MACQUARIE - CASTLEREAGH ALLUVIUM WATER RESOURCE PLAN

Groundwater Resource Description

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More information

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Contents

Glossary

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.
Anabranch	Stable multi-thread channels that are intermediate between single thread and braided channels characterised by vegetation or otherwise stable alluvial islands that divide flows at discharges up to nearly bank-full.
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 25^{o} C. 1 dS/m = 1000 µS/cm
Environmental Value	[2]Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of contamination, waste discharges and deposits.
Fractured rock	Rocks with fractures, joints, bedding planes and cavities in the rock mass.
Geological sequence	A sequence of rocks or sediments occurring in chronological order.
Groundwater	Water that occurs beneath the ground surface in the saturated zone.

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

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

Groundwater Dependent Ecosystem (GDE)	[3]Ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services.
Geological formation	A fundamental lithostratigraphic unit used in the local classification of strata and classified by the distinctive physical and chemical features of the rocks that distinguish it from other formations.
Groundwater equilibrium	A state where the forces driving groundwater flow have reached a balance in a groundwater system, for example where groundwater inflow equals groundwater outflow.
Groundwater system	Any type of saturated sequence of rocks or sediments that is in hydraulic connection. The characteristics can range from low yielding and high salinity water to high yielding and low salinity water.
Hydraulic conductivity	The capacity of a porous medium to transmit water. Measured in meters/day.
Hydraulic connection	A path or conduit allowing fluids to be connected. The degree to which a groundwater system can respond hydraulically to changes in hydraulic head.
Hydraulic head	The height of a water column above a defined point, usually expressed in metres.
Hydrogeology	The branch of geology that relates to the occurrence, distribution and processes of groundwater.
Hydrograph	A plot of water data over time.
Kriging	A method of interpolation using a weighted average of neighbouring samples to estimate an 'unknown' value at a given location to create surfaces.
Long term average annual extraction limit (LTAAEL)	The long term average volume of water (expressed in megalitres per year) in a water source available to be lawfully extracted or otherwise taken.
Igneous rock	Rocks which have solidified from a molten mass.
Infiltration	The movement of water from the land surface into the ground.
Ion	Mineral species dissolved in groundwater.
Make good provisions (in reference to a water supply work)	The requirement to ensure third parties have access to an equivalent supply of water through enhanced infrastructure or other means for example deepening an existing bore, funding extra pumping costs or constructing a new pipeline or bore.
Management zone	A defined area within a water source where a particular set of

[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.

	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 (eg. local water utility, major water utility and domestic and stock).
Sustainable Diversion Limits	The volume of water that can be taken from a Sustainable Diversion Limit resource unit as defined under the Murray Darling *Basin Plan 2012*.
Unassigned water	Exists where current water requirements (including licensed volumes and water to meet basic landholder rights) are less than the extraction limit for a water source.
Unconfined aquifer	A groundwater system usually near the ground surface, which is in connection with atmospheric pressure and whose upper level is represented by the water table.
Unconsolidated sediment	Particles of gravel, sand, silt or clay that are not bound or hardened by mineral cement, pressure, or thermal alteration of the grains.
Unsaturated zone	Area above the water table where soil spaces, pores, fractures and voids are not completely filled with water.
Water balance	A calculation of all water entering and leaving a system.

[4] As defined by Strategic Regional Land Use Plans

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 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 Macquarie-Castlereagh Alluvium Water Resource Plan area is shown in Figure 1 and is located within the Macquarie-Castlereagh catchment that forms part of the Murray-Darling Basin in central-western NSW. The Macquarie – Castlereagh catchment, as shown in Figure 1, covers more than 90,370 km² and represents about 8.5 percent of the Murray-Darling Basin.

The groundwater resources of the Macquarie - Castlereagh Alluvium include all of the main alluvial deposits associated with the Macquarie, Bell, Castlereagh, Cudgegong, Coolaburragundy and Talbragar Rivers. The Macquarie – Castlereagh Alluvium Water Resource Plan area is found in the central portion of the Macquarie – Castlereagh catchment, between Lake Burrendong in the south east and the Macquarie Marshes in the north west.

The Macquarie - Castlereagh Alluvium Water Resource Plan area (GW12 - Murray-Darling Basin reference number) is composed of six SDL resource units: the Bell Valley Alluvium (GS11), Castlereagh Alluvium (GS14), Coolaburragundy – Talbragar Alluvium (GS15), Cudgegong Alluvium (GS16), Lower Macquarie Alluvium (GS26) and Upper Macquarie Alluvium (GS45) shown in Figure 1. The boundaries of these SDL resource units reflect those of the corresponding groundwater sources managed under three NSW water sharing plans:

- Lower Macquarie Groundwater Sources (Zones 1 - 6) managed under the *Water Sharing Plan for the Lower Macquarie Groundwater Source 2003,*
- Bell, Cudgegong, Talbragar and Upper Macquarie Alluvial Groundwater Sources managed under the *Water Sharing Plan for the Macquarie – Bogan Unregulated and Alluvial Water Sources 2012,* and the
- Castlereagh Alluvial Groundwater Sources managed under the *Water Sharing Plan for Castlereagh River Unregulated and Alluvial Water Sources 2011.*

The Lower Macquarie Groundwater Sources are comprised of Cenozoic unconsolidated alluvial deposits and Mesozoic sedimentary rocks which are part of the Great Artesian Basin geological sequence. Although the boundary of Lower Macquarie Alluvium SDL resource unit reflects that of Lower Macquarie Groundwater Sources, only groundwater contained in the Cenozoic unconsolidated alluvial deposits is managed under this SDL resource unit.

The productive aquifers within the Lower Macquarie Groundwater Sources Zone 3, 4 and 5 are within the sandstone of the Great Artesian Basin. Groundwater within the Great Artesian Basin is not included in the Murray Darling Basin water sources as the Commonwealth Water Act 2007 excludes all groundwater that forms part of the Great Artesian Basin. However, for the purposes of reporting historic information, data relating to the sandstone aquifers has been included in this report.

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

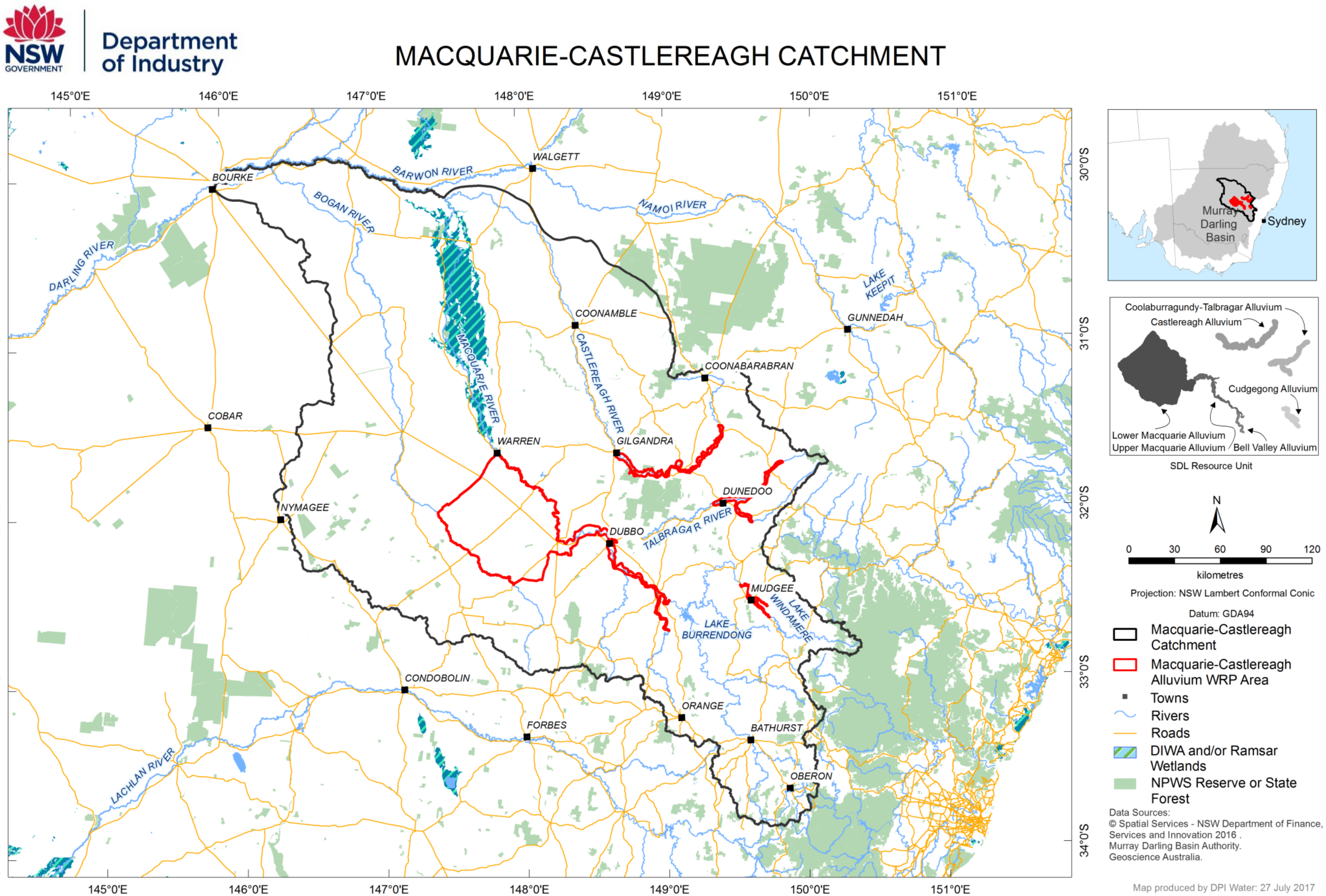

Figure 1 Location of the Macquarie - Castlereagh Alluvium Water Resource Plan Area and SDL Resource Units

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 in the western half of NSW for bores greater than 30 m depth.

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/year), 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 extraction, 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, which included the Lower Macquarie Groundwater Sources. Access to groundwater was reduced to the extraction limit over the ten year plan using an approach that recognised historical extraction.

Since 2007, water sharing plans for unregulated rivers and groundwater systems in NSW have been completed using a 'macro' approach to cover most of the remaining water sources across NSW. Each groundwater macro plan covers a number of similar type of groundwater system (for example, alluvium, fractured rock, or porous 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 History of groundwater management in the Macquarie-Castlereagh catchment

Groundwater development in the Macquarie – Castlereagh catchment started in early 1960s when licenses were issued without volumetric entitlement or restriction.

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. This policy continued until specific policies were developed for individual groundwater management areas.

In December 1984, the Water Resource Commission proclaimed the whole of Macquarie Valley and its tributaries as a restricted ‘sub-surface’ water area under section117 A of the Water Act. This enabled controls to be put on the quantity of water pumped from any licensed bore, including those bores and wells whose licence did not specify a volumetric limit.

2.3.1 Cudgegong Alluvium

The Licensing Policy for High Yield Bores and Wells in Cudgegong Valley, NSW was introduced in July 1987. This policy facilitated the conversion of unrestricted licenses, and the issuance of volumetric licenses on the basis of property area and surface water availability (conjunctive) to a maximum property entitlement of 486 ML/year. The policy also introduced ‘carry-over’ and ‘borrowing’ water accounting.

An embargo was placed on 4 December, 1998 on further licence applications for irrigation and industrial purposes.

Since October 2012, the groundwater resource has been managed under the Water Sharing Plan for Macquarie – Bogan Unregulated and Alluvial Water Sources 2012.

2.3.2 Coolaburragundy - Talbragar Alluvium

These groundwater resources were managed under the 1983 interim policy until 8 March, 2002 when an embargo was placed on further licence applications for irrigation and industrial purposes.

Since October 2012, the groundwater resource has been managed under the Water Sharing Plan for Macquarie – Bogan Unregulated and Alluvial Water Sources 2012.

2.3.3 Castlereagh Alluvium

The groundwater resources of the Castlereagh Alluvium was managed under the 1983 interim policy until 10 January 2007 when an embargo was placed on further applications for groundwater for irrigation and industrial purposes.

Since 1 October 2011, the groundwater resource has been managed under the Water Sharing Plan for Castlereagh River Unregulated and Alluvial Water Sources 2011.

2.3.1 Bell Valley Alluvium

The Management Plan for Groundwater Resources contained in the alluvial sediments of the Bell River Valley, New South Wales (December 1990) set a total volume of 7000 ML/year to be available for allocation. This policy facilitated the conversion of unrestricted licenses, and the issuance of volumetric licenses on the basis of property area and surface water availability (conjunctive) to a maximum property entitlement of 486 ML/year.

An embargo was placed on 23 May, 2003 on further licence applications for irrigation and industrial purposes.

Since October 2012, the groundwater resource has been managed under the Water Sharing Plan for Macquarie – Bogan Unregulated and Alluvial Water Sources 2012.

2.3.2 Upper Macquarie Alluvium

The groundwater resources of the Upper Macquarie Alluvium was managed under the 1983 interim policy until 10 March, 2000 when an embargo was placed on further licence applications for irrigation and industrial purposes.

Since October 2012, the groundwater resource has been managed under the Water Sharing Plan for Macquarie – Bogan Unregulated and Alluvial Water Sources.

2.3.3 Lower Macquarie Alluvium

In July 1992, an interim allocation policy was developed to encourage groundwater development to manage the risk of land salinization due to rising water levels in Lower Macquarie. Under this policy, entitlements were issued at 6 ML/Ha of irrigated land area. In February 1998 it was replaced by the Lower Macquarie Groundwater Policy Area 008 which introduced:

- a total volume which could be allocated,
- distance limits between production bores, based on their anticipated extraction, to minimize interference impacts,
- restrictions to access underlying and adjoining sandstone aquifers of the Great Artesian Basin, and
- water quality considerations.

An embargo was placed on 27 November, 1998 on further licence applications for irrigation and industrial purposes.

Since 1 October 2006, the groundwater resources have been managed under the Water Sharing Plan for Lower Macquarie Groundwater Sources 2003.

3 Regional setting

3.1 Topography and hydrology

The Macquarie, Bogan and Castlereagh river systems and their floodplains, the Macquarie Marshes and the peaks of the Warrumbungle Ranges and the Great Dividing Range are the main topographical features within the catchment. Elevations across the catchment range from over 1,300 m Australian Height Datum (mAHD) in the mountains south of Bathurst to 100 mAHD around Bourke, in the far north-west of the catchment (Figure 2). Downstream of Narromine the catchment is predominantly comprised of open, flat alluvial plains with elevations less than 300 mAHD.

The Macquarie River originates in the Great Dividing Range, south of Bathurst, and the river flows in a north-westerly direction for 960 km until it joins the Barwon River downstream of Walgett. The Bogan River rises in the Harvey Ranges, to the south of Dubbo, and flows roughly parallel to the Macquarie River across the north-western plains before joining the Barwon River upstream of Bourke. A series of creeks from the Macquarie River, in the lower part of the catchment, deliver flows to the Bogan River.

The Macquarie River is regulated by Burrendong Dam which is the major water storage in the valley. The dam was completed in 1967 and is one of the largest water storages in NSW. Burrendong Dam supplies water for irrigation, stock and domestic needs along the Macquarie River and the lower Bogan River as well as providing significant flood mitigation capability to reduce downstream flooding. It also stores water for environmental requirements in the Macquarie Marshes, an extensive wetland complex that is a significant natural feature of the lower valley (NSW Office of Water, 2011).

Windamere Dam, on the Cudgegong River upstream of Burrendong Dam, provides water for the towns of Mudgee and Gulgong and water user requirements along the Cudgegong River (NSW Office of Water, 2011) (Figure 2).

The Castlereagh River rises in rugged country in the Warrumbungle Ranges near Coonabarabran, and flows south-west, then north-west for 549 km to its confluence with the lower Macquarie River. The river passes through Coonamble and at the far end of the catchment runs parallel to the Barwon River. Here the lower floodplain carries flows from the Barwon River through to the Castlereagh River during major floods.

A detailed description of the catchment's surface water systems is provided in the Macquarie – Castlereagh Water Resource Plan – Surface water resource description (June 2017, in prep).

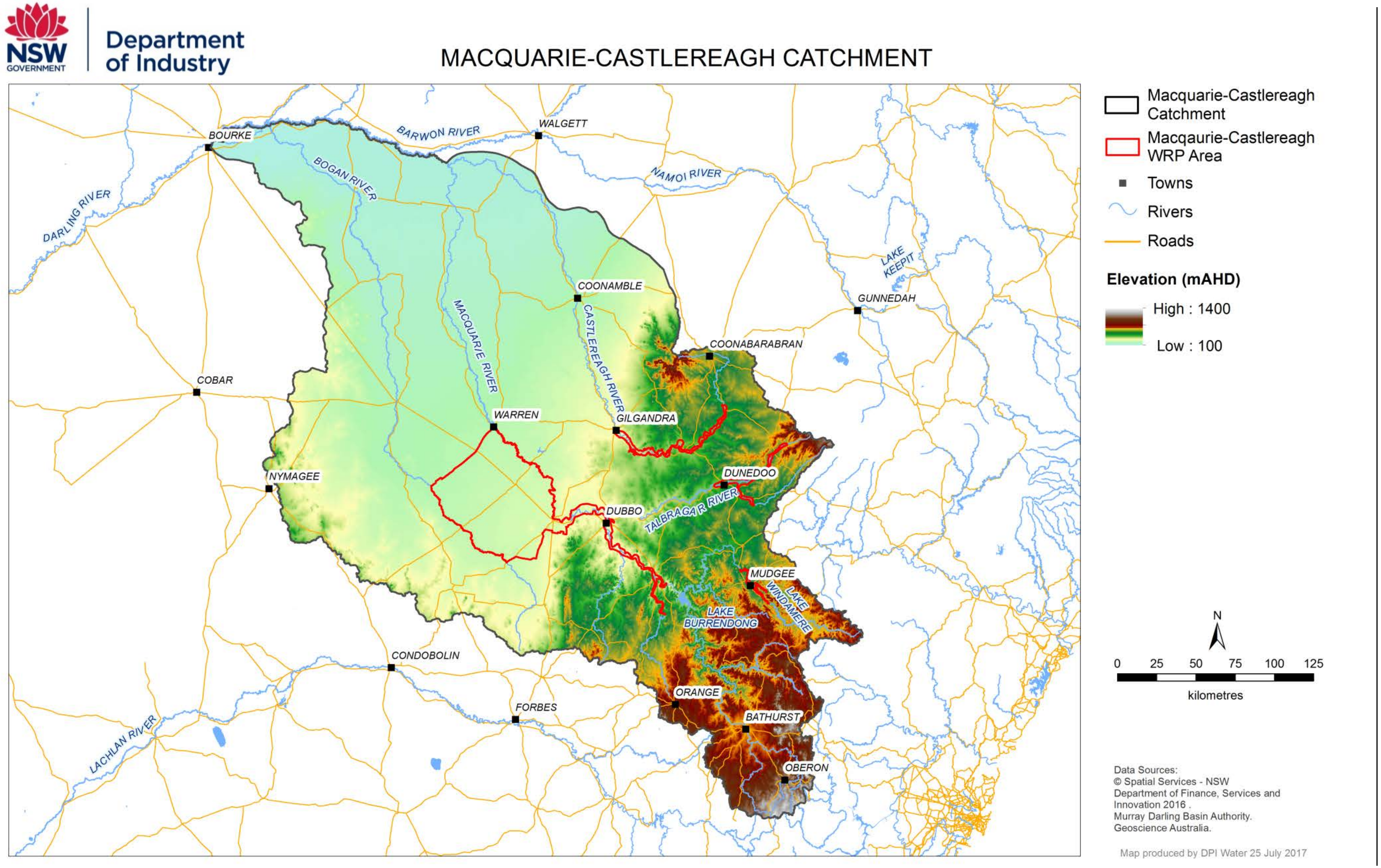

Figure 2 Topography and elevation map of the Macquarie - Castlereagh catchment (Gallant *et al*, 2009)

3.2 Climate

The Macquarie - Castlereagh catchment has a temperate to semi-arid climate, with warm to hot summers and cool winters (NSW OEH, 2003). Across the catchment there is a considerable rainfall gradient from south-east (wetter) to north-west (drier). Average annual rainfall varies from over 840 mm near Oberon at the top of the catchment, 570 mm at Dubbo in the middle of the catchment to around 360 mm in the north-west (Figure 3). Whilst rainfall can vary considerably between years, rainfall in the north will tend to be summer dominant whilst rainfall in the south appears to be more winter dominant (Figure 4).

At the higher elevations in the east, temperatures vary from a winter average minimum of 0°C to a summer average maximum of 25°C. Further west at Bourke, the average winter minimum temperature is around 3°C, ranging up to an average maximum summer temperature of 37°C.

Climate change modelling for the Central West Region (NSW OEH, 2014) predicts that spring rainfall across the region will decrease over the next 50 years while autumn rainfall is projected to increase over this timeframe. Summer rainfall is predicted to decrease slightly in the short term (to 2030) but by 2070 is predicted to increase by 20-30 per cent across the WRP area.

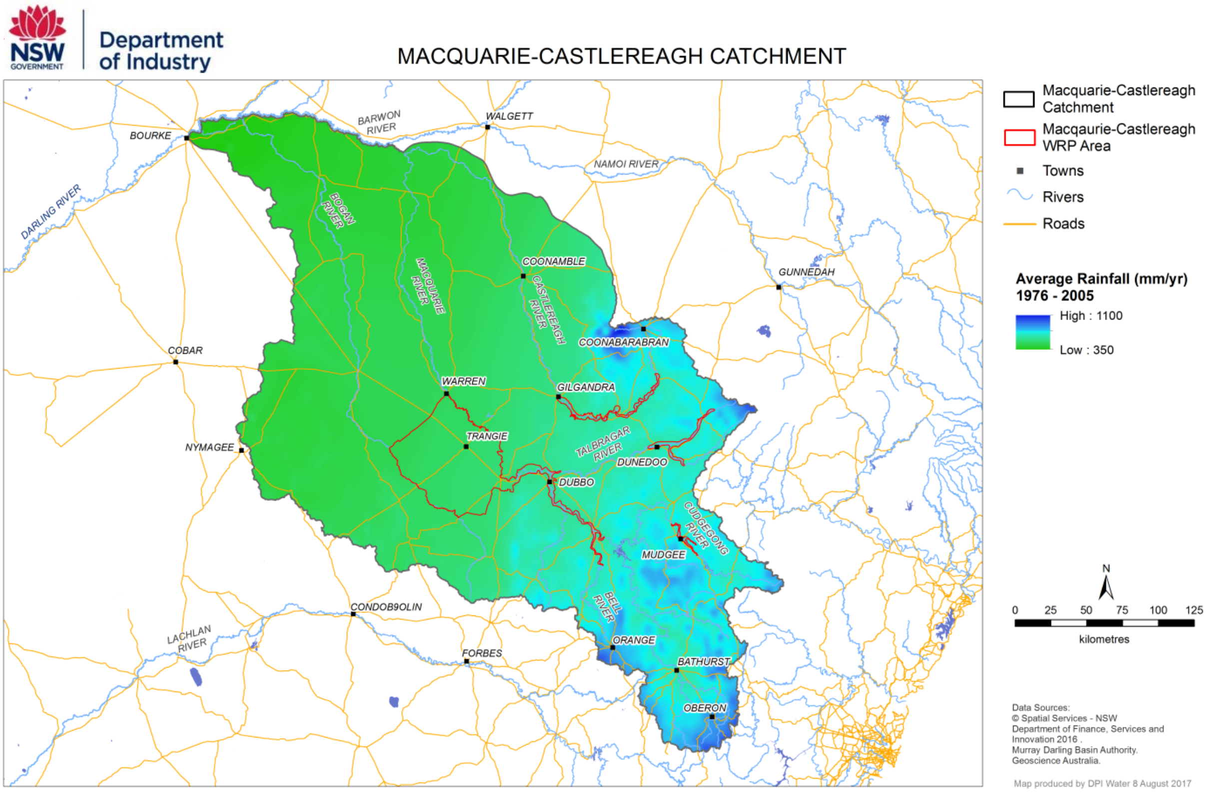

Figure 3 Average annual rainfall map of the Macquarie - Castlereagh catchment (BOM, 2008)[7]

[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.

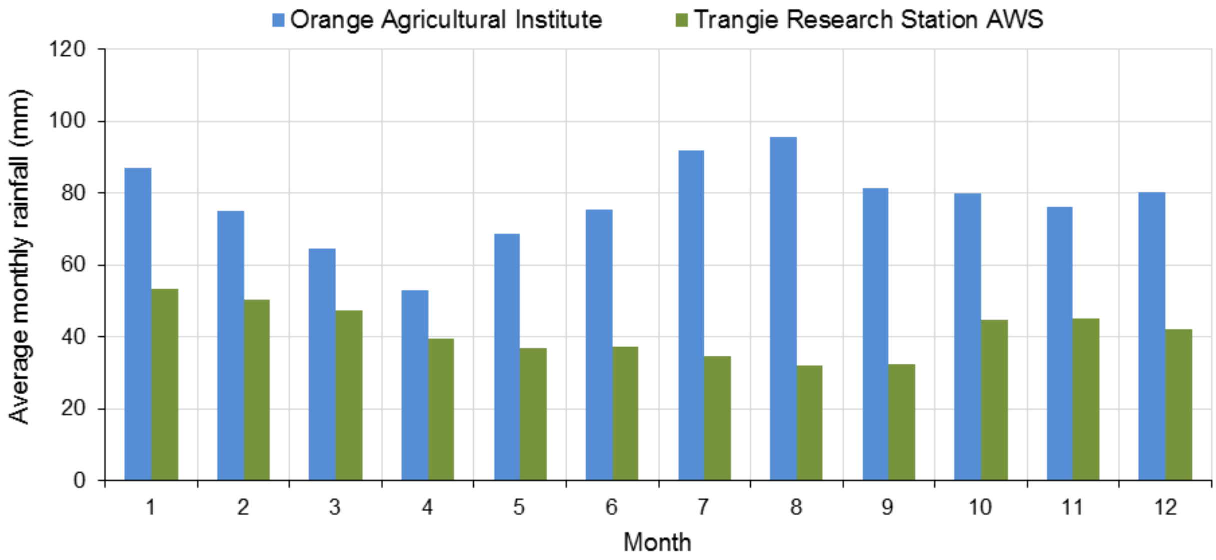

Figure 4 Average monthly rainfall for the Orange Agricultural Institute and Trangie Research Station AWS

Evaporation in the Macquarie – Castlereagh catchment has a strong south-east to north-west gradient. Average Class A pan evaporation varies from around 1,410 mm/year around Bathurst to over 2,200 mm/year in the north-west (Figure 5)(BoM, 2008.

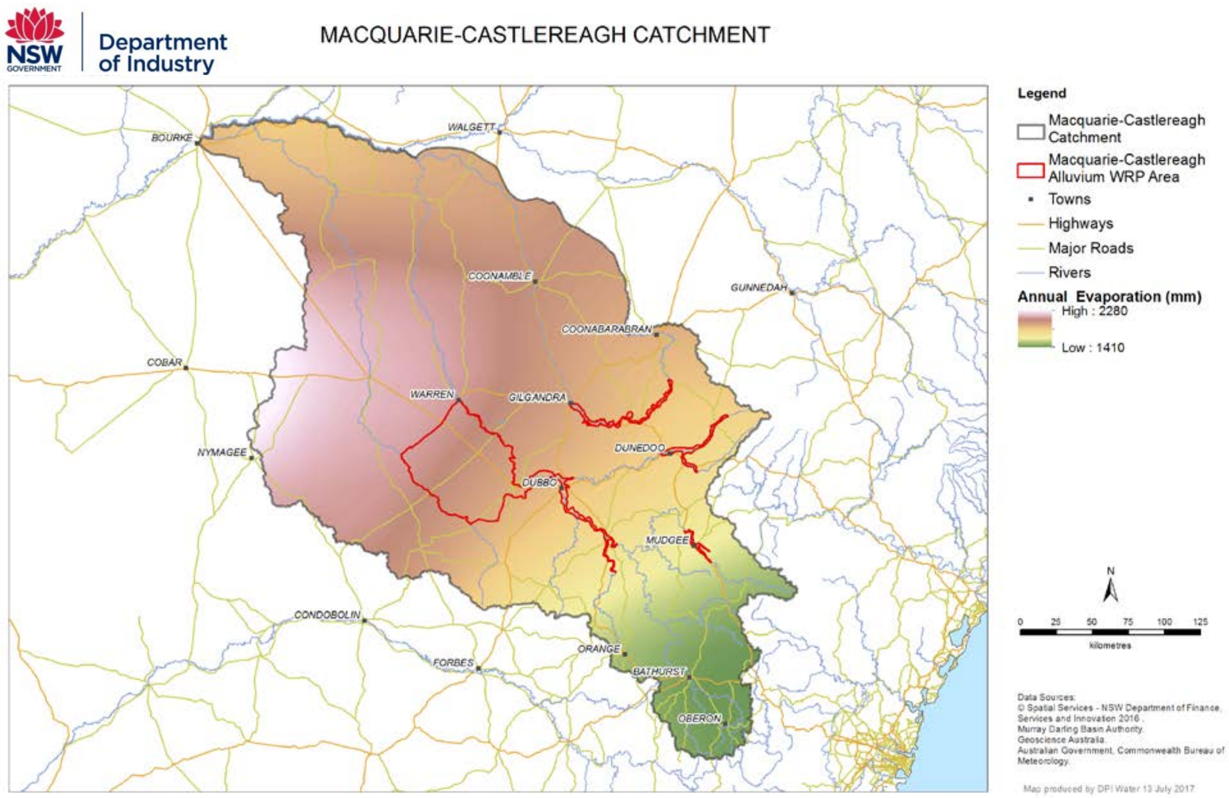

Figure 5 Average annual evaporation map of the Macquarie-Castlereagh catchment (BOM, 2008)[8]

Evaporation is highly seasonal throughout the year, varying from under 2 mm/ day across the catchment in the winter months to a maximum of 7 mm/day (Orange) and 9 mm/day (Trangie) in

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

the summer months (Figure 6). At Trangie mean monthly evaporation in the summer months is more than 250 mm, which is around five times the average rainfall received in those months.

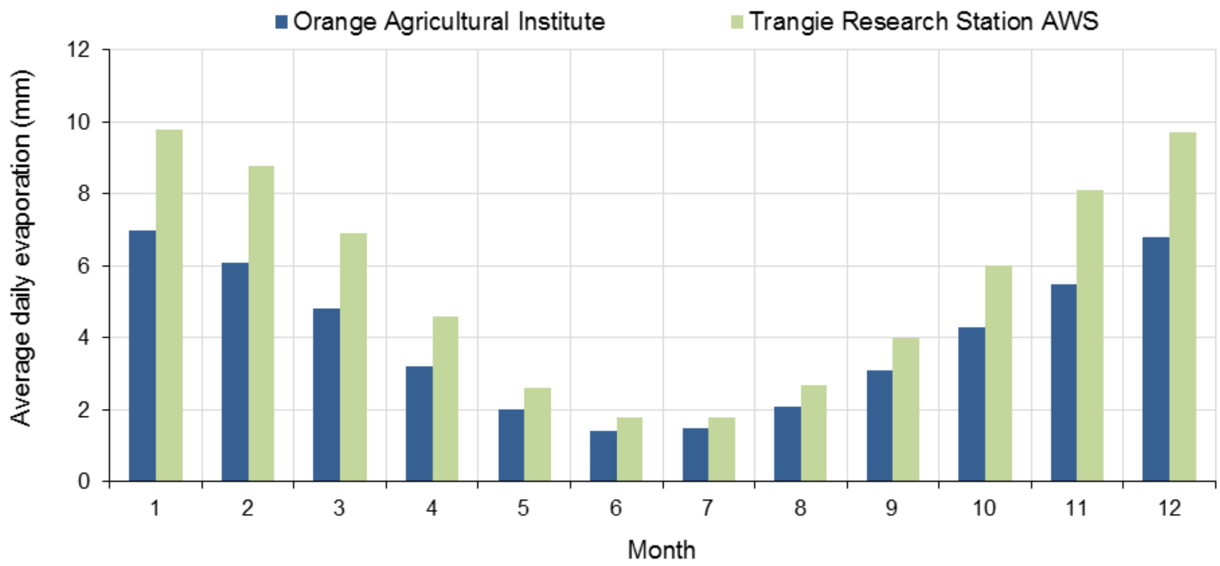

Figure 6 Average daily evaporation for Orange Agricultural Institute and the Trangie Research Station AWS

Residual rainfall plots have been constructed using daily rainfall data from the Bureau of Meteorology. 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 7 shows the residual mass graph of the average monthly rainfall from 1966 to 2016 at Orange and Trangie. This period corresponds to the period when groundwater monitoring commenced in parts of the Macquarie – Castlereagh catchment.

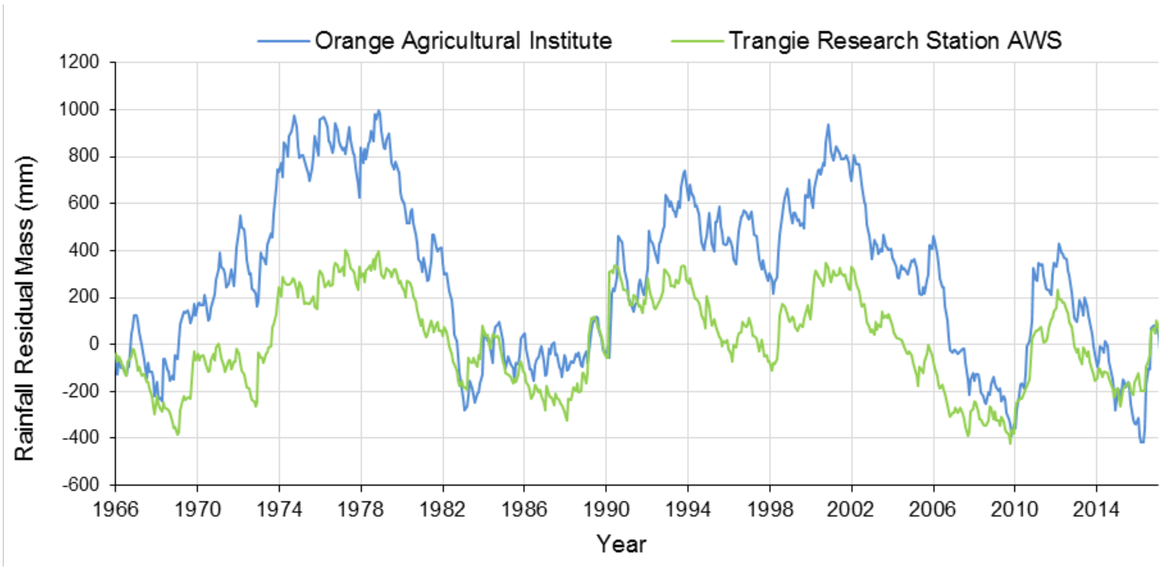

Figure 7 Orange and Trangie rainfall residual mass graph 1966 – 2016

Figure 7 shows a below average rainfall trend during the millennium drought from 2001 – 2010 that was concluded by a short reprieve of above average rainfall from 2010 – 2013. This was then followed by a short but intense period of below average rainfall up to the start of 2016.

3.3 Land use

The Macquarie – Castlereagh Alluvium WRP area is within the traditional lands of Weilwan and Wiradjuri people. There is a significant relationship between groundwater and the traditional owners of these lands. Water and specifically groundwater is embedded into their Lore, their traditional stories and their dreaming. Creation beings live in these stories with cultural knowledge being passed down through these stories. Song and dance demonstrate the significance of this connection to water, and the people's relationship to land (NSW DPI Water, 2017).

Groundwater has provided the life support for generations of traditional owners. Water provided for the trees, the medicinal plants and the animals that sustained the lives of the local communities. Aboriginal people place a high level of value on water as the uses are significant and many, in relation to the survival of Aboriginal people and their culture (NSW DPI Water, 2017).

European settlement of the Macquarie valley commenced in 1818 when settlers took up land along the rivers and alluvial flats where there was good pasture for cattle. As the main river frontages were taken up, settlement spread along the river tributaries into the ranges (MDBA, 2017).

Land use in the Macquarie-Castlereagh catchment is dominated by extensive agriculture with over 70 per cent of the catchment being used for grazing and 15 per cent of the catchment used for dryland cropping (Table 1, Figure 8). Forestry, conservation and other native landscapes together account for about 10 per cent of the catchment area.

Although covering only one per cent of the catchment, irrigated crops are very important to the economy of the region. The Macquarie valley supports a major cotton industry with four cotton gins plus related service providers such as freight, and engineering services to support the industry. In years of high water availability up to 50,000 ha of irrigated cotton is grown producing around 400,000 bales of cotton worth around $244 million (EBC Consortium, 2011). Other irrigated crops include wheat and cereals, fodder and pasture, lucerne, oilseeds and vegetables.

There is a large wine industry around Mudgee with around 160 wine producers, which between them grow around 3,300 ha of wine grapes (EBC Consortium, 2011). The upper catchment also supports around 2,000 ha of lucerne and small plantings of olives, nuts and cherries.

Vegetables are grown on the Macquarie floodplain around Bathurst, while further downstream access to groundwater in the Narromine-Trangie area allows the cultivation of high value crops including citrus, stone fruit, and grapes.

Table 1: Land use in the Macquarie-Castlereagh WRPA

Land use	Area (sq km)	Area (%)
Dryland Cropping and Horticulture	14,730	16
Grazing	67,110	72
Irrigation	919	1
Mining	16	<1
Forestry, conservation reserve and native vegetation	9,707	10
Residential	452	<1
Urban intensive uses	239	<1
Water	439	<1

Source: Australian Bureau of Agricultural and Resource Economics and Sciences, National scale land use 2010-11

The Macquarie – Castlereagh catchment is home to around 214,000 people (9% of the Murray-Darling Basin population (ABS, 2011). Just over half the people live within the regional centres of Bathurst, Orange and Dubbo (around 40,000 people each). Smaller towns within the WRPA include Mudgee, Wellington, Narromine, Coonabarabran, Gilgandra, Coonamble, Nyngan and Warren.

4 Geology

The surface geology of the Macquarie Castlereagh catchment is made up of four main geological sequences including; the Lachlan Fold Belt of Palaeozoic age (541 to 359 million years old), the sedimentary rocks of the Oxley Basin and Great Artesian Basin of Mesozoic age (250 to 65 million years old), the unconsolidated sediments, and the extrusive volcanics of Cenozoic age (65 to 1 million years old) (Figure 9).

The Lachlan Fold Belt is the oldest geological sequence in the catchment. It consists of strongly deformed/metamorphosed sedimentary rocks and volcanic intrusions. The Lachlan Fold Belt underlies the Great Artesian Basin (GAB), Gunnedah Basin and Oxley Basin in the east and Sydney Basin in the south east within the WRP area. The outcropping Lachlan Fold Belt can be seen as the Palaeozoic layer in Figure 9.

The late Palaeozoic to early Mesozoic coal bearing Gunnedah Basin and Sydney Basin unconformably overlie the Lachlan Fold Belt (shown as Mesozoic in Figure 9). These basins comprise of marine and non-marine sediments.

The Mesozoic Great Artesian Basin and Oxley Basin have similar depositional history, with sediments comprising of mudstone, siltstone, shale and sandstone deposited unconformably over the Lachlan Fold Belt in the west and Gunnedah Basin in the east. Although the sediments were seamlessly deposited over the two adjacent basins, deformation and subsequent erosion has rendered the Great Artesian Basin and Oxley Basins hydraulically disconnected.

The Great Artesian Basin is Australia's largest groundwater basin, spreading across New South Wales, Queensland, South Australia and Northern Territory, covering approximately 22% of Australia.

The Cenozoic unconsolidated sediments comprise of clay, silt, sand and gravel, and occur as flood plain deposits and infilled valley deposits along the paleo valleys and modern day rivers.

The main peaks in this catchment near Orange and Coonabarabran are formed by Cenozoic extrusive volcanic rocks of basalts that were associated with widespread volcanic activity throughout the eastern part of the state over the last 65 million years.

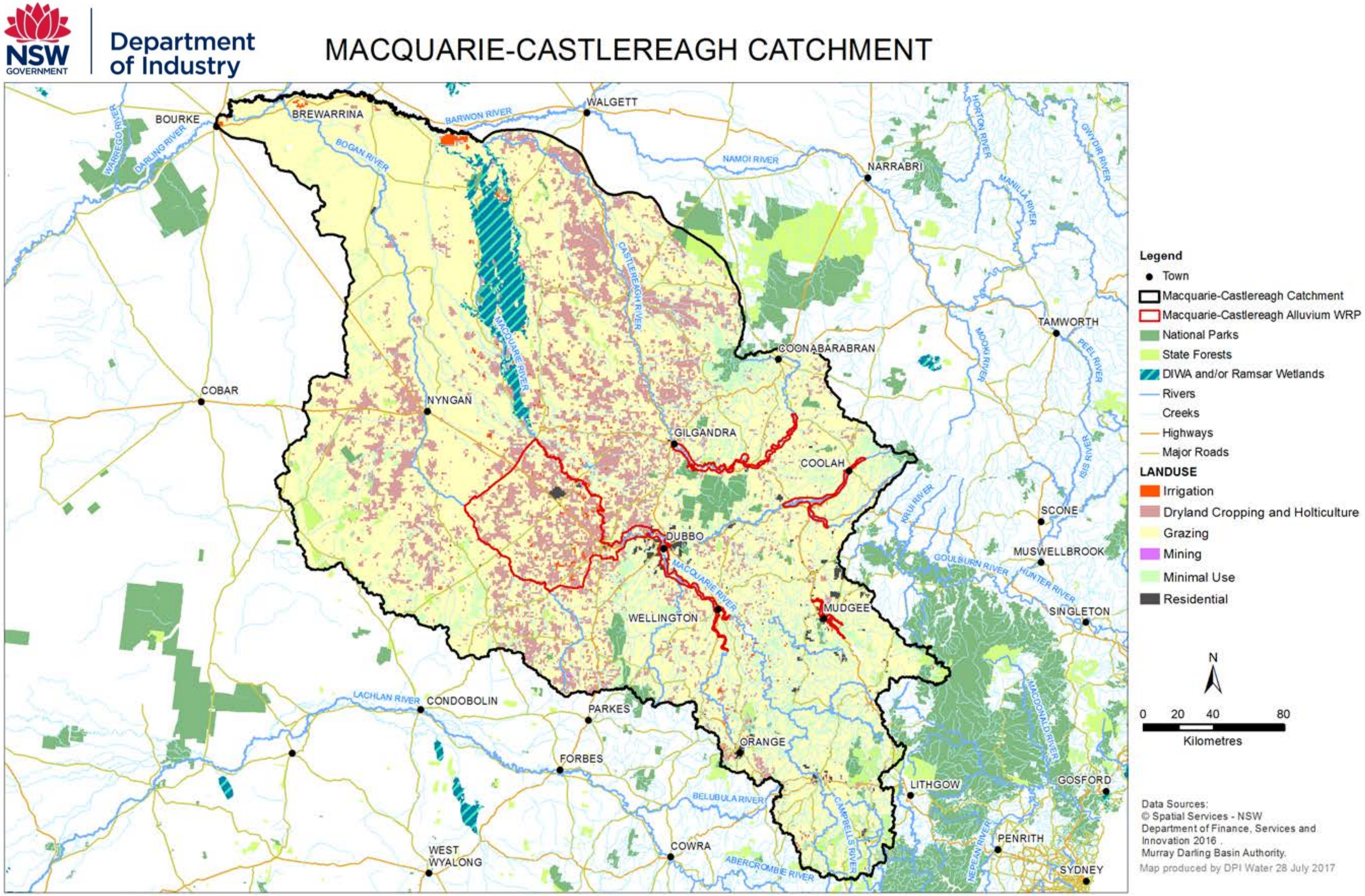

Figure 8 Land use map of the Macquarie - Castlereagh catchment (Smart, 2016)

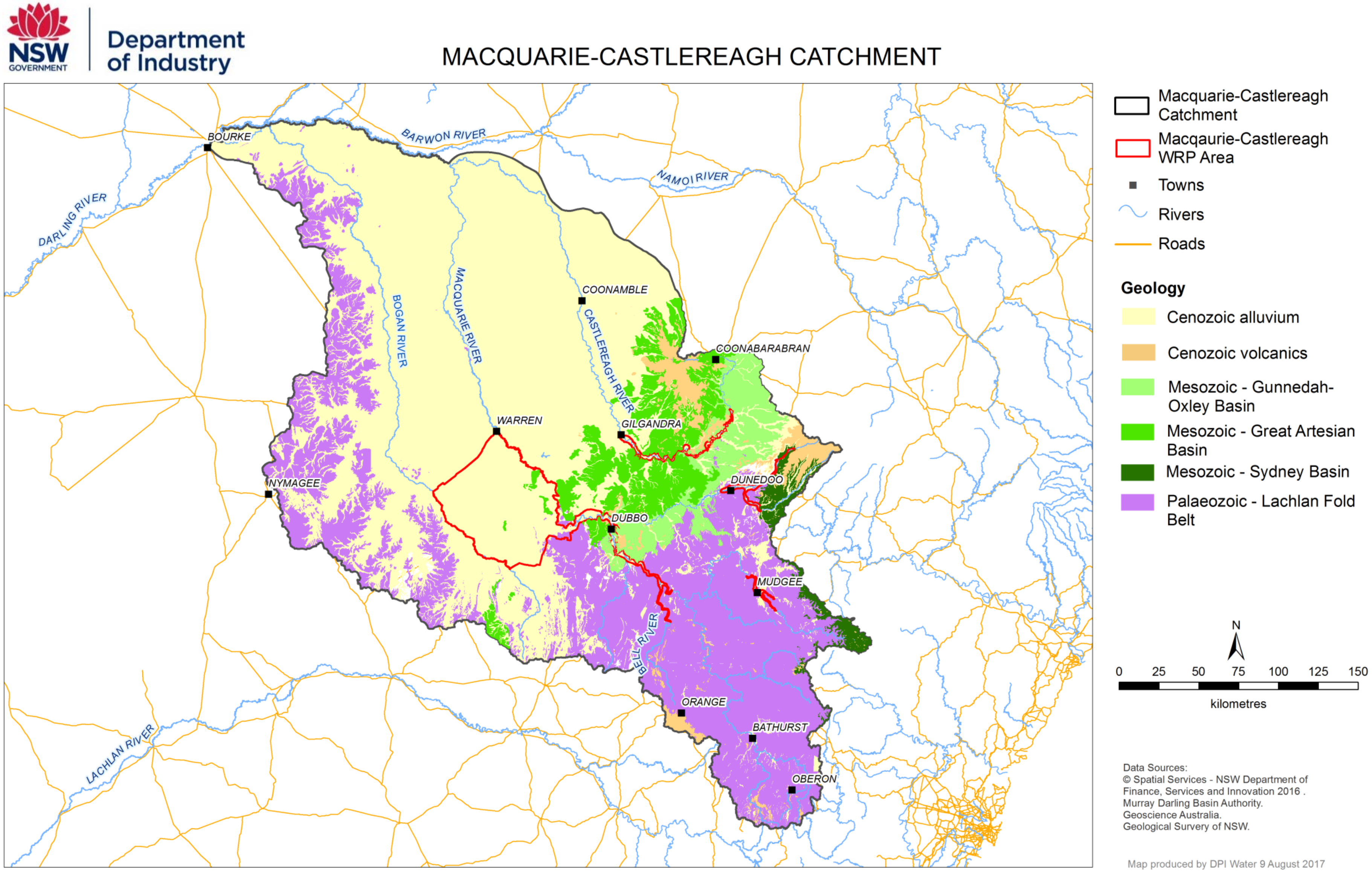

Figure 9 Geology of the Macquarie - Castlereagh catchment

5 Hydrogeology

5.1 Regional context

The Bell, Upper Macquarie and Lower Macquarie alluvial deposits form a continuous sequence of unconsolidated sediments. These sediments grade from thin deposits to broader valley and floodplain sediments down the catchment. Groundwater through flow is uninterrupted down valley and there is hydraulic connection across contiguous boundaries. A basement high exists between the Upper Macquarie Alluvium and the Lower Macquarie Alluvium that restricts but does not block groundwater flow from one groundwater source to the next.

The Lachlan Fold Belt underlies the Bell Alluvium, Cudgegong Alluvium, portions of the Upper Macquarie Alluvium, the Coolaburragundy - Talbragar Alluvium and the Lower Macquarie Alluvium. The permeability of these underlying fractured rocks of the Lachlan Fold Belt is many orders of magnitude lower than that of the alluvium. Groundwater exchange between the alluvium and these underlying rocks would be insignificant in a resource management sense and are not considered hydraulically connected. An area of exception to this is in the mid to lower reaches of the Bell Alluvium which is hydraulically connected with the underlying limestone formation of the Lachlan Fold Belt in which the Wellington cave systems are found.

The Upper Macquarie Alluvium also overlies the Gunnedah-Oxley Basin and the southern margin of the Great Artesian Basin (GAB). Similar to the Lachlan Fold Belt the permeability of the underlying Gunnedah-Oxley Basin rocks in this area is many orders of magnitude lower than that of the alluvium and groundwater exchange with the Upper Macquarie Alluvium and these underlying rocks is expected to be insignificant. The Upper Macquarie Alluvium intersects sandstone sequences of the underlying GAB downstream of the confluence of the Talbragar and Macquarie Rivers. Some degree of groundwater connectivity between the alluvium and the GAB is likely. The hydraulic gradient is expected to be such that groundwater flow would be from the alluvium into the GAB. Yields from the GAB sediments are limited to supporting stock and domestic supplies only in this area indicating low permeability sediments. Due to the low permeability and limited thickness of the GAB at this location, the potential for groundwater extraction impacts from within the GAB on the resources of the Upper Macquarie Alluvium is minimal.

The Lower Macquarie Alluvium corresponds to the Lower Macquarie Zones 1, 2 and 6 groundwater sources. Zone 6, and part of Zone 1, overlie the Lachlan Fold Belt and are not hydraulically connected with the underlying bedrock. The remaining alluvium, (i.e. parts of Zones 1 and 2) overlie the deeply incised palaeochannels eroded into the GAB sediments. There is hydraulic connectivity between the alluvium and these GAB sediments. Groundwater flow direction is from the alluvium into the GAB. The Lower Macquarie Zones 3, 4 and 5 groundwater sources are predominantly GAB sediments and are not included in the Water Resource Plan.

The upper reaches of the Coolaburragundy arm of the Coolabrurragundy - Talbragar Alluvium, in the vicinity of Coolah, overlies permeable sandstone. Some hydraulic connectivity is expected to occur locally between the alluvium and this sandstone unit. Further downstream the alluvium is underlain by the Lachlan Fold Belt.

The Castlereagh Alluvium is a discreet deposit within the Castlereagh sub-catchment. The alluvium overlies the eroded sediments of the Gunnedah-Oxley Basin and the GAB and some degree of connectivity with the underlying rock is expected.

The boundaries of the six alluvial SDL resource units reflect areas of similar hydrogeological characteristics. There is lateral hydraulic connection across contiguous boundaries within and between the SDL resource units. The characteristics of each of the SDL resource units are presented in the following sections.

5.2 Cudgegong Alluvium

The Cudgegong Alluvium is made up of Cenozoic unconsolidated alluvial sediments extending along a 40 km reach of the regulated Cudgegong River through Mudgee and along the lower reaches of the unregulated Lawsons Creek (Figure 11). The total area of the Cudgegong Alluvium is approximately 40 square kilometres.

The Cudgegong Alluvium is comprised of coarse gravel, sand, silt and clay deposits. The floodplain is up to 3 km wide and the sediments are generally 7 to 10 metres thick with sporadic thickness up to 25 m. The sediments are thickest at the confluence of the Cudgegong River and Lawsons Creek (Figure 10). It is an unconfined shallow alluvial system and is in hydraulic connection with the Cudgegong River and Lawsons Creek. Conceptually, the dominant recharge processes are direct rainfall infiltration and leakage from the Cudgegong River and Lawsons Creek.

The hydrogeological cross-section for the Cudgegong Alluvium near Mudgee (Figure 10) also shows the recovered standing water level for the 2015 – 16 water year.

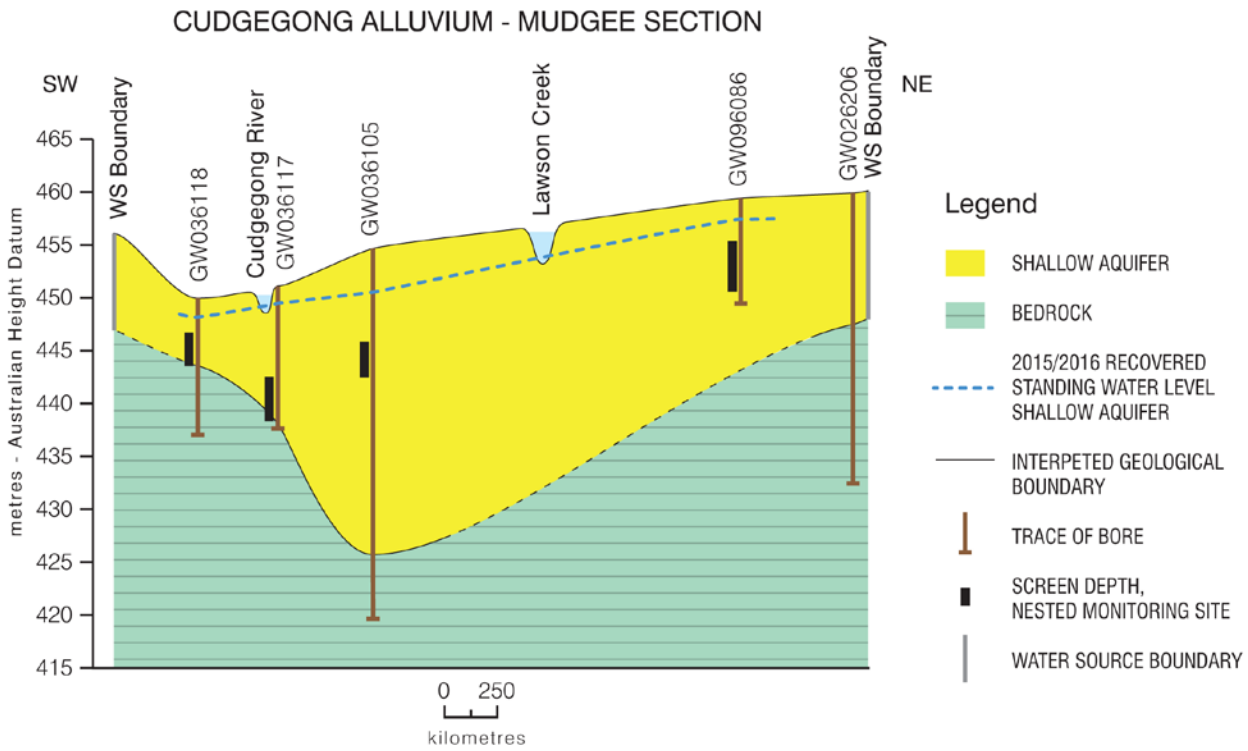

Figure 10 Southwest – northeast cross-section for the Cudgegong Alluvium at Mudgee

The regional groundwater flow direction follows the flow path of Cudgegong River and Lawsons Creek as shown in Figure 11.

Groundwater quality is good (see Section 7) and is used for all purposes such as irrigation (predominantly pasture and viticulture), domestic and stock as well as town water supply for Mudgee. Groundwater yields up to 20 L/s are common from this resource unit.

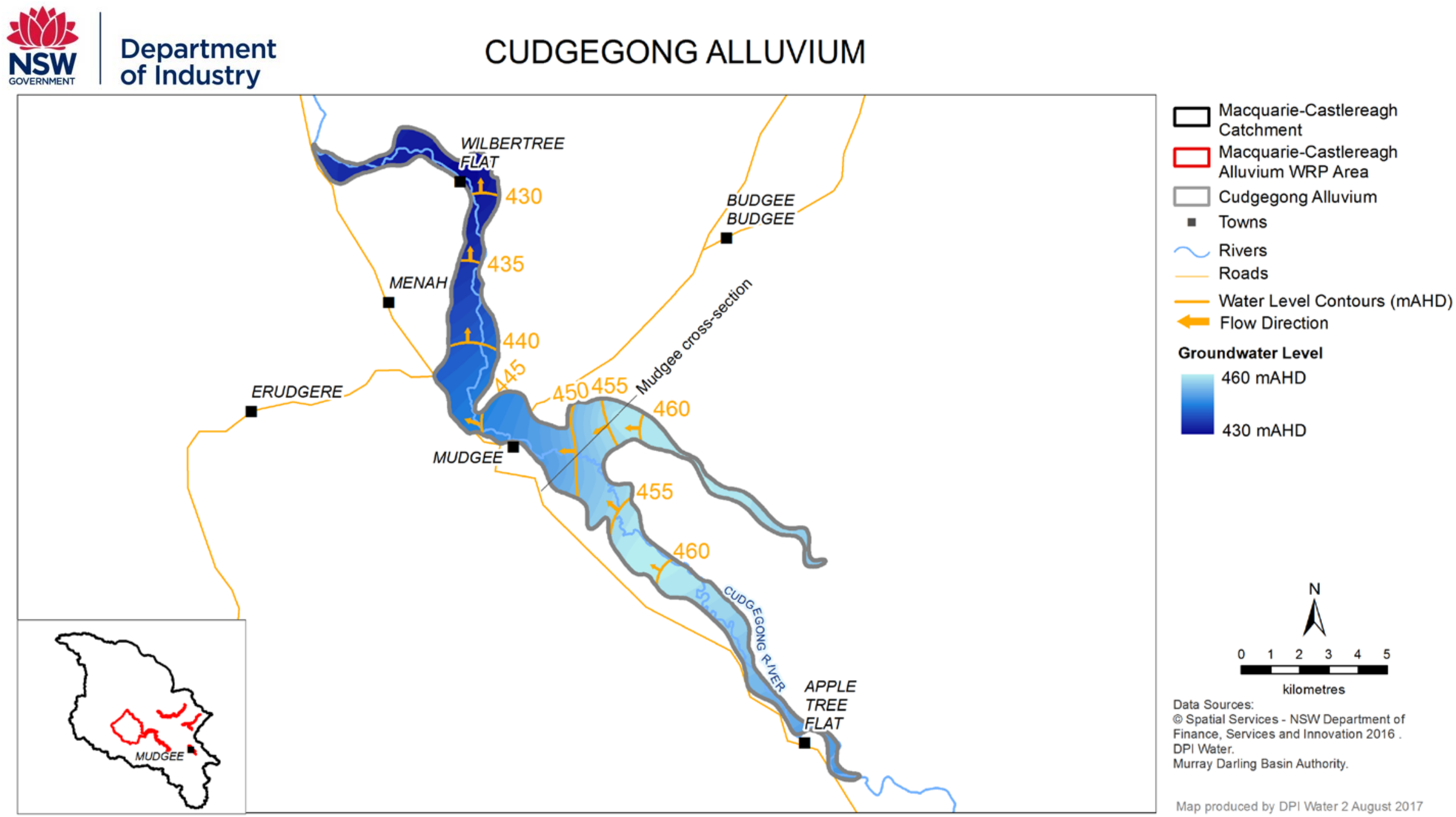

Figure 11 Location map of the Cudgegong Alluvium showing groundwater flow direction

5.3 Coolaburragundy – Talbragar Alluvium

The Coolaburragundy – Talbragar Alluvium is made up of Cenozoic unconsolidated alluvial sediments extending downstream along the Coolaburragundy and Talbragar Rivers to approximately 7 kilometres downstream of Dunedoo (Figure 13). The total area of the Coolaburragundy – Talbragar Alluvium is approximately 150 km^2.

The Coolaburragundy – Talbragar Alluvium is comprised of coarse gravel, sand, silt and clay deposits. The floodplain ranges from 500 m to 4 km wide and the sediments range in thickness from 15 m to 60 m thick. It is considered to be a largely unconfined alluvial system. Conceptually, the dominant recharge processes are direct rainfall infiltration and leakage from the Coolaburragundy and Talbragar Rivers.

The hydrogeological cross-section for the Coolaburragundy – Talbragar Alluvium in Figure 12 shows the thickness of the alluvium and the recovered standing water level for the 2015 – 16 water year at Dunedoo. The groundwater level is within 10 m of the ground surface at this location with the alluvium thickest to the north of the modern day Talbragar River. The base of the alluvium has been interpreted using a combination of sources including drill logs and geological maps.

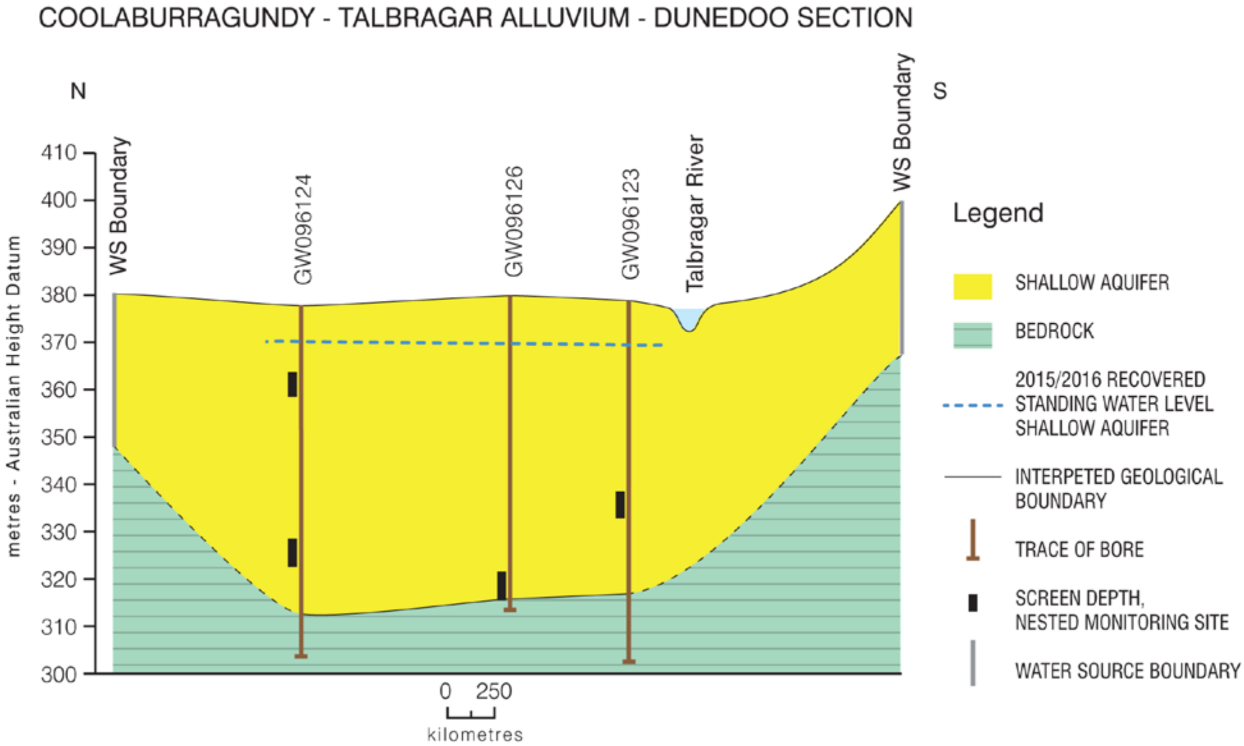

Figure 12 North – south cross-section for the Coolaburragundy – Talbragar Alluvium at Dunedoo

The regional groundwater flow is expected to follow the flow path of Coolaburragundy and Talbragar Rivers as shown in Figure 13.

Groundwater quality within the resource unit is generally good and suitable for all purposes. The resource unit is used for town water supply, irrigation (cereal and fodder crops) and stock and domestic purposes. Groundwater yields range up to 80 L/s.

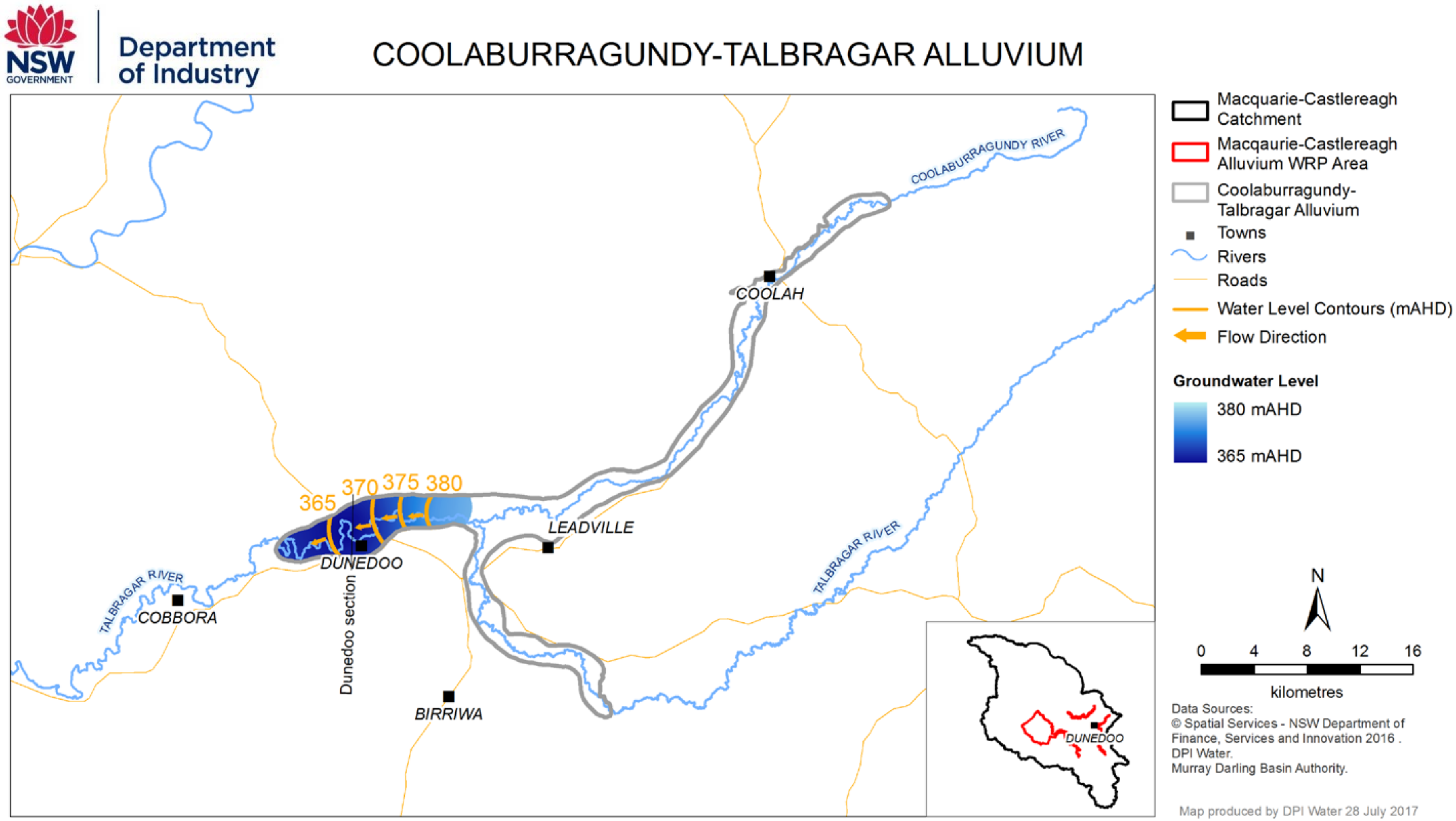

Figure 13 Location map of the Coolaburragundy – Talbragar Alluvium showing groundwater flow direction

5.4 Castlereagh Alluvium

The Castlereagh Alluvium is made up of Cenozoic unconsolidated alluvial sediments extending along the Castlereagh River from Binnaway to Gilgandra (Figure 15). The total area of the groundwater source is approximately 210 square kilometres.

These alluvial sediments were deposited on the eroded surface of older rocks of the Great Artesian Basin. The palaeovalley created on this eroded surface was first filled by high energy deposits of coarser gravels and sands which were then buried by more recent flood plain deposits of silt and clay. The resultant alluvial valley is generally about 2 km wide but narrows down to 200 m in areas where the valley is restricted through more resistive rocks. The thickness of alluvium varies from less than 30 meters around Binnaway to around 80 m near Gilgandra.

The Castlereagh Alluvium is largely an unconfined alluvial system. Conceptually the dominant recharge processes are direct rainfall infiltration and leakage from the Castlereagh River.

Figure 14 shows the hydrogeological cross-section for the Castlereagh Alluvium and the recovered standing water level for the 2015 – 16 water year at Gilgandra. The cross-section also shows that the alluvial aquifer is thickest to the south of the modern day Castlereagh River at this location. Interpretation of the geological boundary between the alluvium and the underlying weathered sandstone toward the south of the section is less distinct than the northern portion of the cross-section due to their similar lithologies.

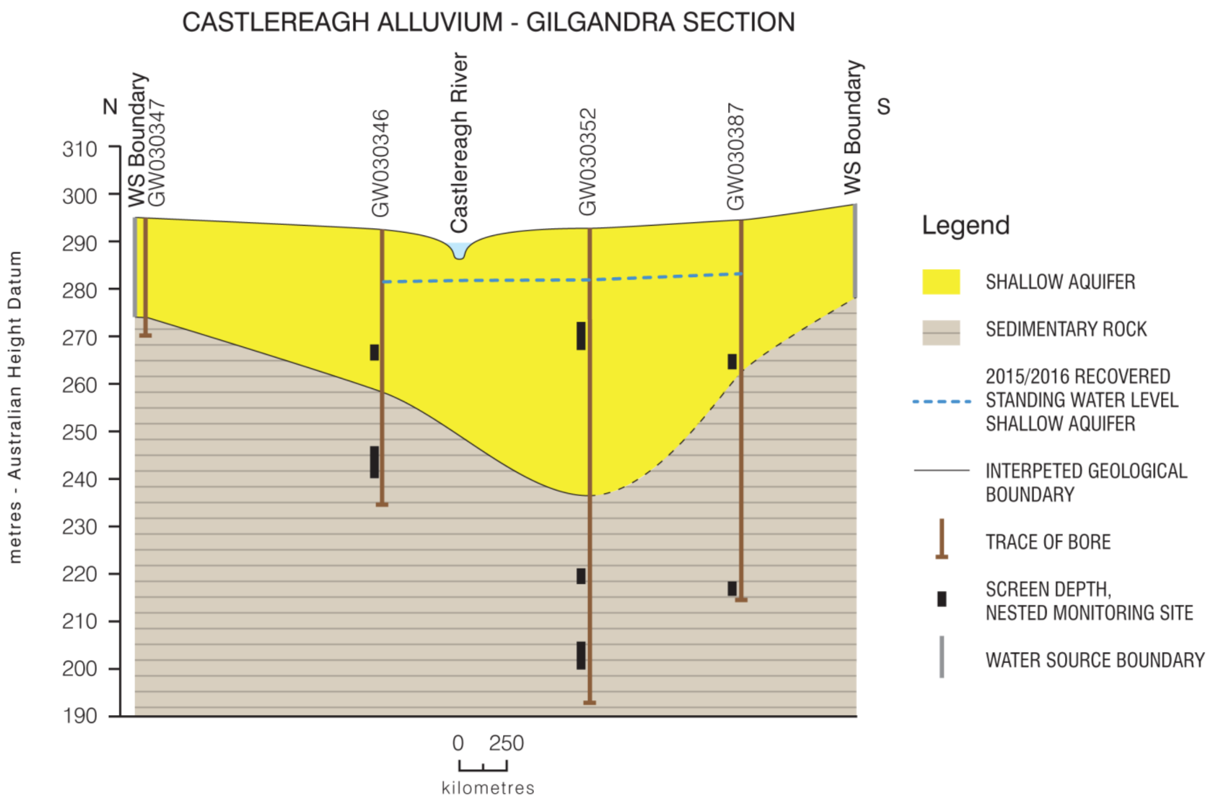

Figure 14 North-south cross-section for the Castlereagh Alluvium at Gilgandra

The regional groundwater flow direction is in a westerly direction toward Gilgandra following the flow path of Castlereagh River (Figure 15). Groundwater quality is generally good and suitable for most purposes. However, the aquifer typically yields less than 10 L/s and does not produce sufficient volumes suitable for large scale irrigation.

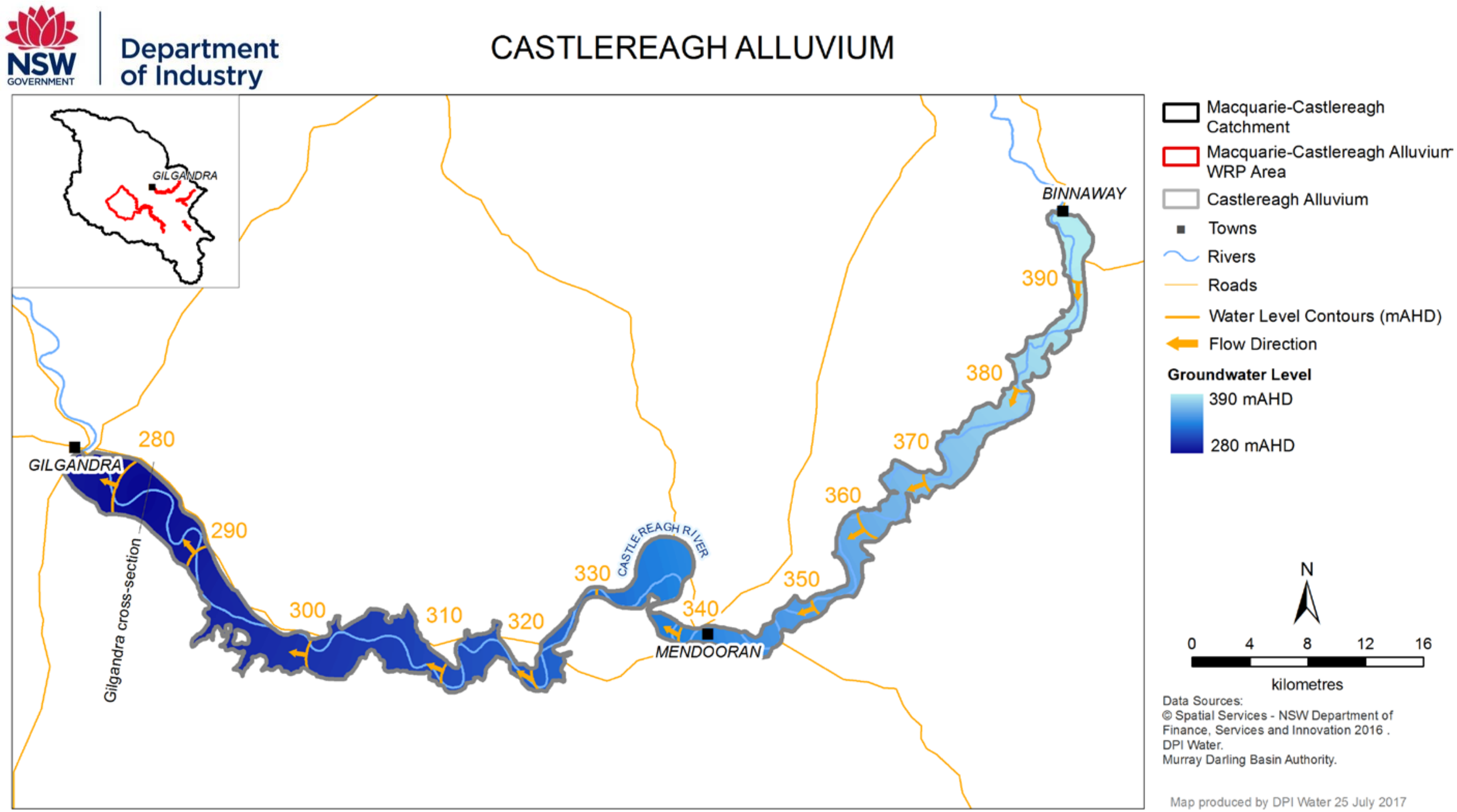

Figure 15 Location map of the Castlereagh Alluvium showing groundwater flow direction based on the 2015 – 16 recovered groundwater levels

5.5 Bell Valley Alluvium

The Bell Valley Alluvium is made up of Cenozoic valley fill unconsolidated alluvial sediments. It extends along the lower 24 km reach of the Bell River upstream from Wellington (Figure 17). The northern boundary of the Bell Valley Alluvium resource unit is shared with the Upper Macquarie Alluvial resource unit. The total area of the Bell Valley Alluvium is approximately 20 square kilometres.

The Bell Valley Alluvium is comprised of coarse gravel, sand, silt and clay deposits. The floodplain ranges from 300 m to 2 km wide and the thickness of the sediments ranges from 10 m to 25 m. It is an unconfined shallow alluvial system that is in hydraulic connection with the Bell River. Rainfall infiltration and leakage from the Bell River are the dominant recharge sources to the system.

Figure 16 shows the hydrogeological cross-section for the Bell Valley Alluvium and the recovered standing water level for the 2015 – 16 water year. This cross-section also shows that the shallow alluvial aquifer is thickest to the east of the modern day Bell River at this location. Although alluvium extends outside the eastern boundary, it has a lower permeability and has not been incorporated into this resource unit.

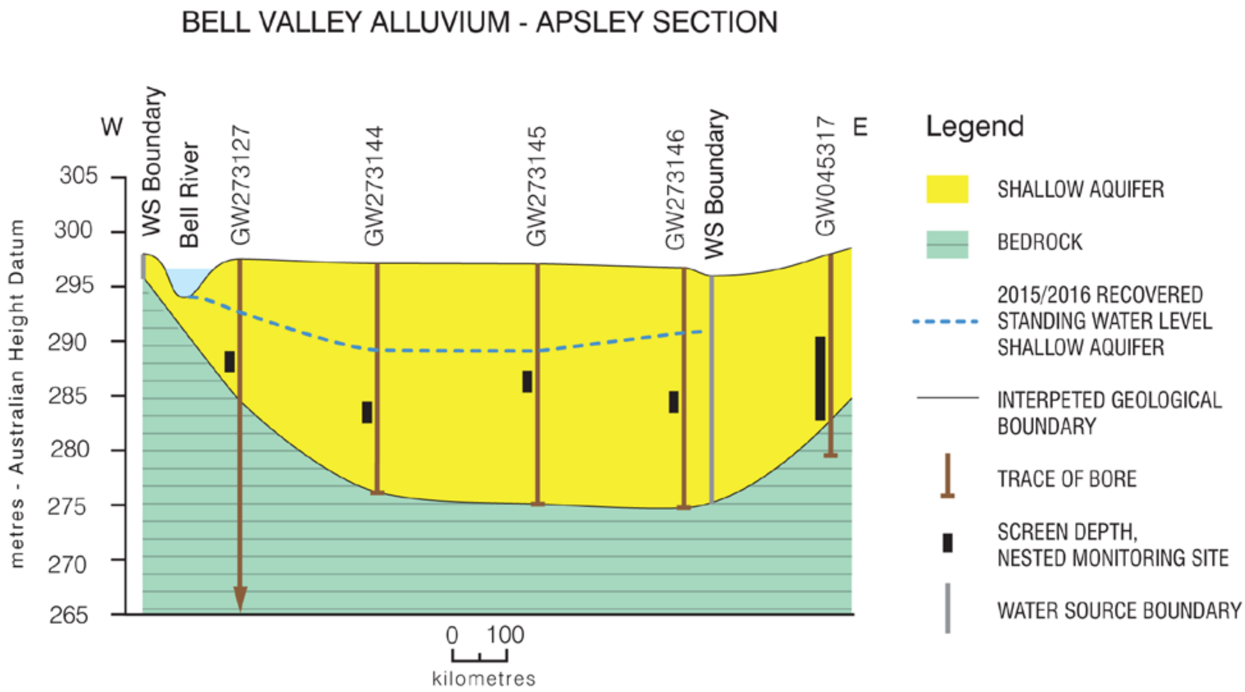

Figure 16 East – west cross-section through the Bell Valley Alluvium at Apsley

Groundwater flows in a northerly direction following the flow path of Bell River as shown in Figure 17.

Groundwater is of fresh quality and suitable for all purposes. Groundwater yields vary between 1 L/s and 20 L/s and average around 10 L/s.

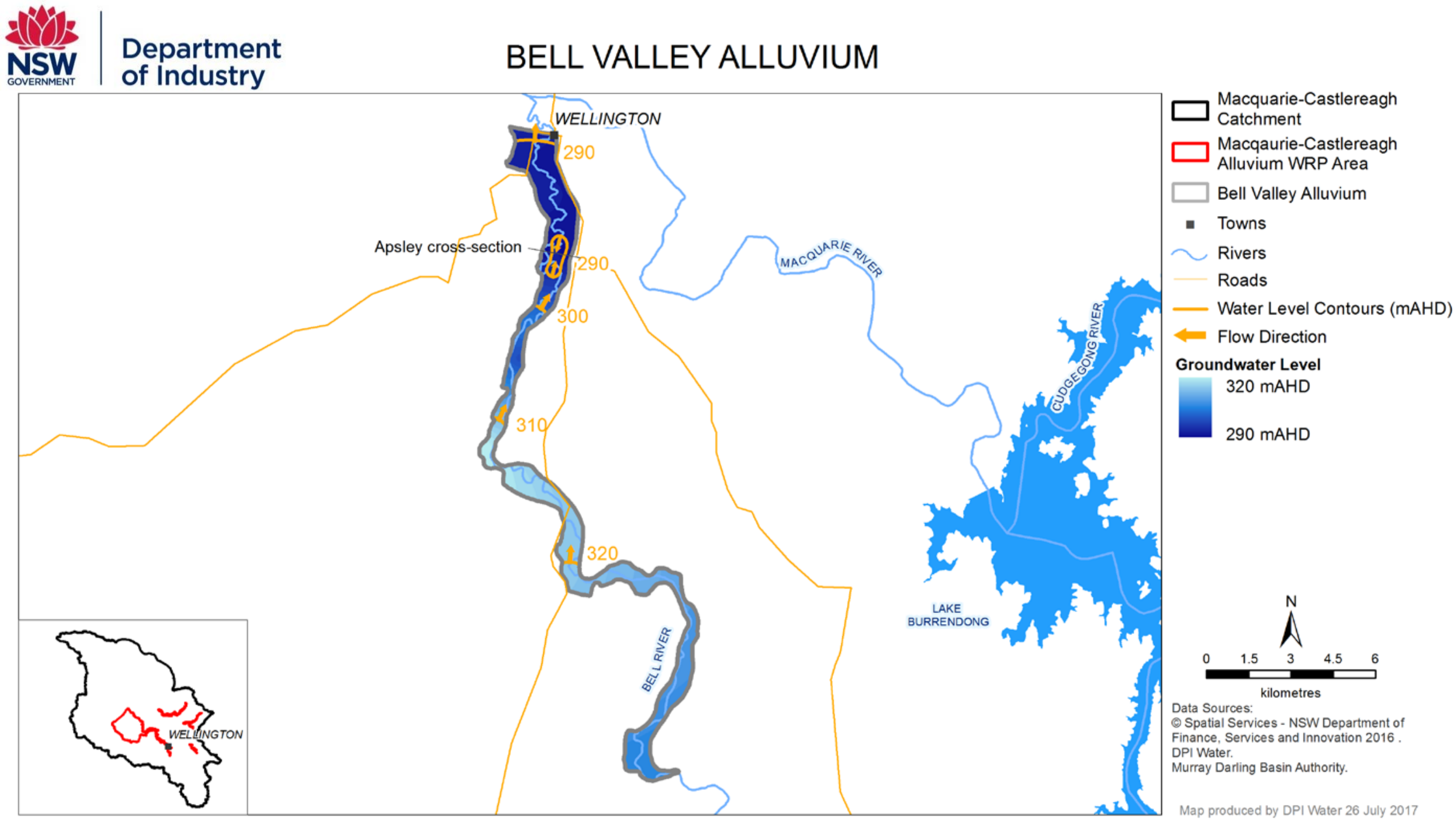

Figure 17 Location map of the Bell Valley Alluvium showing groundwater flow direction based on the 2015 – 16 recovered water levels

5.6 Upper Macquarie Alluvium

The Upper Macquarie Alluvium is made up of unconsolidated Cenozoic alluvial sediments extending along an 80 km reach of the Macquarie River from upstream of Wellington to where it shares a border with the Lower Macquarie Alluvium upstream of Narromine (Figure 19). The total area of the Upper Macquarie Alluvium is approximately 285 square kilometres.

The Upper Macquarie Alluvium is comprised of coarse gravel, sand, silt and clay deposits. The floodplain ranges from 500m to 5 km wide and the thickness of the sediments ranges from 15 m to 60 m. The alluvium can be broadly divided into two aquifer systems referred to here as the shallow aquifer and the deep aquifer.

Figure 18 shows the hydrogeological cross-section for the Upper Macquarie Alluvium and the recovered standing water level for the 2015 – 16 water year. The cross-section also shows that the alluvium is thickest to the north of the modern day Macquarie River. Although the alluvium extends outside the northern boundary, these sediments are generally lower yielding and have not been incorporated into this resource unit.

The shallow aquifer system (down to 25 m) is unconfined whilst the deeper aquifer system is semi-confined. Rainfall infiltration, aquifer through-flow and leakage from the Macquarie River are the dominant recharge sources to the alluvium.

The regional groundwater flow direction follows the Macquarie River in a north-westerly direction as shown in Figure 19. There are localised areas of reversed groundwater flow direction due to extraction.

Groundwater quality is generally fresh and is suitable for all purposes. Groundwater yields range between 5 and 120 L/s and average around 15 litres per second.

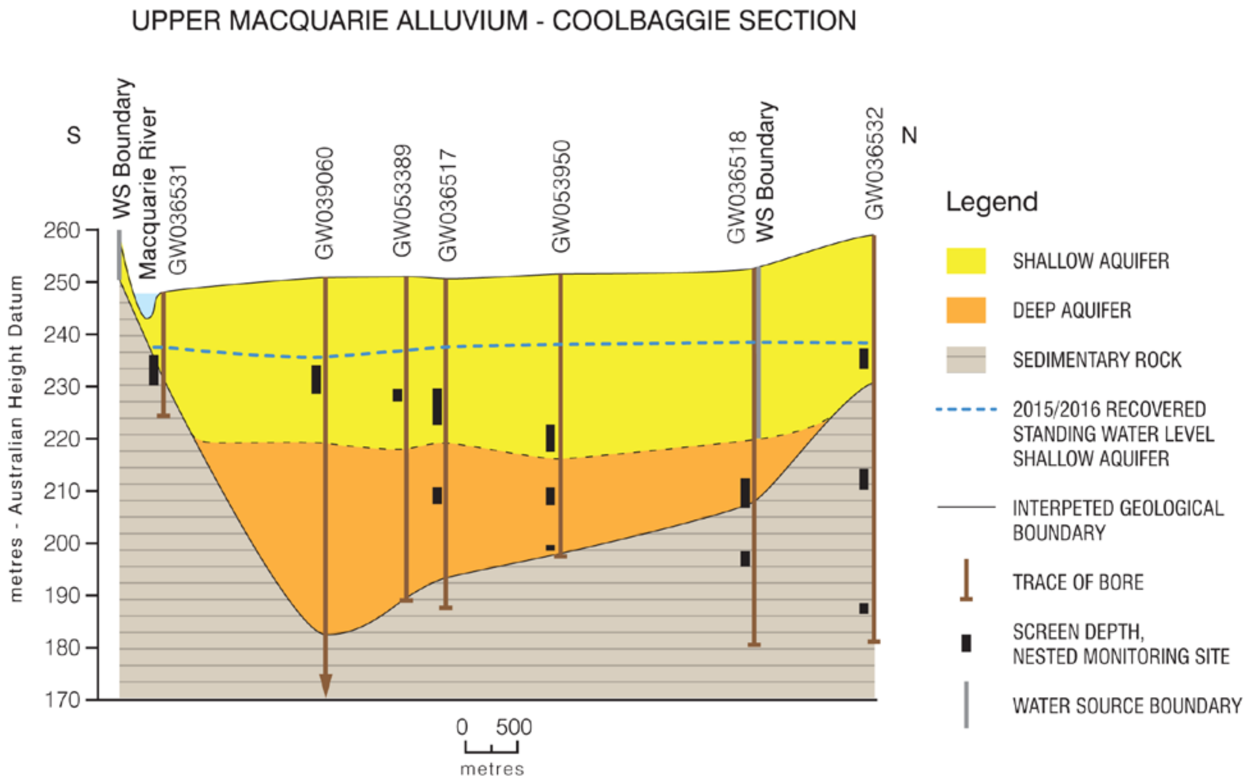

Figure 18 North-south cross-section for the Upper Macquarie Alluvium at Coolbaggie

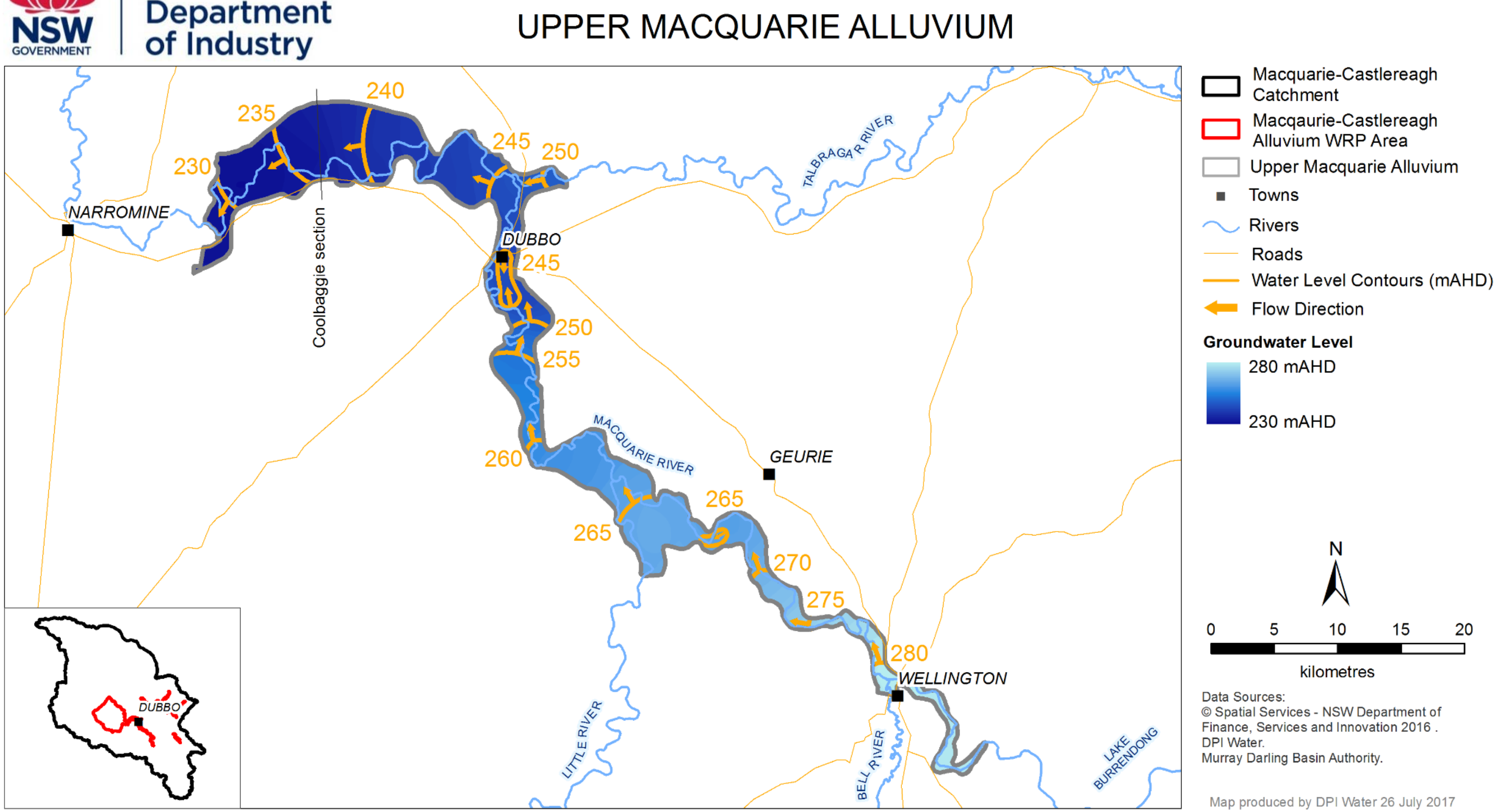

Figure 19 Location map of the Upper Macquarie Alluvium showing groundwater flow direction based on the 2015 – 16 recovered water levels

5.7 Lower Macquarie Alluvium

The Lower Macquarie Alluvium is made up of unconsolidated Cenozoic alluvial sediments extending out from Narromine towards Warren between the Macquarie and Bogan Rivers. The total area of the groundwater source is approximately 4,140 square kilometres.

These alluvial sediments were deposited on the eroded surface of older rocks of the Great Artesian Basin. The palaeovalley created on this eroded surface was first filled by high energy deposits of coarser gravels and sands which were then buried by more recent floodplain deposits of silt and clay. The productive deep alluvial aquifer which is found in the deepest part of the palaeochannel is located between Narromine and Dandaloo covering an area of 743 km^2 (Figure 21). The thickness of the deep alluvium varies from 20 to 90 metres. Outside of the extent of this palaeochannel, the alluvium forms a thin veneer over the Great Artesian Basin within the SDL resource unit boundary. In these areas the sandstone underlying the alluvium is targeted for groundwater extraction.

Note: Groundwater within the Great Artesian Basin is not included in the Murray Darling Basin water sources as the Commonwealth Water Act 2007 excludes all groundwater that forms part of the Great Artesian Basin.

The hydrogeological cross-sections for the Lower Macquarie Alluvium (Figure 20) show the thickness of the shallow and deep alluvium over the underlying sedimentary rock and fractured bedrock. Figure 20 also shows the recovered standing water level for the 2015 – 16 water year.

The shallow alluvium is considered to be unconfined to semi-confined system whereas the deep alluvium is a semi-confined to confined aquifer system. The dominant recharge to the Lower Macquarie Alluvium is through-flow from adjoining aquifers, rainfall infiltration, and leakage from overlying surface water bodies. The regional groundwater flow direction in the deep alluvium is from east to west from Narromine towards Dandaloo. Figure 21 shows the groundwater flow direction that is based on the recovered standing water levels in the 2015 – 16 water year.

In the deep alluvium depth to water is between 20 to 50 m below the surface. The groundwater quality is generally suitable for irrigation, domestic and stock as well as for town water supply. However, the quality deteriorates in areas near Bogan River and the salinity levels reach in excess of 3,000 mg/L (NWC, 2011). Bores completed in the deep alluvium can yield up to 200 L/s of fresh water.

Groundwater within the shallow alluvium is more susceptible to climate variations. The water table is below the base of the alluvium in some areas away from the Macquarie River.

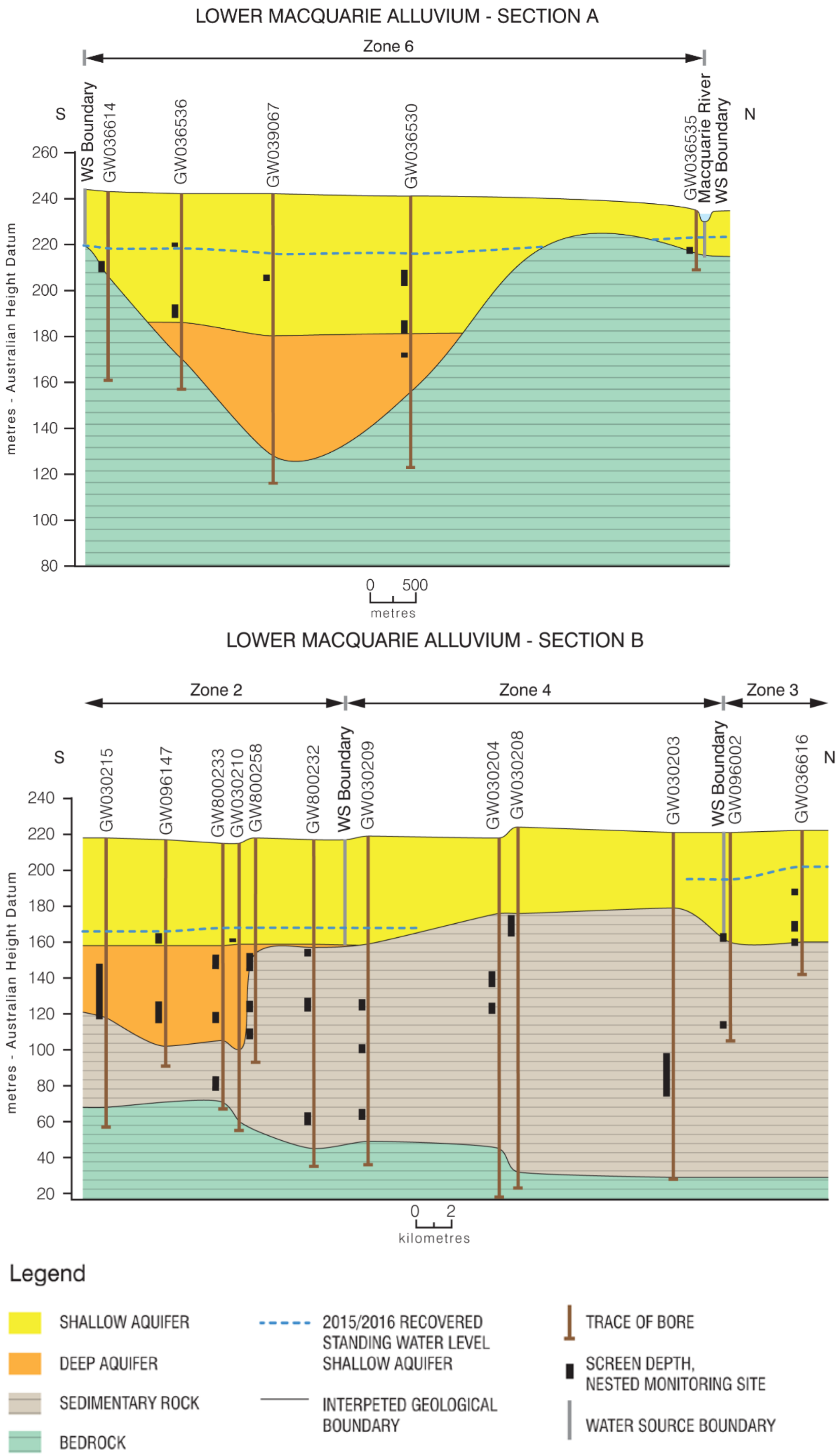

Figure 20 Section A - North-south hydrogeological cross-section for the Lower Macquarie Alluvium. Section B North – south hydrogeological cross-section for the Lower Macquarie Alluvium.

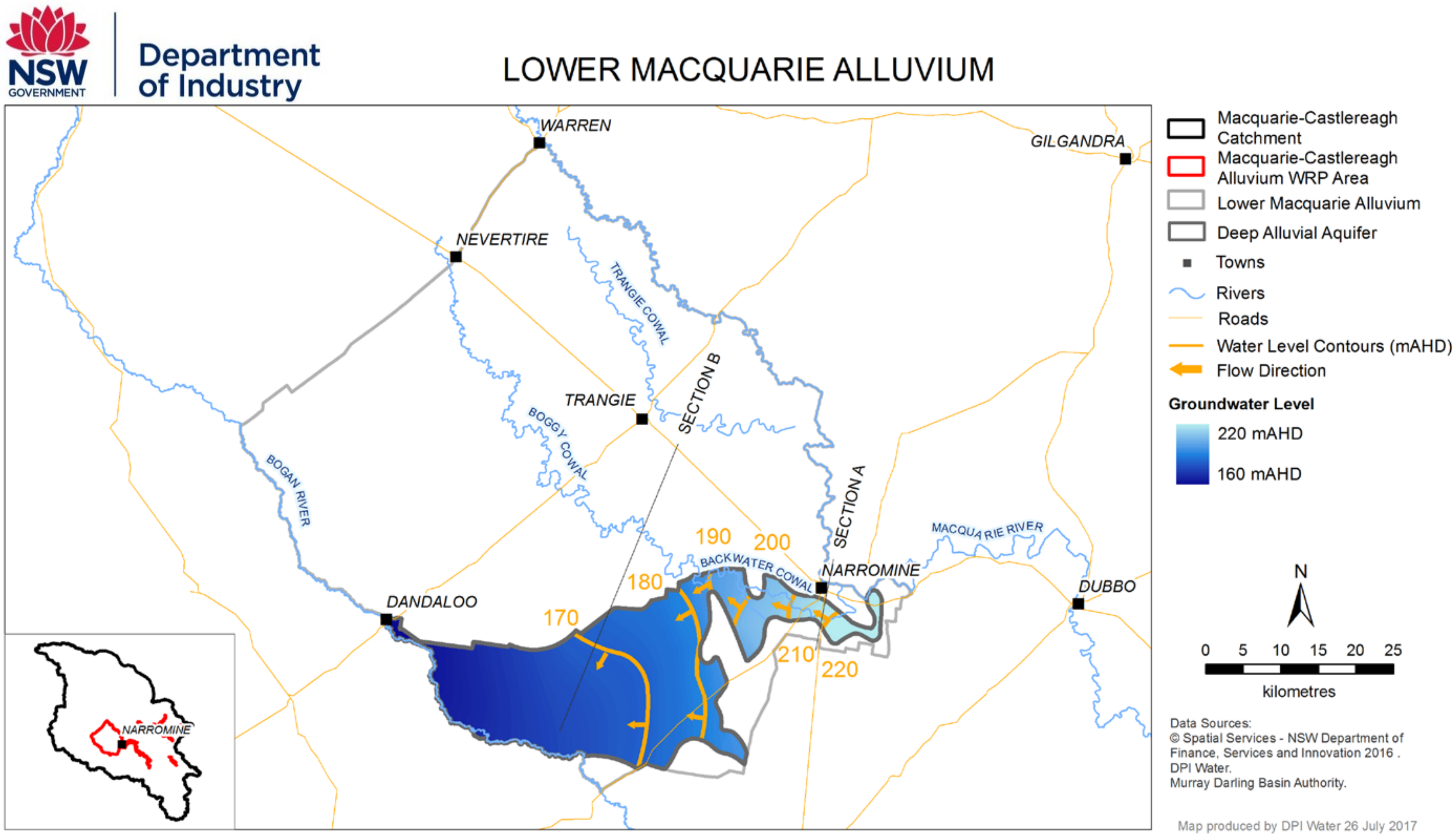

Figure 21 Location map of the Lower Macquarie Alluvium showing the groundwater flow direction in the deep alluvial aquifer

5.8 Connection with surface water

The Castlereagh, Bell and Cudgegong Alluvium resource units, and the Coolaburragundy reach of the Coolaburragundy - Talbragar Alluvium are highly connected to the associated rivers and major tributaries within their resource unit boundary. Of these systems only the Cudgegong Alluvium, where it is overlain by the regulated river, is linked to surface water rules. The other highly connected sections are managed with groundwater rules only as the connected surface water feature is non-perennial.

Figure 22 demonstrates the connectivity between the surface water and groundwater resources for the Cudgegong Alluvium at Wilbertree, located in the north of the resource unit. Monitoring at site GW096087 shows the water table reacts quickly to changes in the river levels. This level of hydraulic connection is recognised in the Water Sharing Plan rules the Cudgegong Alluvium resource unit.

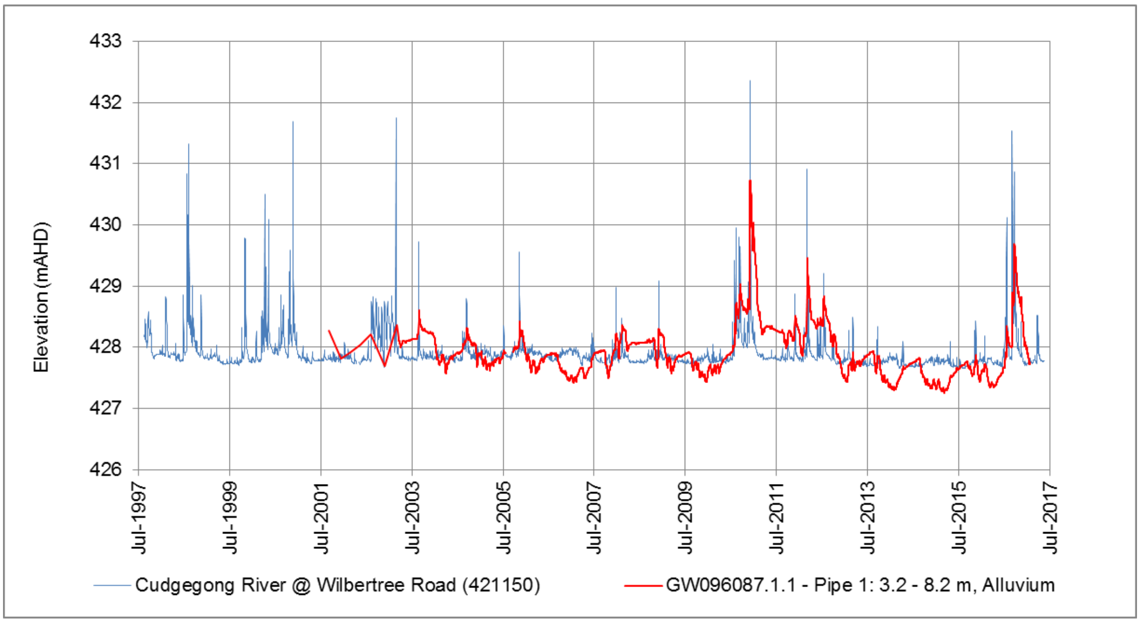

Figure 22 Groundwater-surface water interactions at Wilbertree. Monitoring bore location is shown in Figure 80 in Appendix B.

The downstream reaches of the Talbragar Alluvium resource unit, along the Talbragar River, is less connected to the river. The deeper alluvium has a much greater storage capacity and as a result, short term changes in surface water flows are not as significant to the overall groundwater store.

In the Upper Macquarie Alluvium, the Macquarie River varies between losing and gaining along its course depending on geology, topography, local conditions and prevailing long-term climatic conditions. Previous groundwater modelling (SKM, 2010) of a number of 50 year scenarios over a range of pumping and climatic conditions suggests that the total predicted loss of river flow in the long terms corresponds to 80-90% of the volume of groundwater being extracted. For management purposes this connection is categorised as being less highly connected compared to those managed as highly connected systems due to the slower rate at which groundwater-surface water interactions occur so that within season access rules are not linked to surface water management.

The greater depth to the regional water table in the Lower Macquarie resource unit result in the Macquarie River and its tributaries to be largely hydraulically disconnected from the groundwater for much of their reaches. That is, whilst the Macquarie River would lose water into the underlying alluvium, the rate of loss is not influenced by groundwater pumping. Further analysis of the interconnection between the Macquarie River and the alluvium is given in Lamontagne et al (2011) which characterised the 15 km reach of the river centred around Narromine as being losing-connected.

6 Groundwater dependent ecosystems

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

NSW Department of Industry 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 GDEs in the Macquarie – Castlereagh catchment that range in ecological value from very high to medium value (Figure 23).

In the Bell Valley, Upper and Lower Macquarie Alluvium resource units the ecological value is high, with river red gum communities dominating the riparian and floodplain. There is a high number of recorded threatened bird and flora species. Habitat diversity is also high in this area, providing extensive riparian corridors for habitat.

In the Castlereagh Alluvium, the dominant vegetation communities are river red gum and river oak – rough-barked apple – red gum – box riparian tall woodland/wetland communities. These communities are highly diverse and form connected riparian corridors that provide habitat to threatened bird species resulting in high ecological value.

The Talbragar and Cudgegong Alluvium resource units share similar riparian communities of river red gum, yellow and fuzzy box as well as other threatened flora and fauna. However, their ecological values differ due to the differing diversity and distinctiveness ratings as well as the fragmentation of the riparian communities. Overall those communities in the Talbragar Alluvium have a higher ecological value when compared to the Cudgegong Alluvium.

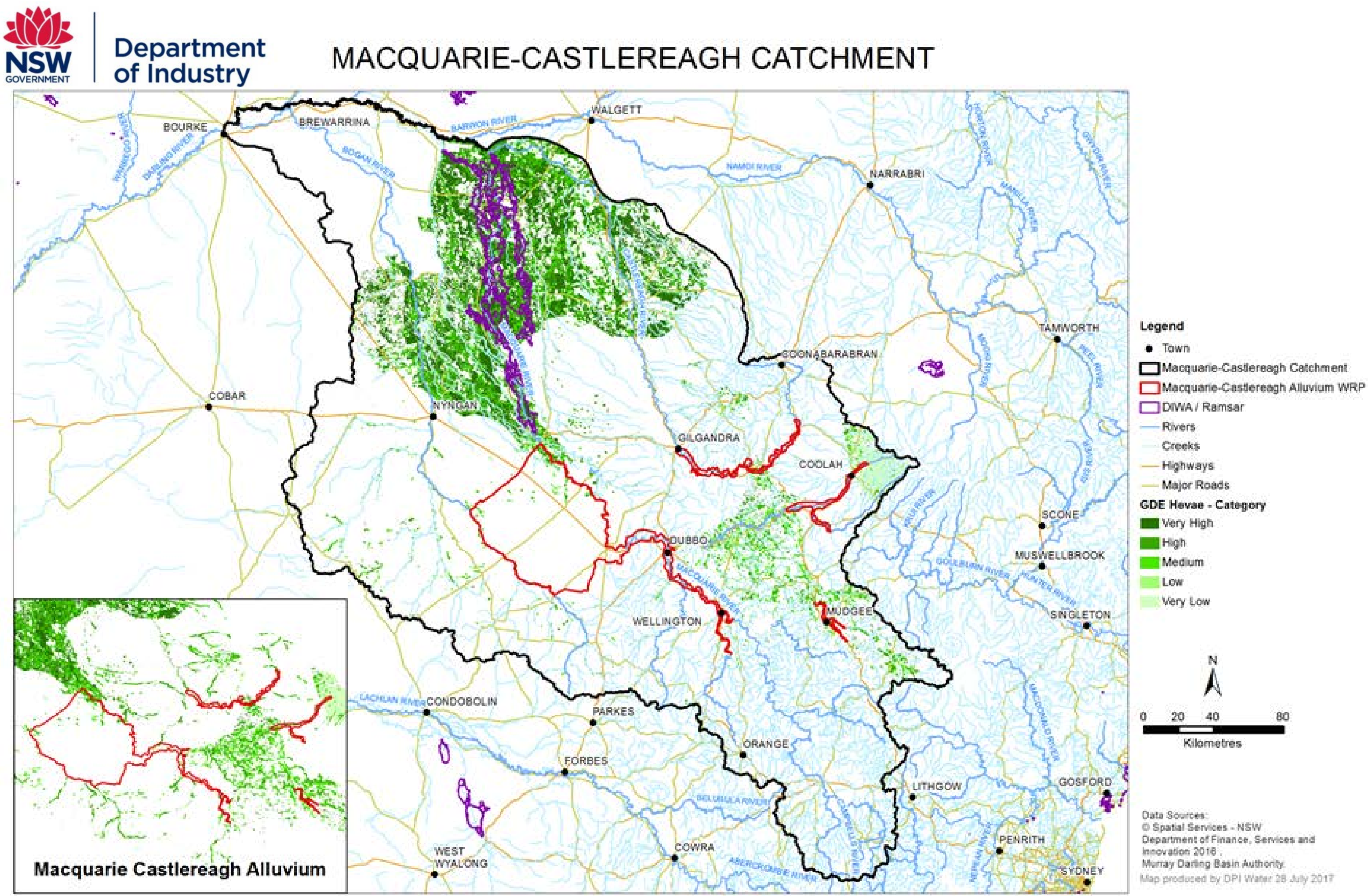

Figure 23 Ecological value for high probability groundwater dependent vegetation ecosystems

7 Groundwater quality

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

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

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 a 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 beneath or on 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 all affect groundwater quality.

7.1 Bell Valley Alluvium and Cudgegong Alluvium

Groundwater quality in these resource units is relatively fresh due to the highly connected nature of the alluvium to the parent river (Keshavarzi et al, 2016). These small upland alluvial systems are known to be dynamic and respond well to recharge events, with a relatively quick rate of groundwater movement; keeping the groundwater quality fresh (Keshavarzi et al, 2016).

Although records from monitoring bores in the Bell Valley Alluvium are spatially and temporally sparse they indicate that salinity ranges from 425 – 780 µS/cm. Whilst there is slightly more groundwater quality information available for the Cudgegong Alluvium, the information is historic with the last monitoring program conducted in 2,000. These records suggest that the salinity in the Cudgegong Alluvium ranges between 245 – 1,300 µS/cm.

7.2 Castlereagh Alluvium and Coolaburragundy – Talbragar Alluvium

Groundwater quality in the Castlereagh Alluvium and the Coolaburragundy - Talbragar Alluvium is likely to be spatially and temporally variable but is suitable for most purposes such as irrigation, domestic and stock and town water supply.

Groundwater quality monitoring information available for these two resource units is sparse. The available information suggests the salinity in the Coolaburragundy – Talbragar Alluvium is around 1,000 µS/cm.

7.3 Upper Macquarie

The groundwater quality in the Upper Macquarie Alluvium is good and suitable for most purposes. Although salinity levels are spatially and temporally variable, on average the electrical conductivity ranges between 300 – 1,500 µS/cm (Smithson, 2010).

An intensive salinity sampling program was undertaken in the summer of 2009/10, where all monitoring sites were sampled (Smithson, 2010) (Table 2). In general, salinity levels of the samples are lower from the deeper aquifer system than in the shallow.

Another observable trend was that salinity levels appear to increase as groundwater moves down the system, with lower salinity levels found upstream of Dubbo. It is also thought that the more saline Talbragar River may contribute salinity to the Upper Macquarie alluvial system where they meet (Smithson, 2010).

Table 2 Summary of salinity by formation

Formation	Location	Range of electrical conductivity (µS/cm)	Average electrical conductivity (µS/cm)
Shallow Alluvium	Upstream of Dubbo	300 – 1,718	896
	Downstream of Dubbo	288 – 18,700	2,433
Deep Alluvium	Upstream of Dubbo	251 – 832	479
	Downstream of Dubbo	312 – 804	519
Basement	Sandstone	599 – 15,700	5,309
	Basalt	1,100 – 5,410	3,255

Source: Upper Macquarie Alluvium, Groundwater Management Area 009, Groundwater Status Report – 2010, Smithson, A. (2010).

7.4 Lower Macquarie

Groundwater quality in the Lower Macquarie Alluvium is good and is suitable for all purposes such as irrigation, domestic and stock as well as town water supply. Outside of the deep alluvial aquifer the groundwater quality is spatially variable ranging from fresh to brackish, therefore the application of its use may be more limited (NWC, 2011).

Although groundwater salinity levels are spatially and temporally variable, on average the electrical conductivity ranges between 500 – 2,000 µS/cm. The deep alluvium can be slightly brackish in some locations along the Bogan River with salinities over 4,000 µS/cm (NWC, 2011).

8 Groundwater management

The boundaries of the six alluvial SDL resource units in the Macquarie – Castlereagh catchment reflect those of the groundwater sources managed under three NSW water sharing plans:

- Bell, Cudgegong, Talbragar and Upper Macquarie Alluvial Groundwater Sources managed under the *Water Sharing Plan for the Macquarie – Bogan Unregulated and Alluvial Water Sources 2012,*
- Lower Macquarie Groundwater Sources (Zones 1 - 6) managed under the *Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003,* and the
- Castlereagh Alluvial Groundwater Sources managed under the *Water Sharing Plan for Castlereagh River Unregulated and Alluvial Water Sources 2011.*

The Lower Macquarie Groundwater Sources are comprised of Cenozoic unconsolidated alluvial deposits and Mesozoic sedimentary rocks which are part of the Great Artesian Basin geological sequence. Although the boundary of Lower Macquarie Alluvium SDL resource unit reflects that of Lower Macquarie Groundwater Sources, only groundwater contained in the Cenozoic unconsolidated alluvial deposits is managed under this SDL resource unit.

The productive aquifers within the Lower Macquarie Groundwater Sources Zone 3, 4 and 5 are within the sandstone of the Great Artesian Basin. Groundwater within the Great Artesian Basin is not included in the Murray Darling Basin water sources as the Commonwealth *Water Act 2007* excludes all groundwater that forms part of the Great Artesian Basin.

Any information relating to the sandstone aquifers located in Zone 3, 4 and 5 are clearly indicated throughout the following sub-sections. A map showing the six Lower Macquarie Groundwater Sources has been included in Appendix A.

8.1 Access rights

Groundwater access licenses for the six alluvial SDL resource units and the corresponding groundwater sources are shown in Table 3.

The local water utility access licences are held by local government for town water supply purposes and the share component is for a specified volume of groundwater. The share components of aquifer access licences and aquifer access licence (high security) are issued for a specified number of unit shares (Table 3).

Owing to the high level of connection between the alluvium and the regulated Cudgegong River, groundwater available under the licence category 'aquifer access licence (high security)' in the Cudgegong Alluvium Management Zone is linked to the availability of high security allocations in the regulated Cudgegong River.

Table 3 Access licences in the Macquarie – Castlereagh Water Resource Plan Area (at May 2017).

SDL Resource Unit	Groundwater Source	Local Water Utility (ML/year)	Aquifer (unit shares)	Aquifer High Security (unit shares)
Cudgegong Alluvium (GS16)	Cudgegong Alluvium	3,000	1,829	8,891
Coolaburragundy – Talbragar Alluvium (GS15)	Talbragar Alluvium	656	5,355	-
Castlereagh Alluvium (GS14)	Castlereagh Alluvium	-	583	-
Bell Valley Alluvium (GS11)	Bell Alluvium	70	4,538	-
Upper Macquarie (GS45)	Upper Macquarie	4,470	27,695	-
Lower Macquarie (GS26)	Lower Macquarie Zone 1 (alluvium)	2,000	19,680	-
	Lower Macquarie Zone 2 (alluvium)	-	22,608	-
	Lower Macquarie Zone 6 (alluvium)	-	7,243	-
	TOTAL	2,000	49,531	
	Lower Macquarie Zone 3 (sandstone)	350	8,264	-
	Lower Macquarie Zone 4 (sandstone)	-	5,103	-
	Lower Macquarie Zone 5 (sandstone)	-	2,477	-
	TOTAL	350	15,844	

Supplementary water access licences were issued to some licence holders in groundwater sources Zones 1, 3 and 4 in the Lower Macquarie. 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.

8.2 Extraction limits

Extraction in a groundwater source is managed to the long-term average annual extraction limit (LTAAEL) as set by the relevant water sharing plans. (Note: In the Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003 this is referred to as the long-term average extraction limit (LTAEL), for ease of reference all water sharing plan extraction limits are referred to as LTAAEL in this report.)

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 4 lists the LTAAEL for the six alluvial SDL resource units in the Macquarie – Castlereagh catchment as well as the SDL for each area. The LTAAEL includes the estimated volumes for basic landholder rights (BLR) that are for domestic and stock purposes as quoted in Table 4.

Table 4 LTAAEL for the six alluvial SDL resource units compared to the SDL (at May 2017)

SDL resource unit	Groundwater source	LTAAEL ML/yr	SDL ML/yr	BLR ML/year
Cudgegong Alluvium (GS16)	Cudgegong Alluvium	2,533	2,530	27
Coolaburragundy – Talbragar Alluvium (GS15)	Talbragar Alluvium	3,473	3,470	69
Castlereagh Alluvium (GS14)	Castlereagh Alluvium	621	620	84
Bell Valley Alluvium (GS11)	Bell Alluvium	3,299	3,290	6
Upper Macquarie Alluvium (GS45)	Upper Macquarie Alluvium	17,935	17,900	304
Lower Macquarie Alluvium (GS26)	Lower Macquarie Zones 1 - 6	71,023	70,700[1]	1730

[1]70,700 ML minus the portion of the limit under the *Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003* of New South Wales that applies to water taken from the Jurassic Sandstone of the Great Artesian Basin

Whilst Table 4 presents the combined LTAAEL for the Lower Macquarie Groundwater Sources, Table 5 shows the LTAAEL for each of the six Groundwater Sources. The estimated volumes for basic landholder rights that are for domestic and stock purposes are also included in the volumes quoted in Table 5.

Table 5 Lower Macquarie Groundwater Source LTAAEL.

Lower Macquarie Groundwater Source	LTAAEL ML/yr	BLR ML/yr
Lower Macquarie Groundwater Source Zone 1 (alluvium)	21,745	70
Lower Macquarie Groundwater Source Zone 2 (alluvium)	22,925	315
Lower Macquarie Groundwater Source Zone 6 (alluvium)	8,325	165
Lower Macquarie Groundwater Source Zone 3 (sandstone)	9,870	520
Lower Macquarie Groundwater Source Zone 4 (sandstone)	5,315	215
Lower Macquarie Groundwater Source Zone 5 (sandstone)	2,843	445

Lower Macquarie Groundwater Source	LTAAEL ML/yr	BLR ML/yr
TOTAL	71,023	1730

To manage any growth in extraction in excess of the LTAAEL, water sharing plans set a trigger for complying with the extraction limit. The following subsections illustrate annual extraction since the commencement of the water sharing plan.

Figure 24 shows the annual extraction in the Cudgegong, Coolaburragundy – Talbragar and Bell Valley alluvial resource units since 2012 when the *Water Sharing Plan for the Macquarie – Bogan Unregulated and Alluvial* water sources commenced. This is a combination of the metered groundwater extraction and the volume of groundwater reserved for basic landholder rights. The plot 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.

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 water extraction to the extraction limit.

The 5 year rolling average of extraction commenced in the second year for the Cudgegong Alluvium whilst it commenced in the third year for the Coolaburragundy – Talbragar and Bell Valley alluvial resource units. The risk of extraction in these resource units exceeding the LTAAEL is low as there is only a moderate amount of groundwater development.

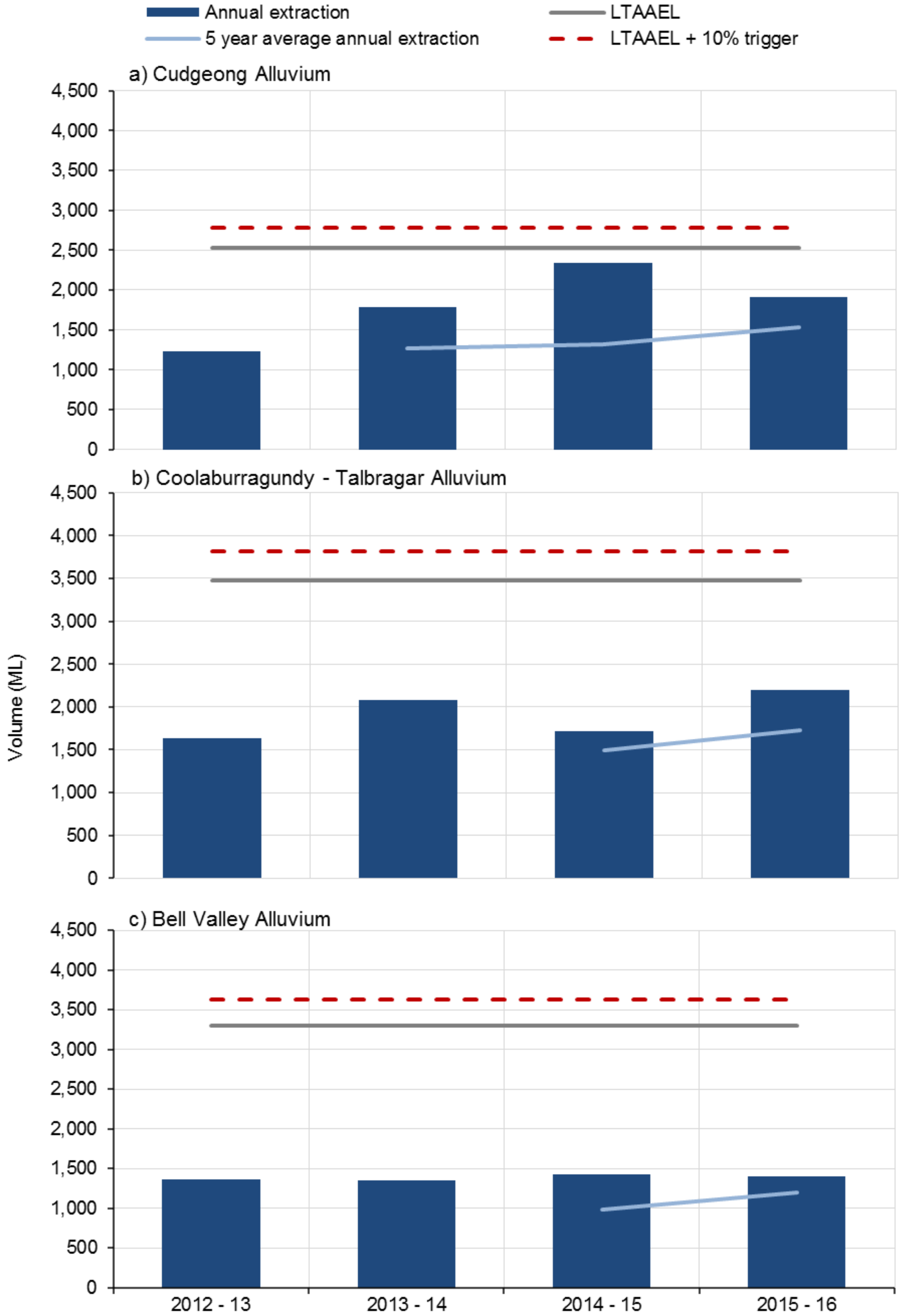

Figure 24 a) Cudgegong, b) Coolaburragundy – Talbragar and c) Bell Valley alluvial resource units annual extraction as compared the to LTAAEL since the commencement of the water sharing plan

For the Castlereagh Alluvium the water sharing plan commenced in 2011 but the 5 year rolling average of extraction does not commence until the sixth year of plan implementation, which is 2016-2017. There has been no recorded extraction in the Castlereagh Alluvium since the commencement of the water sharing plan and the volume reported in Figure 25 is the requirements for domestic and stock rights as defined in the plan (84 ML/year).

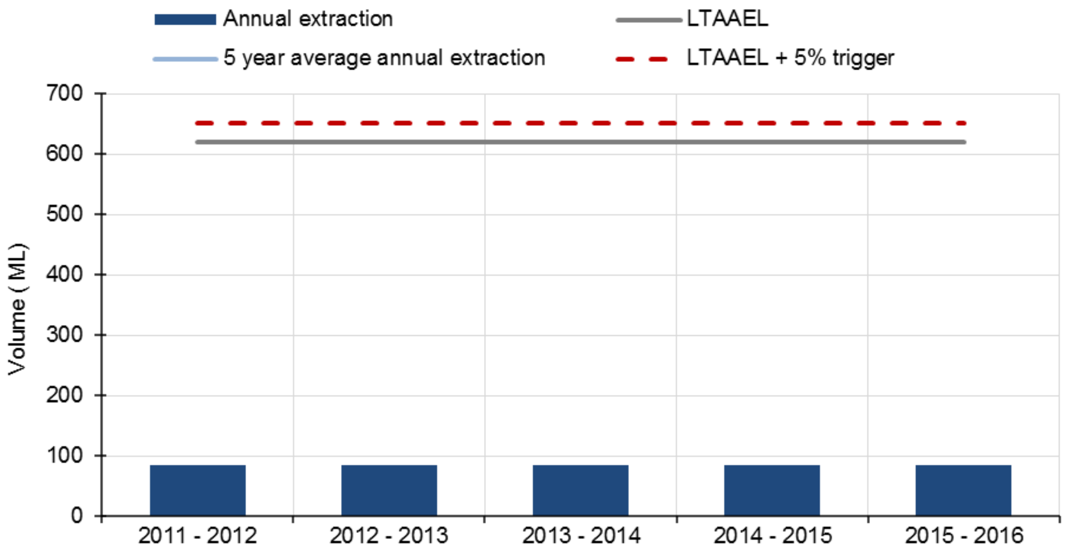

Figure 25 Castlereagh Alluvium units annual extraction as compared the to LTAAEL since the commencement of the water sharing plan

Figure 26 shows that the 5 year rolling average of extraction commenced in the second year of the implementation of the *Water Sharing Plan for the Macquarie – Bogan Unregulated and Alluvial Water Sources* for the Upper Macquarie Alluvium. The risk of extraction in the Upper Macquarie Alluvium exceeding the LTAAEL in the near future is low based on the current trends of extraction.

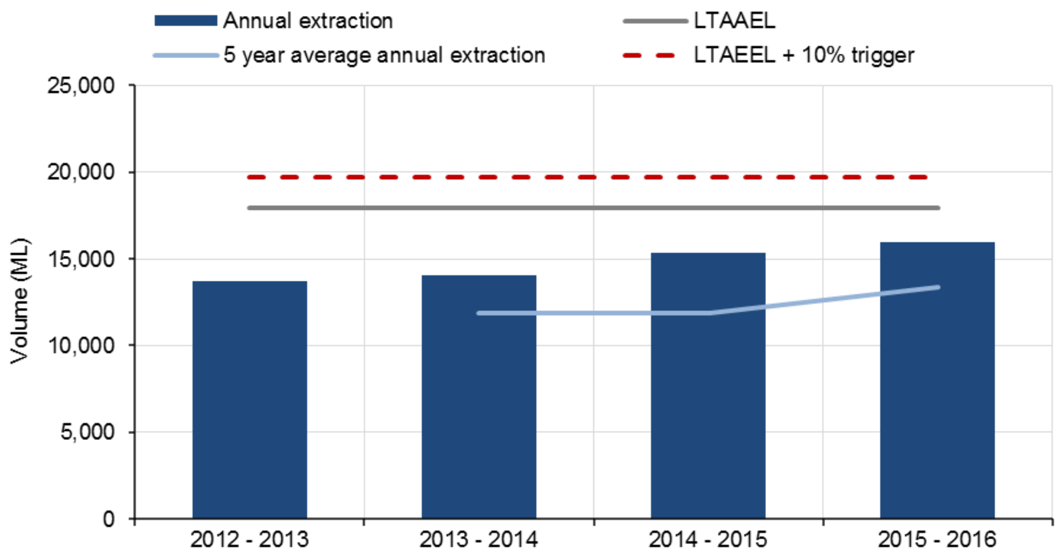

Figure 26 Upper Macquarie Alluvium annual extraction as compared the to LTAAEL since the commencement of the water sharing plan

The *Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003* was the first water sharing plan implemented in the WRP area. This plan states that if the 3 year average of extraction of a groundwater source 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 water extraction to the extraction limit.

Figure 27 and Figure 28 show the LTAAELs for each of the six groundwater sources and the trigger set by the water sharing plan to initiate a management response. Overall, the risk of extraction from these groundwater sources is low based on the current extraction trends.

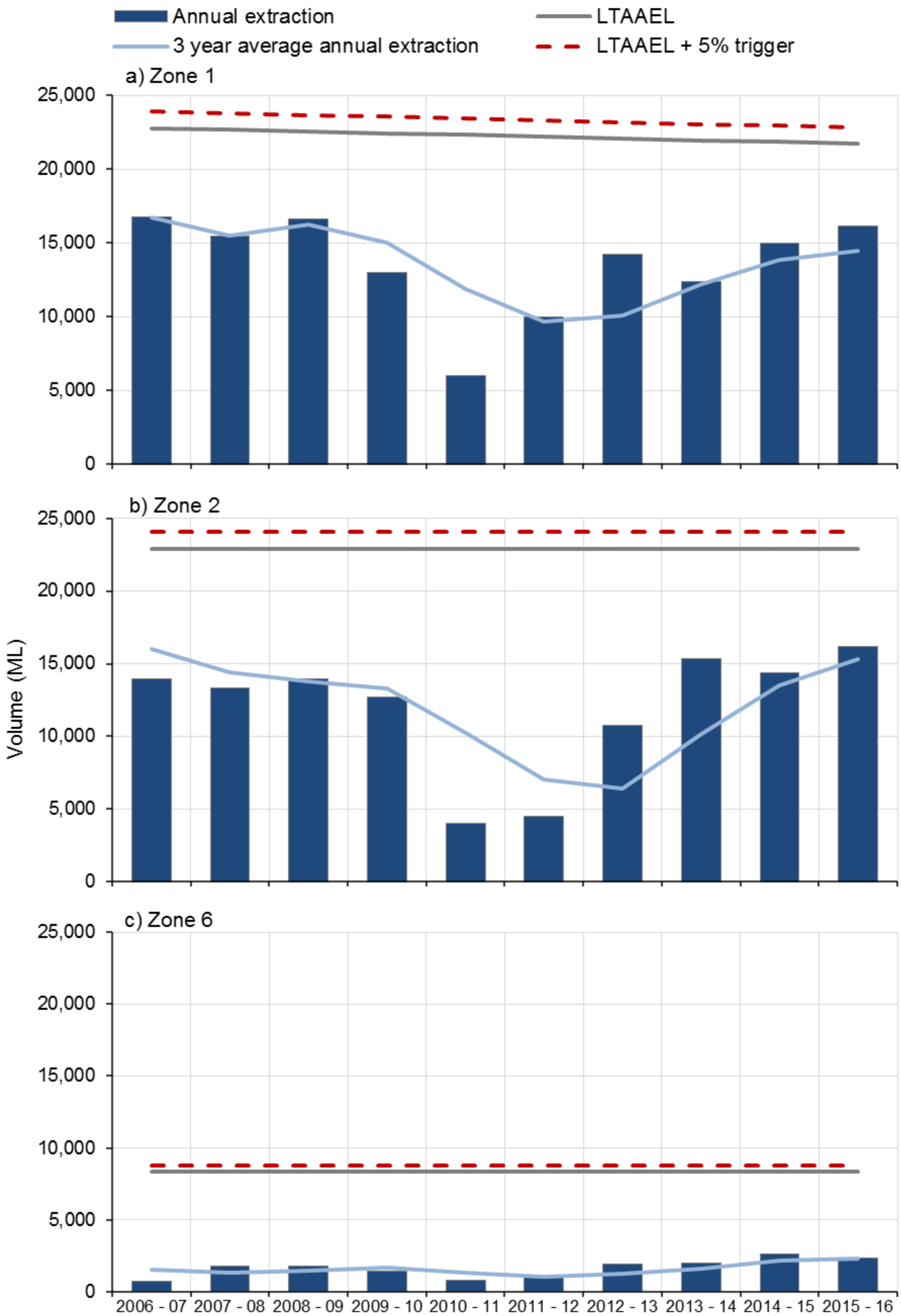

Figure 27 Lower Macquarie Groundwater Sources a) Zone 1 , b) Zone 2 and c) Zone 6 annual extraction as compared the to the LTAAEL since the commencement of the water sharing plan

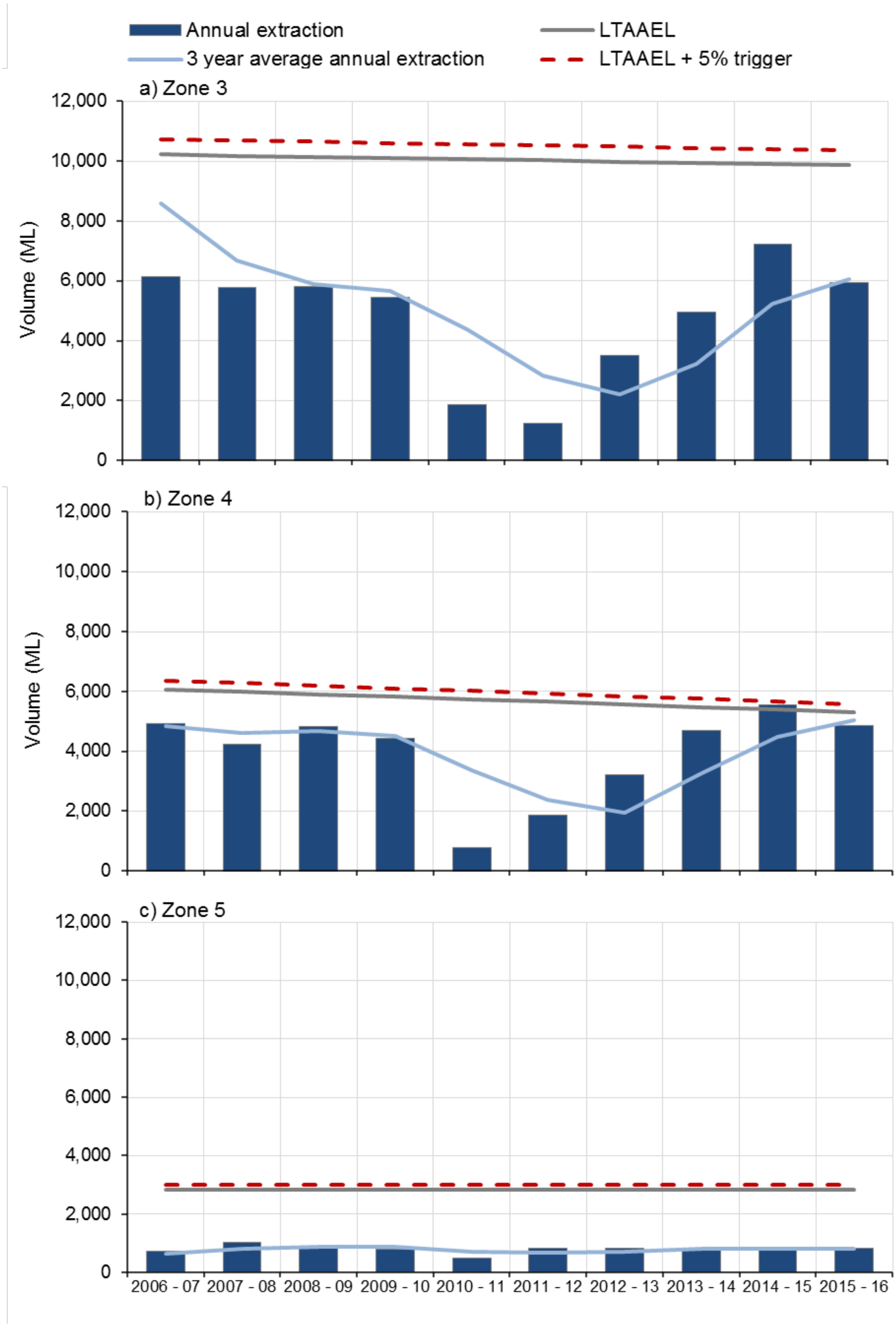

Figure 28 Lower Macquarie Groundwater Sources a) Zone 3 , b) Zone 4 and c) Zone 5 annual extraction as compared the to the LTAAEL since the commencement of the water sharing plan

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 licence.

The available water determination for high security aquifer access licences in the Cudgegong Alluvium Management Zone is linked to the available water determination for the high security regulated river licences. Since the commencement of the water sharing plan, the available water determination for aquifer access (high security) licences in the Cudgegong Alluvium has remained at 1 ML per share or 100% access.

The available water determination for supplementary water access licences (SWAL) in the Lower Macquarie Groundwater Sources was set by the water sharing plan for each year of the plan. Supplementary water access licence allocations decreased each year from 2006 – 2007 and became zero in 2015 – 2016. The allocations for each licence category in the Lower Macquarie Groundwater Sources Zones 1, 3 and 4 which had supplementary water access licences, for each year since commencement of the water sharing plan is shown in Figure 29.

For all resource units in this WRP area the available water determination for aquifer access licences has been set at 1 ML per share and for local water utility access licences has been set at 100% every year since the water sharing plan commenced.

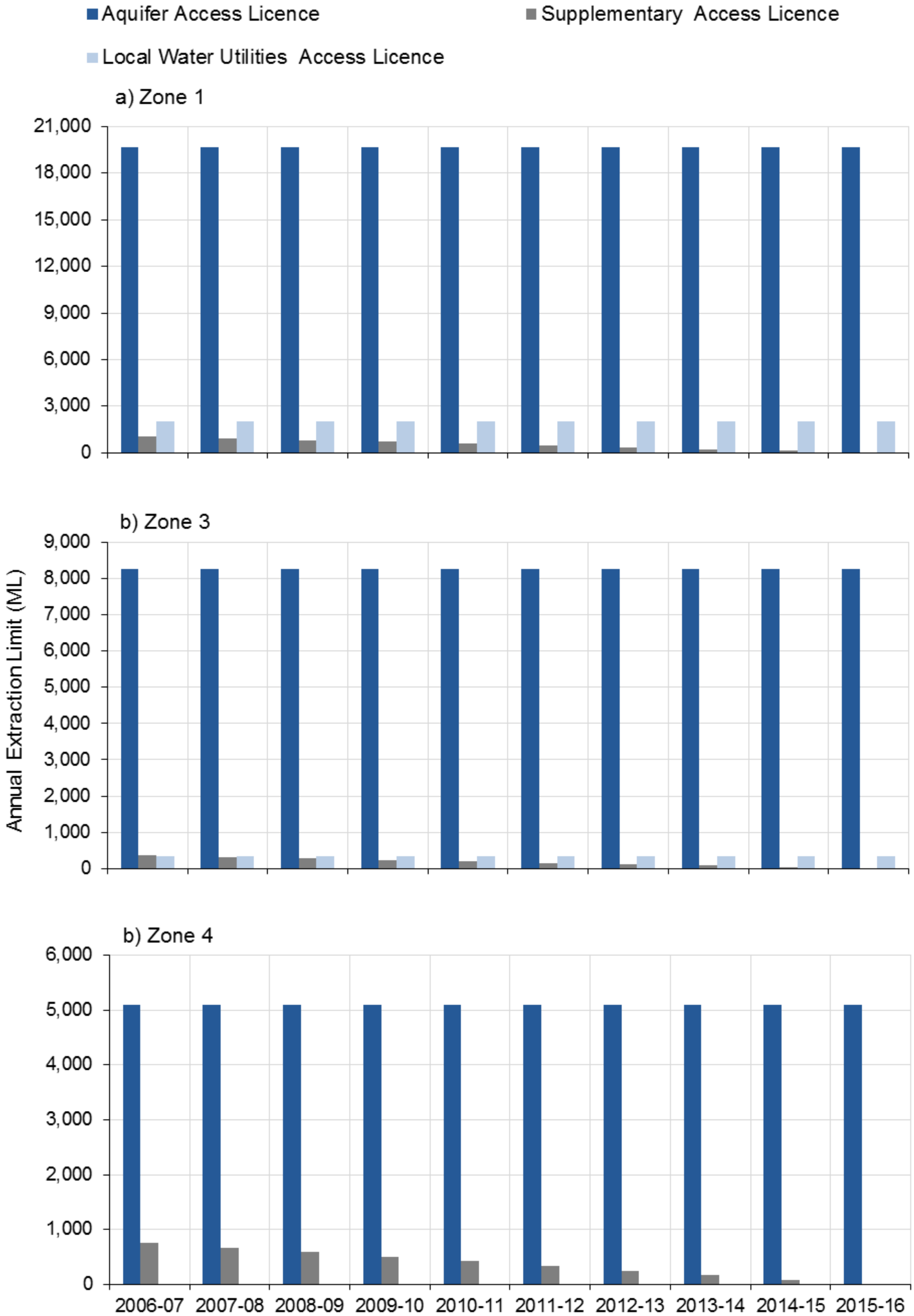

Figure 29 Annual allocations for the Lower Macquarie groundwater sources with supplementary licences

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.

There is no carryover of unused allocation permitted in the Bell Valley, Castlereagh, Coolaburragundy – Talbragar, Cudgegong and Upper Macquarie alluvial SDL resource units from one water year into the next. In these resource units, the maximum amount of water that can be debited from an access licence cannot exceed 1 ML per unit share component plus any allocation transferred in, and minus any allocation transferred out.

The water sharing plan for the Lower Macquarie Groundwater Sources allows carryover of unused allocation up to a maximum of 0.62 ML per unit of share component.

The maximum amount of water that can be debited from an access licence account in any one water year (i.e. account take limit in the Lower Macquarie Groundwater Sources) cannot exceed 1.44 ML per unit share component plus any allocation transferred in, and minus any allocation transferred out.

Figure 30 shows the volumes held in water accounts for the Lower Macquarie Alluvium resource unit (including the sandstone aquifers) since commencement of the water sharing plan.

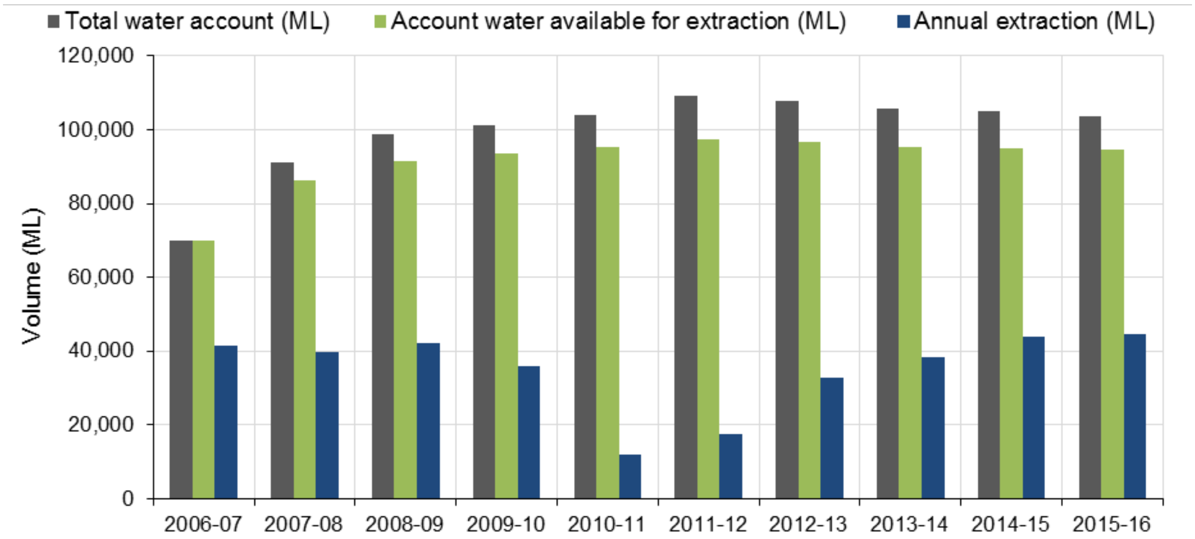

Figure 30 Water accounts since the commencement of the water sharing plan for all Lower Macquarie Zones.

8.5 Groundwater take

Groundwater is taken and used in the Macquarie – Castlereagh catchment for productive purposes such as irrigation and industry as well as for water supply for local water utilities and stock and domestic use. There are over 2,000 registered bores within the alluvial resource units within the Macquarie – Castlereagh water resource plan area. Overall the majority of bores are used for stock and domestic purposes (basic landholder rights) but this pattern varies between resource units (Table 6).

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

Table 6 Summary of registered bores, average extraction and reliance on groundwater for each SDL Resource Unit in the Macquarie – Castlereagh catchment (December 2016)

SDL Resource Unit	Production bores	Local Water Utility bores	Basic Landholder rights bores	Average annual extraction (2006 to 2016)[1.] (ML/year)
Bell Valley Alluvium	62	3	14	1,438
Castlereagh Alluvium	7	-	114	0
Coolaburragundy – Talbragar Alluvium	24	5	73	1,794
Cudgegong Alluvium	138	25	22	1,526
Lower Macquarie Alluvium[2.]	172	16	926	43,281
Upper Macquarie Alluvium	187	13	307	15,596
Total	590	62	1,456	63,635

[1] Average annual extraction from 2006 to 2016 or all years of data where records are shorter

[2] Includes Zones 1 – 6

8.5.1 Cudgegong Alluvium

In the Cudgegong Alluvium the number of production bores exceeds the number of bores used solely for domestic and stock purposes (Table 6).

Groundwater extraction in the Cudgegong Alluvium has been monitored since 2006 (Figure 31). Majority of bores are located around Mudgee (Figure 32). Figure 33 shows the distribution of average extraction over the last 10 years across the Cudgegong Alluvium. Extraction is denser in township of Mudgee and the upstream area. There are a number of registered production bores that do not actively extract groundwater throughout the resource unit.

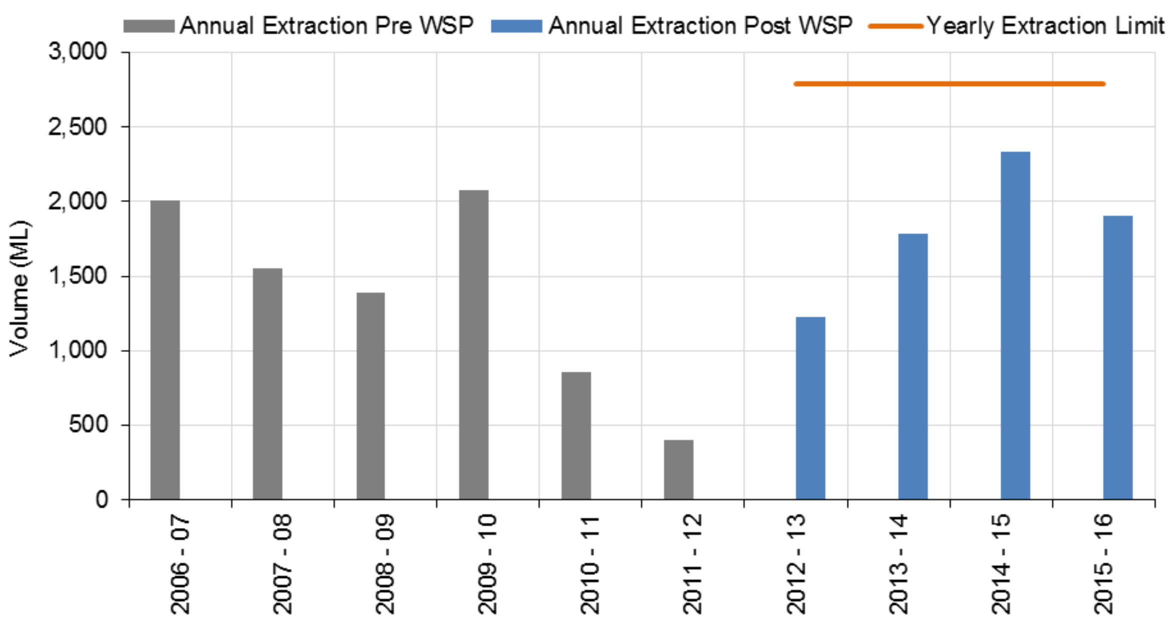

Figure 31 Recorded extraction for the Cudgegong Alluvium

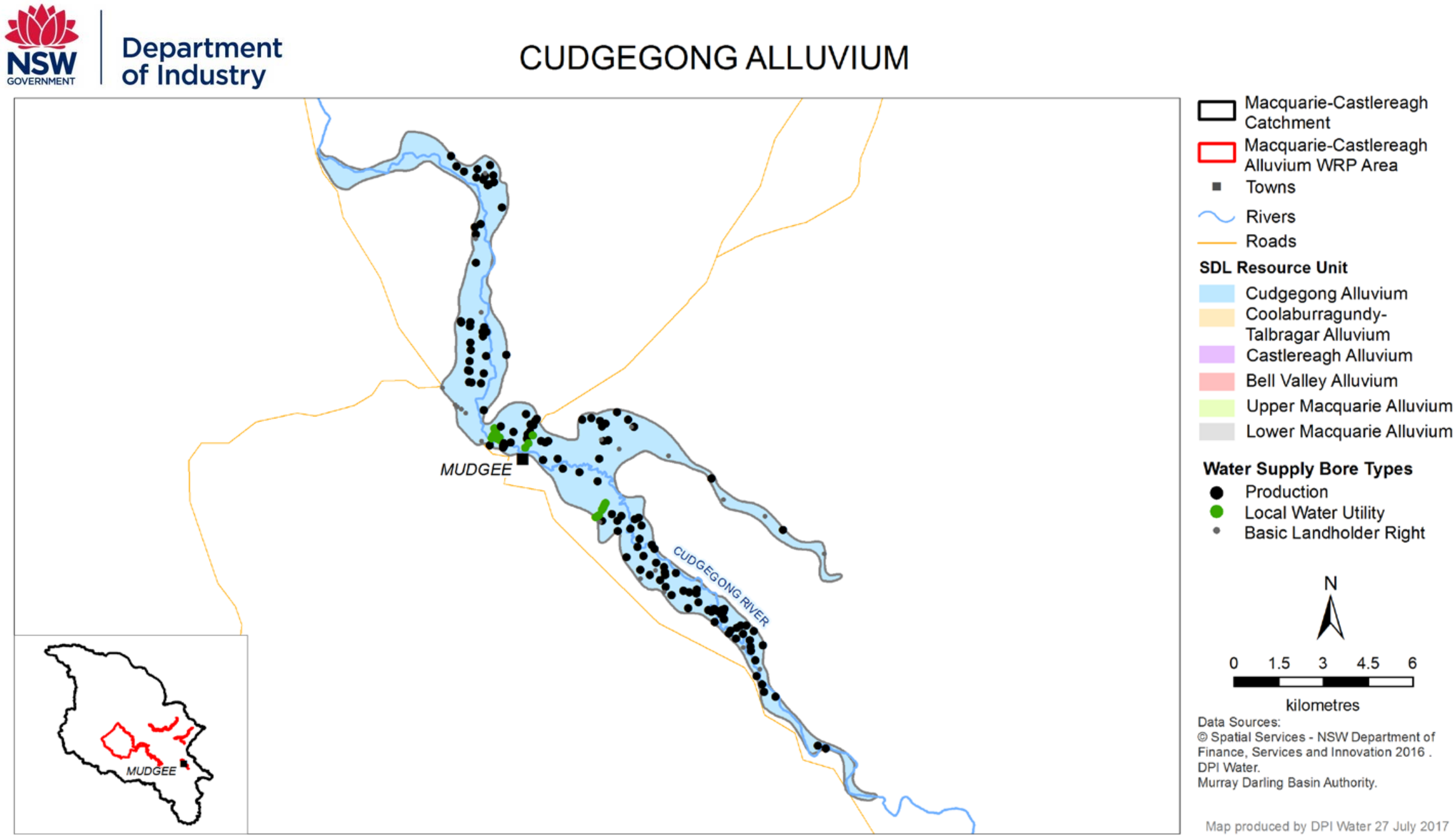

Figure 32 Registered bores in the Cudgegong Alluvium

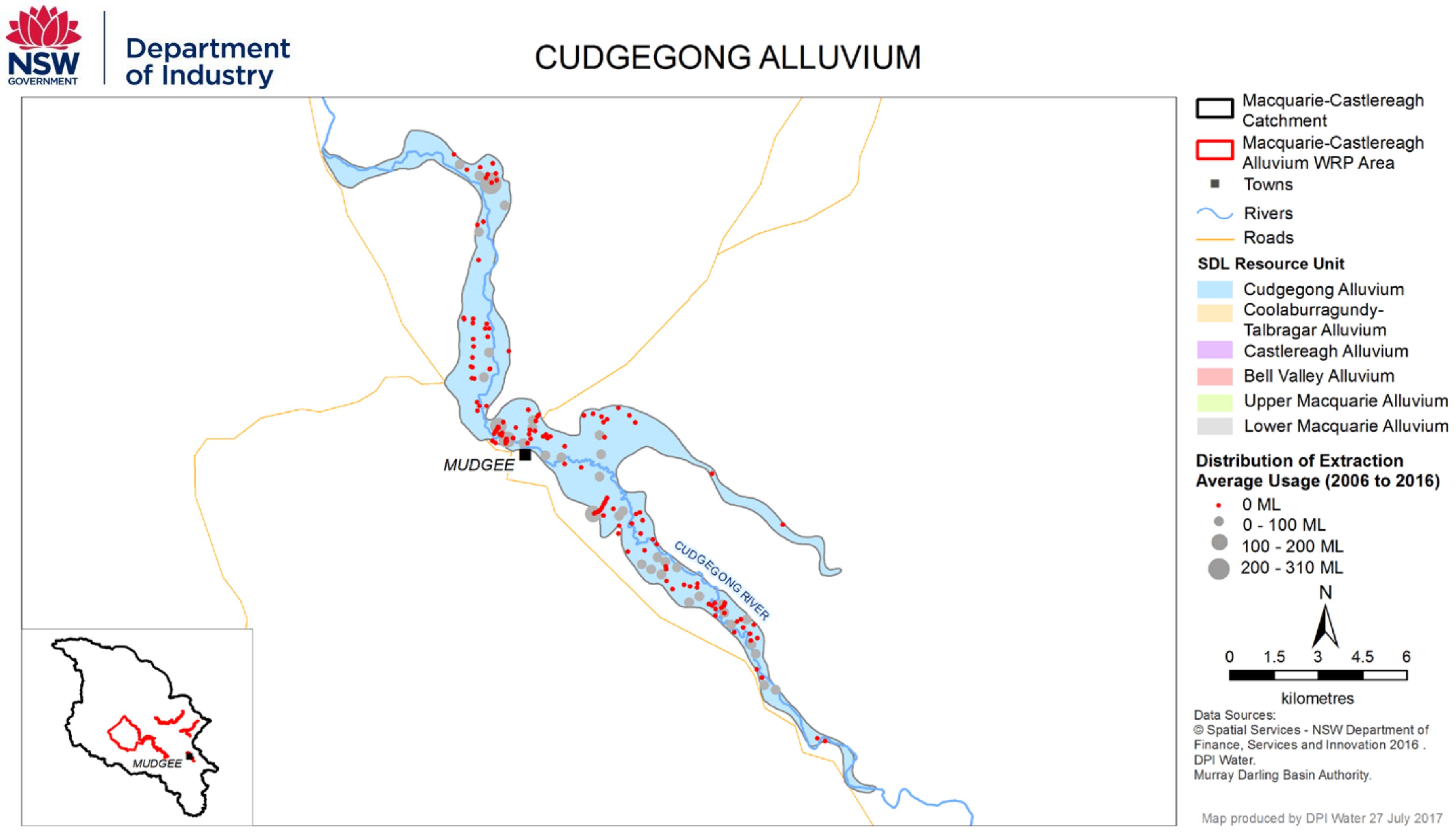

Figure 33 Distribution of extraction – average usage between 2006 to 2016

8.5.2 Coolaburragundy – Talbragar Alluvium

In the Coolaburragundy – Talbragar Alluvium the number of bores used for domestic and stock purposes outnumbers those used for licensed purposes (Table 6). The majority of production bores are located around the townships of Dunedoo and Coolah (Figure 35).

Groundwater extraction in the Coolaburragundy – Talbragar Alluvium has been monitored since 2008 (Figure 34). Figure 36 show the distribution of average extraction between 2008 – 2016 across the Coolaburragundy – Talbragar Alluvium. Extraction is most dense around the township of Dunedoo whilst there are a number of registered production bores that do not actively extract groundwater throughout the resource unit.

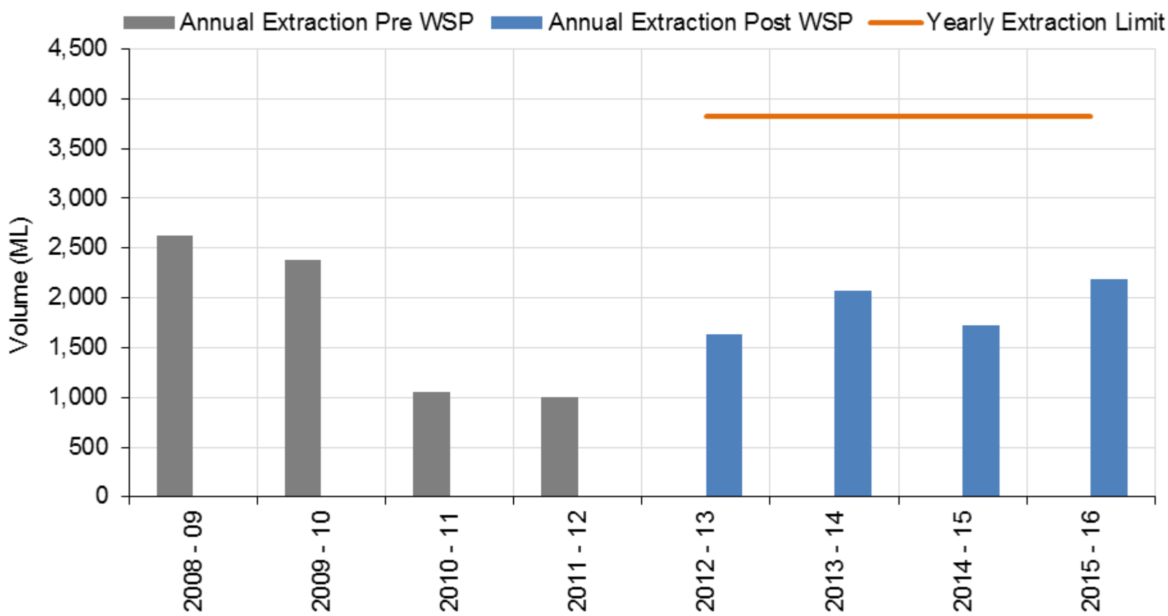

Figure 34 Recorded extraction for the Coolaburragundy – Talbragar

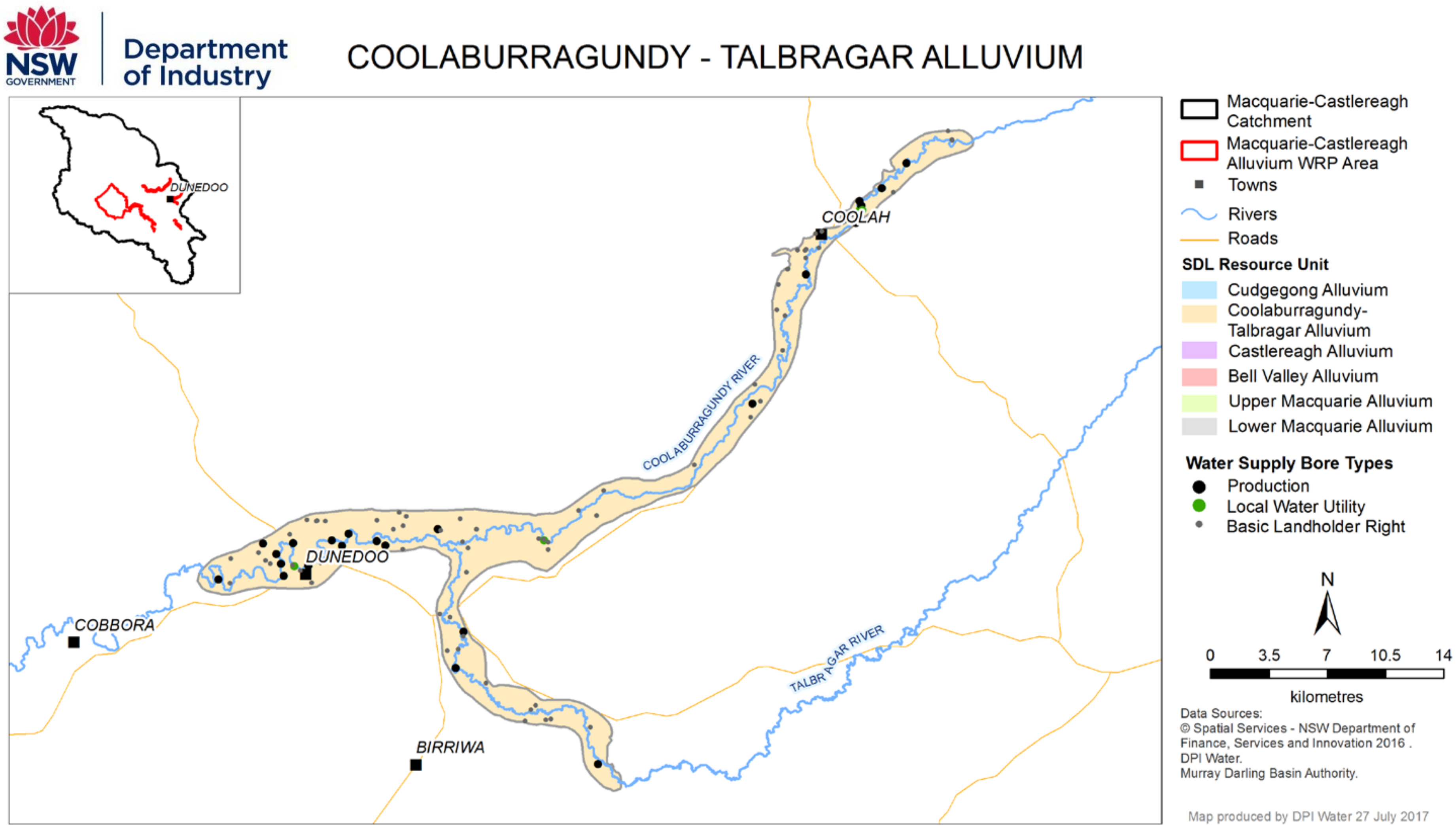

Figure 35 Registered bores in the Coolaburragundy - Talbragar Alluvium

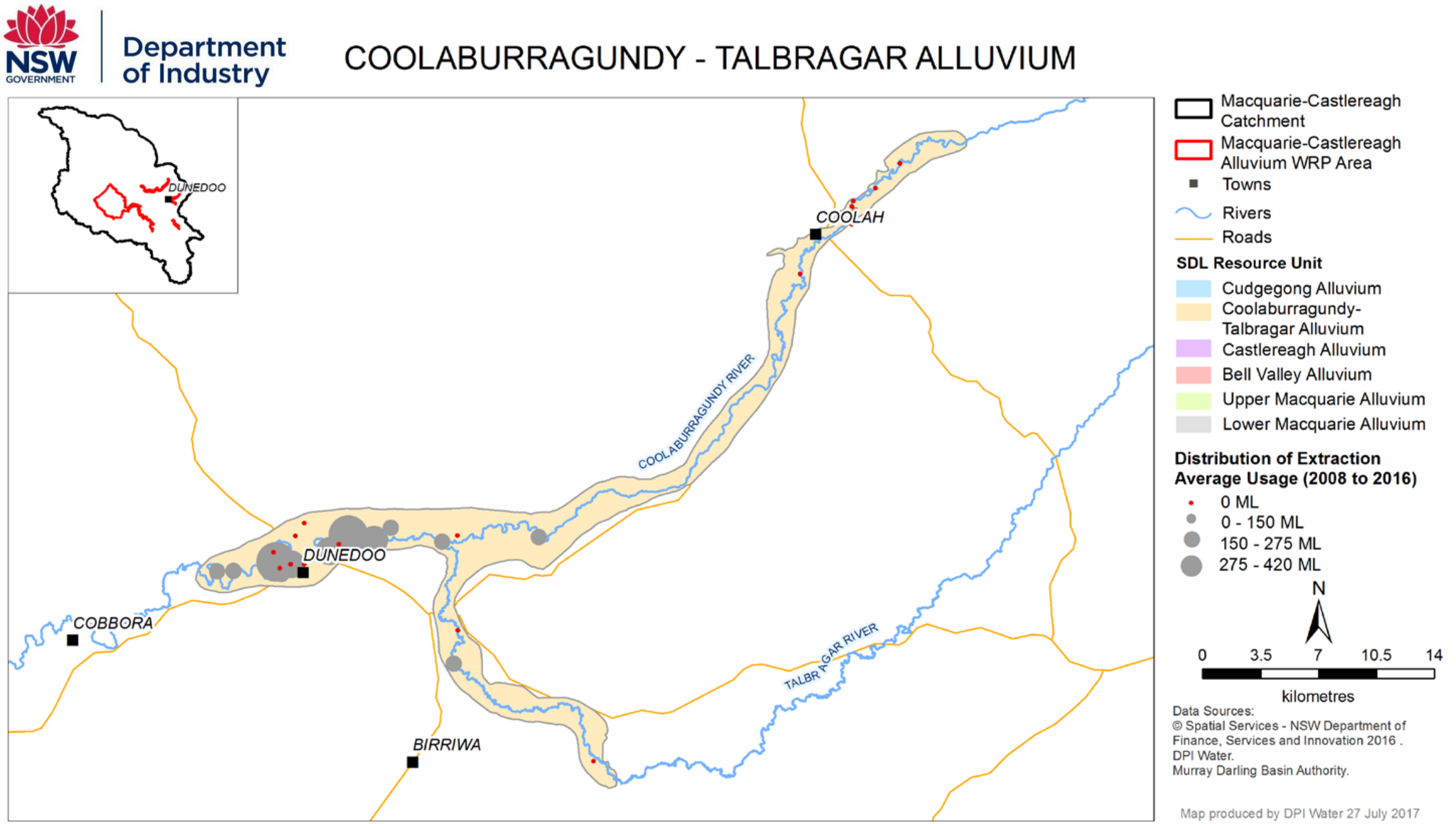

Figure 36 Distribution of extraction – average usage between 2008 to 2016 in the Coolaburragundy-Talbragar Alluvium.

8.5.3 Castlereagh Alluvium

In the Castlereagh Alluvium the number of bores used for domestic and stock purposes significantly outnumbers those used for licensed purposes (Table 6). The low groundwater yields associated with the alluvial aquifer limit large-scale groundwater development. The production bores that are within the Castlereagh Alluvium are spread throughout the resource unit (Figure 37).

There has been no recorded extraction in the Castlereagh Alluvium

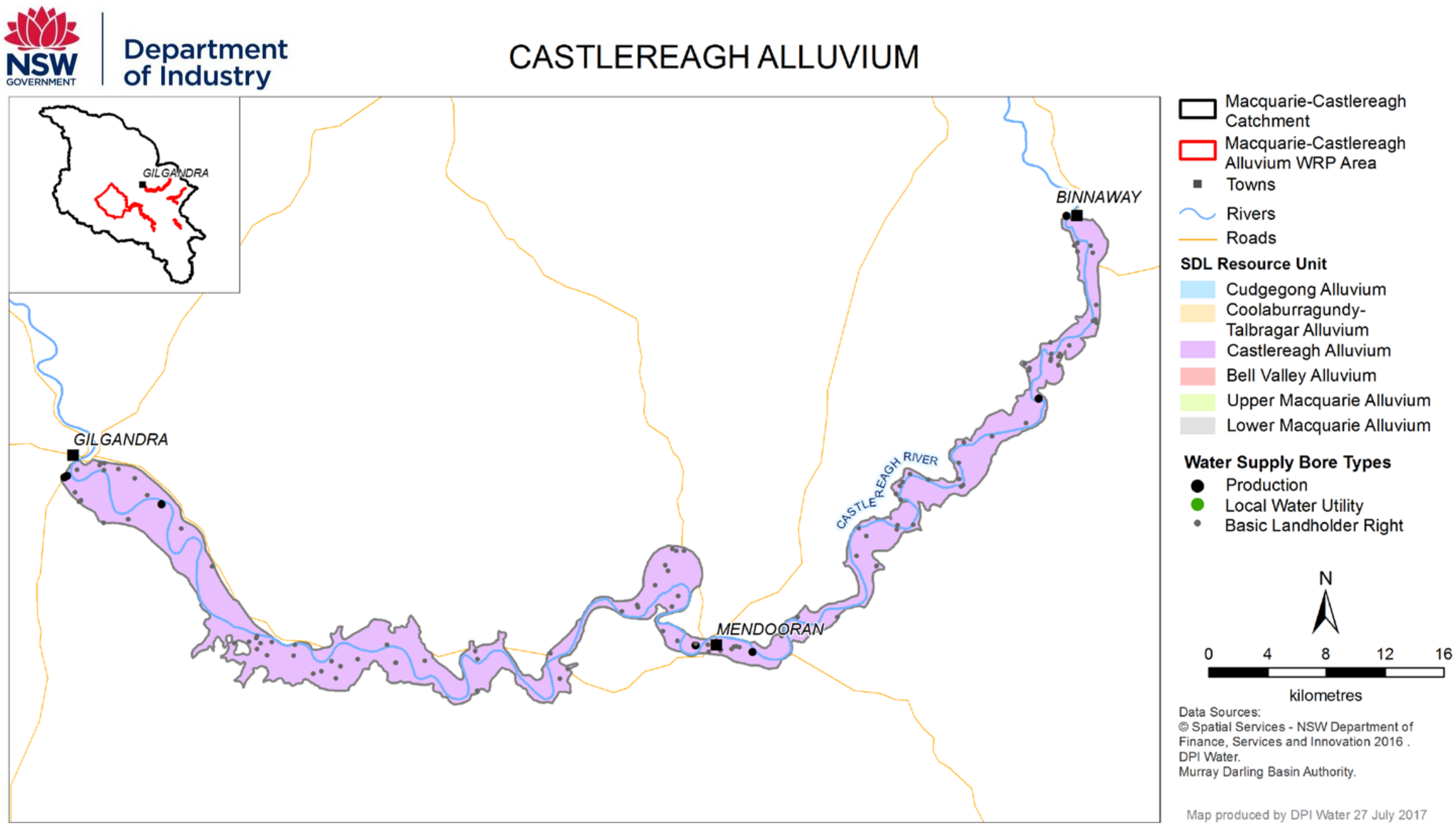

Figure 37 Registered bores in the Castlereagh Alluvium

8.5.4 Bell Valley Alluvium

In the Bell Valley Alluvium the number of production bores exceeds the number of bores used solely for domestic and stock purposes (Table 6).The majority of production bores are found in the lower valley where the alluvium is thicknest (Figure 39).

Groundwater extraction in the Bell Valley has been monitored since 2008 (Figure 38). Figure 40 shows the distribution of average extraction between 2008 - 2016 across the Bell Valley Alluvium. Extraction is more dense in the northern portion of the catchment. There are many registered production bores that do not actively extract groundwater.

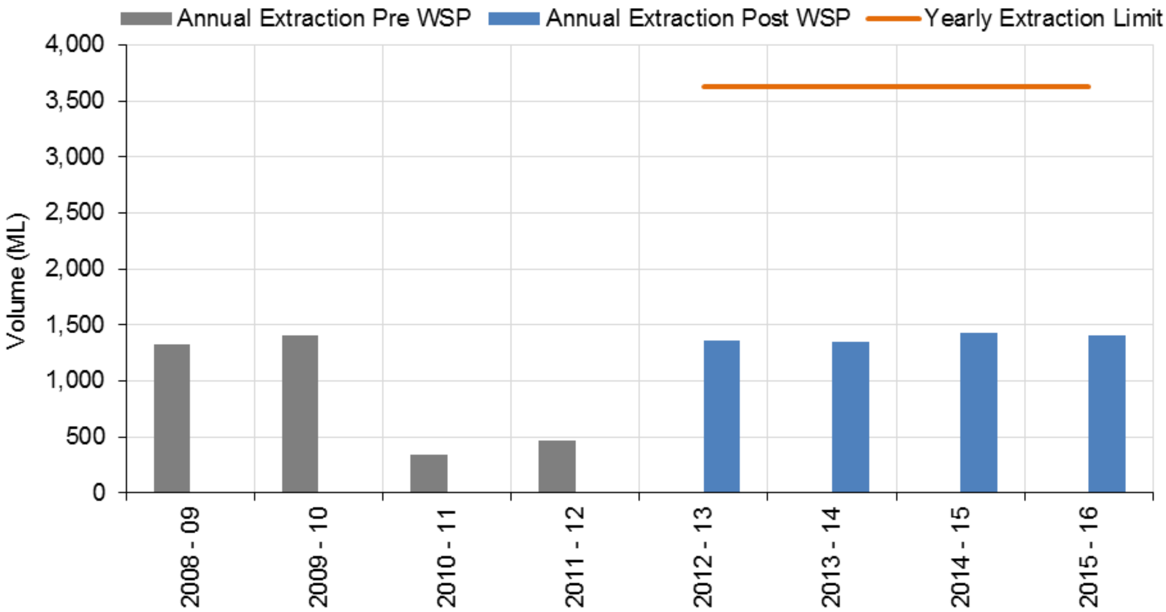

Figure 38 Recorded extraction for the Bell Valley Alluvium

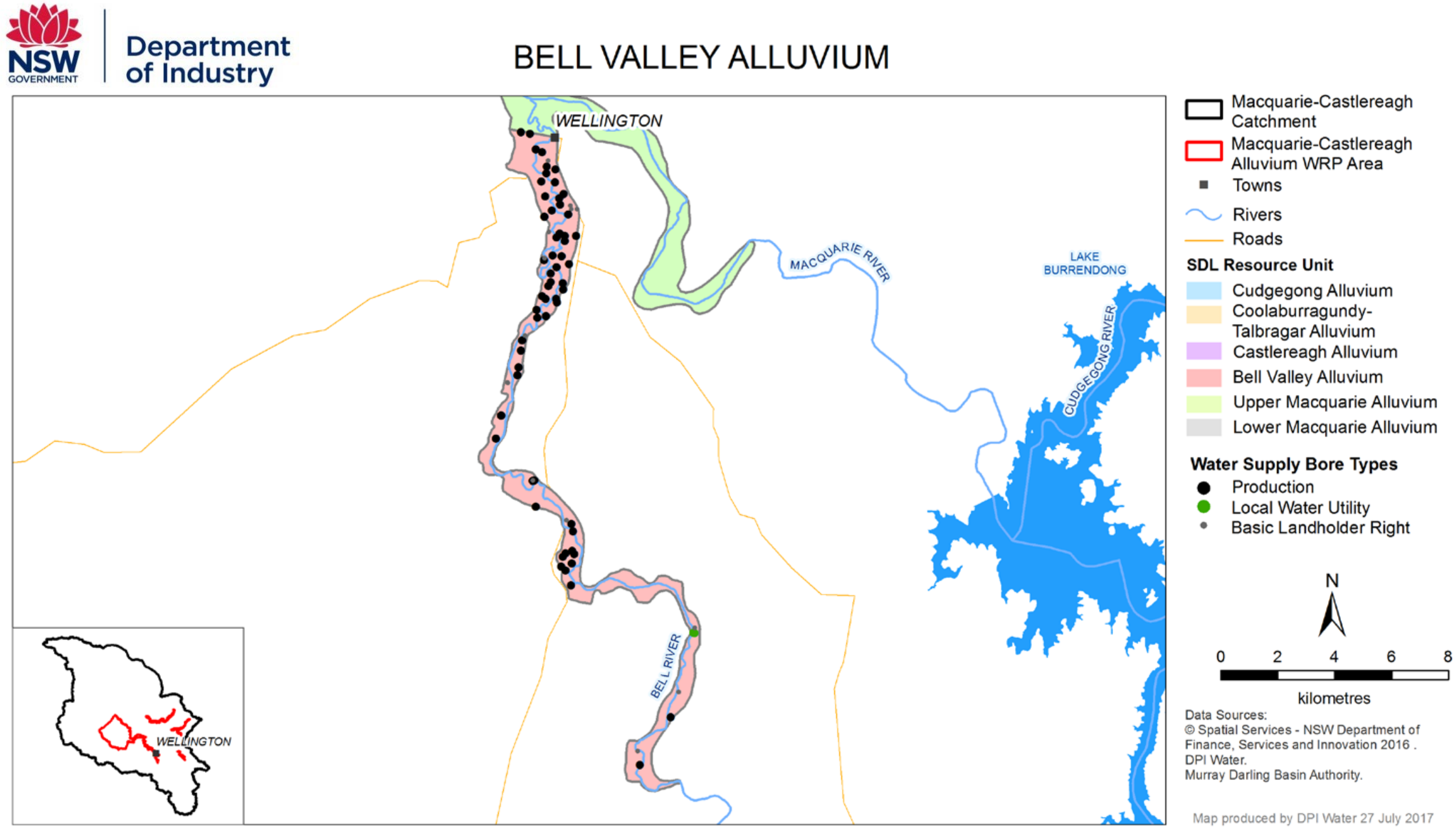

Figure 39 Registered bores in the Bell Valley Alluvium

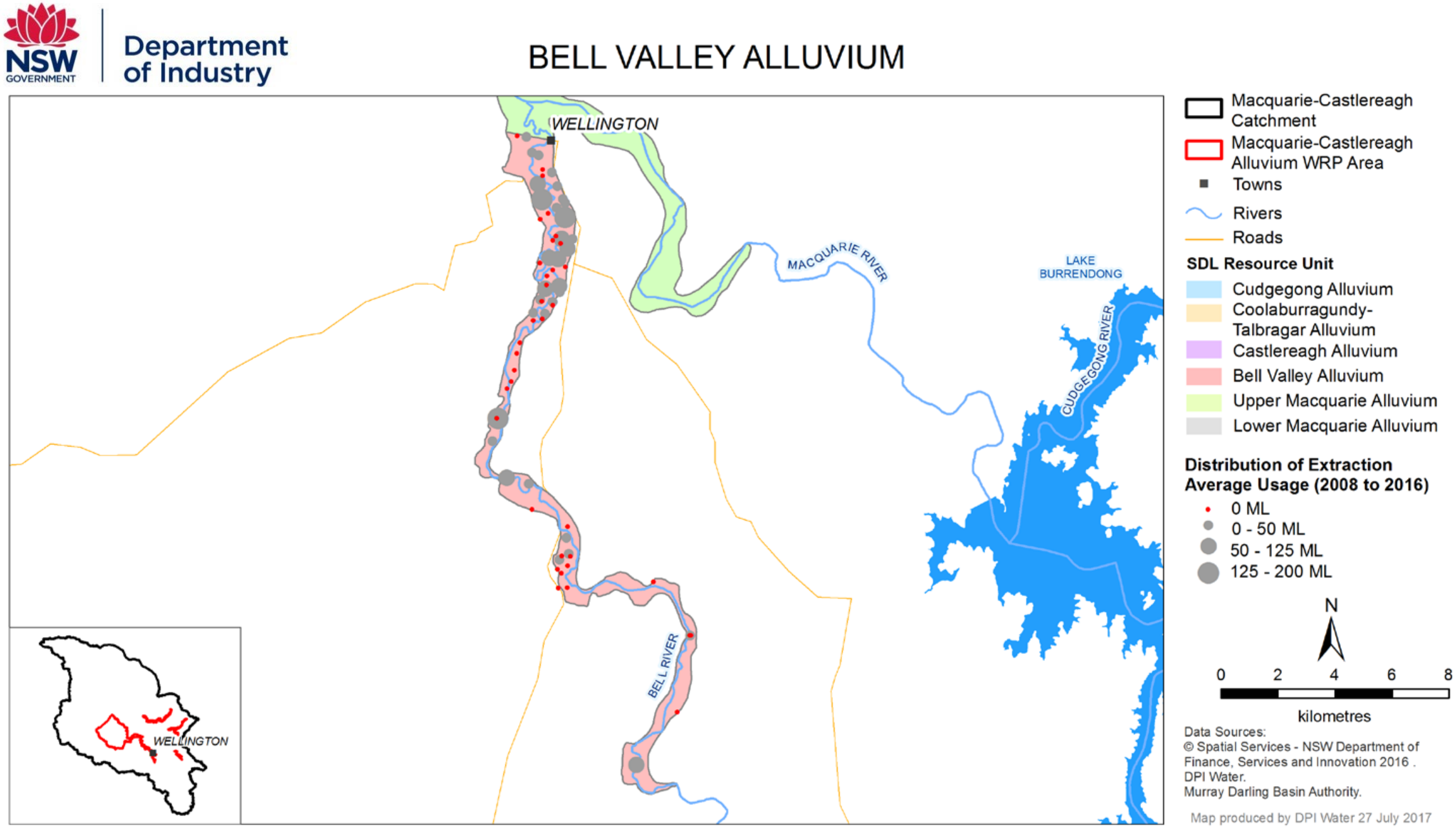

Figure 40 Distribution of extraction – average usage between 2008 to 2016 in the Bell Valley Alluvium

8.5.5 Upper Macquarie Alluvium

In the Upper Macquarie Alluvium the number of bores used for domestic and stock purposes outnumbers those used for licensed purposes (Table 6). The majority of production bores are located in the deeper alluvium particularly around the Dubbo region (Figure 42).

Groundwater extraction in the Upper Macquarie Alluvium has been monitored since 1999. (Figure 41). Figure 43 shows the distribution of average extraction over the last 10 years. Extraction is denser throughout the deep alluvium and in particular around the township of Dubbo. There are a number of production bores that do not actively extract groundwater throughout the resource unit.

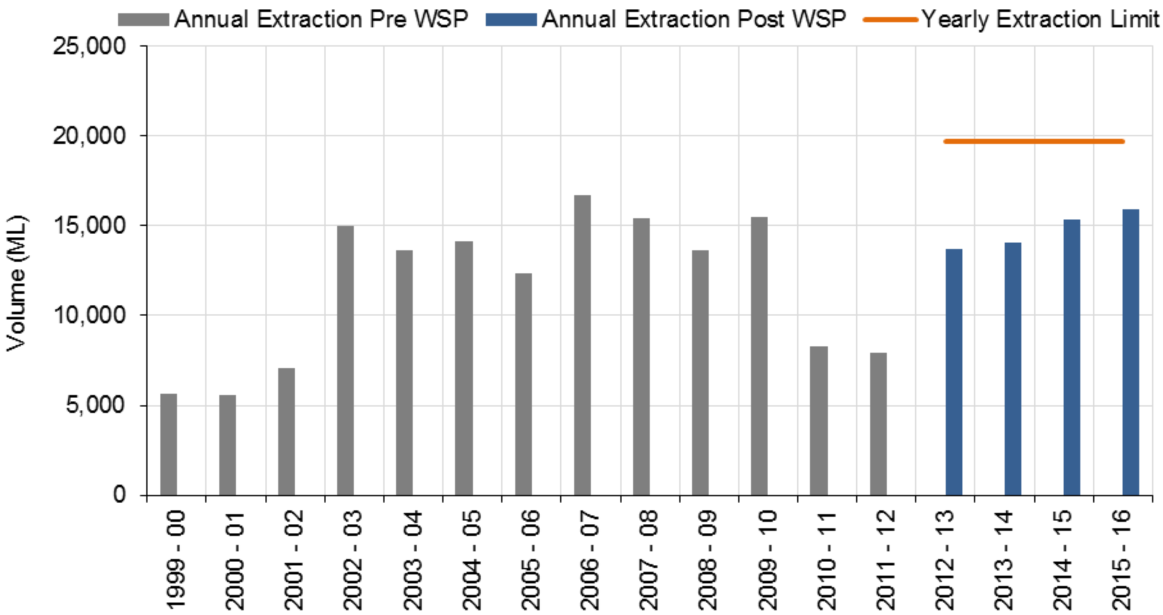

Figure 41 Recorded extraction for the Upper Macquarie

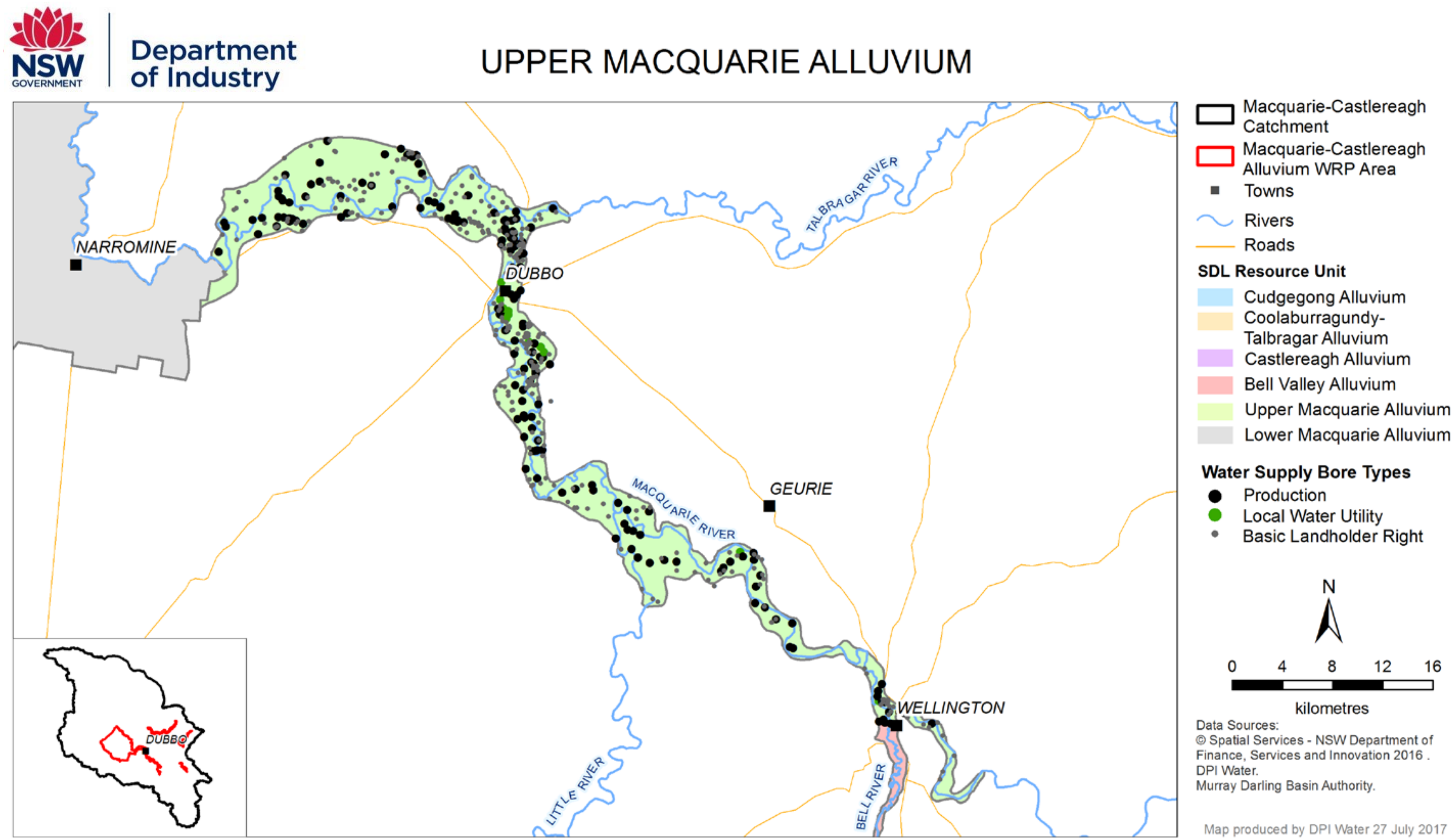

Figure 42 Registered bores in the Upper Macquarie Alluvium

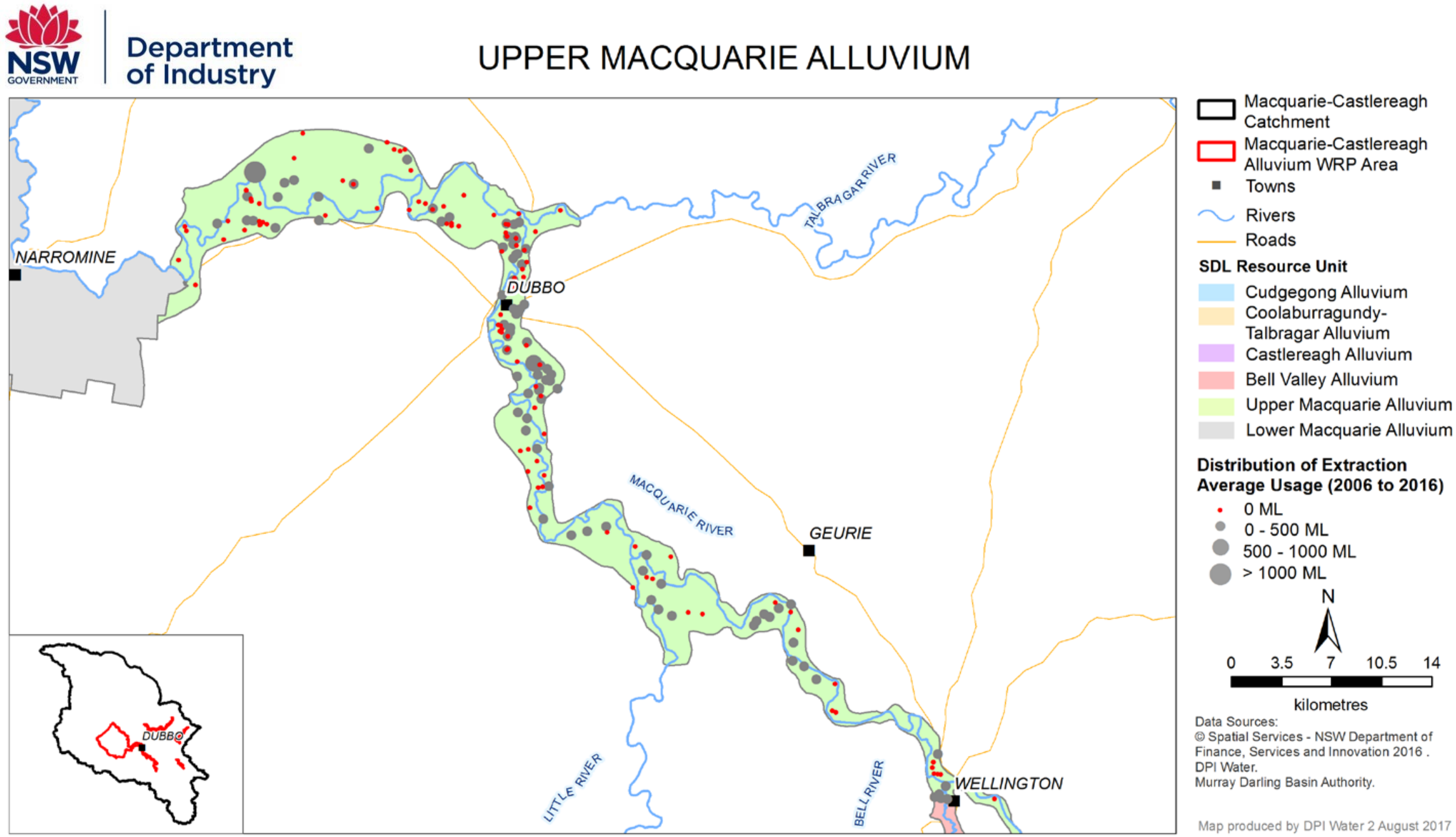

Figure 43 Distribution of extraction – average usage between 2006 to 2016

8.5.6 Lower Macquarie Alluvium

In the Lower Macquarie Alluvium and sandstone aquifers the number of bores used for domestic and stock purposes outnumbers those used for licensed purposes (Table 6). The majority of production bores are located in the deep alluvium between Narromine and Dandaloo where the alluvial aquifer is most productive (Figure 45).

Groundwater extraction in the Lower Macquarie Alluvium and sandstone aquifers has been monitored since 1999 (Figure 44). Figure 46 shows the distribution of average extraction over the last 10 years. Extraction is denser throughout the deep alluvium and in particular around the township of Narromine. There are a number of production bores that do not actively extract groundwater throughout the resource unit.

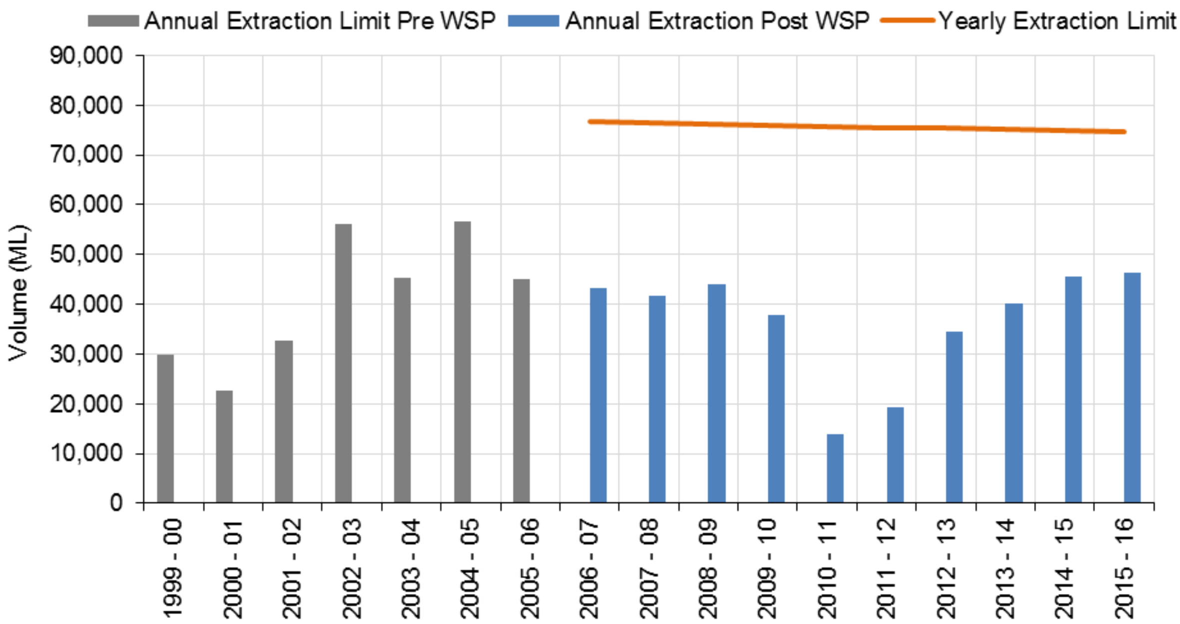

Figure 44 Recorded extraction for the Lower Macquarie

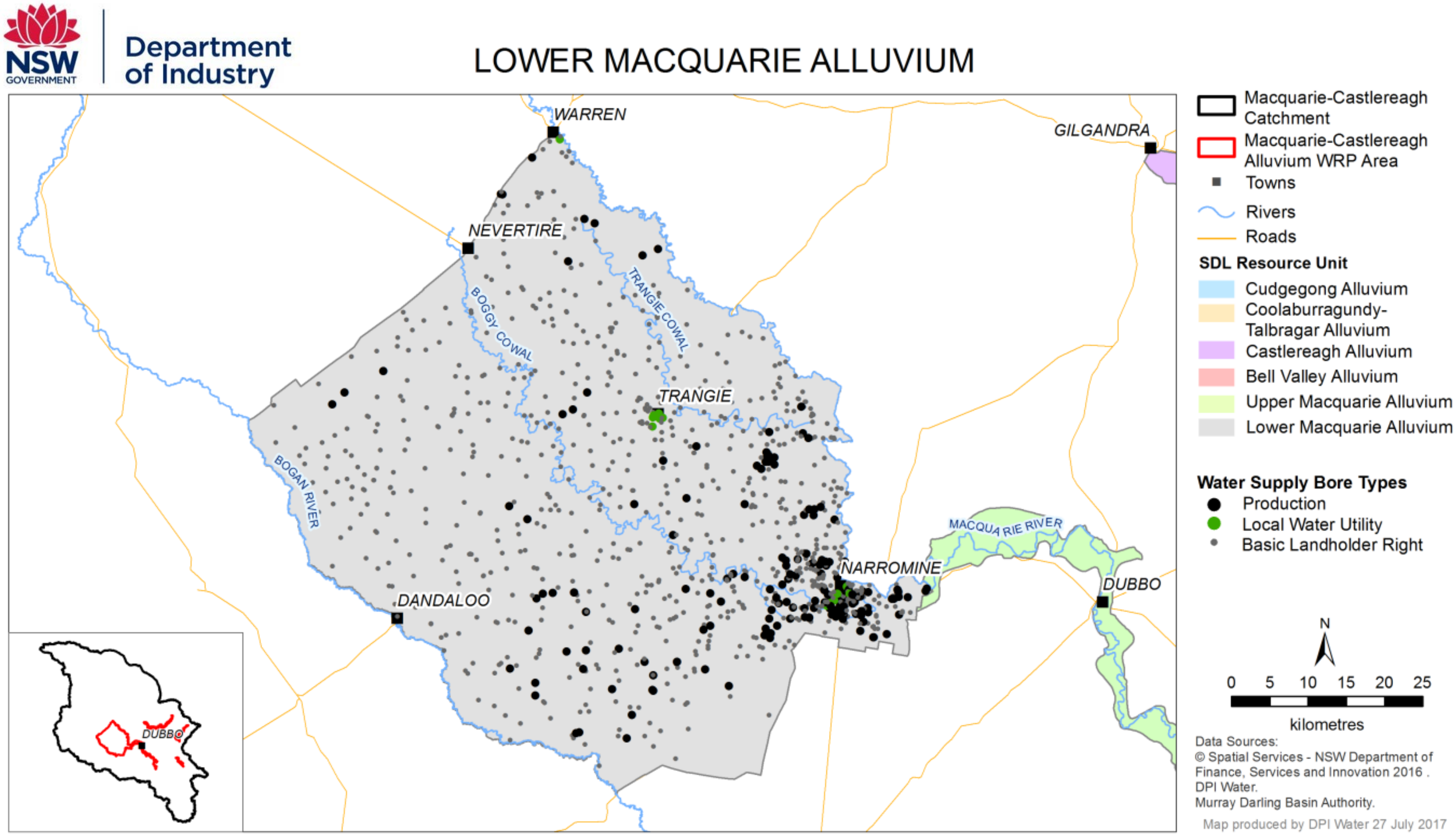

Figure 45 Registered bores in the Lower Macquarie Alluvium including the sandstone aquifers

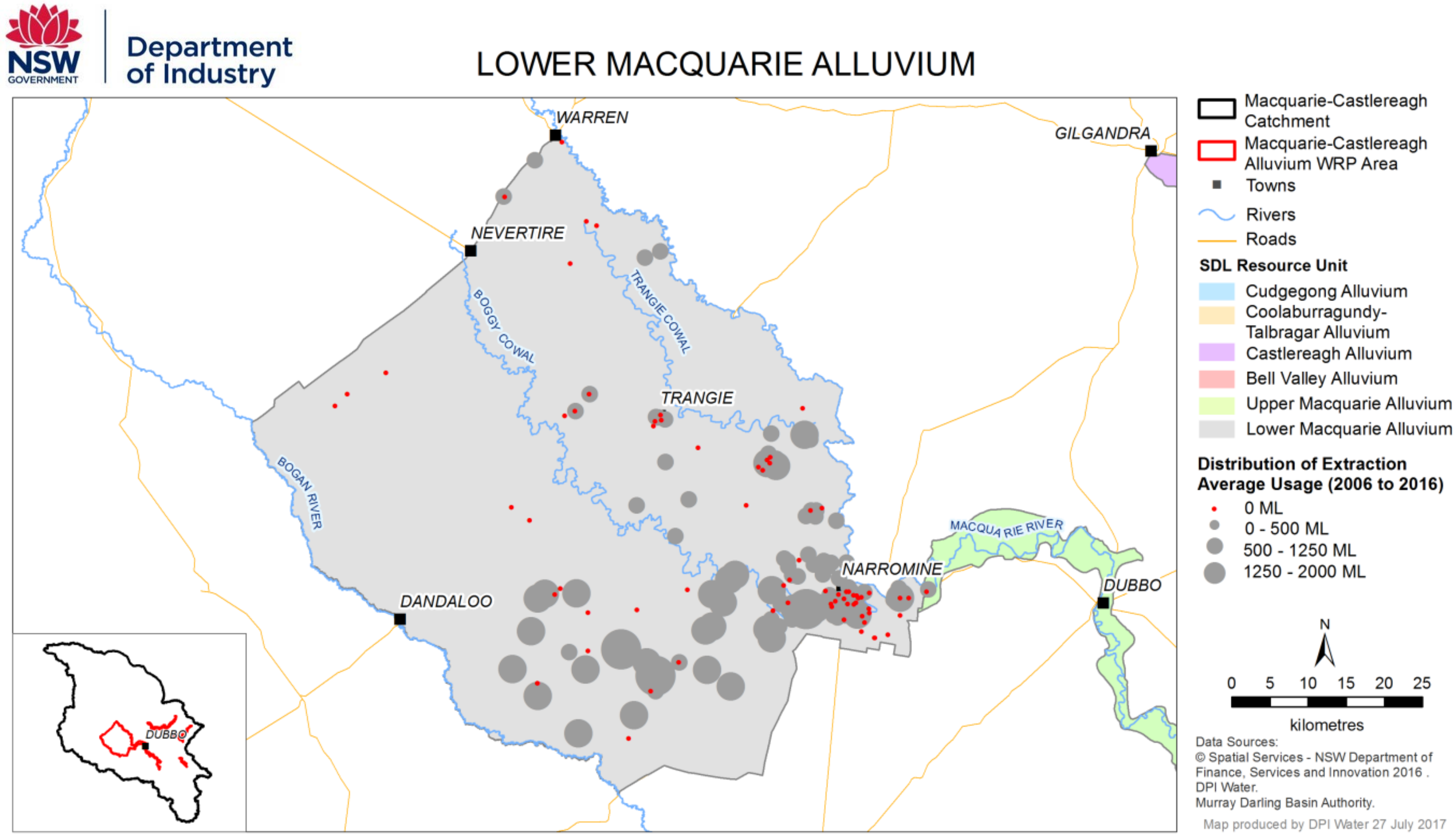

Figure 46 Distribution of extraction – average usage between 2006 to 2016 in the Lower Macquarie Alluvium including the sandstone aquifers

8.6 Groundwater dealings

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

Groundwater trade within the individual resource units of the Bell Valley, Castlereagh, Coolaburragundy – Talbragar and the Upper Macquarie Alluvium is permitted subject to hydrogeological assessment.

The Cudgegong Alluvial Groundwater Source has two management zones; the Cudgegong Alluvial Management Zone and the Lawsons Creek Alluvial Management Zone. Aquifer (high security) access licences within the Cudgegong Alluvial Management Zone are linked to the availability of Regulated River (high security) allocations whilst the Lawsons Creek Alluviual Management Zone access licence allocations are not dependent on flows in the unregulated Lawsons Creek. Trading between these management zones is not permitted.

There are six zones within the Lower Macquarie resource unit boundary that are managed as separate groundwater sources. Trading within and between the six groundwater sources is permitted subject to the dealing rules of the water sharing plan and hydrogeological assessment.

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 total volume of temporary trades worth greater than $1/ML for the Bell Valley Alluvium is shown in Figure 47 and the statistics for the business to business trades worth less than $1/ML are shown in Figure 48.

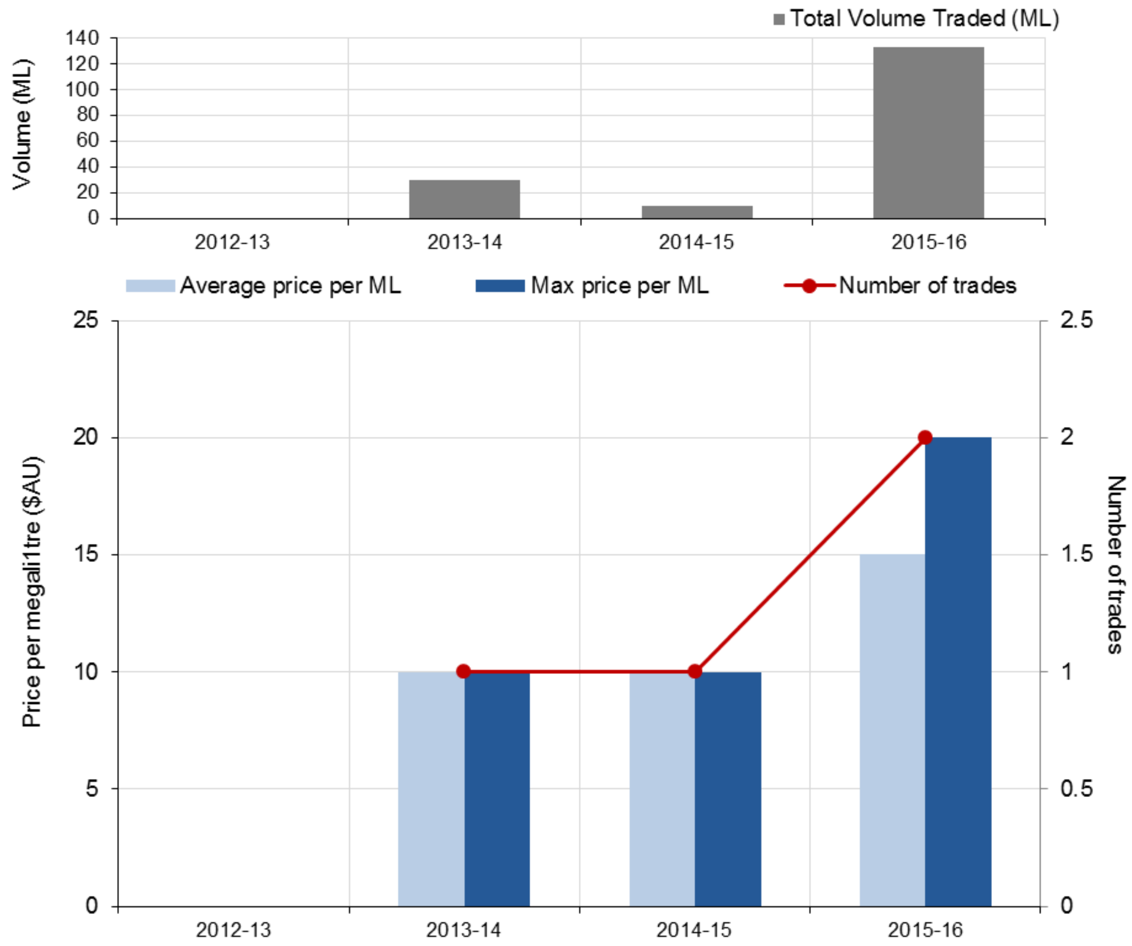

Figure 47 71T dealings statistics for the Bell Valley Alluvium since commencement of the water sharing plan

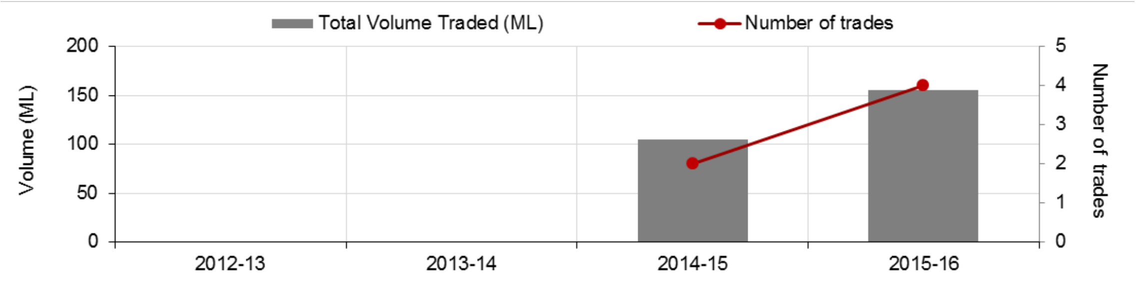

Figure 48 Bell Valley Alluvium < 1$/ML 71T dealings since commencement of the water sharing plan

Temporary dealings in the Bell Valley Alluvium are typically low in number, volume and price although there is an upward trend in all categories.

The total volume of temporary trades worth greater than $1/ML for the Upper Macquarie Alluvium is shown in Figure 49 and the statistics for the business to business trades worth less than $1/ML are shown in Figure 50.

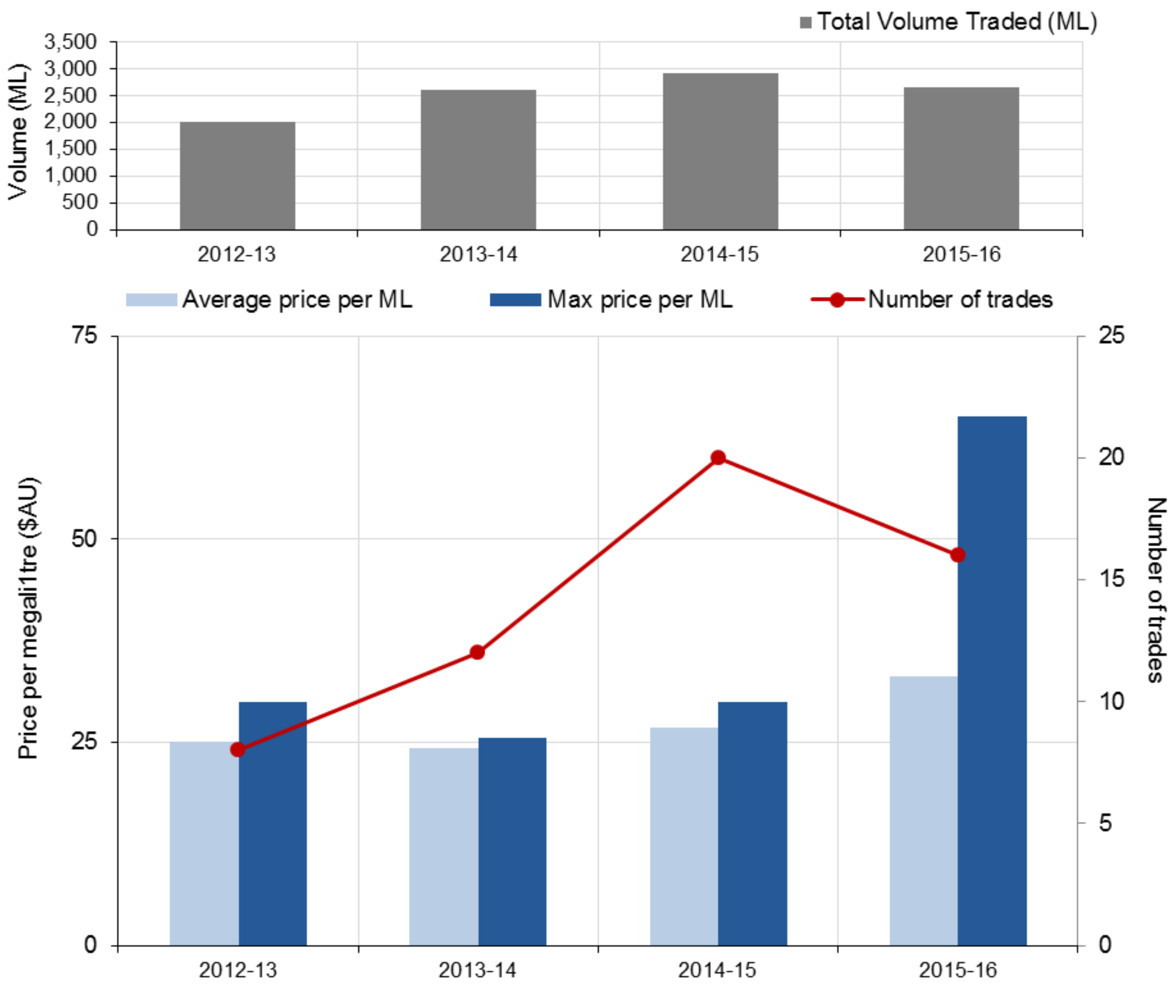

Figure 49 71T dealings statistics for the Upper Macquarie Alluvium since commencement of the water sharing plan

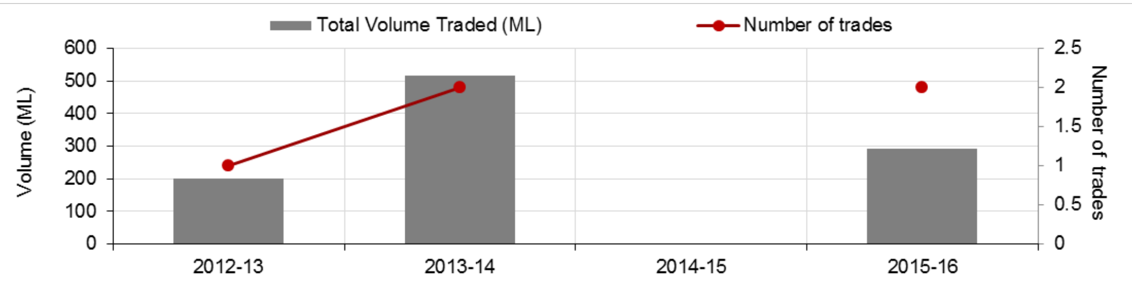

Figure 50 Upper Macquarie Alluvium < 1$/ML 71T dealings since commencement of the water sharing plan

Temporary dealings in the Upper Macquarie tend to be higher in number, volume and have a higher average price per mega litre than those in the Bell Valley Alluvium.

The total volume of temporary trades for the six Lower Macquarie Groundwater Sources is shown as a combined total in Figure 51 and the statistics for the business to business trades worth less than $1/ML are shown in Figure 52. No temporary trades took place in Zone 5 between 2006 and 2016.

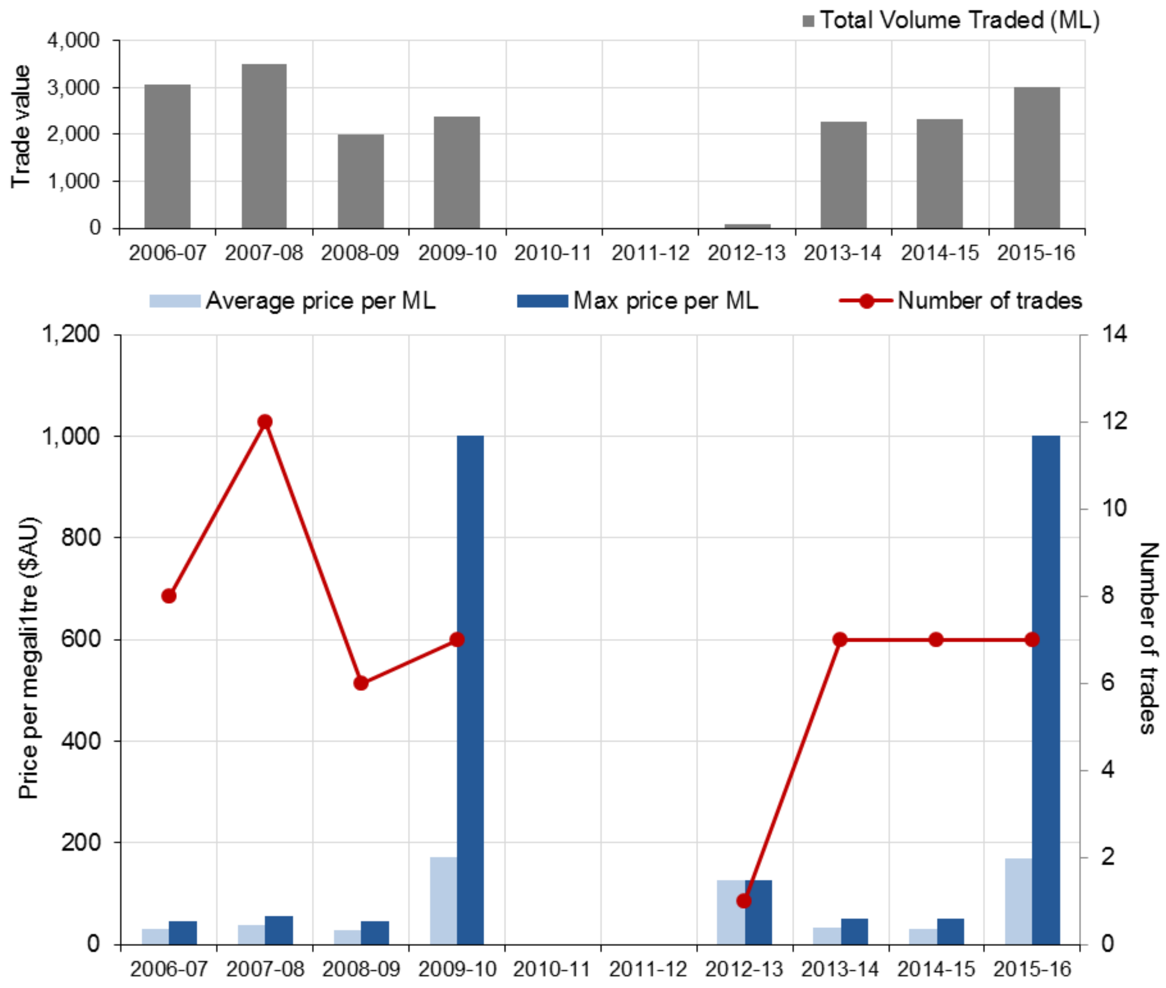

Figure 51 Combined 71T dealings statistics for Lower Macquarie Groundwater Sources since commencement of the water sharing plan

Zones 1, 2 and 3 are associated with the highest number and volume of trades whilst Zone 4 has the highest value trades on average.

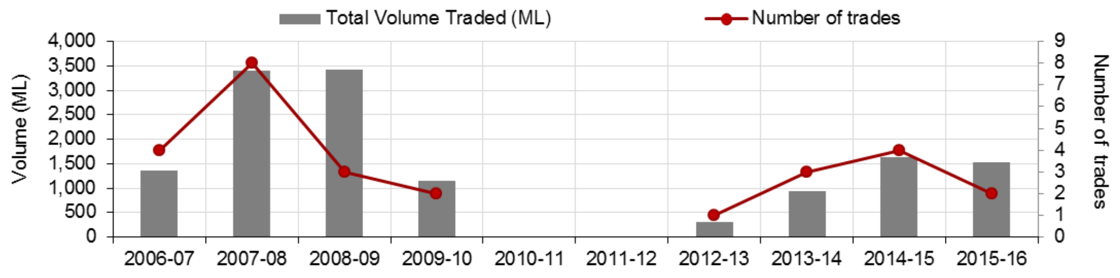

Figure 52 Lower Macquarie Groundwater Sources < 1$/ML 71T dealings since commencement of the water sharing plan

8.6.2 Permanent dealings

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

Dealings that can result in an increased volume being extracted from a work have the potential to cause third party impacts. These dealings 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 53 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 Bell Valley, Coolaburragundy – Talbragar, Cudgegong and Upper Macquarie Alluvium. Figure 54 shows the combined dealing statistics for the Lower Macquarie Groundwater Sources Zones except for Lower Macquarie Zone 3 where no such dealings took place.

71M dealings are not included in Figure 53 and Figure 54 as these are a change in ownership only and therefore have no potential for additional; third party impacts. 71P(a) dealings are also not included as they involve a subdivision of entitlement that results in works being linked to lesser volumes. There have been no 71P(b) dealings (consolidation) in the above-mentioned resource units.

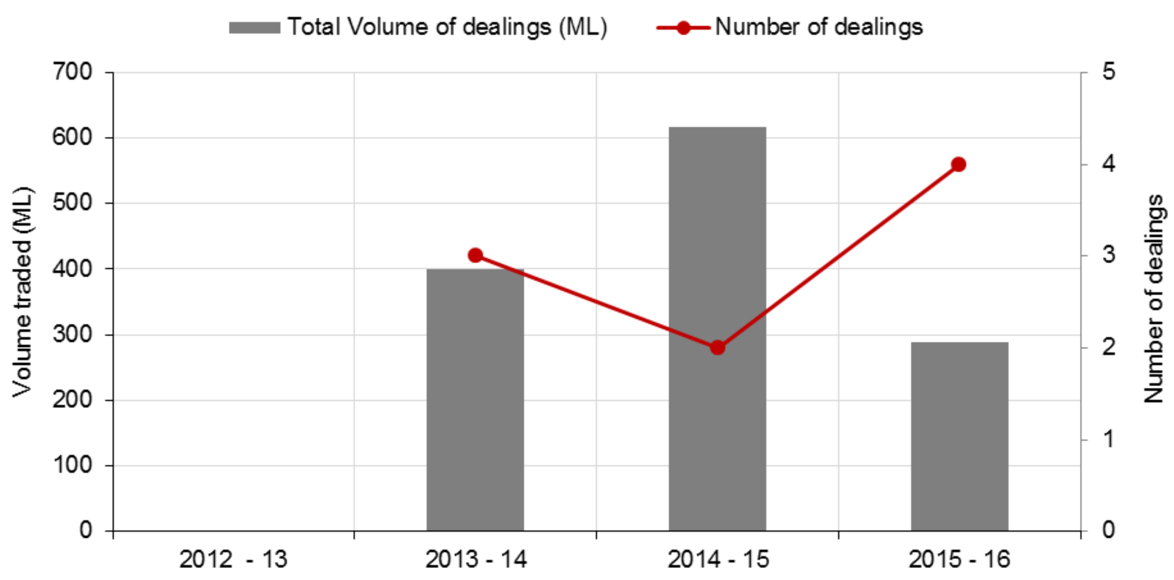

Figure 53 Combined dealing statistics from the Bell Valley, Coolaburragundy – Talbragar, Cudgegong and Upper Macquarie Alluvium resource units that resulted in an increase in shares linked to a work or approval since the commencement of the water sharing plan, 71M and 71P(a) dealings not included.

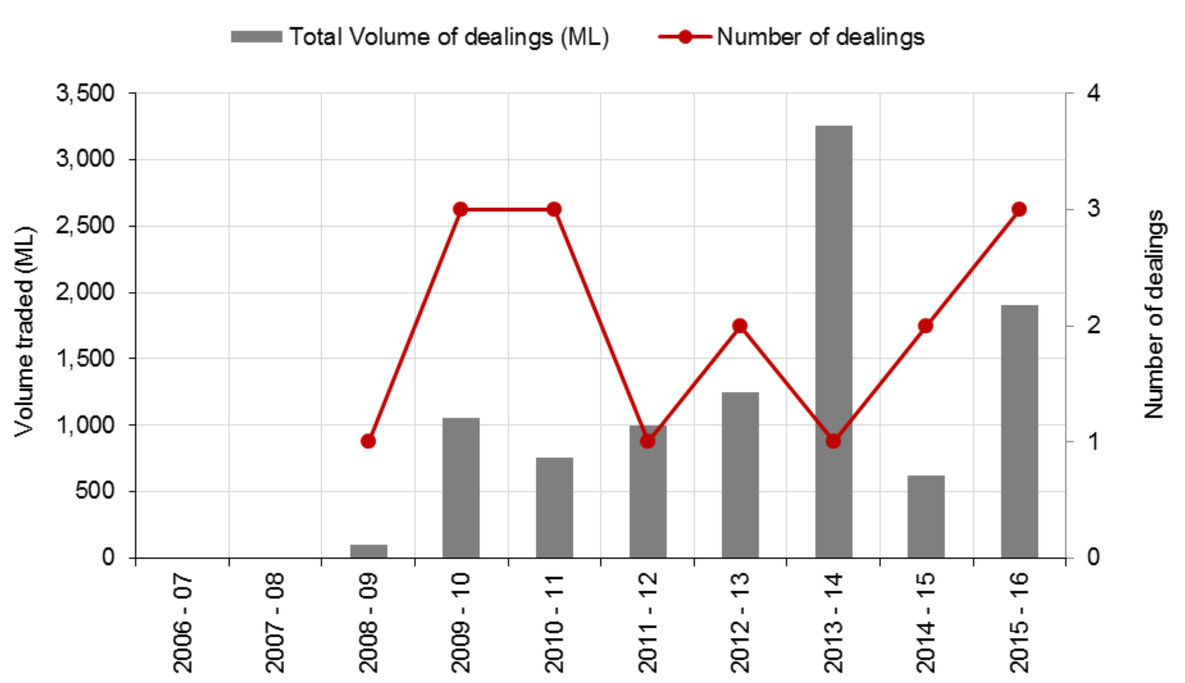

Figure 54 Combined dealing statistics from the Lower Macquarie Groundwater Sources Zones

Trends in permanent dealings are less influenced by short term climatic variances and are more dependent on individual long term business planning.

To date there have been no applications for any type of permanent dealing in the Castlereagh Alluvium or Lower Macquarie Zone 3 Groundwater Source.

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 55 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.

Figure 55 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.

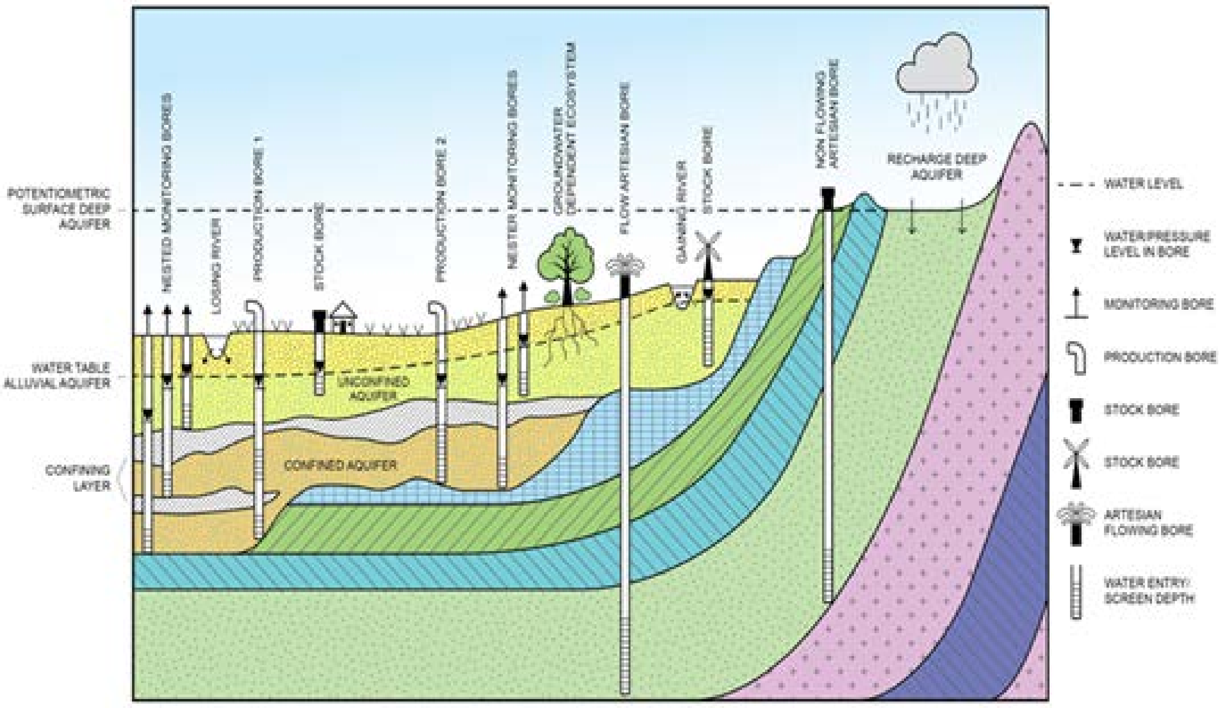

Figure 55 Schematic diagram of different types of aquifers

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 55 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 Macquarie – Castlereagh Alluvium, there are 245 monitoring bores at 170 sites (Figure 80 to Figure 85, Appendix A).Groundwater levels have been monitored as early as 1968 and 1969 in the Upper Macquarie and Lower Macquarie alluvial resource units. The Cudgegong and Castlereagh alluvial resource units also have a long continuous record of measurement with monitoring commencing in the 1970s. The Coolaburragundy – Talbragar and the Bell Valley alluvial resource unit were monitored later with records commencing in 2001 and 2010 respectively.

The manually monitored sites are typically read four to six times a year. Real time water level data are available for 53 monitoring bores at 38 sites via telemetry from: *http://realtimedata.water.nsw.gov.au/water.stm*

10 Groundwater behaviour

10.1 Introduction

For the alluvial resource units within the Macquarie – Castlereagh catchment, monitoring bores constructed and screened less than 25 - 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 intermediate to deep semi confined/confined aquifer system.

The reference condition to which long term trends are compared is the 'pre-development' water level. The 'pre-development' period varies between water sources and can be influenced by the monitoring record in the area. Changes in groundwater levels for each of the alluvial resource units in the Macquarie – Castlereagh are discussed in the following sections presenting data from hydrographs and groundwater head maps.

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (Figure 56). 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 56 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.

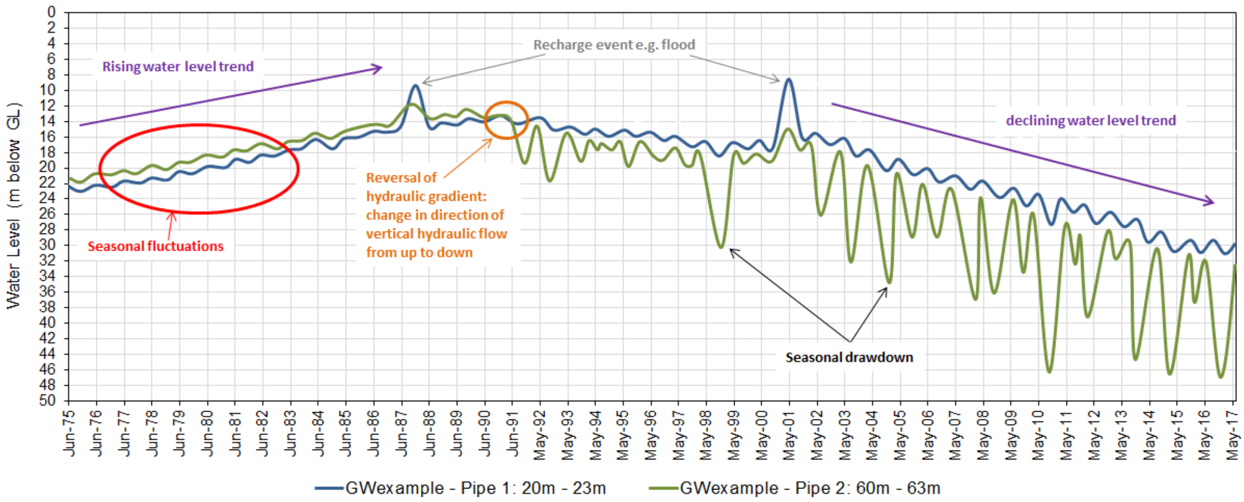

Figure 56 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate.

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

In areas where groundwater extraction occurs, hydrographs show a seasonal cyclic pattern of drawdown and recovery. Drawdown is the maximum level to which groundwater is lowered in a bore due to pumping. It is followed by recovery when pumping has ceased or reduced.

Review of the recovered groundwater level over time can be used to assess how a groundwater system is responding to climate and pumping impacts in the long term. The recovered groundwater level is the highest point to which groundwater has risen in a particular year.

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

10.2 Review of groundwater levels

Representative hydrographs for each of the alluvial resource units in the Macquarie – Castlereagh catchments have been presented below. The location of these sites is highlighted on the maps in Appendix B.

10.2.1 Cudgegong Alluvium

The rapid responses of the water table shown in Figure 57 highlight the connectivity between the Cudgegong Alluvium and the Cudgegong River. The quick responses to the river conditions become more pronounced once the monitoring site had a telemetered data logger instrumentation installed in 2004, recording frequent water level data for over ten years.

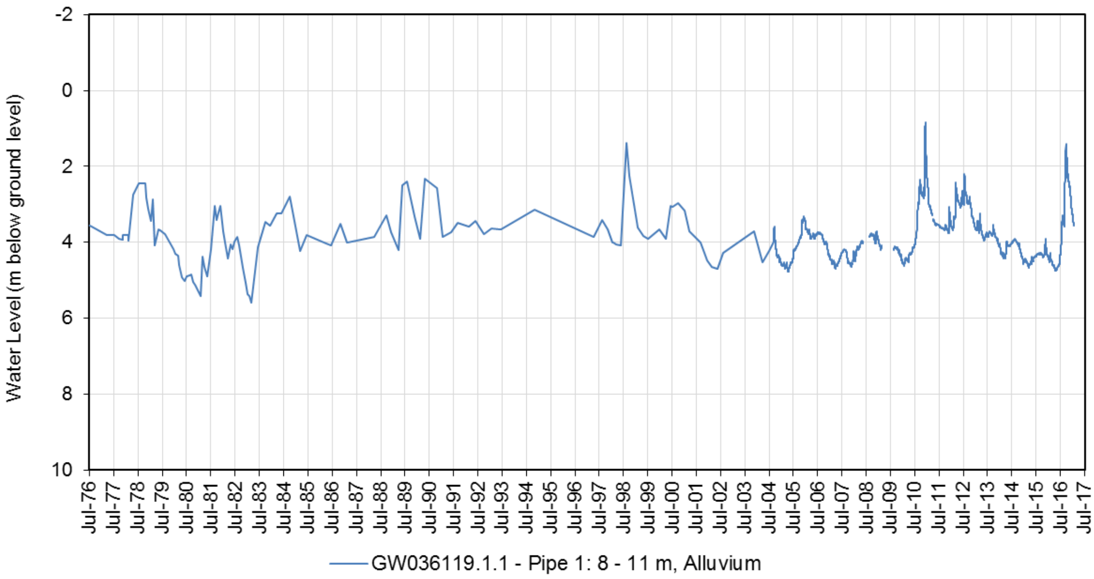

Figure 57 Hydrograph for monitoring site GW036119 – near the Mudgee cross-section

10.2.2 Coolaburragundy – Talbragar Alluvium

Monitoring site GW096124 has two pipes located in the Talbragar alluvium at different depths. Both pipes have been equipped with a telemetered data logger since 2015 which allows a finer analysis of the aquifers response to pumping and climatic variances. Figure 58 highlights the deeper aquifer's response to groundwater extraction. These seasonal oscillations are not observable in the shallow aquifer, indicating a degree of hydraulic separation. Although there is some hydraulic separation, the shallow aquifer reflects the recovery level in the deep aquifer. There is a downward gradient present from the shallow aquifer to the deep.

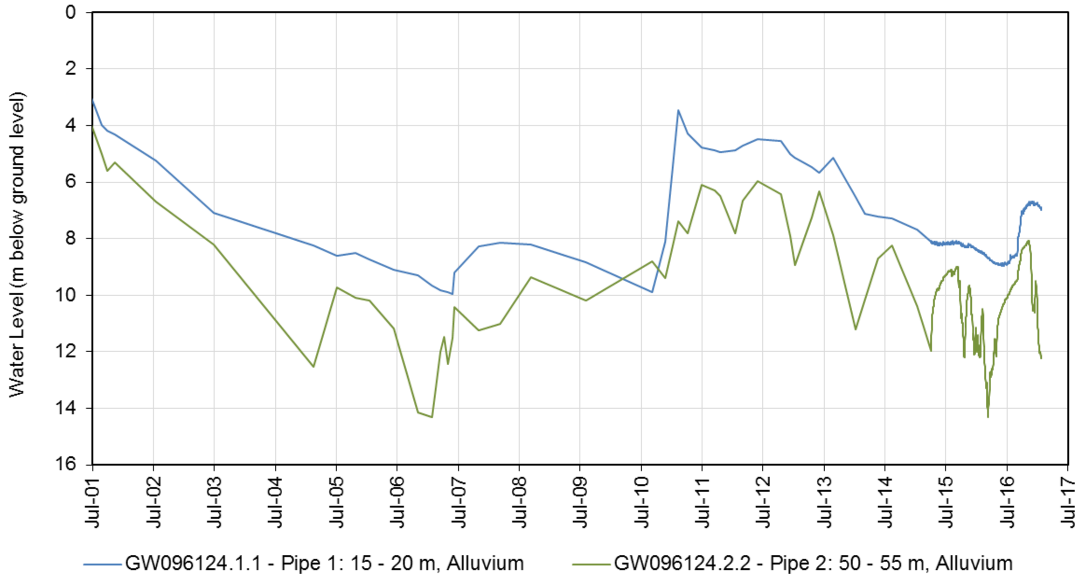

Figure 58 Hydrograph for monitoring site GW096124 – Dunedoo section

10.2.3 Castlereagh Alluvium

Figure 59 illustrates the groundwater level trends for the Castlereagh Alluvium at the Gilgandra cross-section. At this site, the shallowest pipe is screened in the alluvium and the two deeper pipes are screened in the underlying sandstone of the Great Artesian Basin. A reduced frequency in monitoring from 1983 to present makes it difficult to clearly determine the magnitude of change to an event and the associated response times. However, what can be inferred is that there are small responses to changes in climate over time in both the sandstone and the alluvial aquifer and there is a downward gradient from the alluvium to the sandstone.

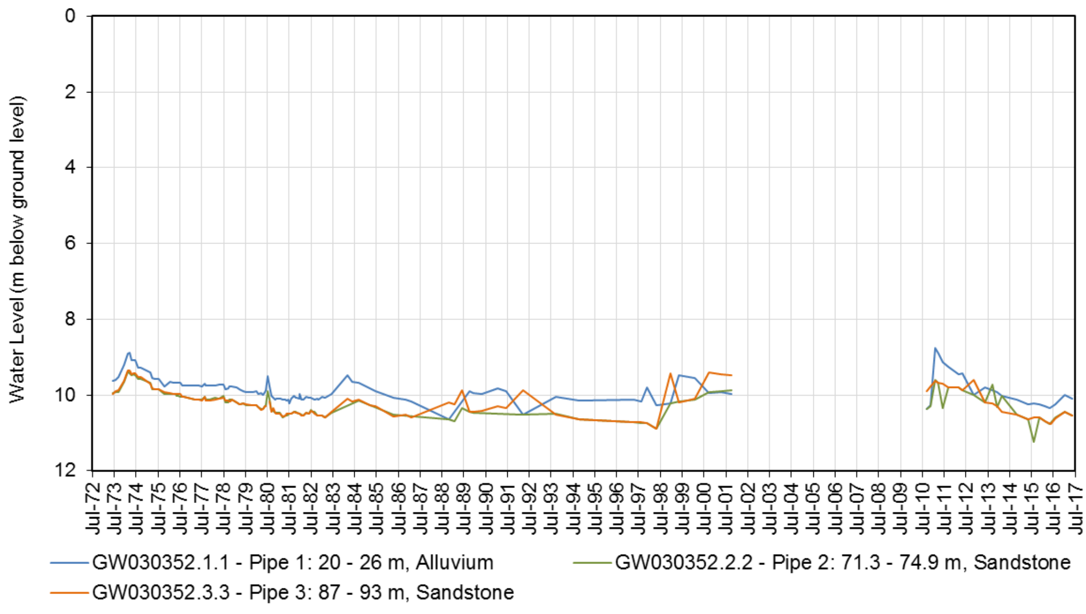

Figure 59 Hydrograph for monitoring site GW030352 – Gilgandra section

10.2.4 Bell Valley Alluvium

Monitoring site GW273147 is located within the Apsley cross-section in the Bell Valley Alluvium and is considered to be fairly representative of water level trends across the system. At this site the shallower pipe is screened in the alluvium and the deeper pipe is screened in the underlying limestone. Both have been equipped with a telemetered data logger since 2015. Figure 60 highlights the connectivity between the river and the alluvium and the underlying fractured rock with identical rapid responses in both aquifers to the moderate floods that passed through the system from July 2016.

Between 2013 and 2016 there are small seasonal responses to irrigation.

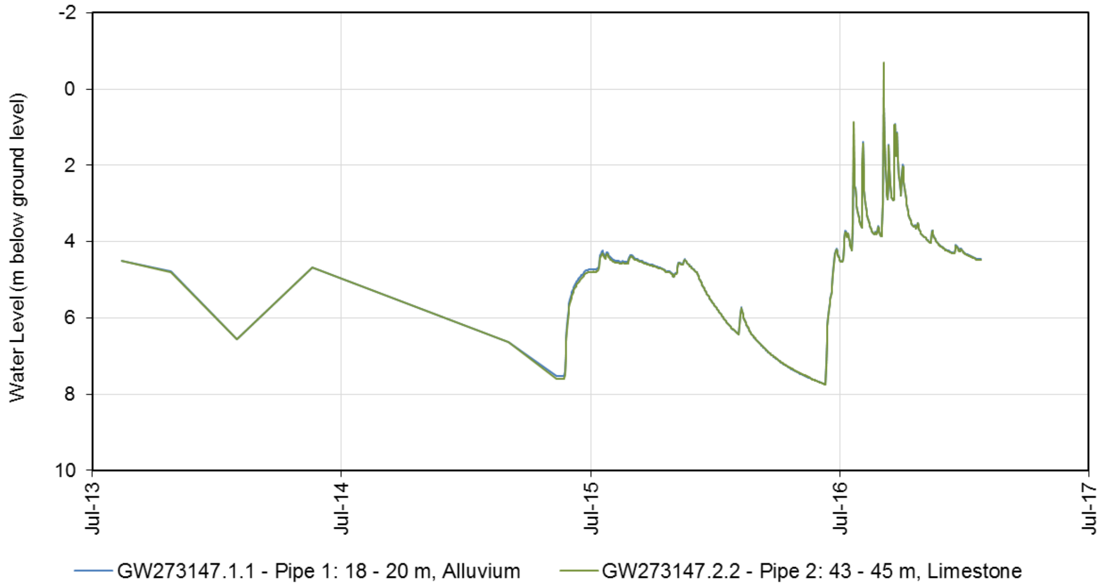

Figure 60 Hydrograph for monitoring bore site GW273147 – Apsley section.

10.2.5 Upper Macquarie alluvium

Monitoring site GW021498 is located in an area of high density of extraction toward the south of Dubbo close to the city's town water supply borefield (Figure 61). The aquifer has experienced long term declining trends between 1972 and 1992. Dubbo Regional Council reduced their extraction in the area and some recovery was observed between 1996 and 2002. The groundwater level was its lowest at the end of the millennium drought in summer 2010. From 2010 to 2017 the groundwater level is now fluctuating around a level that is 10 m below the pre-development level.

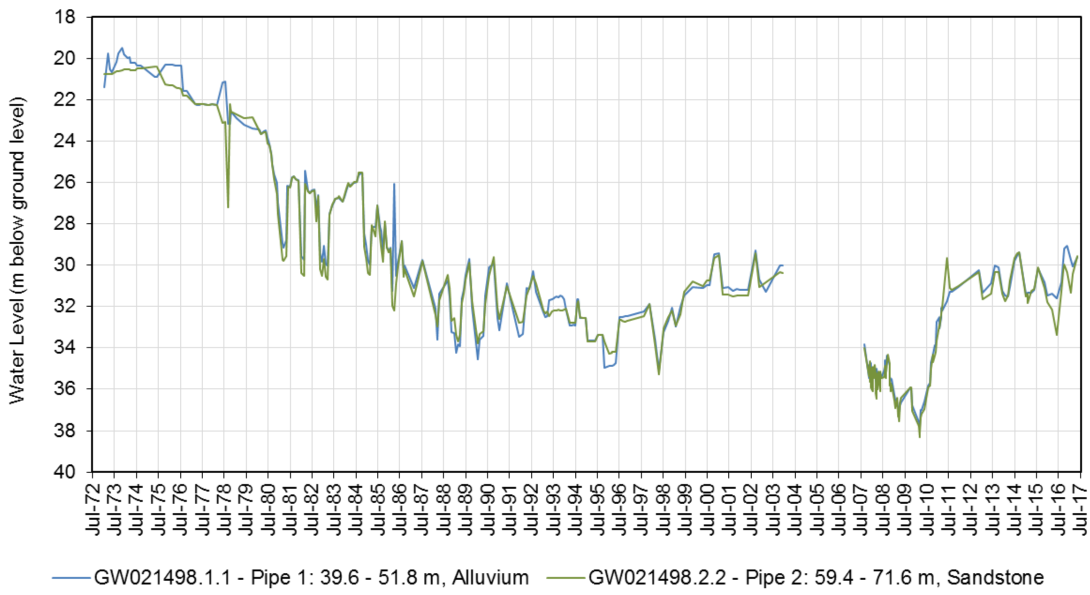

Figure 61 Hydrograph for monitoring site GW021498

Monitoring site GW036517 has two pipes constructed into the alluvium at the Coolbaggie cross-section (Figure 62). Prior to 2012, climatic trends were the main driver of changes in groundwater levels with an obvious response to the millennium drought between 2002 and 2010. Following 2012, the development of the aquifer has increased and seasonal pumping oscillations are observable. The shallow aquifer mirrors the trend in the recovery level of the deep aquifer.

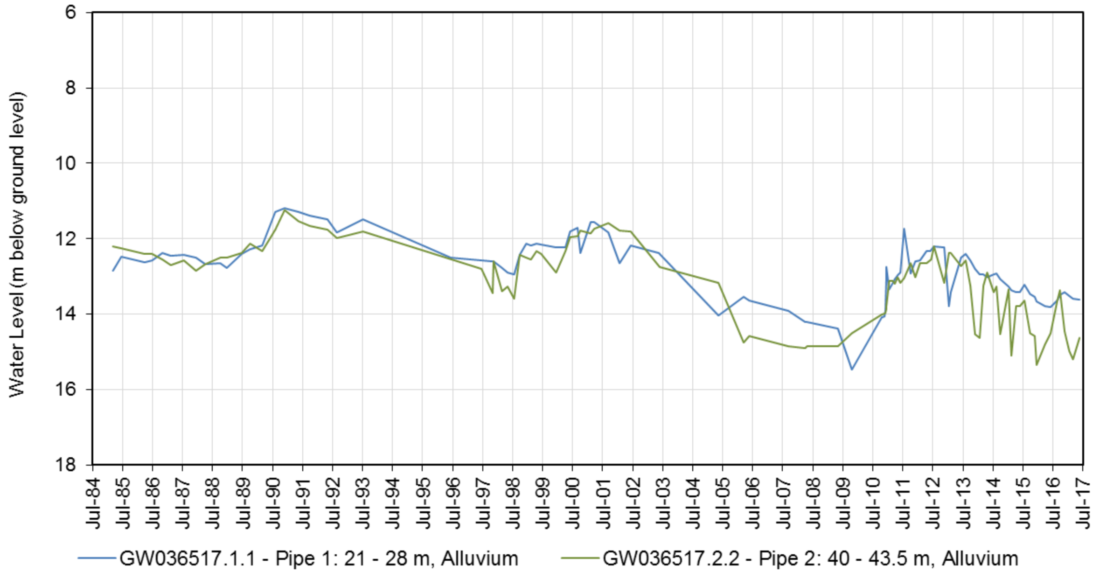

Figure 62 Hydrograph for monitoring site GW036517

10.2.6 Lower Macquarie Alluvium

Long-term changes in groundwater levels reflect climatic variations as well as the impacts of pumping. The hydrograph shown in Figure 63 illustrates a rise in groundwater levels since the 1970’s that is attributed to an increase in recharge associated with the regulation of the Macquarie River and the commencement of large scale irrigation in the area. The seasonal pumping cycles in the deeper alluvial aquifer system of the Lower Macquarie Alluvium commenced in the mid-nineties. The site has had a data logger installed since 2009. Whilst the recovered groundwater levels have declined from the pre-development levels (1990 – 1995), the groundwater levels at this site are now fluctuating around a new pumping equilibrium level.

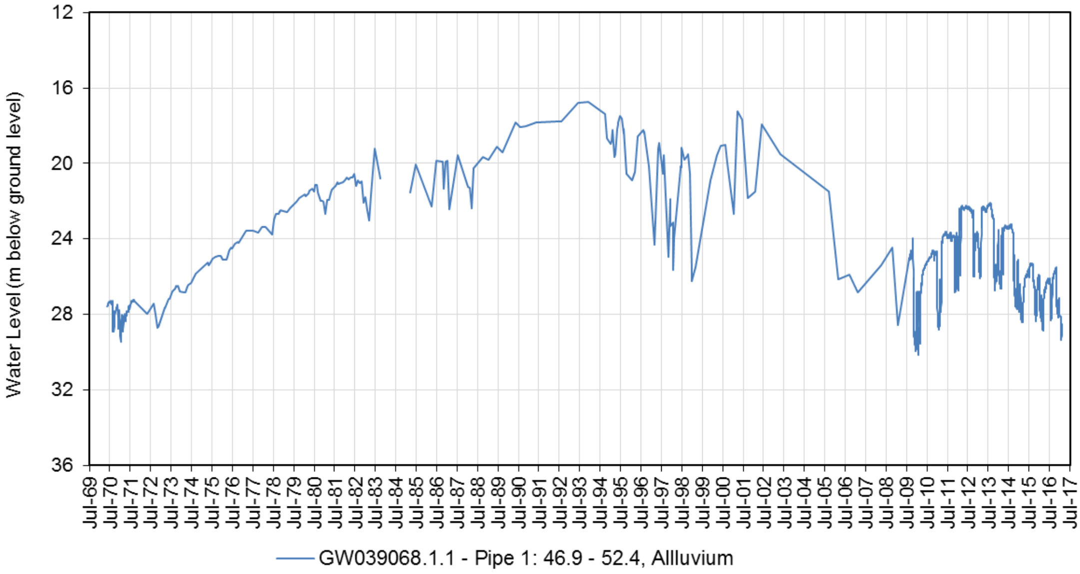

Figure 63 Hydrograph for monitoring site GW039068

Figure 64 demonstrates that despite the large seasonal oscillations of up to 24 m due to pumping in the deeper aquifer system (depth 133 – 139m below ground) there has been a small decline in recovery of around 5 m over the last 15 years. The monitoring data from the intermediate depth of 66-72m shows only a subdued response to pumping giving an indication of the semi confined nature of the deeper alluvium. The site has had a telemetered data logger installed since 2006.

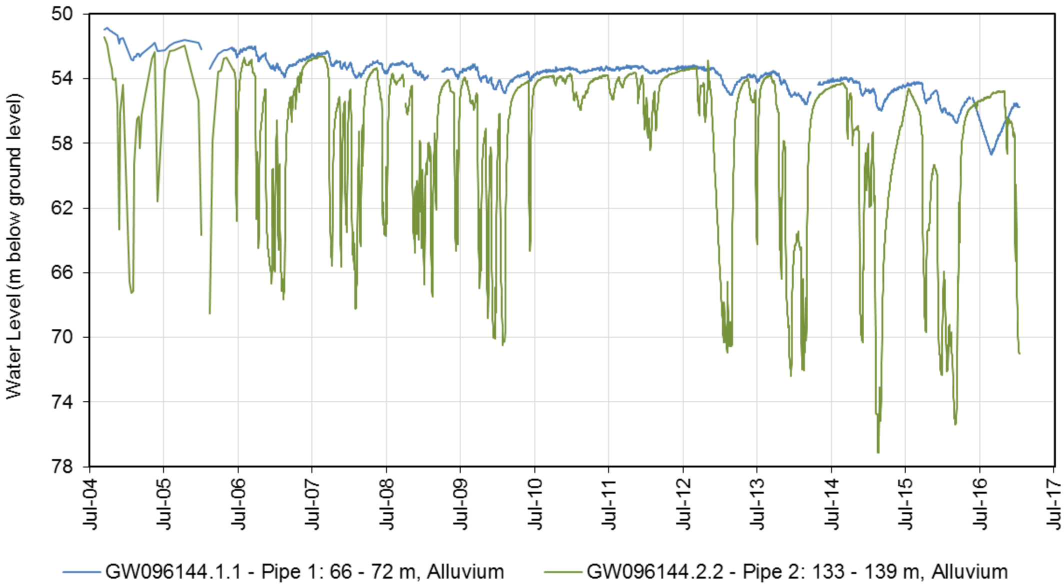

Figure 64 Hydrograph for monitoring site GW096144

10.3 Groundwater level and change 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.

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.

10.3.1 Cudgegong Alluvium

Figure 65 shows that there is little to no difference between the water table maps in the Cudgegong Alluvium when comparing the data from the mid-1970s to 2015 – 16 water year. The regulation of the Cudgegong River provides a constant source of recharge to the alluvium. There is a small difference between the contours in the Lawsons Creek area where the river is unregulated and influenced strongly by climate.

The change in the water table monitored between the irrigation season and non-pumping period in the 2015 – 16 water year was minimal and is not presented here.

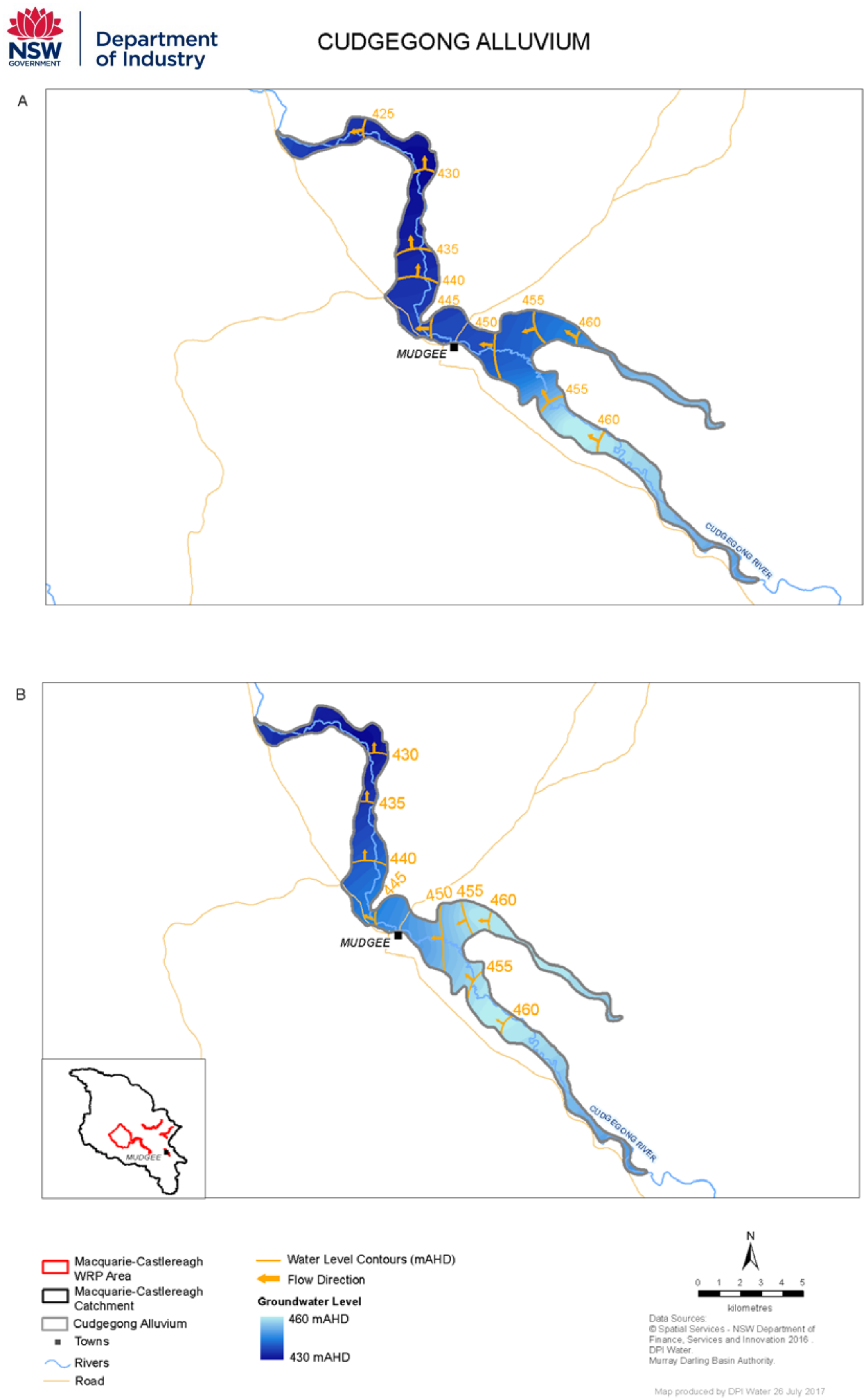

Figure 65 Groundwater flow direction for the pre-development period and the maximum recovery period in and 2015 – 16 in the Cudgegong Alluvium

10.3.2 Coolaburragundy – Talbragar Alluvium

Groundwater levels in the Dunedoo region of the Coolaburragundy – Talbragar Alluvium have been recorded since 2001. Over the last 15 years the direction of groundwater flow has remained the same. Figure 66 shows there has been a small change in groundwater levels with a slightly steeper gradient from upstream to downstream likely caused by climatic influences as well as the extraction of groundwater.

Figure 67 shows the area of drawdown during the 2015 – 16 irrigation as compared to the non-pumping season. Over three metres of drawdown can be observed in the deeper aquifer system close to the Dunedoo township.

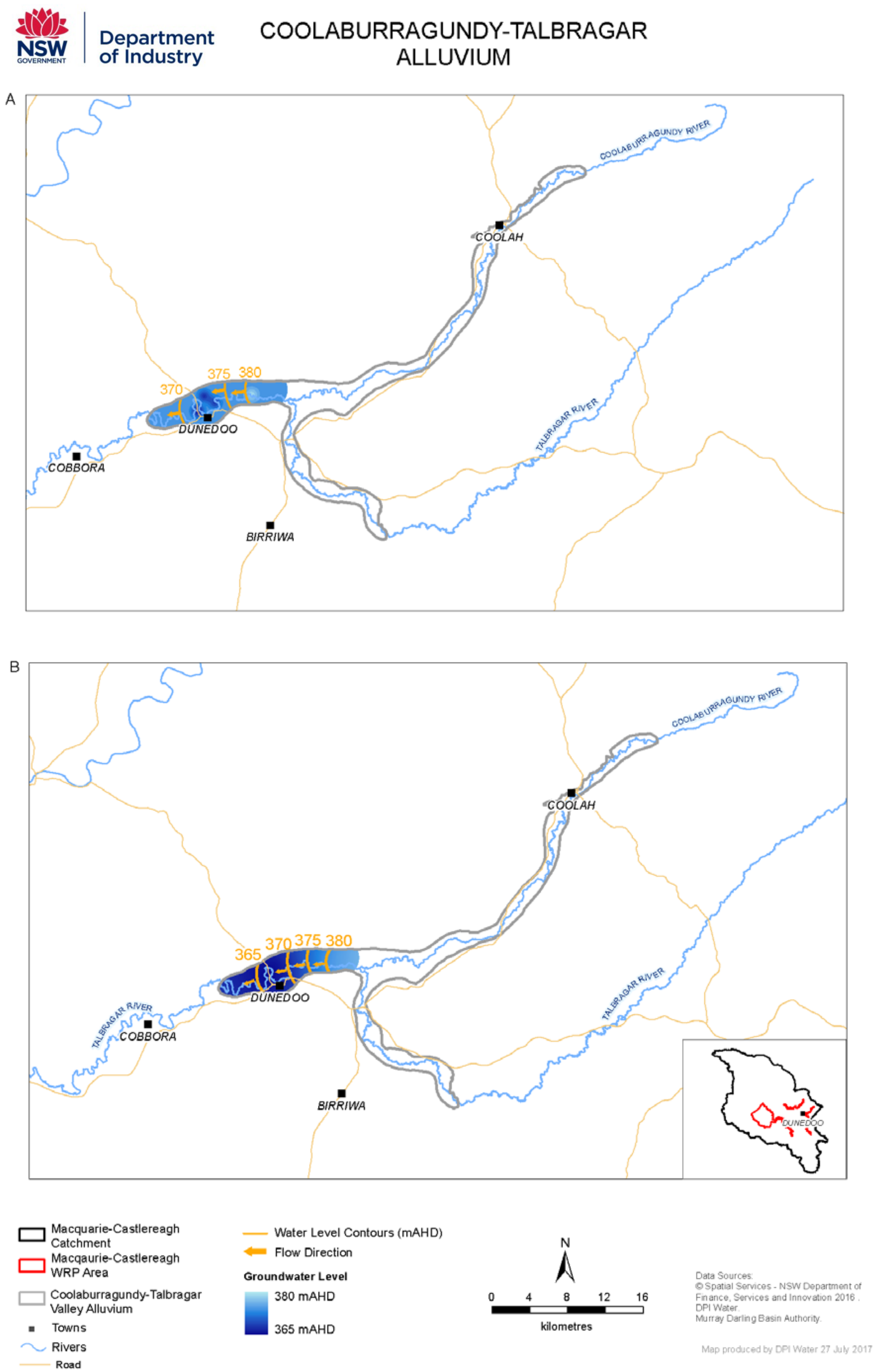

Figure 66 Groundwater flow direction for the maximum recovery period in the 2001-02 and 2015 – 16 water years in the Coolaburragundy-Talbragar Alluvium

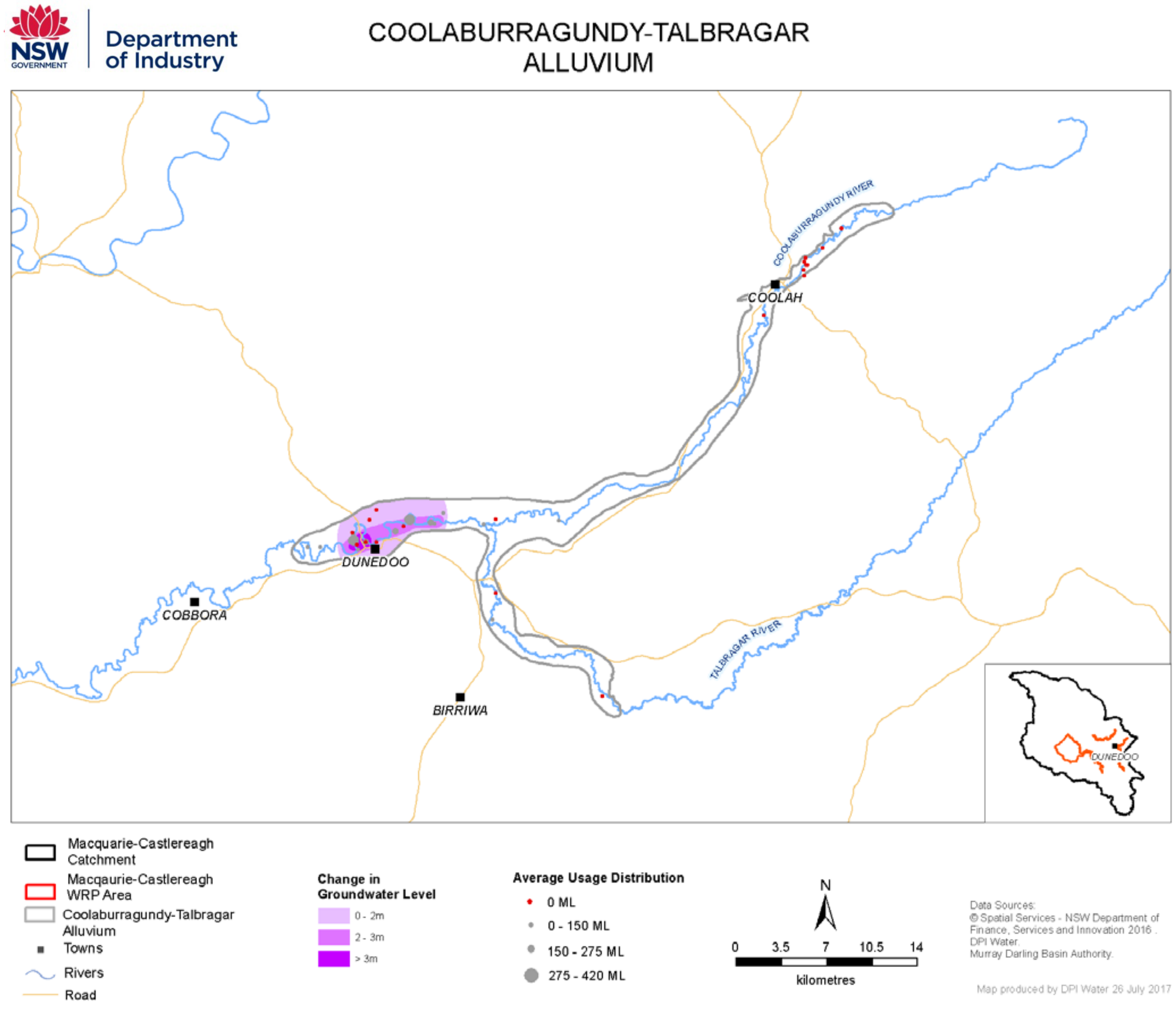

Figure 67 Change in groundwater levels between the pumping and non-pumping season for the 2015 – 16 water year in the Coolaburragundy-Talbragar Alluvium

10.3.3 Castlereagh Alluvium

The potentiometric surface for the 1970s and the 2015 – 16 water year recovery levels are compared side by side in Figure 68. The difference between the two maps is subtle and a product of climatic trends over the last 40 years. There has been a small decline in groundwater levels where contours appear to have moved up the system. The direction of groundwater flow remains the same.

As there is no active groundwater extraction in the Castlereagh Alluvium maps showing the change in groundwater levels over the irrigation season are not presented.

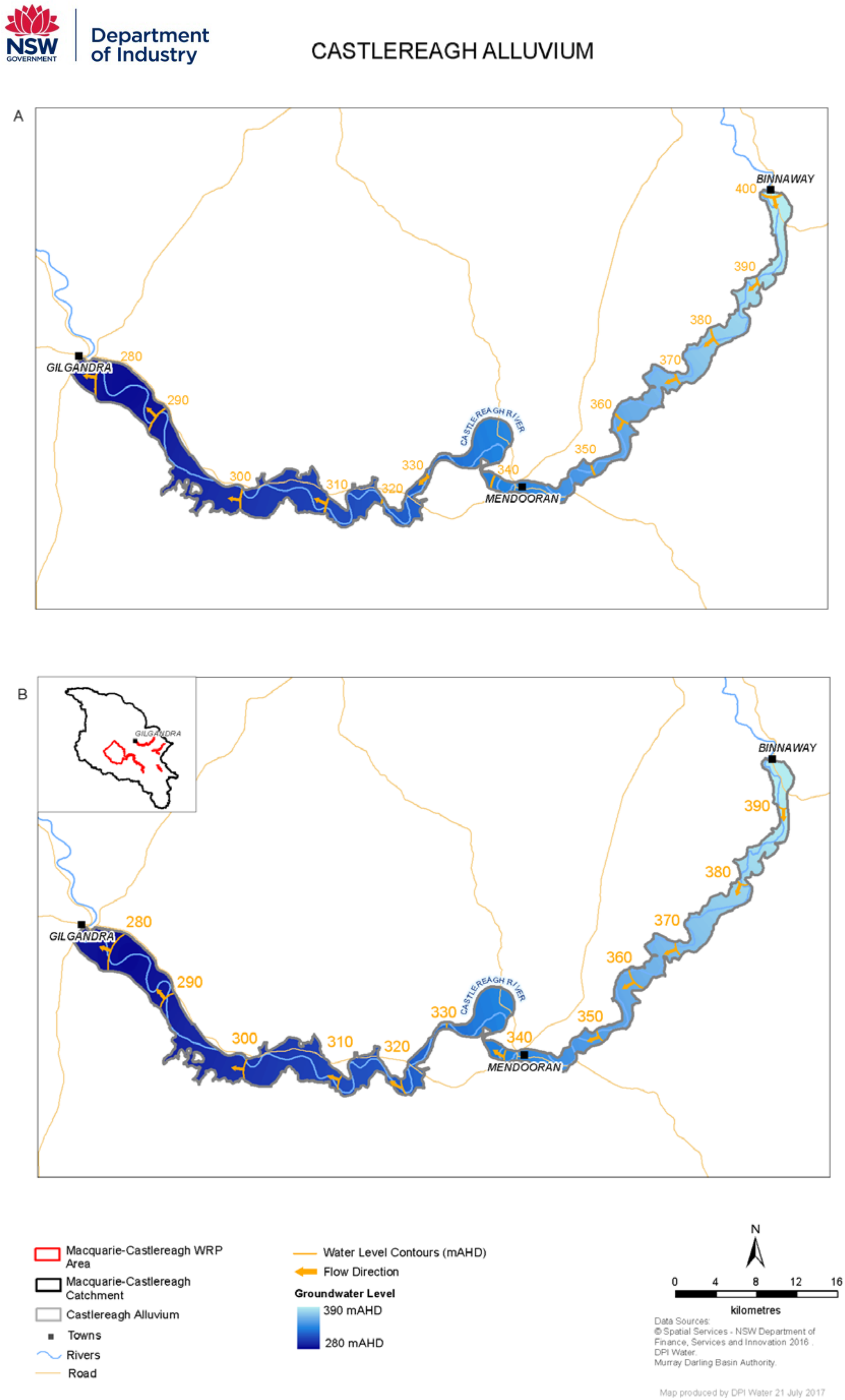

Figure 68 Groundwater flow direction for the pre-development period and the maximum recovery period in and 2015 – 16 in the Castlereagh Alluvium

10.3.4 Bell Valley Alluvium

Monitoring in the Bell Valley Alluvium commenced in 2010 at the height of the millennium drought. This extremely dry period was followed by a wet period that resulted in flooding through the system which allowed groundwater levels to recover. Figure 69 illustrates the potentiometric surface for the 2009 - 10 water year (A) and the 2015 – 16 water year (B). The recovery in the groundwater level following the wet period is observable in the 2015 – 16 water year map (Figure 69 B). The contour lines have moved down the system indicating that the water level is higher, for example the 290 mAHD contour has moved northward toward Wellington.

The drawdown area in the Apsley section is present in both maps and is most clearly demonstrated in Figure 70 where the difference between the irrigation season and the non-pumping season for the 2015 – 16 has been illustrated. Although the extraction volumes from the individual bores in this area is relatively small, the cumulative impact can be observed.

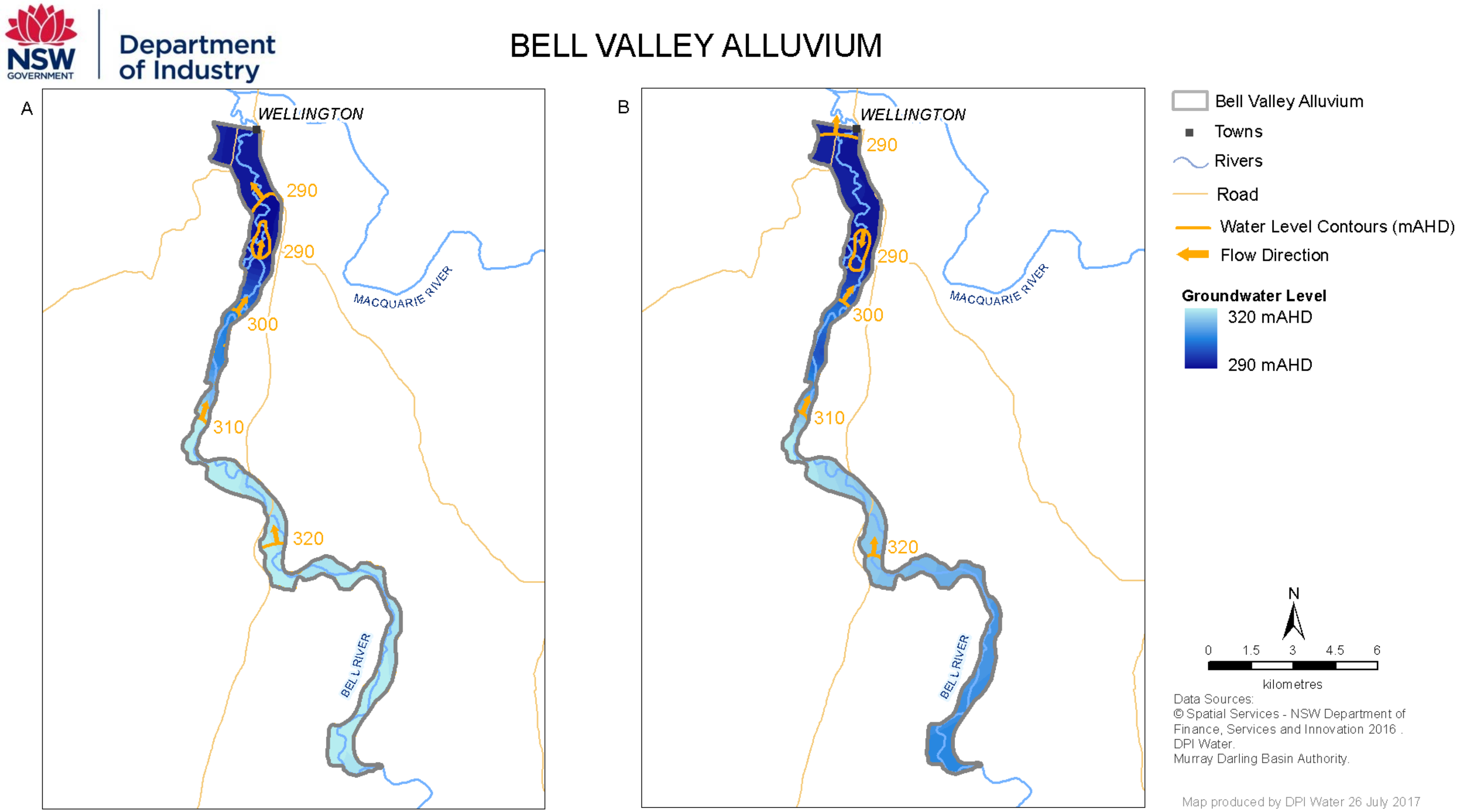

Figure 69 Groundwater flow direction in the water table for the maximum recovery period in 2009-10 and 2015 – 16 in the Bell Valley Alluvium

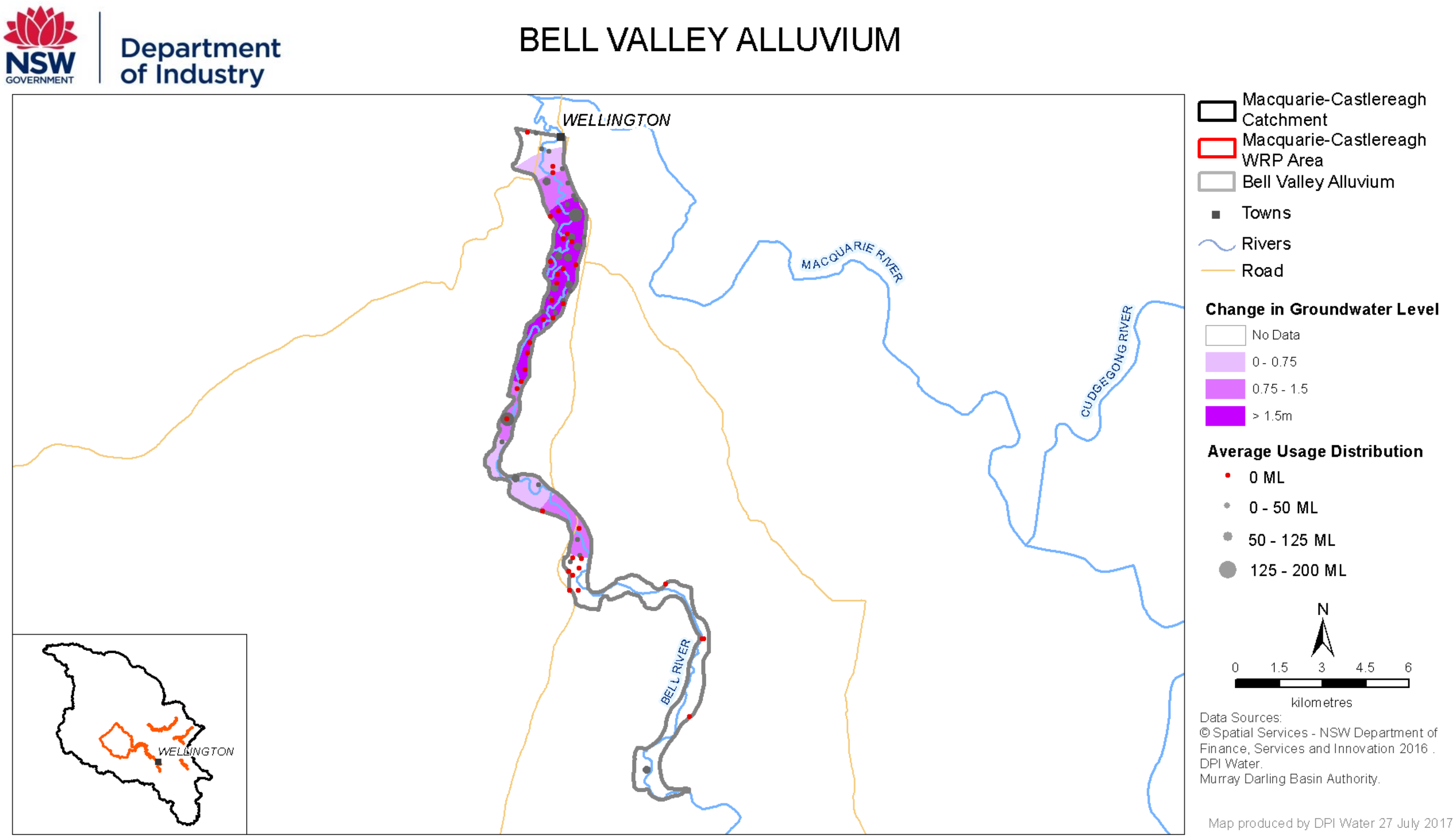

Figure 70 Change in groundwater levels between the pumping and non-pumping season for the 2015 – 16 water year in the Bell Valley Alluvium

10.3.5 Upper Macquarie Alluvium

Figure 71 compares the ‘pre-development’ groundwater levels in the deeper aquifer to the recovery levels in the 2015 – 16 water year. The ‘Pre-development’ level in the Upper Macquarie Alluvium is defined as the average in groundwater level for the first five years of monitoring for bores constructed before 1986. This average is considered to be reflective of the groundwater levels prior to more intensive groundwater extraction in the Upper Macquarie Alluvium.

For the pre-development period, shown in Figure 71 A, there is no evidence of a reversal in the groundwater flow direction in the major pumping districts. In 2015 – 16 the horizontal gradient downstream of Geurie is steeper where the contours have moved up the valley.

Figure 72 highlights the areas within the Upper Macquarie Alluvium that experienced the most pressure from groundwater extraction in the 2015 – 16 water year. In the Geurie, Dubbo and Coolbaggie areas declines in excess of 1.5 m are experienced. There is also an area adjacent to the Lower Macquarie Zone 6 Groundwater Source that is experiencing a level of drawdown.

Figure 73 shows the difference between the recovered levels 14 years ago and the 2015 – 16 water year reflect similar trends with some minor differences. There is a drawdown area between Dubbo and Geurie and another where the Talbragar River meets the Macquarie in excess of 1.5 metre. Groundwater extraction has occurred in these areas in previous years as indicated by the extraction distribution map (Figure 73) but there was no extraction in the 2015 – 16 water year.

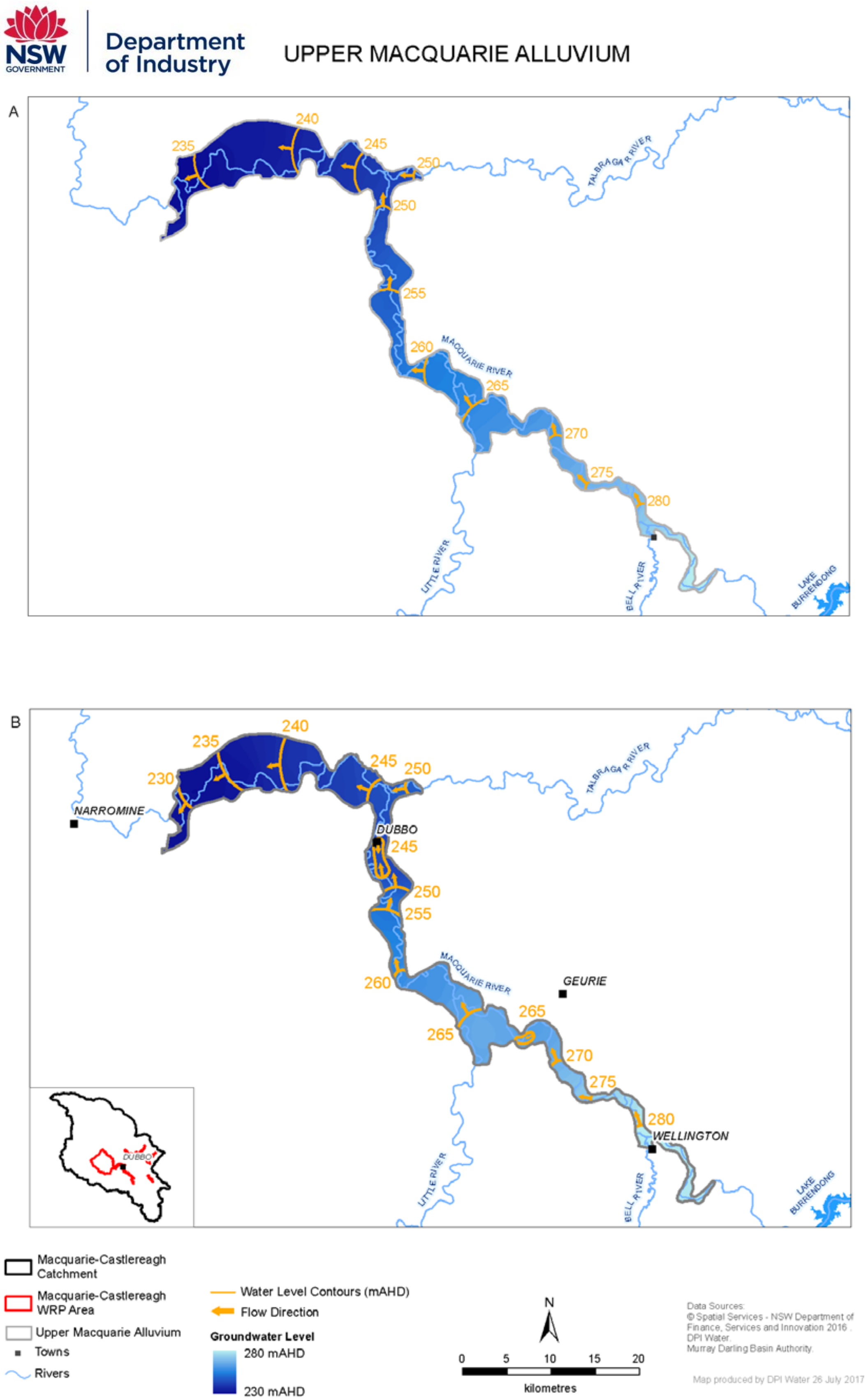

Figure 71 Groundwater flow direction for the pre-development period and the maximum recovery period in and 2015 – 16 in the Upper Macquarie Alluvium

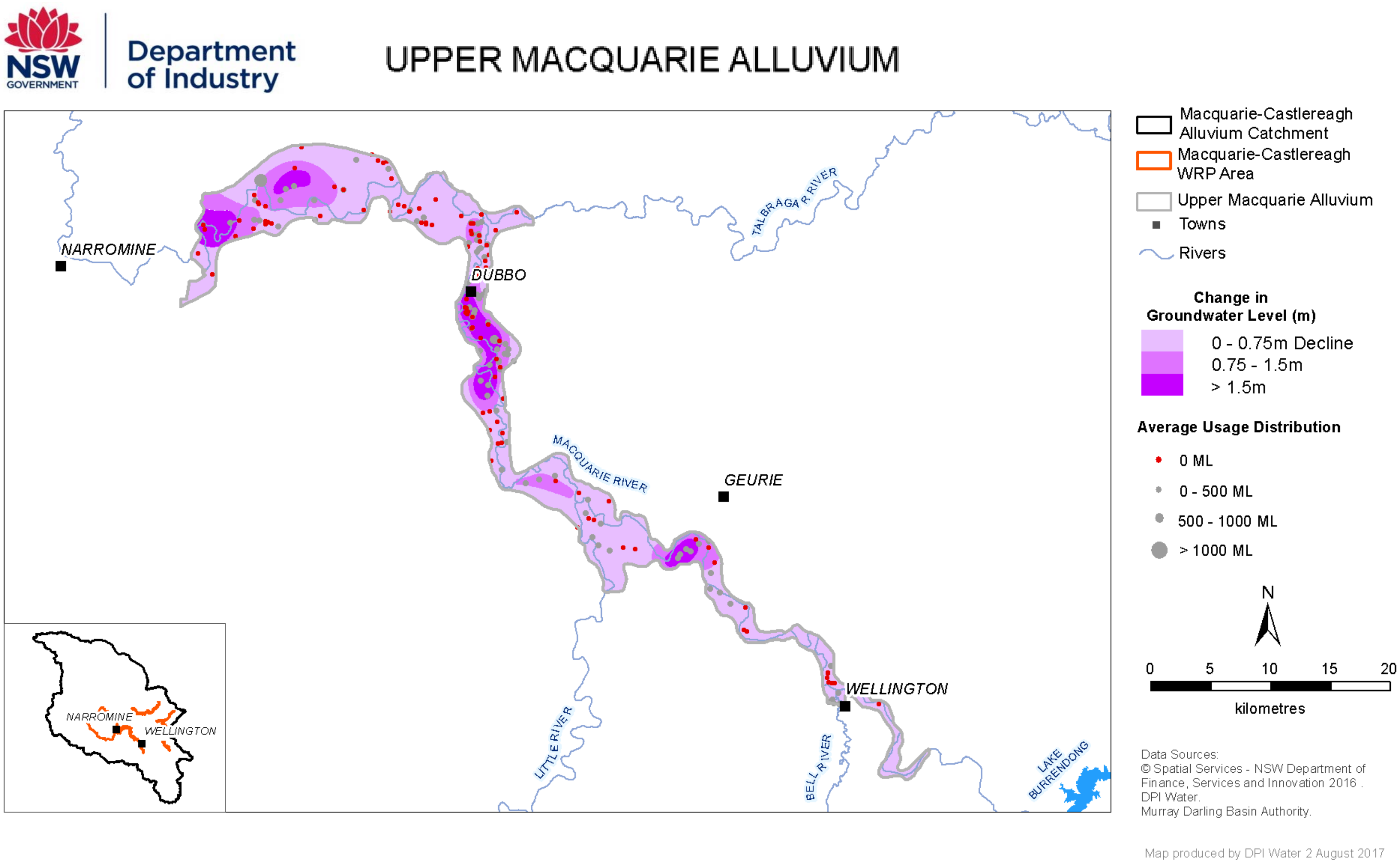

Figure 72 Change in groundwater levels between the pumping and non-pumping season for the 2015 – 16 water year in the Upper Macquarie Alluvium

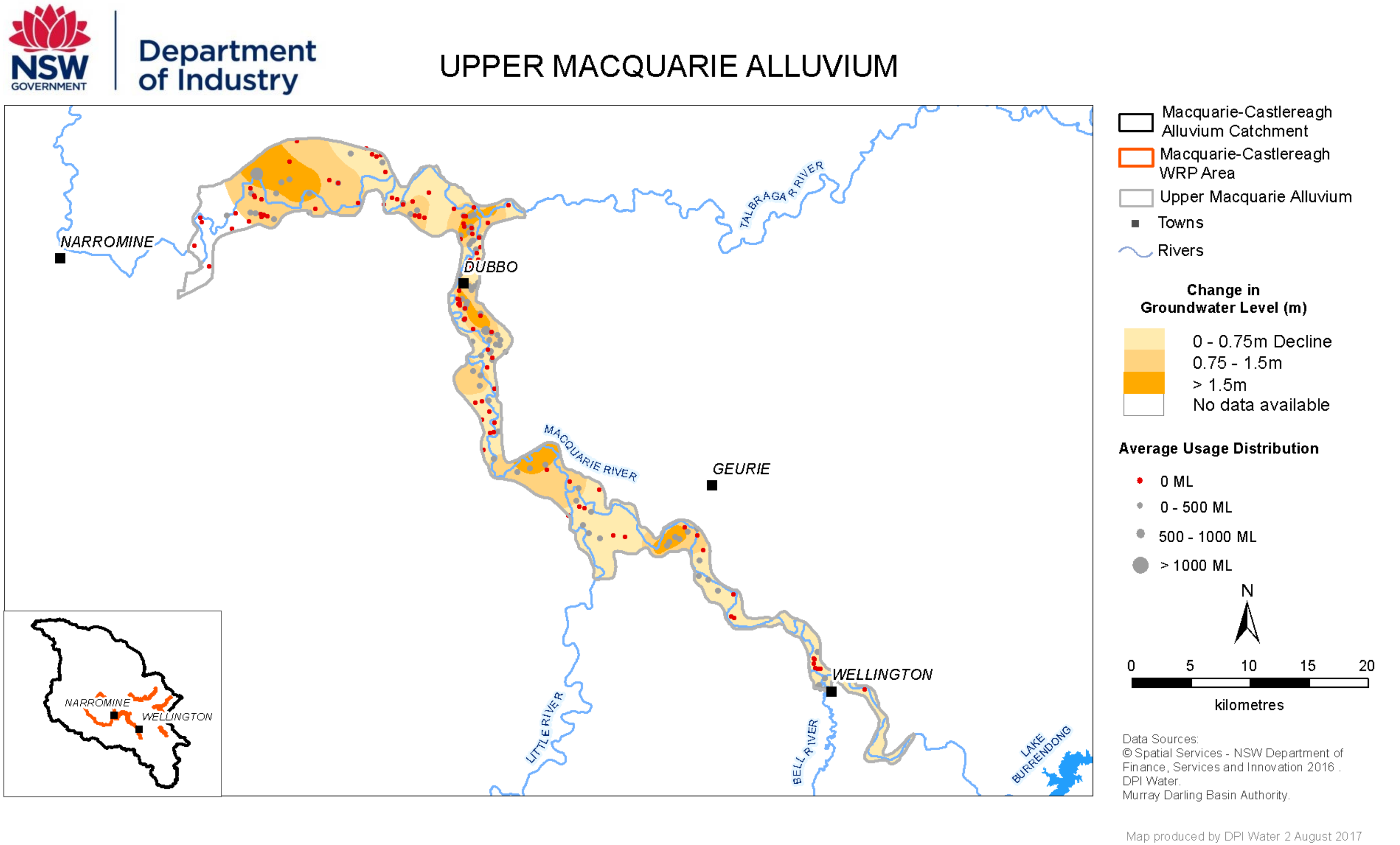

Figure 73 Change in groundwater levels for the maximum recovery periods in 2001 – 02 and 2015 – 16 water years in the Upper Macquarie Alluvium

10.3.6 Lower Macquarie Alluvium

Figure 74 compares the ‘pre-development’ groundwater levels from the deep alluvium to the recovery levels in the 2015 – 16 water year. The ‘Pre-development’ level in the Lower Macquarie Alluvium is defined as the average in groundwater level over five years from 1990 – 1995. This average is considered to be reflective of the groundwater levels prior to more intensive groundwater extraction in the Lower Macquarie Alluvium. As shown in Figure 58 groundwater levels were rising prior to commencement of significant groundwater pumping.

Although the groundwater direction has remained the same at a regional scale, groundwater extraction over time has influenced the horizontal gradient of groundwater flow between Narromine and Dandaloo. The gradient has steepened as groundwater levels have lowered and the contour lines have been pulled up the catchment (Figure 74).

The recovered groundwater levels from 2005 - 06 water year were compared to the 2015 – 16 water year and the difference has been displayed in Figure 75. Over the past 10 years there has be up to 1 m in decline in recovered levels across most of the deep alluvial aquifer. In three discrete locations there has been over 3 m of decline due to the extraction of groundwater.

The change in recovered levels over the last 10 years is relatively small when compared to the seasonal drawdowns that were measured during the 2015 – 16 irrigation season (Figure 76). During the summer the groundwater levels can be in excess of 15 m lower than those levels recorded in the off season for the same year. Across most of the deep alluvium there is between 5 – 10 m decline during the irrigation season.

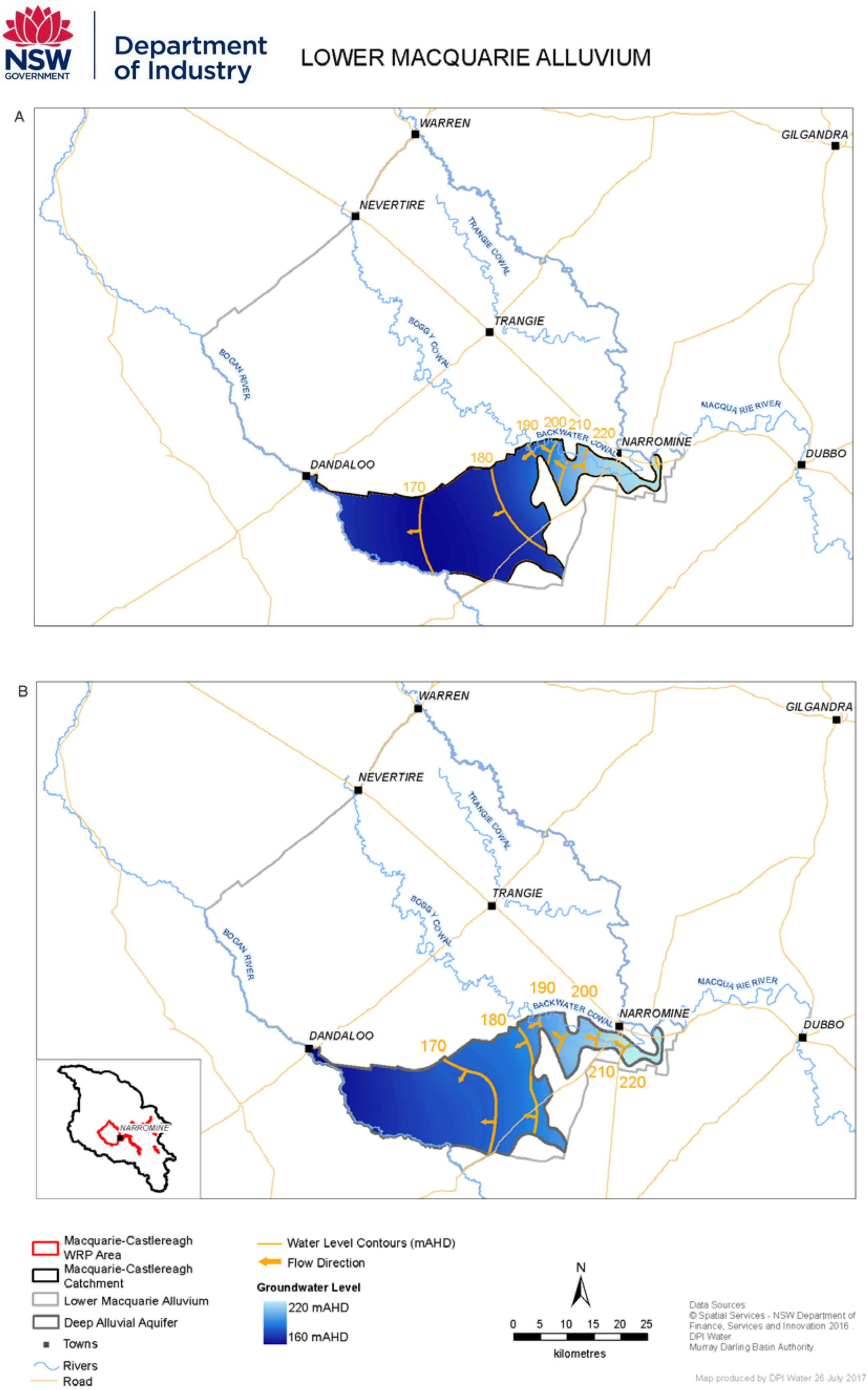

Figure 74 Groundwater flow direction for the pre-development period (1990s) and the maximum recovery period in and 2015 – 16 in the Upper Macquarie Alluvium

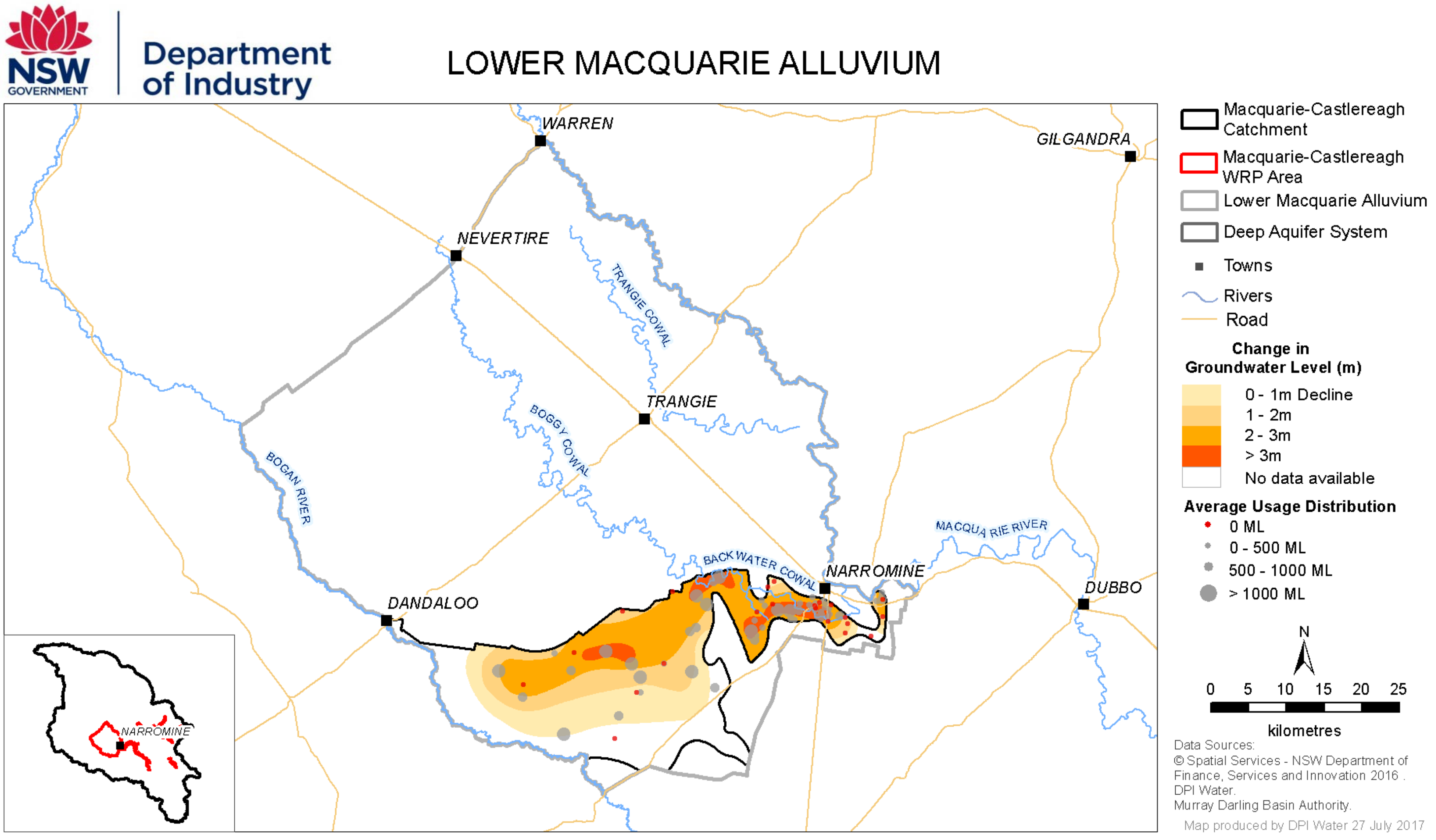

Figure 75 Change in groundwater levels for the maximum recovery periods in 2005 – 06 and 2015 – 16 water years in the Lower Macquarie Alluvium

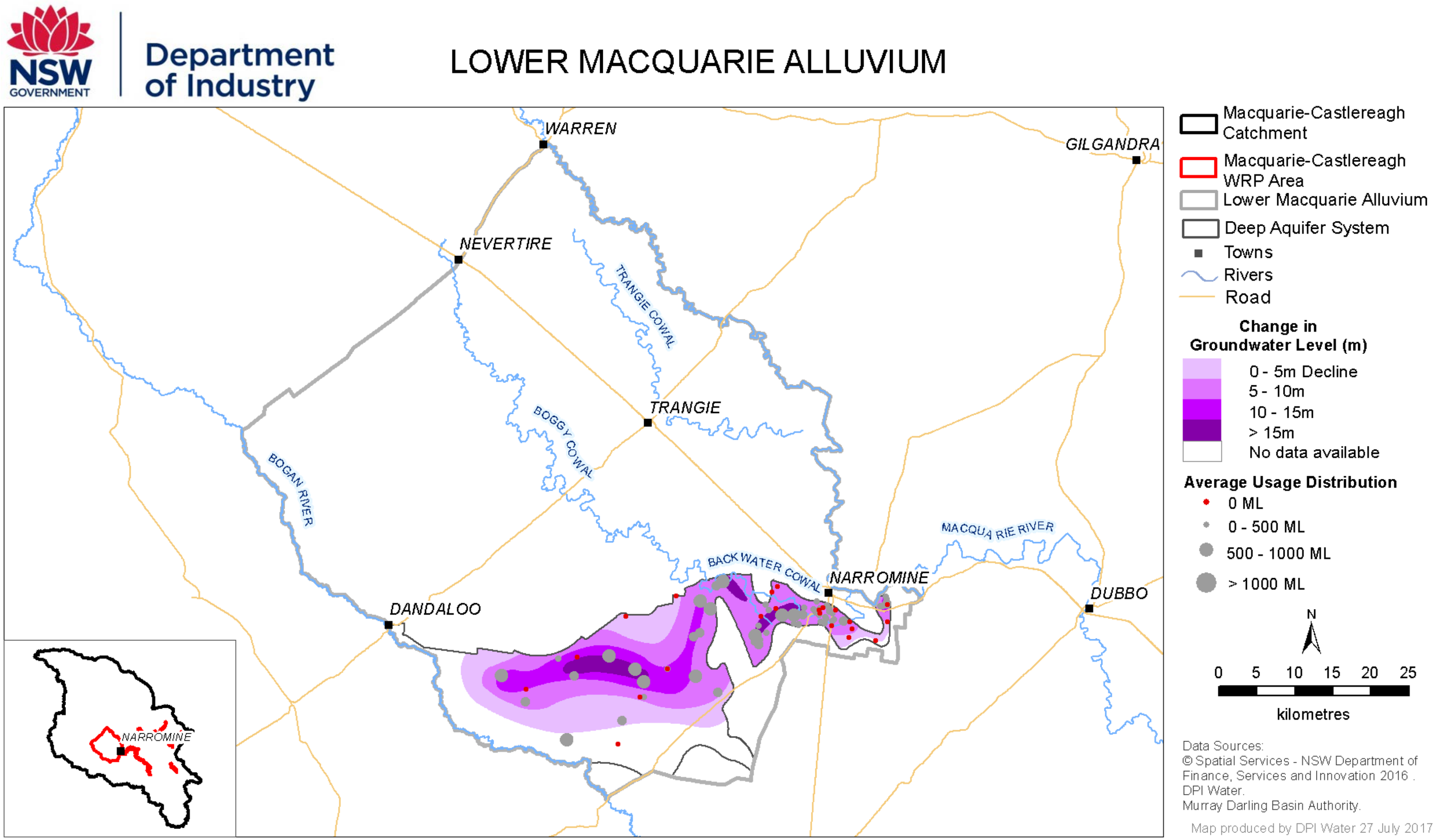

Figure 76 Change in groundwater levels between the pumping and non-pumping season for the 2015 – 16 water year in the Lower Macquarie Alluvium

11 Groundwater model

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

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

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

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

The water budget provides an estimate of the bulk change to the volume of groundwater in storage. If the total outputs such as extraction, and loss to the rivers are greater than the inputs (estimated recharge) over time then there is a net loss of the amount of water stored in the aquifer. No change in storage implies that the level of pumping is potentially sustainable into the future.

In 2007 the groundwater model for the Lower Macquarie groundwater resources was finalised to support groundwater resource management (Bilge, 2007). The model was calibrated for the 23 year period from 1980 to 2003. Aspects of the Lower Macquarie model have been identified as requiring review in future model development. .

The model simulates 4 layers. Layer 1 and Layer 2 represent the shallow and deeper alluvial aquifer systems and Layers 3a and 3b correlate to the underlying strata of the Great Artesian Basin. Layer 3a represents the confining layer overlying the productive sandstone aquifer which is Layer 3b. There is no extraction from Layer 3a.

Figure 77 shows the cumulative water budget output for the Lower Macquarie Groundwater Sources Zones 1, 2 and 6 in the alluvium for the period 2006 - 2007 to 2015 - 2016. This corresponds to the period since commencement of the Water Sharing Plan for the Lower Macquarie Groundwater Sources. For this 10 year period the model has simulated a net loss in the storage volume of the two alluvial aquifers, that is Layer 1 and Layer 2.

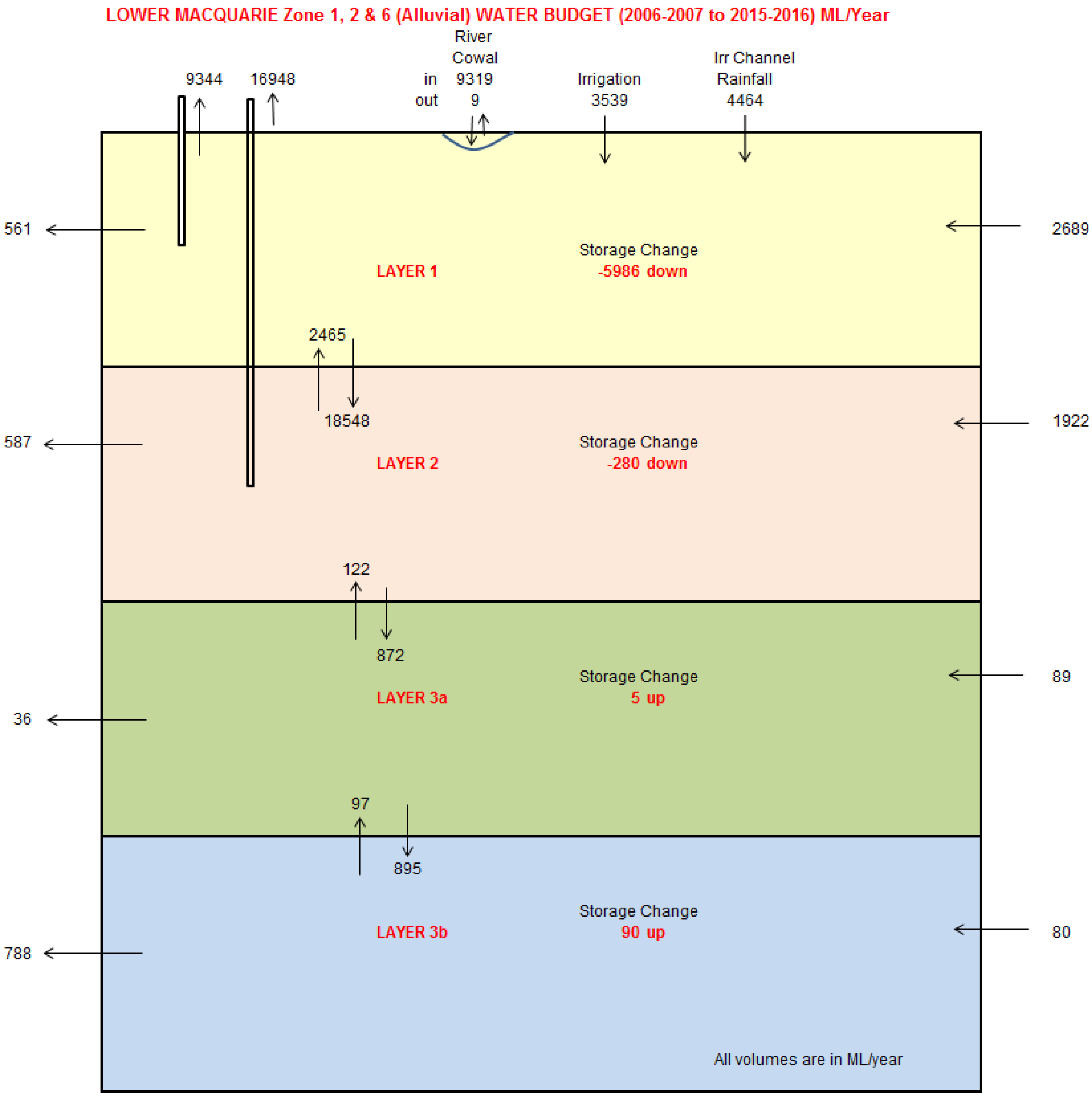

Figure 77 Block diagram for the modelled water budget for Lower Macquarie Groundwater Sources Zones 1, 2 and 6 from 2006 -2007 to 2015 - 2016. Volumes shown are annual averages modelled for this period.

Figure 78 shows the cumulative water budget output for the Lower Macquarie Groundwater Sources Zones 3, 4 and 5 in the sandstone for the period 2006 - 2007 to 2015 – 2016. The model has simulated a net loss of storage volume in the sandstone however it has also shown a net increase in the storage volume of the shallow alluvium.

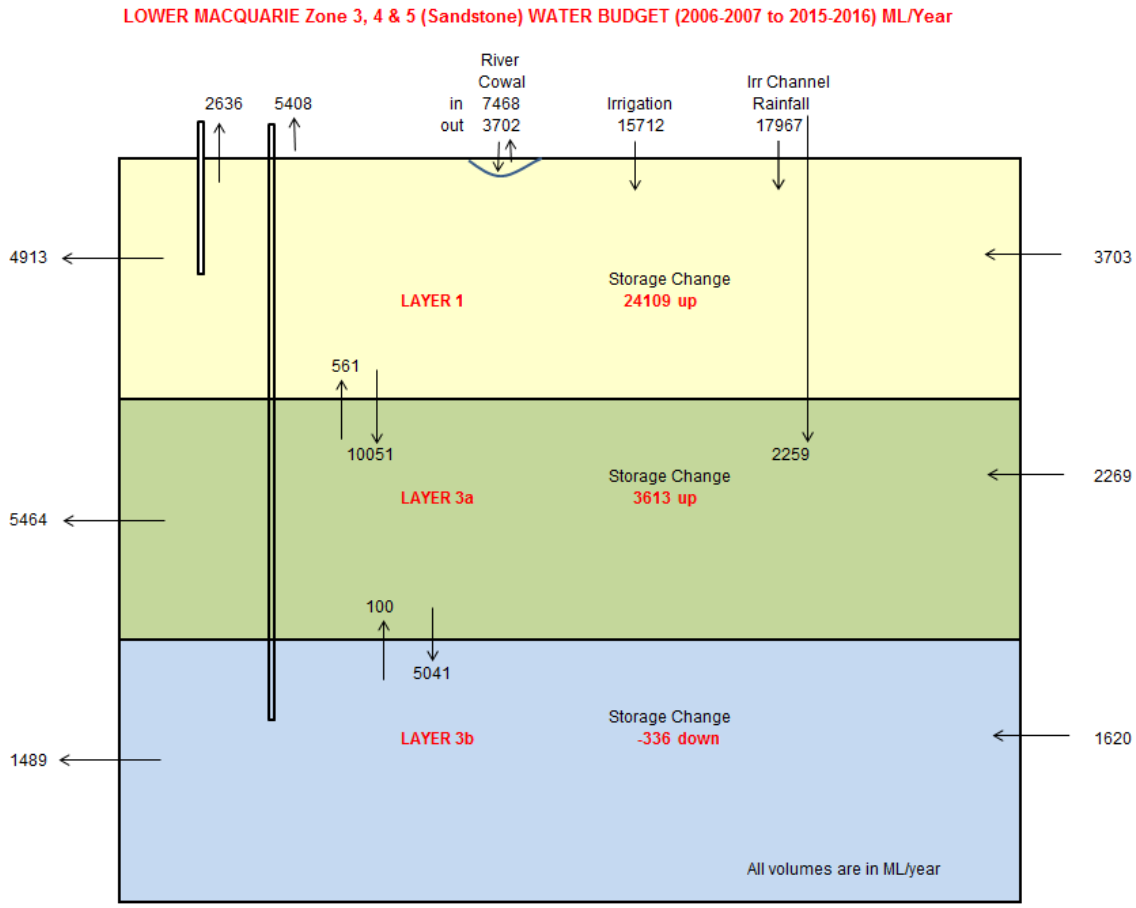

Figure 78 Block diagram for the water budget for Lower Macquarie Groundwater Sources Zones 3, 4 and 5 from 2006 -2007 to 2015 – 2016

In NSW groundwater management aims to ensure that long term extraction does not impact on the sustainability of the resource. Annual groundwater extraction volumes may exceed the plan's extraction limit during periods of high demand provided the resource is able to recover over the longer term

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12 Appendix A – Lower Macquarie Groundwater Sources

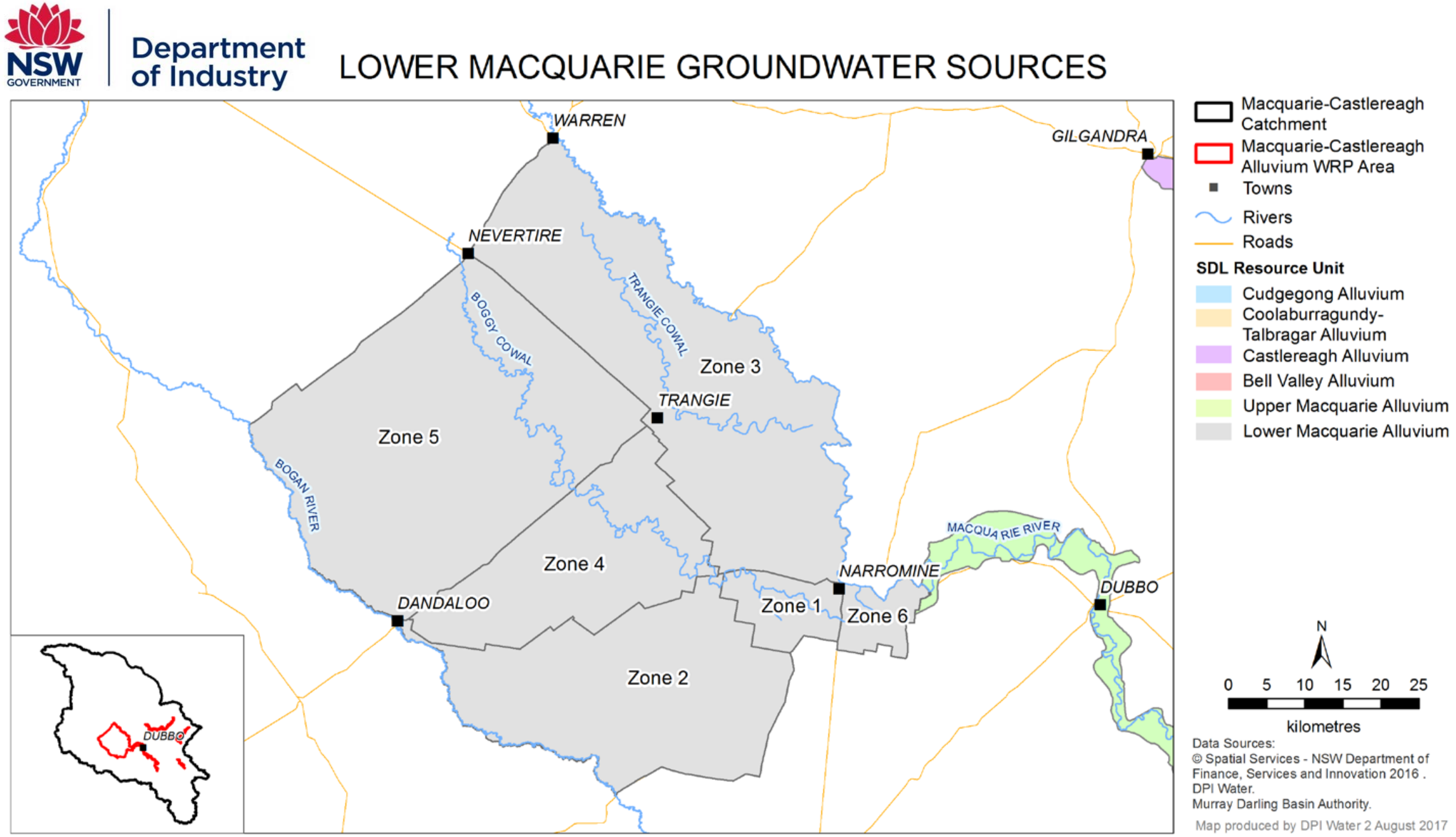

Figure 79

13 Appendix B – Monitoring bore location maps

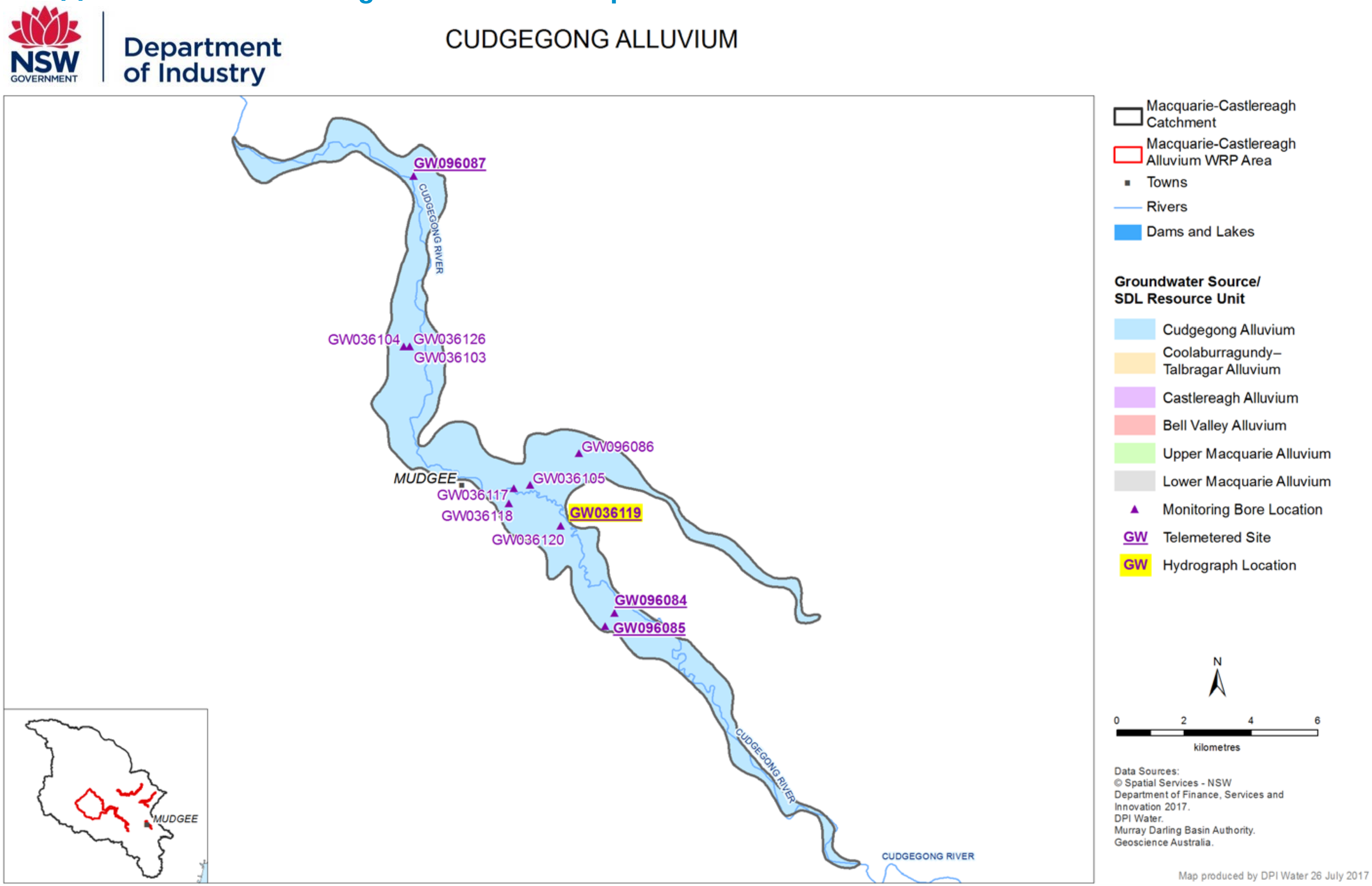

Figure 80 Location map of monitoring bores in the Cudgegong Alluvium

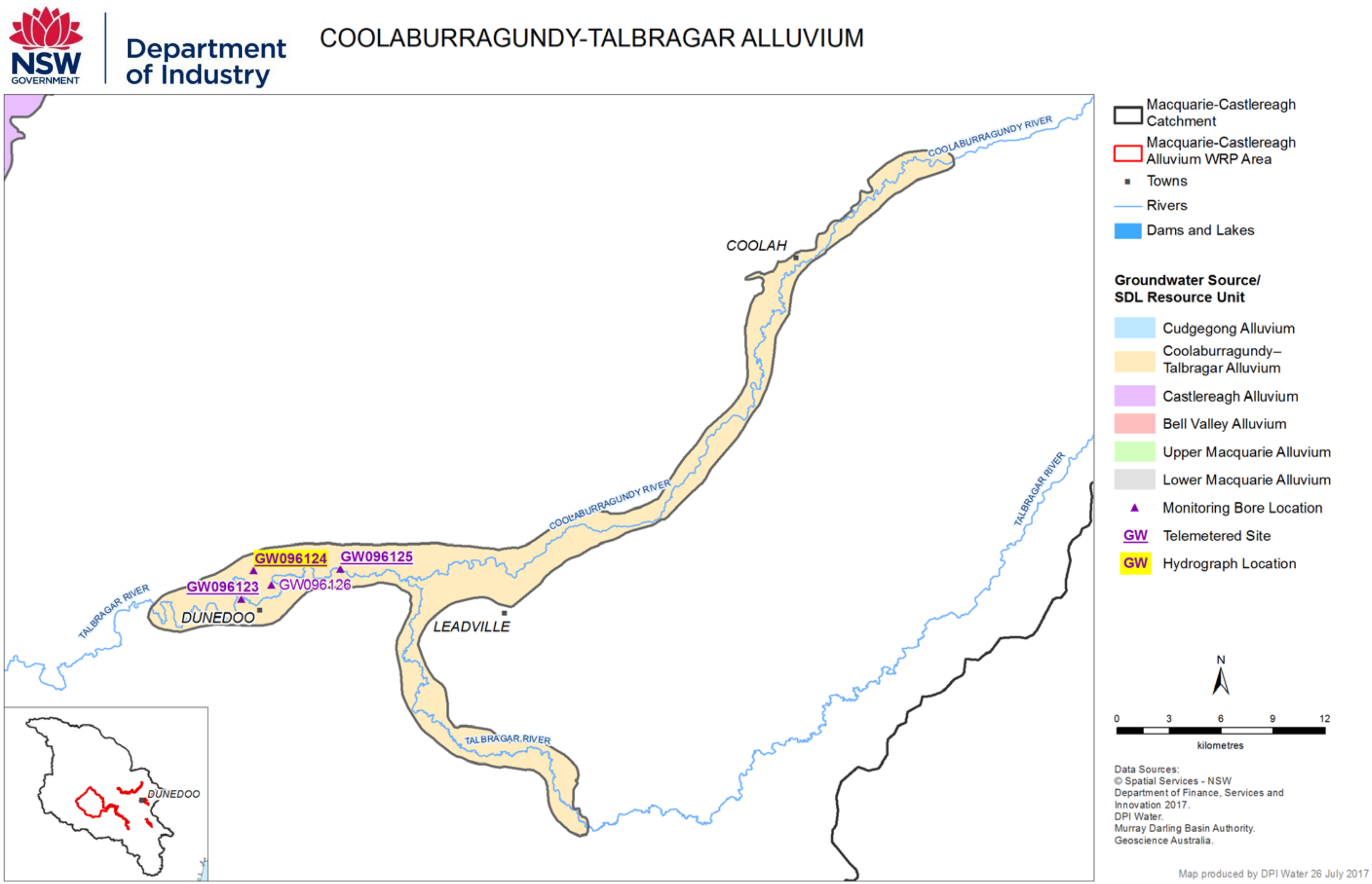

Figure 81 Location map of monitoring bores in the Coolaburragundy-Talbragar Alluvium

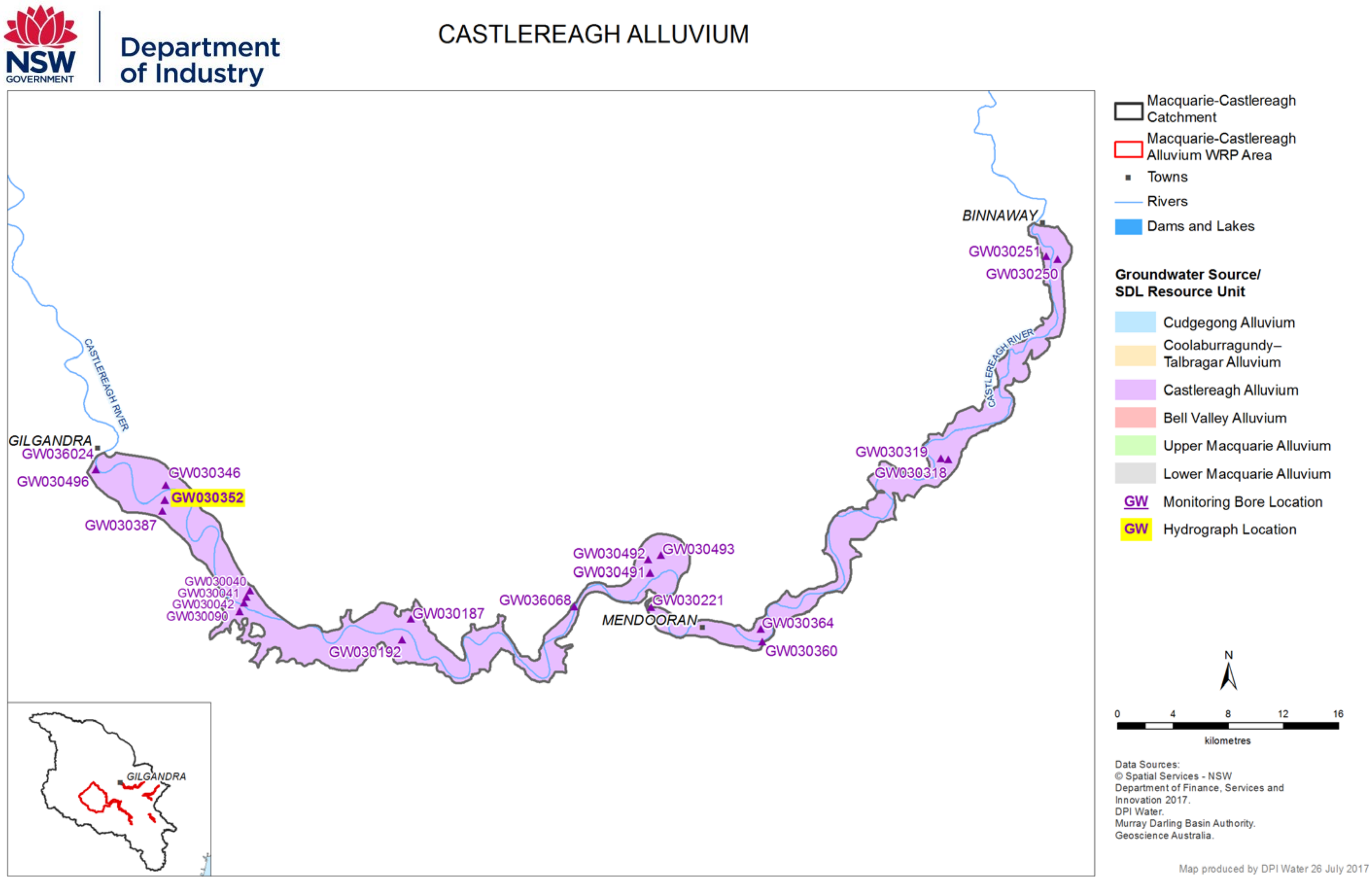

Figure 82 Location map of monitoring bores in the Castlereagh Alluvium

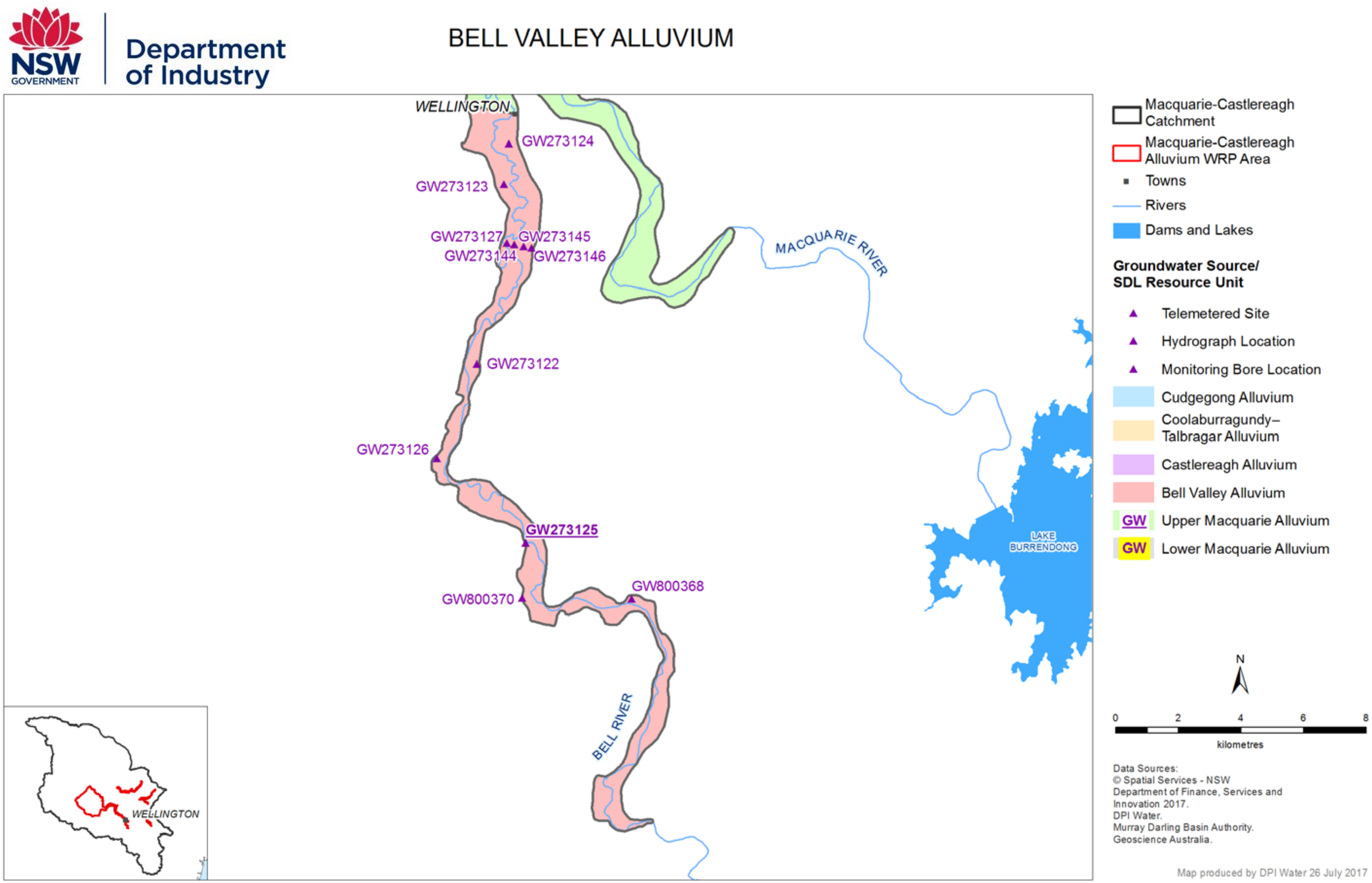

Figure 83 Location map of monitoring bores in the Bell Valley Alluvium

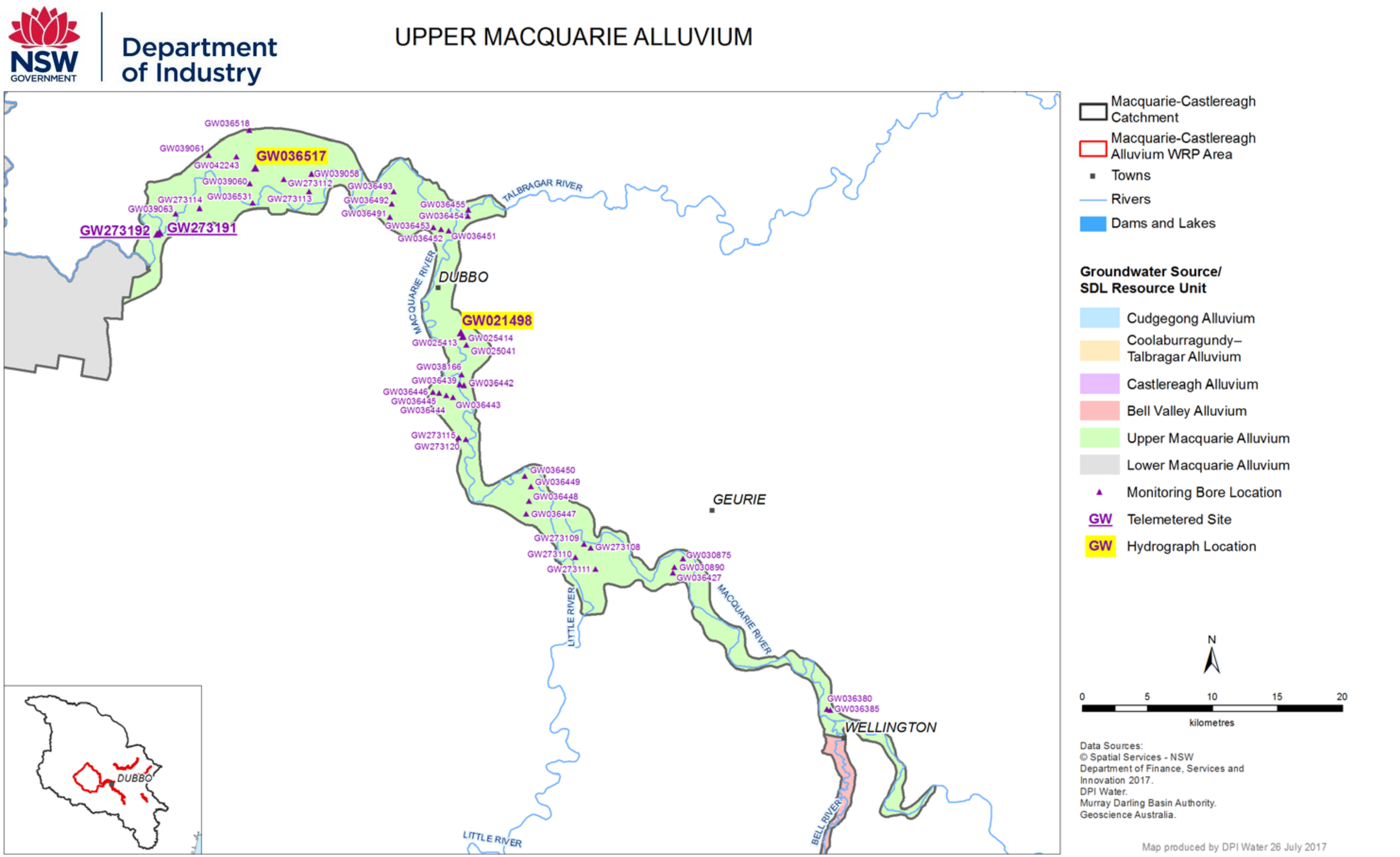

Figure 84 Location map of monitoring bores in the Upper Macquarie Alluvium

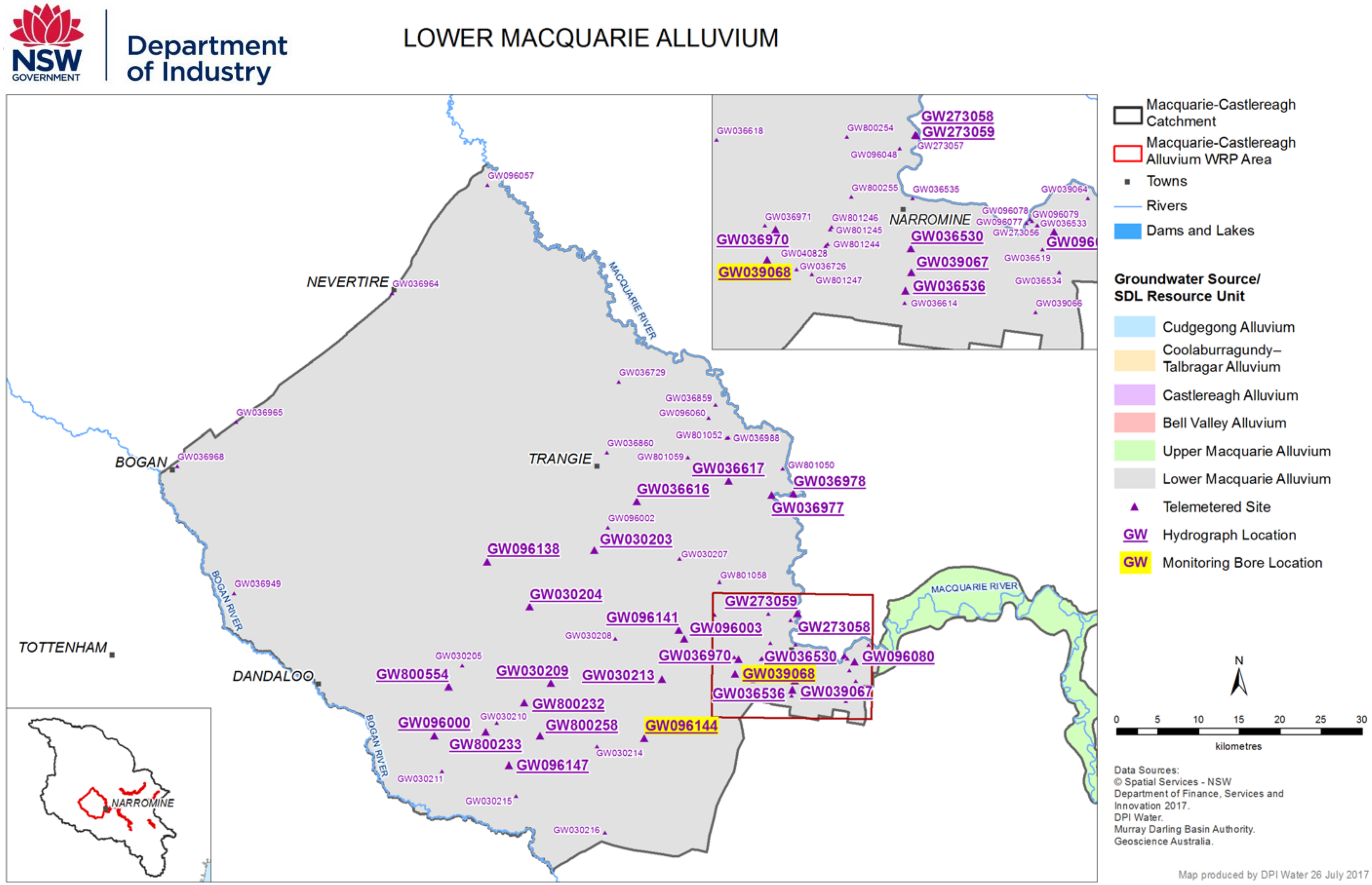

Figure 85 Location map of monitoring bores in the Lower Macquarie Alluvium