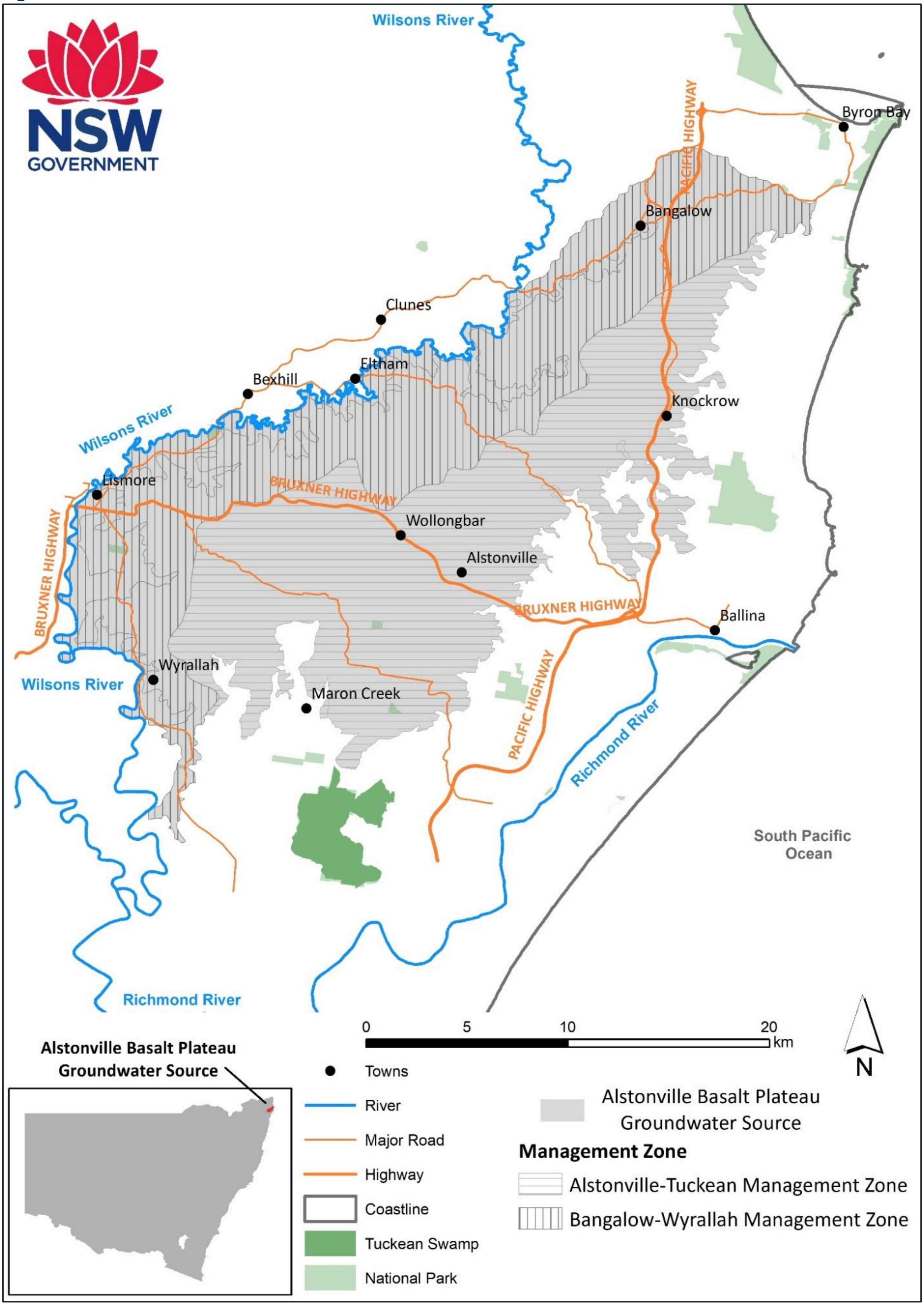
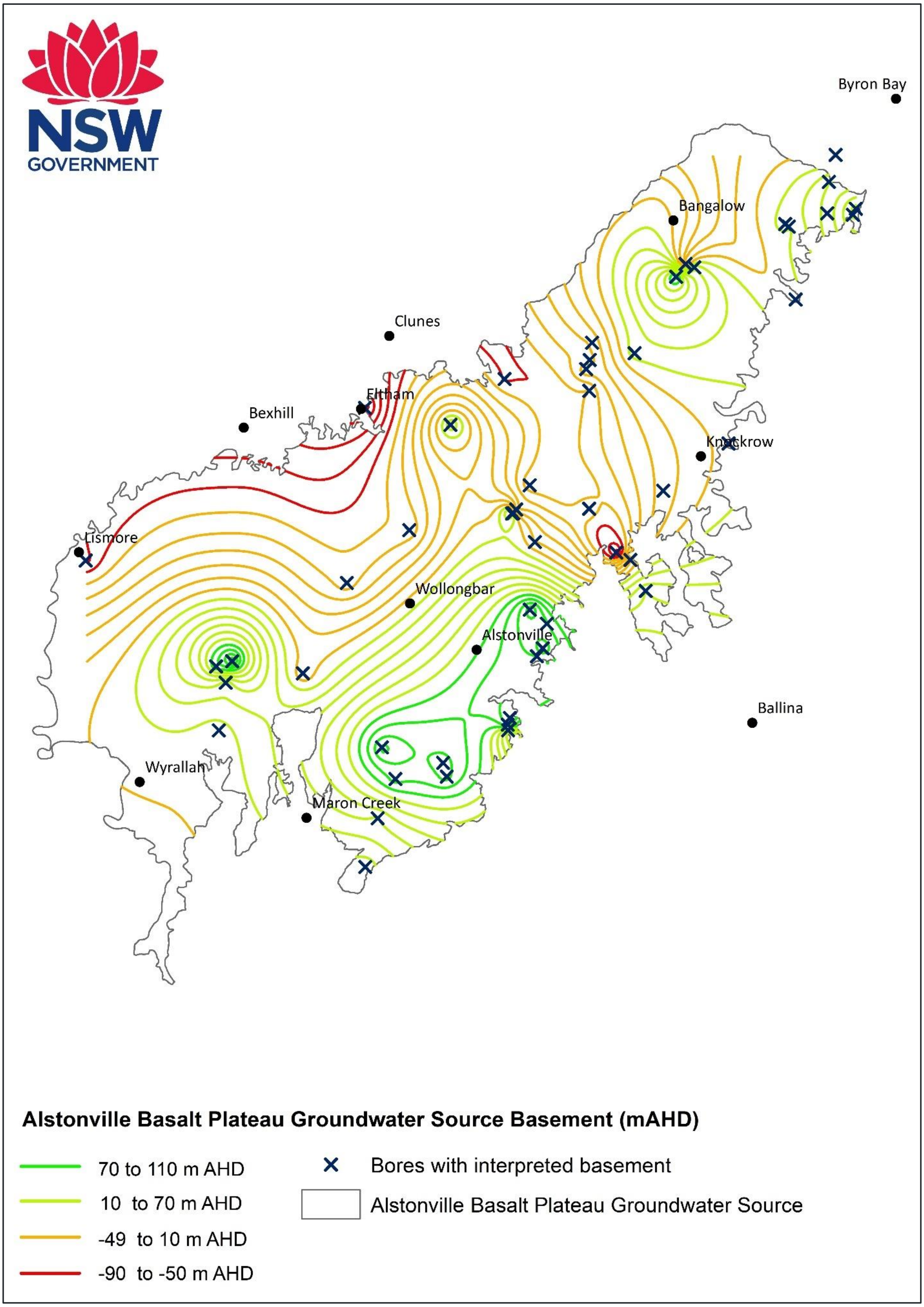


Figure 2 Contours of the base of Alstonville Basalt Plateau Groundwater Source in metres AHD


Byron Bay
Bangalow
Clunes
Eltham
Bexhill
Knockrow
Lismore
Wollongbar
Alstonville
Ballina
Wyrallah
Maron Creek
Alstonville Basalt Plateau Groundwater Source Basement (mAHD)
70 to 110 m AHD
10 to 70 m AHD
-49 to 10 m AHD
-90 to -50 m AHD
Bores with interpreted basement
Alstonville Basalt Plateau Groundwater Source

2 Regional setting

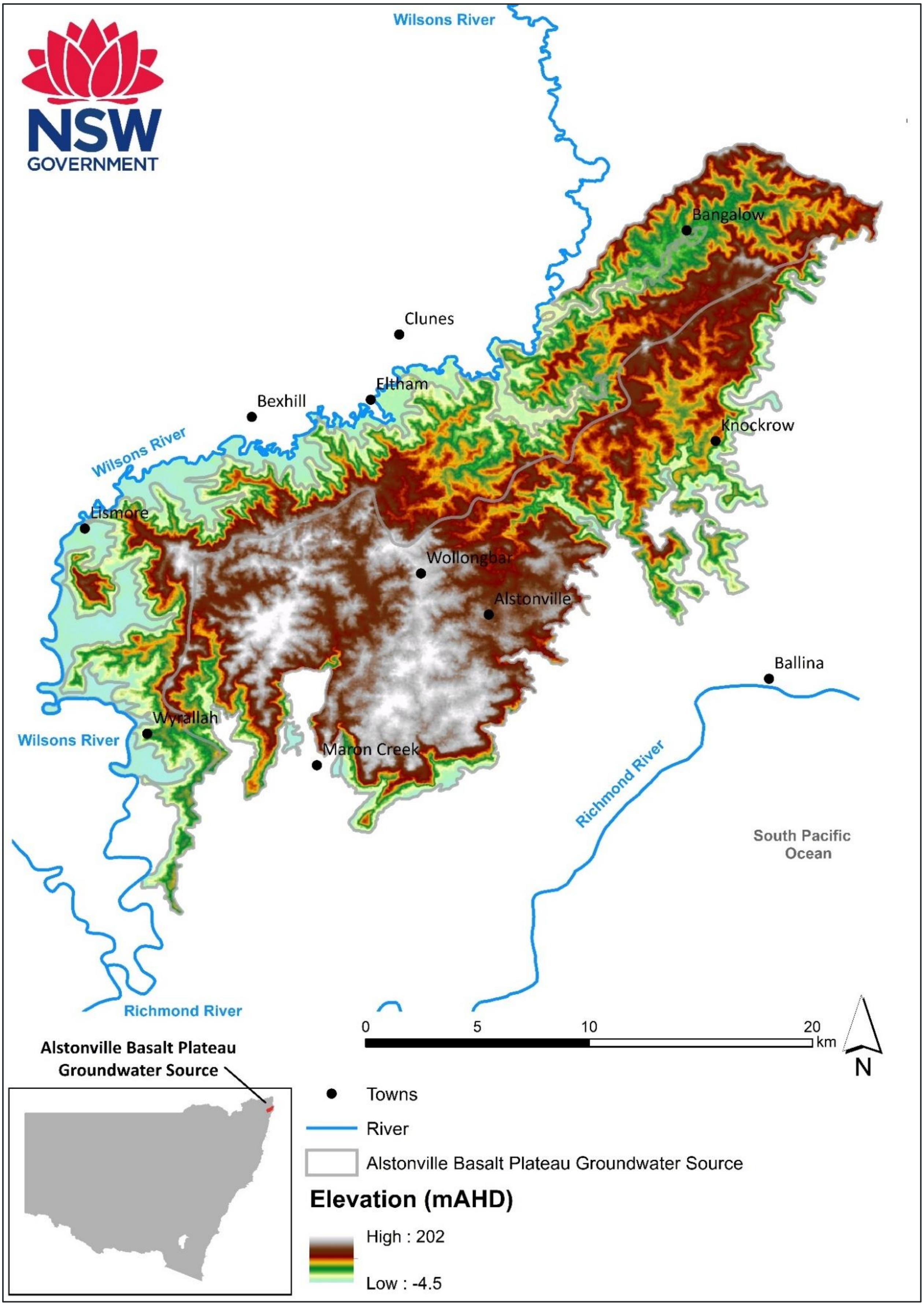
2.1 Topography

The plateau landscape of the Alstonville Basalt is a series of gently undulating hills that rises up to 200 metres above the coastal plain. The southern extent between Marom Creek and Wollongbar has the highest elevation (**Figure 3**) and is less dissected than the northern part.

Landscape features reflect the underlying basalt, such as structural benching caused by resistant basalt. Platforms can create small waterfalls and cascades on the plateau edge when crosscut by drainage lines (Brodie and Green, 2005).

The eastern boundary is characterised by a narrow and low plain of sand dunes, swamps and lagoons along the coastline. The Wilsons River runs along the western boundary of the plateau with low-lying alluvial sediments typically at elevations between 10 to 20 mAHD. The area to the south is defined by the Tuckean Wetland (a low-lying area at or near sea level) and part of the broad alluvial floodplain associated with the Richmond River.

Figure 3 Surface elevation of Alstonville Basalt Plateau Groundwater Source in metres AHD: *NSW Foundation Spatial Data Framework - Elevation and Depth - Digital Elevation Model (ELVIS)*

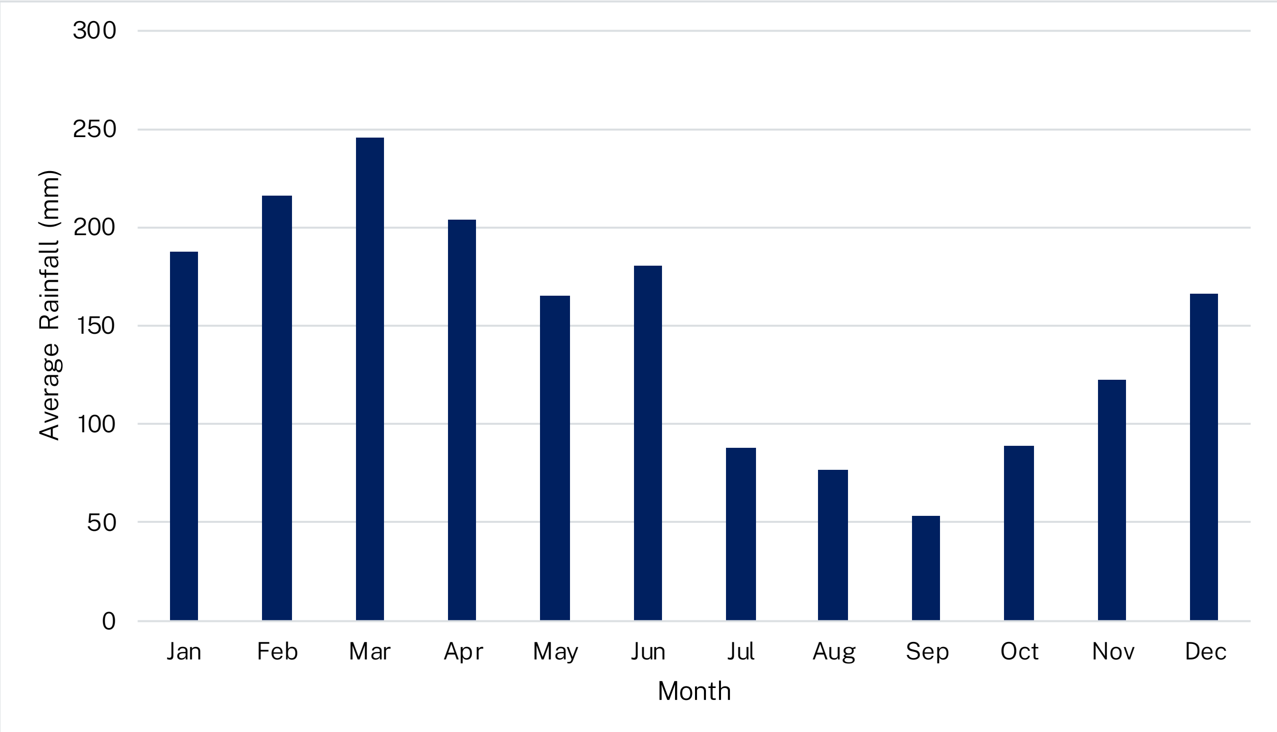


2.2 Climate

The climate on the Alstonville Basalt has relatively mild temperatures and high rainfall. This is due the plateau's latitude and elevation and proximity to the coast. The area is among the wettest in NSW with average annual rainfall at Alstonville township exceeding 1,800 mm/year. February to April are the months with highest long term average rainfall. The minimum and maximum recorded temperatures on the plateau since 2010 were 1.4°C and 37.8°C respectively.

Data from Alstonville Tropical Fruit Research Station (Station 58131) shows monthly rainfall averages between 50 and 250 mm/month, with more than 150 mm/month during December to June (**Figure 4**). March is the wettest month on average.

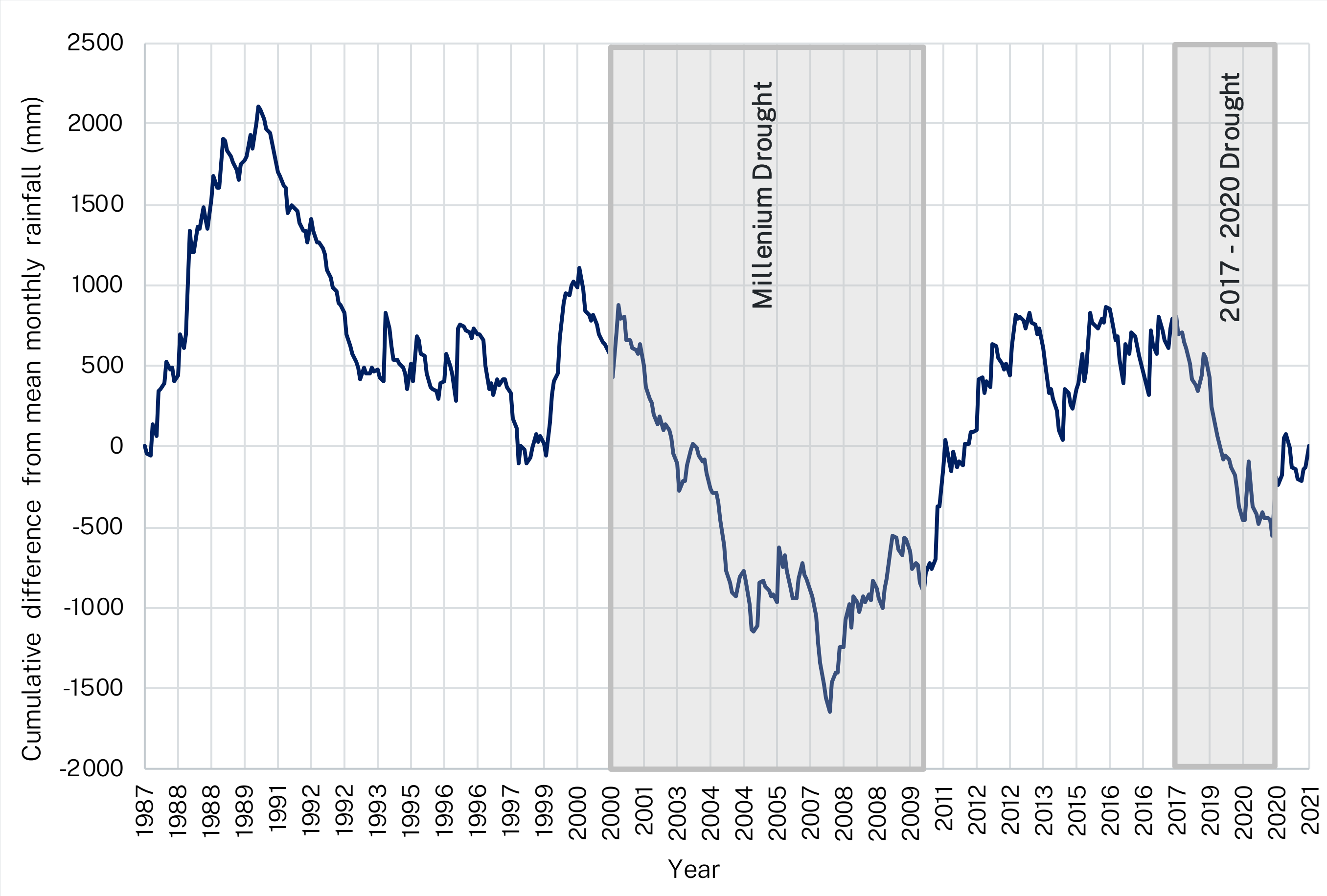
Figure 4 Average monthly rainfall Alstonville Tropical Fruit Research Station (Station 58131) 1987 – 2021



A cumulative deviation from mean rainfall (also known as rainfall residual mass) plot has been constructed for Station 58131, using daily data sourced from the Scientific Information for Landowners (SILO) database. Station 58131 was chosen due to its period of record.

This graph shows the cumulative difference from the monthly mean rainfall and provides a visual representation of the rainfall history in the area and corresponds to the period of groundwater monitoring on the plateau commenced in the late 1980's. A falling trend indicates a period of lower-than-average rainfall while a rising trend shows periods of above average rainfall (**Figure 5**).

Figure 5 Cumulative deviation from mean rainfall at Alstonville Tropical Fruit Research Station (Station number 58131)



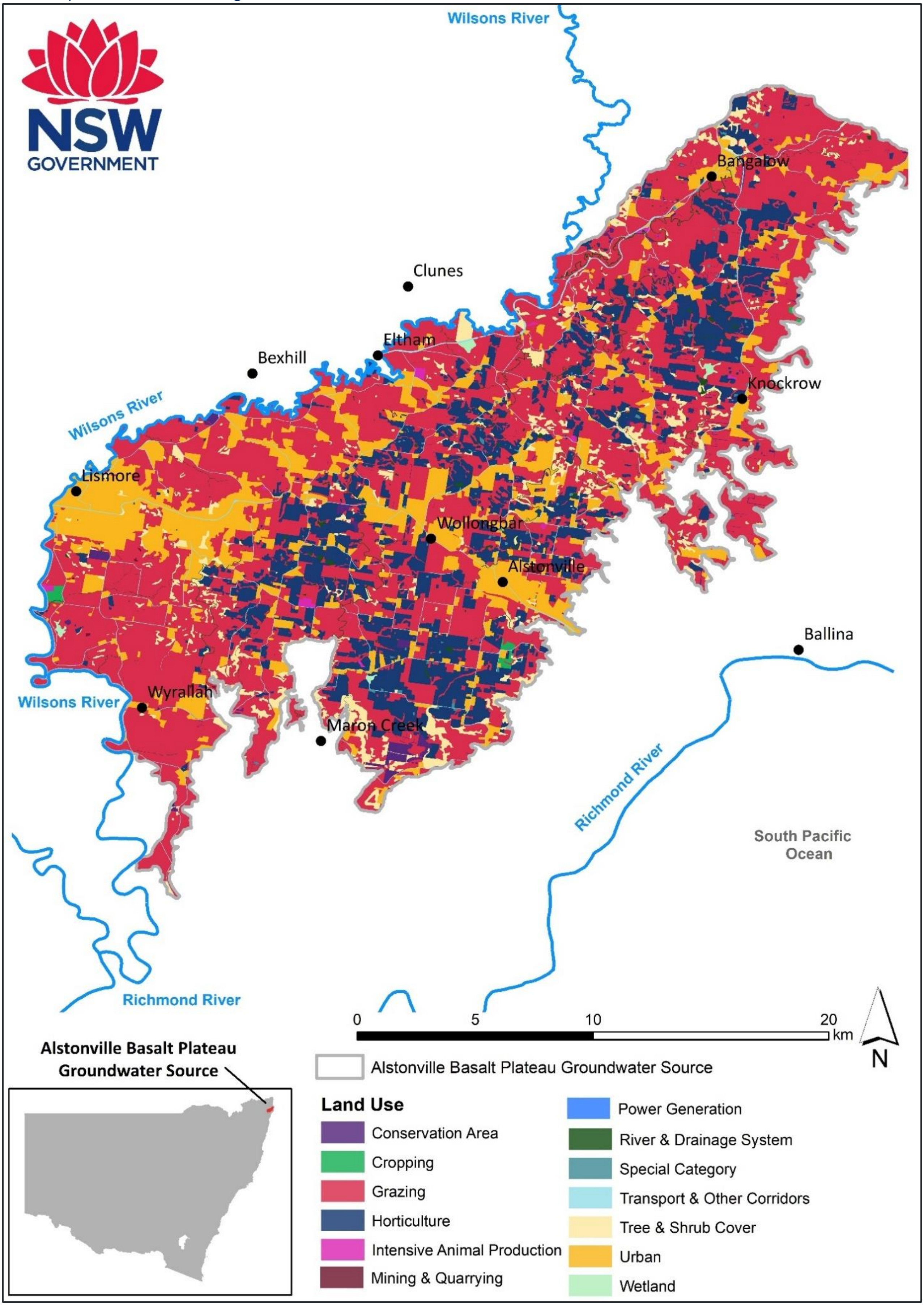
2.3 Land use

Prior to European settlement, the plateau was largely covered by rainforest. The “Big Scrub” as it was known by early settlers, was part of the largest tract of lowland sub-tropical rainforest in Australia.

The area has largely been cleared and replaced by grazing or horticultural crops. These are mostly macadamia nut plantations, with some stone fruit. **Figure 6** shows the land use types within the Plateau. The dominant land use types are grazing (57%), horticulture (17%), urban development (16%) and tree and shrub cover (5%). The area is known for producing high-quality macadamia nuts that are native to the region.

The Plateau area is becoming increasingly urbanised with development encroachment around Goonellabah westward towards Lismore and other areas around already established towns.

Figure 6 Land use on the Alstonville Basalt Plateau Groundwater Source; taken from NSW Landuse 2017 v1.2, June 2020. NSW Department of Planning and Environment, SEED Portal.



2.4 Soils

The soil types on the plateau based on Australian Soil Classification (Isbell, 2021) mapping is shown in **Figure 7**. The main soil types are ferrosols (76.3%), dermosols (16.5%), vertosols (5.1%), kurosol (1.9%).

Ferrosols (previously known as kraznozems) are the dominant soil type. The mineralogy of clays within the ferrosols is mainly kaolin, iron and aluminium oxides. These ferrosols are red clay soils that are known to be free draining.

Dermosols are the other dominant soil type and are found predominantly in the western part. These are often intermingled with vertosols and usually high in organic matter, Dermosols are also known as cracking clay soils that shrink and swell during wetting and drying phases.

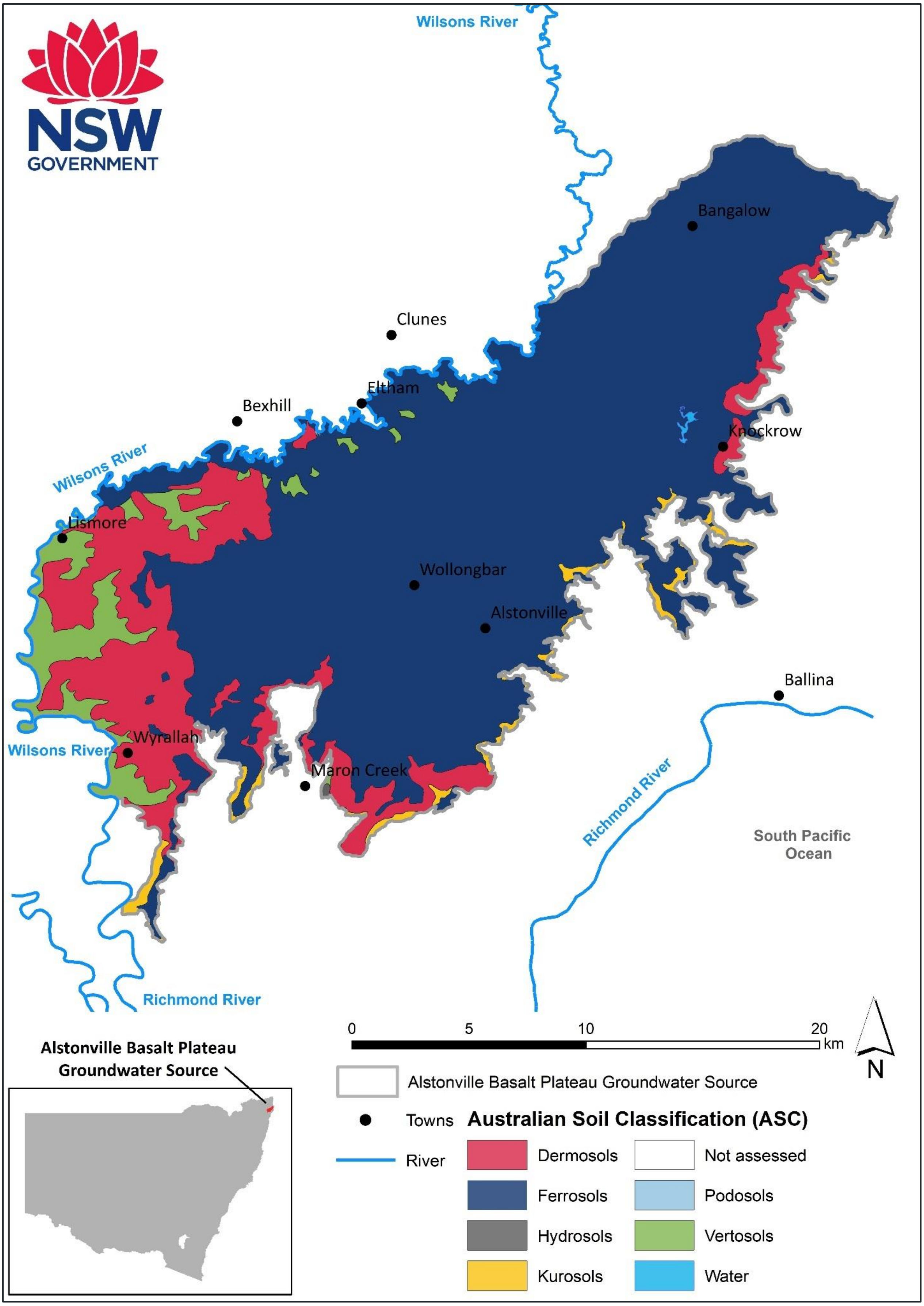
A high proportion of rainfall infiltration on the Plateau occurs from the free draining ferrosols that occupy a very large proportion of the area (76%).

2.5 Vegetation

The plateau is characterised by extensively cleared, closed-subtropical rainforest, which originally dominated the area. Remnants of rainforest can be found in reserves such as Lumley Park, Victoria Park and Davis Scrub Nature Reserves. Native species included white booyong, black bean, hoop pine, and figs such as pepperberry-fig, strangling fig.

Present day vegetation on the Plateau is dominated by closed grassland with extensive areas of closed-forest communities of the non-native camphor laurel. The majority of grass species area kakuya and paspalum, however blady grass and kangaroo grass are also present. Minor areas of coastal banksia are present in places and are demonstrative of the free-draining nature of ferrosols on the Plateau. The western part of the Plateau, in areas of extensively cleared remnant forest, contains Eucalypts such as tallowwood, red bloodwood, Sydney blue gum and black ironbark (Morand 1994).

Figure 7 Soils of the Alstonville Basalt Plateau Groundwater Source; taken from the Australian Soil Classification (ASC) Soil Type map of NSW, Version 4.5. NSW Department of Planning and Environment, 2021. SEED Portal.



2.6 Geology

The geology of the Plateau and surrounding areas has been described in detail by Chesnut and Swane 1976, and Brodie and Green 2005. A brief summary is provided below.

The Alstonville Basalt consists of a sequence of Cenozoic (23 million years in age) basaltic flows and interbedded sediments of the Lismore Basalt. The Lismore Basalt extends further to the west of the Wilsons River and forms part of the North Coast Volcanics Groundwater Source. The sequence unconformably overlies older sediments and metasediments.

The Paleozoic (420 to 220 million years old) metasediments of the New England Fold Belt outcrop to the east and underlie the basalt flows in the eastern part of the groundwater source. The Mesozoic (Triassic to Cretaceous) sediments of the Clarence Moreton Basin forms the basement in the central and western parts of Alstonville Basalt.

2.7 Hydrogeology

The Alstonville Basalt consists of a series of basalt flows with a combined maximum thickness estimated to be 170 m to 220 m. The sequence dips gently to the northwest. Aquifers within the flows generally consist of weathered basalt, medium to highly fractured or vesicular basalt, old soil profiles or sediments.

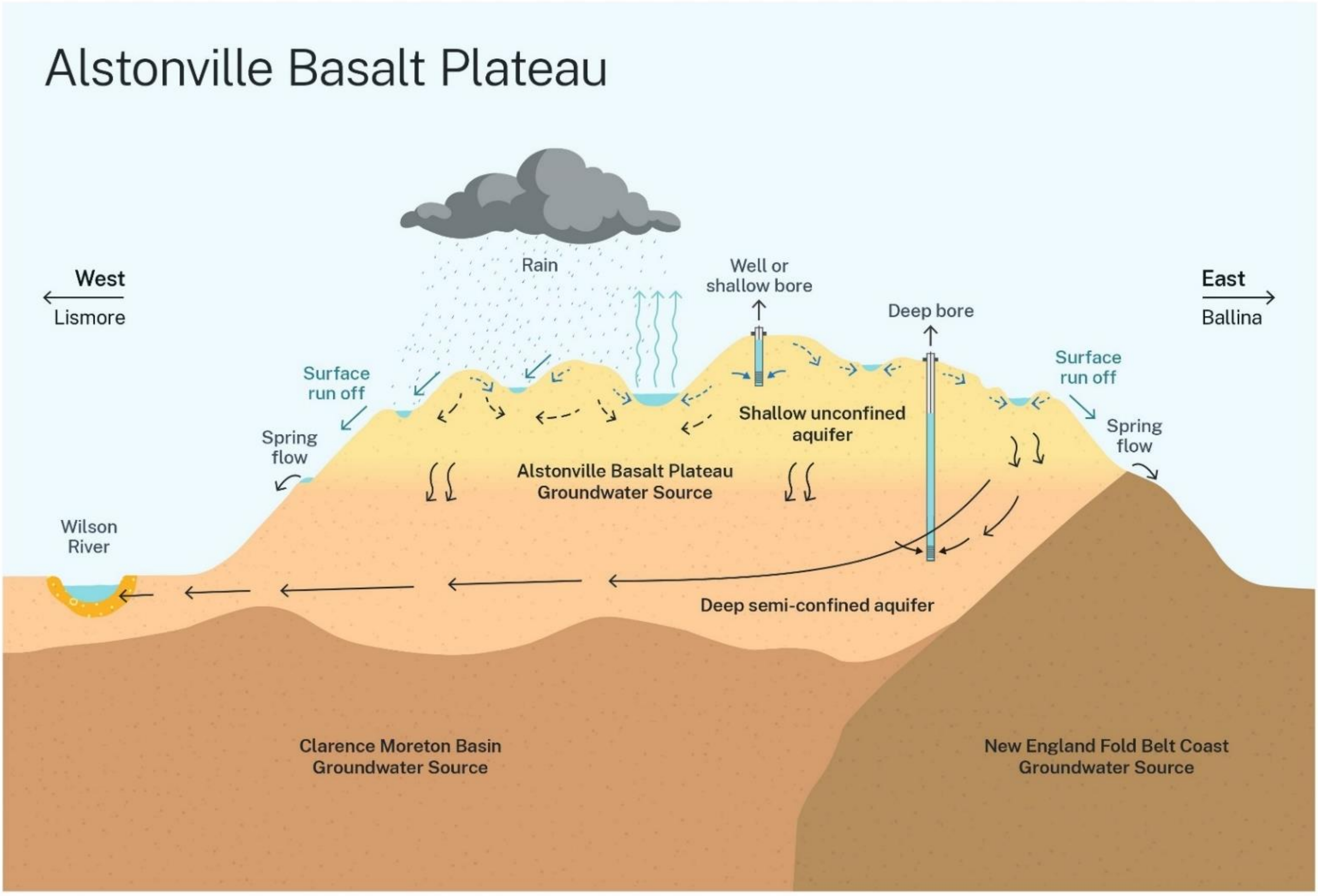
The groundwater can be broadly subdivided into 2 groundwater flow systems, summarised in **Table 1** Alstonville Basalt hydrogeological properties, and below:

- A shallow, generally less than 40 m thick, unconfined system within the upper sequence of the basalt that is weathered or highly fractured. It exceeds 40 m in some places depending largely on the depth of fracturing.
- A deeper, interlayered, and fractured, semi-confined system with a highly variable base and a maximum depth of approximately 170 to 220 m below ground surface.

The deeper aquifers are found in the buried weathered horizons, the vesicular or highly fractured components of basaltic flows and interbedded fluvial deposits. These deeper aquifers discharge to river baseflows, and as springs or seepages at the base of plateau valleys or the plateau escarpment.

A conceptual model of the Alstonville Basalt is shown in **Figure 8**.

Figure 8 Conceptual model of the Alstonville Basalt Plateau Groundwater Source



2.7.1 Shallow aquifer system

The upper most (or shallowest) unconfined aquifer has variable thickness, generally less than 40 m, depending on the depth of weathering or fracturing and local topography. The reported bore yields in the shallow aquifer are highly variable, ranging 0.1 – 12.5 L/s with an average of around 1.4 L /s.

Recharge to this aquifer is predominantly from rainfall. The permeable nature of the overlying soils means there is significant infiltration from rainfall. This is also evident from water level responses in the shallow aquifer due to rainfall (**Figure 9**).

Groundwater flow in the shallow aquifer system depends largely on topography, weathering, degree of fracturing and the nature of the underlying basalt flow (massive and/or degree of fracturing) that separates it from the deeper aquifer.

This shallow aquifer provides important baseflow to streams and creeks, supports the many springs and seepages and is highly vulnerable to droughts, frequency of low rainfall events and shallow pumping. It is also the main source of inflow to the deep aquifer system.

2.7.2 Deep aquifer system

The deep aquifer (or aquifers) consists of a sequence of sub-horizontal, generally vesicular, and highly fractured basalt flows with interbedded fluvial deposits. These interlayered and fractured horizons can be separated and confined by relatively thick sequences of massive to poorly fractured basalt. The tops of lava flows can have high permeability due to vertical columnar jointing (**Figure** 10) and vesicles that formed because of rapid cooling and gas escape (Brodie et al). Drilling information indicates the aquifers have a gentle north-westerly dip that is controlled by the paleo-topography (that is, the pre-Cenozoic surface).

The reported bore yields in the deeper aquifer are also highly variable, ranging 0.1 - 48 L/s with a higher average of 2 L/s. Inflow to this deeper aquifer system occurs mainly through vertical leakage from the overlying shallow aquifer and depends on the degree of vertical interconnection through jointing and fracturing. The thick sequence of massive to poorly fractured basalt between the fractured water bearing horizons (aquifers) restricts vertical leakage or movement of groundwater.

Groundwater levels in these deep aquifers do not respond quickly to significant rainfall events. It flows towards the northwest controlled largely by the dip of the volcanic sequence (Brodie & Green). Isotope samples collected in May 2021 confirm that the deep groundwater age is over 11,000 years BP as a minimum (years before present).

Groundwater in the deep aquifer also discharges at lower levels in the landscape as springs or baseflow depending on the relative position of the aquifer within the basaltic sequence and the level of dissection. The deep aquifers have been developed mostly for more secure groundwater supply.

Table 1 Alstonville Basalt hydrogeological properties

Alstonville Basalt	Description
Geological age	Cenozoic (23 million years)
Depth	Highly variable, with a maximum of approximately 220 m
Bore yields	Shallow aquifer (up to 40 mbgl) range 0.1 to 12.5 L/s with an average of 1.4 L/s. Deep aquifer (greater than 40 mbgl) range 0.1 to 48 L/s with an average of 2 L/s.
Electrical conductivity	Range from 75 to 1,500 µS/cm from 2021 sampling of government monitoring bores.
Aquifer type	Unconfined, semi-confined/confined
Estimated hydraulic conductivity	0.02 to 0.1 m/d (DPE numerical model 2003)
Transmissivity (from pumping tests)	Variable with a maximum of 200 m^2/d

Alstonville Basalt	Description
Specific yield/Storage coefficient	Sy = 0.09 to 0.1 SY (DPE numerical model 2003) S = 0.000001 to 0.001 (DPE numerical model 2003)
Groundwater flow direction	East to northwest
Recharge estimates	50,079 ML per year (based on long-term average annual rainfall recharge)
Age of deep groundwater (years BP)	11,000 to 30,000 (from 2021 age dating results)

Figure 9 Correlation between shallow groundwater levels and rainfall

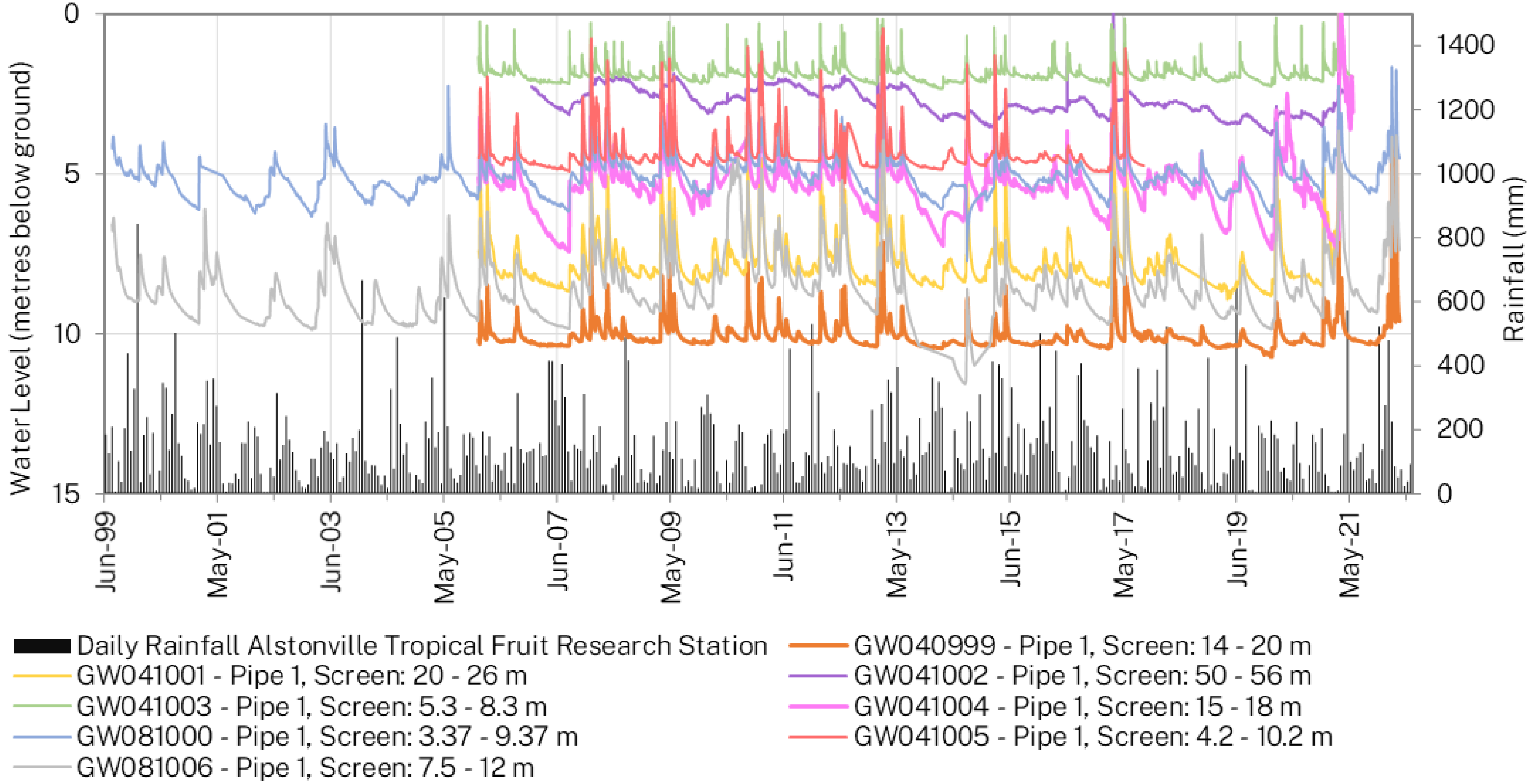


Figure 10 Profile of columnar basalt on Pearces Creek Road cutting, adjacent to Lumley Park, Alstonville

2.8 Geological sections

Five cross sections were constructed for the Alstonville Basalt using the available borehole logs. The locations of these sections are shown on **Figure 11** below. The cross sections were constructed using elevation data from Geoscience Australia's *Elevation and Depth Digital Elevation Model* (ELVIS) and bore logs from government monitoring and private bores.

The contact between the Clarence Moreton Basin and the New England Fold Belt Coast is an inferred boundary. No bore data was available to validate the inferred depth.

Figure 12 below shows a long section (southwest to northeast) that extends the entire length of the water source (approx. 35 km). The Alstonville Basalt overlies the New England Fold Belt Coast Groundwater Source in the north. Its thickness on this section typically ranges between 50 - 100 m. However, to the south it is much thicker (>150 m) and overlies the Clarence Moreton Basin Groundwater Source.

Figure 11 Topographic map with elevation profile showing cross section transects

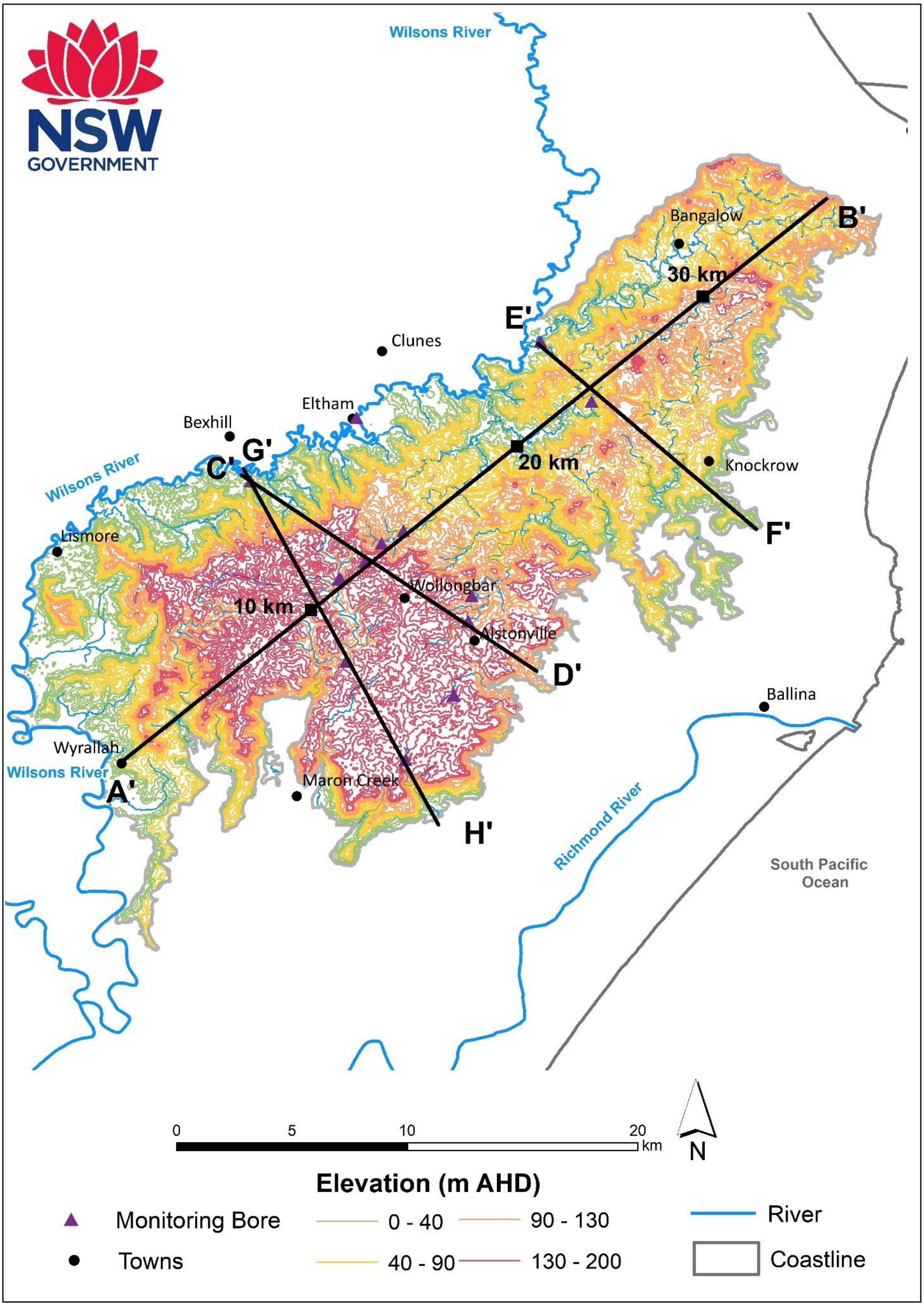


Figure 12 Alstonville Basalt Plateau Cross Section - A' B'

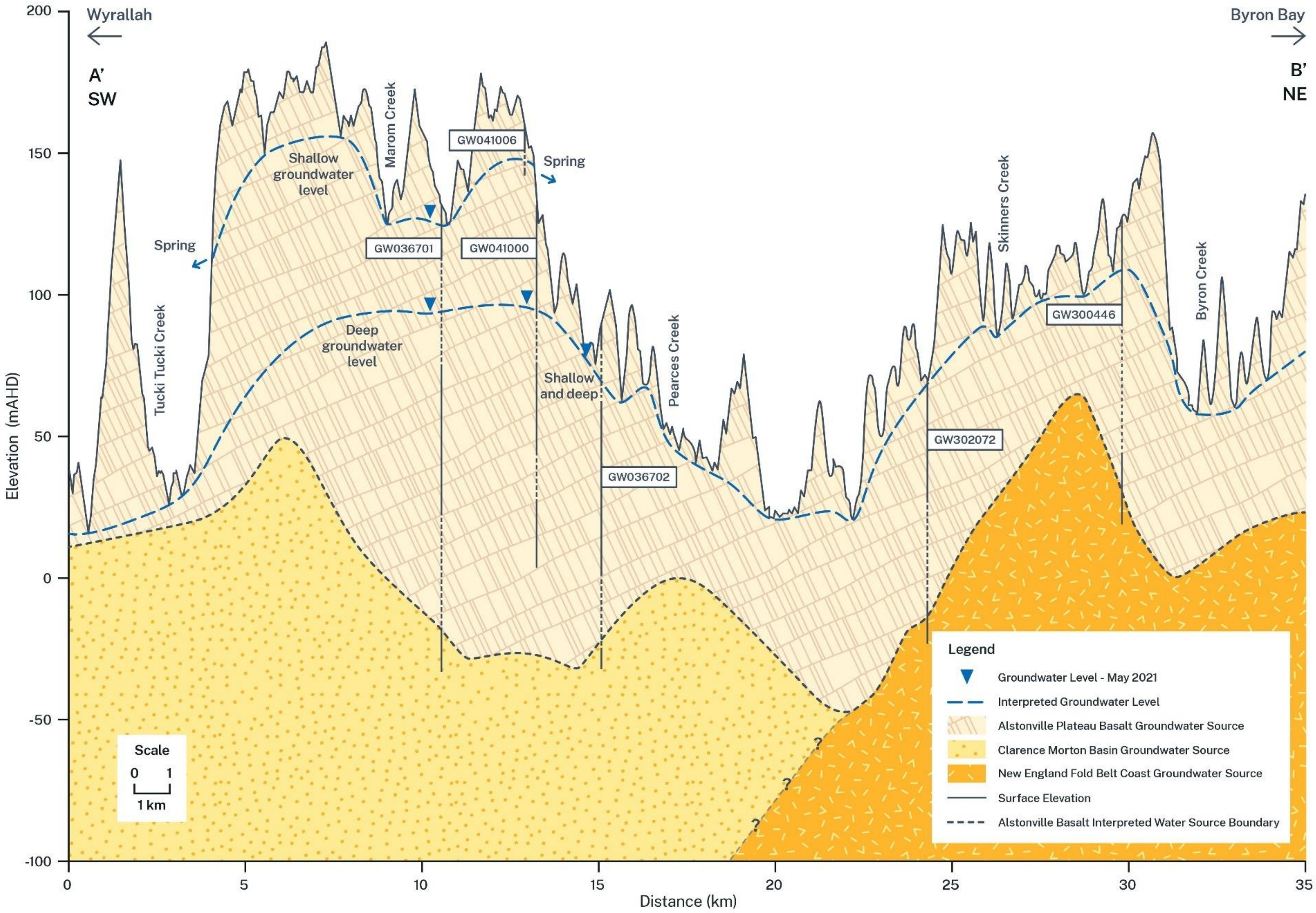


Figure 13 shows a southeast-northwest section in the northern part of the groundwater source. The basalt is relatively thin in the east (50 m). The thickness increases towards the central part to greater than 100 m, before thinning to the west towards Byron Creek.

The Alstonville Basalt is mostly underlain by the fractured rocks of the New England Fold Belt Coast Groundwater Source along this section, except in the west where the porous rocks of the Clarence Moreton Groundwater Source are thought to be present beneath the basalt. Basement mapping however is based on very limited deep bore drilling data in this area.

Figure 13 Alstonville Basalt Plateau Cross Section - E' F'

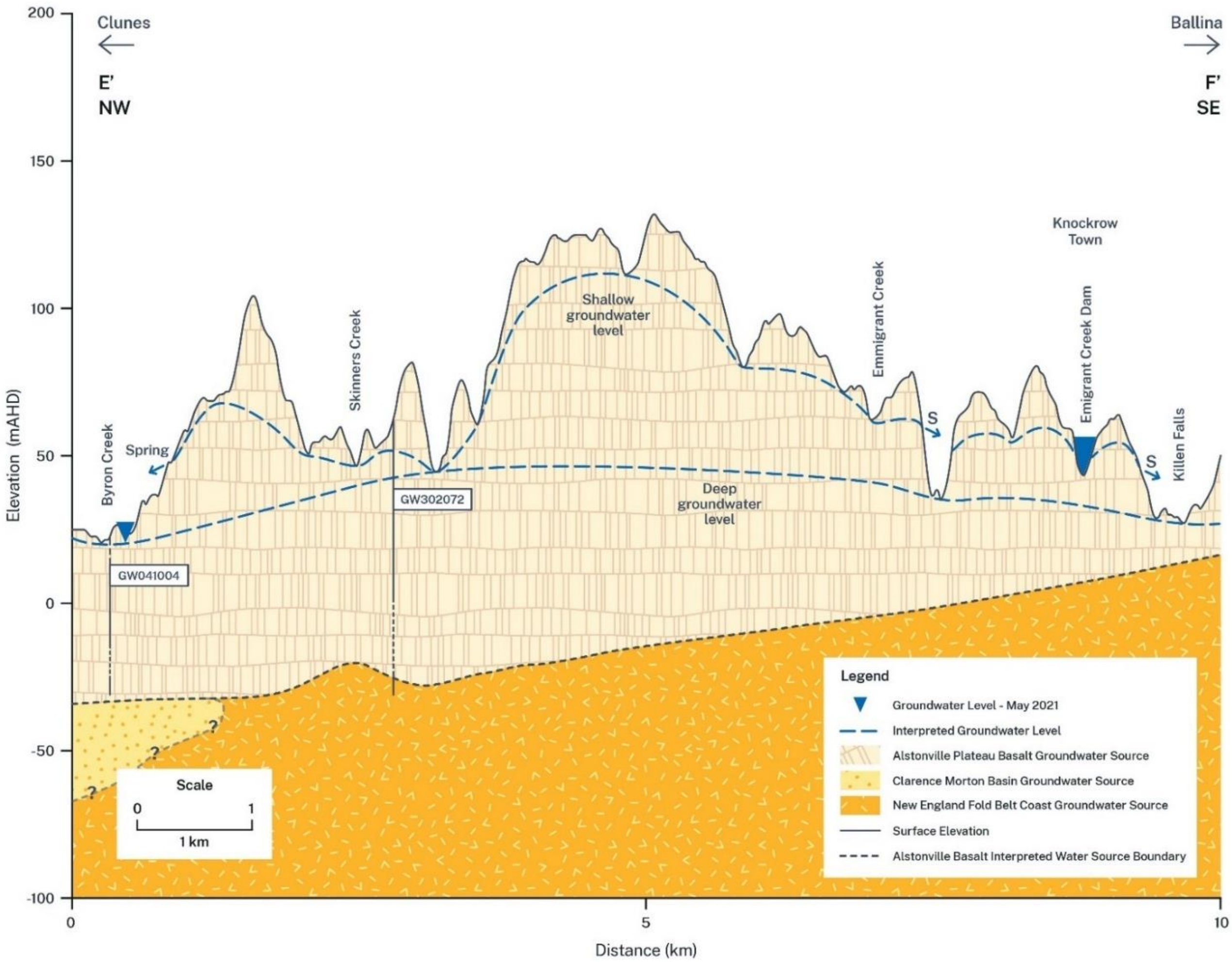


Figure 14 displays a southeast-northwest section in the central part of the groundwater source. The thickness of the basalt increases from east to west with an estimated maximum of about 220 m in the central part of the groundwater source near Wollongbar. The porous rocks of the Clarence Moreton Groundwater Source underlie the basalt along the entire length of the section. These porous rocks are interpreted to be underlain by the fractured rocks of the New England Fold Belt in the eastern part.

The elevation of the Plateau reduces towards the north-western edge close to Wilsons River by some 150 m and it is here the deep system is likely to be providing baseflow to the river. The shallow aquifer in the central and eastern parts provide baseflow to the creeks/streams. Groundwater flow in the deep semi-confined to confined aquifer appears to be influenced by the pre-Cenozoic topography and the gentle north-westerly dip of the basalt flows.

Figure 14 Alstonville Basalt Plateau Cross Section - C' D'

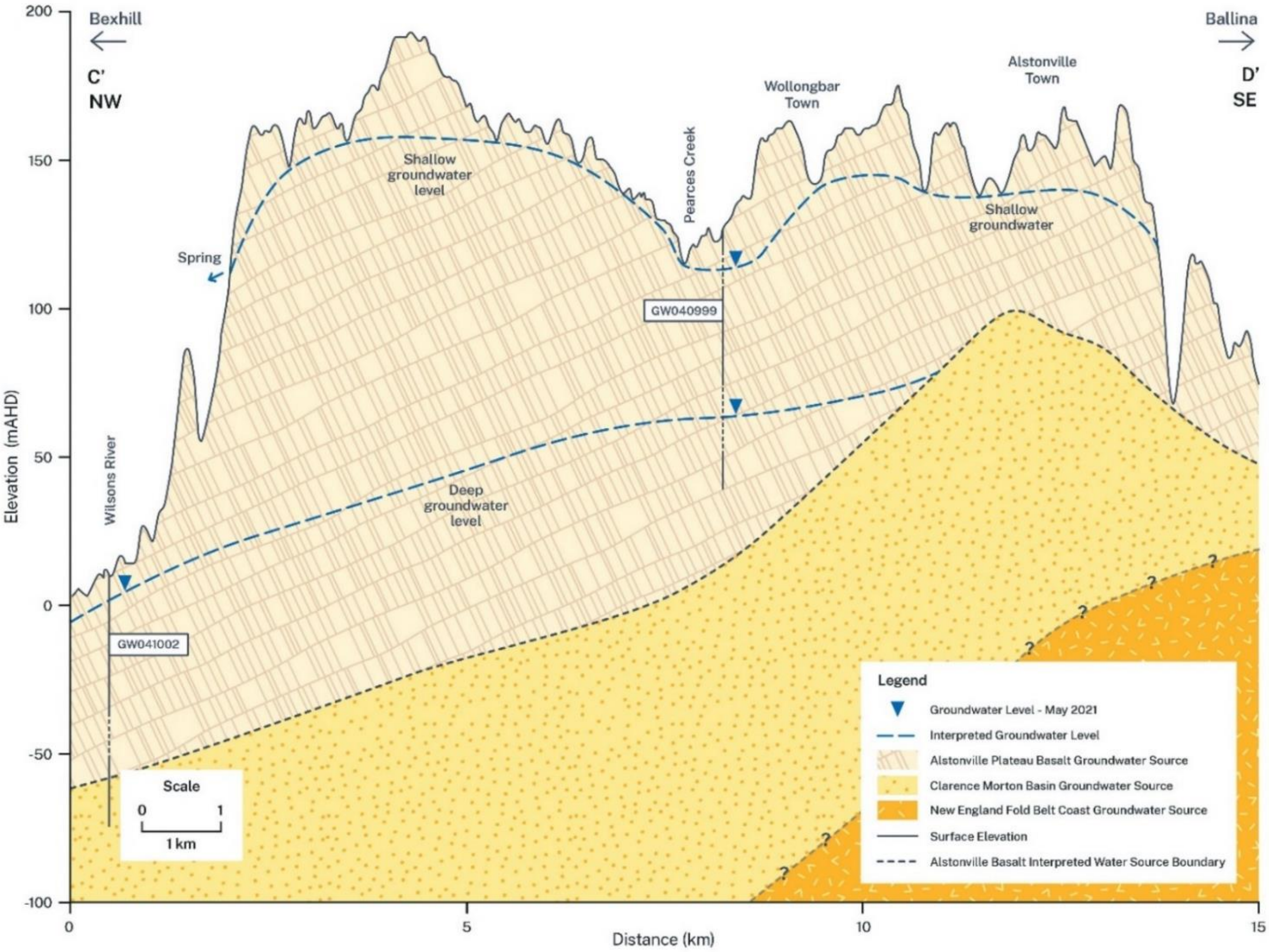
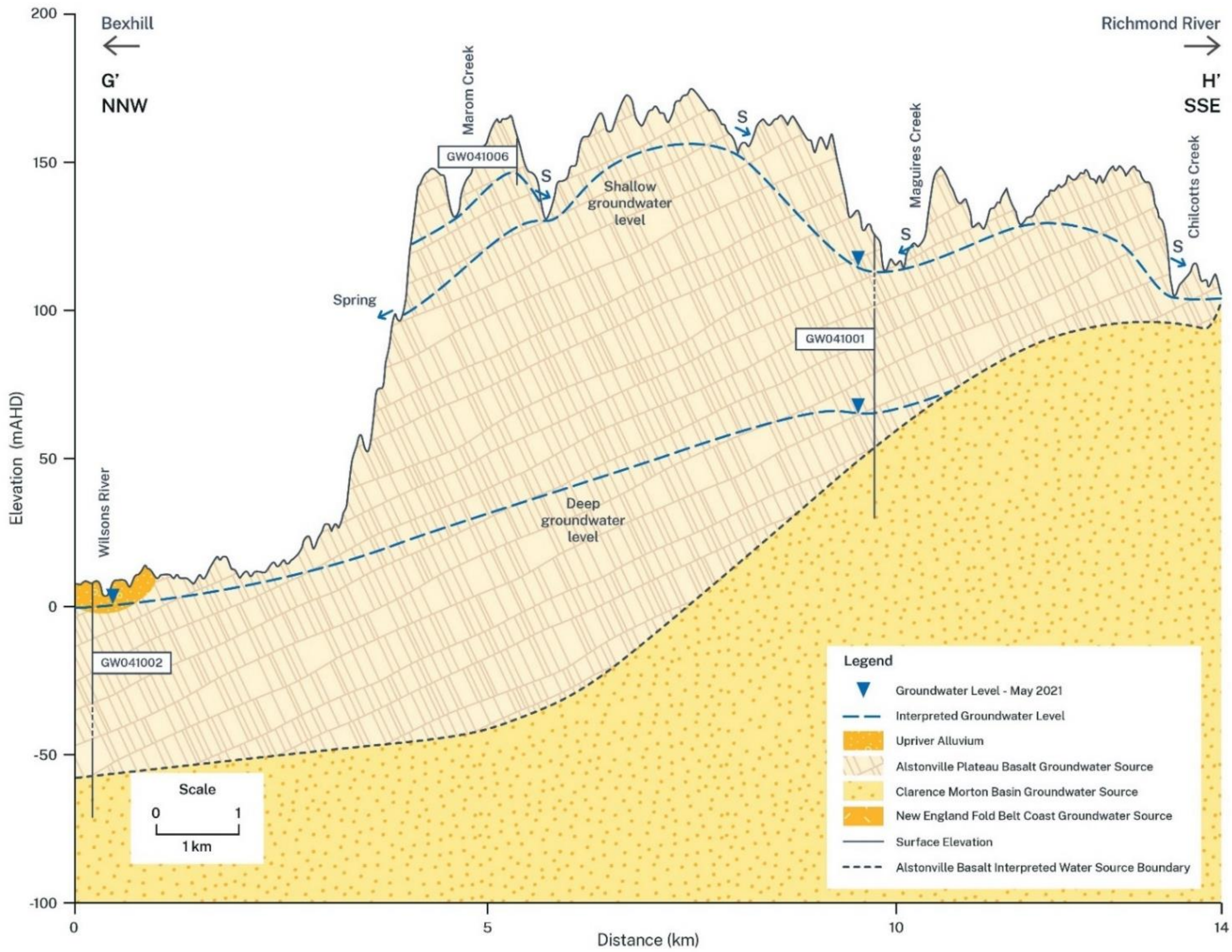


Figure 15 displays a southeast-northwest section in the southern part of the groundwater source. The Alstonville Basalt is the thickest in the central part of the section is underlain by porous rocks of the Clarence Moreton Basin along the entire length of the section. As shown in **Figure 13**, the deep aquifer system is likely to be providing baseflow to Wilsons River and the shallower aquifer discharges into the creeks/streams in the central and eastern parts.

Figure 15 Alstonville Basalt Plateau Cross Section - G' H'



2.9 Recharge

Groundwater sources generally store large volumes of water, and the amount of annual recharge is often relatively small compared to the stored volume. The existing Plan does not allow access to the storage component of the groundwater source over the long-term to protect it from being depleted by extraction.

Recharge to the Alstonville Basalt occurs primarily through infiltration from rainfall and runoff and surface water within the outcropping areas. However, some inflow to the fractured rock aquifer can also occur from leakage from the overlying alluvial sediments. It should also be recognised about 76% of the plateau area is dominated by free draining ferrosols. This results in a high proportion of infiltration from rainfall on the plateau.

The average annual recharge in Alstonville Basalt has been estimated based on a rainfall recharge rate of 8% (Bish & Ross, 2001). This is estimated to be 50,079 megalitres per year.

2.10 Connection with surface water

Surface water features on the Alstonville Basalt are shown in **Figure 16.** Connection between the groundwater and surface water systems within the Alstonville Basalt is largely dependent on the degree and extent of fracturing of the basalt. That is, it depends on whether fractures extend to the bed of the creeks and rivers, or to the base of more permeable weathered surface that the creeks and rivers have eroded into.

There is generally a high degree of connectivity between the shallow aquifer and streams on the plateau. The more dissected major streams on the plateau such as Marom Creek and Maguires Creek can also intersect aquifers at intermediate depths (>50 m), resulting in groundwater discharge as spring and baseflow towards the base of the Plateau.

Figure 8 demonstrates how groundwater contributes to plateau streams from mid-slope springs or seepage areas along the watercourse. Groundwater discharge from even deeper aquifers that are exposed along the plateau scarp can also contribute to flow in downstream reaches of the major streams.

Seepage from the shallow aquifer has been documented (Brodie, 2007) to maintain stream flow for weeks or months after significant rainfall events. The shallow aquifer acts as a storage unit, slowly releasing water to streams long after surface runoff. **Figure 17** below shows characteristic groundwater seepage in the upper reaches of the Plateau. Iron staining is a common feature of the seepage areas. The soils (ferrosols) and the weathered basalt profile are the primary source of the iron.

Ross et al (1989) estimated the groundwater outflow for the Marom Creek catchment between 3 to 8 ML per day (1989). This confirms that a significant cause of water level decline during the dry periods between rainfall events is likely groundwater drainage in the forms of springs and seeps. A photo of Marom Creek is shown in **Figure 21.**

Figure 16 Surface water features on the Alstonville Basalt Plateau

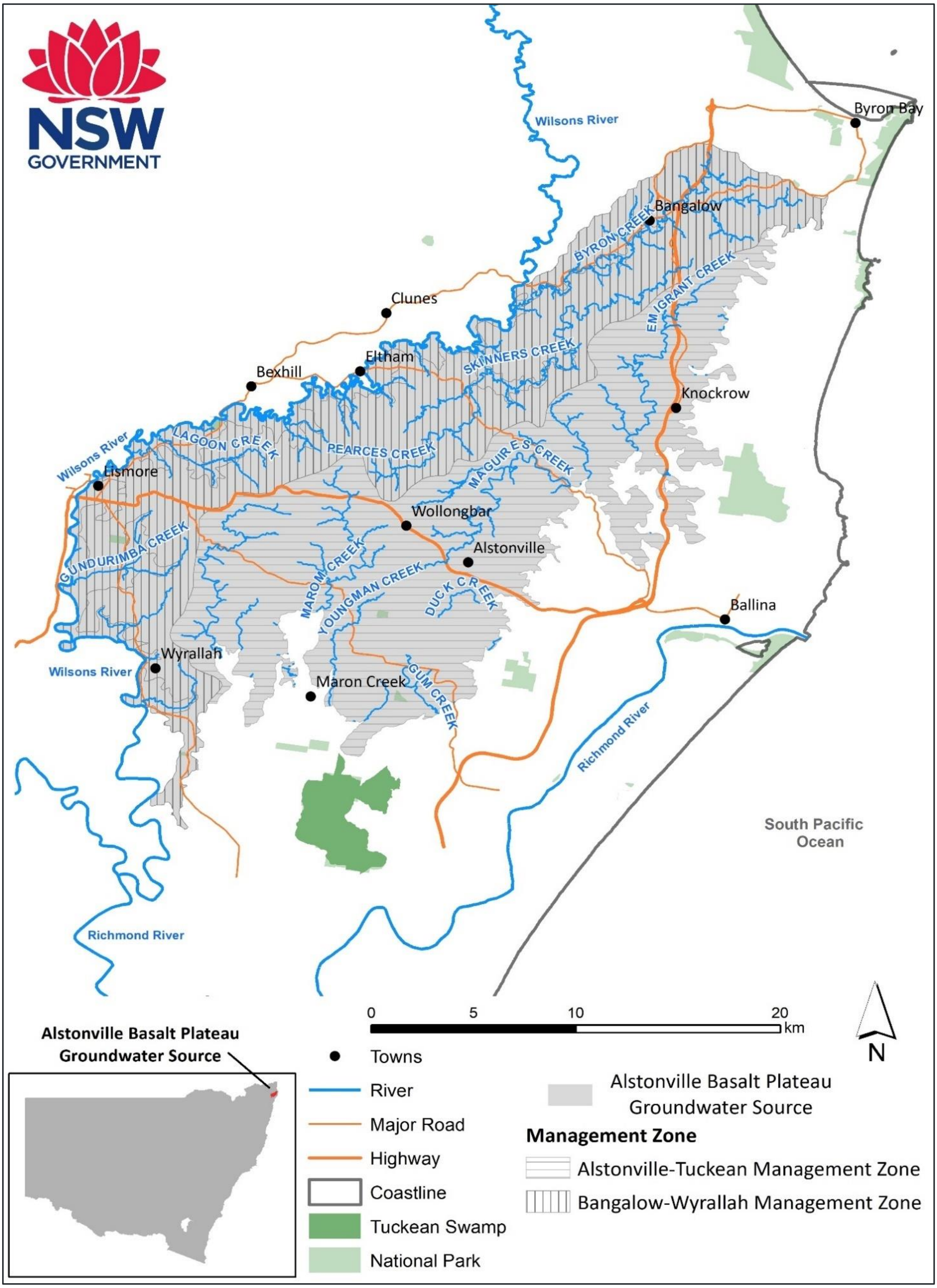


Figure 17 Spring seepage at the Wollongbar Agricultural Station, adjacent to monitoring bore GW036701

The interaction of groundwater with stream flow is shown in **Figure 18**, the hydrograph for shallow monitoring bore GW081000 located approximately 175 metres from Gum Creek, and in **Figure 18**, the cross section at Gum Creek, showing the gaining and losing behaviour of Gum Creek.

Figure 18 Transect through monitoring bore GW081000 and Gum creek, and hydrograph

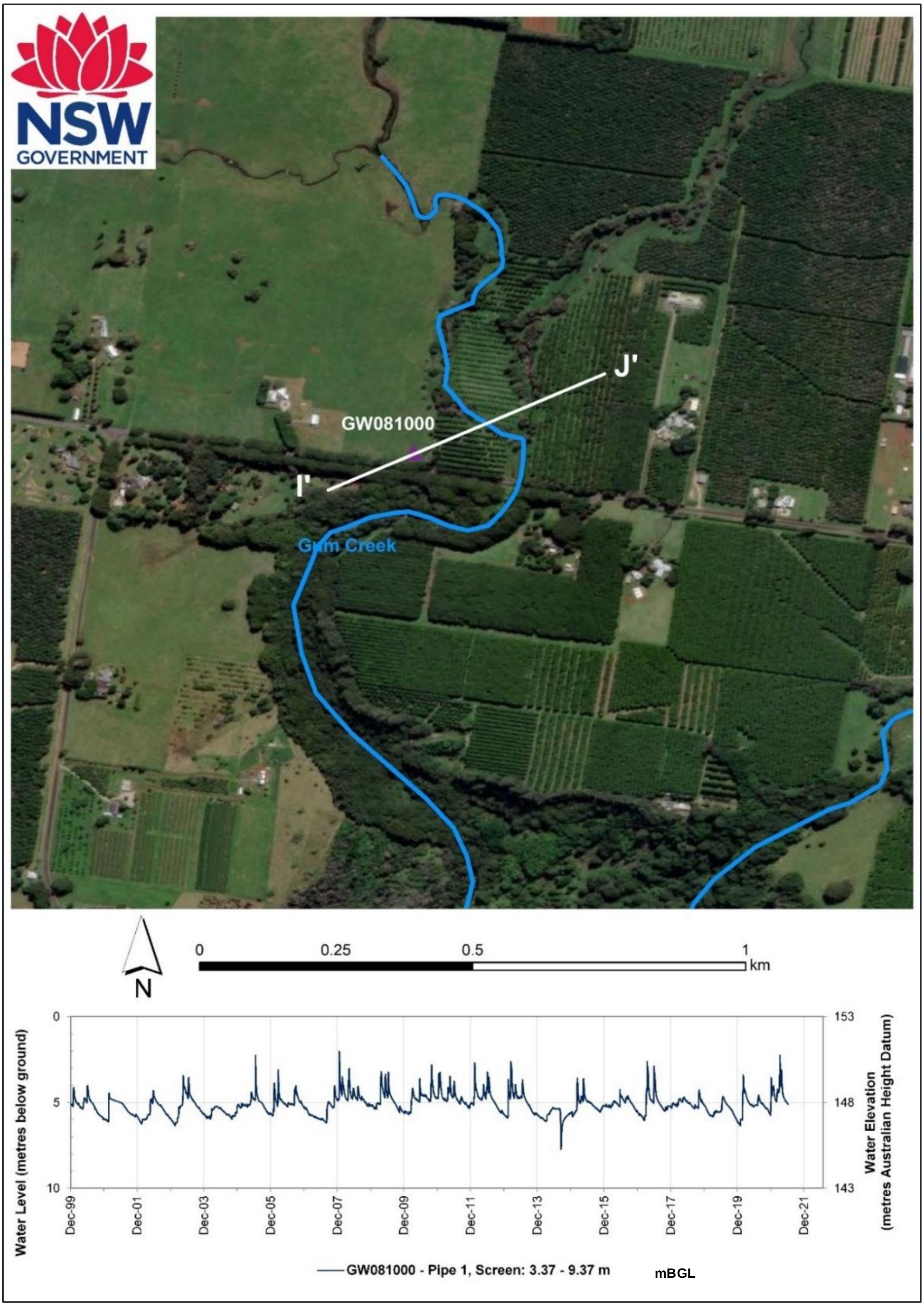
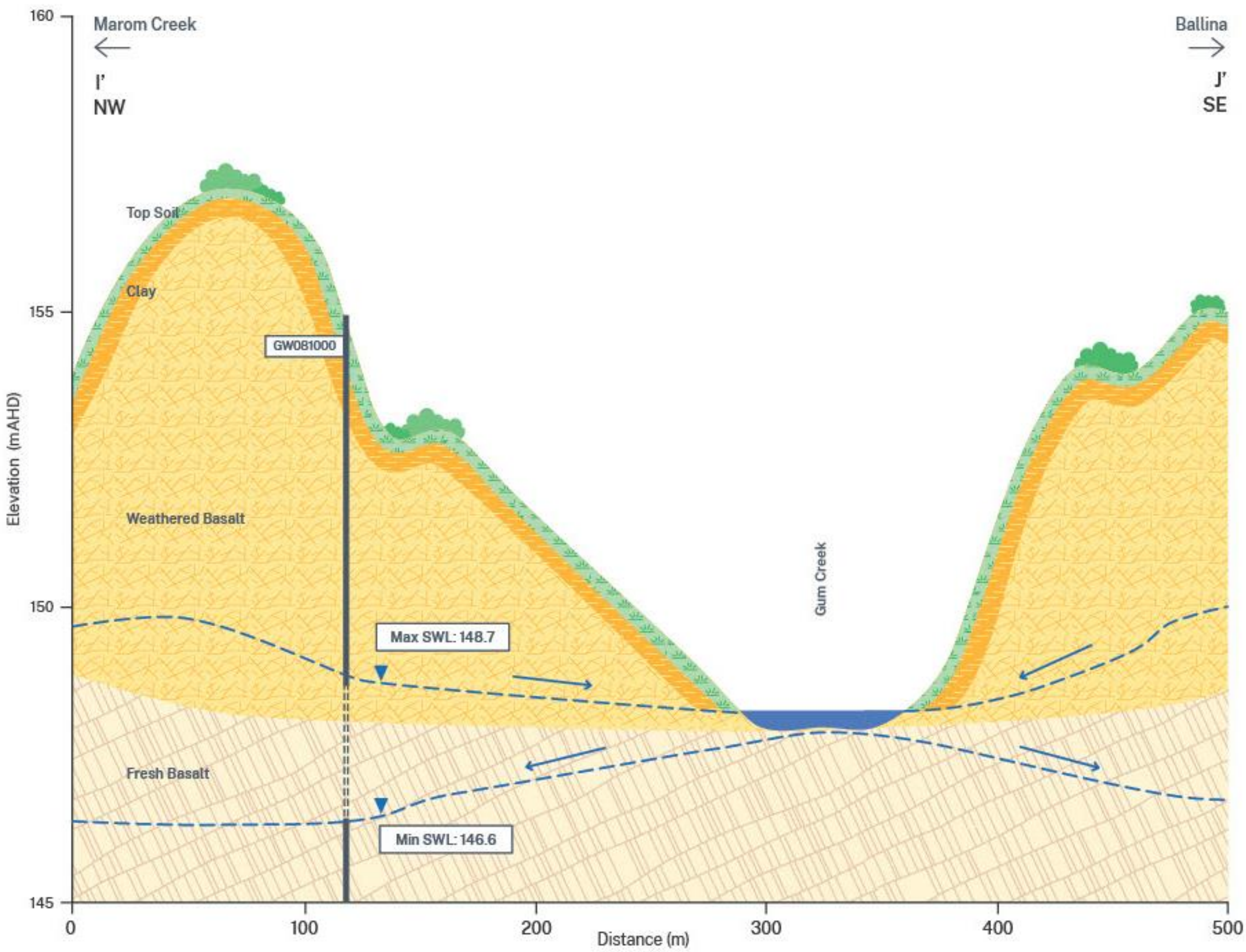


Figure 19 Cross section of Gum Creek and monitoring bore GW081000.



Brodie (2007) found that the southern boundary of the plateau is typical of this type of interaction, particularly in the upper reaches. In this area creeks are incised into locations which correspond to shallow aquifers consisting of mostly weathered and fractured basalts (for example, Duck Creek). The extent of downward leakage from the stream into the deeper aquifer in this area would depend on the hydraulic conductivity of the stream bed material and the weathered basalt profile.

Figure 20, Killen Falls at Emigrant Creek, shows surface flow over an area of massive basalt underlain by columnar-jointed basalt. It is in these jointed reaches of creeks/streams that water is likely to leak to the deeper aquifers. Both Killen Falls at Emigrant Creek and Gum Creek are close to the eastern edge of the Plateau.

Figure 20 Stream flow Killen Falls at Emigrant Creek over laminar basaltic flow and columnar jointed basalt to the far right

Figure 21 Surface water flow at Marom Creek on Wollongbar Agricultural Station

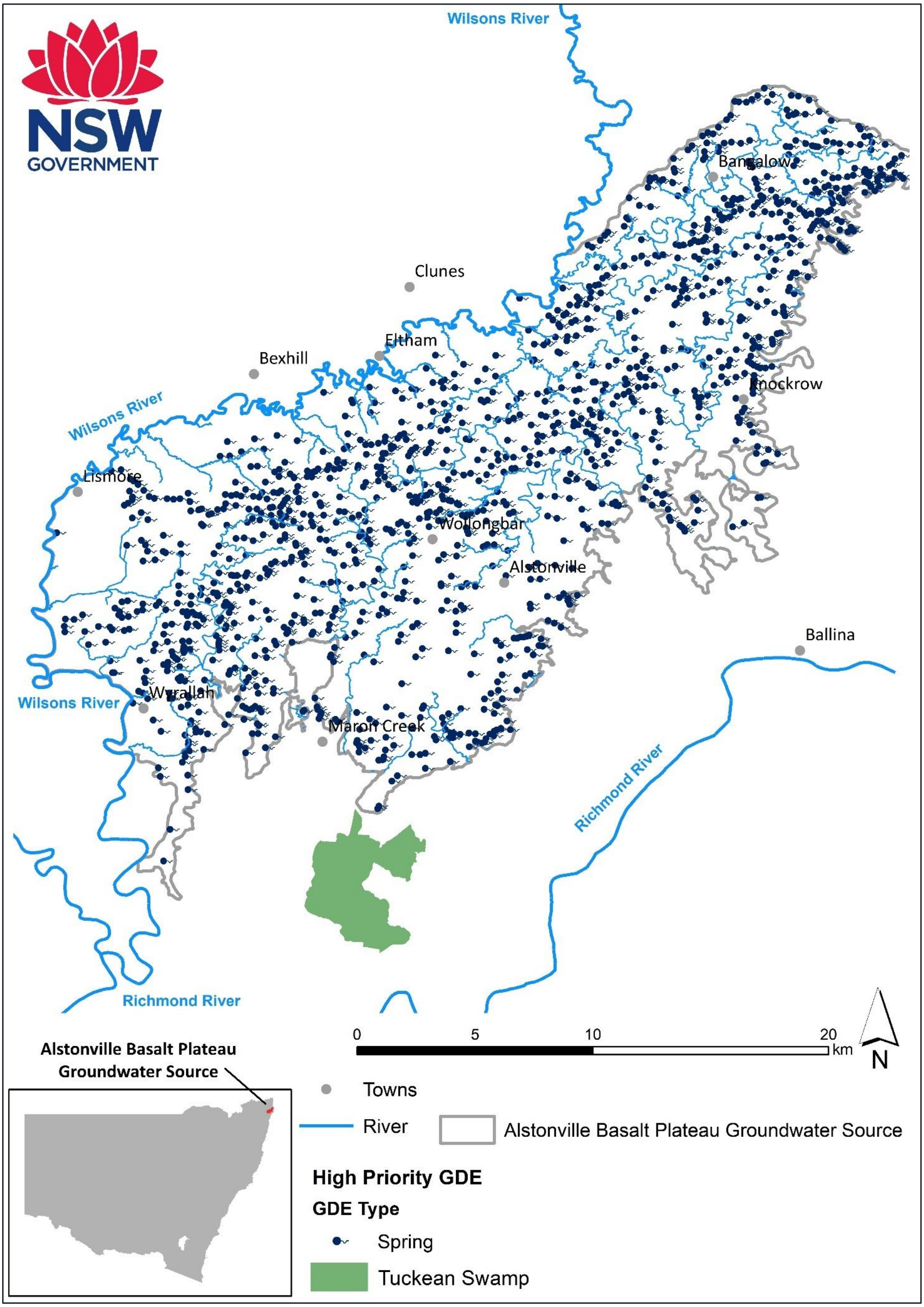
3 Groundwater-dependent ecosystems

Groundwater dependent ecosystems (GDEs) are defined as ‘ecosystems that need access to groundwater to meet all or some of their water requirements to maintain their communities of plants and animals, ecological processes and ecosystem services’. GDEs include a broad range of environments and can be highly specialised, with unique characteristics that ‘separate’ them from other ecosystems.

The Alstonville Basalt has a high degree of connectivity between the surface water and groundwater. The permeable ferrosol soils, in combination with the underlying weathered and fractured basalt, form an important shallow unconfined aquifer, reflected in hill-slope springs and significant base flow to streams (**Figure 19**).

The numerous springs and seepage zones, particularly near local streams, indicate where groundwater emerges at the land surface. These form ecosystems that are highly dependent on groundwater for their water requirements. Some of these wetlands are dominated by melaleuca and are used as an over-wintering food source by migratory birds. Other seepages are dominated by sedges or bull rush and provide important bird habitat. **Figure 22** below shows the mapped ‘High - Priority Groundwater Dependent Ecosystems’ gazetted in the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016.

Figure 22 Groundwater dependent ecosystems (GDEs) of the Alstonville Basalt Plateau Groundwater Source



4 Groundwater management

4.1 History of groundwater management

The *Water Act 1912* was introduced at a time when developing water resources for agriculture and regional development were a government priority (DLWC, 1999). Under this Act, groundwater entitlement was linked to land rights and licences for bores and wells were granted for a fixed term with no restriction on the volume that could be extracted. Bore licences were initially required only for bores greater than 30 m depth in the western half of NSW.

After World War II, there was a drive to expand irrigation and promote economic development in inland NSW. In 1955, the *Water Act 1912* was amended to require all bores to be licensed irrespective of depth or location.

By the 1970s, the rapid expansion of the irrigation industry, increasing competition for water resources and extended periods of drought were affecting the reliability of water supplies in inland NSW.

Acknowledging that groundwater was a finite resource, from 1972 to 1983 new irrigation licences were issued based on the size of the area being irrigated. These licences had to be renewed every 5 years, but still had no volumetric limit on extraction (Gates et al, 1997).

From 1984, all new high yield bores and wells (greater than 20 ML/year), except those in the Great Artesian Basin, were given a volumetric entitlement and old area-based licences were progressively converted into volume-based entitlements. Volumetric entitlements were generally issued based on historical usage, property area or bore capacity.

From 1986, comprehensive volumetric groundwater allocation policies were introduced throughout the state. The objectives were to effectively manage development in those groundwater systems where the resource was fully committed, and to encourage the use of groundwater where it was underutilised.

In 1998, the NSW Government released a state-wide Aquifer Risk Assessment. This listed the Alstonville Basalt (Groundwater Management Area - GWMA804) as an aquifer at 'high risk' due primarily to the reliance of GDEs on groundwater, threats from changing land use, large amount of entitlement issued compared to sustainable yield, local interference due to pumping, relatively small groundwater flow system and vulnerability to pollution.

In 2001, an embargo order was made under the *Water Act 1912* on new applications for groundwater licences for Alstonville Plateau Basalt GWMA804. It remained in place until the first water sharing plan was developed and implemented in 2004.

The Water Sharing Plan for Alstonville Basalt Plateau Groundwater Sources 2004 was one of the first groundwater plans to be implemented in NSW. As a result, access licences were issued on a perpetual basis with greater opportunities to trade through the separation of water access rights from the land. Under the 2004 plan there were 6 groundwater sources: Alstonville Zone 1, Tuckean Zone 2, Bangalow Zone 3, Coopers Zone 4, Wyrallah, Zone 5 and Lennox Zone 6.

The Water Sharing Plan for the Alstonville Plateau Groundwater Sources 2004 was extended for 2 years to allow for sufficient consultation, before it was replaced in July 2016.

4.2 Current management

Groundwater in the Alstonville Basalt is currently managed under the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (the Plan), which commenced on 1 July 2016. It is the principal tool for managing groundwater and defines the long-term average annual extraction limit (LTAAEL), established rules for sharing groundwater between users and the environment, and rules for water trading. The Plan is legislated by the *Water Management Act 2000*.

The 6 groundwater sources from the 2004 water sharing plan were combined into one by the 2016 Plan. It also extended the groundwater source area boundary. The Alstonville Basalt under this new plan consists of a single groundwater source with the following management zones:

- Alstonville Basalt Plateau (Alstonville-Tuckean) Management Zone, and
- Alstonville Basalt Plateau (Bangalow-Wyrallah) Management Zone.

These management zones were established to recognise levels of extraction in the Alstonville-Tuckean area at the time the water sharing plan was developed, and to prevent localised impacts.

4.3 Groundwater access rights

Groundwater entitlements for the Alstonville Basalt are shown in **Table 2** below.

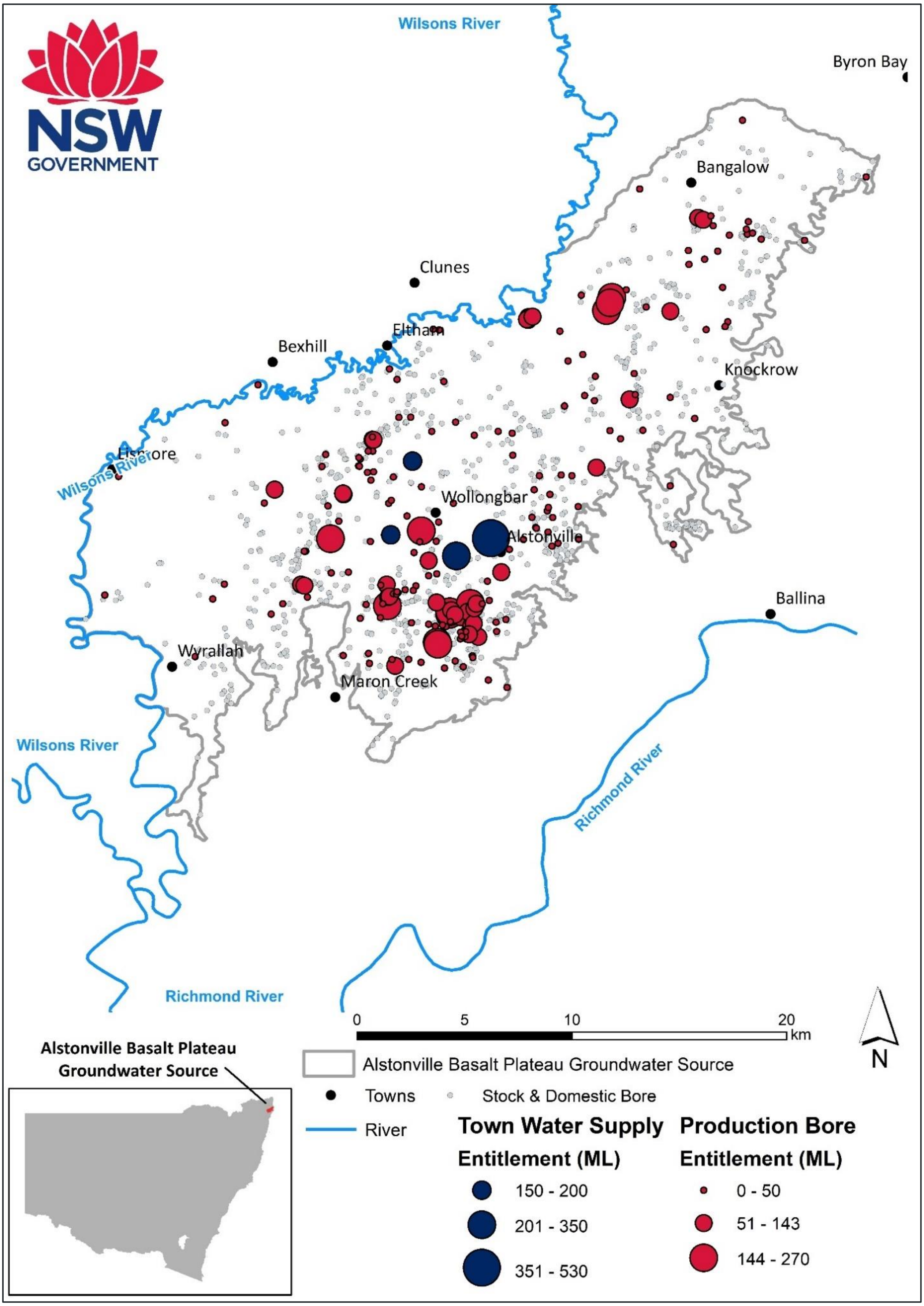
Table 2 Access licence entitlements summary

Access Licence Category	Entitlement
Local Water Utility (ML/year)	1,230
Aquifer (unit shares)	5,852

In addition to the above, 2,014 ML/year has been set aside for basic rights (that is, for native title, stock and domestic use).

Figure 23 shows water supply bores and distribution of potential extraction based on linked entitlement.

Figure 23 Water supply bores and distribution of potential extraction



4.4 Extraction limit

The Plan establishes the extraction limit for the groundwater source. The long-term average annual extraction limit (LTAAEL) for the Alstonville Basalt is equal to the estimated long-term average rainfall recharge minus the amount of recharge reserved as planned environmental water.

The planned environmental water for the Alstonville Basalt is equal to 82% of the long-term average annual rainfall recharge. At the commencement of this Plan the long-term average annual rainfall recharge for the groundwater source was estimated to be 50,079 megalitres per year.

Extraction in a groundwater source is managed to the LTAAEL volume of 8,895 ML/year set by the Plan.

4.5 Available water determinations, groundwater accounts

An available water determination (AWD) is a volume of water that is made available to water access licence accounts. An AWD is issued for each licence category within a water source at the commencement of each water year. It is the main tool that is used to ensure that average water extraction does not exceed the long-term average annual extraction limit.

To manage any growth in extraction in excess of the LTAAEL, the Plan has set a compliance trigger. A growth in extraction response is triggered if average annual extraction over 3 preceding water years exceeds the LTAAEL by more than 5 percent. Then the AWD made for aquifer access licences for the following year, should be reduced by an amount that is necessary to return subsequent water extraction to the extraction limit.

Total water availability in a water year is controlled by the available water determinations credited to an access licence account. The maximum amount of water that can carried over from one water year to the next is 20% of the access licence share component, or 0.2 ML per unit share. This means that metered extraction plus transfers out cannot exceed the 120% of access licence share component, unless water is transferred in. Carryover is not permitted for local water utility licences.

Since the commencement of the water sharing plan, available water determinations have been 100 per cent access for Alstonville Basalt, that is 1 ML per share.

4.6 Groundwater take

There are approximately 1,075 licensed bores made up of 245 production and 830 basic landholder rights (BLR) bores in the Alstonville Basalt. BLR bores are typically used to supplement existing domestic and stock supplies or from rainwater for gardens or non-potable supplies and for household use.

Most production bores are used for irrigation supply with some used for town water supplies. **Figure 23** shows the distribution of water supply bores accessing the groundwater resources.

Annual accounting of groundwater extraction is a requirement in the water sharing plan. However, groundwater take (or use) is not currently monitored and no annual account information is currently available.

Under the NSW Non-Urban Water Metering Policy (November 2020) the following will apply to approval holders in Alstonville Basalt from December 2023:

- A metering and reporting requirement for authorised works (or bores) greater than 200mm
- A measurement and reporting requirement for works (bores) that are not required to have a meter.

This initiative aims to address the requirement for annual accounting.

4.7 Groundwater dealings

Trading (dealing) within the groundwater source is permitted. However, each trade application is subject to hydrogeological impact assessment. The aim of the impact assessment is to allow the development whilst recognising and protecting the needs of the environment and third-party interests.

The Plan prohibits trading between Alstonville Basalt and any other groundwater source. Within the Alstonville Basalt, trade is allowed between management zones as long as there is no increase in the sum of entitlements at the commencement of the Plan in the Alstonville Basalt Plateau (Alstonville-Tuckean) Management Zone.

Table 3 shows the trading statistics within the groundwater source over the last 10 years.

Table 3 Volume of groundwater traded within the Alstonville Basalt groundwater source 2010/11 to 2021/22

Water year	Change in licence ownership (ML)	Transfer of shares between Access Licences (ML)	Total volume permanently traded (ML)	Total volume temporarily traded (ML)
2021-22	142	0	142	33
2020-21	389	0	389	33
2019-20	59	18	77	49
2018-19	335	0	335	33
2017-18	190	0	190	0
2016-17	360	0	360	0
2015-16	159	0	159	0

Water year	Change in licence ownership (ML)	Transfer of shares between Access Licences (ML)	Total volume permanently traded (ML)	Total volume temporarily traded (ML)
2014-15	31	0	31	0
2013-14	291	0	291	0
2012-13	80.5	6	86.5	0
2010-11	149	0	149	-

5 Groundwater behaviour

5.1 Hydrographs

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (**Figure 24 and Figure 25**). Hydrographs can be used to interpret influences on groundwater such as rainfall, drought and climate change, and interpret aquifer response to groundwater extraction.

These figures show the trends observed in groundwater hydrographs, where both short- and long-term water level trends can be identified. In unconfined and semi-confined aquifers, groundwater can be in hydraulic connection with the surface. Where this occurs, groundwater levels rise in response to recharge such as rainfall and decline during periods of reduced rainfall.

Figure 24 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate in a shallow fractured rock aquifer. The depth being monitored at this site is from 20 to 26 metres below ground level.

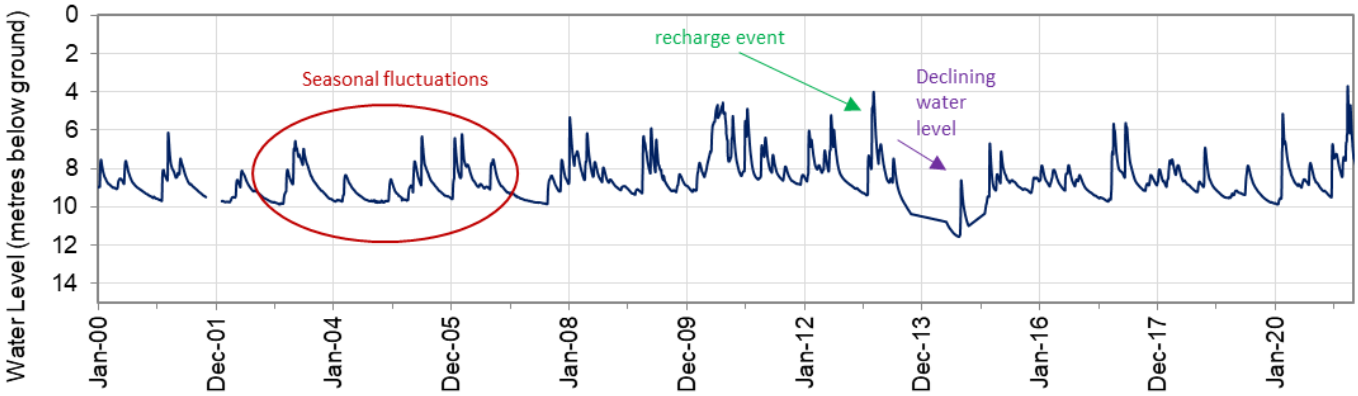
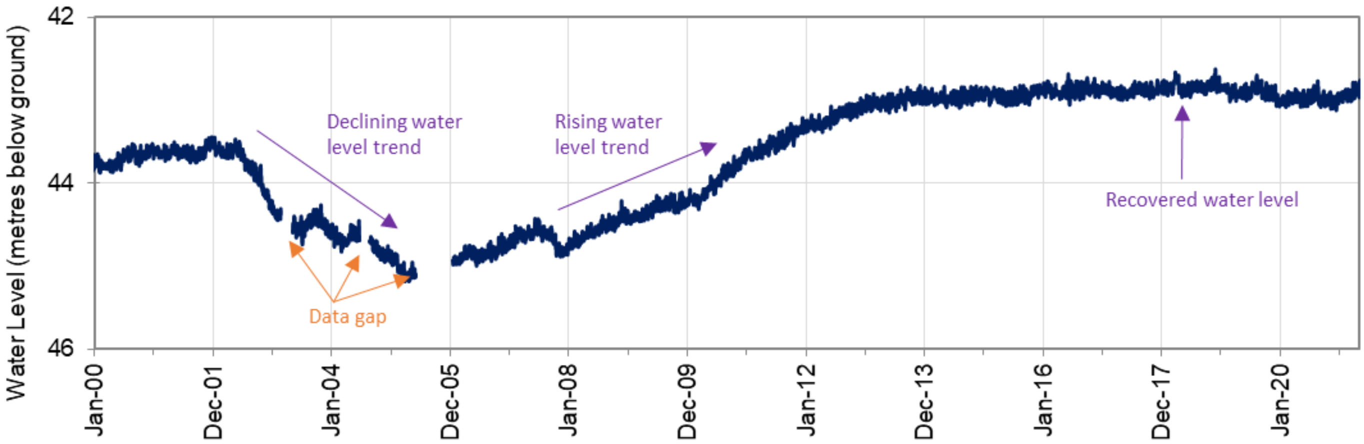


Figure 25 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate in a deep fractured rock aquifer. The depth being monitored at this site is from 32 to 91 metres below ground level.



Significant recharge events such as intense rainfall events can be identified in hydrographs as peaks in the groundwater level record, while droughts tend to result in a slow gradual decline in groundwater levels.

Drawdown is the maximum level to which groundwater is lowered in a bore due to pumping. It is followed by recovery when pumping has ceased or reduced. Review of the recovered groundwater level over time can be used to assess how a groundwater system is responding to climate and pumping impacts in the long term. The recovered groundwater level is the highest point to which groundwater has risen in a particular year.

Drawdown can be used to assess more short-term seasonal impacts in a groundwater system. In areas where drawdown occurs, groundwater recovery may not return to the level of the previous year before pumping resumes. This can result in a long-term reduction in the recovered groundwater levels.

5.2 Groundwater monitoring network

WaterNSW monitors groundwater levels at 25 monitoring bores (pipes) at 12 sites in the Alstonville Basalt Plateau Groundwater Source (**Figure 26**). At several of the monitoring sites there are 2 pipes, which each monitor a different depth.

Each pipe monitors the depth at which the casing is slotted to allow groundwater entry into the pipe. Most of the bores are equipped with continuous data loggers. Eleven of the bores are telemetered and data available in real time. The details of the monitoring bores are summarised in **Table 4** below.

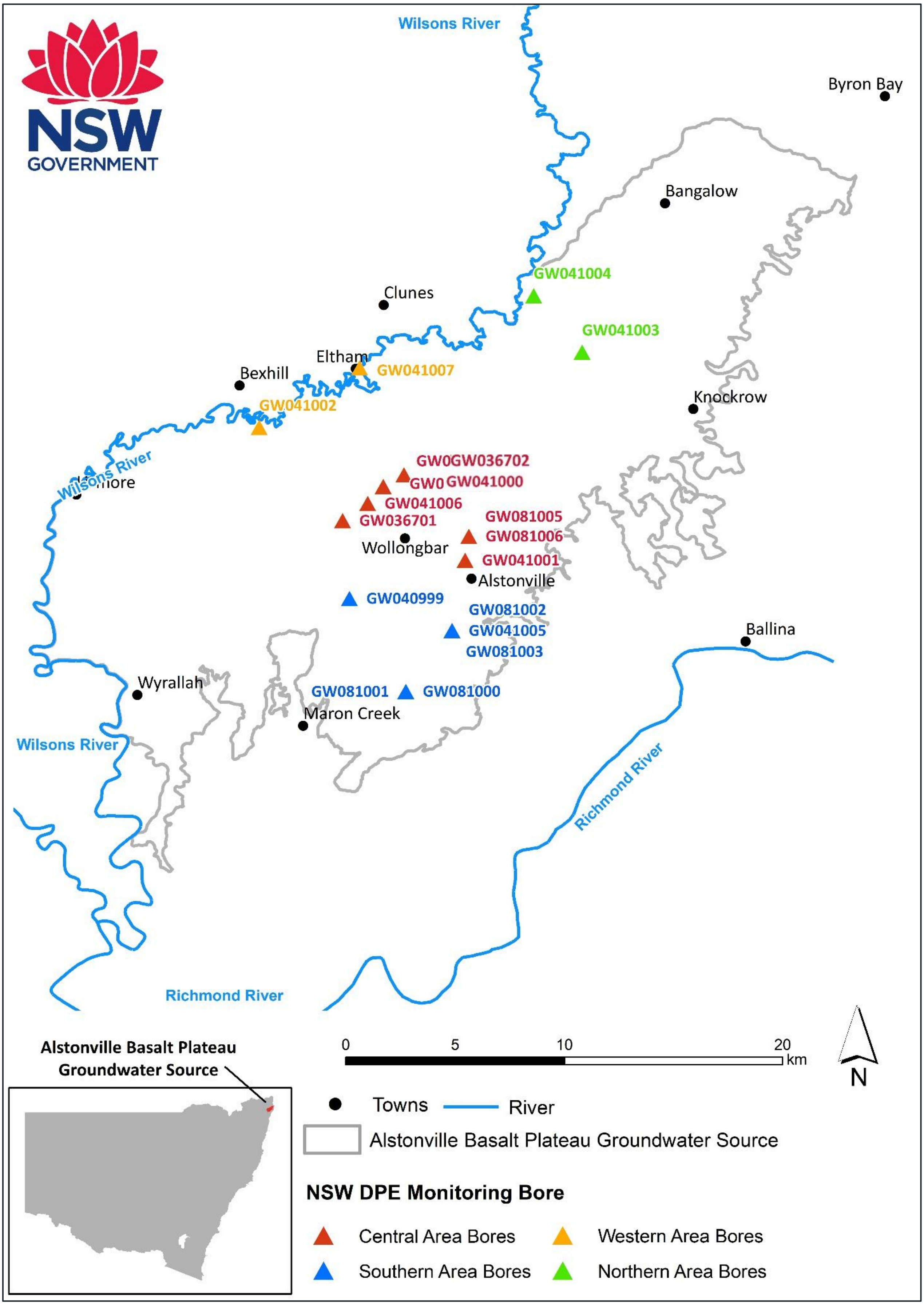
Table 4 Monitoring bore details

Name	Site name	Pipe	Elevation (mAHD)	Completed depth (mbgl)	Screen interval (mbgl)	Year constructed	Monitoring method	Area
GW036701	Wollongbar Agricultural Station	1	131.7	26	24 to 37	1987	Telemetry	Central
GW036701	Wollongbar Agricultural Station	2	131.7	168	88 to 128	1987	Telemetry	Central
GW041006	Wollongbar Agricultural Station	1	155.7	13	4 to 10	2005	Telemetry	Central
GW036702	Pearces Creek Research Centre	2	90.5	73	50 to 57	1987	Telemetry	Central

Name	Site name	Pipe	Elevation (mAHD)	Completed depth (mbgl)	Screen interval (mbgl)	Year constructed	Monitoring method	Area
GW036702	Pearces Creek Research Centre	4	90.5	128	88 to 128	1987	Telemetry	Central
GW041000	Convery Lane	1	101.9	120	63 to 69	2006	Logger	Central
GW041000	Convery Lane	2	101.9	120	89 to 94	2006	Logger	Central
GW041001	Lumley Park	1	128.1	91	20 to 26	2005	Logger	Central
GW041001	Lumley Park Cutting	2	128.1	91	Open Hole: 32 to 91	2005	Logger	Central
GW081005	Maguires Creek	1	110.92	75	59 to 71	1999	Telemetry	Central
GW081006	Maguires Creek	1	110.71	14	7.5 to 12	1999	Telemetry	Central
GW041003	Fernleigh	1	37.9	9.3 (12.5)	5.3 to 8.3	2006	Logger	Northern
GW041003	Fernleigh	2	37.9	161	Open hole: 22 – 160	2006	Logger	Northern
GW041004	Nashua	1	12.3	21	15 to 18	2006	Logger	Northern
GW041004	Nashua	2	12.3	56	40 to 46	2006	Logger	Northern
GW041002	Boat Harbour	1	10	62 (85)	50 to 56	2006	Logger	Western
GW041007	Eltham	1	158	44	38 to 41	2006	Logger	Western
GW041007	Eltham	2	158	100	85 to 91	2006	Logger	Western
GW081000	Dalwood	1	155	10.5	3.4 to 9.4	1999	Telemetry	Southern
GW081001	Dalwood	1	152.8	110	87 to 107	1999	Telemetry	Southern
GW081002	Duck Creek	1	148.9	112	51 to 54	1999	Telemetry	Southern
GW081003	Duck Creek	1	48.3	40	32 to 38	1999	Telemetry	Southern

Name	Site name	Pipe	Elevation (mAHD)	Completed depth (mbgl)	Screen interval (mbgl)	Year constructed	Monitoring method	Area
GW041005	Duck Creek	1	151	11.2	4.2 to 10.2	2005	Telemetry	Southern
GW040999	Marom Creek Weir	1	124.8	21	14 to 20	2005	Telemetry	Southern
GW040999	Marom Creek Weir	2	124.8	84	78 to 84	2005	Logger	Southern

Figure 26 Monitoring bore network in Alstonville Basalt Plateau Groundwater Source



5.3 Groundwater levels

Hydrographs for 18 representative monitoring sites across the Alstonville Plateau Groundwater Source are presented below. The location of these sites is shown in **Figure 26**. The monitoring bores have been grouped into 4 areas (northern, central, western and southern) for the purpose of simplifying water level analysis.

Hydrographs are displayed separately for shallow and deep aquifers, with different vertical scales to clearly explain the groundwater level behaviour and the magnitude of fluctuations in Alstonville Basalt. Therefore, care must be taken when comparing hydrographs.

5.3.1 Northern area

Groundwater monitoring site GW041003 and GW041004 are in the northern part of the Plateau with GW041004 located close to the edge near Wilsons River (**Figure 26**).

Figure 27 and Figure 28 show groundwater level fluctuations in the shallow aquifer. The rapid responses are caused by rainfall events recharging the aquifer, followed by levels dropping due to discharge into connected rivers, creeks and springs in the area. Levels drop and stabilise until recharge from the next rainfall event when they rise again. The hydrograph for GW041004, located close to the edge of the Plateau, shows large fluctuations of up to 7 m. The levels recover quickly following rainfall events.

Monitoring site GW041003 has 2 pipes. Pipe 2 is a bore that is unlined (open hole) from 20 to-162 mbgl, hence the water levels represent a composite groundwater level rather than levels in the shallow or the deep semi-confined aquifer. There is no other monitoring bore in this area constructed in the deep aquifer.

The fluctuations in observed levels are likely to be due to some localised groundwater extractions, discharge as springs and into rivers, and some localised pumping. The hydrographs show a fairly stable long-term trend in water levels in the northern part of the groundwater source.

Figure 27 Hydrograph for monitoring site GW041003 (Fernleigh)

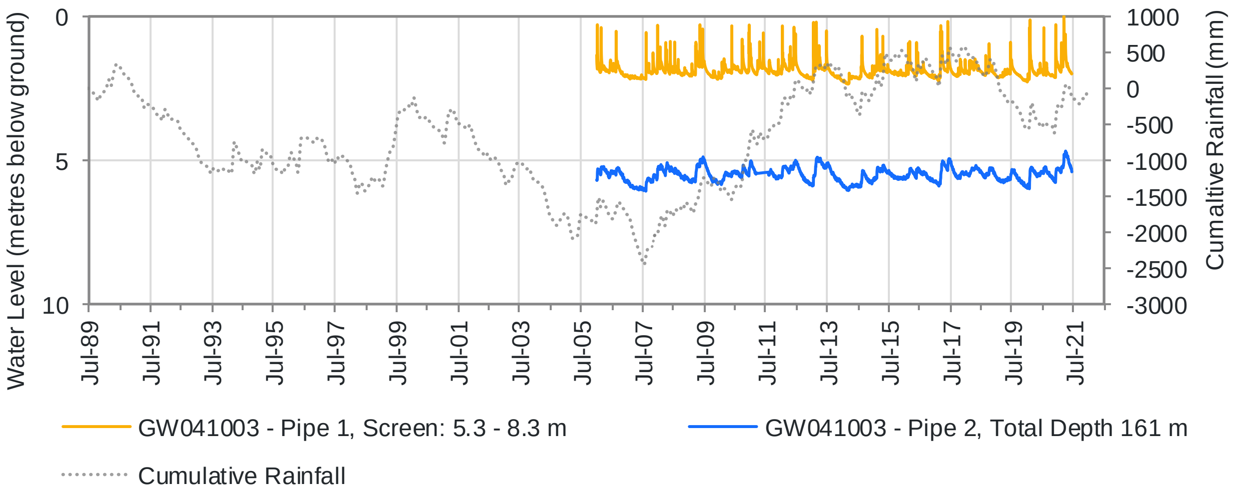
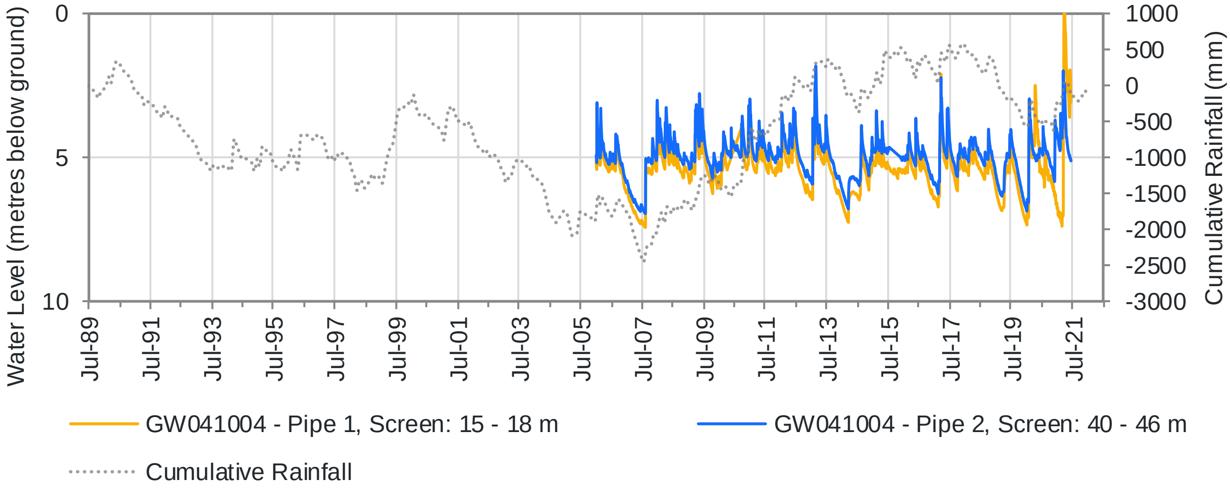


Figure 28 Hydrograph for monitoring site GW041004 (Nashua) - shallow aquifer and deep aquifers



5.3.2 Central area

Groundwater monitoring sites GW041000, GW036701, GW036702 and GW041001 are in the central part of the plateau immediately north of Alstonville and Wollongbar **(Figure 26).** The area to the south of these monitoring bores has several production bores with large groundwater entitlements and potential for high levels of extractions.

The hydrographs for the shallow monitoring bores are shown in **Figures 31, 32, 33, 34.** The shallow aquifer hydrographs with a different vertical scale are shown separately, so that the small fluctuations can be shown. The water level behaviour is identical to that observed in the northern area with water levels responding quickly to rainfall events. Fluctuations at sites GW041001 and GW081006 are notably higher (up to 4 m) than those observed at other sites.

Figure 29 Hydrograph for monitoring site GW041001 (Lumley Park) – shallow aquifer

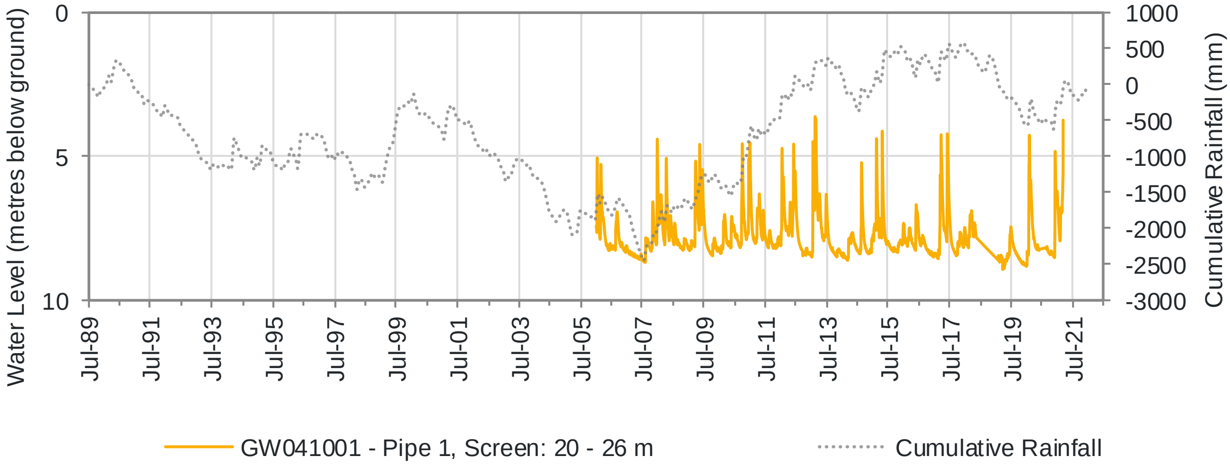


Figure 30 Hydrograph for monitoring site GW081006 (Maguires Creek) – shallow aquifer

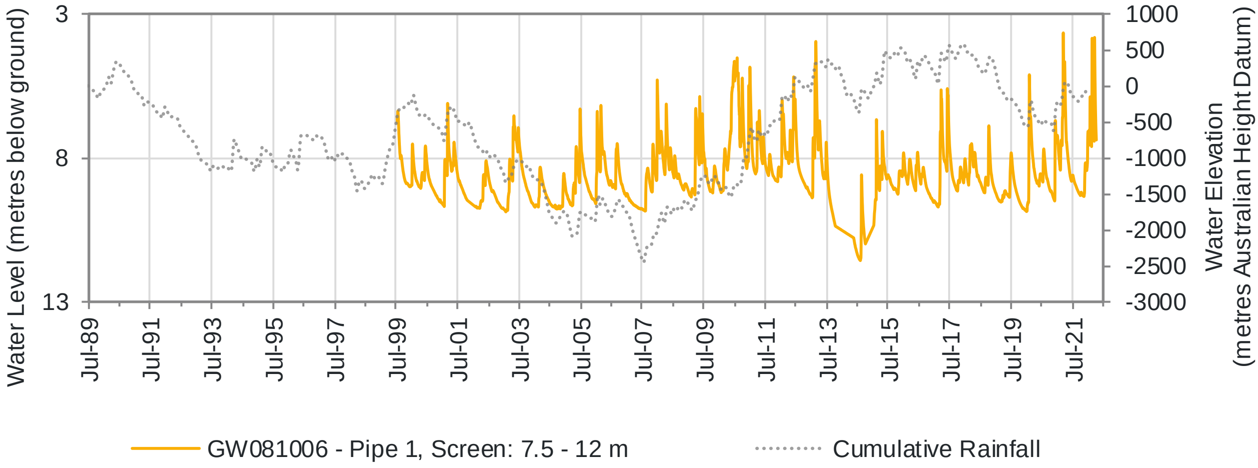


Figure 31 Hydrograph for monitoring site GW036701 (Wollongbar Agricultural Station) – shallow aquifer

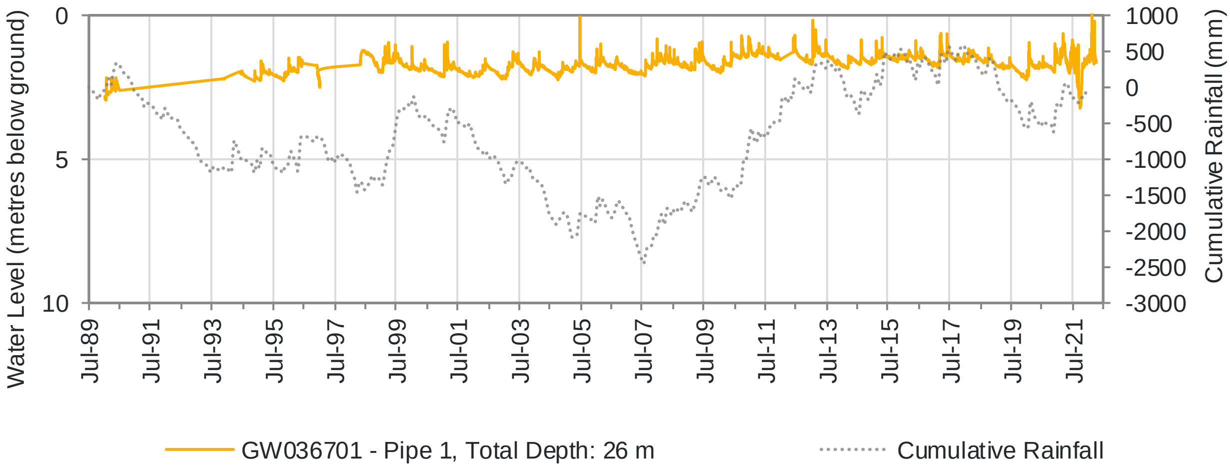
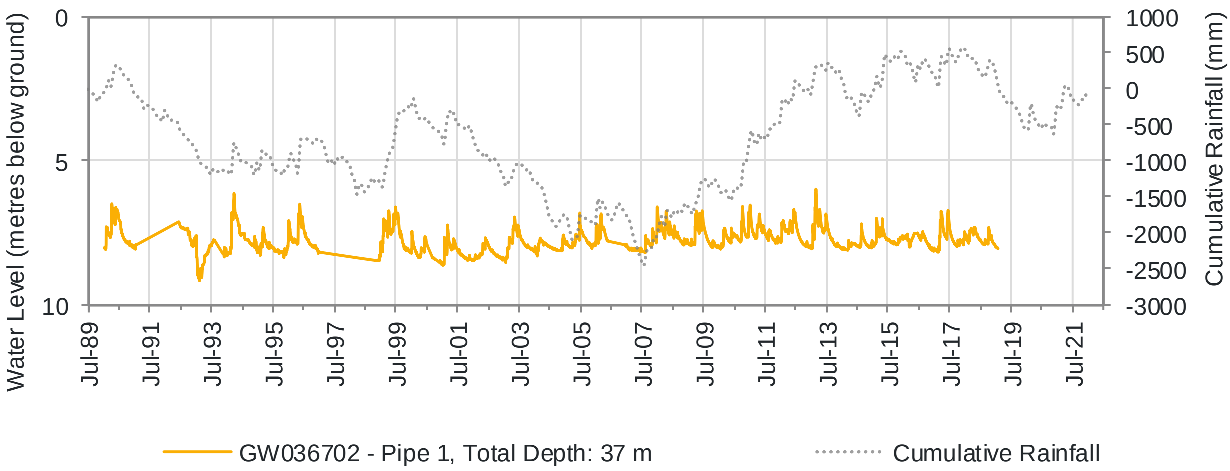


Figure 32 Hydrograph for monitoring site GW036702 (Pearces Creek Research Centre) – shallow aquifer



The hydrographs for the deep monitoring bores are shown in **Figures 35, 36, and 37**. They show a different response from that observed in the shallow aquifer. The levels are correlated to climate and pumping.

Groundwater levels at monitoring site GW041000 (Convery Lane) show a rise from around 2007 from 23.8 mbgl to 20.9 mbgl in 2013, then remaining stable until beginning of 2019 followed be a decline of 7 m. This decline is likely due to nearby pumping.

Groundwater levels at monitoring site GW036701 (Wollongbar Agricultural Station) has a much longer record and show a decline in levels by about seven metres post 1996. This is believed to be from pumping for drought town water supply. The levels have risen by more than 17 metres since 1999. The rise is due to the reduction in pumping (or no pumping) from the town water supply bore post 2003 (**Figure 35**). A similar response is seen at monitoring site GW081005 Maguires Creek (**Figure 36),** except that the rise in levels is less. The rise in levels is likely due to reduced pumping and above average rainfall.

Figure 33 Hydrograph for monitoring bore GW041000 (Convery Lane) – deep aquifer

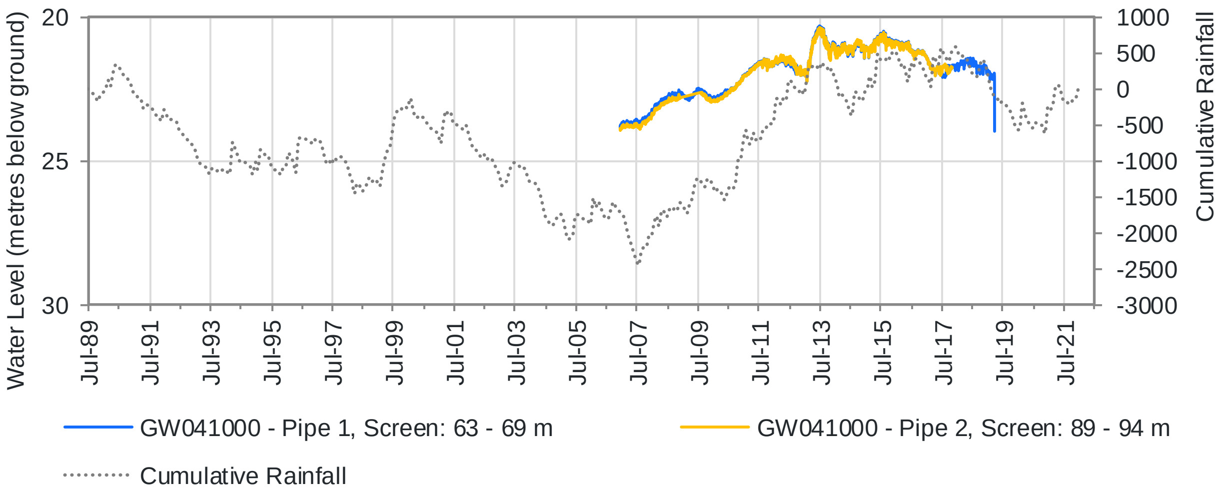


Figure 34 Hydrograph for monitoring bore GW036701(Wollongbar Agricultural Station) – deep aquifer

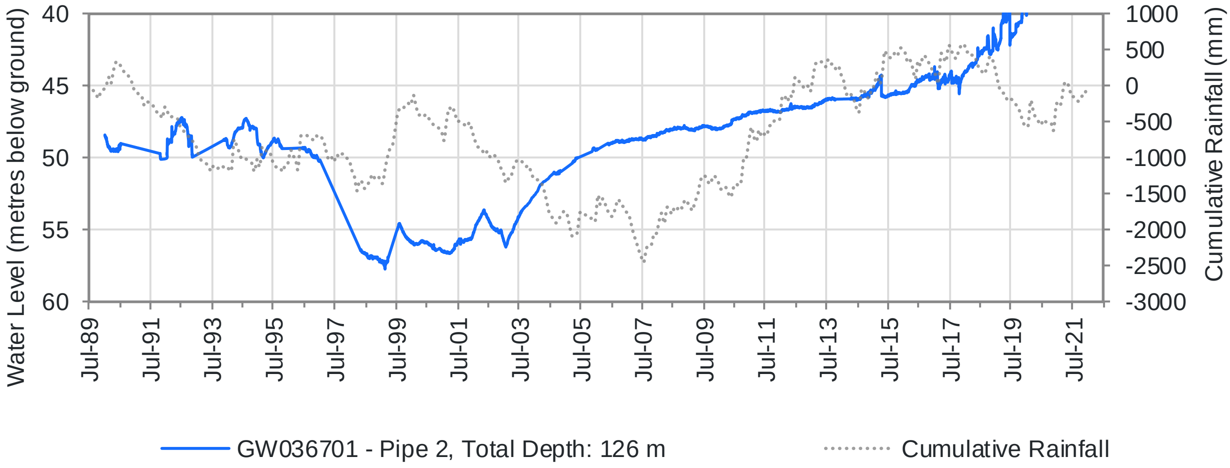
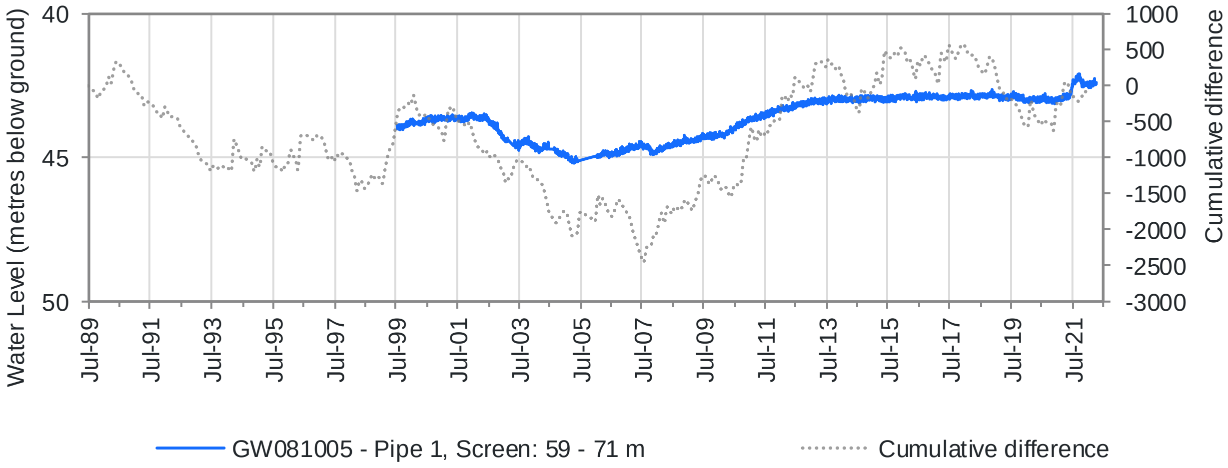


Figure 35 Hydrograph for monitoring site GW081005 Maguires Creek – deep aquifer



5.3.3 Southern area

Groundwater monitoring sites GW040999, GW041005, GW81000 and GW081003 are in the southern part of the Alstonville Plateau south of Wollongbar and Alstonville and **(Figure 26).** The area to the south of these monitoring bores has several production bores with large groundwater entitlements and potential for high levels of extractions.

The hydrographs for the shallow monitoring bores are shown in **Figures 38, 39, 40 and 41**. These all show a similar behaviour and respond rapidly to rainfall events, similar to those in other areas. Fluctuations up to 5 m were observed. Overall these display a stable depth to water table except GW081003 (Duck Creek) which shows a slight decline since 2010 **(Figure 39).**

Figure 36 Hydrograph for monitoring site GW04099 (Marom Creek Weir) – shallow aquifer

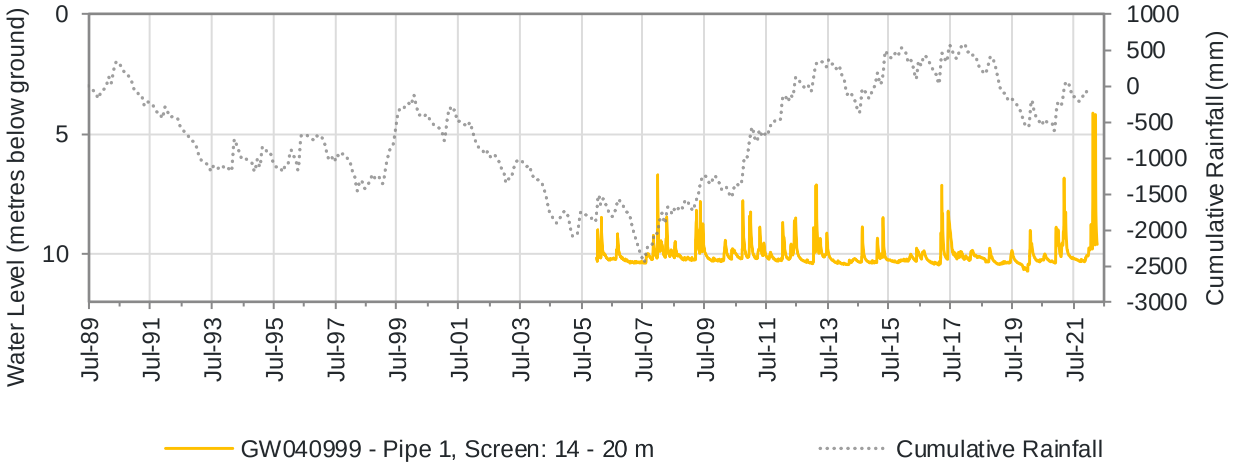


Figure 37 Hydrograph for monitoring site GW041005 (Duck Creek) – shallow aquifer

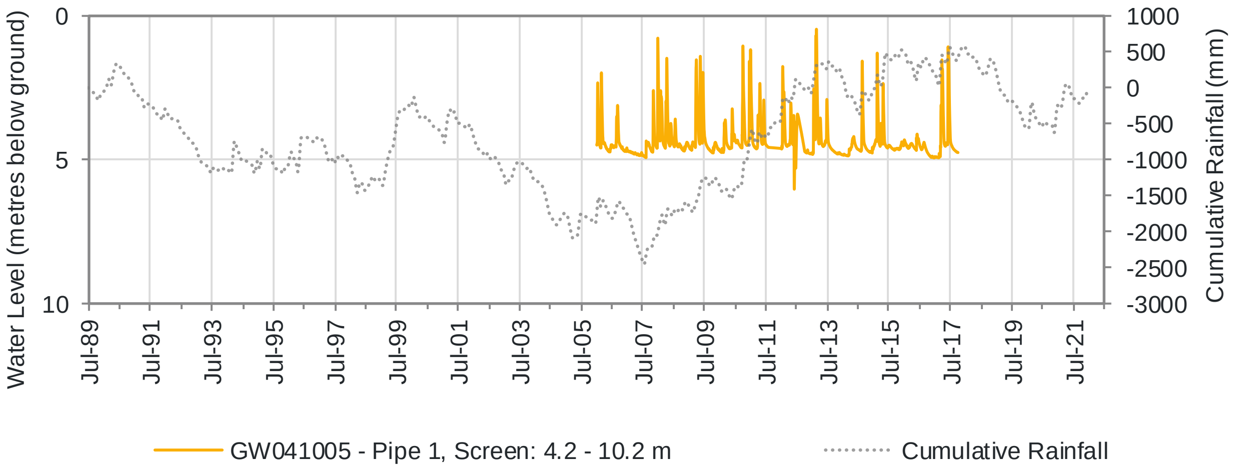


Figure 38 Hydrograph for monitoring site GW081000 (Dalwood) – shallow aquifer

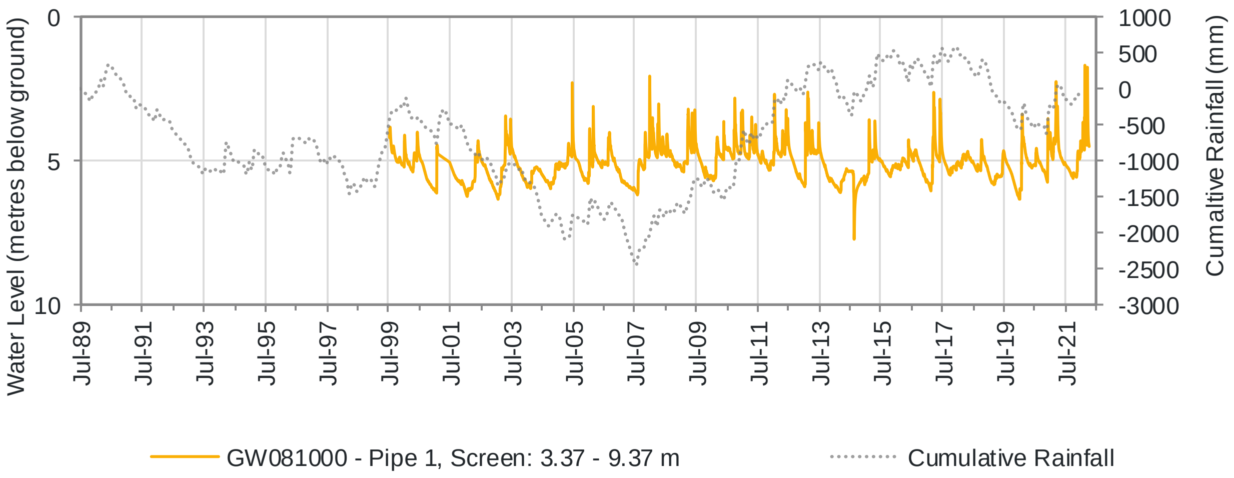
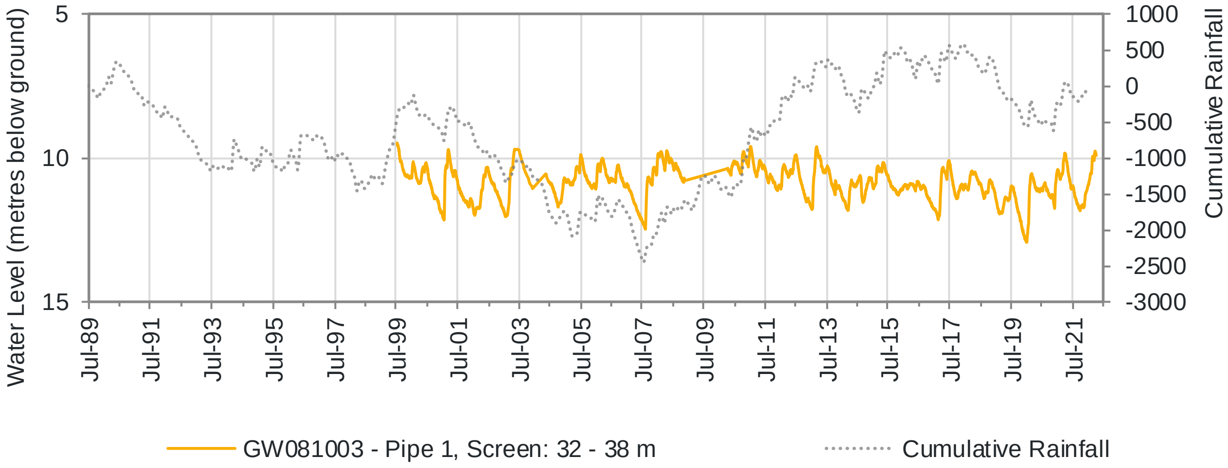


Figure 39 Hydrograph for monitoring site GW081003 (Duck Creek) – shallow aquifer



The hydrographs for deep monitoring bores are shown in **Figures 42, 43, and 44.** Monitoring bores GW040999 and GW081001 (**Figures 42 and 43**) show a similar response to deep bores in the Central area. Levels in the deep aquifer were at its lowest around 2006 and rose steadily and became stable post 2013. The hydrographs do not show seasonal variations. The decline during the period 2002-2006 coincides with a period of below average rainfall.

Figure 40 Hydrograph for monitoring site GW040999 (Marom Creek Weir) – deep aquifer

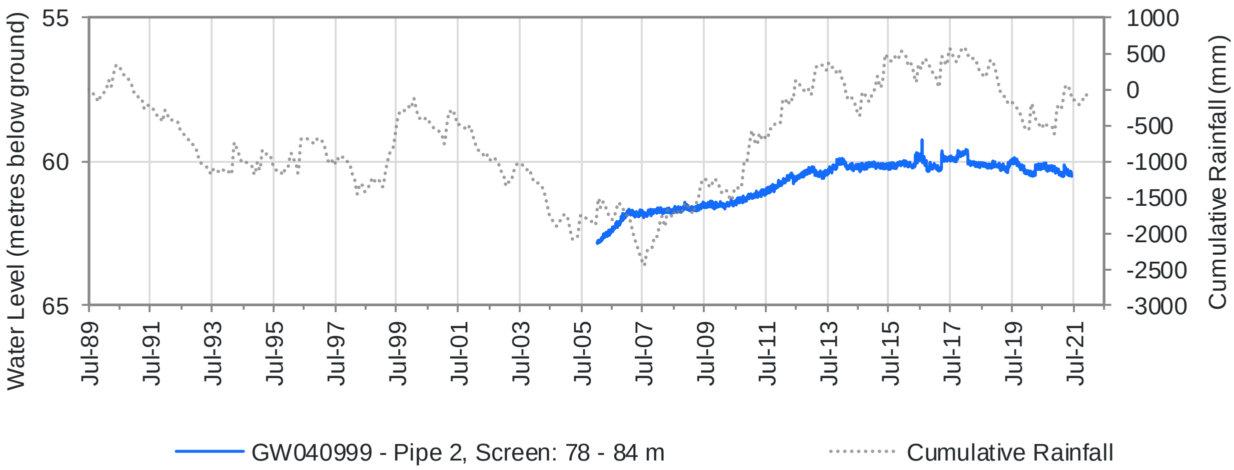
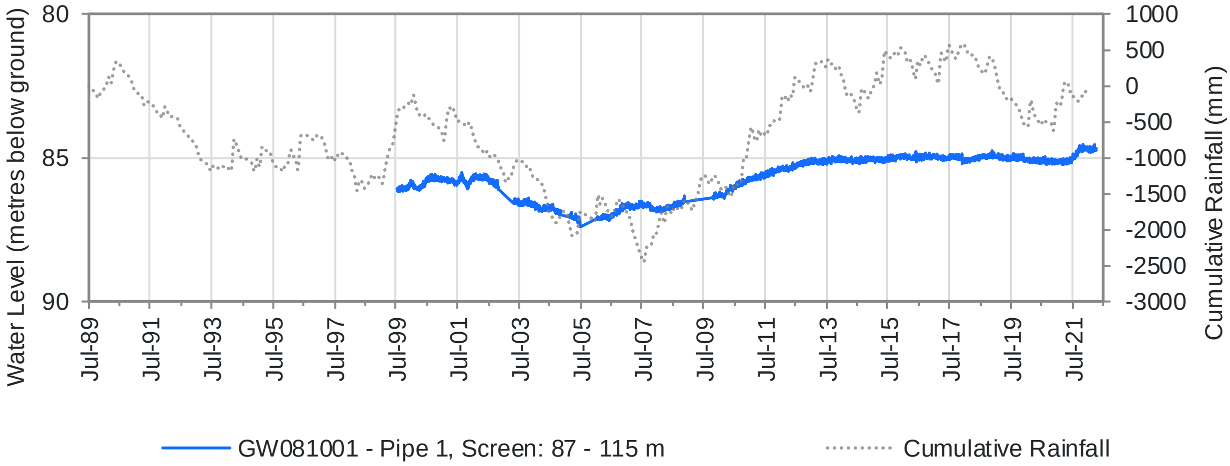
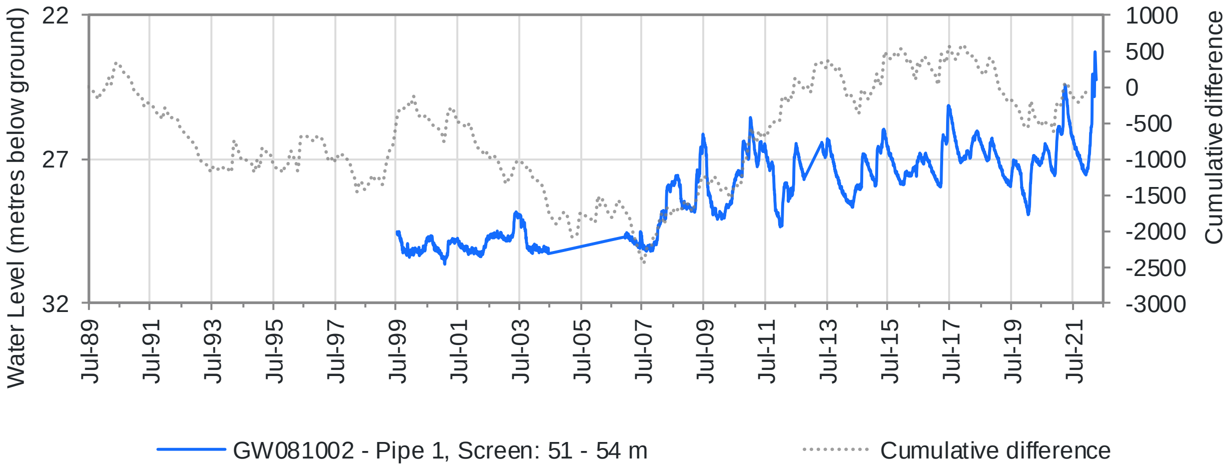


Figure 41 Hydrograph for monitoring site GW081001 (Dalwood) – deep aquifer



Hydrograph for monitoring bore GW081002 (**Figure 42**) shows a much different water level behaviour. Water levels are rising with slightly larger fluctuations. This bore is located at the same site as GW081002 (Duck Creek) and is constructed in an intermediate aquifer. Note: there is a data gap between March 2004 to March 2007.

Figure 42 Hydrograph for monitoring site GW081002 Duck Creek



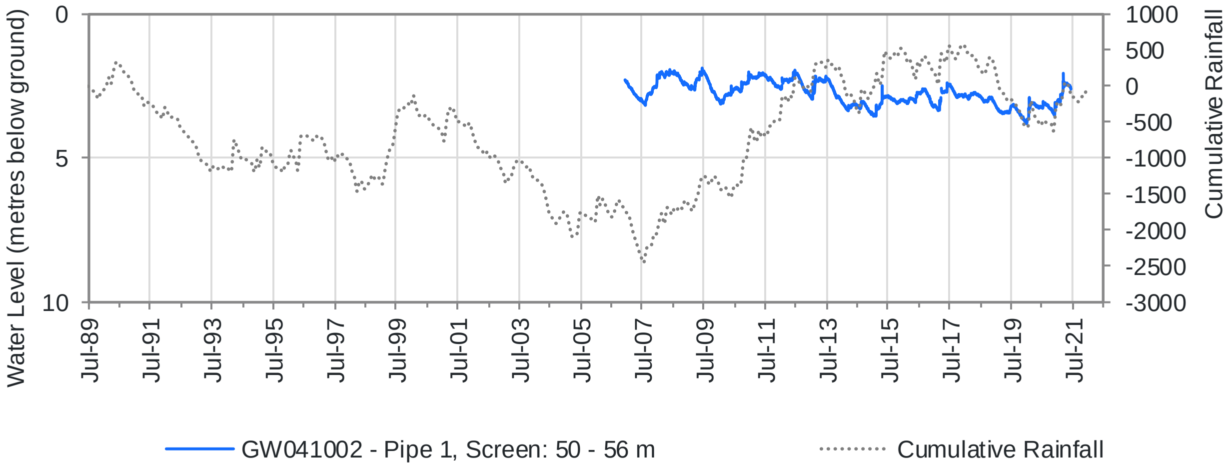
5.3.4 Western Area

Groundwater monitoring sites GW041002 and GW041007 are at the western edge of the Plateau close to Wilsons River **(Figure 26).** It is an area with little groundwater pumping.

The hydrograph for monitoring site GW041002 **(**

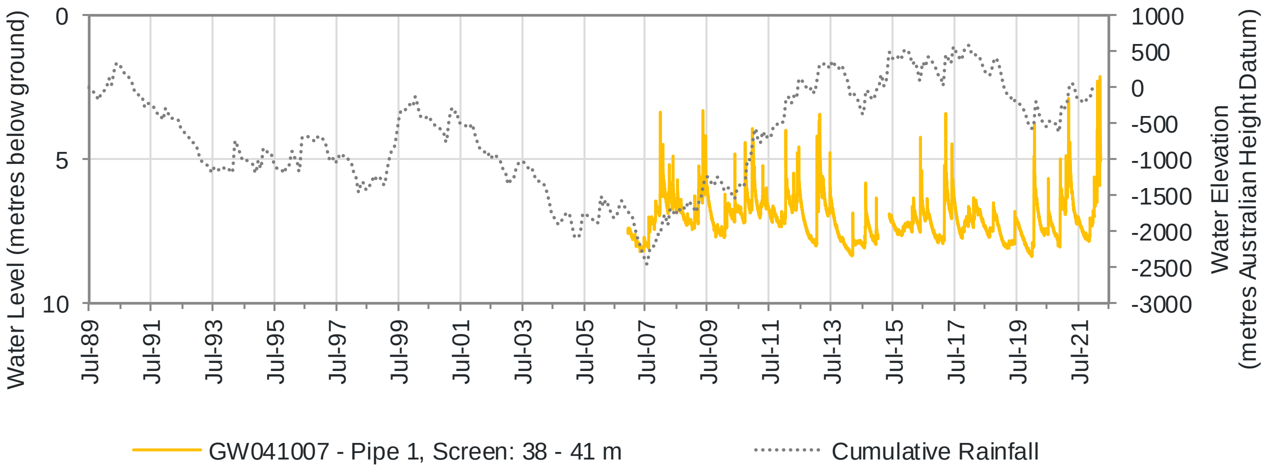
Figure 43**)** shows a slightly declining water table trend perhaps indicating discharge into Wilsons River. This bore is constructed in the deep aquifer as it is not showing the typical rapid response seen elsewhere in the shallow aquifer.

Figure 43 Hydrograph for monitoring site GW041002 (Boat Harbour)



Hydrograph for monitoring site GW041007 **(Figure 44)** is screened in the shallow aquifer between 38 and 41 metres below ground level, and shows similar response to other bores in the shallow aquifer, rapid response to rainfall events and seasonal variation. Fluctuations of up to 4 m are observed.

Figure 44 Hydrograph for monitoring site GW41007 (Eltham) - shallow aquifer



6 Hydrochemistry

6.1 Sampling

The NSW Department of Planning and Environment collected water quality samples from groundwater, surface water, and springs across the plateau in May 2021. This included 14 groundwater samples, 3 surface water samples, and one spring sample (**Figure 45**). Samples were collected for physicochemical, dissolved ion, and dissolved metal and metalloid analysis. A subset of 6 samples were analysed for stable isotopes oxygen 18 and deuterium ($\delta^{18}O$ and $\delta^{2}H$).

Groundwater samples were collected from NSW Government monitoring bores, private monitoring bores, and local water utility town water supply bores. The sampling methodology was developed using the best practice guidelines outlined in '*Groundwater Sampling and Analysis – A Field Guide*' (Sundaram et al., 2010). Surface water and spring samples were taken using the grab sample method. A dedicated sampling container was used and decontaminated thoroughly between samples. The same sample collection, preservation, and storage procedures, as above with groundwater, were followed.

Samples were shipped in an esky container filled with ice to ensure a stable temperature during transit to the laboratory. The suite of parameters tested measured during the field program are provided in **Table 5** Suite of parameters analysed by the laboratorybelow, along with the relevant analytical laboratory and method. **Figure 45** below shows the sites and water types that were sampled during the May 2021 sampling expedition.

Samples were analysed by ALS Environmental in Smithfield, NSW. This laboratory is accredited by the National Association of Testing Authorities (NATA). Samples for stable isotope ($\delta^{2}H$ and $\delta^{18}O$) analysis were sent to the Australian Nuclear Science and Technology Organisation (ANSTO).

Figure 45 Bores sampled during May 2021 sampling event

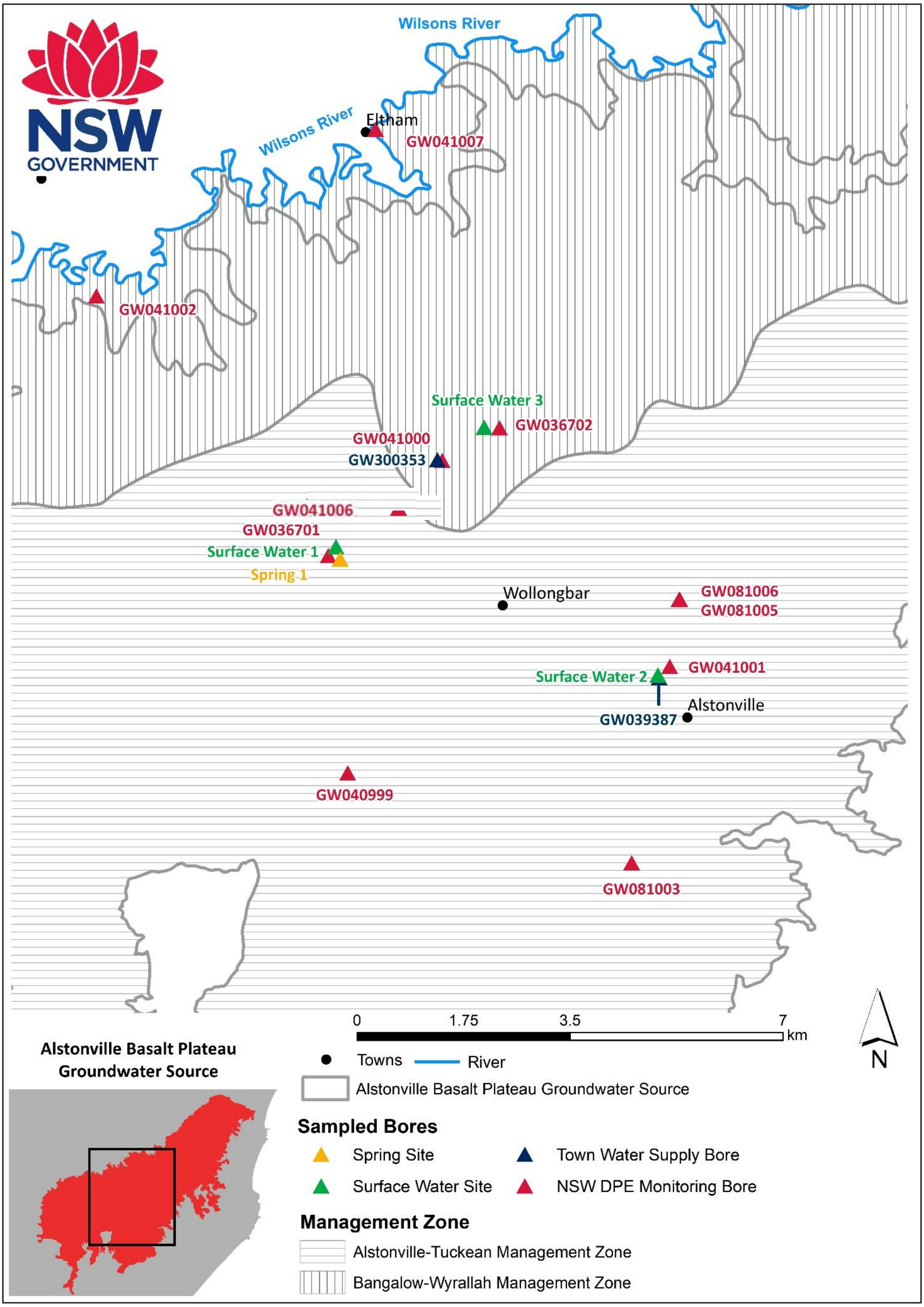


Table 5 Suite of parameters analysed by the laboratory

Laboratory analysis			
Physicochemical parameters	pH	APHA (4500toH$^+$): pH meter and electrode	ALS Laboratory Services (Smithfield, NSW)
	Electrical conductivity	APHA (2510): conductivity cell at 25°C	
	Total dissolved solids	Gravimetrically: solids dried at 180 ±10°C	
Major cations	Ca^{2+}, K^+, Mg^{2+}, Na^+	ICP-AES	
Major anions	F^-, Cl^-, SO_4^{2-} to Br^-	Major anions	
Alkalinity	OH^{--}, CO_3^{2} HCO_3, and total (as $CaCO_3$)	APHA (2320toB): Titration	
Hardness	Total hardness (as $CaCO_3$)	Calculation	
Total and dissolved metals	Al, As, Fe, Pb, Mn, U, Zn	ICP-MS	
Stable isotopes	2H/1H (δ 2H), 18O/16O (δ 18O)	Picarro Cavity Ring-Down Spectroscopy (CRDS)	ANSTO (Lucas Heights, NSW)

6.2 Physicochemical and major ion chemistry

The full set of results from the 2021 groundwater quality monitoring program is presented in **Appendix A.** Summary statistics for physicochemical parameters are presented in **Table 6.** The major ion composition for each of the water samples is also displayed in a Piper diagram **Figure 46** Piper plot for the May 2021 sampling results for Alstonville to assist in determining the water type of each sample, water sources, and potential mixing that may be occurring.

Shallow groundwater, including springs and surface water on the Alstonville Basalt, tends to be acidic (that is, pH <7) to neutral, whereas deeper groundwater is neutral to alkaline (pH >8). Groundwater salinity across both the shallow and deep aquifers is fresh (EC <800 µS/cm) with some occurrence of brackish water (EC 800-5,000 µS/cm) in the deeper bores (**Table 7**).

Table 6 Summary of physicochemical results from May 2021 sampling

Site	Parameter (Laboratory results)	Samples	Non detects	Min	Median	Max
Shallow bores (<40 m deep)	pH	6	0	5.03	6.3	7.59
	Electrical conductivity (µS/cm)	6	0	106	175	843
	Total dissolved solids (mg/L)	6	0	58	99	486
Deep bores (>40 m deep)	pH	9	0	5.03	7.5	8.14
	Electrical conductivity (µS/cm)	9	0	106	485	1590
	Total dissolved solids (mg/L)	9	0	58	276.5	928
Surface water & Spring water	pH	4	0	6.12	6.13	6.78
	Electrical conductivity (µS/cm)	4	0	87	114.5	156
	Total dissolved solids (mg/L)	4	0	52	78.5	91

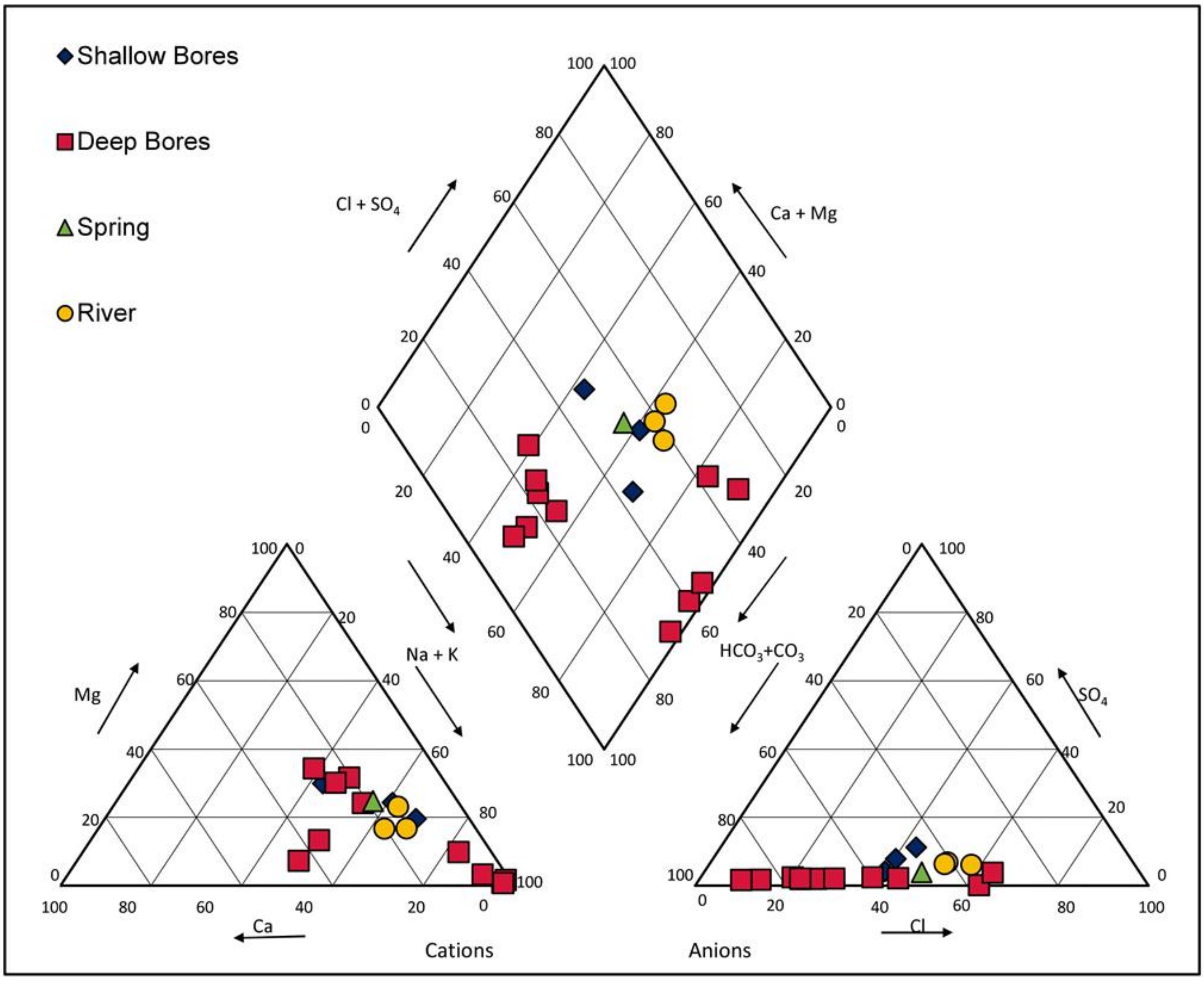
The groundwater on the Alstonville Basalt ranges from mixed type to Na-HCO_3 through Na-Cl to Na-Mg dominant type from the results of the 2021 sampling round (**Figure 46**). The shallow groundwater type in Alstonville Basalt is consistent with the surface water and spring results presenting as mixed to Na-Cl dominant type.

This is consistent with historic water quality data analysis, Ross et al. (1987) found the groundwater associated with the basalt ranged from Na-HCO^3 to Na-Ca-Mg HCO^3 through Na-Cl dominant type, and Brodie et al. (2003) found that the shallow groundwater was mostly Na-Mg-Cl-HCO_3 dominant with the deeper groundwater system being enriched with carbonate. These results suggest mixing occurring with both the shallow and deep aquifers and surface water through leakage. **Table 7** summarises the dominant water type for each sample taken.

Table 7 Summary of major ionic composition from May 2021 sampling results

Bore ID	Water type	Dominant	Screen from (mbgl)	Screen to (mbgl)
GW041002	Na-Cl	Na-Cl	50	56
GW36701.3.4	Mixed type	(Na-Ca)-Cl	88	128
GW041006	Na-Mg	(Na-Mg-Ca)- HCO^3	4	10
GW081006	Na-HCO^3	Na-HCO^3	7.5	12
GW081005	Na-HCO^3	Na-HCO^3	59	71
GW041001.1	Mixed type	Na-(HCO^3-Cl)	20	26
GW041000.1.2	Na-HCO^3	Na-HCO^3	88	94
GW081003	Mixed type	(Na-Mg-Ca)- HCO^3	32	38
GW41007.1	Na-Cl	Na-Cl	38	41
GW41007.2	Na-HCO^3	Na-HCO^3	85	91
GW36702.1	(Ca-Na)- HCO^3	(Ca-Na)- HCO^3	24	31
GW300353	Na-HCO^3	Na-HCO^3	-	-
GW039387	Mixed type	(Na-Mg-Ca)- HCO^3	-	-
GW41001.2	Mixed type	(Na-Mg-Ca)- HCO^3	65	68
Spring 1	Mixed type	Na-(HCO^3 -Cl)	Surface water discharge Upstream of GW036701	
SW 1	Na-Cl	Na-Cl	Marom Creek	
SW 2	Na-Cl	Na-Cl	Maguires Ck / Lumley Park	
SW 3	Na-Cl	Na-Cl	Pearces Creek	

Figure 46 Piper plot for the May 2021 sampling results for Alstonville Basalt



6.3 Isotope analysis

6.3.1 Stable Isotopes

The stable isotope ratios of hydrogen and oxygen in water molecules can help us identify what processes water molecules have been exposed to and can help us understand how water is flowing through the landscape. This allows us to determine the source of the water sampled, to assess how much evaporation a water sample has been exposed to, and if water sources are mixing.

There are two stable isotopes of hydrogen and oxygen. They are hydrogen-1 (1H) and hydrogen-2 (2H); and oxygen-16 (16^{O}) and oxygen-18 (18^{O}). The ratio 2H/1H is expressed as δ 2H, while the ratio $18^{O}/16^{O}$ is expressed as δ 18^{O}. The ratios are compared to an international standard known as the Vienna Standard Mean Ocean Water (VSMOW). The ratio values are reported as parts per thousand (‰).

6.3.2 Results

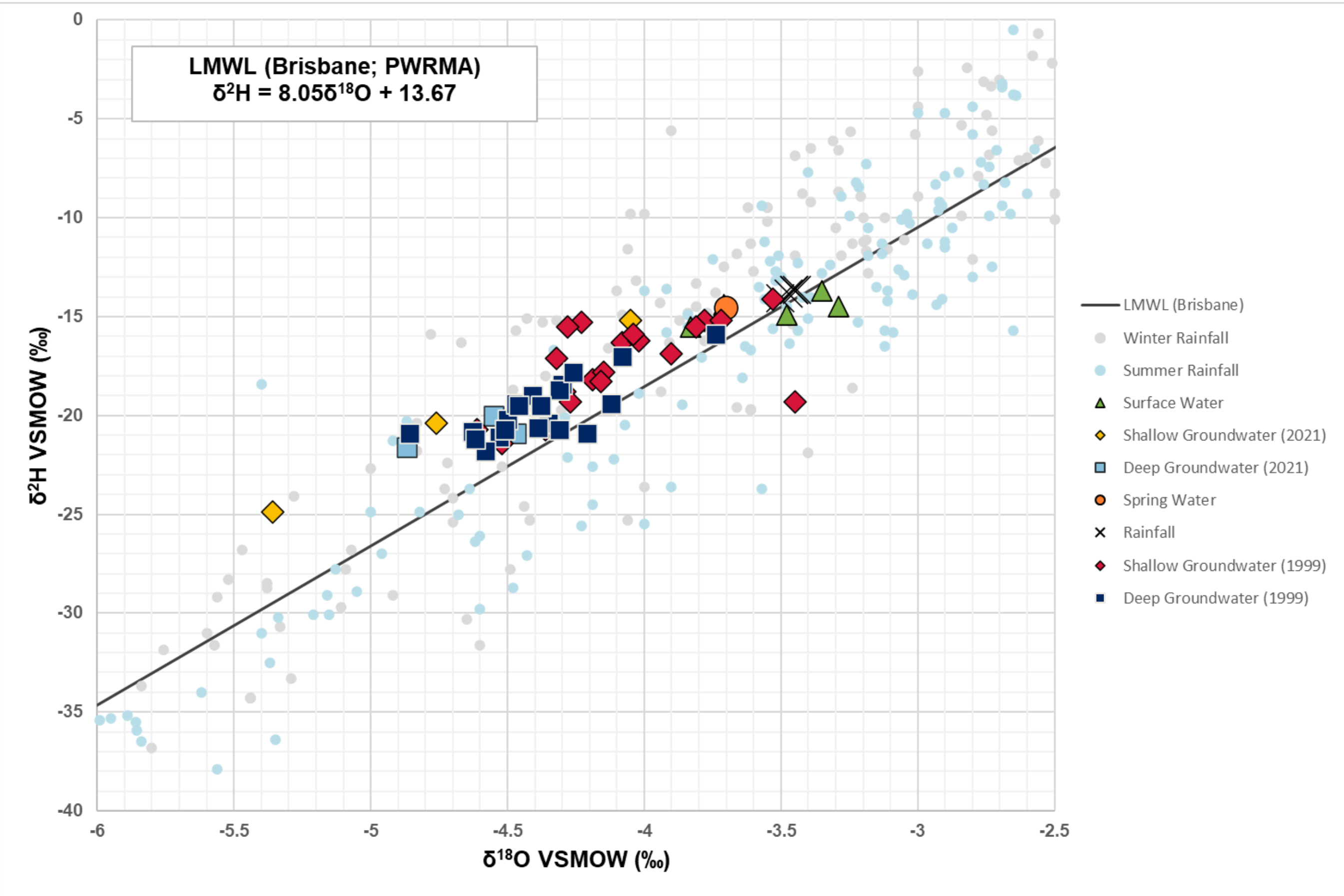
The δ 2H and δ 18^{0} composition of the Alstonville Basalt Plateau Groundwater Source is shown in **Figure 47.** The Local Meteoric Water Line (LMWL) for Brisbane is also shown, along with the projected isotopic composition of local rainfall based on the continent-wide isoscape (Hollins et al, 2018).

The groundwater is depleted in isotopic signature compared to the Brisbane LMWL, due to altitude effect. This can be explained by the lower elevation of the Brisbane LMWL and projected rainfall composition points and the influence of altitude has on water vapour masses and rainfall.

The δ ^{2}H and δ ^{18}O composition of samples within the shallow groundwater system plot close to the Brisbane LMWL, with most of these samples being depleted in δ 18O and δ 2H in comparison to the LMWL for Brisbane. This, along with the spread of data indicates that (a) local rainfall is the dominant recharge source, (b) there is variation in the precipitation stable isotope composition that is recharging the shallow aquifers, and (c) minimal evaporation is occurring during infiltration **(Figure 47)**.

The δ ^{2}H and δ ^{18}O composition of samples within the deep groundwater system have a narrower spread relative to the shallower groundwater samples. This suggests that homogenisation processes are occurring, as expected in the deep aquifer.

Figure 47 Local meteoric water level for Brisbane with isotopic composition of water on the Alstonville Basalt Plateau



6.3.3 Carbon isotopes

Carbon isotope samples were obtained during the May 2021 sampling expedition; however, detailed analysis has not been conducted yet. These results will be presented in future work. Preliminary analysis indicates the groundwater in the deep aquifer to be up to 30,000 years old. The shallow groundwater is believed to be very young (<50 years).

References

APHA, AWWA, and WEF (2017) ‘Section 1030 E. Checking Analyses’ Correctness’ in Standard Methods for the Examination of Water and Wastewater 23rd Edition; prepared and published jointly by the American Public Health Association, the American Water Works Association, and the Water Environment Federation; American Public Health Association, Washington, Section 1030 pp 8to9.

AS/NZS 5667.1:1998: Water quality to Sampling to Guidance on the design of sampling programs; sampling techniques and the preservation and handling of samples.

Australian Soil Classification (ASC) Third Edition, by R.F. Isbell and the National Committee on Soil and Terrain. CSIRO Publishing, March 2021

Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australian and New Zealand (ARMCANZ) (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. www.waterquality.gov.au/anztoguideline

Bish, S., and Ross, J., (2001). Recharge Assessment for Priority Groundwater Systems within NSW.

Bilge H (2003) Alstonville plateau groundwater model: model development and calibration. NSW Department of Sustainable Natural Resources. (Unpublished Report)

Brodie, R. S., and Green, R., (2005). A hydrogeological Assessment of Fractured Basalt Aquifers on the Alstonville Plateau, NSW. Bureau of Rural Sciences Australia]

Brodie, R. S., Green, R. and Graham, M., (2002). Groundwater dependent ecosystems of the Alstonville Plateau (1:50,000 scale). In: NRWMC, 2002, Water Sharing Plan for the Alstonville Plateau Basalt Groundwater Source, July 1, 2002. Northern Rivers Water Management Committee

Brodie R.S.,2007 Conjunctive Water Management in the Lower Richmond Water Catchment. PhD ANU

Budd, L. K., Plazinska, A.J, Brodie, R.S. A Groundwater Quality Assessment of the Fractured Basalt Aquifers on the Alstonville Plateau, NSW. Land & Water Sciences Division, Bureau of Rural Sciences, Canberra, 2000.

DWR (1989). Interim guidelines for a water management plan for the Alstonville Plateau, NSW. NSW Department of Water Resources.

Green, R. T., (2006). Alstonville Groundwater Investigations Status Report 2006 (unpublished), NSW Department of Natural Resources.

Hollins, S.E., Hughes, C.E., Crawford, J., Cendón, D.I., & Meredith, K.T. (2018) Rainfall isotope variations over the Australian continent – Implications for hydrology and isoscape applications. Science of the Total Environment, 645, 630to645

Hughes, C.E., and Crawford, J. (2012) A new precipitation weighted method for determining the meteoric water line for hydrological applications demonstrated using Australian and global GNIP data. Journal of Hydrology, 464, 344to351

International Atomic Energy Agency (IAEA) (1992) Statistical Treatment of Data on Environmental Isotopes in Precipitation: Technical Reports Series No. 3311. International Atomic Energy Agency, Vienna, p.781

International Atomic Energy Agency. (2018). Australian Global Network of Isotope in Precipitation (GNIP) database 1960to2014 (p. MS Excel dataset).

Madden, A., Mclean, W., Wash, J., Fanning, M. Microbiological, Hydrochemical, and Isotopic Characterisation of the Aquifers at Alstonville, NSW, Australia. Parsons Brinkerhoff, 2004.

Morand, D.T., (1994). Soil landscapes of the Lismore to Ballina 1:100,000 map sheet. Report, Soil Conservation Service of NSW, Sydney.

Morand DT (1994) 'Soil Landscapes of the Lismore-Ballina 1: 100 000 Sheet Map and Report'.

Ross, J.B, Williams, R.M, Rolfe, C. (1989) Groundwater Recharge and Management for the Alstonville Plateau, New South Wales. Department of Water Resources, Parramatta, NSW.

Sundaram, B., Feitz, J. A., Caritat, D. P., Plazinska, A., Brodie, S. R., Coram, J., Ransley, T., & Geoscience Australia. (2010). Groundwater Sampling and Analysis to A Field Guide.

Appendix A – Laboratory results

Bore number	Sample date	Sample time	pH value	Electrical Conductivity @ 25°C	Total Dissolved Solids @180°C	Hydroxide Alkalinity as CaCO3	Carbonate Alkalinity as CaCO3	Bicarbonate Alkalinity as CaCO3	Total Alkalinity as CaCO3	Sulfate as SO4 - Turbidimetric
			pH unit	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
GW39387	20/05/2021	09:13	7.16	358	232	<1	<1	157	157	4
Duplicate 1	20/05/2021	08:20	8.13	524	318	<1	<1	152	152	6
GW300353	20/05/2021	08:16	7.85	525	322	<1	<1	153	153	5
Spring 1	19/05/2021	16:04	6.13	156	91	<1	<1	30	30	2
GW041006	19/05/2021	13:27	5.03	208	117	<1	<1	41	41	5
GW41001.2	20/05/2021	14:15	5.81	343	228	<1	<1	135	135	3
GW041002	21/05/2021	11:00	7.94	1590	928	<1	<1	348	348	<1
GW41007.1	22/05/2021	12:26	6.91	843	486	<1	<1	152	152	14
GW41007.2	23/05/2021	10:34	7.92	487	285	<1	<1	166	166	4
GW36702.1	24/05/2021	17:22	6.11	136	74	<1	<1	65	65	<1
GW81006	25/05/2021	11:46	7.59	106	58	<1	<1	33	33	2
GW81005	25/05/2021	16:01	6.59	358	216	<1	<1	151	151	3
DUP2	25/05/2021	16:55	6.77	366	212	<1	<1	147	147	2
GW41001	26/05/2021	12:51	5.63	142	81	<1	<1	30	30	6
GW41007	26/05/2021	16:39	----	----	----	----	----	----	----	----
GW041000.1.2	27/05/2021	11:48	8.14	483	268	<1	<1	151	151	5
GW081003	28/05/2021	07:14	6.48	232	152	<1	<1	91	91	2
Trip Spike	10/05/2021	10:31	----	----	----	----	----	----	----	----
Trip Blank	10/05/2021	10:31	----	----	----	----	----	----	----	----

			Dissolved Major Cations					
Bore number	Sample date	Sample time	Chloride	Calcium	Magnesium	Sodium	Potassium	Sodium Adsorption Ratio
			mg/L	mg/L	mg/L	mg/L	mg/L	-
GW39387	20/05/2021	09:13	24	15	14	37	5	1.65
Duplicate 1	20/05/2021	08:20	70	1	<1	107	5	21.8
GW300353	20/05/2021	08:16	72	2	<1	109	5	17.8
Spring 1	19/05/2021	16:04	18	5	4	17	<1	1.37
GW041006	19/05/2021	13:27	19	9	6	16	<1	1.01
GW41001.2	20/05/2021	14:15	23	16	12	32	4	1.47
GW041002	21/05/2021	11:00	339	22	18	283	6	10.8
GW41007.1	22/05/2021	12:26	174	8	3	157	2	12.0
GW41007.2	23/05/2021	10:34	42	1	<1	108	1	22.0
GW36702.1	24/05/2021	17:22	4	10	<1	11	3	0.92
GW81006	25/05/2021	11:46	14	2	2	13	<1	1.55
GW81005	25/05/2021	16:01	26	16	11	44	5	2.07
DUP2	25/05/2021	16:55	26	17	11	43	5	2.00
GW41001	26/05/2021	12:51	17	3	3	14	<1	1.37
GW41007	26/05/2021	16:39	----	----	----	----	----	----
GW041000.1.2	27/05/2021	11:48	56	2	<1	101	5	16.5
GW081003	28/05/2021	07:14	19	13	10	19	4	0.96
Trip Spike	10/05/2021	10:31	----	----	----	----	----	----
Trip Blank	10/05/2021	10:31	----	----	----	----	----	----

Bore number	Sample date	Sample time	Dissolved Metals							**Total Metals**			
			Aluminium	Arsenic	Lead	Manganese	Uranium	Zinc	Iron	Arsenic2	Selenium	Uranium2	Iron2
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
GW39387	20/05/2021	09:13	<0.01	<0.001	<0.001	0.027	<0.001	<0.005	0.06	<0.001	<0.01	<0.001	0.08
Duplicate 1	20/05/2021	08:20	<0.01	0.001	<0.001	<0.001	<0.001	<0.005	<0.05	<0.001	<0.01	<0.001	<0.05
GW300353	20/05/2021	08:16	<0.01	<0.001	<0.001	<0.001	<0.001	<0.005	0.05	<0.001	<0.01	<0.001	<0.05
Spring 1	19/05/2021	16:04	0.03	<0.001	<0.001	0.086	<0.001	<0.005	0.12	<0.001	<0.01	<0.001	3.79
GW041006	19/05/2021	13:27	<0.01	<0.001	<0.001	0.124	<0.001	0.026	0.32	0.002	<0.01	<0.001	1.66
GW41001.2	20/05/2021	14:15	<0.01	<0.001	<0.001	0.030	<0.001	0.011	0.09	<0.001	<0.01	<0.001	0.21
GW041002	21/05/2021	11:00	<0.01	0.001	<0.001	0.051	<0.001	<0.005	1.20	0.002	<0.01	<0.001	4.62
GW41007.1	22/05/2021	12:26	0.04	0.002	<0.001	0.011	<0.001	0.013	<0.05	0.002	<0.01	<0.001	<0.05
GW41007.2	23/05/2021	10:34	0.10	0.002	0.001	0.004	<0.001	0.018	0.31	0.002	<0.01	<0.001	0.76
GW36702.1	24/05/2021	17:22	<0.01	<0.001	<0.001	0.885	<0.001	0.036	11.5	<0.001	<0.01	<0.001	11.7
GW81006	25/05/2021	11:46	0.01	<0.001	<0.001	0.015	<0.001	0.041	<0.05	<0.001	<0.01	<0.001	<0.05
GW81005	25/05/2021	16:01	<0.01	<0.001	<0.001	0.032	<0.001	<0.005	0.07	<0.001	<0.01	<0.001	0.16
DUP2	25/05/2021	16:55	<0.01	<0.001	<0.001	0.031	<0.001	<0.005	0.07	<0.001	<0.01	<0.001	0.15
GW41001	26/05/2021	12:51	0.01	<0.001	<0.001	0.010	<0.001	0.014	<0.05	<0.001	<0.01	<0.001	<0.05
GW41007	26/05/2021	16:39	----	----	----	----	----	----	----	----	----	----	----
GW041000.1.2	27/05/2021	11:48	<0.01	<0.001	<0.001	<0.001	<0.001	<0.005	<0.05	<0.001	<0.01	<0.001	<0.05

GW081003	28/05/2021	07:14	<0.01	<0.001	<0.001	0.124	<0.001	0.017	0.63	<0.001	<0.01	<0.001	0.74
Trip Spike	10/05/2021	10:31	----	----	----	----	----	----	----	----	----	----	----
Trip Blank	10/05/2021	10:31	----	----	----	----	----	----	----	----	----	----	----

Bore number	Sample date	Sample time	Ferrous Iron	Reactive Silica	Reactive Silica as Silicon	Fluoride	Ammonium as N	Ammonia as N	Nitrite as N	Nitrate as N
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
GW39387	20/05/2021	09:13	<0.05	53.6	25.0	0.1	0.08	0.08	<0.01	<0.01
Duplicate 1	20/05/2021	08:20	<0.05	29.4	13.7	0.1	0.03	0.04	<0.01	<0.01
GW300353	20/05/2021	08:16	<0.05	29.3	13.7	0.1	0.03	0.04	<0.01	<0.01
Spring 1	19/05/2021	16:04	0.09	14.0	6.54	<0.1	0.06	0.06	<0.01	3.02
GW041006	19/05/2021	13:27	0.38	33.9	15.8	<0.1	0.06	0.06	<0.01	1.81
GW41001.2	20/05/2021	14:15	0.08	55.8	26.1	0.1	0.07	0.07	<0.01	0.02
GW041002	21/05/2021	11:00	1.58	29.2	13.6	0.2	2.68	2.71	<0.01	<0.01
GW41007.1	22/05/2021	12:26	<0.05	19.7	9.21	<0.1	0.02	0.02	<0.01	0.03
GW41007.2	23/05/2021	10:34	<0.05	19.0	8.88	0.1	<0.01	<0.01	<0.01	0.05
GW36702.1	24/05/2021	17:22	11.8	7.25	3.39	<0.1	0.86	0.86	0.01	<0.01
GW81006	25/05/2021	11:46	<0.05	18.9	8.84	<0.1	<0.01	<0.01	<0.01	0.54
GW81005	25/05/2021	16:01	0.06	51.2	23.9	0.1	0.05	0.05	<0.01	0.02
DUP2	25/05/2021	16:55	0.05	51.1	23.9	0.2	0.06	0.06	<0.01	0.02
GW41001	26/05/2021	12:51	<0.05	24.3	11.4	<0.1	<0.01	<0.01	<0.01	0.64
GW41007	26/05/2021	16:39	----	----	----	----	----	<0.01	<0.01	1.12
GW041000.1.2	27/05/2021	11:48	<0.05	45.2	21.1	0.2	0.08	0.09	<0.01	0.02
GW081003	28/05/2021	07:14	0.77	67.3	31.5	0.2	0.10	0.10	<0.01	0.02
Trip Spike	10/05/2021	10:31	----	----	----	----	----	----	----	----
Trip Blank	10/05/2021	10:31	----	----	----	----	----	----	----	----

Bore number	Sample date	Sample time	Nitrite + Nitrate as N	Total Kjeldahl Nitrogen as N	Total Nitrogen as N	Total Phosphorus as P	Reactive Phosphorus as P	Ionic Balance		
								Total Anions	Total Cations	Ionic Balance
			mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	meq/L	%
GW39387	20/05/2021	09:13	<0.01	<0.1	<0.1	0.07	0.08	3.90	3.64	3.44
Duplicate 1	20/05/2021	08:20	<0.01	<0.1	<0.1	0.05	0.04	5.09	4.83	2.65
GW300353	20/05/2021	08:16	<0.01	<0.1	<0.1	0.04	0.04	5.19	4.97	2.20
Spring 1	19/05/2021	16:04	3.02	1.0	4.0	0.17	<0.01	1.15	1.32	----
GW041006	19/05/2021	13:27	1.81	0.3	2.1	0.05	0.01	1.46	1.64	----
GW41001.2	20/05/2021	14:15	0.02	<0.1	<0.1	0.08	0.09	3.39	3.28	1.61
GW041002	21/05/2021	11:00	<0.01	2.8	2.8	0.23	0.01	16.5	15.0	4.67
GW41007.1	22/05/2021	12:26	0.03	<0.1	<0.1	0.10	0.08	8.20	7.53	4.25
GW41007.2	23/05/2021	10:34	0.05	<0.1	<0.1	0.09	0.08	4.58	4.77	2.01
GW36702.1	24/05/2021	17:22	0.01	1.0	1.0	0.04	<0.01	1.41	1.66	----
GW81006	25/05/2021	11:46	0.54	0.1	0.6	0.02	<0.01	1.08	0.83	----
GW81005	25/05/2021	16:01	0.02	<0.1	<0.1	0.07	0.05	3.79	3.74	0.62
DUP2	25/05/2021	16:55	0.02	0.2	0.2	0.09	0.05	3.71	3.75	0.53
GW41001	26/05/2021	12:51	0.64	0.1	0.7	0.02	<0.01	1.16	1.00	----
GW41007	26/05/2021	16:39	1.12	0.2	1.3	0.04	0.03	----	----	----
GW041000.1.2	27/05/2021	11:48	0.02	0.1	0.1	0.09	0.08	4.68	4.62	0.64
GW081003	28/05/2021	07:14	0.02	0.2	0.2	0.13	0.11	2.37	2.40	----
Trip Spike	10/05/2021	10:31	----	----	----	----	----	----	----	----
Trip Blank	10/05/2021	10:31	----	----	----	----	----	----	----	

							BTEXN			
Bore number	Sample date	Sample time	Dissolved Organic Carbon	C6 - C9 Fraction	C6 - C10 Fraction	C6 - C10 Fraction minus BTEX (F1)	Benzene	Toluene	Ethylbenzene	meta- & para-Xylene
			mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
GW39387	20/05/2021	09:13	0.4	----	----	----	----	----	----	----
Duplicate 1	20/05/2021	08:20	0.4	----	----	----	----	----	----	----
GW300353	20/05/2021	08:16	0.4	----	----	----	----	----	----	----
Spring 1	19/05/2021	16:04	0.7	----	----	----	----	----	----	----
GW041006	19/05/2021	13:27	1.5	----	----	----	----	----	----	----
GW41001.2	20/05/2021	14:15	2.0	----	----	----	----	----	----	----
GW041002	21/05/2021	11:00	1.2	----	----	----	----	----	----	----
GW41007.1	22/05/2021	12:26	0.6	----	----	----	----	----	----	----
GW41007.2	23/05/2021	10:34	0.8	----	----	----	----	----	----	----
GW36702.1	24/05/2021	17:22	1.6	----	----	----	----	----	----	----
GW81006	25/05/2021	11:46	1.0	----	----	----	----	----	----	----
GW81005	25/05/2021	16:01	0.5	----	----	----	----	----	----	----
DUP2	25/05/2021	16:55	0.4	----	----	----	----	----	----	----
GW41001	26/05/2021	12:51	0.7	----	----	----	----	----	----	----
GW41007	26/05/2021	16:39	----	----	----	----	----	----	----	----
GW041000.1.2	27/05/2021	11:48	0.4	----	----	----	----	----	----	----
GW081003	28/05/2021	07:14	0.8	----	----	----	----	----	----	----
Trip Spike	10/05/2021	10:31	----	----	----	----	16	16	16	16
Trip Blank	10/05/2021	10:31	----	<20	<20	<20	<1	<2	<2	<2

			BTEXN							
Bore number	Sample date	Sample time	ortho-Xylene	Total Xylenes	Sum of BTEX	Naphthalene	Bromide	1.2-Dichloroethane-D4	Toluene-D8	4-Bromofluorobenzene
			µg/L	µg/L	µg/L	µg/L	mg/L	%	%	%
GW39387	20/05/2021	09:13	----	----	----	----	0.054	----	----	----
Duplicate 1	20/05/2021	08:20	----	----	----	----	0.146	----	----	----
GW300353	20/05/2021	08:16	----	----	----	----	0.147	----	----	----
Spring 1	19/05/2021	16:04	----	----	----	----	0.083	----	----	----
GW041006	19/05/2021	13:27	----	----	----	----	0.076	----	----	----
GW41001.2	20/05/2021	14:15	----	----	----	----	0.051	----	----	----
GW041002	21/05/2021	11:00	----	----	----	----	0.549	----	----	----
GW41007.1	22/05/2021	12:26	----	----	----	----	0.377	----	----	----
GW41007.2	23/05/2021	10:34	----	----	----	----	0.099	----	----	----
GW36702.1	24/05/2021	17:22	----	----	----	----	0.011	----	----	----
GW81006	25/05/2021	11:46	----	----	----	----	0.045	----	----	----
GW81005	25/05/2021	16:01	----	----	----	----	0.056	----	----	----
DUP2	25/05/2021	16:55	----	----	----	----	0.056	----	----	----
GW41001	26/05/2021	12:51	----	----	----	----	0.070	----	----	----
GW41007	26/05/2021	16:39	----	----	----	----	----	----	----	----
GW041000.1.2	27/05/2021	11:48	----	----	----	----	0.120	----	----	----
GW081003	28/05/2021	07:14	----	----	----	----	0.043	----	----	----
Trip Spike	10/05/2021	10:31	16	32	80	17	----	108	102	104
Trip Blank	10/05/2021	10:31	<2	<2	<1	<5	----	112	104	105

Appendix B – Field results

Sample ID	Date/Time	Hole	Pipe	Screen 1 Begin	Screen 1 End	*m bgl*	*Litres*	*m bgl*	*unit*	*µS/cm*	*°C*	*%*	*mV*
						SWL (Pre-Sample)	**Purge Volume**	**SWL (Post-Sample)**	**pH**	**Conductivity**	**Temperature**	**Dissolved Oxygen**	**Redox Potential**
GW041002	21/05/2021 11:00	1	1	50	56	2.59	6	2.59	7.31	1461	21.6	7.9	-148.9
SW 3	21/05/2021 14:54	-	-	-	-	-	-	-	7.29	98.2	17.8	70.2	665
GW36701.3.4	18/05/2021 13:13	3	4	88	128	33.18	10	34.41	5.27	494.3	19.8	14.4	369.3
GW041006	19/05/2021 13:27	1	1	4	10	2.13	3	2.15	4.69	177.2	19.9	9.1	-512.5
SW 1	19/05/2021 15:15	-	-	-	-	-	-	-	5.93	96.6	16.7	50.8	-139.4
Spring 1	19/05/2021 16:04	-	-	-	-	-	-	-	5.72	133.8	19.4	28.9	-235.8
GW081006	25/05/2021 11:46	1	1	8	12	8.31	5	8.3	4.23	-	21.3	33.4	335.1
GW081005	25/05/2021 16:01	1	1	59	71	42.22	9.5	43.02	6.24	320	21.4	10.4	201
Duplicate 2 (81005)	25/05/2021 16:55	1	1	59	71	42.22	9.5	43.02	6.24	320	21.4	10.4	201
GW041001	26/05/2021 12:51	1	1	20	26	8.83	6	8.83	4.05	97.2	21.9	8.9	238.4
GW041007	26/05/2021 16:39	-	-	-	-	-	-	-	-	-	-	-	-
GW041000.1.2	27/05/2021 11:48	2	1	88	94	-	8	-	8.27	364.8	19.6	10.9	-58.8
GW081003	28/05/2021 7:14	1	1	32	38	10.62	9		5.59	187.3	20.1	7.1	32.6
GW41007.1	22/05/2021 12:26	1	1	38	41	6.63	8	7.01	7.09	734	21	7.7	158.4
GW41007.2	23/05/2021 10:34	1	2	85	91	6.69	11	6.98	5.81	374.3	21.1	9.6	68.2
GW36702.1	24/05/2021 17:22	1	1	24	31	7.54	6	7.78	5.55	131.6	21.8	9.8	169.4
GW300353	20/05/2021 8:16	-	-	-	-	N/A	40, 000	N/A	8.91	483.2	20.7	53	101.2
Duplicate 1 (300353)	20/05/2021 8:20	-	-	-	-	N/A	40, 000	N/A	8.91	483.2	20.7	53	101.2

Sample ID	Date/Time	Hole	Pipe	Screen 1 Begin	Screen 1 End	*m bgl*	*Litres*	*m bgl*	*unit*	*µS/cm*	*°C*	*%*	*mV*
						SWL (Pre-Sample)	**Purge Volume**	**SWL (Post-Sample)**	**pH**	**Conductivity**	**Temperature**	**Dissolved Oxygen**	**Redox Potential**
GW039387	20/05/2021 9:13	-	-	-	-	N/A	20, 000	N/A	8	325.5	20.4	45	182.1
GW41001.2	20/05/2021 14:15	2	1	65	68	58.05	7	59.05	5.09	297.6	20.9	12.3	209.2
SW 2	20/05/2021 12:08	-	-	-	-	-	-	-	6.66	73.6	18	69.5	190.6
Trip Spike	10/05/2021 10:31	-	-	-	-	-	-	-	-	-	-	-	-
Trip Blank	10/05/2021 10:31	-	-	-	-	-	-	-	-	-	-	-	-