NSW MURRAY–DARLING BASIN FRACTURED ROCK WATER RESOURCE PLAN

Groundwater Resource Description

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NSW Murray–Darling Basin Fractured Rock Water Resource Plan, Groundwater Resource Description

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More information

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Glossary

Note: these terms are presented in the context that they are used for groundwater.

Term	Meaning
Alluvial aquifer	A groundwater system whose geological matrix is composed of unconsolidated sediments consisting of gravel, sand, silt and clay transported and deposited by rivers and streams.
Alluvium	Unconsolidated sediments deposited by rivers or streams consisting of gravel, sand, silt and clay, and found in terraces, valleys, alluvial fans and floodplains.
Aquifer	Under the *Water Management Act 2000* an aquifer is a geological structure or formation, or an artificial landfill that is permeated with water or is capable of being permeated with water. More generally, the term aquifer is commonly understood to mean a groundwater system that can yield useful volumes of groundwater. For the purposes of groundwater management in NSW the term 'aquifer' has the same meaning as 'groundwater system' and includes low yielding and saline systems.
Aquitard	A confining low permeability layer that retards but does not completely stop the flow of water to or from an adjacent aquifer, and that can store groundwater but does not readily release it.
Artesian	Groundwater which rises above the surface of the ground under its own pressure by way of a spring or when accessed by a bore..
Archean	The Archean Era spanned 4.56 to 2.5 billion years ago.
Australian Height Datum (AHD)	Elevation in metres above mean sea level.
Available water determination	A determination referred to in section 59 of the *Water Management Act 2000* that defines a volume of water or the proportion of the share component (also known as an 'allocation) that will be credited to respective water accounts under specified categories of water access licence. Initial allocations are made on 1 July each year and, if not already fully allocated, may be incremented during the water year.
Baseflow	Discharge of groundwater into a surface water system.
Basement (rock)	See Bedrock
Basic landholder rights (BLR)	Domestic and stock rights, harvestable rights or native title rights.
Bedding	Discrete sedimentary layers that were deposited one on top of another.
Bedrock	A general term used for solid rock that underlies aquifers, soils or other unconsolidated material. .
Beneficial use (category)	[1]A general categorisation of groundwater uses based on water quality and the presence or absence of contaminants. Beneficial use is the equivalent to the 'environmental value' of water.
Bore (or well)	A hole or shaft drilled or dug into the ground...

[1] As defined in '*Macro water sharing plans – the approach for groundwater*' (NSW Office of Water, 2011)

Term	Meaning
Brackish water	Water with a salinity between 3,000 and 7,000 mg/L total dissolved solids.
Cenozoic	The Cenozoic Era spanned from 66 million years ago to present
Confined aquifer	. An aquifer which is bounded above and below by impermeable layers causing it to be under pressure so that when the aquifer is penetrated by a bore, the groundwater will rise above the top of the aquifer.
Connected water sources	Water sources that have some level of hydraulic connection.
Development (of a groundwater resource)	The commencement of extraction of significant volumes of water from a water source.
Discharge	Flow of groundwater from a groundwater source.
Drawdown	The difference between groundwater level/pressure before take and that during take.
Dual porosity	Where a groundwater system has two types of porosity; primary porosity resulting from the voids between the constituent particles forming the rock mass, and secondary porosity resulting from dissolution, faulting and jointing of the rock mass.
Electrical conductivity (EC)	Ability of a substance to conduct an electrical current. Used as a measure of the concentration of dissolved ions (salts) in water (i.e. water salinity). Measured in micro-Siemens per centimetre (µS/cm) or deci-Siemens per metre (dS/m) at 25^{o} C. 1 dS/m = 1000 µS/cm
Environmental Value	[2]Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of contamination, waste discharges and deposits.
Fractured rock	Rocks with fractures, joints, bedding planes and cavities in the rock mass.
Geological sequence	A sequence of rocks or sediments occurring in chronological order.
Groundwater	Water that occurs beneath the ground surface in the saturated zone.
Groundwater Dependent Ecosystem (GDE)	[3]Ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services.
Geological formation	A fundamental lithostratigraphic unit used in the local classification of strata and classified by the distinctive physical and chemical features of the rocks that distinguish it from other formations.
Groundwater equilibrium	A state where the forces driving groundwater flow have reached a balance in a groundwater system, for example where groundwater inflow equals groundwater outflow.
Groundwater system	Any type of saturated sequence of rocks or sediments that is in hydraulic connection. The characteristics can range from low yielding and high salinity water to high yielding and low salinity water.

[2] As defined in '*Guidelines for Groundwater Quality Protection in Australia 2013'* published by the National Water Quality Management Strategy.

[3] Kuginis L., Dabovic, J., Byrne, G., Raine, A., and Hemakumara, H. 2016, *Methods for the identification of high probability groundwater dependent vegetation ecosystems.* DPI Water, Sydney, NSW.

Term	Meaning
Highly Productive Aquifer	An aquifer system with potential bore yields of greater than 5 L/s and salinity concentration of less than 500 mg/L.
Hydraulic conductivity	The capacity of a porous medium to transmit water. Measured in meters/day.
Hydraulic connection	A path or conduit allowing fluids to be connected. The degree to which a groundwater system can respond hydraulically to changes in hydraulic head.
Hydraulic head	. The height of a water column above a defined point, usually expressed in metres.
Hydrogeology	The branch of geology that relates to the occurrence, distribution and processes of groundwater.
Hydrograph	A plot of water data over time.
Kriging	A method of interpolation using a weighted average of neighbouring samples to estimate an 'unknown' value at a given location to create surfaces.
Long term average annual extraction limit (LTAAEL)	The long term average volume of water (expressed in megalitres per year) in a water source available to be lawfully extracted or otherwise taken.
Igneous rock	Rocks which have solidified from a molten mass.
Infiltration	The movement of water from the land surface into the ground.
Ion	Mineral species dissolved in groundwater.
Make good provisions (in reference to a water supply work)	The requirement to ensure third parties have access to an equivalent supply of water through enhanced infrastructure or other means for example deepening an existing bore, funding extra pumping costs or constructing a new pipeline or bore.
Management zone	A defined area within a water source where a particular set of water sharing rules applies.
Mesozoic	The Mesozoic Era spanned 252 to 66 million years ago
Metamorphic rock	Rocks that result from partial or complete recrystallisation in the solid state of pre-existing rocks under conditions of temperature and pressure.
Minimal impact considerations	Factors that need to be assessed to determine the potential effect of aquifer interference activities on groundwater and its dependent assets.
Monitoring bore	A specially constructed bore used to measure groundwater level or pressure and groundwater quality at a specific depth. Not intended to supply water.
Ongoing take	The take of groundwater that occurs after part or all of the principal activity has ceased. For example extraction of groundwater (active take) entering completed structures, groundwater filling abandoned underground workings (passive take) or the evaporation of water (passive take) from an abandoned excavation that has filled with groundwater.
Outcrop	Rocks which are exposed at the land surface.
Piezometric or Potentiometric head	The pressure or hydraulic head of the groundwater at a particular depth in the ground. In unconfined aquifers this is the same as the water table.

Term	Meaning
Palaeozoic	The Palaeozoic Era spanned 541 to 252 million years ago.
Perched water table	A local water table of very limited extent which is separated from the underlying groundwater by an unsaturated zone.
Permeability	The capacity of earth materials to transmit a fluid.
Porous rock	Consolidated sedimentary rock containing voids, pores or other openings in the rock (such as joints, cleats and/or fractures.
Pre-development	Prior to development of a groundwater resource.
Proterozoic	The Proterozoic Era spanned 2.5 billion to 541 million years ago.
Recharge	The addition of water into a groundwater system by infiltration, flow or injection from sources such as rainfall, overland flow, adjacent groundwater sources, irrigation, or surface water sources.
Recovery	The rise of groundwater levels or pressures after groundwater take has ceased. Where water is being added, recovery will be a fall.
Recovery decline	Where groundwater levels or pressures do not fully return to the previous level after a period of groundwater removal or addition.
Reliable water supply	[4]Rainfall of 350mm or more per annum (9 out of 10 years); or a regulated river, or unregulated rivers where there are flows for at least 95% of the time (i.e. the 95th percentile flow of each month of the year is greater than zero) or 5th order and higher rivers; or groundwater aquifers (excluding miscellaneous alluvial aquifers, also known as small storage aquifers) which have a yield rate greater than 5L/s and total dissolved solids of less than 1,500mg/L.
River Condition Index (RCI)	This is a spatial tool used to measure and monitor the long term trend of river condition, but also reports on instream values and risk to instream values from extraction and geomorphic disturbance.
Salinity	The concentration of dissolved minerals in water, usually expressed in EC units or milligrams of total dissolved solids per litre.
Salt	A mineral which in a liquid will readily dissociate into its component ionic species for example NaCl into Na^+ and Cl^- ions.
Saturated zone	Area below the water table where all soil spaces, pores, fractures and voids are filled with water.
Sedimentary rock	A rock formed by consolidation of sediments deposited in layers, for example sandstone, siltstone and limestone.
Share component	An entitlement to water specified on an access licence, expressed as a unit share or for specific purpose licences a volume in megalitres (eg. local water utility, major water utility and domestic and stock).
Sustainable Diversion Limits	The volume of water that can be taken from a Sustainable Diversion Limit resource unit as defined under the Murray Darling *Basin Plan 2012*.

[4] As defined by Strategic Regional Land Use Plans

Term	Meaning
Unassigned water	Exists where current water requirements (including licensed volumes and water to meet basic landholder rights) are less than the extraction limit for a water source.
Unconfined aquifer	A groundwater system usually near the ground surface, which is in connection with atmospheric pressure and whose upper level is represented by the water table.
Unconsolidated sediment	Particles of gravel, sand, silt or clay that are not bound or hardened by mineral cement, pressure, or thermal alteration of the grains.
Unsaturated zone	Area above the water table where soil spaces, pores, fractures and voids are not completely filled with water.
Water balance	A calculation of all water entering and leaving a system.
Water resource plan	[5]A plan made under the *Commonwealth Water Act 2007* that outlines how a particular area of the Murray–Darling Basin's water resources will be managed to be consistent with the Murray–Darling Basin Plan. These plans set out the water sharing rules and arrangements relating to issues such as annual limits on water take, environmental water, managing water during extreme events and strategies to achieve water quality standards and manage risks.
Water sharing plan	[6]A plan made under the *Water Management Act 2000* which set out the rules for sharing water between the environment and water users within whole or part of a water management area or water source.
Water source	Defined under the *Water Management Act 2000* as 'The whole or any part of one or more rivers, lakes or estuaries, or one or more places where water occurs naturally on or below the surface of the ground and includes the coastal waters of the State. Individual water sources are more specifically defined in water sharing plans.
Water table	Upper surface of groundwater at atmospheric pressure, below which the ground is saturated.
Yield	The amount of water that can be supplied over a specific period.

[5] https://www.mdba.gov.au/basin-plan-roll-out/water-resource-plans 21/03/17

[6] As defined in '*Macro water sharing plans – the approach for groundwater*' (NSW Office of Water, 2011)

1 Introduction

The NSW Government is developing water resource plans as part of implementing the Murray-Darling Basin Plan 2012 (the Basin Plan). Water resource plans align Basin-wide and state-based water resource management in each water resource plan area. The water resource plans recognise and build on the existing water planning and management frameworks that have been established in NSW.

Under the Basin Plan, individual water resources are known as sustainable diversion limit (SDL) resource units and each water resource plan covers a number of SDL resource units within an area.

The NSW Murray - Darling Basin Fractured Rock Water Resource Plan (WRP) area is shown in Figure 1 and covers the entire NSW portion of the Murray Darling Basin (MDB). The larger portion of the fractured rock systems is buried and forms the basement for the overlying porous rocks and alluvial groundwater resource units covered in other water resource plans.

The WRP area encapsulates nine SDL resource units as shown in Figure 1. These are:

- Adelaide Fold Belt (GS10)
- Inverell Basalt (GS18)
- Kanmantoo Fold Belt (GS19)
- Lachlan Fold Belt (GS20)
- Liverpool Ranges Basalt (GS22)
- New England Fold Belt (GS37)
- Orange Basalt (GS39)
- Warrumbungle Basalt (GS49)
- Young Granite (GS51)

Collectively the WRP area covers 597,926 km² with the basement geology extending laterally beneath both the alluvial and porous rock groundwater resource units (Figure 1). Only twenty three percent of the NSW MDB landscape (approx.137,500 km²) is covered by the outcrop of these fractured rocks.

The groundwater resources of the WRP area include all of the groundwater stored within the fractures, joints, bedding planes, faults and cavities within the rock mass for the above nine SDL resource units. It also includes alluvial sediments that overly the fractured rock that have not been separately mapped out and incorporated into other water resource plans as individual SDL resource units. This alluvial cover is typically spatially restricted and/or limited in depth.

Seven of these SDL resource units correlate directly to groundwater sources currently administered by the *Water Sharing Plan for the NSW Murray - Darling Basin Fractured Rock Groundwater Sources 2011*. Under this WRP, the Yass Catchment groundwater source is included within the Lachlan Fold Belt SDL resource unit. The Peel Fractured Rock groundwater source, which is currently administered under the *Water Sharing Plan for the Peel Valley Regulated, Unregulated and Fractured Rock Water Sources 2010*, is included within the New England Fold Belt SDL resource unit.

This report describes the location, climate and physical attributes of the WRP area and explains their geological and hydrogeological context, environmental assets, groundwater quality and management. It also presents the current status of these groundwater resources including groundwater rights, accounts, dealings, take and groundwater behaviour.

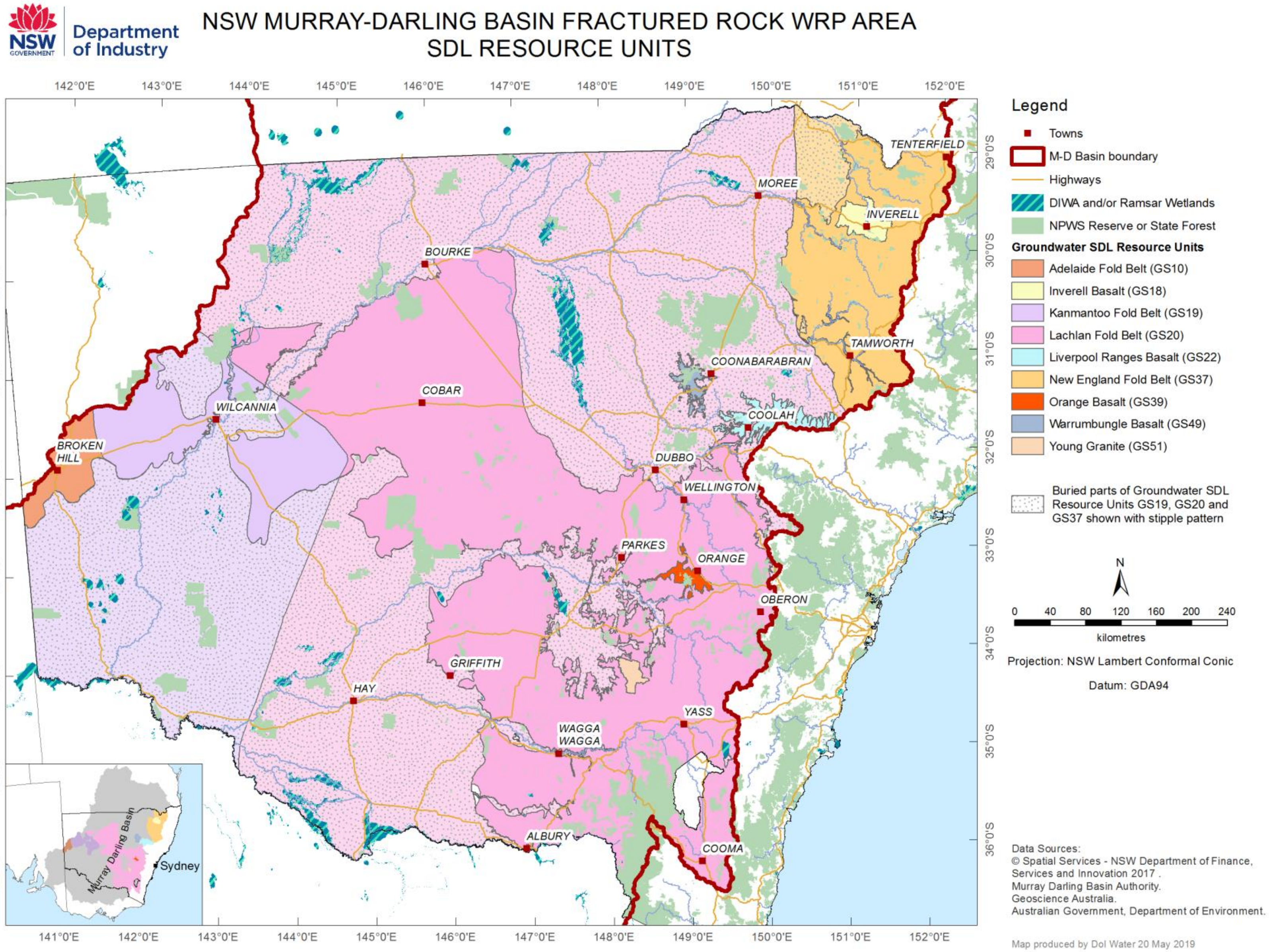

Figure 1 Location of the Murray Darling Basin Fractured Rock WRP area and SDL Resource Units (buried areas shown in hatched colouring)

2 History of Groundwater Management

2.1 **Early groundwater management**

The *Water Act 1912* (*WA 1912*) was introduced at a time when the development of water resources for agriculture and regional development were the priority of government (DLWC, 1999). Under the *WA 1912*, water 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 metres (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 *WA 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 five 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 megalitres / year (ML/yr)) except those in the Great Artesian Basin, were given a volumetric entitlement and old area based licences were progressively converted. 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 more effectively manage development in those groundwater systems where the resource was fully committed and to encourage the use of groundwater where it was underutilised.

2.2 **NSW water reforms**

In 1994, the Council of Australian Governments (COAG) endorsed a strategic framework for reform of the Australian water industry. The framework included identifying and recovering the costs of water management and supply from beneficiaries, recognising the environment as a water user through formal allocations and ensuring that water rights could move by trade to where they would generate the highest value.

By the late 1990s, NSW had embarked on a major program of water policy reforms. This included the development of the NSW State Groundwater Policy Framework Document, the NSW Groundwater Quality Protection Policy, and an assessment of risk to the State's groundwater systems from over-extraction and/or contamination. The NSW State Groundwater Dependent Ecosystems Policy was released in 2002.

The 1990s policy reforms drove the development of the *Water Management Act 2000 (WMA 2000)*. The *WMA 2000* establishes water for the environment as a priority while also providing licence holders with more security through perpetual licences and greater opportunities to trade through the separation of water access rights from the land.

The *WMA 2000* considers other users of water such as groundwater dependent ecosystems, and aquifer interference activities; cumulative impacts; climate change; Aboriginal cultural rights and connectivity between groundwater and surface water. The *WMA 2000* also sets up the framework for developing statutory plans to manage water.

Water sharing plans are the principle tool for managing the State's water resources including groundwater. These ten year plans manage groundwater resources at the 'water source' scale, define the long term average annual extraction limit (LTAAEL), establish rules for sharing groundwater between users and the environment, establish basic landholder rights and set rules for water trading.

Priority for developing water sharing plans was based on the groundwater systems identified by the risk assessment as being at highest risk. The first groundwater sharing plans in the Murray-Darling Basin commenced between 2006 and 2008 across six large alluvial groundwater systems in the Murray-Darling Basin. Access to groundwater was reduced to the extraction limit over the ten year plan using an approach that recognised historical extraction.

Since 2007, water sharing plans for unregulated rivers and groundwater systems in NSW have been completed using a 'macro' approach to cover most of the remaining water sources across NSW. Each groundwater macro plan covers a number of a particular type of groundwater system (for example, fractured rock).

In 2008, two embargo orders covering the remaining inland groundwater resources were made under the *WA 1912* on new applications for groundwater licences. These embargoes remained in effect until the commencement of water sharing plans for the groundwater sources that they covered.

In 2012, the ‘NSW Aquifer Interference Policy’ was released. The purpose of this Policy is to explain the water licensing and assessment requirements for aquifer interference activities under the *WMA 2000* and other relevant legislative frameworks.

2.3 **Adelaide Fold Belt and Kanmantoo Fold Belt**

There has been little demand for groundwater within the Adelaide Fold Belt and the Kanmantoo Fold Belt in far western NSW primarily as the groundwater quality is poor with limited beneficial use potential. Consequently there has been little historic need for area specific management plans. The 2008 embargo order that prevented new applications for bore licences to be lodged across the entire MDB within NSW was the first gazetted embargo for these systems. This was in place until the commencement of the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011.

2.4 **Lachlan Fold Belt**

Groundwater development across the Lachlan Fold Belt is relatively limited however there are some areas of intense groundwater utilisation due to locally favourable groundwater availability and water quality.

The 2008 embargo order across the entire NSW portion of the MDB was the first embargo order that applied comprehensively across the Lachlan Fold Belt. However previously there were three areas within the Lachlan Fold Belt that had locally significant levels of groundwater utilisation that were recognised via earlier embargoes. These relate to an area around the township of Mudgee, the Yass catchment and the Young Granite. The Young Granite has been managed separately for a number of years and this has been recognised in the Basin Plan defining it as a separate SDL resource unit from the Lachlan Fold Belt (refer Section 2.3.3).

In December 2002, an embargo on applications for new groundwater entitlements was put in place in four parishes near Mudgee in central NSW. These were the parishes of Galambine, Wilbertree, Eurundury and Bumberra within the County of Phillip. This 2002 embargo remained in place until being replaced by the 2008 embargo which in turn remained until the commencement of the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011. The boundaries of the original 2002 embargo remains as a management zone within the Lachlan Fold Belt in the NSW water sharing plan.

In April 2004, in response to pressure on the groundwater systems in the Yass River catchment due to extraction, an embargo was gazetted on any further applications for groundwater licences in the Yass catchment. This was primarily to address the growth in domestic and stock supplies associated with rural subdivisions given the area is within commuting distance to Canberra. The December 2008 embargo was gazetted on further applications for groundwater licences included the Yass catchment and replaced the 2004 embargo.

2.5 **Young Granite**

Geologically the Young Granite is part of the larger surrounding Lachlan Fold Belt however due to the level of groundwater based development in the locality it has historically been managed as a separate groundwater management area. In May 2003, in response to pressure on the groundwater system an embargo was gazetted on applications for additional groundwater entitlements. This embargo was replaced by the December 2008 embargo that applied across all areas of the NSW Murray Darling Basin. This in turn was replaced by the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011

2.6 **New England Fold Belt**

Groundwater development across the New England Fold Belt is relatively limited and there is significant variation in groundwater availability and water quality.

Except for within the Peel Valley catchment, there has been no gazetted embargo for the New England Fold Belt until the December 2008 embargo that applied across the Murray Darling Basin in NSW.

In June 2007, in response to the prevailing drought conditions at the time, an embargo was gazetted on any further applications for groundwater licences in the Peel Valley Fractured Rock. Additionally in June 2007 an Order under section 323 of the WMA 2000 for temporary water restrictions included the Peel Valley Fractured Rock in conjunction with the Peel Valley Alluvium. The 323 Order restricted the use of domestic bores where there was access to alternate water supply such as reticulated town water or community supplies, the 343 Order applied until December 2007.

The 2008 embargo replaced the 2007 embargo in the Peel Fractured Rocks and remained in place until the commencement of the Water Sharing Plan for the Peel Valley Regulated, Unregulated, Alluvial and Fractured Rock Water Sources 2010 on 1 July 2010. For the remainder of the New England Fold Belt the 2008 embargo ceased with the commencement of the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011.

2.7 **Inverell Basalt, Liverpool Ranges Basalt and Warrumbungle Basalt**

The December 2008 embargo that applied across the Murray-Darling Basin within NSW was the first embargo that applied to the Inverell, Liverpool Ranges and Warrumbungle Basalts. This embargo remained until the commencement of the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011.

2.8 **Orange Basalt**

In May 2003, in response to pressure on the groundwater systems due to extraction, an embargo was gazetted on any further applications for groundwater licences in the Orange Basalt. This continued until it was replaced by the December 2008 an embargo that applied across the Murray-Darling Basin in NSW. The 2008 embargo remained in place until the commencement of the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011.

3 Regional Setting

3.1 Topography

The Murray - Darling Basin is the catchment of Australia's largest river system and comprises a number of distinct geographical and physical landscape units (Figure 2). The eastern boundary is Australia's most substantial mountain range and the third longest land based range in the world, the Great Dividing Range. The Great Dividing Range (GDR) extends along the entire NSW eastern coastline containing a complex of mountain ranges, plateaus, upland areas and escarpments typically ranging from 300 to 1600m in elevation and 160 to 300km wide. The elevated plateau areas in NSW have three regional divisions comprising the Northern, Central and Southern Tablelands, each with a corresponding western slope region that progressively transitions into broad flat plains in the west.

Townships of the northern tablelands include Tenterfield (850m AHD), Glen Innes (1062m AHD), Armidale (980m AHD)and Inverell (582m AHD). Drainage runoff from these areas includes the headwaters of the Macintyre River, Gwydir River and Namoi River catchments respectively from north to south (Figure 10). The north eastern most catchment of the Macintyre River includes the smaller tributary of Dumaresq River which marks the state boundary with Queensland.

The towns of Gunnedah (264m AHD), Narrabri (212m AHD) and the city of Tamworth (404m AHD) are situated on the north-west slopes. Elevations range from 1300 m AHD near Mount Kaputar located approximately 30km east of Narrabri, down to 110 m AHD near Collarenebri on the north west plains (Bioregional Assessments 2014). The Macintyre, Gwydir, and Namoi Rivers flow westward across the north west plains into the Barwon River. The Barwon River flows south west to form the Darling River upstream of the township of Bourke at its confluence with the Culgoa River which flows in from the north. The Warrego and Paroo Rivers which have their headwaters in Queensland, join the Darling River downstream of Bourke.

The main towns of the central tablelands include Oberon (1113m AHD), Bathurst (650m AHD), Orange (863m AHD) and Mudgee (454m AHD). Drainage runoff from the central tablelands includes the headwaters of the Macquarie River and Castlereagh River catchments.

West of the Central Tablelands and North West Slopes is the Orana region in central northern NSW and is the largest region in NSW with an area of 198,561 square kilometres, approximately 25% of the state. The major localities are Dubbo (275m AHD) and Cobar (260m AHD).

The Southern Highlands geographically sit between 500m and 900m AHD on the Great Dividing Range and is readily accessible from the Capital city of Canberra (577m AHD). The South West Slopes covers the western lower inland slopes of the Great Dividing Range extending from north of Cowra (310m AHD) into eastern Victoria. It includes parts of the Murray, Murrumbidgee, Lachlan and Macquarie River catchments.

Moving further west the landscape transitions to broad flat plains known as the Riverina which covers about 10% of NSW. The Riverina is distinguished from other regions by the combination of flat plains, warm climate and ample supply of water making it an agricultural food hub. The Riverina covers those areas of lower south western slopes of NSW in the Murray and Murrumbidgee drainage zones to their confluence to the west. Major population centres include Wagga Wagga (147m AHD), Albury (165m AHD) and Griffith (129m AHD). Within NSW the Murray River is made up of the Lachlan River, Murrumbidgee River and northern catchment of the Murray River. The Murray River and Darling River join at the township of Wentworth near the south western border of NSW where it flows into South Australia.

The Far West region of NSW is a generally flat low lying area in the western part of the state with low rainfall. It's only city is Broken Hill (315m AHD) and other significant towns are Bourke (106m AHD), Brewarrina (115m AHD), Cobar (260m AHD), Ivanhoe (90m AHD), and Wentworth (37m AHD).

3.2 Climate

The WRP area varies in its climatic conditions from being sub-tropical in the north, semi-arid in the west and temperate in the south. Figure 3 presents a spatial map of the average annual rainfall showing the general steady decline in rainfall from east to west, whilst monthly rainfall averages for four larger population centres is presented in Figure 4 depicting seasonal rainfall variability.

The high elevation of the northern tablelands means cool summers and cold winters with occasional snowfalls. The tableland have relatively high rainfall region with average annual rainfall around 770mm at Armidale and 902mm at Glen Innes with about 60 percent of this rainfall occurring during the summer months. The mean annual temperature range is 9-17^{o}C, with a minimum average monthly temperature range of-3.6-6^{o}C and maximum average monthly temperature range of 20.8-31.6^{o}C (OEH, Bioregional Assessments). The north west slopes and plains are dryer and hotter than the tablelands.

The southern tablelands have an average annual rainfall of 600-1800mm and is categorised as sub-tropical temperate with no dry season. The mean annual temperature range is 6-16^{o}C, with a minimum average monthly temperature range of -3.8-4.7^{o}C and maximum average monthly temperature range of 18-31.3^{o}C (OEH, Bioregional Assessments). Autumn and spring seasons are cooler with winter temperatures ranging from high teens down to freezing.

The south west slopes are dominated by a sub-humid *climate* characterised by hot summers and no dry season. A temperate *climate*, with warm summers, occurs at higher elevations along the Great Dividing Range. The mean annual temperature range is 11-17^{o}C, with a minimum average monthly temperature range of -0.7-3.2^{o}C and maximum average monthly temperature range of 24.6-33.5^{o}C (OEH, Bioregional Assessments). Mean annual rainfall 710mm at Albury, 790mm at Tumut and 593mm at Cootamundra.

The southern plains have a hot semi-arid climate characterised by hot summers and cool winters. Mean annual temperature is 15 -18^{o}C with minimal seasonal variations. Highest rainfall occurs in May and September and generally increases from west to east and north to south (OEH, 26 April 2016).

The arid far western areas of the Murray Darling Basin has a hot, dry climate. Mean annual rainfall at Broken Hill is 254mm with a mean annual temperature range of 17-20^{o}C, a minimum average monthly temperature range of 3.8-5.5^{o}C and maximum average monthly temperature range of 32.1-35.8^{o}C (OEH, Bioregional Assessments).

Residual rainfall plots have been constructed for the WRP area using daily data sourced from the Scientific Information for Land Owners (SILO) database. The rainfall residual mass graph plots the cumulative difference from the monthly average rainfall and provides a visual representation of the rainfall history in an area. A falling trend indicates a period of lower than average rainfall, a rising trend showing periods of above average rainfall.

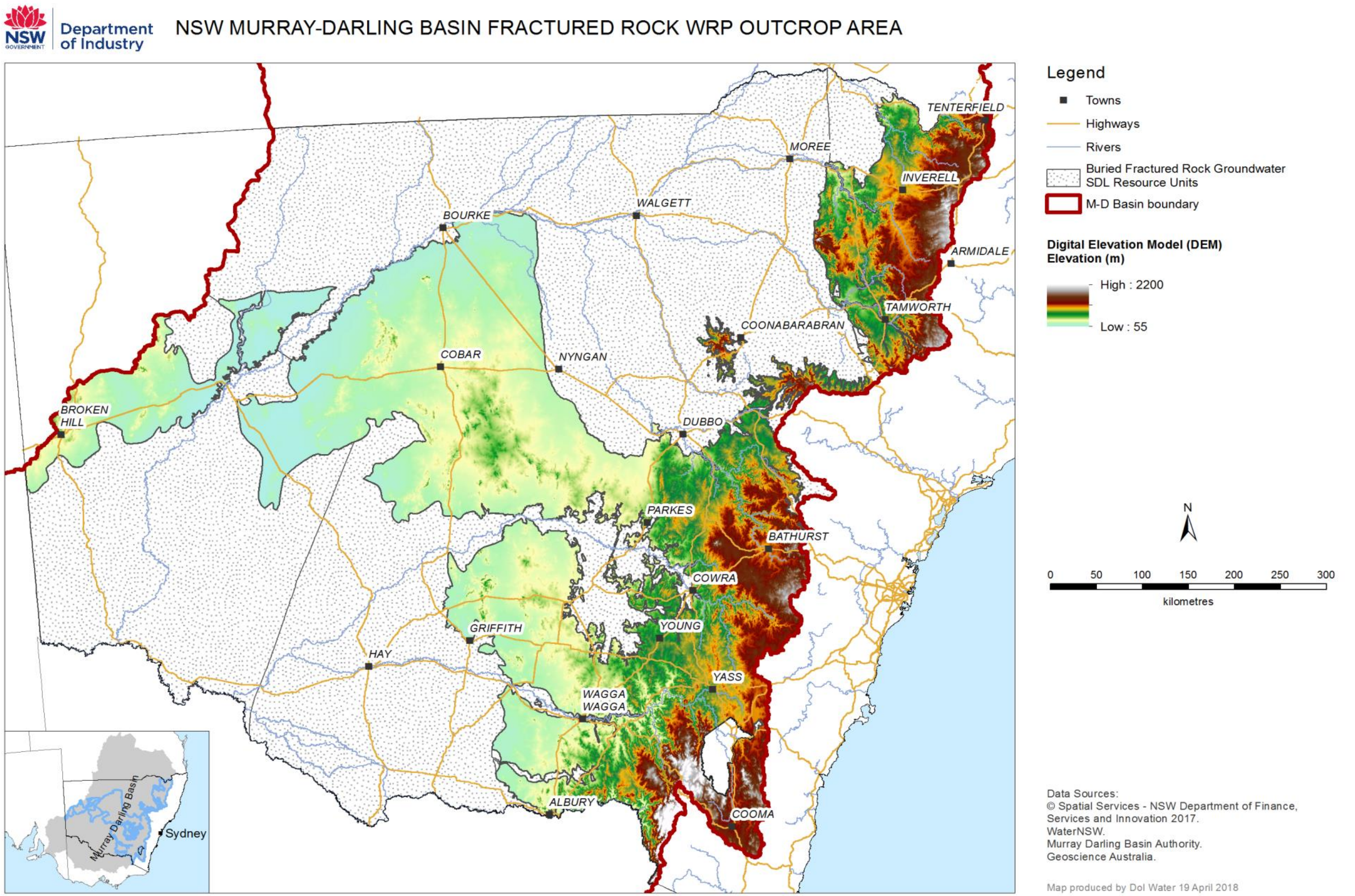

Figure 2 Elevation map of the WRP rock outcrop only area

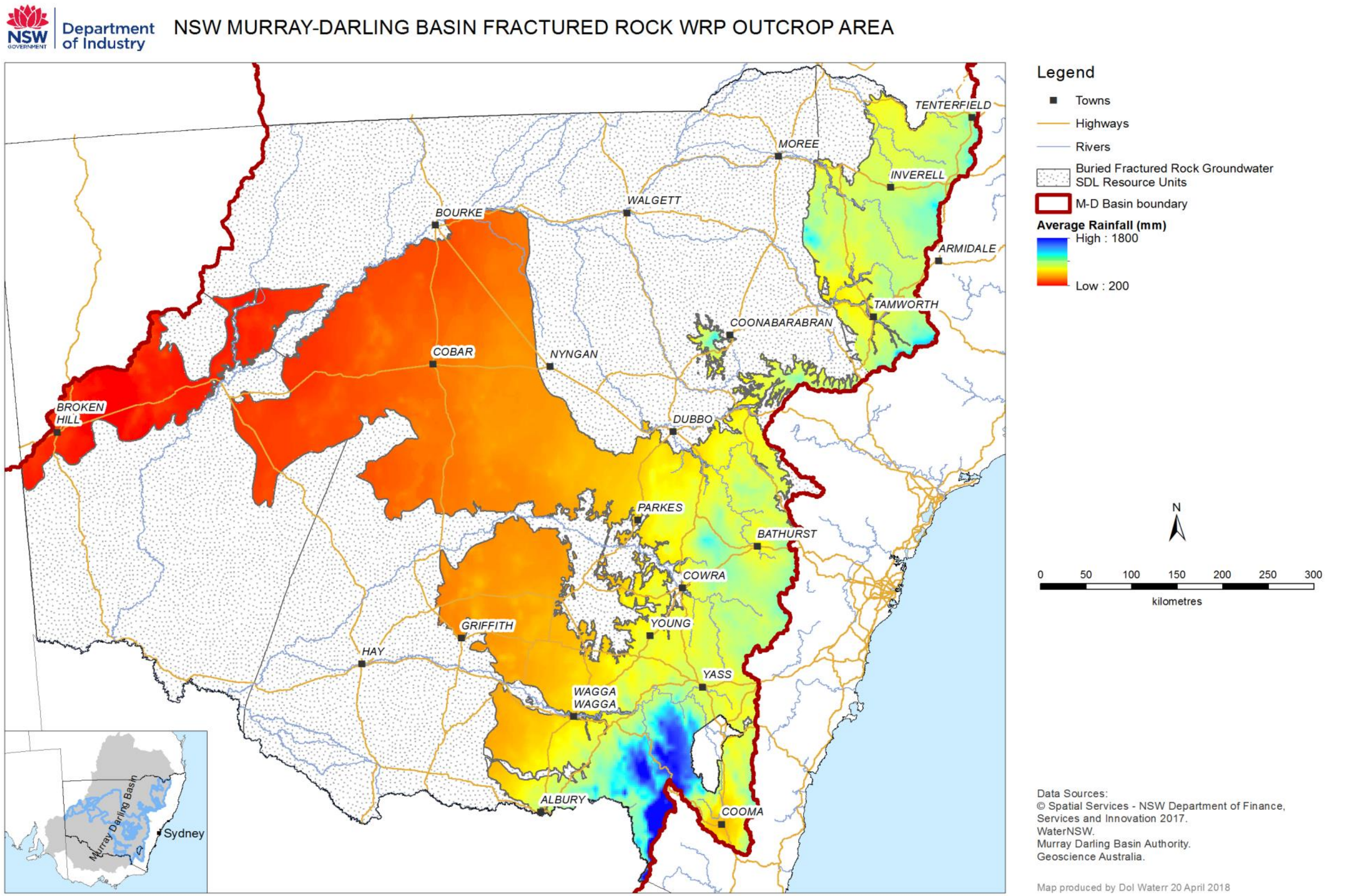

Figure 3 Average annual rainfall map of the WRP rock outcrop only area

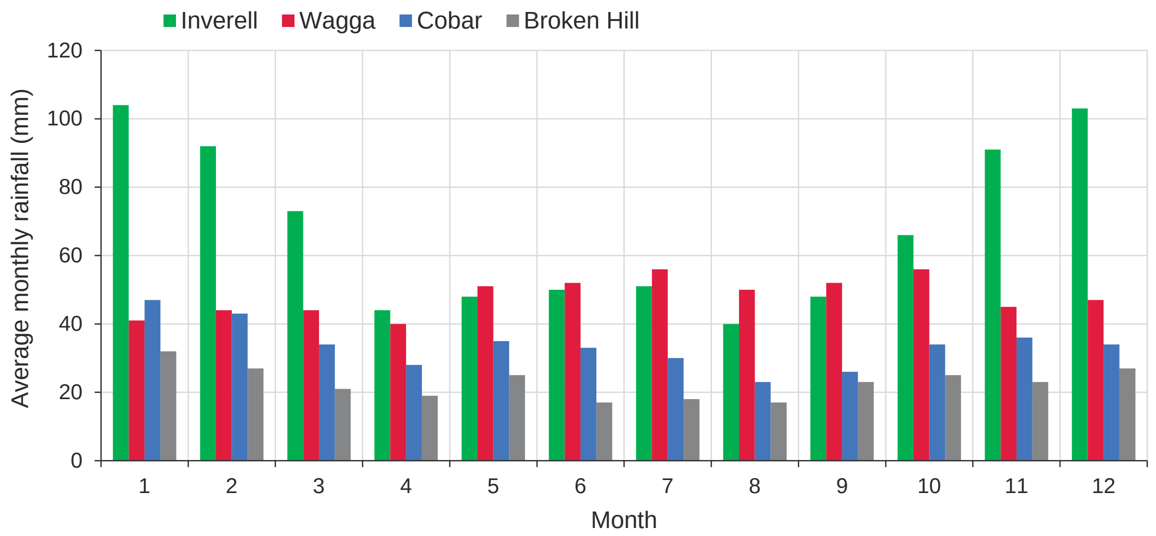

Figure 4 Average monthly rainfall 1974-2016 (BOM)

Figure 5 shows the residual mass graph of average monthly rainfall from 1974 to 2016 for the WRP area where a below average rainfall trend during the millennium drought from 2002 to 2010, followed by an above average spike over the 2011 to 2013 period, with generally average conditions to present.

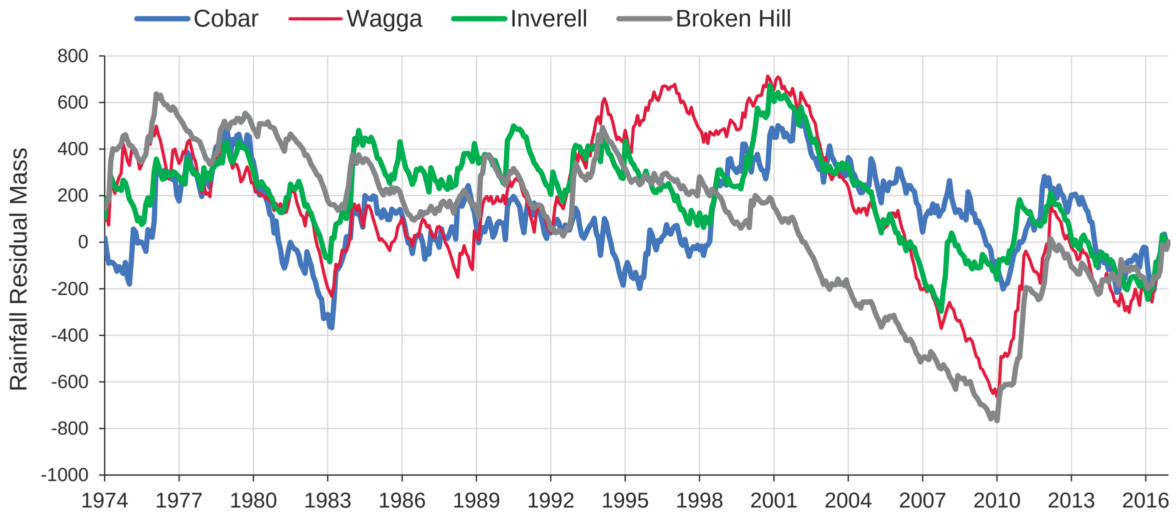

Figure 5 WRP area cumulative residual rainfall mass 1974-2016 (BOM)

Similar to the rainfall pattern, evaporation (Class A pan evaporation) in the WRP area has a strong east-west gradient with relatively low evaporation along the GDR and high evaporation on the western plains of Broken Hill and Cobar (Figure 6). Yearly evaporation varies from around 1,600 mm at Inverell in the north-east to over 2,300 mm in the west at Broken Hill. Evaporation is strongly seasonal (Figure 7) varying from as little as 50 mm a month over winter (June/July) at Wagga. Evaporation significantly exceeds average monthly rainfall over the year. The greatest exceedance occurs over the summer months when up to 300 mm of evaporation occurs per month compared with less than 40 mm of rainfall per month for the same period in the Far West at Broken Hill and Cobar.

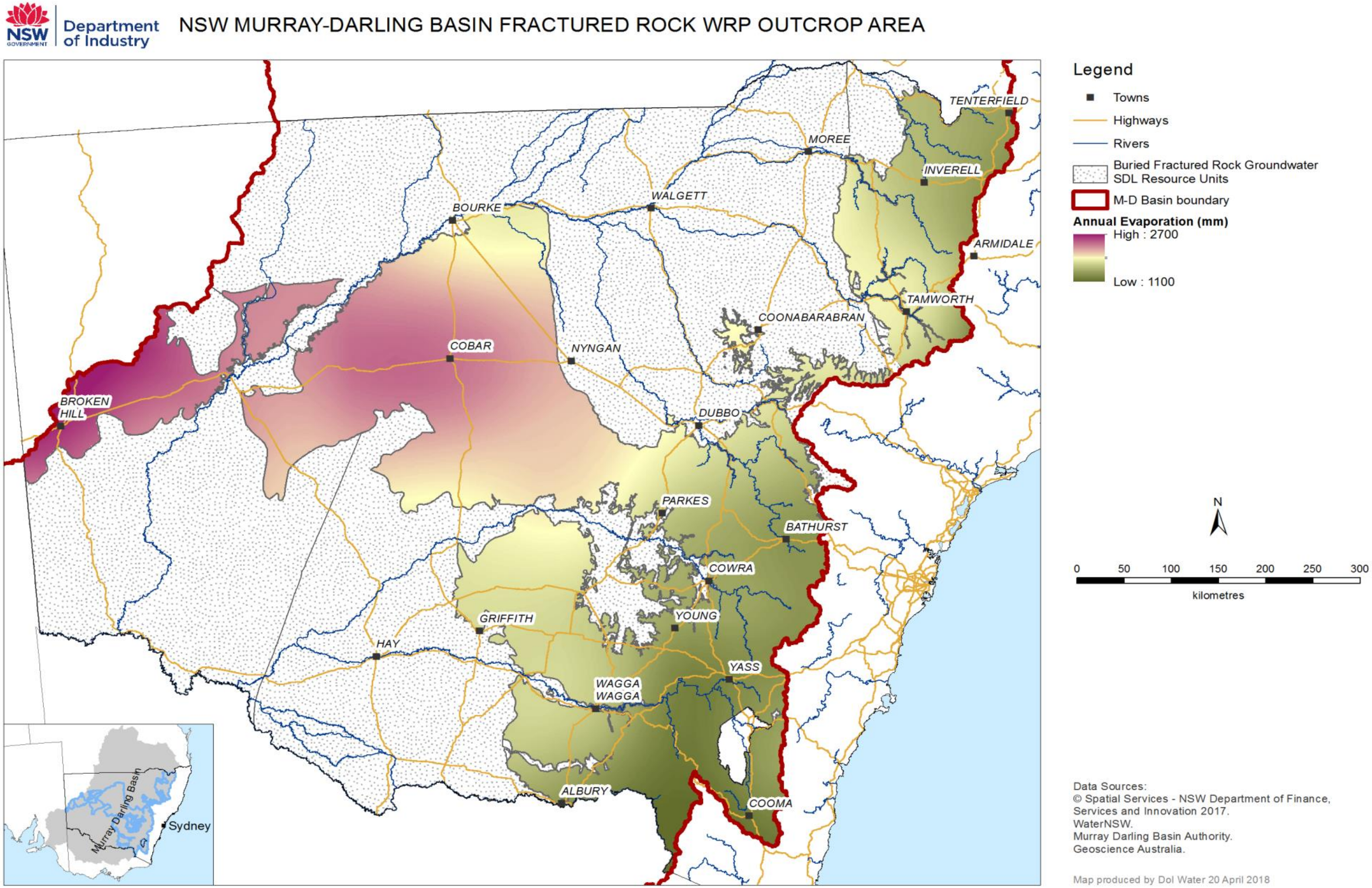

Figure 6 Average annual evaporation map of the WRP rock outcrop only area (BOM)

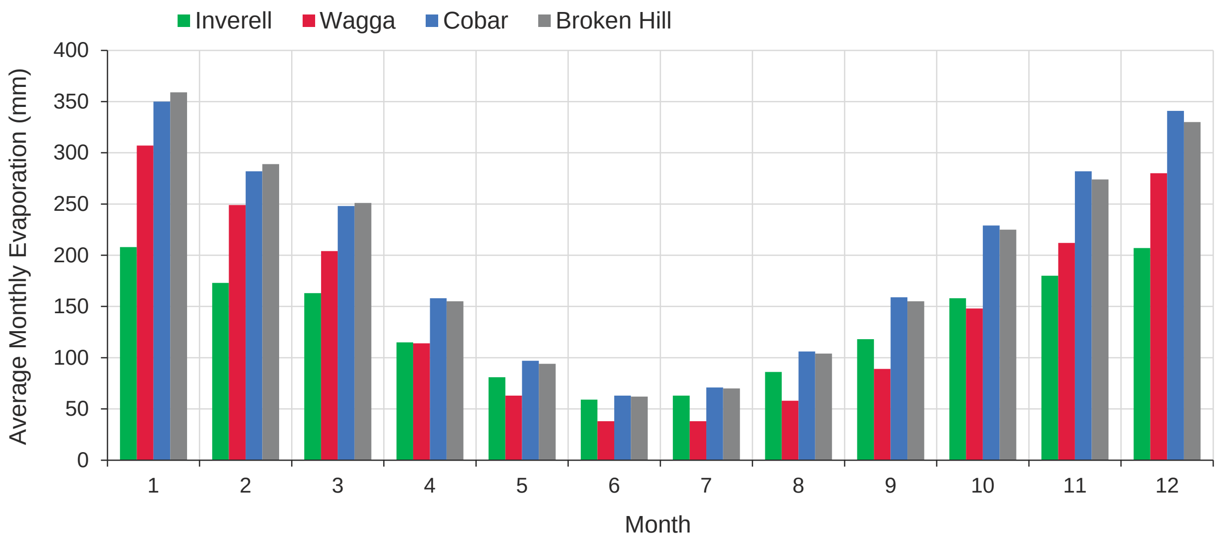

Figure 7 WRP area average monthly evaporation (BOM)

3.3 Land use

Land use in the WRP area is diverse, reflecting the differences in geography and climate across the region (Figure 8). Most of the land use activities are climate dependant.

Livestock grazing and dryland cereal grain cropping account for 70 to 80 percent of the land use. Other agricultural land use activities include forestry, viticulture and horticulture. Land along the river systems is irrigated for fruit, vegetables, fodder crops and cereal grains, and other livestock industry like dairying, feedlots, poultry and piggeries (MDBC, 2008).

Other major industries in the area include mining (gold, lead, silver, copper), renewable energy (hydroelectricity, solar and wind power), and tourism, retail and service industries.

Sheep, cattle grazing, broad acre cereal crops, irrigated cotton, intensive livestock, plant agriculture and poultry production are the main contributors to the economy of the northern tablelands and the north west slopes and plains (DP&I, 2012). The region is also rich in resources such as gold deposits and sapphire gemstones at Inverell.

Within the central tablelands there is a range of industries with mining operations focused around Orange and Lithgow, tourism at Mudgee and wineries at Orange, Cowra and Mudgee. Productive cropping systems support extensive grazing followed by irrigated farming, broad acres crops and horticultural enterprises of fruit, vegetables and viticulture (Local Land Services Central Tablelands, 14 Sept 2017).

In the Southern Highlands the economy is dependent upon natural resources supporting a variety of land including traditional farming (beef, sheep, dairy and cropping), horse studs and intensive agriculture production which has expanded over the past decade. Emerging markets include alpacas, emus, long haired sheep, preserves, cider, cooler climate vineyards and olives. The Snowy Mountains Hydro-Electric Scheme altered the bioregion both physically and demographically. The Scheme of produces electricity and diverts water from coastal catchments for use in irrigation around the Murray and Murrumbidgee catchments (OEH, 18 Apr 2017).

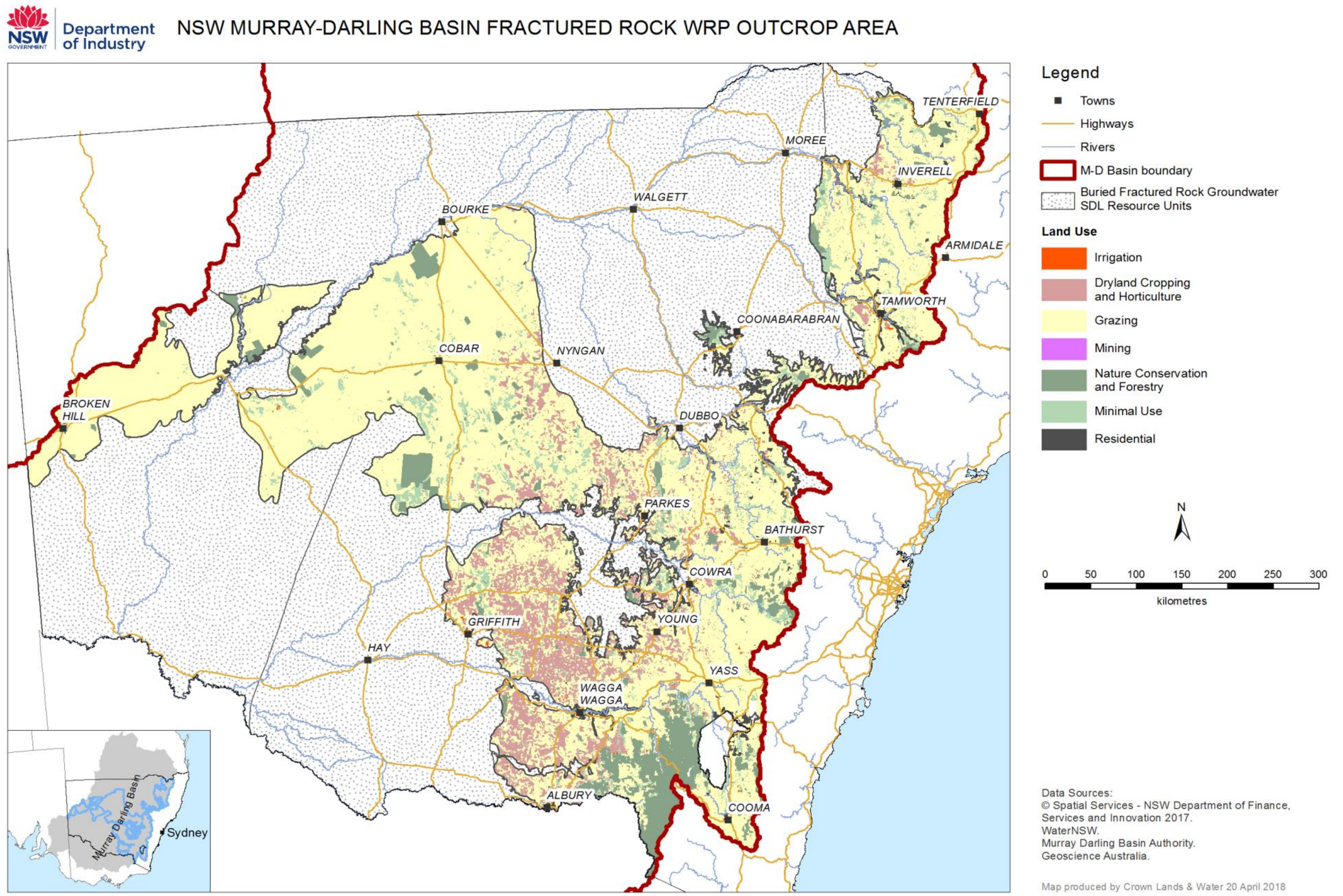

Figure 8 Land use map of the WRP rock outcrop only area

The 13 local government areas in the central west and western region of NSW have a combined population of 122,897. Gross regional product is $7 billion with the major industries being mining, agriculture and public administration, health and community services (Regional Development Australia Orana NSW, 2014). The south western area supports a thriving mining industry around Cobar producing copper lead silver, zinc and gold. The northern portions of Brewarrina and Walgett and the north western area of Bourke are built around sheep, goat and cattle farming, tourism and some fruit, canola, chickpeas and cotton cropping. In addition to cattle and sheep grazing practices, agriculturally the south eastern area includes growing wheat, oats and other grains. Land use in the Riverina is mainly agricultural with dry land grazing and cereal based cropping accounting for 80% of land use.

Mining continues to play a major role in the economy in the far west due to the abundance of base metals and mineral sands. In 2013, $2.9 billion was generated in Gross Regional Product (Department of Industry Far West, 14 Sep 2017). The Darling and Murray Rivers and Menindee Lakes support irrigated farming with wetlands and bushlands forming part of the natural landscape.

4 Geology

The WRP area is made up of nine SDL resource units (Figure 1) which generally coincides with geological boundaries (Figure 9). Four of the SDL units are geological fold belts where the strata has been significantly folded and faulted. The oldest SDL resource units are the Adelaide Fold Belt (2,500 to 1,600 million years old); and the Kanmantoo Fold Belt (541 to 485 million years old). They consist of metamorphosed shale rock sediments, schists and gneisses and minor volcanic intrusions.

The Adelaide Fold Belt hosts the famous silver, lead and zinc deposits at Broken Hill. Only a small portion of the Adelaide Fold Belt is in NSW. It extends further south west into South Australia forming the Flinders Ranges and extending further south beneath Kangaroo Island (Griessmann, 2011). Its eastern extent in NSW truncates at a north-south uplifted geological fault structure, approximately 55 kilometres east of Broken Hill (DP&E 2017). This fault structure also forms the western boundary of the Kanmantoo Fold Belt (Figure 17).

Whilst Kanmantoo Fold Belt is extensive in area, large tracts of this fold belt are concealed below the Great Artesian Basin to the north and the Murray Basin to the south (DMR, 1996). The Kanmantoo Fold Belt is also truncated with the younger Lachlan Fold Belt in a northwest-southeast geological structure.

The largest SDL resource unit is the Lachlan Fold Belt (541 to 359 million years old) which consists of strongly deformed/metamorphosed marine sedimentary rocks, cherts, siltstones and mafic volcanic basalts and rhyolites, and plutonic granitic intrusions (DPI Water 2017). The Lachlan Fold Belt extends from the Great Dividing Range through to the western rangelands around the Darling River near Bourke and Louth (Figure 15).

The youngest fold belt SDL unit is the New England Fold Belt (420 to 220 million years old) and is located in the north eastern portion of the WRP area, extending west from the Great Dividing Range (Figure 16). The rocks consist of sedimentary sandstones, siltstones, limestones, conglomerates, interbedded with volcanic tuffs and rhyolites, and granitic intrusions.

The Young Granite is a large elongate volcanic intrusive granodiorite rock formed as part of the Lachlan Fold Belt orogeny approximately 420 million years ago. This SDL unit covers an area of approximately 71,500 hectares extending from the north near Greenethorpe (east of Grenfell) to Talbingo southeast of Tumut. It is located around Young within the southwest slopes region of NSW and hosts significant gold mineralisation near Young, Wombat and Harden-Murrumbarrah areas (Figure 19). The Young Granodiorite is a coarse-grained, grey, granodiorite that grades to quartz monzonite (Kumar 2013).

There are four Tertiary Basalt SDL resource units included in this WRP. These are Cenozoic in age, ranging from 30 to 70 million years, and include:

- Inverell Basalt
- Liverpool Ranges Basalt
- Orange Basalt
- Warrumbungle Basalt

Dawson, et al (2004) describes the geological evolution of the basalts as major volcanic eruptions during the Tertiary Period. Two residual volcanic vents include Mount Canobolas near Orange and Warrumbungle National Park west of Coonabarabran (Figures 18 & 19). Outcrops of slower cooled basaltic magma can form vertical to sub-vertical columns with examples noted near Murrurundi and south of Orange. Thickness of the basalts is highly variable depending on proximity to the source volcano, number of deposited layers and subsequent extent of erosion.

The Liverpool Ranges Basalt (Figure 18) is highly dissected with a present-day thickness of 850m, as compared with the Orange Basalt with an upper thickness at only 150m.

The Inverell Basalt (Figure 18) is the erosional remnant flow from the Nandewar Volcano which currently remains as exposed plugs and dykes at Mount Kaputar near Narrabri. The maximum preserved thickness of the flows is 800 metres (OEH 2016).

Erosion of basalts has exposed ancient buried river gravels and lake sediments containing deposits of tin at Tinga, sapphires at Glen Innes and Inverell and diamonds at Copeton, Bingara and Cudgegong. Australia has been the source of up to 70% of the world's sapphires, with New South Wales accounting for more than half of the production (DPI, 2017b).

5 Hydrogeology

5.1 Regional context

Each SDL unit is a unique geological unit. A change in geology marks a difference in both the physical properties of the rock medium and the soluble inputs contributing to aquifer water quality. These fractured rock SDL units grade into other adjoining fractured rock SDL units across the border with Queensland, South Australia and Victoria and other groundwater sources outside the Murray Darling Basin in NSW with similar hydrogeological characteristics.

For these SDL units, the flow of water is largely governed by fractures which are made up of a combination of joints, bedding plane separation, faults and cavities within the rock mass. The ability to transmit economic quantities of water depends on the continuous interconnection of these higher permeability features. Groundwater flow is highest where fractures are both continuous, interconnected and retain sufficient dilation without impediments that would otherwise impede flow such as secondary mineralisation of hydrothermal fluids, e.g. quartz veins, and/or weathered precipitates e.g. iron oxides. Groundwater flow is also often strongly influenced by the degree of weathering of the rock mass.

Recharge to these systems is primarily through infiltration from rainfall, runoff and surface water within the outcropping and sub-cropping areas. However, inflow to these fractured rock SDL units can also occur from downward percolation of groundwater from overlying strata that has sufficient permeability for groundwater exchange to occur. The fractured rocks are overlain by the Great Artesian Basin, other porous rock SDL units such as the MDB Sydney Basin, MDB Gunnedah-Oxley Basin and the Western Porous Rock, as well as the alluvial aquifer systems.

Extracting large volumes of water from the overlying alluvial and porous SDL units could result in reduced groundwater exchange with the underlying MDB fractured rock SDL units. However, the permeability of the underlying fractured rocks is many orders of magnitude lower than that of the alluvium and several orders less than the porous rock units. Groundwater exchange between the fractured rock with the alluvium and/or porous rock SDL units is expected to be insignificant. Consequently these fractured rock systems are not considered hydraulically connected in a resource management sense to the overlying groundwater resources.

Groundwater may discharge naturally in localised areas as springs where there is a permeability change in the rock mass, at the break-of-slope or where there is a change in soil texture. Groundwater discharges may also contribute base flows to streams particularly in the high rainfall, topographically dissected landscape of the tablelands and slopes.

In general it is expected that the groundwater flow would replicate the topography. However, due to the fractured nature of the rocks it would be restricted and controlled by both the localised fracture systems and regional structural features.

5.2 Adelaide and Kanmantoo Fold Belt SDL Units

There is limited hydrogeological information in these fold belts due to poor water quality and low aquifer yields. The vast majority of bores are constructed to supply limited stock and domestic purposes in the arid environment. Due to the high evaporation and low rainfall, recharge events are limited to sporadic and very infrequent deluge rainfall events.

5.3 Inverell, Orange, Liverpool Ranges and Warrumbungle Basalt SDL Units

The geology of these SDL units consists of basaltic flows with interbedded sediments. The geometry of basalts deposits was largely controlled by the topography at the time volcanic eruptions and/or magma flows occurred. Weathering of the basalts between magma flow events allowed deposition of fluvial sediments forming marker horizons. Subsequent erosion of the basalt has formed a series of plateaus and undulating terrain landscapes with incised drainage channels.

The groundwater systems for these SDL units can be sub-divided into: (i) a shallow unconfined aquifer that is typically weathered and fractured and conducive to higher aquifer recharge; and (ii) deeper confined system to semi-confined with extensive vertical jointing; and fracturing (formed from cooling magma) that provides interconnection between these aquifers. Recharge to these SDL units occurs primarily through infiltration from rainfall mostly on hilltop plateau areas and side slopes areas where colluvium build up is minimal. Groundwater flow and discharge from these aquifer systems are topographically controlled occurring as springs and seepages along incised drainage channels and localised break-of-slope areas. These seepages may provide baseflow to the numerous streams.

With typically good quality groundwater these SDL units have been well developed for stock, domestic and commercial purposes including viticulture and horticulture, even more so in the Orange Basalt. The median depth of bores is generally shallow with the large majority constructed to depths less than 60m. Drilling construction information shows that most bores are generally low yielding. Approximately 80 percent of bores yield less than 3 litres per second with the majority being less than 1 litre per second. Within the Orange Basalt the maximum reported yield was 40 L/s during airlift pressure test, however it is not reported if this was sustained.

5.4 Lachlan Fold Belt

The Lachlan Fold Belt is the most extensive of the groundwater systems and ranges from the Great Dividing Range through to the western rangelands around Cobar. It provides stock and domestic groundwater supplies. Groundwater is stored and moves through fractures, joints, bedding plains, faults and cavities within the rock mass.

The Yass Catchment groundwater source is geologically within the Lachlan Fold Belt formations and is included in Lachlan Fold Belt SDL resource unit. There are over 1,000 registered water supply works within the Yass Catchment with the large majority constructed for domestic and stock purposes. A significant proportion of these bores (at least 70%) are constructed to depths of less than 60 metres with the deepest bore constructed to a depth of 280 metres. Bore yields are generally low supplying less than 3 litres per second. Bores constructed in regional faults, fractures and shatter zones yield high volumes and is used for town water supplies and small scale irrigation.

5.5 Young Granite

Water bearing zones within the Young Granite is generally associated with weathering, especially in heavily fractured and faulted zones that has led to the development of secondary porosity and permeability. There are a little over 150 production bores for irrigation within the water source and approximately a third of these constructed to depths greater than 80 m, with the deepest bore constructed to a just under 300m depth.

Construction bore logs indicate an average weathering depth of 28 m compared to the average construction depth of 79 m. In addition to this, there are over 600 stock and domestic bores with an average depth of about 59 m. Hence, water bearing zones associated with fractures extend well beyond the weathered zone. Recharge to the groundwater source occurs primarily through infiltration from rainfall and runoff. It occurs mostly on hilltops and slopes where weathered sequences are likely to be thin or absent. Discharge occurs in localised areas at the break-of-slope, at lateral changes in soil texture and in the bases of some valleys (CSIRO, 2008).

The boundary for Lachlan and Murrumbidgee catchments located south of Young forms the surface drainage divide. Although influenced by fractures (etc.) groundwater flow appears to follow the topography and flows both north and south of this catchment divide.

5.6 New England Fold Belt

Like the basalt aquifers and other fold belt SDL units, the New England Fold Belt can be sub-divided into: (i) a shallow unconfined aquifer that is typically weathered and fractured; and (ii) deeper confined system to semi-confined with highly variable jointing and fracturing formed from tectonic structural deformation. It is these fractures that provides for the interconnection between the shallow and deep aquifers and the mixing of groundwater.

The New England Fold Belt MDB consists predominantly of low yielding stock and domestic supplies.

5.7 Connection with surface water

Connection between the groundwater and surface water systems (Figure 10) is limited to the degree of fracturing extending to the bed of the overlying surface water features, or to the base of more permeable weathered profile that connects with surface water feature.

The aquifers with higher elevated areas, having high rainfall, are expected to be discharging water as springs providing some baseflow along the upper catchments of Macintyre, Gwydir, Namoi, Castlereagh, Macquarie, Lachlan, Murrumbidgee, and Murray river systems.

The Young Granite having both significant fractures and permeable weathered profile has the capacity to interact and provide baseflow to surface water in this area during high rainfall seasons.

Much of the Kanmantoo Fold Belt and the broader Lachlan Fold Belt buried beneath porous rock systems are listed as being less productive and considered as not having a significant connection with the overlying surface water systems and other contiguous groundwater systems.

The Adelaide Fold Belt with low elevation and low rainfall is similarly not linked to the surface water flow.

Whilst the New England Fold Belt and Warrumbungle Basalt are more elevated, the lack of bore yield suggests that any structural deformation has not resulted in significant fracture permeability. For this reason these SDL units are also listed as being less productive and do not exhibit a significant connection with the overlying surface water systems.

Typically the surface water systems within the WRP area are considered to be in low hydraulic connection with groundwater in the fractured rock. Hence the surface and groundwater systems are managed separately.

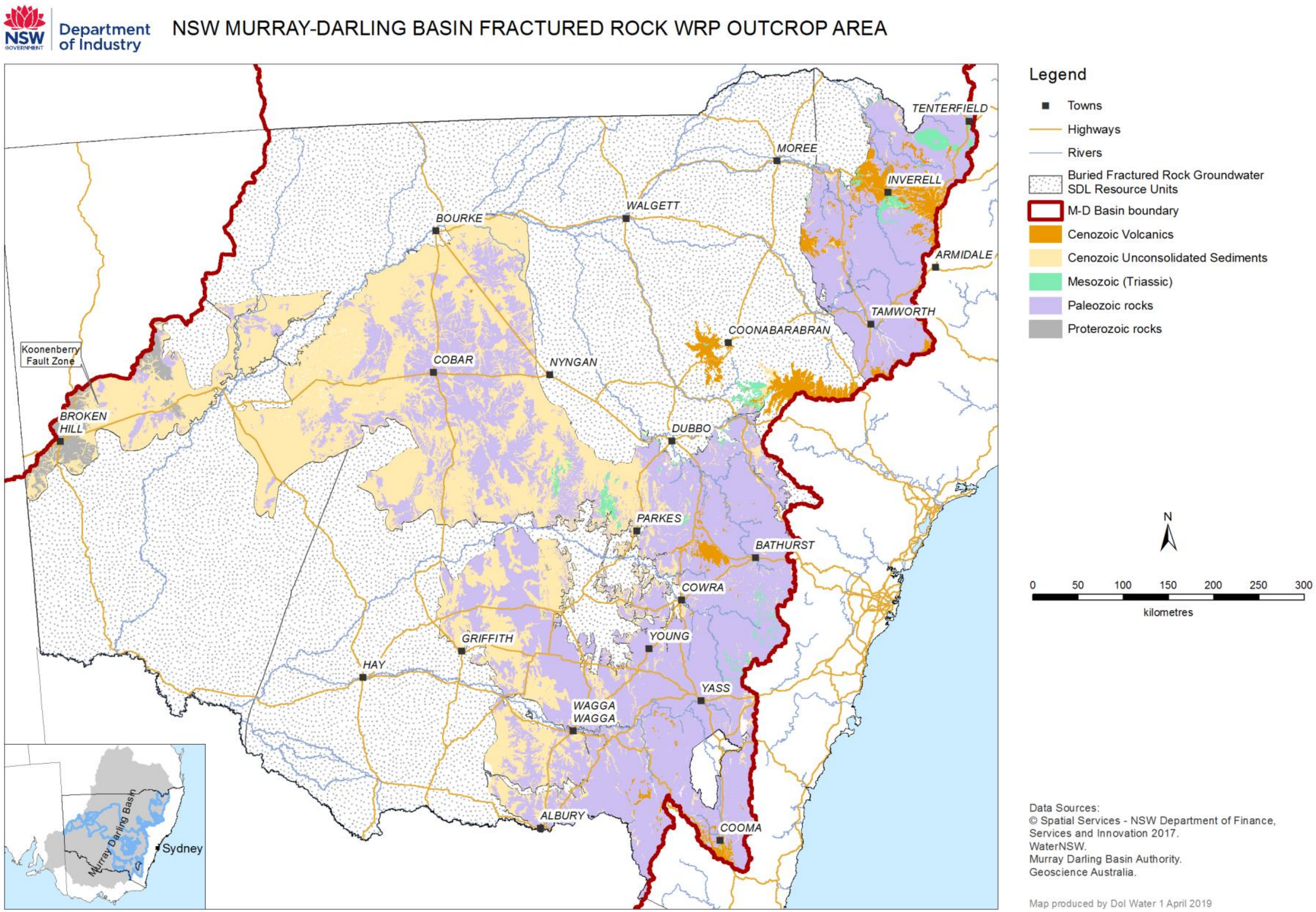

Figure 9 Geology map of the WRP rock outcrop only area

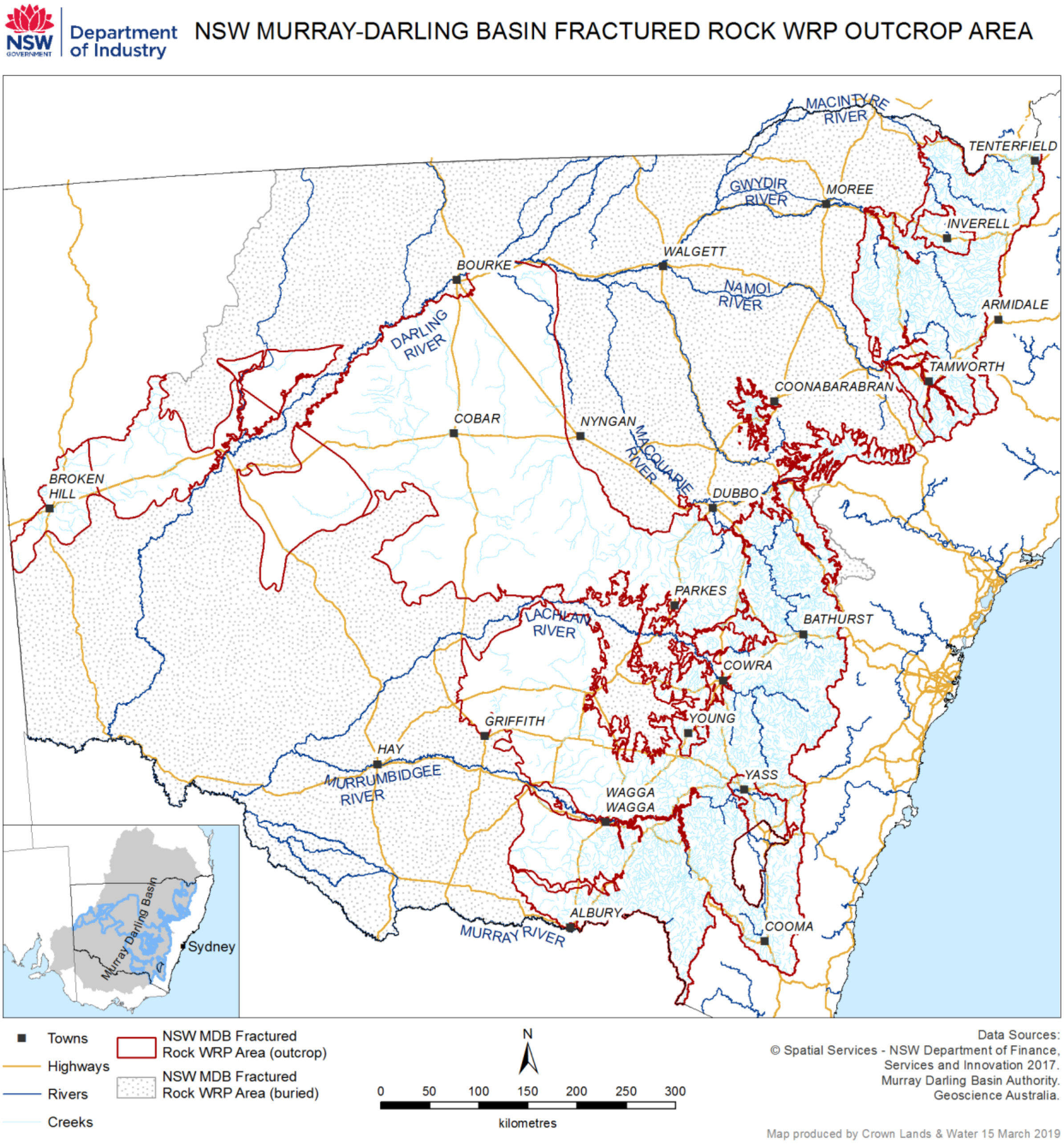

Figure 10 Surface water map of the WRP outcrop area

6 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems are defined as ‘ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services’ (modified from Richardson et al. 2011).

Department of Planning, Industry and Environment has developed a method for the identification of high probability groundwater dependent vegetation ecosystems (Kuginis et al. 2016) and associated ecological value (Dabovic et al. in prep). The risks to these GDEs from extraction will be further considered to determine if any controls are required to manage the risks and what monitoring or further information may be required.

6.1 High Probability GDEs in the WRP area

The WRP area supports significant GDEs of ecological value, including karst, springs, wetlands and vegetation ecosystems.

The determined ecological value of vegetation GDEs in the Lachlan Fold Belt, Orange Basalt, Young Granite, Adelaide Fold Belt and Kanmantoo Fold Belt SDL units in Figure 11, Figure 12 and Figure 13 are mainly categorised as medium to very high. The GDE communities consist of Belah/Black Oak-Western Rosewood-Leopard Wood woodlands, Black Bluebush shrublands, Black Box, Canegrass swamps, Coolabah-River Coobah-Lignum woodland wetlands, Lignum shrubland wetlands, Nitre Goosefoot shrubland wetlands, permanent and semi-permanent wetlands, Poplar Box, River Red Gum woodland wetlands, Blakely's Red Gum-Yellow Box woodlands, Fuzzy Box woodlands, Yellow Box woodlands, Western Grey Box-Cyprus Pine woodlands, Rough-Barked Apple-Red Gum-Yellow Box woodland, River Oak-Rough-Barked Apple-Red Gum Box riparian woodlands and Poplar Box-White Cypress Pine-Wilga-Ironwood shrubby woodlands (DPI Water, 2017).

These communities are characterised by having endangered ecological communities and basin target vegetation species (MDBA 2014) of Black Box, Lignum and River Red Gums. The vegetation communities provide vital habitat to nesting species. Generally the GDE communities with high ecological value have large vegetation patches, are highly connected and have a moderate number of threatened species present. Small areas of DIWA/Ramsar wetlands are located in this WRP area (DPI Water, 2017).

The determined ecological value of vegetation GDEs in the Liverpool Ranges Basalt, Warrumbungle Basalt, Inverell Basalt and New England Fractured Rock SDL units in Figure 14 is predominantly categorised as high to very high. New England Fractured Rock SDL is dominated by the vegetation GDE communities of White Box woodlands, Tea-Tree shrubland wetlands, Rough-Barked Apple-White Cypress Pine-Blakley's Red Gum riparian woodlands, River Red Gum riparian woodlands, River Oak-Roughed-Barked Apple-Red Gum Box riparian woodlands, Ribbon Gum-Rough-Barked Apple-Yellow Box woodlands, montane bogs, heath swamps and Grey Box woodlands (DPI Water, 2017).

These communities are characterised by having endangered ecological communities, DIWA/Ramsar wetlands (Paroo Wetlands, Narran Lake, Macquarie Marshes, Gwydir Wetlands), extensive connected riparian corridors and basin target vegetation species (MDBA 2014) of Black Box, Lignum and River Red Gums. The riparian communities provide vital habitat to nesting species and contributes to ecosystem function of instream ecosystems. Generally the GDE communities with high ecological value have large vegetation patches, are highly connected (such as riparian corridors) and have a moderate number of threatened species present, especially in the wetland areas (DPI Water, 2017).

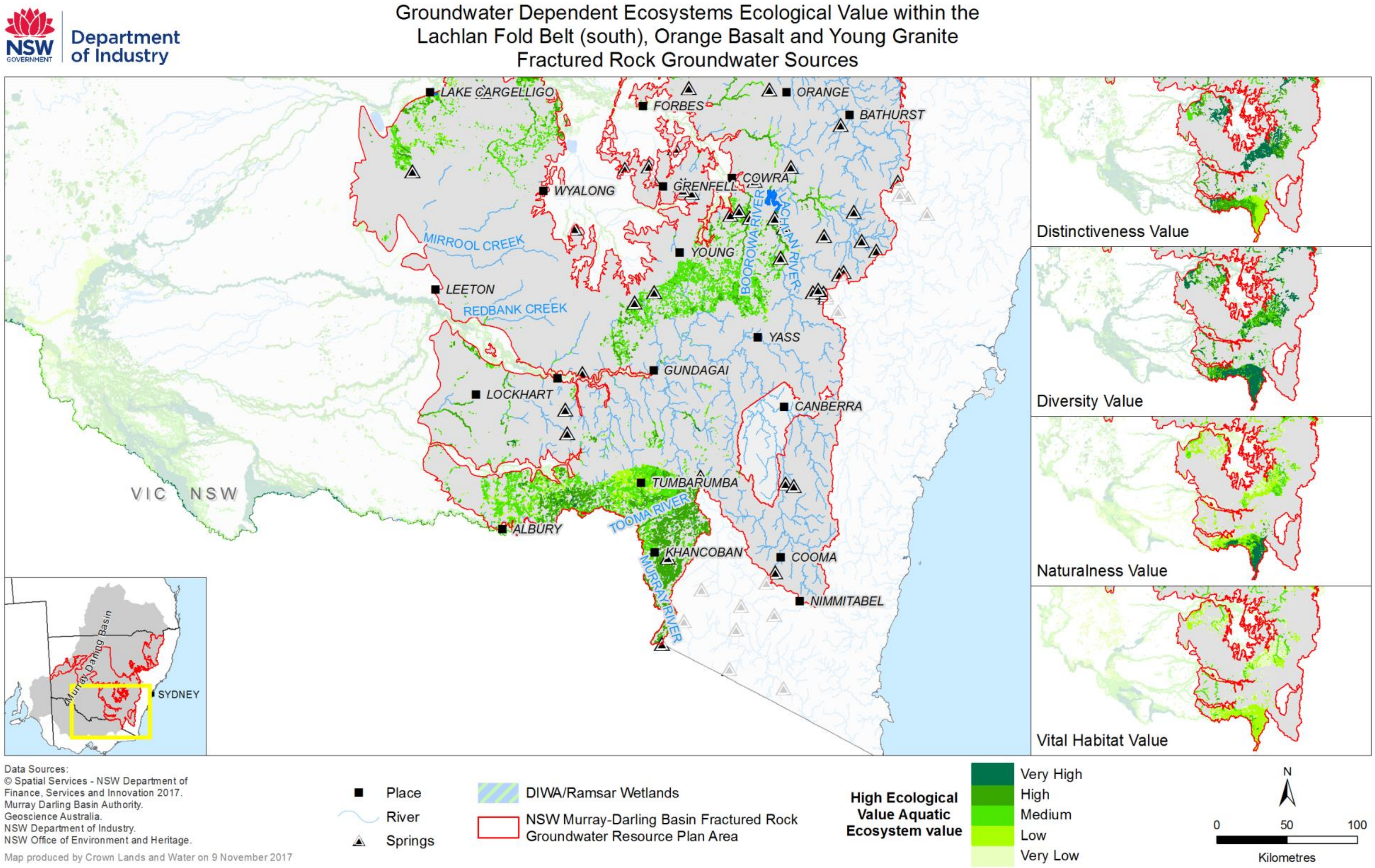

Figure 11 Ecological value for high probability groundwater dependent vegetation ecosystems within the Lachlan Fold Belt (south), Orange Basalt and Young Granite SDL resource units.

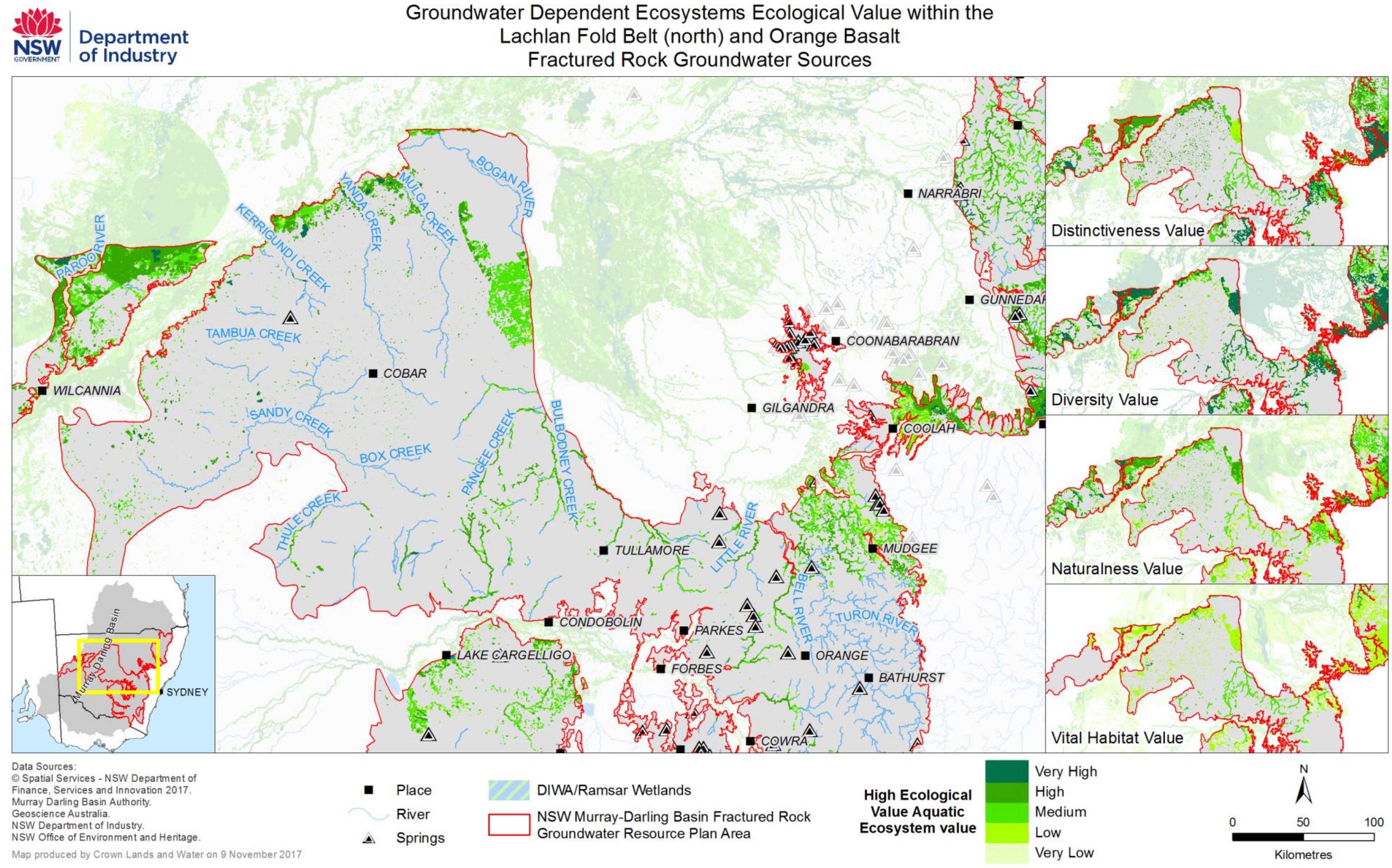

Figure 12 Ecological value for high probability groundwater dependent vegetation ecosystems within the Lachlan Fold Belt SDL (north) and Orange Basalt SDL resource units

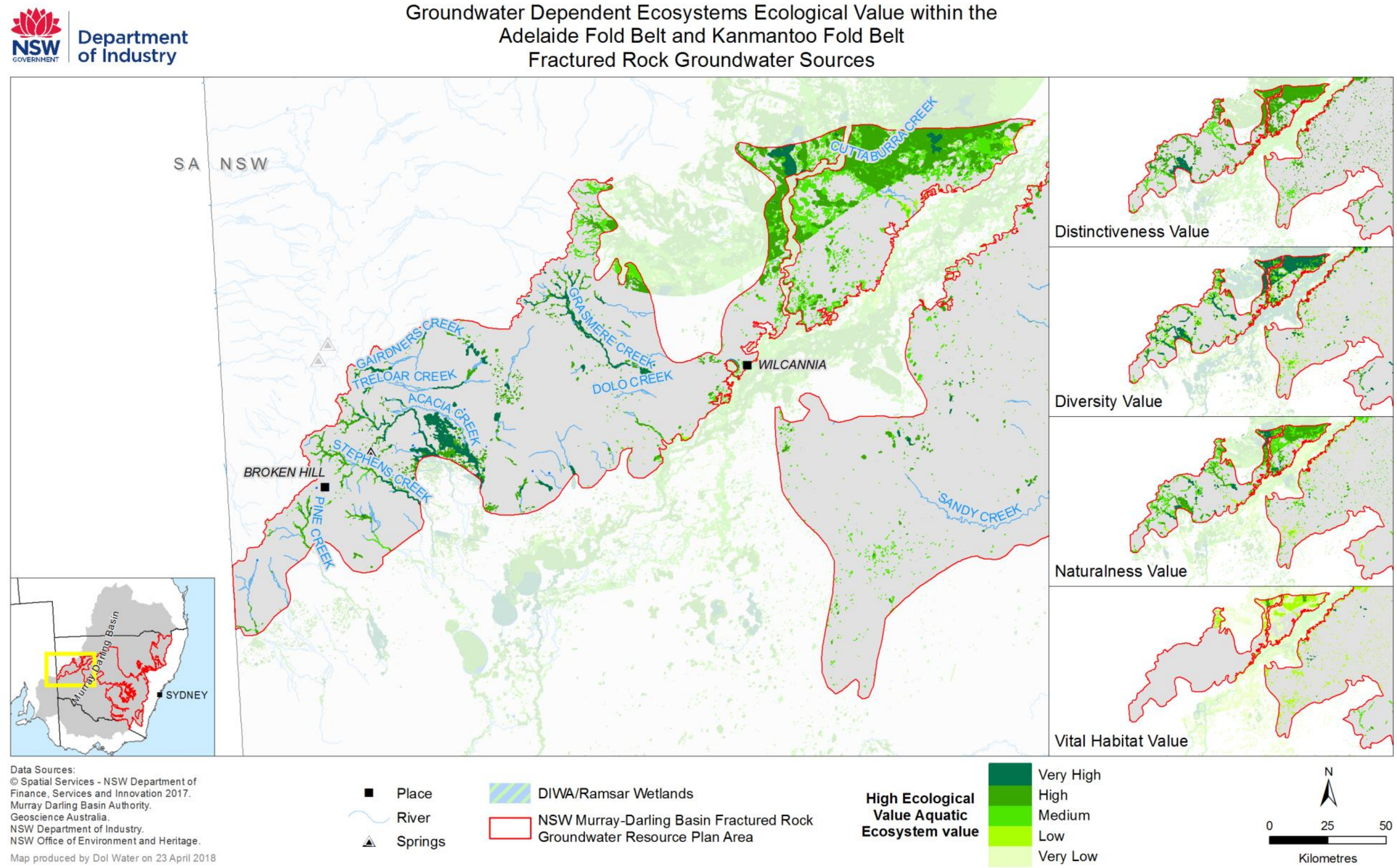

Figure 13 Ecological value for high probability groundwater dependent vegetation ecosystems within the Adelaide Fold Belt and Kanmantoo Fold Belt SDL resource units

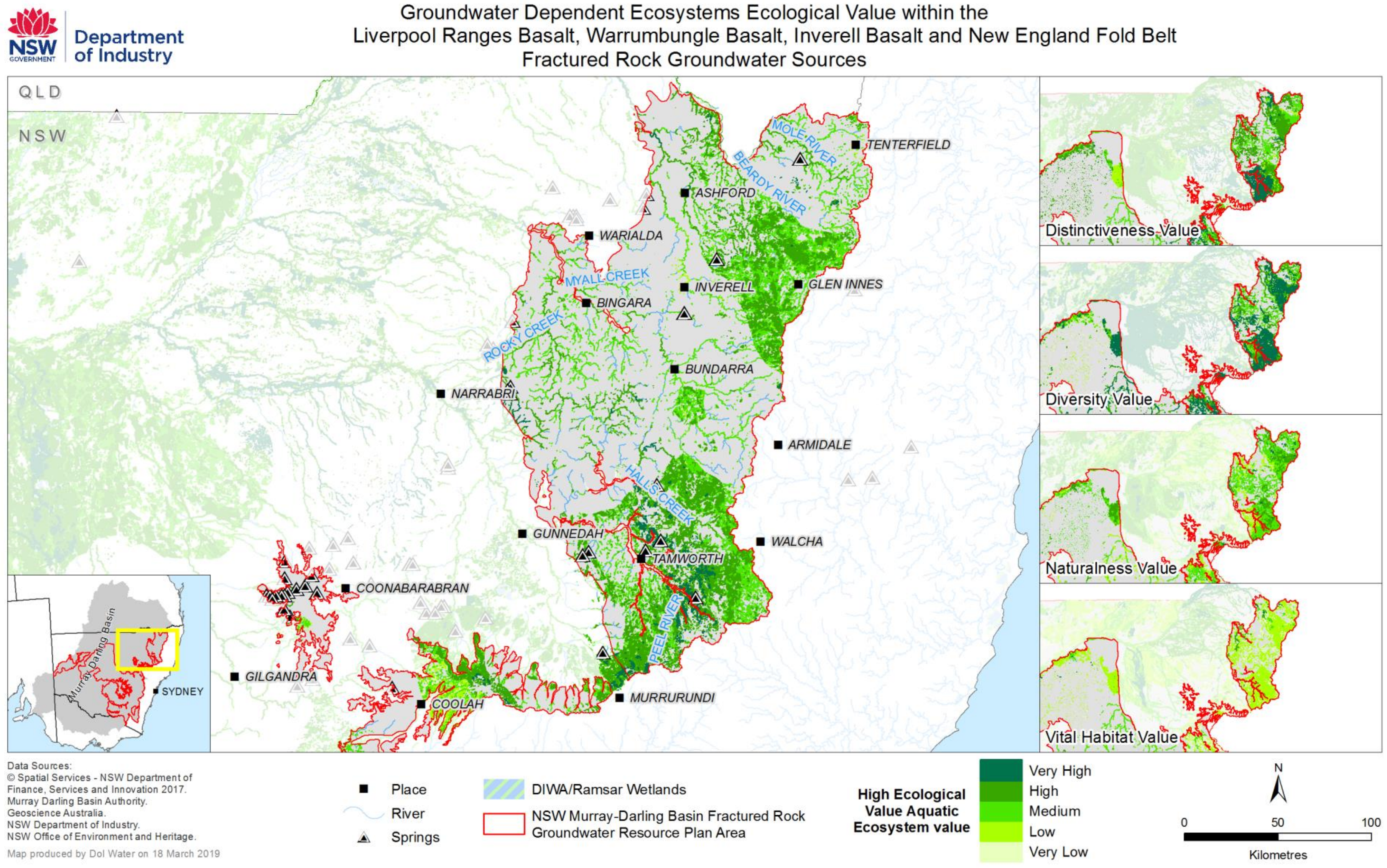

Figure 14 Ecological value for high probability groundwater dependent vegetation ecosystems within the New England Fold Belt, Inverell Basalt, Liverpool Ranges Basalt, and Warrumbungle Basalt SDL resource units

7 Groundwater Quality

Water quality describes the condition of water within a water source and its related suitability for different purposes. The water quality characteristic of a groundwater system influence how that water is used by humans for town water or stock and domestic supply, or for commercial purposes such as farming and irrigation. If water quality is not maintained, it can impact on the environment as well as the commercial and recreational value of a groundwater resource.

One measure of quality most relevant to the end use is the level of salt present in groundwater, or groundwater salinity. This is determined by measuring the electrical conductivity (EC) and is generally reported in microsiemens per centimetre (µS/cm).

In NSW, groundwater salinity levels can range from that of rainwater (<250 µS/cm) to greater than that of sea water (~60,000 µS/cm). Groundwater with salinity suitable for a range of productive uses is generally found in the large unconsolidated alluvial systems associated with the major westward draining rivers.

Groundwater suitability can be changed by contaminants infiltrating into the groundwater system. This can be from spills or leaks onto land surface but it can also occur more broadly from the overlying land use. Seasonal variations and longer-term changes in climate as well as groundwater extraction can all affect groundwater quality. There is no dedicated program for groundwater quality monitoring within the WRP area. Most of the domestic and stock and irrigation bores do not have electrical conductivity (EC) or salinity information. The following information is based on a limited dataset and general hydrogeological knowledge.

7.1 Adelaide and Kanmantoo Fold Belt

The relatively flat hydraulic gradient within these two SDL units leads to very slow groundwater movement and long residence times. With long flow paths and slow movement in groundwater, there is increased dissolution of soluble salts from the host geology. Combined with low average annual rainfall and high evaporation, aquifer recharge is minimal and limited to sporadic and infrequent high rainfall events. The combined effects of minimal recharge, flat hydraulic gradients and long flow paths result in the Adelaide and Kanmantoo Fold Belts containing saline to very saline groundwater. The high salinity and low aquifer yield limits use of groundwater domestically e.g. toilet flushing and for salt tolerant stock. There are only a small number of access class licences in these aquifer systems.

7.2 Inverell, Orange, Liverpool Ranges and Warrumbungle Basalts

The shallow aquifers, which tend to be responsive to rainfall events, have typically low salinity groundwater. The deeper aquifers have longer flow paths and increased residence times. Consequently the aquifer water quality is influenced by soluble salts from weathering of the host geology. The deeper aquifer systems have higher concentrations of silica and bicarbonates with a rise in alkalinity. Groundwater quality samples collected at the time of construction in 2011 from GW090103 and GW090104 located in the Orange Basalt, present a low electrical conductivity (salinity) of less than 600 µS/cm and a slightly alkaline pH of between about 7.8 and 8.5. Major ion compositions of Ca-Mg-Na-HCO_3 and Ca-Mg-Na-HCO_3 , this being suitable for most domestic and horticultural purposes (DPI Water 2013).

7.3 Lachlan Fold Belt

Water quality within the Lachlan Fold Belt varies significantly based on rock type, fracture density, aquifer depth, and climate. Salinity can range across all beneficial use classes from fresh to saline. The Lachlan Fold Belt is the host rock for a number of ore bodies and so the background trace metal chemistry of the groundwater is heavily influenced by these deposits.

There are areas where the water quality has been monitored intensely on a local scale such as the Wellington Caves and there are also large areas where there is no information with few to no groundwater users or mines.

Analysis of groundwater quality data sampled from bores in the Yass Catchment groundwater source indicates there is a broad range of groundwater salinities throughout the catchment, ranging from 300 to 6,100 µS/cm. The hardness of the water (the $CaCO_3$ concentration) ranges between 230 and 1,100 mg/L. This indicates that it is very hard to extremely hard water based on the Australian and New Zealand guidelines for fresh and marine water quality (2000). Water quality results for NSW Government monitoring bores located in the Murrumbateman area shows a neutral pH, a salinity range of between 800 and 5,360 µS/cm with an average of 1940 µS/cm. Sodium is the dominant cation, while bicarbonate and chloride being the dominant anion, which is considered to reflect the volcanic geology.

7.4 **Young Granite**

Water quality results for NSW Government monitoring bores indicates that groundwater within the Young Granite water source has salinity concentrations ranging 470-3,200 µS/cm. Major ion groundwater chemistry data from five of the monitoring bores identifies sodium and chloride as the dominant cations and anions. Groundwater residence times are expected to be young given the generally low salinity results and relatively higher rainfall of about 650 mm/year.

7.5 **New England Fold Belt**

Due to the broad range in geology and depositional environment of the sediments that make up New England Fold Belt, water quality is variable. The higher annual rainfall with relatively higher recharge combined with high elevation creates steeper hydraulic gradients improving the groundwater through flow. Groundwater salinity is typically low in the shallow aquifer systems and more variable in the deeper aquifers subject to longer residence times.

8 Groundwater Management

Collectively the fold belt fractured rock SDL units extend, either at surface or subsurface where overlain by other SDL units, across all of the MDB. Whilst some of the fractured rock units share a geological boundary, for management purposes it has been subdivided into ten separate management units. Groundwater exchange between the fractured rock with the alluvium and/or porous rock SDL units is expected to be insignificant. Consequently these fractured rock systems are not considered hydraulically connected in a resource management sense to the overlying and underlying groundwater resources and are managed as nine separate management units.

Groundwater in these resource units is currently managed under the Water Sharing Plan for NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011 and the Water Sharing Plan for the Peel Valley Regulated, Unregulated, Alluvium and Fractured Rock. For this WRP, the Yass Catchment Groundwater Source is incorporated into the Lachlan Fold Belt SDL resource unit and the Peel Fractured Rock Water Source within the New England Fold Belt SDL resource unit.

8.1 **Access rights and extraction limits**

Groundwater access licenses for the nine SDL resource units, and the corresponding eleven groundwater sources, are shown in Table 1. The local water utility access licences are held by local government for town water supply purposes and the share component is for a specified volume of groundwater. The share components of aquifer access licences are issued for a specified number of unit shares.

Extraction in a groundwater source is managed to the long term average annual extraction limit (LTAAEL) set by the water sharing plan. Water resource plans will set limits, in the same way as water sharing plans, on the quantities of water that can be taken from Basin water resources. These limits are known as sustainable diversion limits (SDLs). Under the water resource plans, NSW will manage extraction to ensure compliance with the SDLs.

Table 1 lists the LTAAEL for the individual groundwater sources as well as the SDL for each resource unit. The estimated requirement for basic landholder rights is included in both the LTAAEL and the SDL.

To manage any growth in extraction in excess of the LTAAEL, water sharing plans set a trigger for complying with the extraction limit. A growth in extraction response is triggered if average annual extraction over three preceding water years exceeds the LTAAEL by more than five percent. Then the available water determination made for aquifer access licences for the following year, should be reduced by an amount that is necessary to return subsequent water extraction to extraction limit. Table 1 presents the average annual extraction since commencement of the water sharing plan for each water source where metered extraction data has been collected.

8.2 **Available water determinations**

An available water determination is made at the start of each water year which sets the allocation of groundwater for the different categories of access licence. Since the commencement of the water sharing plans, available water determinations have been 100 per cent access for all water sources, i.e. 1 ML per share.

Table 1 Access Licence share components , LTAAEL and average measured extraction in the WRP area.

SDL Resource Unit	Groundwater Source	SDL volume (ML/yr)	LTAAEL (ML/yr)	Aquifer Access Share Component (unit shares)	Town Water / Water Utility Share Component (ML/yr)	Salinity and Water Table Management (ML/yr)	Stock and Domestic Access (ML/yr)	Average Annual Extraction (ML/yr)
Adelaide Fold Belt	Adelaide Fold Belt MDB	6,900	26,018	3,627	0	0	0	Not monitored
Kanmantoo Fold Belt	Kanmantoo Fold Belt MDB	18,700	121,524	750	5	5	5	500
Lachlan Fold Belt	Lachlan Fold Belt MDB	---	875,652	66,871	2838	236	0	4,244
	Yass Catchment	---	26,163	2941.5	258	0	3	406
	TOTAL	259,000	901,815	69812.5	3096	236	3	4650
New England Fold Belt	New England Fold Belt MDB	---	204,784	9057	614	0	0	122
	Peel Fractured Rock	---	71,218	11,208	204	0	344	1217
	Total	55,100		20,265	818	0	344	1339
Inverell Basalt	Inverell Basalt	4,150	25,807	3,382	0	0	0	324
Liverpool Ranges Basalt	Liverpool Ranges Basalt MDB	2,160	19,075	422	0	0	0	13
Orange Basalt	Orange Basalt	10,700	16,208	9,561	250	0	0	550

SDL Resource Unit	Groundwater Source	SDL volume (ML/yr)	LTAAEL (ML/yr)	Aquifer Access Share Component (unit shares)	Town Water / Water Utility Share Component (ML/yr)	Salinity and Water Table Management (ML/yr)	Stock and Domestic Access (ML/yr)	Average Annual Extraction (ML/yr)
Warrumbungle Basalt	Warrumbungle Basalt	550	5,710	71	0	0	0	Not monitored
Young Granite	Young Granite	7,110	9,529	6,368	0	0	0	1,030
Total		364,370	1,401,688	114,259	4,169	241	352	8,406

* Entitlement shares are reported here as 1ML/share.

8.3 **Groundwater accounts**

Under the water sharing plan a water allocation account is established for each water access licence. Water is credited to the account when an available water determination is made or water is traded in, and debited from the account when water is physically taken or traded out.

The water sharing plan for the MDB Fractured Rock Groundwater Sources allows for accrual of unused allocation in aquifer access licence accounts. This includes the yearly allocations for the aquifer access licences made through available water determinations plus any carryover of unused allocation up to a maximum of:

- 0.2 ML per unit of share component for Inverell Basalt Groundwater Source, Liverpool Ranges Basalt Groundwater Source and the Warrumbungle Basalt Groundwater Source; and
- 0.1 ML per unit of share component for Adelaide Fold Belt MDB Groundwater Source, Kanmantoo Fold Belt MDB Groundwater Source, Lachlan Fold Belt MDB Groundwater Source, New England Fold Belt MDB Groundwater Source, Orange Basalt Groundwater Source, Yass Catchment Groundwater Source or the Young Granite Groundwater Source.

The Water Sharing Plan for the Peel Valley Regulated, Unregulated, Alluvium and Fractured Rock does not permit accrual of unused allocation in aquifer access licence accounts to be carried over from one water year to the next in the Peel Fractured Rock Groundwater Source.

The maximum amount of water that can be debited from aquifer access licence accounts in any one water year (i.e. account take limit) is equal to the sum of water allocations accrued to the water allocation plus any allocation transferred in, and minus any allocation transferred out.

8.4 **Groundwater take**

Groundwater is taken and used in the WRP area for productive purposes such as irrigation and industry as well as for water supply for local water utilities and stock and domestic use. Figures 15 to 19 show the distribution of water supply bores across the nine SDL resource units.

Groundwater use is influenced by climate and access to surface water. Reliance on groundwater increases in drier years and when there is reduced access to surface water.

There are approximately 26,700 registered bores in the WRP area (Table 2), the majority used for stock and domestic purposes. There is also a moderate reliance on groundwater for irrigation with approximately fifteen hundred production bores, the majority located within the Lachlan Fold Belt SDL resource unit.

Within the Lachlan Fold Belt, Inverell Basalt, Young Granite and Orange Basalt SDL resource units, groundwater extraction volumes from individual works approvals are typically less than 20 ML/yr. More significant volumes of groundwater are achieved via the construction of multiple works spread across larger properties where the drawdown interference between bores can be minimised.

Annual accounting of groundwater extraction is a generic requirement specified in each water sharing plan. Average annual reported extraction for all SDL resource units is presented in Table 1, however groundwater take is not currently monitored in the Adelaide Fold Belt and Warrumbungle Basalt with no annual account information currently available.

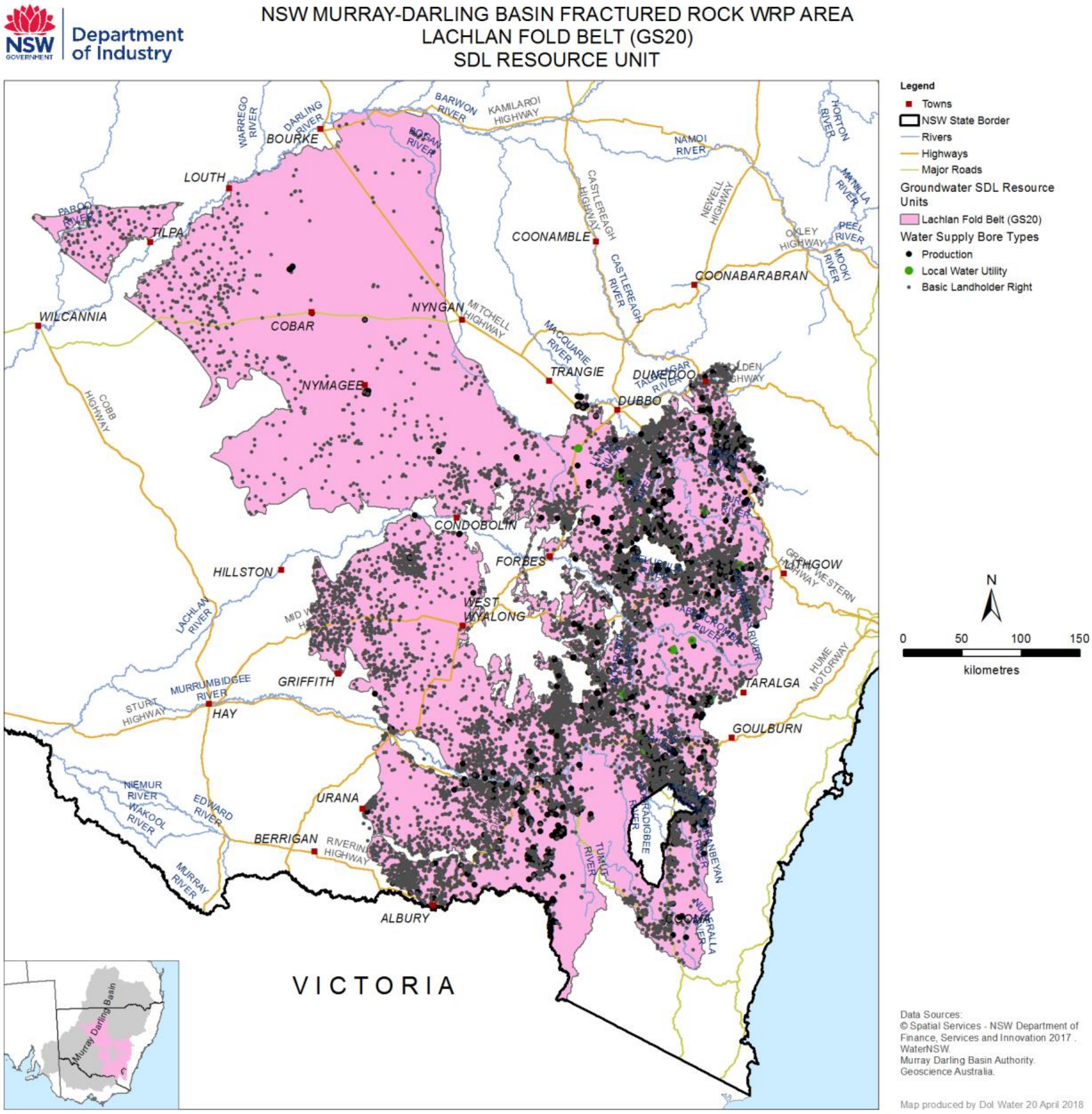

Figure 15 Location of registered water supply bores within the outcrop area of the Lachlan Fold Belt

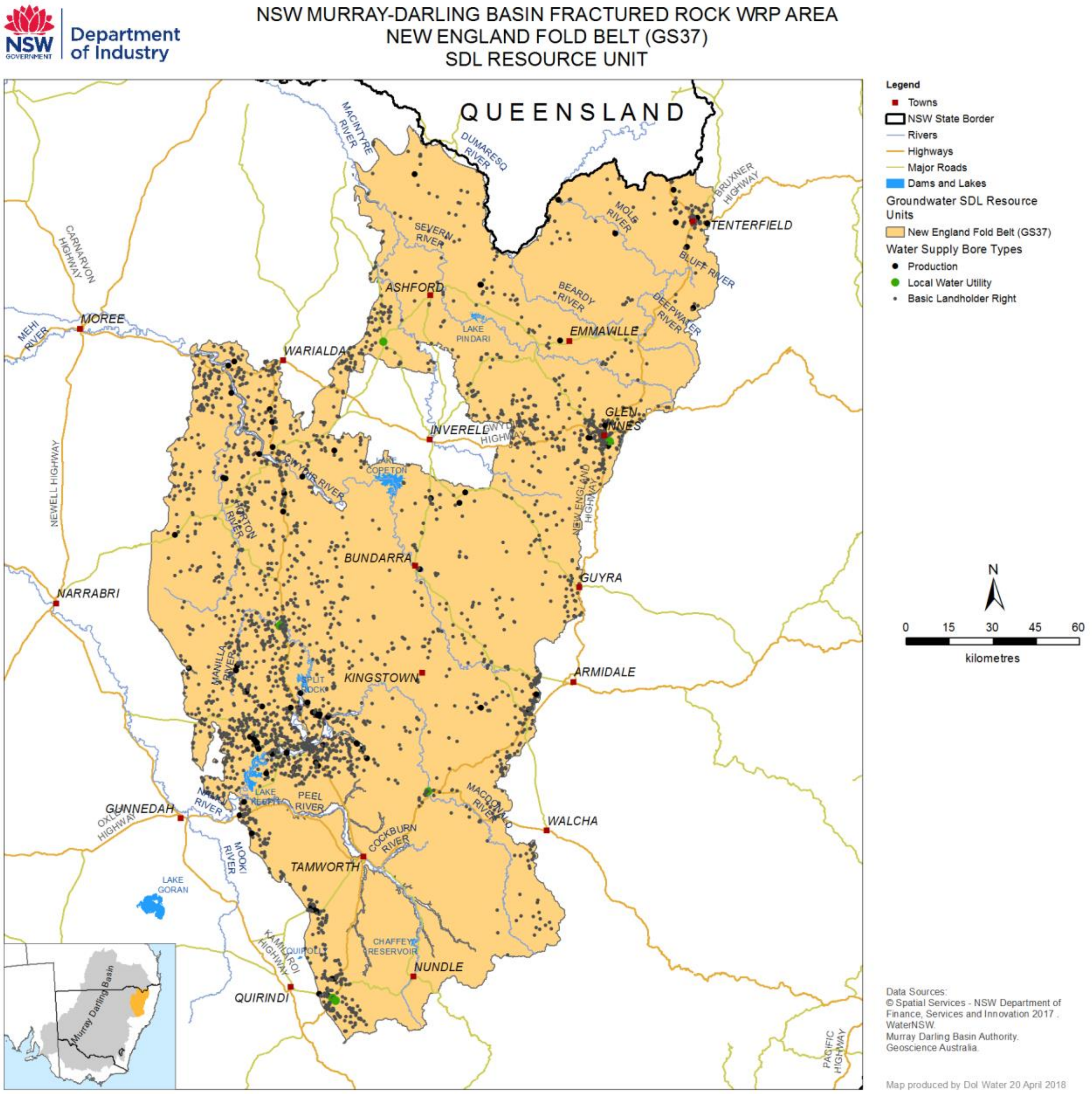

Figure 16 Location of registered water supply bores within the outcrop area of the New England Fold Belt

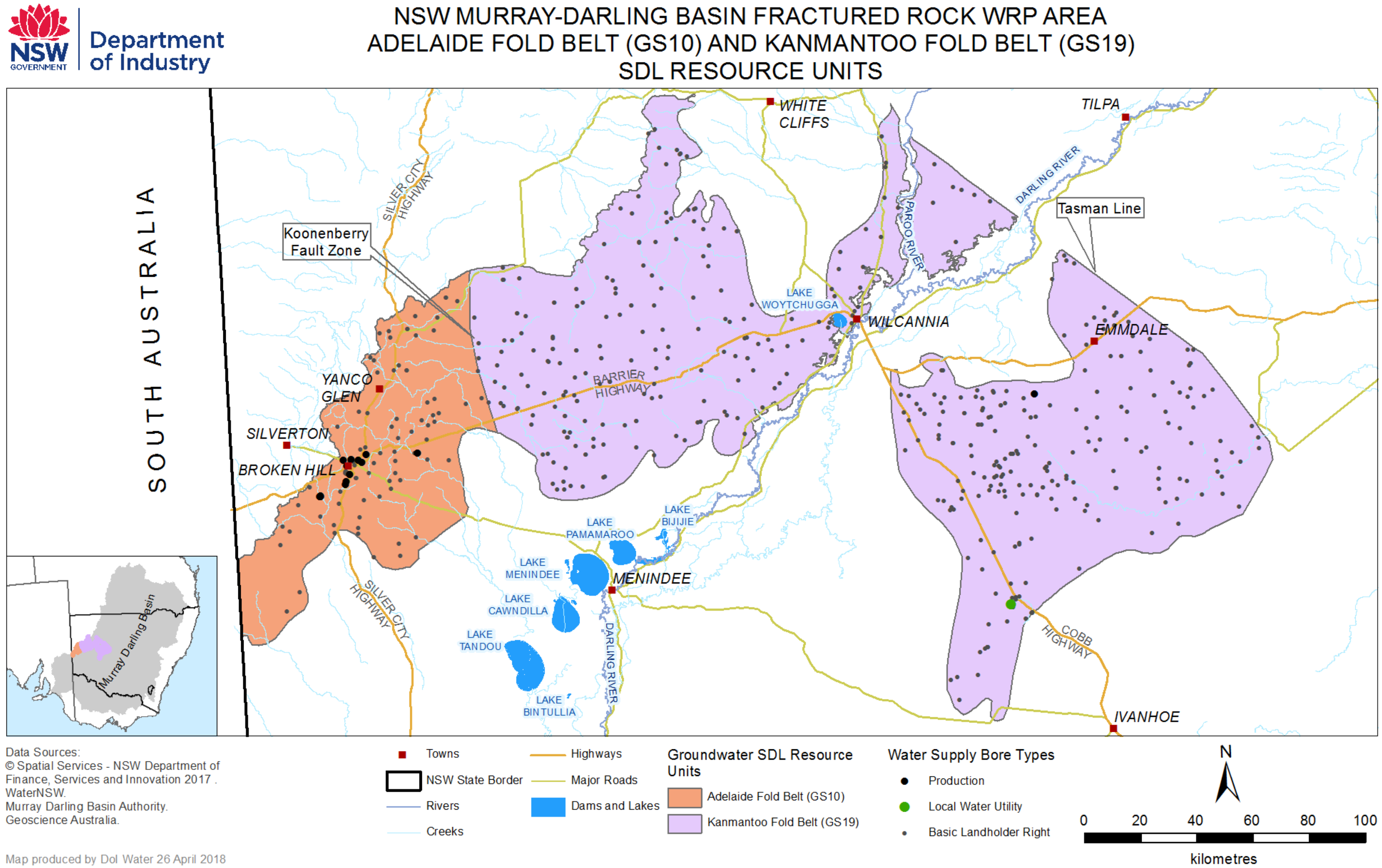

Figure 17 Location of registered water supply bores within the outcrop areas of the Adelaide Fold Belt and Kanmantoo Fold Belt

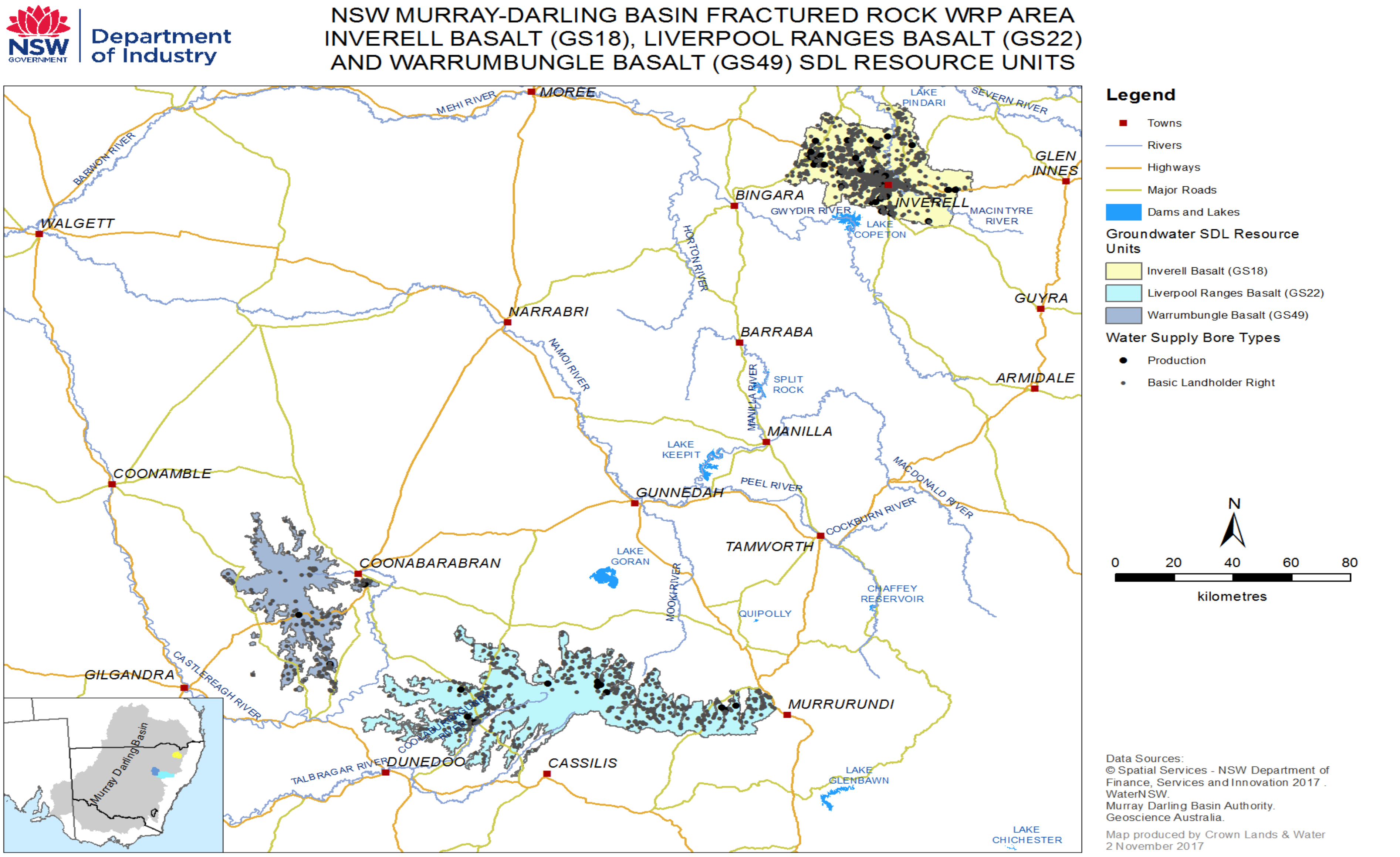

Figure 18 Location of registered water supply bores within the Inverell Basalt, Liverpool Ranges Basalt, and Warrumbungle Basalt

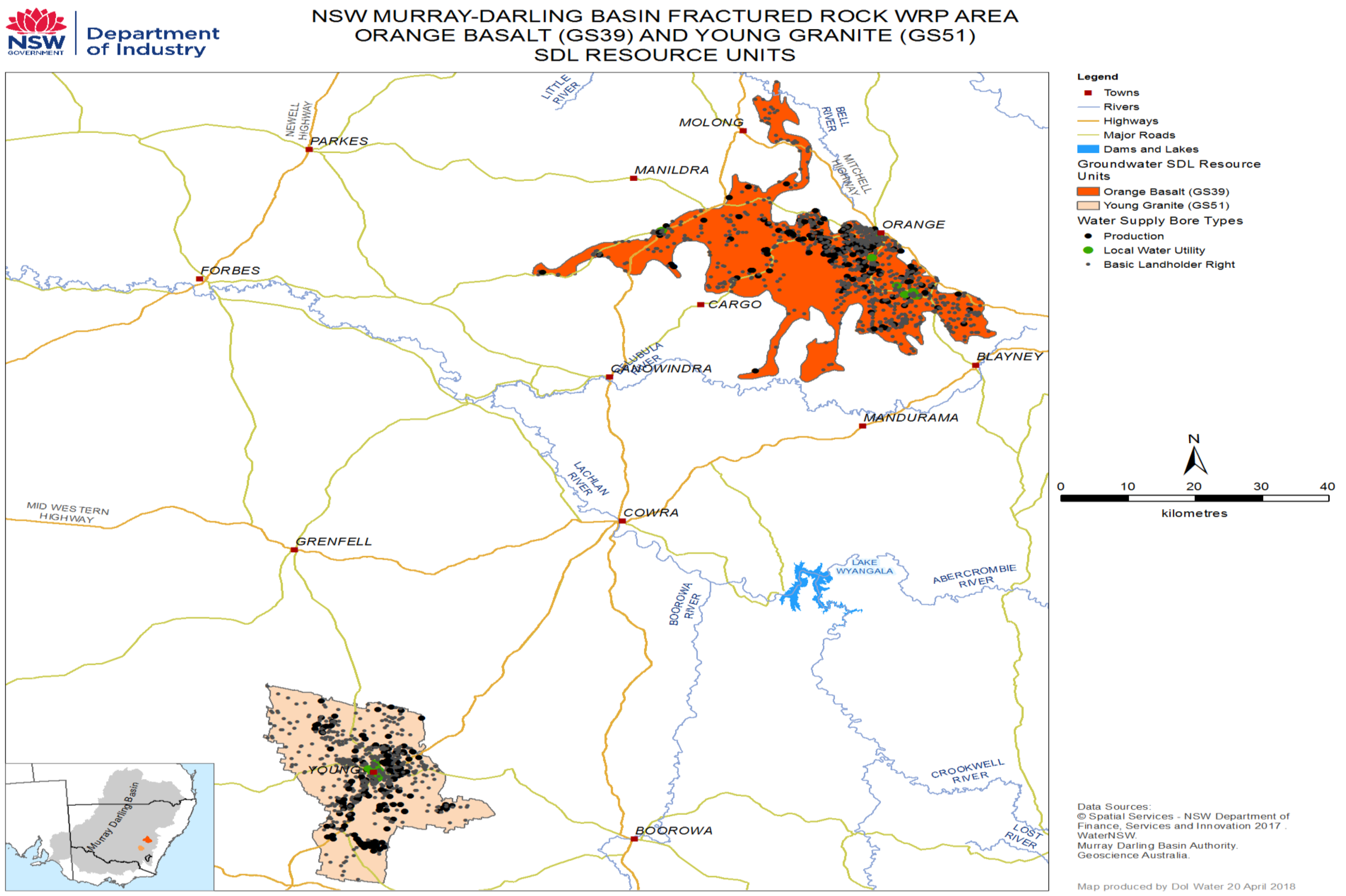

Figure 19 Location of registered water supply bores within the Orange Basalt and Young Granite

Table 2 Water supply bores in the WRP area.

SDL Resource Unit	Basic Rights	Production Bores	Local Water Utility	Total
Adelaide Fold Belt	92	15	0	107
Kanmantoo Fold Belt	426	1	1	428
Lachlan Fold Belt	18,110	1,024	31	19,165
New England Fold Belt	3,106	97	9	3,212
Inverell Basalt	997	39	0	1035
Liverpool Ranges Basalt	514	11	0	525
Orange Basalt	1,152	170	10	1,332
Warrumbungle Basalt	132	3	0	135
Young Granite	636	155	12	803
Total	25,165	1,515	63	26,742

8.5 Groundwater dealings

Under the *Water Management Act 2000,* dealings are permitted in access licences, shares, account water and the nomination of supply works.

Dealings under section 71Q between Lachlan Fold Belt MDB (Other) Management Zone to Lachlan Fold Belt MDB (Mudgee) Management Zone in the Lachlan Fold Belt MDB Groundwater Source is permitted provided the sum of share components stays the same as when the plan commenced. The same rule applies for trade dealings under section 71S of the Act.

There are no other trade restricted areas defined in the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011.

8.5.1 Temporary

The most common type of dealings between groundwater licences are allocation assignments (temporary trades) made under section 71T of the *Water Management Act 2000*. The volume of temporary trades within the WRP area is shown in

Table 3.

Table 3 Temporary Trade 71T dealings over the past 3 years.

SDL Resource Unit	2014-2015 Yr	2015-2016 Yr	2016-2017 Yr
Adelaide Fold Belt	0	0	0
Kanmantoo Fold Belt	0	0	0
Lachlan Fold Belt*	3 trades (216 ML)	6 trades (475 ML)	6 trades (271 ML)
New England Fold + Belt	1 trade (28 ML)	1 trade(10 ML)	0
Inverell Basalt	0	0	0
Liverpool Ranges Basalt	0	0	0
Orange Basalt	1 trade (140 ML)	1 trade (50 ML)	1 trade (190 ML)
Warrumbungle Basalt	0	0	0
Young Granite	0	0	2 trades (37 ML)
Total	5 trades (384 (ML)	8 trades (535 (ML)	9 trades (498 ML)

* Dealings within the Yass Catchment Water Source are grouped into Lachlan Fold Belt SDL

+ Dealings within the Peel Fractured Rock Water Source are grouped into New England Fold Belt SDLPermanent

Other dealings for groundwater licences are made under sections 71M (licence transfer), 71N (term licence transfer), 71P (subdivision/consolidation) and 71Q (assignment of shares) and 71W (nomination of works) of the *Water Management Act 2000*.

Dealings that can result in a change in the potential volume that can be extracted from a location and therefore have the potential to cause third party impacts are subject to a hydrogeological assessment and may be approved subject to conditions being placed on the nominated work or combined approvals such as bore extraction limits to minimise potential impact on neighbouring bores.

Table 4 shows the statistics for dealings that result in a change in the potential volume that can be extracted from a location since commencement of the water sharing plan in the WRP area. 71M dealings are not included as these are a change in ownership only and therefore have no potential for additional; third party impacts. The majority of SDL units have had either no dealings or limited to one to two dealings per year.

Table 4 Permanent dealings over the past 3 years, 71M dealings not included.

SDL Resource Unit	2014-2015 Yr	2015-2016 Yr	2016-2017 Yr
Adelaide Fold Belt	0	0	0
Kanmantoo Fold Belt	0	0	0
Lachlan Fold Belt*	1 trade (10 shares)	3 trades (314 shares)	6 trades (185 shares)
New England Fold + Belt	0	0	1 trade (12 shares)
Inverell Basalt	0	1 trade (26 shares)	0
Liverpool Ranges Basalt	0	0	0
Orange Basalt	1 trade (15 shares)	1 trade (140 shares)	0
Warrumbungle Basalt	0	0	0
Young Granite	2 trades (205 shares)	0	1 trade (100 shares)
Total	4 trades (230 shares)	5 trades (480 shares)	8 trades (297 shares)

* Dealings within the Yass Catchment Water Source are grouped into Lachlan Fold Belt SDL

+ Dealings within the Peel Fractured Rock Water Source are grouped into New England Fold Belt SDL

9 Groundwater Monitoring

Water NSW monitors groundwater level, pressure and quality through its network of groundwater observation bores across New South Wales. The groundwater monitoring network plays an important role in:

- assessing groundwater conditions;
- managing groundwater, including groundwater access and extraction; and
- providing data for the development of groundwater sharing plans.

Figure 20 shows a generalised conceptualisation of a layered groundwater system illustrating how the water level height in bores in an area can vary depending on the depth of the screened interval of the bore.

Groundwater systems typically include a number of aquifers which may be confined or unconfined. An unconfined aquifer is an aquifer whose upper water surface (water table) is at atmospheric pressure.

A confined aquifer is completely saturated with water and is overlain by impermeable material (aquitard) causing the water to be under pressure. If the hydraulic head of groundwater is plotted and contoured on a map this is referred to as the potentiometric surface.

Figure 20 also illustrates the difference between stock and domestic, production and monitoring bores. Stock and domestic bores are often constructed into the shallowest aquifer and have a relatively small diameter and limited extraction capacity. Because they are typically shallow they can be more susceptible to climatic fluctuations in water levels and influence from surrounding pumping.

Production bores are generally much larger diameter and have significantly larger extraction capacity. They are usually constructed into the deepest most productive part of a groundwater system and can be screened in multiple aquifers.

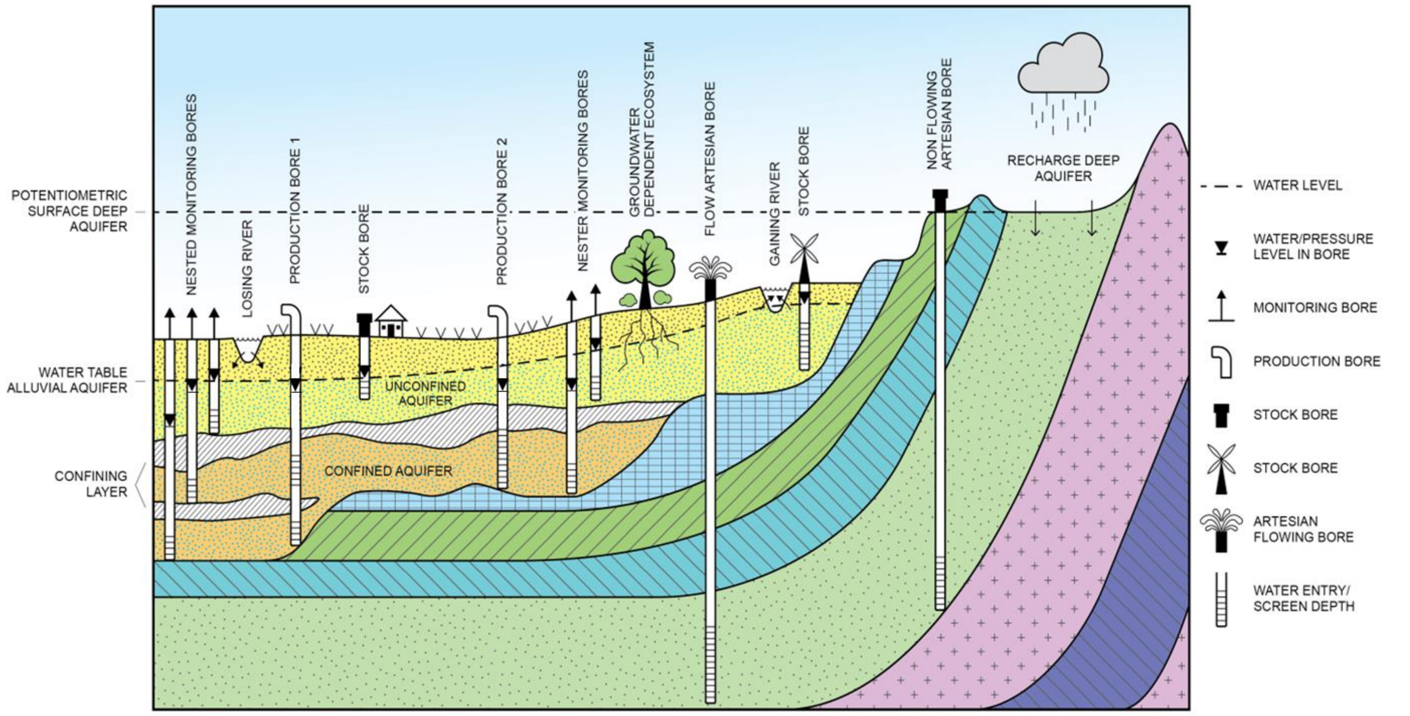

Figure 20 Schematic diagram of different types of aquifers

Monitoring bores are designed to monitor a specific aquifer for water level and water quality and are generally relatively small diameter. At some monitoring bore locations there are multiple monitoring bores which are screened at different depths to observe the hydraulic relationship between different aquifers.

Figure 20 illustrates how the water level in some of the monitoring bores can be at different levels to nearby production and stock bores because the monitoring bores are screened at a single depth and the water level represents the water table or hydraulic head at that depth. Whereas the water level in a multiple screened production bore is a composite water level influenced by the hydraulic head in all screened aquifers.

Groundwater level and pressure data collected from monitoring bores can be plotted and analysed at a water source scale to assess long and short term changes in the system, this data is used to identify areas where there may be a potential management issue.

Groundwater monitoring is carried out at 47 monitoring sites across the WRP area. The monitoring bores are located in areas where groundwater is taken for commercial production (Figure 21). They are distributed across the SDL resource units in the following way:

- 4 bores in the Kanmantoo Fold Belt (GS19)
- 24 bores in the Lachlan Fold Belt (GS20)
- 2 bores in the New England Fold Belt (GS37)
- 1 bore in the Liverpool Ranges Basalt (GS22)
- 6 bores in the Orange Basalt (GS39)
- 10 bores in the Young Granite (GS51)

There are no monitoring bores in the Adelaide Fold Belt, the Inverell Basalt and the Warrumbungle Basalt.

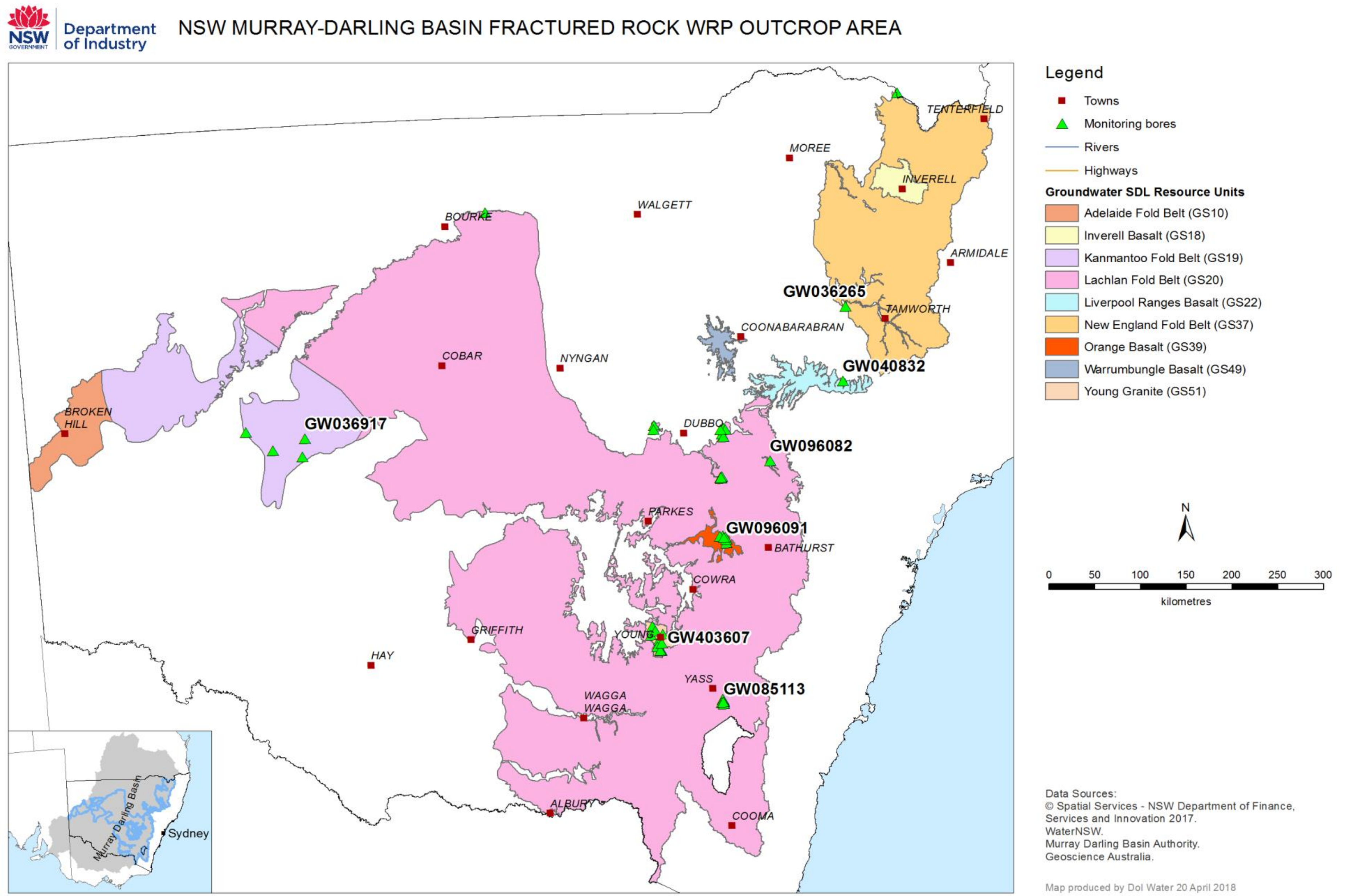

Figure 21 Location map of monitoring bores in the outcrop areas of the WRP

10 Groundwater Behaviour in the WRP area

10.1 Introduction

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (Figure 22). Hydrographs can be used to interpret influences on groundwater such as rainfall, floods, drought and climate change, as well as interpret aquifer response to groundwater extraction.

Figure 22 explains the trends that can be observed in groundwater hydrographs. Both short and longer 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 or flooding and decline during periods of reduced rainfall.

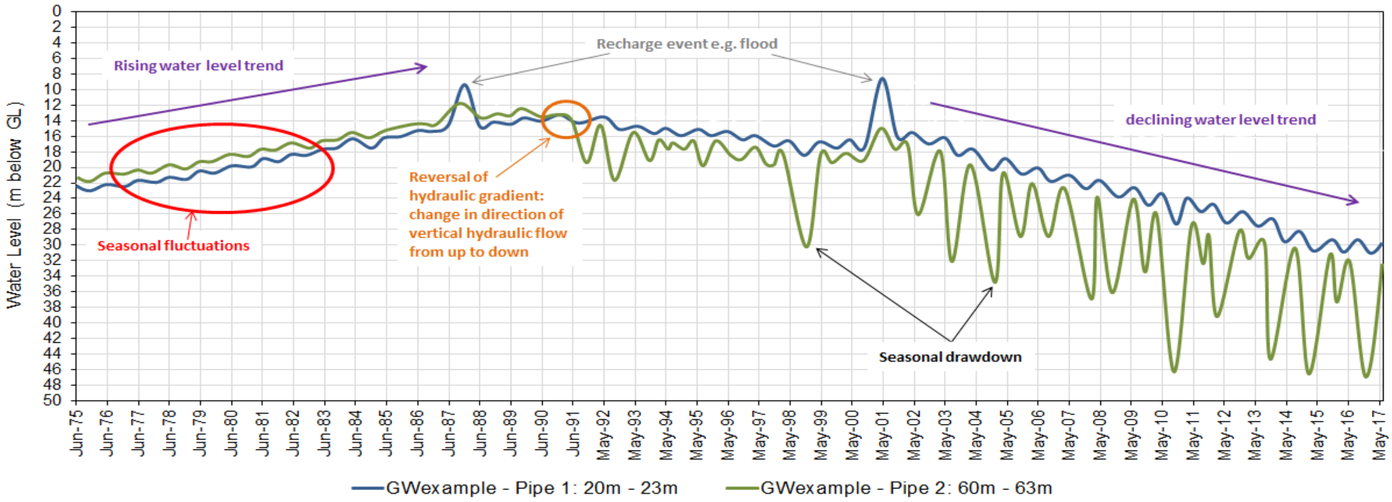

Figure 22 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate.

Significant recharge events such as floods 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.

In areas where groundwater extraction occurs, hydrographs show a seasonal cyclic pattern of drawdown and recovery. 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 resulting in a long term reduction in the recovered groundwater levels.

10.2 Review of groundwater levels

Figure 23 to Figure 29 display water level variations in selected representative monitoring bores.

Groundwater monitoring in the eastern tablelands occurs at a range of interconnected depths from 5 metres to more than 150 metres below ground level depending on the degree and intensity of fracturing and weathering. Monitoring data show that the groundwater levels are strongly influenced by climatic variations and generally fluctuate between 2 and 23 metres depending on the depth of the water bearing zones being monitored.

Groundwater monitoring in the western areas is typically at greater depths ranging from 40 to 225 metres below ground level. Water levels are less influenced by climate due to their greater depths and are consequently more stable.

Figure 23 to Figure 29 show no long term change in water level over the periods of record which is consistent with the relatively low extraction volumes reported since the Plan commenced in 2012 / 2013 coinciding with average climatic conditions.

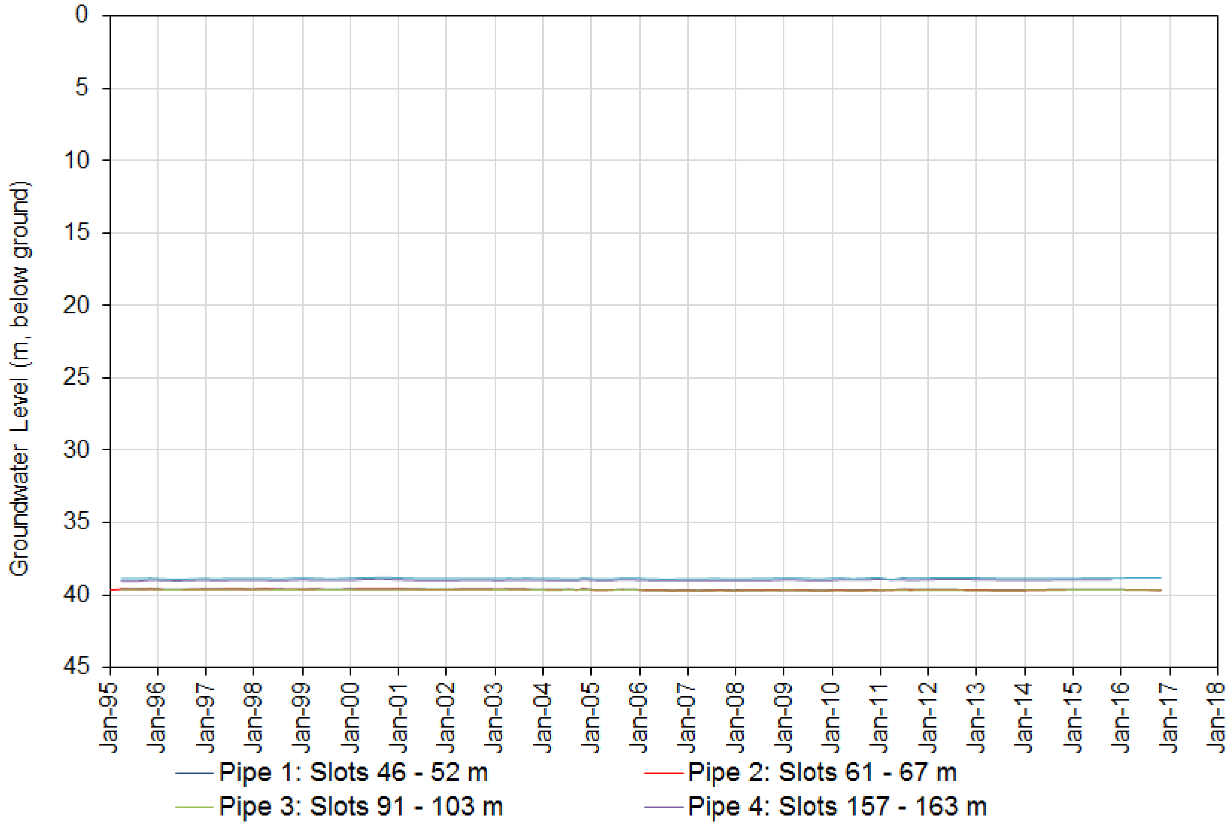

Figure 23 Kanmantoo Fold Belt groundwater level at bore GW036917.

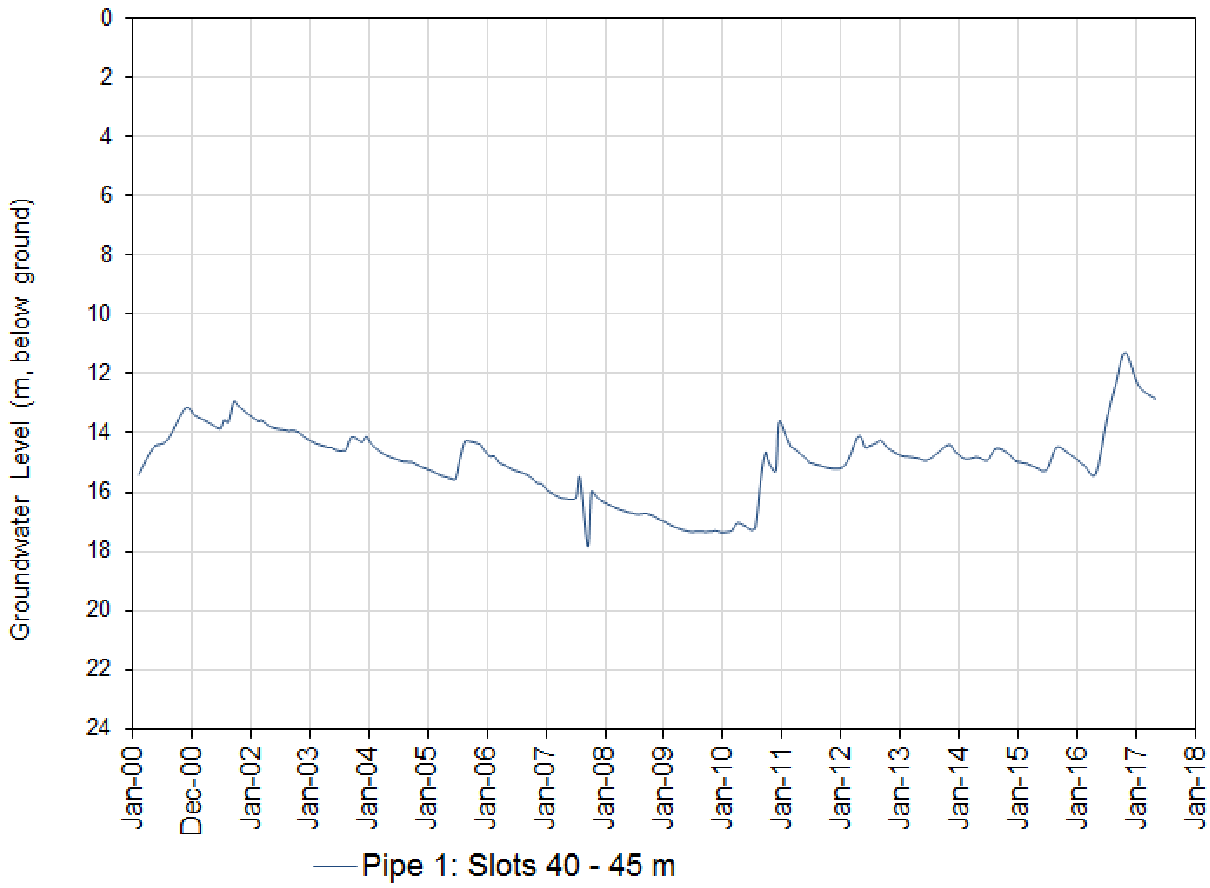

Figure 24 Lachlan Fold Belt groundwater level at bore GW085113.

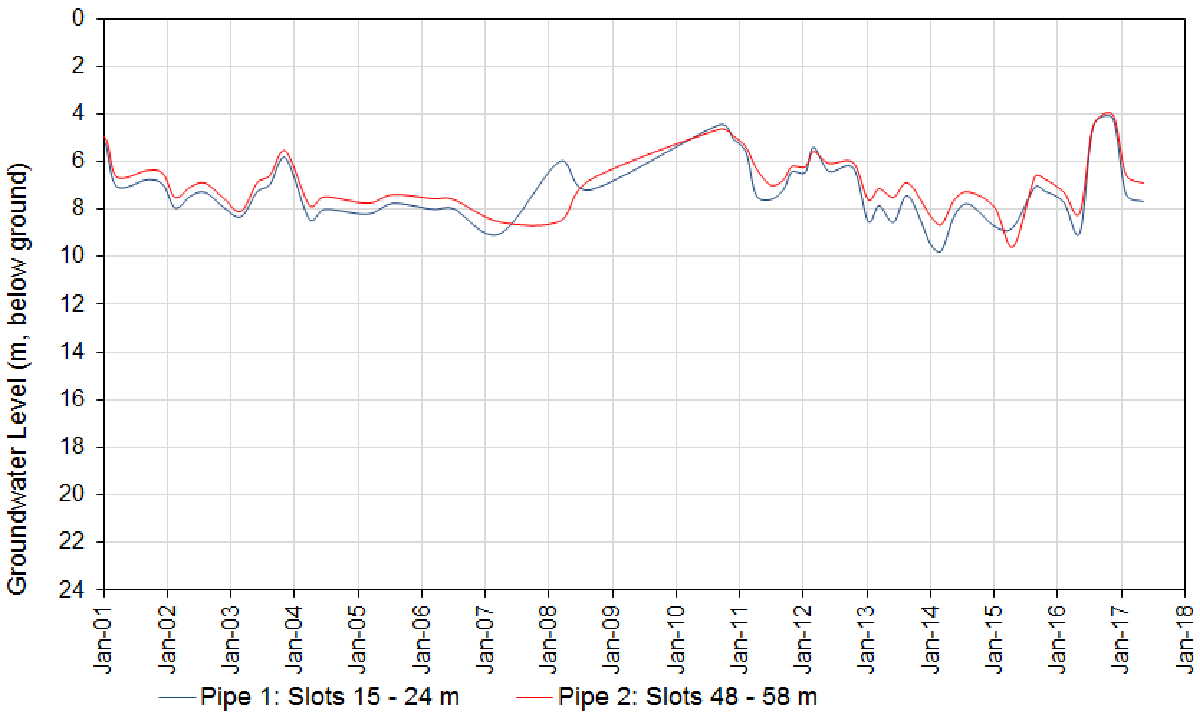

Figure 25 Lachlan Fold Belt groundwater level at GW096082.

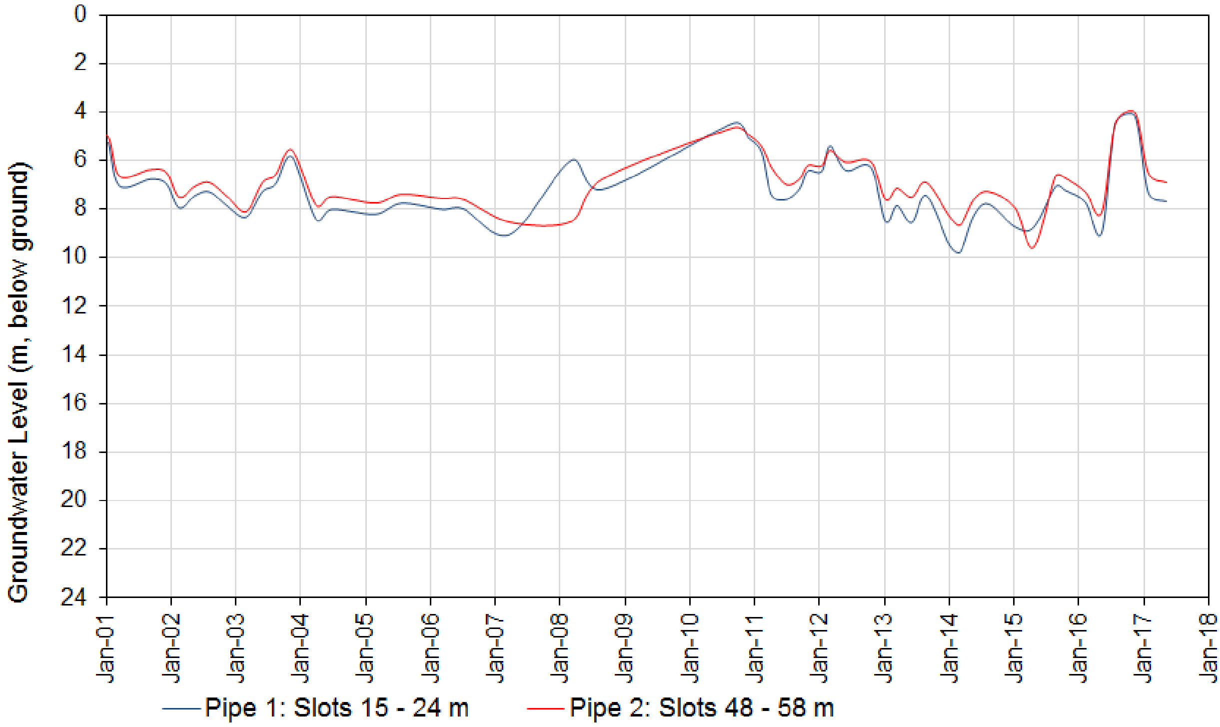

Figure 26 New England Fold Belt groundwater level at GW036265.

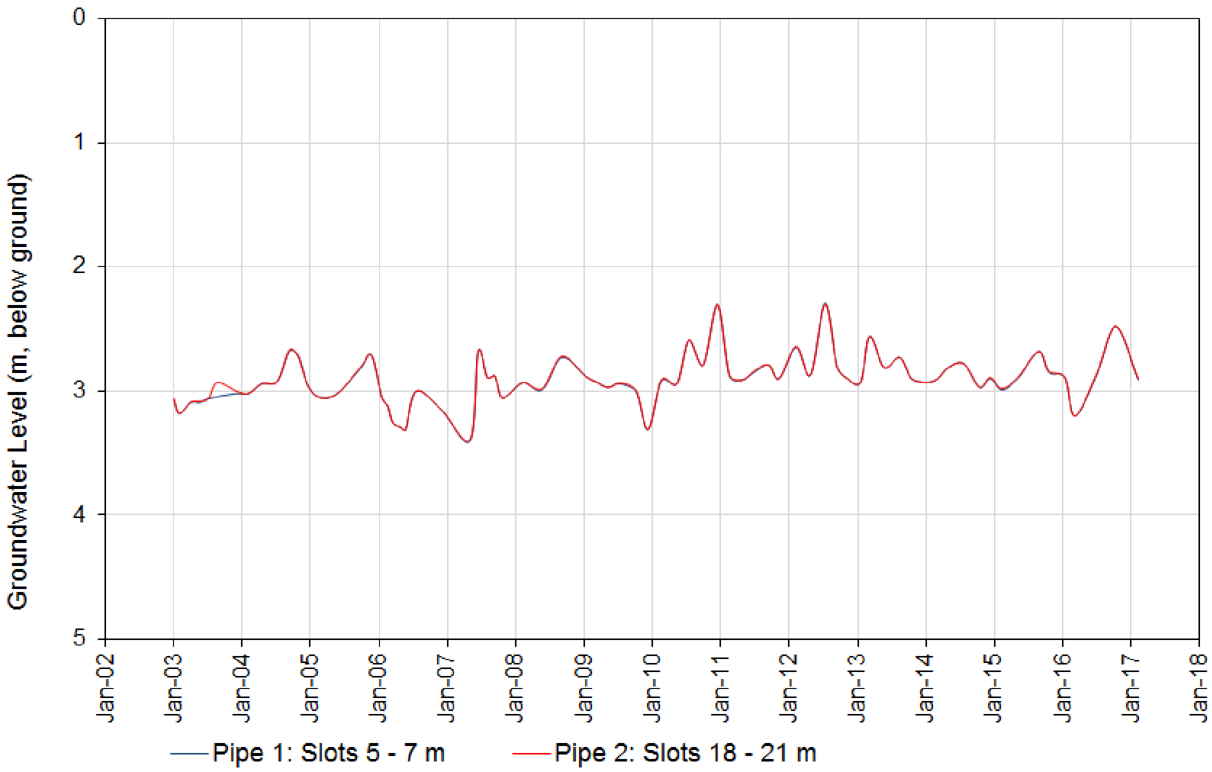

Figure 27 Liverpool Ranges Basalt groundwater level at bore site GW040832.

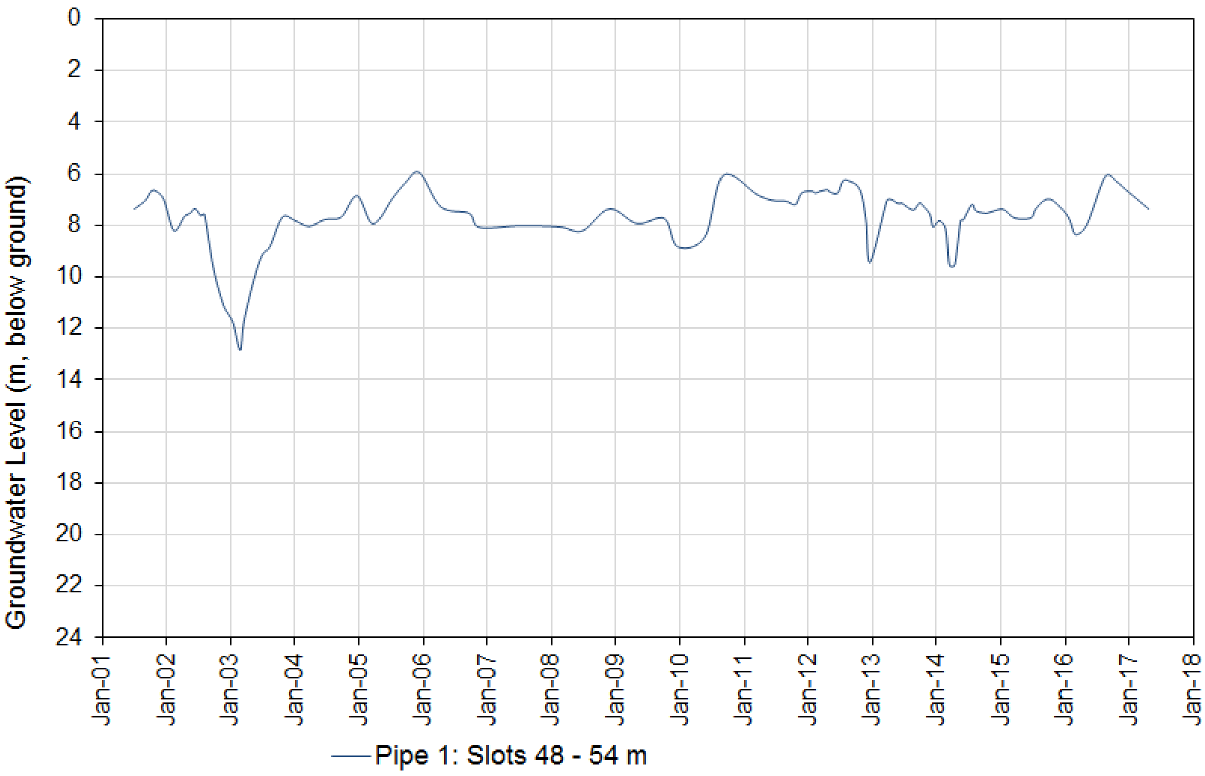

Figure 28 Orange Basalt groundwater level at bore site GW096091.

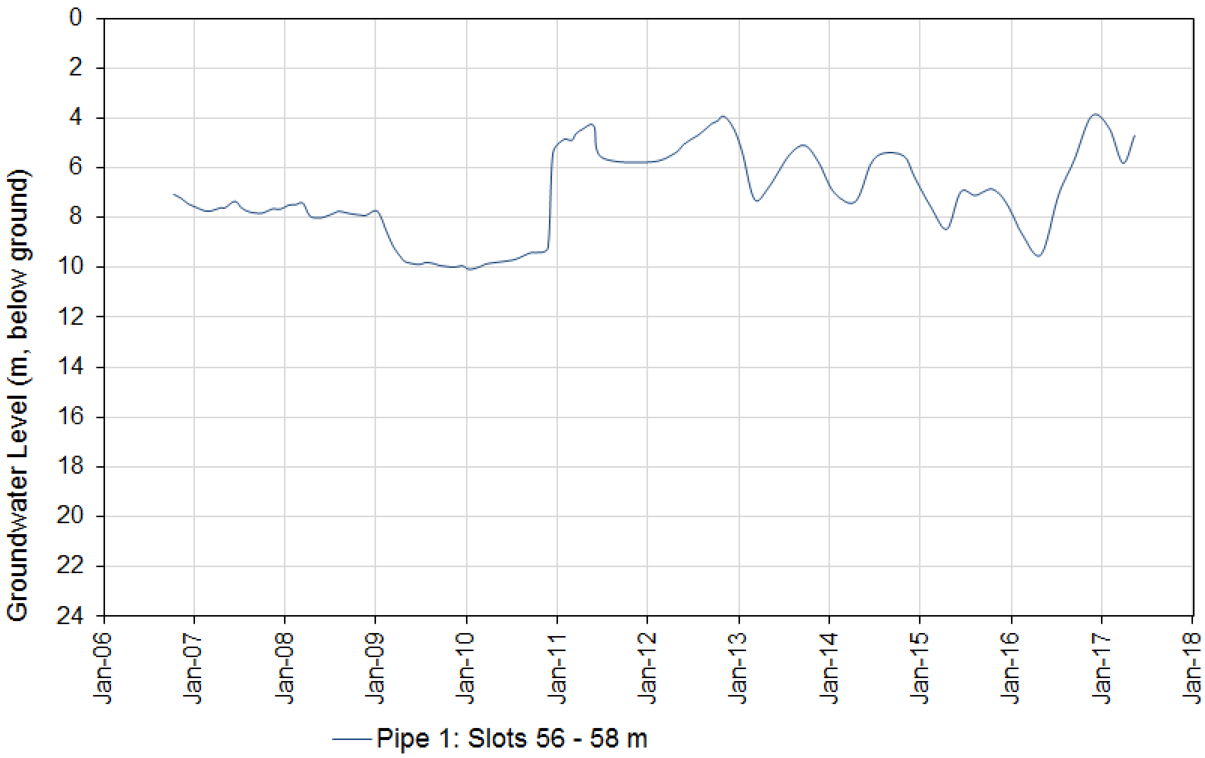

Figure 29 Young Granite groundwater level at bore site GW0403607.

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