MURRAY ALLUVIUM WATER RESOURCE PLAN

Groundwater Resource Description

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Glossary

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

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

Beneficial use (category)	[1]A general categorisation of groundwater uses based on water quality and the presence or absence of contaminants. Beneficial use is the equivalent to the 'environmental value' of water.
Bore (or well)	A hole or shaft drilled or dug into the ground.
Brackish water	Water with 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 25º C. 1 dS/m = 1000 µS/cm
Environmental Value	[2]Particular values or uses of the environment that is 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.

[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	Water that occurs beneath the ground surface in the saturated zone.
Groundwater Dependent Ecosystem (GDE)	[3]Ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services.
Geological formation	A fundamental lithostratigraphic unit used in the local classification of strata and classified by the distinctive physical and chemical features of the rocks that distinguish it from other formations.
Groundwater equilibrium	A state where the forces driving groundwater flow have reached a balance in a groundwater system, for example where groundwater inflow equals groundwater outflow.
Groundwater system	Any type of saturated sequence of rocks or sediments that is in hydraulic connection. The characteristics can range from low yielding and high salinity water to high yielding and low salinity water.
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

[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.

	other means for example deepening an existing bore, funding extra pumping costs or constructing a new pipeline or bore.
Management zone	A defined area within a water source where a particular set of water sharing rules applies.
Mesozoic	The Mesozoic Era spanned 252 to 66 million years ago
Metamorphic rock	Rocks that result from partial or complete recrystallisation in the solid state of pre-existing rocks under conditions of temperature and pressure.
Minimal impact considerations	Factors that need to be assessed to determine the potential effect of aquifer interference activities on groundwater and its dependent assets.
Monitoring bore	A specially constructed bore used to measure groundwater level or pressure and groundwater quality at a specific depth. Not intended to supply water.
Ongoing take	The take of groundwater that occurs after part or all of the principal activity has ceased. For example extraction of groundwater (active take) entering completed structures, groundwater filling abandoned underground workings (passive take) or the evaporation of water (passive take) from an abandoned excavation that has filled with groundwater.
Outcrop	Rocks which are exposed at the land surface.
Piezometric or Potentiometric head	The pressure or hydraulic head of the groundwater at a particular depth in the ground. In unconfined aquifers this is the same as the water table.
Palaeozoic	The Palaeozoic Era spanned 541 to 252 million years ago.
Perched water table	A local water table of very limited extent which is separated from the underlying groundwater by an unsaturated zone.
Permeability	The capacity of earth materials to transmit a fluid.
Porous rock	Consolidated sedimentary rock containing voids, pores or other openings in the rock (such as joints, cleats and/or fractures.
Pre-development	Prior to development of a groundwater resource.
Proterozoic	The Proterozoic Era spanned 2.5 billion to 541 million years ago.
Recharge	The addition of water into a groundwater system by infiltration, flow or injection from sources such as rainfall, overland flow, adjacent groundwater sources, irrigation, or surface water sources.
Recovery	The rise of groundwater levels or pressures after groundwater take has ceased. Where water is being added, recovery will be a fall.

Recovery decline	Where groundwater levels or pressures do not fully return to the previous level after a period of groundwater removal or addition.
Reliable water supply	[4]Rainfall of 350mm or more per annum (9 out of 10 years); or a regulated river, or unregulated rivers where there are flows for at least 95% of the time (i.e. the 95th percentile flow of each month of the year is greater than zero) or 5th order and higher rivers; or groundwater aquifers (excluding miscellaneous alluvial aquifers, also known as small storage aquifers) which have a yield rate greater than 5L/s and total dissolved solids of less than 1,500mg/L.
River Condition Index (RCI)	This is a spatial tool used to measure and monitor the long term trend of river condition, but also reports on instream values and risk to instream values from extraction and geomorphic disturbance.
Salinity	The concentration of dissolved minerals in water, usually expressed in EC units or milligrams of total dissolved solids per litre.
Salt	A mineral which in a liquid will readily dissociate into its component ionic species for example NaCl into Na^+ and Cl^- ions.
Saturated zone	Area below the water table where all soil spaces, pores, fractures and voids are filled with water.
Sedimentary rock	A rock formed by consolidation of sediments deposited in layers, for example sandstone, siltstone and limestone.
Share component	An entitlement to water specified on an access licence, expressed as a unit share or for specific purpose licences a volume in megalitres (e.g. 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.

[4] As defined by Strategic Regional Land Use Plans

Water balance	A calculation of all water entering and leaving a system.
Water resource plan	[5]A plan made under the *Commonwealth Water Act 2007* that outlines how a particular area of the Murray–Darling Basin's water resources will be managed to be consistent with the Murray–Darling Basin Plan. These plans set out the water sharing rules and arrangements relating to issues such as annual limits on water take, environmental water, managing water during extreme events and strategies to achieve water quality standards and manage risks.
Water sharing plan	[6]A plan made under the *Water Management Act 2000* which set out the rules for sharing water between the environment and water users within whole or part of a water management area or water source.
Water source	Defined under the *Water Management Act 2000* as 'The whole or any part of one or more rivers, lakes or estuaries, or one or more places where water occurs naturally on or below the surface of the ground and includes the coastal waters of the State. Individual water sources are more specifically defined in water sharing plans.
Water table	Upper surface of groundwater at atmospheric pressure, below which the ground is saturated.
Water year	Twelve month period from 1 July to 30 June
Yield	The amount of water that can be supplied over a specific period.

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

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

1 Introduction

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

Under the Murray-Darling 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 Murray Alluvium Water Resource Plan area is shown in Figure 1 and is located within the Murray and Murrumbidgee catchments that form part of the Murray-Darling Basin in southern NSW. It covers an area of about 19,200 km² and represents about two percent of the Murray-Darling Basin.

The Murray Alluvium Water Resource Plan will cover groundwater within alluvial deposits of the Murray River from the Hume Dam, upstream of Albury, to approximately 15 km west of Kyalite and the alluvium along Billabong Creek between Little Billabong and Rand.

The Murray Alluvium Water Resource Plan area (GW8 - Murray-Darling Basin reference number) is composed of four SDL resource units: the Lower Murray Deep Alluvium (GS24), Lower Murray Shallow Alluvium (GS27), Upper Murray Alluvium (GS46), and the Billabong Creek Alluvium (GS13) shown in Figure 1. These SDL resource units correlate directly to groundwater sources currently covered by water sharing plans. They are the:

- Lower Murray Groundwater Source (Lower Murray Deep Alluvium) managed under *Water Sharing Plan for Lower Murray Groundwater Source ,*
- Lower Murray Shallow Groundwater Source (Lower Murray Shallow Alluvium) managed under *Water Sharing Plan for Lower Murray Shallow Groundwater Source 2012,*
- Upper Murray Groundwater Source (Upper Murray Alluvium) managed under the *Water Sharing Plan for the Murray Unregulated and Alluvial Water Sources 2011,* and the
- Billabong Creek Alluvial Groundwater Source (Billabong Creek Alluvium) managed under the *Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012.*

The Lower Murray Deep Alluvium and the Lower Murray Shallow Alluvium extends between Billabong Creek and Murray River from Corowa to Goodnight. The Upper Murray Alluvium extends from Hume Dam near Albury to Corowa. Billabong Creek Alluvium extends between Little Billabong and Rand.

This report describes the location, climate and physical attributes of the Murray 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 and groundwater behaviour.

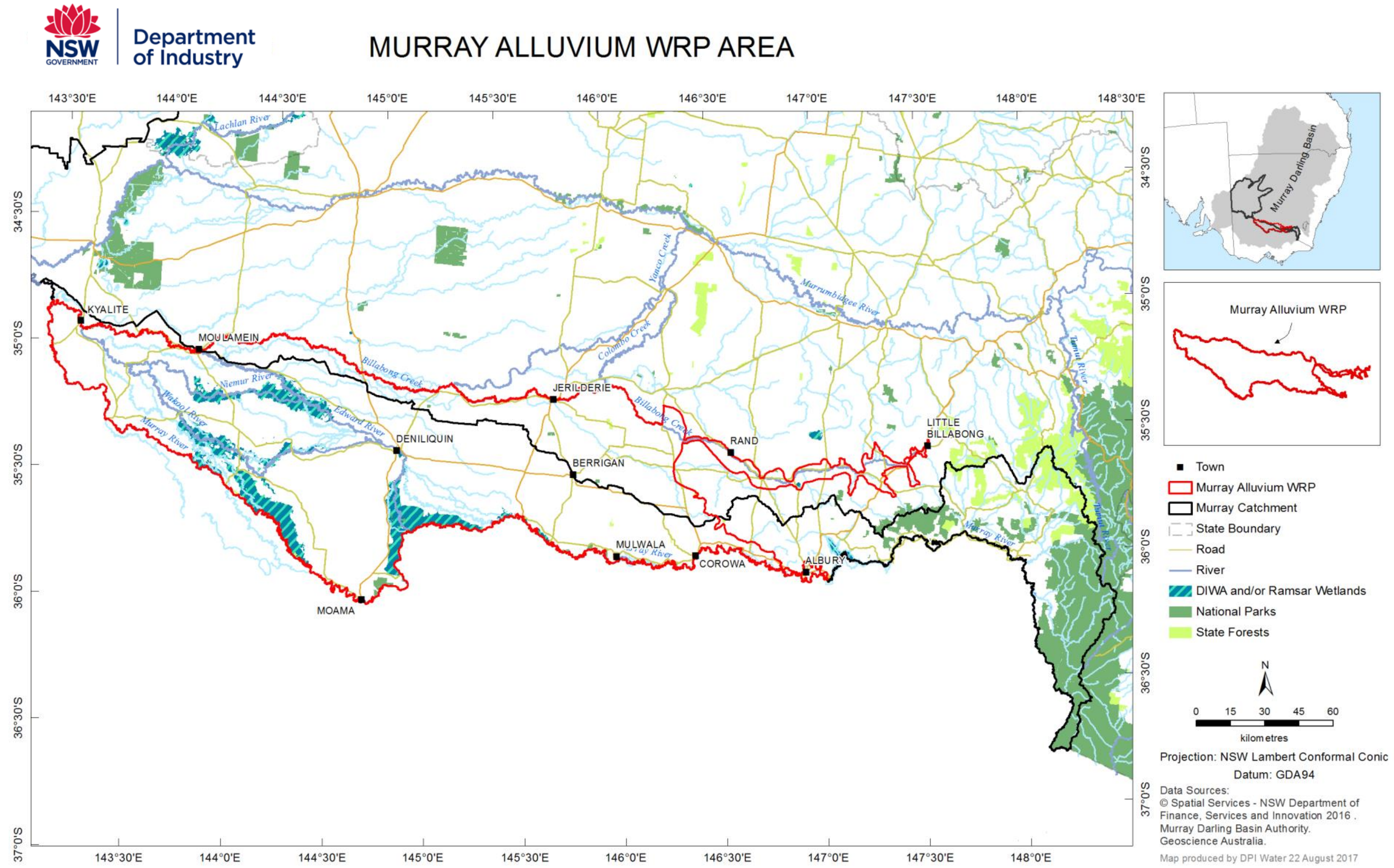


Figure 1 Location of the Murray Alluvium water resource plan Area

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 inland NSW.

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

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

From 1986, comprehensive volumetric groundwater allocation policies were introduced throughout the State.

The objectives were to more effectively manage development in those groundwater systems where the resource was fully committed and to encourage the use of groundwater where it was underutilised.

2.2 NSW water reforms

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

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

The 1990s policy reforms drove the development of the *Water Management Act 2000*. 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 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 in 22 groundwater sources within the Murray-Darling Basin. These embargoes remained in effect until the commencement of water sharing plans for the groundwater sources that they covered.

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

2.3 Lower Murray Alluvium

Rising shallow water tables has been a significant environmental issue in the Lower Murray since the 1970s due to irrigation from surface water. Groundwater pumping from the shallow water table aquifer was encouraged via unrestricted licences since the 1990s as a way of mitigating the associated waterlogging and land salinisation. From 2001, new licences for shallow groundwater extraction were granted with a volumetric entitlement and in 2004 an embargo on additional entitlements was introduced. The previously unrestricted licences were progressively converted to volumetric licences and this process was completed in 2010. The *Water Sharing Plan for Lower Murray Shallow Groundwater Source* was developed and commenced in April 2012. Prior to this, groundwater access in the shallow water table aquifer was regulated under the *Water Act 1912*.

For the regional, highly productive aquifers of the Lower Murray, the first volumetric groundwater policy, 'An Interim Volumetric Bore Licensing Policy' for the Lachlan, Murrumbidgee, Murray, and Macquarie Valleys, was introduced in 1983. Under this interim policy, entitlements were issued for new bores based on property area and surface water availability, capped to a maximum property entitlement of 972 ML/year.

Non-volumetric licences were converted to volumetric entitlements based on property areas in 1984. In 1991 the "Revised Groundwater Allocation Guidelines for the groundwater resources of the Murray Geological Basin, NSW" commenced which introduced 'carry-over' and 'borrowing' water accounting and also increased the property entitlement limits.

The deeper alluvium of the Lower Murray was identified as a groundwater system at high risk under a state-wide aquifer evaluation program in 1998 (DLWC, 1998). Those risks included over-allocation and groundwater level decline. An embargo was introduced in 1998 that prohibited applications for new entitlements.

A groundwater management committee was established for the Lower Murray Alluvium in 1998. This group contributed to the development of water sharing plan for the Lower Murray

Groundwater Source. The *Water Sharing Plan for Lower Murray Groundwater Source 2006* commenced in November 2006.

2.4 Upper Murray Alluvium

Groundwater access in this water source was regulated under the Water Act 1912 until the *Murray Unregulated and Alluvial Water Sharing Plan* was implemented in January 2012.

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.

An embargo on new entitlements was placed in 2000 and continued until the commencement the water sharing plan in 2012. Temporary trades of groundwater however, were allowed with some restrictions.

2.5 Billabong Creek Alluvium

Prior to 1984, groundwater for irrigation was authorised based on the irrigation area (and crops) and a volume wasn't specified in the licence. These licences were converted to volumetric entitlements in 1984. Since 1984, all bore licences issued have volumetric entitlements. Purposes such as town water, recreation and industry were determined based on the water requirement.

An embargo on new entitlements was placed in late 2005 and remained effective until the commencement of *Murrumbidgee Unregulated and Alluvial Water Sharing Plan in 2012*.

3 Regional Setting

3.1 Topography

The Murray River system and its floodplain are the main topographic features of the WRP area (Figure 2). From its headwaters near Mt. Kosciusko, at around 1,430 m above sea level, the Murray River flows westerly through steep-sided valleys into the Hume Dam near Albury.

Hume Dam is the major water storage facility with a capacity of 3,000 gigalitres that provides water for town water supplies, irrigation, stock and domestic use, industry, and environmental flows for New South Wales, Victoria and South Australia.

Downstream of Hume Dam near Albury, the river flows in a westerly direction through the Upper Murray Alluvium entering the flat plains near Corowa and into the Lower Murray Alluvium. It flows out of the Murray Alluvium WRP Area west of the junction of Murray and Wakool rivers and continues flowing on the much wider flood plain towards the South Australian Border. Billabong Creek flows through the Billabong Creek Alluvium and along the northern boundary of the Lower Murray Alluvium to its junction with the Edward River near Moulamein.
The Murray River and its anabranches support the extensive Barmah-Millewa and Koondrook-Perricoota floodplain red gum forests and numerous wetlands which provide valuable habitat for waterbirds and are listed as sites of international significance under the Ramsar Convention.
The Upper Murray Alluvium is made up of the valley infill alluvial sediments associated with the Murray River between Hume Dam and Corowa.

West of Corowa the valley widens and the landscape changes to alluvial floodplains where the elevation is less than 150 m above sea level. The alluvial fan of the Lower Murray Alluvium occurs from Corowa to Kyalite.

A detailed description of the catchment's surface water systems is provided in the NSW Murray and Lower Darling Surface Water Resource Description report.

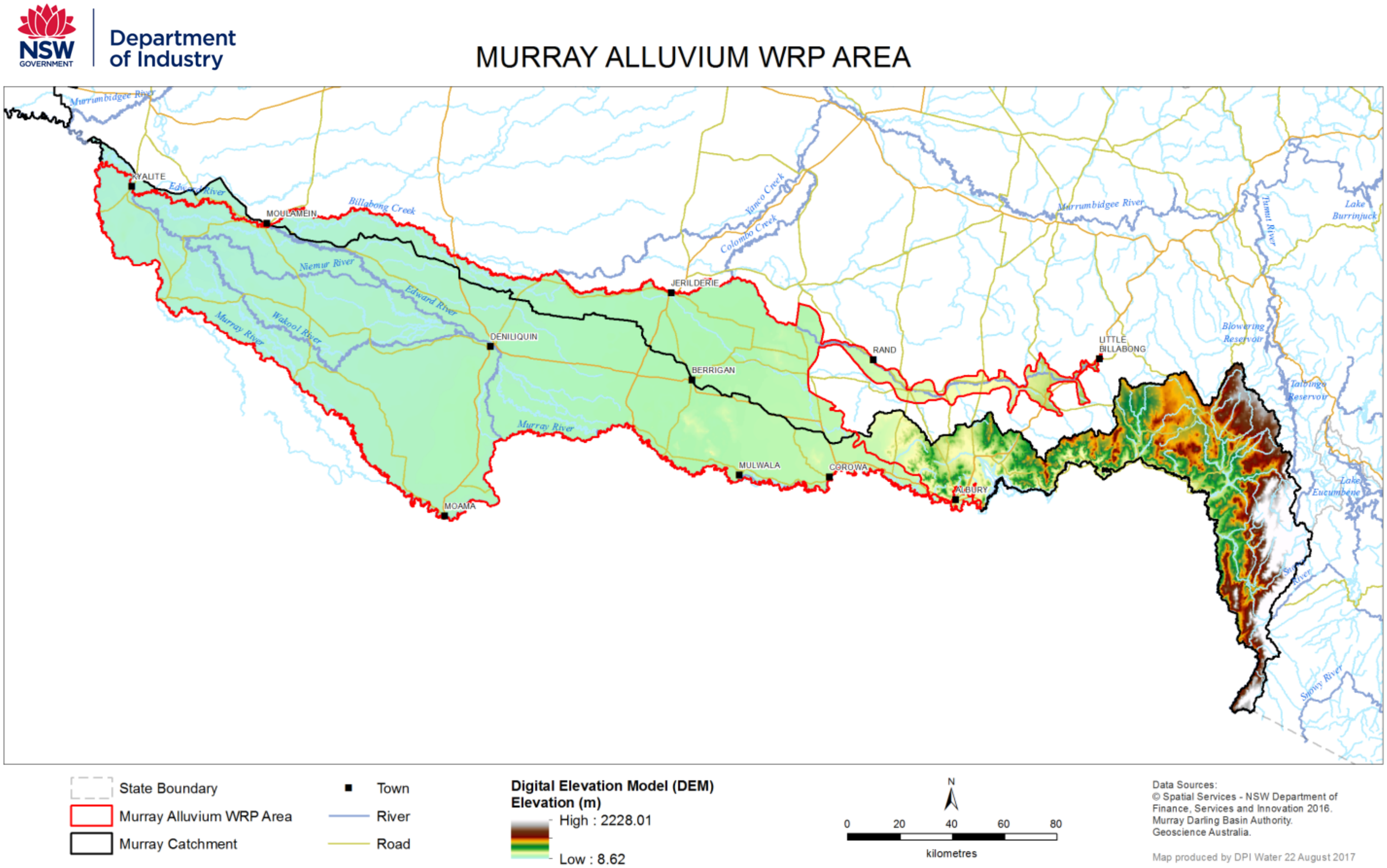


Figure 2 Topography and elevation map of the Murray catchment (Gallant et al, 2009)

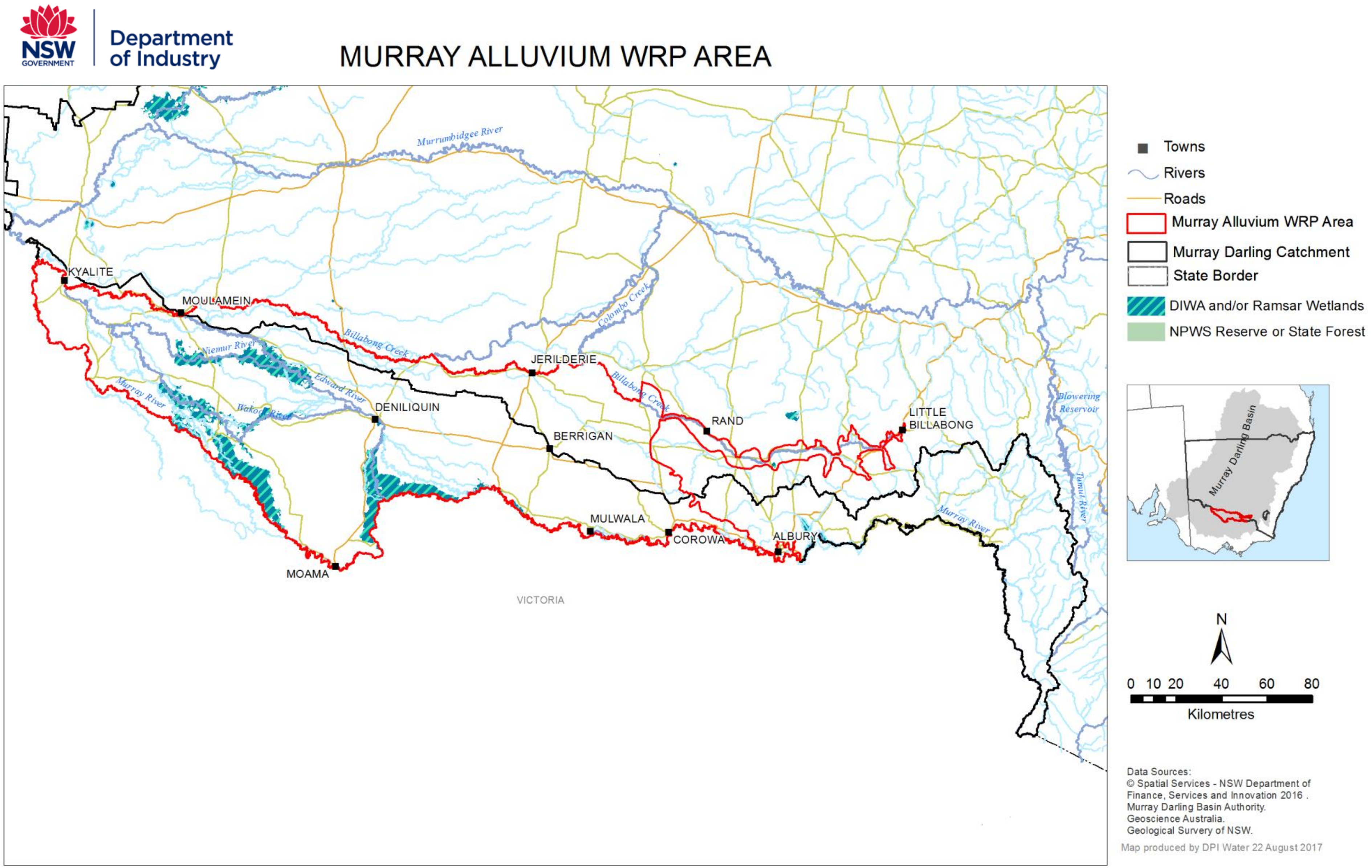


Figure 3 Surface water map of the Murray catchment

3.2 Climate

The climate of the WRP area is generally characterised by hot summer temperatures with moderate winter rainfall that can vary between years. There is a significant variation in temperatures and rainfall, between Albury in the east to Swan Hill in the west. Average annual rainfall decreases westward and varies from approximately 600 mm at Albury at the eastern end of the area to approximately 300 mm at Swan Hill near Kyalite in the western end of the area (Figure 4). Rainfall is generally winter dominant with the heaviest rainfall occurring from June to August (Figure 5). Summer rainfall is typically 40-50 mm per month at Culcairn, and 28-30 mm per month at Deniliquin.

Average temperature ranges from 26 to 35°C in the summer months and 11 to 17°C in the winter months in Albury while average temperature ranges from 33 to 36°C in the summer months and 13 to 18°C in the winter months at Swan Hill.

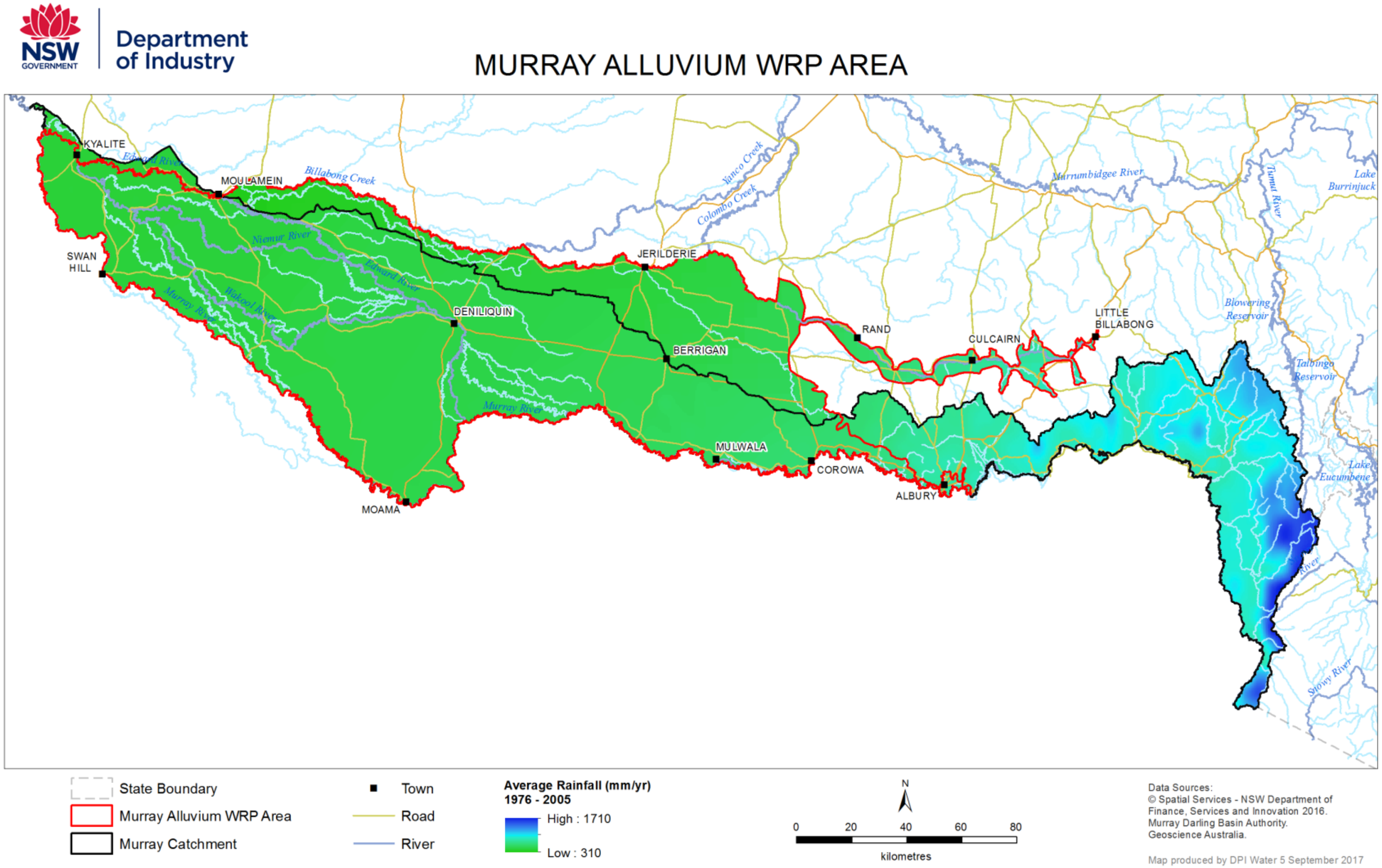


Figure 4 Average annual rainfall map of the Murray catchment (BOM, 2008)[7]

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

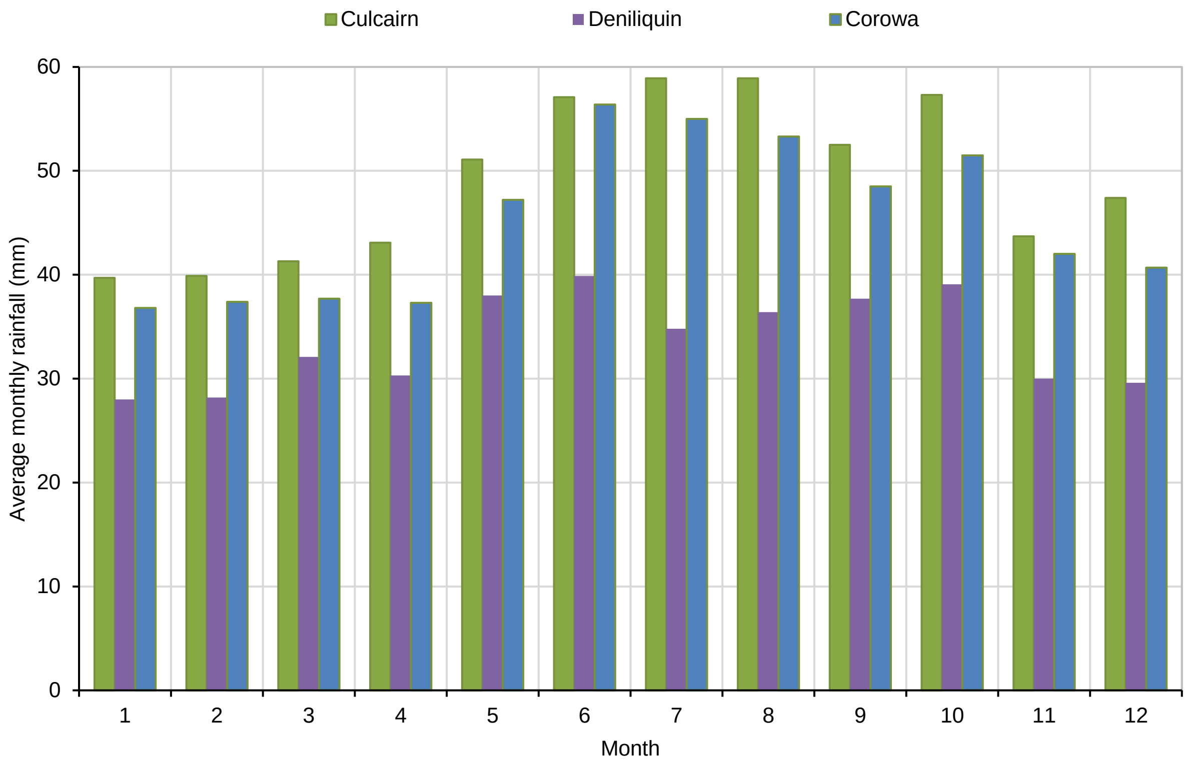


Figure 5 Average monthly rainfall (BOM) 1975 – 2016 for Culcairn, Deniliquin and Corowa

Evaporation (Class A pan evaporation) in the Murray catchment has a strong east-west gradient (Figure 6). Yearly evaporation varies from around 1,100 mm in the east to over 1,900 mm in the west.

Evaporation is strongly seasonal (Figure 7) varying from 29 - 63 mm a month over winter (June/August). Evaporation significantly exceeds average monthly rainfall over the year. The greatest exceedance occurs over the summer months (December/January), when up to 290 mm of evaporation occurs per month compared to up to 40 mm of rainfall per month for the same period. In most of the climate data stations in the Murray Alluvium area, evaporation data is not available therefore the closest station at the eastern end (Hume Reservoir near Albury) with evaporation data was selected as one of the stations for presentation in the report.

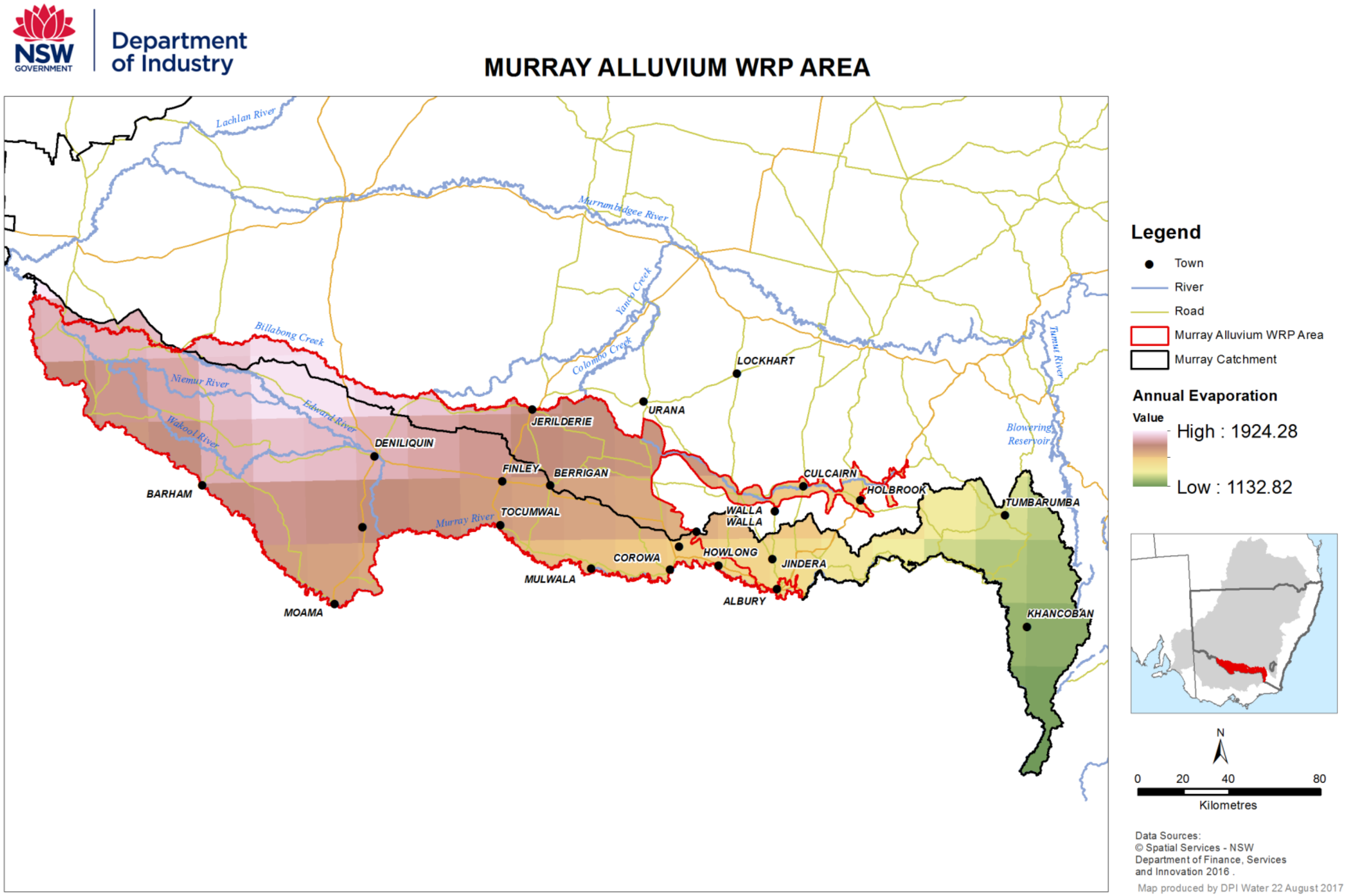


Figure 6 Average annual evaporation map of the Murray catchment (BOM, 2008)[8]

8 The average evaporation period 1976 - 2005 displayed in this map is the standardised average conditions gridded data set available from the Burea

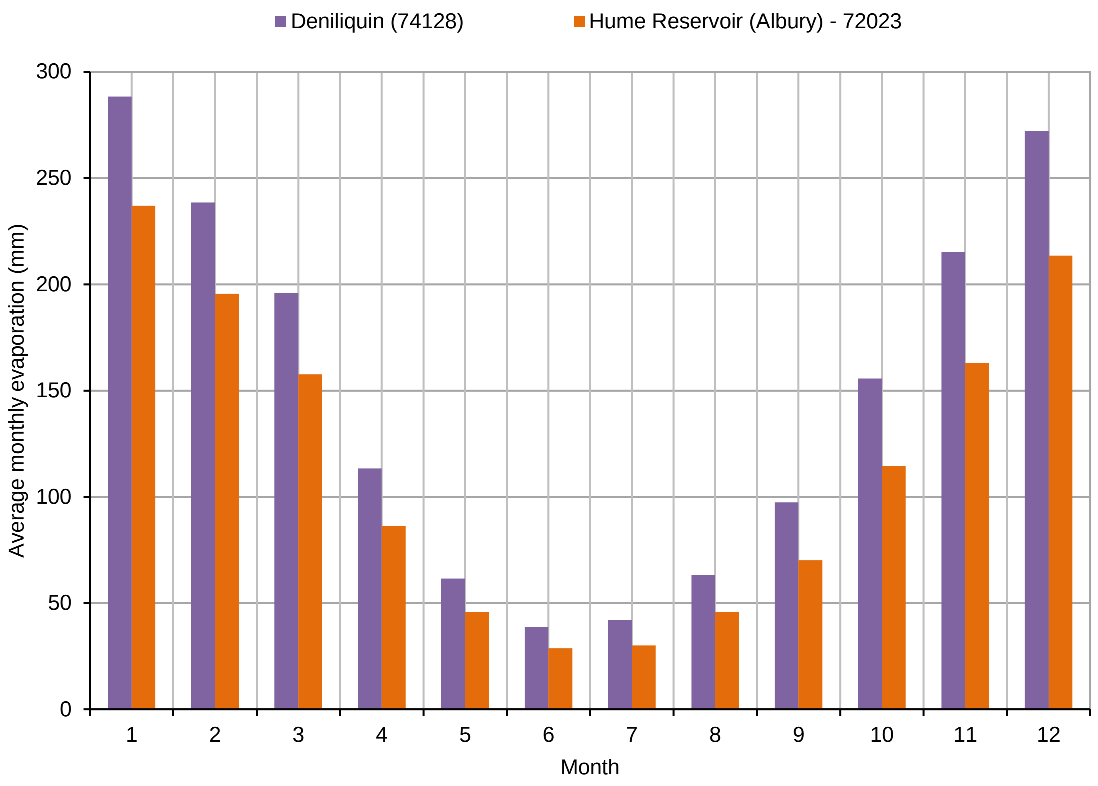


Figure 7 Hume Reservoir (near Albury) and Deniliquin average monthly evaporation (BOM) 1975 – 2016

Residual rainfall plots have been constructed for the Murray using daily data sourced from the Bureau of Meteorology website. The rainfall residual mass graph plots the cumulative difference from the monthly average rainfall and provides a visual representation of the rainfall history in an area. A falling trend indicates a period of lower than average rainfall, a rising trend showing periods of above average rainfall.

Figure 8 shows the residual mass graphs of average monthly rainfall from 1975 to 2016 at Culcairn, Corowa and Deniliquin. This period corresponds to the period of groundwater monitoring in the Murray Alluvium which commenced around 1975.

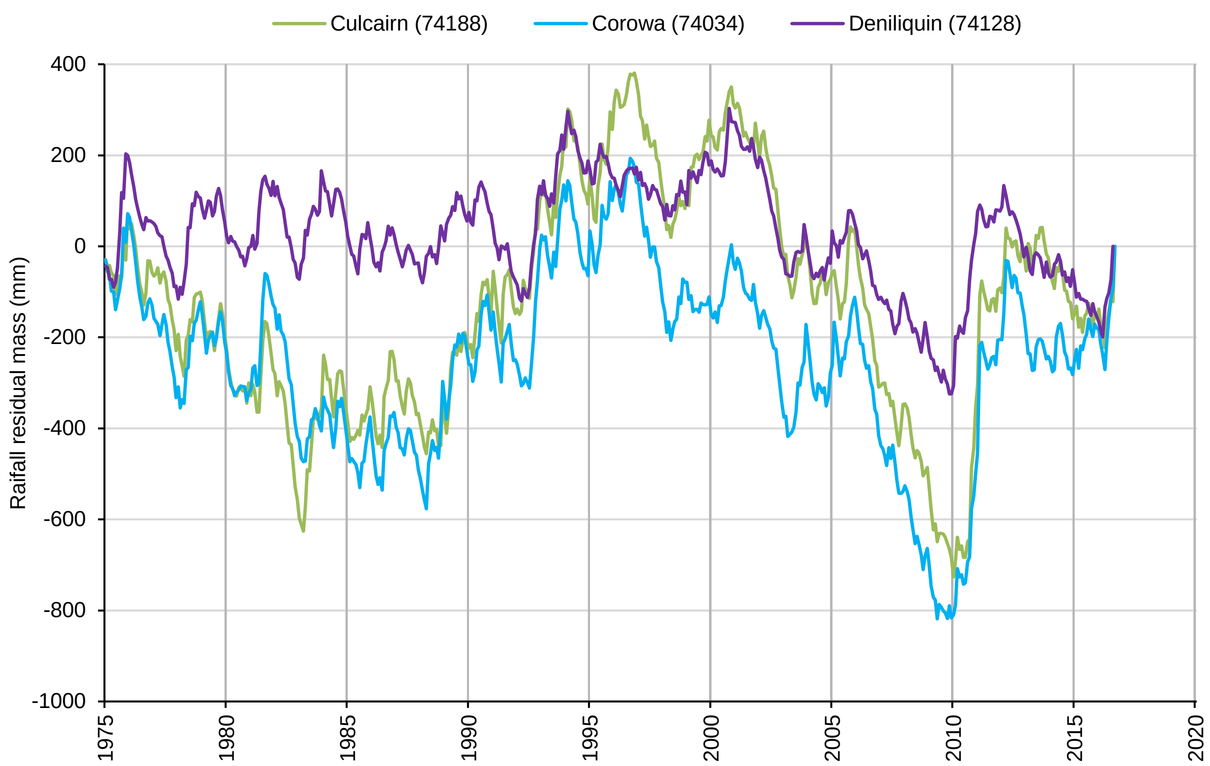


Figure 8 Rainfall residual mass graphs (BOM) 1975 – 2016 for Culcairn, Corowa and Deniliquin

3.3 Land use

Grazing is the most common agricultural business carried out in the upper Murray catchment occupying around 29 per cent of the catchment above Hume Dam. It occurs on the slopes and valley floors downstream of Khancoban, in the lower Mitta Mitta Valley, and the high country near Omeo. The rugged nature of the landscape means that less than one percent is used for cropping or irrigation. Conservation and forestry account for around 69 per cent of the upper Murray catchment. Extensive areas of national parks in the east of the catchment conserve the alpine environments where the headwaters of the Murray River begin. In NSW large areas of state forest occur in the Tumbarumba region and in Woomargama State Forest in the upper reaches of Hume Dam.

Agriculture including grazing, dryland cropping, and irrigation, is the dominant land use along the Murray River downstream of Hume Dam, accounting for around 90 per cent of the land area. Crops produced include wheat, rice, barley, vegetables, and oats for grain and pastures for hay. Extensive irrigation occurs in the mid-lower reaches of the Murray River within three private irrigation areas (Murray Irrigation, West Corrurgan Irrigation, and Moira Irrigation) and through private diversions from the Murray, Edward and Wakool Rivers.

The Murray region hosts some of the largest irrigation schemes in Australia which produces broadacre crops, including rice and cereals, permanent pasture and annual pasture. Important crops include wheat and rice, with the Murray Irrigation Area producing 42% of Australia's rice.

The crops are processed locally at a mill in Deniliquin and the majority of the processed grain is transported by rail to Melbourne for export (EBC Consortium 2011). Other industries that have developed around irrigation include dairying around Finley, citrus orchards around Barham and also irrigated winter and summer crops (EBC Consortium 2011).

The primary water supply for irrigation in the Murray valley is the regulated Murray River, followed by alluvial groundwater sources.

Important areas of forestry occur along the Murray and Edward Rivers. In 2010, large areas of state forests were converted to national parks to create the largest river red gum conservation area in Australia.

Albury–Wodonga is the largest regional centre in the Murray alluvium, with a population of over 100,000 people (ABS 2011). Other major centres include Corowa (population 6,000), Yarrawonga (7,000), Mulwala (2,000), Deniliquin (7,000), and Swan Hill (10,000) (ABS 2011).

Figure 9 shows land use information across the Murray catchment based on the Australian Bureau of Agricultural and Resource Economics and Sciences 2010 -11 land use data (Smart, 2016).

The Bangerang, Barapa Barapa, Nyeri Nyeri, Tati Tati, Wadi Wadi, Wamba Wamba, Weki Weki, Wiradjuri people were the original inhabitants of the Murray catchment. The land and waters of the Murray catchment contain places of deep significance to Aboriginal people and are central to their spiritual and religious belief systems, and are often celebrated in ritual, ceremony, story, dance and art work.

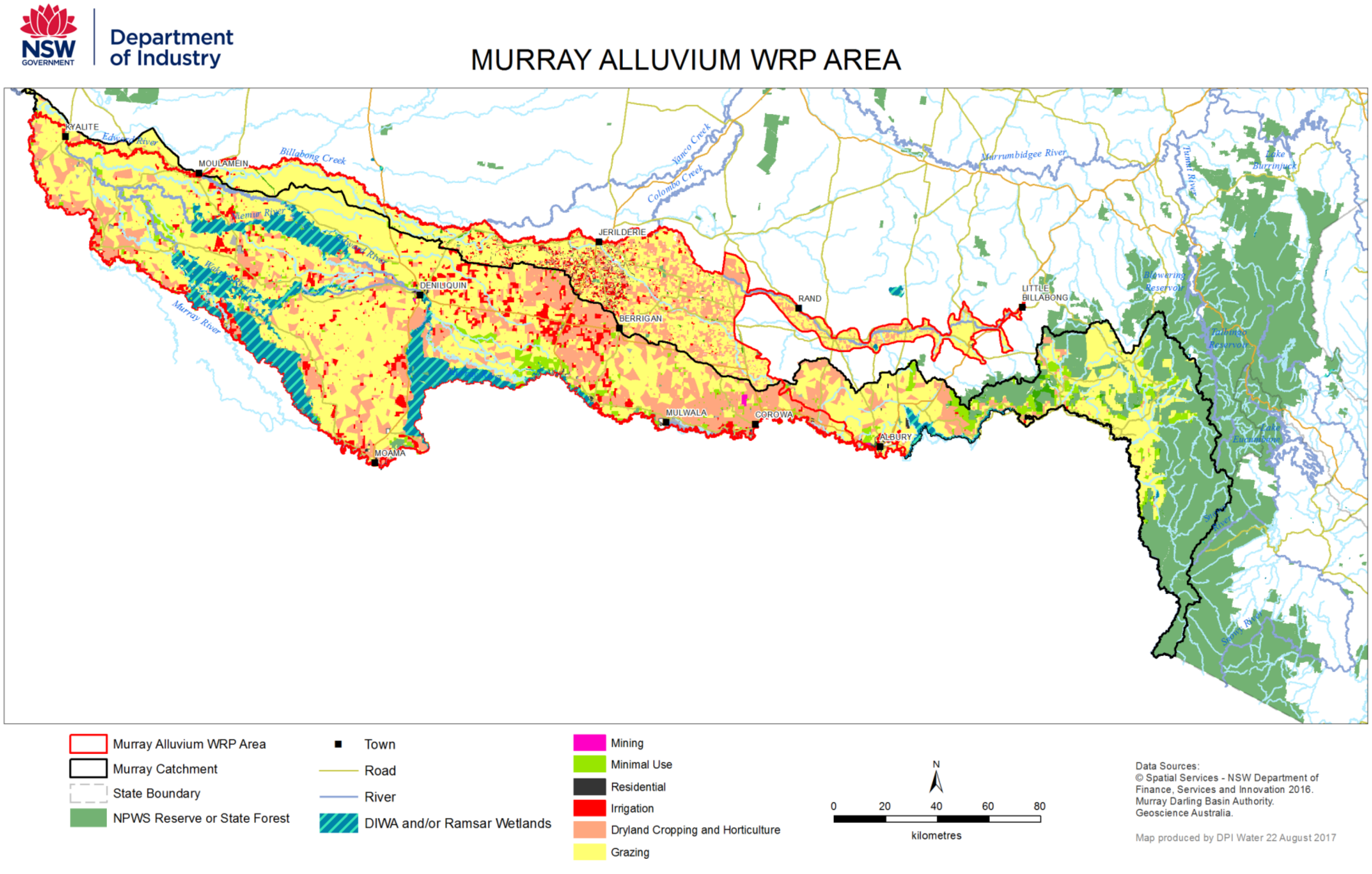


Figure 9 Land use map of the Murray catchment (Smart, 2016)

4 Geology

The surface geology of the Murray River catchment is made up of three main geological units; namely Cenozoic unconsolidated sediments of the Murray (geological) Basin and upland alluvium, Palaeozoic Lachlan Fold Belt basement rocks and Cenozoic intrusive volcanics (Figure 10).

The Lachlan Fold Belt is the oldest geological unit in the area and consists of sedimentary, metamorphic and igneous rocks up to 545 million-years old.

The Permian Oaklands Basin is a sedimentary coal basin that occurs at depth underlying the Cenozoic alluvium to the east of Jerilderie and Berrigan. It does not outcrop within the WRP area.

The Cenozoic sediments of the Lower Murray Groundwater Alluvium are within the Murray Basin which in total covers an area of over 300,000 square kilometres across south-eastern Australia. They were deposited over three major depositional sequences and are up to 600 m thick (Brown and Stephenson, 1989).

The shallow Shepparton Formation, deeper Calivil Formation and Renmark Group sequences are the main geological units within the Lower Murray Alluvium. The Renmark Group is the basal formation which sits upon a pre-Cenozoic basement. The Calivil Formation unconformably overlies the Renmark group and was deposited in the late Miocene to Pliocene. The youngest sequence is the Shepparton Formation which was deposited between the Pliocene to the Pleistocene and conformably overlies the Calivil Formation.

The Cenozoic unconsolidated sediments of Upper Murray and Billabong Creek Alluvium (belonging to the Lachlan, Cowra and Coonambidgal formations[9]) comprise of clay, silt, sand and gravel, and occur as flood plain deposits and infilled valley deposits along the palaeo valleys and modern day valleys. These overlie the fractured rocks of the Lachlan Fold Belt.

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

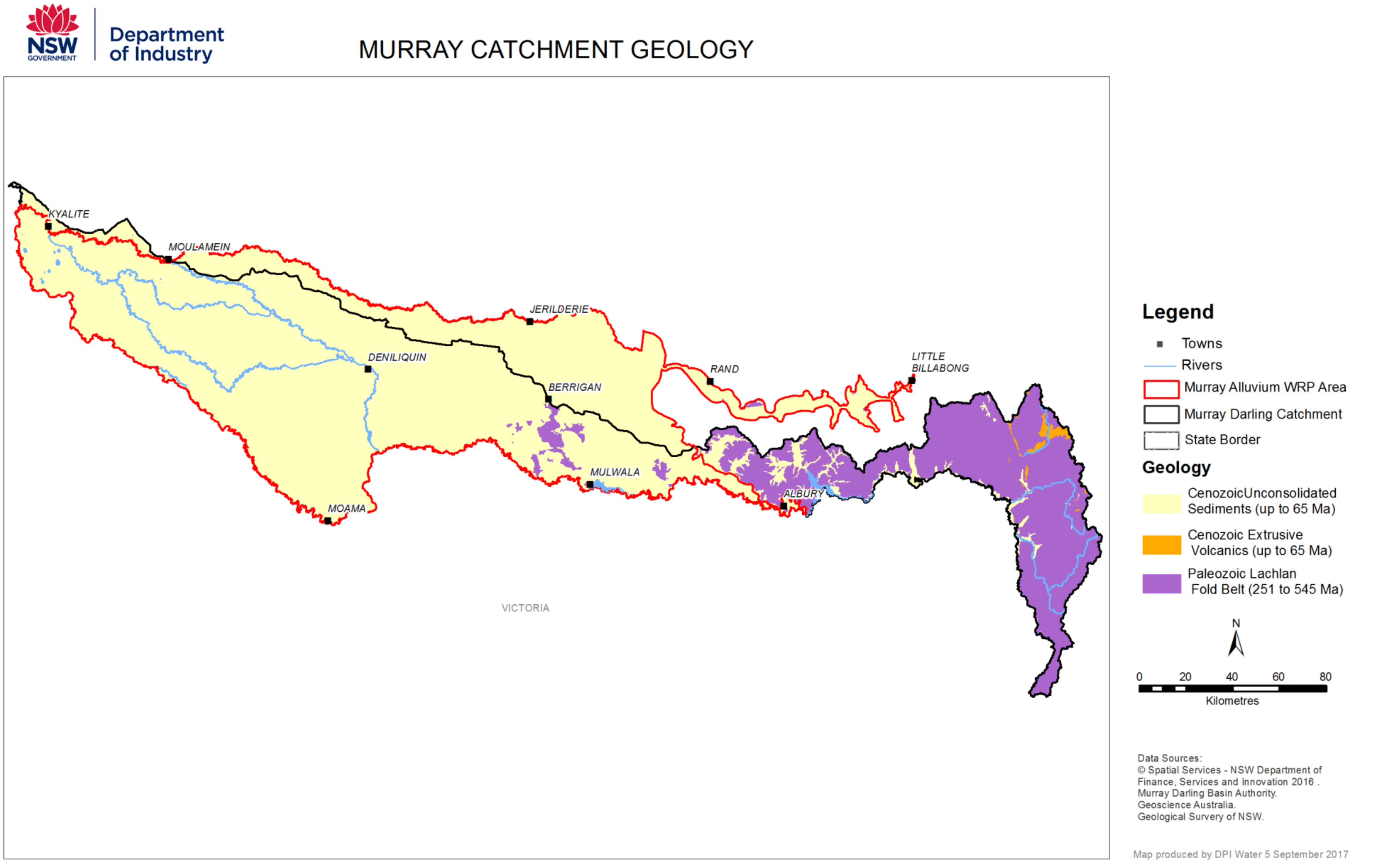


Figure 10 Geology of the Murray catchment

5 Hydrogeology

5.1 Regional context

The Murray Alluvium is a continuous sequence of unconsolidated sediments deposited as valley fill in the upper areas of the catchment and grades into broader valley and floodplain sediments in the mid catchment. The Lower Murray Alluvium in turn grades into the Murray Geological Basin (MGB) sediments which also incorporate the Lower Murrumbidgee Alluvium SDL resource unit on the northern boundary and the adjoining Victorian SDL units on its southern boundary.

Whilst the geometry of the alluvium is varied over the 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 Murray Alluvium and the MGB sediments.

The Murray Alluvium sits over and adjacent to the fractured rock management unit of the Lachlan Fold Belt and the Oaklands Basin in the eastern part of Lower Murray Alluvium in NSW. 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 this fractured rock system 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 Murray Alluvium reflect areas of similar hydrogeological characteristics. There is hydraulic connection across contiguous boundaries between the management units in NSW and those SDL resource units across the border in Victoria. The characteristics of each of the SDL resource units in Murray Alluvium in NSW are presented in the following sections.

5.2 Lower Murray Alluvium

The alluvium of the Lower Murray is made up of Cenozoic alluvial sediments and extends from Corowa in the east to Kyalite in the west. The thickness of the alluvium increases from east to west reaching its maximum in the Moulamein area, west of Wakool.

The alluvium is broadly divided into two main regional aquifer systems: a shallow aquifer system up to approximately 70 m deep (correlating to the Shepparton Formation), and the deeper aquifer system approximately 350 m deep that incorporates the Calivil Formation and the Renmark Group.

The Renmark Group overlies the basement rock occurring at depths between 140 m to 350 m below ground surface. It consists of sand and gravel layers up to 40 m thick inter-bedded with carbonaceous clay and lignite layers. The sand and gravel layers typically constitute important aquifers where low salinity groundwater is available. These typically form very transmissive aquifers although in some areas the poorly sorted nature of the sands and gravel mixed with clay reduces the transmissivity resulting in lower yields.

The Calivil Formation overlies the Renmark Group occupying depths between 40 m and 140 m below ground surface and consists of sand and gravel, inter-bedded with clay layers. The upper surface of this formation slopes to the north-west and its thickness reduces towards the west (Williams & Woolley, 1992). The Calivil Formation is dominated by sand and gravel beds with individual layers up to 12 m thick. It is an important source of groundwater and efficiently constructed bores within these formations can yield up to 15 ML/day.

The Shepparton Formation overlies the Calivil Formation and consists of clay and silty clay interbedded with sand layers. The groundwater within the uppermost 20 m of the Shepparton

Formation aquifer is mostly saline although low salinity and high yielding groundwater supplies can be obtained from the coarser sediments associated with prior streams.

Groundwater within the upper portion of the Shepparton Formation is unconfined. Shallow spearpoints (or battery of spear points) can yield up to 5 ML/day from local aquifers within the sand lenses associated with prior streams. This upper unconfined portion of the Shepparton Formation is managed separately from the deeper regionally extensive productive aquifers. The Lower Murray Shallow Alluvium corresponds to the sand and clay sediments of the upper portion of the Lachlan Formation to a depth of 20 m below the ground surface.

The Lower Murray Deep Alluvium incorporates the remainder of the alluvium to its base, that is the lower portion of the Shepparton Formation, the Calivil Formation and the Renmark Group sediments. The shallow and deep aquifer systems referred to in this report are both within the Lower Murray Deep Alluvium which is the dominant groundwater source in the area.

The general direction of groundwater flow in the Lower Murray Alluvium is from east to west as illustrated in Figure 11.

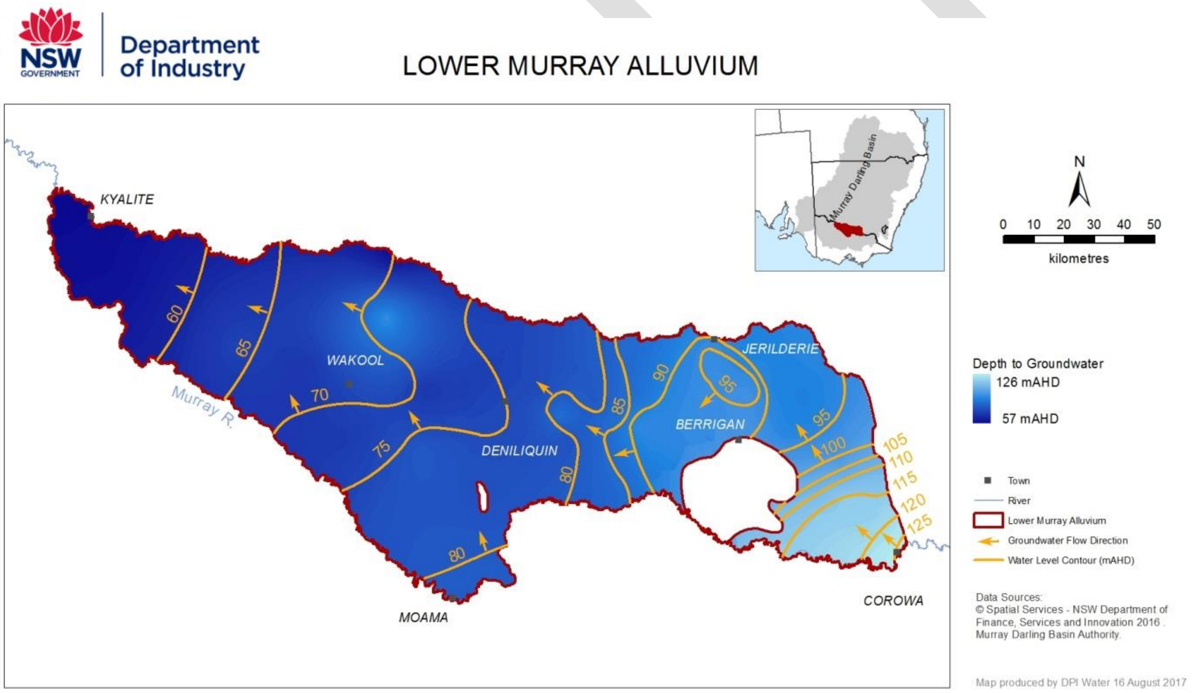


Figure 11 Location map of the Lower Murray Alluvium showing groundwater [10]flow direction in deep aquifer system

Figure12 shows the location of three geological cross sections that have been produced for the alluvium of the Lower Murray.

Figure13A displays a long-section that extends the entire length of the water source. Figure13B and Figure14 illustrate southwest-northeast and north-south sections respectively. The dominant recharge process into the alluvium is direct rainfall infiltration, leakage from irrigation activity including canals and leakage from the Murray River and its anabranches.

The main discharge is extraction for irrigation and through-flow to the west. Other sources of discharge include base flow into the Wakool River and other creeks (downstream of Deniliquin)

[10] Groundwater contours and flow direction shown on this map were prepared for Calivil aquifer which is part of the deep aquifer system given that Renmark Group is absent in the areas east of Berrigan and it is expected that Renmark aquifer has similar contours and flow direction where it is present.

from the shallow alluvium. Evaporation through the soil surface where water table is close to surface is another process of discharge in this area.

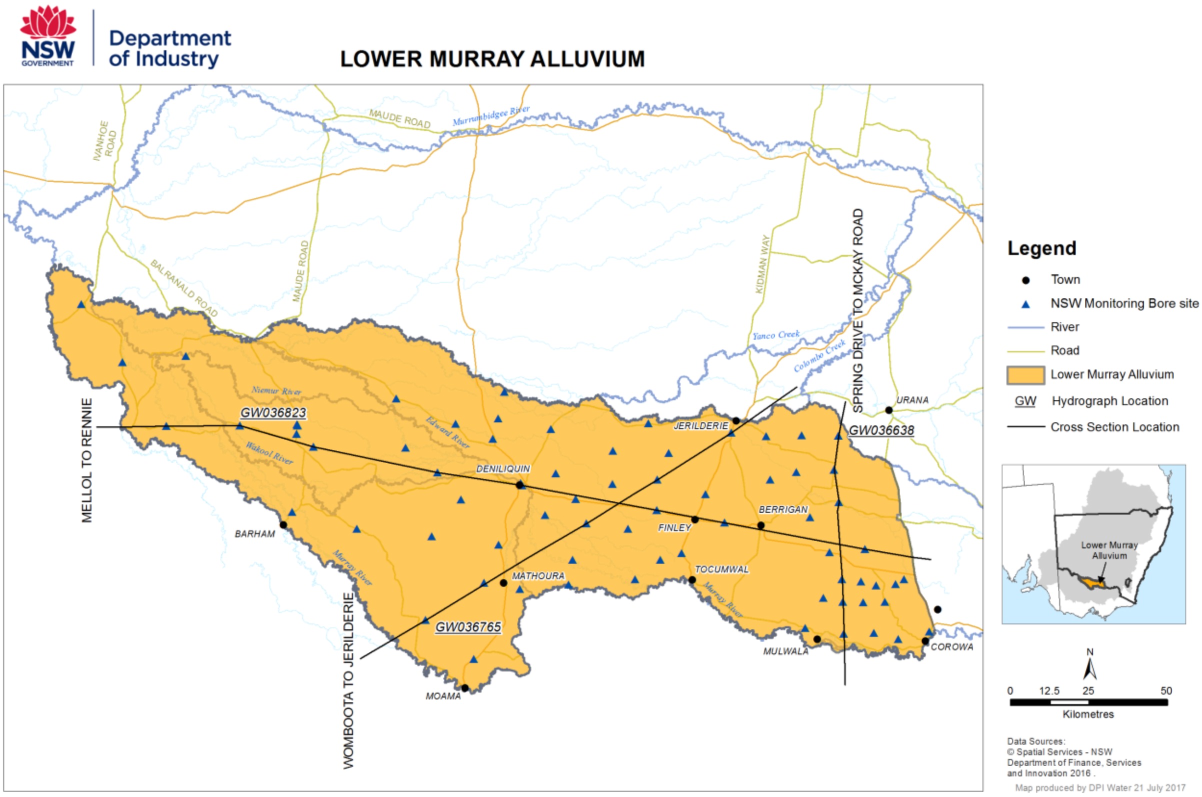


Figure12 Cross sections location map Lower Murray Alluvium

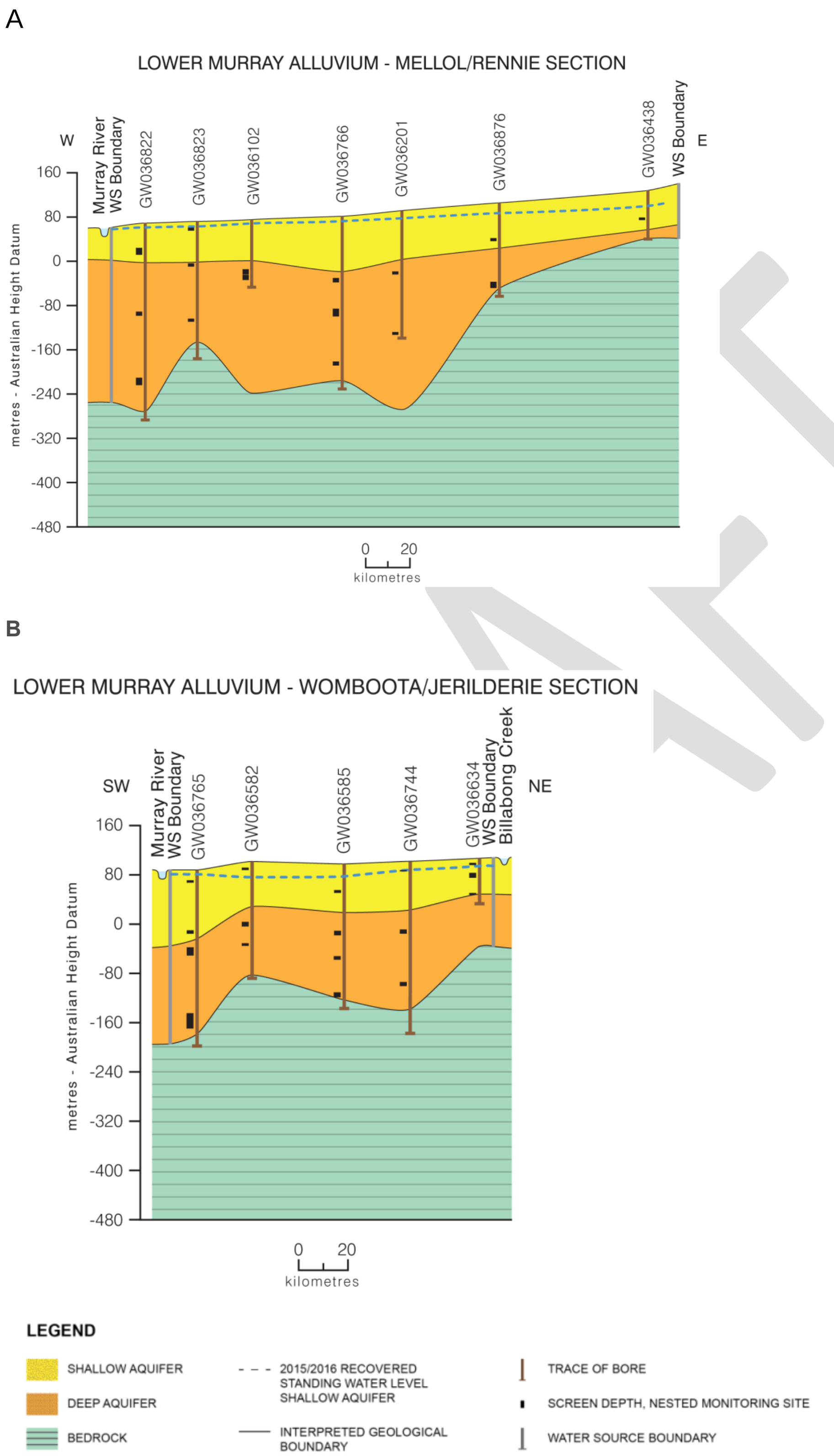


Figure13 East-west long section (Mellol/Rennie) through the Lower Murray Alluvium and Woomboota/Jerilderie cross section

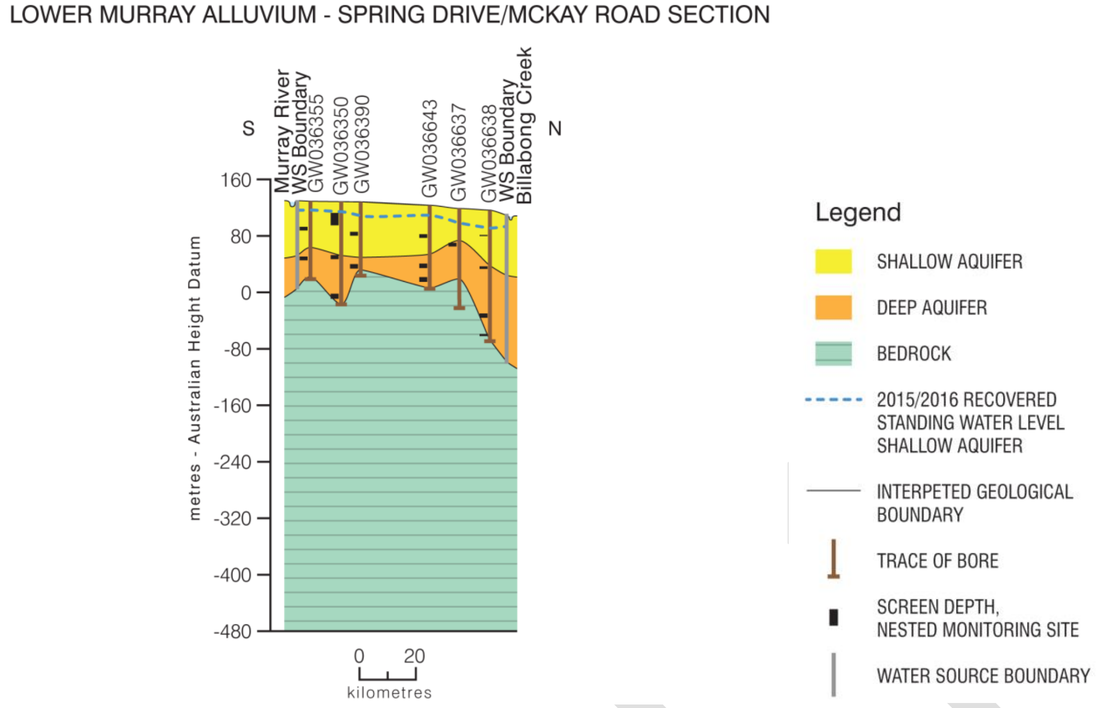


Figure14 Spring Drive/McKay Road section - Lower Murray Alluvium

5.3 Upper Murray Alluvium

The Upper Murray Alluvium is made up of Cenozoic unconsolidated valley fill alluvial sediments. It consists of clay, fine sand to cobbles and is characterised by its grey colour.

The water bearing sands and gravels are broadly divided into two main aquifer systems; a shallow aquifer system up to approximately 40 m deep, and a deep aquifer system up to a maximum of approximately 100 m deep. The shallow unconfined/semi confined aquifer is within the Shepparton Formation and the deeper semi confined aquifer is within Lachlan formation. The sediments of the Coonambidgal formation are part of the shallow aquifer system but associated only with the present river system and located within the floodplain. It consists of sand, silt and clay and is generally unconfined.

The main productive aquifers are the sand and gravel deposits within the Lachlan formation. Bores in the deep aquifer system have yields up to 10 ML/day. The shallow aquifers have much lower yields compared to deeper aquifers and are the main source for stock and domestic supply.

The general direction of groundwater flow is from southeast to northwest (Figure 15).

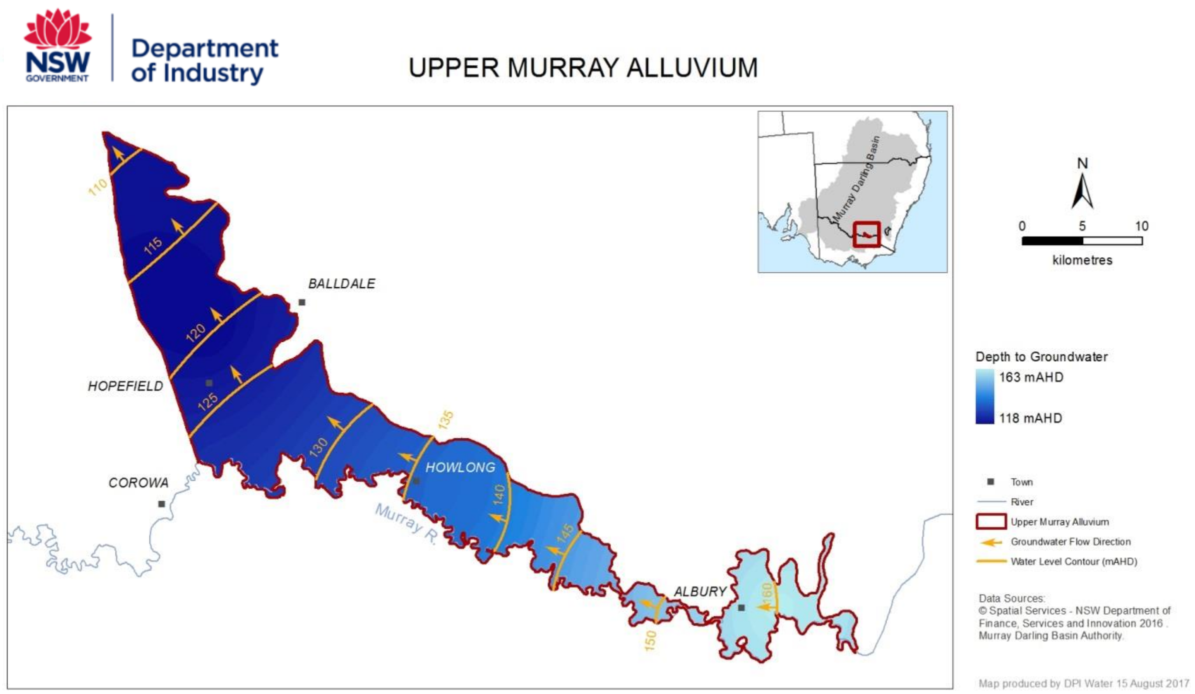


Figure 15 Location map of Upper Murray Alluvium showing groundwater flow direction in the deep aquifer system

Figure16 shows the location of two geological cross sections that have been produced for the Upper Murray Alluvium. Figure17 shows southwest-northeast cross sections across the water source.

Rainfall and leakage from the Murray River are the dominant sources of recharge with minor contributions from leakage from irrigation activity.

The main discharge in the Upper Murray Alluvium is extraction for irrigation. Other source of discharge is the through flow towards west into the Lower Murray Alluvium.

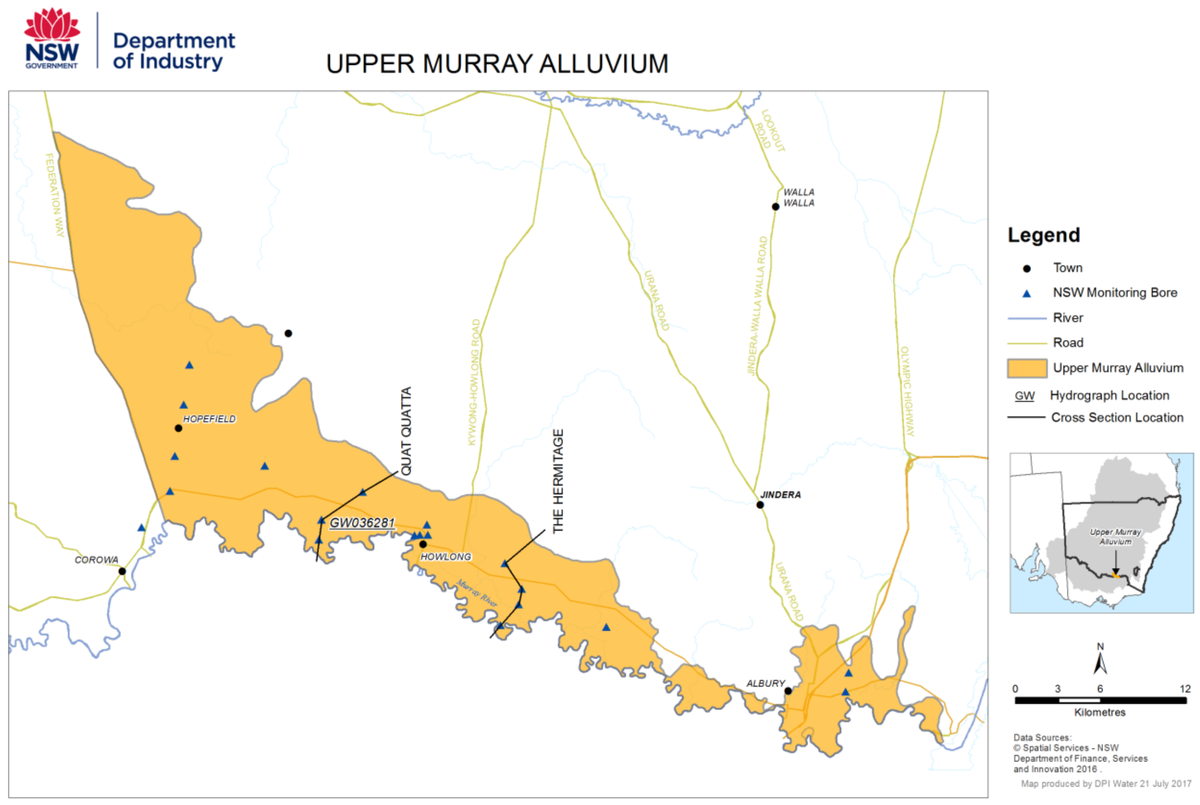


Figure16 Cross sections location map - Upper Murray Alluvium

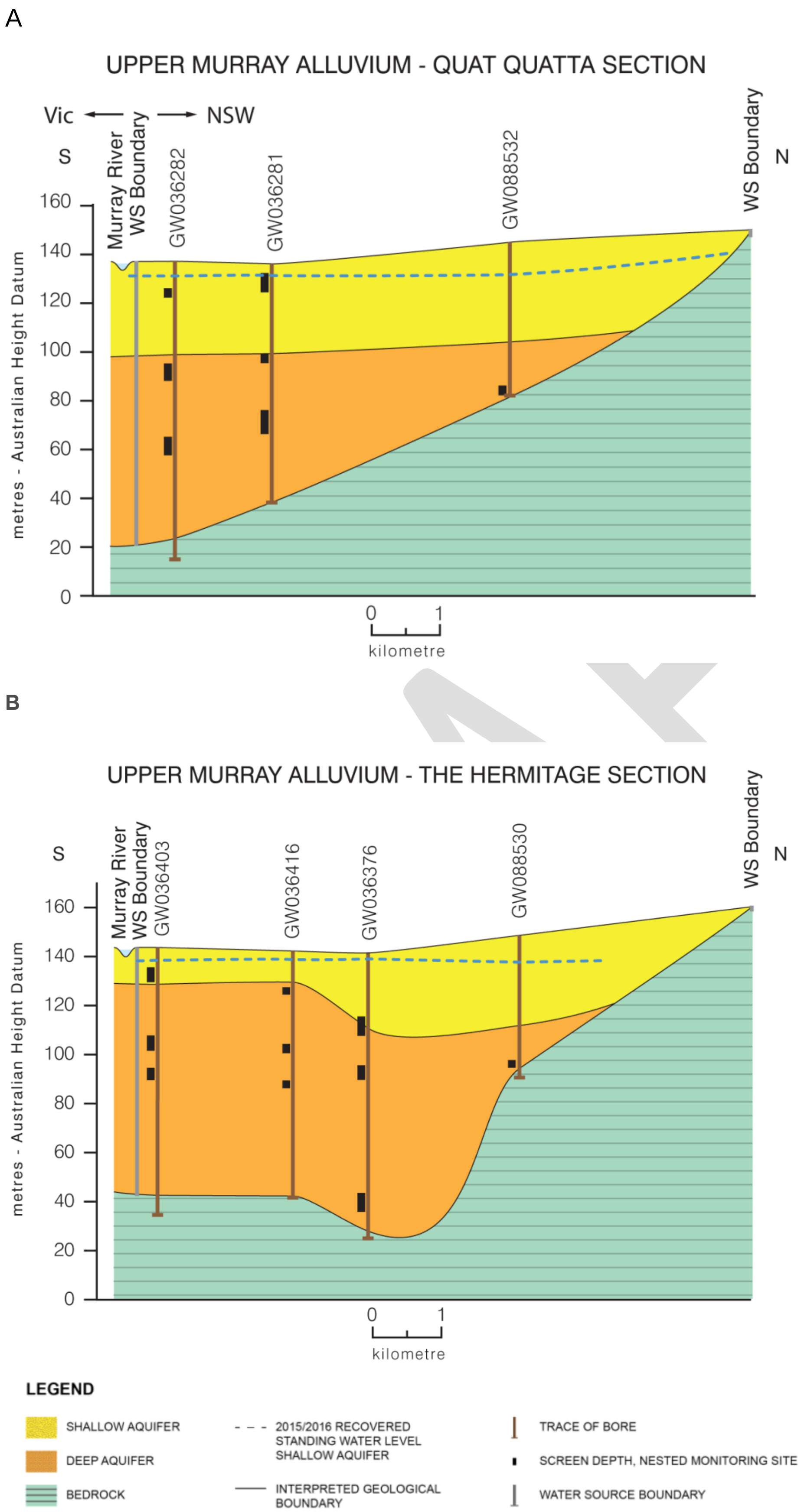


Figure17 Quat Quatta cross section and The Hermitage cross section - Upper Murray Alluvium

5.4 Billabong Creek Alluvium

The Billabong Creek Alluvium can be divided into two main aquifer systems: a shallow aquifer system of up to approximately 40 m and a deep aquifer system of up to approximately 100 m deep.

The deep aquifer system is within the informally named Lachlan formation which does not outcrop within the catchment. It consists predominantly of quartz sand and fine gravel that can be interbedded with greyish clays and forms the channel lag deposits that infill the palaeochannel at depth. It is up to about one kilometre wide and is continuous from upstream of Ralvana Gap (near Little Billabong) in the east to Rand in the west. Further west, the sediments merge into the Calivil Formation of the Lower Murray deep aquifer system.

The sand and gravel layers within the deep aquifer system (palaeochannel deposits) form the most productive aquifers with bore yields of up to 5 ML/day. These layers are about ten metres thick and often intercalated with grey clays. All town water supply bores and the majority of irrigation bores obtain groundwater from this aquifer. The Billabong Creek Salt Interception Scheme (SIS) is located near Walla Walla. This freshwater aquifer (deep) is constricted by the geology that pushes groundwater upward, forcing the saline water in the shallow aquifer system into the creek. The SIS has a bore that extracts freshwater from the deep paleochannel, about 80 metres below the ground, directly into the creek reducing the saline flow into the creek.

The sediments of the Cowra formation unconformably overlie the Lachlan formation and the basement rocks where Lachlan formation is absent. It consists of shoestring deposits of poorly sorted polymictic sand and gravel that are interbedded with yellow to brown clay.

The shallow aquifer system is less productive than the deeper system. Almost all the basic landholder rights bores access groundwater from the shallow aquifer system. Yields are generally less than 0.5 ML/day from a bore.

The shallow aquifer system is generally in hydraulic connection with Billabong Creek along its length. The general direction of groundwater flow is from east to west (Figure 18).

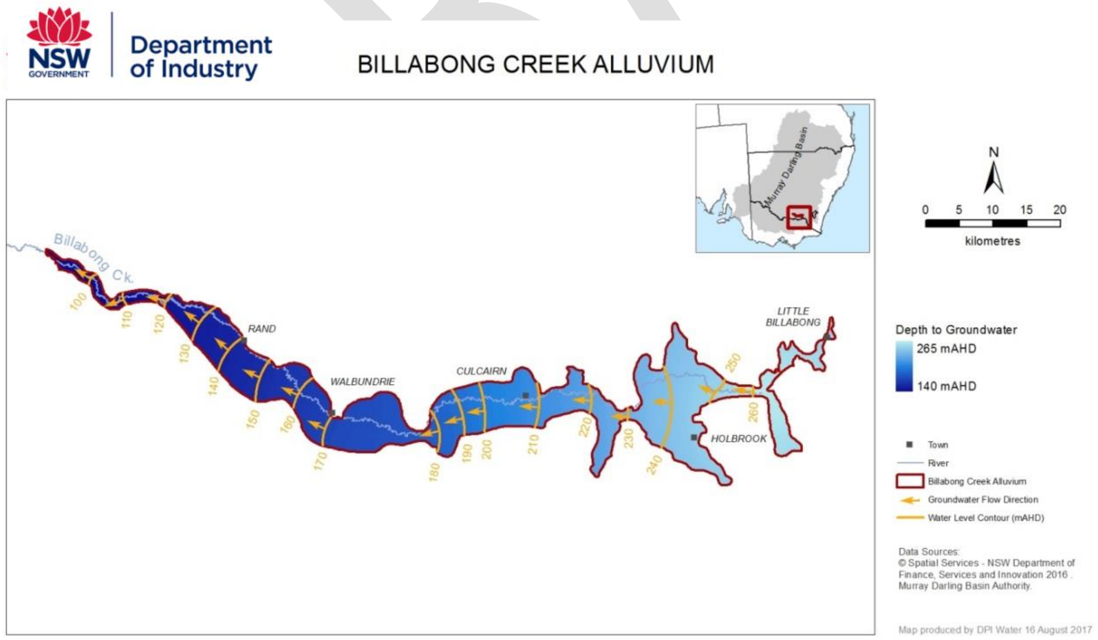


Figure 18 Location map of Billabong Creek Alluvium showing groundwater flow direction in the deep aquifer system

Figure 19 shows the location of two approximately north-south geological cross sections in the Billabong Creek Alluvium that are illustrated in Figure 20.

The three main sources of groundwater recharge are rainfall, leakage from Billabong Creek and floodplain recharge during flood events. The loss from the creek mainly occurs downstream of Walla Walla in the western half of the water source.

The main discharge in the Billabong Creek Alluvium is extraction for irrigation, water supply for townships of Walbundrie, Walla Walla, Culcairn and Holbrook and also the Billabong Creek Salt Interception Scheme.

Figure 19 Cross sections location map – Billabong Creek Alluvium

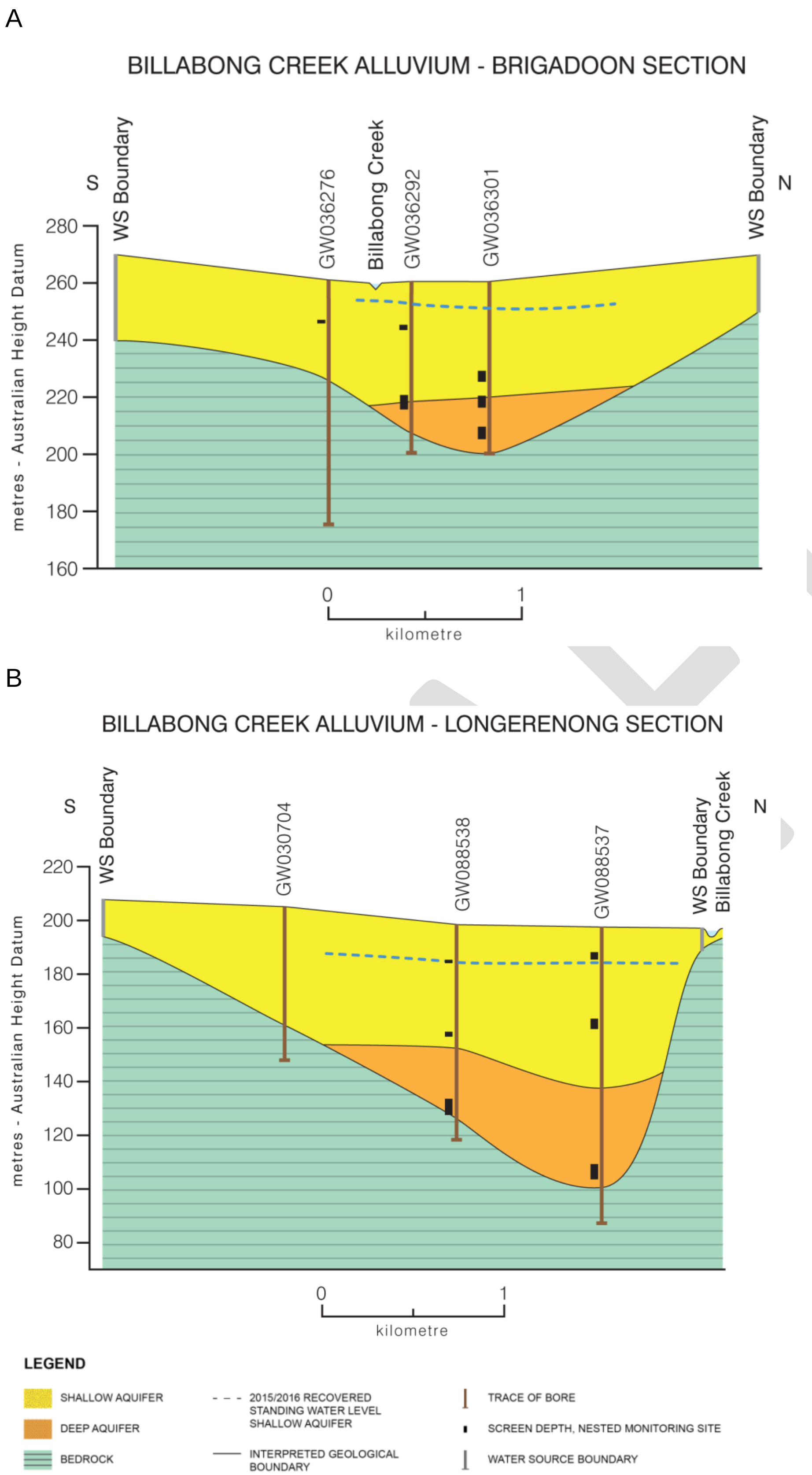


Figure 20 Brigadoon cross section and Longerenong cross section – Billabong Creek Alluvium

5.5 Connection with surface water

The Murray River is generally considered to be under losing conditions downstream of Albury and gaining between Albury and Hume Dam. Whilst the regulated Murray River is considered to be hydraulically connected along its reach within the Upper Murray Alluvium, 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 hence the Upper Murray Alluvium is managed independently from the river.

Shallow aquifers of the Lower Murray Shallow Alluvium are also considered to be in hydraulic connection to major rivers, creeks, irrigation channels and other water bodies. In the western part of the water source, saline groundwater discharges do occur intermittently depending on the river height. However, due to the lag time of pumping impacts at the river the Lower Murray Shallow Alluvium is also managed independently from the river.

The Billabong Creek Alluvium is within the unregulated section of Billabong Creek. Overall it is under losing conditions west of Walla Walla and gaining in the eastern half of the water source. Low flows in the creek during summer months are sustained by groundwater seepage from shallow aquifers in the upper Billabong area. Similar to the Upper Murray and Lower Murray Shallow alluvium groundwater pumping impacts at the river are subdued and/or delayed and the resource is managed independently from the river.

Further analysis of the interconnection between surface water and groundwater is given by Brownbill *et al* (2011).

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).

DPI Water has developed a method for the identification of high probability groundwater dependent vegetation ecosystems (Kuginis *et al*. 2016) and associated ecological value (Dabovic *et al*. in prep). This process has identified a number of vegetation GDEs in the Murray catchment. Expected ecological value of vegetation GDEs within the Murray WRP area is shown in Figure 21.

According to the mapping exercise, the Murray alluvium supports significant GDEs of ecological value including wetlands, vegetation and base flow ecosystems.

In the Murray Alluvium WRP area, high probability existence GDEs are mainly classified as very high, high and medium ecological value. The very high values are due to the extent of internationally significant Ramsar wetlands and wetlands listed under the Directory of Important Wetlands in Australia (DIWA) which supports habitat for a large number of threatened species. The method for GDE identification (Kuginis *et al.* 2016) identifies that the Murray alluvium is dominated by the groundwater dependent communities of river red gum woodland wetlands, lignum wetlands, freshwater wetlands, black box-lignum, black box and yellow box woodlands. These communities are generally characterised by having a high number of threatened species, endangered ecological communities, an extensive connected riparian corridors and basin target vegetation species (MDBA 2014) of black box, lignum and river red gums. The riparian communities are expected to provide vital habitat to nesting species and contributes to ecosystem function of instream ecosystems. Generally the GDE communities with high ecological value have large vegetation patches, are highly connected (such as riparian corridors) and have a high number of threatened species present.

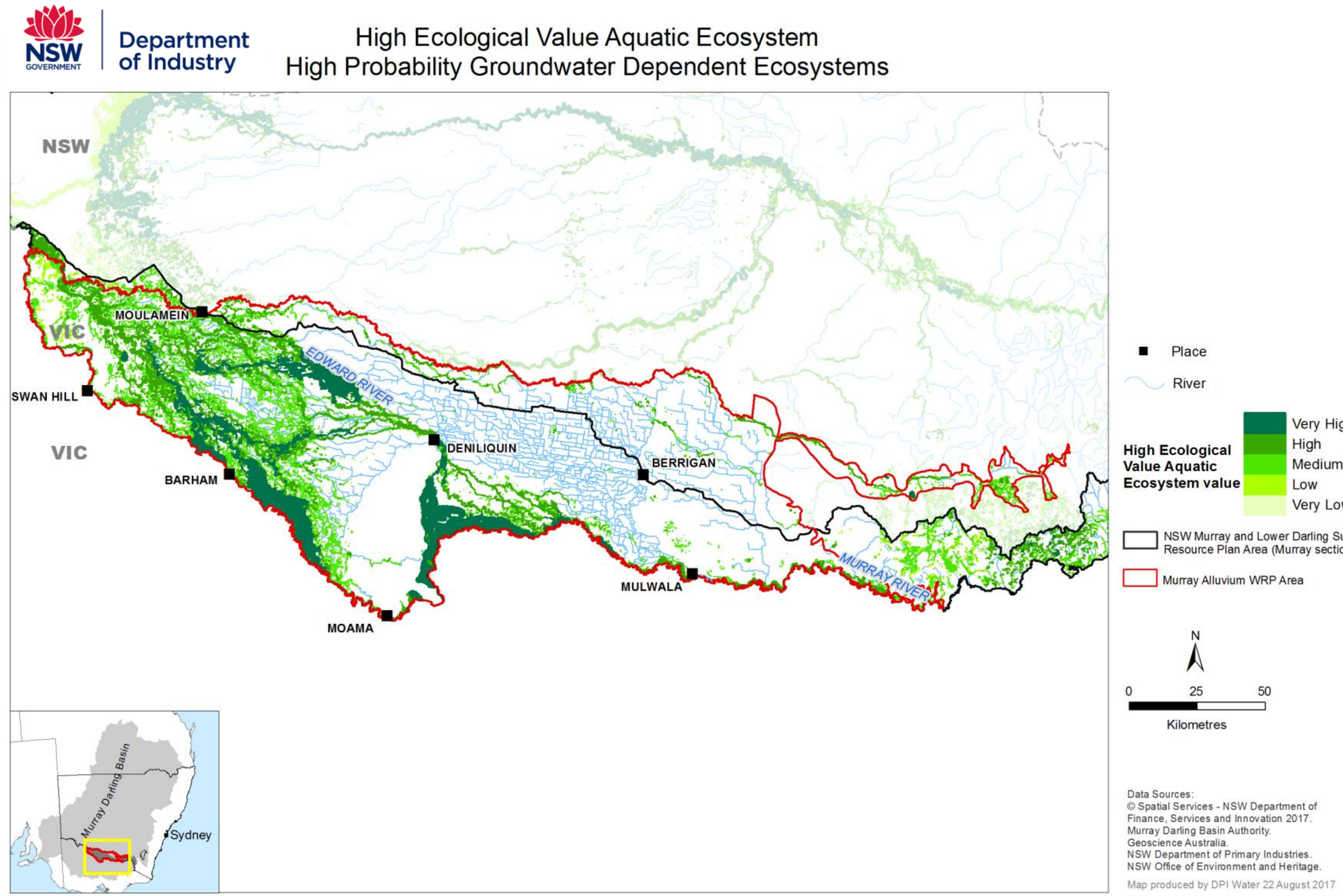


Figure 21 Ecological value for high probability groundwater dependent vegetation ecosystems

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 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 micro Siemens per centimetre (µS/cm).

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

Groundwater suitability can be changed by contaminants infiltrating into the groundwater system. This can be from spills or leaks onto the land surface but it can also occur more broadly from the overlying land use. Seasonal variations and longer-term changes in climate as well as groundwater extraction can also affect groundwater quality.

7.1 Lower Murray Alluvium

Routine groundwater sampling has continued since 2003. It has generated valuable groundwater quality data which has been used to better understand the hydro-chemical processes in this water source. Groundwater quality is typically highly variable. The electrical conductivity ranges from 200 to 65,000 µS/cm.

In 2009, the former NSW Office of Water commissioned Parsons Brinckerhoff to characterise the hydrochemistry and investigate the risks posed by groundwater pumping on groundwater quality in six alluvial systems including the Lower Murray Deep Alluvium. Twenty-eight monitoring bores were sampled during 2009 and 2011 with a focus in the Murray Irrigation District area. The results indicated rising trends in salinity in both of the aquifer systems at some locations between Deniliquin and Tocumwal. The increasing trends in salinity are attributed to a range of processes, reflecting the heterogeneity of the formations and complex aquifer interactions. This has not resulted in a change in beneficial use class in the shallow system. However, increases in salinity at some locations in the deep aquifer system have resulted in a change in the suitability of groundwater for the irrigation of some crops (Parsons Brinckerhoff 2011).

Groundwater salinity in the Lower Murray Shallow Alluvium varies from 400 µS/cm to greater than 50,000 µS/cm with a median value of around 25,000 µS/cm (Watkins & Bould, 1999). The Wakool–Tullakool Subsurface Drainage Scheme, located west of Wakool was commissioned about 30 years ago with 55 shallow bores to extract groundwater and dispose into evaporation basins to combat shallow watertables and land salinisation issues in the area. Most of the shallow groundwater extracted under the scheme is very saline.

7.2 Upper Murray Alluvium

There has been no groundwater quality monitoring program in this water source. Williams (1989) had reported on groundwater quality of the Upper Murray Alluvium aquifers in detail in an assessment using data from monitoring and production bores obtained at the time of drilling. Thereafter, only limited data is available from production bores.

Groundwater salinity in the Upper Murray Alluvium is fresh and generally less than 800 µS/cm especially within five kilometres of the Murray River. Higher salinity values (up to 5,000 µS/cm) have been recorded in the northern half of the water source towards the foothills.

7.3 Billabong Creek Alluvium

Groundwater salinity in the shallow aquifer system can vary from 200 µS/cm to 12,000 µS/cm. Low salinity groundwater predominantly occurs in the upper part of the catchment or in sand lenses close to the Billabong Creek where direct river recharge occurs. In the middle and the lower parts of the catchment, the salinities are medium to high due to low hydraulic conductivities, low hydraulic gradients and evapotranspiration effects.

In contrast, salinity in the deeper palaeochannel is relatively low (300 – 2000 µS/cm). The salinity increases from east to the west as groundwater progressively flows west.

8 Groundwater Management

Whilst the Murray Alluvium forms a large, laterally continuous and hydraulically connected system, for management purposes it has been subdivided into four separate management units.

Groundwater in the Murray Alluvium Water Resource Plan Area is managed as below.

- Lower Murray Groundwater Source (Lower Murray Deep Alluvium) managed under *Water Sharing Plan for Lower Murray Groundwater Source 2006*
- Lower Murray Shallow Groundwater Source (Lower Murray Shallow Alluvium) managed under Water Sharing Plan for *Lower Murray Shallow Groundwater Source 2012*
- Upper Murray Alluvial Groundwater Source (Upper Murray Alluvium) managed under the *Water Sharing Plan for the Murray Unregulated and Alluvial Water Sources 2011,* and the
- Billabong Creek Alluvial Groundwater Source (Billabong Creek Alluvium) managed under the *Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012.*

The groundwater sources in water sharing plans above correlate directly to the four SDL resource units in the Murray Alluvium WRP.

The Murray Alluvium sits over and adjacent to the fractured rock management units of the Lachlan Fold Belt and the porous rocks of the Oaklands Basin in the eastern part of Lower Murray Alluvium. These fractured and porous rocks 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 and Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2012.

To the south and across the border, the adjoining SDL resource units are managed through the relevant management plans and local management plans for the specific groundwater management units in Victoria.

8.1 Access rights

Groundwater access licenses for the Lower Murray Deep Alluvium, Lower Murray Shallow Alluvium, Upper Murray Alluvium and the Billabong Creek Alluvium are shown in Table **1**

Supplementary water access licences were issued to some licence holders in the Lower Murray 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 aquifer access licences (sub category town water supply) and salinity and water table management licences also have specific volumes. The share components of aquifer access licences are issued for a specified number of unit shares (Table **1**).

Table 1 Access licence share component in the Murray Water resource plan area (June 2017)

Access Licence Category	Lower Murray Deep Alluvium	Lower Murray Shallow Alluvium	Upper Murray Alluvium	Billabong Creek Alluvium
Local Water Utility (ML/year)	12	0	59	1,475
Aquifer (unit shares)	86,142	57,740	41,158	3,856
Salinity and water table management (ML/year)	0	20,010	0	1,500

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 continue to manage extractions to the LTAAEL, ensuring compliance with the SDLs. Table 2 lists the LTAAEL for the Lower Murray Deep Alluvium, Lower Murray Shallow Alluvium, Upper Murray Alluvium and the Billabong Creek Alluvium under the current water sharing plan rules as well as the SDL for each area.

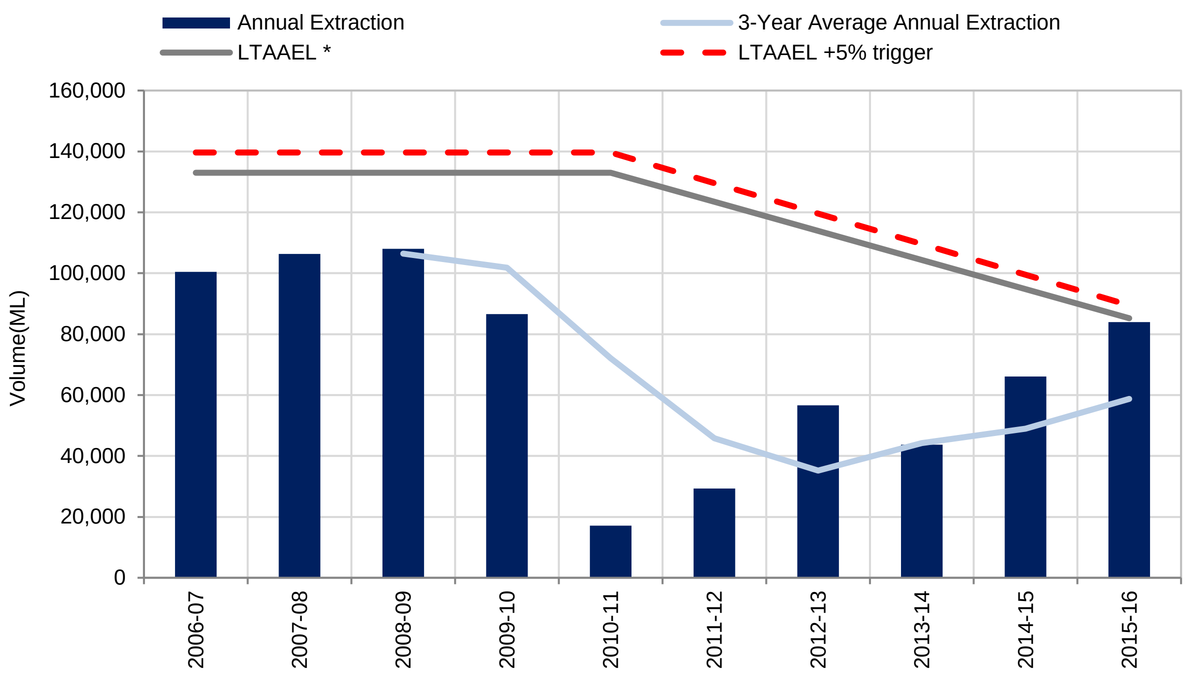
To manage any growth in extraction in excess of the LTAAEL, water sharing plans set a trigger for complying with the extraction limit.

Figure 22, Figure 23 and Figure 24 show the annual extraction since commencement of the respective water sharing plans. Extractions include BLR provisions under water sharing plans. It also shows the LTAAEL and the trigger set by the water sharing plan to initiate a management response to ensure there is no growth in extraction above the LTAAEL in the long term.

Table 2 LTAAEL for Murray Alluvium Water Sources compared to the SDL (at June 2017)

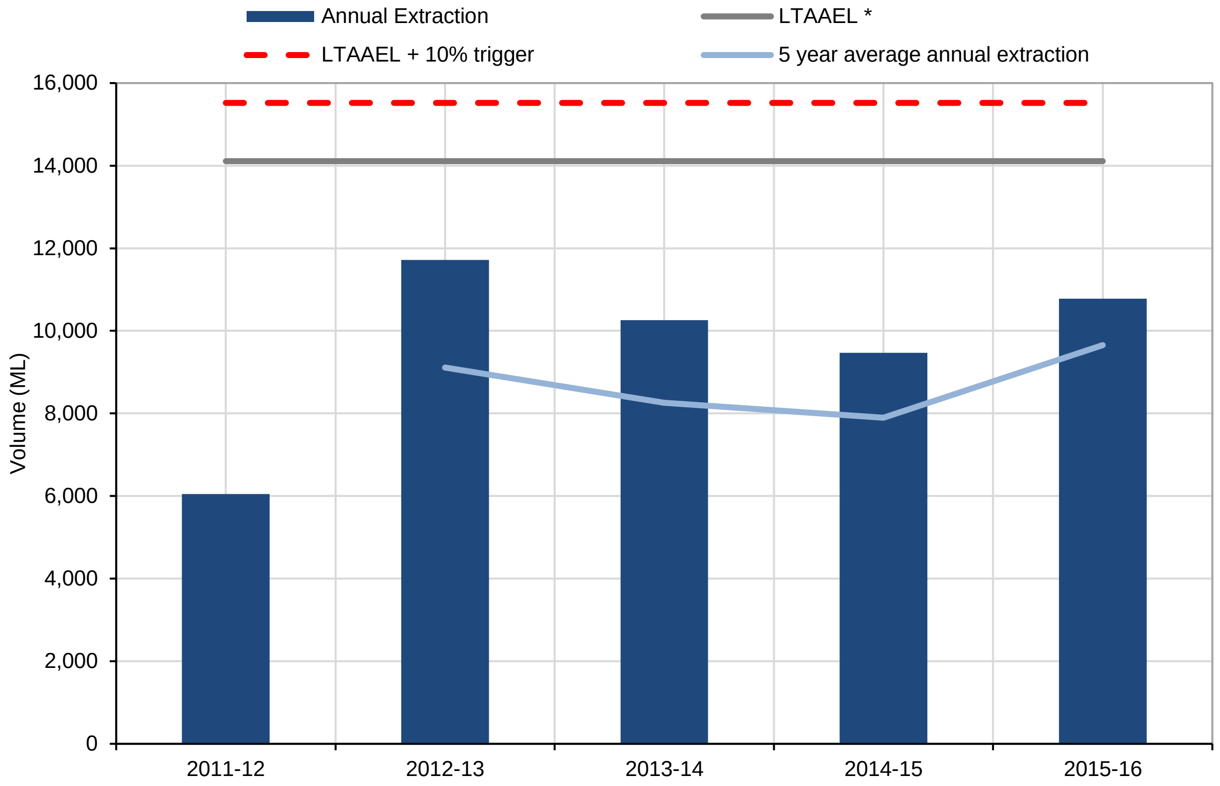
Water Source	LTAAEL* ML/yr	SDL ML/yr
Lower Murray Deep Alluvium	85,225	88,900
Lower Murray Shallow Alluvium	81,893	81,900
Upper Murray Alluvium	14,109	14,100
Billabong Creek Alluvium	7,500	7,500

* It is proposed to align the LTAAEL with the SDL in the future water sharing plan



* If the 3 year average of extraction 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.

Figure 22 Lower Murray Deep Alluvium annual extraction compared to the LTAAEL

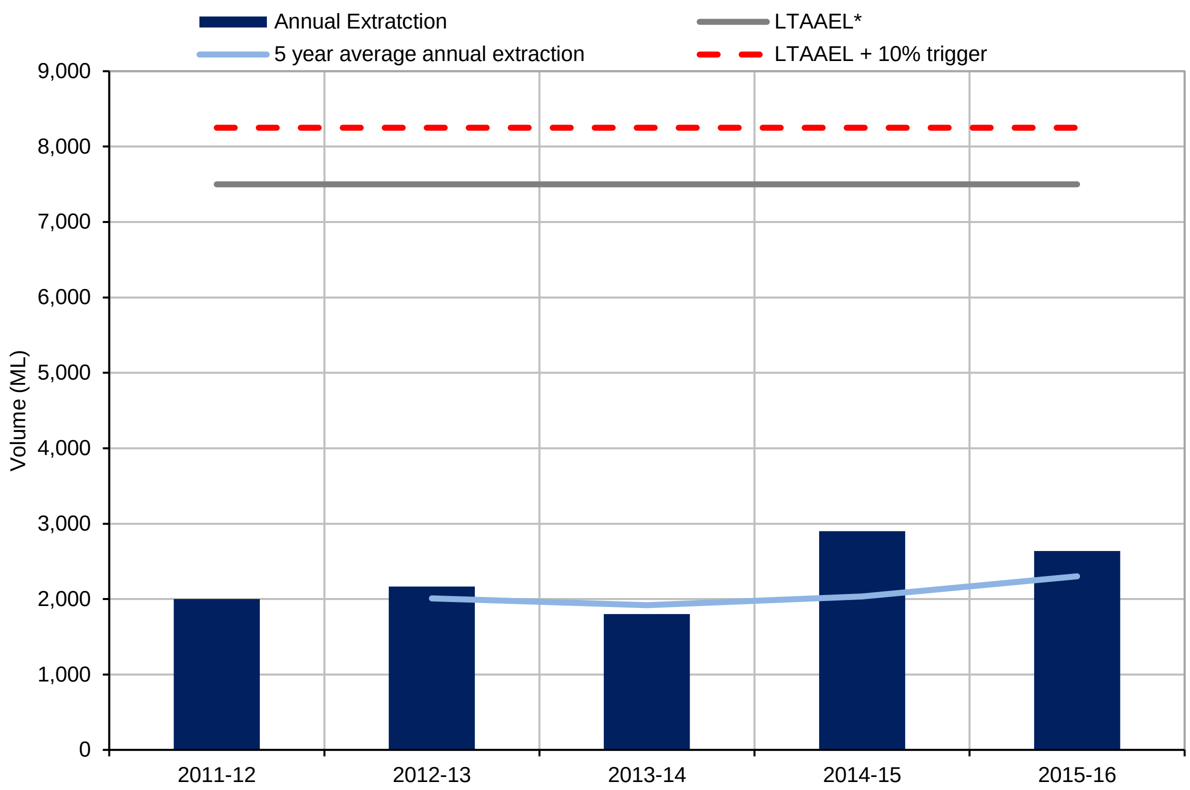


* If the 5 year average of extraction exceeds the LTAAEL by 10% or greater, then the available water determination made for aquifer access licences for the following water year, should be reduced by an amount that is assessed necessary by the Minister to return subsequent total water extraction to the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

Figure 23 Upper Murray Alluvium annual extraction compared to the LTAAEL

The risk of extraction in the Billabong Creek Alluvium exceeding the LTAAEL is low as there is relatively low groundwater development compared to Lower Murray Alluvium and Upper Murray Alluvium.

A large majority of bores in the Lower Murray Shallow Alluvium is not metered, therefore a similar chart as above has not been provided for that water source.



* If the 5 year average of extraction 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.

Figure 24 Billabong Creek Alluvium annual extraction compared to the LTAAEL

8.3 Available water determinations

An available water determination is made at the start of each water year which sets the allocation of groundwater for the different categories of access licences.

The available water determination for each licence category in the Lower Murray Deep Alluvium is shown in Figure 25. The available water determination for aquifer access licences has been set at 1 ML per share every year since the commencement of water sharing plan. The local water utility access licences have been set at 100% every year for the same period. The volumes made available are too small to be shown in Figure 25.

The available water determination for supplementary water access licences (SWAL) in the Lower Murray Deep Alluvium was set by the water sharing plan for each year of the plan until 2015/2016. Supplementary water access licence allocations decreased each year from 2009/2010 to 2015/2016.

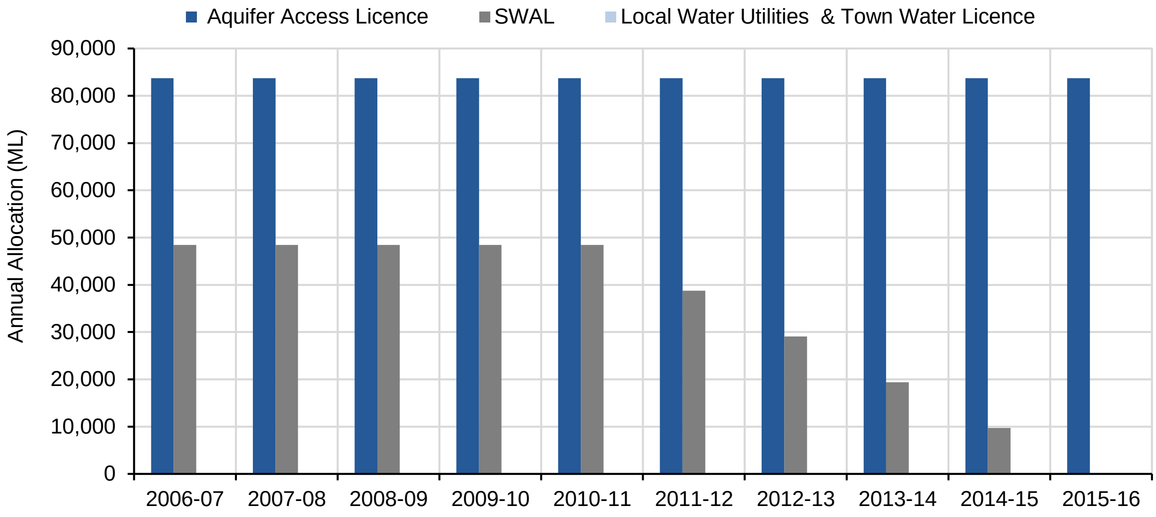


Figure 25 Annual allocations for the Lower Murray Deep Alluvium

The available water determination for aquifer access licences in the Lower Murray Shallow, Upper Murray and Billabong Creek Alluvium has been set at 1 ML per share (i.e. 100% access) every year since the commencement of the water sharing plans. The local water utility access licences, aquifer access (sub-category town water supply) licences, and salinity and watertable management licences have been set at 100% every year for the same period.

8.4 Groundwater accounts

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

8.4.1 Lower Murray Deep Alluvium

The water sharing plan for the Lower Murray Deep Alluvium allows for accrual of unused allocation in aquifer access licence accounts. This includes the yearly allocation for aquifer access licences made through available water determinations plus any carryover of unused allocation up to a maximum of 2 ML per unit of share component. Local water utility, aquifer access licences (sub-category town water supply) and supplementary access licences do not have any provisions for carryover.

The amount of water that can be debited from an account in any one water year (i.e. account take limit) in the Lower Murray Deep Alluvium cannot exceed 1.5 ML per unit share component plus any allocation transferred in, and minus any allocation transferred out. This means that metered extraction plus transfers out cannot exceed 150% of the of share component, unless water is transferred in.

Figure 26 shows the volumes held in water accounts for the Lower Murray Deep Alluvium since commencement of the water sharing plan.

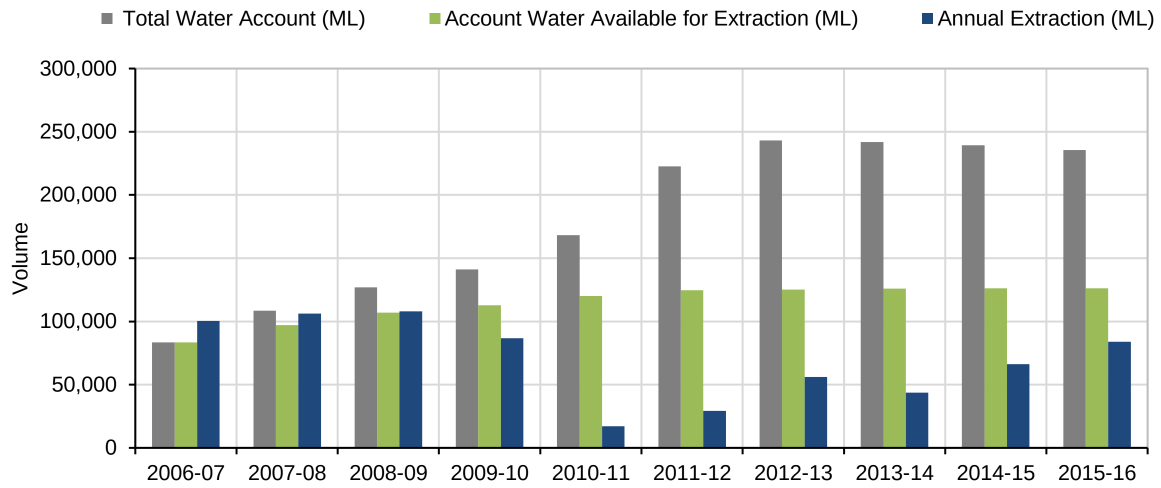


Figure 26 Water accounts since the commencement of the water sharing plan for the Lower Murray Deep Alluvium.

8.4.2 Lower Murray Shallow Alluvium

The water sharing plan for the Lower Murray Shallow Alluvium allows for accrual of unused allocation in aquifer access licence accounts. This includes the yearly allocation for aquifer access licences made through available water determinations plus any carryover of unused allocation up to a maximum of 1 ML per unit of share component. Local water utility access licence and salinity and water table management access licences do not have provisions for carryover.

The maximum amount of water that can be debited from an account in any one water year (i.e. account take limit) in the Lower Murray Shallow Alluvium cannot exceed 1.5 ML per unit share component plus any allocation transferred in, and minus any allocation transferred out. This means that metered extraction plus transfers out cannot exceed 150% of the of share component, unless water is transferred in.

Figure 27 shows the volumes held in water accounts for the Lower Murray Shallow Alluvium since commencement of the water sharing plan.

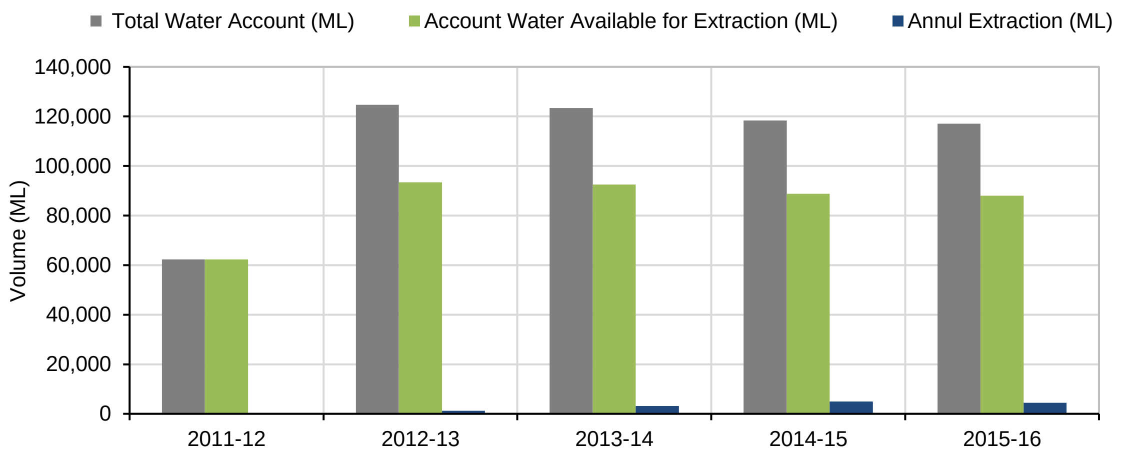


Figure 27 Water accounts since the commencement of the water sharing plan for the Lower Murray Shallow Alluvium.

8.4.3 Upper Murray Alluvium

The water sharing plan for the Upper Murray Alluvium allows for accrual of unused allocation in aquifer access licence accounts. This includes the yearly allocation for aquifer access licences made through available water determinations plus any carryover of unused allocation up to a maximum of 0.74 ML per unit of share component. Local water utility access licences do not have provisions for carryover.

The maximum amount of water that can be debited from an account in any one water year (i.e. account take limit) in the Upper Murray Alluvium cannot exceed 1.37 ML per unit share component plus any allocation transferred in, and minus any allocation transferred out. This means that metered extraction plus transfers out cannot exceed 137% of the of share component, unless water is transferred in.

Figure 28 shows the volumes held in water accounts for the Upper Murray Alluvium since commencement of the water sharing plan.

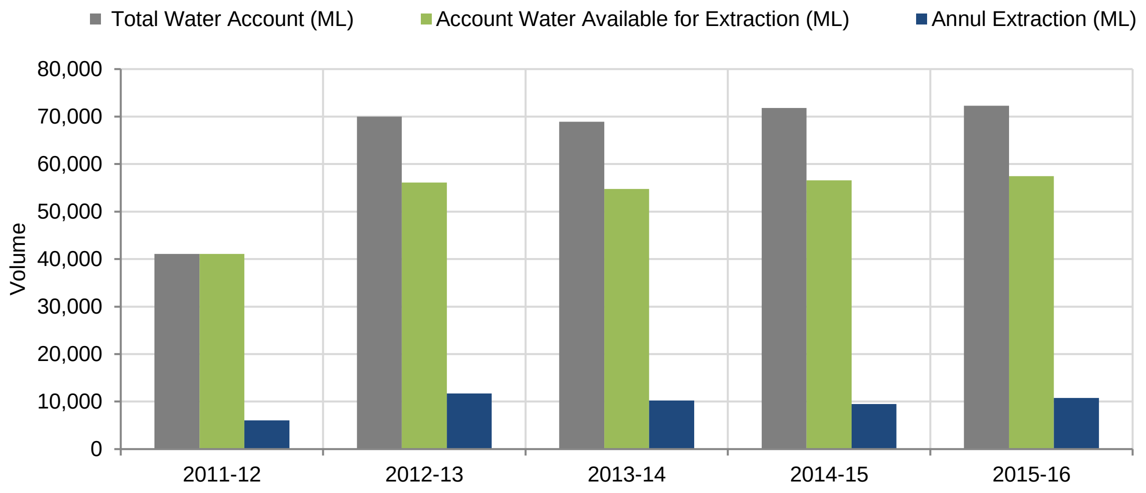


Figure 28 Water accounts since the commencement of the water sharing plan for the Upper Murray Alluvium.

8.4.4 Billabong Creek Alluvium

The water sharing plan for the Billabong Creek Alluvium allows for accrual of unused allocation in aquifer access licence accounts. This includes the yearly allocation for aquifer access licences made through available water determinations plus any carryover of unused allocation up to a maximum of 2 ML per unit of share component. Local water utility access licence and salinity and water table management access licences do not have provisions for carryover.

The plan does not specify the maximum limit of water that can be debited from an account in any one water year.

Figure 29 shows the volumes held in water accounts for the Billabong Creek Alluvium since commencement of the water sharing plan.

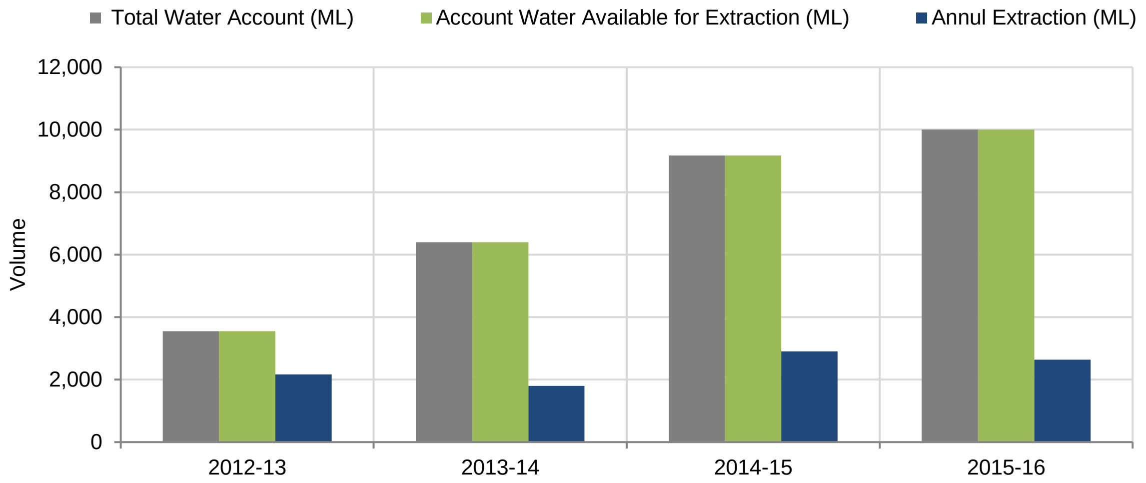


Figure 29 Water accounts since the commencement of the water sharing plan for the Billabong Creek.

8.5 Groundwater take

Groundwater is taken and used in the Murray valley for productive purposes such as irrigation and industry as well as for water supply for local water utilities and stock and domestic use. 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.

8.5.1 Lower Murray Deep Alluvium

Figure 30 shows the distribution of water supply bores in the Lower Murray Deep Alluvium.

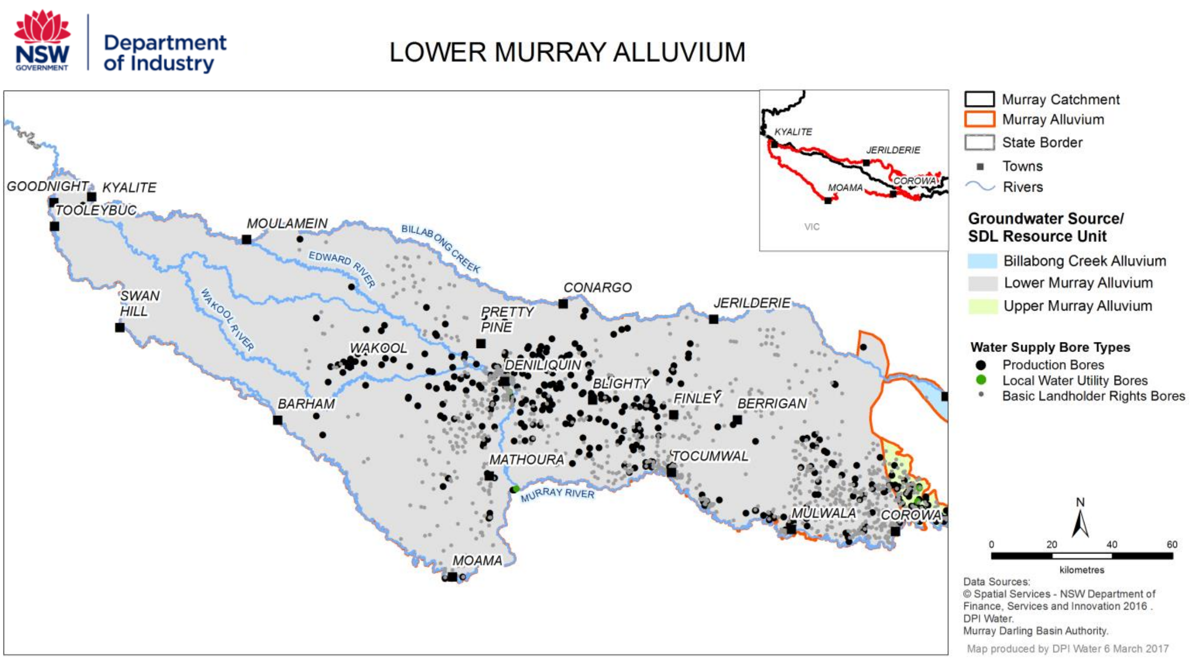


Figure 30 Registered bores in the Lower Murray Deep Alluvial Water Source.

There are approximately 2,600 registered bores in the Lower Murray Alluvium, the majority used for stock and domestic purposes. There is also significant reliance on groundwater for irrigation with approximately 385 production bores, the majority concentrated in the central area of the water source between Wakool and Finley.

Bores constructed in the deeper and more productive aquifer system can yield up to 15 ML/day, extracting up to about 1,500 ML/year (Figure 31).

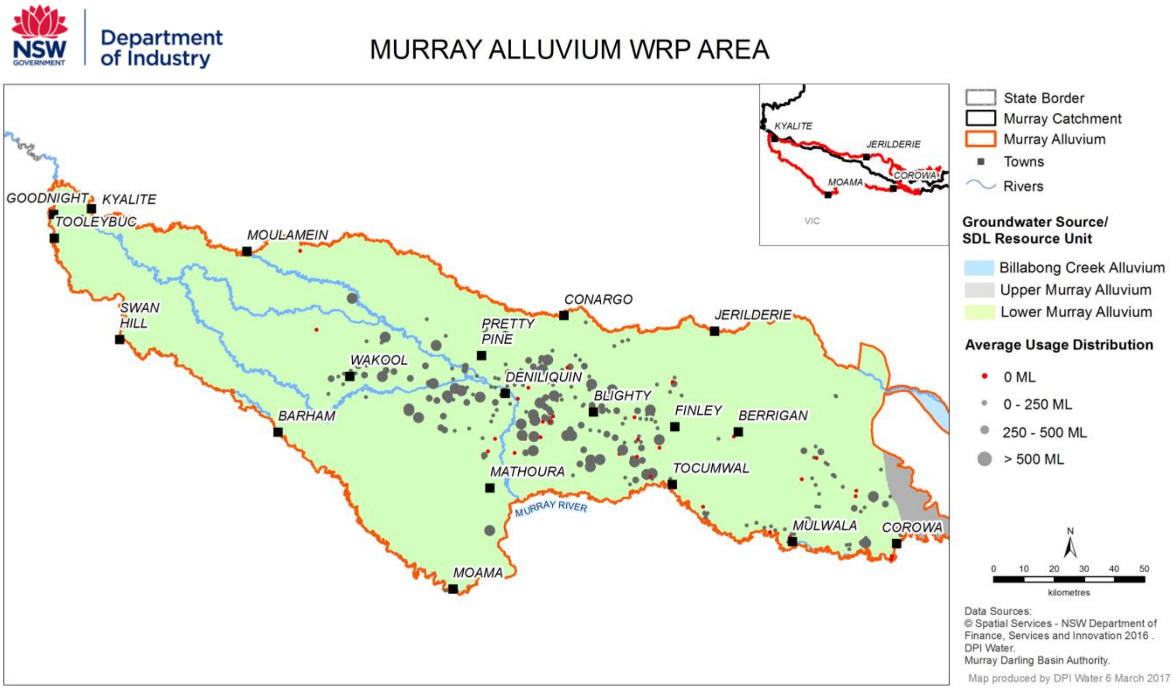


Figure 31 Lower Murray Deep Alluvial Water Source distribution of extraction

Annual groundwater extraction since 2000 and the annual extraction limit for the Lower Murray Deep Alluvium since the commencement of the water sharing plan is provided in Figure 32. The extraction volumes shown are from production bores under access licences and do not include extraction under basic landholder rights (BLR).

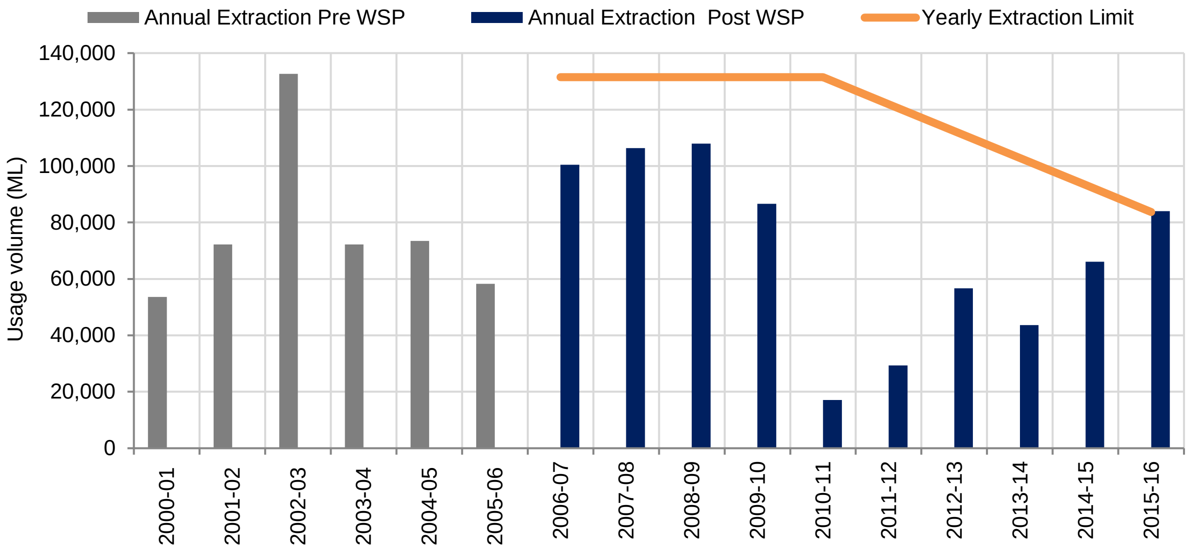


Figure 32 Metered extraction for the Lower Murray Deep Alluvium

8.5.2 Lower Murray Shallow Alluvium

There are approximately 550 registered bores in the Lower Murray Shallow Alluvium, the majority used for stock and domestic purposes. There is less reliance on groundwater for irrigation with approximately 250 production bores (spearpoint systems). The majority is concentrated between Deniliquin and Finley in the Berriquin Irrigation District where water quality is suitable for irrigation. A properly constructed battery of spearpoints can yield up to 5 ML/day.

A large majority of bores in the Lower Murray Shallow Alluvium is not metered hence a chart showing metered extraction is not shown.

8.5.3 Upper Murray Alluvium

Figure 33 shows the distribution of water supply bores in the Upper Murray Alluvium.

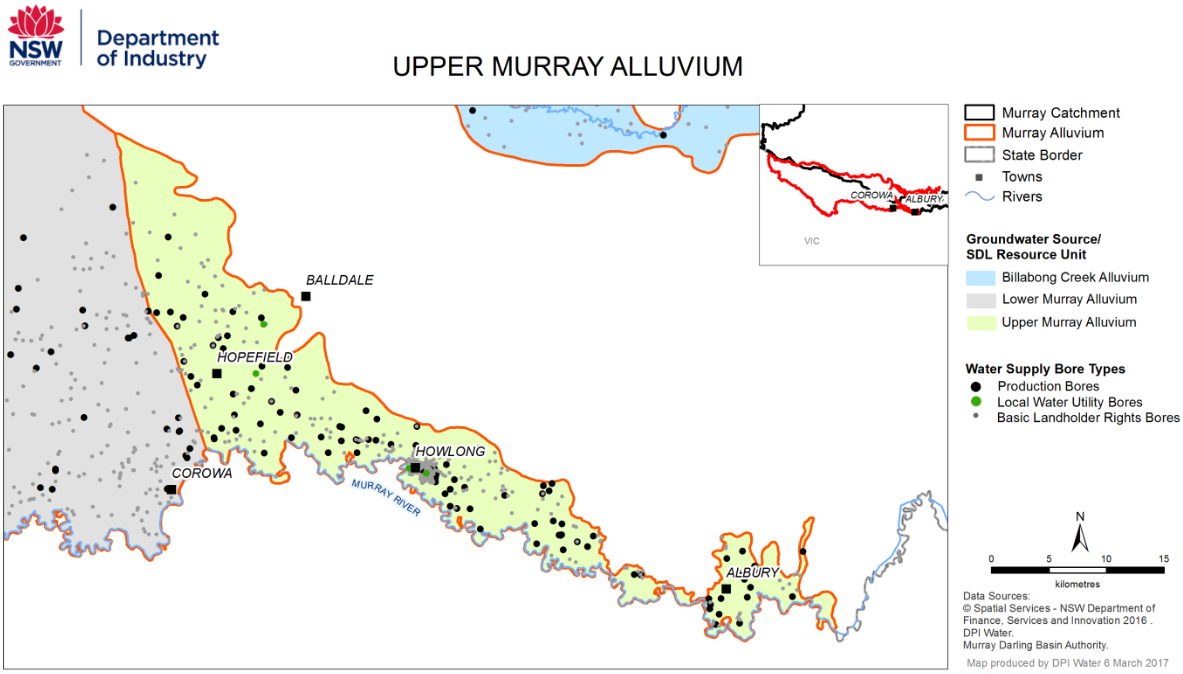


Figure 33 Registered bores in the Upper Murray Alluvial Water Source.

There are approximately 750 registered bores in the Upper Murray Alluvium, the majority used for stock and domestic purposes. There is moderate reliance on groundwater for irrigation with approximately 100 production bores. The small township of Balldale uses groundwater as their only water supply for local water utility.

Bores constructed in the deeper and more productive aquifer system can yield up to 10 ML/day extracting up to about 1,000 ML/year (Figure 34). However, the majority of production bores produce supply less than 500 ML/year.

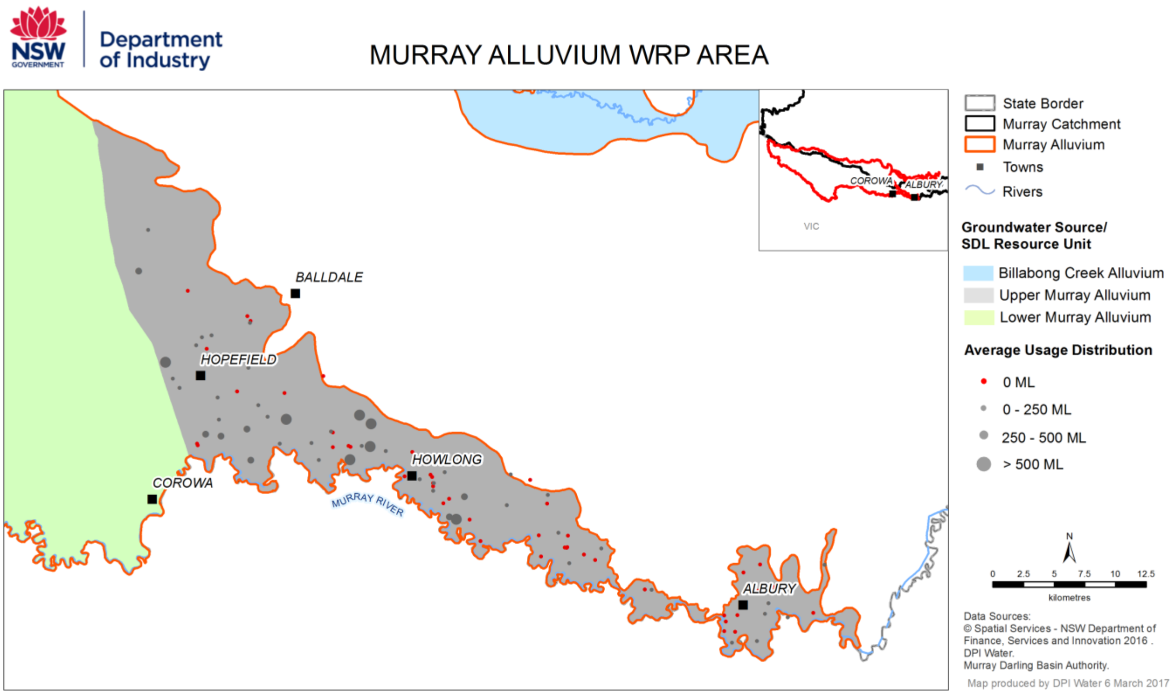


Figure 34 Upper Murray Alluvial Water Source distribution of extraction

Annual groundwater extraction since 2000 and the annual extraction limit for the Upper Murray Alluvium since the commencement of the water sharing plan is provided in Figure 35. The extraction volumes shown are from production bores under access licences and do not include extractions under BLR.

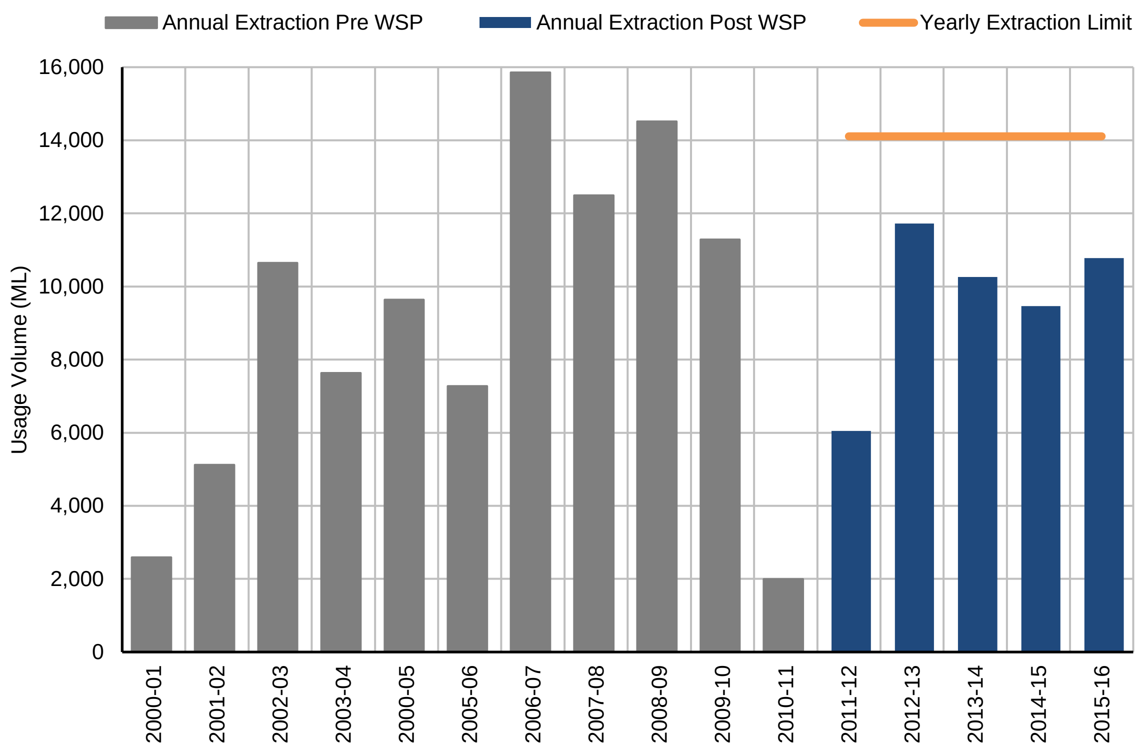


Figure 35 Metered extraction for the Upper Murray Alluvium

8.5.4 Billabong Creek Alluvium

Figure 36 shows the distribution of water supply bores in the Billabong Creek Alluvium.

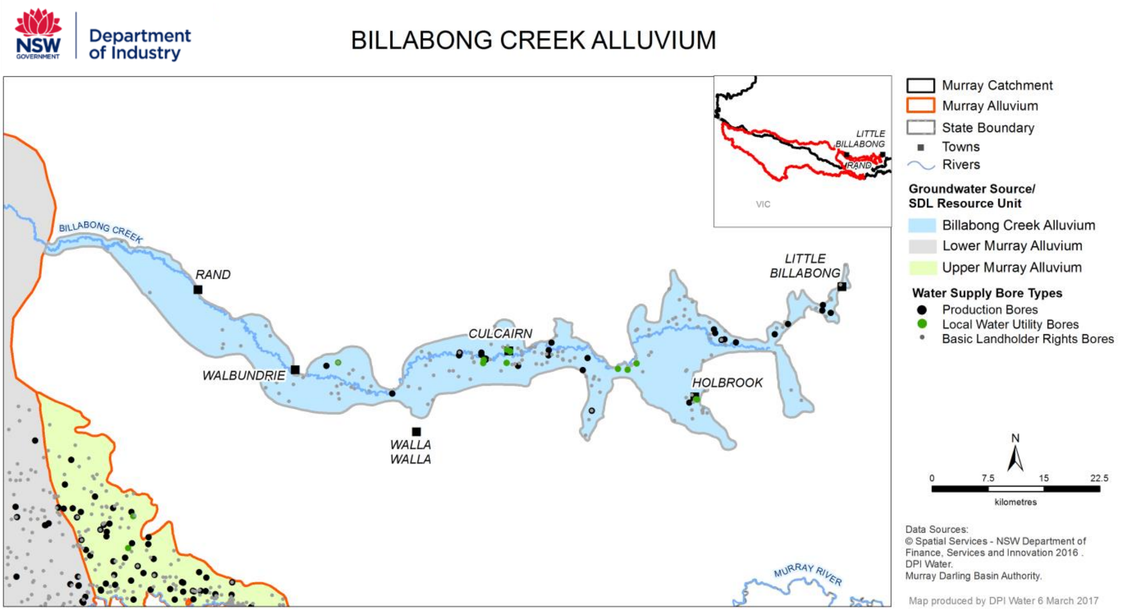


Figure 36 Registered bores in the Billabong Creek Alluvial Water Source.

There are approximately 275 registered bores in the Billabong Creek Alluvium, the majority used for stock and domestic purposes. The area is generally dominated by dryland farming . There is less reliance on groundwater for irrigation with approximately 34 production bores. The towns of Culcairn, Holbrook, Walla Walla and Walbundrie use groundwater as their main water supply for local water utility.

Bores constructed in the deeper more productive aquifer system can yield up to 5 ML/day extracting up to about 1,500 ML/year (Figure 37). However, the majority of production bores produce supply less than 250 ML/year

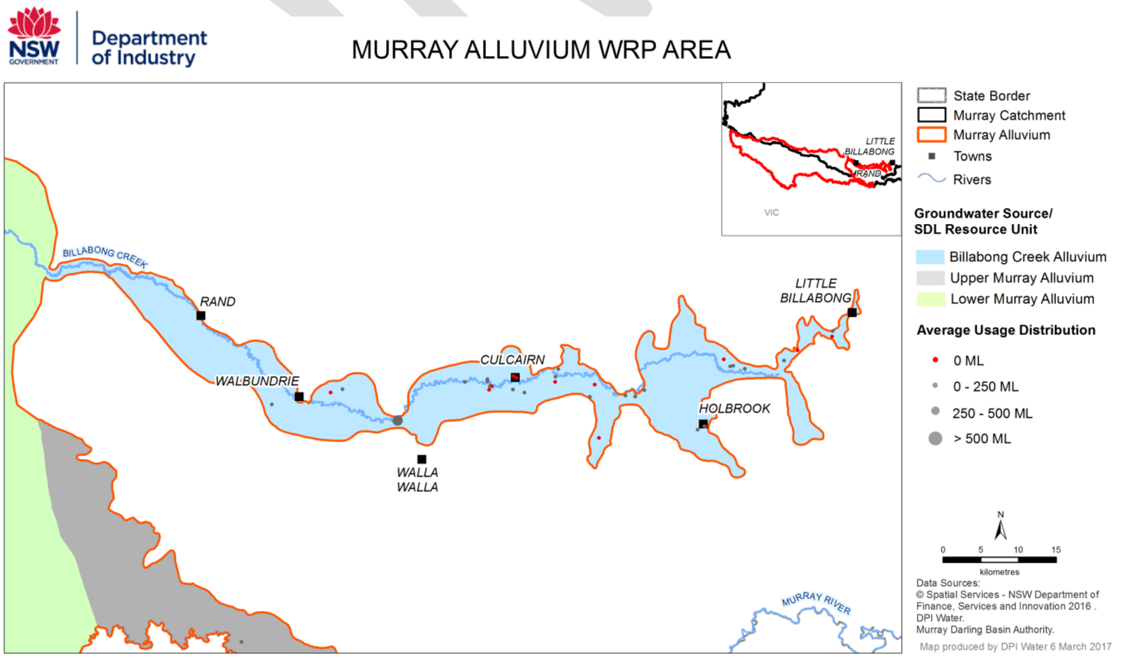


Figure 37 Billabong Alluvial Water Source distribution of extraction

Annual groundwater extraction since 2000 and the annual extraction limit for the Billabong Creek Alluvium since the commencement of the water sharing plan is provided in Figure 38. The extraction volumes shown are from production bores under access licences and do not include BLR.

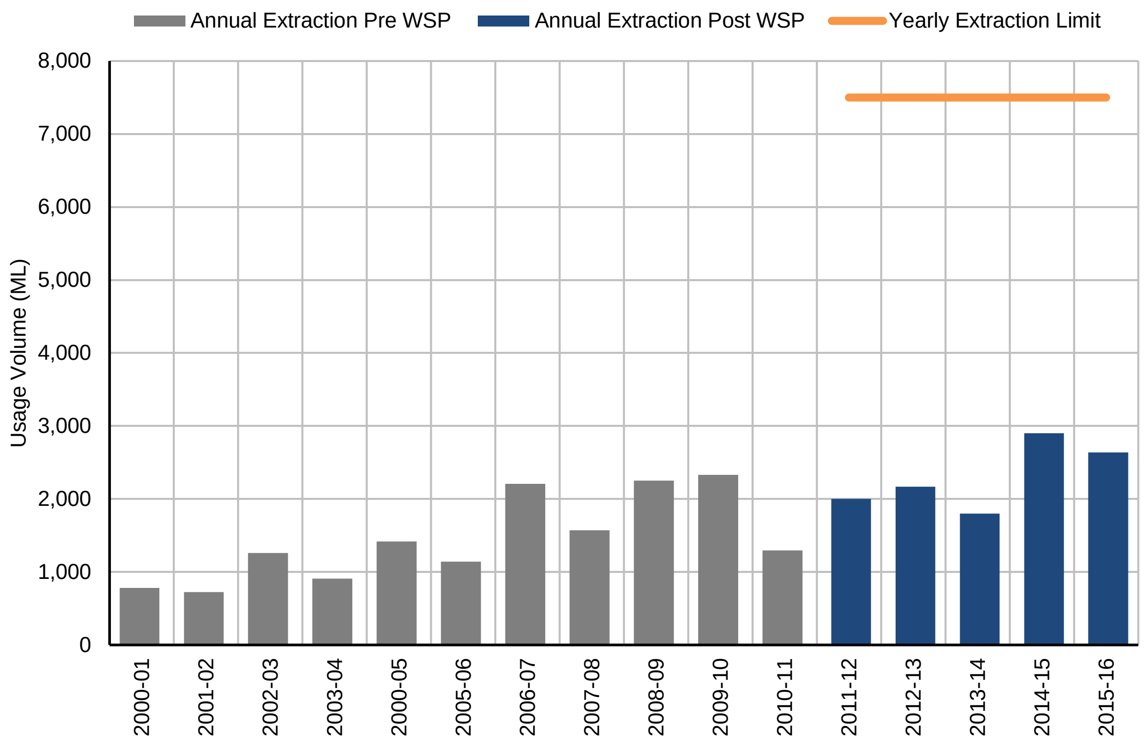


Figure 38 Metered extraction for the Billabong Creek Alluvium

8.6 Groundwater dealings

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

There are no trade restricted areas defined in the Murray Alluvium water sources. Almost all the groundwater dealings in the Murray Alluvium have taken place in the Lower Murray Deep 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 is shown in Figure 39 and the statistics for the business to business trades worth less than $1/ML are shown in Figure 40.

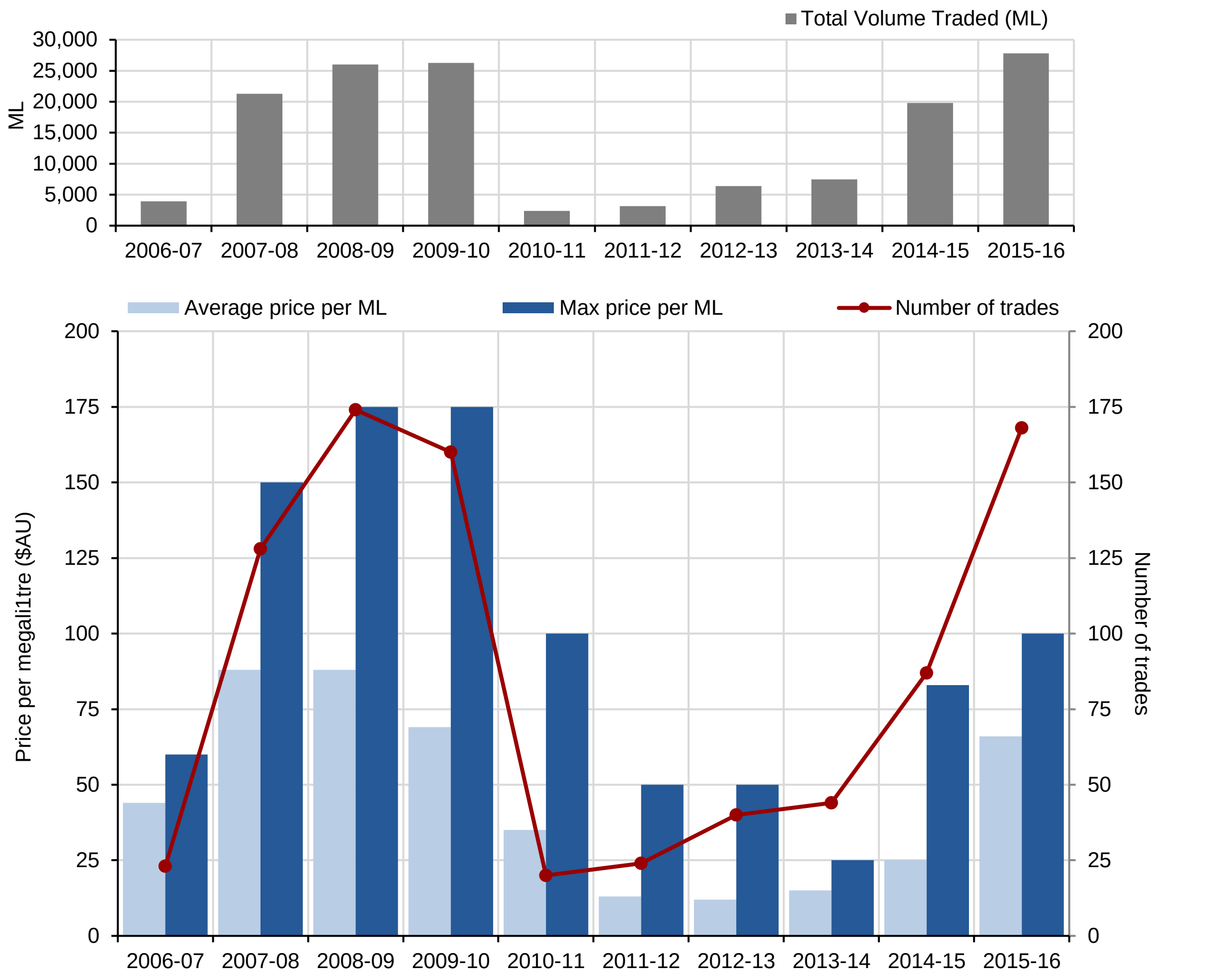


Figure 39 Lower Murray Deep Alluvium >1$/ML 71T dealings since commencement of the water sharing plan

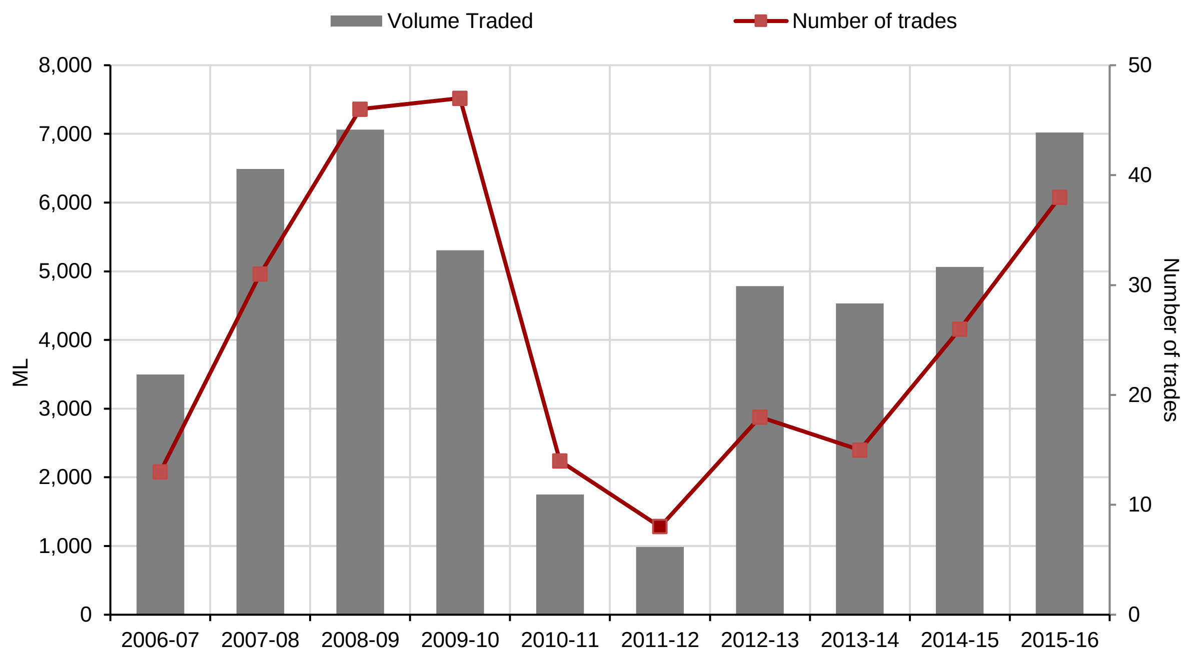


Figure 40 Lower Murray Deep Alluvium < 1$/ML 71T dealings since commencement of the water sharing plan

There have been only 11 temporary dealings (3,800 ML) in the Upper Murray since the commencement of the water sharing plan. To date there have been no applications for temporary dealings in the Billabong Creek Alluvium or the Lower Murray Shallow Alluvium.

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.

Figure 41 shows the statistics for dealings that result in a change in the potential volume that can be extracted from a location since commencement of the water sharing plan in the Lower Murray Deep Alluvium. 71M dealings are not included as these are a change in ownership only and therefore have no potential for additional third party impacts.

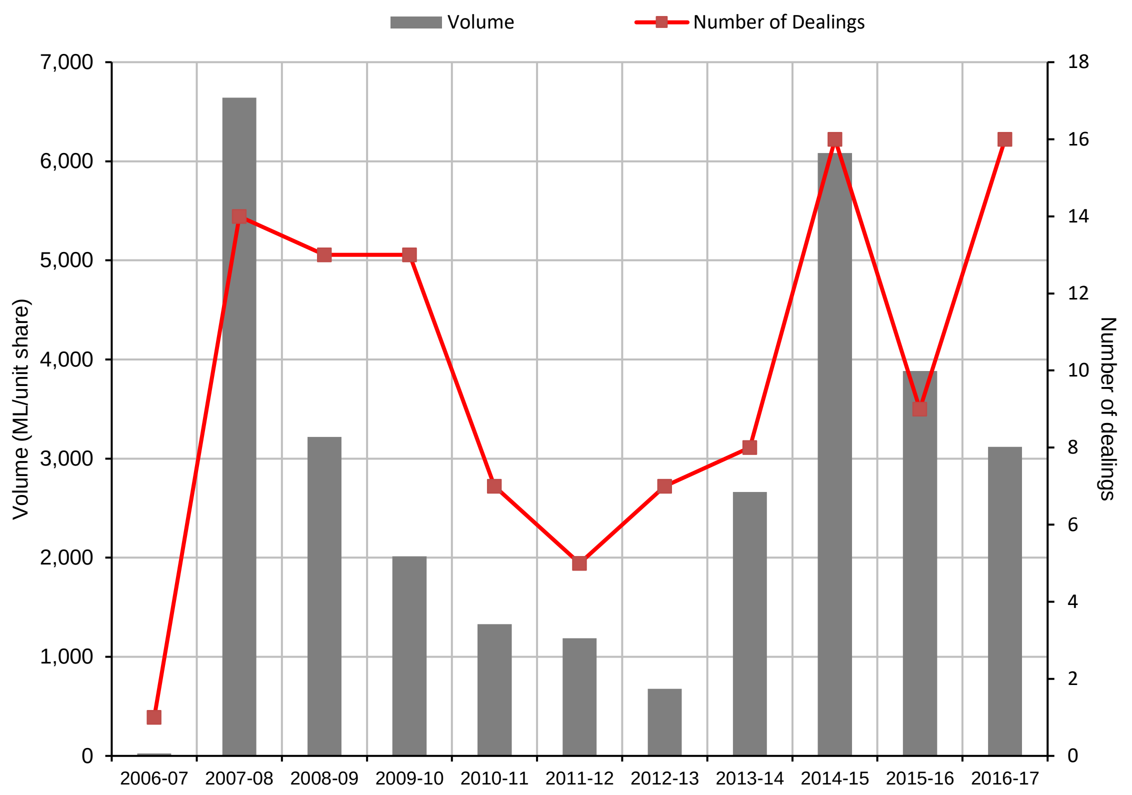


Figure 41 Lower Murray Deep Alluvium permanent dealings since commencement of the water sharing plan, 71M dealings not included.

There have been only 3 permanent dealings (650 shares) in the Upper Murray Alluvium since the commencement of the water sharing plan. To date there have been no applications for permanent dealings in the Billabong Creek Alluvium or the Lower Murray Shallow Alluvium.

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 42 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 42 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.

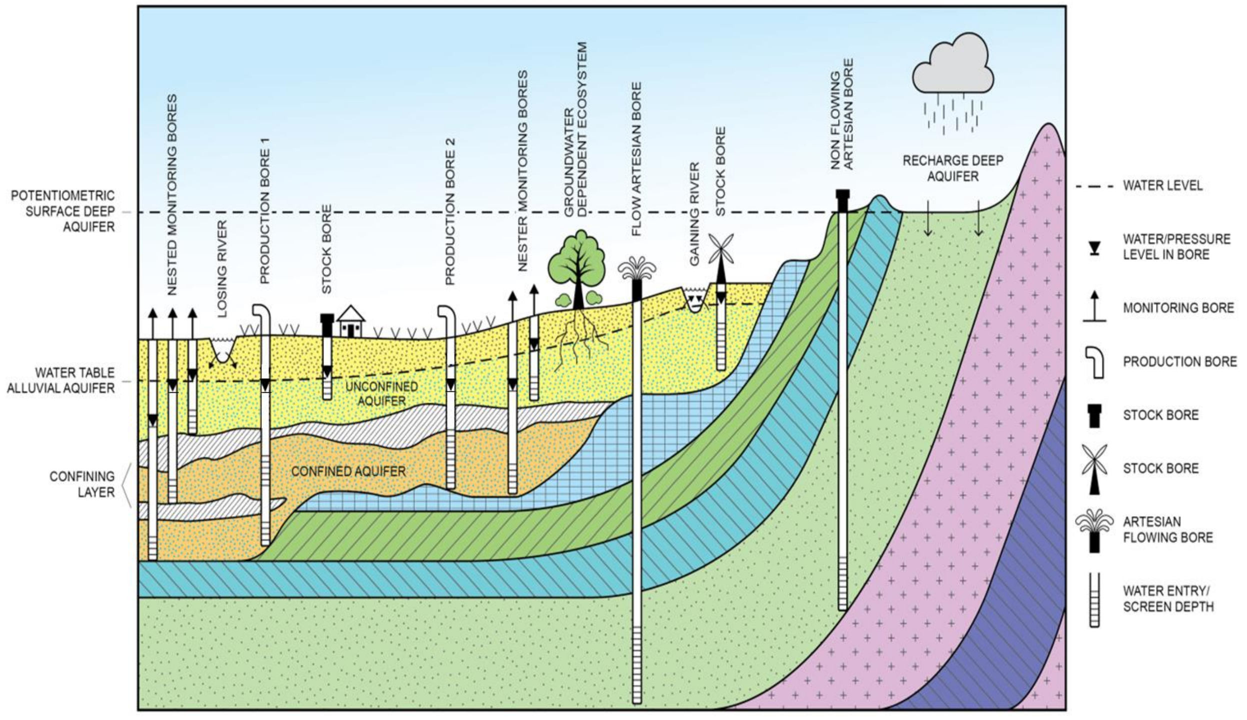


Figure 42 Schematic diagram of different types of aquifers

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

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

Across the Lower Murray Alluvium there are 123 monitoring bores at 58 sites (Figure 43). In the Upper Murray Alluvium there are 37 monitoring bores at 18 sites (Figure 44) while the Billabong Creek Alluvium has 32 monitoring bores at 22 sites (Figure 45). Monitoring of groundwater levels and pressures commenced in the mid -1970s. New sites have been added to the monitoring network on needs basis when funds were made available under different projects.

The manually monitored sites are read every twelve weeks. Data is available for 27 of these groundwater monitoring sites in the Lower Murray Deep Alluvium in real-time via telemetry from: *http://realtimedata.waternsw.com.au/water.stm*

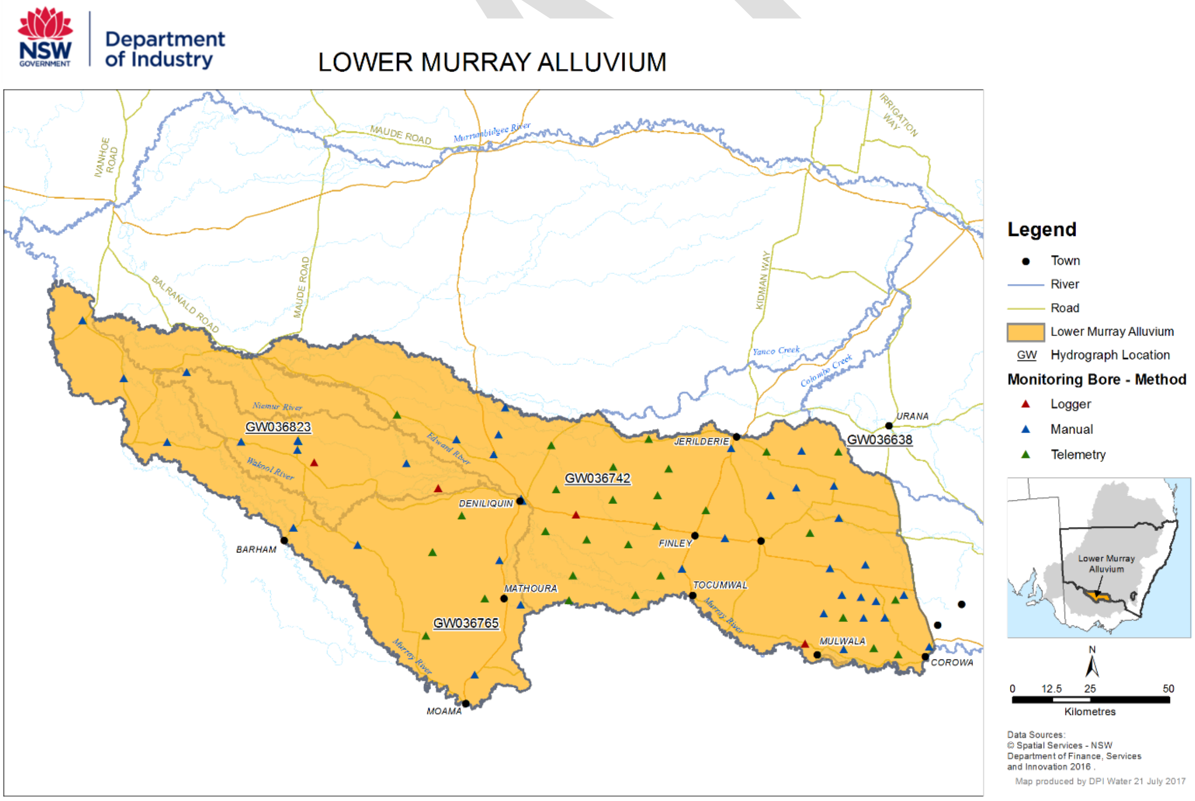


Figure 43 Location map of monitoring bores in the Lower Murray Deep Alluvium

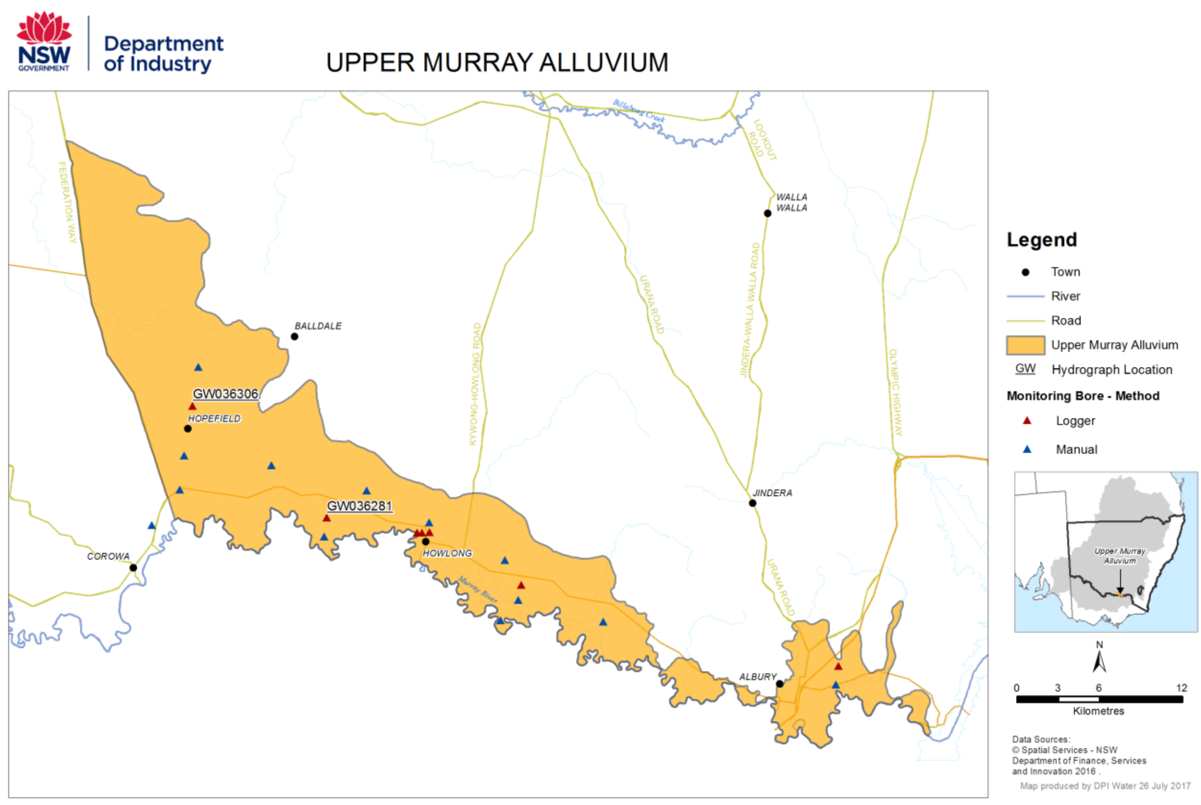


Figure 44 Location map of monitoring bores in the Upper Murray Alluvium

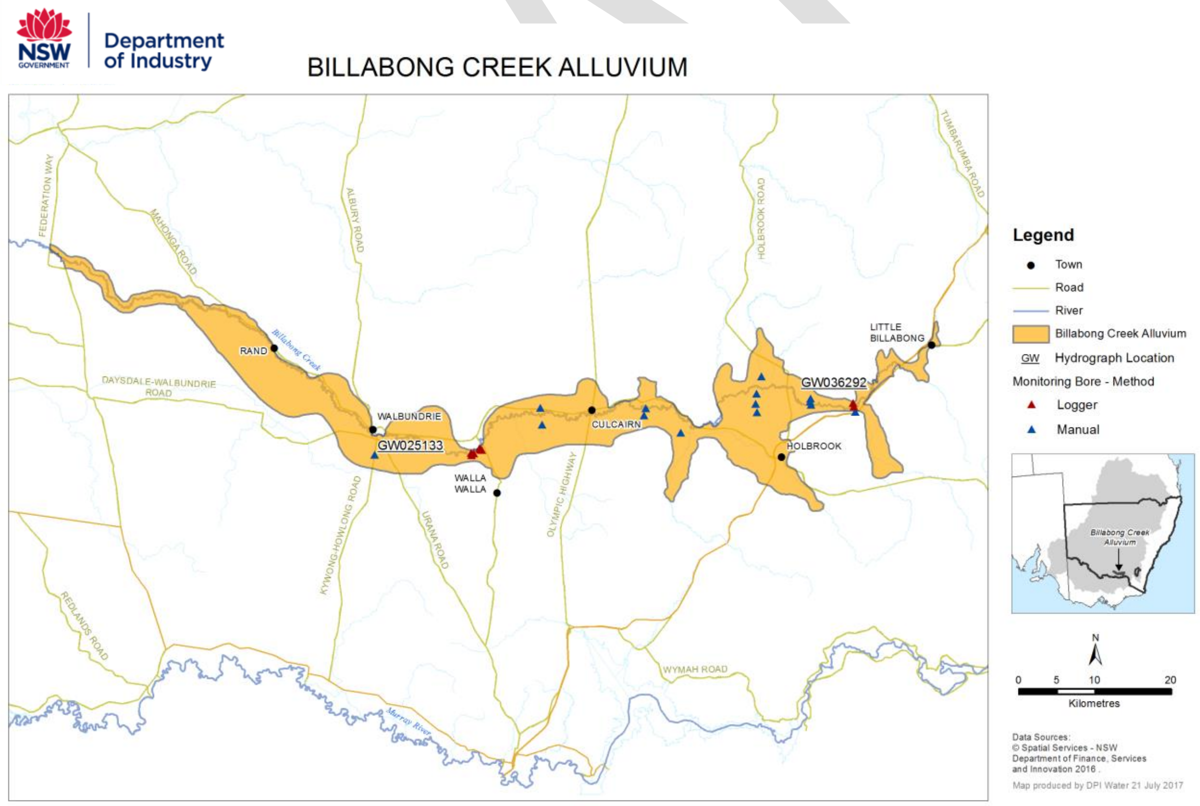


Figure 45 Location map of monitoring bores in the Billabong Creek Alluvium

10 Groundwater Behaviour in the Murray Alluvium

10.1 Introduction

Generally for the Murray Alluvium, monitoring bores constructed and screened less than 30 m deep are considered to be within the unconfined shallow aquifer system, while monitoring bores constructed deeper than 30 m have been assessed to be in the semi confined/confined aquifer system.

Significant groundwater extraction in the Murray Alluvium water sources started at different times. The reference condition to which long term trends are compared is the ‘pre-development’ water level. In the Lower Murray Alluvium the ‘pre-development’ is defined as the average recovered water level from 1985 to 1990. In the Upper Murray Alluvium ‘pre-development’ is defined as the average recovered water level from 1992 to 1997. In the Billabong Creek Alluvium ‘pre-development’ is defined as the average recovered water level from 1995 to 2000. Changes in groundwater levels in the Murray Alluvium water sources are discussed in the following sections presenting data from hydrographs.

10.2 Hydrographs

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (Figure 46). 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 46 explains the trends that can be observed in groundwater hydrographs. Both short and longer term water level trends can be identified. In unconfined and semi-confined aquifers, groundwater can be in hydraulic connection with the surface. Where this occurs, groundwater levels rise in response to recharge such as rainfall or flooding and decline during periods of reduced rainfall.

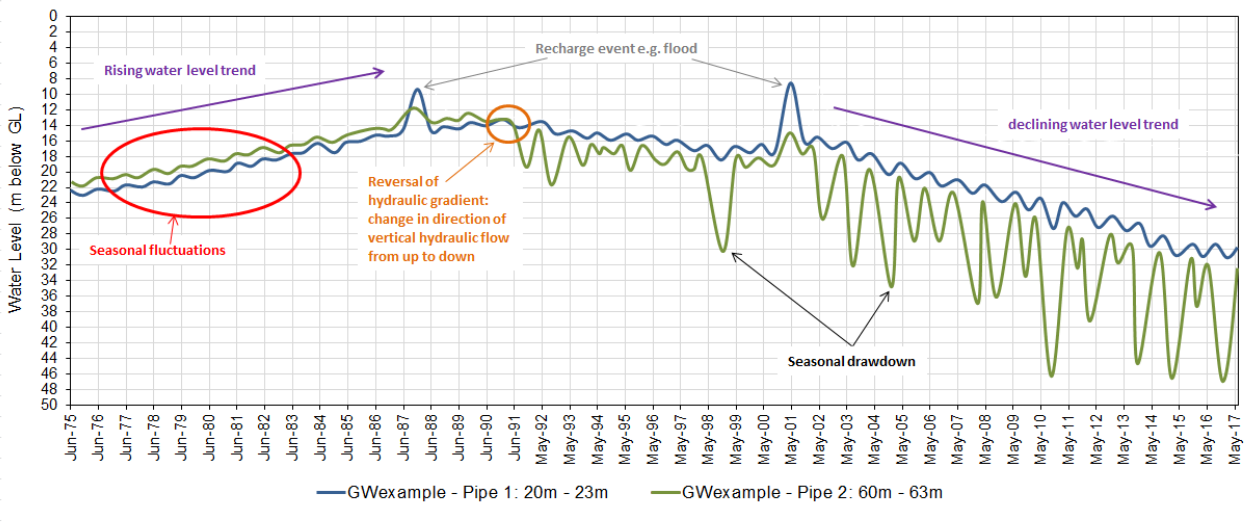


Figure 46 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate.

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

In areas where groundwater extraction occurs, hydrographs show a seasonal cyclic pattern of drawdown and recovery. Drawdown is the maximum level to which groundwater is lowered in a bore due to pumping. It is followed by recovery when pumping has ceased or reduced. Review of the recovered groundwater level over time can be used to assess how a groundwater system is responding to climate and pumping impacts in the long term. The recovered groundwater level is the highest point to which groundwater has risen in a particular year.

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

10.3 Review of groundwater levels

10.3.1 Lower Murray Deep Alluvium

Hydrographs for four representative groundwater monitoring sites across the Lower Murray Deep Alluvium are presented below. The location of these sites is shown in Figure 47. Each hydrograph is displayed on the same scale for ease of comparison.

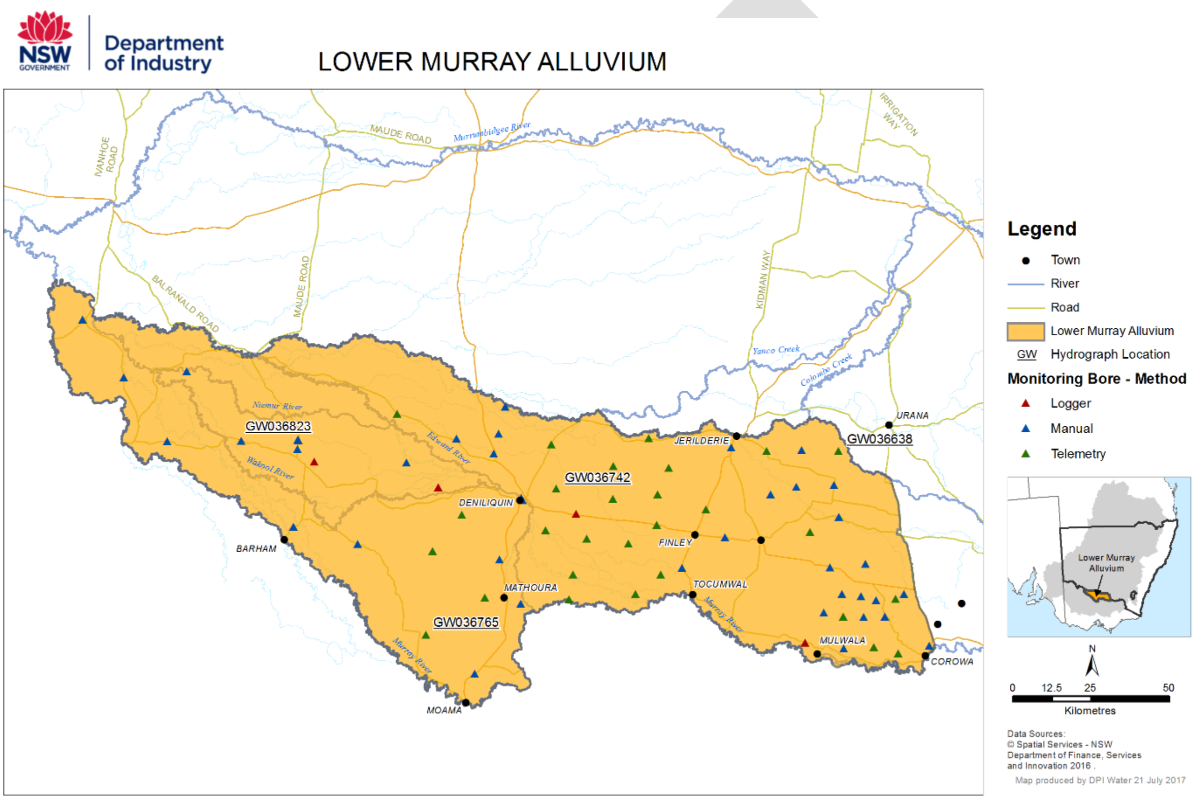


Figure 47 Lower Murray Deep Alluvium hydrograph locations

The Lower Murray Alluvium becomes deeper from east to west. The system is relatively shallow (approximately 100 m) around Rennie in the east. The hydrograph for GW036823 (Figure 48) shows the pressure level in the deep aquifer is higher than the pressure level in the shallow aquifer indicating an upward vertical hydraulic gradient. There is limited number of production bores in the western part of the water source and therefore no significant drawdowns are observed (Figure 48). The slight declining trend since mid-nineteen nineties is due to regional pumping effects towards east.

The hydrograph for monitoring bore GW036765 (Figure 49) shows a moderate rate of decline as it is located a little closer to the area of significant groundwater extractions but does not show seasonal fluctuations There is a reversal of hydraulic gradient from upward to downward around mid-1995 at the onset of extraction. Other bores in the area also show reversals in hydraulic gradient due to the commencement of extraction.

Large drawdowns and longer term recovery decline are observed (Figure 50) in areas where the majority of extraction occurs. This is mainly in the central area of the water source between Deniliquin and Finley. The wetter years between 2010 and 2012, correspond to a period of reduced extraction and water level recovery.

In the eastern part of the water source, water levels show a rising trend (Figure 51). Groundwater extractions in this area are low due to the occurrence of generally higher salinity groundwater. There is little or no direct response to groundwater extraction towards the west.

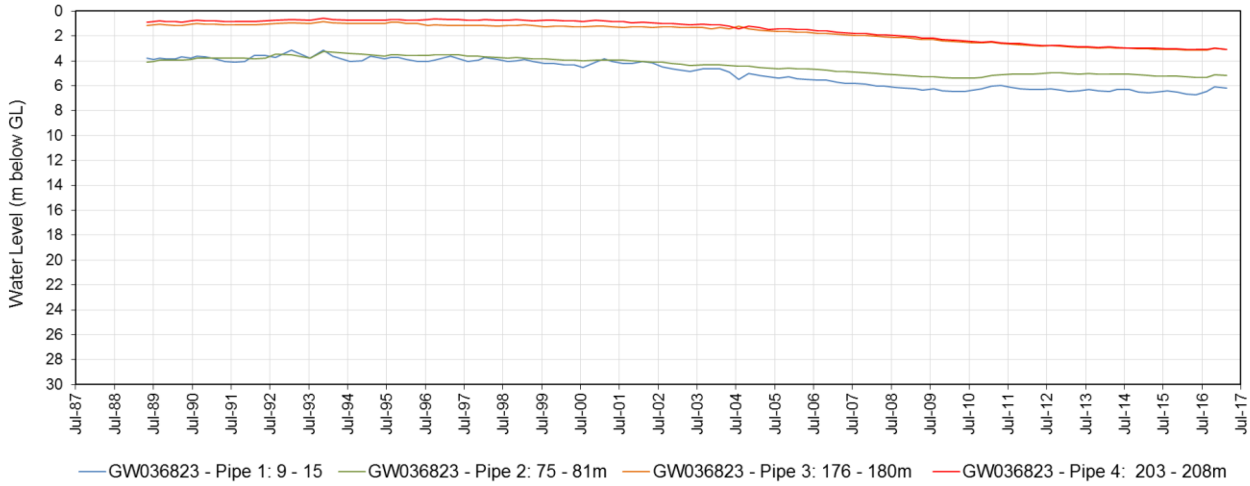


Figure 48 Hydrograph for monitoring bore site GW036823 – Mellol/Rennie section

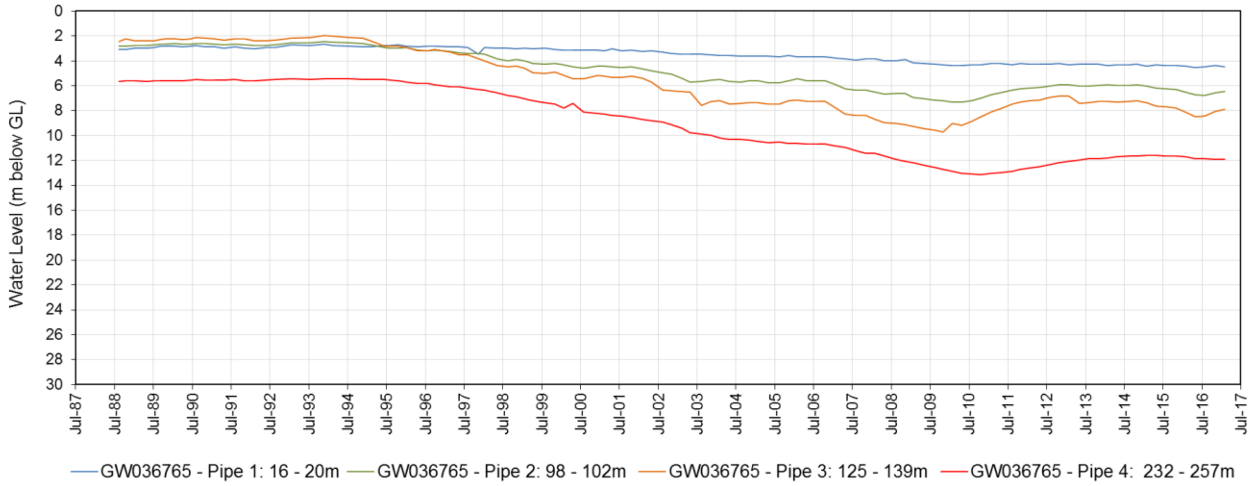


Figure 49 Hydrograph for monitoring bore site GW036765 – Womboota/ Jerilderie section

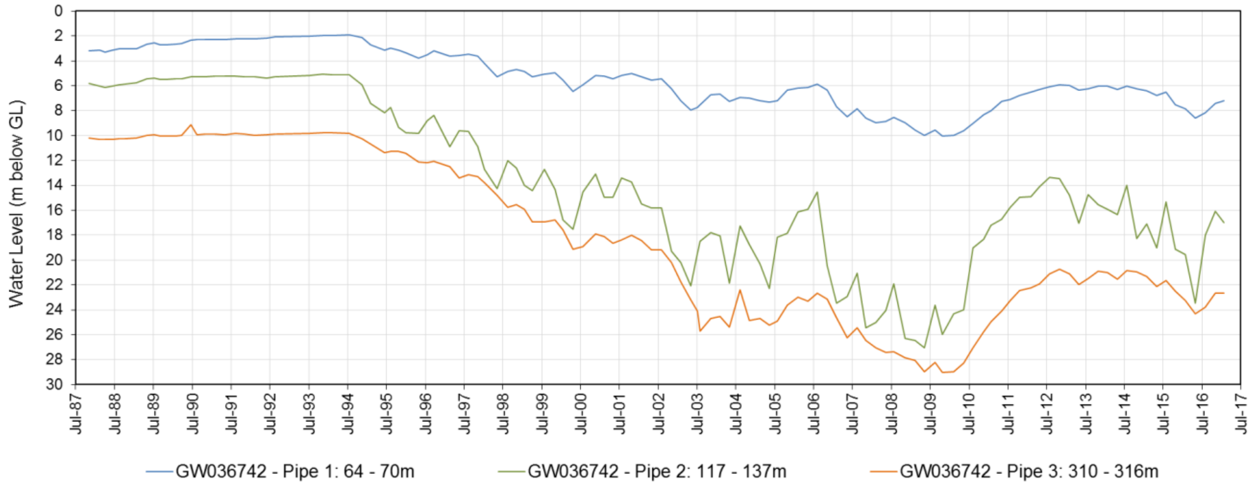


Figure 50 Hydrograph for monitoring bore site GW036742 – Deniliquin.

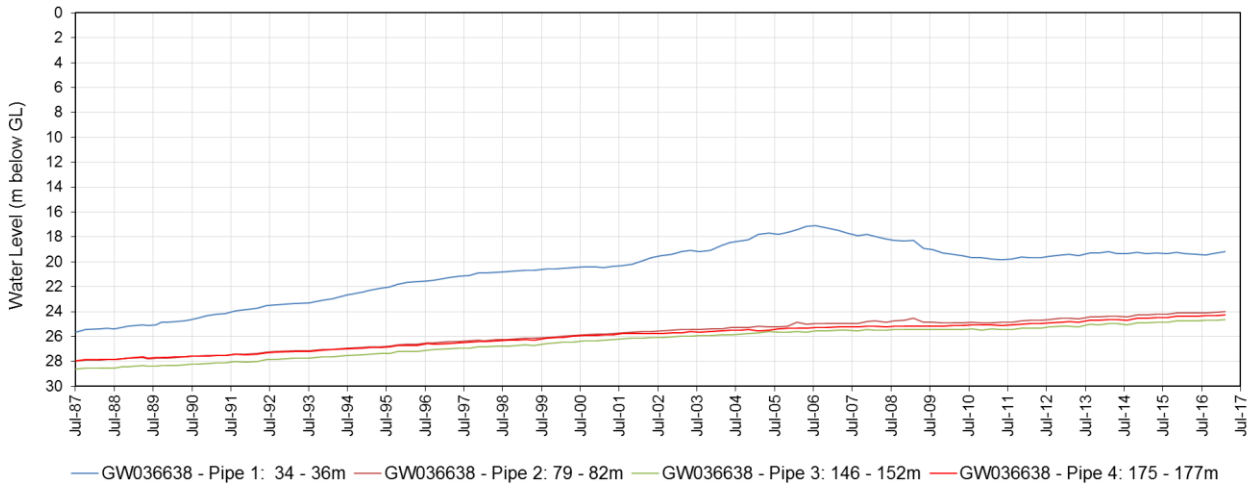


Figure 51 Hydrograph for monitoring bore site GW036638 – Spring Drive/ McKay Road section

10.3.2 Upper Murray Alluvium

Hydrographs for two representative groundwater monitoring sites across the Upper Murray Alluvium are presented below. The location of these sites is shown in Figure 52. Each hydrograph is displayed on the same scale for ease of comparison.

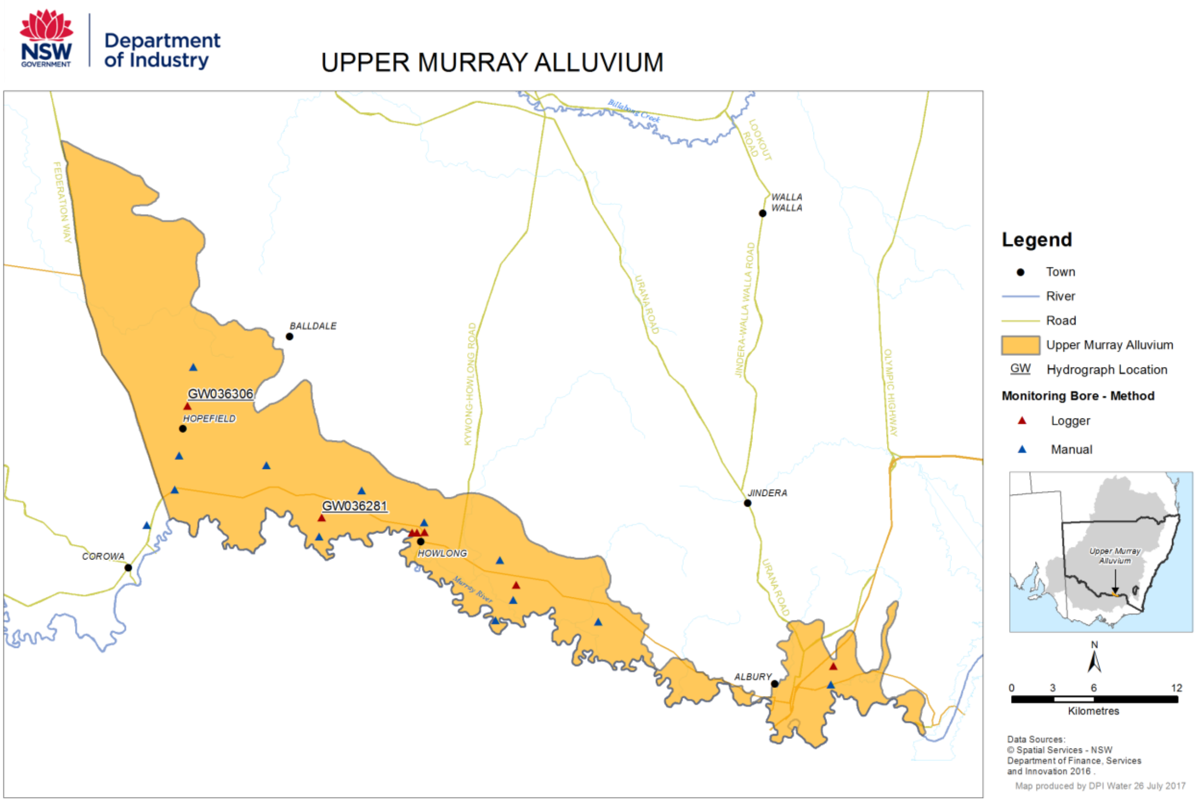


Figure 52 Upper Murray Alluvium hydrograph locations

Monitoring bore GW036306 (Figure 53) is located in the western part of the water source at Hopefield. Pipe 1 is constructed in the shallow aquifer while pipes 2 and 3 are in the deeper aquifer. There is a fairly steady trend in recovered levels in the deep aquifer following the seasonal fluctuations from pumping at this location. The shallow aquifer water levels also show a steady trend but do not respond to pumping in the deep aquifer suggesting a low level of connectivity between the two in this area.

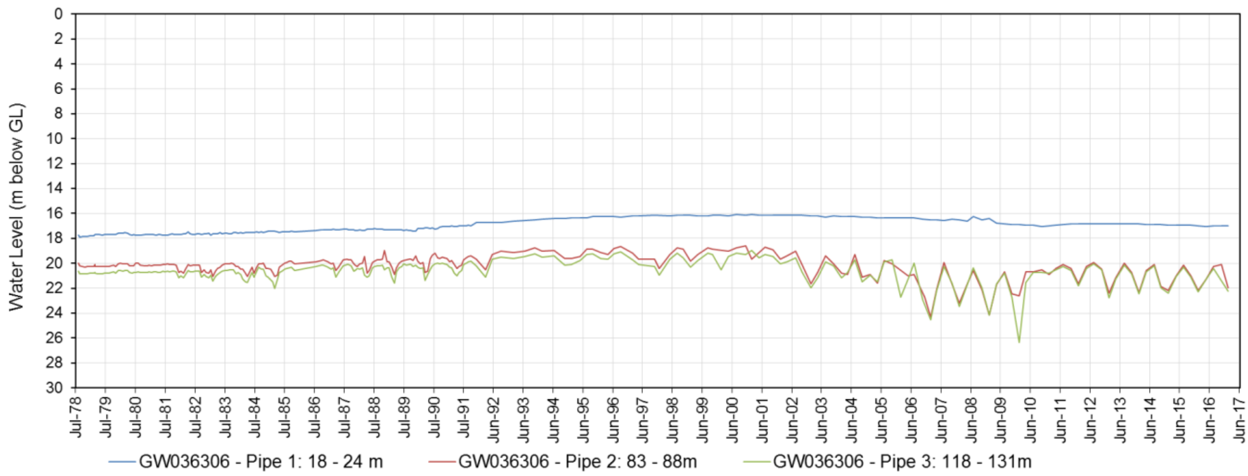


Figure 53 Hydrograph for monitoring bore site GW036306 – Hopefield.

Monitoring site GW036282 (Figure 54) is located in the Howlong area about two kilometres from the Murray River. Pipe 1 is constructed in the shallow aquifer while pipes 2 and 3 are in the deep aquifer (Quat Quatta Cross Section). There was little groundwater development in the area until mid-1990s and the water levels for all aquifers remained fairly static. Since the commencement of pumping the water levels in the deep aquifer show seasonal fluctuations and a slightly declining trend in recovered water levels. The shallow aquifer hydrographs also shows similar trends with more subdued fluctuations.

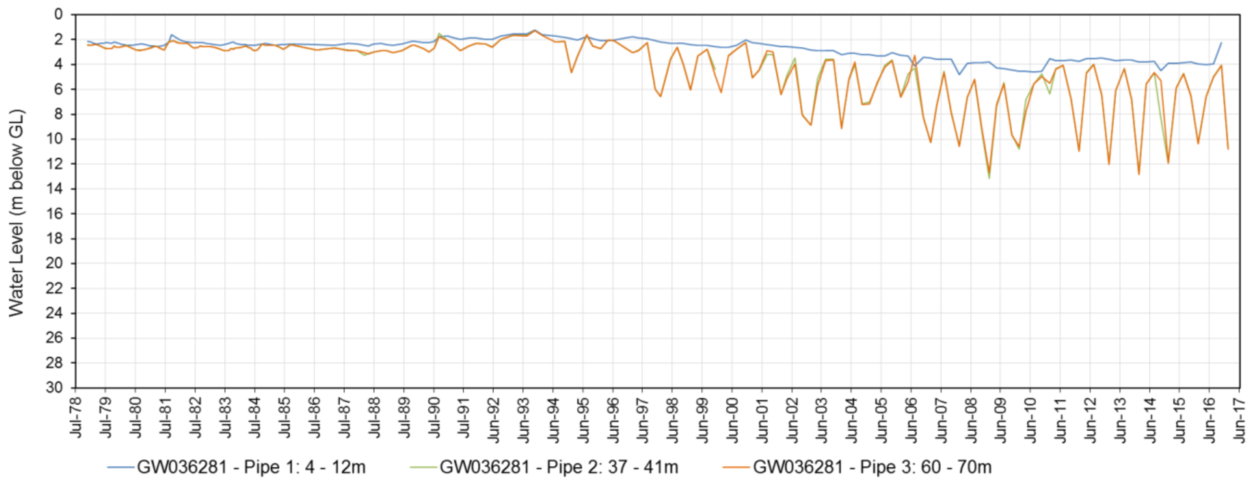


Figure 54 Hydrograph for monitoring bore site GW036281 – Quat Quatta section.

10.3.3 Billabong Creek Alluvium

Hydrographs for two representative groundwater monitoring sites across the Billabong Creek Alluvium are presented below. The location of these sites is shown in Figure 55. Each hydrograph is displayed on the same scale for ease of comparison.

Figure 55 Billabong Creek Alluvium hydrograph locations

Monitoring bore GW25133 (Figure 56) is located in the western part of the water source near Walbundrie where there is limited groundwater pumping as shown by the lack of water level fluctuation in the hydrograph in the deep aquifer. Water levels had risen steadily until mid-nineties followed by a gentle downward trend until 2011 and steady thereafter.

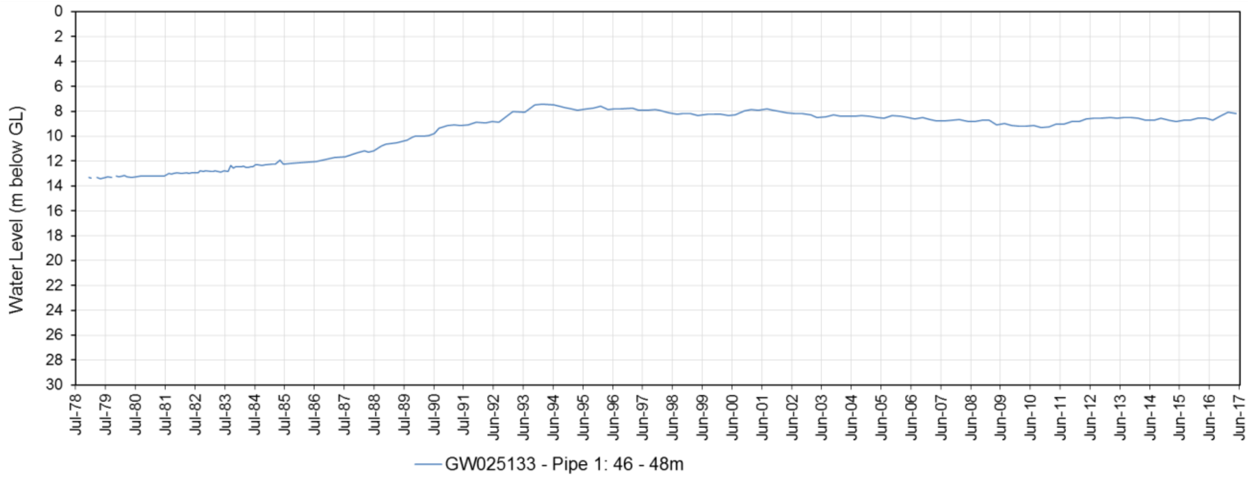


Figure 56 Hydrograph for monitoring bore site GW025133 – Walbundrie.

Monitoring site GW036292 **(**Figure 57) is located in the eastern part of the water source in the Holbrook area. Pipe 1 is constructed in the shallow aquifer while Pipe 2 is within the deeper aquifer (Brigadoon Section). Water levels in both aquifers were steady or slightly rising until groundwater pumping started in late nineties. There was a marked decline in water levels in 1999 responding to groundwater pumping in both shallow and deep aquifers. The seasonal fluctuation in the shallow aquifer is more subdued compared to the deep aquifer. Water levels have a slight downward trend for the past 4 years in both shallow and deep aquifers.

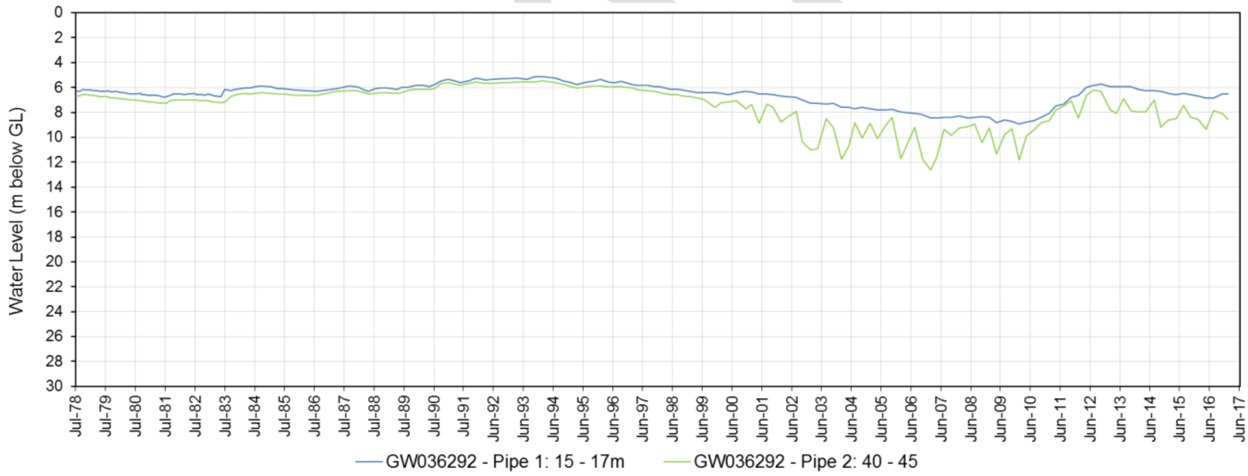


Figure 57 Hydrograph for monitoring bore site GW036292 – Garryowen (Brigadoon Section)

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.

Groundwater level and pressure contour maps have been prepared for the deep groundwater systems using the 'kriging' method.

For comparison purposes, contour maps have been prepared at maximum recovery level commencing with pre-development, 2005/2006 and 2015/2016. Pre-development reference periods are different for Lower Murray Alluvium, Upper Murray Alluvium and Billabong Creek Alluvium water sources as stated in Chapter 10.1. 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.

Maximum drawdown contours have been prepared for the deep systems for 2015/2016. These are displayed with the maximum recovery contour for the same year to demonstrate the change in flow direction that can occur during the pumping season.

10.4.1 Lower Murray Deep Alluvium

Groundwater level contours of recovered water levels generally show the regional groundwater flow direction across the Lower Murray Alluvium is east to west. The absence of the deep aquifer of the Lower Murray Alluvium around Berrigan explains the north-north westerly flow in the eastern end of the water source as shown in Figure 58.

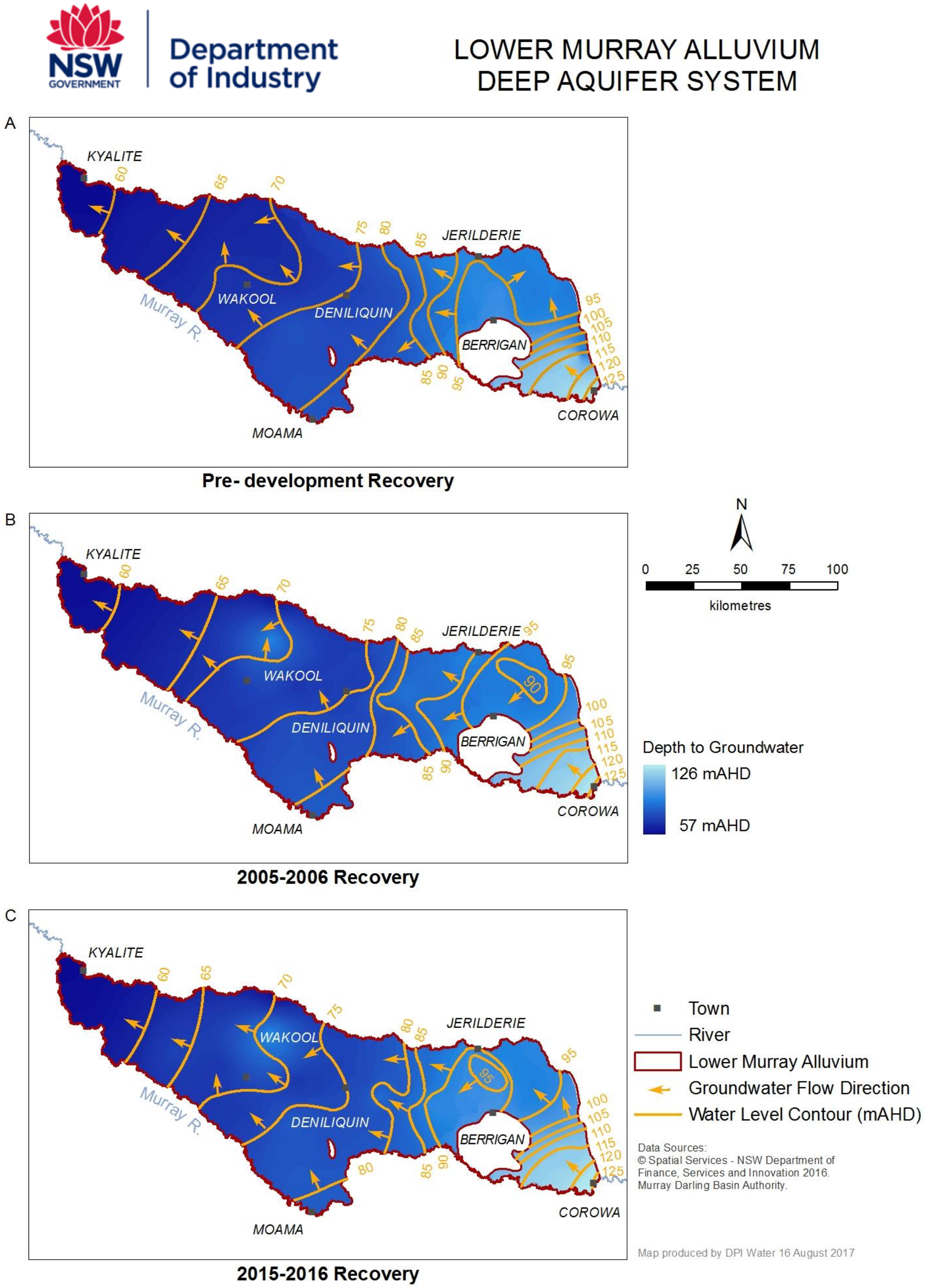


Figure 58 Groundwater level contours for the maximum recovery for different periods - Lower Murray Deep Alluvium.

Figure 59 compares the recovered water levels in the deep aquifer system with the corresponding maximum drawdown water level in 2015/2016. Figure 59 highlights the change of pattern in the flow direction over a season in areas where extraction occurs. The area of greatest extraction impacts is at the central area of the water source around Deniliquin

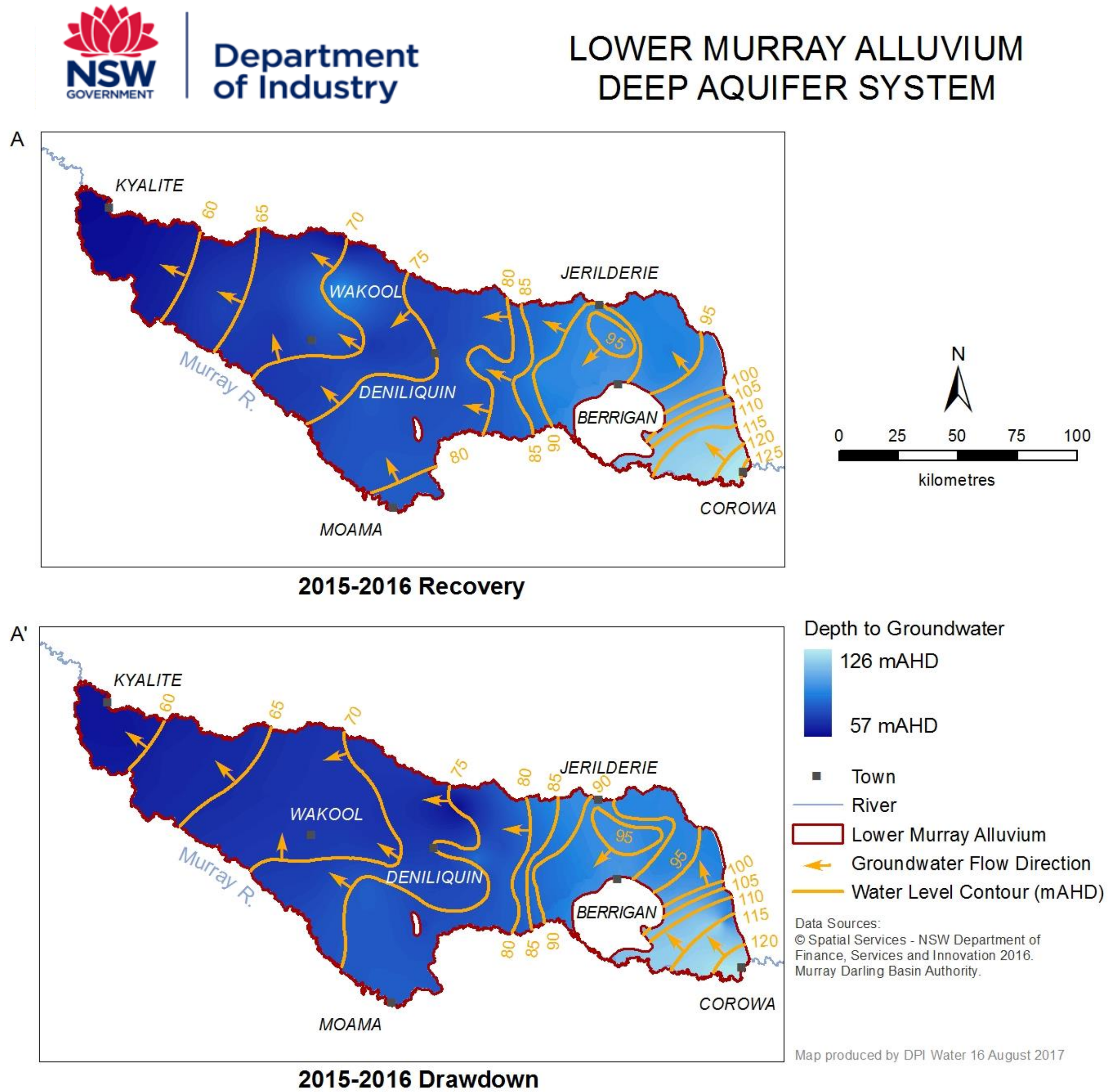


Figure 59 Groundwater level contours for the maximum recovery and maximum drawdown in 2015/2016; Lower Murray Deep Alluvium.

10.4.2 Upper Murray Alluvium

Groundwater level contours of recovered water levels show the regional groundwater flow direction across the Upper Murray Alluvium is from southeast to northwest which is the topographic gradient of the landscape. There is no significant change of groundwater contours or flow direction from pre-development time to present (Figure 60).

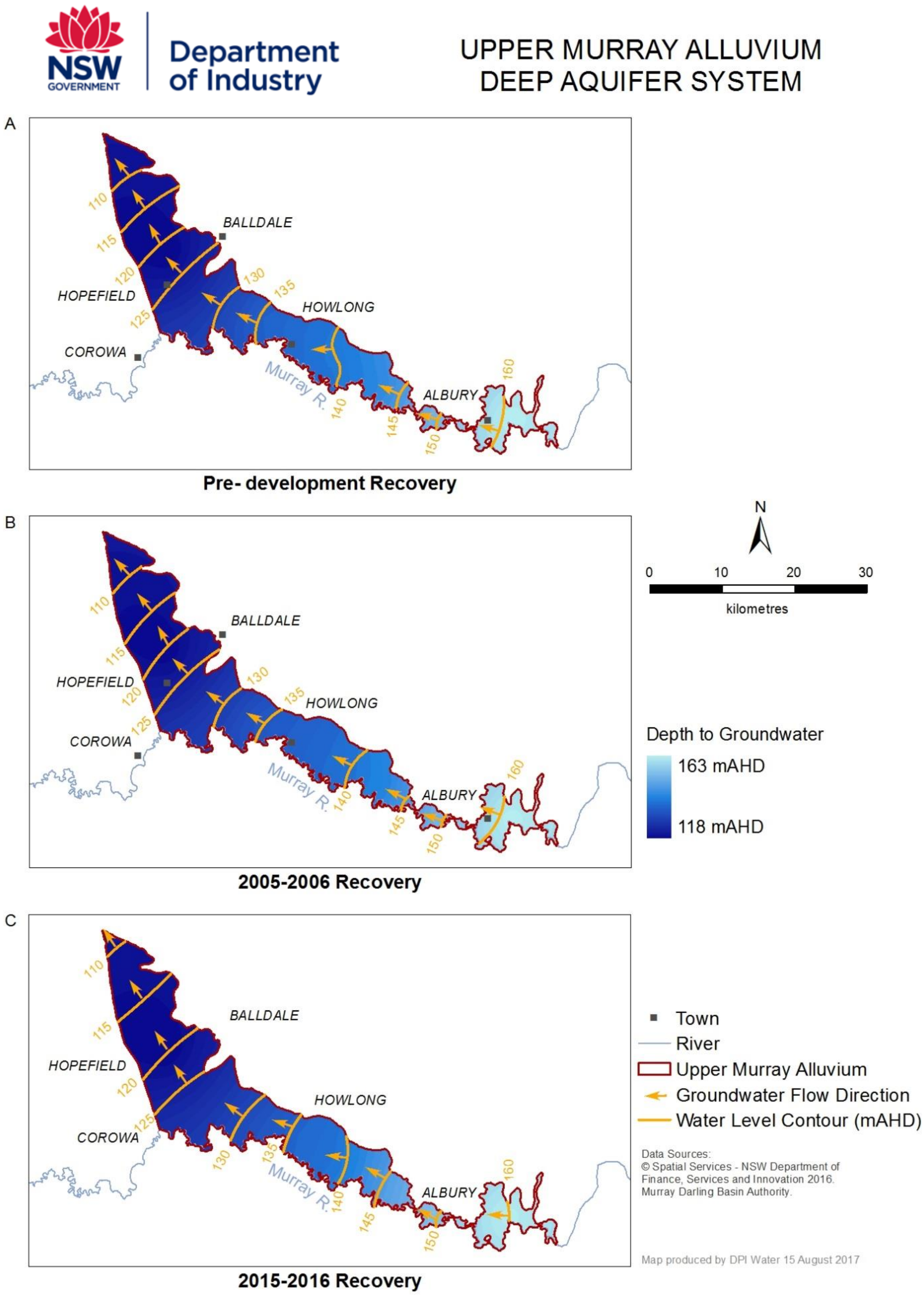


Figure 60 Groundwater level contours for the maximum recovery for different periods - Upper Murray Deep Alluvium.

Figure 61 compares the recovered water levels in the deep aquifer system with the corresponding maximum drawdown water level in 2015/2016. There is no significant change of contours or flow direction.

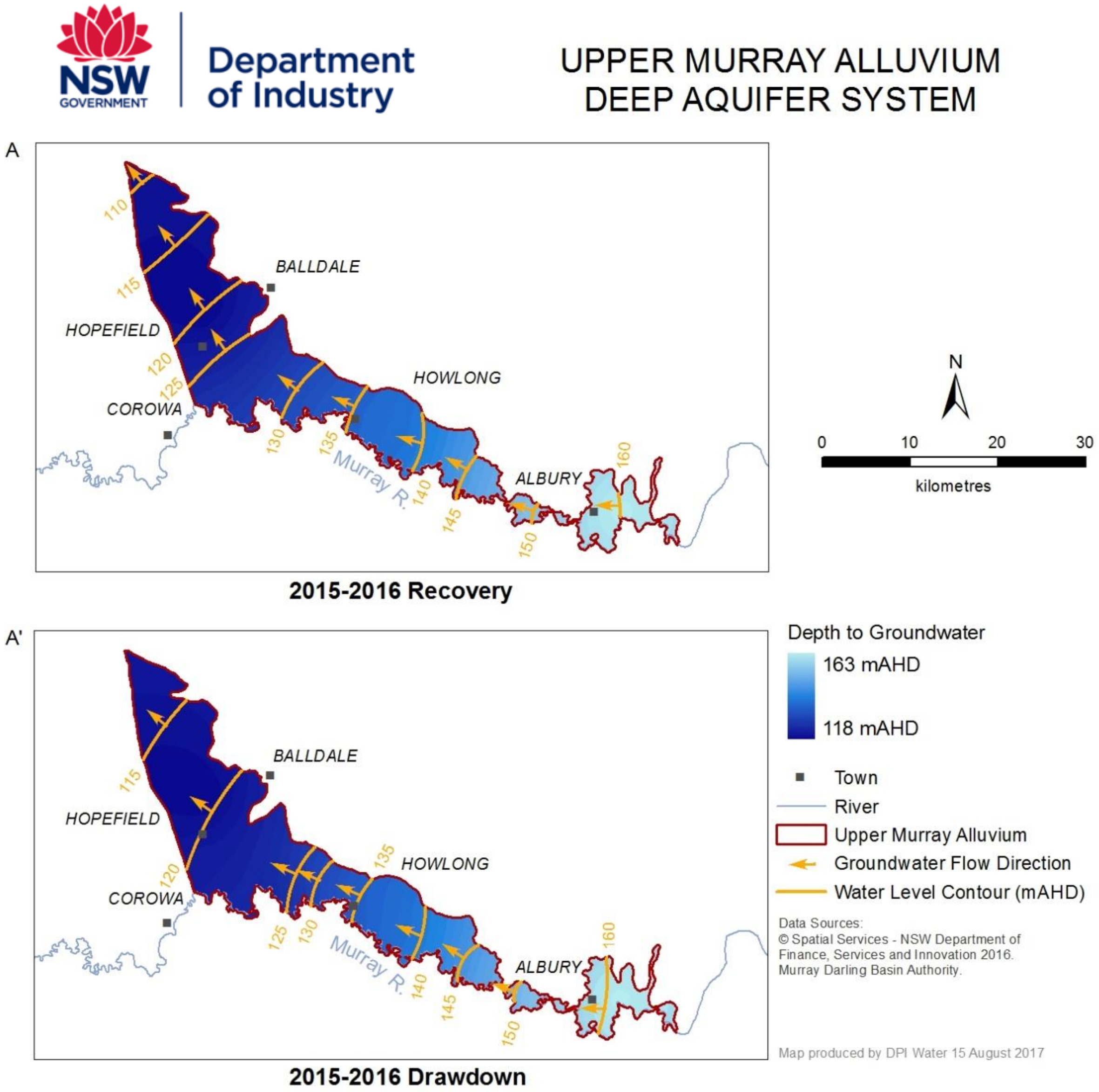


Figure 61 Groundwater level contours for the maximum recovery and maximum drawdown in 2015/2016; Upper Murray Deep Alluvium.

10.4.3 Billabong Creek Alluvium

Groundwater level contours of recovered water levels show the regional groundwater flow direction across the Billabong Creek Alluvium is from east to west which is the topographic gradient of the landscape. There is no significant change or groundwater contours or flow direction from pre-development time to present (Figure 62).

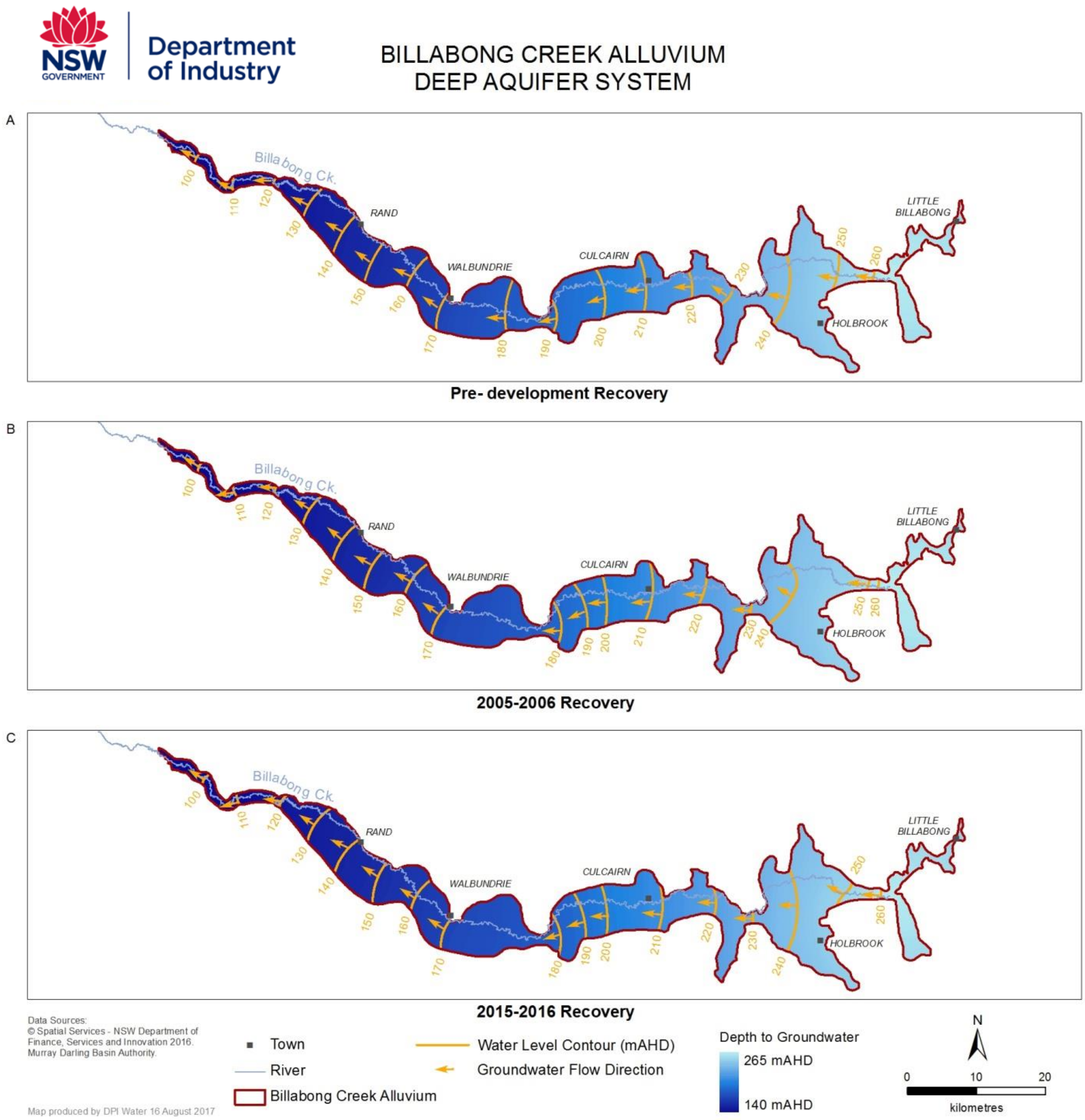


Figure 62 Groundwater level contours for the maximum recovery for different periods – Billabong Creek Deep Alluvium.

Figure 63 compares the recovered water levels in the deep aquifer system with the corresponding maximum drawdown water level in 2015/2016. There is no significant change of contours or flow direction except near the Billabong Creek Salt Interception Scheme bore is located. Groundwater extraction in the water source is low and also the extent of current monitoring network is insufficient to show water level changes over a season given the elongated shape of the water source.

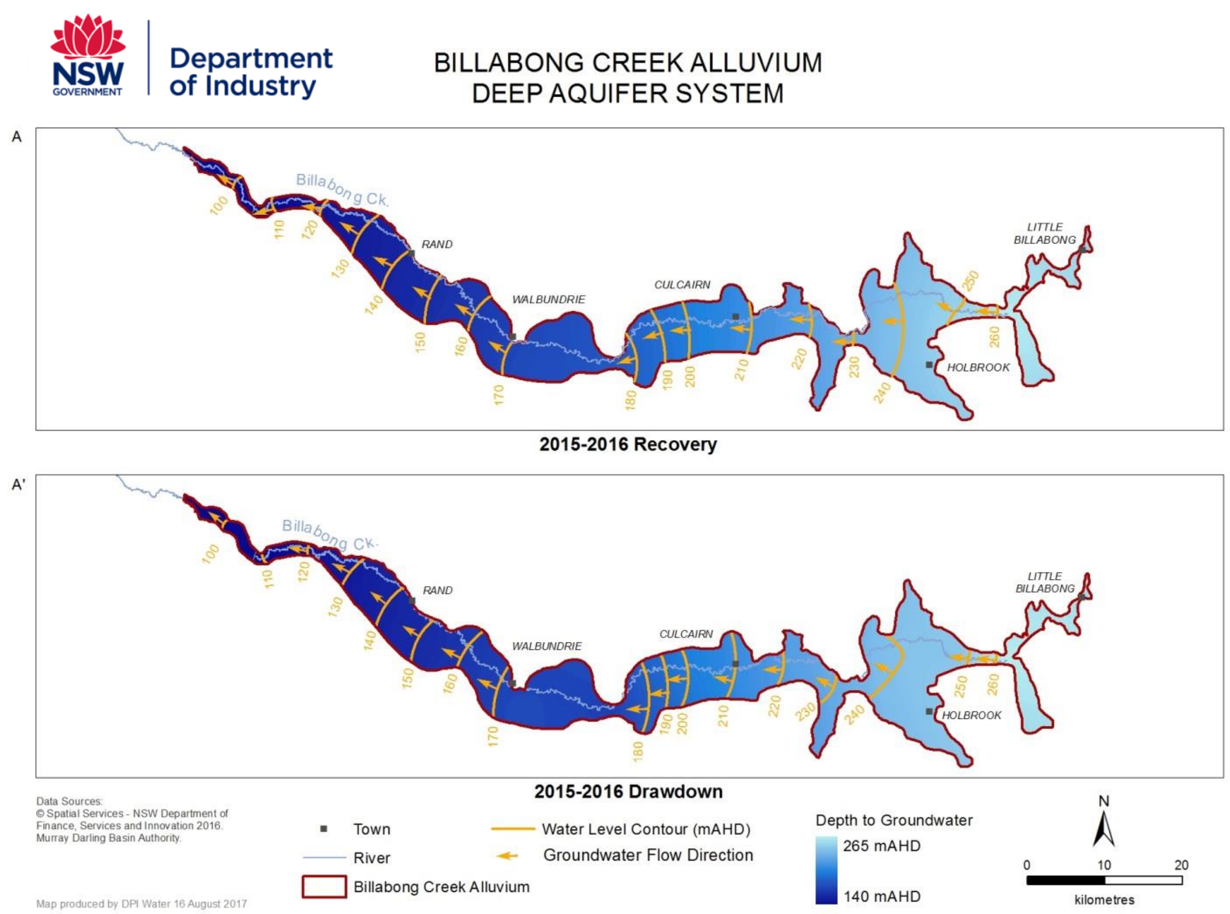


Figure 63 Groundwater level contours for the maximum recovery and maximum drawdown in 2015/2016; Billabong Creek Deep Alluvium.

10.5 Long term changes

10.5.1 Lower Murray Deep Alluvium

The long term (30-year) change in recovered water level from pre-development to 2015/2016 (Figure 64) shows significant water level decline up to 8 m or greater, across the central part of the resource where the majority of extraction is occurring. Water levels in the eastern part of the water source have risen.

Figure 65 illustrates the overall change in water levels over a 10 year period starting from the pre-water sharing plan to 2015/16. In most of the water source area, water levels have recovered after 2010/11 rainfall events to above pre-plan levels. However water level declines in the same period were observed only in the western part of the water source along the Murray River where no groundwater extractions are taking place.

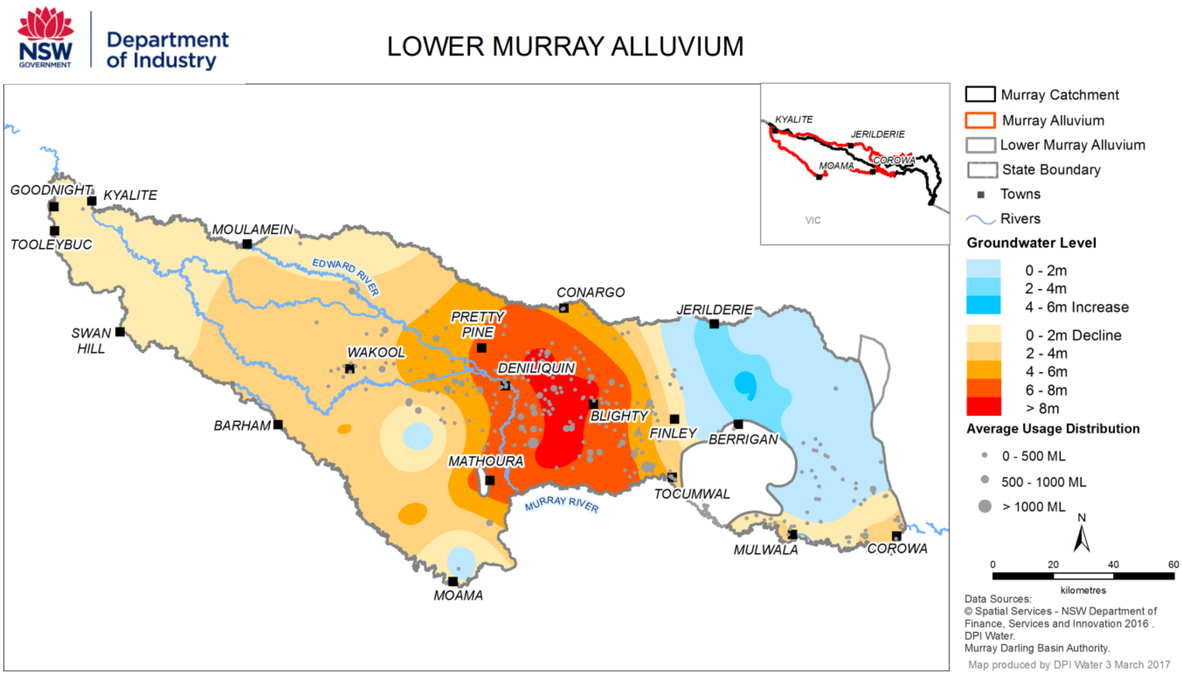


Figure 64 Lower Murray Deep Alluvium – deep aquifer system; map showing the change in recovered water level from pre-development to 2015/2016.

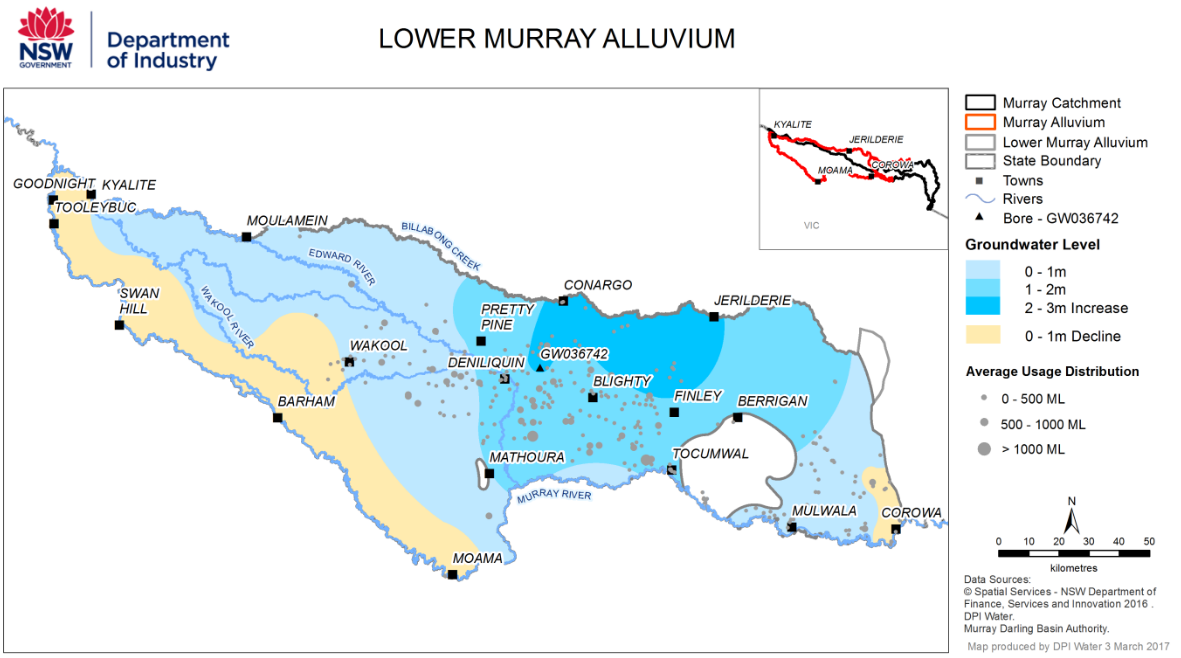


Figure 65 Lower Murray Deep Alluvium – deep aquifer system; map showing the change in recovered water level from 2005/2006 to 2015/2016.

10.5.2 Upper Murray Alluvium

Figure 66 illustrates the change in water levels over a 20 year period from the pre-development to 2015/2016. Water levels have declined by up to three metres or greater during that period across the water source. The water sharing plan for this water source commenced about six years ago. Figure 67 illustrates the change in water levels over a ten year period. Water levels have declined by up to about 1m across most of the water source except in an area between Albury and Howlong.

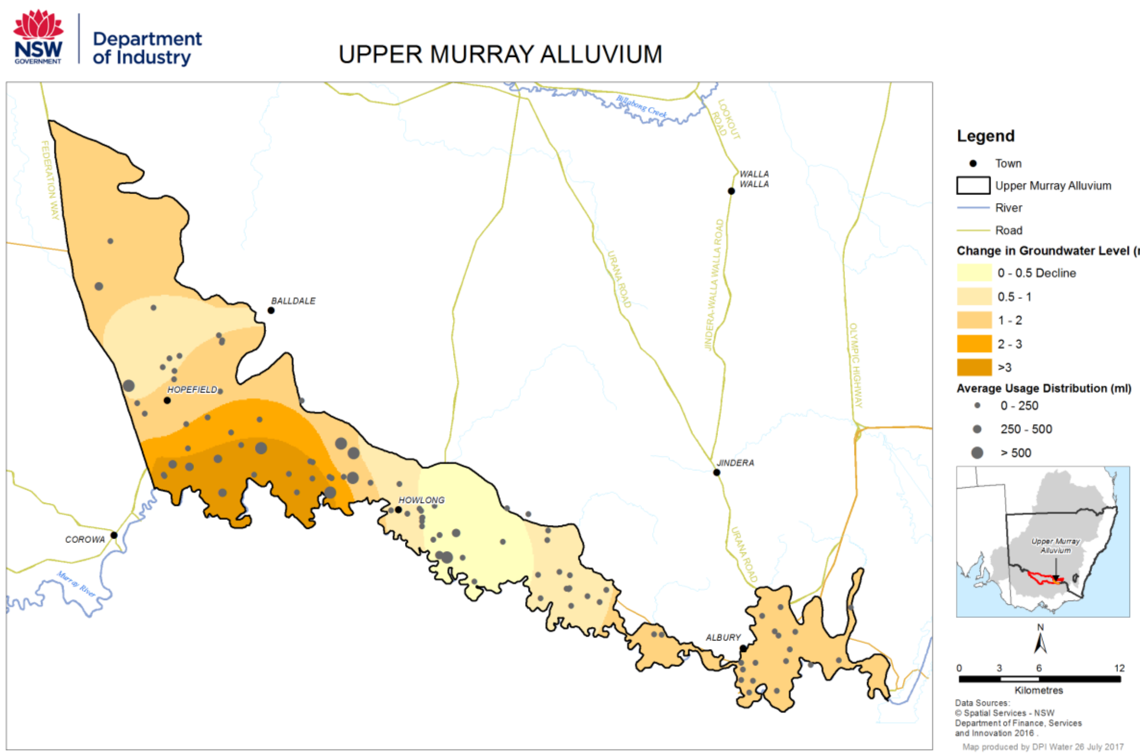


Figure 66 Upper Murray Alluvium – deep aquifer system; map showing the change in recovered water level from pre-development to 2015/2016.

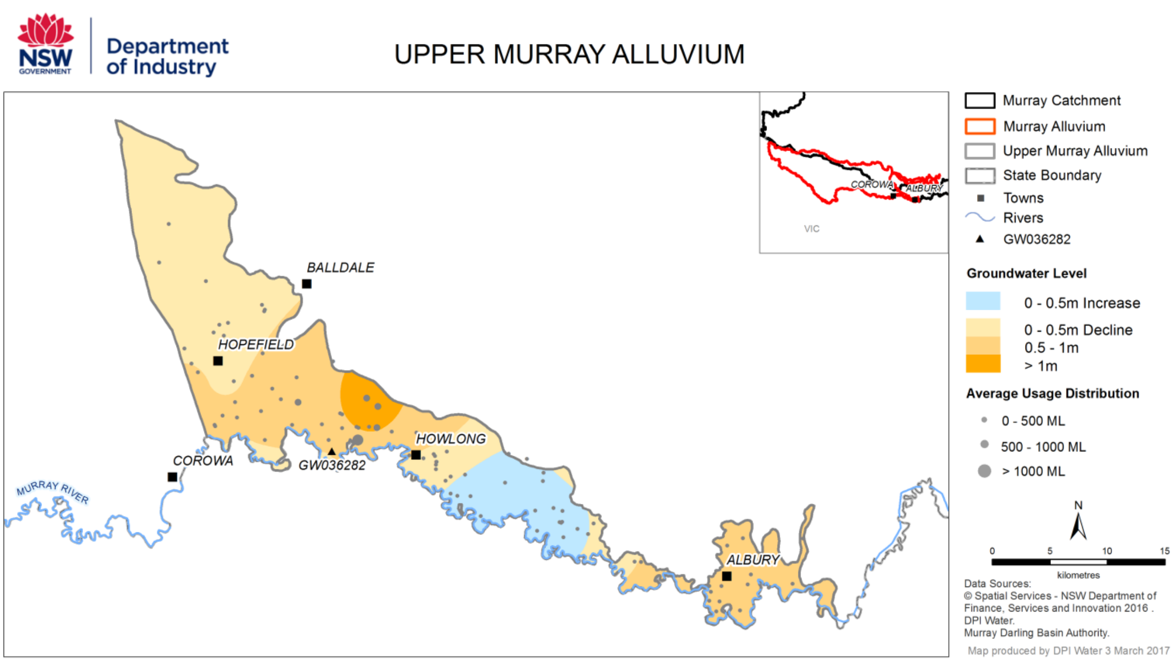


Figure 67 Upper Murray Alluvium – deep aquifer system; map showing the change in recovered water level from 2005/2006 to 2015/2016.

10.5.3 Billabong Creek Alluvium

Figure 68 illustrates the change in water levels over a 20-year period from the pre-development to 2015/16. Water levels have declined by up to 2 m or greater during that period across the water source. The impact of Billabong Creek SIS Scheme with declines over two metres is also shown on Figure 68.

The water sharing plan for this water source commenced about five years ago. Figure 69Figure 69 illustrates the change in water levels over a ten-year period. Water levels have increased by up to about a metre across most of the water source except in the central part of the water source around the Walla Walla area. This decline could be attributed to the operation of the Billabong Creek SIS Scheme. Rainfall events in 2010/11 might have contributed to the rise in water levels across the water source in general.

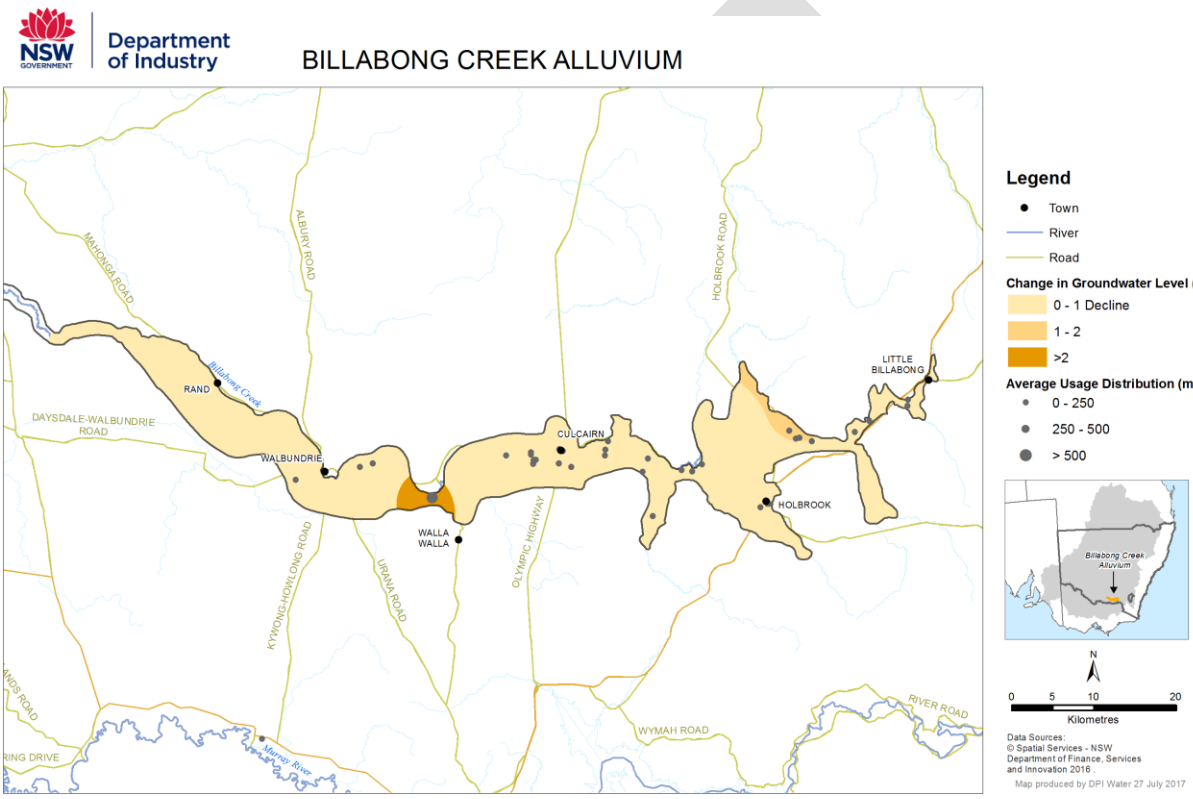


Figure 68 Billabong Creek Alluvium – deep aquifer system; map showing the change in recovered water level from pre-development to 2016.

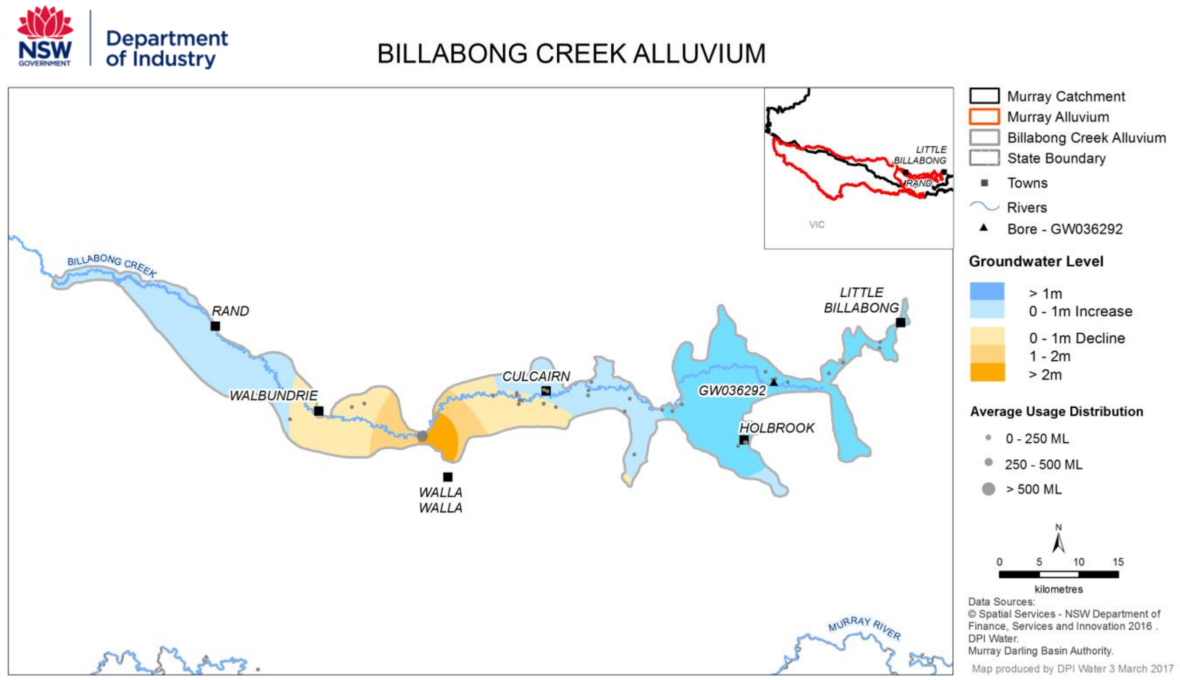


Figure 69 Billabong Creek Alluvium – deep aquifer system; map showing the change in recovered water level from 2005/2006 to 2015/2016.

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