GWYDIR ALLUVIUM WATER RESOURCE PLAN

Groundwater Resource Description

Published by NSW Department of Industry.

Gwydir Alluvium Water Resource Plan – Groundwater Resource Description.

First published November 2018

ISBN number

More information

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www.industry.nsw.gov.au

Acknowledgments

Cover image: Lou Gall GVIA / Irrigated cotton Lower Gwydir / NSW

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Glossary

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

Beneficial use (category)	[1]A general categorisation of groundwater uses based on water quality and the presence or absence of contaminants. Beneficial use is the equivalent to the ‘environmental value’ of water.
Bore (or well)	A hole or shaft drilled or dug into the ground...
Brackish water	Water with salinity between 3,000 and 7,000 mg/L total dissolved solids.
Cenozoic	The Cenozoic Era spanned from 66 million years ago to present
Confined aquifer	. An aquifer which is bounded above and below by impermeable layers causing it to be under pressure so that when the aquifer is penetrated by a bore, the groundwater will rise above the top of the aquifer.
Connected water sources	Water sources that have some level of hydraulic connection.
Development (of a groundwater resource)	The commencement of extraction of significant volumes of water from a water source.
Discharge	Flow of groundwater from a groundwater source.
Drawdown	The difference between groundwater level/pressure before take and that during take.
Dual porosity	Where a groundwater system has two types of porosity; primary porosity resulting from the voids between the constituent particles forming the rock mass, and secondary porosity resulting from dissolution, faulting and jointing of the rock mass.
Electrical conductivity (EC)	Ability of a substance to conduct an electrical current. Used as a measure of the concentration of dissolved ions (salts) in water (i.e. water salinity). Measured in micro-Siemens per centimetre (µS/cm) or deci-Siemens per metre (dS/m) at 25^{o} C. 1 dS/m = 1000 µS/cm
Environmental Value	[2]Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of contamination, waste discharges and deposits.
Fractured rock	Rocks with fractures, joints, bedding planes and cavities in the rock mass.
Geological sequence	A sequence of rocks or sediments occurring in chronological order.
Groundwater	Water that occurs beneath the ground surface in the saturated zone.

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

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

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

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

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

Reliable water supply	[4]Rainfall of 350mm or more per annum (9 out of 10 years); or a regulated river, or unregulated rivers where there are flows for at least 95% of the time (i.e. the 95th percentile flow of each month of the year is greater than zero) or 5th order and higher rivers; or groundwater aquifers (excluding miscellaneous alluvial aquifers, also known as small storage aquifers) which have a yield rate greater than 5L/s and total dissolved solids of less than 1,500mg/L.
River Condition Index (RCI)	This is a spatial tool used to measure and monitor the long term trend of river condition, but also reports on instream values and risk to instream values from extraction and geomorphic disturbance.
Salinity	The concentration of dissolved minerals in water, usually expressed in EC units or milligrams of total dissolved solids per litre.
Salt	A mineral which in a liquid will readily dissociate into its component ionic species for example NaCl into Na^+ and Cl^- ions.
Saturated zone	Area below the water table where all soil spaces, pores, fractures and voids are filled with water.
Sedimentary rock	A rock formed by consolidation of sediments deposited in layers, for example sandstone, siltstone and limestone.
Share component	An entitlement to water specified on an access licence, expressed as a unit share or for specific purpose licences a volume in megalitres (eg. local water utility, major water utility and domestic and stock).
Sustainable Diversion Limits	The volume of water that can be taken from a Sustainable Diversion Limit resource unit as defined under the Murray Darling *Basin Plan 2012*.
Unassigned water	Exists where current water requirements (including licensed volumes and water to meet basic landholder rights) are less than the extraction limit for a water source.
Unconfined aquifer	A groundwater system usually near the ground surface, which is in connection with atmospheric pressure and whose upper level is represented by the water table.
Unconsolidated sediment	Particles of gravel, sand, silt or clay that are not bound or hardened by mineral cement, pressure, or thermal alteration of the grains.
Unsaturated zone	Area above the water table where soil spaces, pores, fractures and voids are not completely filled with water.
Water balance	A calculation of all water entering and leaving a system.

[4] As defined by Strategic Regional Land Use Plans

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

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

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

1 Introduction

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

Under the 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 Gwydir Alluvium Water Resource Plan area is shown in Figure 1 and is located within the Gwydir catchment that forms part of the Murray-Darling Basin in northern NSW. The Gwydir catchment covers approximately 26,600 km² and represents approximately 2.4 percent of the Murray-Darling Basin.

The groundwater resources of the Gwydir Alluvium include all of the main alluvial deposits associated with the Gwydir River. The Gwydir Alluvium Water Resource Plan area extends from approximately 20 kilometres (km) downstream of Copeton Dam, north-west through Bingara to Biniguy and continues approximately 45 km west of Moree.

The Gwydir Alluvium Water Resource Plan area (GW15 - Murray-Darling Basin reference number) is composed of two SDL resource units: the Lower Gwydir Alluvium (GS24) and the Upper Gwydir Alluvium (GS43) shown in Figure 1. These SDL resource units correlate directly to groundwater sources currently covered by water sharing plans. They are the:

- Lower Gwydir Groundwater Source (Lower Gwydir Alluvium) managed under the *Water Sharing Plan for the Lower Gwydir Groundwater Source 2003,* and the
- Upper Gwydir Alluvial Groundwater Source (Upper Gwydir Alluvium) managed under the *Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012.*

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

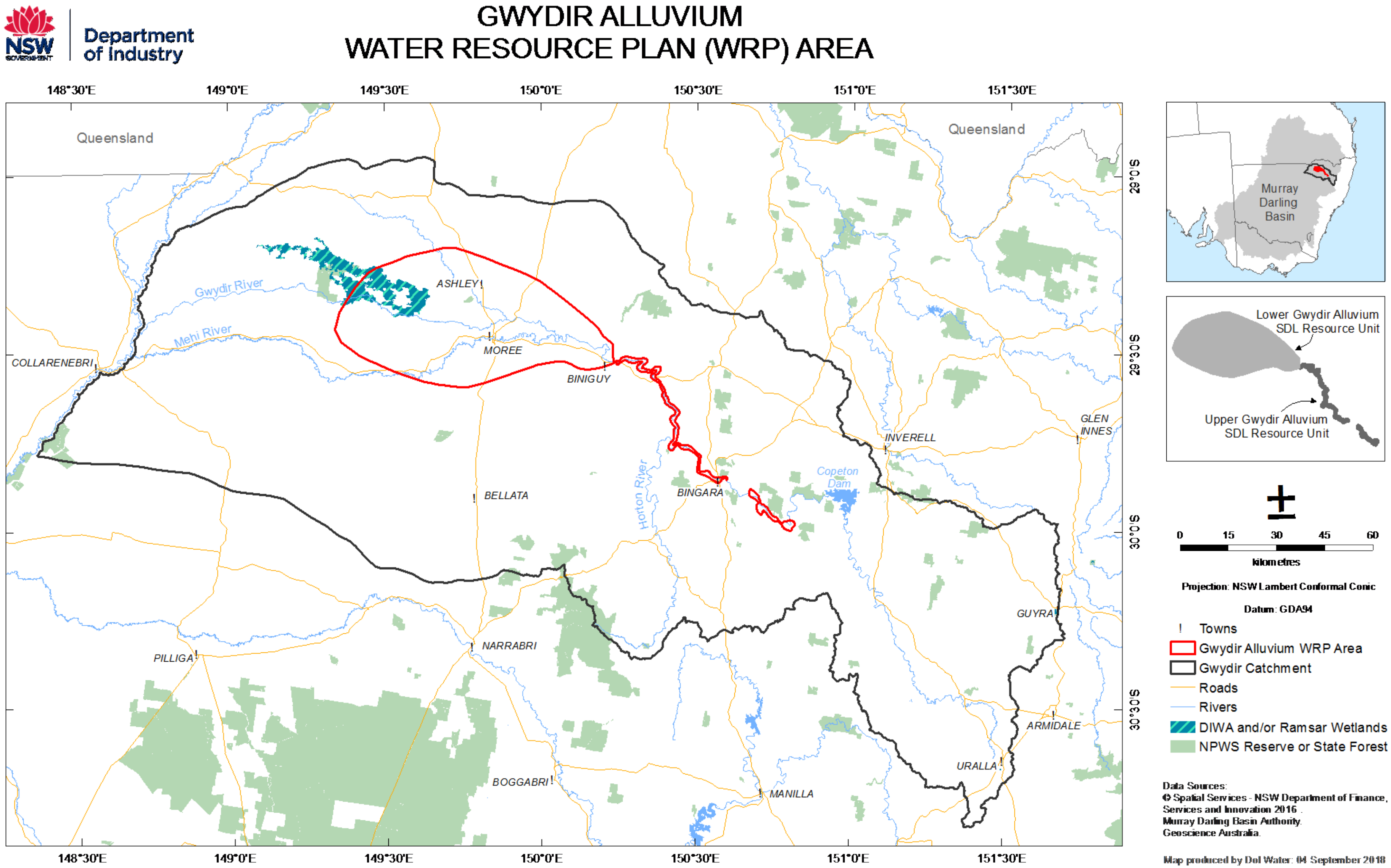


Figure 1 Location of the Gwydir Alluvium water resource plan Area and SDL Resource Units

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 megalitres (ML)) 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.

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

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

2.3 Upper Gwydir Alluvium

There has been little groundwater based development in the Upper Gwydir Alluvium. The area was included in the 1984 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.

The Upper Gwydir Alluvium was part of the groundwater management area previously referred to as the ‘Miscellaneous Alluvium of the Barwon Region’. In 2008, an embargo on new applications for groundwater licences was introduced and this included the Miscellaneous Alluvium of the Barwon Region. This embargo remained in place until the commencement of the *Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012*.

2.4 Lower Gwydir Alluvium

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

A moratorium on new groundwater entitlements was imposed in November 1993 (Kalaitzis, 1999) and no new entitlement was issued for new or replacement bores. The *Water Sharing Plan for the Lower Gwydir Groundwater Source 2003* commenced in October 2006.

Total entitlements in the Lower Gwydir Alluvium were reduced from approximately 70,000 ML to the 32,300 ML under the water sharing plan that commenced in 2006. Access to groundwater was 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.

3 Regional Setting

3.1 Topography

The Gwydir River system and its floodplain are the main topographic features of the Gwydir catchment (Figure 2). From its headwaters near Uralla, at around 1,200 m above sea level, the Gwydir River flows north-west through tablelands and steep-sided valleys into Copeton Dam.

Copeton Dam was completed in 1976 and is the valley's major water storage facility with a capacity of 1,364,000 ML that provides water for town water supplies, irrigation, stock and domestic use, industry, and environmental flows. Copeton Dam is located on the Gwydir River about 35 km south-west of Inverell between Bingara and Bundarra.

The flow regime of Gwydir River has been substantially altered by the construction of Copeton Dam and various weirs and regulators that divert water along distributary channels including the Mehi River, Moomin Creek and Carole Creek (Figure 3).

Downstream of the dam, the river continues flowing north-west through an alluvial valley before it enters the plains near Biniguy.

The Gwydir River reaches it maximum capacity at Pallamallawa upstream of Moree where the mean daily flow is 2,053 ML per day. After this the main channel of the Gwydir begins to lose its flow to the many anabranches and effluent channels that characterise the lower part of the catchment.

The channel capacity at Pallamallawa is greater than the combined capacity of the four major distributary streams (the Gwydir, Mehi, Moomin Creek and Carole Creek) and so even small rises at Pallamallawa can cause overbank flow downstream (Pietsch 2006). All of the effluents leaving the river are regulated.

Downstream of Moree, the Gwydir River splits into two major streams: the Gingham Watercourse and the Lower Gwydir Watercourse, which is also known as the Big Leather Watercourse. These watercourses support the extensive Gwydir floodplain wetlands that form one of the most extensive and significant semi-permanent terminal wetlands in north-west NSW. These wetlands are not groundwater dependent.

The Lower Gwydir Wetlands provide valuable habitat for waterbirds and are listed as a site of international significance under the Ramsar Convention.

The Upper Gwydir Alluvium is made up of the valley infill alluvial sediments associated with the Gwydir River between Copeton Dam and Biniguy.

West of Biniguy the valley widens and the landscape changes to alluvial floodplains where the elevation is generally less than 200 m. The alluvial fan of the Lower Gwydir Alluvium occurs from Biniguy to approximately 45 km west of Moree.

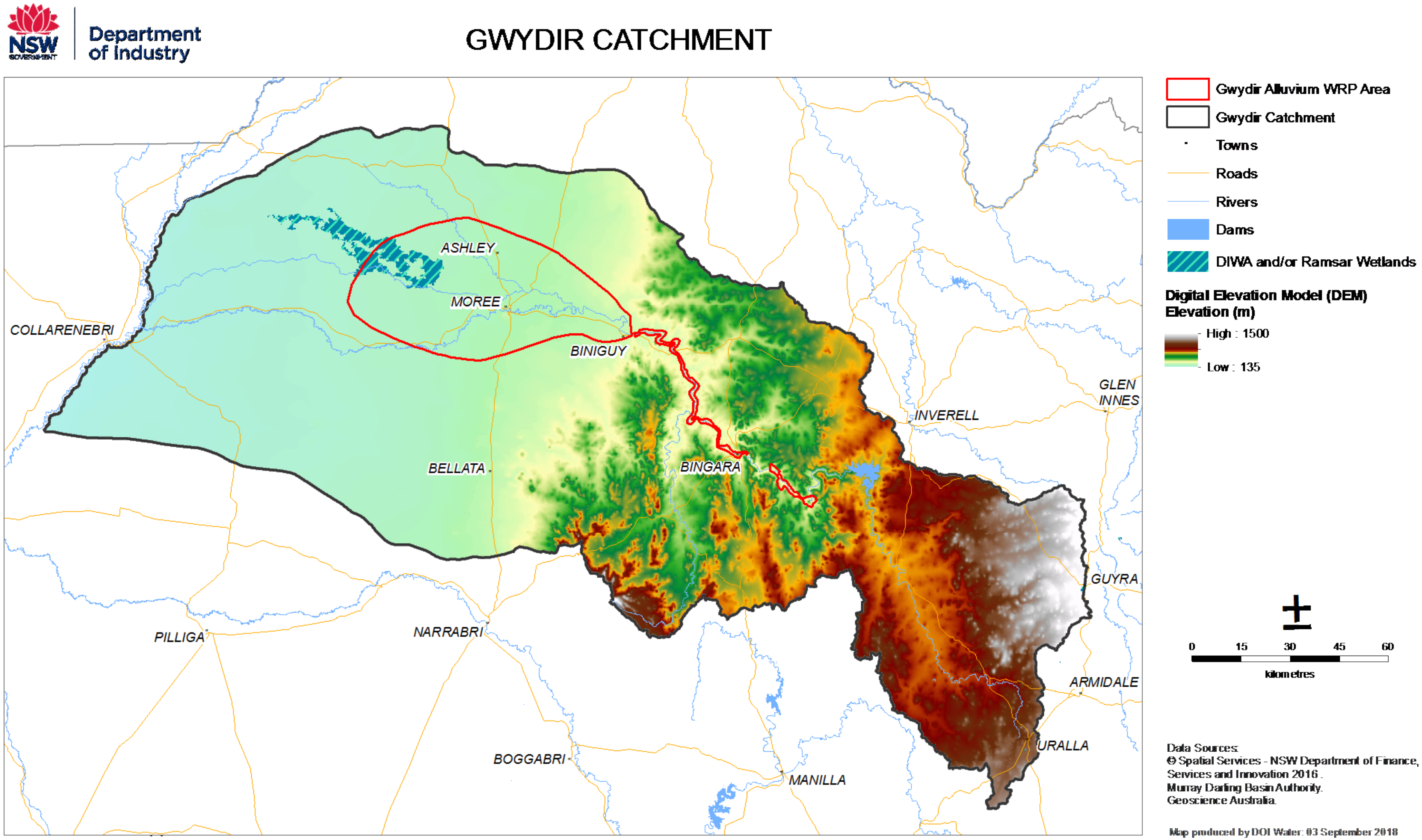


Figure 2 Topography and elevation map of the Gwydir catchment (Gallant *et al*, 2009)

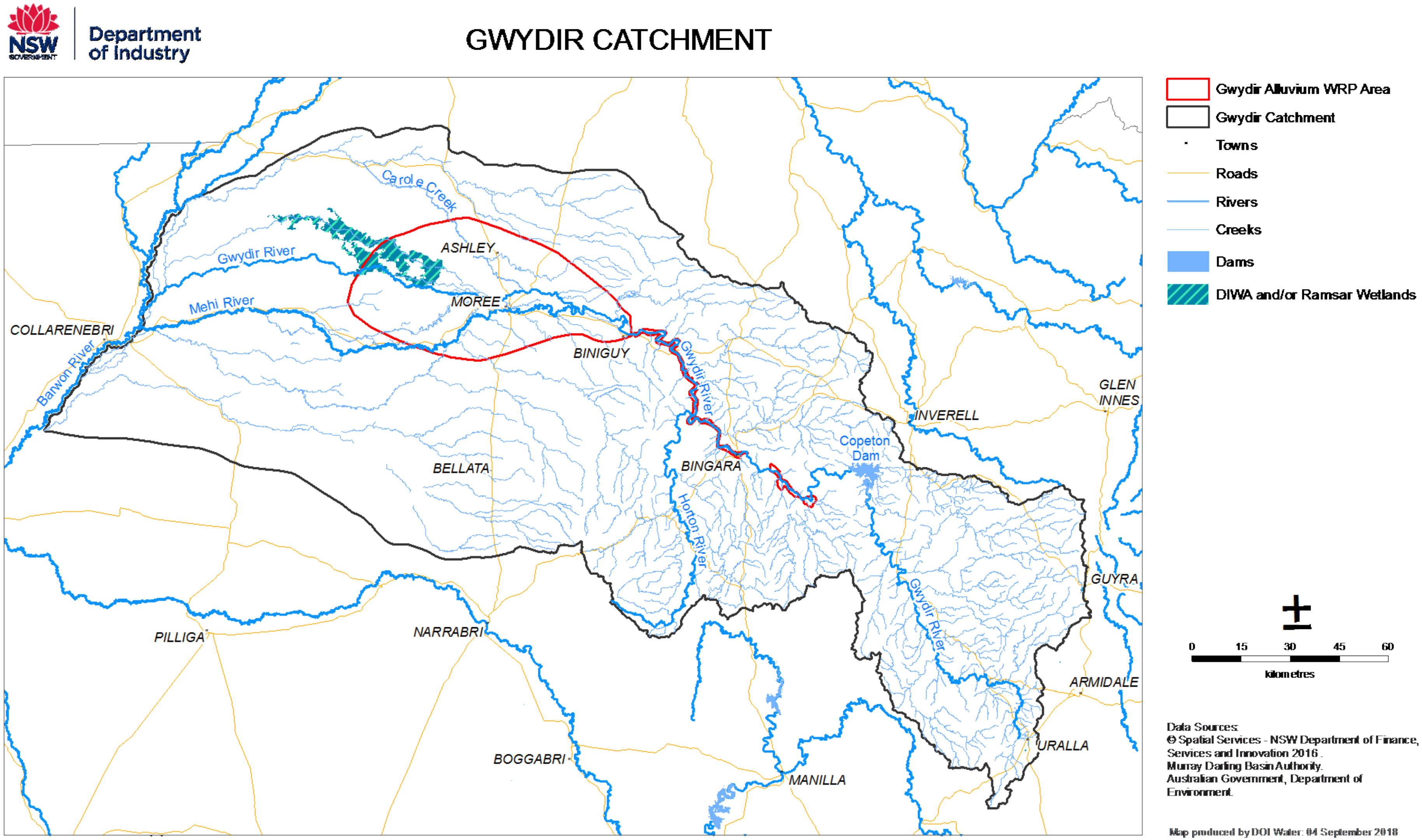


Figure 3 Surface water map of the Gwydir catchment

3.2 Climate

The Gwydir 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 Gwydir catchment can range from -8° Celsius (C) in the winter to 48° C in the summer. Average maximum temperature is 26° C and average minimum 11° C. The average temperature is similar across the Gwydir catchment.

Average annual rainfall varies from over 900 millimetres (mm) near Guyra at the top of the catchment to around 500 mm in the far west (Figure 4).

Annual rainfall across the Gwydir catchment decreases westward. Bingara in the Upper Gwydir Alluvium receives an average yearly rainfall of 728 mm while Moree in the Lower Gwydir Alluvium has an average of 575 mm. Rainfall is generally summer dominant with the heaviest rainfall occurring from October to March (Figure 5). Summer rainfall is typically 80 - 90 mm per month at Bingara, and 60 - 80 mm per month at Moree.

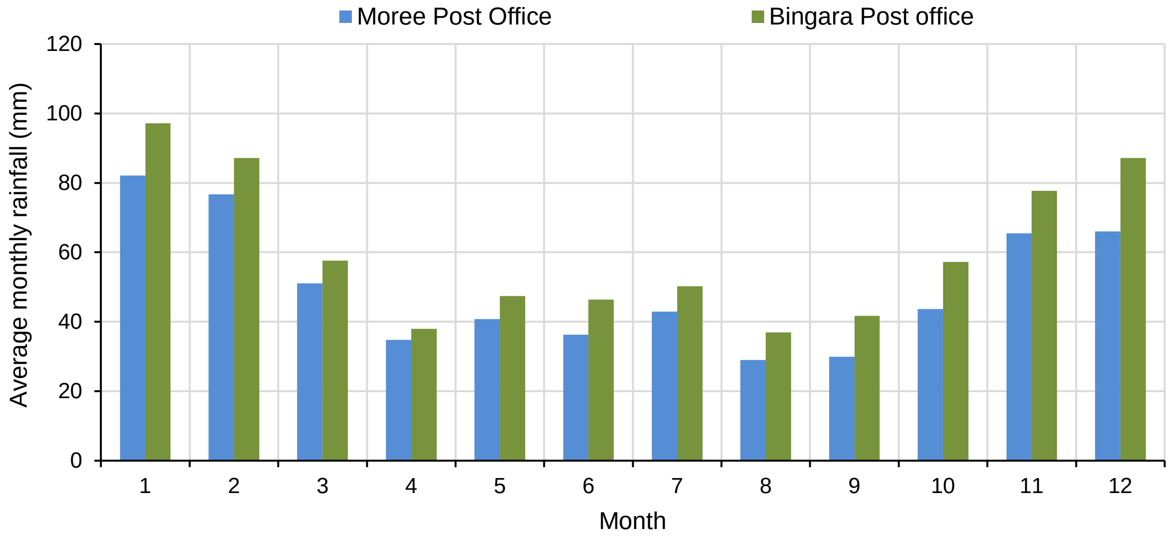


Figure 4 Average monthly rainfall 1974 – 2016 for Bingara and Moree. This period corresponds to the period of record for groundwater monitoring within the Gwydir Alluvium.

Evaporation (Class A pan evaporation) in the Gwydir catchment has a strong east-west gradient (Figure 6). Yearly evaporation varies from around 1,500 mm in the south-east to over 2,000 mm in the west.

Evaporation is strongly seasonal (Figure 7) varying from 65 - 75 mm a month over winter (June/July). Evaporation significantly exceeds average monthly rainfall over the year. The greatest exceedance occurs over the summer months (December/January), when up to 300 mm of evaporation occurs per month compared to up to 95 mm of rainfall per month for the same period.

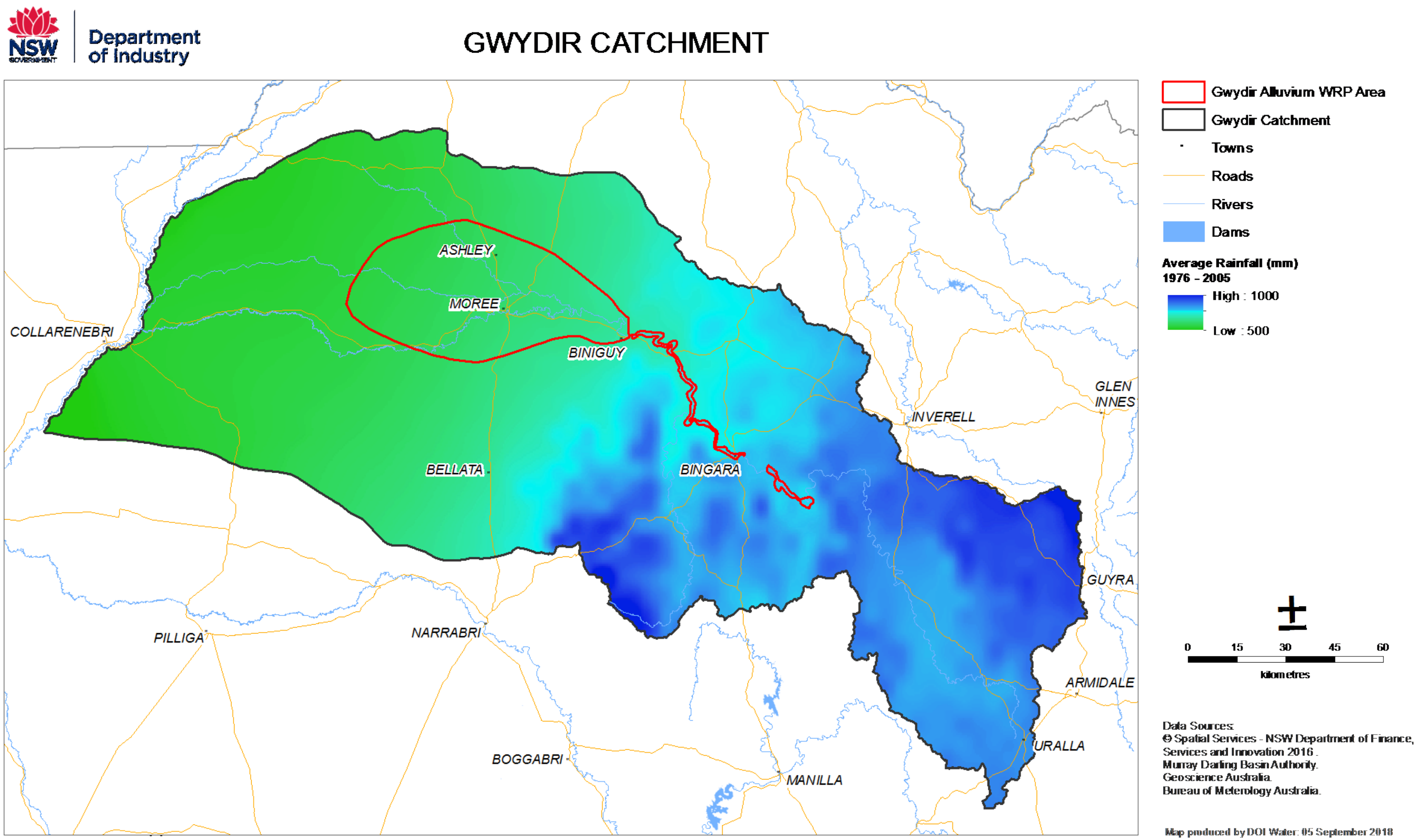
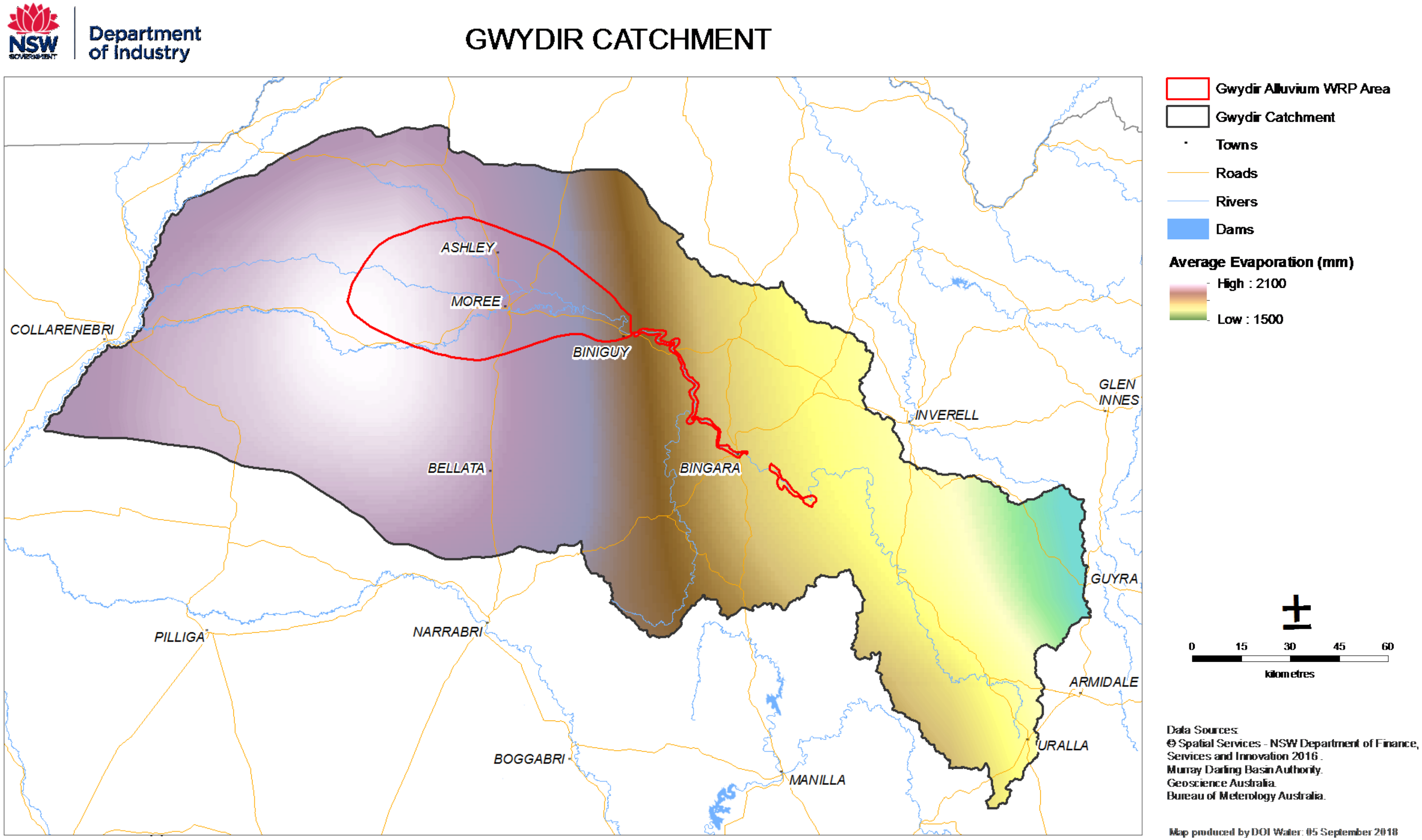


Figure 5 Average annual rainfall map of the Gwydir catchment (BOM, 2008)[7]

[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.



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NARRABRI
ARMIDALE
URALLA
BOGGABRI
MANILLA
Gwydir Alluvium WRP Area
Gwydir Catchment
Towns
Roads
Rivers
Dams
Average Evaporation (mm)
High : 2100
Low : 1500
0 15 30 45 60
kilometres
Data Sources:
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Murray Darling Basin Authority.
Geoscience Australia.
Bureau of Meterology Australia.
Map produced by DOI Water: 05 September 2018

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

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

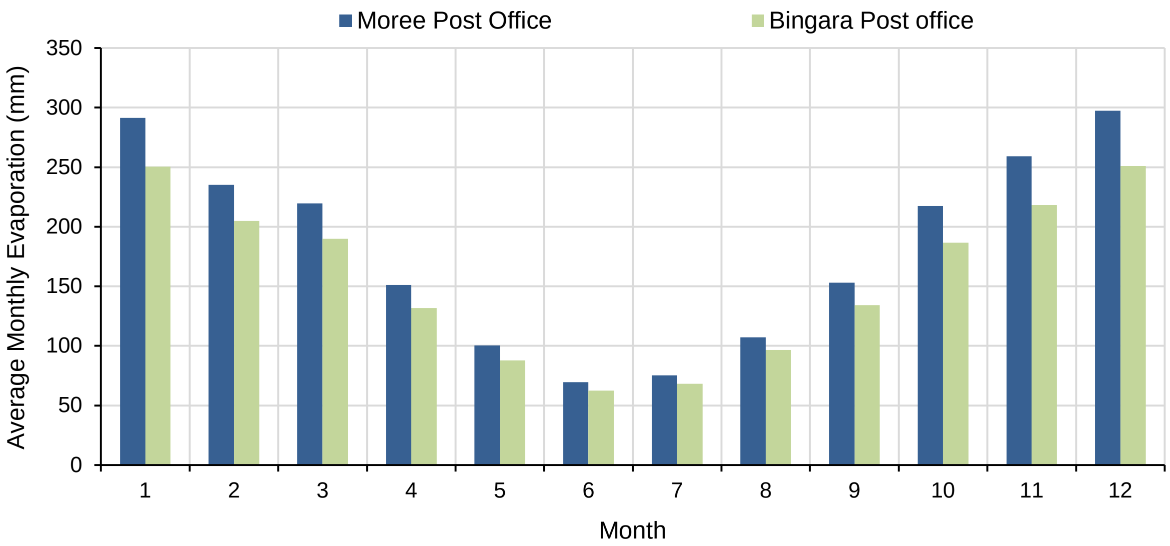


Figure 7 Bingara and Moree average monthly evaporation 1974 - 2016

Residual rainfall plots have been constructed for the Gwydir 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 1974 to 2016 at Bingara and Moree is displayed in Figure 8. 1974 to 2016 corresponds to the period of groundwater monitoring in the Lower Gwydir Alluvium which commenced around 1974.

The trend during the millennium drought from 2002 to 2010 shows below average rainfall, followed by an above average spike over the 2011 to 2013 period then a below average trend to present.

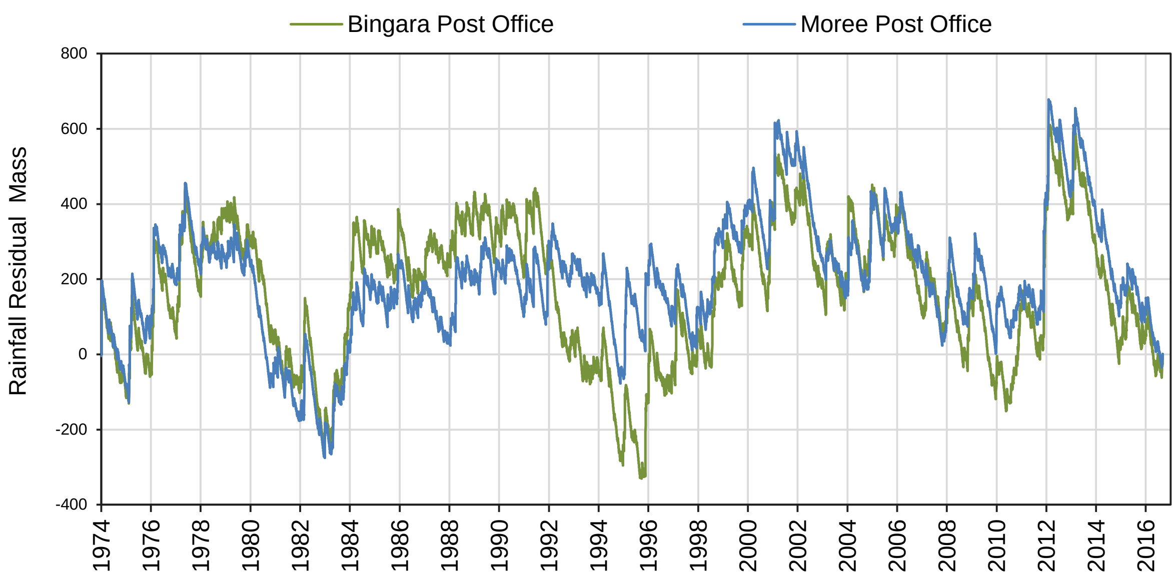


Figure 8 Bingara and Moree rainfall residual mass graph 1974 – 2016

3.3 Land use

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

European settlement of the valley was encouraged by the discovery of gold at Bingara in the 1850’s and later diamonds. However since the 1900’s land use within the valley has been largely agricultural.

Today the main land uses across the Gwydir catchment are livestock grazing and dryland agriculture which together account for some 90 per cent of land use (MDBC 2007). Lucerne and pasture are grown on the narrow alluvial floodplains of the Gwydir and Mehi Rivers and dry land crops are grown on the western floodplain.

Figure 9 shows land use information across the Gwydir catchment based on the Australian Bureau of Agricultural and Resource Economics and Sciences 2010/2011 land use data (Smart, 2016).

Areas of irrigated cropping occur on the heavy clay soils of the western half of the catchment with the major crop being cotton. Other irrigated crops include wheat, lucerne, vegetables, fruit trees, oil seeds and fodder as well as pastures for sheep and cattle (SWC 2009). The water is sourced from the regulated Gwydir River and the alluvial groundwater resources.

There is approximately 533 km^2 of conservation land in the Gwydir catchment made up of national parks and nature reserves (Green *et al*, 2011). Within the Lower Gwydir Alluvium there is an area of conservation land associated with the RAMSAR wetlands north-west of Moree. There are no significant areas of conservation land within the Upper Gwydir Alluvium.

There are over twenty six thousand people living within the Gwydir catchment (Green *et al*, 2011). The largest town within the catchment is Moree (eight thousand people).

Moree is located within Lower Gwydir Alluvium and is the main commercial centre for the surrounding agricultural areas. Bingara is the only town located within the boundary of the Upper Gwydir Alluvium and has a population of approximately one thousand people.

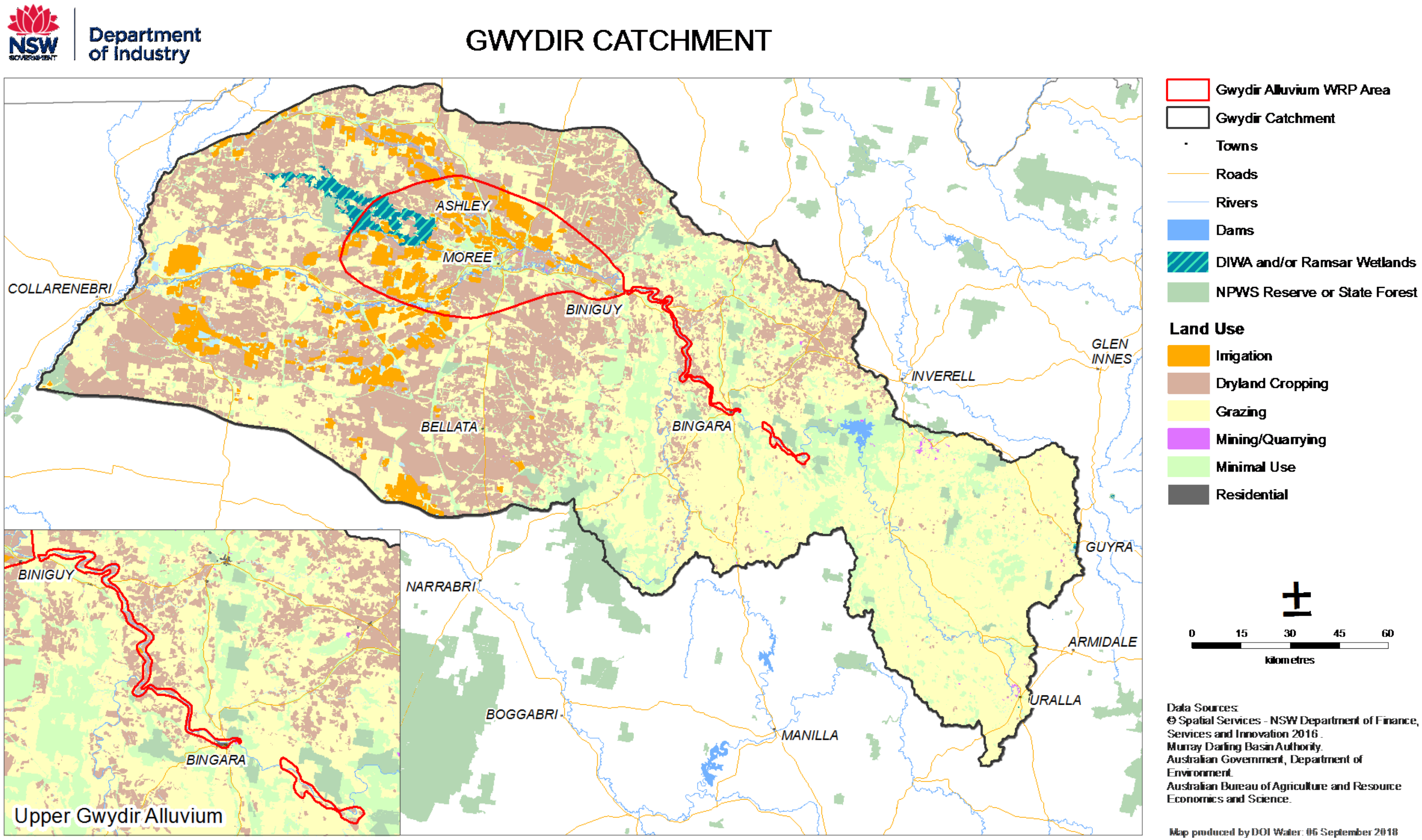


Figure 9 Land use map of the Gwydir catchment (Smart, 2016)

3.4 Geology

The surface geology of the Gwydir catchment is made up of four main geological sequences including; the Palaeozoic New England Fold Belt, the Mesozoic Great Artesian Basin (GAB), the Cenozoic unconsolidated sediments, and the Cenozoic extrusive volcanics (Figure 10).

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 two hundred million years ago.

The late Palaeozoic Gunnedah Basin is a sedimentary coal basin that occurs only at depth, and does not outcrop at the surface within the Gwydir catchment.

The Gunnedah Basin is overlain by the Mesozoic Great Artesian Basin (GAB). The GAB is one of the largest and deepest artesian basins in the world. It covers approximately 22 per cent of Australia across four states including New South Wales, South Australia, the Northern Territory and Queensland and is a significant source of water in New South Wales. The GAB is made up of Mesozoic shales, conglomerates and sandstone.

The GAB is overlain by extensive Cenozoic unconsolidated sediments that cover the majority of the area west of Biniguy, including the Lower Gwydir Alluvium. These sediments extend outside of the Gwydir catchment to cover the majority of north western NSW.

The Cenozoic unconsolidated sediments are made up of mud, silt, sand, and gravels generally deposited by river systems (alluvial deposits) or as wash from hill slopes (colluvial deposits). The Cenozoic sediments also occur to a lesser extent as infilled valleys southeast of Biniguy.

The main peaks in the Gwydir catchment are formed by Cenozoic extrusive volcanic rocks, including basalts that were erupted during widespread volcanic activity throughout the eastern part of the state over the last sixty five million years. The basalt also occurs at depth beneath the alluvium northeast of Moree.

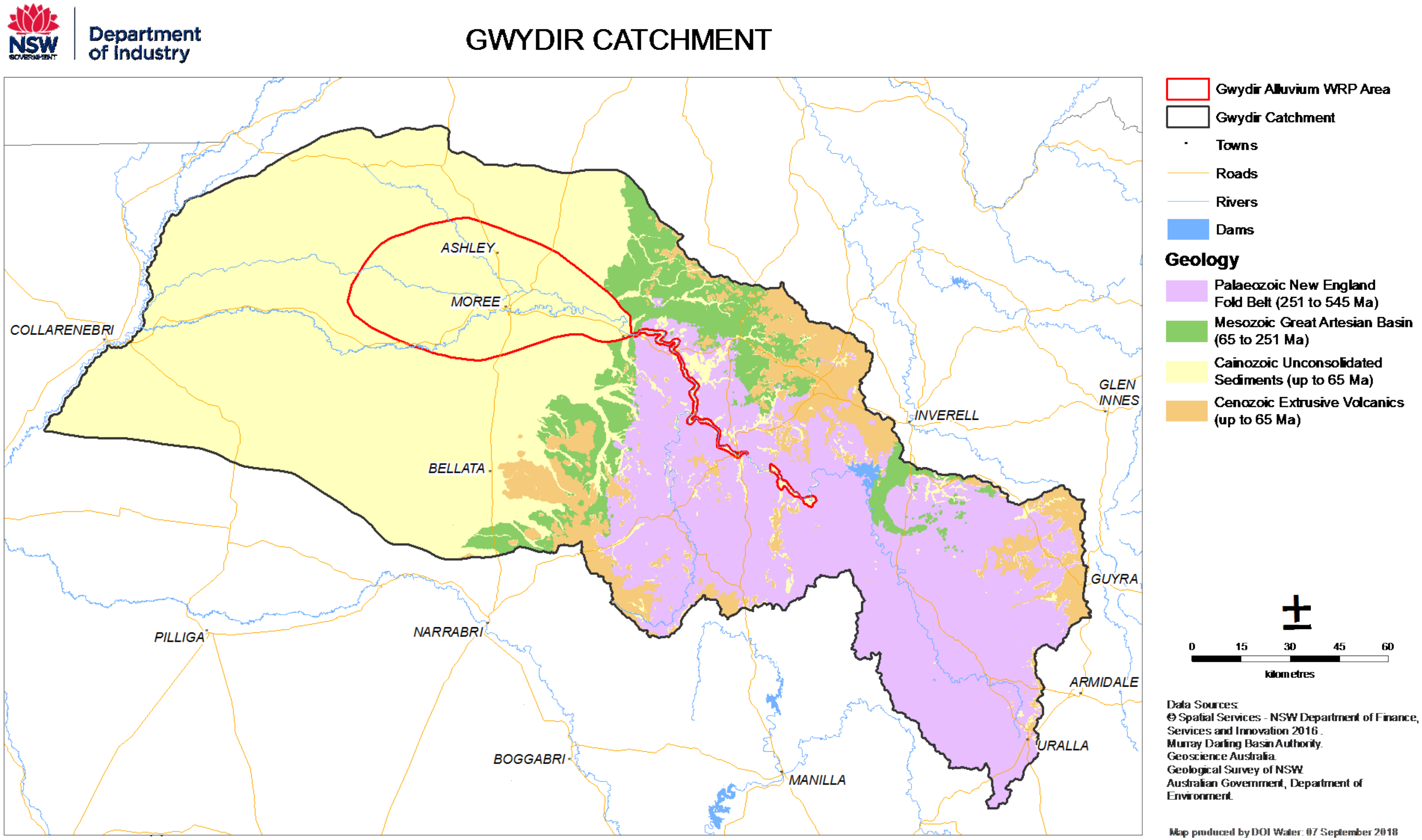


Figure 10 Geology of the Gwydir catchment

4 Hydrogeology

4.1 Regional Context

The Gwydir Alluvium is a continuous sequence of unconsolidated sediments deposited as shallow valley fills in the upper areas of the catchment that grade into broader alluvial fan floodplain sediments in the mid catchment west of Biniguy.

The Upper Gwydir Alluvium is divided into two sections. Whilst the unconsolidated sediments of the Upper Gwydir are continuous, they become very shallow and narrow along a section upstream of Bingara that is not included within the alluvial water source. A basement high exists between the Upper Gwydir Alluvium and the Lower Gwydir Alluvium that restricts groundwater flow from one groundwater source to the next.

The Upper Gwydir Alluvium sits over the fractured rock of the New England Fold Belt in the eastern portion of the Gwydir catchment. The permeability of these underlying fractured rocks is many orders of magnitude lower than that of the alluvium and groundwater exchange is expected to be insignificant. Consequently these fractured rock systems are not considered hydraulically connected in a resource management sense to the groundwater resources in the alluvium.

The sediments of the Great Artesian Basin (GAB) Surat Shallow Groundwater Source adjoins the Lower Gwydir alluvium, the sediments are laterally continuous however whilst there is some connectivity it is expected to be insignificant as the sediments of the GAB Surat Shallow are low permeability and not a target for water supply.

The Lower Gwydir overlies the sediments of the GAB. The permeability of the GAB under the Lower Gwydir is many orders of magnitude lower than that of the alluvium and any groundwater exchange is expected to be insignificant. In the deeper parts of the Lower Gwydir Alluvium, generally west of Moree, the palaeochannel has eroded into the weathered Cretaceous of the GAB (Ransley *et al* 2015) and whilst there may be some connectivity it is also expected to be insignificant as these formations are low permeability and not a target for water supply.

4.2 Upper Gwydir Alluvium

The Upper Gwydir Alluvium (Figure 11) is made up of Cenozoic valley fill alluvial sediments. It extends from approximately 20 km downstream of Copeton Dam along the river north - west for approximately 25 km where the alluvial sediments decrease over a bed rock high. The alluvial sediments occur again near Bingara, continuing north - west to approximately 5 km east of Biniguy where they thin out at their western extent.

The Upper Gwydir Alluvium is comprised of clay, silt, sand and gravel generally less than 30 m thick. The Upper Gwydir Alluvium is in hydraulic connection with the Gwydir River along its length. Conceptually, the dominant recharge processes are direct rainfall infiltration and leakage from Gwydir River as well as side slope run on (DPI Water, 2012).

There is currently no groundwater level information available for the Upper Gwydir Alluvium; however groundwater flow direction is likely to be north - west in the same direction as the Gwydir River.

The limited available information for the Upper Gwydir Alluvium indicates bore yields are likely to be less than 10 litres per second (L/sec). Irrigation development from groundwater in the Upper Gwydir Alluvium is relatively small by comparison to other larger groundwater sources in NSW such as the Lower Gwydir Alluvium.

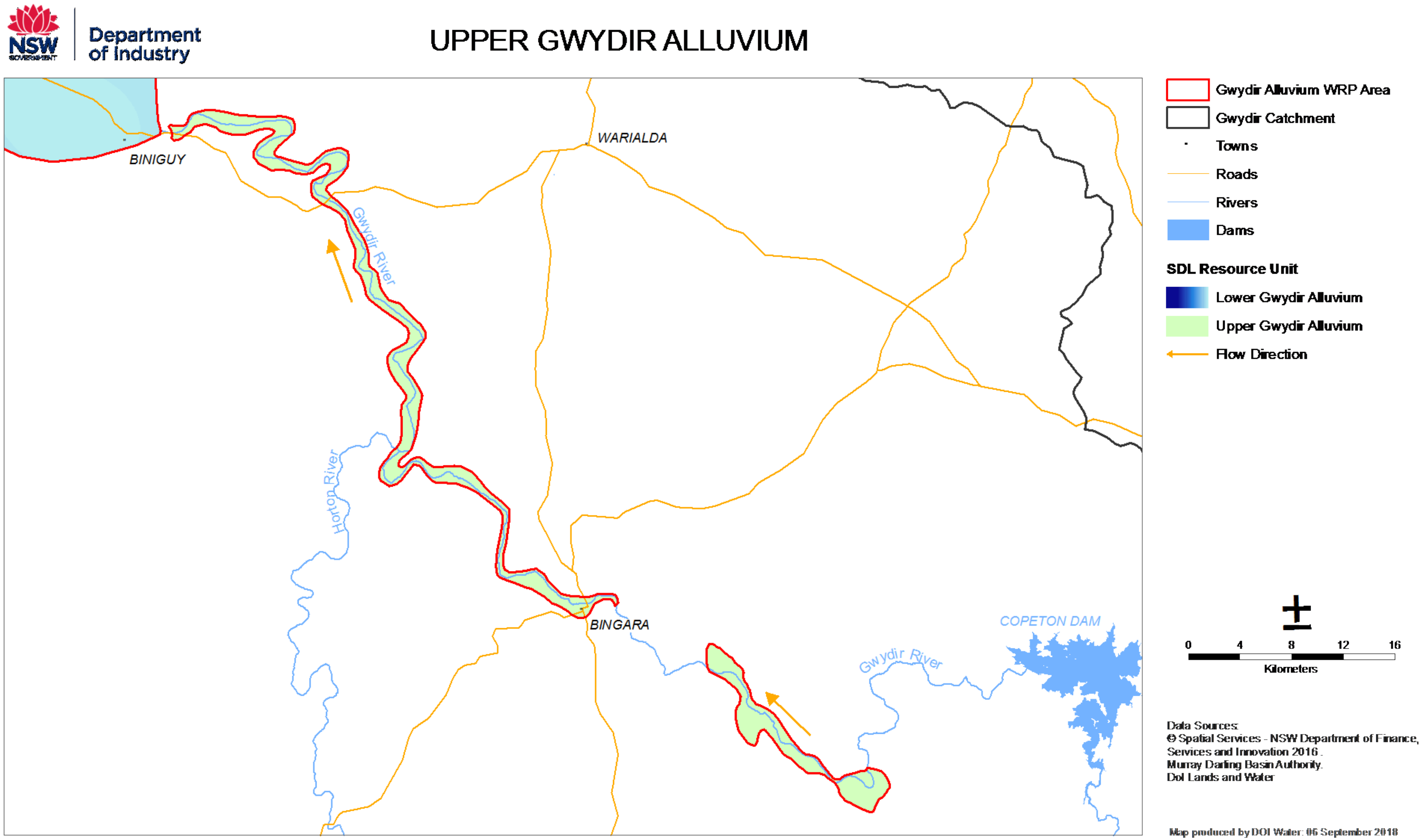


Figure 11 Location map of the Upper Gwydir Alluvium showing groundwater flow direction

4.3 Lower Gwydir Alluvium

The Lower Gwydir Alluvium (Figure 12) is made up of the Cenozoic alluvial sediments extending from Biniguy west approximately 90 km. These sediments form an extensive alluvial fan deposited by the Gwydir River and its tributaries, comprised of clay, silt, sand and gravel.

The water bearing sands and gravels within the alluvial sediments of the Lower Gwydir Alluvium are broadly divided into two main aquifer systems; a shallow aquifer system up to approximately 30 m deep, and a deep aquifer system up to a maximum of approximately 90 m deep.

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.

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'[9].

Within each system there may be more than one aquifer which varies in thickness and in lateral and longitudinal extent. These aquifers are more extensive in thickness and lateral extent in the upstream area near Moree and consist of coarse gravels in the shallow aquifers and fine to medium sand and gravel in the deep aquifers. Further downstream the aquifers grade into finer sands and become more irregular in their occurrence.

Figure 13 shows the location of four geological cross sections that have been produced for the Lower Gwydir Alluvium. Figure 14 shows a long-section through the Lower Gwydir that extends across the entire length of the water source, and Figures 15 and 16 show the three north - south sections; the Royden and Moree/Ashley section (Figure 15) and the Gingham section (Figure 16).

These sections show the depth of the water source, the location of the shallow and deep aquifer systems, and the current (2016) recovered standing water level in the shallow system. The variation in thickness of the aquifer systems can be seen as well as the variation in depth to bedrock across the Lower Gwydir.

The water level height on the long section (Figure 14) shows the east to west groundwater flow direction as the water level becomes deeper towards the west.

Within the Lower Gwydir Alluvium bores constructed in the deeper aquifer system can yield up to 1,000 ML per year. However, the majority of high yield bores produce supplies in the range of 500 ML/yr of low salinity water suitable for irrigation purposes. The highest yielding bores are located in an area between Moree and Ashley.

Conceptually the dominant recharge process for the Lower Gwydir Alluvium is direct rainfall, flood infiltration and river leakage. In addition, leakage from other watercourses and irrigation, along with groundwater inflows from the east also contribute to recharge.

In some areas upstream of Moree, the alluvial sediments are in direct hydraulic connection with the rivers allowing direct recharge from the river into the aquifer system.

The main discharge in the Lower Gwydir Alluvium is extraction for irrigation. Other sources of discharge are base flow in areas upstream of Moree and through flow towards the west.

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

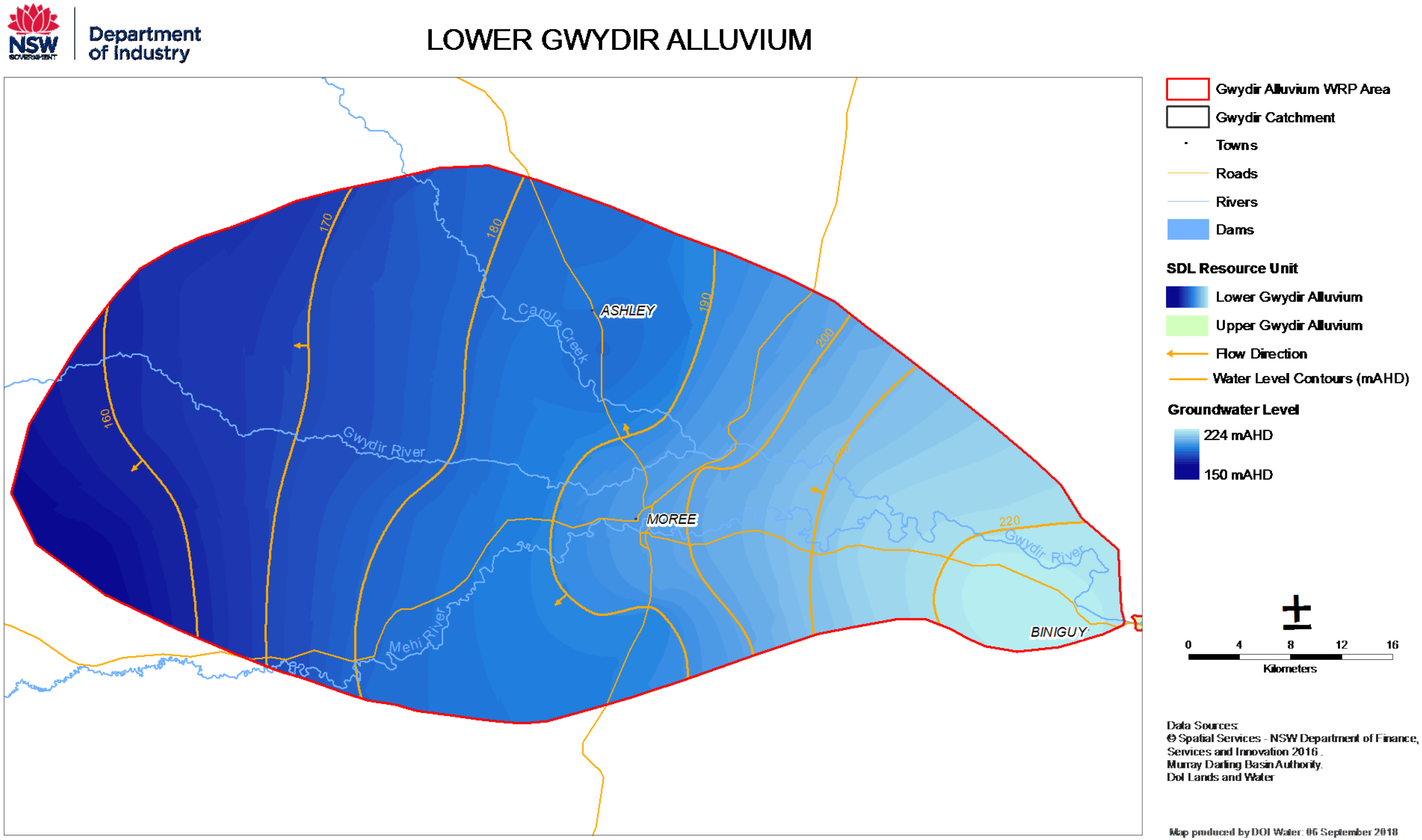


Figure 12 Location map Lower Gwydir Alluvium showing groundwater flow direction in the deep aquifer system

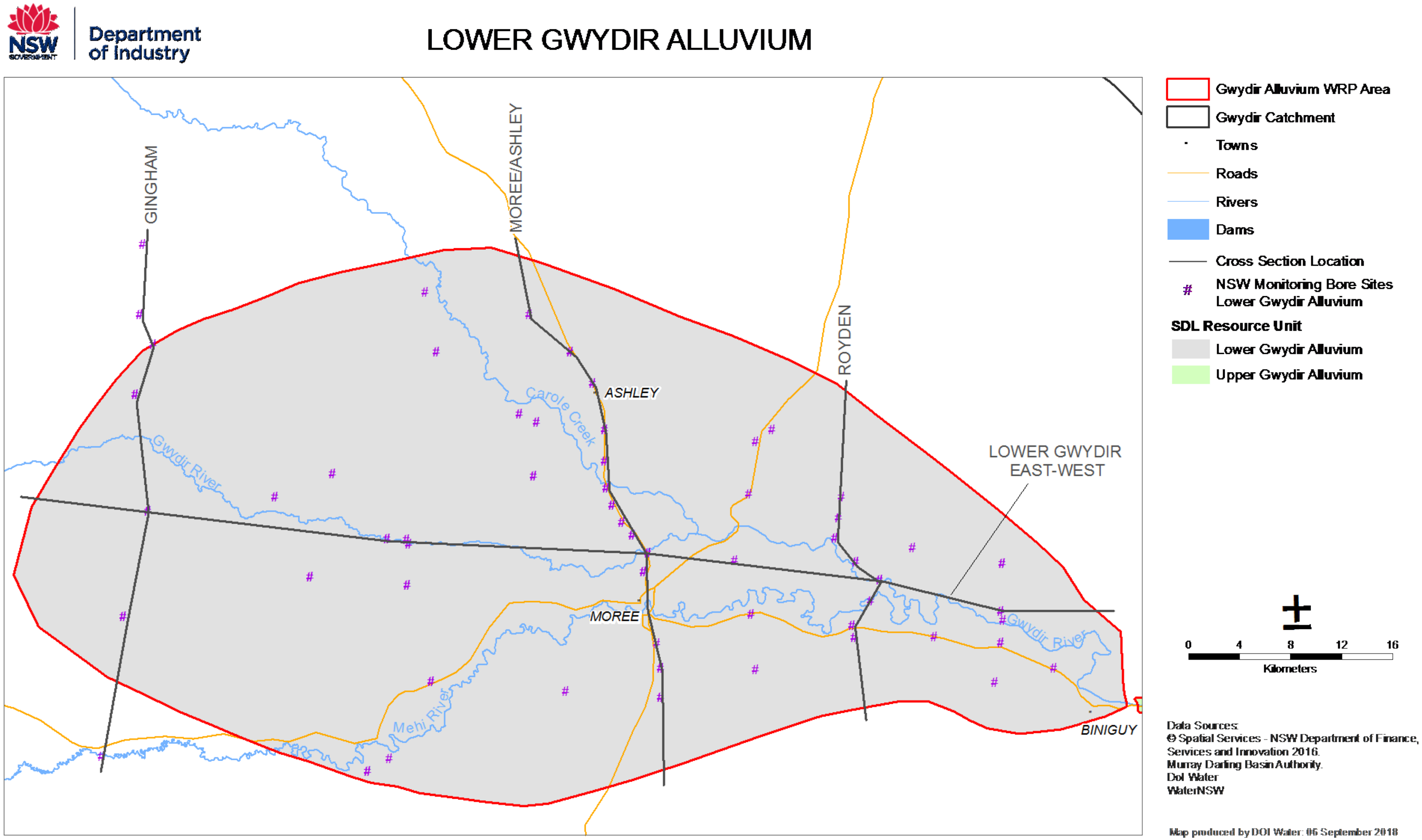


Figure13 Cross section location map Lower Gwydir Alluvium

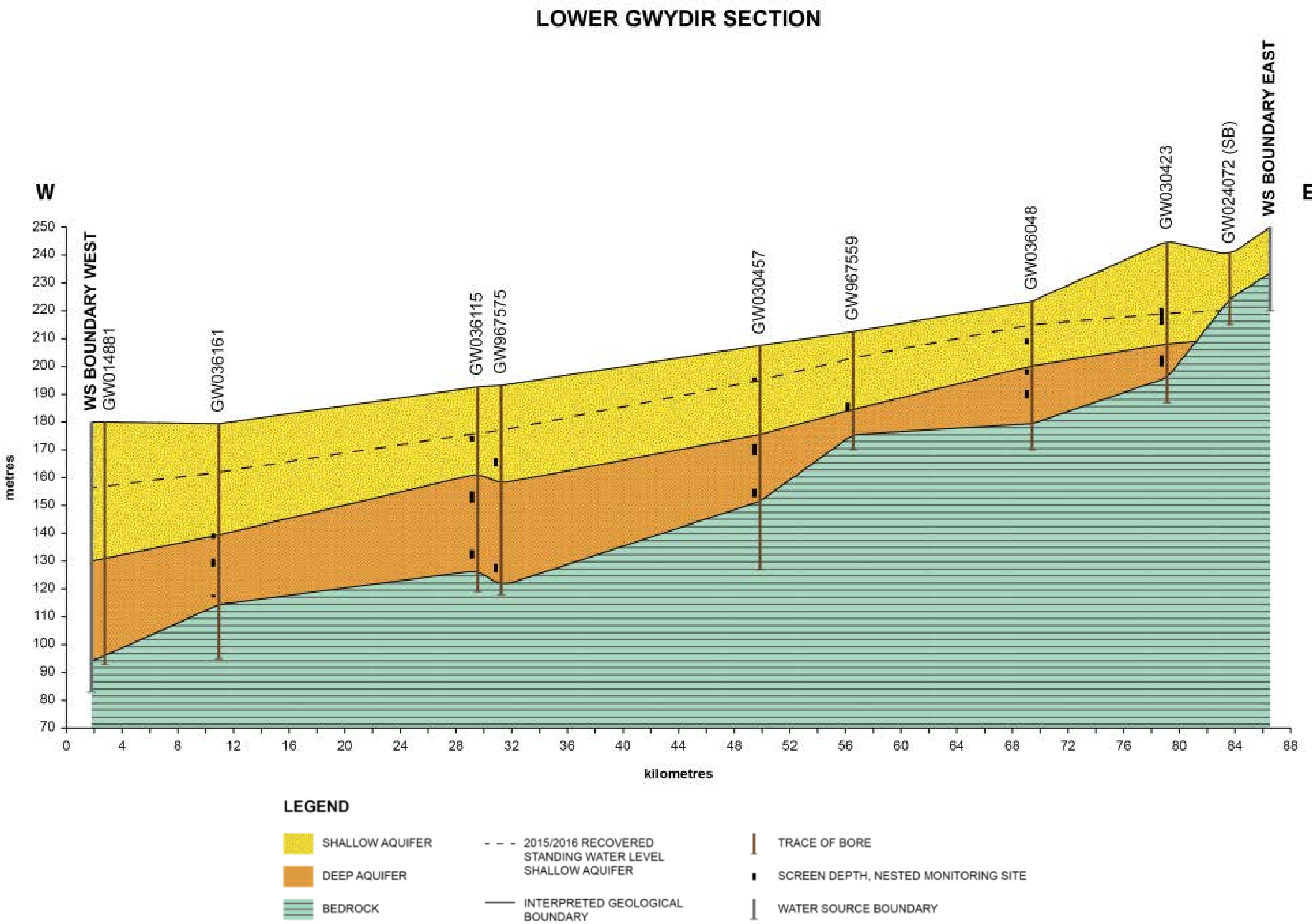


Figure14 East-west long section through the Lower Gwydir Alluvium, vertical axis in metres Australian Height Datum. Note the boundary between the deep and shallow aquifers is approximate.

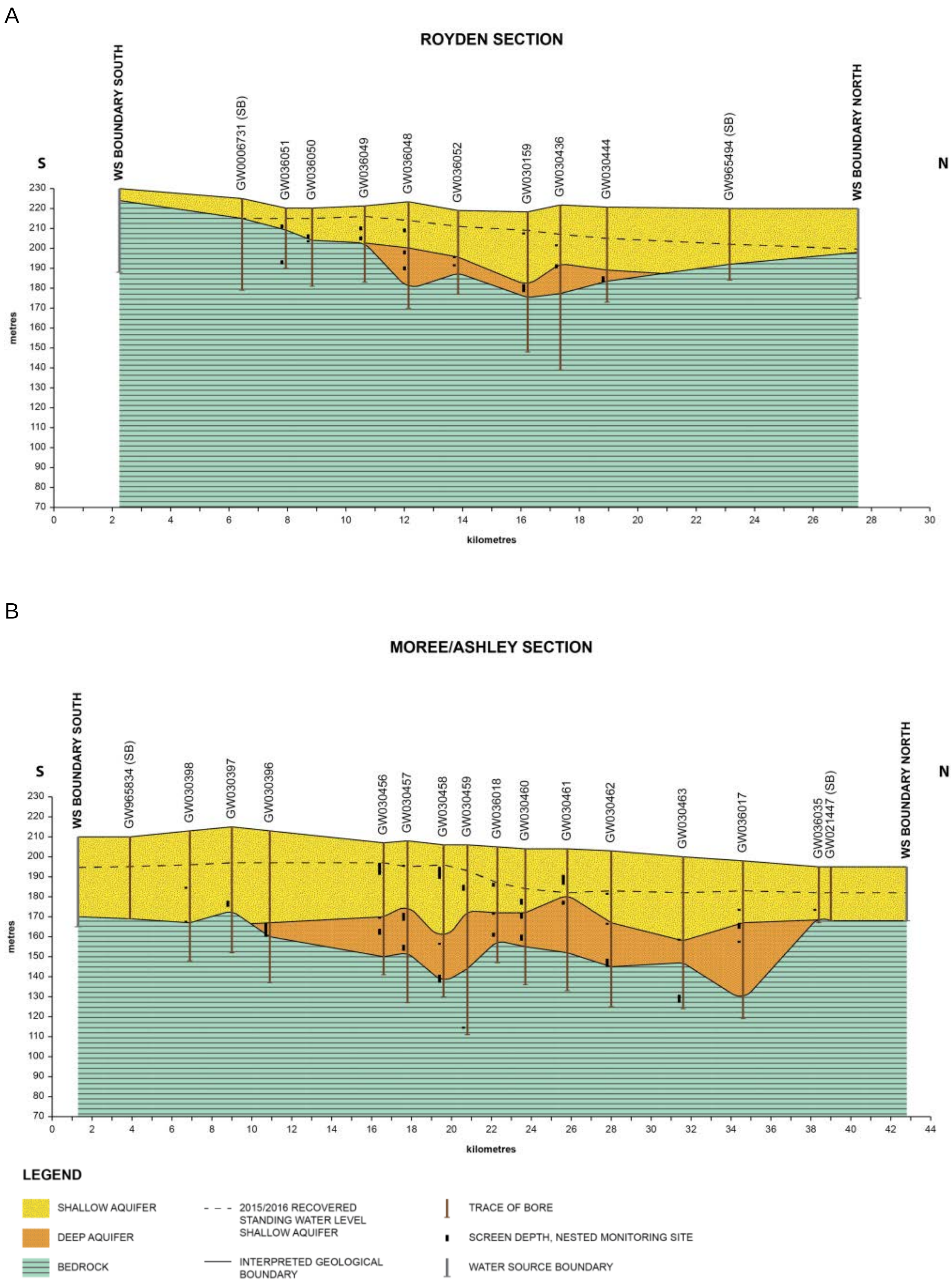


Figure 15 A Royden cross section and B Moree/Ashley cross section - Lower Gwydir Alluvium, vertical axis in metres Australian Height Datum. Note the boundary between the deep and shallow aquifers is interpreted based on limited information.

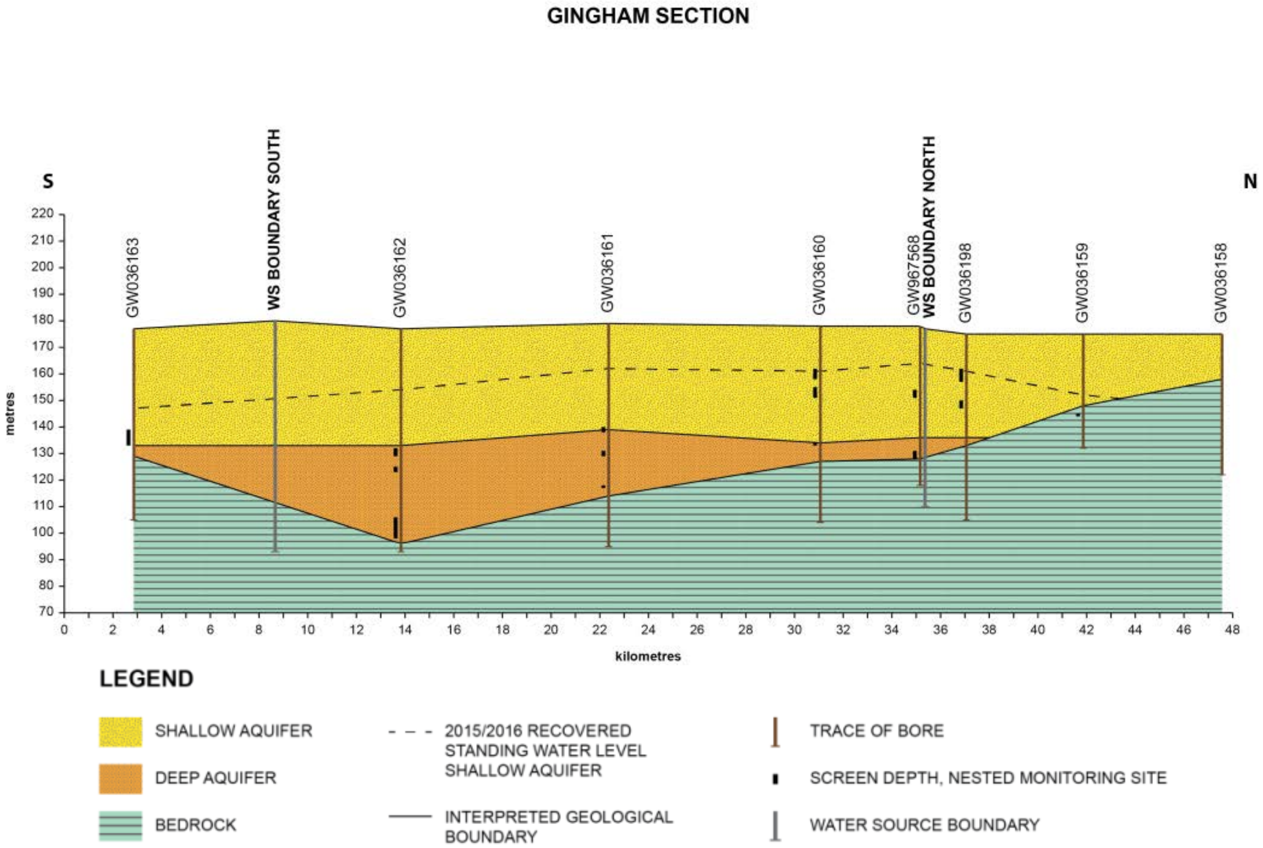


Figure 16 Gingham cross section - Lower Gwydir Alluvium, vertical axis in metres Australian Height Datum. Note the boundary between the deep and shallow aquifers is approximate.

4.4 Connection with surface water

The Upper Gwydir Alluvium is considered to be highly connected to the regulated Gwydir River. The narrow and shallow nature of the Upper Gwydir Alluvium means 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 the Water Sharing Plan rules for the Upper Gwydir Alluvium resource unit.

Analysis of available stream gauge and groundwater level information indicates the Lower Gwydir Alluvium varies from losing/gaining system east of Moree to a disconnected system in the west.

Although the Gwydir and Mehi Rivers are considered to be hydraulically connected with the Lower Gwydir Alluvium east of Moree, the depth and width of the alluvium means groundwater pumping impacts at the river are subdued and / or delayed. This lag time of groundwater pumping impacts is acknowledged in setting the extraction limit of the resource however the Lower Gwydir Alluvium is managed independently from the river.

Further analysis of the interconnection between surface water and groundwater in the Lower Gwydir Alluvium near Moree is given by Lamontagne *et al* (2011).

5 Groundwater Dependent Ecosystems

Groundwater dependent 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*' (modified from Richardson et al. 2011).

NSW Department of Industry has developed a method for the identification of high probability groundwater dependent vegetation ecosystems (Kuginis et al. 2016) and associated ecological value (Dabovic *et al*. in prep). This process has identified a number of vegetation GDEs in the upper and lower parts of the Gwydir catchment. The determined ecological value of vegetation GDEs within the Gwydir catchment is shown in Figure 17.

The GDEs in the north - western section of the Upper Gwydir Alluvium have been classified as high ecological value, this area is dominated by River Red Gum riparian woodland communities that have a high number of threatened species and extensive connected riparian corridors.

The eastern section of the Upper Gwydir Alluvium is dominated by River Oak-Rough Barked Apple-Red Gum-Box riparian woodland GDE communities. The GDEs in this area have been classified as medium ecological value as these communities are not basin target species and have a lower value for vital habitat.

High and very high ecological value GDEs have been identified in the western part of the Lower Gwydir Alluvium. These high values are associated to the GDEs being registered in the 'Directory of Important Wetlands in Australia' (DIWA) and/or Ramsar Wetlands. The western part of the Lower Gwydir Alluvium also has a high number of threated flora and fauna species, endangered ecological communities and the target basin vegetation species of Coolabah, Lignum and River Red Gums.

The GDEs identified across the remainder of the Lower Gwydir Alluvium generally have a high ecological value. These GDE communities are mostly associated with the riparian corridors of the Gwydir regulated river and major tributaries. The dominate vegetation communities are Coolabah-River Coobah-Lignum woodland wetlands and River Red Gum woodland wetlands.

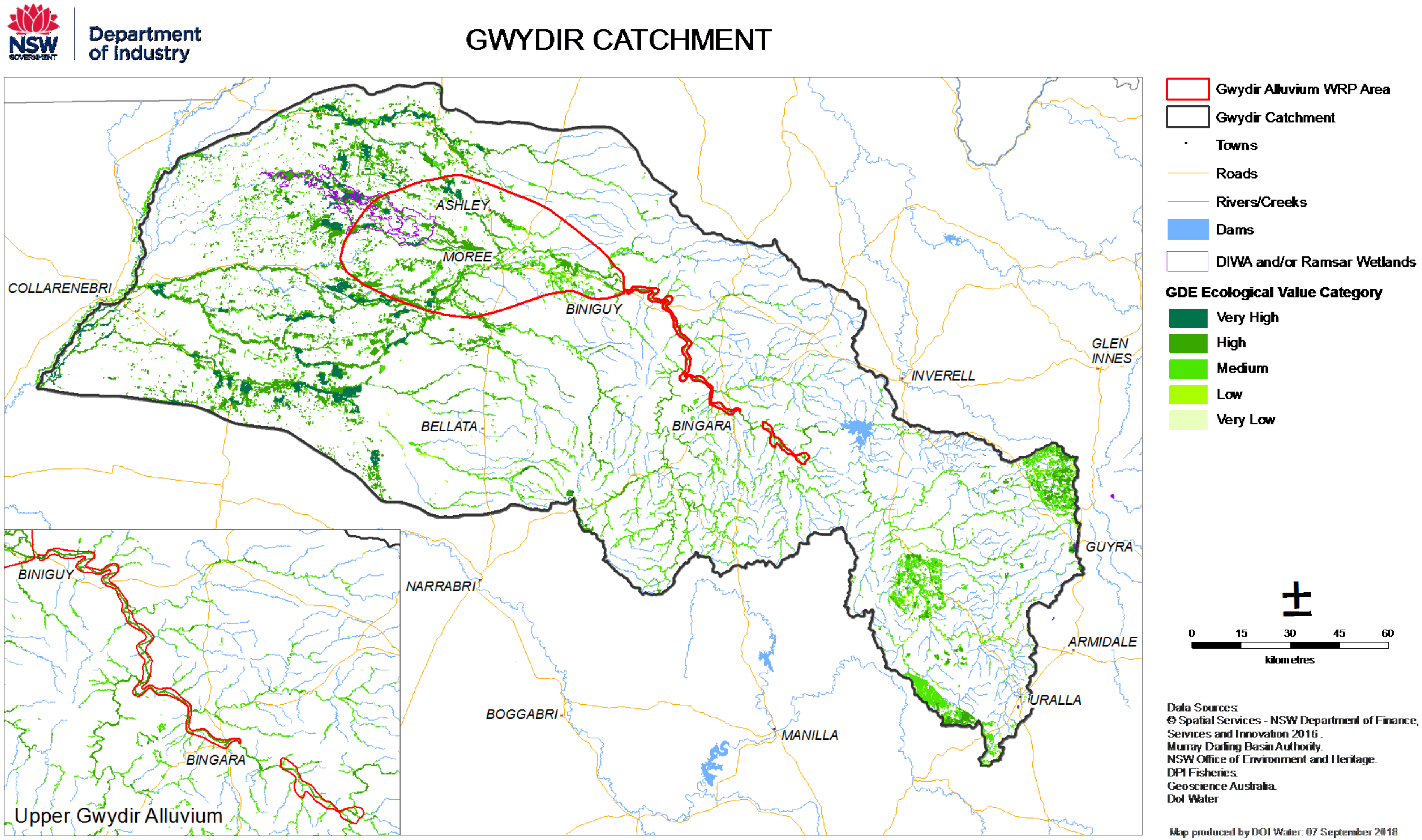


Figure 17 Ecological value for high probability groundwater dependent vegetation ecosystems

6 Groundwater Quality

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

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

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

Groundwater suitability can be changed by contaminants infiltrating into the groundwater system. This can be from spills or leaks 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.

6.1 Upper Gwydir Alluvium

Groundwater from the Upper Gwydir Alluvium is mainly used for irrigating field crops and pastures, and for stock watering.

There is no water quality information for the Upper Gwydir 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 Gwydir River.

The salinity in the Gwydir River between Copeton Dam and Gravesend ranges between approximately 100 and 900 µS/cm (based on data from 2007 to 2016 WaterNSW).

6.2 Lower Gwydir Alluvium

The NSW Government groundwater monitoring bores were sampled for salinity at the time of construction (up to approximately forty five years ago). The salinity readings from these groundwater samples range from 200 µS/cm close to the rivers to over 3,000 µS/cm in the far west and on the outer limits of the alluvium.

The former NSW Office of Water commissioned a groundwater quality analysis (Parsons Brinkerhoff, 2011) that involved water quality and isotope sampling from a number of NSW government monitoring bores across the Lower Gwydir Alluvium between November 2009 and September 2010.

Groundwater samples were taken on a monthly basis at six sites, with an additional ten sites monitored on a three monthly basis. Surface water sampling was undertaken at two locations on the Gwydir River on a monthly basis. In total, one hundred and ninety six groundwater samples and eighteen surface water samples were analysed.

The Parsons Brinkerhoff (2011) study found that groundwater in the deeper aquifer system is fresh (EC < 750 µS/cm). As a result, groundwater is suitable for multiple beneficial uses including drinking water supply, irrigation (cotton, barley and wheat) and stock water supply.

Groundwater in the shallow aquifer system is fresh to brackish, and is suitable for irrigation and stock water supply. In the main irrigation areas, groundwater from the shallow system is suitable for drinking water supply (based on EC) but in the western and marginal areas of the Lower Gwydir Alluvium groundwater is unsuitable for drinking water supply (EC > 1,500 µS/cm).

7 Groundwater Management

Groundwater in the Upper Gwydir Alluvium is managed under the *Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012*. Groundwater in the Lower Gwydir Alluvium is managed under the *Water Sharing Plan for the Lower Gwydir Groundwater Source 2003.* The Upper and Lower Gwydir groundwater sources in water sharing plans correlate directly to the two SDL resource units in the Gwydir WRP.

The Upper Gwydir Alluvium sits over and adjacent to the fractured rock management units of the New England Fold Belt. These fractured rocks have very different hydrogeological characteristics and are not considered to be hydraulically connected in a resource management sense to the groundwater resources in the alluvium. Groundwater in the adjacent management units are managed under the Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011.

The Lower Gwydir Alluvium overlies the Great Artesian Basin; Eastern Recharge and Surat groundwater sources. The permeability of the GAB under the Lower Gwydir is many orders of magnitude lower than that of the alluvium not considered to be hydraulically connected in a resource management sense. Groundwater in the GAB is managed under the Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008.

7.1 Access rights

Groundwater access licenses for the Upper Gwydir Alluvium and the Lower Gwydir are shown in Table 1.

Supplementary water access licences were issued to some licence holders in the Lower Gwydir 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.

The local water utility access licences are held by local government for town water supply purposes and the share component is for a specified volume of groundwater. The share components of aquifer access licences and aquifer access licence (high security) are issued for a specified number of unit shares (Table 1).

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

Access Licence Category	Upper Gwydir Alluvium Share Component	Lower Gwydir Alluvium Share Component
Local Water Utility	60 ML/year	3,572 ML/year
Aquifer	0	28,858 ML/share
Aquifer (High Security)	1,133 ML/share	0

Owing to the high level of connection of the alluvium with the regulated Gwydir River, groundwater available under the licence category ‘aquifer access licence (high security)’ in the Upper Gwydir Alluvium is linked to the availability of high security allocations in the regulated Gwydir River.

7.2 Extraction limits

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

Water resource plans will set limits, in the same way as water sharing plans, on the quantities of water that can be taken from Basin water resources. These limits are known as sustainable diversion limits (SDLs). Under the water resource plans, NSW will continue to manage extractions to the LTAAEL, ensuring compliance with the SDLs.

Table 2 lists the LTAAEL for the Upper Gwydir Alluvium and the Lower Gwydir Alluvium as well as the SDL for each area. The SDL includes the estimated requirements for basic landholder rights which for the Lower Gwydir Alluvium is 700 ML/year.

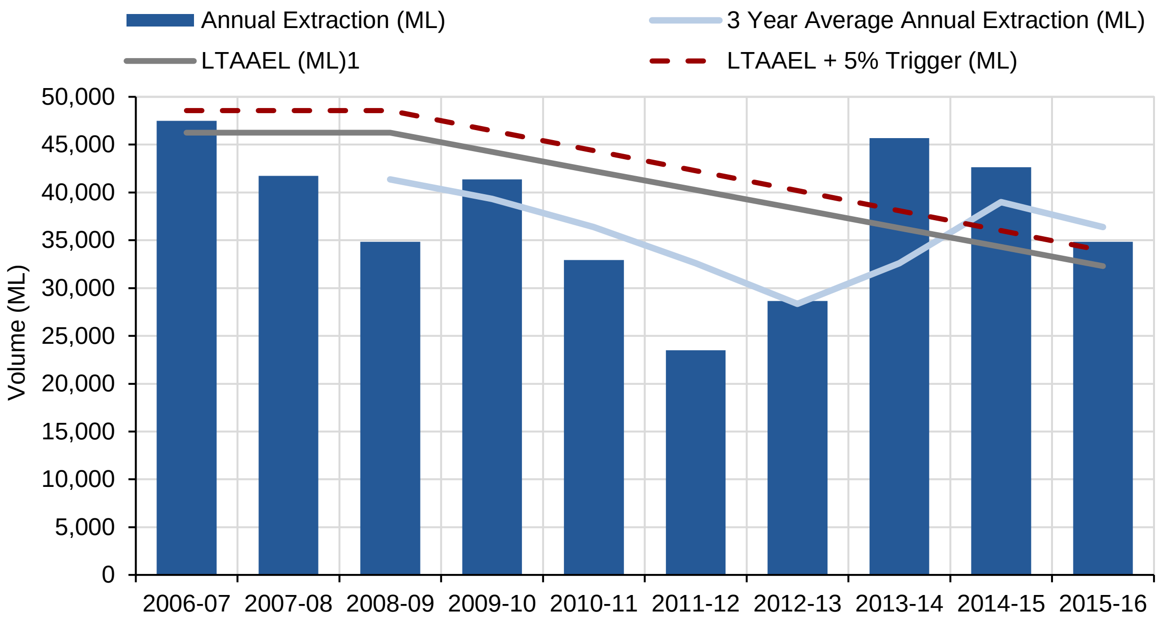
Table 2 LTAAEL for the Upper Gwydir Alluvium and Lower Gwydir Alluvium compared to the SDL (at May 2017)

Water Source	LTAAEL ML/yr	SDL ML/yr
Upper Gwydir Alluvium	721	720
Lower Gwydir Alluvium	33,000[1]	33,000

[1] This includes 700 ML/year for Basic Landholder – domestic and stock rights.

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

Figure 18 shows the annual extraction since commencement of the water sharing plan. It also shows the LTAAEL and the trigger set by the water sharing plan to initiate a management response to ensure there is no growth in extraction above the LTAAEL in the long term.



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

Figure 18 Lower Gwydir Alluvium annual extraction compared to the LTAAEL

The risk of extraction in the Upper Gwydir Alluvium exceeding the LTAAEL is low as there is very little groundwater development.

7.3 Available water determinations

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

The available water determination for high security aquifer access licences in the Upper Gwydir Alluvium is linked to the available water determination for the high security regulated river licences. Since the commencement of the water sharing plan this has been 100 per cent access therefore the available water determination for aquifer access (high security) licences in the Upper Gwydir Alluvium has remained at 1 ML per share or 100 per cent access.

The allocations for each licence category in the Lower Gwydir Alluvium for each year since commencement of the water sharing plan is shown in Figure 19. The available water determination for aquifer access licences has been set at 1 ML per share and for local water utility access licences has been set at 100 per cent every year since the water sharing plan commenced.

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

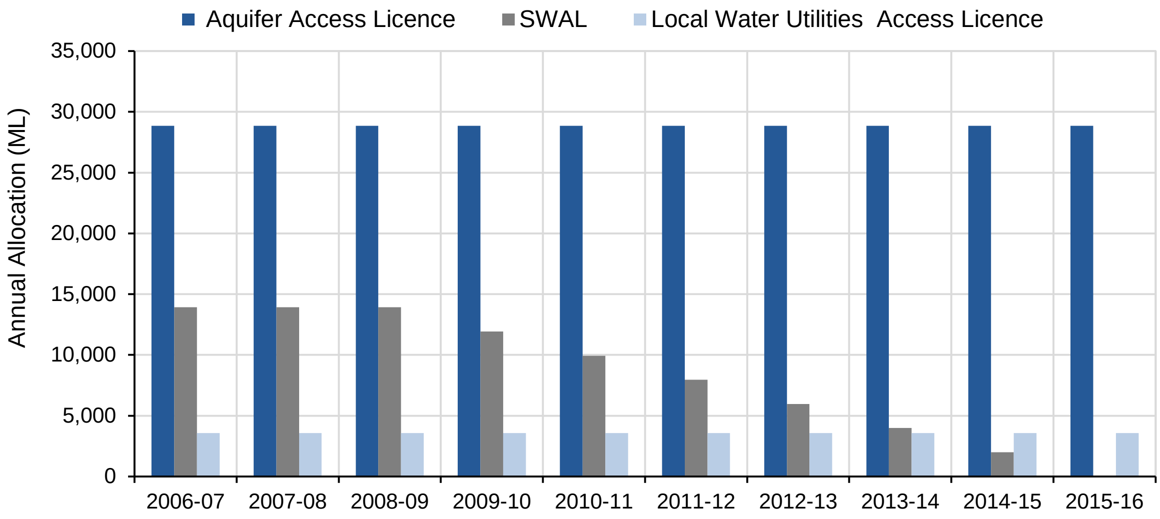


Figure 19 Annual allocations for the Lower Gwydir Alluvium

7.4 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.

The water sharing plan for the Lower Gwydir Alluvium allows a maximum limit of 3 ML per unit of share component to be held in a water account. This includes the yearly allocation for aquifer access licences made through available water determinations plus any carryover of unused allocation up to a maximum of 2 ML per unit of share component.

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

Figure 20 shows the volumes held in water accounts for the Lower Gwydir Alluvium since commencement of the water sharing plan.

There is no carryover of allocation permitted in the Upper Gwydir Alluvium for any licence category.

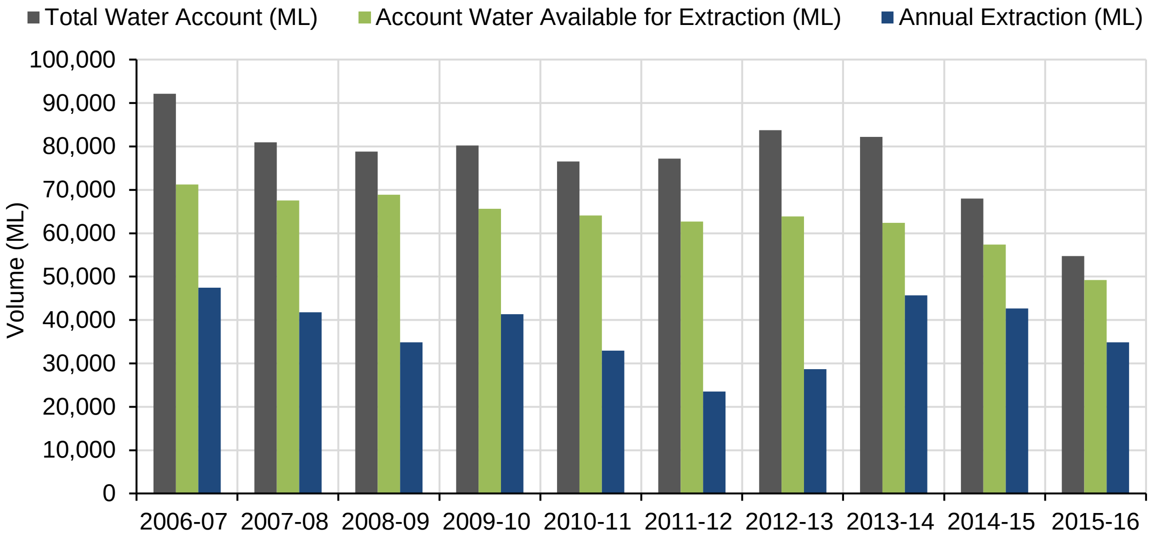


Figure 20 Water accounts since the commencement of the water sharing plan for the Lower Gwydir.

7.5 Groundwater take

Groundwater is taken and used in the Gwydir valley for productive purposes such as irrigation and industry as well as for water supply for local water utilities and stock and domestic use. Figure 21 shows the distribution of water supply bores across the Gwydir groundwater resources.

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

There are approximately fifteen hundred registered bores in the Lower Gwydir Alluvium, the majority used for stock and domestic purposes. There is also significant reliance on groundwater for irrigation with approximately four hundred production bores, the majority concentrated along the Gwydir and Mehi Rivers and between Moree and Ashley. The towns of Moree and Pallamallawa use groundwater as their main water supply for local water utility.

Bores constructed in the deeper more productive aquifer system can yield up to 1,000 ML per year (Figure 22). However, the majority of production bores produce supply in the range of 500 ML/yr.

There are approximately sevently registered bores in the Upper Gwydir, the majority of groundwater is used for stock and domestic purpose, with eleven production bores and four local water utility bores for the town of Gravesend.

Groundwater take in the Lower Gwydir is metered, in the Upper Gwydir it is not currently measured.

Annual groundwater extraction since 1993 and the annual extraction limit for the Lower Gwydir Alluvium since the commencement of the water sharing plan is provided in Figure 23.

Average usage pre water sharing plan was around 35,800 ML/yr, post commencement of the water sharing plan average usage is approximately 37,300 ML/yr. The increase in average usage post plan is due to the dry climatic conditions during this time.

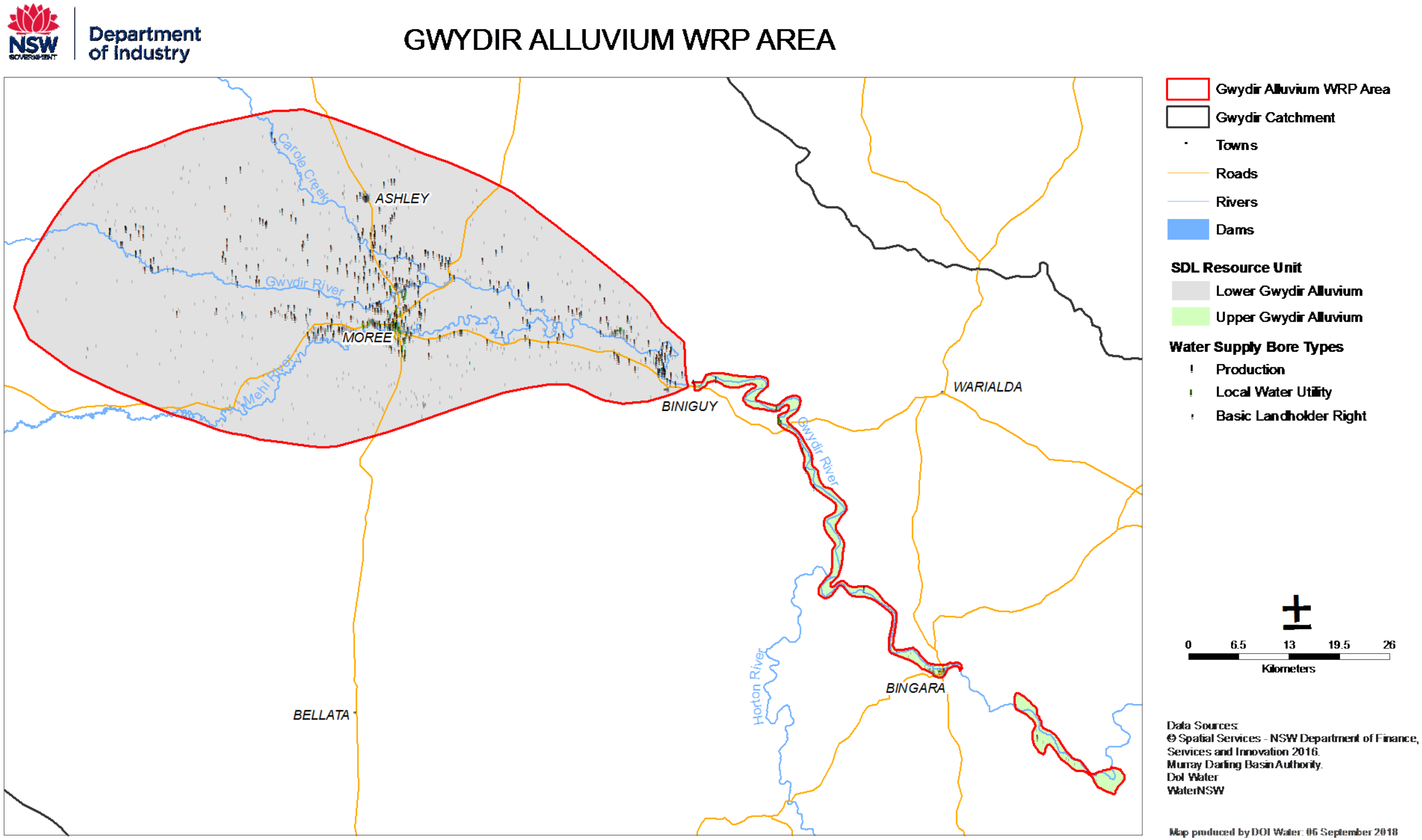


Figure 21 Registered bores in the Gwydir Alluvial Water Resource Plan Area.

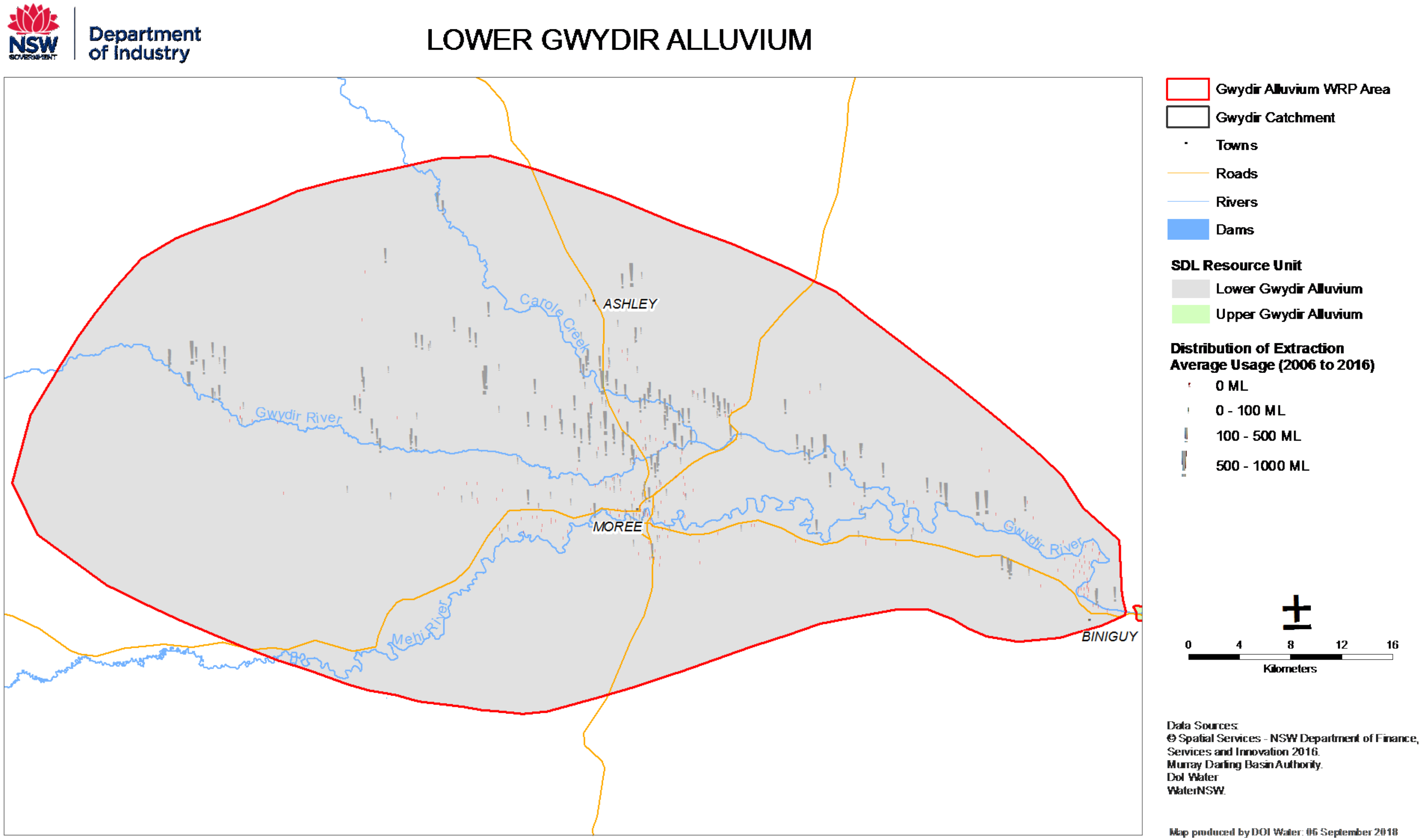


Figure 22 Gwydir Alluvial Water Resource Plan Area distribution of extraction

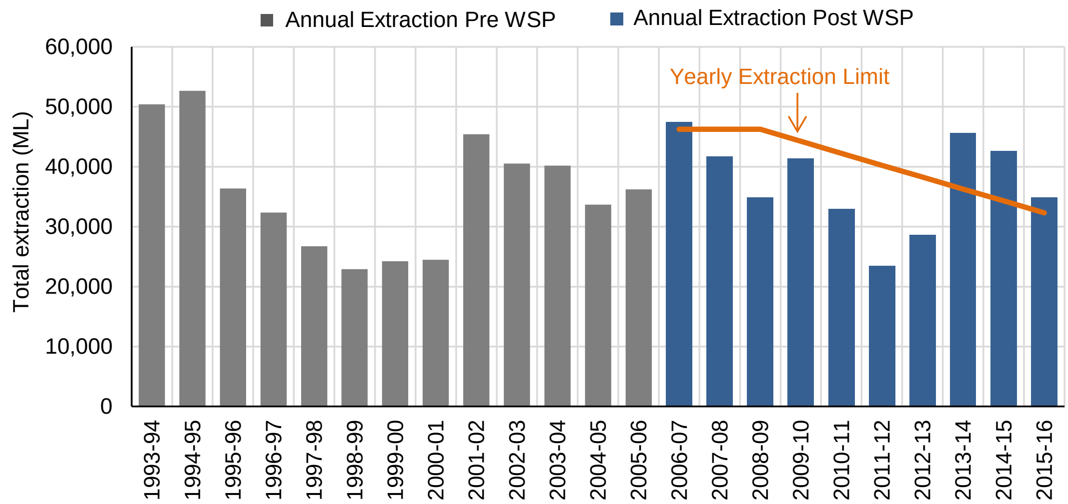


Figure 23 Metered extraction for the Lower Gwydir Alluvium

7.6 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 Gwydir Alluvium indicated an area between Moree and Ashley that had 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 the Upper Gwydir Alluvium.

7.6.1 Temporary dealings

The most common type of dealings between groundwater licences are allocation assignments (temporary trades) made under section 71T of the *Water Management Act 2000*. The total volume of temporary trades is shown in Figure 24 and the statistics for the business to business trades worth less than $1/ML are shown in Figure 25.

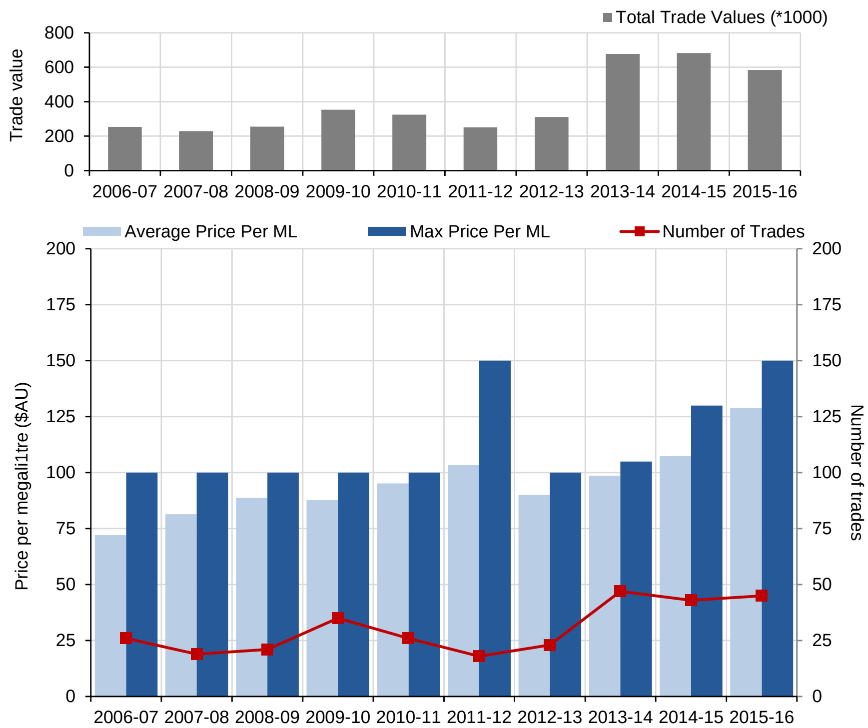


Figure 24 Lower Gwydir Alluvium 71T dealings since commencement of the water sharing plan

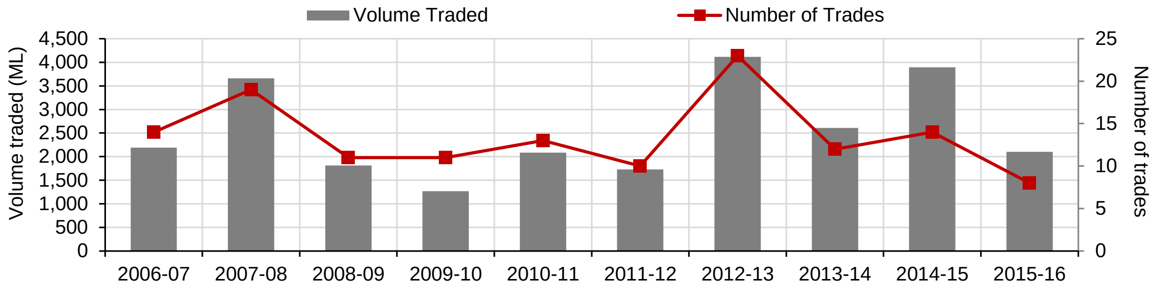


Figure 25 Lower Gwydir Alluvium > 1$/ML 71T dealings since commencement of the water sharing plan

To date, there have been no applications for temporary dealings in the Upper Gwydir Alluvium.

7.6.2 Permanent dealings

Permanent 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*.

In the Lower Gwydir Alluvium, all permanent dealings are subject to a hydrogeological assessment, with the exception of 71M dealings as these do not result in a change in extraction and therefore no potential for third party impacts.

Dealings may be approved subject to conditions being placed on the nominated work or combined approvals such as bore extraction limits to minimise potential impact on neighbouring bores.

Figure 26 shows the statistic for permanent dealings since commencement of the water sharing plan.

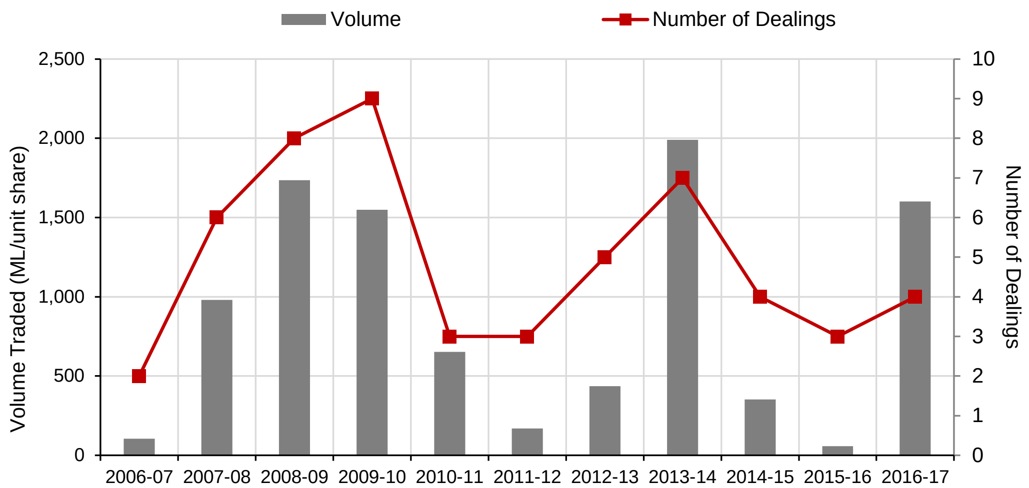


Figure 26 Lower Gwydir Alluvium permanent dealings since commencement of the water sharing plan, 71M dealings not included.

To date there have been no applications for any type of permanent dealing in the Upper Gwydir Alluvium in the Upper Gwydir Alluvium.

8 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 27 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.

The difference between stock and domestic, production and monitoring bores is also illustrated in Figure 27. 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 26 illustrates how the water level in some of the monitoring bores can be at different levels to nearby production and stock bores because the monitoring bores are screened at a single depth and the water level represents the water table or hydraulic head at that depth. Whereas the water level in a multiple screened production bore is a composite water level influenced by the hydraulic head in all screened aquifers.

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

Across the Lower Gwydir Alluvium there are 123 monitoring bores at 58 sites (Figure 28). Groundwater levels and pressures have been monitored since the early 1970s at 39 of the sites, with a continuous record of measurement for 30 to 40 years. In 2007/2008, 19 new sites were drilled and incorporated into the monitoring network.

The manually monitored sites are read every four to eight weeks. Data is available for 19 of these groundwater monitoring sites in real-time via telemetry from: *http://realtimedata.water.nsw.gov.au/water.stm*

There are currently no monitoring bores located within the Upper Gwydir Alluvium.

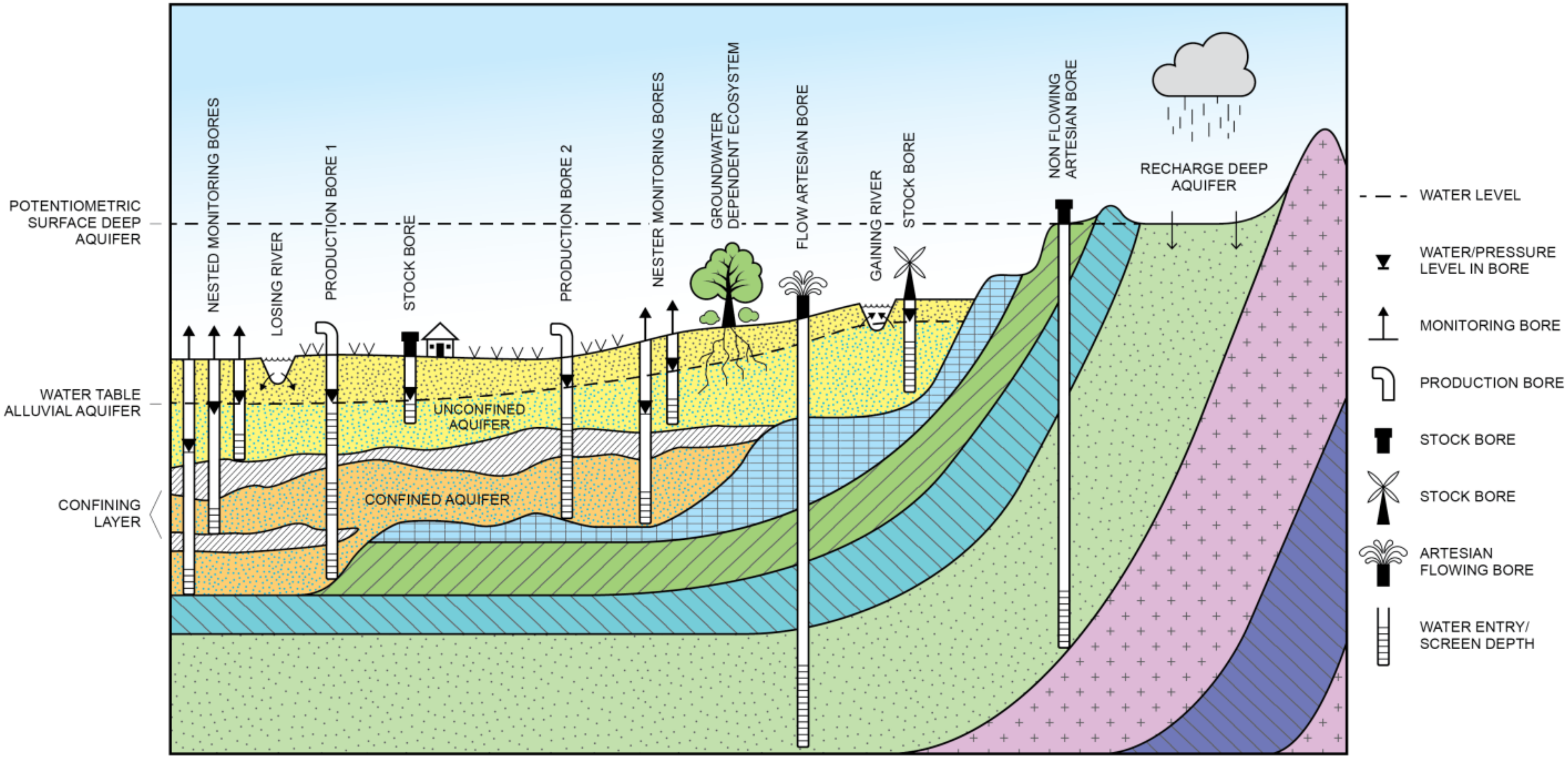


Figure 27 Schematic diagram of different types of aquifers

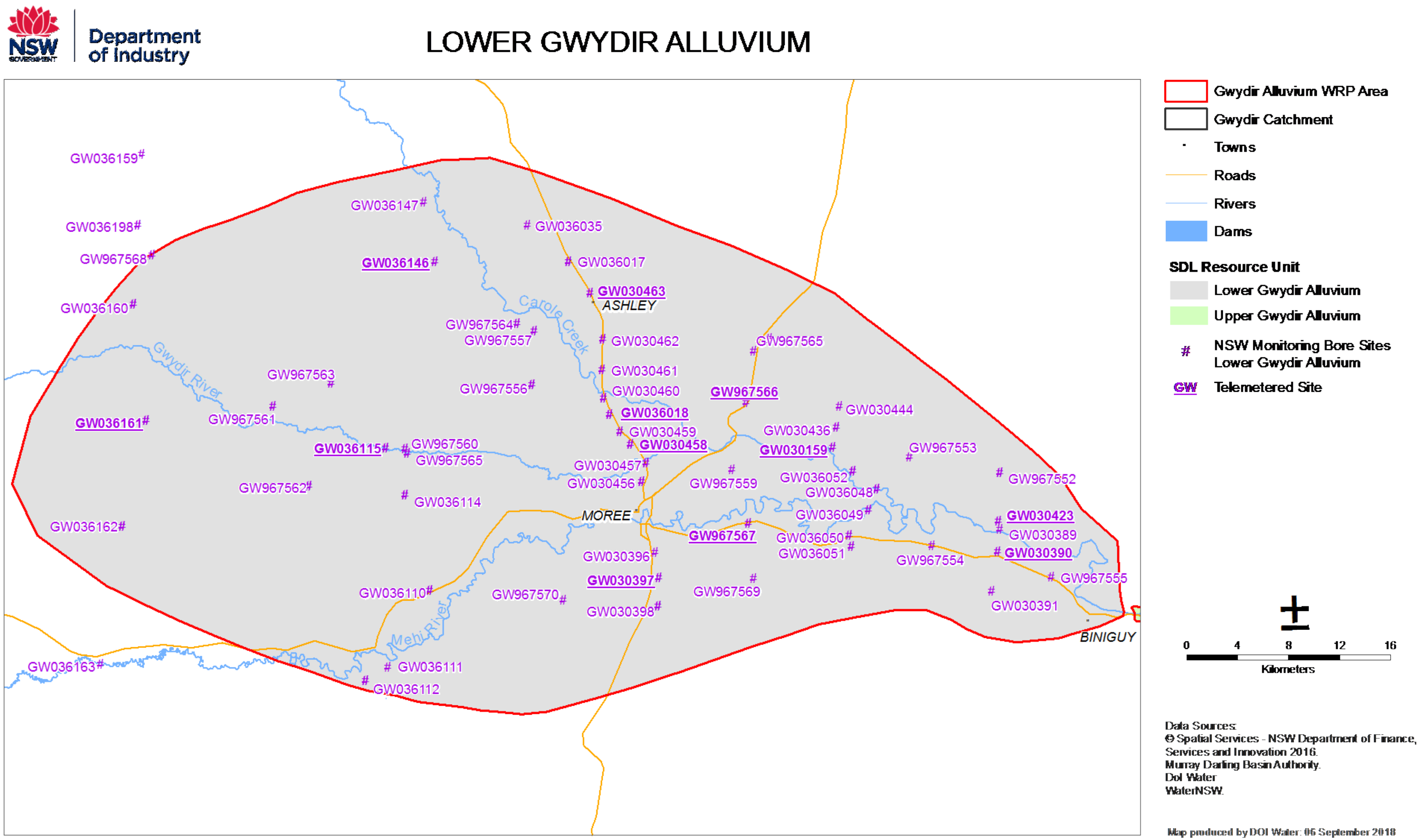


Figure 28 Location map of monitoring bore in the Lower Gwydir Alluvium

9 Groundwater Behaviour in the Lower Gwydir Alluvium

9.1 Introduction

For the Lower Gwydir Alluvium, monitoring bores constructed and screened less than 40 m deep are considered to be within the unconfined shallow aquifer system, while monitoring bores constructed deeper than 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 Lower Gwydir Alluvium the ‘pre-development’ is defined as the average recovered water level from 1974 to 1978. Changes in groundwater levels in the Lower Gwydir Alluvium are discussed in the following sections presenting data from hydrographs and groundwater head maps.

9.2 Hydrographs

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (Figure 29). Hydrographs can be used to interpret influences on groundwater such as rainfall, floods, drought and climate change, as well as interpret aquifer response to groundwater extraction.

Figure 29 explains the trends that can be observed in groundwater hydrographs. Both short and longer term water level trends can be identified. In unconfined and semi-confined aquifers, groundwater can be in hydraulic connection with the surface. Where this occurs, groundwater levels rise in response to recharge such as rainfall or flooding and decline during periods of reduced rainfall.

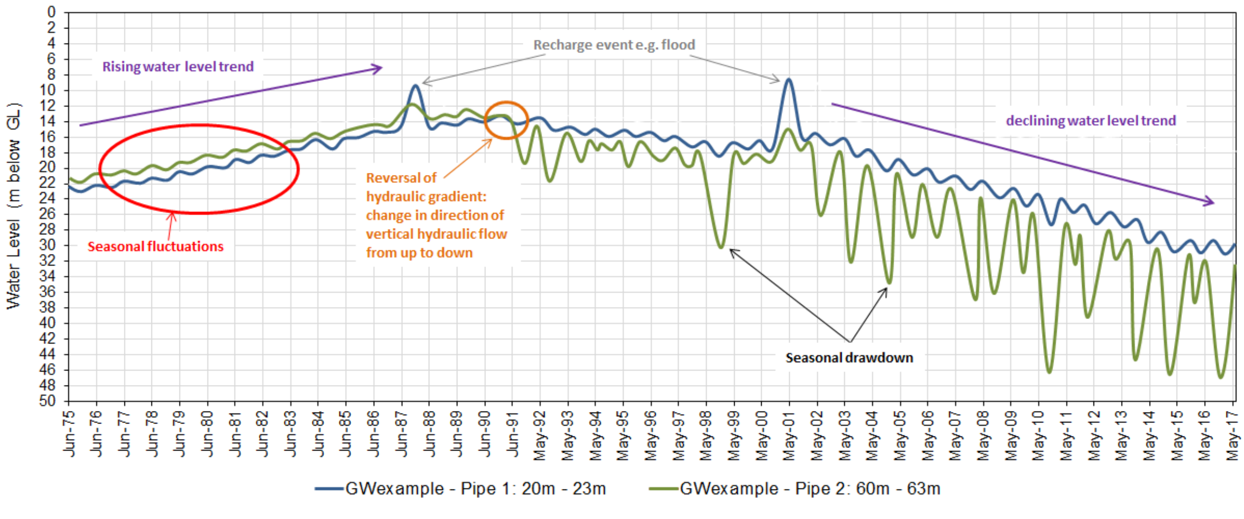


Figure 29 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate.

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.

9.3 Review of groundwater levels

Hydrographs for five representative groundwater monitoring sites across the Lower Gwydir Alluvium are presented below. The location of these sites is displayed in Figure 30. Each hydrograph is displayed on the same scale for ease of comparison.).

As described in Section 5.2, the Lower Gwydir Alluvium becomes deeper from east to west. The system is relatively shallow around the Pallamallawa section (Figure 31) where the aquifer is generally unconfined. The shallow and deep aquifer systems become more defined west of the Royden section (Figure 32).

In the area east of the Royden section, the groundwater recovery peaks (Figures 31 and 32) correspond to flood events in the Gwydir River in 2011, 2001, 1998, 1984 and 1976 (Welsh *et al*, 2014).This indicates a good hydraulic connection to the river. The long term trend is generally stable to declining in this area.

Large drawdowns and longer term recovery decline are observed along the Royden (Figure 32), Moree/Ashley (Figure 33) and Raft Sections (Figure 34) north of the Gwydir River where the majority of extraction occurs.

The most significant drawdowns occur in the area between Moree and Ashley. With growth in groundwater usage from the deep aquifer since the 1980s groundwater pressure in this aquifer has fallen. The reduction in pressure is inducing downwards leakage from the shallow aquifer, causing a decline in water levels in the shallow aquifers and reversal in the hydraulic gradient in some bores.

Figures 32 and 33 both show a reversal in the hydraulic gradient from upward to downward from around 1986/1987 at the onset of extraction.

The wetter years of 1996 to 2001 and again between 2010 and 2013, correspond to a period of reduced extraction and recovery. Water levels in most parts of the aquifer stabilised or rose slightly. However, from 2013, water levels have continued to decline in these areas.

Across the Lower Gwydir Alluvium, bores close to the Gwydir River and Gingham Watercourse show influence from climatic cycles and water level peaks after major flood events, this becomes more subdued west of the Raft Section.

The bores in the northern and central part of the Gingham section show no drawdown response but have long term water level declines (Figure 35). This may be in part due to reduced through-flow associated with extraction to the east.

On the peripheral edges and in the south west of the water source, water level responses show stable to rising water level trends and little or no direct response to groundwater extraction.

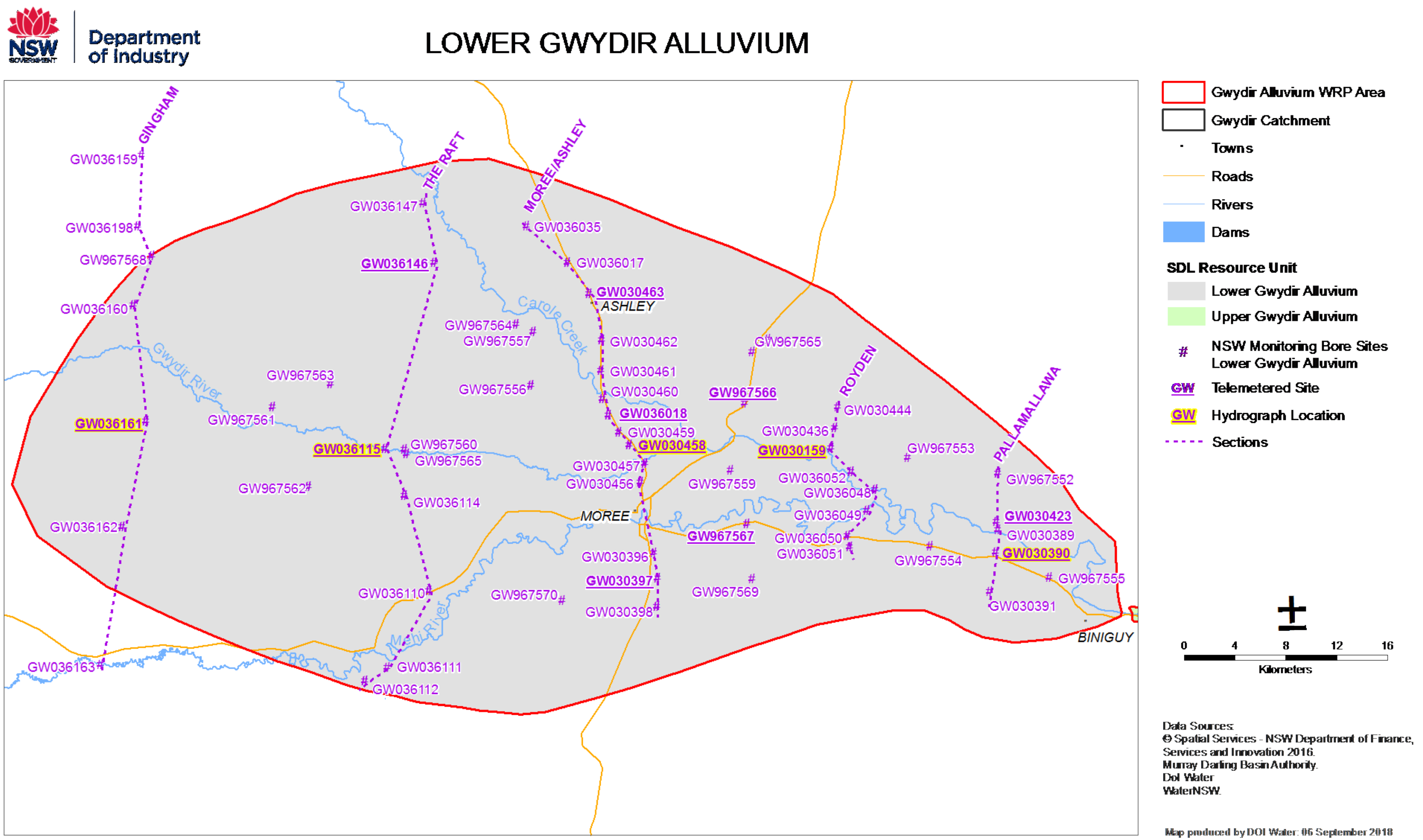


Figure 30 Lower Gwydir Alluvium hydrograph locations.

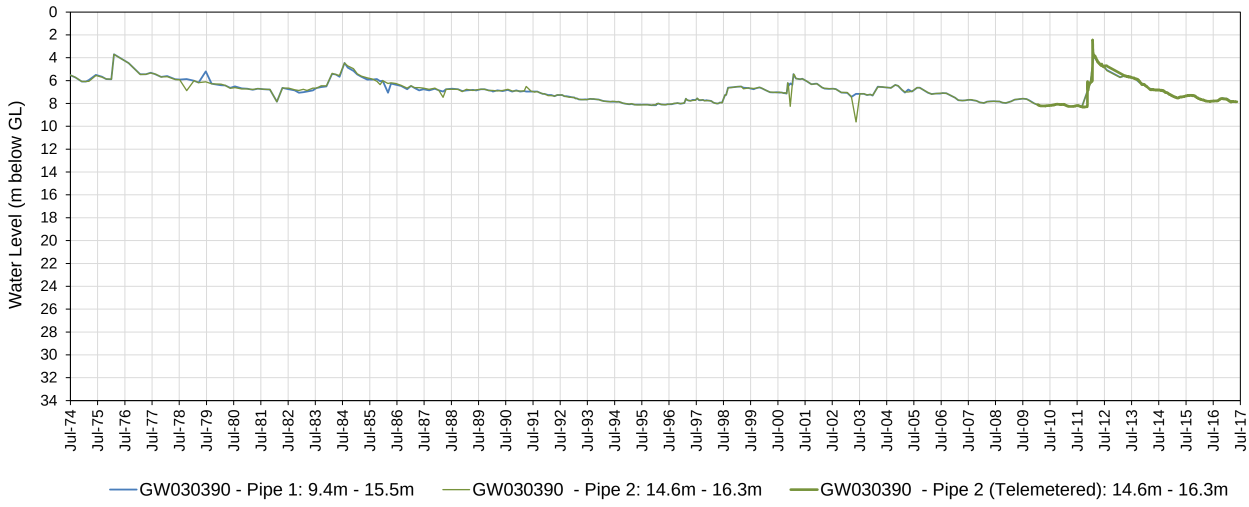


Figure 31 Hydrograph for monitoring bore site GW030390 – Pallamallawa section.

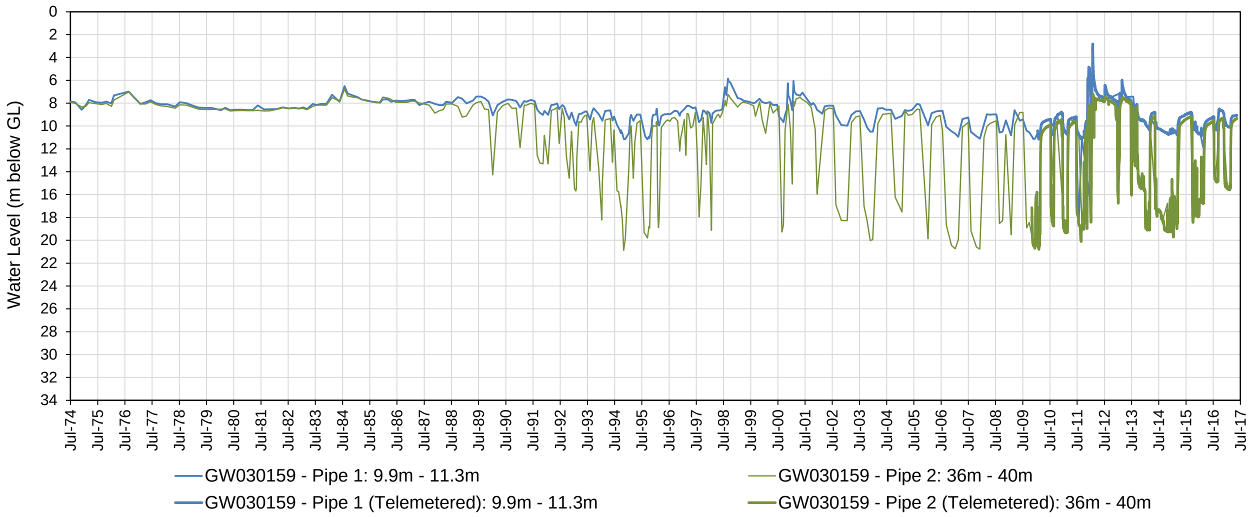


Figure 32 Hydrograph for monitoring bore site GW030390 – Royden section.

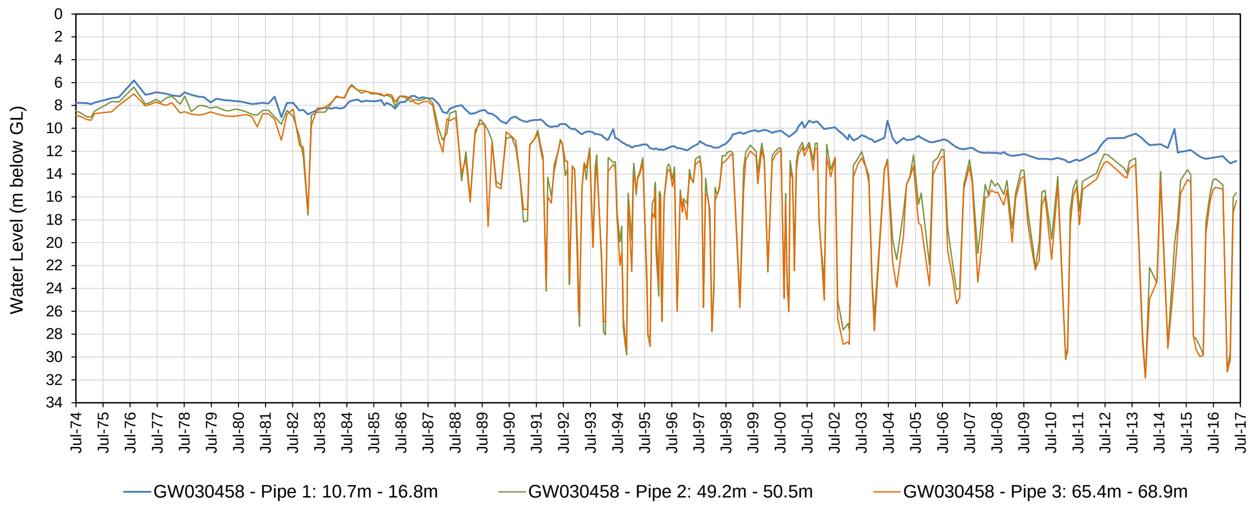


Figure 33 Hydrograph for monitoring bore site GW030458 – Moree/Ashley section.

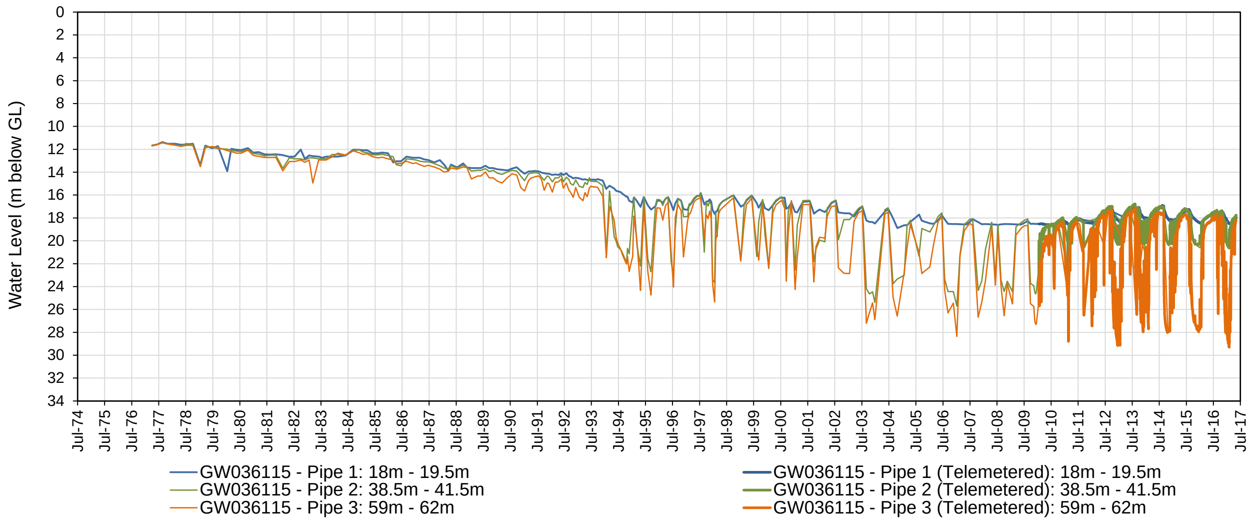


Figure 34 Hydrograph for monitoring bore site GW036115 – The Raft section.

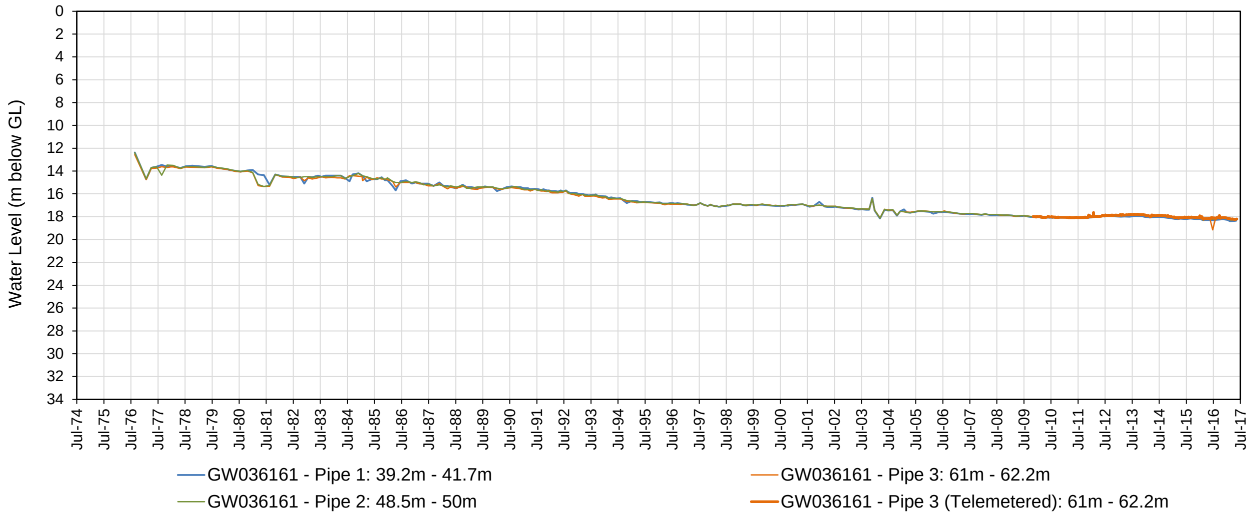


Figure 35 Hydrograph for monitoring bore site GW036115 – Gingham section.

9.4 Groundwater contour maps

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

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

For comparison purposes, contour maps have been prepared at maximum recovery level at twenty year intervals commencing with pre-development (average 1974 - 1978). Contours are displayed in metres Australian Height Datum (m AHD) which provides a reference level for the measurement of groundwater level or pressure that is independent of topography.

Maximum drawdown contours have been prepared for the deep system for 1995/1996 and 2015/2016. These are displayed with the maximum recovery contour for the same year to demonstrate the change in flow direct that can occur during the pumping season.

Groundwater level contours of recovered water levels show the regional groundwater flow direction across the Lower Gwydir Alluvium is east to west, matching the formation thickness distribution (Figure 36).

Prior to development of the resource in both the shallow and deep systems (Figure 36 A and A'), groundwater contours bulge westward along the rivers, indicating that the rivers are losing water to the groundwater system. The contour maps for 1995/96 (Figure 36 B and B') and 2015/2016 (Figure 36 C and C') show this effect reducing with time west of Moree.

Figure 37 compares the recovered water levels in the deep aquifer system with the corresponding maximum drawdown water level in 1995/1996 and 2015/2016. Figure 37 highlights the change of pattern in the flow direction over a season in areas where extraction occurs. The area of greatest extraction impacts is between Moree and Ashley where a drawdown low develops over the pumping season. The annual variations are particularly evident over the 2015/2016 pumping season (Figure 37 B).

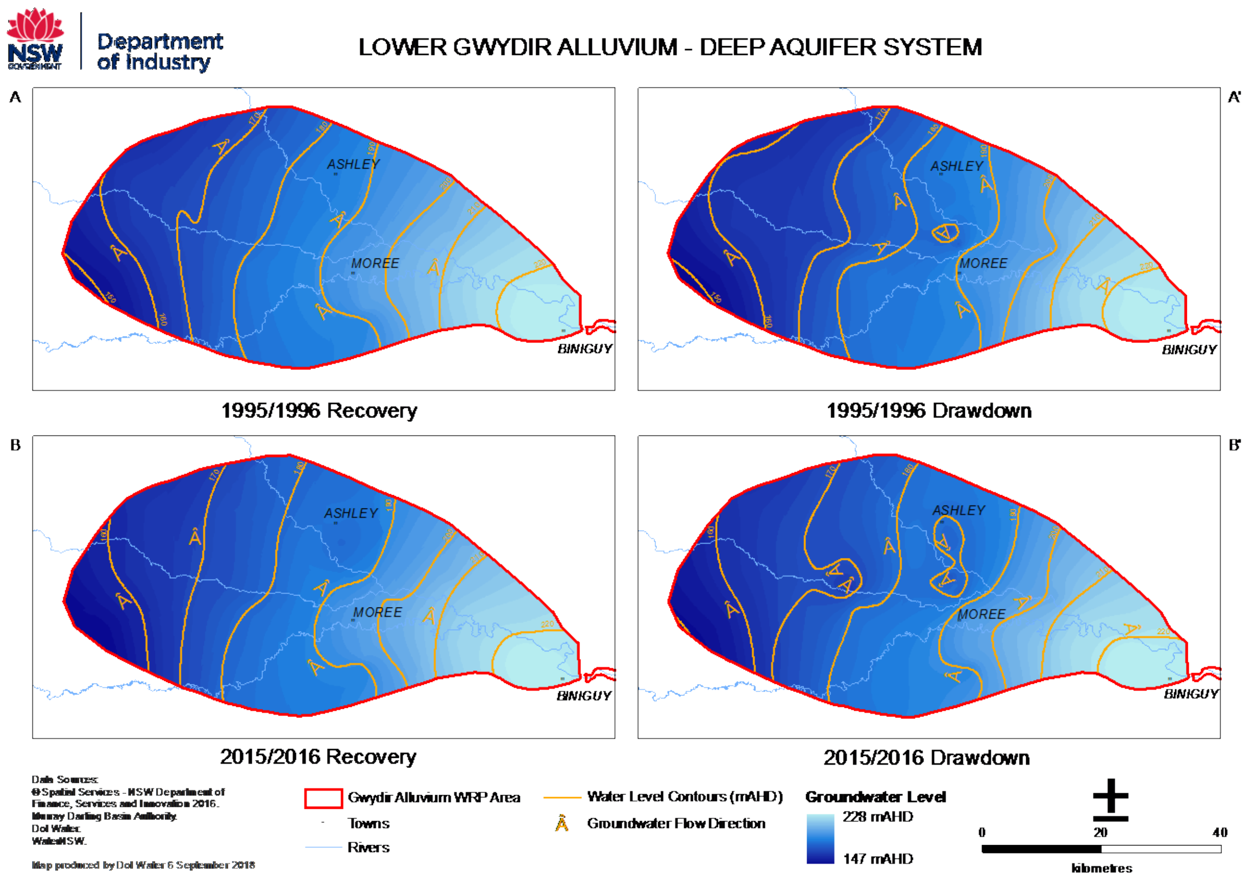


Figure 36 Groundwater level contours for the maximum recovery period, every 20 years starting from the pre-development period for the shallow and deep aquifer systems, Lower Gwydir Alluvium.

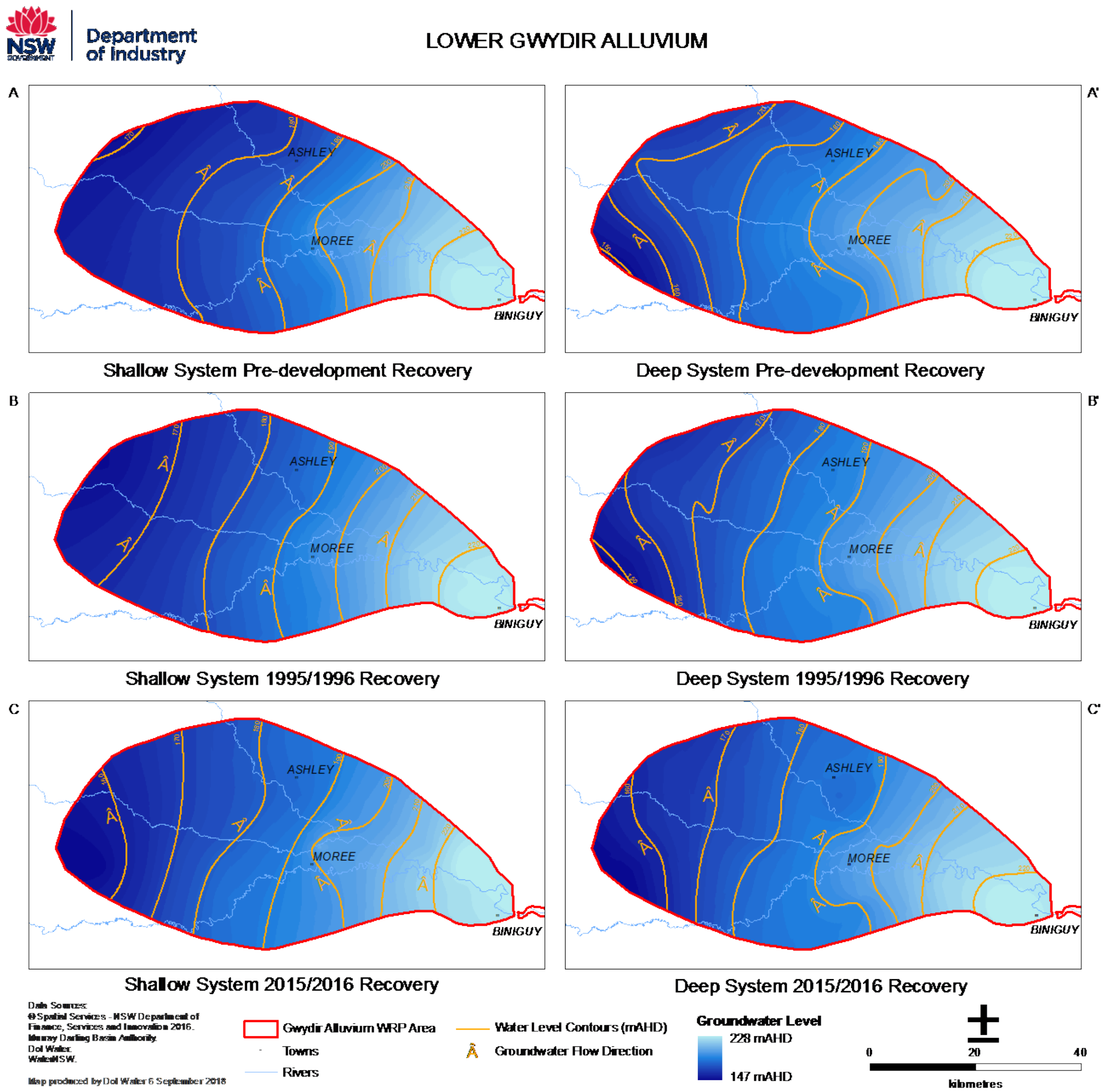


Figure 37 Groundwater level contours for the maximum recovery and maximum drawdown periods in 1995/1996 and 2015/2016; deep aquifer system, Lower Gwydir Alluvium.

9.5 Long term changes

Change in recovered groundwater levels over time are shown in Figures 38 for the deep aquifer systems.

Figure 38; maps A, B C and D illustrate the change in water level over the 10 year periods starting from the pre-development. Figure 38 E illustrate the overall long term water level change between pre-development to 2015/2016.

Over the period of initial development in the Lower Gwydir Alluvium (Figure 38 A), a decline of up to 2m in the eastern and western margins is observed, as well as a rising trend through the central part of the resource. Extraction across the Lower Gwydir Alluvium ramped up over the 1985/1986 to 1995/1996 period (Figure 38 B), which is reflected in the more significant declining trend across most of the resource.

Between 1995/1996 and 2005/2006 (Figure 38 C) there was significant rainfall and flooding across the Lower Gwydir, resulting in reduced groundwater extraction and some recovery of groundwater levels across most of the area.

The water sharing plan for the Lower Gwydir Alluvial groundwater source commenced in 2006/2007, this coincided with the Millennium drought with dry conditions continuing through to 2008/2009. During this period, large volumes of groundwater were extracted and no significant recharge event took place.

The Millennium drought was followed by a flood event in 2011/2012 that eased the pressure on the resource.

The trend over the 2005/2006 to 2015/2016 period (Figure 38 D) shows a rising water level (up to 2m) in the area south west of Moree. The trend across the rest of the area shows a decline of up to 2m. Where the majority of extraction occurs between Moree and Ashley there has been decline of up to 6m over this period.

The long term change in recovered water level from pre-development to 2015/2016 (Map E Figure 38) shows significant water level decline across the central part of the resource where the majority of extraction is occurring, with up to 10m decline in the area between Moree and Ashley.

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

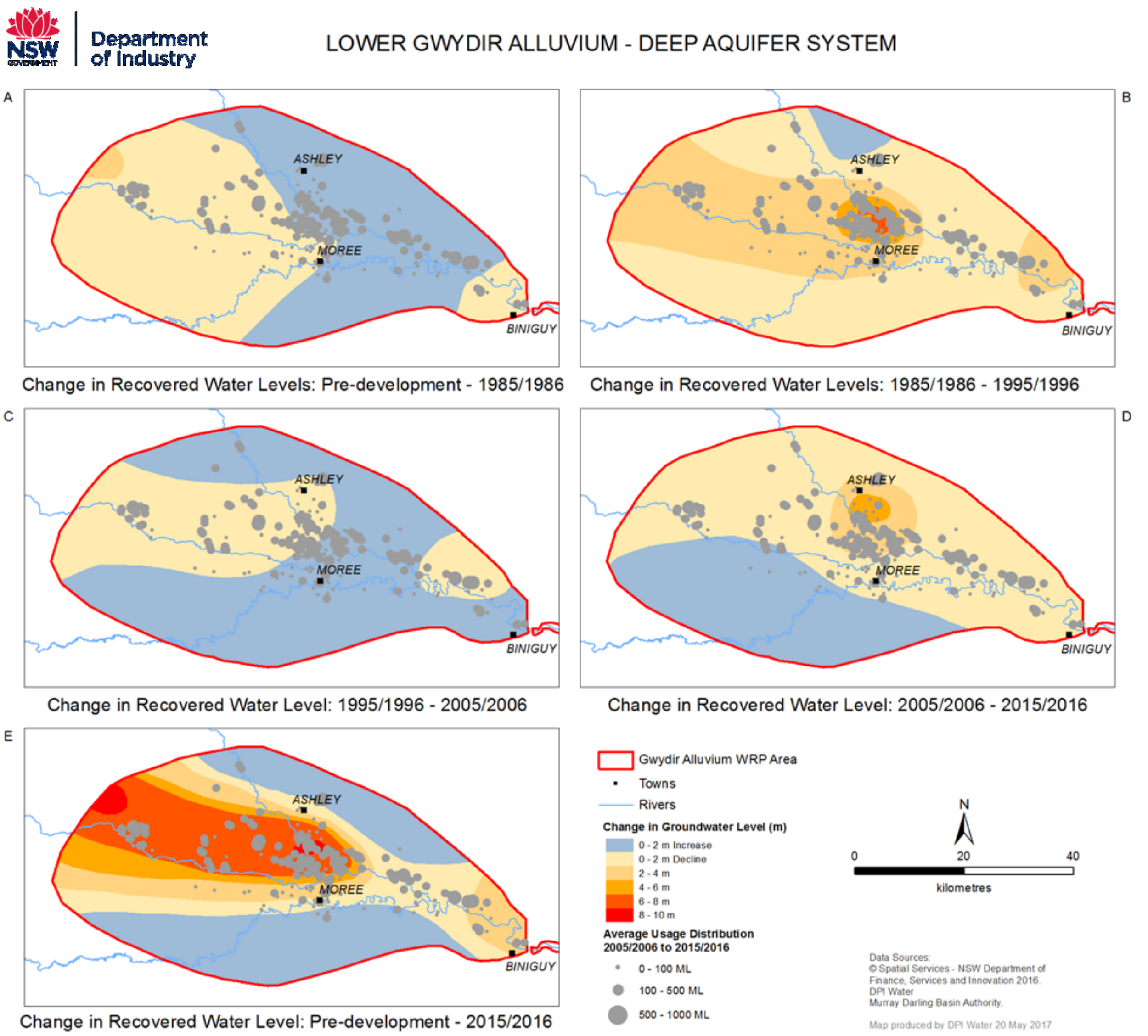


Figure 38 Lower Gwydir Alluvium – deep aquifer system; five maps showing the change in recovered water level over a range of periods.

10 Groundwater model

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

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

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

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

In 2002 the groundwater model for the Lower Gwydir Alluvium was finalised to support resource management and the development of the water sharing plan.

The updated version of the groundwater model for the Lower Gwydir Alluvium (2016) has refined the modelled area and includes a calibration period from 1986 to 2015 (Wijesinghe *et al*, 2016. In Prep).

Figure 39 shows the cumulative water budget output from the 2016 Lower Gwydir Alluvium groundwater model for the period 2006/2007 to 2015/2016. This corresponds to the period since commencement of the water sharing plan for the Lower Gwydir Alluvium.

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.

Figure 39 shows that since the commencement of the water sharing plan in 2006/2007, the modelled total net change in storage in the Lower Gwydir Alluvium has decreased (storage change -5.48 GL) over this 10 years.

This decrease in storage reflects the water sharing plan for the Lower Gwydir 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 Lower Gwydir Alluvium extraction is now being managed to ensure depletion of the groundwater storage does not continue into the longer term.

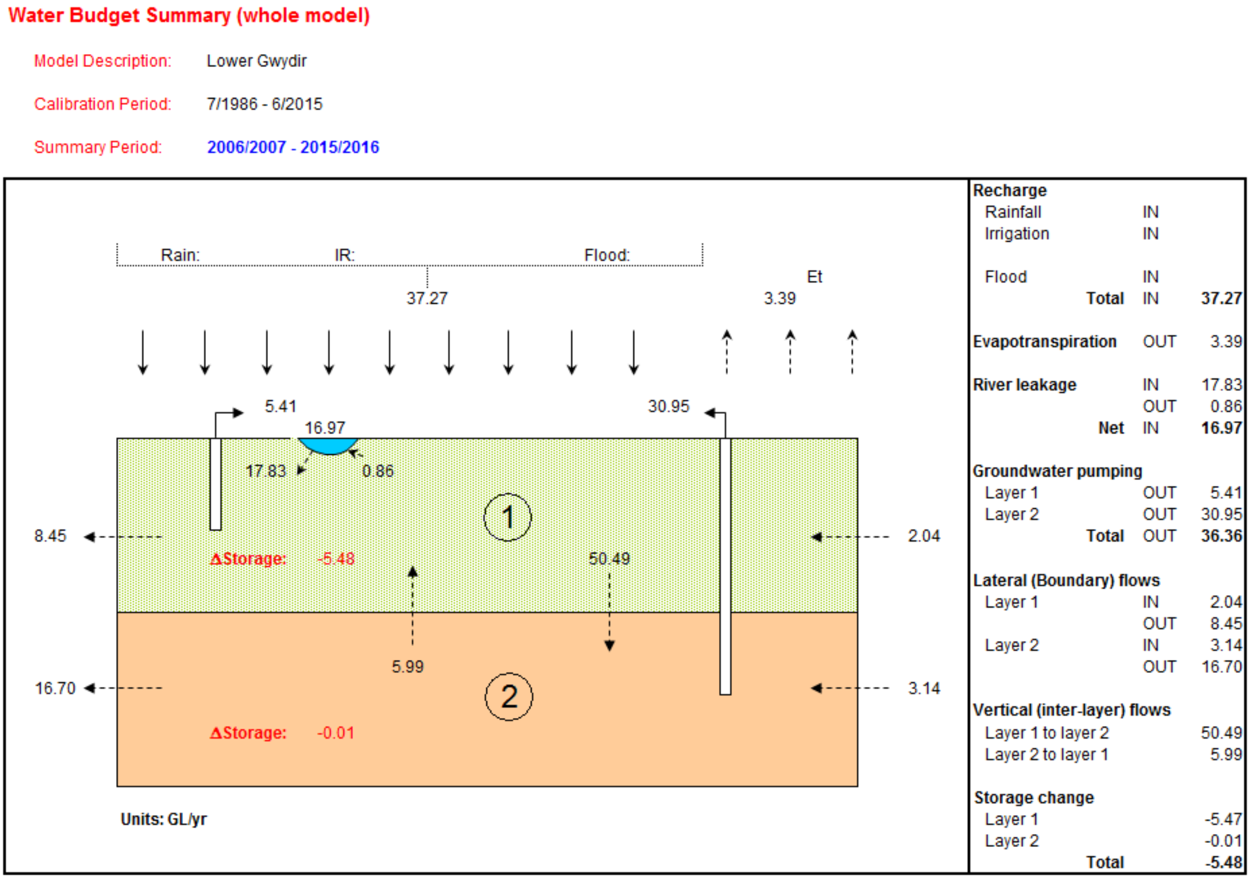


Figure 39 Lower Gwydir Alluvium groundwater flow model water budget output 2006/2007 to 2015/2016.

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Appendix A

Lower Gwydir Alluvium – shallow aquifer system; maps showing the change in recovered water level over a range of periods.