NAMOI ALLUVIUM WATER RESOURCE PLAN

Groundwater Resource Description

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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 water sharing rules applies.

[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.

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.
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

[4] As defined by Strategic Regional Land Use Plans

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

	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.

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

1. Introduction

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

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

The Namoi Alluvium Water Resource Plan area is shown in Map 1 and is located within the Namoi catchment that forms part of the Murray-Darling Basin in northern NSW. The Namoi catchment covers more than 42,000 km² and represents about four percent of the Murray-Darling Basin.

The groundwater resources of the Namoi Alluvium include all of the main alluvial deposits associated with the Namoi River and its tributaries. The Namoi Alluvium Water Resource Plan area extends from Chaffey Dam, north-west through Tamworth to Wee Waa and continues west to Walgett.

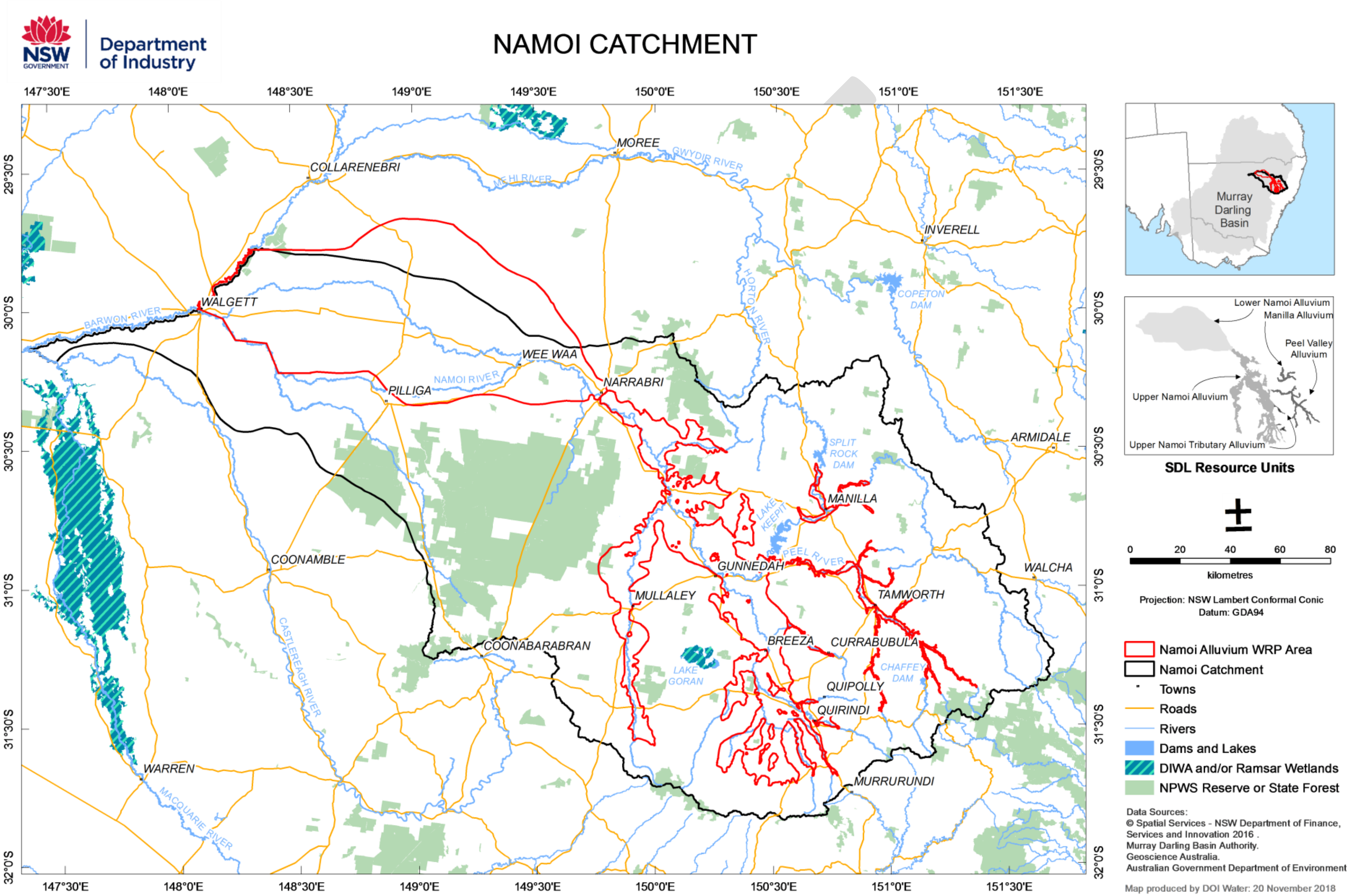
The Namoi Alluvium Water Resource Plan area (GW14 - Murray-Darling Basin reference number) is composed of five SDL resource units shown in Map 1, these are listed in Table 1 with their corresponding NSW groundwater sources:

Table 1 SDL resource units in the Namoi Alluvial Water Resource Plan area with their corresponding NSW groundwater sources

SDL Resource Units	Corresponding NSW Groundwater Source/s*
Peel Valley Alluvium (GS40)	Peel Alluvium
Manilla Alluvium (GS30)	Manilla Alluvial
Upper Namoi Tributary Alluvium (GS48)	Currabubula Alluvial, Quipolly Alluvial and Quirindi Alluvial
Upper Namoi Alluvium (GS47)	Upper Namoi Zones 1 to 12
Lower Namoi Alluvium (GS29)	Lower Namoi

* The fulling NSW groundwater sources information is given in Chapter 8.

This report describes the location, climate and physical attributes of the Namoi 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.



Map 1 Location of the Namoi Alluvium water resource plan Area and SDL Resource Units

2. History of Groundwater Management

2.1. Early groundwater management

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

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

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

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

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

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

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

2.2. NSW water reforms

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

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

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

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

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

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

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

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

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

2.3. Peel Valley Alluvium

Groundwater allocation for the Peel Alluvium was changed in 1983 from an unrestricted area-based licence to a volumetric-based policy. The maximum allocations per property for the alluvial sediments along the Peel upstream of Carroll Gap and along all tributaries were based on historical groundwater use or authorised area of 6 ML/ha up to a maximum property allocation of 486 ML/yr (O'Rourke, 2010).

In 1995 the Peel Alluvium was embargoed for new allocations greater than 19 ML/yr (O'Rourke, 2010).

In 2005 the volume of groundwater that could be extracted was linked to the announced surface water allocation for the regulated Peel River. These allocations were announced at the start of each water year. Announcement allocations could be varied over the water year as the surface water allocation changed with fluctuating Chaffey Dam levels (O'Rourke, 2010).

In June 2007, in response to the prevailing drought conditions at the time, an embargo was gazetted on any further applications for ground water licences in the Peel Valley Alluvium.

In December 2008, an embargo was gazetted on further applications for groundwater licences that included a number of groundwater sources across the Murray-Darling Basin in NSW. This embargo included the Peel Valley Alluvium and replaced the 2007 embargo. The 2008 embargo remained in place until the commencement of the *Water Sharing Plan for the Peel Valley Regulated, Unregulated, Alluvial and Fractured Rock Water Sources 2010*.

The *Water Sharing Plan for the Peel Valley Regulated, Unregulated, Alluvium and Fractured Rock Water Sources 2010* commenced on the 1st July 2010 and applies until the 30th June 2020.

2.4. Manilla Alluvium and Upper Namoi Tributary Alluvium

There has been little groundwater based development in the Manilla Alluvium and the Upper Namoi Tributary Alluvium. These areas were included in the 1983 state policy that introduced volumetric entitlements for all new high yielding bores and the progressive conversion of the earlier licences that were issued for a given area of irrigation.

These alluvial systems were part of the groundwater management area previously referred to as the 'Miscellaneous Alluvium of the Barwon Region'.

The Miscellaneous Alluvium of the Barwon Region was included in the 2008 embargo on new applications for groundwater licences that applied to a number of groundwater sources across the Murray-Darling Basin in NSW. This embargo remained in place until the commencement of the *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012*.

The Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012 commenced on the 4th October 2012 and applies until the 31st June 2023.

2.5. Upper and Lower Namoi Alluvium

There has been extensive groundwater based development in the Upper Namoi Alluvium and Lower Namoi Alluvium. Under the volumetric policy introduced in 1983 area-based and unrestricted licences were converted to volumetric entitlements on a property basis. In July 1995, the groundwater sources of the Upper and Lower Namoi were embargoed for new groundwater entitlement applications, with the exception of Upper Namoi Zone 6 management zone.

In March 1997, the first groundwater management plan for the Upper and Lower Namoi valleys was released, this implemented a 10% to 35% allocation reduction phased in over three years.

Applications for new bore licences were embargoed across the Namoi Valley in July 1999 (Sinclair *et al*, 2004).

The Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003 commenced on the 1st November 2006 and applied until the 30th June 2019.

3. Regional Setting

3.1. Topography

The Namoi catchment drains north-west from the Great Dividing Range in the north east. The eastern half of the catchment is bounded by the Nandewar ranges in the north and Liverpool and Warrumbungle ranges in the south with the floodplains of the Liverpool Plains following the Namoi River and its tributaries to Narrabri.

West of Narrabri the land flattens out to a riverine floodplain extending to where the Namoi River joins the Barwon River near Walgett as the western boundary of the catchment. Elevation ranges from approximately 1,500 m above sea level at the Great Dividing Range to around 100 m on the floodplain west of Narrabri (Map 2).

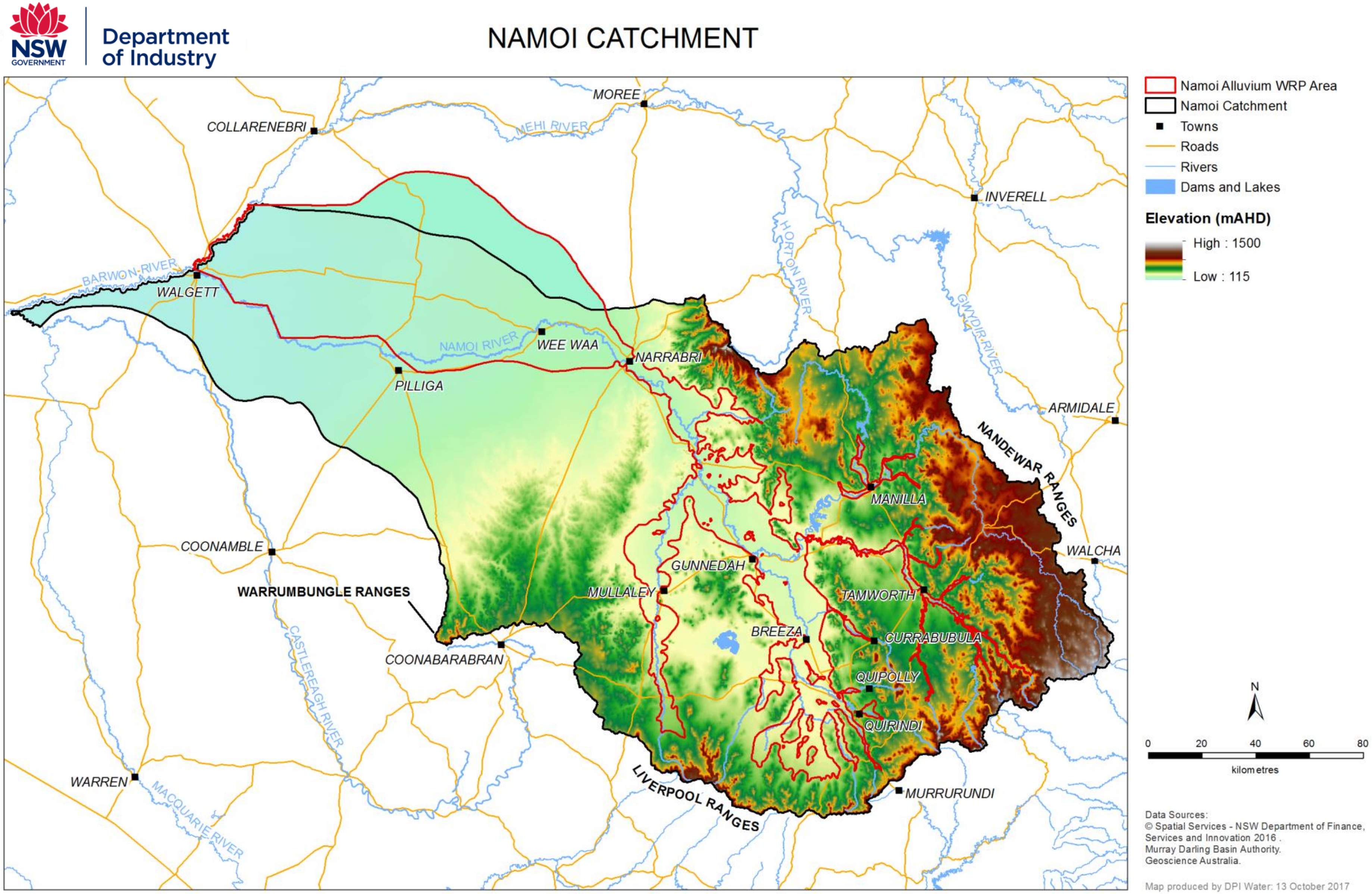
The major tributaries of the Namoi River upstream of Narrabri include the Coxs Creek and the Mooki, Peel, Manilla, and McDonald Rivers. Downstream of Narrabri, Baradine, Bohena and Pian Creeks flow into the Namoi River. Major tributaries of the Peel River are Goonoo Goonoo Creek, Cockburn River, and Dungowan Creek (Map 3).

Stream flows in the Namoi catchment are regulated by Keepit Dam on the Namoi River, Split Rock Dam on the Manilla River and Chaffey Dam on the Peel River. Keepit Dam was completed in 1960 as the major irrigation storage for the Namoi Catchment with a capacity of 425,000 megalitres (ML). Split Rock Dam (approximately 397,000 ML capacity), was completed in 1987 to augment the supply from Keepit Dam as well as supplying users along the Manilla River.

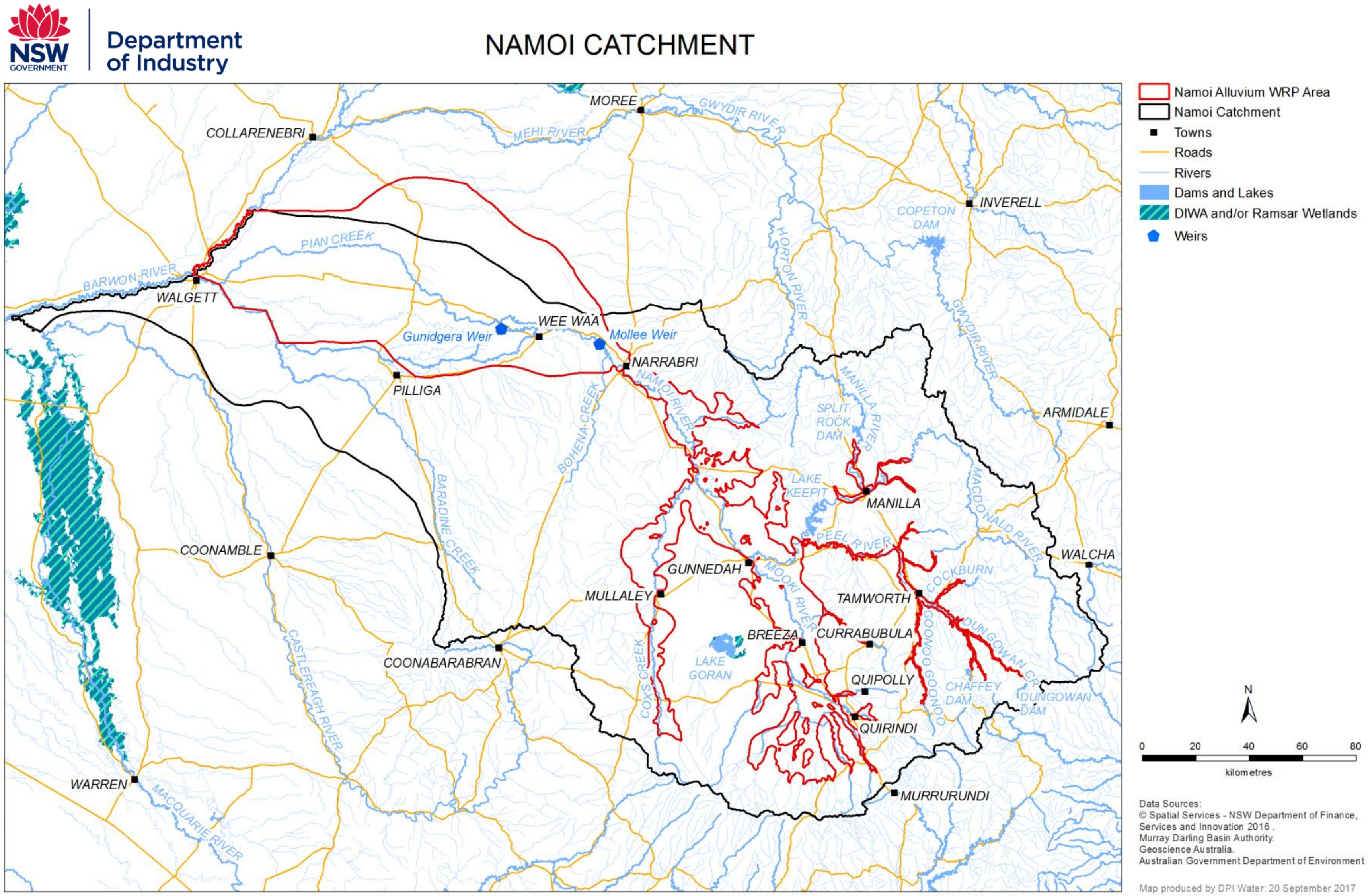
Chaffey Dam, about 45 km south-east of Tamworth, was completed with a capacity of approximately 62,000 ML in 1980 to regulate the flow of the Peel River and augment water supply to Tamworth. Chaffey Dam was augmented in 2016 to a capacity of 100,000 ML. The Tamworth water supply is supplemented by the Dungowan Dam of 6,300 ML capacity, which was completed in 1958 as the first major water storage facility for Tamworth. Dungowan Dam is located on Dungowan Creek at the eastern edge of the catchment.

Water regulation for irrigation, stock and domestic users in the lower Namoi River, downstream of Narrabri, is managed via the Mollee and Gunidgera Weirs of 3,300 ML and 1,900 ML storage capacity, respectively, as well as several small weirs on Pian and Gunidgera Creeks, which are anabranches of the Namoi River.

A detailed description of the catchment's surface water systems is provided in the Namoi Water Resource Plan Surface Water Resource Description (DPI Water 2017, Draft).



Map 2 Topography and elevation map of the Namoi catchment (Gallant *et al*, 2009)



Map 3 Surface water map of the Namoi catchment

3.2. Climate

The Namoi catchment has a temperate to sub-tropical climate, with a considerable gradient from east (cooler and wetter) to west (hotter and drier).

The temperature extremes across the Namoi catchment can range from -5 °Celsius (C) in the winter to 49 °C in the summer. Average maximum temperature is 26 °C and average minimum 11 °C. The average temperature of the Namoi catchment increases about 2 - 3 °C from east to west.

Rainfall is generally summer dominant with the heaviest rainfall occurring from October to February (Figure 1). Summer rainfall is typically 70 - 90 mm per month at Tamworth and about 45 - 70 mm per month at Walgett.

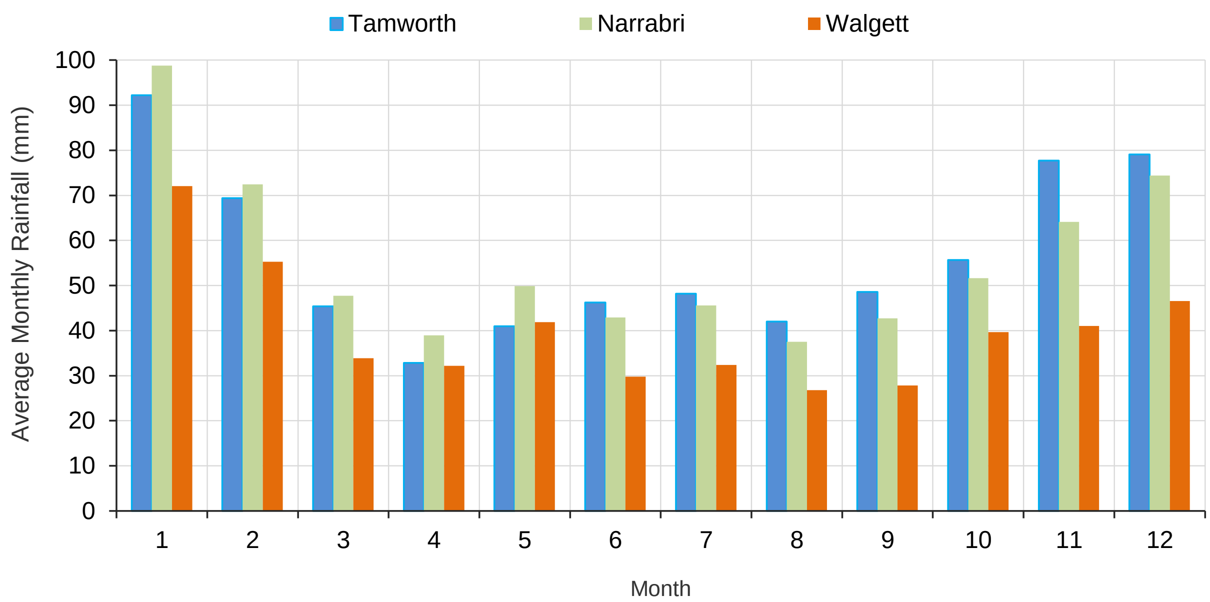
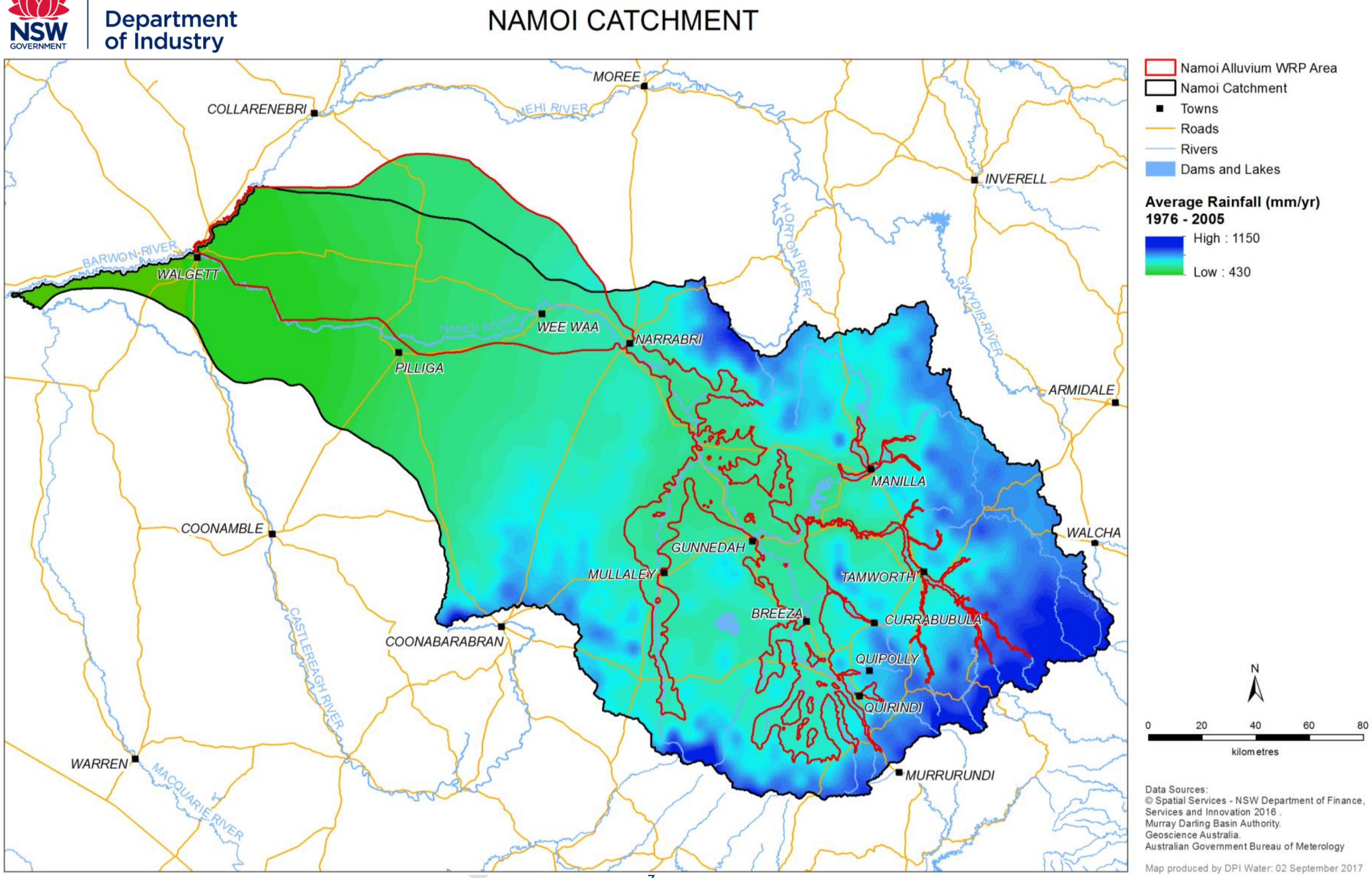


Figure 1 Average monthly rainfall 1967 - 2016 for Tamworth, Narrabri and Walgett. This period corresponds to the period of record for groundwater monitoring within the Namoi Alluvium.

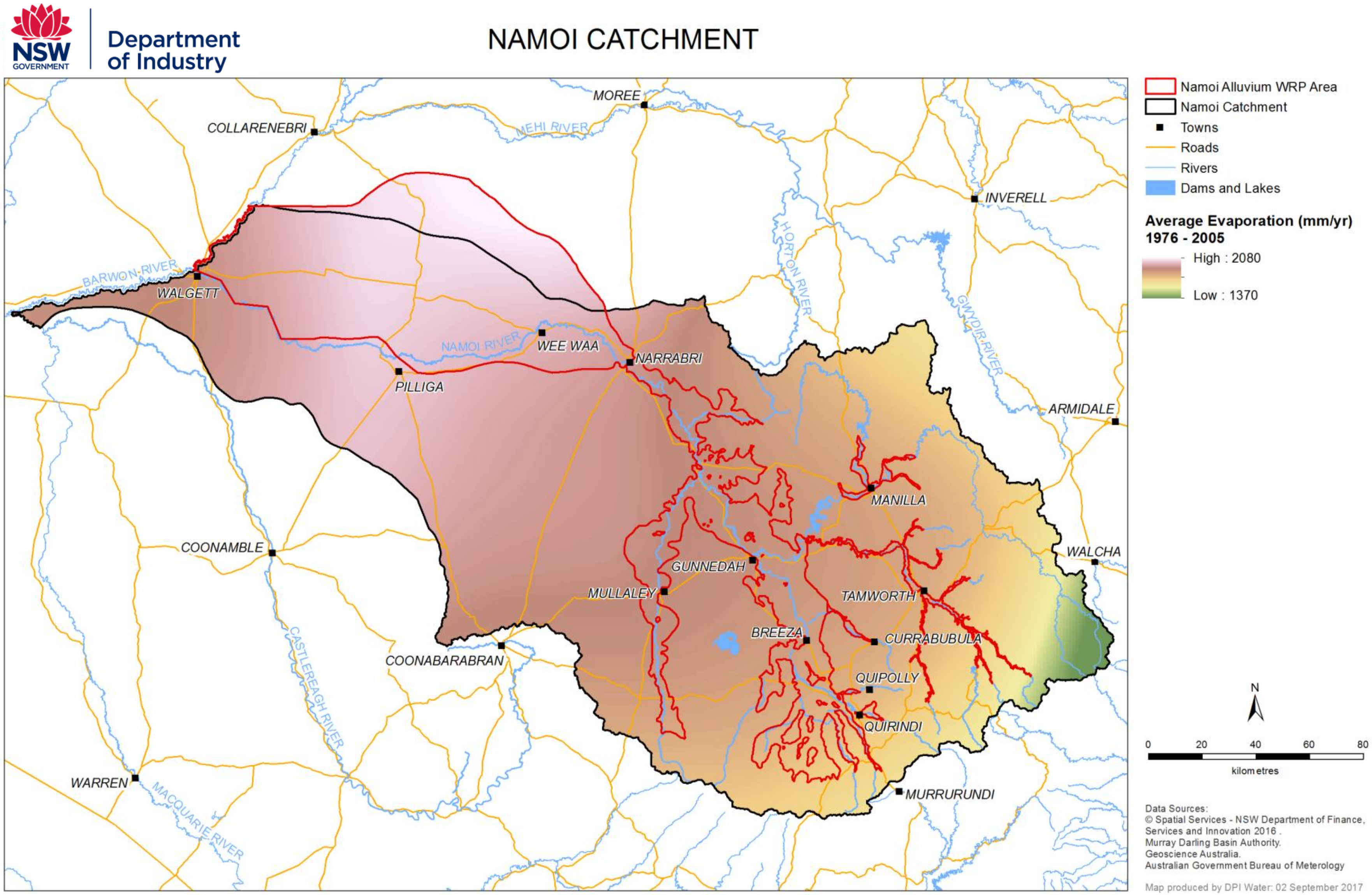
Average annual rainfall varies from about 1,150 millimetres (mm) at the top of the catchment to about 450 mm in the far west (Map 4). Tamworth, located in the Peel Alluvium, receives an average yearly rainfall of 668 mm while Walgett, in the Lower Namoi Alluvium, has an average rainfall of 474 mm per year.

Evaporation (Class A pan evaporation) in the Namoi catchment has a strong east-west gradient (Map 5). Yearly evaporation varies from around 1,000 mm at the top of the catchment to over 2,000 mm in the west.



Map 4 Average annual rainfall map of the Namoi 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.



Map 5 Average annual evaporation map of the Namoi catchment (BOM, 2008)[8]

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

Evaporation is strongly seasonal (Figure 2 varying from about 55 - 70 mm a month over winter (June/July) to about 245 – 280 mm per month over summer (December/January). Evaporation significantly exceeds average monthly rainfall over the year. The greatest exceedance occurs over the summer months (December/January), when at Walgett the average monthly evaporation of 280 mm coincides with as little as about 45 mm average monthly rainfall.

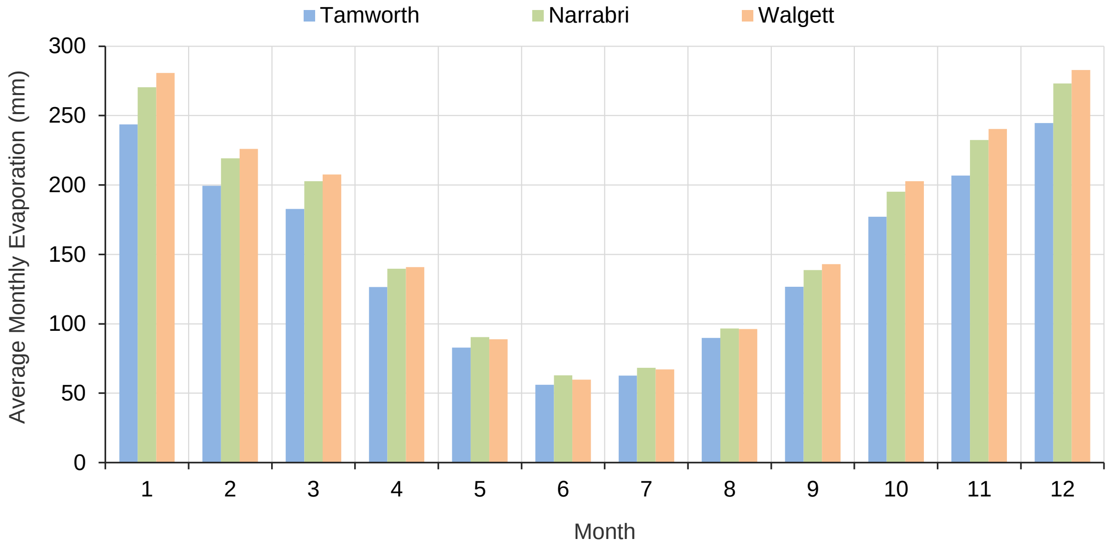


Figure 2 Average monthly evaporation 1974 ‑ 2016 for Tamworth, Narrabri and Walgett

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

The residual mass graph of average monthly rainfall from 1967 to 2016 at Tamworth, Narrabri and Walgett is displayed in Figure 3. This period corresponds to the period of groundwater monitoring in the Namoi Alluvium which commenced in 1967.

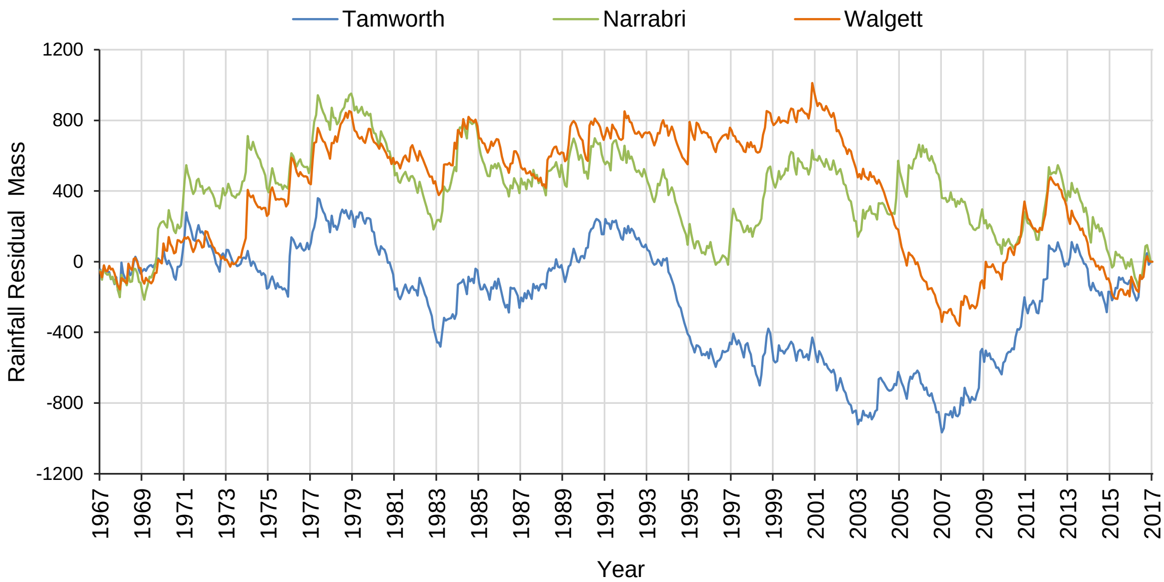


Figure 3 Rainfall residual mass graph 1967 – 2016 for Tamworth, Narrabri and Walgett

Below average rainfall trends during the droughts of 1982-1983, 1993-1995, 2002-2003, 2006-2007 and 2013-2015 (Figure 3), specific occurrence and duration of these events differs over the

Namoi Catchment. Notably, the below average trend at Walgett persists over 2002 to 2007. A prominent above average rainfall trend is apparent for the 2010-2012 period.

3.3. Land use

The Gomeroi people were the original inhabitants of the Namoi catchment. The land and waters of the Namoi catchment contain places of deep significance to Indigenous people and are central to their spiritual and religious belief systems.

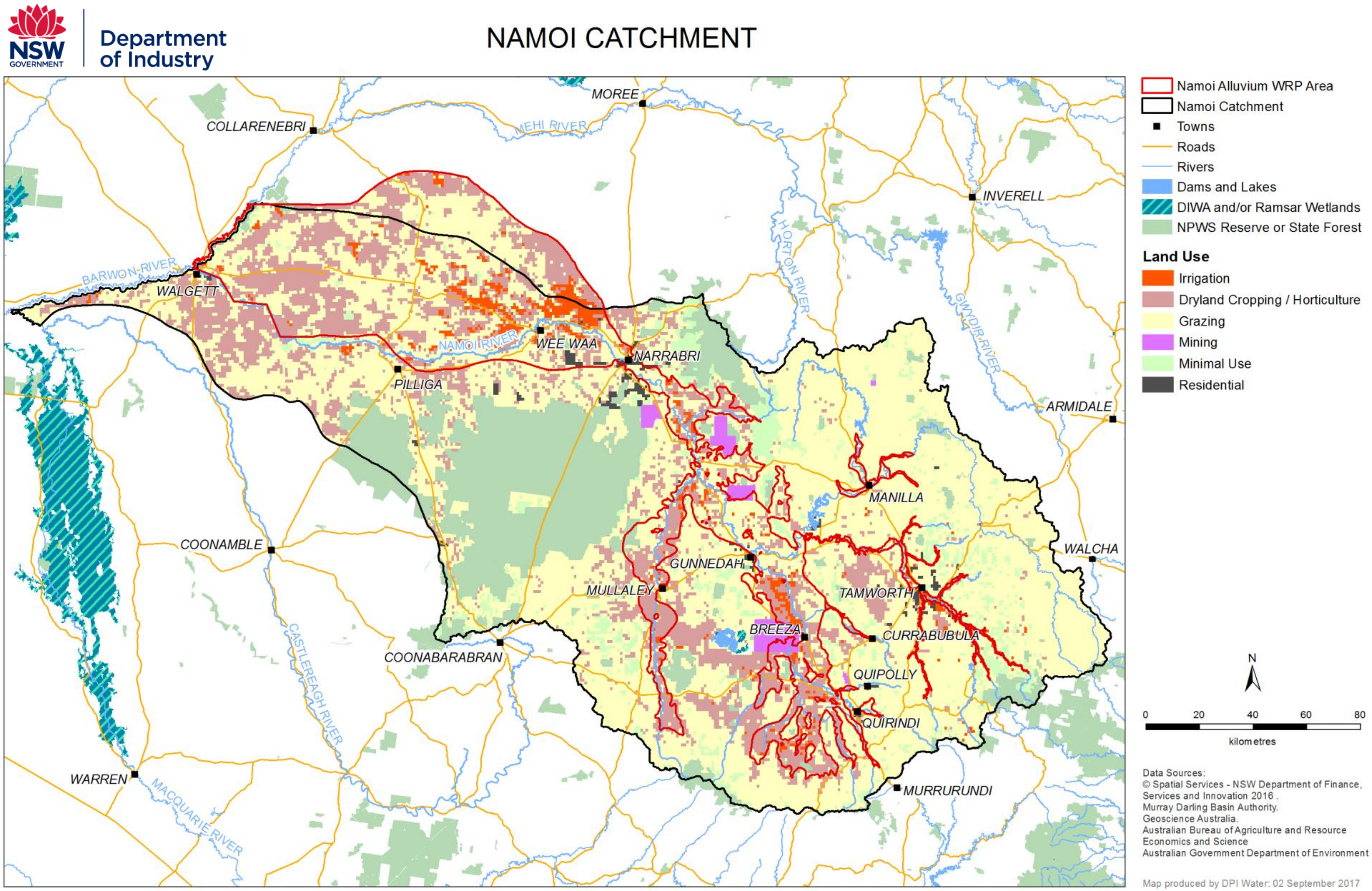
European settlement of the Namoi catchment commenced in the 1830s, primarily for sheep and cattle grazing and wool production. Dams were built in the 1960s to enable irrigation, which permitted the establishment of cotton production and ginning on the western plains. Coal has been mined since its discovery in the catchment in the 1870s. There is currently a proposal to develop coal seam gas production in the catchment.

Small areas of irrigated cropping occur on the heavy clay soils of the western half of the catchment and on the Liverpool Plains with the major crop being cotton. The greatest concentration of irrigation is around Wee Waa and Breeza. Other irrigated crops include wheat, cereals, oilseed and legumes in rotation with cotton. Water for irrigation is sourced from the alluvial groundwater resources and from surface sources such as the Pian and Gunidgera Creeks off the Namoi River. Lucerne production for hay is significant especially around Tamworth. Cattle and sheep grazing currently account for about 60 per cent of land use by area (Smart, 2016).

Broad areas of conservation land and forestry exist in the middle of the Namoi catchment to the south-west and east of Narrabri. Much of this area comprises the Pilliga Scrub, a significant area of remnant dry sclerophyll forest.

About 100,000 people live within the Namoi catchment, mostly along the Namoi River and its tributaries between Tamworth and Narrabri. Tamworth, located on the Peel River, is the largest urban centre in the catchment with a population of about 33,500 people. Gunnedah, on the Namoi River, has a population of 7,500 people, and Narrabri, also on the Namoi River, has a population of 6,100 people. A number of smaller towns throughout the catchment, such as Barraba, Manilla, Quirindi, Walgett, Wee Waa and Werris Creek, support between 1,000 and 3,000 people.

Land use information across the Namoi catchment based on the Australian Bureau of Agricultural and Resource Economics and Sciences 2010-2011 land use data (Smart, 2016) is shown in Map 6.



Map 6 Land use map of the Namoi catchment (Smart, 2016)

4. Geology

The surface geology of the Namoi Catchment comprises five main units namely the Palaeozoic New England Fold Belt, Palaeozoic to Mesozoic Gunnedah Basin, Mesozoic Great Artesian Basin (GAB), and unconsolidated sediments and Cenozoic extrusive volcanics (Map 7).

The New England Fold Belt is the oldest geology in the area and consists of sedimentary, metamorphic and igneous rocks. The New England Fold Belt is extensively faulted due to tectonic events around 200 million years ago.

The Gunnedah Basin is a sedimentary coal basin that outcrops in the middle of the Namoi Catchment. The basin comprises of conglomerate, sandstone, siltstone and claystone with coal-rich layers up to 18 m in thickness.

Sediments of the Great Artesian Basin (GAB) were deposited on and outcrop immediately to the west of the Gunnedah Basin outcrop.

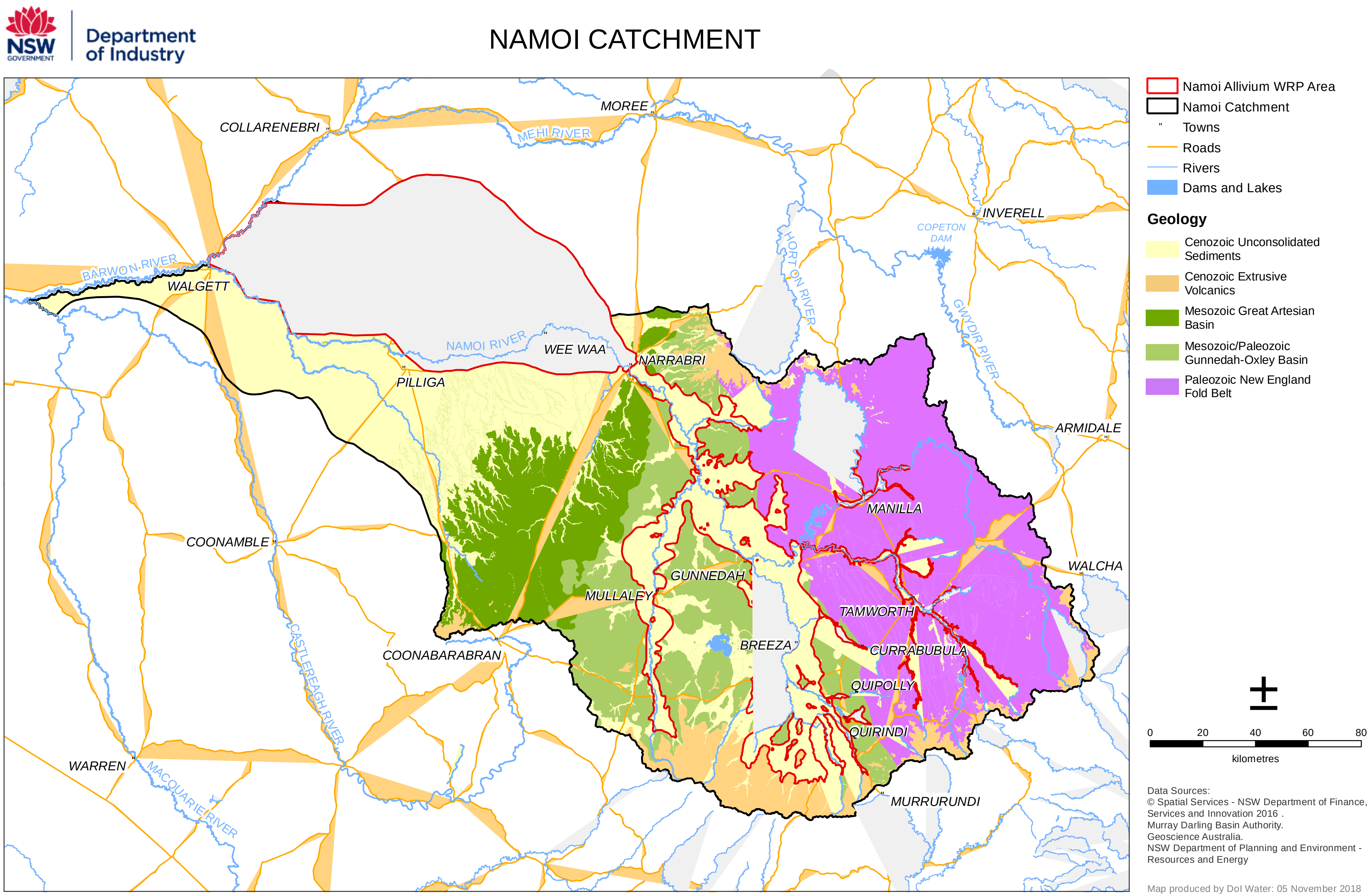
The GAB is one of the largest and deepest artesian basins in the world. It covers approximately 22% of Australia across four states including NSW, South Australia, the Northern Territory and Queensland and is a significant source of water in NSW.

The GAB is primarily made up of Mesozoic shales, conglomerates and sandstone. At its base are the volcanic rocks and intrusive plugs of the Garrawilla Volcanics.

The GAB is overlain by extensive Cenozoic unconsolidated sediments that cover the majority of the area west of Narrabri and include the Lower Namoi Alluvium. These sediments extend outside of the Namoi Catchment to cover the majority of north western NSW.

The Cenozoic sediments are made up of clay, silt, sand and gravel generally deposited by river systems (alluvial deposits) or as wash from hill slopes (colluvial deposits). These sediments also make up the Liverpool Plains and the narrow-valley fill associated with the Peel River.

The main peaks of the Namoi Catchment comprise Cenozoic extrusive volcanic rocks, predominantly basalt, which were erupted during widespread volcanic activity throughout the eastern part of the state over the last 65 million years. These rocks include the Liverpool Ranges, the Warrumbungle Volcanic Complex, and the Nandewar Volcanic field.



Map 7 Geology of the Namoi catchment

5. Hydrogeology

5.1. Regional Context

The Namoi Alluvium SDL resource units overly different porous or fractured rock SDL resource units with different levels of hydraulic connectivity between them; these are listed in Table 2.

Table 2 Namoi SDL resource units and their underlying water sources

SDL Resource Unit	Underlying SDL Resource Unit/
Peel Valley Alluvium	New England Fold Belt
Lower Namoi Alluvium	Great Artesian Basin (GAB) *
Manilla Alluvium	New England Fold Belt
Upper Namoi Tributary Alluvium	Gunnedah-Oxley Basin MDB
Upper Namoi Alluvium	Gunnedah-Oxley Basin MDB, GAB and New England Fold Belt

* The GAB is not part of the Murray Darling Basin.

The permeability of the New England Fold Belt and the Gunnedah-Oxley Basin is many orders of magnitude lower than that of the alluvium and groundwater exchange is expected to be insignificant. Consequently these fractured and porous rock systems are not considered hydraulically connected in a resource management sense to the groundwater resources in the alluvium.

The northern portion of Upper Namoi Alluvium and the entire Lower Namoi Alluvium sit over the GAB. East of Wee Waa the alluvium is in contact with sandstone units of the GAB and some degree of hydraulic connection with these units is expected.

There is very little groundwater extraction from the GAB in this area and consequently this extraction would not compromise water availability or access rights in the alluvium. Groundwater discharge from the GAB, which occurs naturally due to the greater hydraulic head in the GAB, was accounted for in the setting of the SDL for the Lower Namoi Alluvium.

In the north western area of the Upper Namoi Alluvium potential groundwater exchange with the GAB was not accounted as part of the SDL. The spatial distribution of this exchange is less well understood and recent drilling has indicated the GAB sandstone is dry below the base of the alluvium on the eastern margin of the GAB. The volume of groundwater exchange is expected to be insignificant with regard to impacts on water availability and access rights in either resource.

The Lower Namoi Alluvium west of Wee Waa sits over low permeability formations of the GAB and groundwater exchange is expected to be insignificant and is not considered hydraulically connected in a resource management sense.

There is no break in the sedimentation from the Upper Namoi Tributary Alluvium which adjoins the Upper Namoi Alluvium which in-turn is connected to the Lower Namoi Alluvium at its most northern extent. Consequently groundwater through flow is uninterrupted down-valley and there is hydraulic connection across contiguous boundaries of these SDL Resource units. However, constriction in groundwater movement exists where the bed-rock valley narrows, notably at the Upper Namoi Zone 4 and Zone 5 groundwater source boundary just north of Boggabri.

There is a bed-rock high between the Peel Valley Alluvium and the Upper Namoi Alluvium causing a constriction in groundwater movement and therefore restricted hydraulic connection. The Manilla Alluvium is hydraulically separated from the Upper Namoi Alluvium as the alluvium thins out and the river flows over the New England Fold before reaching the Upper Namoi Alluvium.

5.2. Peel Valley Alluvium

The Peel Valley Alluvium (Map 8) consists of unconsolidated Cenozoic valley-filling alluvial sediments associated with the Peel River and its tributaries the Cockburn River and the Attunga, Moore, Dungowan, Duncans and Goonoo Goonoo Creeks. The alluvium extends northwest along these systems to Carroll Gap where it meets the Namoi River Alluvium.

In total the alluvium spreads over 250 km^2 and exists as narrow, shallow deposits up to about three kilometres in width and 40 m in thickness. It comprises gravel, sand, silt and clay, including cobbles and boulders, and is generally overlain by one to five metres of clay-rich sediment (O'Rourke, 2010).

The alluvium is recharged by direct rainfall infiltration, river and creek leakage, and some side slope seepage. Groundwater levels fluctuate with rainfall and stream-flow events and are maintained along the regulated Peel River by leakage from the regulated river flows.

Groundwater flows down gradient parallel to the direction of the river or creek flow. The river and creeks also locally act as a drain for groundwater discharges from the alluvium. In areas where the alluvium is limited due to the geometry of the underlying bedrock, groundwater may continue to discharge base flows into the overlying streams in times of low rainfall. For example, near the lower end of the catchment where the alluvium becomes restricted, groundwater discharges back into the Peel River (O'Rourke, 2010).

Two north-south cross sections through the Peel Valley Alluvium that extend across the width of the water source are displayed in Figure 4. These sections highlight the very thin nature of this aquifer compared to the Upper and Lower Namoi Alluvium. The land surface and groundwater levels are relatively flat. Groundwater levels gradually rise subtly toward the rivers and intersect the Peel and Cockburn Rivers in response to direct aquifer recharge from the rivers.

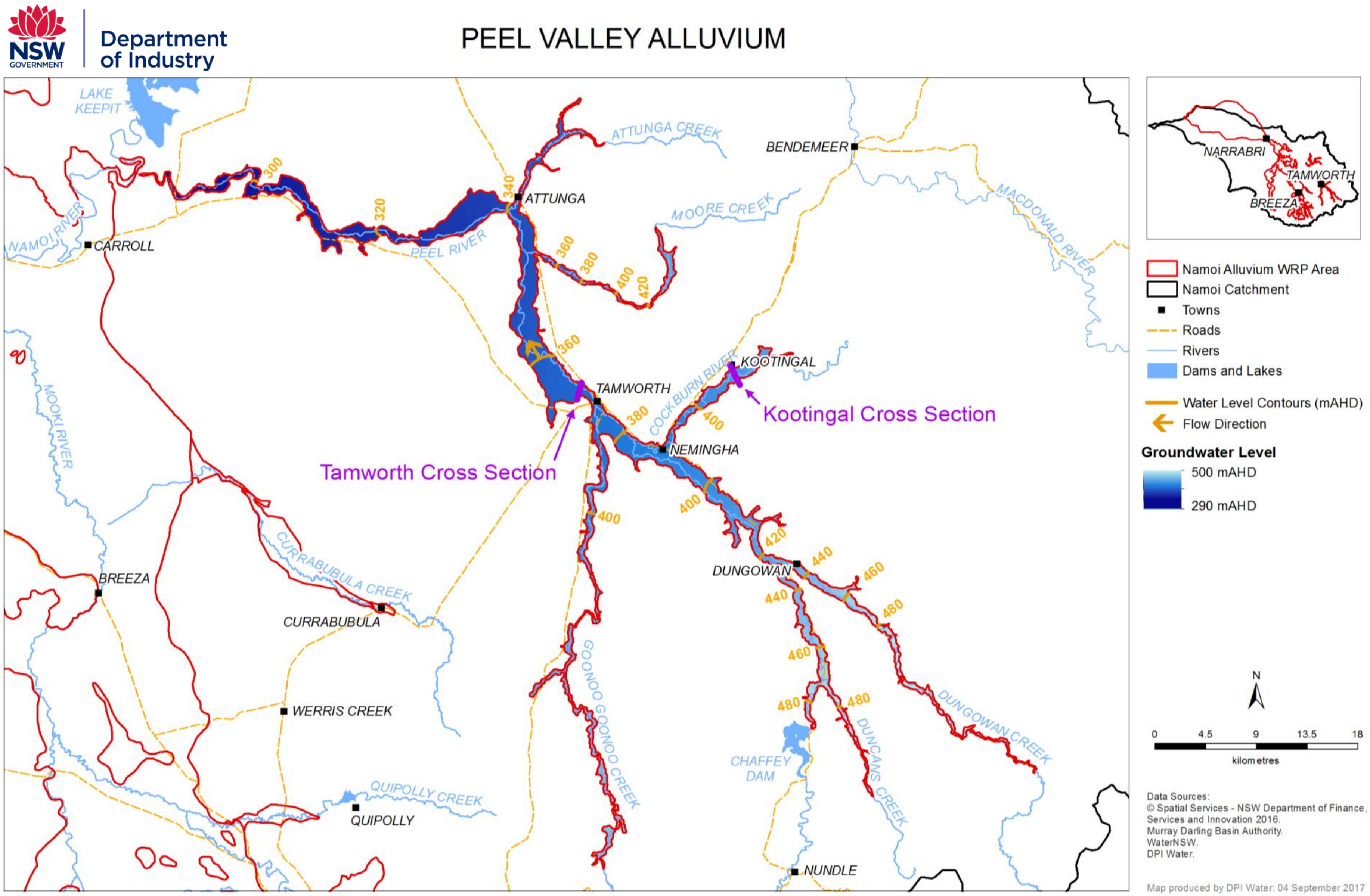
5.3. Manilla Alluvium and Upper Namoi Tributary Alluvium

The Manilla, Currabubula, Quipolly and Quirindi groundwater sources are discrete alluvial aquifers that are in hydraulic connection with overlying river and creek water sources.

These aquifers comprise unconsolidated Cenozoic gravel, sand, silt and clay. They range in width from 100 m to over one kilometre, with the Quirindi alluvium reaching up to 4.7 km. Their thickness varies from two metres in the thinnest part of the Quipolly alluvium up to a maximum of 20 m in the Currabubula and Manilla Alluvium (DPI Water, 2012).

These systems are recharged by direct rainfall infiltration, river and creek leakage, and some side slope seepage.

In the Manilla Alluvium, where stream flow is regulated from Split Rock Dam (and hence more reliable), groundwater often supplements surface water sources. Quipolly and Quirindi Alluvium, The streams associated with the Quipolly Alluvium and Quirindi Alluvium are non-perennial and more reliance is placed on groundwater.



Map 8 Location map Peel Valley Alluvium showing flow direction and cross section.

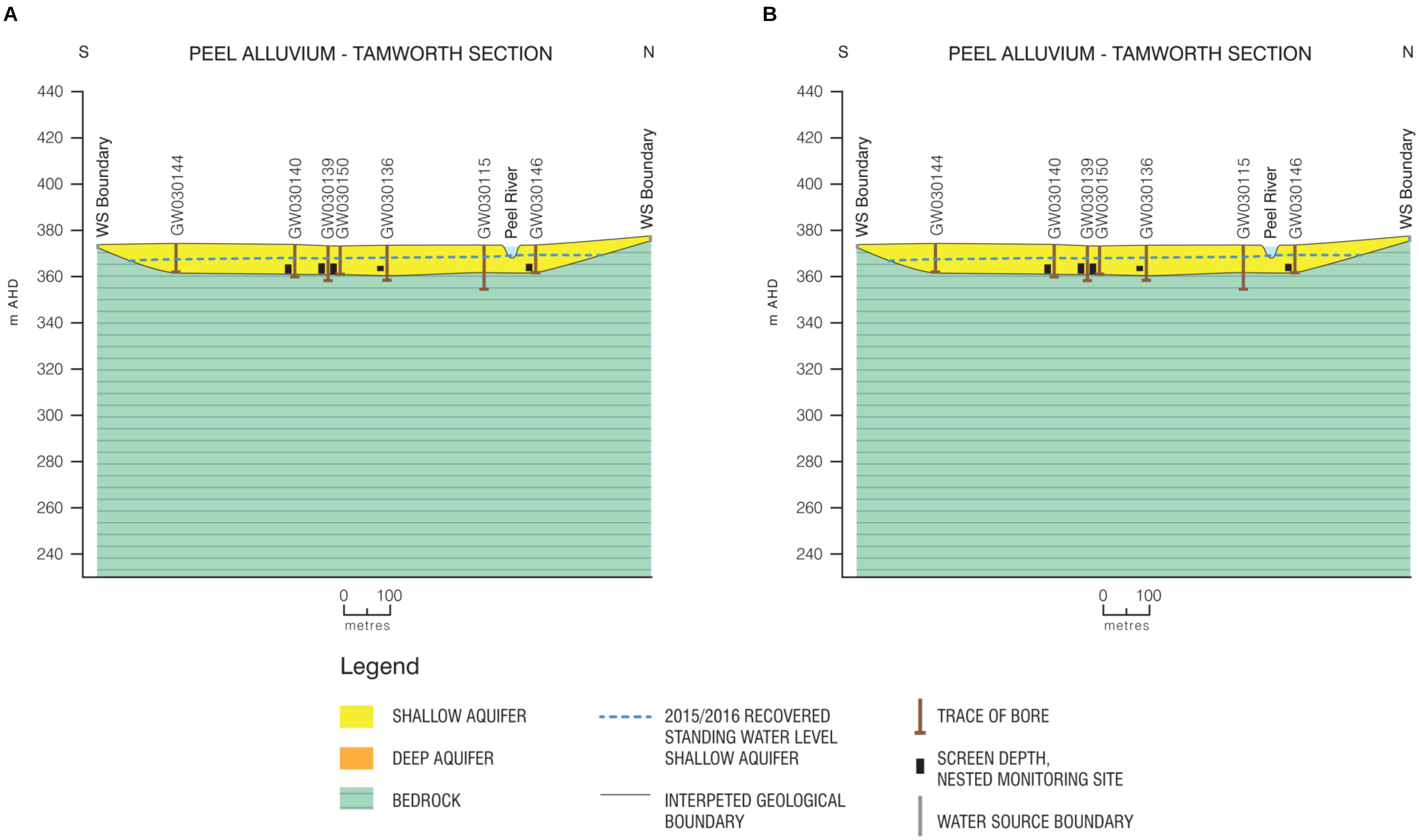


Figure 4 Peel Valley Alluvium north-south cross sections: (A) Tamworth, (B) Kootingal

5.4. Upper Namoi Alluvium

The Upper Namoi Alluvium (Map 9) consists of unconsolidated Cenozoic valley-filling alluvial sediments associated with the Namoi River and its tributaries the Mooki River and Cox's Creek.

The alluvium occupies an area of 3,800 km^2, extending about 175 km south from Narrabri (Green et al. 2011). The water bearing sands and gravels within the alluvial sediments of the Upper Namoi Alluvium are broadly divided into two main aquifer systems; a shallow aquifer system up to approximately 40 m deep, and a deep aquifer system up to a maximum of approximately 170 m combined depth depending on bedrock topography (Barrett, 2012).

There is no laterally continuous horizon or marker layer to define a distinct boundary between the shallow and deep systems, however where the boundary occurs, the shallow system is generally separated from the deep system by a relatively impermeable clayey layer of variable thickness.

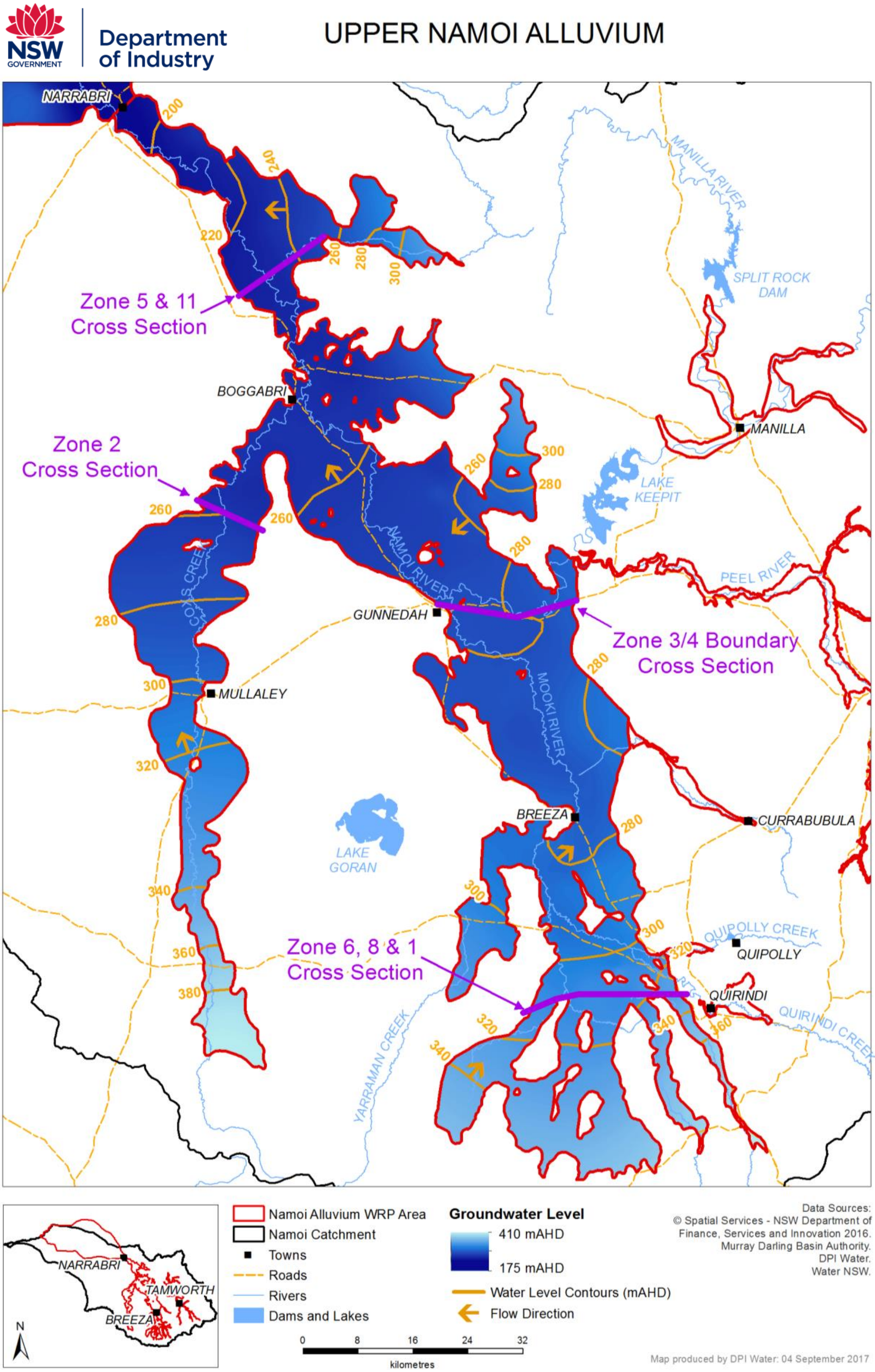
Within each system there may be more than one aquifer which varies in thickness and in lateral and longitudinal extent. The shallow, mainly unconfined aquifer system is informally referred to as the 'Narrabri formation' and the deeper confined/semi confined aquifer system is informally referred to as the 'Gunnedah formation'[9].

Groundwater flow is generally northward (Map 9) and drains into the Lower Namoi Alluvium through a bedrock constriction north of Narrabri.

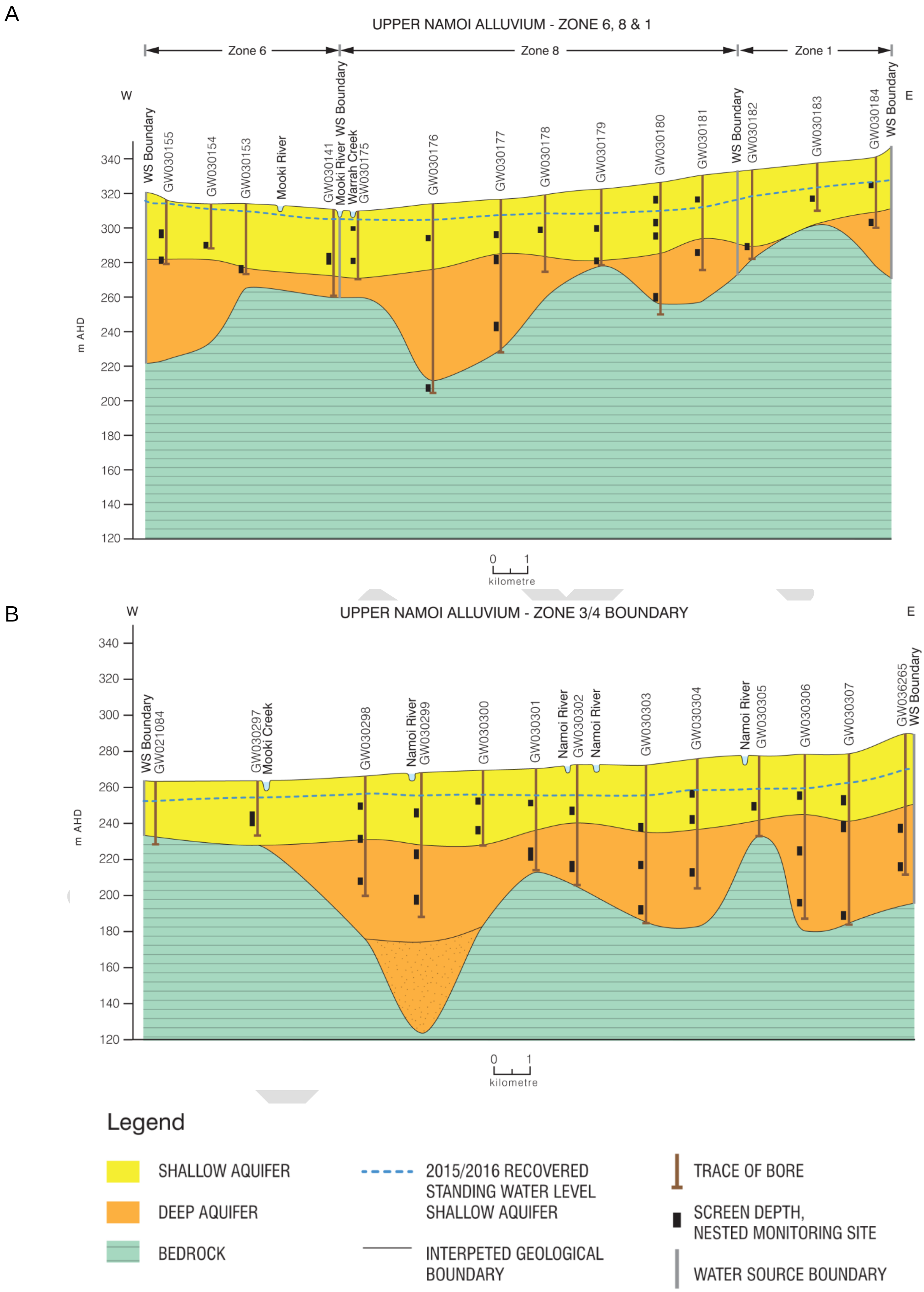
Conceptually the dominant recharge process for the Upper Namoi Alluvium is via rainfall, flood infiltration and river leakage, irrigation, through flow from surrounding aquifers, and the upward leakage of groundwater from the underlying rock aquifers (DLWC 1997; Salotti 1997).

The main discharge in the Upper Namoi Alluvium is extraction for irrigation. Other sources of discharge are base flow to rivers and through flow towards the north. Cross sections for the Upper Namoi Alluvium are displayed in Figure 5 and 6.

[9] The 'Narrabri formation' and 'Gunnedah formation' are not recognised as official formation names by the Australian Stratigraphic Commission.

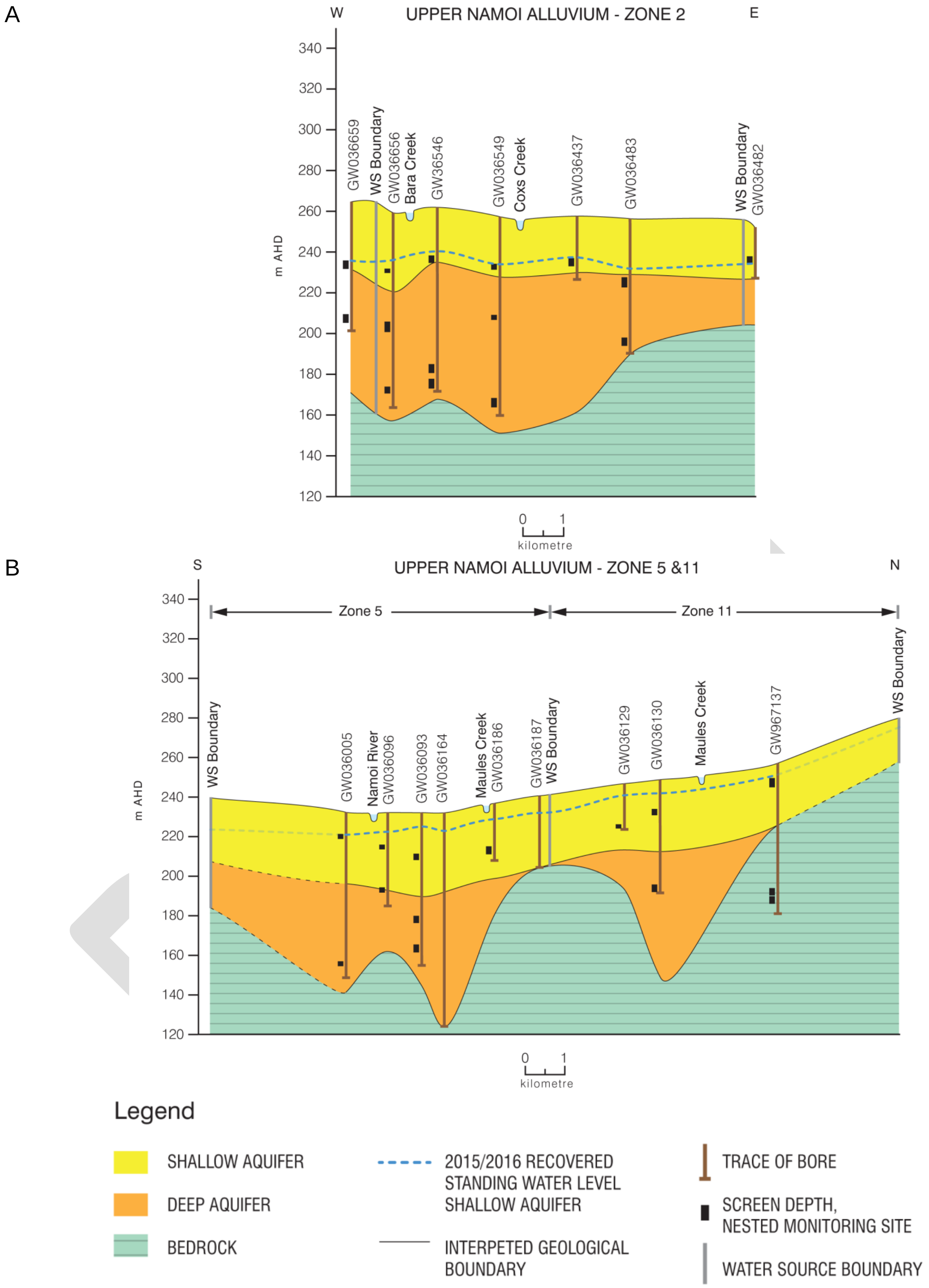


Map 9 Location map of the Upper Namoi Alluvium showing groundwater flow direction in the shallow aquifer system



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

Figure 5 Upper Namoi Alluvium east-west cross sections (A) Zones 6, 8 and 10, (B) Boundary between Zones 3 and 4. Note the palaeochannel is displayed in (B) shown as textured orange beneath bore GW030299.



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

Figure 6 Upper Namoi Alluvium east-west and north-south cross sections (A) Zone 2, (B) Zone 5 and 11

5.5. Lower Namoi Alluvium

The Lower Namoi Alluvium (Map 10) consists of unconsolidated Cenozoic sediments deposited as an extensive alluvial fan by the Namoi River and its tributaries. The alluvium extends approximately 160 km west from Narrabri to beyond Walgett and covers an area of about 7,630 km^2 (WRC, 1986).

Similar to the Upper Namoi Alluvium, the water bearing sands and gravels within the alluvial sediments of the Lower Namoi Alluvium are broadly divided into two main aquifer systems; a shallow aquifer system up to approximately 40 m deep, and a deep aquifer system up to 90m to a maximum of approximately 120 m deep depending on bedrock topography (Kalaitzis *et al*, 2000).

A palaeochannel (considered part of the ‘deep system’) extends about 60 km north-west from Narrabri and then curves around to cross beneath the existing Namoi River east of Walgett. The palaeochannel is constricted by a bedrock high north-west of Wee Waa.

As with the Upper Namoi Alluvium there is no laterally continuous horizon or marker layer to define a distinct boundary between the shallow and deep systems, however where the boundary occurs, the shallow system is generally separated from the deep system by a relatively impermeable clayey layer of variable thickness.

Within each system there may be more than one aquifer which varies in thickness and in lateral and longitudinal extent. The shallow, mainly unconfined aquifer is informally referred to as the ‘Narrabri formation’ and the deeper confined/semi confined aquifer is informally referred to as the ‘Gunnedah formation’ and the ‘Cubbaroo formation’[10], reiterating.

Groundwater flow is generally westward (Map 10). The highest bore yields are between Narrabri through to Burren Junction. The bore yields are lower in the west and far south of the system as the sediments contain more clay and less sand and gravel in these areas Kalaitzis *et al*, 2000).

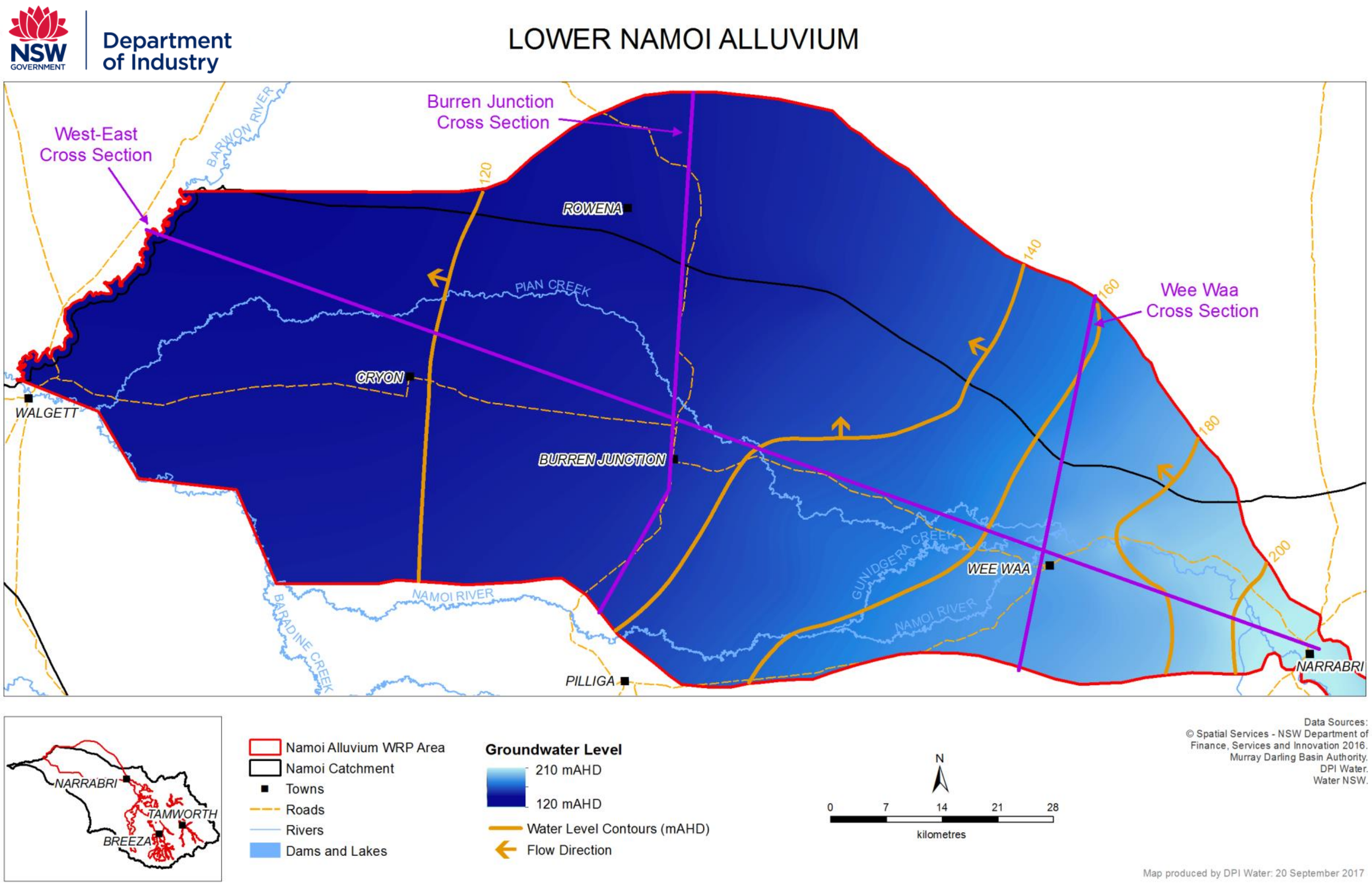
Conceptually the dominant recharge process for the Lower Namoi Alluvium is via rainfall, flood infiltration and river leakage, irrigation, through flow from surrounding aquifers. There is also upward leakage from the underlying Great Artesian Basin east of Wee Waa into the alluvium (Merrick, 1999).

Figure 7 shows an east-west cross section through the Lower Namoi Alluvium that extends across the entire length of the water source, and Figure 8 shows two north-south sections through Wee Waa and Burren Junction. The location of the cross sections are shown in Map 10.

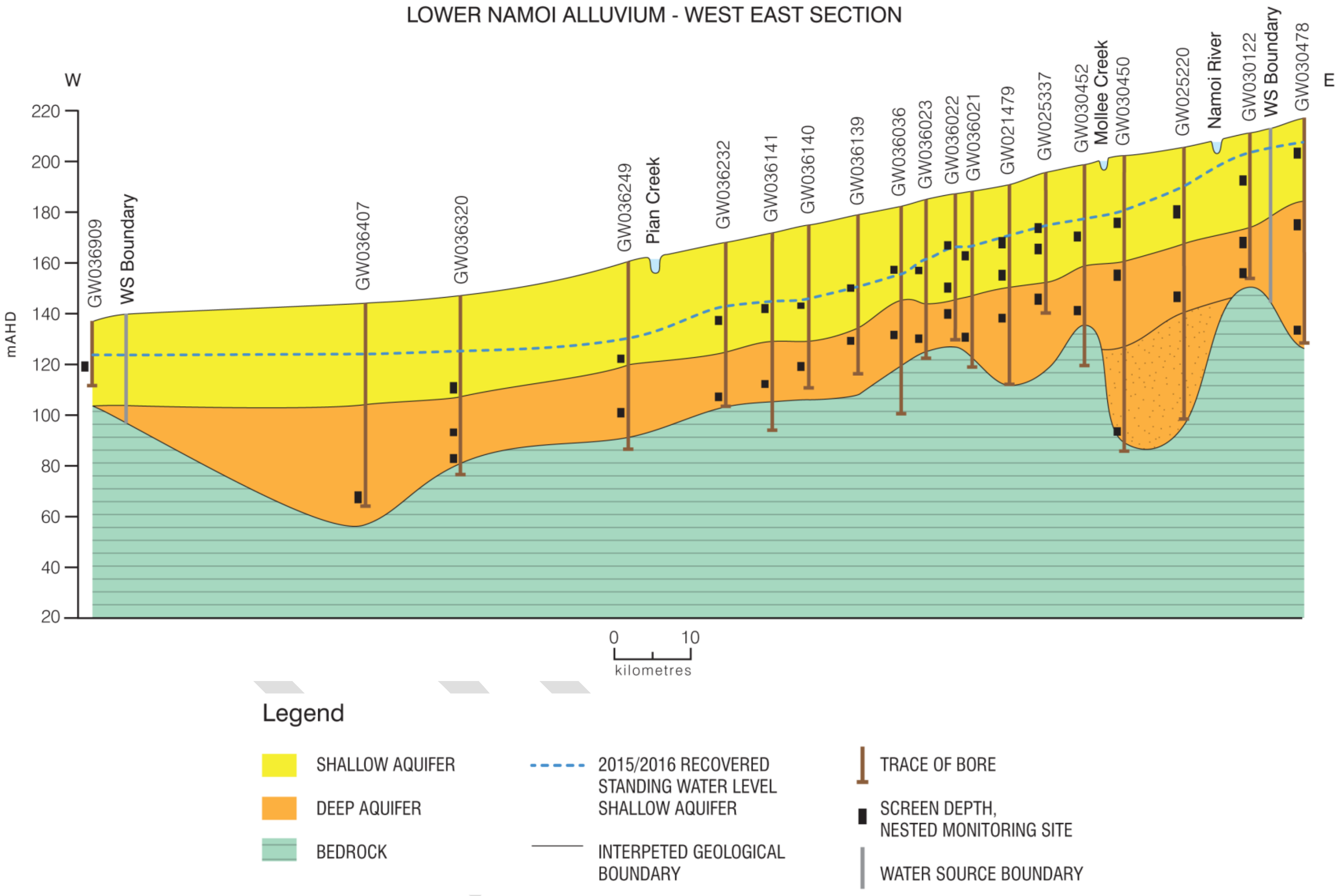
Figure 7 shows the groundwater flow direction is towards the west as the water level deepens toward Pian Creek. Beyond Pian Creek, the slope of the landscape decreases and the groundwater level accordingly becomes shallower.

Figure 8A shows that the aquifer systems and groundwater level locally deepen considerably to the north of the bedrock high where the palaeochannel occurs. This is due to the lack of recharge and historic groundwater extraction in this area and to the east.

[10] The ‘Narrabri formation’, ‘Gunnedah formation’ and ‘Cubbaroo formation’ are not recognised as official formation names by the Australian Stratigraphic Commission.

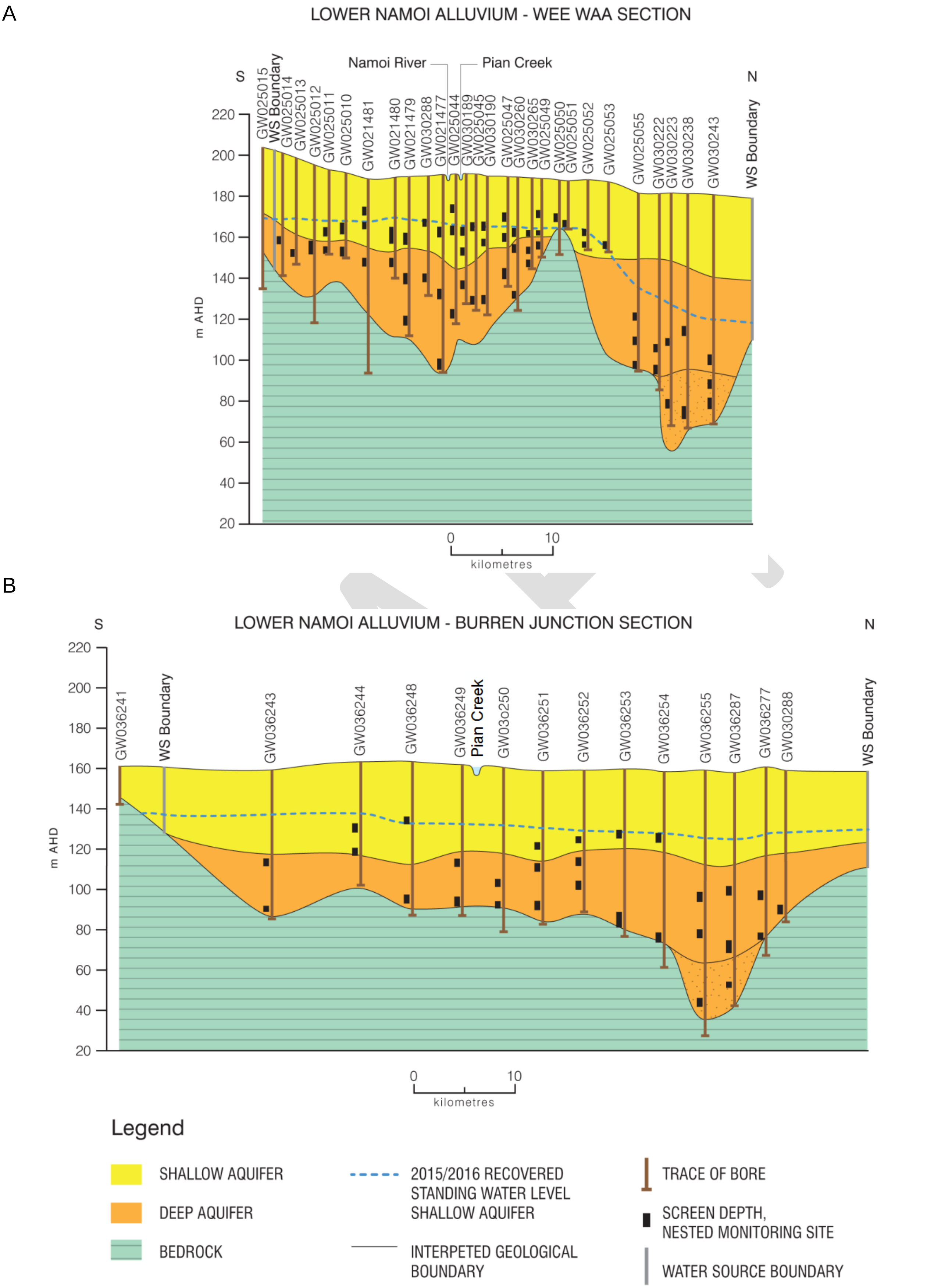


Map 10 Location map Lower Namoi Alluvium showing groundwater flow direction in the shallow aquifer system



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

Figure 7 Lower Namoi Alluvium east-west cross section. Note the palaeochannel shown as textured orange beneath bore GW030450.



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

Figure 8 Lower Namoi Alluvium north-south cross sections: (A) Wee Waa section, (B) Burren Junction section. Note the palaeochannel is displayed in (A) shown as textured orange beneath bore GW030223, (B) beneath GW036255.

5.5.1. Structural Integrity

Compaction can occur when groundwater is removed by pumping or drainage from highly compressible sediments (Galloway and Sneed 2013). The reduction of fluid pressure in the pores of unconsolidated sediments is inevitably accompanied by some deformation of the aquifer system. Both the aquifers and aquitards that constitute the groundwater system can undergo deformation, but to different degrees.

Typical aquifer sediments such as sand and gravel have low compressibility as their lower porosity and crystalline grains create a more structurally competent aquifer matrix that is less prone to deformation. Changes in aquifer pressure therefore have to be large before collapse of the aquifer matrix occurs. Conversely, typical aquitard sediments such as clay and silt have a higher porosity.

Compaction of sediments within an aquifer system can be either reversible or irreversible. Reversible compaction occurs in all aquifer systems to various extents in response to groundwater level changes. Seasonal discharge and recharge processes result in some compaction when groundwater levels are low, which is then fully recovered when groundwater levels increase again (Galloway et al.1999).

In the Lower Namoi between Narrabri and Merah North were the palaeochannel occurs, compaction and subsidence of the aquifer system occurred. The large scale groundwater extraction in the 1970’s and early 1980’s, resulting in subsidence of 70 mm to 210 mm over an area of up to 360 km^2 measure between 1981 and 1990 (Ross and Jeffery, 1991). Some bore collapses at the time were also attributed to this subsidence.

Subsidence is interpreted to have occurred due to the dewatering and subsequent compaction of aquifers and aquitards above the main deeper productive aquifers (which themselves occur mainly at depths below 60 m).

There is no known compaction and subsidence in the Upper Namoi Alluvium or the other SDL Resource Units in the Namoi Alluvium.

5.6. Connection with surface water

The Peel Regulated River Alluvium, Cockburn River Alluvium and Goonoo Goonoo Creek Alluvium management zones of the Peel Valley Alluvium as well as the Namoi and Manilla Regulated Rivers Alluvial Management Zone in the Manilla Alluvium are considered to be highly connected to their associated creek and rivers. The narrow and shallow nature of these systems mean it is likely to change between losing and gaining conditions along its length depending on geology, topography, and local conditions. This high level of hydraulic connection is recognised in their Water Sharing Plan rules.

The remainder of the management zones in the Manilla Alluvium and Peel Valley Alluvium and as well as the Upper Namoi Tributary Alluvium are also considered highly connected to surface water however these systems are ephemeral and therefore not managed as highly connected in the Water Sharing Plan.

Parts of the Upper Namoi Alluvium and Lower Namoi Alluvium are in varying degrees of hydraulic connection to surface water however this connection is not considered significant on a whole of water source scale, these systems are currently managed independently of the surface water sources however if assessed necessary local scale management options can be applied via Section 324 of the Water Management Act 2000 to address impacts on surface water from groundwater extraction.

6. Groundwater Dependent Ecosystems

Groundwater dependant ecosystems (GDEs) 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*' (after Richardson et al. 2011).

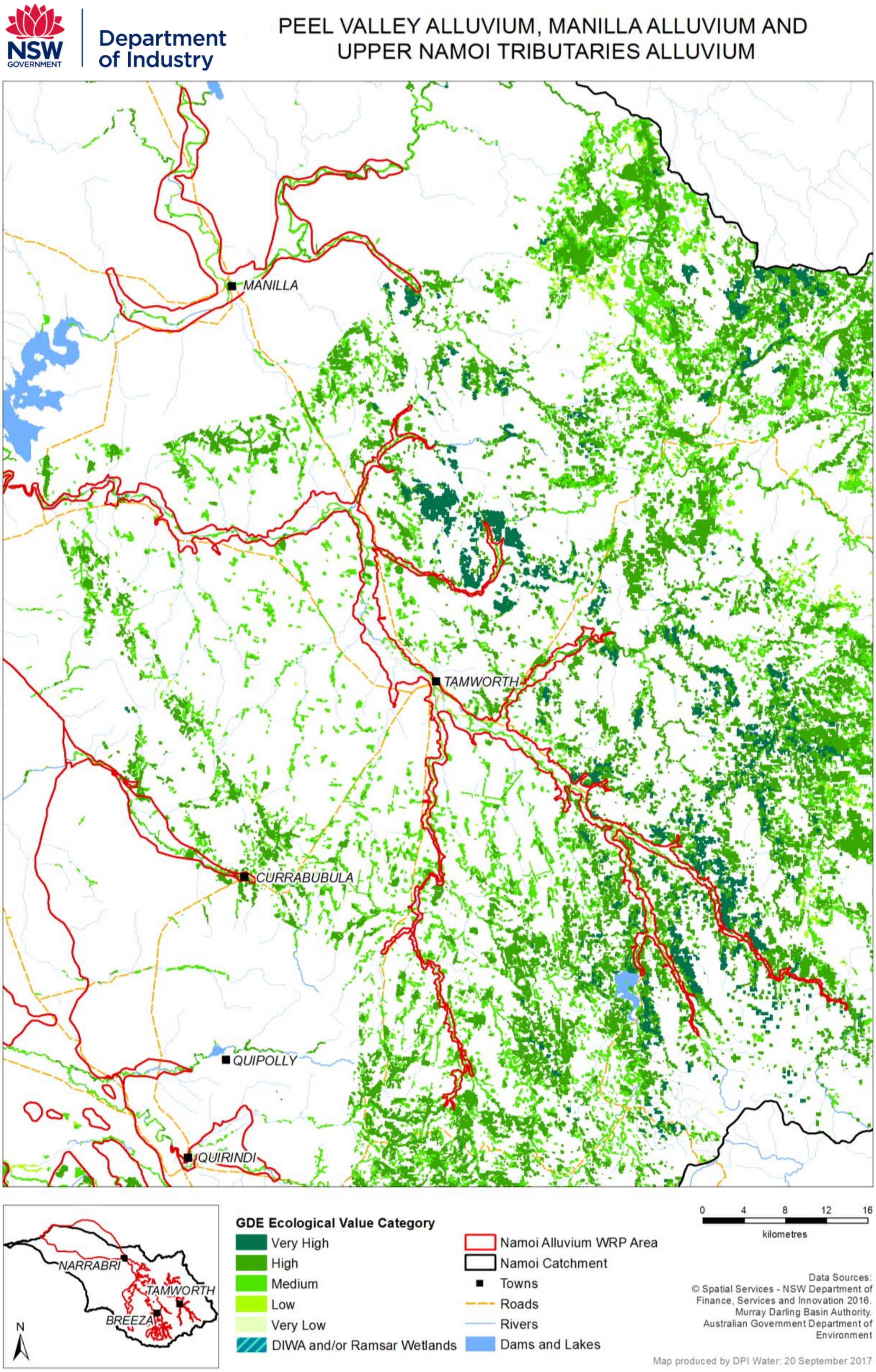
DoI Water has developed a method for the identification of high probability groundwater dependent vegetation ecosystems (Kuginis *et al*., 2016) and associated ecological value (Dabovic *et al*., in prep). This process has identified vegetation GDEs in the upper and lower parts of the Namoi Catchment.

Maps 11 and 12 show the determined ecological value of vegetation GDEs in the Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary Alluvium and the Upper Namoi Alluvium respectively. According to the mapping exercise, GDE ecological values in these areas showed a large proportion of medium and high values. These areas are known to have a high number of threated flora and fauna species and high habitat diversity for a range of species, especially of birds and mammals.

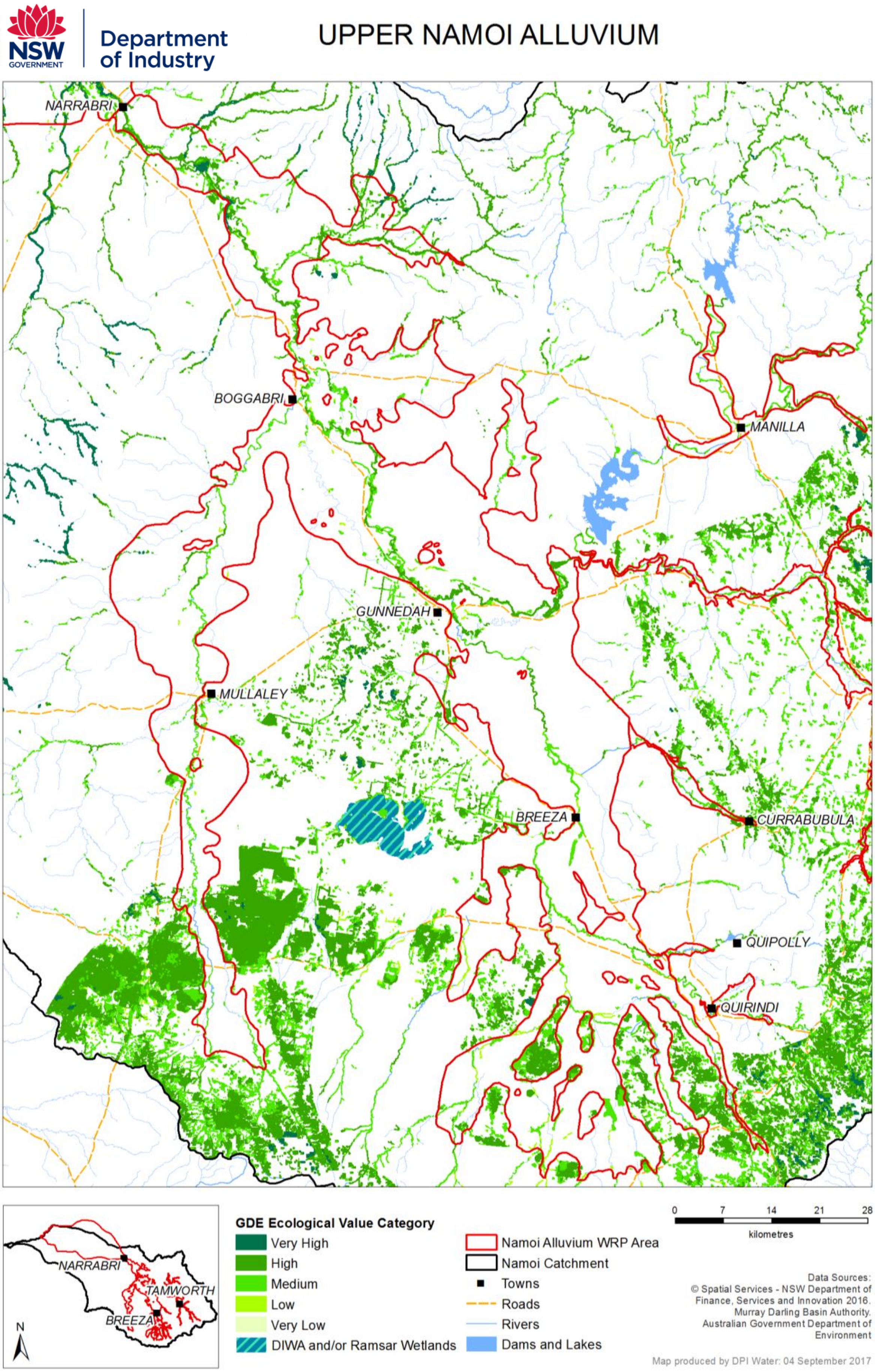
The dominant GDE vegetation communities include river red gum riparian woodland, black tea tree-river oak-Wilga riparian forest, poplar box-yellow box-western grey woodlands, shallow freshwater wetlands and river oak-rough barked apple-red gum-box riparian woodland (DPI Water, 2017).

GDE ecological values in the Lower Namoi Alluvium for high probability of existence GDEs (Map 13) have been classified as mainly high or very high. The method for GDE identification (Kuginis *et al*., 2016) identifies that this area is dominated by river red gum riparian and coolabah-river coobah-lignum woodland wetlands GDE communities. These communities are generally characterised by having a high number of threatened species, endangered ecological community, extensive connected riparian corridors and basin target vegetation species (MDBA, 2014) of coolibah, lignum and river red gums (Map 12).

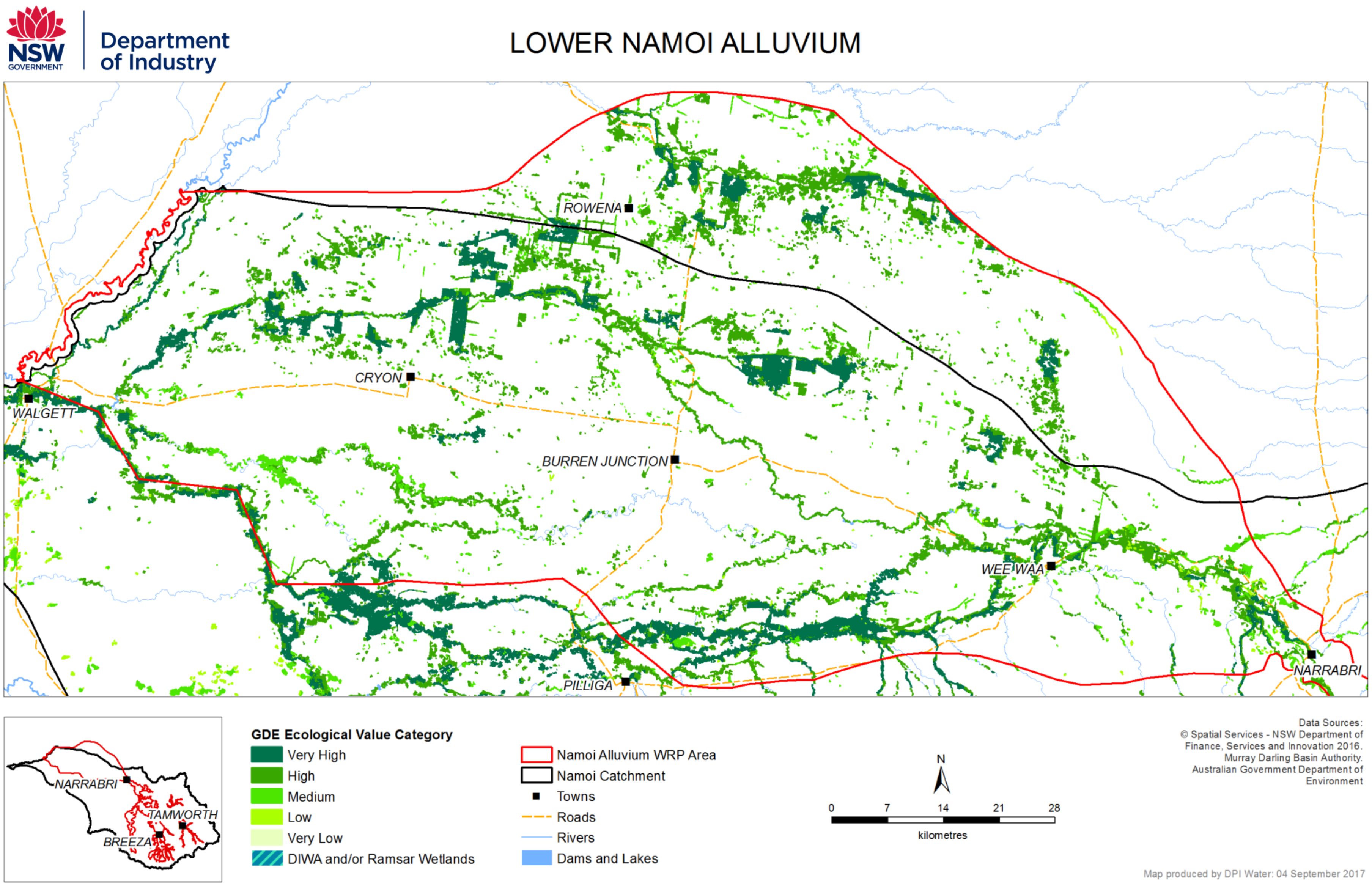
The riparian communities provide vital habitat to nesting species and contribute to ecosystem function of instream ecosystems. Generally, GDE communities with very high or high ecological value have large vegetation patches, are highly connected (such as riparian corridors) and have a high number of threatened species present.



Map 11 Ecological value for high probability groundwater dependent vegetation ecosystems in the Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary Alluvium



Map 12 Ecological value for high probability groundwater dependent vegetation ecosystems in the Upper Namoi Alluvium



Map 13 Ecological value for high probability groundwater dependent vegetation ecosystems in the Lower Namoi Alluvium

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 influences 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 indicated by measuring the electrical conductivity (EC) and is generally reported in microsiemens per centimetre (µS/cm).

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

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

In the Upper Namoi, Lower Namoi and Peel Valley Alluvium, groundwater monitoring bores were sampled for water quality upon construction, and in some areas periodically for a number of years after construction. Groundwater has been analysed for major ions, pH and electrical conductivity (EC).

Timms *et al*. (2010) and Parsons Brinkerhoff (2011) provide more recent information on groundwater quality distribution within the Peel Valley, Upper Namoi and Lower Namoi Alluvium. In 2009, the Cotton Catchment Communities CRC and the Namoi Catchment Management Authority commissioned the University of New South Wales Water Research Laboratory to run a project entitled ‘Groundwater Monitoring, Evaluation and Grower Survey, Namoi Catchment’ (Timms *et al*., 2010).

In 2011, the former NSW Office of Water commissioned Parsons Brinckerhoff to characterise the hydrogeochemistry and investigate the risks posed by groundwater pumping on groundwater quality in six alluvial groundwater systems across inland NSW, including the Lower Namoi Alluvium and part of the Upper Namoi Alluvium (Parsons Brinkerhoff, 2011).

Groundwater across the Namoi Alluvium WRP Area is mainly used for irrigating field crops and pastures, and for stock watering.

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

7.1. Upper Namoi Alluvium

Groundwater salinity across the Upper Namoi Alluvium is generally less than 1,500 µS/cm, with areas of higher salinity up to 20,000 µS/cm.

Localised sampling of the Upper Namoi Zone 3 between November 2009 and January 2011 (Parsons Brinkerhoff 2011) identified that with increasing depth, groundwater salinity typically decreases but its chemistry becomes more variable in the area.

The shallow alluvium reported salinity ranges from approximately 6,000-18,000 µS/cm and the deeper aquifer ranged between 600 and 14,000 µS/cm. This variability at depth is the result of the laterally discontinuous nature of the aquifer.

During the same sampling period, nitrate concentrations across the Upper Namoi Alluvium were reported to range from 0.3 mg/L to 12 mg/L (Parsons Brinkerhoff 2011).

7.2. Lower Namoi Alluvium

Groundwater salinity in the main body of the Lower Namoi Alluvium is generally less than 1,500 µS/cm. Salinity increases with distance from the recharge areas to more than 20,000 µS/cm in the southern and western margins of the area (DLWC, 1997).

At the western margin of the Lower Namoi Alluvium, deeper low salinity groundwater is overlain by a highly saline water table aquifer. As the area is remote from river recharge the potential for deep aquifer salinisation due to vertical leakage and mixing has been identified (Barrett *et al*, 2006).

Salinity values up to approximately 29,000 µS/cm have been measured near Cryon west of Burren Junction (Parsons Brinkerhoff, 2011).

Nitrate analysis during the 2009-2011 study in the Lower Namoi, although very limited (two bores sampled), reported concentrations ranging from 0.3 mg/L to 6.1 mg/L (Parsons Brinkerhoff 2011).

7.3. Peel Valley Alluvium

Groundwater salinity in the Peel Valley Alluvium is generally less than 500 µS/cm, with areas of higher salinity up to 650 µS/cm (Timms *et al*., 2010).

7.4. Manilla Alluvium and Upper Namoi Tributary Alluvium

There is no water quality information for the for the Manilla Alluvium and Upper Namoi Tributary Alluvium, however, it can be inferred that the groundwater quality is likely to be relatively fresh based on its current uses and the highly connected nature of the alluvium with the respective surface water systems.

8. Groundwater Management

The five SDL resource units of the Namoi Alluvium WRP area are managed under a number of water sharing plans as groundwater sources.

The Peel Valley Alluvium, Manilla Alluvium and Lower Namoi Alluvium SDL resource units correlate directly with a groundwater source in the NSW water sharing plans.

Whilst the Upper Namoi Alluvium forms a large laterally continuous and hydraulically connected system, for management purposes it has been subdivided into 12 separate management units The Upper Namoi Tributary Alluvium SDL resource unit includes three groundwater sources and each are connected to the Upper Namoi Alluvium.

The five SDL resource units of the Namoi Alluvium WRP area sits over the fractured and porous rock management units of the New England Fold Belt, Gunnedah-Oxley Basin and Great Artesian Basin. Groundwater in these adjacent management units are managed under the Water Sharing Plans for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011, the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011, the Peel Regulated, Unregulated, Alluvial and Fractured Rock Water Sources 2010 and the NSW Great Artesian Basin Groundwater Sources 2008.

The underlying units have different hydrogeological characteristics and are not typically hydraulically connected in a resource management sense to the groundwater resources in the alluvium. However, groundwater discharge from the underlying Great Artesian Basin into the Lower Namoi Alluvium does contribute to the water budget sufficiently to be accounted for under the SDL volume.

Table 3 lists the SDL resource units of the Namoi Alluvium WRP Area with the corresponding groundwater sources and water sharing plans.

8.1. Access rights

Groundwater access licenses for the five SDL resource units of the Namoi Alluvium WRP Area are shown in Table 4.

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. Domestic and stock access licences are also issued for a specified volume of groundwater.

The share components of aquifer access licences and aquifer (general security) access licences are issued for a specified number of unit shares.

Owing to the high level of connection to the surface water sources, groundwater allocations under the licence category ‘aquifer (general security) access licence’ in the Peel Valley Alluvium is linked to the regulated river (general security) access licence allocations in the Peel Regulated River. Similarly aquifer (general security) access licence allocations in the Manilla Alluvium are linked to those of the Upper Namoi Regulated River Water Sources.

Supplementary water access licences were issued to some licence holders in the Upper Namoi Alluvium and Lower Namoi Alluvium. 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.

Table 3 Namoi Alluvium Water Resource Plan area (GS14)

SDL Resource Unit	Groundwater Source	Water Sharing Plan
Peel Valley Alluvium (GS40)	Peel Alluvium Water Source	*Water Sharing Plan for the Peel Valley Regulated, Unregulated, Alluvium and Fractured Rock Water Sources 2010*
Manilla Alluvium (GS30)	Manilla Alluvial Groundwater Source	*Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012*
Upper Namoi Tributary Alluvium (GS48)	Currabubula Alluvial Groundwater Source, Quipolly Creek Alluvial Groundwater Source, and Quirindi Creek Alluvial Groundwater Source	*Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012*
Upper Namoi Alluvium (GS47)	Upper Namoi Zone 1, Borambil Creek Groundwater Source, Upper Namoi Zone 2, Cox's Creek (Mullaley to Boggabri) Groundwater Source, Upper Namoi Zone 3, Mooki Valley (Breeza to Gunnedah) Groundwater Source, Upper Namoi Zone 4, Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source, Upper Namoi Zone 5, Namoi Valley (Gin's Leap to Narrabri) Groundwater Source, Upper Namoi Zone 6, Tributaries of the Liverpool Range (South to Pine Ridge Road) Groundwater Source, Upper Namoi Zone 7, Yarraman Creek (East of Lake Goran to Mooki River) Groundwater Source, Upper Namoi Zone 8, Mooki Valley (Quirindi - Pine Ridge Road to Breeza) Groundwater Source, Upper Namoi Zone 9, Cox's Creek (up-stream Mullaley) Groundwater Source, Upper Namoi Zone 10, Warrah Creek Groundwater Source, Upper Namoi Zone 11, Maules Creek Groundwater Source, and Upper Namoi Zone 12, Kelvin Valley Groundwater Source	*Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*
Lower Namoi Alluvium (GS29)	Lower Namoi Groundwater Source	*Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*

Table 4 Access Licence share components in the Namoi Alluvium Water Resource Plan area (at June 2017).

SDL Resource Unit	Groundwater Source	Local Water Utility (ML/yr)	Aquifer (unit shares)	Aquifer (General Security) (unit shares)	Domestic and Stock (ML/yr)	Aquifer (Town Water Supply) (ML/yr)
Peel Valley Alluvium (GS40)	Peel Alluvium	660	18,676	32,368	182	0
Manilla Alluvium (GS30)	Manilla Alluvium	0	1,164	2,311	0	60
Upper Namoi Tributary Alluvium (GS48)	Currabubula Alluvial	0	302	0	0	25
	Quipolly Alluvium	0	737	0	0	0
	Quirindi Alluvium	0	2,596	0	0	200
	TOTAL	**0**	**3,635**	**0**	**0**	**225**
Lower Namoi Alluvium (GS29)	Lower Namoi	4,407	81,586	0	0	0

Table 4 Continued Access Licence share components in the Namoi Alluvium Water Resource Plan area (at June 2017).

SDL Resource Unit	Groundwater Source	Local Water Utility (ML/yr)	Aquifer (unit shares)	Aquifer (General Security) (unit shares)	Domestic and Stock (ML/yr)	Aquifer (Town Water Supply) (ML/yr)
Upper Namoi Alluvium (GS47)	Upper Namoi Zone 1	1,216	384	0	0	0
	Upper Namoi Zone 2	59	7,141	0	0	0
	Upper Namoi Zone 3	198	17,101	0	0	0
	Upper Namoi Zone 4	4,660	21,032	0	0	0
	Upper Namoi Zone 5	0	15,992	0	0	0
	Upper Namoi Zone 6	0	11,448	0	0	0
	Upper Namoi Zone 7	0	3,697	0	0	0
	Upper Namoi Zone 8	50	16,000	0	0	0
	Upper Namoi Zone 9	97	11,245	0	0	0
	Upper Namoi Zone 10	0	1,420	0	0	0
	Upper Namoi Zone 11	0	2,223	0	0	0
	Upper Namoi Zone 12	0	1,999	0	0	0
	TOTAL	**6,280**	**109,690**	**0**	**0**	**0**

8.2. Extraction limits

Extraction in a groundwater source is managed to the long term average annual extraction limit (LTAAEL) set by the water sharing plans.

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 5 lists the LTAAEL, BLR and SDL for each SDL resource unit as well as the LTAAEL for the individual groundwater sources in the Upper Namoi Tributary Alluvium and Upper Namoi Alluvium.

Table 5 LTAAEL for the Namoi Alluvium Water Resource Plan area (GS14) compared to the SDL (at August 2017)

SDL Resource Unit	Groundwater Source	LTAAEL[1] ML/year	SDL ML/year	BLR ML/year
Peel Valley Alluvium (GS40)	Peel Alluvium	9,344	9,340	240.9
Manilla Alluvium (GS30)	Manilla Alluvium	1,229	1,230	24.7
Upper Namoi Tributary Alluvium (GS48)	Currabubula Alluvial	60.1		17.8
	Quipolly Alluvium	475.6		3.9
	Quirindi Alluvium	1231.4		14.1
	TOTAL	**1,767.1**	**1,770**	**35.8**
Upper Namoi Alluvium (GS47)*	Upper Namoi Zone 1	2,127		27
	Upper Namoi Zone 2	7,327		127
	Upper Namoi Zone 3	17,499		199
	Upper Namoi Zone 4	26,121		421
	Upper Namoi Zone 5	16,128		128
	Upper Namoi Zone 6	14,096		96
	Upper Namoi Zone 7	3,721		21
	Upper Namoi Zone 8	16,114		114
	Upper Namoi Zone 9	11,441		41
	Upper Namoi Zone 10	4,518		18
	Upper Namoi Zone 11	2,269		69
	Upper Namoi Zone 12	2,042		42
	TOTAL	**123,403**	**123,400**	**1,303**
Lower Namoi Alluvium (GS29)*	Lower Namoi Alluvium	88,255	88,300	2,255

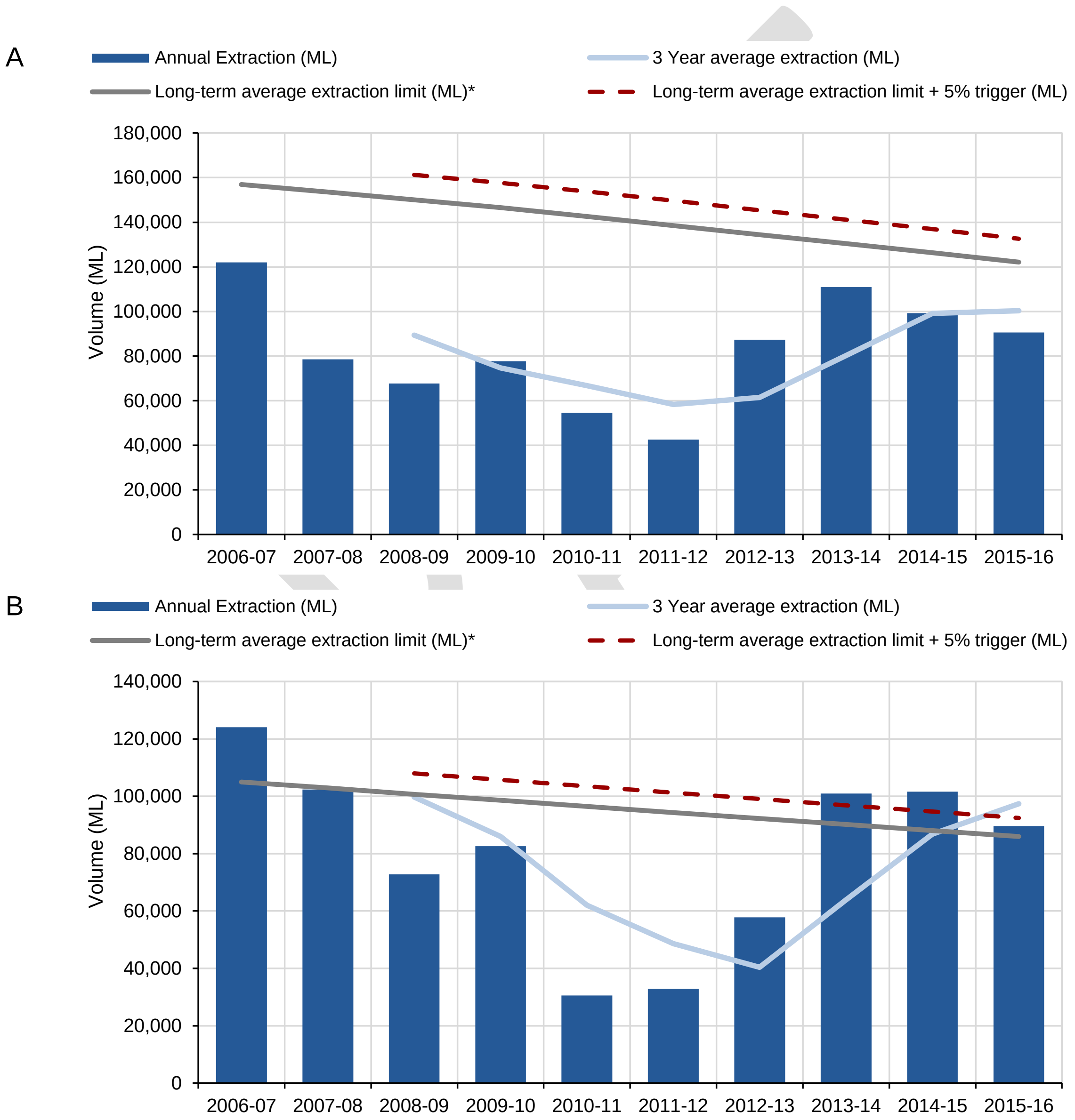
[1]This volume includes annual requirements for domestic and stock rights and native title rights where applicable.

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

Annual extraction since commencement of the water sharing plan for the Upper Namoi Alluvium and Lower Namoi Alluvium is shown in Figures 9 (A and B). These graphs also show 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.

Extraction in the Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary Alluvium is well below the water sharing plans trigger for complying with their extraction limits.

Appendix A shows annual extraction graphs comparing the LTAAEL and extraction limit trigger for a number of individual high use groundwater sources in the Upper Namoi Alluvium.



*If the 3 year average of extraction exceeds the LTAAEL by 5% or greater, then the available water determination made for aquifer access licences for the following water year, should be reduced by an amount that is assessed necessary by the Minister to return subsequent total water extraction to the extraction limit.
Note, total requirements for basic landholder rights is not included in the LTAAEL or annual extraction in this graph.

Figure 9 Annual extraction compared to the LTAAEL: (A) Upper Namoi Alluvium, (B) Lower Namoi Alluvium

8.3. Available water determinations

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

The AWD for aquifer (general security) access licences in the Peel Valley Alluvium and Manilla Alluvium is linked to the available water determination for the regulated river (general security) licences. Since the commencement of the water sharing plan, the available water determination for aquifer (general security) access licences since commencements of the respective water sharing plans is listed in Table 6.

Table 6 Available Water Determinations for aquifer (general security) access licences in the Peel Valley Alluvium and Manilla Alluvium

SDL Resource Unit	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
Peel Valley Alluvium	1	1	0.92	0.73	0.51	0.60
Manilla Alluvium*	NA	NA	1	1	1	0.925

* The water sharing planning for Namoi Unregulated and Alluvial Water Sources 2012 commenced 4 October 2012.

The AWD for aquifer access licences in all SDL resource units within the Namoi Alluvium WRP area has been set at 1 ML since commencement of the water sharing plans with the following exceptions:

- The AWD for aquifer access licences was set at 2 ML/share in the first year of the water sharing plan for the of the Peel Valley Alluvium and
- In Zone 1 of the Upper Namoi Alluvium, the AWD was initially set at 1 ML per share, but was raised to 2.3 ML/ share since the 2010/2011 water year[11].

The AWD for local water utility access licences has been set at 100% every year since the water sharing plan commenced for all SDL resource units across the WRP area.

The available water determination for supplementary water access licences (SWAL) in the Upper Namoi Alluvium and Lower Namoi Alluvium was set by the water sharing plan for each year of the plan to 2014/2015. These licences were cancelled in June 2016.

The allocations for each licence category in the Upper Namoi Alluvium and Lower Namoi Alluvium for each year since commencement of the water sharing plan is shown in Figure 10 and Figure 11 respectively.

[11] The AWD for aquifer access licences in Upper Namoi Zone 1 has been set a 2.3 ML/Share since 2010/2011 to distribute 500 ML of un used local water utility between the licence holders.

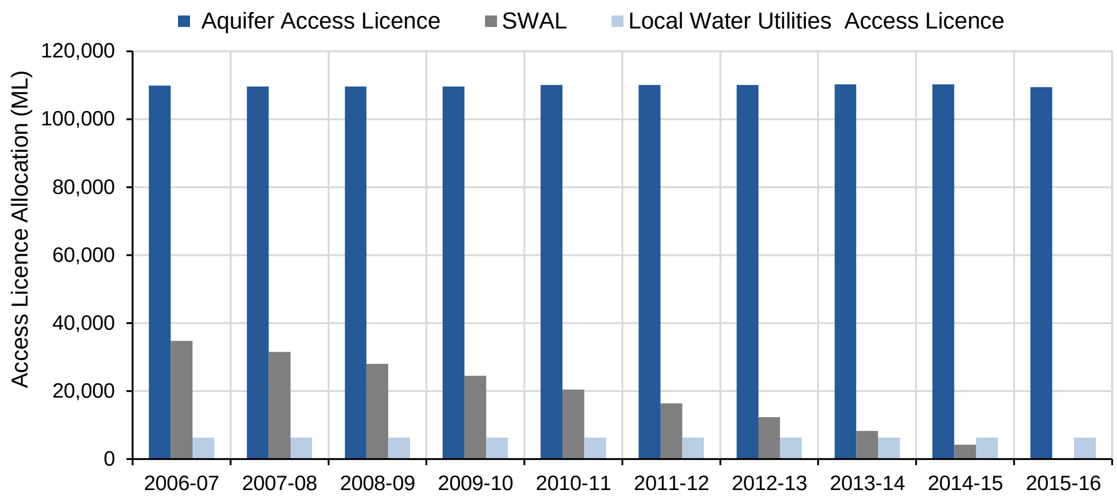


Figure 10 Annual allocations for access licences in the Upper Namoi Alluvium

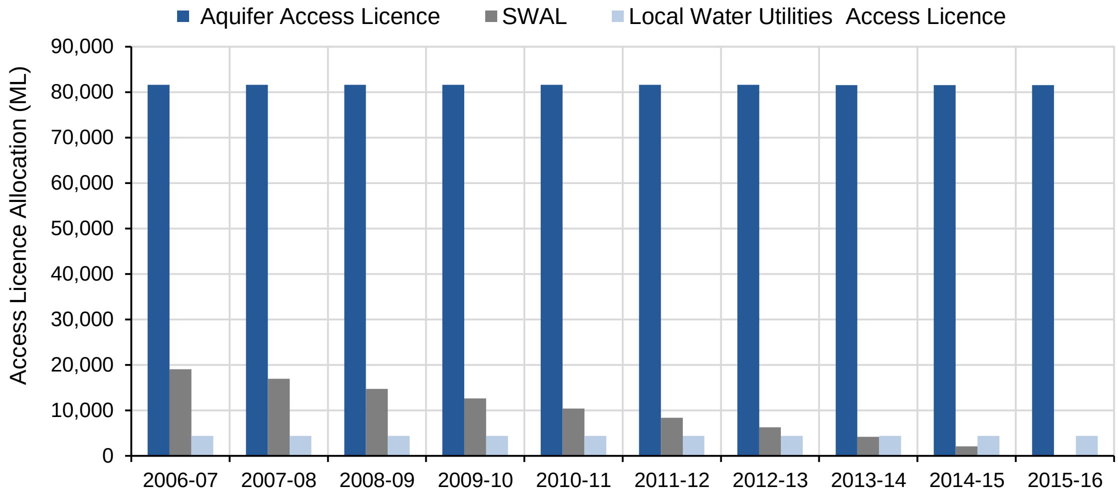


Figure 11 Annual allocations for access licences in the Lower Namoi Alluvium

8.4. Groundwater accounts

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

8.4.1. Peel Alluvium, Manilla Alluvium and Upper Namoi Tributary

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

(a) 100% of the access licence share component, for an access licence with share components expressed as ML/year, or

(b) 1 ML per unit share of access licence share component, for access licences with share components expressed as a number of unit shares.

There is no carryover of allocation permitted for any licence category in the Manilla Alluvium and the Upper Namoi Tributary Alluvium, nor for aquifer (general security) access licences in the Peel Valley Alluvium.

For all licence categories in the Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary Alluvium the maximum amount of water that can be debited from an account in any one water year (i.e. account take limit) cannot exceed 1 ML / share component plus any allocation transferred in, and minus any allocation transferred out.

8.4.2. Upper Namoi Alluvium and Lower Namoi Alluvium

The water sharing plan for the Upper Namoi Alluvium and Lower Namoi Alluvium allows for accrual of unused allocation in aquifer access licence accounts. This includes the yearly allocations for the aquifer access licences made through available water determinations plus any carryover of unused allocation up to a maximum of 2 ML[12]/share component.

The maximum amount of water that can be debited from an account in any one water year (i.e. account take limit) cannot exceed 2 ML[12]/share component plus any allocation transferred in, and minus any allocation transferred out. This means that metered extraction plus transfers out cannot exceed 200% of the of share component, unless water is transferred in.

Figure 12 and Figure 13 show the volumes held in water accounts for access licences for the Upper Namoi Alluvium and Lower Namoi Alluvium respectively since commencement of the water sharing plan.

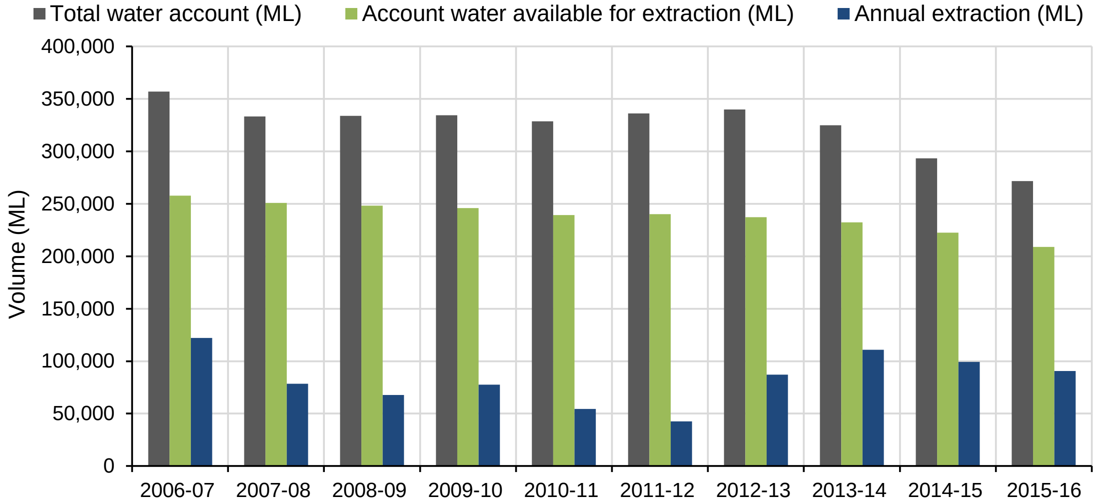


Figure 12 Water accounts since the commencement of the water sharing plan for the Upper Namoi Alluvium

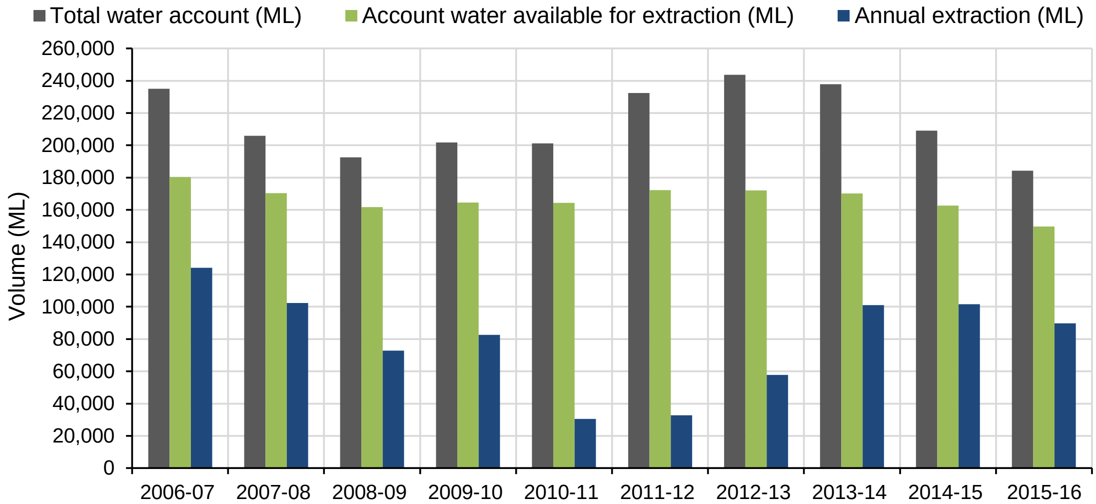


Figure 13 Water accounts since the commencement of the water sharing plan for the Lower Namoi Alluvium

[12] The maximum amount of water that can be debited and carried over from an account in any one year for Upper Namoi Zone 1 is 2.3 ML/share plus any allocation transferred in and minus any allocation transferred out, this is to allow for the AWD of 2.3 ML/share.

8.5. Groundwater take

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

Groundwater use is influenced by climate and access to surface water. Reliance on groundwater increases in drier years and when there is reduced access to surface water. Groundwater take from production bores is metered across the WRP area. Average take pre and post commencement of the water sharing plans is shown in Table 7. The Currabubula Alluvium groundwater source is not included in Table 7 as there is very little use of groundwater for irrigation from in the area and hence no metered usage.

Table 7 Average metered take from production bores pre and post commencement of the water sharing plan

Average Usage ML (Number of years of data)	Peel Valley Alluvium	Manilla Alluvium	Upper Namoi Tributary Alluvium	Upper Namoi Alluvium	Lower Namoi Alluvium
Pre WSP	7,077 (13)	No Data	No Data	104,190 (15)	87,712 (15)
Post WSP	6,113 (6)	206 (4)	358 (4)	83,121 ML (10)	79,535 (10)

Note: WSP – Water Sharing Plan
Number of years of data provided into brackets .

8.5.1. Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary

There are approximately 1,200 registered bores across the Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary (Map 14). The majority of these bores are used for stock and domestic purposes. There is also significant reliance on groundwater for irrigation in the Peel Valley Alluvium (Table 8).

Table 8 Approximate number of licenced water supply bores in the Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary Alluvium (at June 2017).

SDL Resource Unit	Registered Bore Purpose		
	Stock / Domestic	Production	Local Water Utility
Peel Valley Alluvium	425	540	20
Manilla Alluvium	40	25	0
Upper Namoi Tributary Alluvium	90	38	3

Annual groundwater extraction since 1997/98 and the annual extraction limit since the commencement of the water sharing plan is shown in Figure 14 for the Peel Valley Alluvium. Extraction data is incomplete prior to 1997 in the Peel Valley Alluvium.

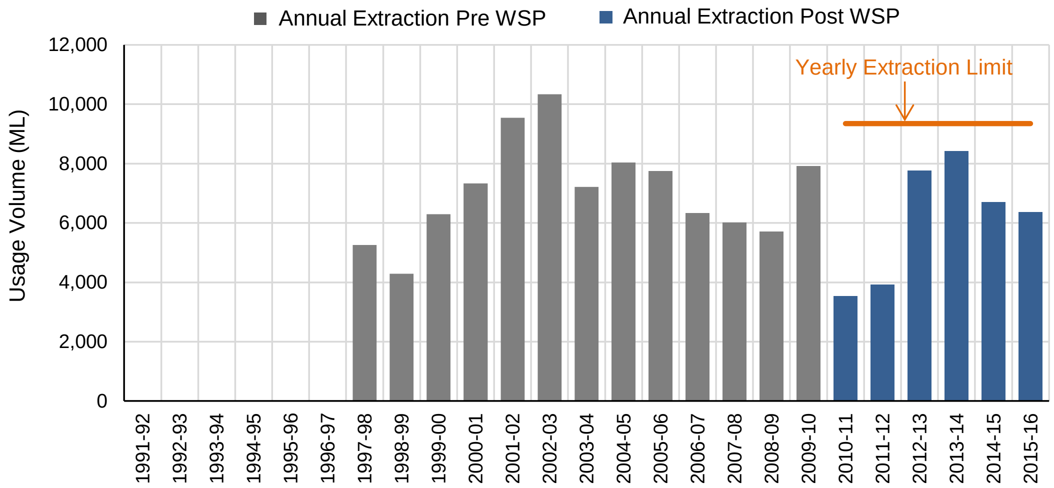
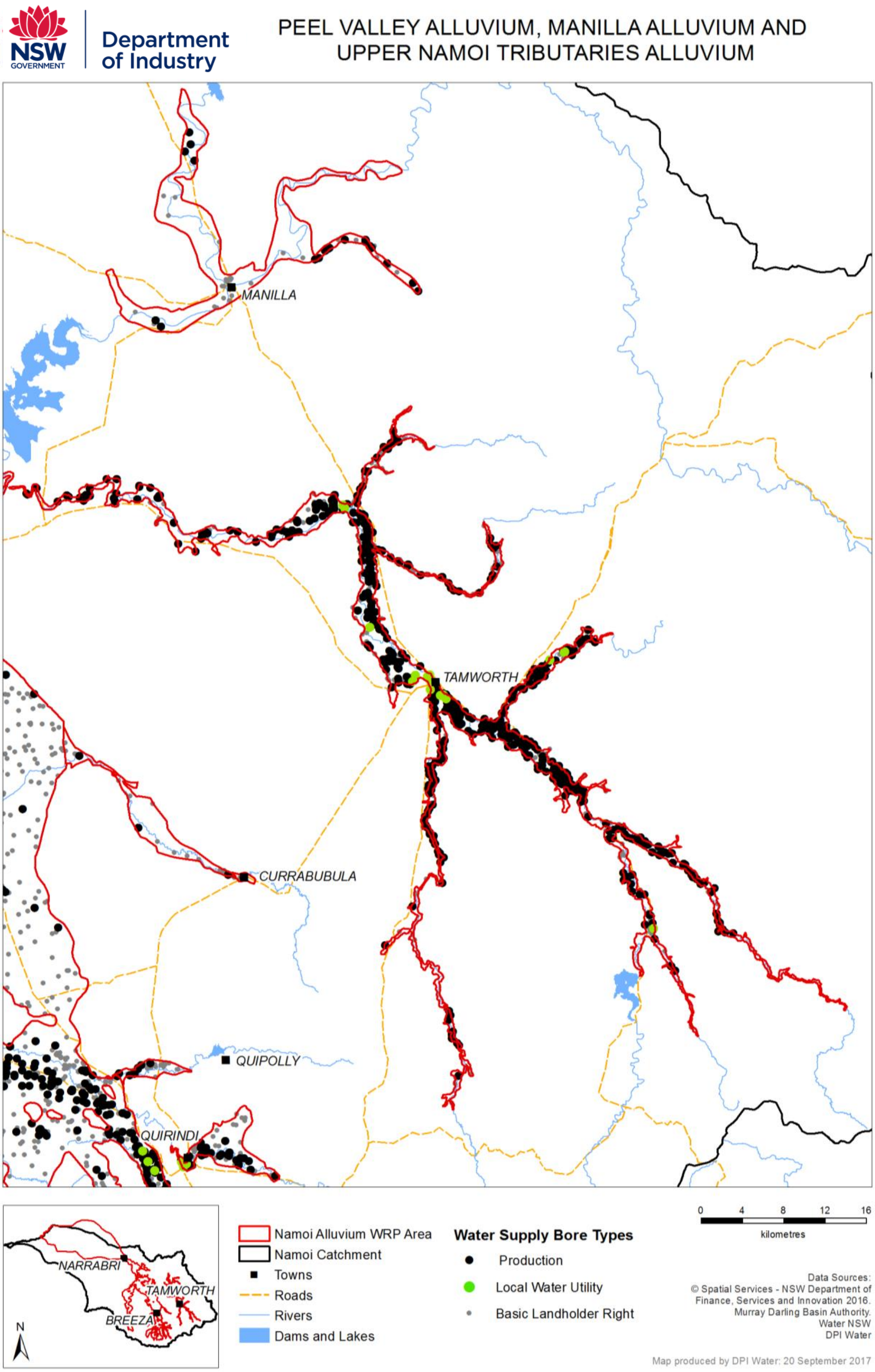


Figure 14 Metered extraction for the Peel Valley Alluvium



Map 14 Registered bores in the Peel Valley Alluvium, Manilla Alluvium and Upper Namoi Tributary Alluvium

8.5.2. Upper Namoi Alluvium

There are approximately 3,500 registered bores across the Upper Namoi Alluvium (Map 15). The majority of these bores are used for stock and domestic purposes. There is also significant reliance on groundwater for irrigation (Table 9).

Table 9 Approximate number of licenced water supply bores in the Upper Namoi Alluvium (at June 2017).

SDL Resource Unit	Registered Bore Purpose		
	Stock / Domestic	Production	Local Water Utility
Upper Namoi Alluvium	2,360	1,110	30

Annual metered groundwater extraction since 1991/92 and the annual extraction limit since the commencement of the water sharing plan is provided in Figure 15 for the Upper Namoi Alluvium.

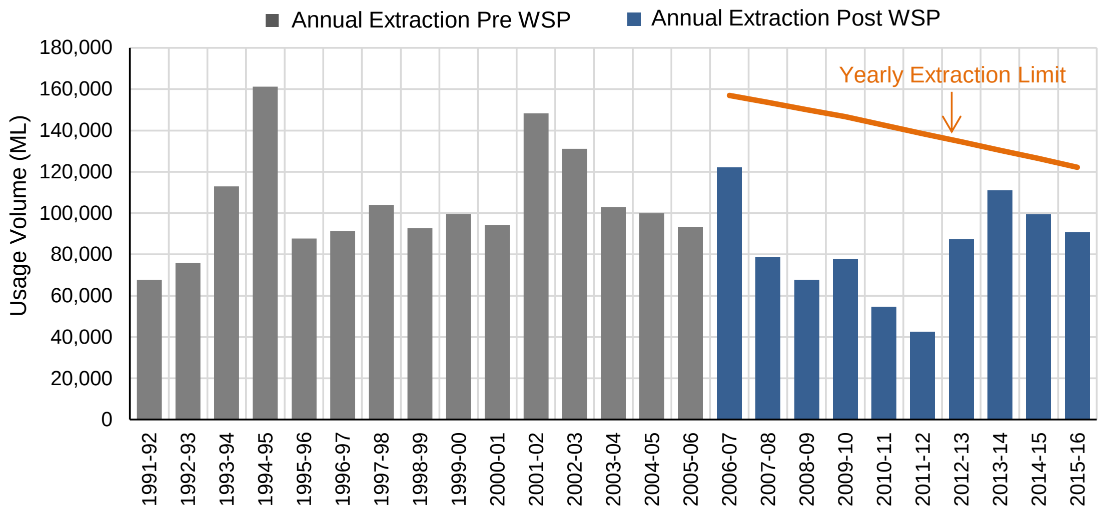
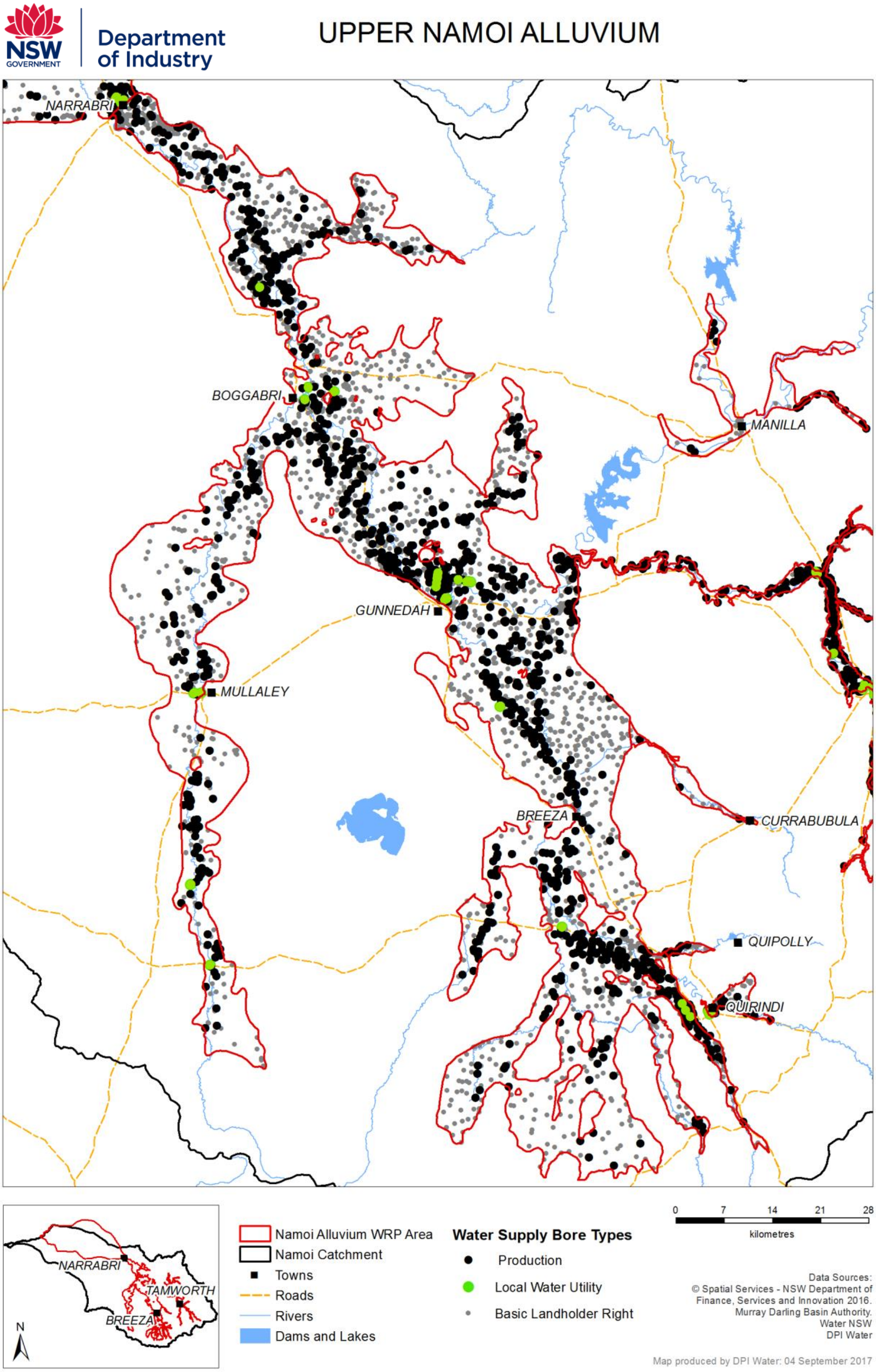
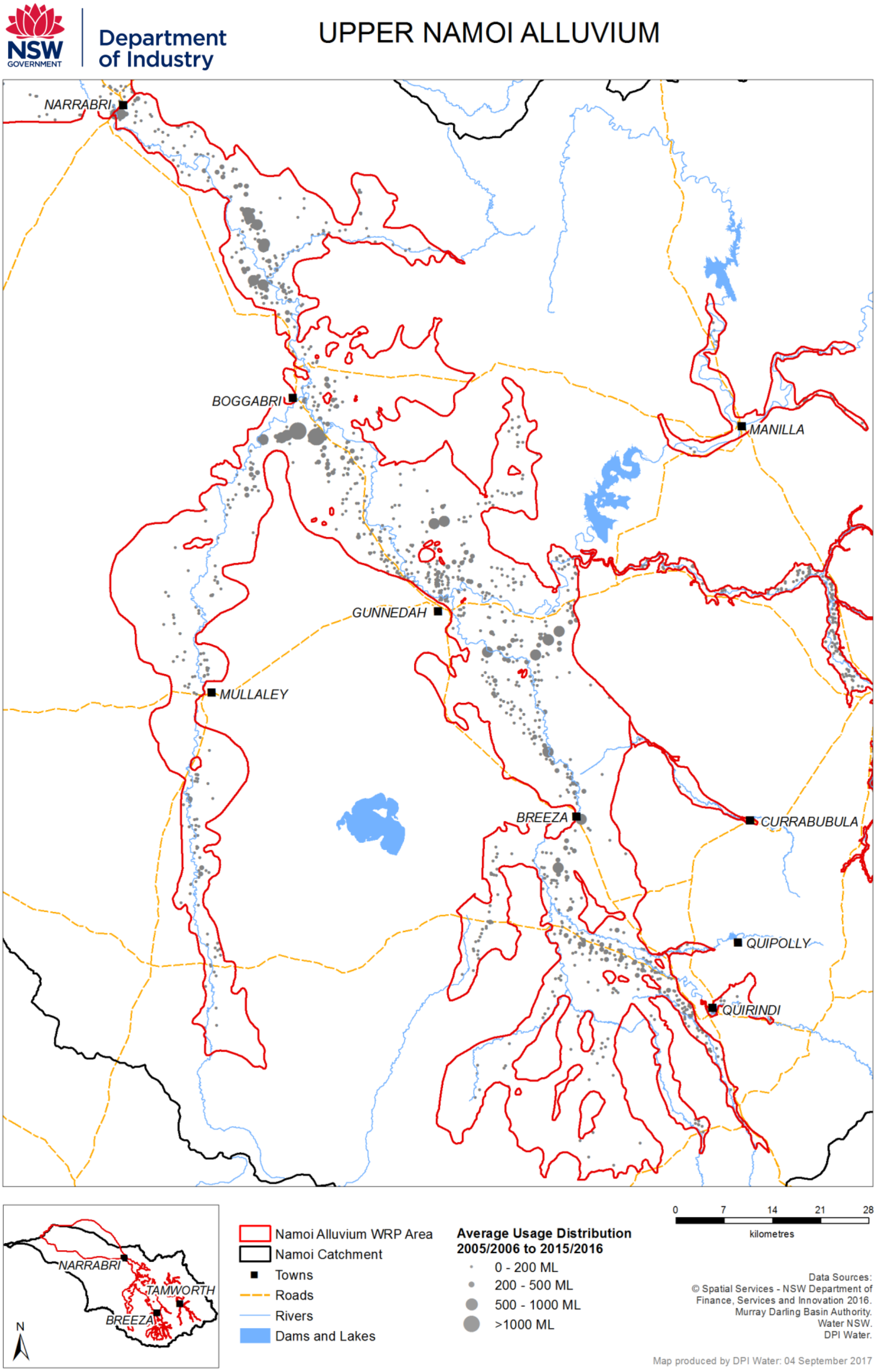


Figure 15 Metered extraction for the Upper Namoi Alluvium

Production bores in the Upper Namoi Alluvium are concentrated along the Mooki and Namoi Rivers and Cox's Creek. Bores constructed in the deeper more productive aquifer systems of the Upper Namoi Alluvium can yield up to 1,500 ML/yr, the majority of production bores produce supply in the range of 200 ML/yr (Map 16).



Map 15 Registered bores in the Upper Namoi Alluvium



Map 16 Upper Namoi Alluvium distribution of extraction

8.5.3. Lower Namoi Alluvium

There are approximately 2,000 registered bores across the Lower Namoi Alluvium (Map 17). The majority of these bores are used for stock and domestic purposes. There is also significant reliance on groundwater for irrigation (Table 10).

Table 10 Approximate number of licenced water supply bores in the Lower Namoi Alluvium (at June 2017).

SDL Resource Unit	Registered Bore Purpose		
	Stock / Domestic	Production	Local Water Utility
Upper Namoi Alluvium	1,400	580	10

Annual metered groundwater extraction since 1991/92 and the annual extraction limit since the commencement of the water sharing plan is provided in Figure 16 for the Lower Namoi Alluvium.

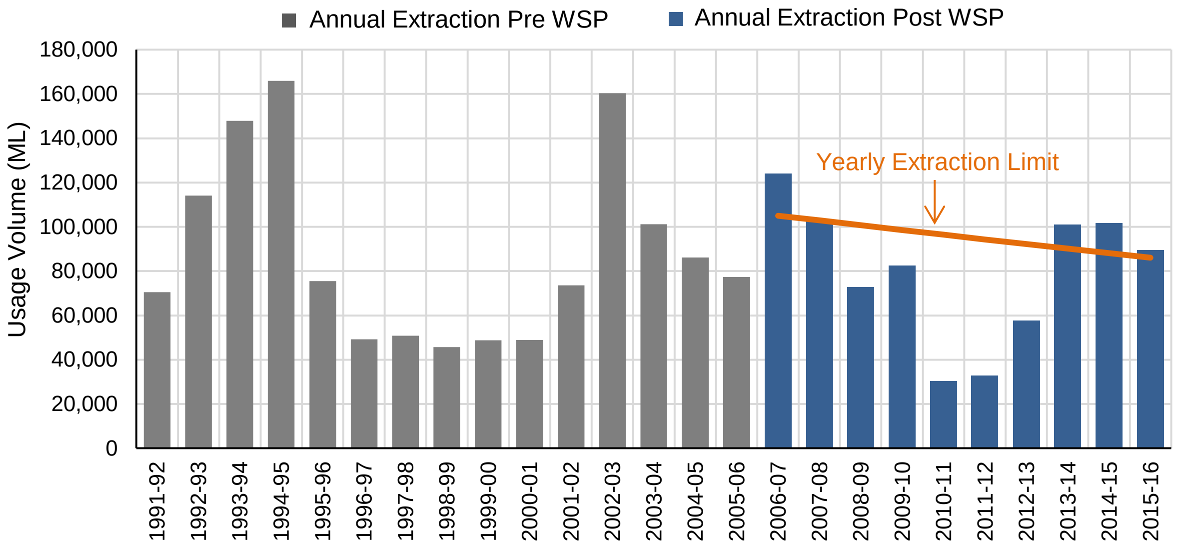
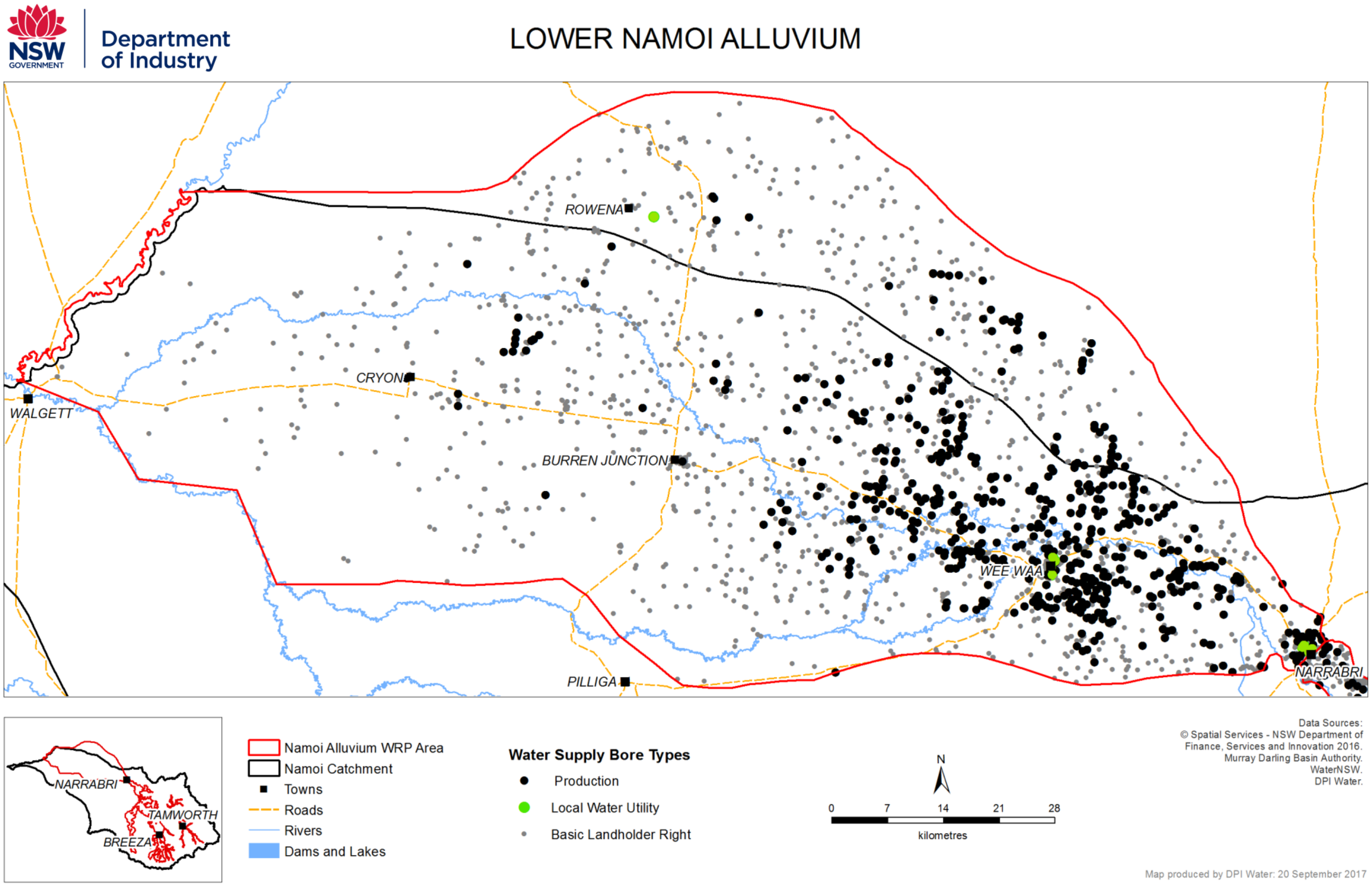
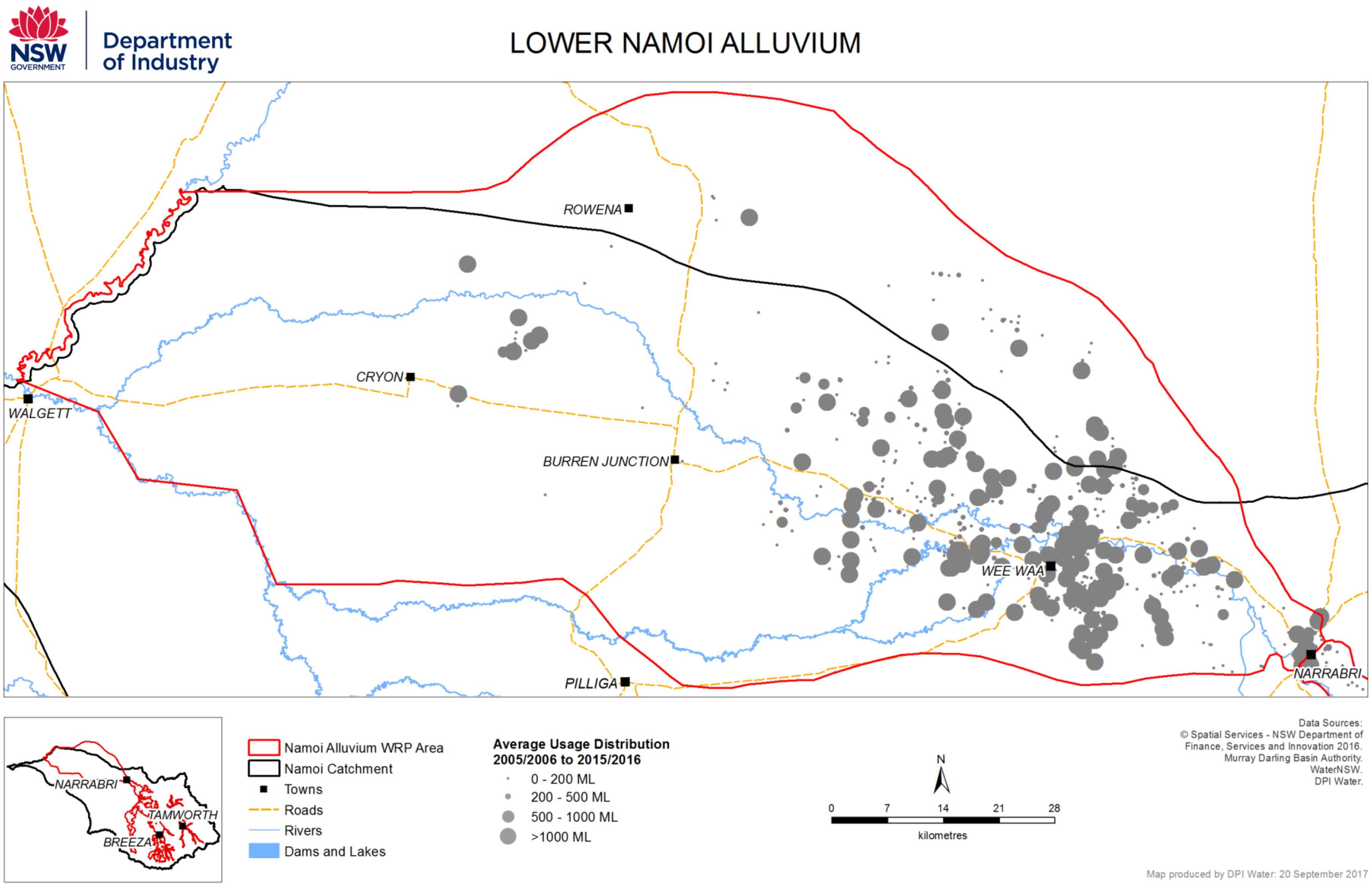


Figure 16 Metered extraction for the Lower Namoi Alluvium

Production bores in theLower Namoi Alluvium are concentrated mainly mainly east of Burren Junction. Bores constructed in the deeper more productive aquifer systems can yield up to 1,500 ML/yr, the majority of production bores produce supply in the range of 200 ML/yr (Map 18).



Map 17 Registered bores in the Lower Namoi Alluvium



Map 18 Lower Namoi Alluvium distribution of extraction

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.

In 2008, a review of the water level data in the Lower Namoi Alluvium indicated an area north of the Kamilaroi Highway between Narrabri and Burren Junction with significant drawdown and recovery declines. Trade of water into that area has been restricted to manage potential cumulative impacts of extraction on the groundwater source and water users in the area.

There are no trade restricted areas defined in any other groundwater sources within the WRP area. No trading is currently permitted between the twelve groundwater sources that make up the Upper Namoi Alluvium with the exception of Zone 10 subject to the access licence dealing rules in the water sharing plan.

8.6.1. Temporary dealings

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

The volume traded and number of trades since the commencement of the water sharing plans for the Peel Valley Alluvium, Upper Namoi Alluvium and Lower Namoi Alluvium are shown in Figures 17, 18 and 19 respectively.

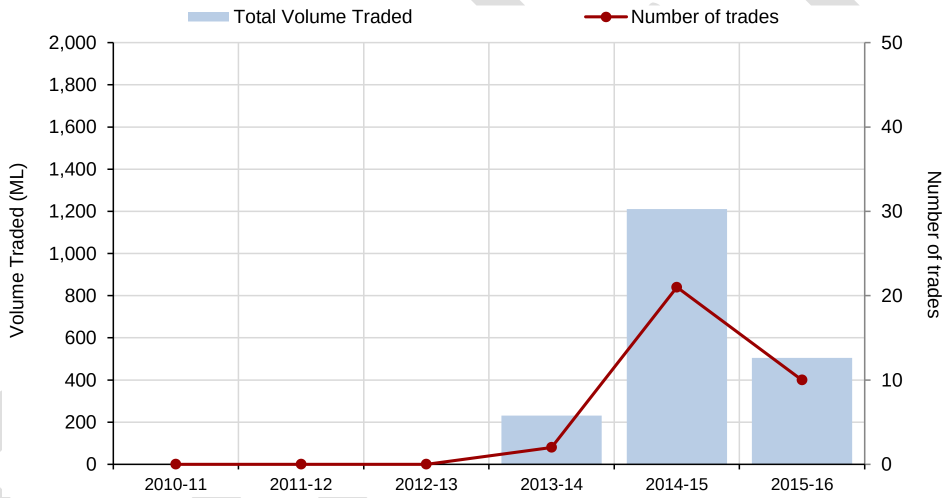


Figure 17 Peel Valley Alluvium 71T dealings since commencement of the water sharing plan

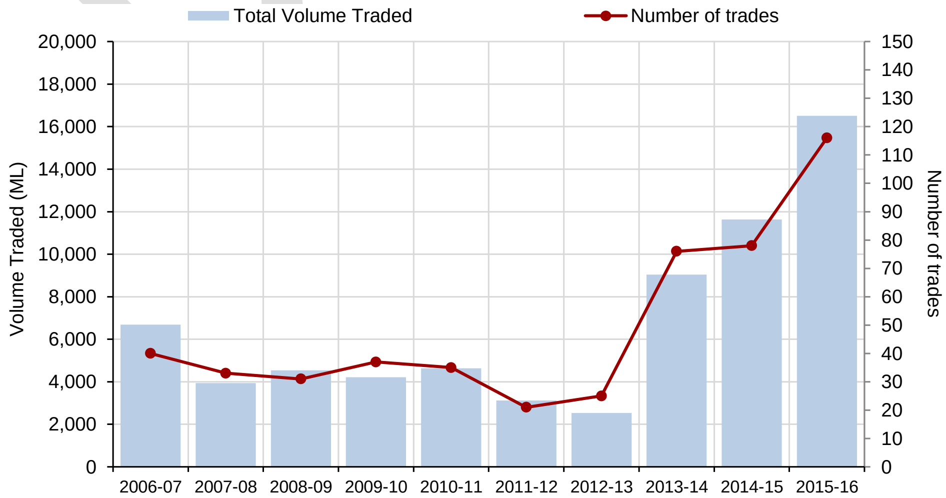


Figure 18 Lower Namoi Alluvium 71T dealings since commencement of the water sharing plan

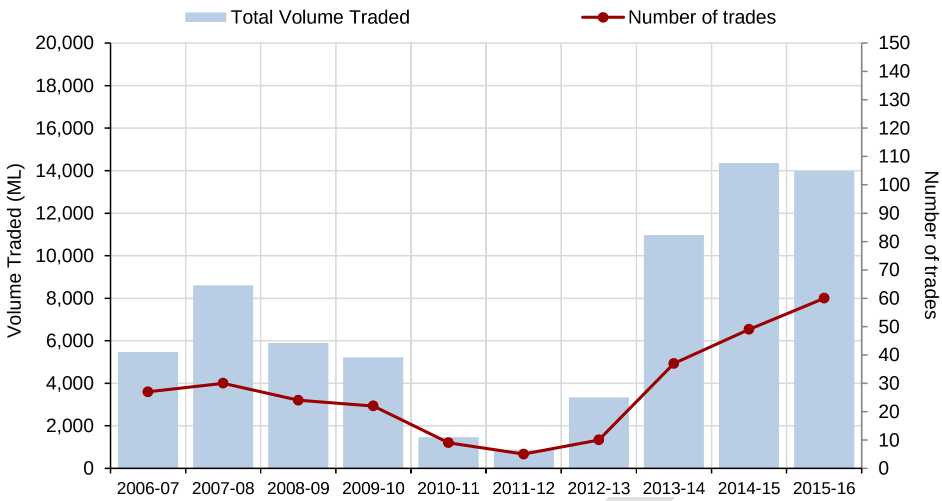


Figure 19 Upper Namoi Alluvium 71T dealings since commencement of the water sharing plan

The average and maximum price per ML excluding business to business trades worth less than $1/ML is shown in Table 11.

Table 11 Statistics on price per ML since commencement of the water sharing plans

	Peel Valley Alluvium	Upper Namoi Alluvium	Lower Namoi Alluvium
Average Price Per ML	$55	$97	$65
Max Price Per ML	$300	$3,500	$160

To date, there have been no applications for temporary dealings in the Manilla Alluvium or Upper Namoi Tributary Alluvium.

8.6.2. Permanent dealings

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

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

Figures 20, Figure 21 and Figure 22 show the statistics for dealings that result in a change in the potential volume that can be extracted from a location since commencement of the water sharing plans for the Peel Valley Alluvium, Upper Namoi Alluvium and Lower Namoi Alluvium respectively. 71M dealings are not included as these are a change in ownership only and therefore have no potential for additional third-party impacts.

To date there have been no applications for any type of permanent dealing in the Manilla Alluvium and the Upper Namoi Tributary Alluvium.

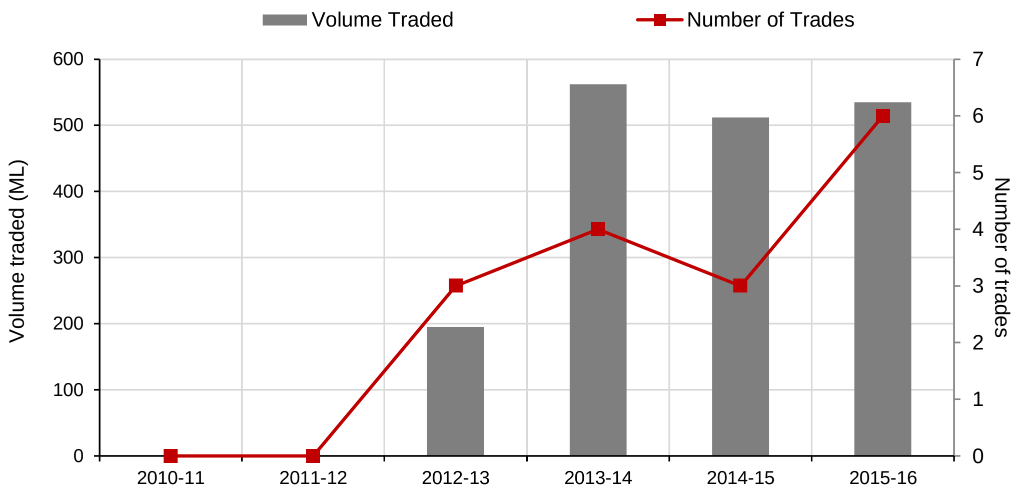


Figure 20 Peel Valley Alluvium permanent dealings since commencement of the water sharing plan; 71M dealings are not included

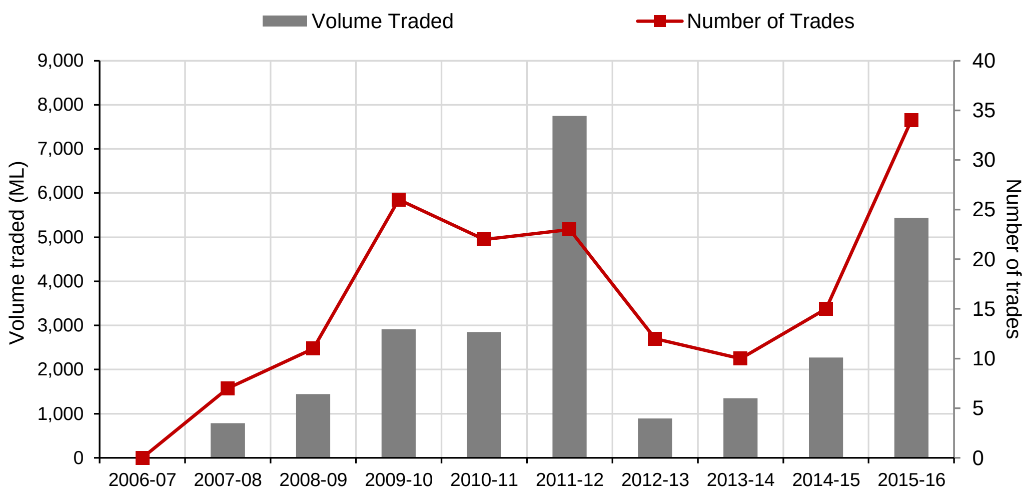


Figure 21 Upper Namoi Alluvium permanent dealings since commencement of the water sharing plan; 71M dealings are not included

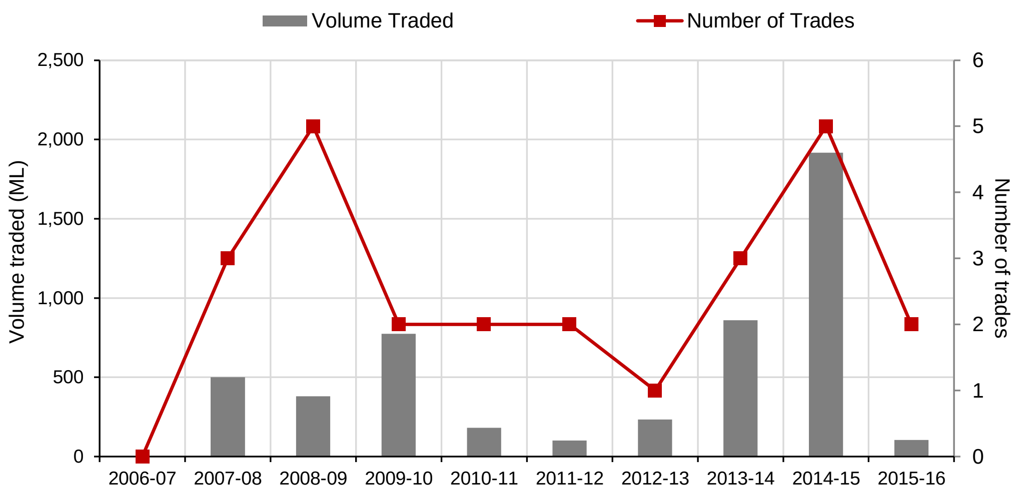


Figure 22 Lower Namoi Alluvium permanent dealings since commencement of the water sharing plan; 71M dealings are not included

9. Groundwater monitoring

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

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

Figure 23 shows a generalised conceptualisation of a layered groundwater system illustrating how the water level height in bores in an area can vary depending on the depth of the screened interval of the bore.

Groundwater systems typically include a number of aquifers which may be confined or unconfined. An unconfined aquifer is an aquifer whose upper water surface (water table) is at atmospheric pressure. A confined aquifer is completely saturated with water and is overlain by impermeable material (aquitard) causing the water to be under pressure. If the hydraulic head of groundwater is plotted and contoured on a map this is referred to as the potentiometric surface.

Figure 23 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.

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 23 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. The manually monitored sites are read every four to eight weeks (Table 12). The data monitored in real-time via telemetry (Table 12) is available from: *http://realtimedata.waternsw.com.au/water.stm.*

Table 12 Active monitoring bores statistics, Namoi Alluvium WRP area

Monitoring Bores	Peel Valley Alluvium	Manilla Alluvium	Upper Namoi Tributary Alluvium	Upper Namoi Alluvium	Lower Namoi Alluvium
Total Number of SItes	51	2	2	330	250
Total Number of Bores	52	2	2	640	580
Number of Telemetered Sites	3	0	0	25	24

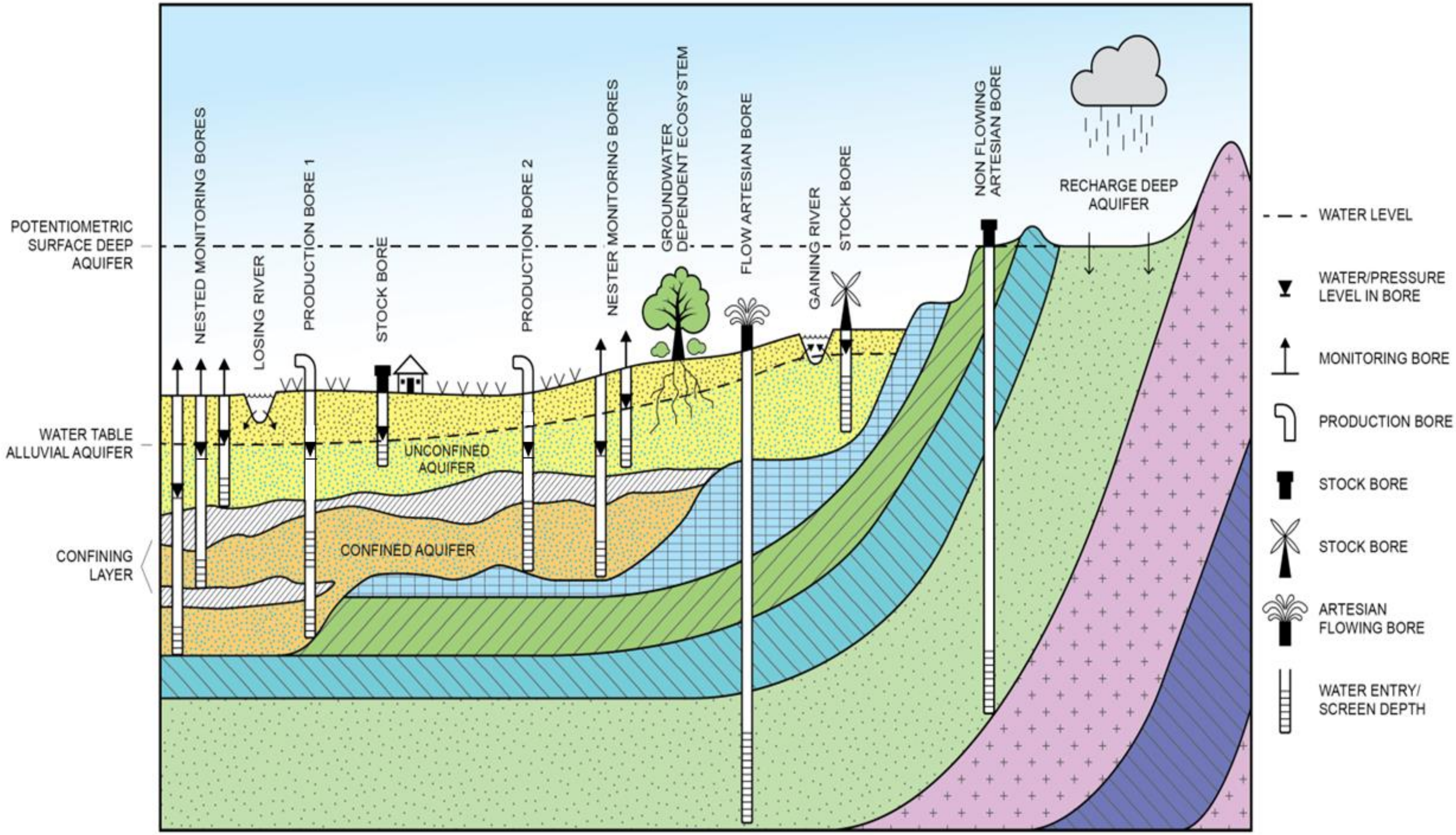


Figure 23 Schematic diagram of different types of aquifers

10. Groundwater Behaviour in the Namoi Alluvium

10.1. Introduction

For the Namoi Alluvium, monitoring bores constructed and screened less than 40 m deep are generally considered to be within the unconfined shallow aquifer system, while monitoring bores constructed deeper than approximately 40 m have been assessed to be in the deep semi-confined/confined aquifer system.

The reference condition to which long-term trends are compared is the ‘pre-development’ water level. In the Namoi Alluvium the ‘pre-development’ is defined as the average recovered water level over the first five years of the monitoring record, typically in the 1970s. Changes in groundwater levels in the Namoi Alluvium are discussed in the following sections presenting data from hydrographs and groundwater head maps.

10.2. Hydrographs

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (Figure 24). 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.

Trends that can be observed in groundwater hydrographs are shown in Figure 24. 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.

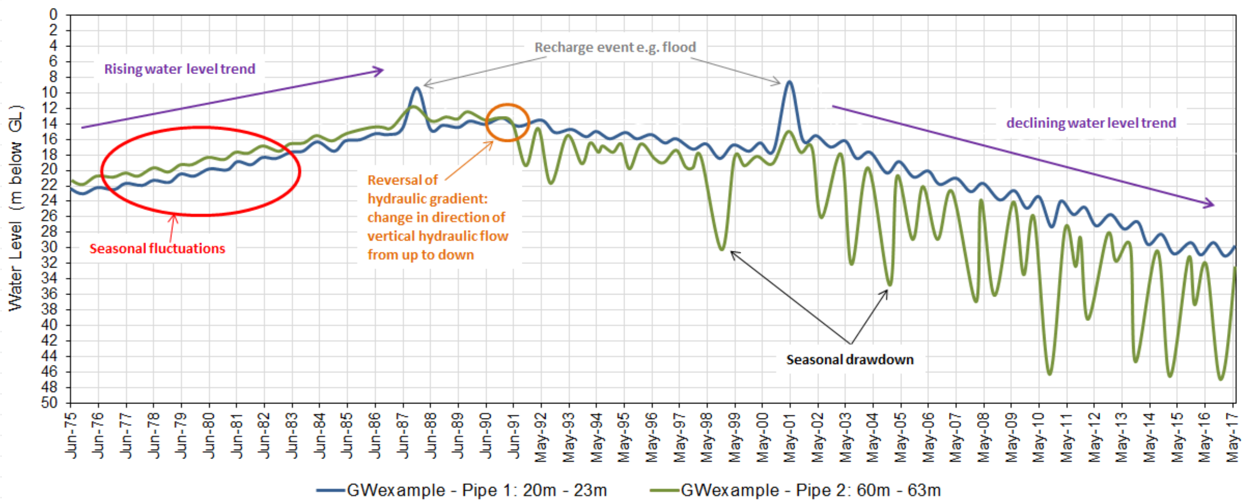


Figure 24 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate

Significant recharge events such as floods can be identified in hydrographs as peaks in the groundwater level record while droughts tend to result in a slow gradual decline in groundwater levels. In areas where groundwater extraction occurs, hydrographs show a seasonal cyclic pattern of drawdown and recovery. Drawdown is the maximum level to which groundwater is lowered in a bore due to pumping. It is followed by recovery when pumping has ceased or reduced.

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

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

10.3. Review of groundwater levels

Hydrographs for 13 representative groundwater monitoring sites across the Namoi Alluvium are presented below. Each hydrograph is displayed on the same scale for ease of comparison. For those bores with fluctuations within a 5 m range, a larger scale version is also shown to enable the detail of the data to be observed.

10.3.1. Peel Valley Alluvium

The monitoring bore locations for the hydrographs displayed for the Peel Valley Alluvium is shown in Map 19. As described in section 5.1, groundwater levels in the Peel Valley Alluvium fluctuate with rainfall and stream-flow events as demonstrated by the peaks in the data in Figures 25 and 26. The long term trend over the period of record is relatively stable.

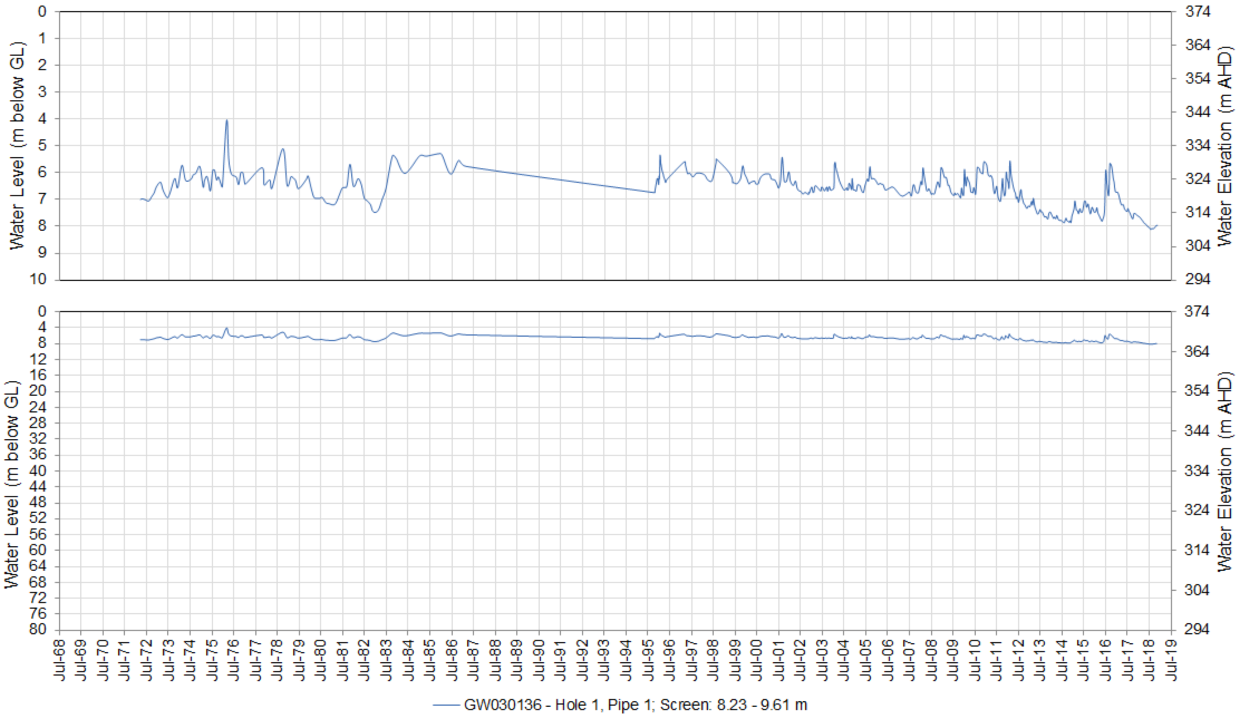


Figure 25 Hydrograph for monitoring bore site GW030136 – Tamworth

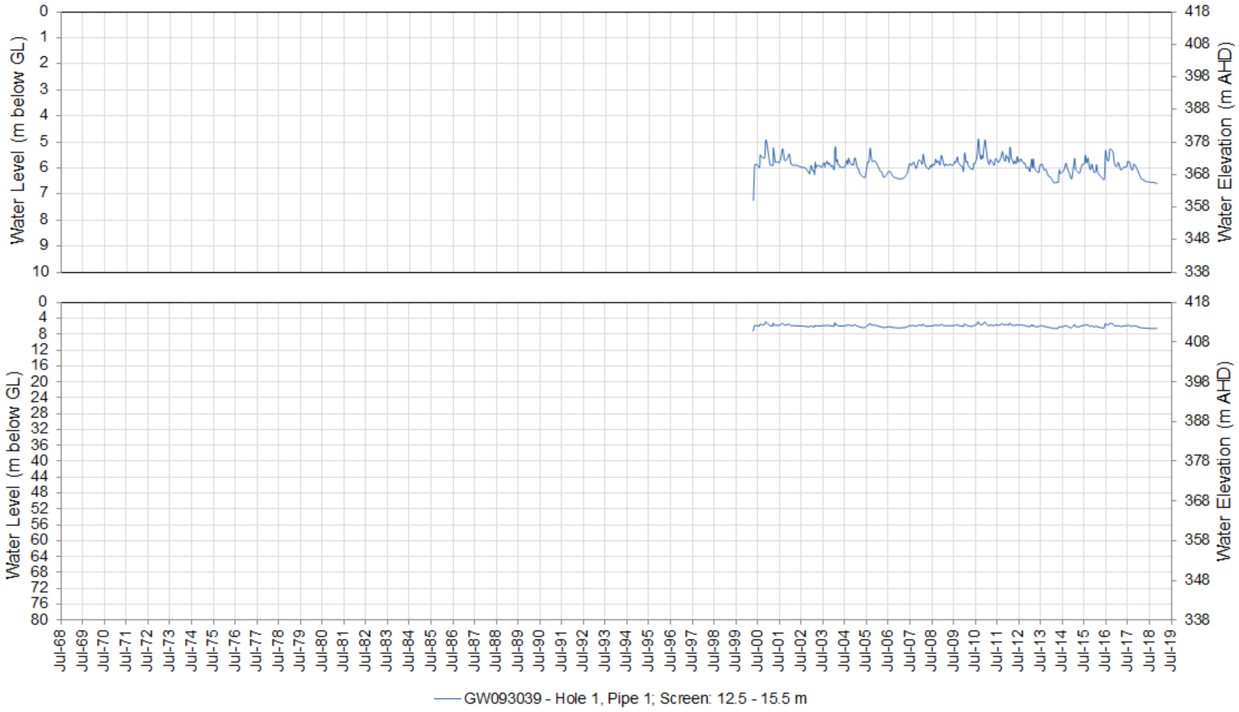
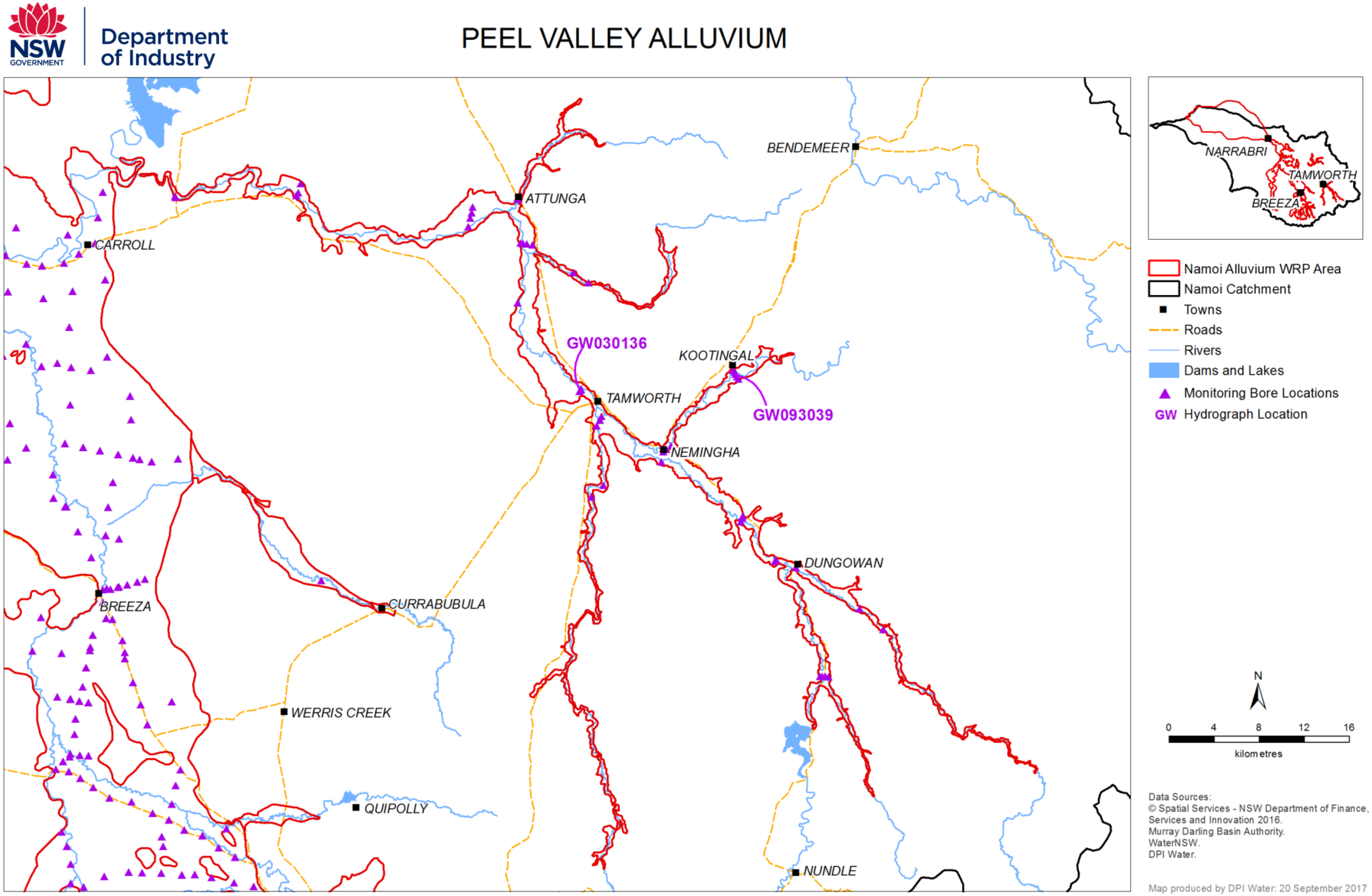


Figure 26 Hydrograph for monitoring bore site GW093039 – Kootingal



Map 19 Peel Valley Alluvium hydrograph locations

10.3.2. Upper Namoi Alluvium

Due to the geographic nature of the Upper Namoi Alluvium the groundwater trends across the system are highly variable. The monitoring bore locations for the hydrographs displayed for the Upper Namoi Alluvium are shown in Map 20.

In the southern end of the system the groundwater level response to seasonal groundwater extraction is small reflecting the shallow unconfined nature of the groundwater system in this area. The long term water level trend is relatively stable with the dominant rises and falls in groundwater levels being in response to climate (Figure 27).

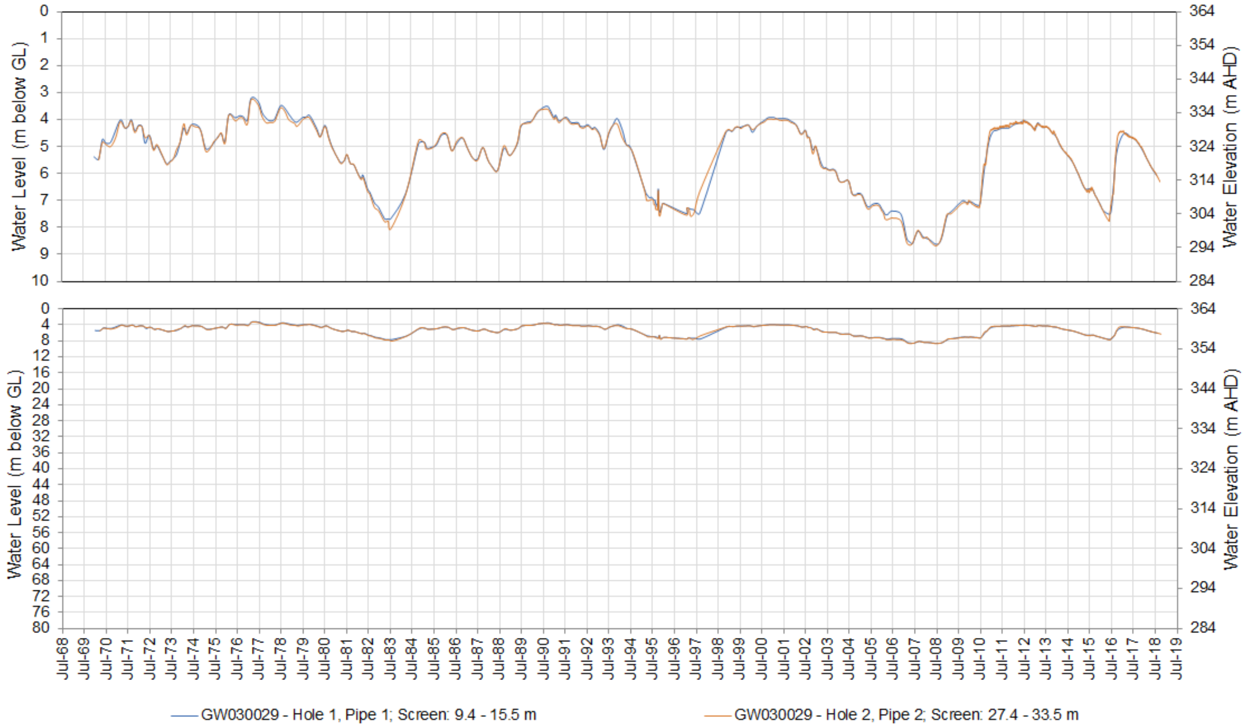


Figure 27 Hydrograph for monitoring bore site GW030029 – Upper Namoi Alluvium (Zone 1)

Intensity of groundwater extraction increases as the alluvium becomes deeper towards the north. Groundwater levels in the alluvium along the Mooki River show more intense seasonal drawdown in response to groundwater extraction (Figures 28 and 29), these sites also show subdued longer term rises and falls in response to climate. A long term declining trend is observed in Figure 28.

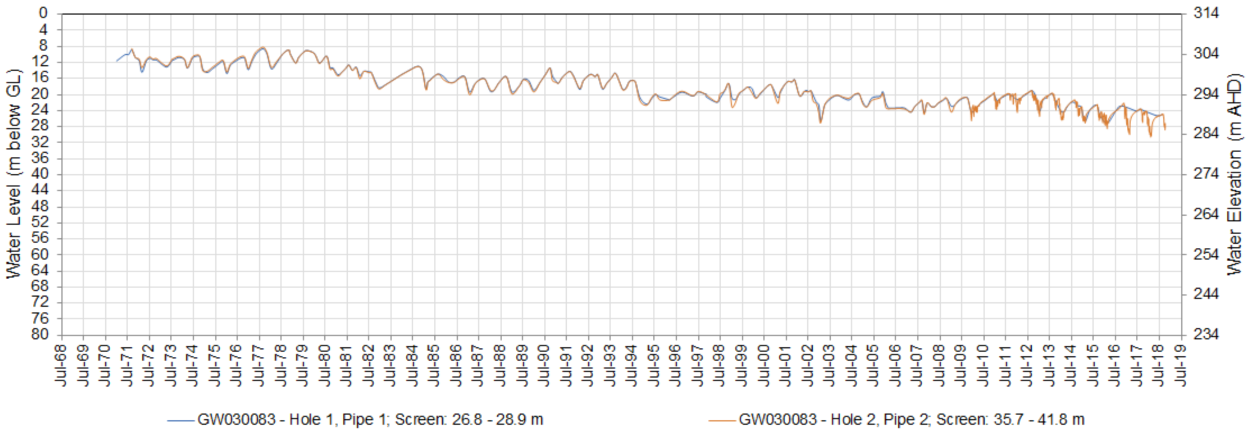


Figure 28 Hydrograph for monitoring bore site GW030083 telemetered – Upper Namoi Alluvium (Zone 8)

Figure 29 (Pipe 1) shows hydraulic connection between the surface water and the shallow aquifer systems in the area as demonstrated by the peaks in the data shown since the installation of a data logger providing continuous groundwater level data from 2010. The overall long term trend at this site is declining to stable.

Figure 29 Hydrograph for monitoring bore site GW036213, – Upper Namoi Alluvium (Zone 3), Data logger installed in 2010

Similarly groundwater levels in the alluvium along Coxs Creek and the Namoi River (Figure 30 and 31) show seasonal drawdown in response to groundwater extraction, the long term trend in this area is declining to stable.

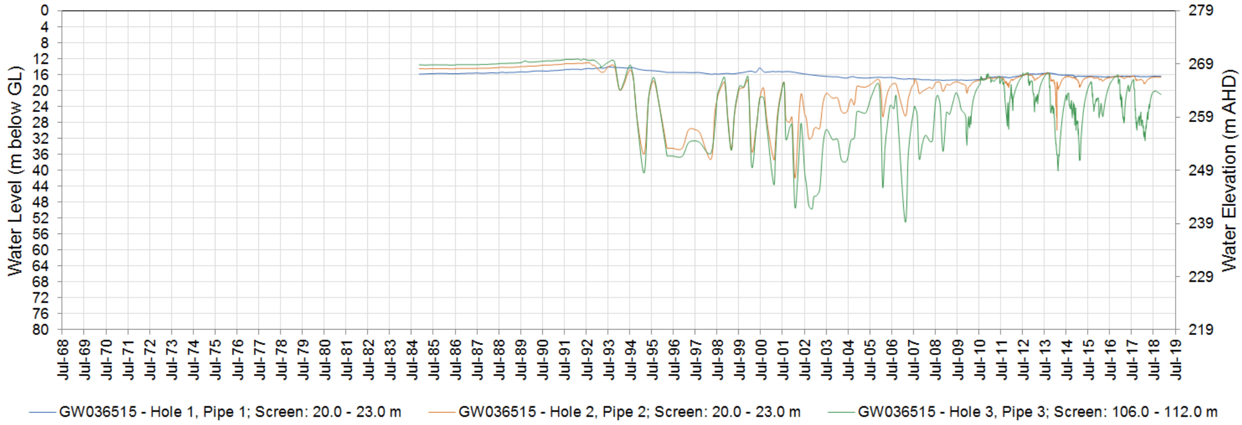


Figure 30 Hydrograph for monitoring bore site GW036515 telemetered – Upper Namoi Alluvium (Zone 2)

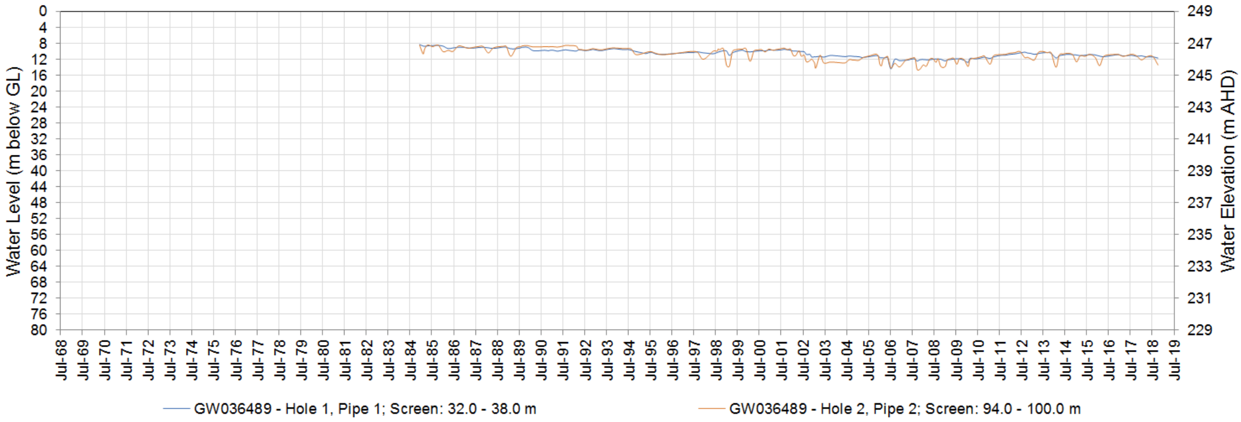
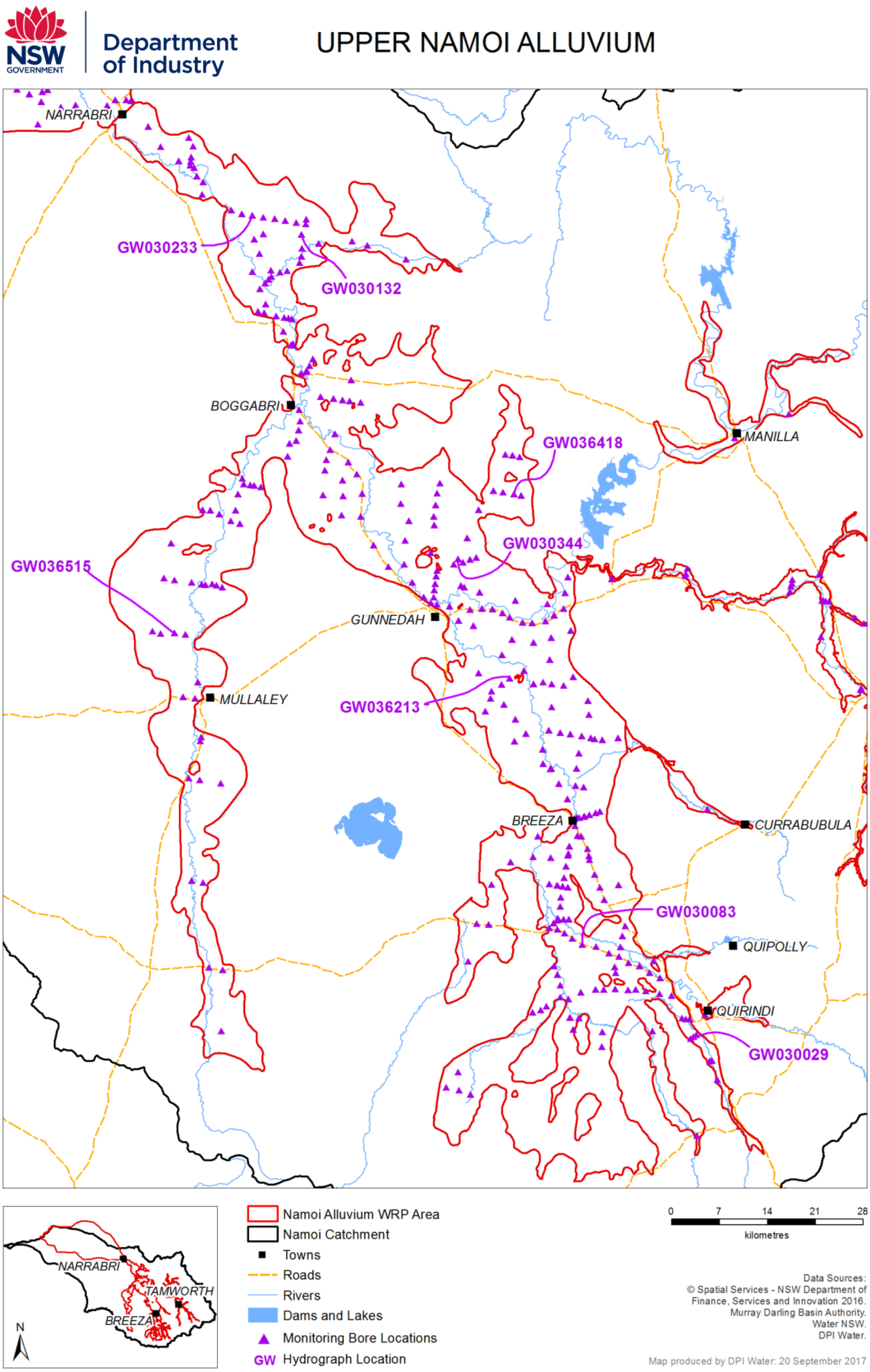


Figure 31 Hydrograph for monitoring bore site GW036489 telemetered – Upper Namoi Alluvium (Zone 4)



Map 20 Upper Namoi Alluvium hydrograph locations

Groundwater levels in the Kelvin area (Figure 32) show minor response to seasonal drawdown with a pronounced long term declining trend since the mid-1990s in this area. The onset of this decline corresponds to a period of below average rainfall and related increase in groundwater extraction across the Namoi Valley. The groundwater systems in the Kelvin area are also relatively steeply draining towards the Namoi.

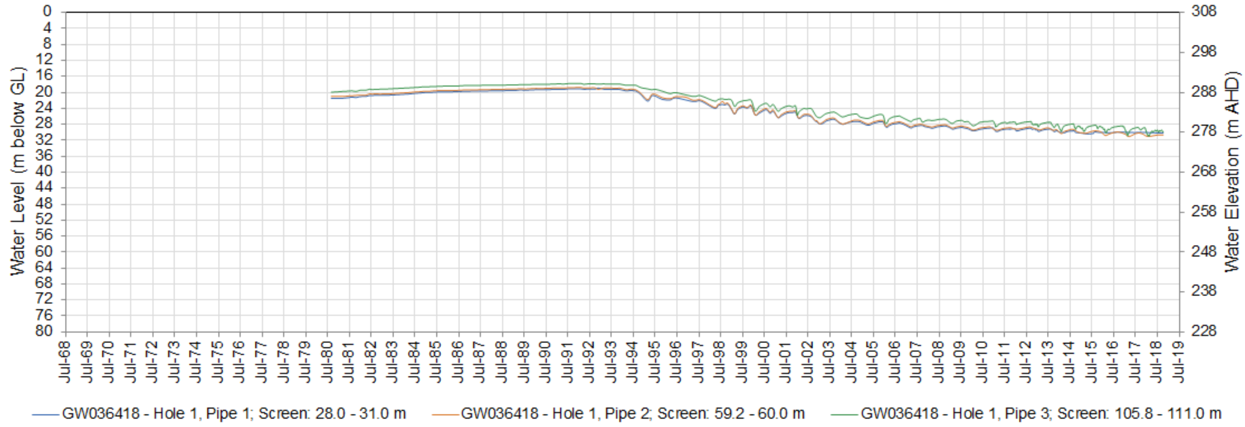


Figure 32 Hydrograph for monitoring bore site GW036418 telemetered – Upper Namoi Alluvium (Zone 12)

Towards the northern end of the Upper Namoi system (Figure 33), groundwater levels show pronounced seasonal drawdown in response to extraction and subdued longer term rises and falls in response to climate. There is a declining to stable long term water level trend. In the Maules Creek area (Figure 34) the aquifer system is in good hydraulic connection with surface water as demonstrated by the peaks in the data.

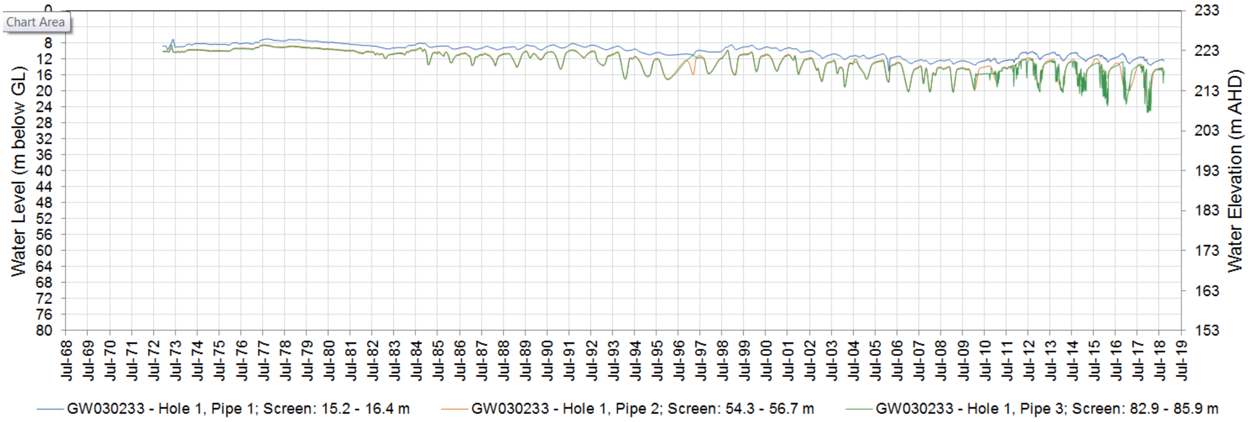


Figure 33 Hydrograph for monitoring bore site GW030233 telemetered – Upper Namoi Alluvium (Zone 5)

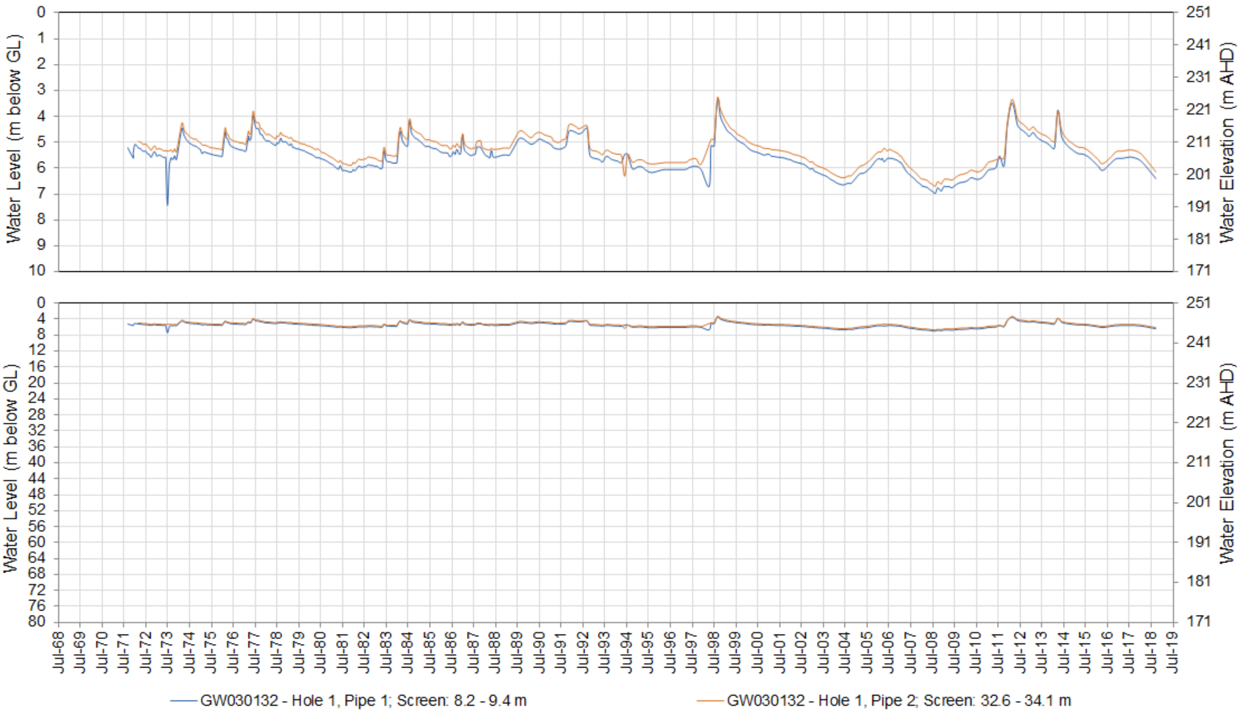


Figure 34 Hydrograph for monitoring bore site GW030132 telemetered – Upper Namoi Alluvium (Zone 11).

10.3.3. Lower Namoi Alluvium

The monitoring bore locations for the hydrographs displayed for the Lower Namoi Alluvium is shown in Map 21.

There is significant seasonal drawdown in response to groundwater extraction across the central and northern parts of the Lower Namoi Alluvium and as far west as Cryon (Figure 35 to 39) where the majority of pumping is occurring.

East of the Merah North section, the majority of sites show longer term rises and falls in response to climate (Figure 35 to 37), with sites close to surface water sources showing varying degrees of hydraulic connection in the shallow aquifer system.

As the system deepens towards the west, groundwater level trends show less influence from climatic variations (Figures 38 and 39).

The long term trend across the majority of the central and north parts of the Lower Namoi Alluvium is declining to stable, with the areas to the north of Pian Creek and east of Burren Junction experiencing the most significant declines (Figure 36 and 37). West of the Burren Junction the long term trend is relatively stable (Figure 39).

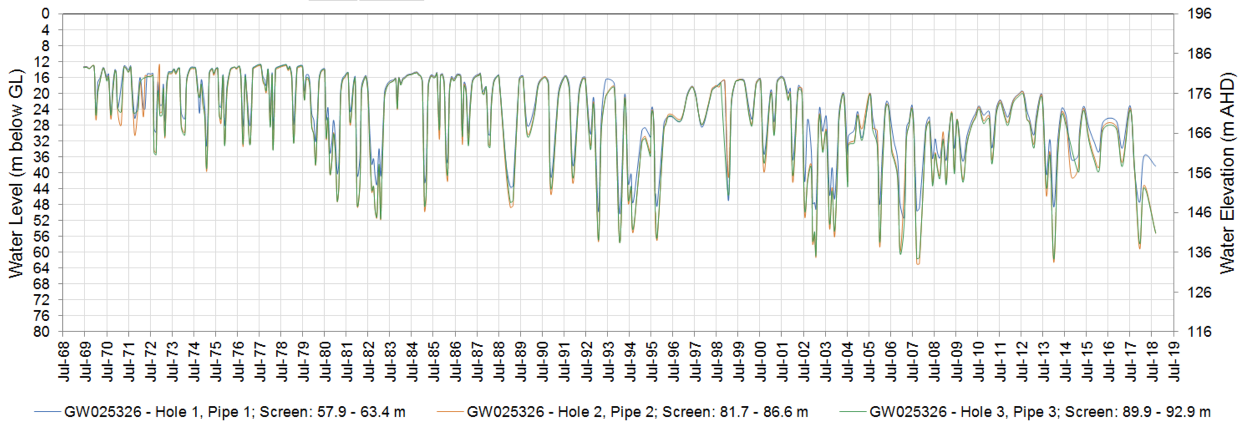


Figure 35 Hydrograph for monitoring bore site GW025326 Gurleigh section

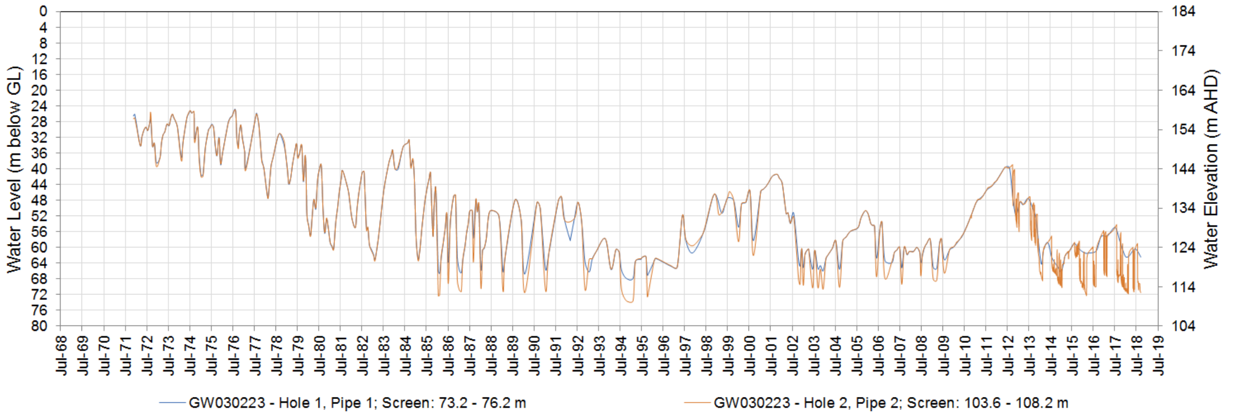


Figure 36 Hydrograph for monitoring bore site GW030223 telemetered Wee Waa section

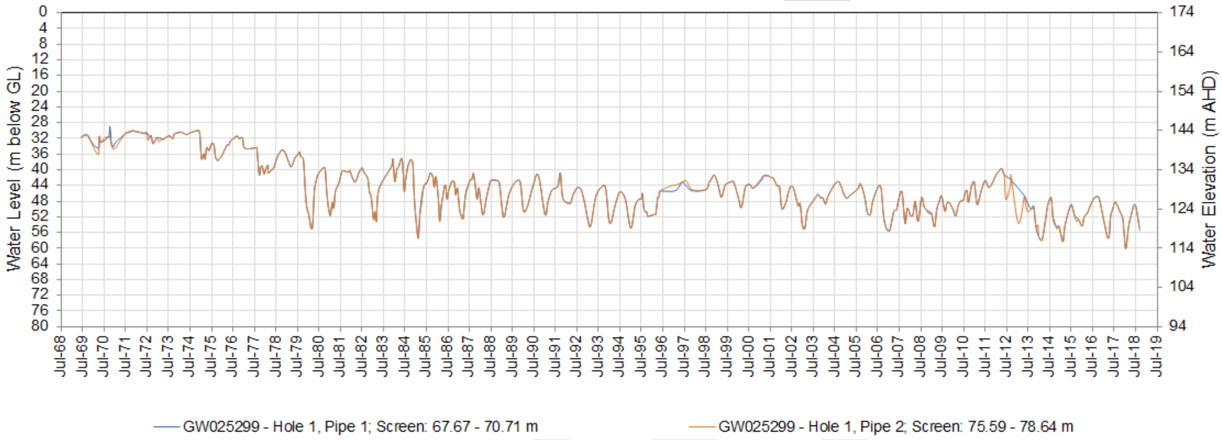


Figure 37 Hydrograph for monitoring bore site GW025299 telemetered Merah North section

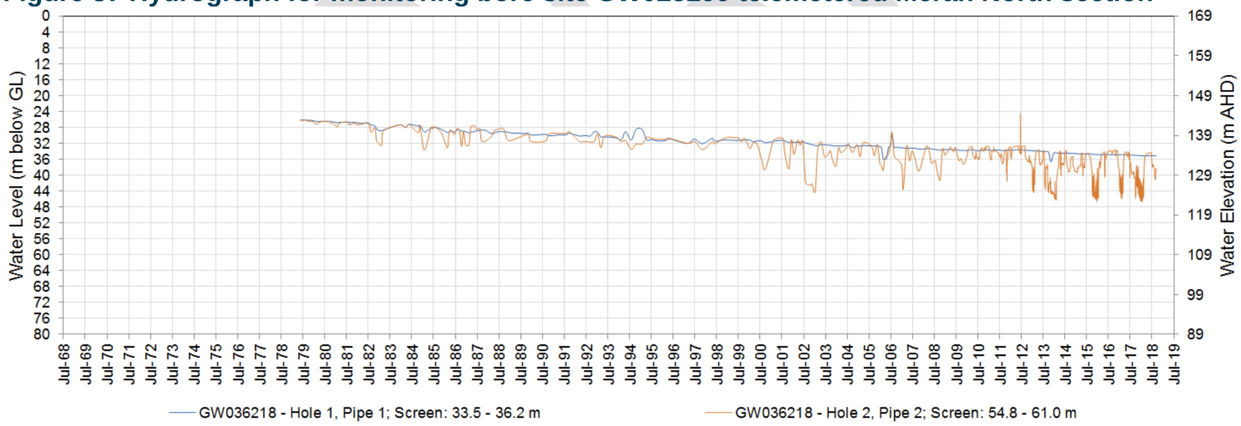


Figure 38 Hydrograph for monitoring bore site GW036218 telemetered Cubbaroo section

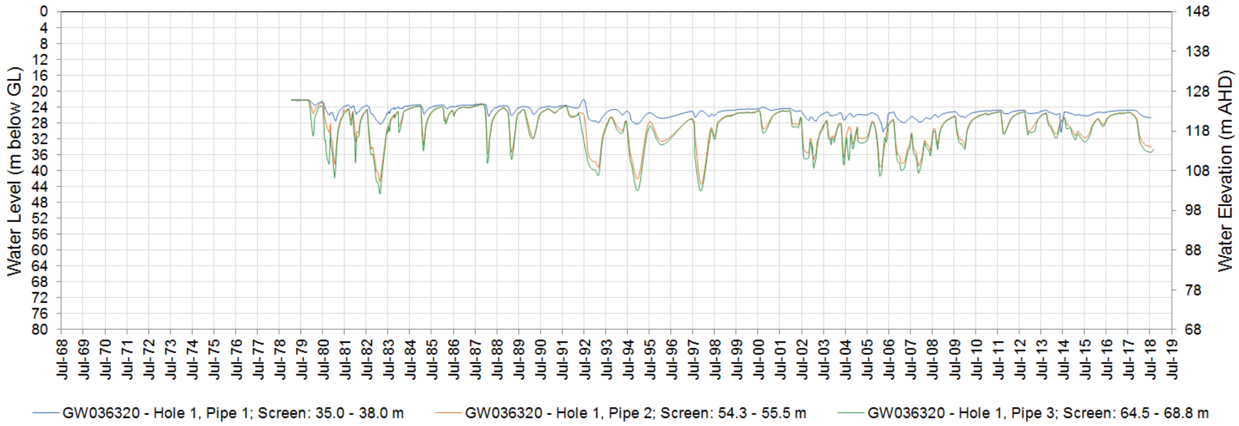
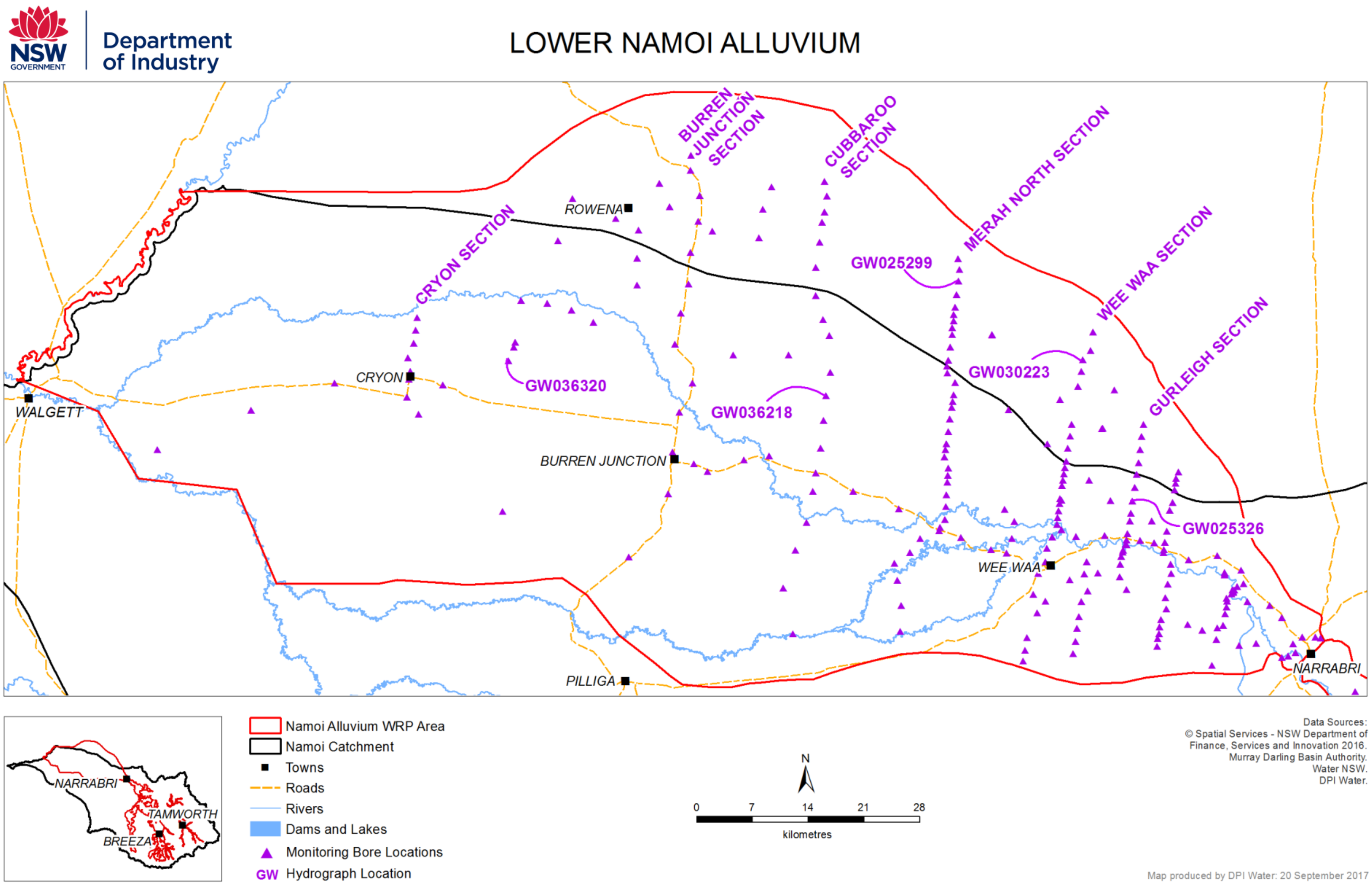


Figure 39 Hydrograph for monitoring bore site GW036320 telemetered Burren Junction/Cryon Sections



Map 21 Lower Namoi Alluvium hydrograph locations

10.4. Groundwater contour maps

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

Contour maps have been prepared for the Upper Namoi Alluvium and Lower Namoi Alluvium. 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.

10.4.1. Upper Namoi Alluvium

The recovered water levels (Map 22 A) in the deep aquifer system are compared with the corresponding maximum drawdown water levels (Map 22 B) in 2015/2016.

The change of pattern in the flow direction over a season in areas where extraction occurs is highlighted in Map 22 B. The areas of greatest extraction impact are south of Breeza (Zone 8), east of Gunnedah (Zone 3) and between Boggabri and Narrabri (Zone 5) where drawdown lows develop over the pumping season.

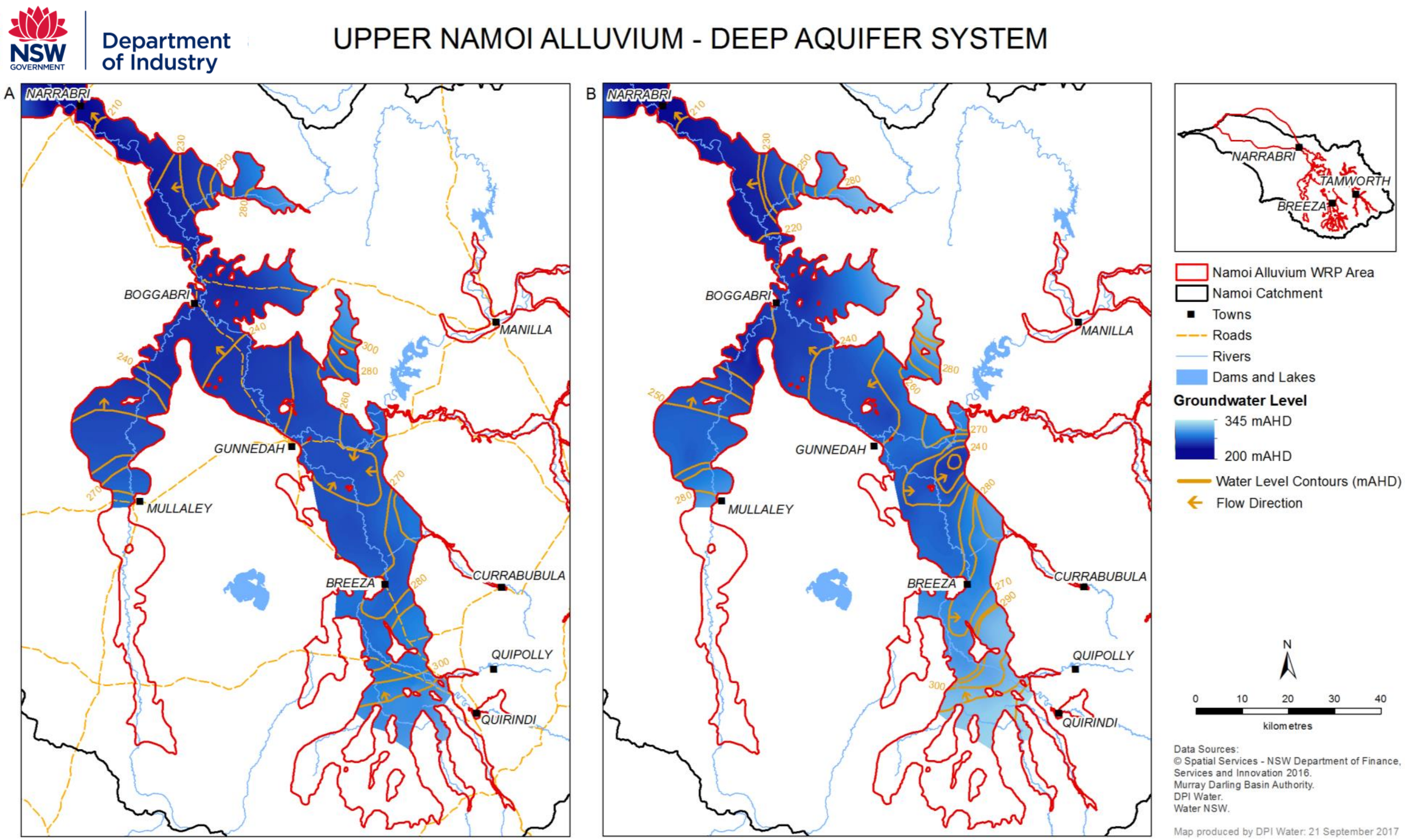
Groundwater level contours of recovered water levels (Map 22 A) show the regional groundwater flow direction across the Upper Namoi Alluvium is south to north draining into the Lower Namoi Alluvium.

10.4.2. Lower Namoi Alluvium

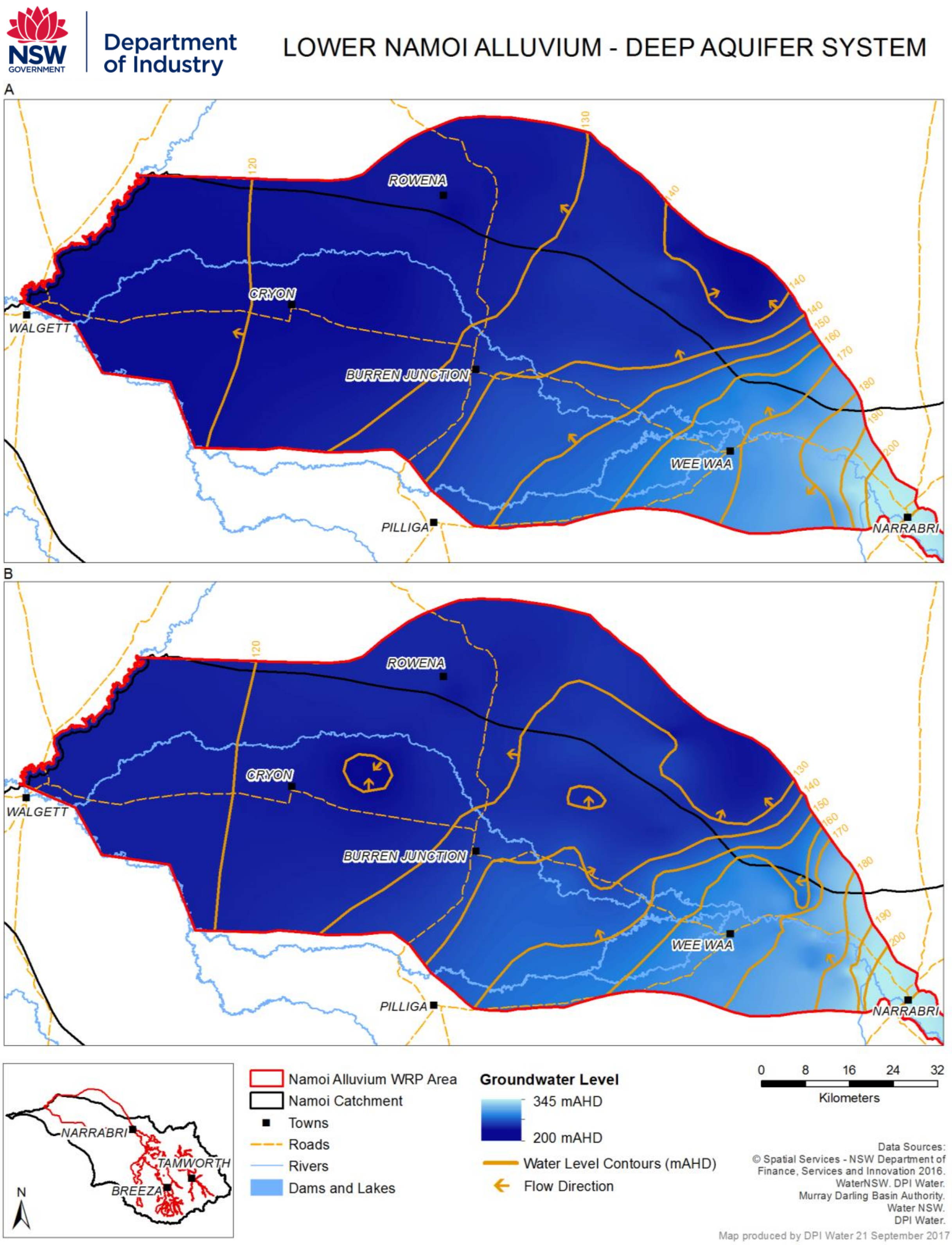
The recovered water levels (Map 23 A) in the deep aquifer system of the Lower Namoi are compared with the corresponding maximum drawdown water levels (Map 23 B) in 2015/2016.

The maximum recovered water level in 2015/2016 is shown in Map 23 A, the flow direction is generally towards the west. However north of Wee Waa, in the area north of the bedrock high shown in Figure 8A (Section 5.4), an area has developed where water levels remain low. This area of low groundwater levels persists through the non-pumping season and has resulted in a permanent change from the westward groundwater flow direction under predevelopment conditions.

The areas where extraction is causing change in flow direction over the pumping season is shown in Map 23 B. The area north of Wee Waa showing low water levels in Map 23 A expands further to the east during the pumping season. There are also drawdown lows east of Burren Junction and near Cryon.



Map 22 Upper Namoi Alluvium deep aquifer system 2015/2016 groundwater level contours (A) maximum recovery, (B) maximum drawdown



Map 23 Lower Namoi Alluvium deep aquifer system 2015/2016 groundwater level contours (A) maximum recovery, (B) maximum drawdown

10.5. Long term changes

Change in recovered groundwater levels over time have been prepared for the deep aquifer system of the Upper Namoi Alluvium and the Lower Namoi Alluvium.

Two periods are shown for these areas, the long term change from pre-development to 2015/2016 to show the change from pre commencement of large scale extraction to recent groundwater levels, also 2005/2006 to 2015/2016 corresponding to the start of the water sharing plans to recent.

The change in water level trend is similar between the shallow and deep aquifer systems in both the Upper Namoi Alluvium and Lower Namoi Alluvium, the same change in recovered water level maps have been produced for the shallow aquifer system and are provided in Appendix B.

10.5.1. Upper Namoi Alluvium

The change maps for the Upper Namoi Alluvium for the deep aquifer system are displayed in Map 24.

The long term change in groundwater levels from pre-development to 2015/2016 is shown in Map 24 A. The majority of the Upper Namoi Alluvium shows at least a 2 m decline in groundwater levels over time where the deep aquifer system occurs. From Gunnedah to Breeza groundwater levels have declined from 6 to 10 m, there are also large declines of greater than 10 m in the Kelvin area and south of Breeza.

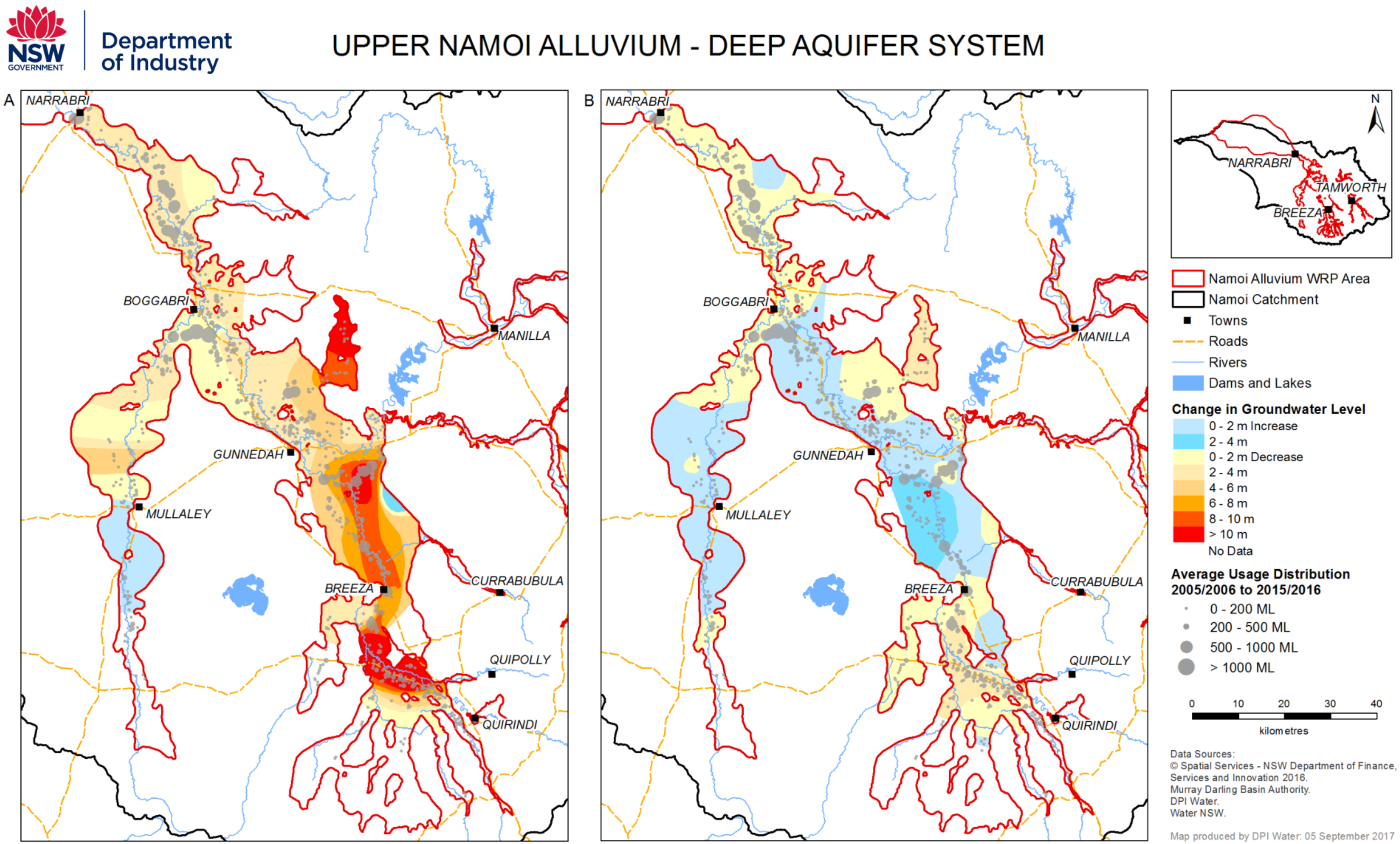
The change in groundwater levels over the period of the water sharing plan (2005/2006 to 2015/2016) is displayed in Map 24 B. Groundwater levels have declined over this period in the order of 0 to 2 m, with the exception of Kelvin where the decline is up to 6 m over this period. Large areas show a rise in groundwater levels of up to 4 metres.

10.5.2. Lower Namoi Alluvium

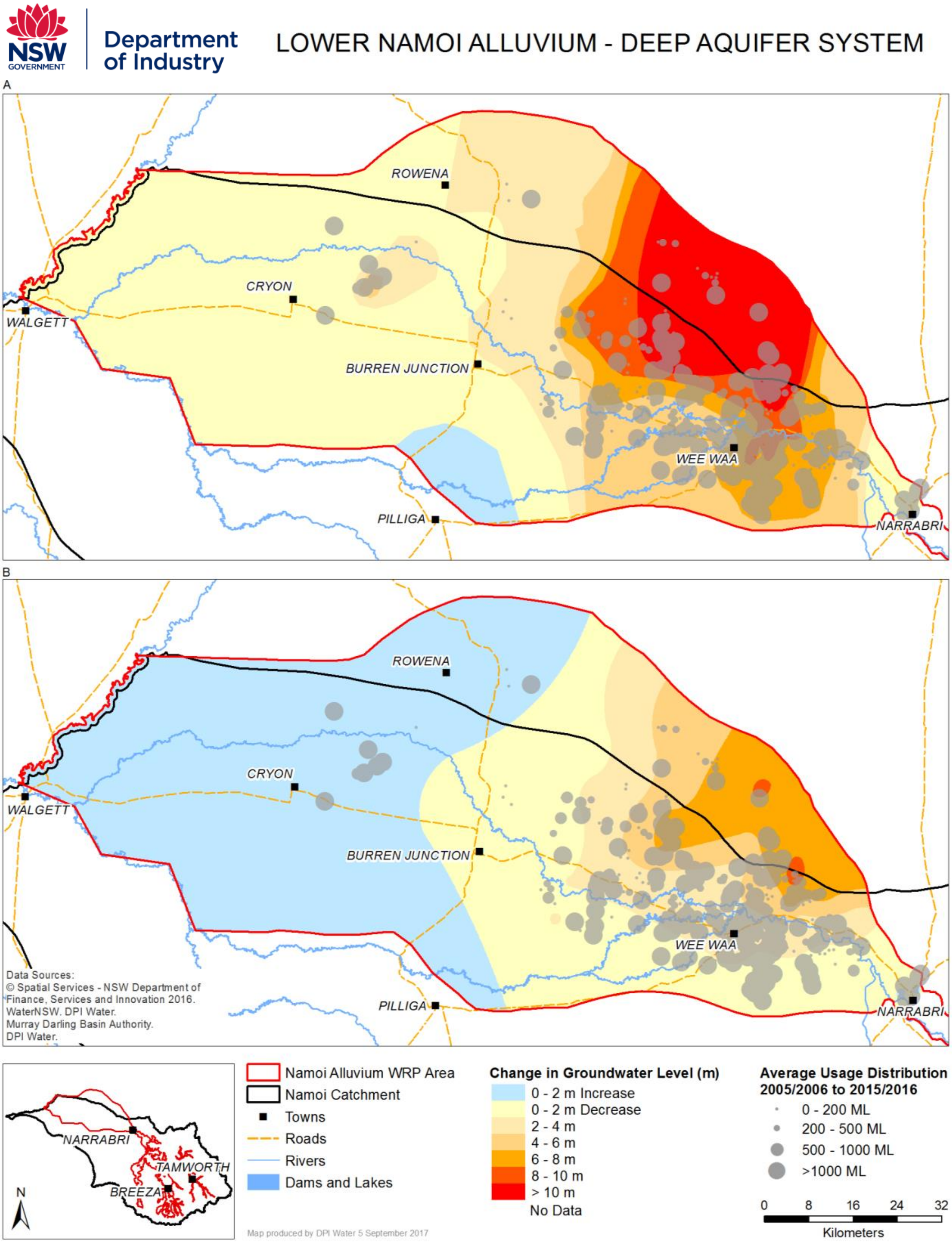
The change maps for the Lower Namoi Alluvium for the deep aquifer system are displayed in Map 25.

The long term change in groundwater level from pre-development to 2015/2016 is shown in Map 25 A. With the exception of a small area north of Pilliga on the southern boundary, the Lower Namoi Alluvium shows at least a 2 m decline groundwater levels. Larger long term decline has occurred east of Burren Junction, with 6 to 10m decline and greater than 10m in the area identified previously north of Wee Waa.

The change in groundwater levels over the period of the water sharing plan (2005/2006 to 2015/2016) is displayed in Map 25 B. Similar to the Upper Namoi Alluvium, the decline over this period is not as large, with a rise in groundwater levels west of Burren Junction. However the majority of the eastern portion of the Lower Namoi Alluvium shows at least a 2 m decline with up to 8m in the area north of Wee Waa.



Map 24 Change in recovered water level Upper Namoi Alluvium (A) Pre-development to 2015/2016, (B) 2005/2006 to 2015/2016



Map 25 Change in recovered water level Lower Namoi Alluvium (A) Pre-development to 2015/2016, (B) 2005/2006 to 2015/2016

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 (McDonald and Harbaugh 1984), 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 parameter 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.

11.1. Upper Namoi Alluvium

In 2006, the groundwater model for the Upper Namoi Alluvium was finalised to support resource management and the development of the water sharing plan. This model included Zones 2, 3, 4, 5, 11 and 12 of the Upper Namoi Alluvium.

This groundwater model is being updated and expanded to include the entire Upper Namoi Alluvium. As this model has not yet been finalised the cumulative water budget data for the Upper Namoi Alluvium has not been included in this report as the 2006 modelling does not cover the entire area..

11.2. Lower Namoi Alluvium

In 2001, the groundwater model for the Lower Namoi Alluvium was finalised to support resource management and the development of the water sharing plan. The model for the Lower Namoi Alluvium is currently being updated.

The cumulative water budget output from the 2001 Lower Namoi Alluvium groundwater model for the period 2006/2007 to 2015/2016 is shown in Figure 40. This corresponds to the period since commencement of the water sharing plan for the Lower Namoi Alluvium. This shows that since commencement of the water sharing plan in 2006/2007, the modelled net change in storage in the Lower Namoi Alluvium has Lower Namoi Alluvium has decreased (storage change of -1.3 GL/year) over the 10 years.

This decrease in storage reflects the water sharing plan for the Lower Namoi Alluvium allowing extraction to be in excess of the estimated average annual recharge to enable users to adjust to the reduction in entitlements that occurred at the beginning of the plan. Access to groundwater has been progressively reduced over the ten year life of the plan via supplementary licences which were cancelled at the end of the 2014/2015 water year.

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. With the cancellation of the supplementary licences in the Namoi Alluvium extraction is now being managed to ensure depletion of the groundwater storage does not continue into the longer term.

Water Budget Summary - Whole Model

Model Description: Lower Namoi - version LN6

Calibration Period: 1/7/1980 TO 30/6/1998

Summary Period: **2006/16**

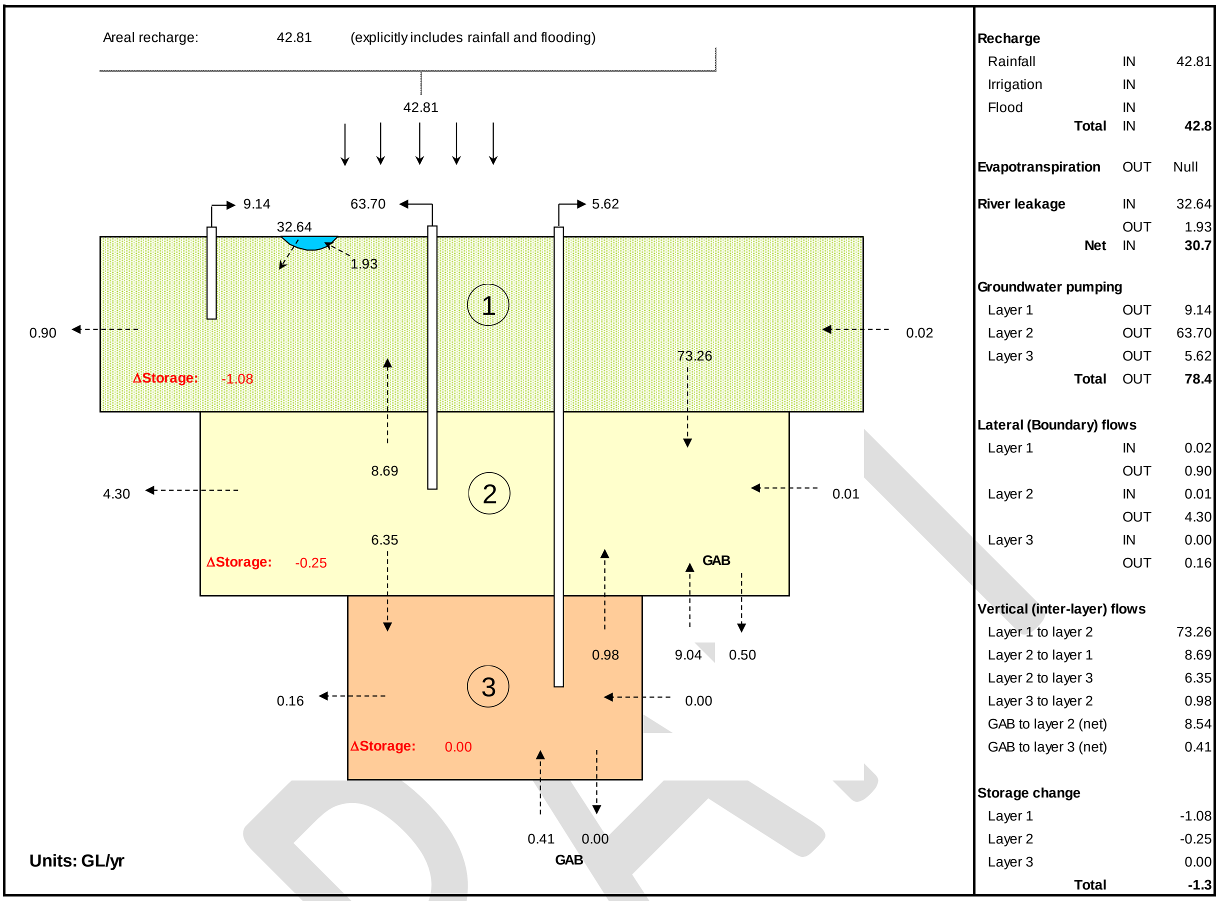


Figure 40 Lower Namoi Alluvium groundwater flow model water budget output 2006/2007 to 2015/2016, numbers are in GL/year.

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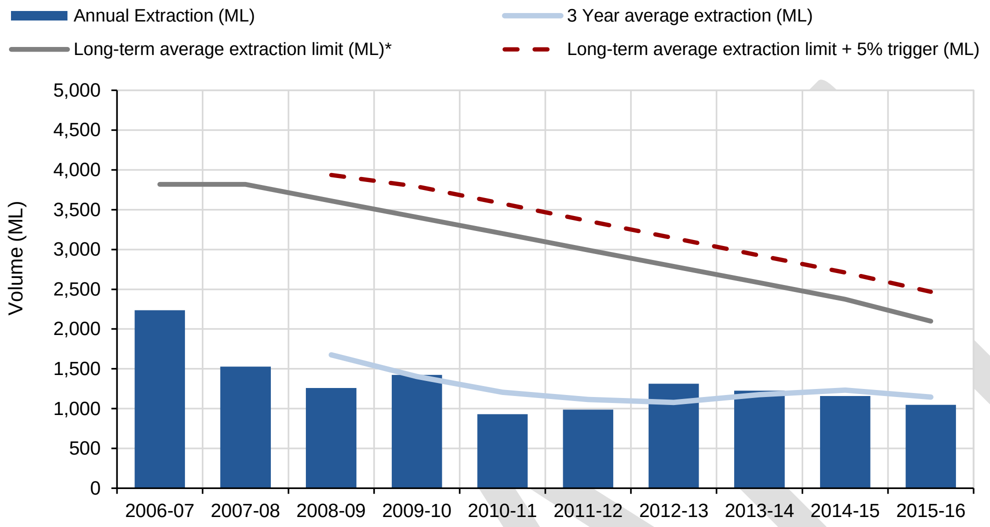
Appendix A

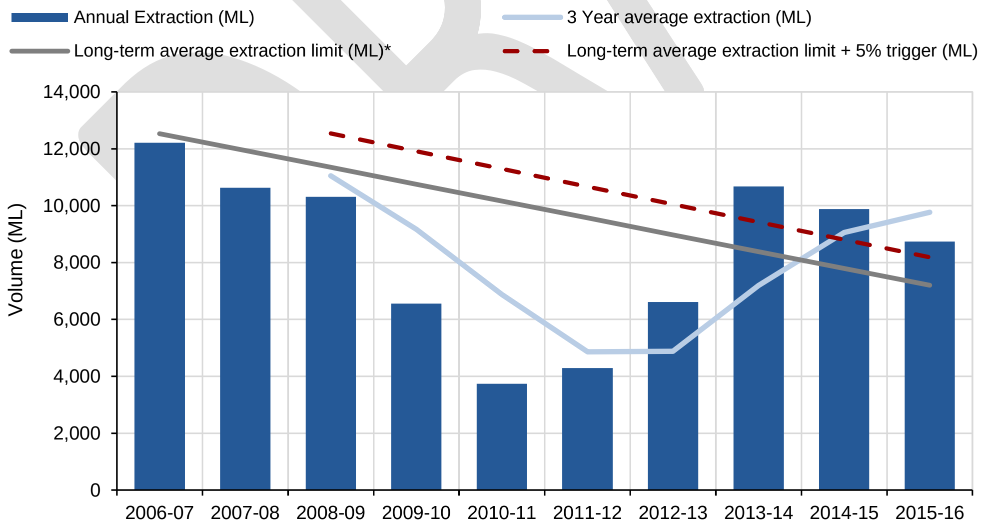
Groundwater source of the Upper Namoi Alluvium – annual extraction since commencement of the water sharing plan compared to the LTAAEL and the trigger set by the water sharing plan to initiate a management response to ensure there is no growth in extraction above the LTAAEL in the long term.

Note – Upper Namoi Zone 10 is not included as there is very little usage.

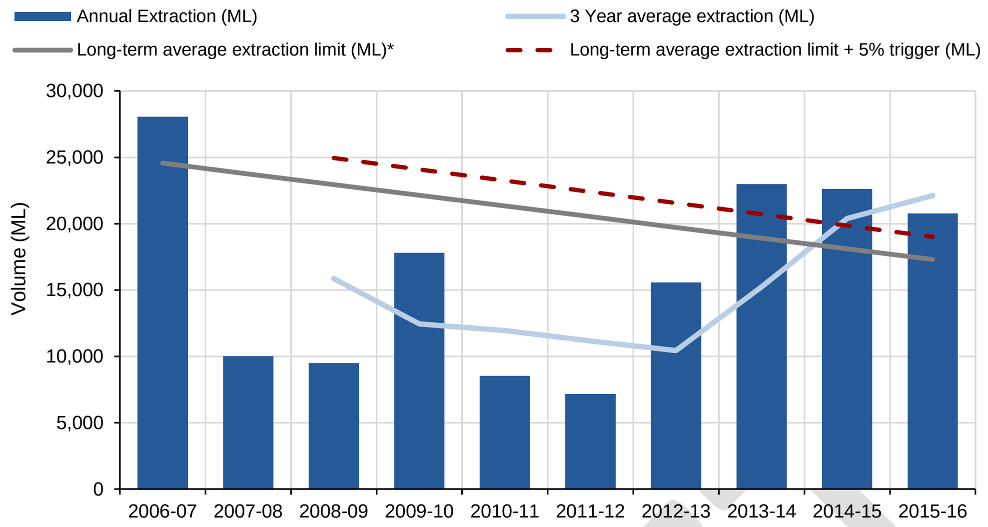
Upper Namoi Zone 1



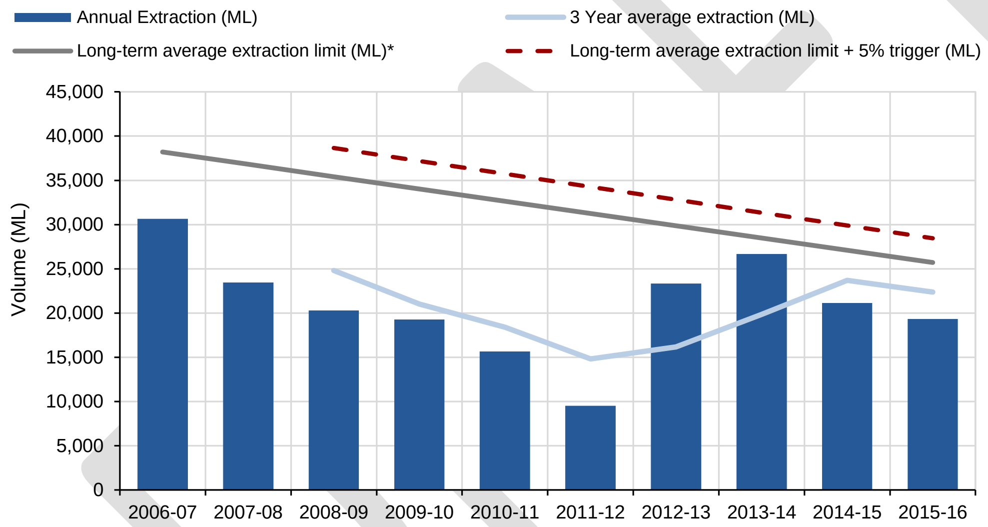
Upper Namoi Zone 2



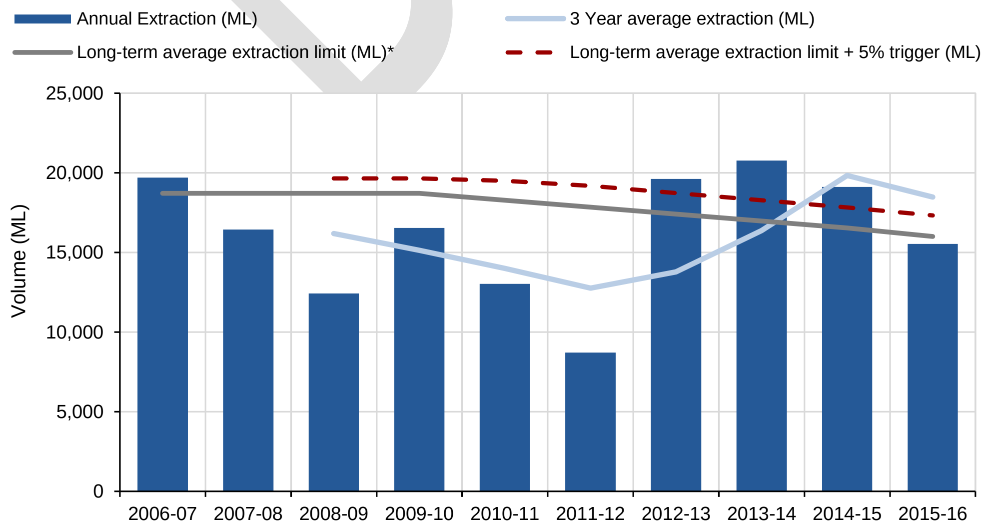
Upper Namoi Zone 3



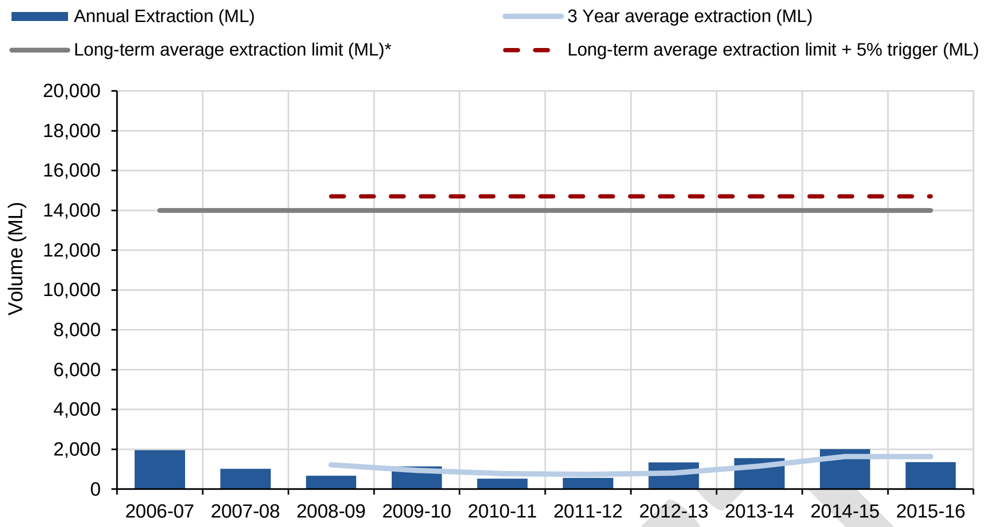
Upper Namoi Zone 4



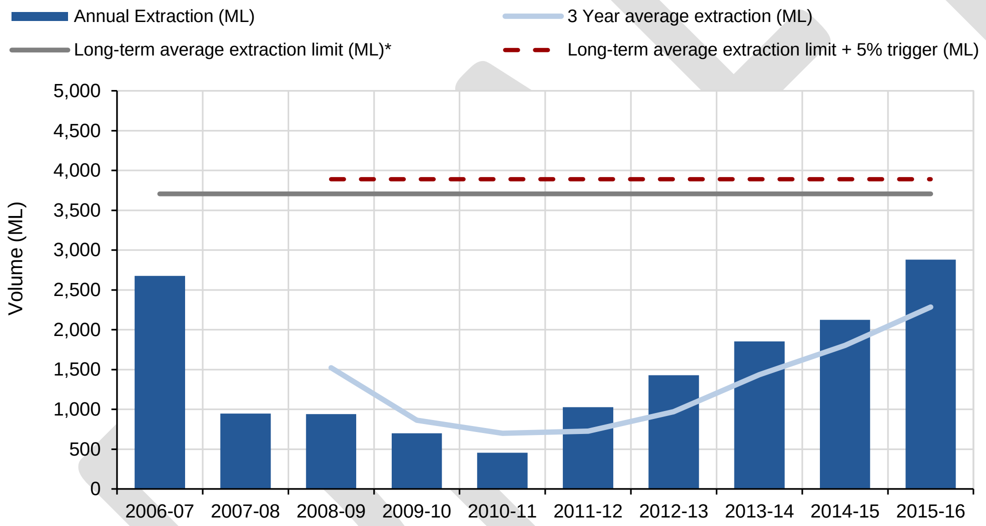
Upper Namoi Zone 5



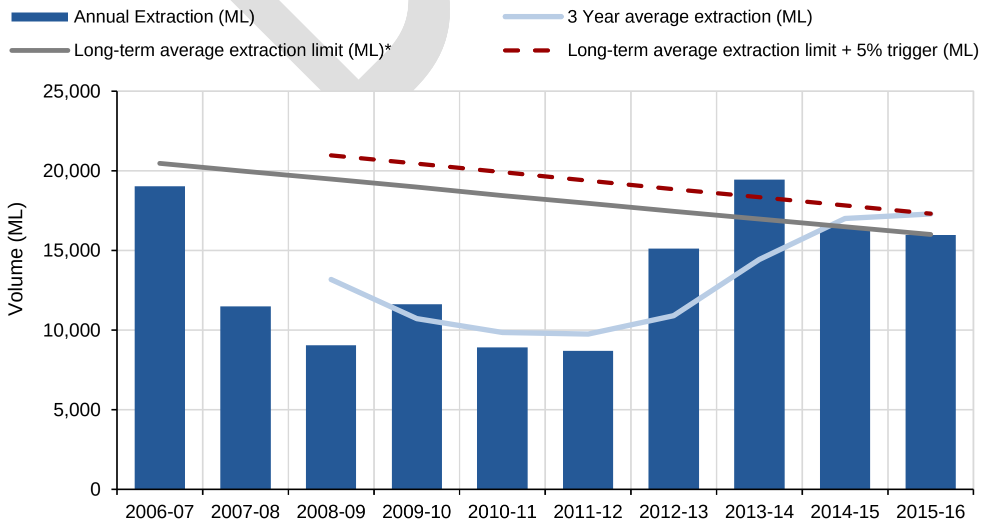
Upper Namoi Zone 6



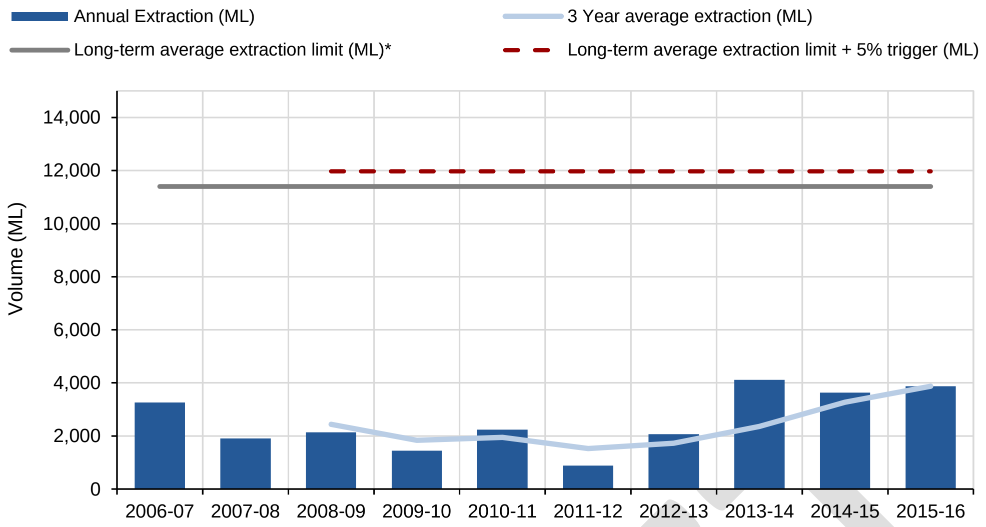
Upper Namoi Zone 7



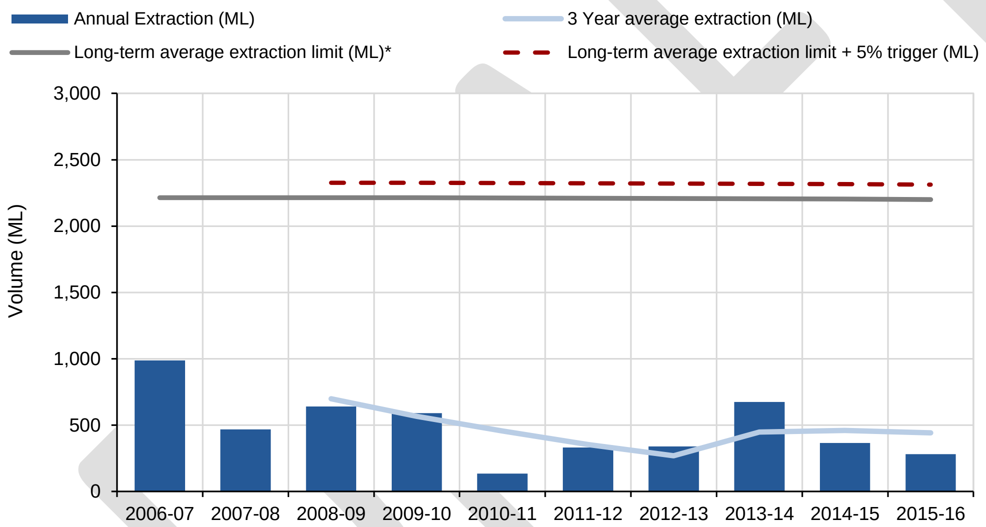
Upper Namoi Zone 8



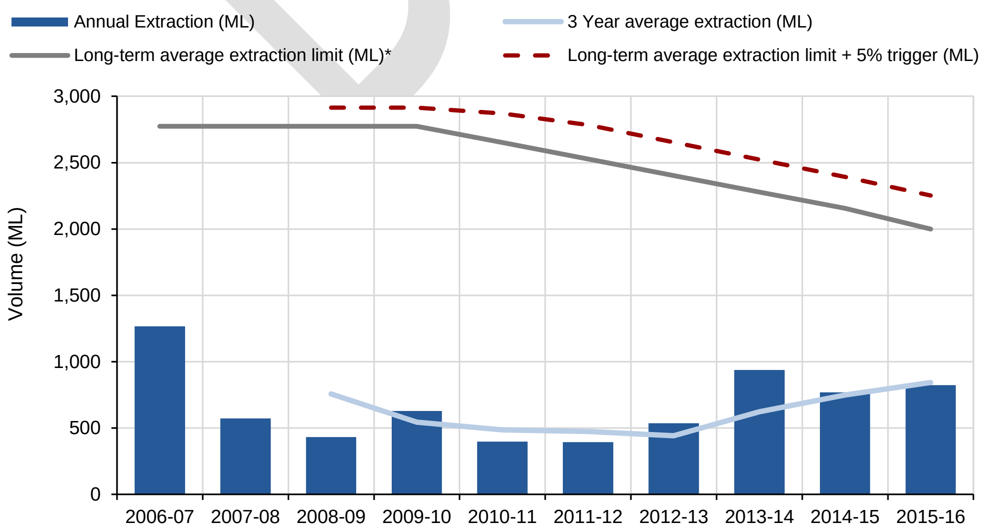
Upper Namoi Zone 9



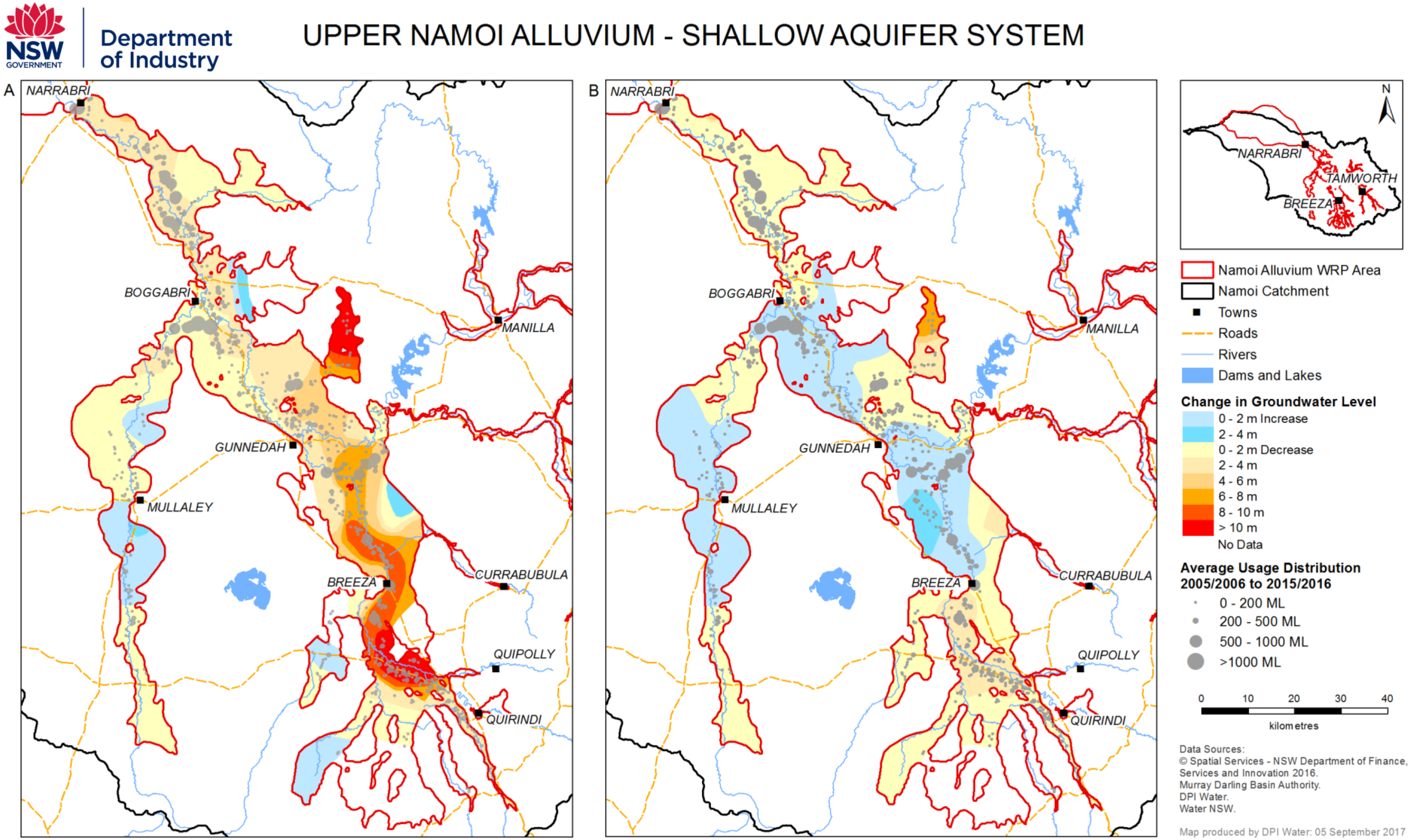
Upper Namoi Zone 11



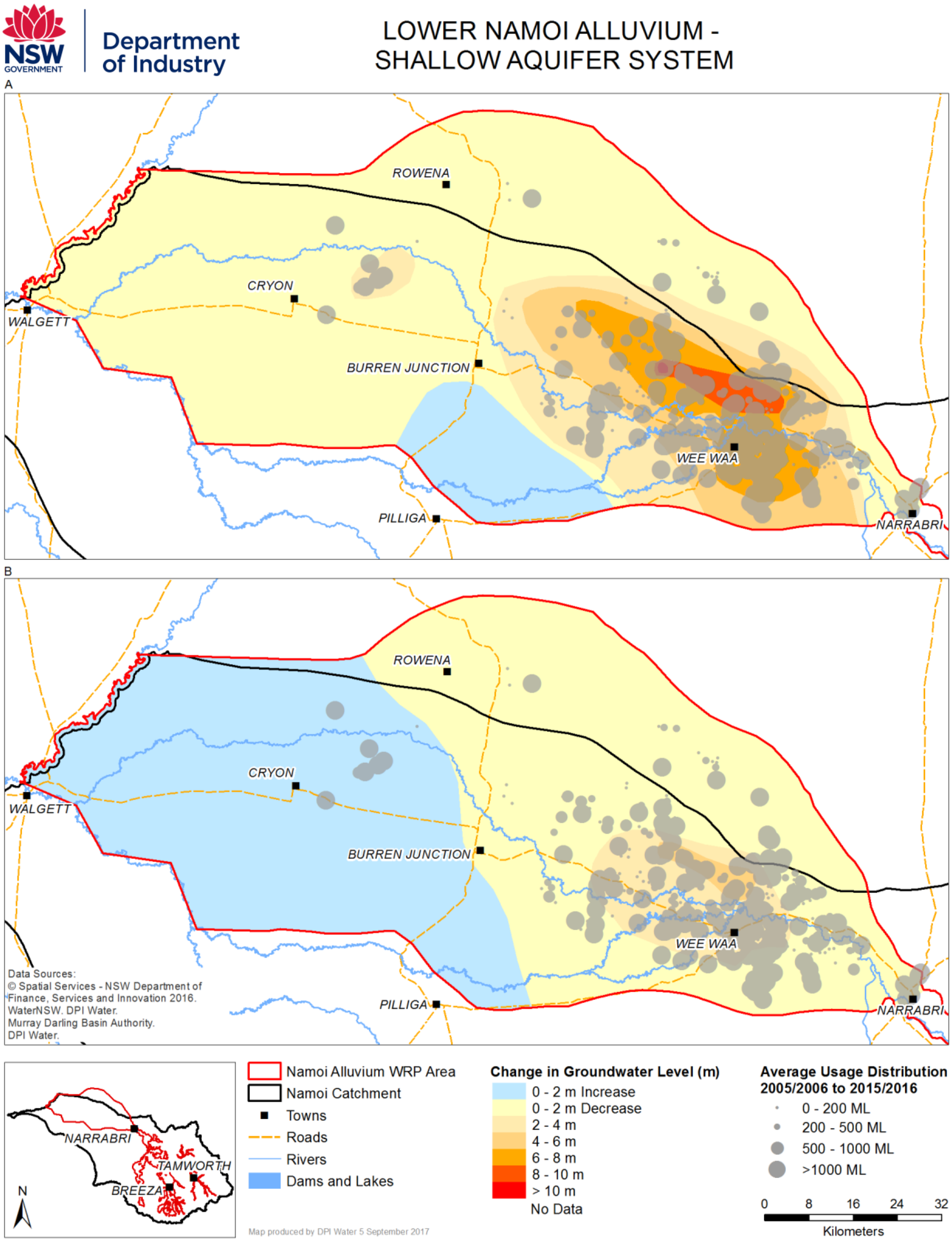
Upper Namoi Zone 12



Appendix B



Map A – Change in recovered water level Pre-development to 2015/2016, Map B – Change in recovered water level 2005/2006 to 2015/2016.



Map A – Change in recovered water level Pre-development to 2015/2016.

Map B – Change in recovered water level 2005/2006 to 2015/2016.