THE BASIN PLAN IMPLEMENTATION

Murrumbidgee Alluvium Water Resource Plan Resource Description

Appendix A

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Glossary

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

Term	Description
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.
Anabranch	Stable multi-thread channels that are intermediate between single thread and braided channels characterised by vegetation or otherwise stable alluvial islands that divide flows at discharges up to nearly bank-full.
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...
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.

[1] As defined in '*Macro water sharing plans – the approach for groundwater*' (NSW Office of Water, 2011)
[2] As defined in '*Guidelines for Groundwater Quality Protection in Australia 2013'* published by the National Water Quality Management Strategy.

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.
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.

[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.

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.
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

[4] As defined by Strategic Regional Land Use Plans

	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*.
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.

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

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.
Water year	Twelve month period from 1 July to 30 June.
Yield	The amount of water that can be supplied over a specific period.

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

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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 Murrumbidgee Alluvium Water Resource Plan area is shown in Figure 1 and is located within the Murrumbidgee catchment that forms part of the Murray-Darling Basin in southern NSW. The Murrumbidgee catchment covers about 84,000 km^2 and represents about eight percent of the Murray-Darling Basin.

The groundwater resources of the Murrumbidgee Alluvium include the main alluvial deposits associated with the Murrumbidgee River, including its tributaries and anabranches from the Jugiong area at its eastern extent to Balranald at its western extremity. They also include the alluvial deposits of the internally draining Lake George catchment which occur to the south of Lake George.

The Murrumbidgee Alluvium Water Resource Plan area (GW9 – Murray-Darling Basin reference number) is composed of four SDL resource units: the Lake George Alluvium (GS21), Mid Murrumbidgee Alluvium (GS31), and Lower Murrumbidgee Alluvium Shallow (GS28) and Lower Murrumbidgee Alluvium Deep) (also GS28). The boundaries of these SDL resource units reflect those of the corresponding groundwater sources managed under two NSW water sharing plans. The groundwater sources are the:

- Bungendore Alluvial Groundwater Source (Lake George Alluvium) and the Gundagai, Kyeamba, Wagga Wagga and Mid Murrumbidgee Zone3 Alluvial Groundwater Sources (Mid-Murrumbidgee Alluvium) managed under the Water Sharing Plan for Murrumbidgee Unregulated and Alluvial Water Sources 2012, and
- Lower Murrumbidgee Shallow Groundwater Source and the Lower Murrumbidgee Deep Groundwater Source[7] (Lower Murrumbidgee Alluvium Shallow and Lower Murrumbidgee Alluvium Deep) managed under the Water Sharing Plan for the Lower Murrumbidgee Groundwater Sources 2003.

This report describes the location, climate and physical attributes of the Murrumbidgee Alluvium groundwater resources, 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, groundwater behaviour and modelling.

[7] These water source names are those proposed under Basin Plan amendments and refer to Lower Murrumbidgee Alluvium (shallow; Shepparton Formation) and Lower Murrumbidgee Alluvium (deep; Calivil Formation and Renmark Group) as listed in Schedule 4.

2. History of groundwater management

2.1. Early groundwater management

The *Water Act 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 this Act, 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 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 some parts of inland NSW, whilst broad scale surface water diversion and irrigation were contributing to rising water tables and salinisation in other areas.

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 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.

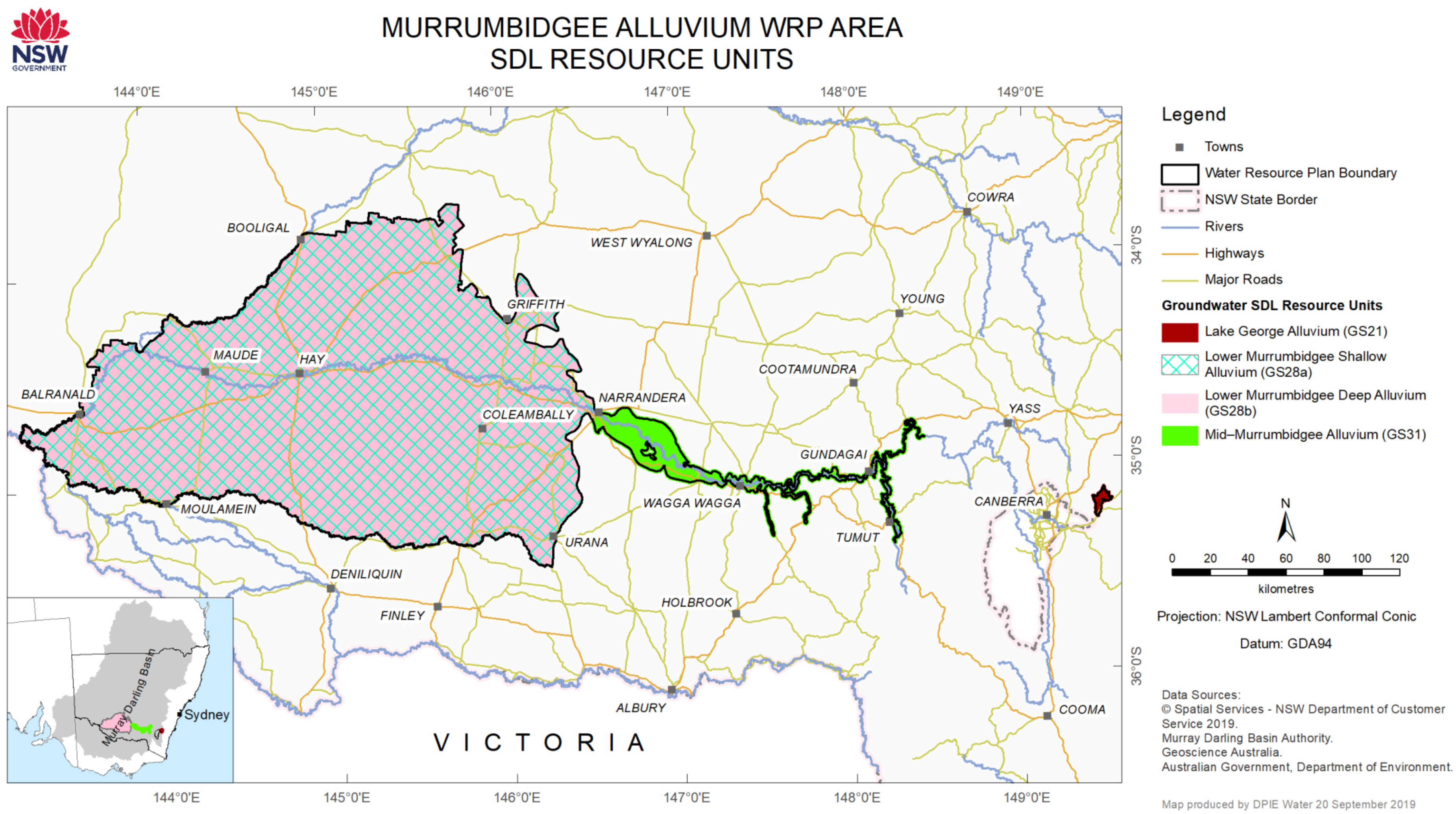

Figure 1. Location of the Murrumbidgee Alluvium Water Resource Plan Area.

2.2. NSW water reform

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*. This Act 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 *Water Management Act 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 *Water Management Act 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 *Water Act 1912* on new applications for groundwater licences. These included 22 groundwater sources within the Murray-Darling Basin, and remained in effect until the commencement of water sharing plans for the groundwater sources that they covered.

A groundwater management committee was first established for the Murrumbidgee valley in 1998. This group contributed to the development of water sharing plans for the valley. The Lower Murrumbidgee Water Sharing Plan commenced in 2006 and the Murrumbidgee Unregulated and Alluvial Water Sharing Plan commenced in 2012.

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 *Water Management Act 2000* and other relevant legislative frameworks.

2.3. Lake George Alluvium

The groundwater resources of the Lake George Alluvium were managed under the *Water Act 1912* until October 2012, when management commenced under the *Water Management Act 2000* via the *Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012* (in which they are referred to as the 'Bungendore Alluvial Groundwater Source').

Prior to 1984, groundwater for irrigation was authorised based on irrigated area. These licences were converted to volumetric entitlements in 1984 under the Interim Volumetric Bore Licensing Policy for the Lachlan, Murrumbidgee, Murray, and Macquarie Valleys. Licences were later issued under *Draft Murrumbidgee Bore Licensing Procedures & Policy Summary* developed in 1999.

2.4. Mid-Murrumbidgee Alluvium

The groundwater resources of the Mid Murrumbidgee Alluvium were managed under the Water Act 1912 when, in September 2002, an embargo was placed on further licence applications for irrigation and industrial purposes. Prior to 1984, groundwater for irrigation was authorised based on irrigated area. These licences were converted to volumetric entitlements in 1984 under the Interim Volumetric Bore Licensing Policy for the Lachlan, Murrumbidgee, Murray, and Macquarie Valleys. Licences were later issued under *Draft Murrumbidgee Bore Licensing Procedures & Policy Summary* developed in 1999.

The Mid-Murrumbidgee Alluvium was designated as a high risk aquifer by Ross (1999). This was based on the high yielding and low salinity nature of the aquifer, vulnerability to pollution, and the reliance of Wagga Wagga and other towns on the system for urban water supply.

Since October 2012, the groundwater resources have been managed under the *Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012*, which incorporates the following groundwater sources:

- Gundagai Alluvial Groundwater Source;
- Kyeamba Alluvial Groundwater Source;
- Wagga Wagga Alluvial Groundwater Source; and
- Mid Murrumbidgee Zone 3 Alluvial Groundwater Source.

2.5. Lower Murrumbidgee Alluvium

The first volumetric groundwater allocation policy for the Lower Murrumbidgee Valley was introduced in November 1983 and this was developed into the *Licensing Policy for High Yield Bores in the Lower Murrumbidgee Valley, NSW* in 1984. Under this policy the existing unrestricted area based licences were converted to an annual volumetric entitlement and new licences were given an annual volumetric entitlement.

In September 1997, a 12-month moratorium was put in place that prevented the issue of groundwater entitlement for irrigation use. In 1998, the Lower Murrumbidgee was identified as a high-risk groundwater system as part of a state-wide program for Aquifer Risk Assessment (NSW Department of Land and Water Conservation, 1998). The major risks identified for the Lower Murrumbidgee were over-allocation, local drawdown and interference between bores, and invasion of aquifers by saline groundwater. In September that year the moratorium was extended for an additional 18 month period. It was then replaced by a statutory embargo in September 1999.

In May 2000 a moratorium was placed on all new bore licenses for irrigation and industrial purposes. This prevented the drilling of additional bores even where entitlements existed and was effective until the commencement of the Water Sharing Plan for this area.

In March 2001 the NSW Government requested the Murrumbidgee Groundwater Management Committee to advise on the formulation of a water sharing plan (the Plan) for the Lower Murrumbidgee groundwater sources. In 2003 a plan for the Lower Murrumbidgee groundwater sources was finalised by the Minister for Water but implementation was deferred until October 2006. Under the plan, total entitlements in the Lower Murrumbidgee Deep Alluvium were reduced from 514.6 GL to the 270.0 GL.

3. Regional setting

3.1. Topography

The topography of the Murrumbidgee catchment (Figure 2) is diverse, ranging from snow–capped mountains with elevations of approximately 2,000 m above sea level in the upper catchment, to the rolling hills of the mid catchment, and the extensive riverine plains of the lower catchment which decline gradually to an elevation of about 50 m above sea level in the west (Murrumbidgee Catchment Management Authority, 2013).

The Murrumbidgee River system and its floodplain are major topographic features of the Murrumbidgee catchment (Figure 3). Its headwaters are at an elevation of about 2,200 m above sea level on the Monaro plains southwest of the ACT, and it terminates at the junction with the Murray River near Balranald. (Green et al, 2011).

The Murrumbidgee River initially flows southeast before heading north along the eastern side of the Brindabella Ranges and into Burrinjuck Dam (Figure 3). Downstream of Burrinjuck Dam, the river flows southwest to Gundagai then west to Wagga Wagga through an alluvial valley before it enters the riverine plains near Narrandera.

Burrinjuck Dam was initially completed in 1928, then enlarged in 1957, and is the valley's major water storage facility. It has a capacity of 1,028,000 ML that provides water for town water supplies, irrigation, stock and domestic use, industry, and environmental flows, and has a total catchment area of 13,100 square kilometres.

The Murrumbidgee River reaches its maximum capacity at Wagga Wagga where the mean daily flow is 10,326 ML per day. After this the main channel of the Murrumbidgee begins to lose its flow to anabranches, effluent channels and irrigation area offtakes that characterise the lower part of the catchment, as well as to the underlying alluvial sediments.

The Tumut River is the largest tributary of the Murrumbidgee, rising in the Snowy Mountains and flowing westwards to meet the Murrumbidgee River near Gundagai. Blowering Dam is located on the Tumut River just south of Tumut. It has a relatively small catchment area of only 1,630 square kilometres, but in addition to the inflows from its mountainous and largely forested catchment, the dam also receives water from outside its natural catchment via the Snowy Mountains Scheme.

The flow regime of the Murrumbidgee River has been substantially altered by the construction of Burrinjuck Dam and various structures of the Snowy Mountains Scheme (including Blowering Dam), as well as various weirs and regulators that divert water along distributary channels including the Yanco Creek system, the main canals of the Murrumbidgee and Coleambally irrigation areas, and the Lowbidgee Flood Control and Irrigation District.

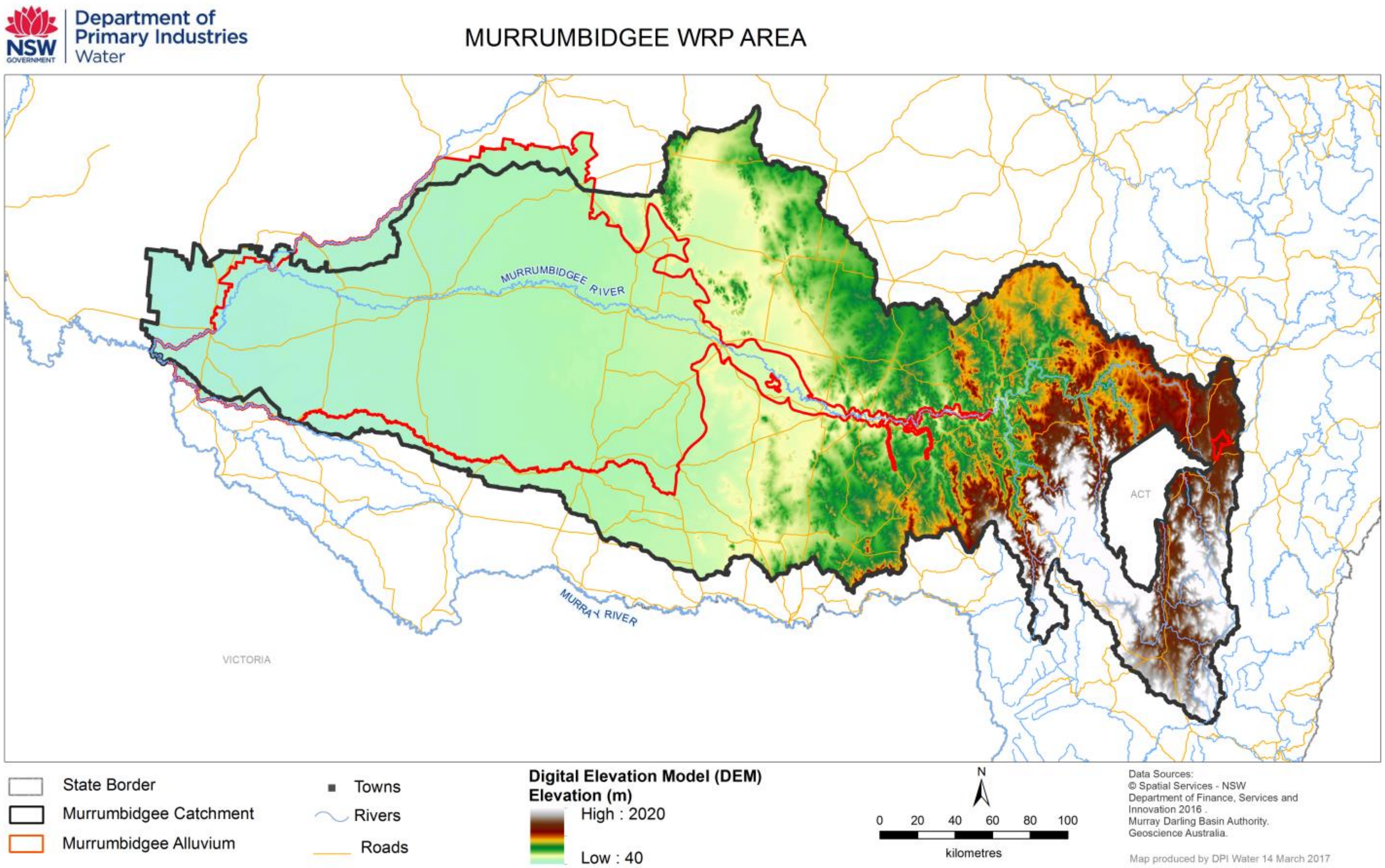

Figure 2. Topography and elevation map of the Murrumbidgee catchment (Gallant et al, 2009).

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MURRUMBIDGEE CATCHMENT

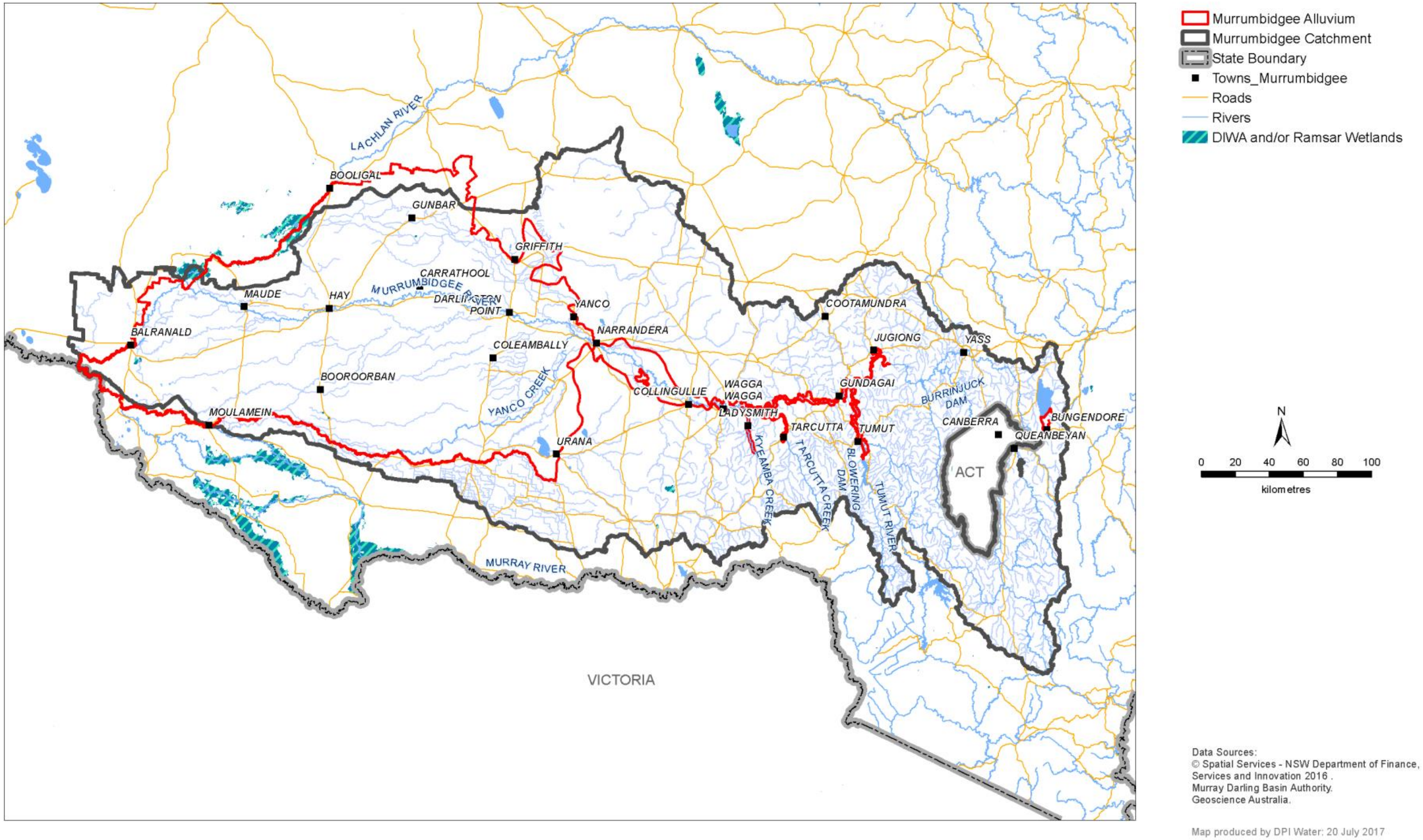


Figure 3. Surface water map of the Murrumbidgee catchment.

3.2. Climate

The Murrumbidgee Catchment has one of the most diverse climates in NSW which reflect on the diversity of landscapes – ranging from the alpine areas of Kosciuszko National Park and the Monaro plains, through to the grazing and grain belts of the South West Slopes and Plains, and the shrub lands and grasslands of the semi-arid western Riverina (CSIRO, 2006).

The WRP area is generally characterised by hot summer temperatures with moderate winter rainfall that can vary between years. There is a significant range in temperatures and rainfall, between Bungendore in the east to Balranald in the west.

The temperature extremes across the Murrumbidgee WRP area can range from -8.7°C in the winter (Bungendore) to 47.7°C in the summer (Balranald). Average maximum temperature ranges from 31.1°C to 38.4°C and average minimum temperature ranges from -3.2°C to 0.4°C at Bungendore and Balranald respectively.

The average annual rainfall in the Murrumbidgee catchment (Figure 4) ranges from over 1,700 millimetres in the higher elevations of the Snowy Mountains, to less than 350 millimetres on the western plains (Green et al, 2011). Average annual rainfall at Wagga Wagga is 518 millimetres (based on 112 years of data from 1898 to 2010). The wettest year on record at Wagga Wagga was 1950 with 882 millimetres and the driest year was 1914 with just 231 millimetres. Rainfall in the upper catchment is slightly summer dominant, and in the mid to lower catchment is neutral to slightly winter dominant (Figure 5).

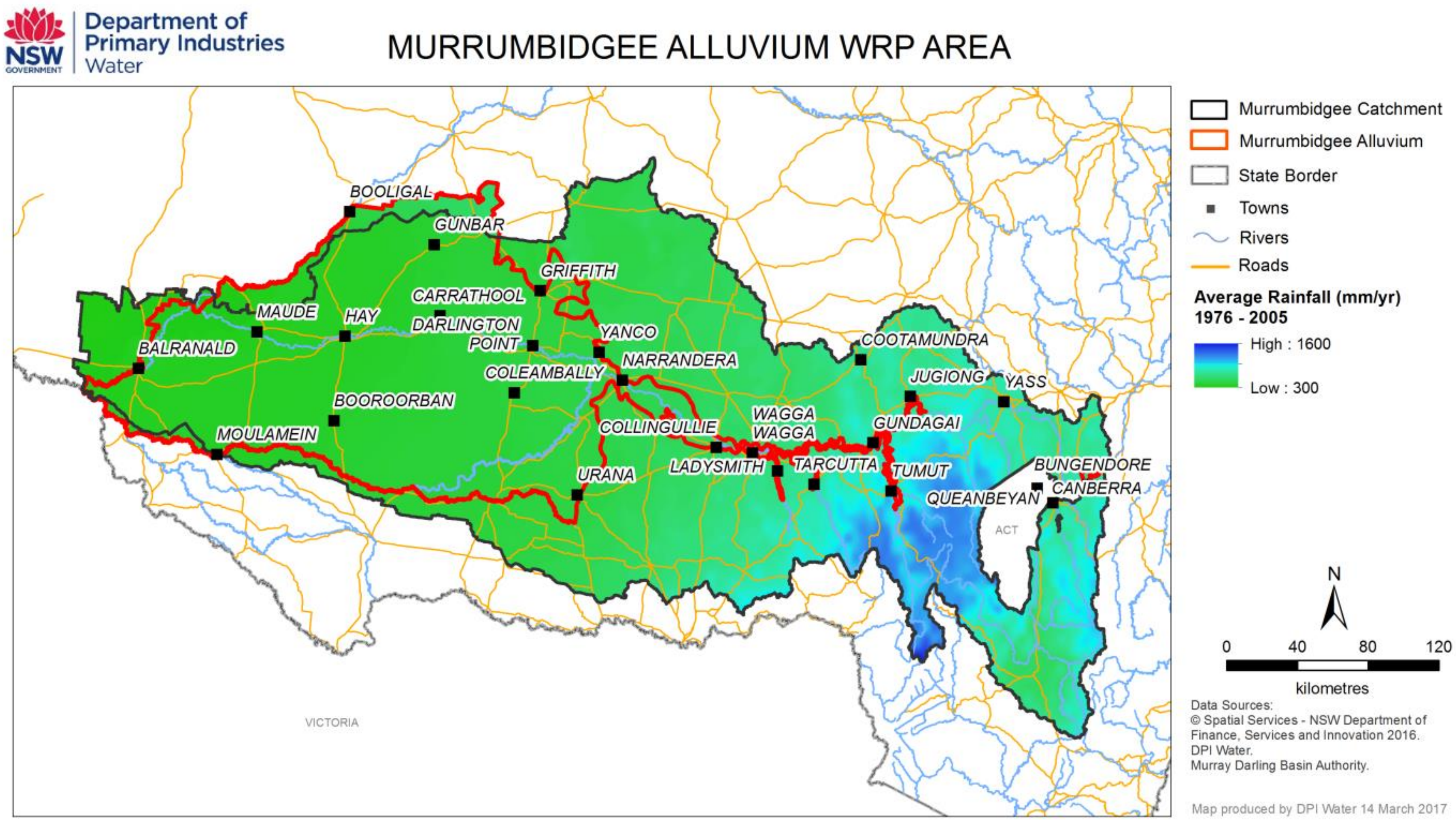


Figure 4. Average annual rainfall map of the Murrumbidgee catchment (BOM, 2008).[8]

[8] The average rainfall for the period 1976 - 2005 displayed in this map is the current 'standardised average conditions' gridded data set available from the Bureau of Meteorology.

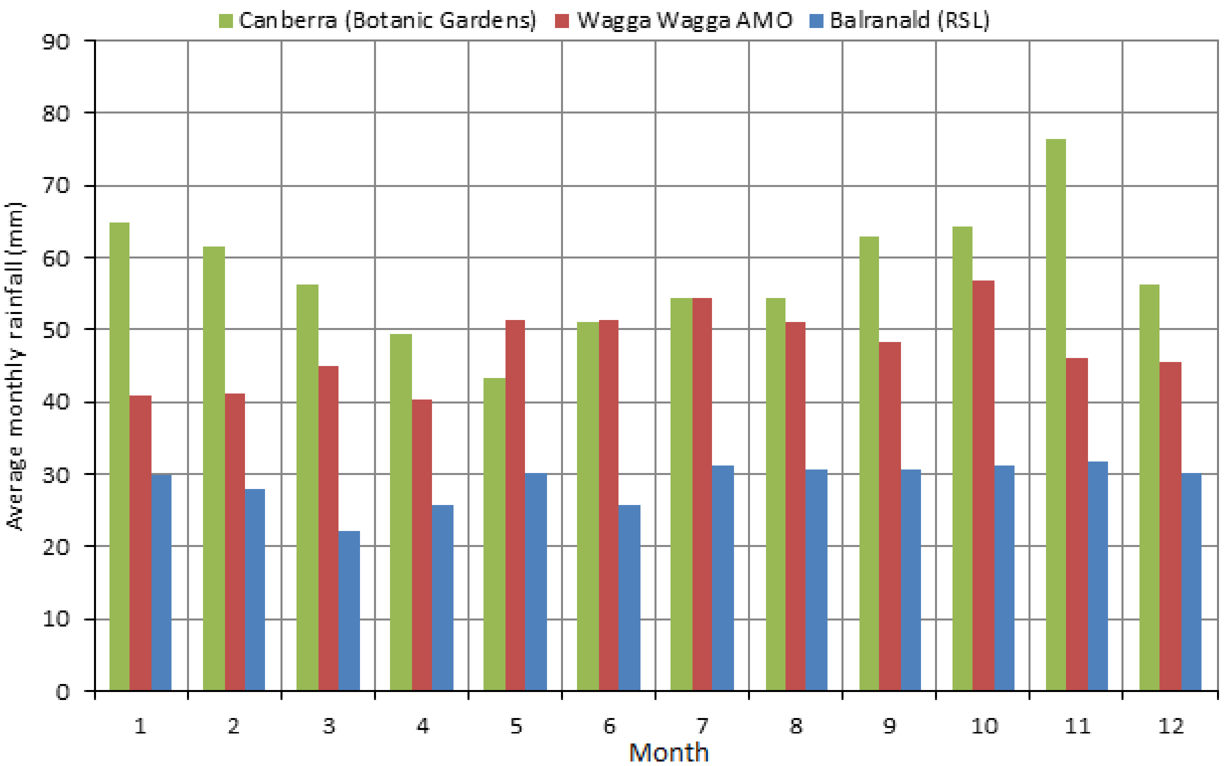


Figure 5. Average monthly rainfall (BOM) 1972 – 2016 for Canberra (upper catchment), Wagga Wagga (mid catchment) and Balranald (lower catchment).

(Note: This period corresponds to the period of record for groundwater monitoring within the Murrumbidgee Alluvium mid and lower catchment.)

Potential evaporation (Class A pan evaporation) in the Murrumbidgee catchment has a strong east-west gradient (Figure 6). Yearly evaporation varies from around 1,300 mm in the east (Bungendore) to 1,890 mm in the west (Balranald).

Evaporation is strongly seasonal throughout the catchment (Figure 7), varying in Wagga Wagga (for example) from a low of 38 mm per month over winter (June and July), to 305 mm in summer (January). Evaporation significantly exceeds average monthly rainfall over the year. The greatest exceedance occurs over the summer months (December/January), with Wagga Wagga receiving 40-45 mm per month of rainfall on average, compared with 282-305 mm per month of evaporation.

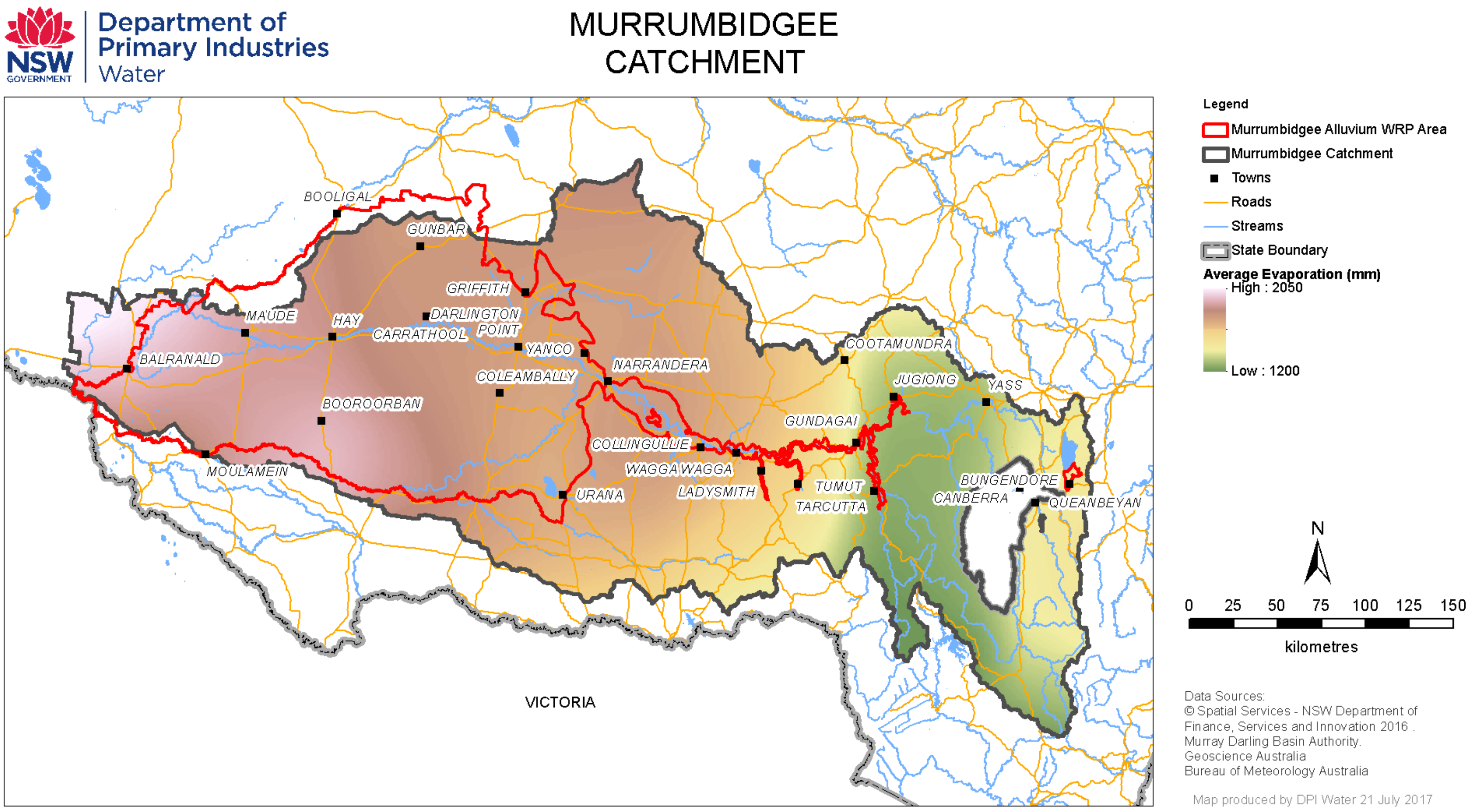


Figure 6. Average annual evaporation map of the Murrumbidgee catchment (BOM, 2008).

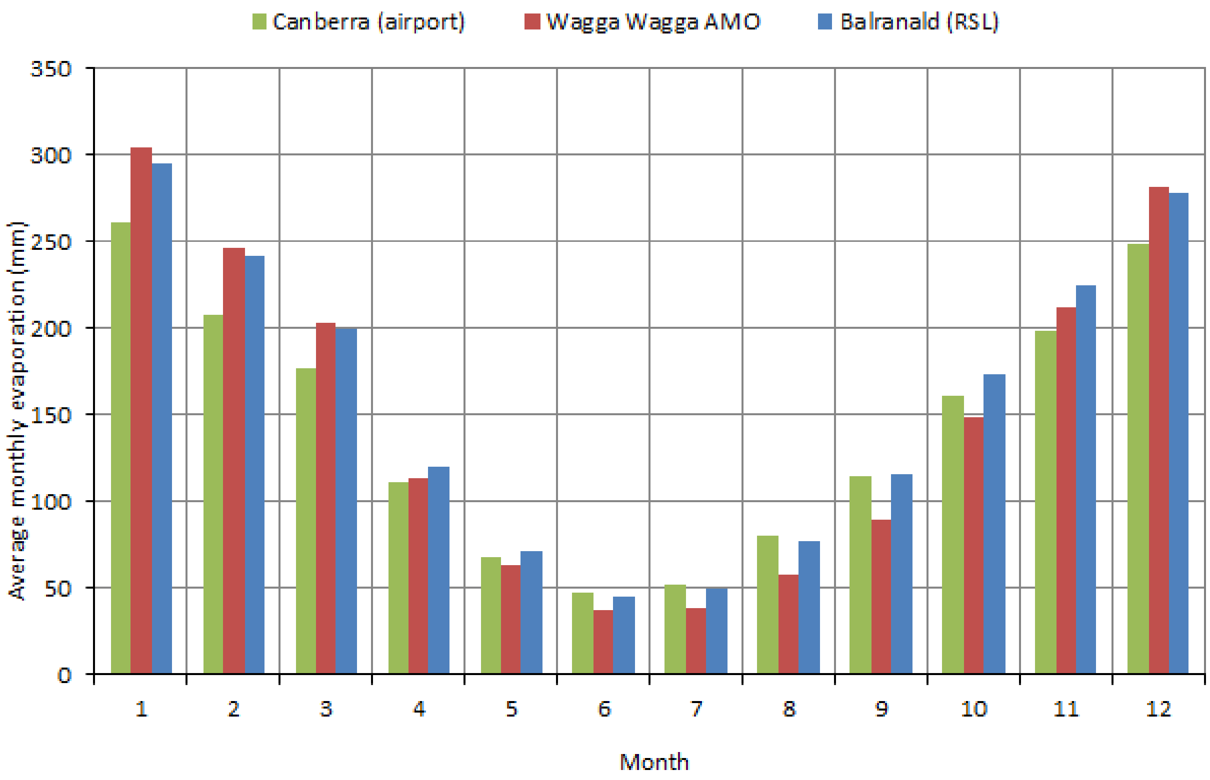


Figure 7. Average monthly evaporation (BOM) 1972 to 2016 – for Canberra (upper catchment), Wagga Wagga (mid catchment) and Balranald (lower catchment).

(Note: This period corresponds to the period of record for groundwater monitoring within the Murrumbidgee Alluvium mid and lower catchment.)

Residual rainfall plots have been constructed for the mid and lower Murrumbidgee catchment using daily data sourced from the Scientific Information for Land Owners (SILO) database. The rainfall residual mass graph plots the cumulative difference of actual monthly rainfall from the average monthly 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 8 shows residual mass graphs of monthly rainfall, from 1972 to 2016, for stations in the upper, mid and lower catchment. This period corresponds to the period of groundwater monitoring in the Murrumbidgee Alluvium which commenced around 1972.

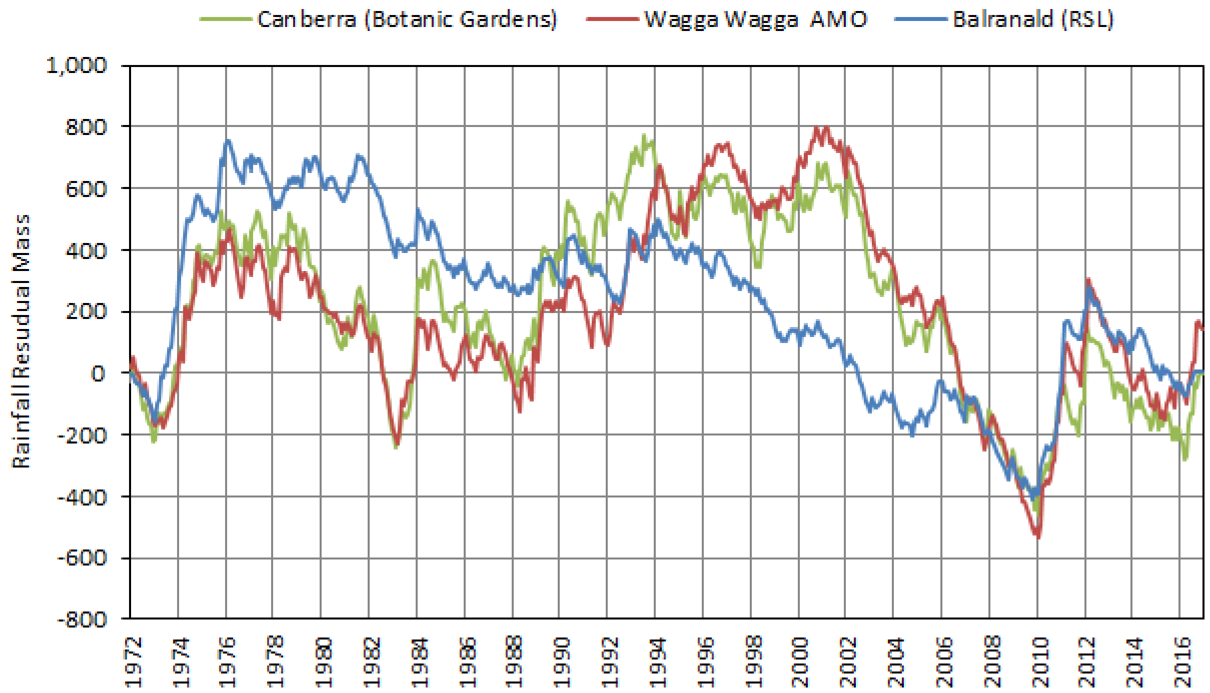


Figure 8. Rainfall residual mass graphs (BOM) 1972 – 2016 for Canberra, Wagga Wagga and Balranald.

3.3. Land use

The Aboriginal people of the slopes and plains of the Murrumbidgee catchment are the Wiradjuri, whose nation is the largest Aboriginal Nation in New South Wales, and extends from the River Murray to beyond Dubbo in the north, and west to Balranald. In addition to the Wiradjuri, there are several smaller nations at the western end of the catchment, including the Barapa Barapa, Muthi Muthi, Nari Nari, Nyeri Nyeri, Wadi Wadi, Wamba Wamba, Weki Weki, and Wolgalu. The mountains at the eastern end of the Murrumbidgee catchment are the country of the Ngunawal and Ngarigo nations (MDBA website).

European graziers began to establish pastoral runs in the Murrumbidgee catchment area in the 1820s, initially farming cattle, then sheep and later growing grain crops. The introduction of river steamboats encouraged trade of timber, wool and other goods from the 1860s until the early 20th century. The Murrumbidgee Irrigation Area was established in 1912. The production of a wide range of horticultural crops commenced; and with further development of the area and the construction of more dams in the upper catchment, rice production was established in the 1920s.

Land use in the Murrumbidgee catchment is dominated by extensive agriculture (Green et al, 2011). The largest industry is grazing which occupies 64 per cent of the catchment. Much of the remainder is used for dryland cropping and horticulture. Irrigated crops are economically very important for the catchment and cover five per cent of its area. Forests, conservation areas and other native vegetation together cover about 13 per cent of the land use (Figure 9). The grazing land is distributed throughout the catchment and features heavily in all the regions.

Dryland agriculture occurs mostly in the mid-Murrumbidgee between Gundagai and Narrandera. Irrigated cropping occurs within the Murrumbidgee Irrigation Area on the northern side of the river, in the Coleambally Irrigation Area on the southern side of the river, and along the Yanco Creek system. The prominent crops produced in the Murrumbidgee Irrigation Area are rice, corn, wheat, grapes and citrus. In Coleambally Irrigation Area rice, soybeans and corn are grown in summer while wheat, oats and barley are produced over winter. Irrigated pasture for grazing is grown throughout the year. The main irrigated crops along the Yanco Creek system are citrus, stone fruit, wine grapes and rice.

The largest areas of conservation land and commercial forest are in the east of the catchment, upstream of Burrinjuck and Blowering Dams. Kosciusko National Park and Namadgi National Park protect alpine and sub-alpine habitats and represent the largest conservation areas in the catchment.

The population of the Murrumbidgee catchment is about 550,000 (ABS 2011) (MDBA, 2017). The Australian capital city of Canberra, located in the east of the catchment, has a population of 356,000 (ABS 2011). Across the border, Queanbeyan has a population of nearly 40,000. Wagga Wagga in the centre of the catchment is the largest inland city of New South Wales, with a population of 60,000. Other major centres include Cooma (7,000) in the upper catchment, and Griffith (25,000) and Leeton (11,000) in the lower catchment.

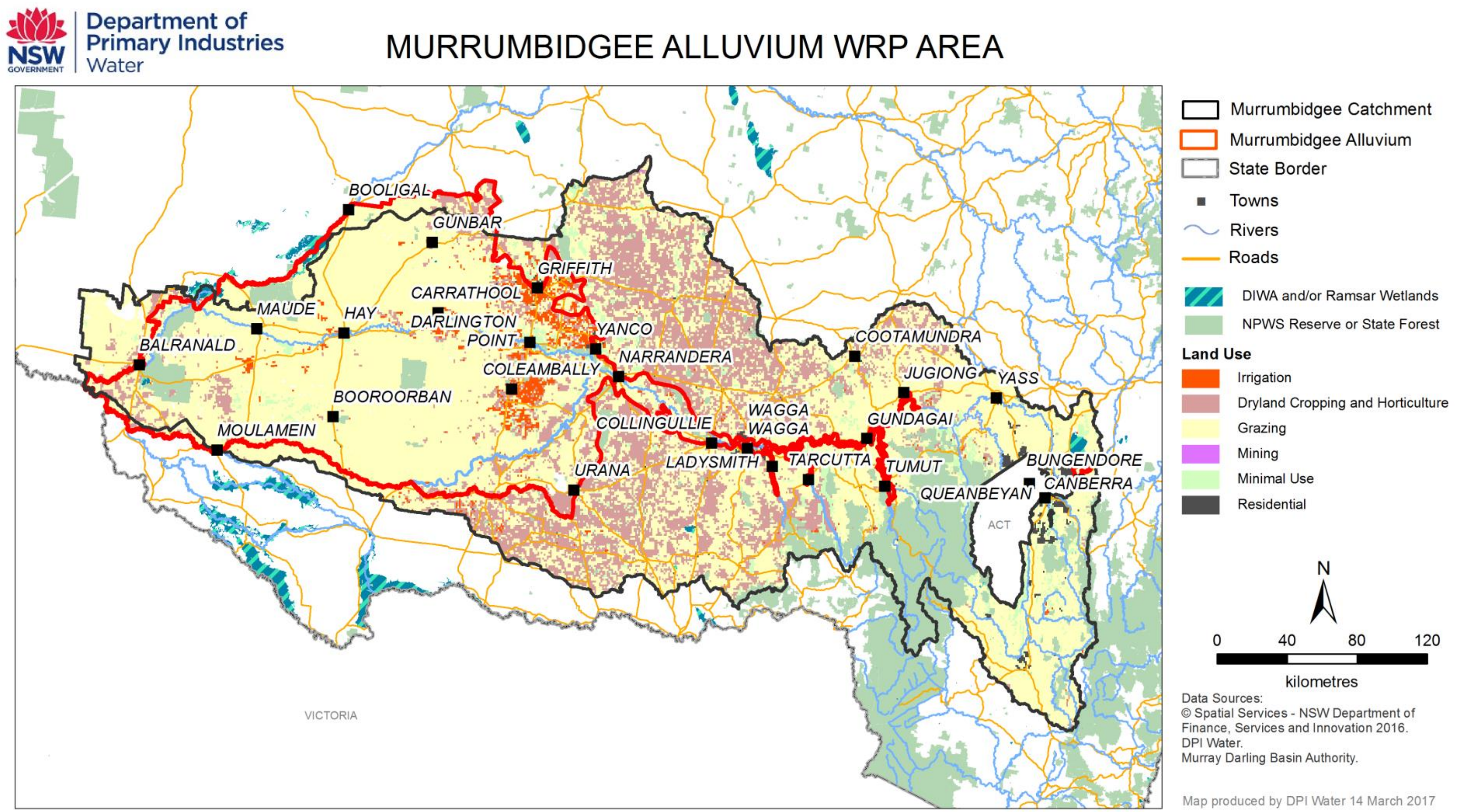


Figure 9. Land use map of the Murrumbidgee catchment (Smart, 2016).

4. Geology

The main geological features of the Murrumbidgee catchment are the Palaezoic-age fractured rocks of the mid and upper catchment, and the Cenozoic alluvial deposits associated with the Murrumbidgee and other rivers, including the sediments of the Murray (geological) Basin underlying the riverine plains in the lower catchment (Figure 10).

The fractured rocks of the upper Murrumbidgee catchment are mostly associated with the Lachlan fold belt, a major geological province of eastern Australia (Carter, 2000), and tend to occur in broad, north-south trending structural belts of folding and faulting. The youngest fractured rocks are the flat-lying tertiary basalts that form a capping on the Palaeozoic rocks in the highland plateau areas south of Cooma.

The youngest geological formations of the catchment are the Cenozoic alluvial deposits that occur within creeks and rivers and have been derived largely from weathering of the Palaeozoic bedrock. These deposits generally increase in width and depth down-catchment, with the broad and relatively deep deposits of the Lake George basin in the upper catchment being an anomaly. From the Wagga Wagga area downstream to Narrandera two distinct units can be recognised. In order of youngest (uppermost) to oldest (lowermost) they are the:

- Cowra formation, and
- Lachlan formation[9].

These alluvial deposits reach a maximum depth of about 170 m at Narrandera, beyond which they are defined as part of the Murray Basin.

The Murray Basin is a large saucer-shaped structure which extends into three states (NSW, Vic and SA) and covers about 300,000 km^2 of south-eastern Australia (Lawson and Webb, 1998). The Basin consists of a sequence of mostly semi-consolidated to unconsolidated flat lying sedimentary deposits which began accumulating about 50 million years ago (within the Cenozoic era). They have a maximum thickness of about 600 m in the central area near Mildura and, within the Lower Murrumbidgee, a maximum of about 400 m near Balranald. The maximum thickness at Narrandera, where the Murrumbidgee River enters the Murray Basin, is about 170 m.

The sedimentary deposits of the Murray Basin, including the Lower Murrumbidgee, can be subdivided into three main units, or layers. These layers are not actually separate, distinct aquifers. Rather, they represent different time periods and types of sedimentary deposition, and at any location each layer could contain a number of aquifers. The three layers, in order of youngest (uppermost) to oldest (lowermost) are:

- Shepparton Formation
- Calivil Formation, and
- Renmark Group.

Underlying the Murray Basin in the Jerilderie–Coleambally area is the Oaklands Basin, a coal-bearing basin of Permian-Triassic age.

[9] The Cowra formation and Lachlan formation are not recognised as official formation names by the Australian Stratigraphic Commission

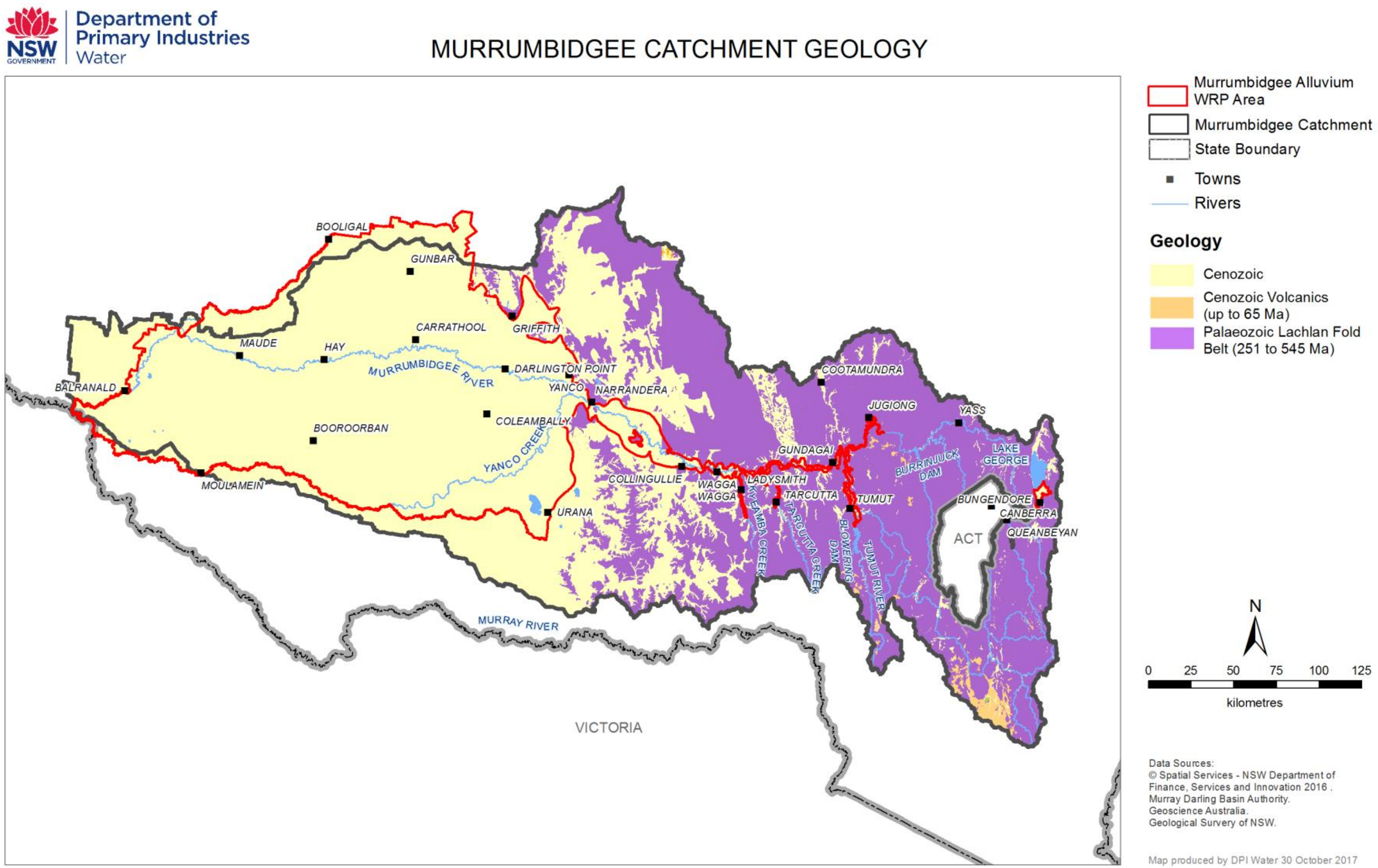


Figure 10. Geology of the Murrumbidgee catchment.

5. Hydrogeology

The Murrumbidgee Alluvium consists of the Cenozoic sediments of the Lake George, Mid Murrumbidgee and Lower Murrumbidgee Shallow and Lower Murrumbidgee Deep Alluvium.

5.1. Regional context

The Murrumbidgee Alluvium, with the exception of Lake George Alluvium, is a continuous sequence of unconsolidated sediments which were deposited as valley fill in the upper areas of the catchment and grades into broader valley and floodplain sediments in the mid catchment and the lower catchment. The Lower Murrumbidgee Alluvium in turn grades into the Murray Geological Basin (MGB) sediments which also incorporates the Western Porous Rocks SDL resource unit on the western boundary of the Murrumbidgee Alluvium, the Lower Lachlan Alluvium SDL resource unit on the north western boundary and the Lower Murray Alluvium SDL resource unit on its south western boundary. Lake George Alluvium underlies the internally draining Lake George Basin and is disconnected with the rest of the Murrumbidgee Alluvium.

Whilst the geometry of the alluvium is varied over the 1,400 plus kilometres of valley length, there is no break in the sedimentation. Consequently groundwater through flow is uninterrupted down valley and there is hydraulic connection across contiguous boundaries between the Murrumbidgee Alluvium and the MGB sediments.

The Murrumbidgee Alluvium sits over and adjacent to the fractured rock management units of the Lachlan Fold Belt Fold Belt and the Oaklands Basin. The permeability of the underlying fractured and porous rocks is many orders of magnitude lower than that of the alluvium. Groundwater exchange between the alluvium and the underlying rock is expected to be insignificant in the context of the groundwater resources of the alluvium. Consequently these fractured rock systems and the porous rocks of the Oaklands Basin are not considered hydraulically connected in a resource management sense to the groundwater resources in the alluvium.

The boundaries of the SDL resource units within the Murrumbidgee Alluvium reflect areas of similar hydrogeological characteristics. There is hydraulic connection across contiguous boundaries between the management units in NSW with the exception of Lake George Alluvium. The characteristics of each of the SDL resource units in Murrumbidgee Alluvium in NSW are presented in the following sections.

5.2. Lake George Alluvium

The Lake George Alluvium underlies the internally draining Lake George Basin, located between Canberra and Goulburn. The origin of the Basin is largely fault controlled, and the major geological north-south trending Lake George fault that runs along the western side of the lake, and other minor faulting in the area, have contributed to the occurrence and nature of sediments in the basin.

The Lake George Basin is a natural drainage basin fed by 10 major tributaries that originally drained to the Yass River before they were cut off by the faulting and uplift of the Lake George Range (DPI Water, 2017). The lake itself is underlain by Cenozoic alluvium, which overlies deeply weathered Palaeozoic bedrock and extends beyond the lake to underlie the floodplains of tributary streams.

The main freshwater-bearing sediments underlie the floodplain around Bungendore, and are the source of groundwater supply to the town. Here the alluvium is about 45 to 50 m thick and consists of interbedded sand, clay and gravel. The sands form productive aquifers with yields of up to about 15 L/s, and salinity levels around 800 micro Siemens per centimetre (µS/cm) (Carter, 2000).

5.3. Mid-Murrumbidgee Alluvium

The water bearing sands and gravels of the Mid Murrumbidgee Alluvium are divided into two main aquifer systems; a shallow aquifer system (Cowra formation) extending to depths of approximately

40 m, and an underlying deep aquifer system (Lachlan formation) extending to depths of approximately 90 m.

Yields from the shallow and deep aquifer systems have in general been reported as high as 40 and 150 L/s respectively. Recharge to the Mid Murrumbidgee Alluvium occurs through leakage from the Murrumbidgee River and its various tributaries and anabranches, and infiltration from rainfall and irrigation activity. Recharge may also occur as discharge from the underlying bedrock.

In some areas in the vicinity of Wagga Wagga, and particularly further upstream, the shallowest alluvial aquifer is in direct hydraulic connection with the rivers, allowing direct recharge from the river into the aquifer system. It is the main discharge where there is little or no groundwater extractions.

The main discharge in the Mid Murrumbidgee Alluvium is extraction for irrigation. Other pathways of discharge are base flow to the Murrumbidgee River, particularly in areas upstream of Wagga Wagga, and through-flow to the west.

Groundwater contours and flow directions for the Mid Murrumbidgee Alluvium (deep aquifer system) are displayed in Figure 11. The closed contours reveal locations of intensive groundwater extraction.

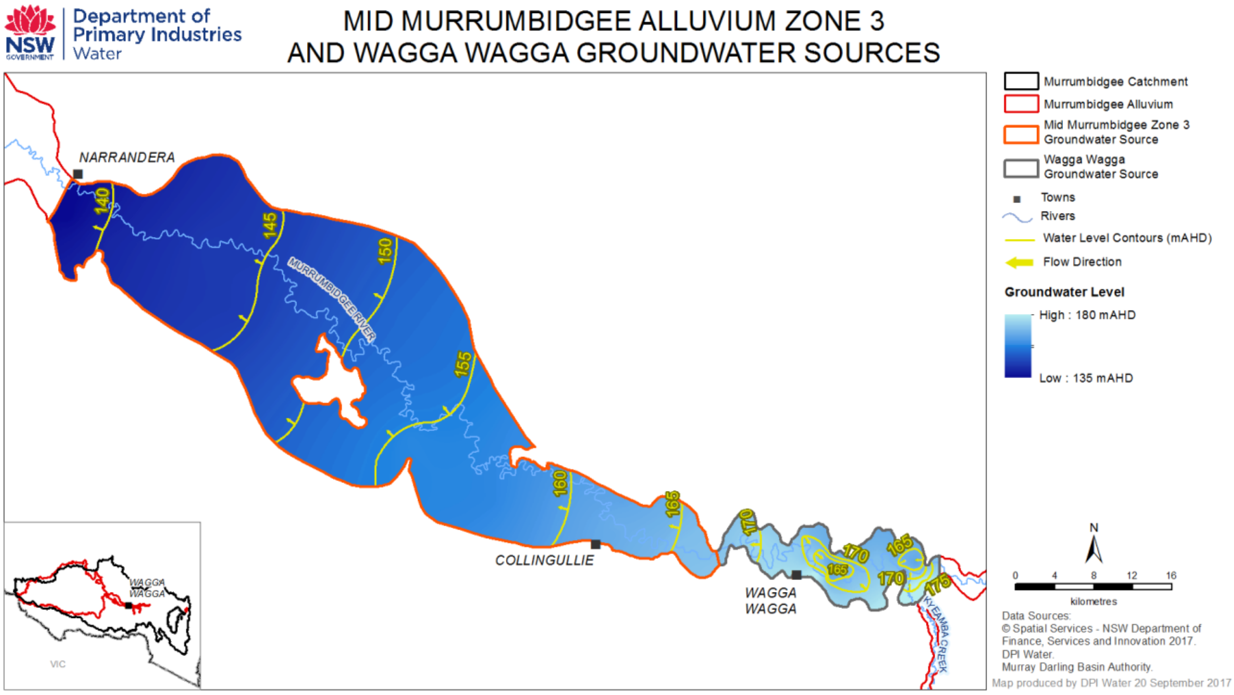


Figure 11. Location map of the Wagga Wagga and Mid Murrumbidgee Zone 3 Alluvial Groundwater Sources and groundwater flow direction in the deep aquifer (based on 2015-16 recovered groundwater levels).

Figure 12 shows the locations of three north-south geological cross sections that have been produced for the Mid Murrumbidgee Alluvium. The cross sections are for locations at Wagga Wagga, downstream of Collingullie and upstream of Narrandera, and are shown in Figures 13 to 15.

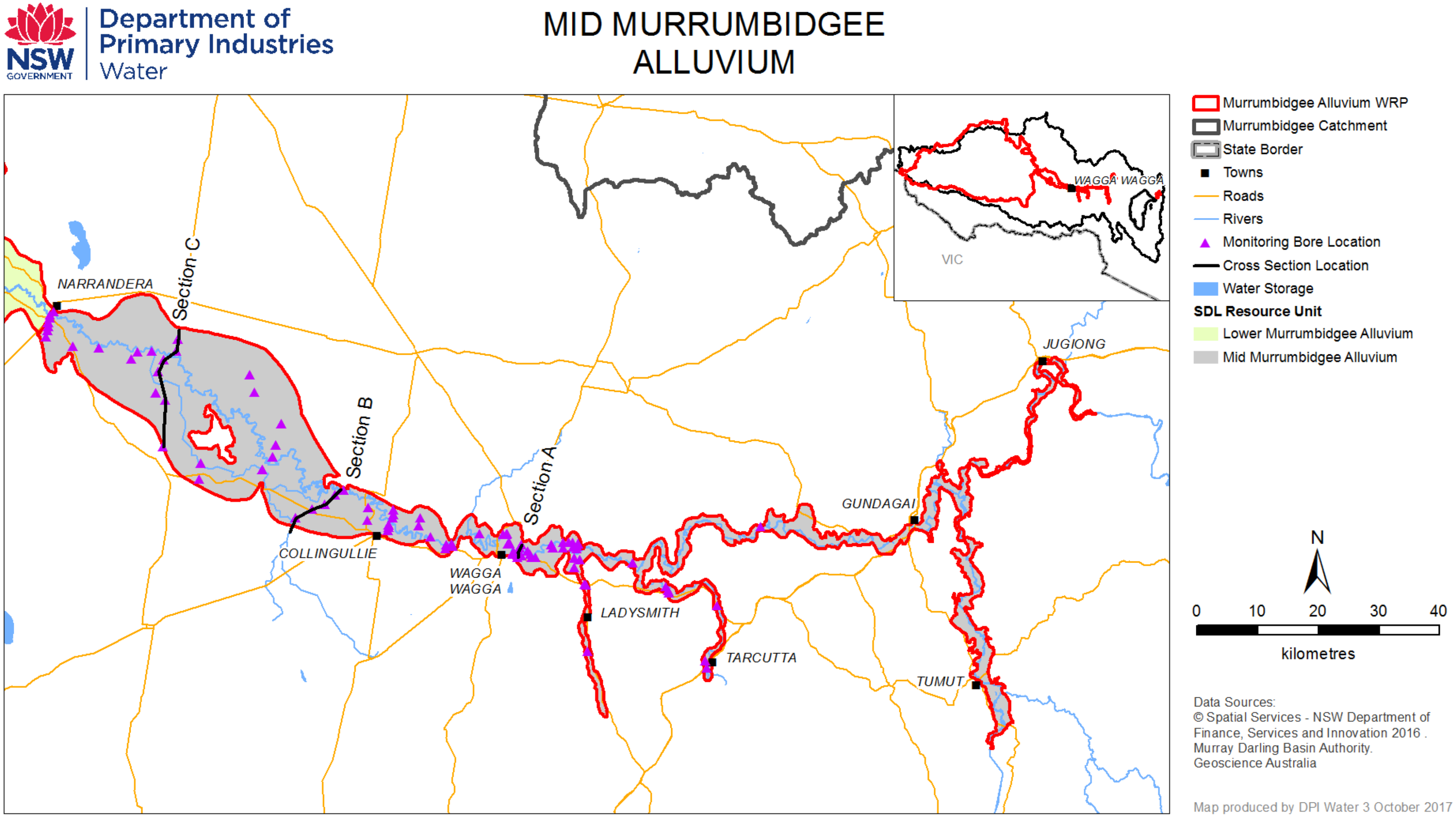
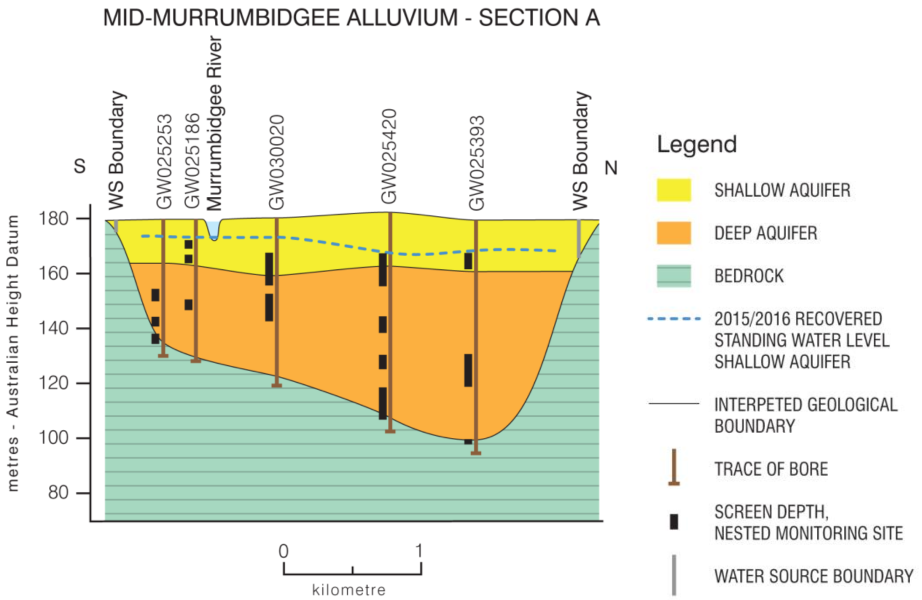
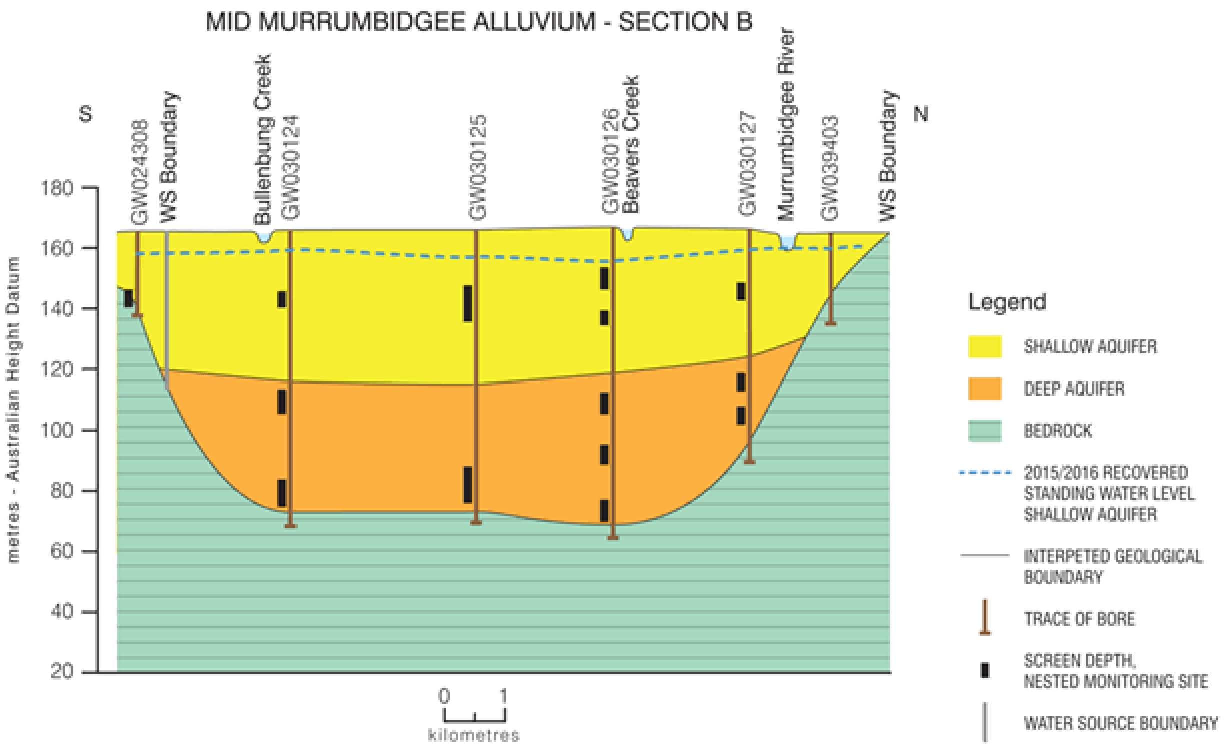


Figure 12. Cross section map for the Mid Murrumbidgee Alluvium.



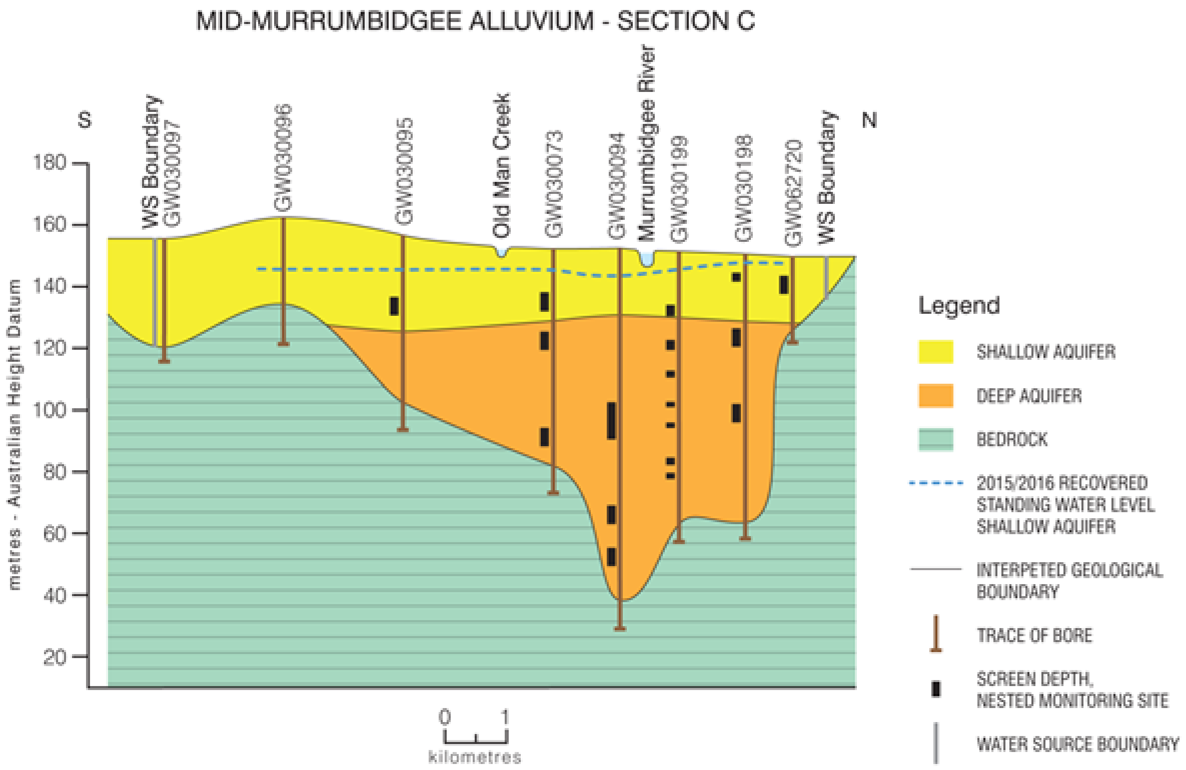
Note the boundary between the deep and shallow aquifers is interpreted based on limited information.

Figure 13. North-south cross section through the Mid Murrumbidgee Alluvium (Section A) at Wagga Wagga.



Note the boundary between the deep and shallow aquifers is interpreted based on limited information.

Figure 14. North-south cross section through the Mid Murrumbidgee Alluvium (Section B) near Currawarna.



Note the boundary between the deep and shallow aquifers is interpreted based on limited information.

Figure 15. North-south cross section through the Mid Murrumbidgee Alluvium (Section C) near Galore.

5.4. Lower Murrumbidgee Alluvium

The Lower Murrumbidgee Alluvium (shallow) represents the Shepparton Formation, which generally consists of yellow and brown poorly sorted sand and clay sediments that extend to depths of between 50 and 70 m below ground surface. For management purposes, the shallow aquifer is defined as extending to a depth of 40 m, or the bottom of the Shepparton Formation, whichever is the deeper. Groundwater in the shallow aquifer is not necessarily the ‘watertable’, and may be overlain by shallower ‘perched’ groundwater that is leaking downwards from recharge sources such as irrigated fields and the Murrumbidgee River.

Recharge to the Lower Murrumbidgee Alluvium (shallow) occurs through leakage from the Murrumbidgee River and its various tributaries and anabranches, infiltration from rainfall and irrigation activity, and through flow from the Mid Murrumbidgee Alluvium.

Groundwater contours and flow directions for the Lower Murrumbidgee (shallow) are displayed in Figure 16.

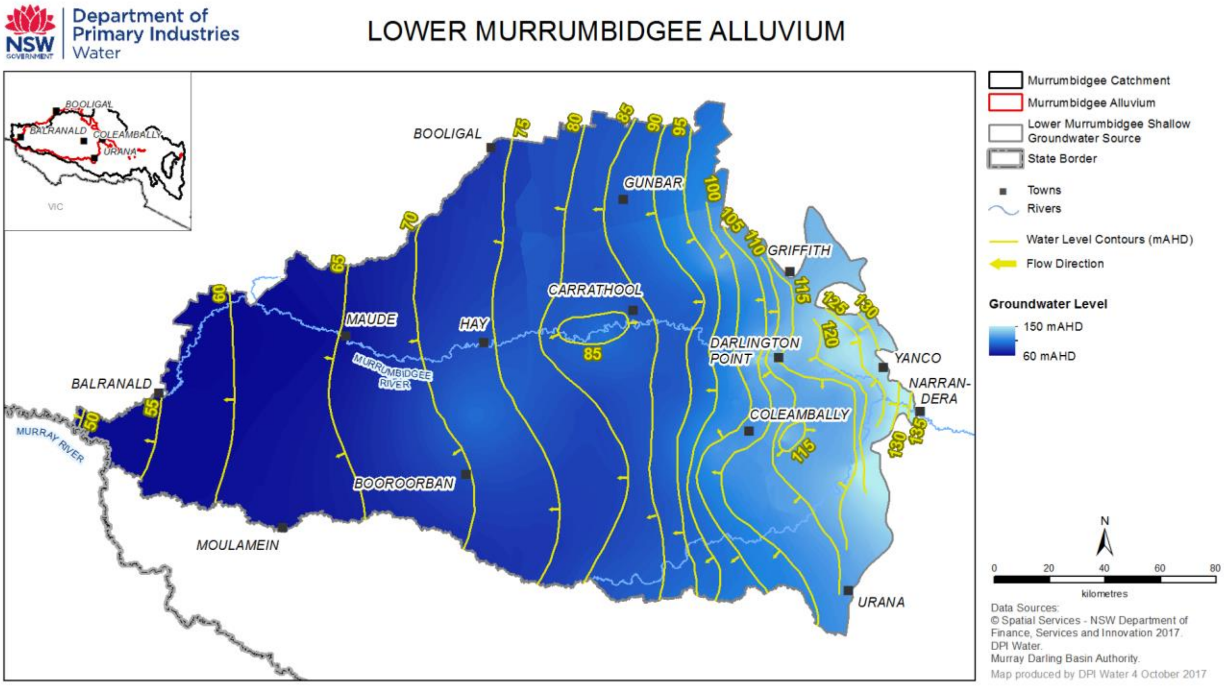


Figure 16. The Lower Murrumbidgee Alluvial Groundwater Source (shallow) and groundwater flow directions (based on 2015-16 recovered groundwater levels).

The Lower Murrumbidgee Deep Alluvium underlies the Lower Murrumbidgee Alluvium (shallow), and represents the Calivil Formation and Renmark Group. These geological formations are characterised by pale grey to white quartz sand layers, with lenses of grey to white clay, extending from the bottom of the Shepparton Formation to a maximum of approximately 400 m below ground. For management purposes it is defined as the sand and clay deposits of the Calivil Formation and Renmark Group greater than 40 m down to its base.

Bore yields vary and are reported as high as 350 L/s. Recharge to the Lower Murrumbidgee Deep Alluvium occurs primarily through downward leakage from the overlying shallow alluvium and through flow from the Mid Murrumbidgee Alluvium.

Groundwater contours and flow directions for the Lower Murrumbidgee Deep Alluvium are displayed in Figure 17.

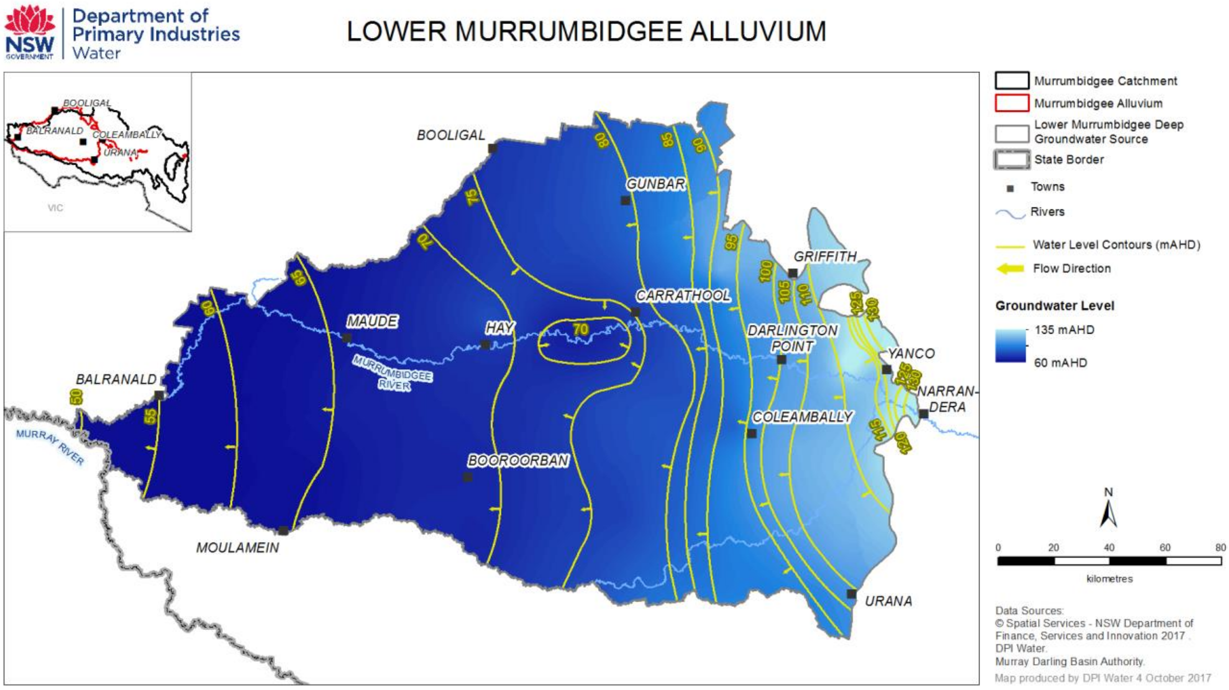


Figure 17. The Lower Murrumbidgee Alluvial Deep Alluvium and groundwater flow directions (based on 2015-16 recovered groundwater levels).

Figure 18 shows the locations of three geological cross sections that have been produced for the Lower Murrumbidgee Alluvium. Figure 19 shows an east-west long-section through the Lower Murrumbidgee that extends across the entire length of the water source, and Figures 20 and 21 show the two north-south sections - the eastern section (Figure 20) and the western section (Figure 21).

The water level height on the long section (Figure 19) shows the east to west groundwater flow direction as the water level becomes lower towards the west.

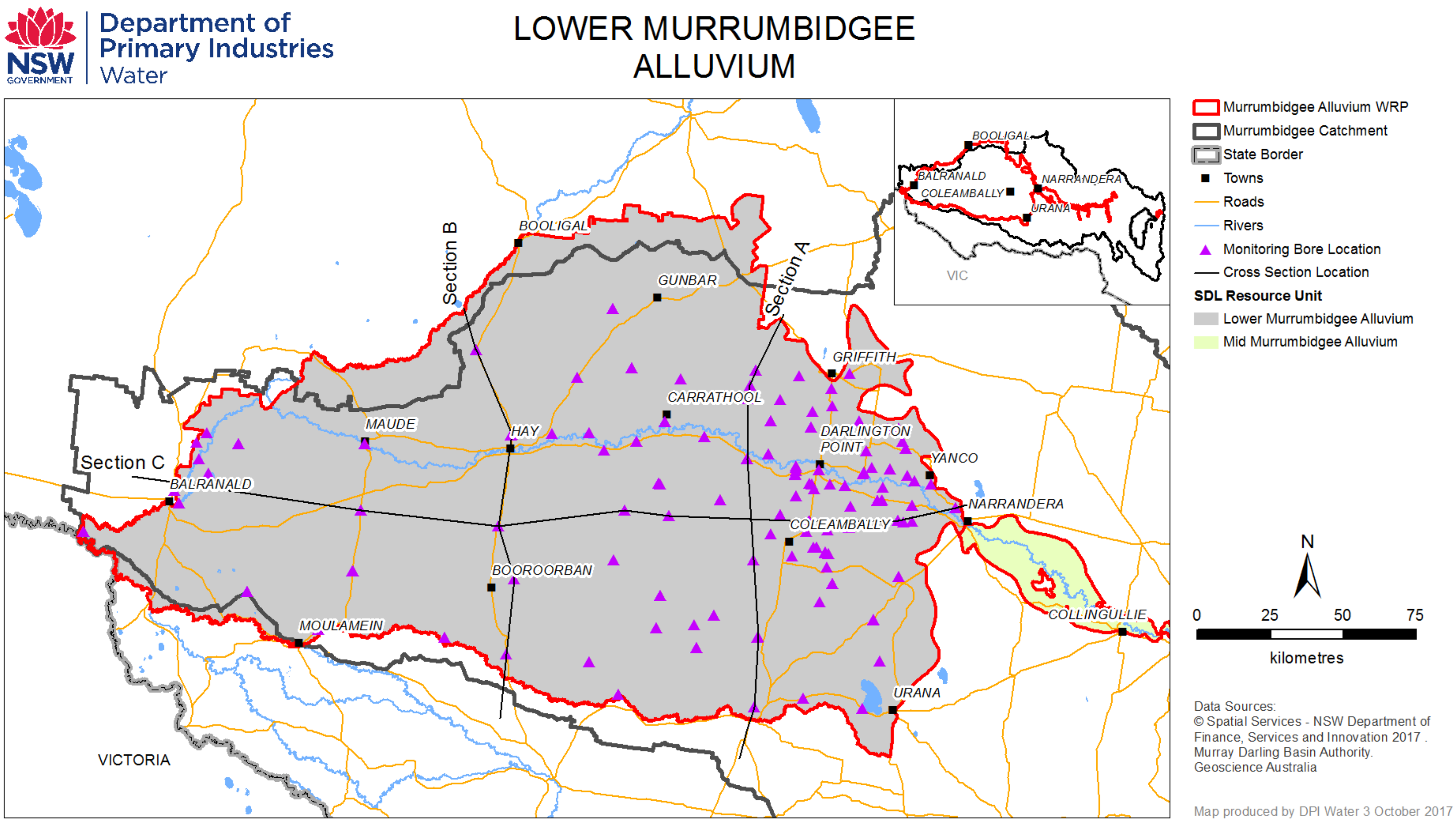
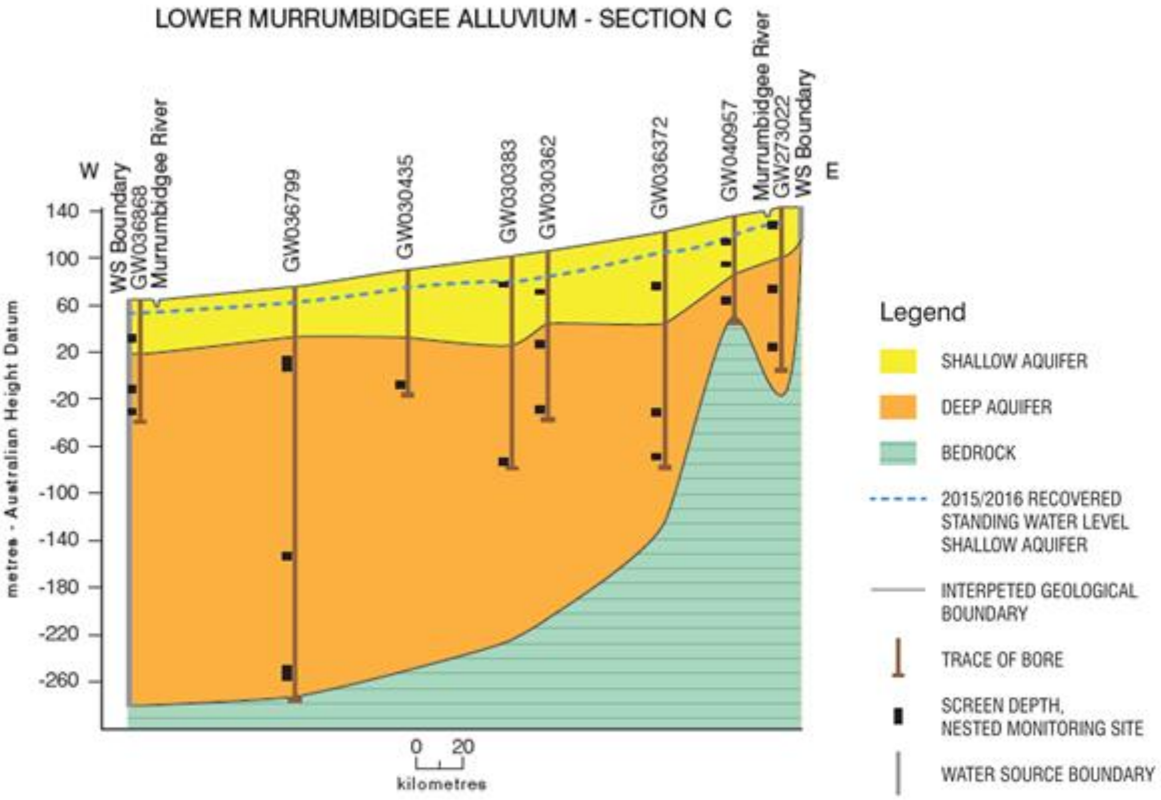
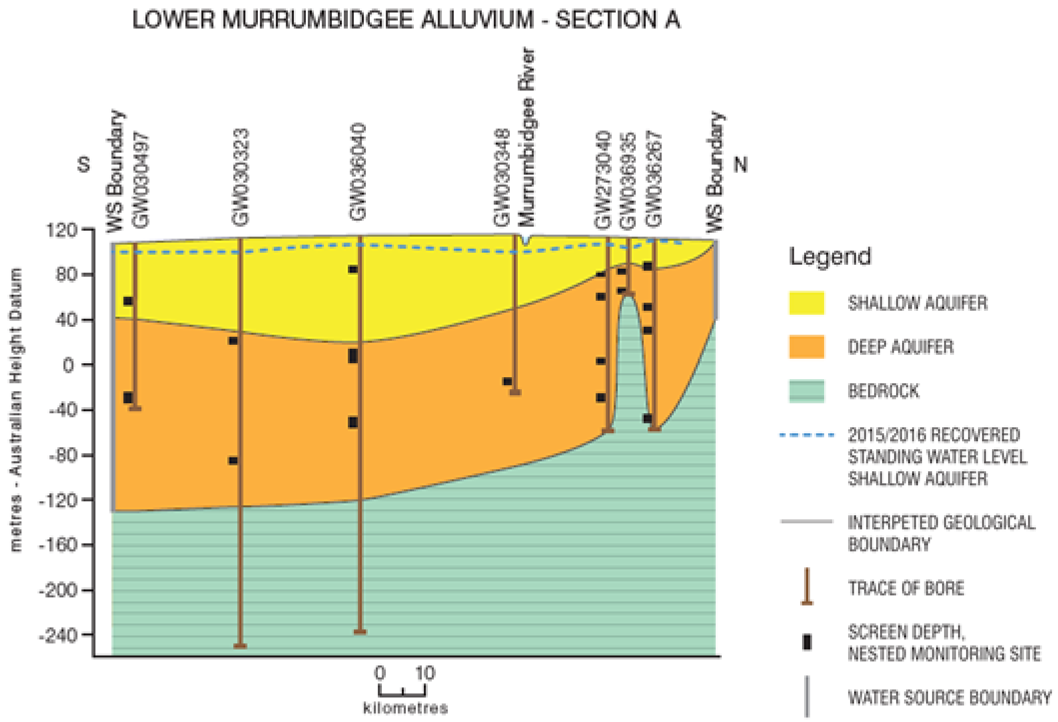


Figure 18. Cross section location map Lower Murrumbidgee Alluvium.



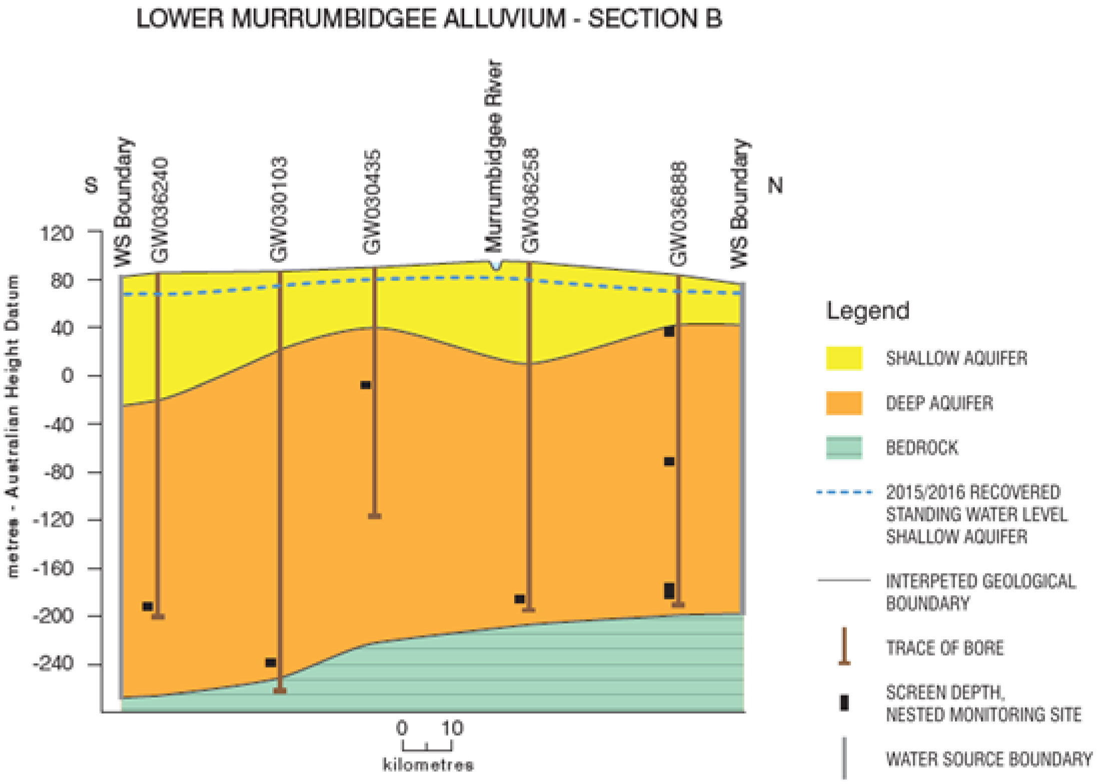
Note the boundary between the deep and shallow aquifers is interpreted based on limited information.

Figure 19. East-west long section through the Lower Murrumbidgee Alluvium (Section C).



Note the boundary between the deep and shallow aquifers is interpreted based on limited information.

Figure 20. North-south cross section through the eastern Lower Murrumbidgee Alluvium (Section A).



Note the boundary between the deep and shallow aquifers is interpreted based on limited information.

Figure 21. North-south cross section through the western Lower Murrumbidgee Alluvium (Section B).

5.5. Connection with surface water

The Mid Murrumbidgee Alluvium is considered to be in hydraulic connection with the regulated Murrumbidgee River and its tributaries.

Upstream of Tarcutta Creek junction to Jugiong it is considered to be highly connected to the regulated Murrumbidgee River. The alluvium along Tumut River downstream of Blowering Dam is also considered to be highly connected to the Tumut River. This high level of hydraulic connection is recognised in the Water Sharing Plan rules for the Gundagai Alluvial Groundwater Source.

The narrow and shallow nature of the Mid Murrumbidgee Alluvium means it is likely to experience change between losing and gaining conditions along its length depending on geology, topography, river flow and local conditions. CSIRO (2008) interpreted that the Murrumbidgee River:

- above Wagga Wagga is a gaining stream.
- at Wagga Wagga is a losing stream, and
- downstream near Narrandera is a gaining stream.

It is also interpreted that at Wagga Wagga, prior to groundwater development, the Murrumbidgee River was gaining, and that downstream of Wagga Wagga a losing reach has increased since the mid 1970’s due to extraction of groundwater (CSIRO, 2008).

In the Lower Murrumbidgee Alluvium, the Murrumbidgee River below Narrandera is losing over a substantial length. Anabranches and distributary channels such as Yanco Creek and Colombo Creek are also losing.

Figure 22 shows groundwater and surface water levels for the Borambola area of Tarcutta Creek, upstream of Wagga Wagga. Tarcutta Creek is a gaining stream in this area as groundwater levels in the shallow alluvial aquifer are mostly higher than the water level in the creek. Monitoring bore GW030385 is 900 m from the surface water gauging station 410047 and its location is shown in Figure 67.

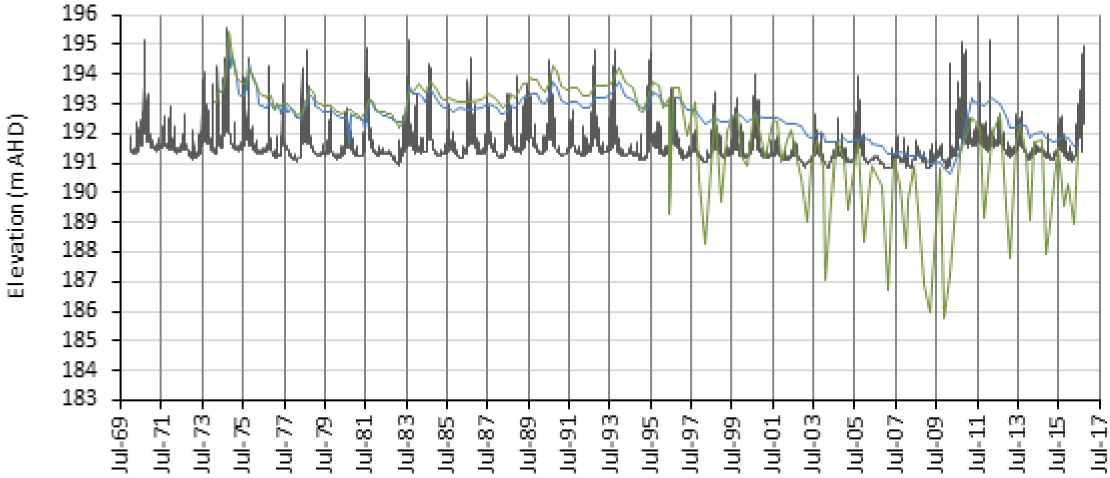


Figure 22. Surface water hydrograph (station 410047) and groundwater hydrographs for Tarcutta Creek (upstream of Wagga Wagga).

Although the Murrumbidgee Alluvium downstream of Tarcutta Creek Junction is considered to be hydraulically connected to the Murrumbidgee River, due to the depth and width of the alluvium groundwater pumping impacts at the river are subdued and / or delayed. This lag time of groundwater pumping impacts is acknowledged in setting the extraction limit of the resource and this part of the alluvium is managed independently from the river.

The Lake George Alluvium underlies the internally draining Lake George Basin. The unregulated Tullaroo and Butmaroo Creeks that drain into the basin are ephemeral and considered to be losing to shallow groundwater inside the SDL area when they are flowing. Stream flows may contribute to recharge but it is unlikely to be significant due to its ephemeral nature. Ground and surface water are not considered to be highly connected within the alluvium.

6. Groundwater Dependent Ecosystems

Groundwater dependant 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).

NSW 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 their associated ecological value (Dabovic *et al*. in prep). This process has identified a number of vegetation GDEs in the Mid and Lower parts of the Murrumbidgee catchment. The expected ecological value of vegetation GDEs within the Murrumbidgee catchment is shown in Figure 23.

From this identification process, the GDE ecological values in the Murrumbidgee alluvium are mainly classified as very high, high and medium. The very high values are due to the extent of DIWA/Ramsar wetlands in the area which support habitat for a large number of threatened species (NSW Department of Primary Industries, 2017). The method for GDE identification (Kuginis *et al*., 2016) identifies that the Murrumbidgee alluvium is dominated by the vegetation GDE communities of River Red Gum woodland wetlands, River Red Gum-Lignum wetlands, freshwater wetlands, River Red Gum-Black Box and River Red Gum-Yellow Box woodland wetlands and Cumbungi rushland. These communities are generally characterised by having a high number of threatened species, endangered ecological communities, 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 contribute to ecosystem function of instream ecosystems. Generally the GDE communities with high ecological value have large vegetation patches, are highly connected (such as along riparian corridors) and have a high number of threatened species present.

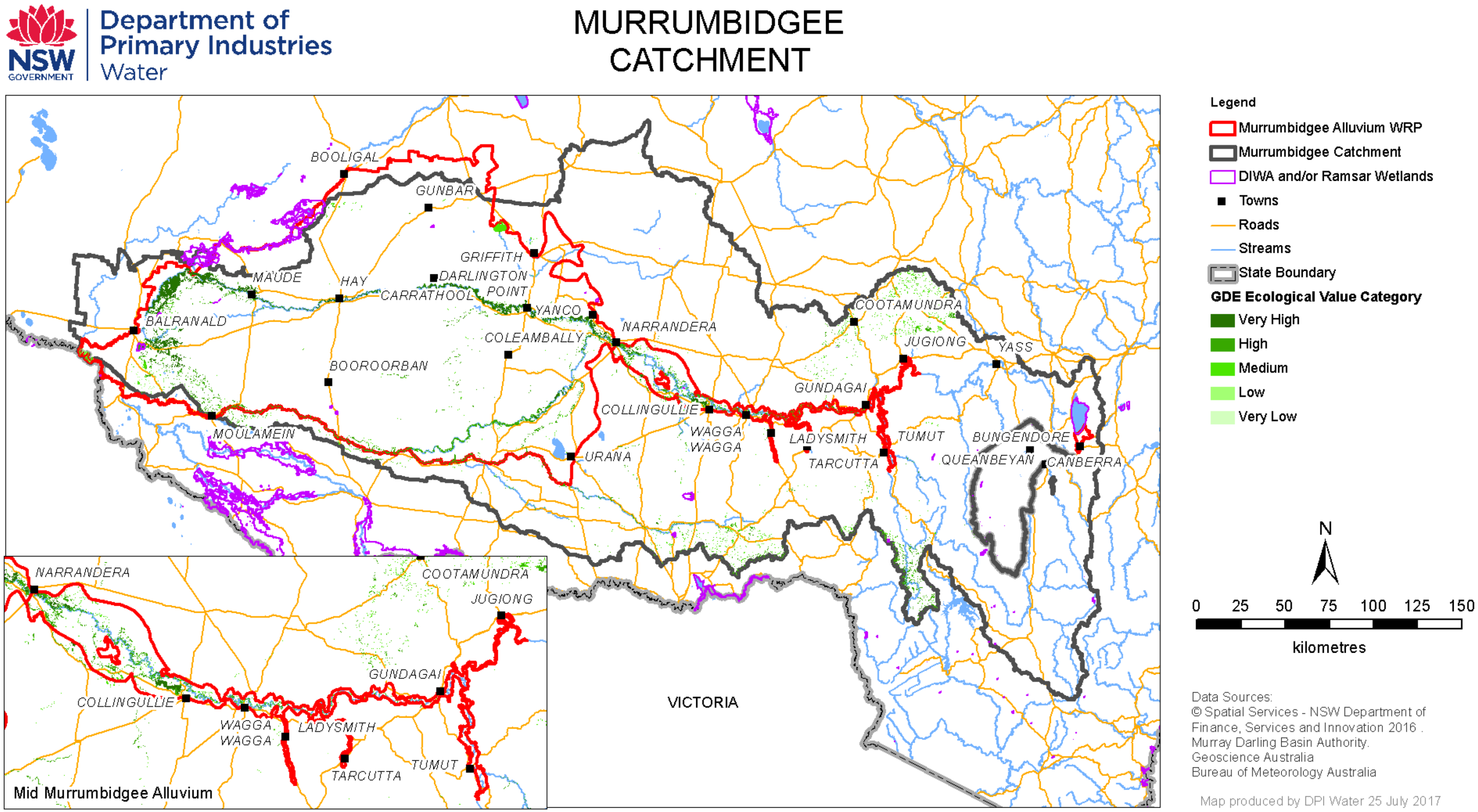


Figure 23. Ecological value for high probability groundwater dependent vegetation ecosystems.

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 i.e. 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), whereby water with an EC of 1,000 µS/cm has a salt concentration of about 640 mg/L.

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 levels 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 the land surface but it can also occur more broadly from the overlying in land use. Seasonal variations and longer-term changes in climate as well as groundwater extraction can all affect groundwater quality.

7.1. Lake George Alluvium

Groundwater quality in the Lake George Alluvium is relatively fresh. The salinity in groundwater samples from monitoring bores at the time of construction (1999) varied from 313 to 1,006 µS/cm, with most in the range of 500 to 600 µS/cm (Carter, 2000b).

7.2. Mid Murrumbidgee Alluvium

Across the Mid Murrumbidgee Alluvium, salinity in groundwater samples from groundwater monitoring bores at the time of construction ranged generally from 150 µS/cm close to the rivers to about 950 µS/cm in the deep aquifer. However, salinity readings of greater than1,500 µS/cm have been recorded in the western area towards Narrandera. The quality in the shallow aquifer is quite variable but is generally below 1,660 µS/cm and fresh adjacent to the Murrumbidgee River. Overall, those values remain those of fresh water (in most places) to slightly brackish water.

7.3. Lower Murrumbidgee Alluvium

Groundwater quality sampling has been undertaken in the Lower Murrumbidgee Alluvium since initial monitoring bores were installed in the 1970's, and includes repeat sampling of a range of bores during the period 2009-2011 (Parsons Brinkerhoff, 2011).

The Lower Murrumbidgee Alluvium displays significant differences in groundwater quality both vertically and laterally. The Lower Murrumbidgee Shallow Alluvium has salinity ranging from fresh (585 µS/cm) to saline (32,800 µS/cm), with a mean of 8,314 µS/cm. In contrast, the Lower Murrumbidgee Deep Alluvium has lower salinity, ranging from 364 to 8,930 µS/cm (brackish) with a mean of about 1,300 µS/cm, and less variability. Laterally, groundwater in the deep alluvium is freshest in the eastern part of the region close to the Murrumbidgee River.

Based on salinity levels, groundwater in the deep alluvium east of Hay is suitable for drinking water, but may require treatment for manganese, and for irrigation. West of Hay, groundwater in the Lower Murrumbidgee Deep Alluvium is generally unsuitable for irrigation.

Recent sampling (Parsons Brinkerhoff, 2011) identified a long term increasing salinity trend in three deep aquifer monitoring bores within the irrigation areas east of Hay. This is attributed to leakage from overlying formations. No significant long-term trends in salinity were identified in bores in shallow alluvium

8. Groundwater management

Whilst the Murrumbidgee Alluvium (excluding Lake George Alluvium) forms a large laterally continuous and hydraulically connected system, for management purposes it has been subdivided into seven separate management units.

Groundwater in the Lake George Alluvium (Bungendore Alluvial Groundwater Source) and Mid-Murrumbidgee Alluvium is managed under the *Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012*, which commenced in 2012. Groundwater in the Lower Murrumbidgee Alluvium is managed under the *Water Sharing Plan for the Lower Murrumbidgee Groundwater Sources 2003*, which commenced in 2006. The groundwater sources in water sharing plans above correlate directly to the four SDL resource units in the Murrumbidgee WRP.

The fractured and porous rocks that underlie the Murrumbidgee Alluvium have very different hydrogeological characteristics and are not considered to be hydraulically connected in a resource management sense to the groundwater resources in the alluvium. Groundwater in these management units are managed under the Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011.

8.1. Access rights

Groundwater access licenses for the Lake George Alluvium, Mid Murrumbidgee Alluvium and the Lower Murrumbidgee Alluvium are shown in Table 1.

Supplementary water access licences were issued to some licence holders in the Lower Murrumbidgee Alluvium at the commencement of the water sharing plan. These licences provided temporary access to water to adjust to the reduction in entitlements at the commencement of the water sharing plan. The volume of water available under the supplementary water access licences gradually decreased each year and these licences were cancelled at the end of the 2014/2015 water year.

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 and aquifer access licence (high security) are issued for a specified number of unit shares (Table 1).

Table 1. Access licences in the Murrumbidgee Water Resource Plan Area (at May 2017).

SDL Resource Unit	Alluvial Groundwater Source	Local Water Utility (ML/year)	Aquifer (unit shares)	Aquifer (High Security) (unit shares)	Domestic and Stock (ML/year)
Lake George Alluvium (GS21)	Bungendore	472	766	0	0
Mid-Murrumbidgee Alluvium (GS31)	Gundagai	100	2,033	1,913	0
	Kyeamba	0	2,070	0	0
	Wagga Wagga	20,200	7,939	0	22
	Mid Murrumbidgee Zone 3	4,912	42,868	0	189
	Total	25,212	54,910	1,913	211
Lower Murrumbidgee Alluvium (shallow) (GS28)	Lower Murrumbidgee Shallow	0	5,201	0	0
Lower Murrumbidgee Alluvium and (deep) (GS28)	Lower Murrumbidgee Deep	2,210	272,868	0	324
	Total	2,210	278,069	0	324

Owing to the high level of connection of the alluvium with the regulated Tumut River, a tributary of the Murrumbidgee River, groundwater available under aquifer (high security) licences in the Gundagai Alluvial Groundwater Source of the Mid Murrumbidgee Alluvium is linked to the availability of high security allocations in the Murrumbidgee Regulated River water source.

8.2. Extraction limits

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 extractions to ensure compliance with the SDLs.

Table 2 lists the LTAAEL for the Lake George Alluvium, Mid-Murrumbidgee Alluvium and the Lower Murrumbidgee Alluvium as well as the SDL for each area. The SDL includes the estimated requirements for basic landholder rights.

If the 3 year average of extraction in the Lake George Alluvium exceeds the LTAAEL by 5% or greater, then the available water determination made for aquifer access licences for the following water year should be reduced by an amount that is assessed necessary by the Minister to return subsequent total water extraction to the extraction limit.

If the 5 year average of extraction in the Mid Murrumbidgee Alluvium exceeds the LTAAEL by 10% or greater, then the available water determination made for aquifer access licences for the following water year should be reduced by an amount that is assessed necessary by the Minister to return subsequent total water extraction to the extraction limit.

If the 3 year average of extraction in the Lower Murrumbidgee Shallow Alluvium or Lower Murrumbidgee Deep Alluvium exceeds the LTAAEL by 5% or greater, then the available water determination made for aquifer access licences for the following water year should be reduced by an amount that is assessed necessary by the Minister to return subsequent total water extraction to the extraction limit.

Table 2. LTAAEL for the Lake George Alluvium, Mid Murrumbidgee Alluvium and Lower Murrumbidgee Alluvium compared to the SDL (at May 2017).

SDL Resource Unit	Alluvial Groundwater Source	LTAAEL ML/yr	SDL ML/yr	BLR (ML/yr)
Lake George Alluvium (GS21)	Bungendore	1,268	1,270	25
Mid-Murrumbidgee Alluvium (GS31)	Gundagai	1,926	n/a	156
	Kyeamba	723	n/a	12
	Wagga Wagga	20,648	n/a	135
	Mid Murrumbidgee Zone 3	30,176	n/a	496
	Total	53,473	53,500	799
Lower Murrumbidgee Alluvium (shallow) (GS28)	Lower Murrumbidgee Shallow	13,000	26,900*	3,000
Lower Murrumbidgee Alluvium (deep) (GS28)	Lower Murrumbidgee Deep	271,000	273,600*	1,000
	Total	284,000	300,500	4,000

* Note:

- The SDL for the Lower Murrumbidgee Shallow Alluvium is higher than the LTAAEL to account for revised basic landholder rights estimates and provisions for issuing of salinity and water table management access licences.
- The SDL for the Lower Murrumbidgee Deep Alluvium is higher than the LTAAEL to account for the revised basic landholder rights estimates.

To manage any growth in extraction in excess of the LTAAEL, water sharing plans set a trigger for complying with the extraction limit. Figures 24 to 30 compare recent annual extraction and LTAAEL's for each groundwater source. They also show the LTAAEL's and the triggers set by each water sharing plan to initiate a management response to ensure there is no growth in extraction above the LTAAEL in the long term.

The risk of extraction in the Lake George Alluvium (Figure 24) exceeding the LTAAEL is low due to the low level of development to date. Assessment of extraction against the LTAAEL commenced in 2015-16 using extraction records commencing in 2012-13.

Extraction in the Mid-Murrumbidgee Alluvium (Figures 25 to 28) has been mostly below the LTAAEL, with the exception being in the Wagga Wagga Alluvial Groundwater Source (Figure 27) where extraction exceeded the LTAAEL for three consecutive years from 2012-13 to 2014-15, but the 5 year average annual extraction has not exceeded the trigger level of LTAAEL plus 10%.

Demand for water in the Lower Murrumbidgee Shallow Alluvium is low, given its quality and yield constraints, and annual, extraction has been well below the LTAAEL. Extraction in the Lower Murrumbidgee Deep Alluvium has responded to varying demand associated with drought and flood conditions, and to the declining access available under the Water Sharing Plan for that area.

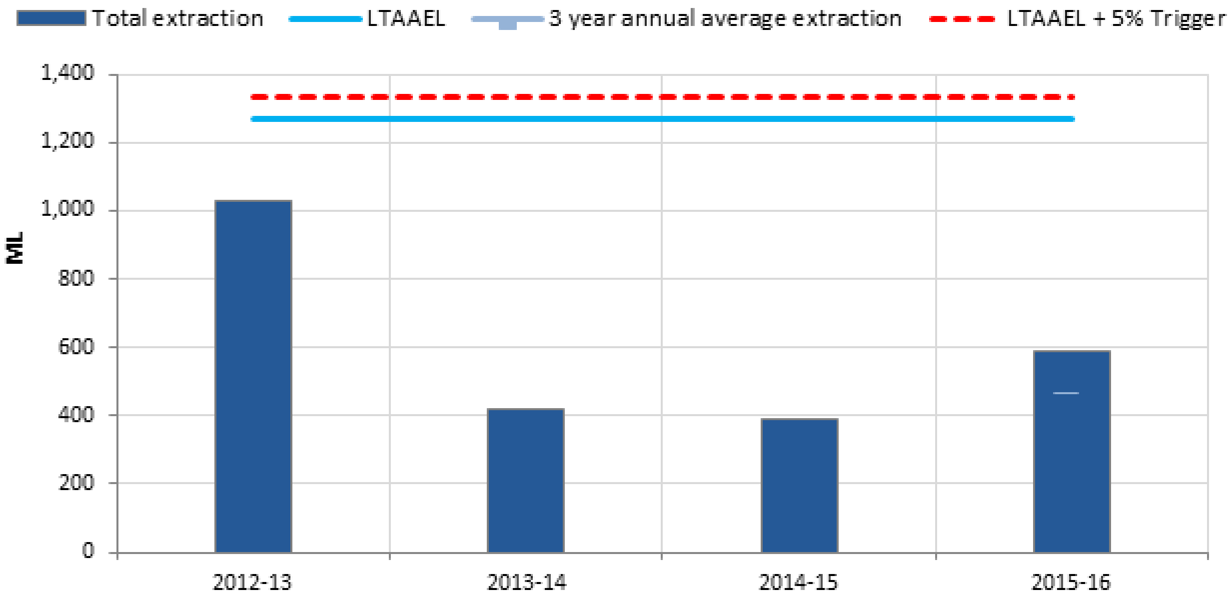


Figure 24. Lake George Alluvium annual extraction compared to the LTAAEL.

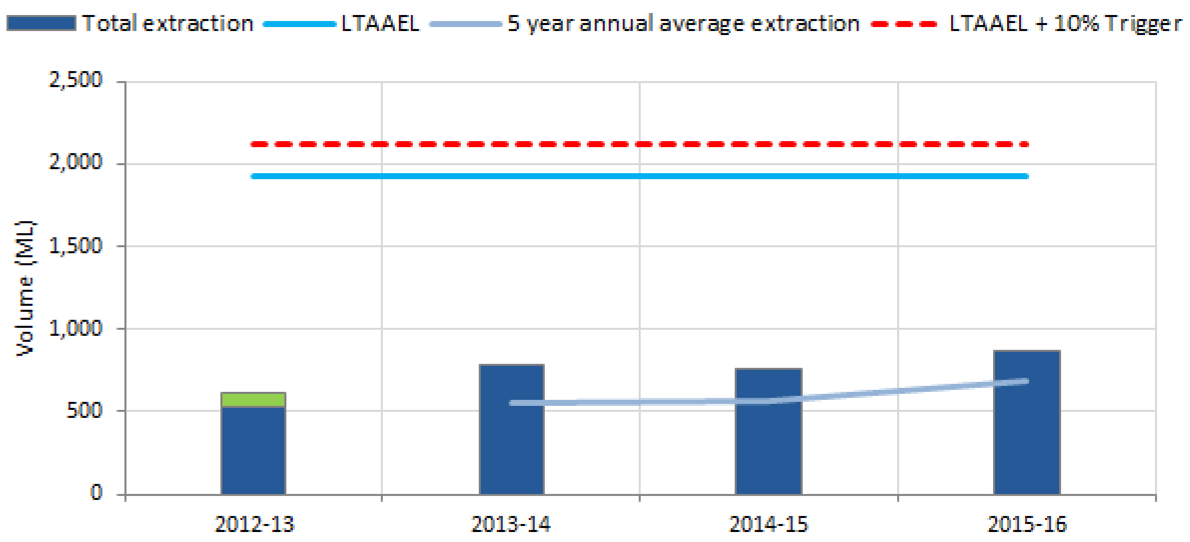


Figure 25. Mid-Murrumbidgee Alluvium - Gundagai Alluvial Groundwater Source annual extraction compared to the LTAAEL.

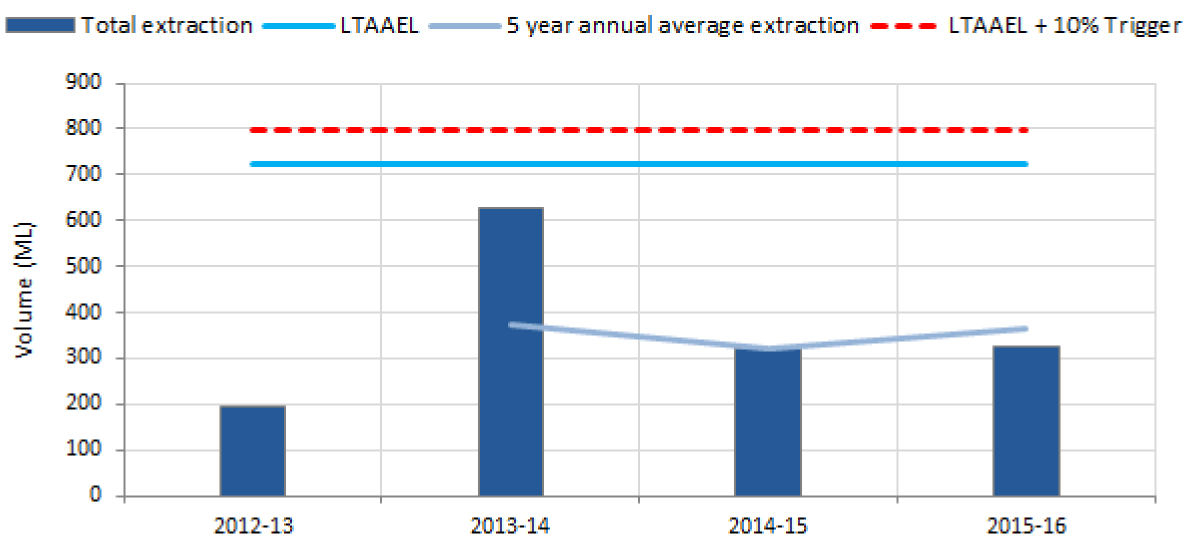


Figure 26. Mid-Murrumbidgee Alluvium - Kyeamba Alluvial Groundwater Source annual extraction compared to the LTAAEL.

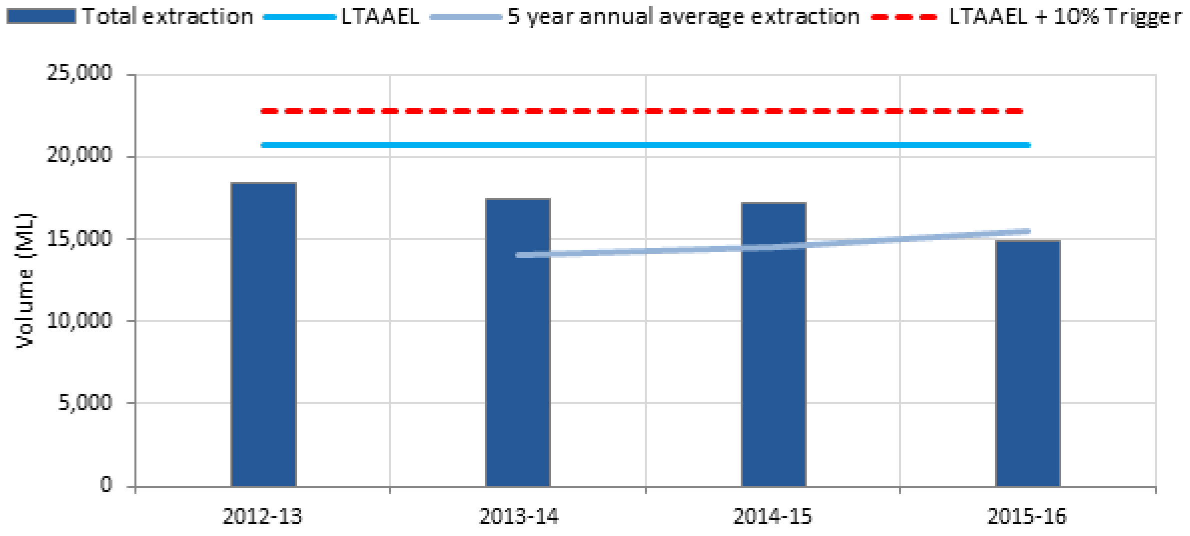


Figure 27. Mid-Murrumbidgee Alluvium - Wagga Wagga Alluvial Groundwater Source annual extraction compared to the LTAAEL.

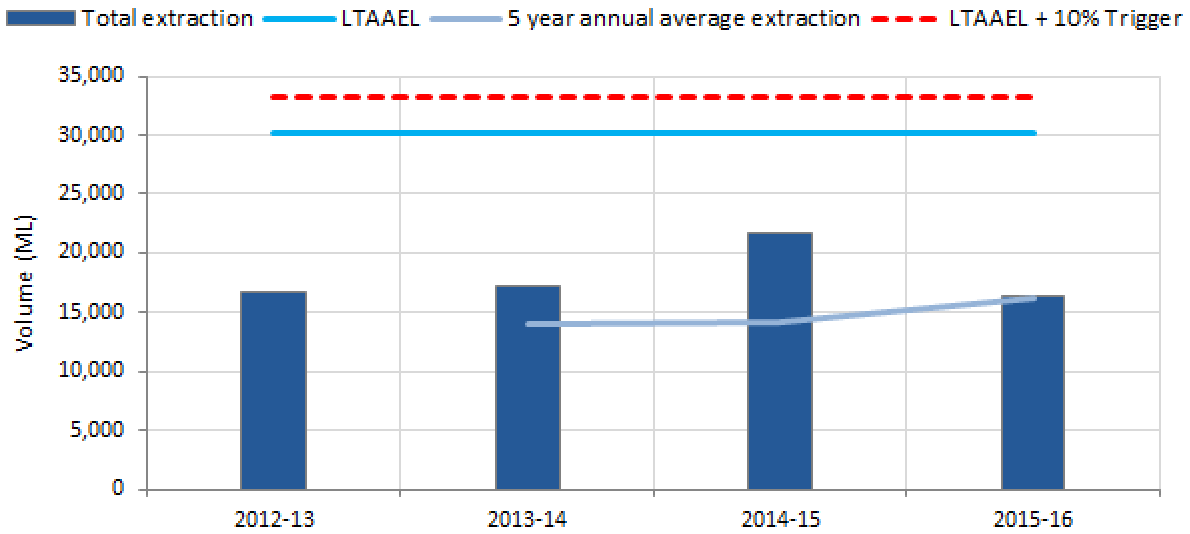


Figure 28. Mid-Murrumbidgee Alluvium – Mid Murrumbidgee Zone 3 Groundwater Source annual extraction compared to the LTAAEL.

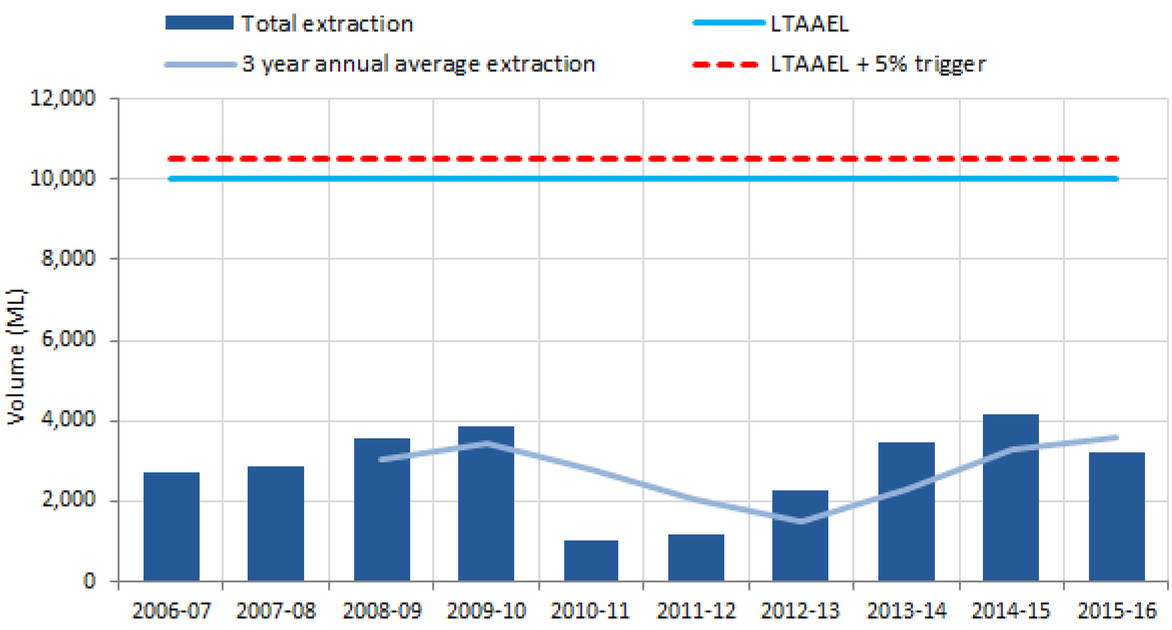


Figure 29. Lower Murrumbidgee Shallow Alluvium annual extraction compared to the LTAAEL.

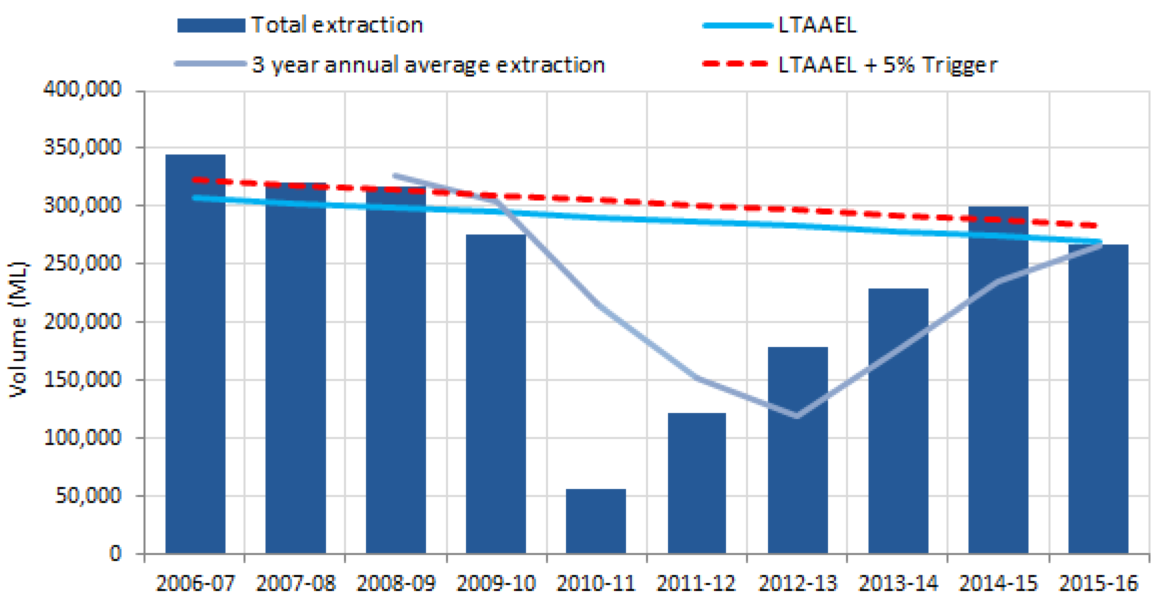


Figure 30. Lower Murrumbidgee Deep Alluvium annual extraction compared to the LTAAEL.

8.3. Available water determinations

The available water determination for aquifer access licences in the Lake George Alluvium has been set at 1 ML per share (i.e. 100% access) every year since the commencement of the water sharing plan. The local water utility access licences have been set at 100% every year for the same period.

The AWD's for aquifer access licences in all sections of the Mid Murrumbidgee Alluvium have been set at 1 ML per share (i.e. 100% access) every year since the commencement of the water sharing plan. Aquifer (high security) access licences exist only in the Gundagai Alluvial Groundwater Source, and their AWD is linked to the available water determination for the high security regulated river licences. Since the commencement of the water sharing plan this has been 98.4% access in all years except for 2013/14, when it was 100%. Therefore the available water determination for aquifer access (high security) licences in the Mid Murrumbidgee Alluvium has remained at 0.984 ML per share, except in 2013/14.

The AWD for aquifer access licences in the Lower Murrumbidgee Shallow Alluvium has been set at 1 ML per share (i.e. 100% access) every year since the commencement of the water sharing plan.

The AWD for aquifer access licences in the Lower Murrumbidgee Deep Alluvium (Figure 31) has been set at 1 ML per share (i.e. 100% access) every year since the commencement of the water sharing plan. A determination of 0.95 ML per share was made for 2009/10 water year based on projected use but was later increased to 1 ML per share due the final usage not breaching the plan compliance trigger. The local water utility access licences have been set at 100% every year for the same period. The AWD for supplementary water access licences in the Lower Murrumbidgee Deep Alluvium was set by the water sharing plan in 2006 for each year of the plan until 2015/2016. Supplementary water access licence allocations decreased each year from 2006/2007 to 2015/2016.

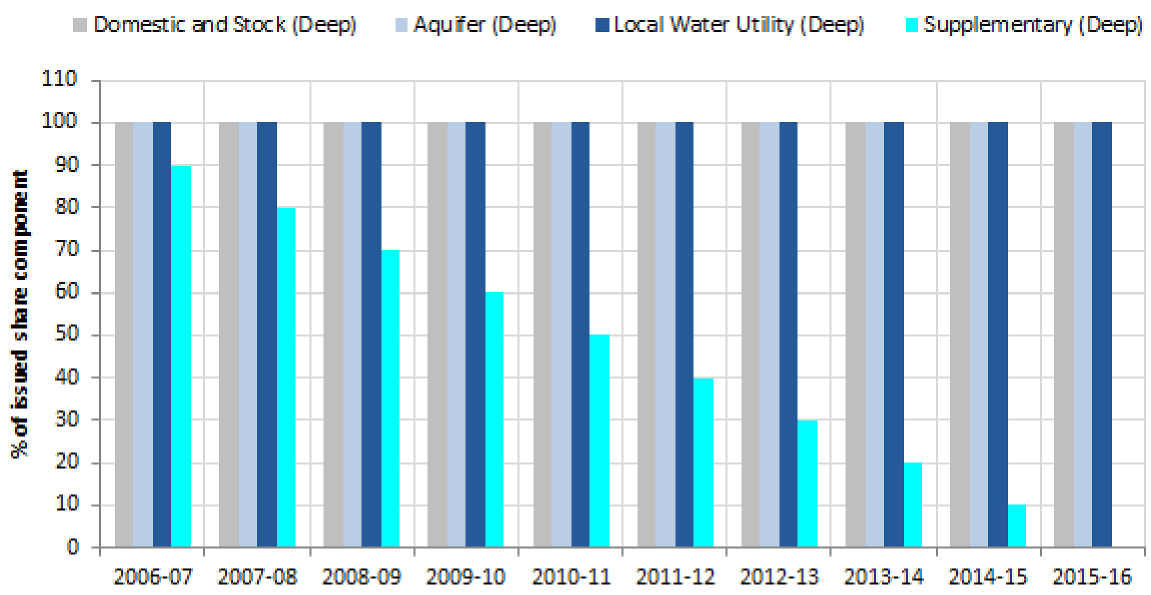


Figure 31. Annual allocations for the Lower Murrumbidgee Deep Alluvium.

8.4. Groundwater accounts

Under the water sharing plans 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 plans allow 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:

- 0.3 ML per unit share of access licence share component for the Gundagai and Mid Murrumbidgee Zone 3 Alluvial Groundwater Sources in the Mid Murrumbidgee Alluvium
- 0.4 ML per unit share of access licence share component for the Kyeamba and Wagga Wagga Water Alluvial Groundwater Sources in the Mid Murrumbidgee Alluvium
- 2 ML per unit share of the aquifer access licence share component in Lower Murrumbidgee Alluvium.

Carryover of unused allocation is not permitted in the Lake George Alluvium.

Figures 33 to 35 show the volumes held in water accounts for the Murrumbidgee Alluvium Groundwater SDL resource units since water sharing plan commencement.

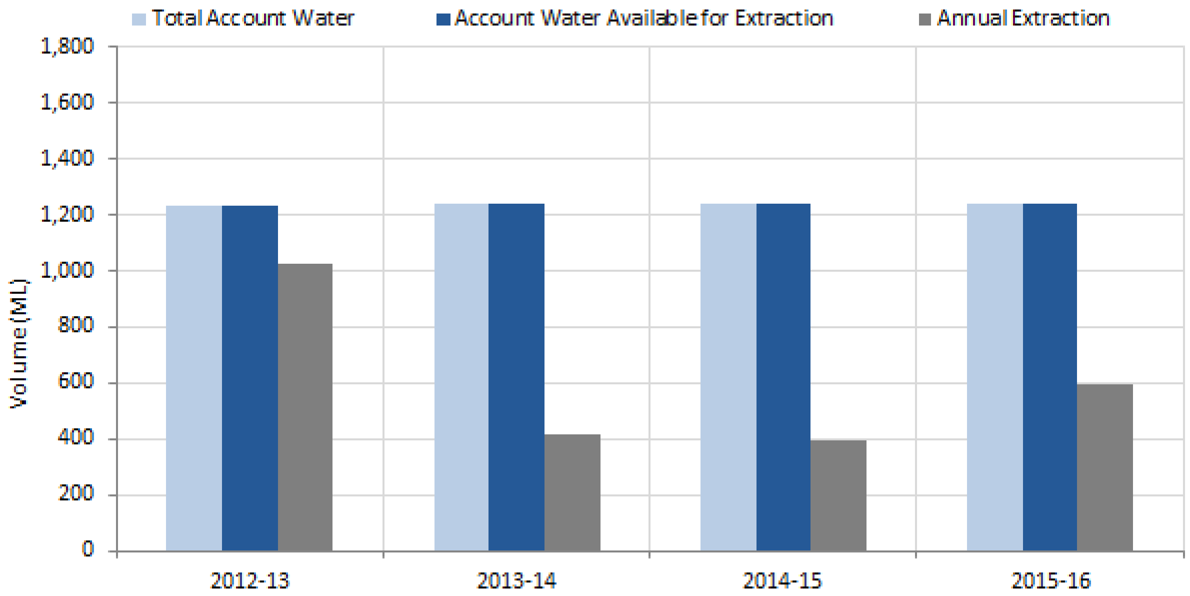


Figure 32. Water accounts since the commencement of the water sharing plan for the Lake George Alluvium.

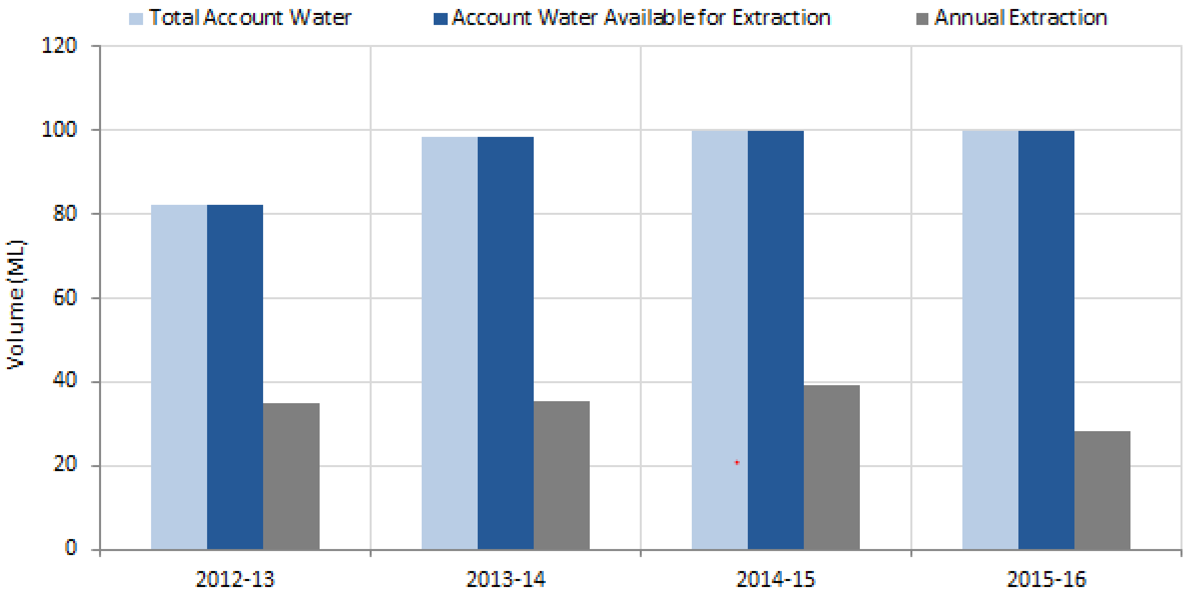


Figure 33. Water accounts since the commencement of the water sharing plan for the Mid-Murrumbidgee Alluvium.

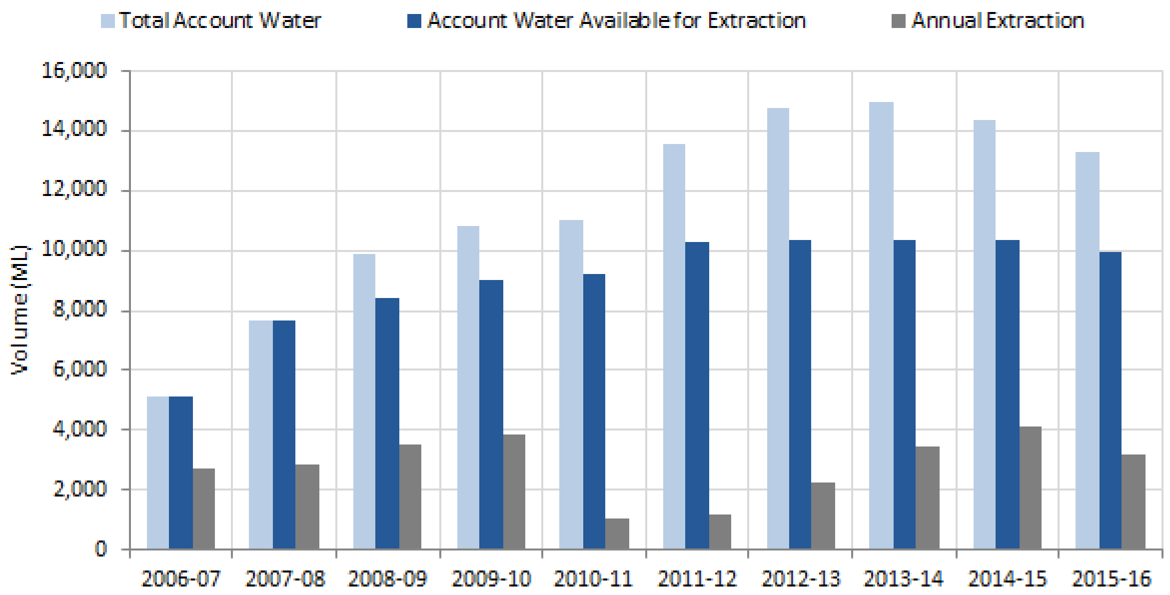


Figure 34. Water accounts since the commencement of the water sharing plan for the Lower Murrumbidgee Shallow Alluvium.

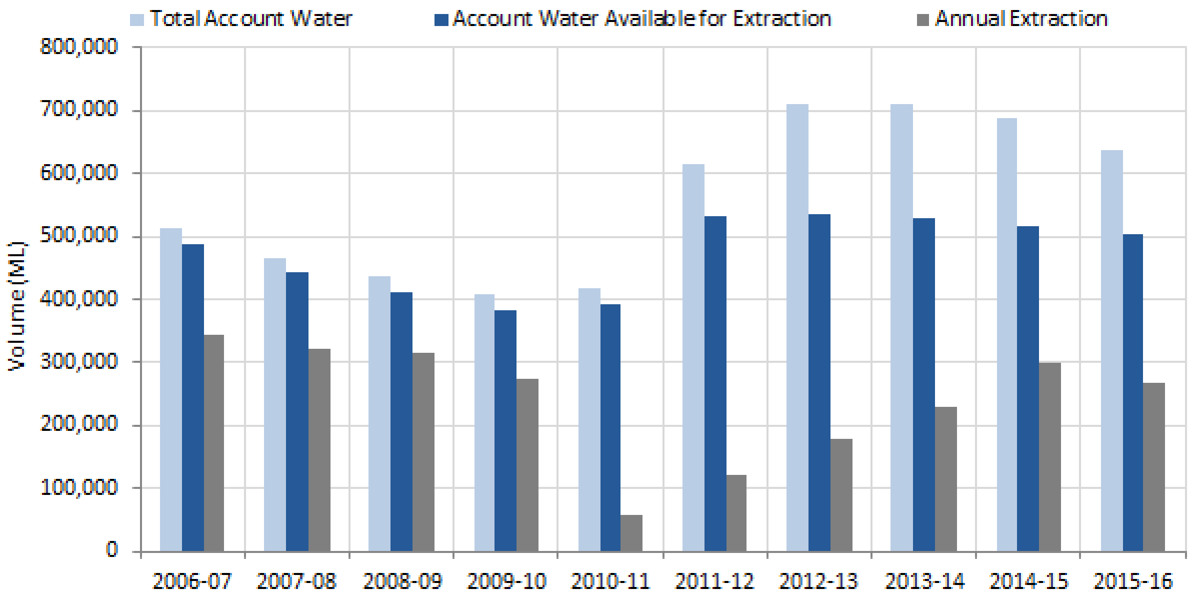


Figure 35. Water accounts since the commencement of the water sharing plan for the Lower Murrumbidgee Deep Alluvium.

8.5. Groundwater take

Groundwater is taken and used in the Murrumbidgee valley for productive purposes such as irrigation and industry as well as for water supply for local water utilities and stock and domestic use. Figures 36 to 38 show the distribution of water supply bores accessing the Murrumbidgee alluvial groundwater resources.

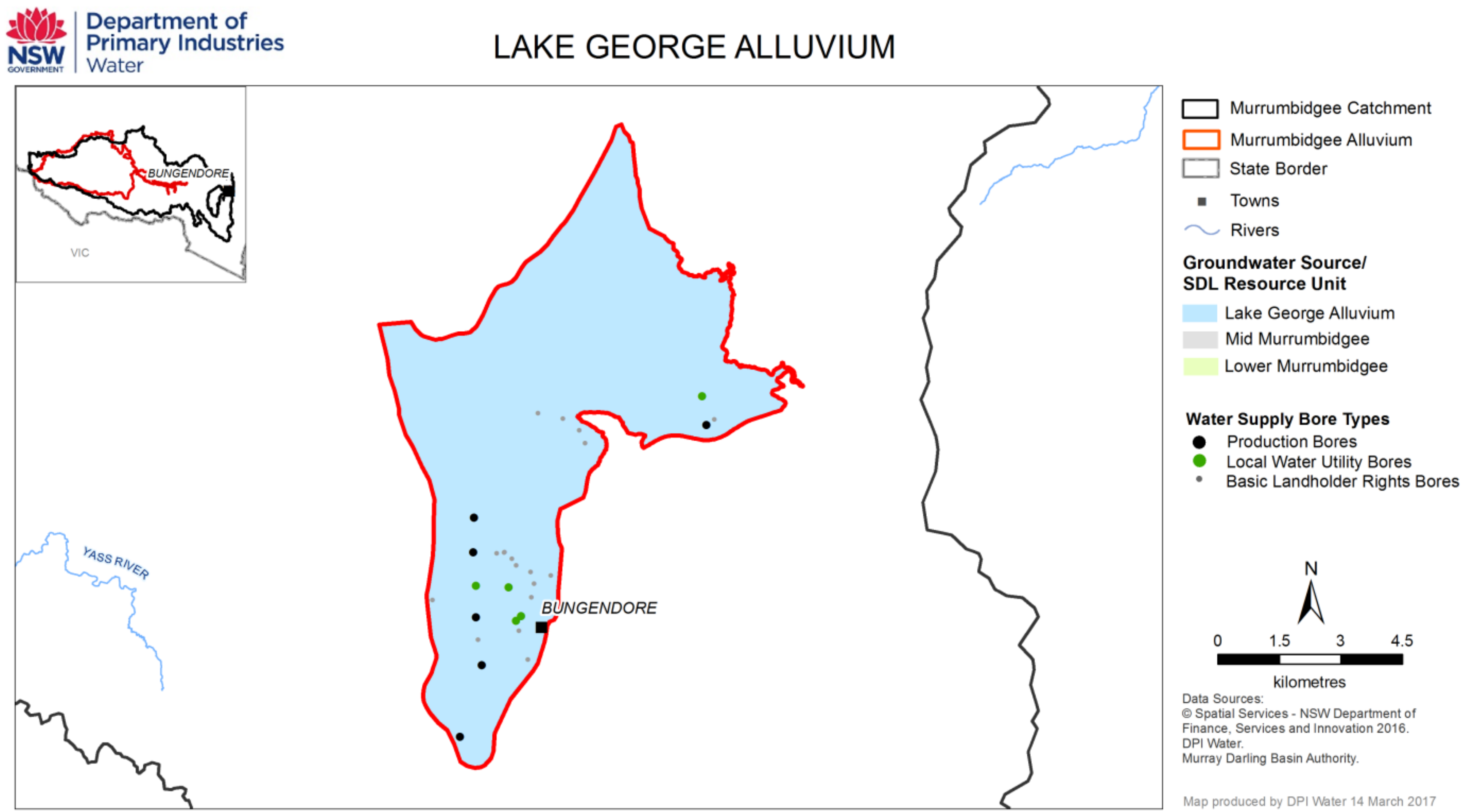


Figure 36. Registered bores in the Lake George Alluvium SDL Resource Unit.

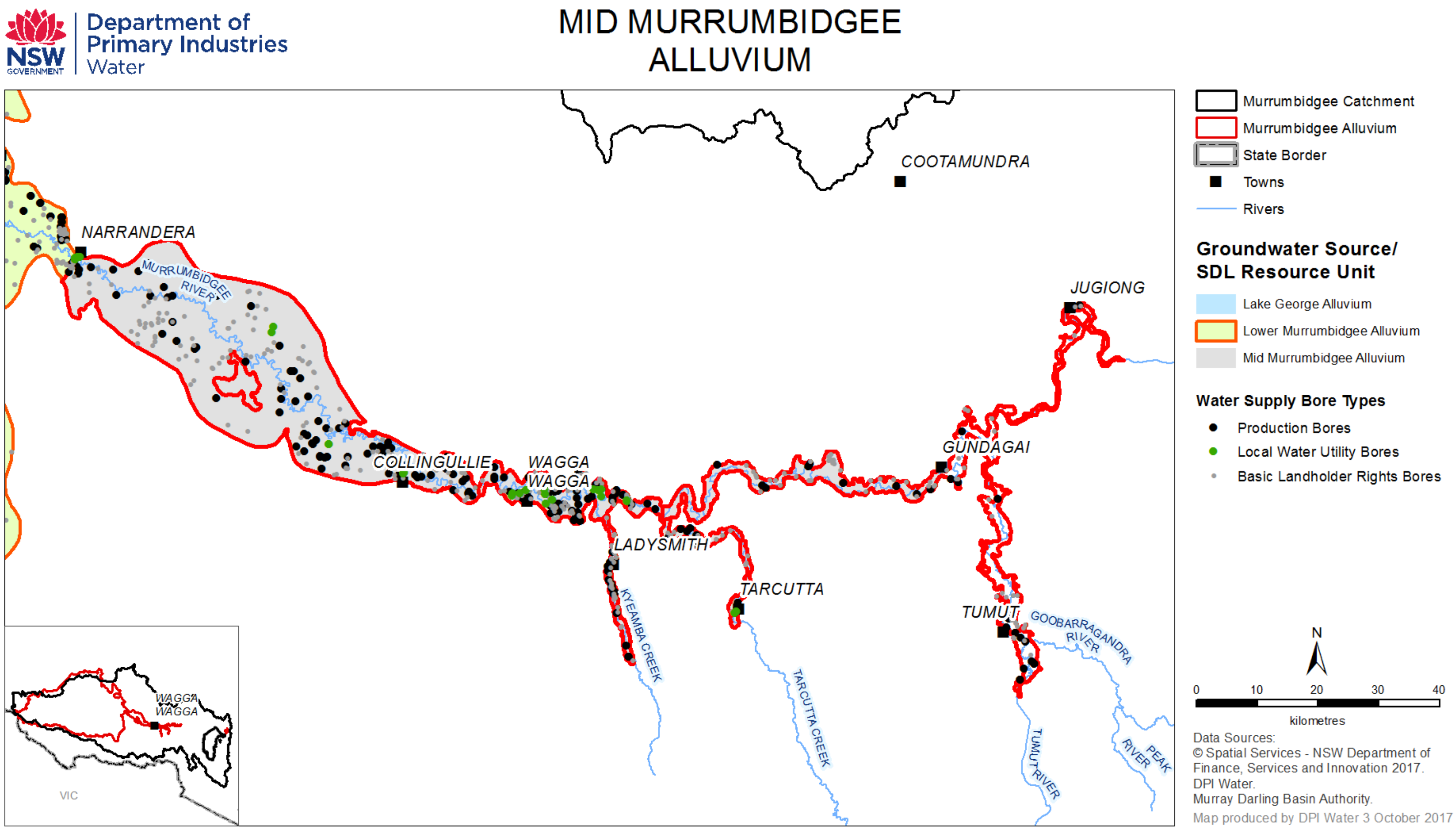


Figure 37. Registered bores in the Mid-Murrumbidgee Alluvium.

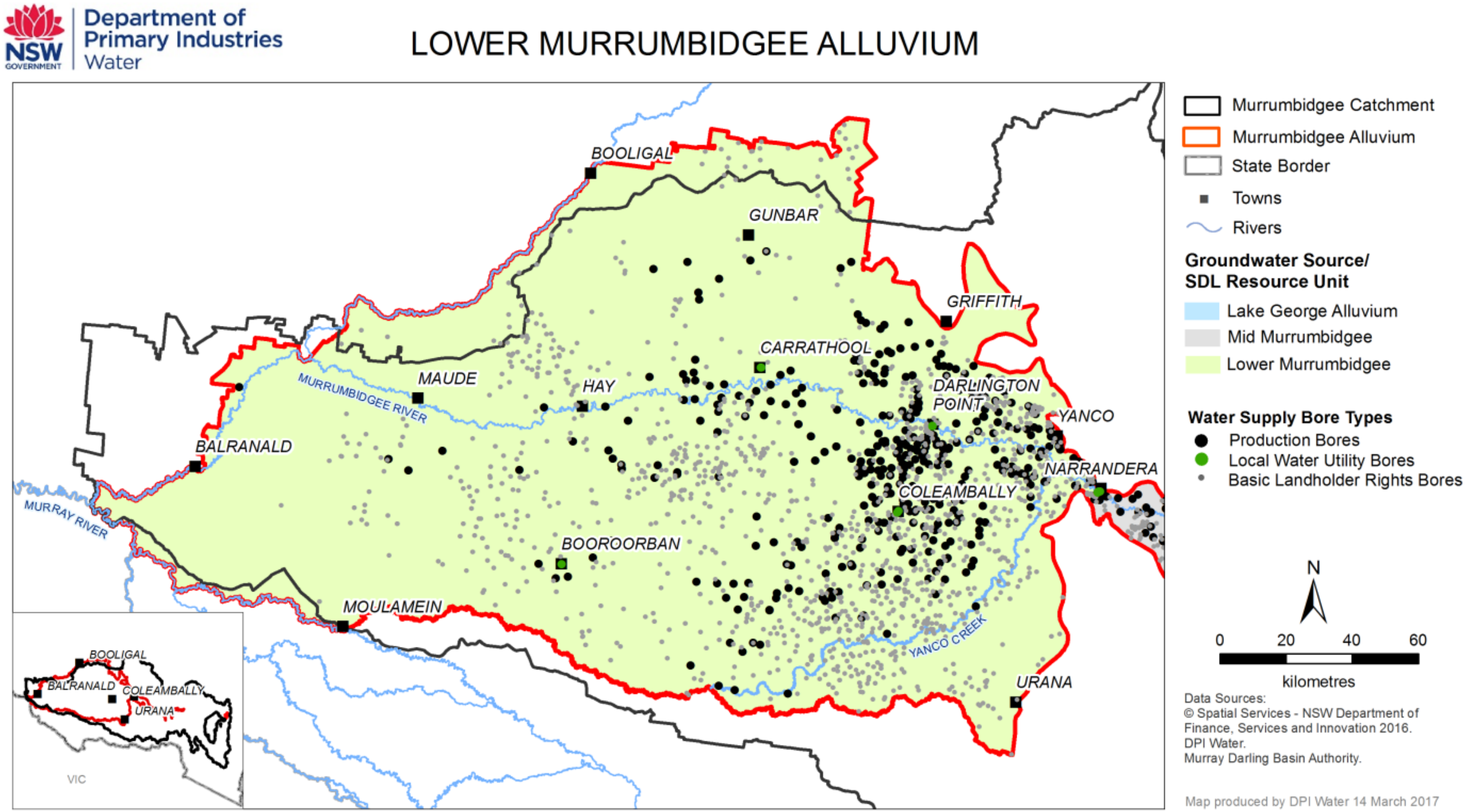


Figure 38. Registered bores in the Lower Murrumbidgee Alluvium.

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. The numbers of registered bores in the various Murrumbidgee Alluvium SDL resource units are provided in Table 3.

Table 3. Numbers of registered bores in the Murrumbidgee Alluvium SDL resource units.

Water Source	Basic Rights	Water Supply Works and Use	Total
Lake George Alluvium	18	11	29
Mid-Murrumbidgee Alluvium	345	260	605
Lower Murrumbidgee Shallow Alluvium	715	52	767
Lower Murrumbidgee Deep Alluvium	777	488	1,265
Total	1,855	811	2,666

The Lake George Alluvium has about 29 registered bores, with most being for stock and domestic supply. However, most groundwater extraction is for irrigation and town supply.

There are over 600 registered bores in the Mid Murrumbidgee. Whilst the majority of bores are used for stock and domestic purposes, most groundwater extraction is for irrigation and town supply.

In the Lower Murrumbidgee there is a large reliance on groundwater for irrigation with almost 500 production bores - the majority drawing from the deep aquifers and concentrated between Narrandera, Coleambally, Hay and Griffith. The townships of Coleambally and Darlington Point use groundwater as their main water supply for local water utility. Bores constructed in the deeper aquifers can yield up to 350 L/sec, and extract over 1,000 ML per year.

Licensed groundwater take in the Lake George, Mid-Murrumbidgee and Lower Murrumbidgee Alluvium is metered. The distribution of groundwater extraction within the Lake George, Mid Murrumbdigee and Lower Murrumbidgee Alluvium is shown in Figures 39 to 41.

Figure 39. Lake George Alluvium - distribution of groundwater extraction.

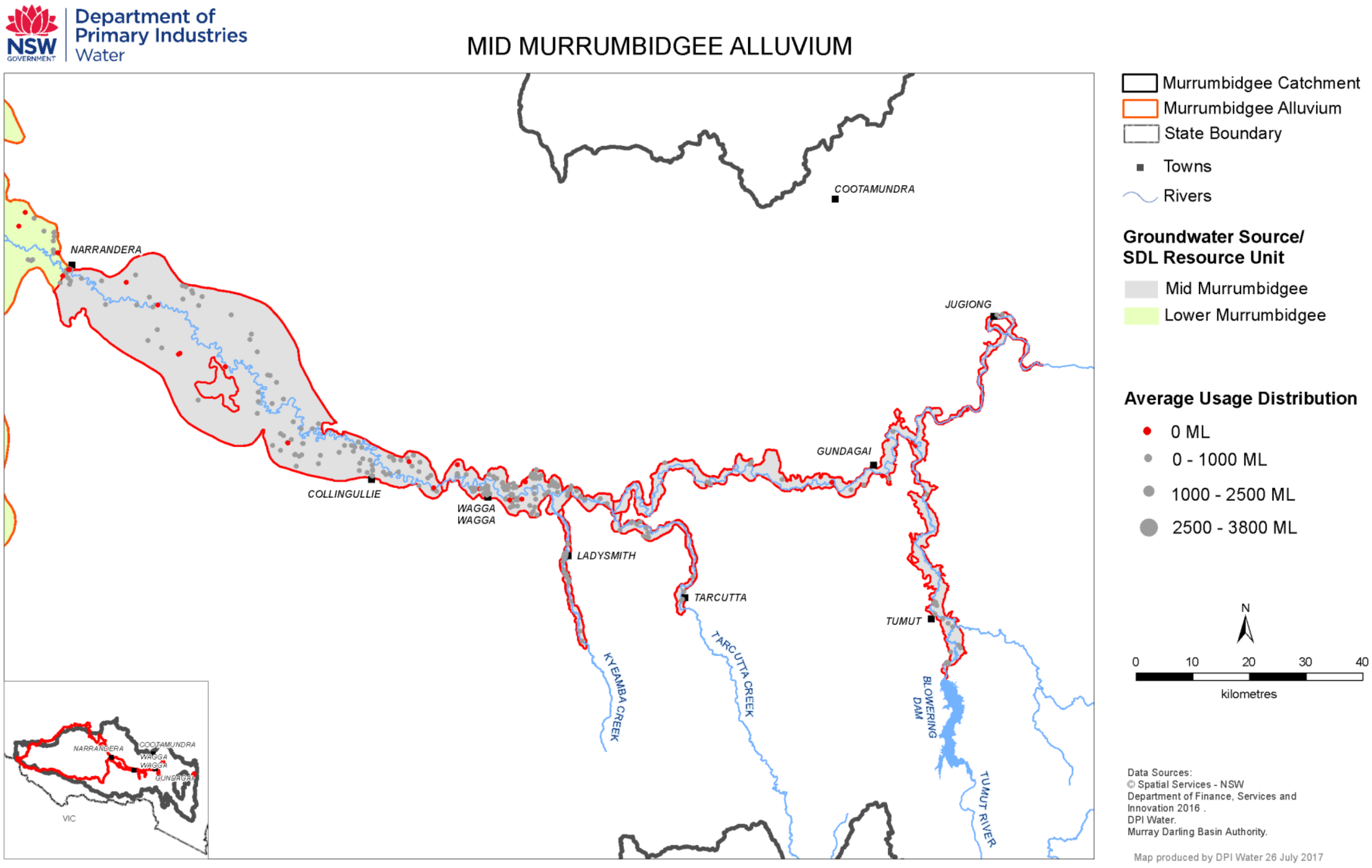


Figure 40. Mid-Murrumbidgee Alluvium - distribution of groundwater extraction.

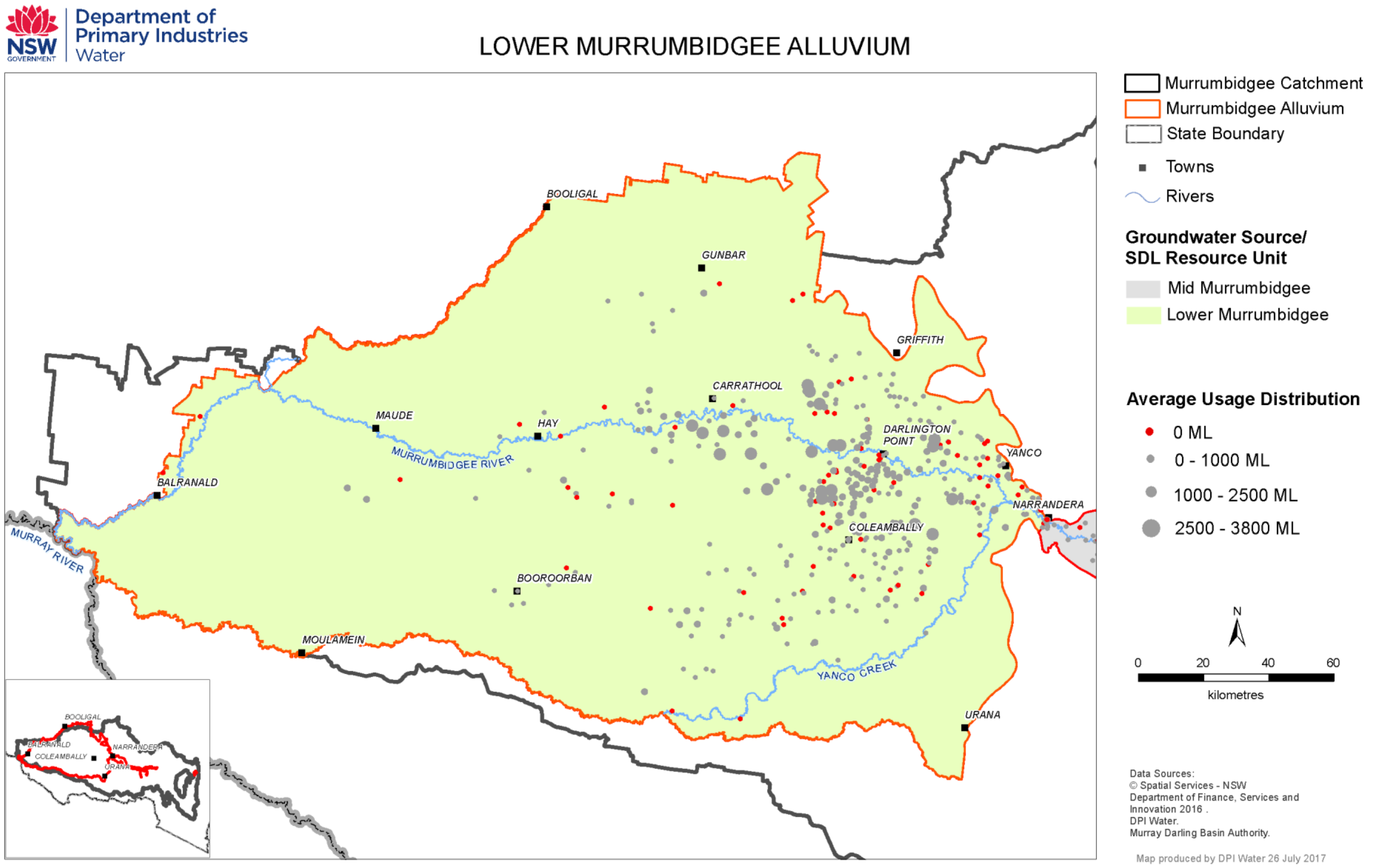


Figure 41. Lower-Murrumbidgee Alluvium - distribution of groundwater extraction.

Annual groundwater extraction and the annual extraction limit for each groundwater source are provided in Figures 42 to 48.

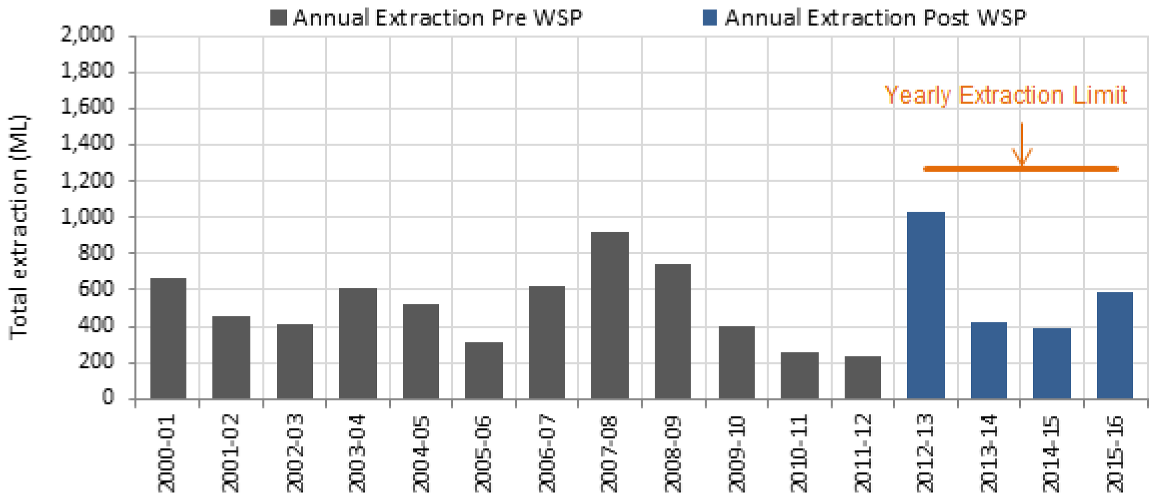


Figure 42. Metered extraction for the Lake George Alluvium.

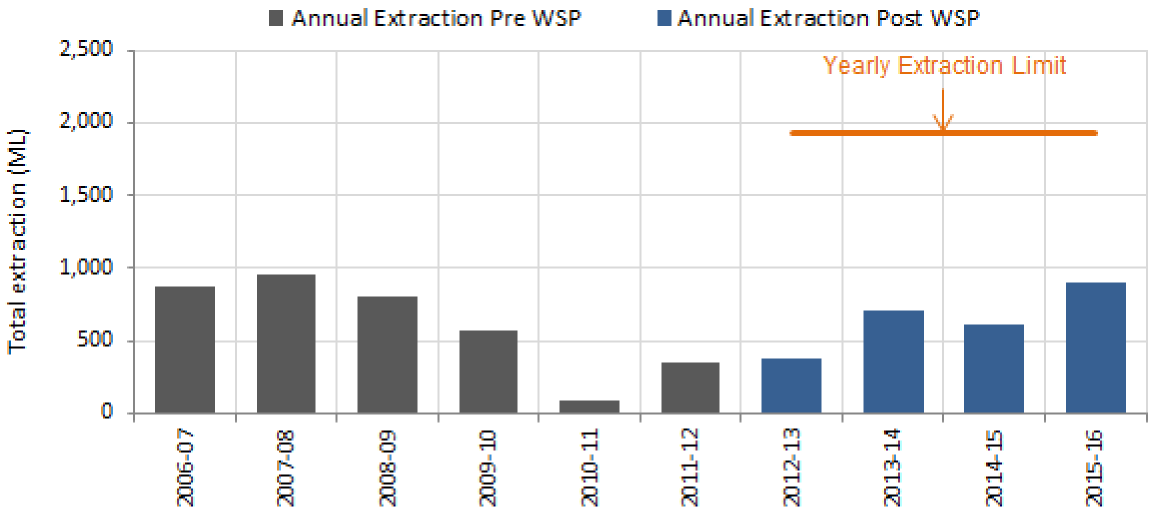


Figure 43. Metered extraction for the Gundagai Alluvium.

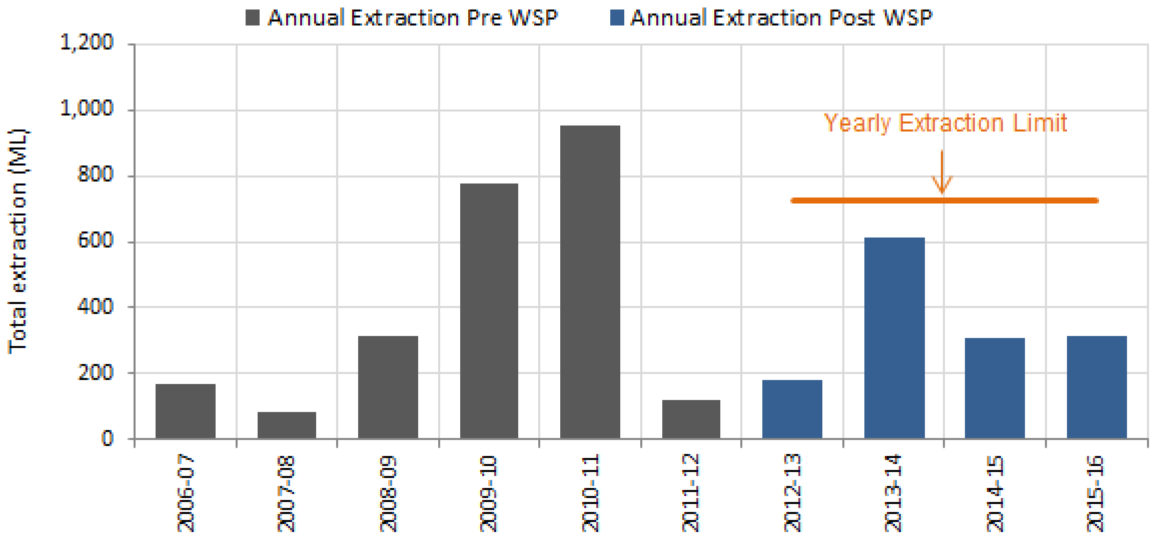


Figure 44.Metered extraction for the Kyeamba Alluvium.

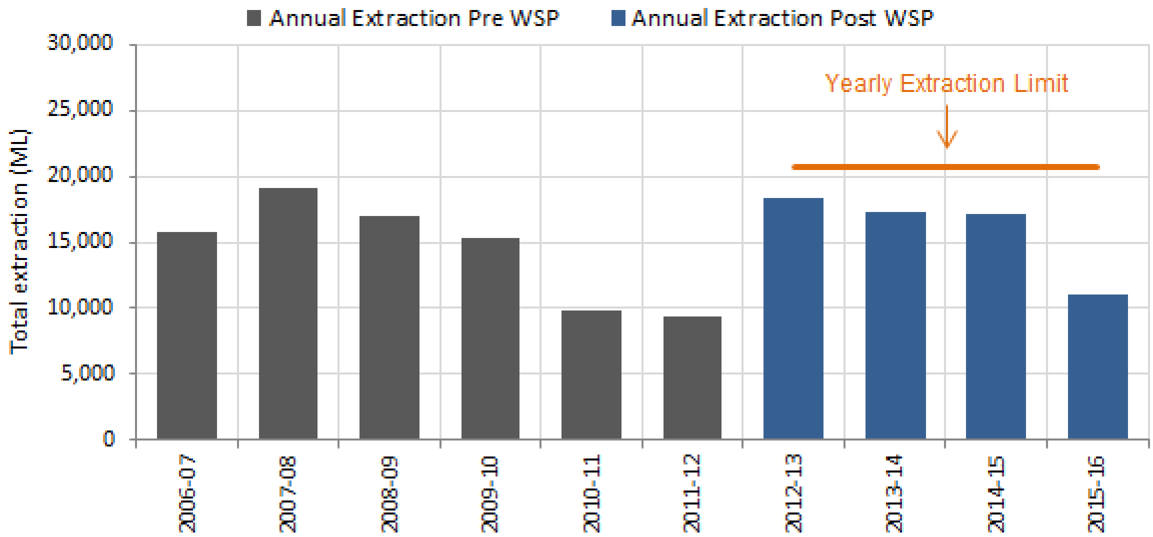


Figure 45. Metered extraction for the Wagga Wagga Alluvium.

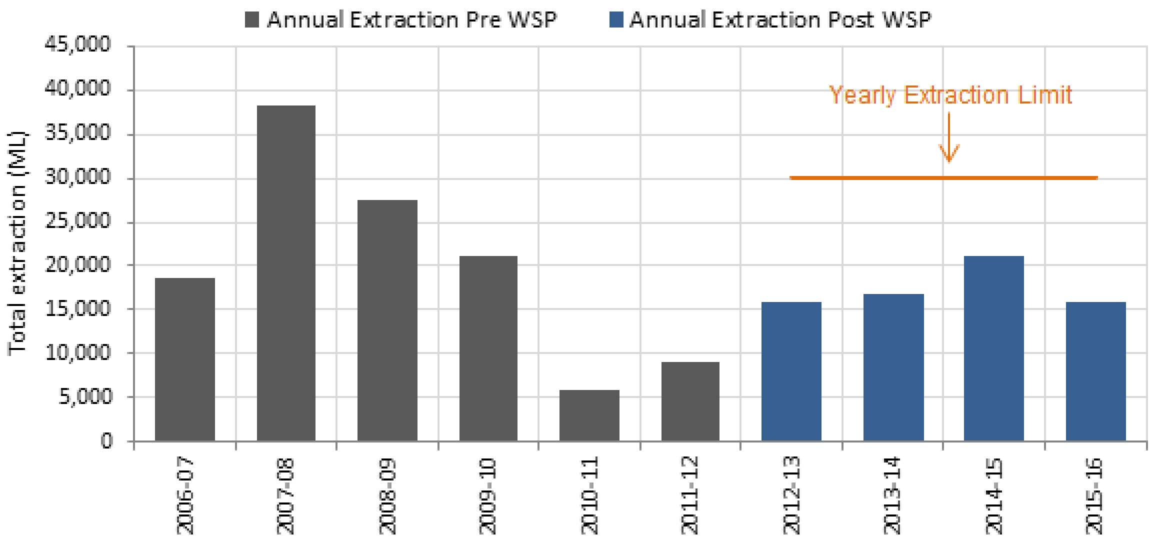


Figure 46. Metered extraction for the Mid Murrumbidgee Zone 3 Alluvium.

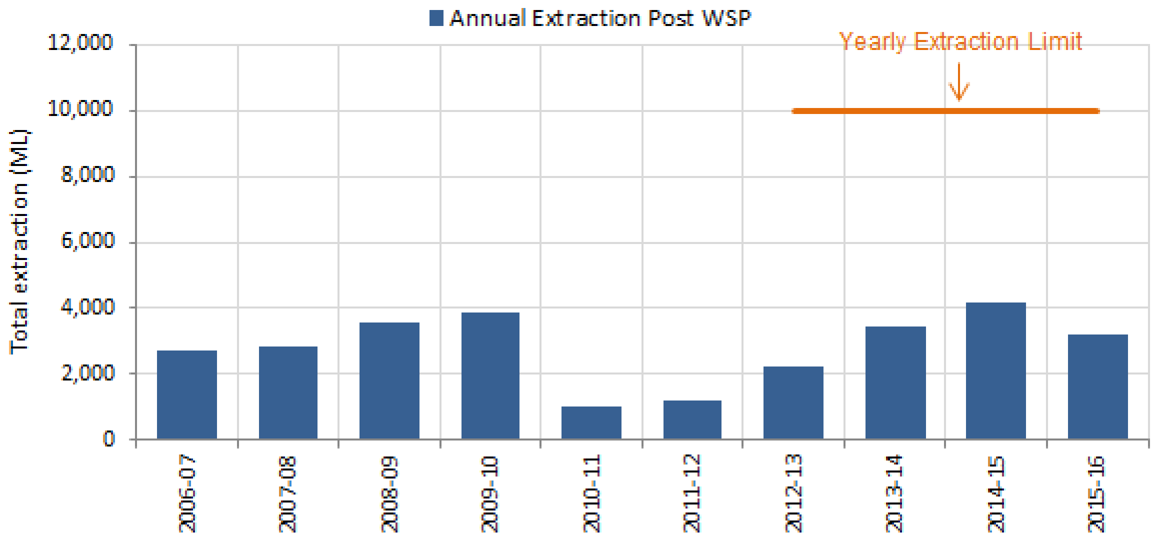


Figure 47. Metered extraction for the Lower Murrumbidgee Shallow Alluvium.

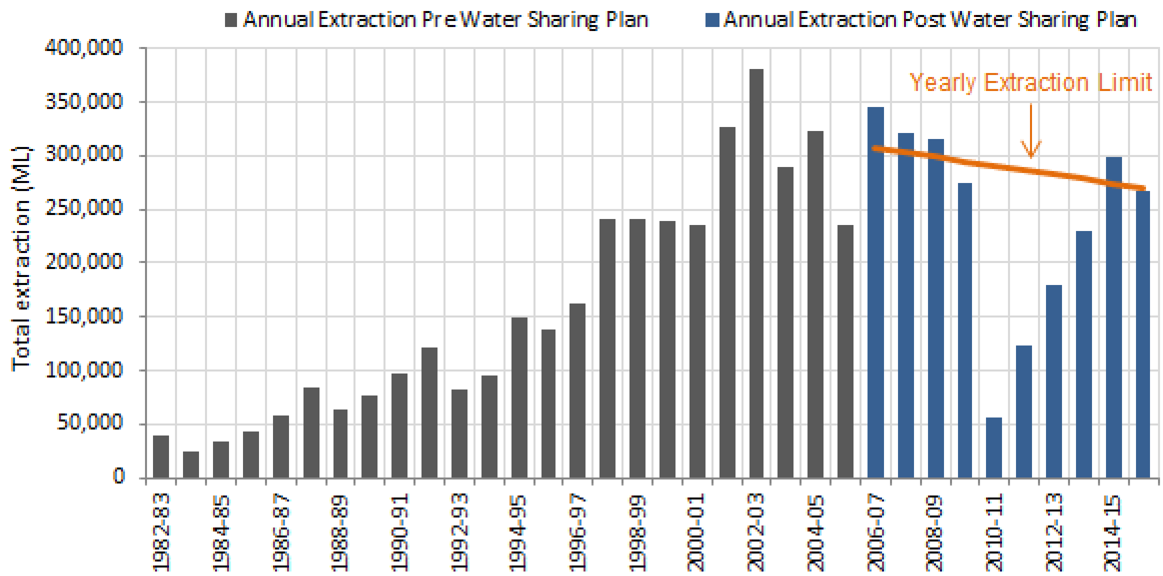


Figure 48. Metered extraction for the Lower Murrumbidgee Deep Alluvium.

Groundwater usage is highly influenced by rainfall and surface water availability, with high levels of extraction occurring throughout much of the 'millenium drought' (from the late 1990's to mid 2010), and much lower levels during and following the 2010 to 2012 high rainfall and flood events.

Groundwater extraction in the Lake George and Mid-Murrumbidgee (Gundagai, Kyeamba, Wagga Wagga and Mid Murrumbidgee Zone 3 alluvial groundwater sources) reflects the changing climatic conditons, with commencement of the water sharing plan for this area coinciding with increasing demand for groundwater following low usage during the high rainfall and flood events.

Average usage pre water sharing plan for Lake George Alluvium was around 500 ML/yr, and post commencement of the water sharing plan average usage is approximately 600 ML/yr. The slight increase is well below the LTAAEL of 1,268 ML/yr.

Average usage pre water sharing plan for the Gundagai Alluvium was 608 ML/yr, and post plan is 651 ML/yr, which is slighlty more than pre plan, but is well below the LTAAEL of 1,926 ML.

Average usage pre water sharing plan for the Kyeamba Alluvium was 402 ML/yr, and post plan is 355 ML/yr, well below the LTAAEL of 723 ML/yr.

Average usage pre water sharing plan or the Wagga Wagga Alluvium was 14,405 ML/yr, and post plan is slightly higher at 15,922 ML/yr, which is well below the LTAAEL of 20648 ML/yr.

Average usage pre water sharing plan for the Mid Murrumbidgee Zone 3 Alluvium was 20,094 ML/yr, and post plan is lower at 17,423 ML/yr, which is well below the LTAAEL of 30,176 ML/yr.

In the Lower Murrumbidge, there is no data for pre-plan extraction from the shallow aquifer, but post-plan annual average extraction is 2,825 ML, which is well below the LTAAEL (10,000 ML) and the SDL (26,900 ML/yr).

Extraction pre water sharing plan for the Lower Murrumbidgee Deep Alluvium grew from a range of about 40,000 to 100,000 ML per year in the 1980's, to a high of 381,405 ML in 2002-03. Average extraction over the six years leading up to the Water Sharing Plan (2000-01 to 2005-06) was 298,483 ML/yr. Post water sharing plan commencement, and including the 2010 to 2012 high rainfall (low groundwater useage) period, extraction has averaged 241,062 ML/yr, and in about 50% of years has been close to the declining LTAAEL, with minor exceedences balanced by under-extraction.

Groundwater extraction can result in drawdown of groundwater pressure levels and the watertable surface, subject to extraction intensity and aquifer properties. 'Local impacts', such as reduced bore yields and declining groundwater quality, can arise even in under-allocated systems or where extraction is below the LTAAEL, and are particularly at risk of occurring where groundwater trading enables migration of existing entitlements to preferred areas of groundwater sources. To minimise the risks of local impacts occurrring, water sharing plans stipulate minimum distances between bores and areas of local impacts may be managed to include local restrictions on groundwater extraction that are in addition to managing extraction to the LTAAEL.

8.6. Groundwater dealings

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

Trading may occur within, but not between, individual groundwater sources of the Murrumbidgee Alluvium WRP area. In addition:

- Within the Gundagai Alluvium, trade cannot occur from the Tarcutta Alluvial Management Zone to Jugiong Alluvial Management Zone, and
- Within the Lower Murrumbidgee Alluvium, a 2007 review of groundwater level data indicated an area between Griffith, Coleambally and Hay that had significant drawdown and recovery declines (Kumar, 2013). Trade of water into that area has been restricted to manage potential cumulative impacts of extraction on the groundwater source and water users in the area

There are no trade restricted areas defined in the Mid-Murrumbidgee Alluvium, Wagga Wagga Alluvium, Kyeamba Alluvium and Lake George Alluvium.

8.6.1. Temporary dealings

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 worth greater than $1/ML are shown in Figures 49 to 53 and the statistics for the business to business trades worth less than $1/ML are shown in Figures 54 to 58.

To date there have been no applications for temporary dealings in the Lake George Alluvium and Gundagai Alluvium.

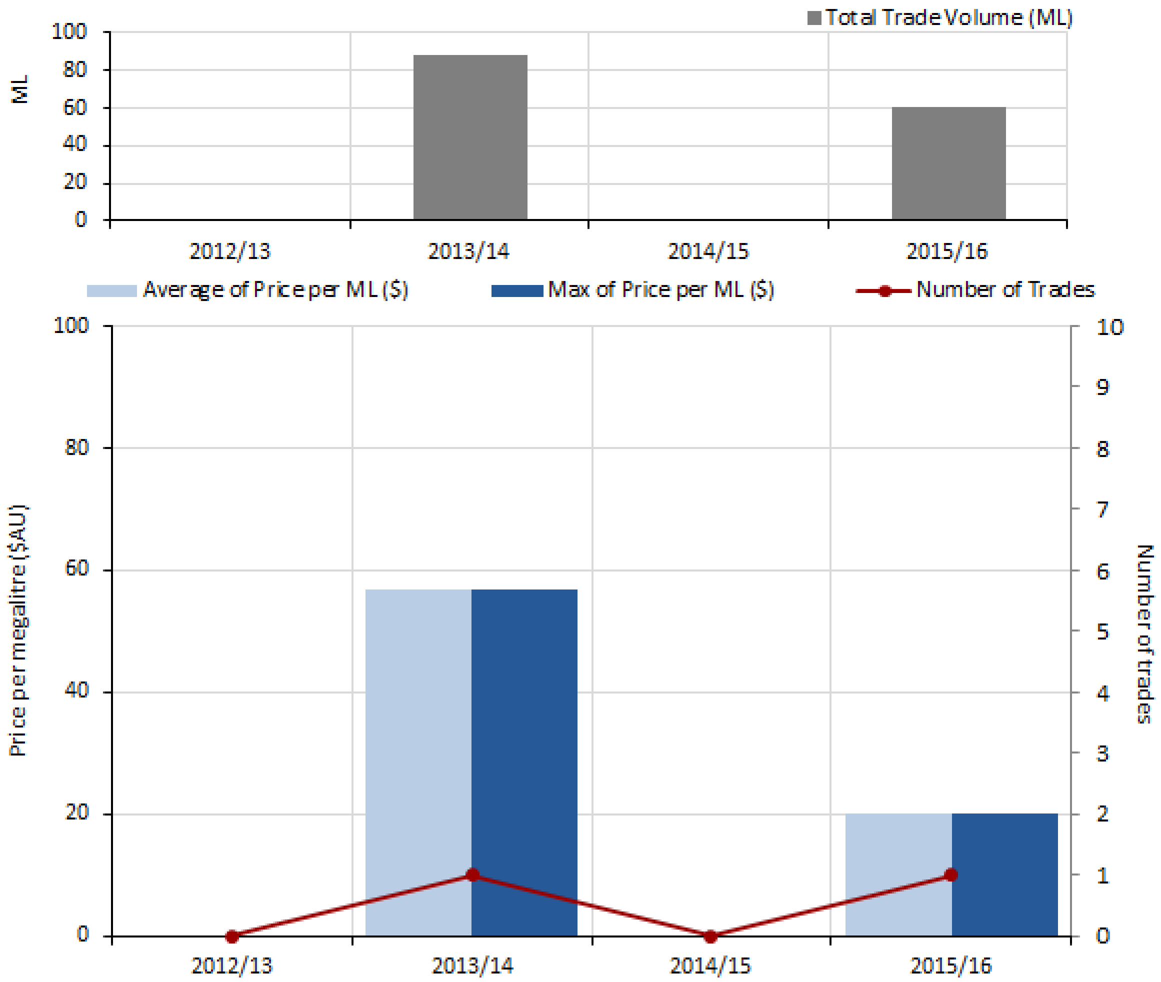


Figure 49. Kyeamba Alluvium 71T dealings > $1/ML since commencement of the water sharing plan.

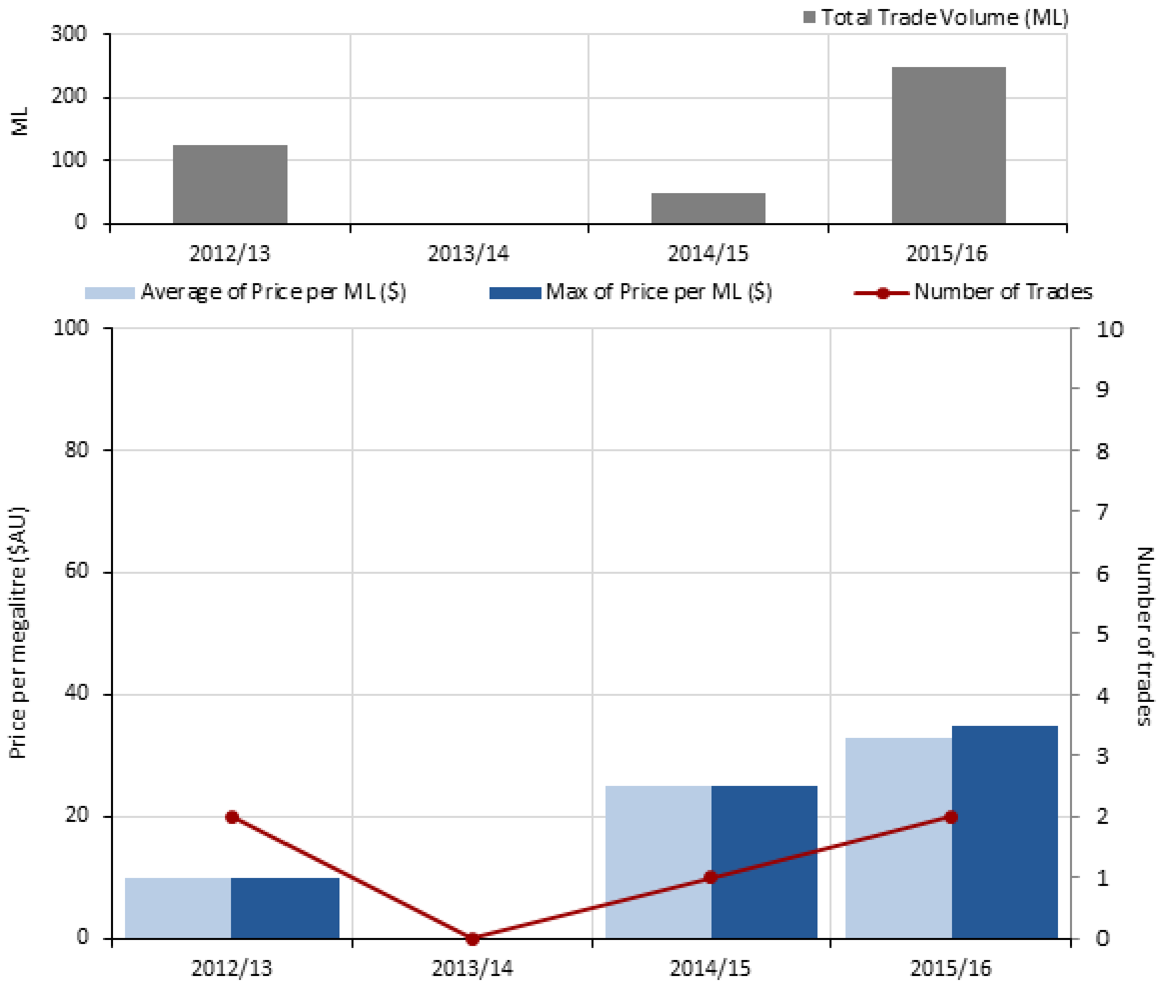


Figure 50. Wagga Wagga Alluvium 71T dealings > $1/ML since commencement of the water sharing plan.

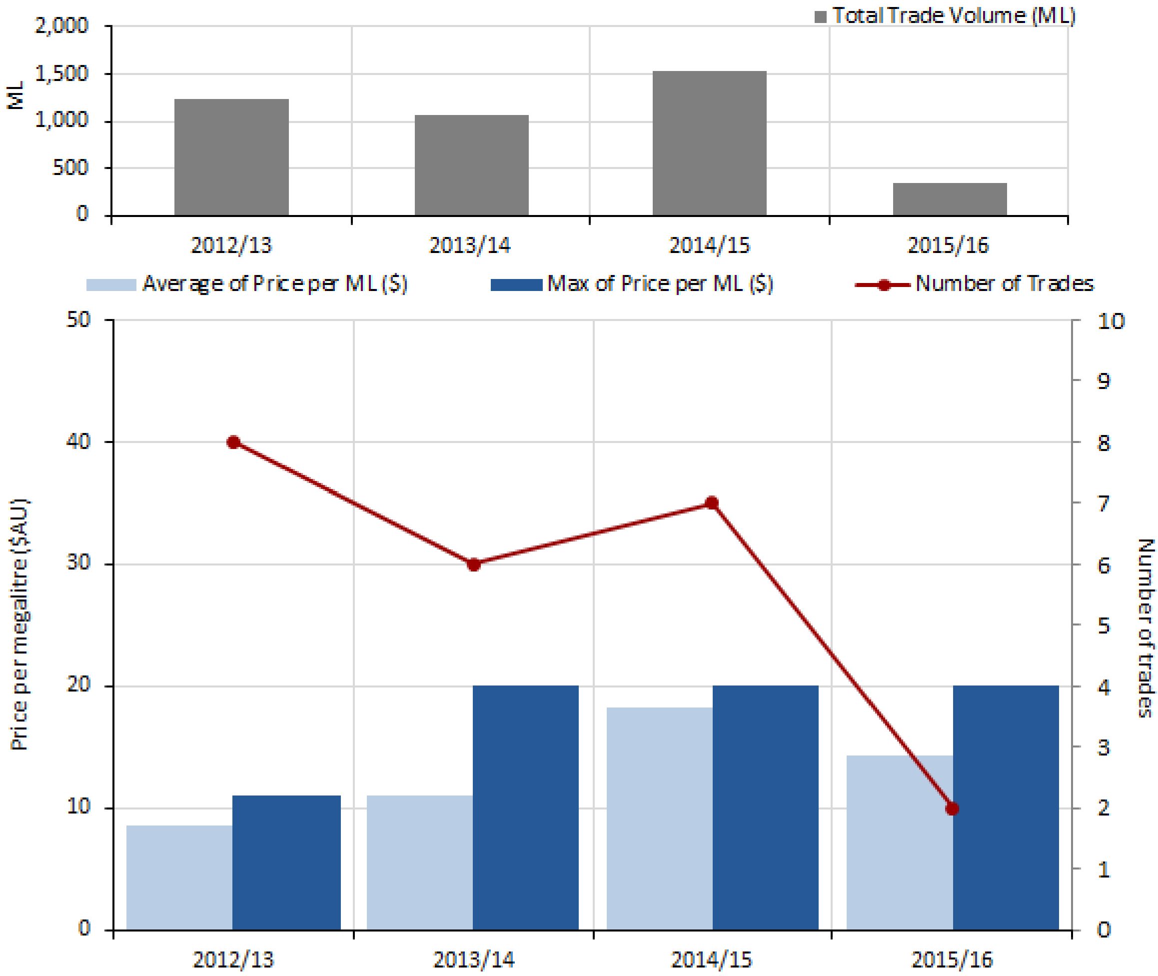


Figure 51. Mid Murrumbidgee Zone 3 Alluvium 71T dealings > $1/ML since commencement of the water sharing plan.

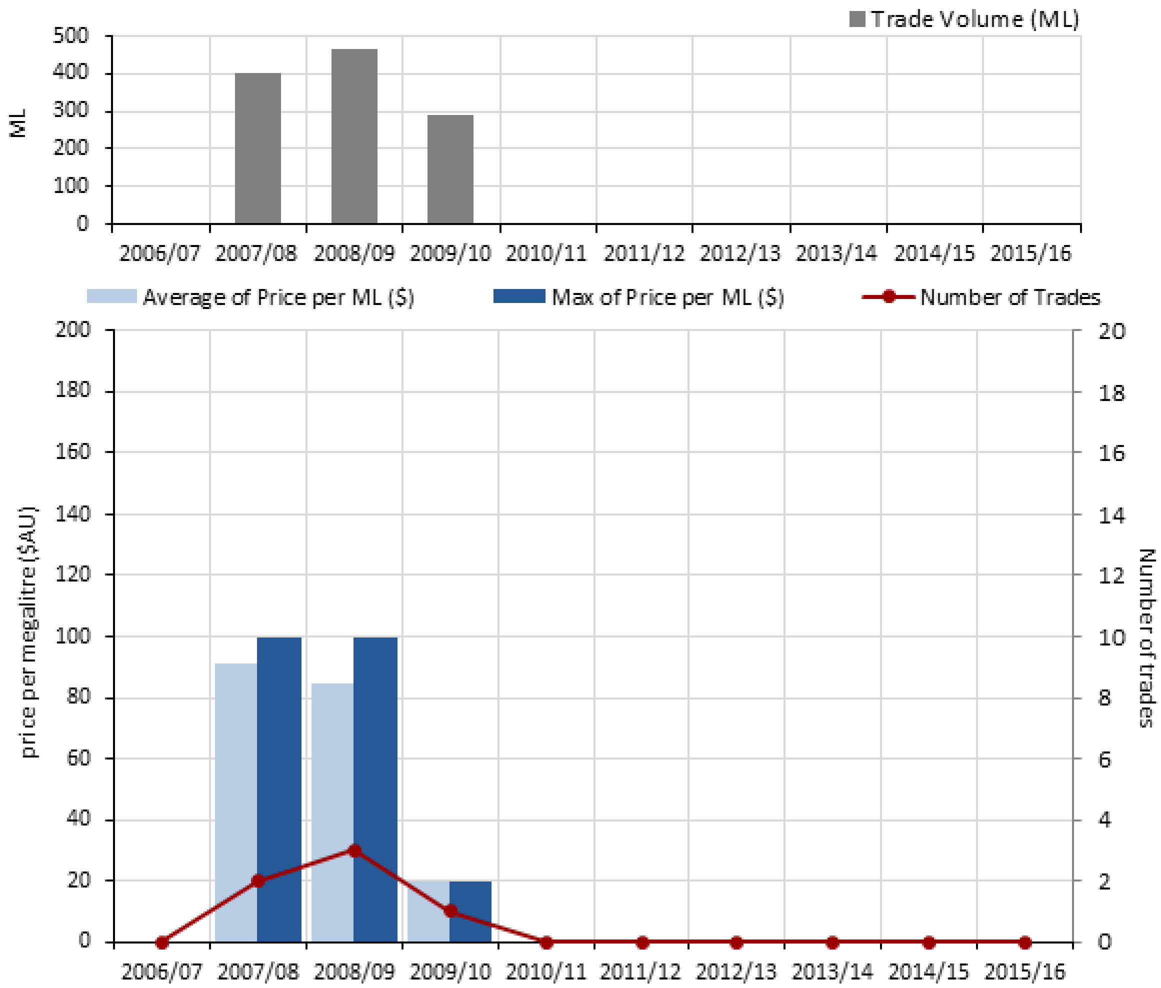


Figure 52. Lower Murrumbidgee Alluvium (Shallow) 71T dealings > $1/ML since commencement of the water sharing plan.

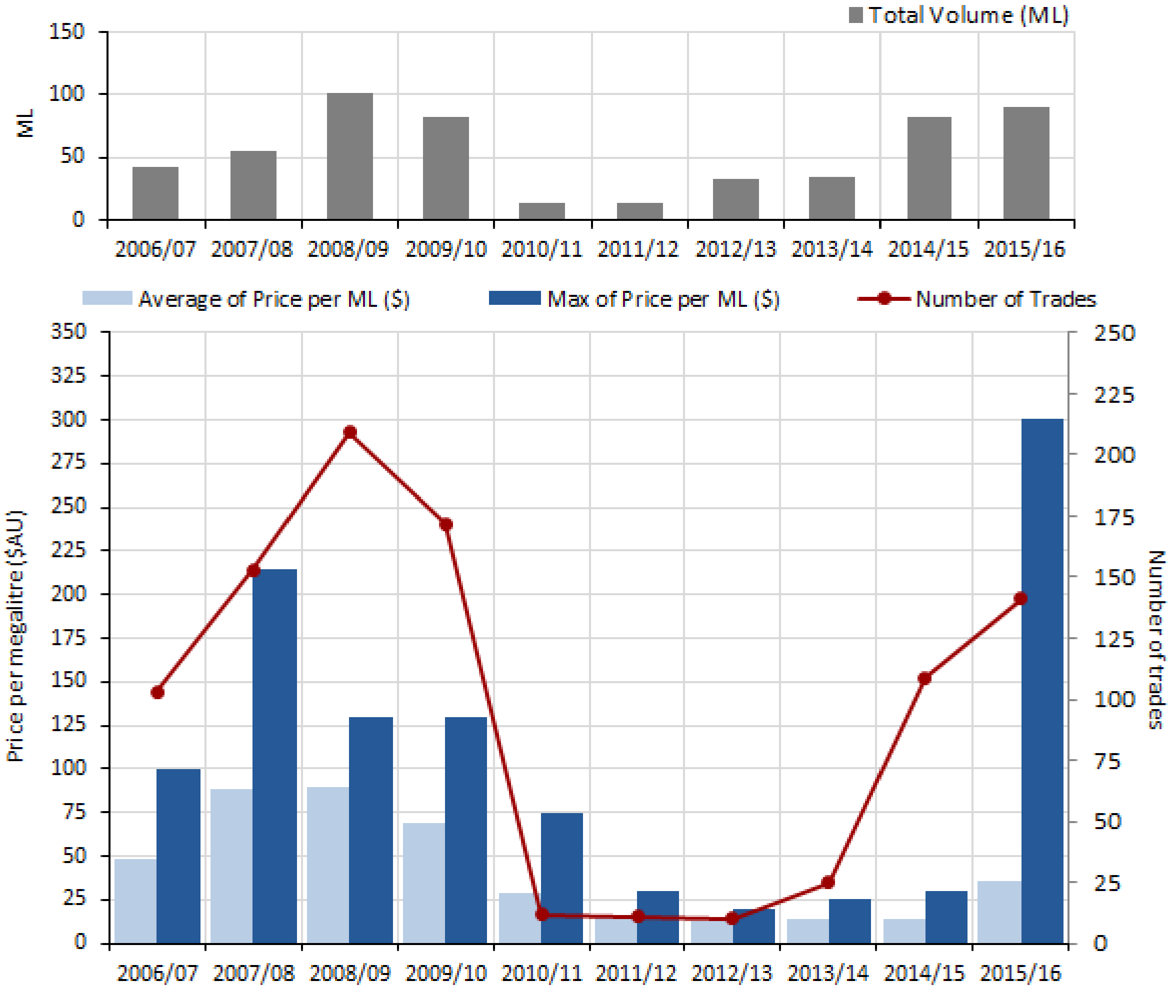


Figure 53. Lower Murrumbidgee Alluvium (Deep) 71T dealings > $1/ML since commencement of the water sharing plan.

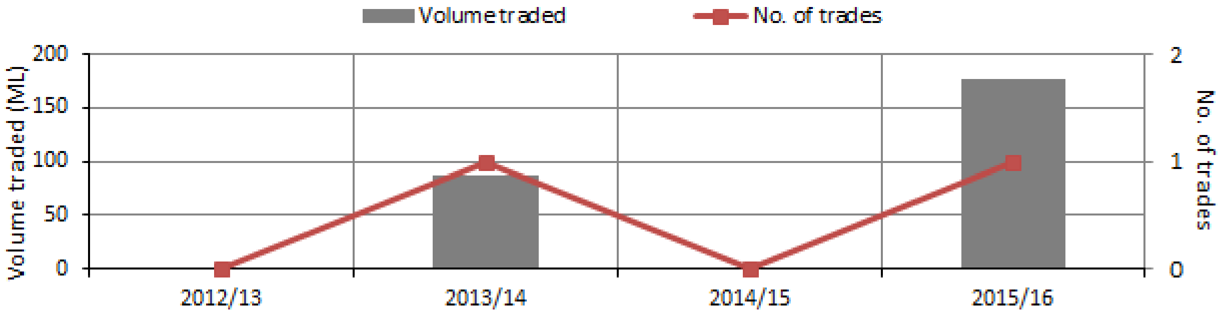


Figure 54. Kyeamba Alluvium 71T dealings < $1/ML since commencement of the water sharing plan.

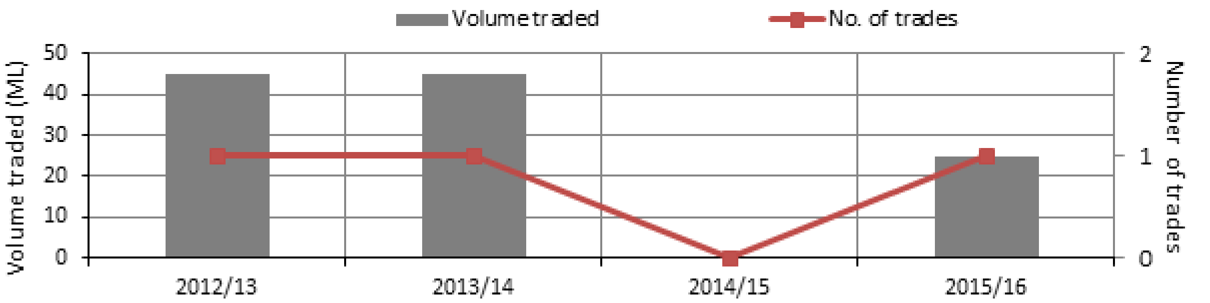


Figure 55. Wagga Wagga Alluvium 71T dealings < $1/ML since commencement of the water sharing plan.

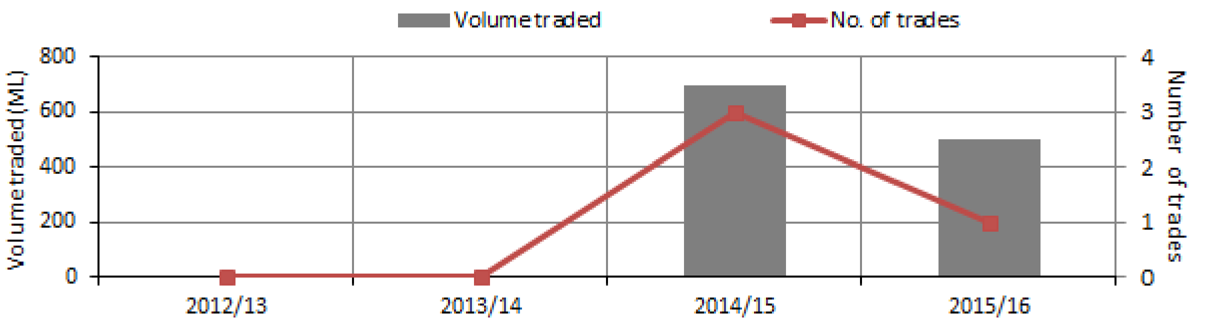


Figure 56. Mid Murrumbidgee Zone 3 Alluvium 71T dealings < $1/ML since commencement of the water sharing plan.

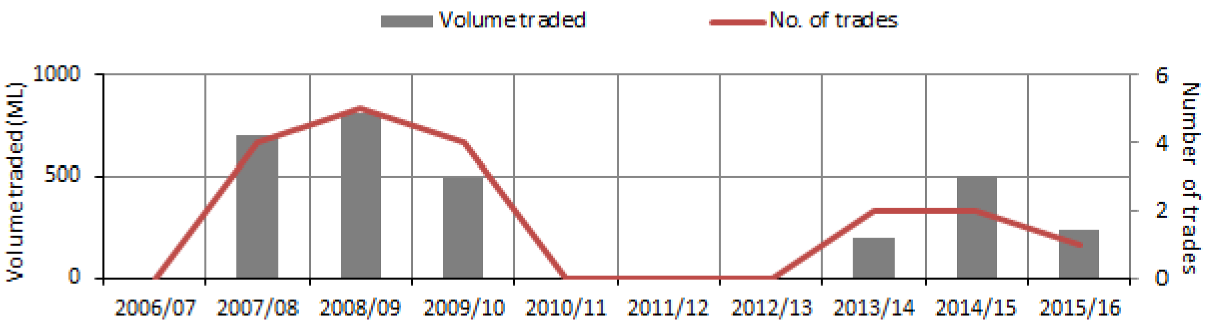


Figure 57. Lower Murrumbidgee Alluvium (Shallow) 71T dealings < $1/ML since commencement of the water sharing plan.

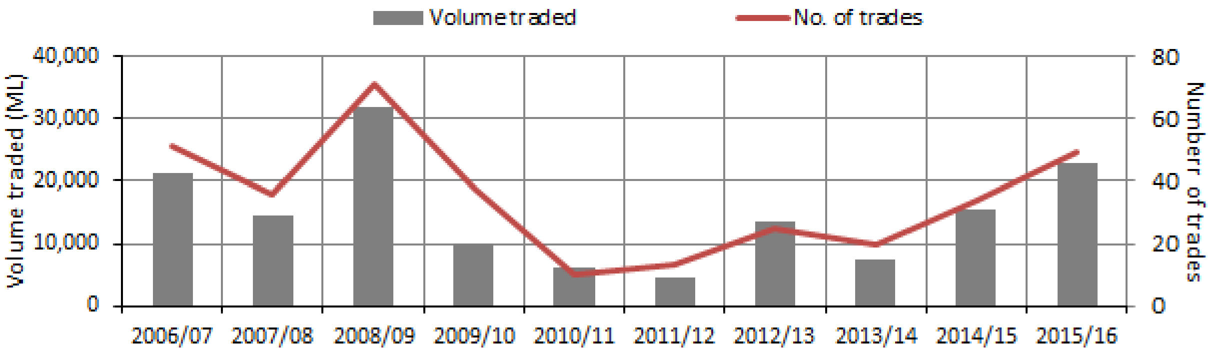


Figure 58. Lower Murrumbidgee Alluvium (Deep) 71T dealings < $1/ML since commencement of the water sharing plan.

8.6.2. Permanent dealings

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.

Figures 59 to 61 show 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 plans in the Mid Murrumbidgee (comprising the Gundagai, Kyeamba, Wagga Wagga and Mid Murrumbidgee Zone 3 groundwater sources) and Lower Murrumbidgee Alluvium. 71M dealings are not included as these are a change in ownership only and therefore have no potential for additional, third party impacts.

To date there have been no applications for permanent dealings in the Lake George Alluvium.

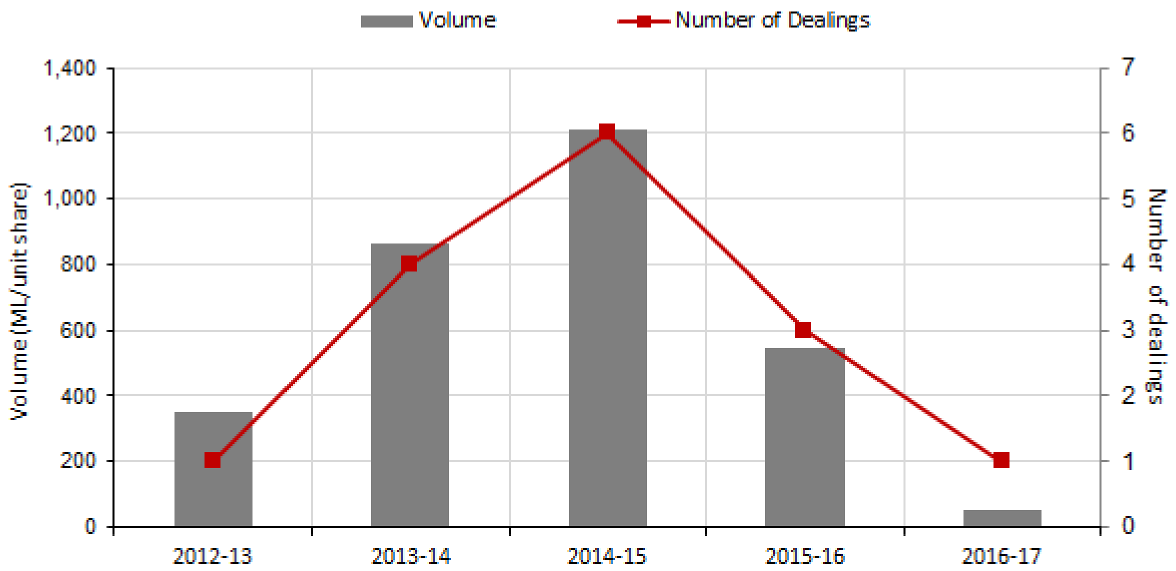


Figure 59. Mid-Murrumbidgee Alluvium dealings that resulted in shares changing location since commencement of the water sharing plan; 71M dealings not included.

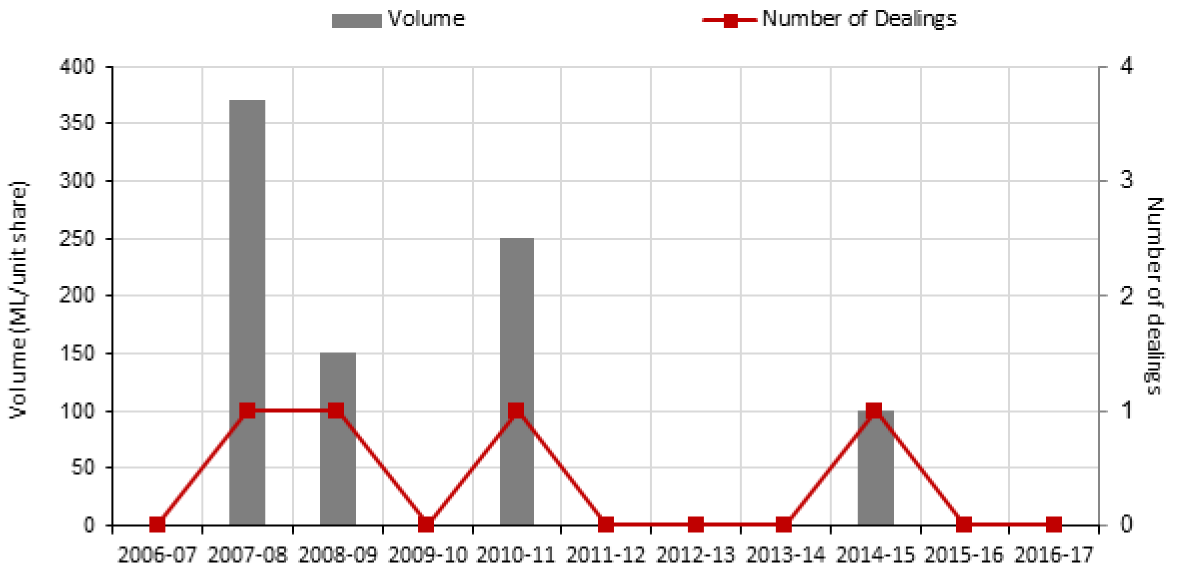


Figure 60. Lower Murrumbidgee Alluvium (Shallow) dealings that resulted in shares changing location since commencement of the water sharing plan; 71M dealings not included.

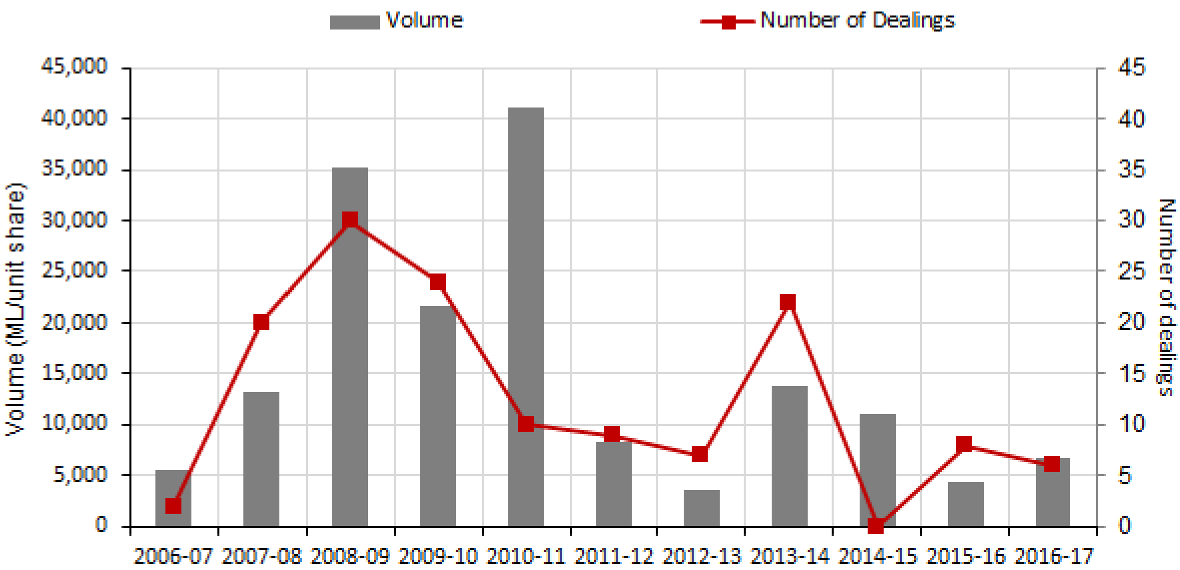


Figure 61. Lower Murrumbidgee Alluvium (Deep) dealings that resulted in shares changing location since commencement of the water sharing plan; 71M dealings not included.

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 62 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 62 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.

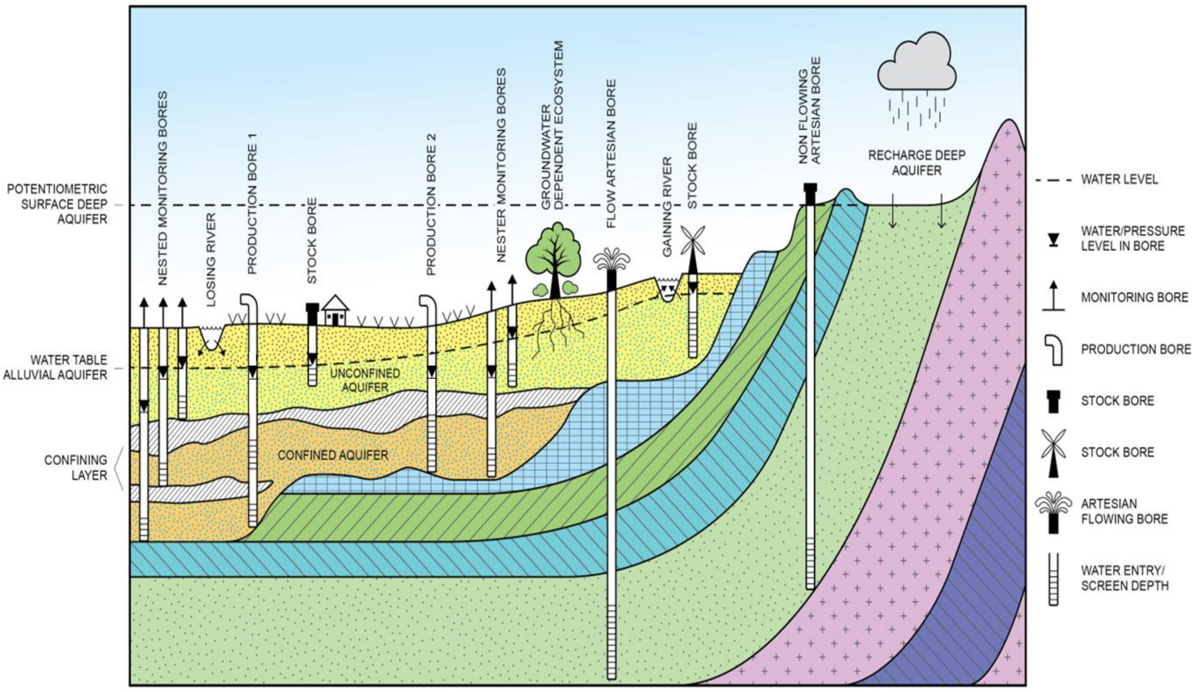


Figure 62. Schematic diagram of different types of aquifers.

Monitoring bores are designed to monitor a specific aquifer for water levels 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 63 illustrates how the water level in some of the monitoring bores can be at different levels to nearby production and stock bores. This is 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.

Across the Murrumbidgee Alluvium there are 474 state government monitoring bores at 253 sites, with bores located in each of the groundwater SDL resource units. In addition, Murrumbidgee Irrigation Limited (MIL) and Coleambally Irrigation Co-operative Limited (CICL) maintain intensive monitoring bore networks focused on the shallow aquifers within their areas of operation. The total number of individual monitoring bores is greater than the total number of sites as many sites have several bores located close to each other that access aquifers at different depths.

In the Lake George Alluvium, monitoring bores were first established in 1999 (Carter, 2000). Six bores were established at three sites to the west of Bungendore in an area where groundwater extraction occurs for both town supply and irrigation. The monitoring bores are constructed to various depths ranging from 4 to 54 m.

In the Mid and Lower Murrumbidgee Alluvium, groundwater levels and pressures have been monitored at some sites since the early 1970s, providing continuous records of measurement for 30 to 40 years. Additional sites have been established over time, with the most recent sites drilled and incorporated into the monitoring network in 2006.

The manually monitored sites are read monthly, 3-monthly or 6-monthly subject to site significance and groundwater level behaviour. Data is available for selected groundwater monitoring sites in real-time via telemetry from: *http://realtimedata.water.nsw.gov.au/water.stm*

The number of sites and individual monitoring bores within each management unit are listed in Table 4 below, and locations are indicated in Figures 65, 67, and 72.

Table 4. Murrumbidgee Alluvium monitoring bores.

SDL Resource Unit	Number of monitoring bores	Number of sites
Lake George	6	3
Mid-Murrumbidgee	204	95
Lower Murrumbidgee (shallow and deep)	264	152
Total	**474**	**253**

10. Groundwater Behaviour in the Murrumbidgee Alluvium

10.1. Introduction

For the Mid Murrumbidgee, monitoring bores constructed and screened less than about 25 m deep in the Gundagai area, and increasing to about 40 m at Narrandera, are considered to be within the unconfined shallow aquifer system, while monitoring bores constructed to greater depths have been assessed to be in the deep semi confined/confined aquifer system. This approach has been adopted to be consistent with the interpreted depths of the Cowra and Lachlan formations in the Mid Murrumbidgee.

For the Lower Murrumbidgee, monitoring bores constructed and screened less than about 40 m deep are considered to be within the unconfined shallow aquifer system, while monitoring bores constructed beyond 40 m to depths of up to 70 m are assessed on a geological basis to confirm the monitored aquifer system. Bores constructed and screened to depths beyond 70 m have been assessed to be in the deep semi confined/confined aquifer system. This approach has been adopted to be consistent with the water sharing plan definitions for the shallow and deep aquifers of the Lower Murrumbidgee.

The Lake George Alluvium does consist of an upper unconfined aquifer and a deeper semi confined aquifer. However, no clear distinction between shallow and deep aquifers has been made due to insufficient data.

The reference condition to which long term trends are compared is the ‘pre-development’ water level. In the Mid and Lower Murrumbidgee the ‘pre-development’ is defined as the average recovered water level from 1972 to 1976. In the Lake George Alluvium, monitoring has only been undertaken since 1999, well after extraction for irrigation and town supplies had been established. Hence, no pre-development data exists, and no pre-development condition is defined.

Changes in groundwater levels in the Murrumbidgee Alluvium are discussed in the following sections presenting data from hydrographs and groundwater head maps.

10.2. Hydrographs

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (Figure 63). 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 63 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.

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.

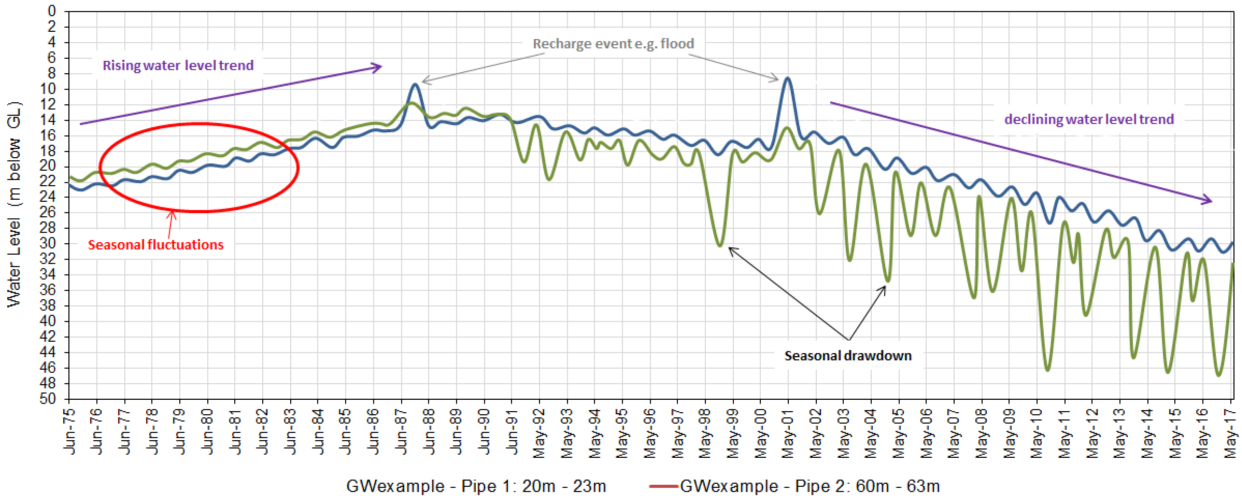


Figure 63. Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate.

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.

10.3. Review of groundwater levels

Hydrographs for representative groundwater monitoring sites in each SDL resource unit area of the Murrumbidgee Alluvium are presented below. The locations of these sites are displayed in Figures 64, 66 and 71. Within each area, each hydrograph is displayed at the same scale for ease of comparison.

10.3.1. Lake George Alluvium

Most of the groundwater extracted from the Lake George Alluvium occurs within the vicinity of the township of Bungendore, and is used for both town supply and commercial irrigation.

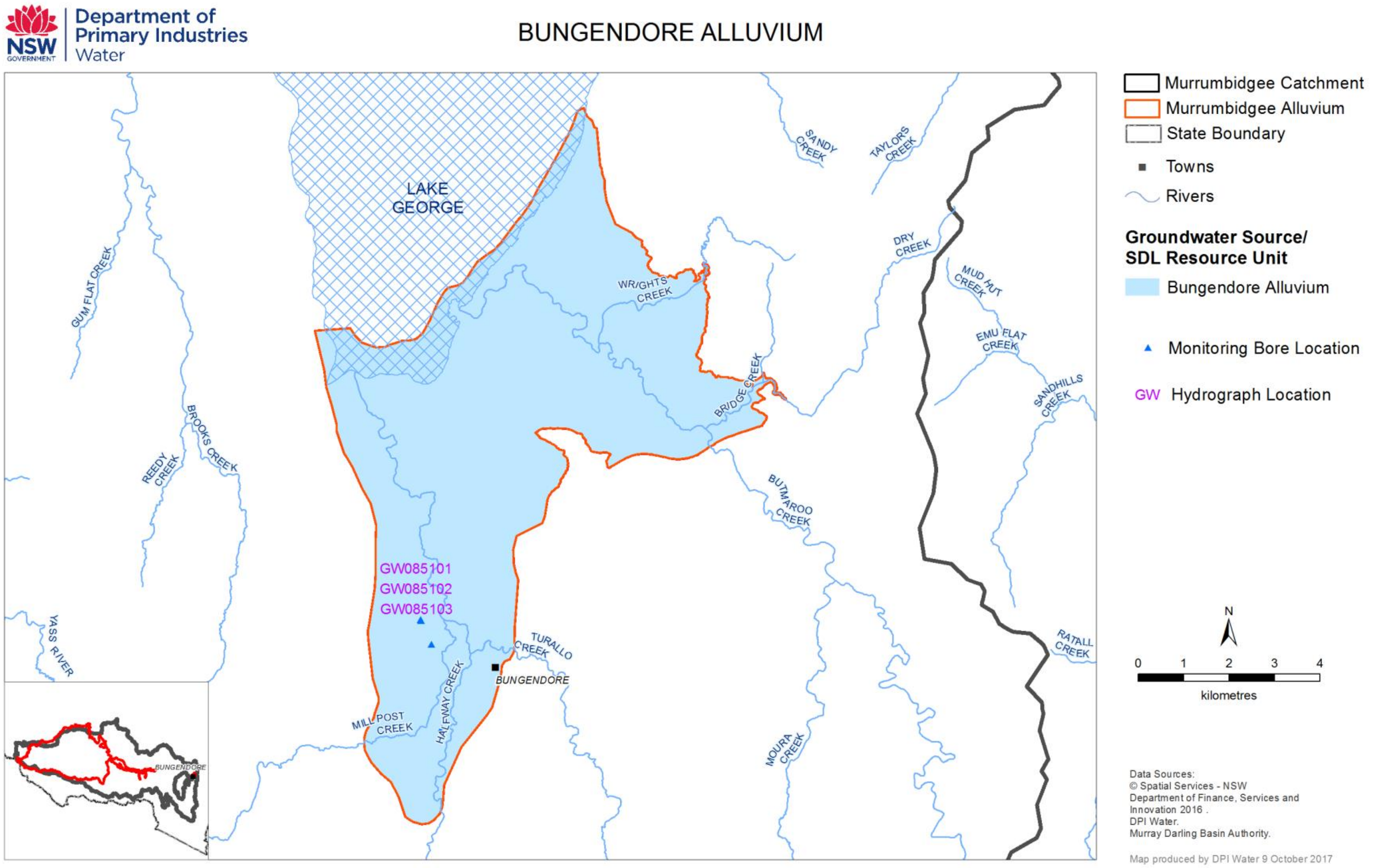


Figure 64. Lake George Alluvium hydrograph locations.

Hydrographs for monitoring bores GW085101, GW085102 and GW085103 are provided in Figure 65. Groundwater pumping for both irrigation and town supply occurs near to these bores, and the subsequent seasonal drawdown and recovery effects in the deep aquifer are clearly displayed. In the shallow aquifer, the long term trend includes a downward component in the early 2000's as the 'millennium drought' was taking effect, and recovery in 2010 – 2012 associated with high rainfall periods, but otherwise is relatively stable.

The observed levels indicate a downward hydraulic gradient occurs in this area, as the water level in the shallow aquifer (at 6 – 11 m depth) is higher than that in the deeper aquifers (at 39 – 54 m depth). There is also a lack of connectivity between the shallow and deep aquifers, as the groundwater in the shallow aquifer shows little response to the short term drawdown and recovery in the deep aquifer.

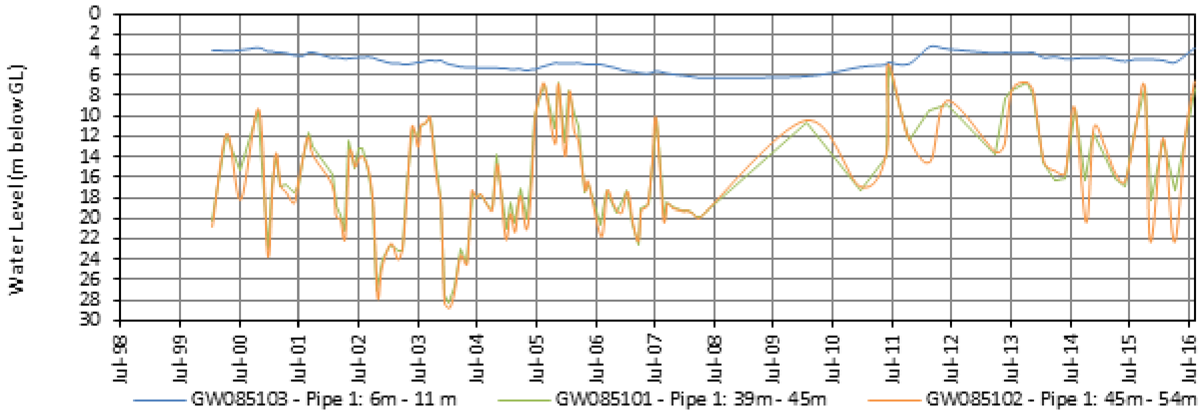


Figure 65. Hydrograph for monitoring bore site GW085101 / GW085102 / GW085103.

10.3.2. Mid-Murrumbidgee Alluvium

The Mid Murrumbidgee alluvium extends from the Jugiong area downstream to Narrandera, and includes the Tumut River, Tarcutta Creek and Kyeamba Creek tributary alluvial systems (Figure 67). For management purposes it comprises four groundwater sources - the Gundagai, Kyeamba, Wagga Wagga and Mid Murrumbidgee Zone 3 groundwater sources.

Hydrographs of groundwater levels for representative sites in the Mid Murrumbidgee Alluvium are provided in Figures 67 to 70, in order from upstream to downstream. The selected sites are located in the Gundagai (GW030385), Wagga Wagga (GW025393) and Mid Murrumbidgee Zone 3 (GW030125 and GW025395) groundwater sources. To assist in comparing trends, all charts span the timeframe from 1969 to 2016, and a vertical range of 8 m above ground to 24 m below ground.

All charts display declining groundwater level trends from the late 1990's to the end of the 'millennium drought' in 2010, with the trend at GW030385 in Tarcutta Creek being less pronounced than the others, and the declining trend in GW025393 (at Wagga Wagga) commencing as far back as 1976 – largely in response to groundwater extraction for town supply. The declines have occurred not only in the deep aquifers from which most pumping occurs, but also from shallow aquifers, indicating a significant degree of vertical connectivity. Some recovery has occurred during 2010 to 2012, in response to post-drought rainfall, flooding and reduced water demand, but not to pre-development levels.

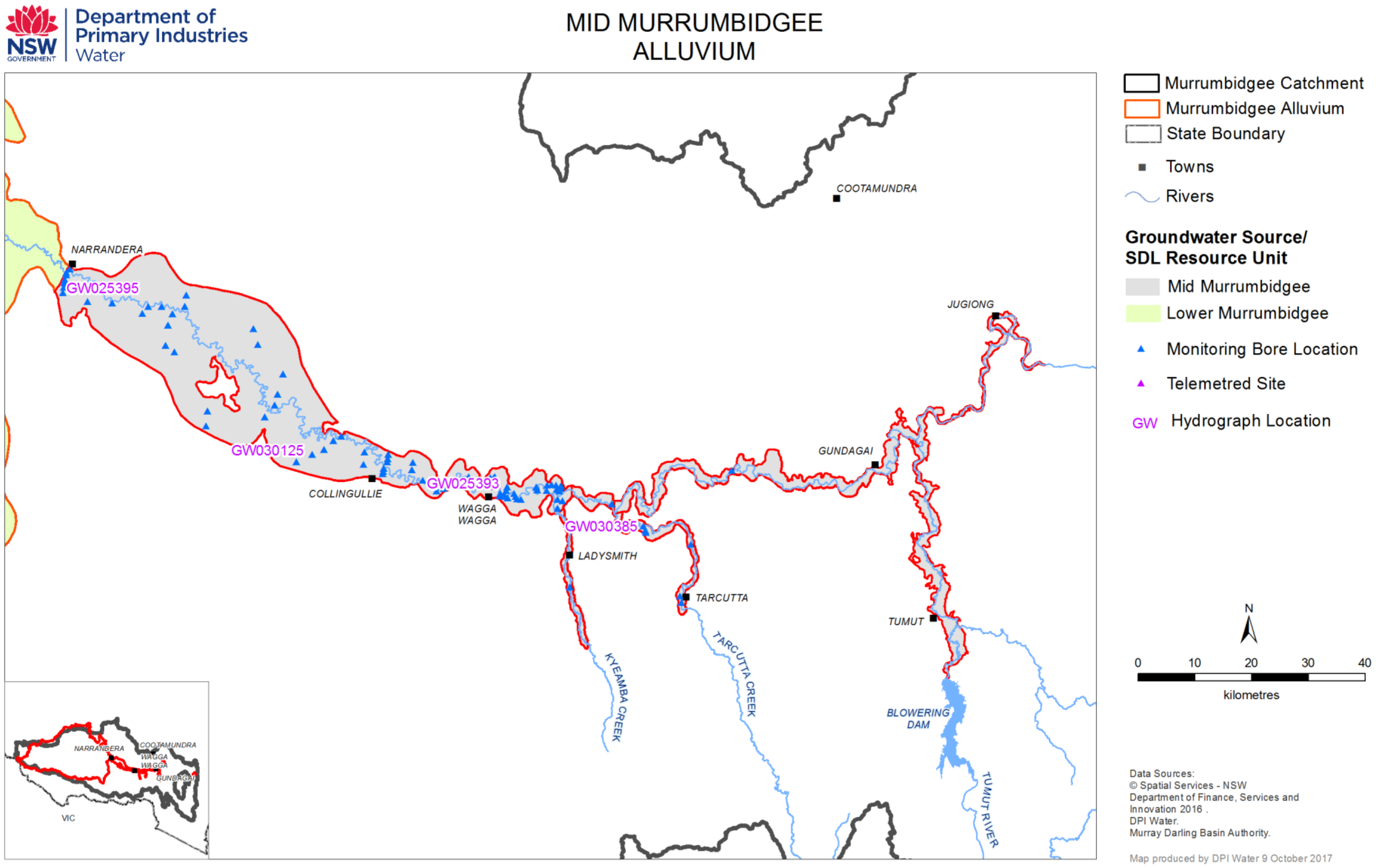


Figure 66. Mid-Murrumbidgee hydrograph locations.

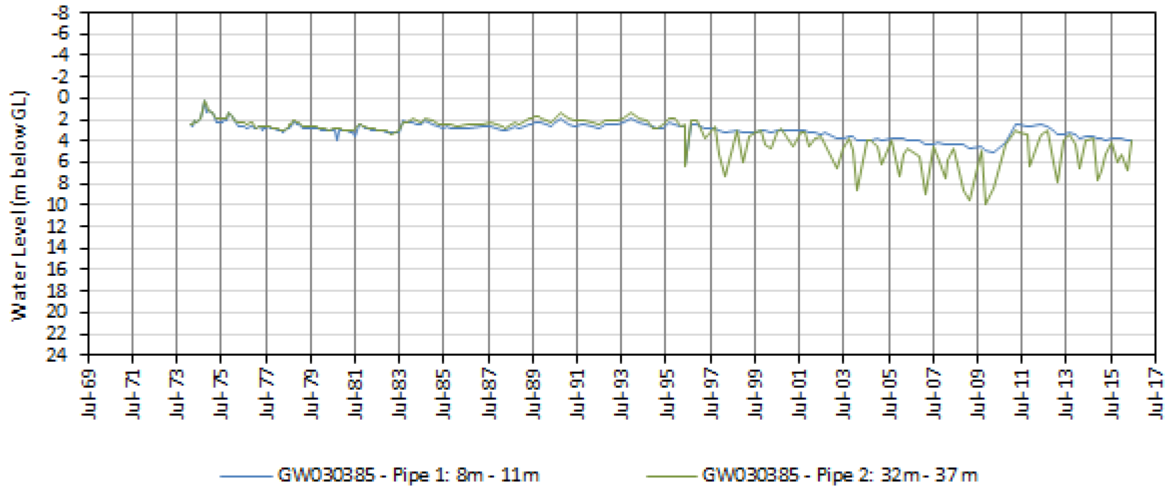


Figure 67. Hydrograph for monitoring bore site GW030385 (Tarcutta Creek, upstream of Wagga Wagga), with Tarcutta Ck surface water hydrograph.

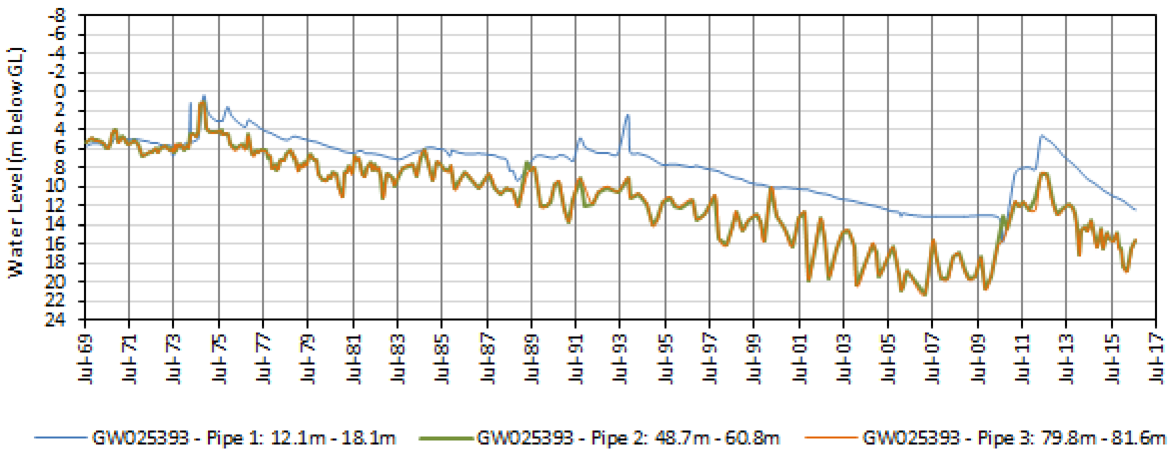


Figure 68. Hydrograph for monitoring bore site GW025393 (Wagga Wagga).

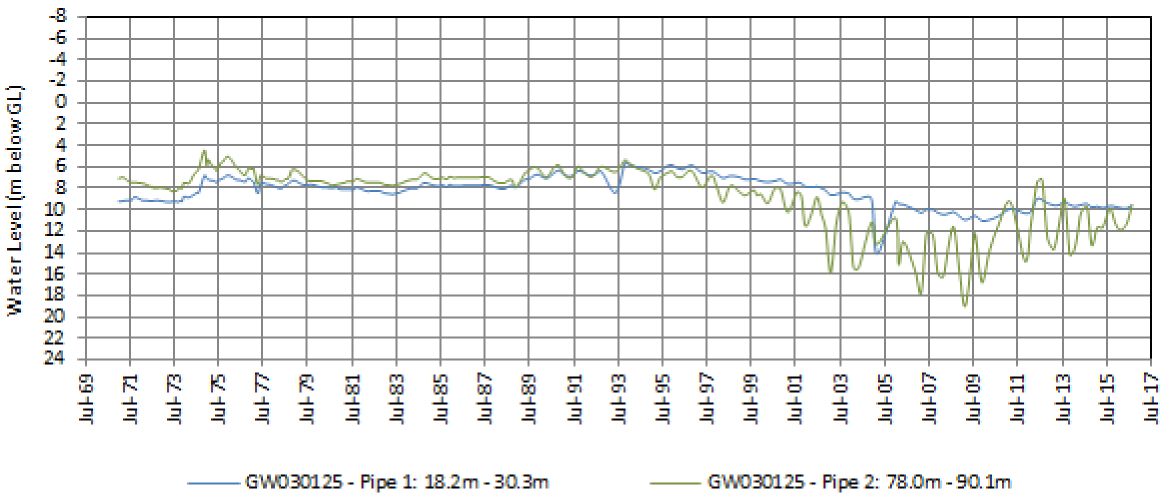


Figure 69. Hydrograph for monitoring bore site GW030125 (downstream of Wagga Wagga).

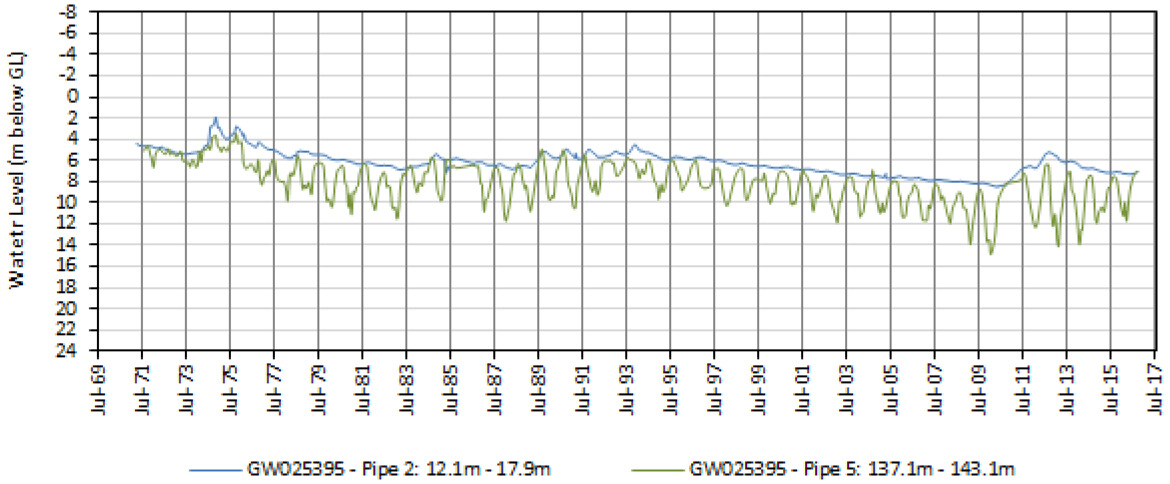


Figure 70. Hydrograph for monitoring bore site GW025395 (Narrandera) with Murrumbidgee River hydrograph.

10.3.3. Lower Murrumbidgee Alluvium

The Lower Murrumbidgee alluvium covers a large area, extending from Narrandera westwards to Balranald, and from Booligal southwards to Moulamein and Urana (Figure 71).

Hydrographs of groundwater levels for representative sites in the Lower Murrumbidgee Alluvium are provided in Figures 72 to 75, in order from east to west (upstream to downstream).

Monitoring sites GW040862 and GW040863 are located in areas of long term groundwater extraction and demonstrate initial seasonal drawdown in the early 1980’s, followed by long term decline commencing in the 1990’s and extending through the millennium drought period. Reduced groundwater extraction during the 2010-11 high rainfall and flood events allowed for some partial recovery. The two sites display different degrees of connectivity between shallow and deep aquifers, with a relatively high level of connectivity at site GW040862. Seasonal fluctuation in the deep aquifer is much greater at site GW040863, and is largely a factor of proximity to individual production bores.

At the GW040862 and GW040863 sites, new monitoring bores were constructed in 2002 to replace deteriorated older bores and maintain a continuous hydrographic record. Both the old and new bores are recognised in the legends for these hydrographs, with the newer bore at each site having a thicker hydrograph trace.

Further downstream, the pressure in the deep aquifer at site GW036025 has drawn down rapidly since pumping commenced in that area, whilst the groundwater in the shallow aquifer has been rising, possibly in response to local irrigation accessions, and appears to be relatively disconnected from the deep aquifer.

The hydrograph for GW036799 demonstrates an upward gradient in hydraulic head, which is typical of the downstream areas of groundwater systems, and reversal of the gradient since the year 2000 in response to local groundwater extraction from the deep aquifer.

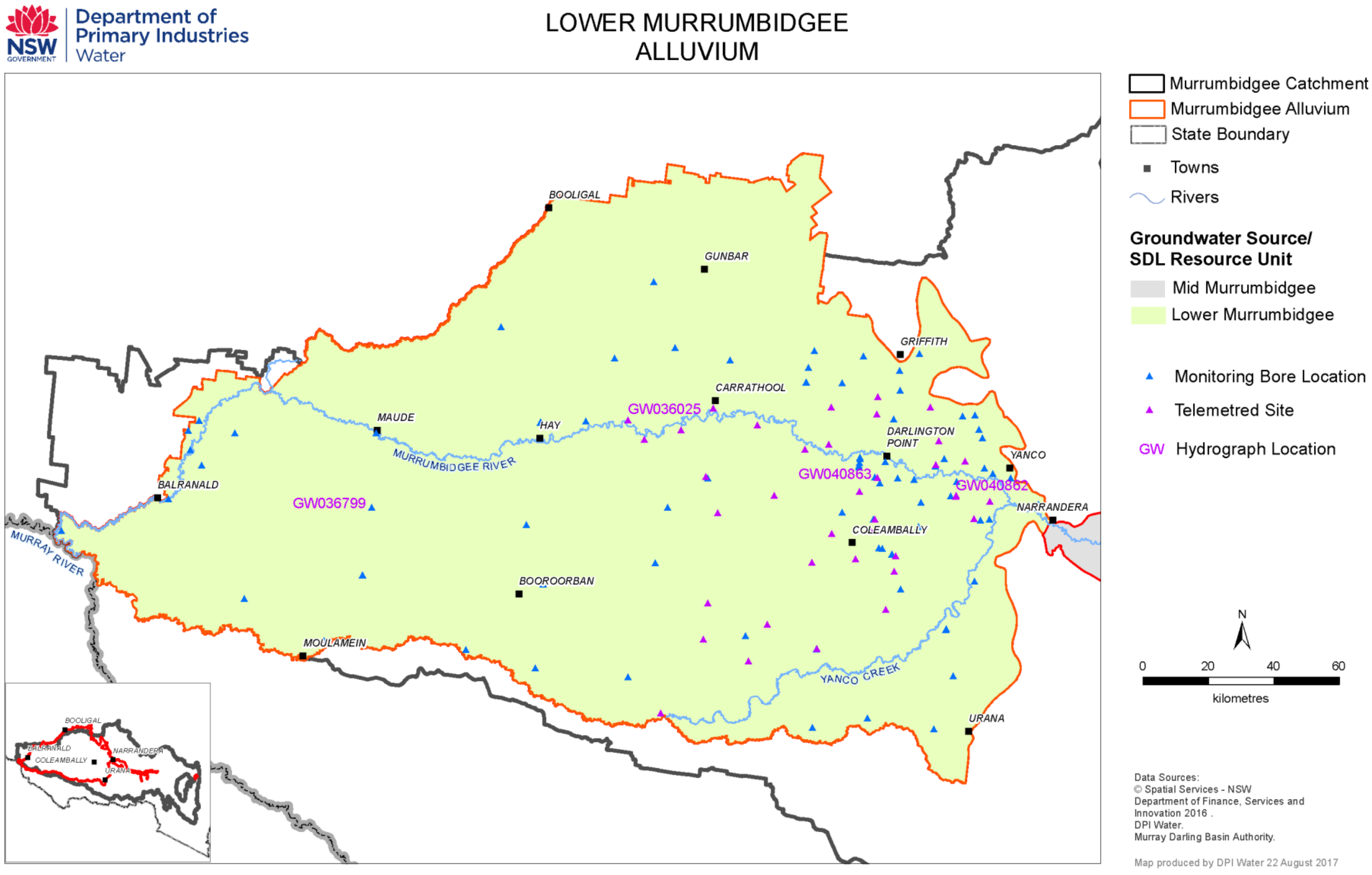


Figure 71. Lower Murrumbidgee hydrograph locations.

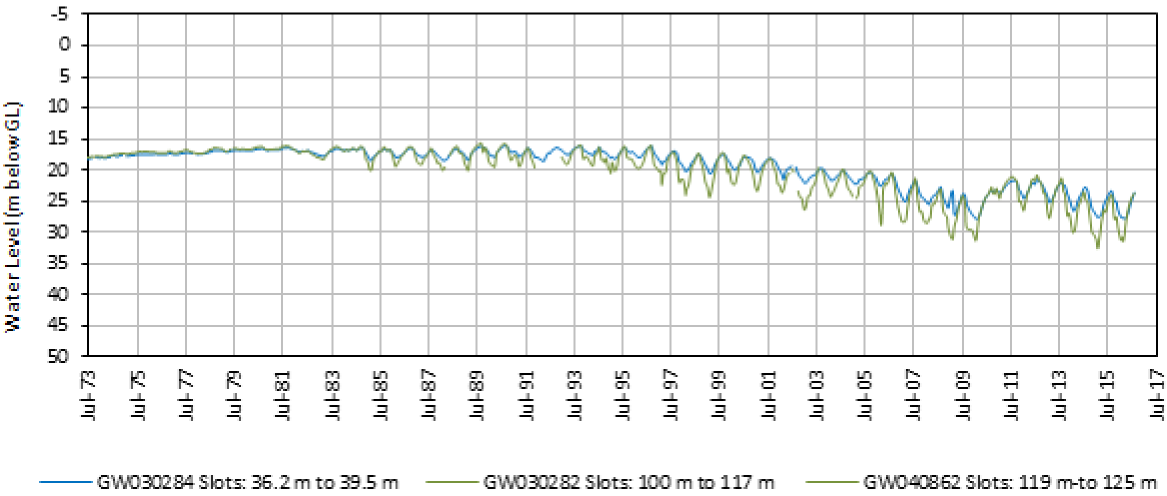


Figure 72. Hydrograph for monitoring bore site GW030284/30282/40862 – between Narrandera and Darlington Point.

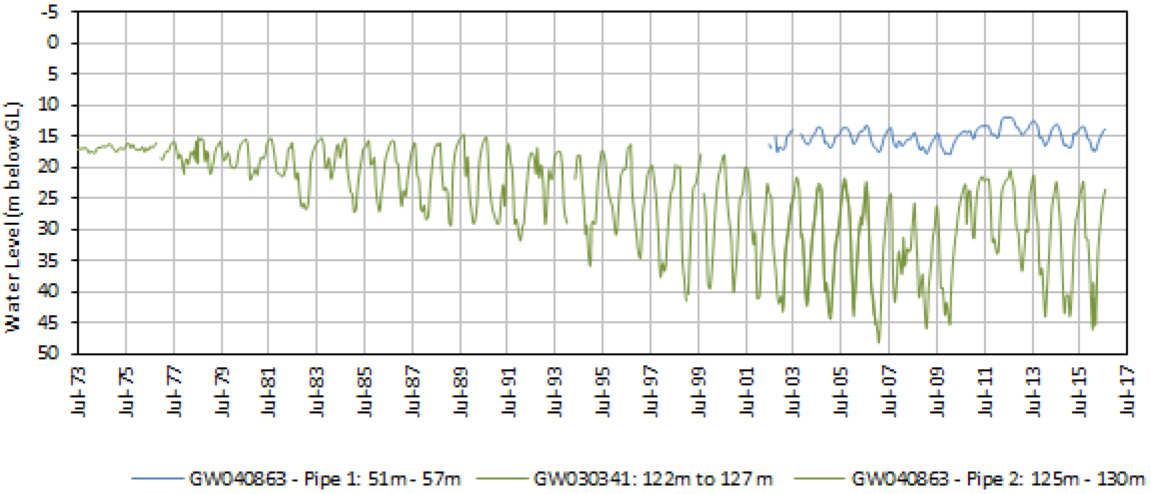


Figure 73. Hydrograph for monitoring bore site GW030341/40863 – Darlington Point.

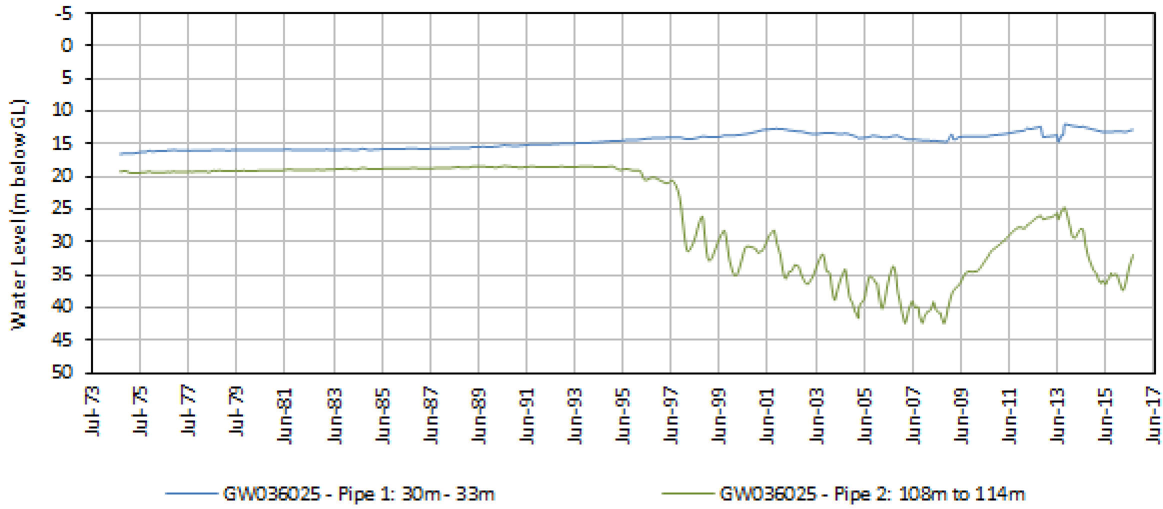


Figure 74. Hydrograph for monitoring bore site GW036025 – 30 km upstream of Hay.

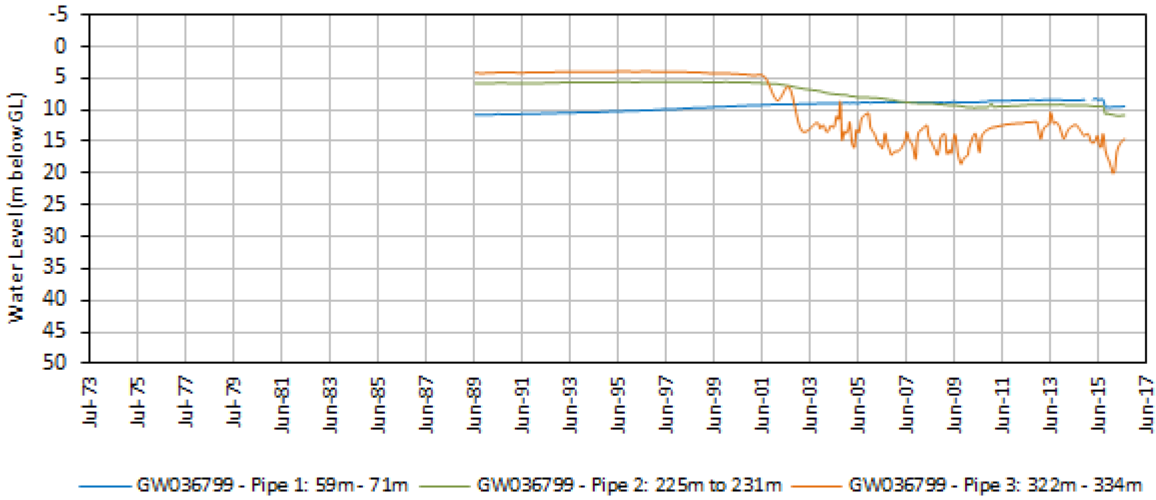


Figure 75. Hydrograph for monitoring bore site GW036799 – between Hay and Balranald.

10.4. Groundwater contour maps

Groundwater level contour maps are used to display the distribution of groundwater levels or pressures from a specific aquifer and indicate groundwater flow direction which is perpendicular to the contour lines.

For comparison purposes, contour maps have been prepared at maximum recovery level (typically in winter) for three points in time – pre development, 2006 and 2016. Contours are displayed in metres Australian Height Datum (m AHD) which provides a reference level for the measurement of groundwater level or pressure that is independent of topography.

The groundwater level contours of recovered water levels show the systems in their most natural or 'stable' states, and demonstrate the regional groundwater flow direction across the Mid and Lower Murrumbidgee aquifer systems, which is east to west, matching the formation thickness distribution and river flow. The grouping of pre-development, 2006 and 2016 recovery provides an indication of how the pressure and flow directions in the groundwater systems have changed over the long term.

In developed groundwater systems, groundwater levels typically experience seasonal fluctuation with maximum 'drawdown' in mid to late summer (when most pumping occurs), and maximum 'recovery' in mid to late winter.

Maximum drawdown contours have been prepared for the 2015/16 water year. These are displayed with the maximum recovery contours for the same year to demonstrate the change in groundwater levels and flow that can occur between the pumping and non-pumping seasons.

10.4.1. Lake George

Groundwater contour maps have not been produced for Lake George as there are insufficient monitoring bores and data for this level of presentation.

10.4.2. Mid-Murrumbidgee

The Mid Murrumbidgee is represented in this section by the Wagga Wagga and Mid Murrumbidgee Zone 3 groundwater sources, which have the most suitable monitoring networks in the Mid Murrumbidgee for displaying groundwater level contours.

The shallow aquifer throughout much of the Mid Murrumbidgee is in hydraulic connection with flows in the Murrumbidgee River, which are generally at their highest during spring and summer (due to irrigation water delivery) and may subsequently offset some of the impact, on the shallow aquifer, of seasonal groundwater pumping from the underlying deep aquifer.

Figure 76 displays groundwater level recovery maps for the shallow system and clearly reveals westward (downstream) flow in the shallow aquifer interrupted by drawdown zones in the Wagga Wagga area where significant groundwater pumping occurs from the underlying deep aquifer for town supply. A significant difference occurs between pre-development (Map A) and 2006 (Map B), in that the groundwater contours have migrated upstream, particularly in the downstream (Mid Murrumbidgee Zone 3) area, indicating a general lowering of the shallow groundwater system.

Figure 77 shows that the drawdown zones in the shallow aquifer near Wagga Wagga persist between seasons. This may be due to both continual demand on the deep groundwater system for town supply, and the effects of river regulation. There is little seasonal variation evident in the downstream (Mid Murrumbidgee Zone 3) area.

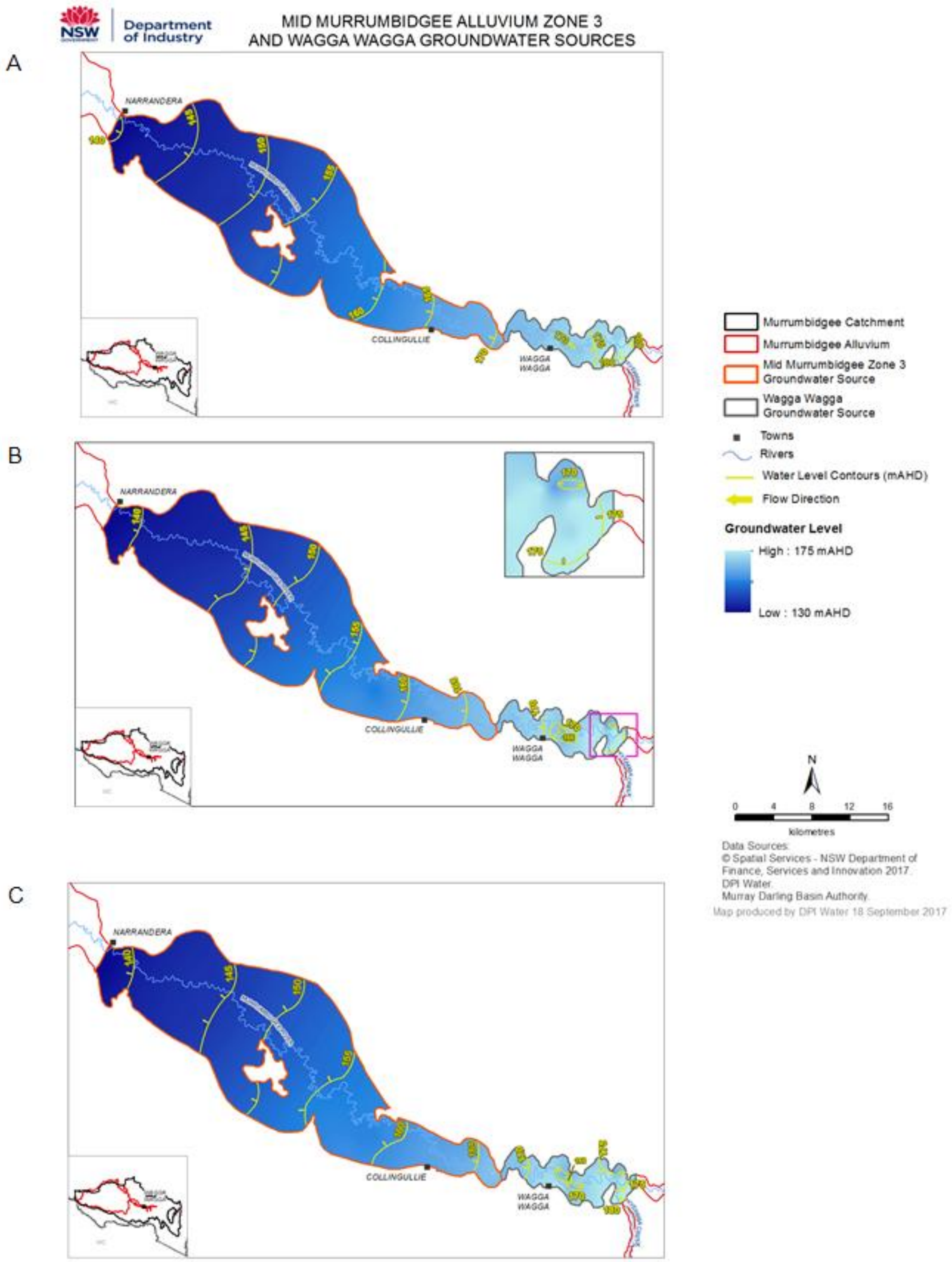


Figure 76. Groundwater level contours for the maximum recovery period: pre-development (A), 2006 (B) and 2016 (C); Mid Murrumbidgee Alluvium (Shallow).

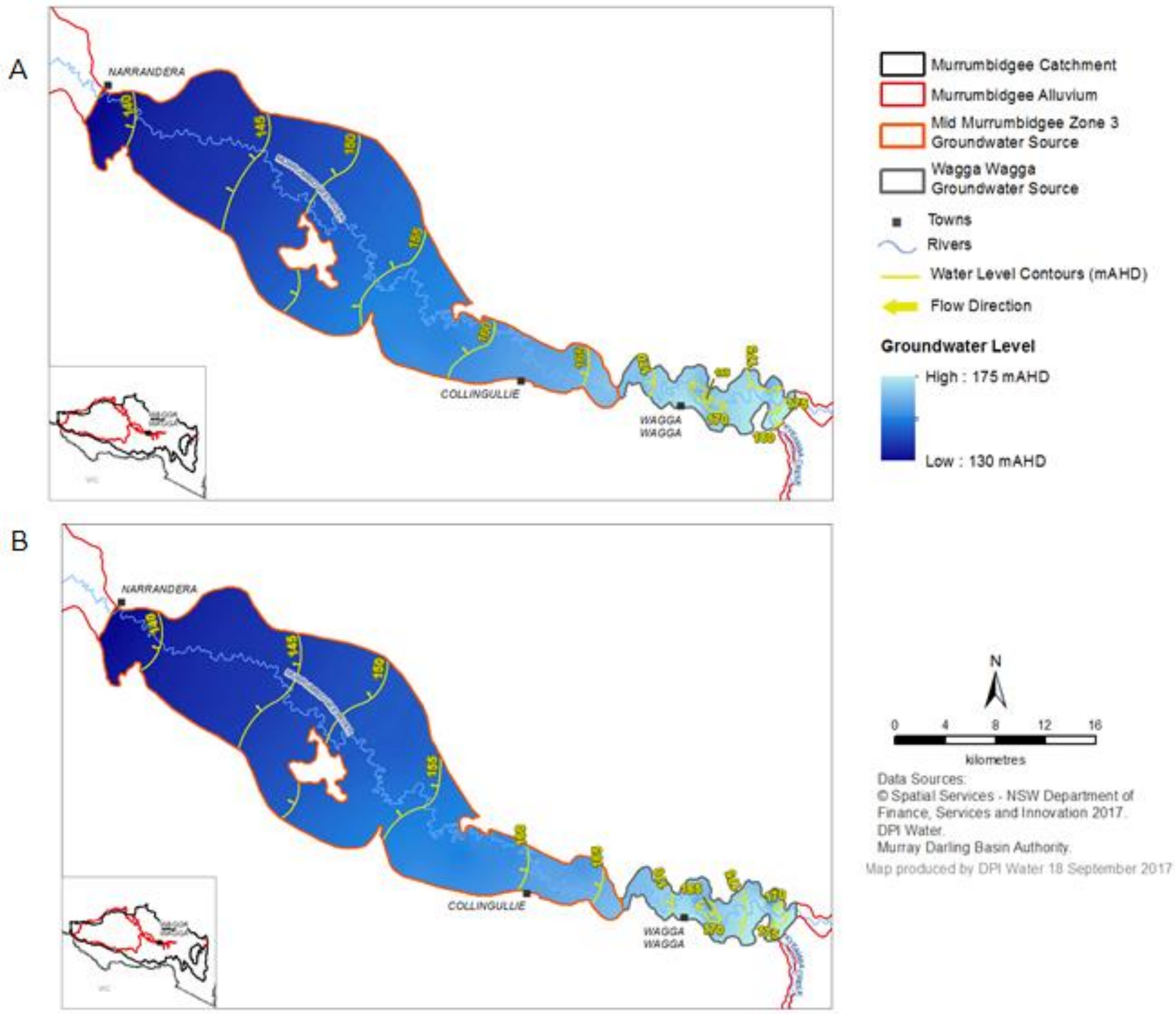


Figure 77. Groundwater level contours for the maximum recovery (A) and maximum drawdown (B) periods in 2015/16; Mid Murrumbidgee Alluvium (Shallow).

The deep aquifer in the Mid Murrumbidgee is subject to high levels of pumping for both irrigation and town supply, with most occurring in the summer months, but significant extraction occurring year-round for town supply.

Figure 78 reveals similar conditions to those of the shallow aquifer, with westward (downstream) groundwater flow, interrupted by drawdown zones in the Wagga Wagga area, and long term increasing drawdown from pre development to 2006 in the Mid Murrumbidgee Zone 3 area as indicated by the upstream migration of contours.

Figure 79 shows significant seasonal variation in 2015/16, with increased drawdown in Map B in both the Wagga Wagga area (as indicated by the greater area of the 165 m contour) and throughout the Mid Murrumbidgee Zone 3 (as indicated by the upstream migration of contours, particularly in the Collingullie area).

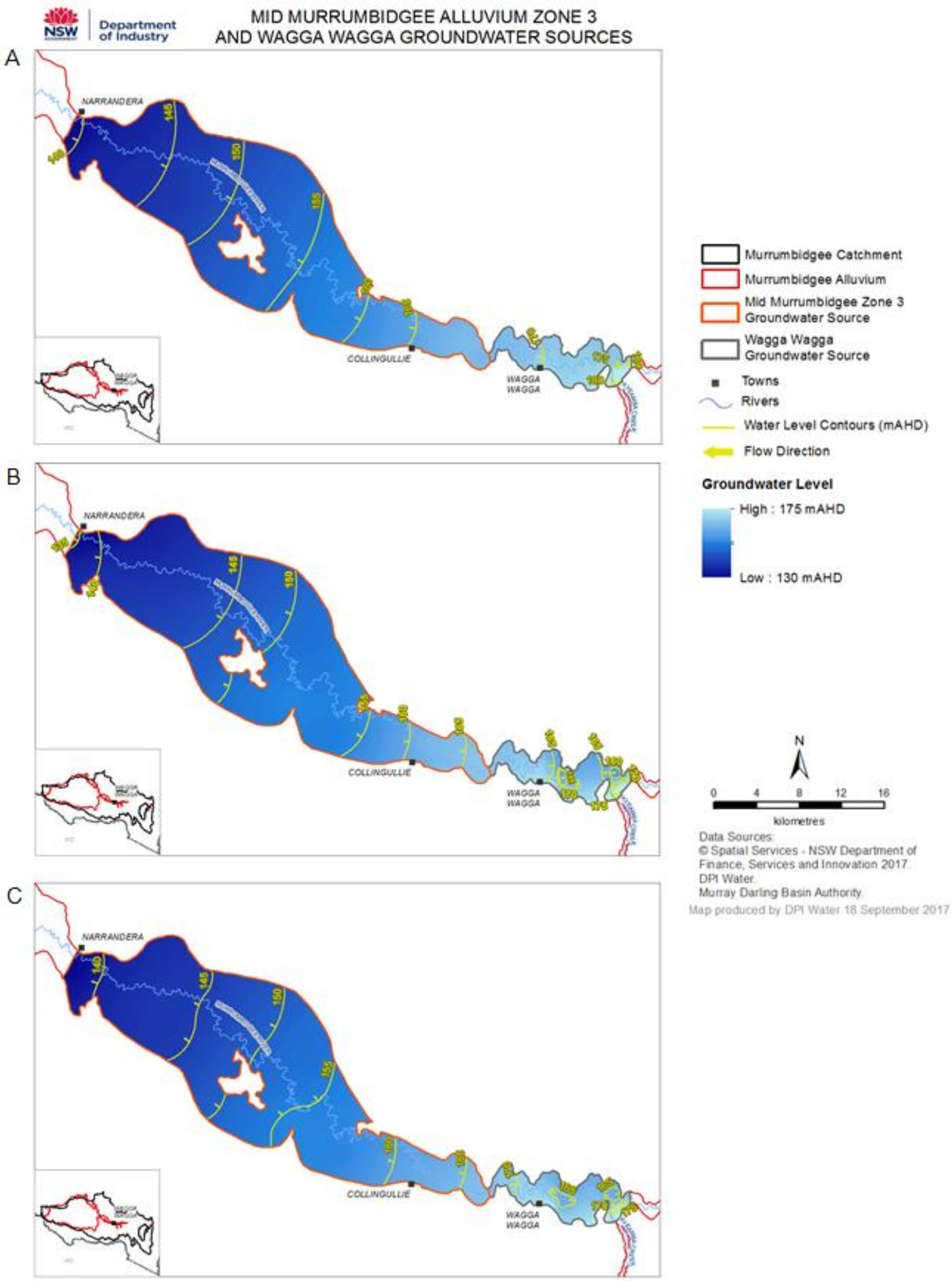


Figure 78. Groundwater level contours for the maximum recovery period: pre-development (A), 2005/06 (B) and 2015/16 (C); Mid Murrumbidgee Alluvium (Deep).

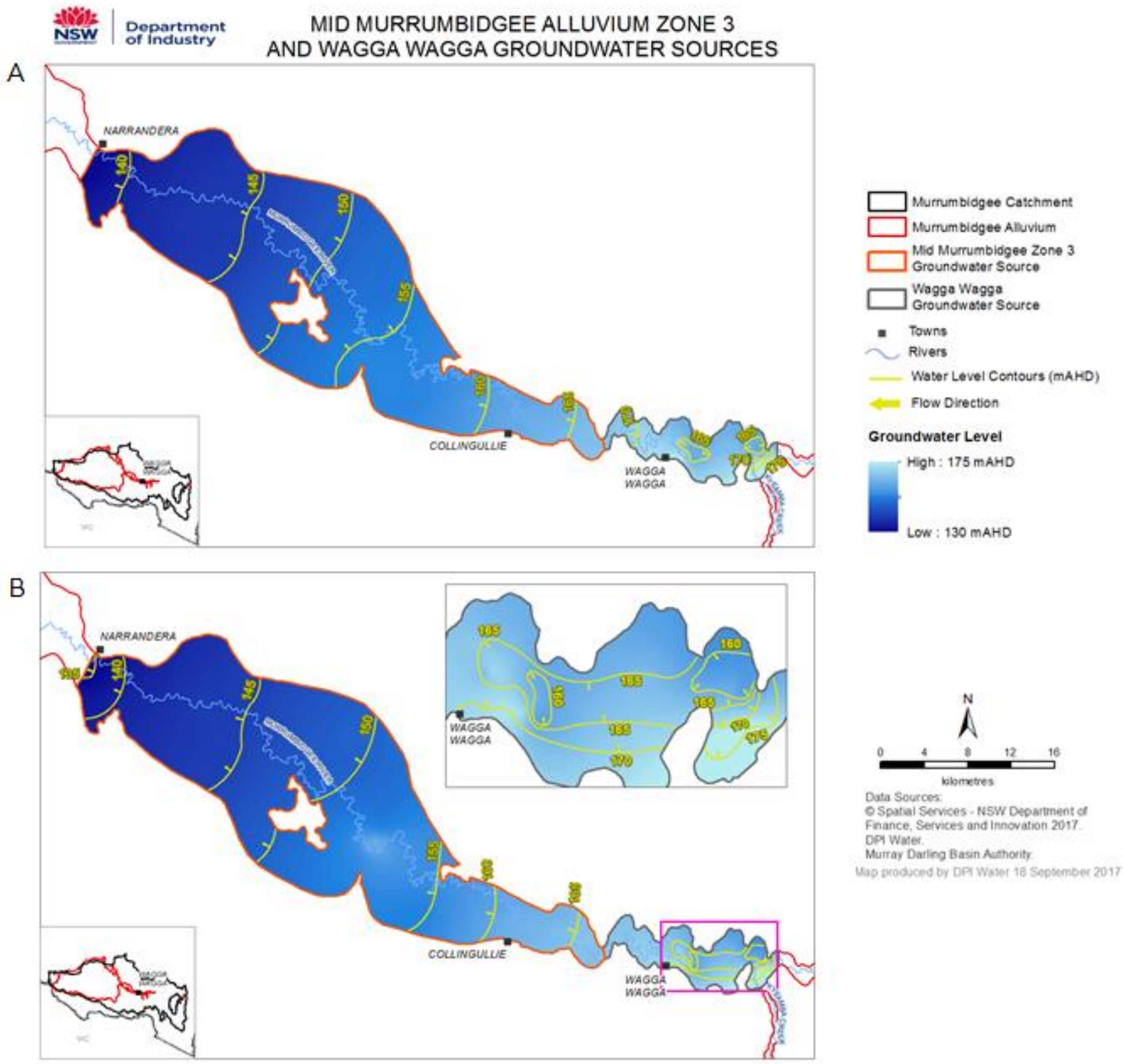


Figure 79. Groundwater level contours for the maximum recovery (A) and maximum drawdown (B) periods in 2015/16; Mid Murrumbidgee Alluvium (Deep).

10.4.3. Lower Murrumbidgee Shallow

The Lower Murrumbidgee shallow aquifer is generally not targeted for groundwater extraction, except for stock use, and being very broad cannot be considered highly connected to flows in the Murrumbidgee River. However, in the past it has been subject to unnaturally high levels of recharge in the east from irrigation and associated water delivery, leading to increased groundwater levels. In the last few decades pumping from deep aquifer has drawn groundwater from the shallow aquifer, particularly where there is natural connectivity between the two.

Groundwater levels within the shallow aquifer of the Lower Murrumbidgee require careful interpretation, as:

1. the ‘aquifer’ may vary considerably in depth and thickness, and in its hydraulic properties;
2. depending on location, the upper part of the aquifer may be subject to direct recharge from overlying shallow watertables, while the lower part may be subject to drawdown and groundwater loss in response to pumping from the underlying deep aquifer, and
3. being an unconfined to semi-confined aquifer, groundwater levels are slow to equilibrate spatially.

The above factors mean that the spatial groundwater level variation may be much more intricate than the monitoring network can identify, and the ‘local’ scale spatial variation in groundwater level may be large in relation to that of the regional scale. They also mean that the information presented is highly subject to the locations and depths of individual monitoring bores.

Figure 80 reveals groundwater flowing westwards, and a relatively stable piezometric surface over time. There is evidence of groundwater ‘mounds’ associated with overlying shallow watertables in the Murrumbidgee and Coleambally irrigation areas, and with recent irrigation development to the east of Hay. There appears to be a slight reduction of the Murrumbidgee and Coleambally shallow groundwater mounds between 2006 and 2016.

Figure 81 indicates little overall seasonal change in groundwater levels within the shallow system.

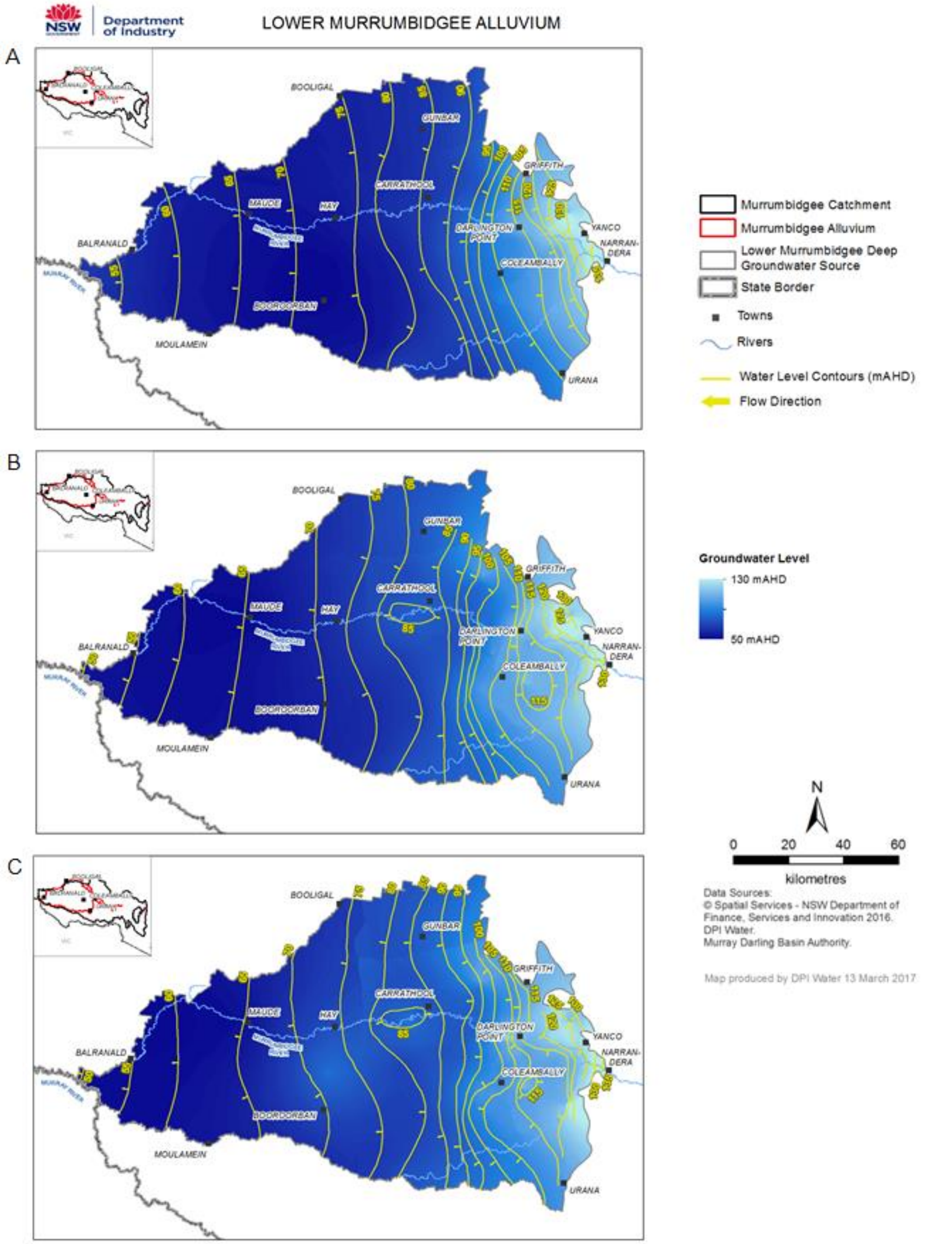


Figure 80. Groundwater level contours for the maximum recovery period: pre-development (A), 2005/06 (B) and 2015/16 (C); Lower Murrumbidgee Alluvium (Shallow).

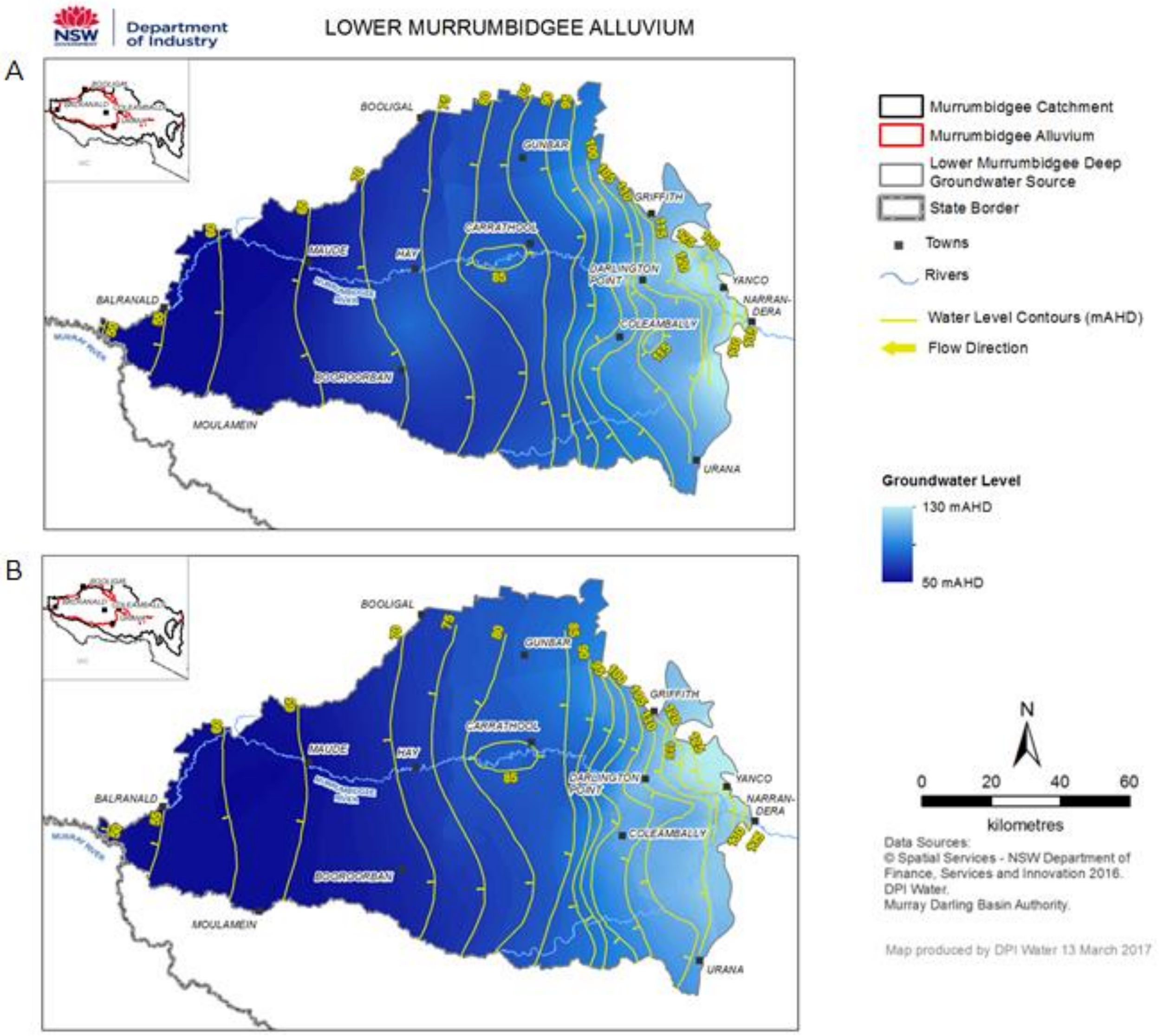


Figure 81. Groundwater level contours for the maximum recovery (A) and maximum drawdown (B) periods in 2015/16; Lower Murrumbidgee Alluvium (Shallow).

10.4.4. Lower Murrumbidgee Deep

The deep aquifer in the Lower Murrumbidgee is subject to high levels of groundwater pumping – mostly for irrigation and in the broad area from Carrathool to Narrandera (Figure 42). Groundwater extraction began in the 1970's and grew to levels up to 381,000 ML/yr (Figure 49) until a Water Sharing Plan was established in 2006/07.

Figure 82 indicates a westward flowing groundwater system, with increasing broadscale drawdown in the east, and recent localised drawdown occurring between Hay and Carrathool, and to the east of Booroorban. Significant groundwater pressure decline, of about 10 m from pre-development to 2005/06, has occurred in the east (particularly in the Carrathool to Darlington Point area), with little change during the following 10 years to 2015/16.

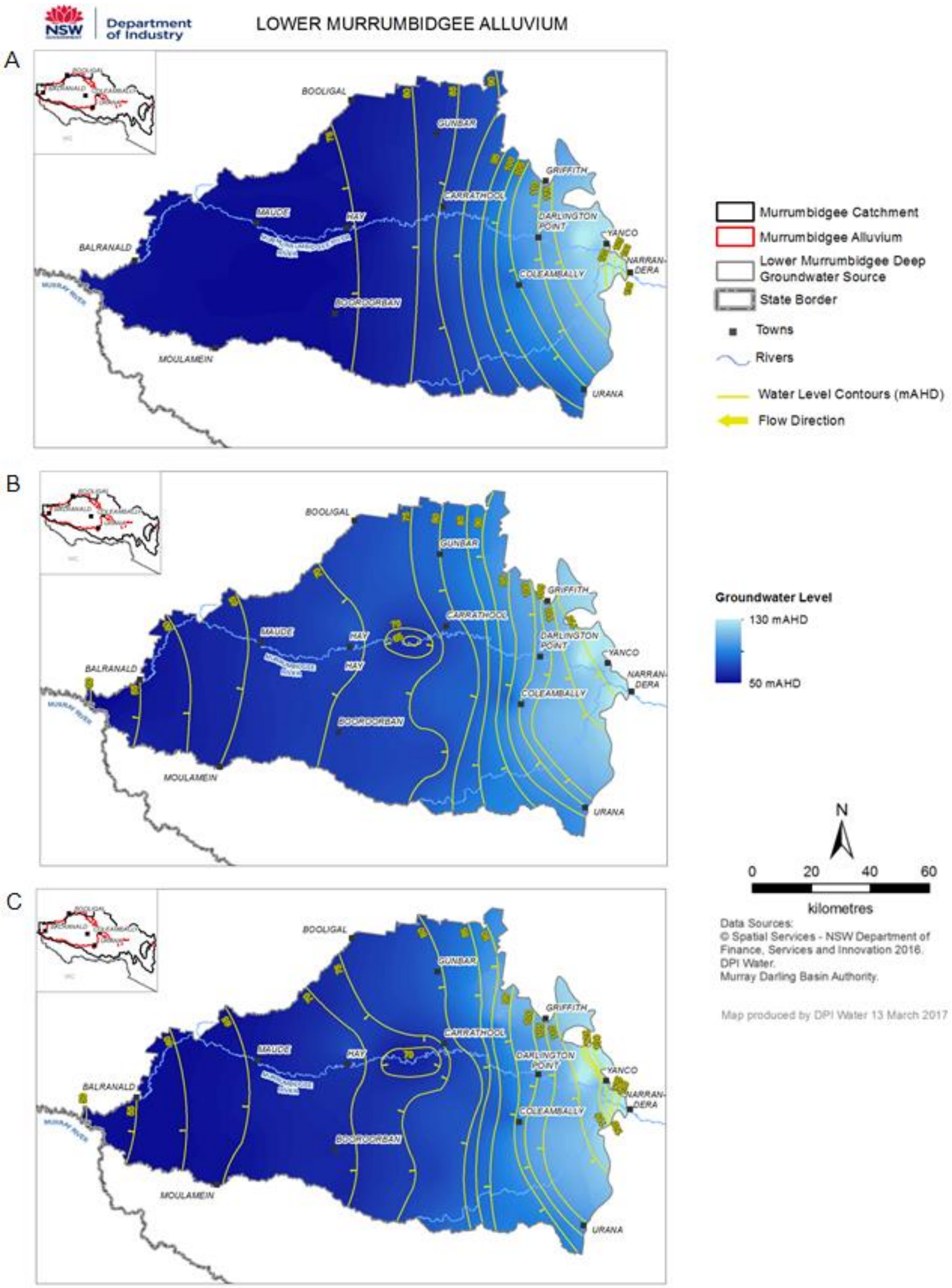


Figure 82. Groundwater level contours for the maximum recovery period: pre-development (A), 2005/06 (B) and 2015/16 (C): Lower Murrumbidgee Alluvium (Deep).

Figure 83 shows significant seasonal change occurring, with a large area of up to 15 m drawdown occurring between Carrathool, Darlington Point and Coleambally during the irrigation season.

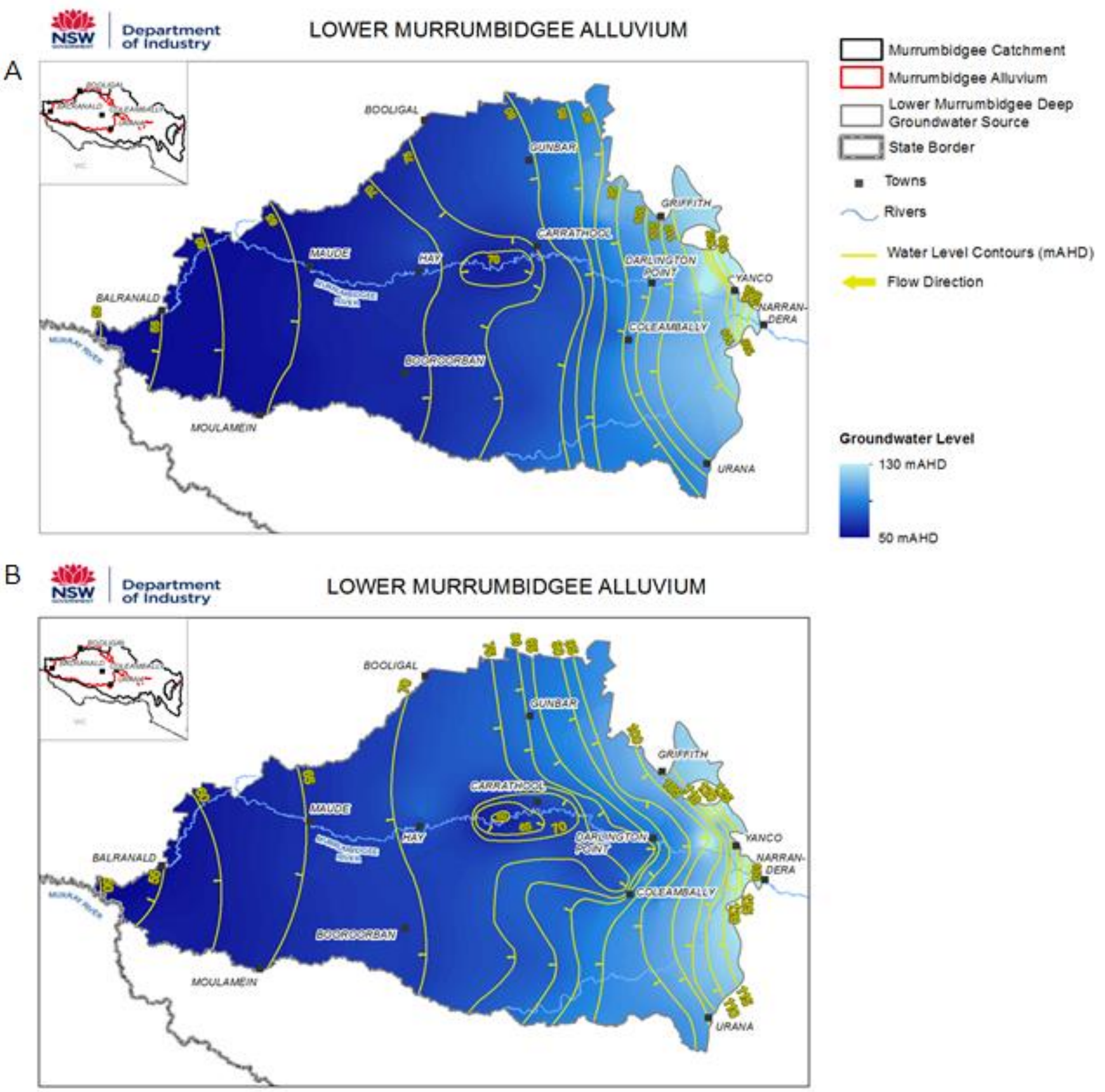


Figure 83. Groundwater level contours for the maximum recovery (A) and maximum drawdown (B) periods in 2015/16; Lower Murrumbidgee Alluvium (Deep).

10.5. Long term changes

Maps of changes in recovered groundwater levels over the time periods 2005/06 to 2015/16, and pre-development to 2015/16, are shown in Figures 85 to 88 for the Mid and Lower Murrumbidgee aquifer systems. These figures include information on average annual groundwater extraction (‘usage distribution’) to assist with interpreting the mapped groundwater level changes.

10.5.1. Mid Murrumbidgee

The maps for the shallow and deep aquifers (Figures 84 and 87) of the Mid Murrumbidgee Alluvium indicate groundwater level rises of more than 3 m in areas upstream of Wagga Wagga in both aquifers since 2005/06, and no declines.

The rise in groundwater levels is consistent with the hydrograph for monitoring bore GW025393 (Figure 69) which shows recent shallow and deep aquifer groundwater levels at that site to be similar to or slightly higher than in 2005/06 – possibly due to significant groundwater level rises associated with flooding during 2010 to 2012. The variation in the amount of rise (change) across the area may be due to some areas having significantly lower groundwater levels, due to local pumping, than others areas prior to the floods.

Downstream of Wagga Wagga a similar situation occurs, with local groundwater level rises of more than two metres in the shallow aquifer, and greater than four metres in the deep aquifer. Groundwater level declines have only occurred, in both aquifers, in a small central area. Groundwater level decline in the shallow aquifer has exceeded one metre, but in the deep aquifer is less than one metre. The changes displayed downstream of Wagga Wagga are consistent with the trends indicated in the hydrograph for monitoring bore GW030125 (Figure 70).

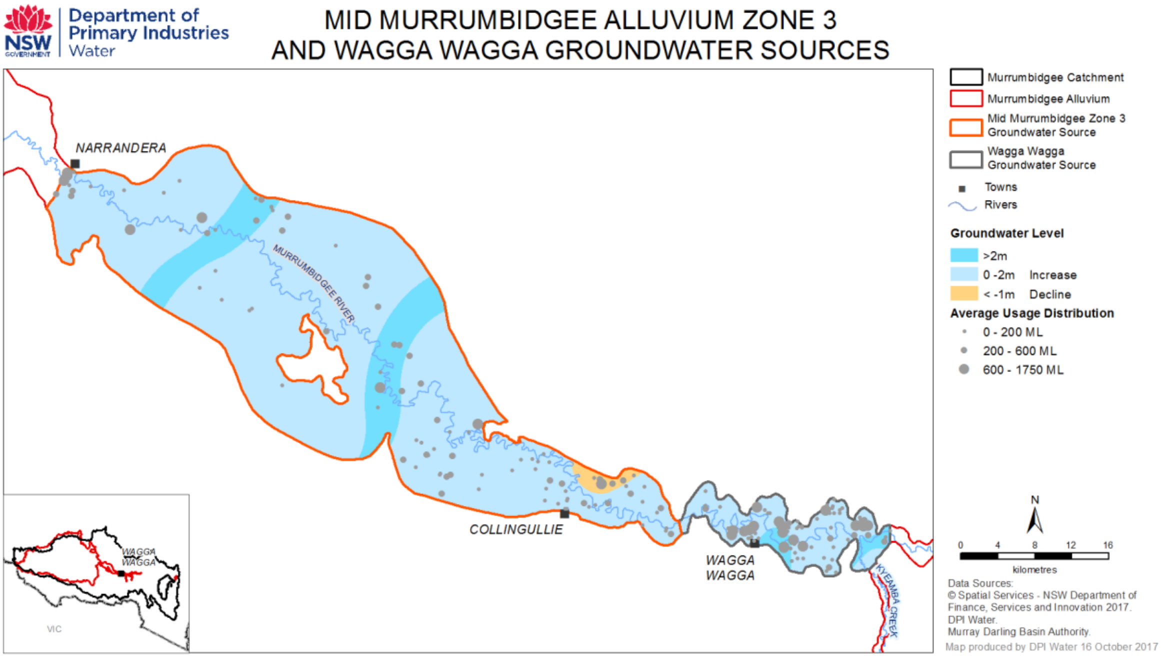


Figure 84. Change in recovered water level from 2005/06 to 2015/16 Mid Murrumbidgee Alluvium (Shallow).

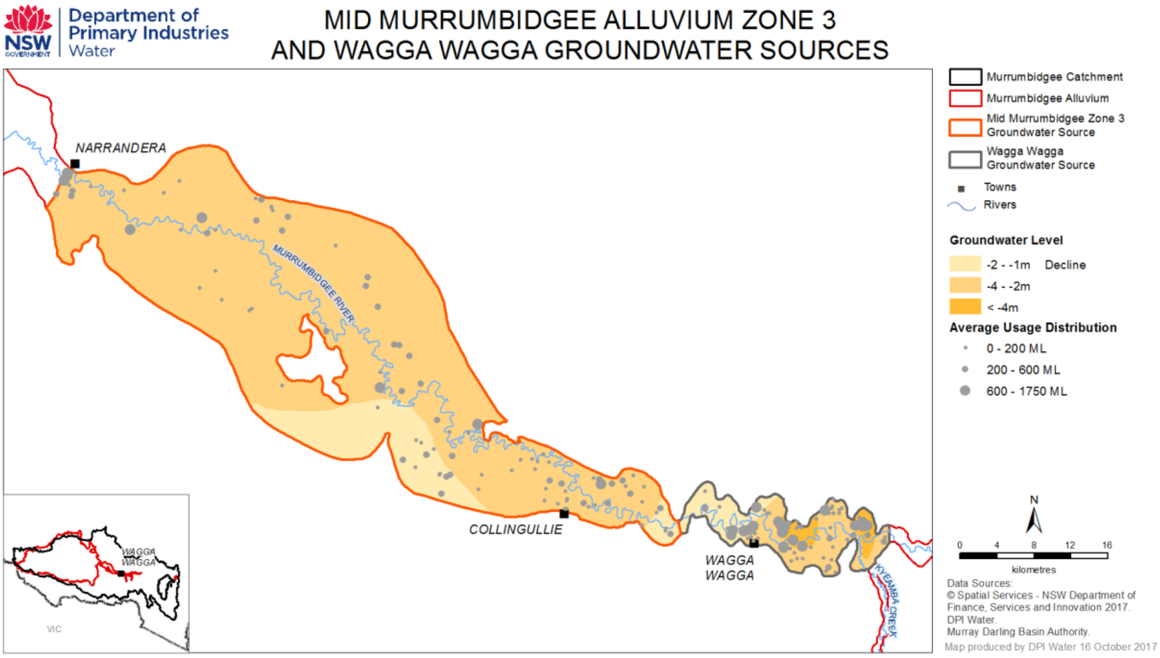


Figure 85. Change in recovered water level from pre-development to 2015/16 Mid Murrumbidgee Alluvium (Shallow).

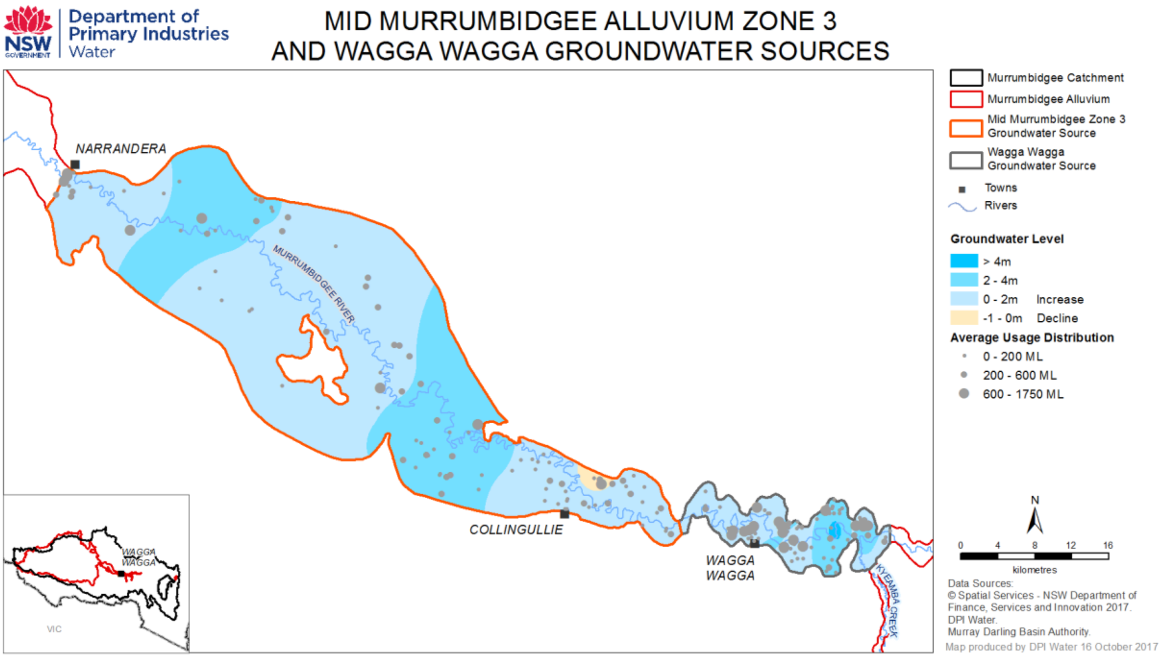


Figure 86. Change in recovered water level from 2005/06 to 2015/16 Mid Murrumbidgee Alluvium (Deep).

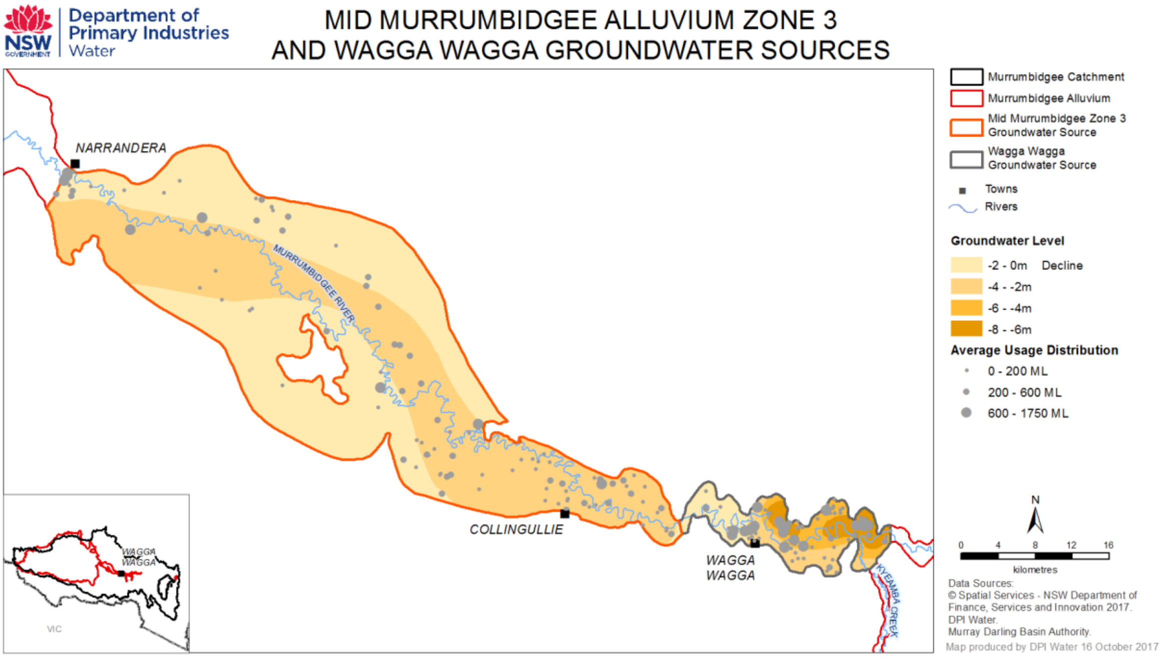


Figure 87. Change in recovered water level from pre-development to 2015/16 Mid Murrumbidgee Alluvium (Deep).

10.5.2. Lower Murrumbidgee Shallow

The map of groundwater level change from 2005/06 to 2015/16 (Figure 88) shows groundwater level decline throughout the upper (eastern) half of the water resource plan area, and stable to very minor rising conditions in the lower (western) half. Most change has been relatively minor (less than 1 m), but declines of greater than three metres have occurred in an area between Darlington Point and Narrandera where there appears to be a high level of connectivity between shallow and deep aquifers (see hydrograph for monitoring bore GW030284/30282/40862 in Figure 73). It is also coincides with an area of intense groundwater extractions. The availability of surface water for irrigation within the Murrumbidgee and Coleambally irrigation areas and improved irrigation practices may also have contributed to the observed declines.

The general decline in the eastern half of the area, which was interrupted by the high rainfall and floods in 2010-2012, is consistent with high levels of groundwater extraction, long term declines in the deep aquifer, and a moderate level of connectivity between the shallow and deep aquifers.

To the west, shallow aquifer groundwater levels have been gradually rising since the early 1970’s in response to groundwater outflow from the Murrumbidgee and Murray irrigation areas, which experienced several decades of inefficient surface water distribution and irrigation after they were first established. This flow process has a high level of momentum and, being less connected to the underlying deep aquifers than areas to the east, is not being significantly affected by deep groundwater extraction.

The changes displayed are consistent with the trends indicated in the hydrographs for monitoring bores GW030284 and GW040863 (Figures 72 and 73) in the east, and for bores GW036025 and GW036799 (Figures 74 and 77) in the west. The locations of these monitoring sites are shown in Figure 71.

The map for pre-development to 2015/16 is limited by the available data for the pre-development component. However it shows a pattern of change that is similar to that for 2005/06 to 2015/16, but with some additional variation in both groundwater level rise and decline.

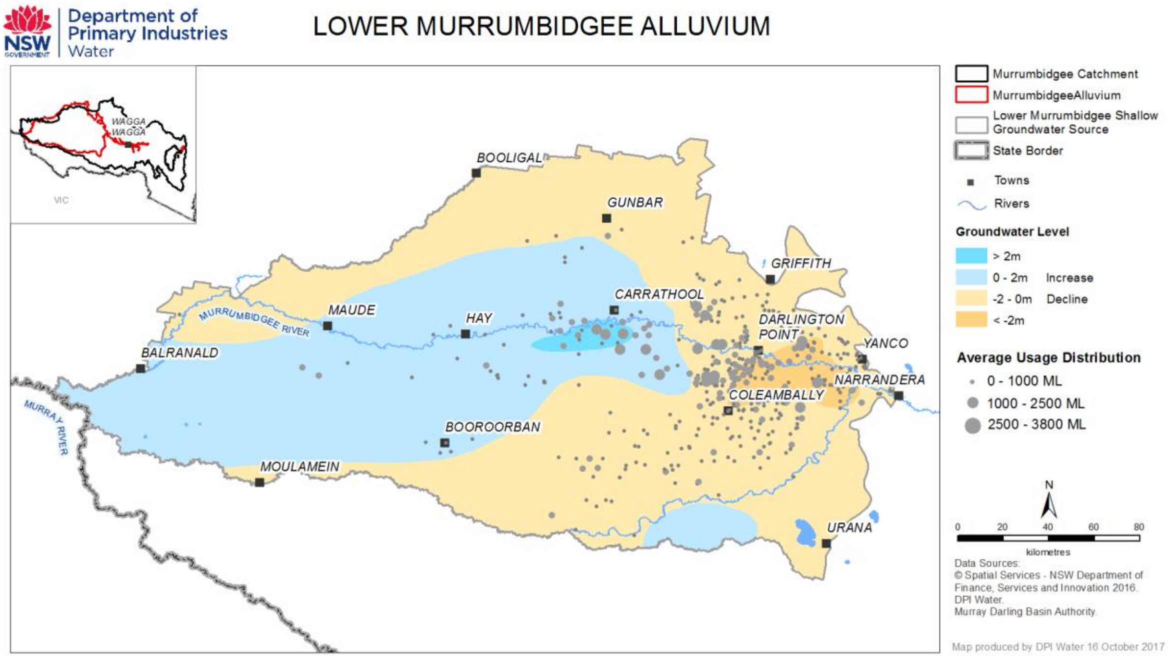


Figure 88. Change in recovered water level from 2005/06 to 2015/16 Lower Murrumbidgee Alluvium (Shallow).

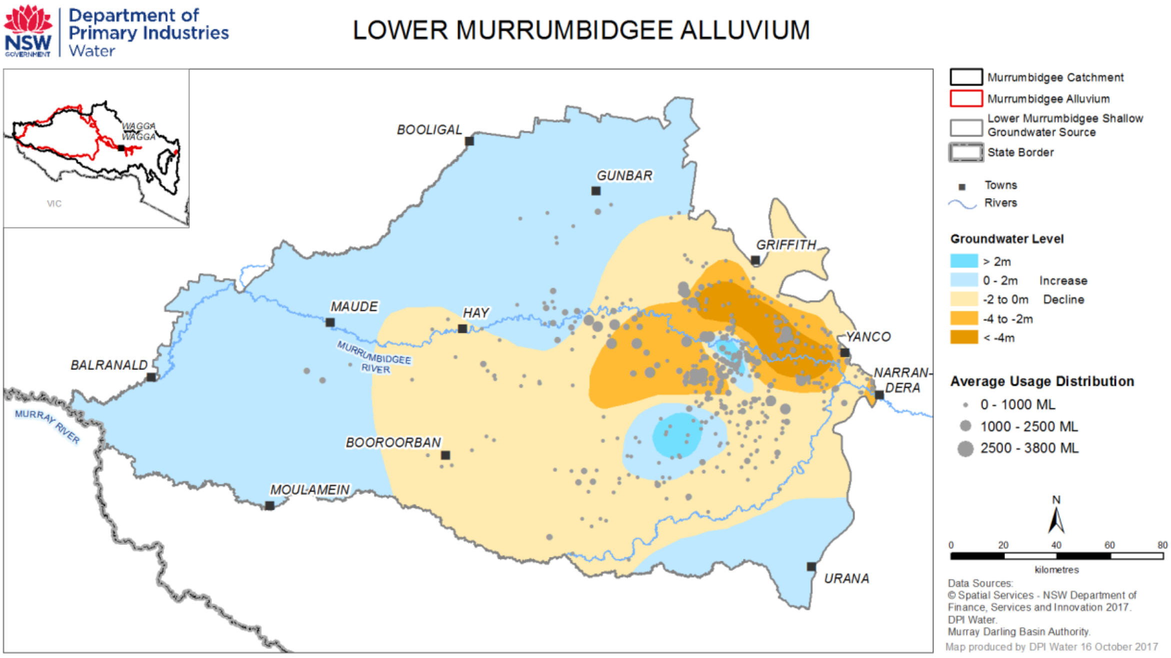


Figure 89. Change in recovered water level from pre-development to 2015/16 Lower Murrumbidgee Alluvium (Shallow).

10.5.3. Lower Murrumbidgee Deep

The map for the deep aquifer of the Lower Murrumbidgee (Figures 90 and 91) shows significant groundwater level decline in the far eastern part of the water resource plan area where most groundwater extraction occurs, and a zone of groundwater level rise in the central and southern-central parts. Elsewhere the changes have been relatively minor (less than one metre).

The higher level decline in the east is a continuing trend that is associated with high rates of groundwater extraction. This area now includes two areas that are subject to 'local impact management' restrictions that limit the trading of groundwater entitlement in order to prevent the degradation of water quality, maintain aquifer integrity, reduce third party impacts and reduce pumping and associated costs (Kumar, 2013).

The higher level rise in the central-south is in area where drawdown from groundwater extraction became noticeable in the late 1990's, and increased through the drought years through to the 2010-2012 period of high rainfall and flooding. Since then there has been decreased groundwater extraction and significant recovery of groundwater pressure.

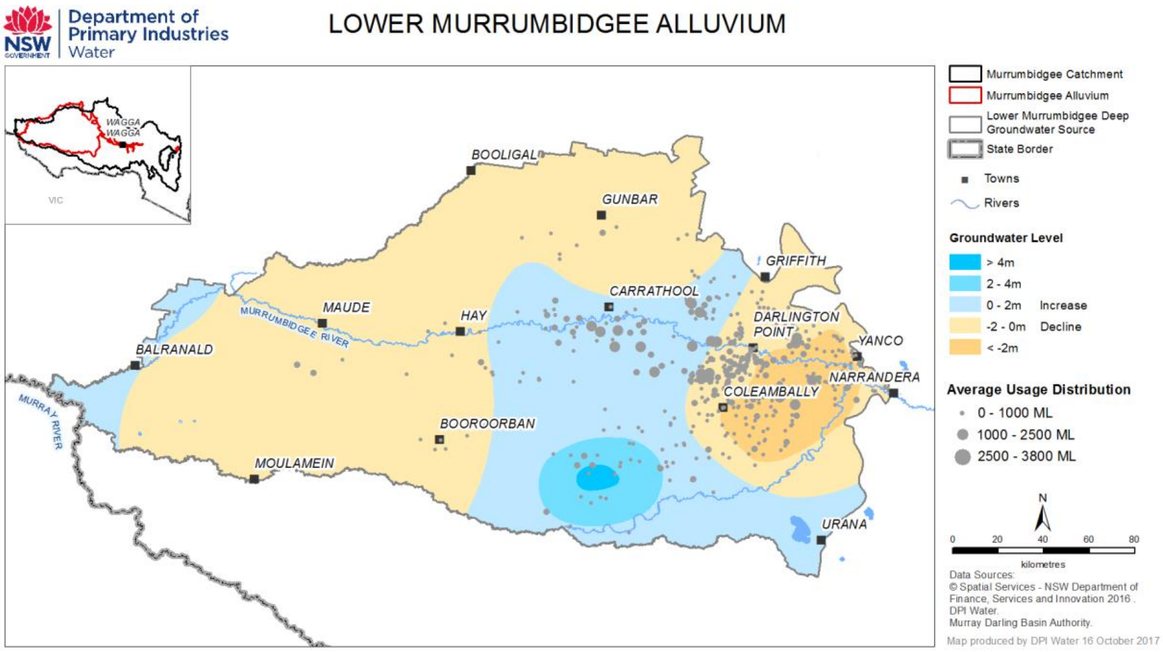


Figure 90. Change in recovered water level for 2005/06 to 2015/16 Lower Murrumbidgee Alluvium (Deep).

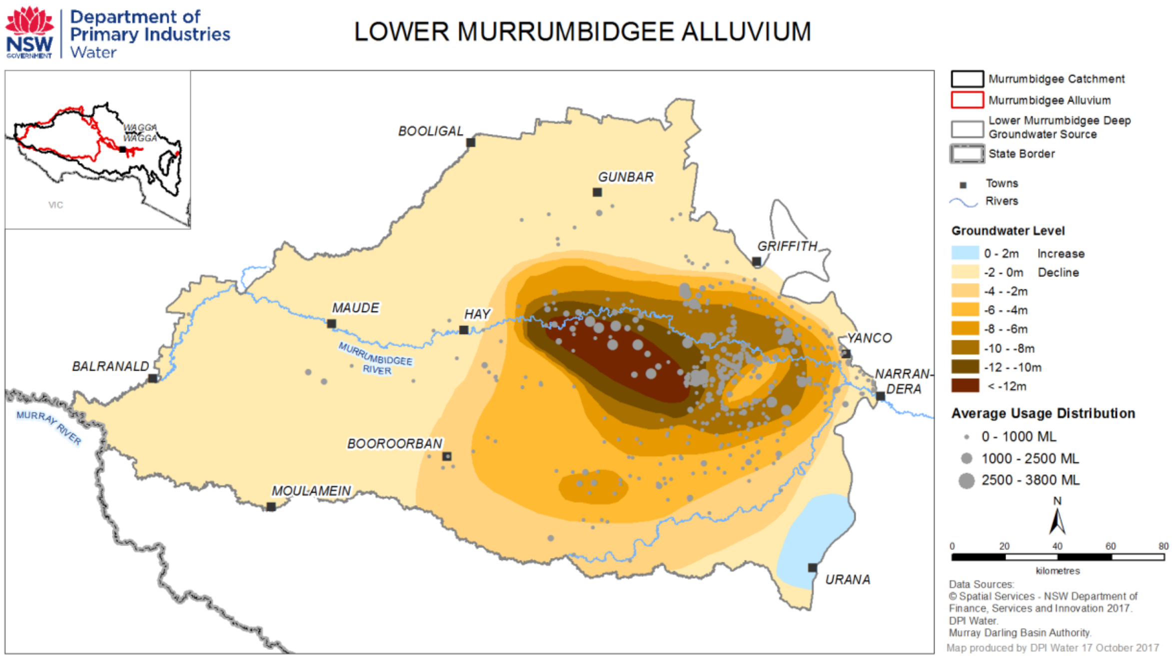


Figure 91. Change in recovered water level pre-development to 2015/16 Lower Murrumbidgee Alluvium (Deep).

11.Groundwater model

A groundwater model is any computer based method that simulates a groundwater flow system.

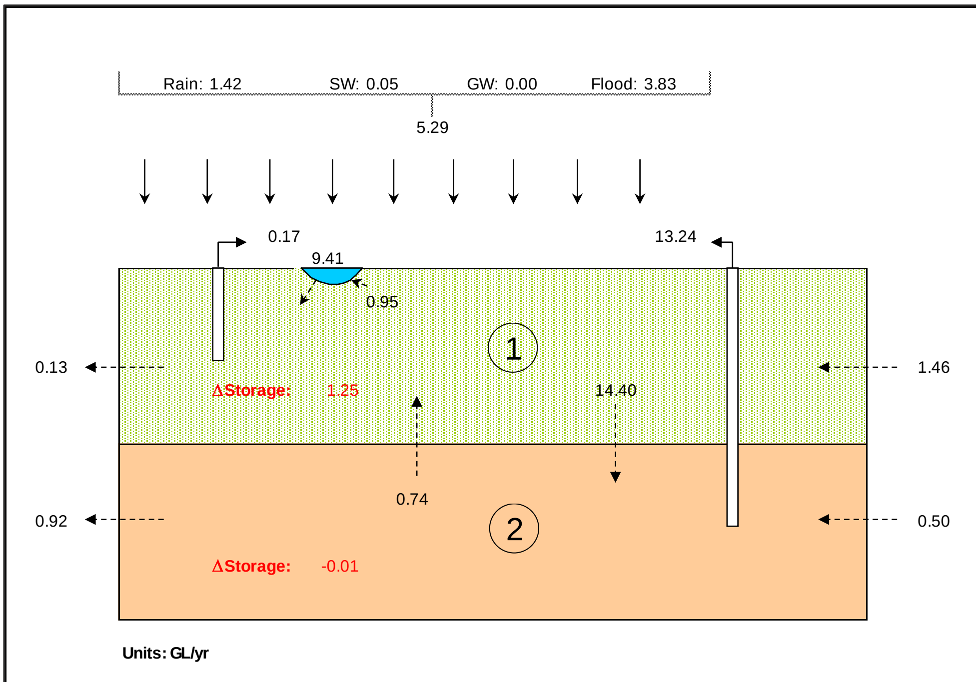
Groundwater models enable spatial and temporal prediction estimates based on simulation of inputs (rain, floods, irrigation, rivers,) and outputs (pumping, rivers, evaporation,) to and from the groundwater system.

There are many computer programs which model groundwater systems, the NSW Government generally uses a commonly used and worldwide accepted standard code called MODFLOW, developed by the United States Geological Survey (USGS).

The modelling process involves several stages such as data collation, hydrogeological system conceptualisation, software selection, model design and model calibration against measured and observed data. A sensitivity analysis is also undertaken to evaluate the influence of parameters uncertainty on model outputs.

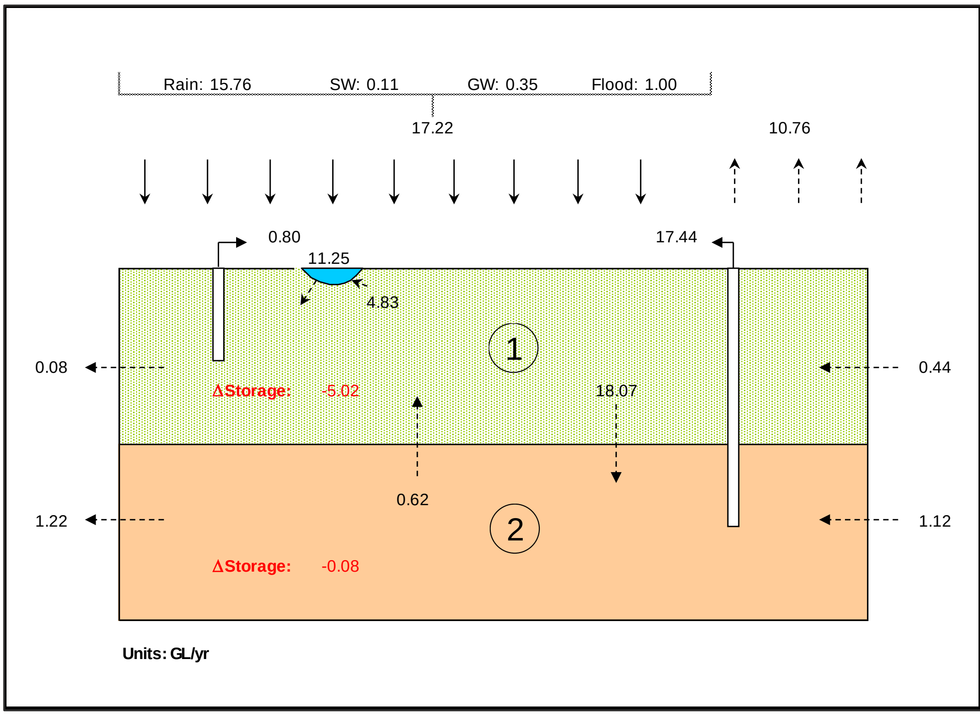
Groundwater models for the Wagga Wagga Zone (O'Neill, 2007)and Mid Murrumbidgee Zone 3 (O'Neill, 2010) of the Mid Murrumbidgee Alluvium were developed in 2007 and 2010 respectively to support resource management and the development of the water sharing plan for the Murrumbidgee Unregulated and Alluvial Groundwater Sources, which commenced in 2012.

Figures 89 and 90 show the average annual water budget output from the Wagga Wagga and Zone 3 groundwater models over the period 2006/07 to 2015/16.



Recharge		
Rainfall	IN	1.42
Irrigation - SW	IN	0.05
Irrigation - GW	IN	
Total	IN	**5.29**
Evapotranspiration	OUT	
River leakage	IN	9.41
	OUT	0.95
Net	IN	**8.46**
Groundwater pumping		
Layer 1	OUT	0.17
Layer 2	OUT	13.24
Total	OUT	**13.42**
Lateral (Boundary) flows		
Layer 1	IN	1.46
	OUT	0.13
Layer 2	IN	0.50
	OUT	0.92
Vertical (inter-layer) flows		
Layer 1 to layer 2		14.40
Layer 2 to layer 1		0.74
Storage change		
Layer 1		1.25
Layer 2		-0.01
Total		**1.24**

Figure 92. Mid Murrumbidgee Alluvium (Wagga Wagga Zone) groundwater flow model water budget output 2006/2007 to 2015/2016.



Recharge		
Rainfall	IN	15.76
Irrigation - SW	IN	0.11
Irrigation - GW	IN	0.35
Flood	IN	1.00
Total	IN	**17.22**
Evapotranspiration	OUT	10.76
River leakage	IN	11.25
	OUT	4.83
Net	IN	**6.42**
Groundwater pumping		
Layer 1	OUT	0.80
Layer 2	OUT	17.44
Total	OUT	**18.24**
Lateral (Boundary) flows		
Layer 1	IN	0.44
	OUT	0.08
Layer 2	IN	1.12
	OUT	1.22
Vertical (inter-layer) flows		
Layer 1 to layer 2		18.07
Layer 2 to layer 1		0.62
Storage change		
Layer 1		-5.02
Layer 2		-0.08
Total		**-5.11**

Figure 93. Mid Murrumbidgee Alluvium (Zone 3) groundwater flow model water budget output 2006/2007 to 2015/2016.

The water budget for Lower Murrumbidgee groundwater sources was not available at the time this report was prepared as the numerical model is currently under revision. It will be provided later.

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