WATER SHARING PLAN FOR THE NSW GREAT ARTESIAN BASIN GROUNDWATER SOURCES

Groundwater Resource Description

NSW Great Artesian Basin

February 2020

Published by NSW Department of Planning, Industry and Environment

dpie.nsw.gov.au

Title: Groundwater Resource Description

Subtitle: NSW Great Artesian Basin

First published: February 2020

Department reference number: PUB20/74

More information

S Haridharan / Water Assessment / Dubbo

Acknowledgements

Some maps in the report are produced using Geoscience Australia's online digital dataset on water quality and surface elevation of stratigraphic units.

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Acronyms

AHD	Australian Height Datum
AWD	Available Water Determination
BLR	Basic landholder rights
Ca	Calcium
Cl	Chloride
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPIE	NSW Department of Planning, Industry and Environment
EC	Electrical Conductivity
GAB	Great Artesian Basin
GABSI	Great Artesian Basin Sustainability Initiative
HCO_3	Bicarbonate
kPa	Kilo Pascals
L/s	Litre per Second
LTAAEL	Long-Term Average Annual Extraction Limit
MDB	Murray Darling Basin
Mg	Magnesium
mg/L	Milligram per Litre
ML	Megalitre
ML/yr	Megalitre per year
Na	Sodium
NSW	New South Wales
pH	Measurement of alkalinity or acidity
Qld	Queensland
SA	South Australia
SAR	Sodium absorption ratio
TWS	Town Water Supply
WA1912	Water Act 1912
WMA2000	Water Management Act 2000
WSP	Water Sharing Plan
WSP 2008	Water Sharing Plan for the NSW Great Artesian Groundwater Sources 2008
WSP 2020	Water Sharing Plan for the NSW Great Artesian Groundwater Sources 2020

Glossary

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

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

Bedrock	A general term used for solid rock that underlies aquifers, soils or other unconsolidated material.
Beneficial use (category)	[1]A general categorisation of groundwater uses based on water quality and the presence or absence of contaminants. Beneficial use is the equivalent to the 'environmental value' of water.
Bore (or well)	A hole or shaft drilled or dug into the ground...
Brackish water	Water with salinity between 3,000 and 7,000 mg/L total dissolved solids.
Cenozoic	The Cenozoic Era spanned from 66 million years ago to present
Confined aquifer	An aquifer which is bounded above and below by impermeable layers causing it to be under pressure so that when the aquifer is penetrated by a bore, the groundwater will rise above the top of the aquifer.
Connected water sources	Water sources that have some level of hydraulic connection.
Development (of a groundwater resource)	The commencement of extraction of significant volumes of water from a water source.
Discharge	Flow of groundwater from a groundwater source.
Drawdown	The difference between groundwater level/pressure before take and that during take.
Dual porosity	Where a groundwater system has two types of porosity; primary porosity resulting from the voids between the constituent particles forming the rock mass, and secondary porosity resulting from dissolution, faulting and jointing of the rock mass.
Electrical conductivity (EC)	Ability of a substance to conduct an electrical current. Used as a measure of the concentration of dissolved ions (salts) in water (i.e. water salinity). Measured in micro-Siemens per centimetre (µS/cm) or deci-Siemens per metre (dS/m) at 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.

[1] As defined in '*Macro water sharing plans – the approach for groundwater*' (DPI Water, 2015)
[2] As defined in '*Guidelines for Groundwater Quality Protection in Australia 2013'* (Australian Government, 2013)

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.
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.

[3] As defined in '*Methods for the identification of high probability groundwater dependent vegetation ecosystems'* (DPI Water, 2016)

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

Proterozoic	The Proterozoic Era spanned 2.5 billion to 541 million years ago.
Recharge	The addition of water into a groundwater system by infiltration, flow or injection from sources such as rainfall, overland flow, adjacent groundwater sources, irrigation, or surface water sources.
Recovery	The rise of groundwater levels or pressures after groundwater take has ceased. Where water is being added, recovery will be a fall.
Recovery decline	Where groundwater levels or pressures do not fully return to the previous level after a period of groundwater removal or addition.
Reliable water supply	[4]Rainfall of 350mm or more per annum (9 out of 10 years); or a regulated river, or unregulated rivers where there are flows for at least 95% of the time (i.e. the 95th percentile flow of each month of the year is greater than zero) or 5th order and higher rivers; or groundwater aquifers (excluding miscellaneous alluvial aquifers, also known as small storage aquifers) which have a yield rate greater than 5L/s and total dissolved solids of less than 1,500mg/L.
River Condition Index (RCI)	This is a spatial tool used to measure and monitor the long-term trend of river condition, but also reports on instream values and risk to instream values from extraction and geomorphic disturbance.
Salinity	The concentration of dissolved minerals in water, usually expressed in EC units or milligrams of total dissolved solids per litre.
Salt	A mineral which in a liquid will readily dissociate into its component ionic species for example NaCl into Na^+ and Cl^- ions.
Saturated zone	Area below the water table where all soil spaces, pores, fractures and voids are filled with water.
Sedimentary rock	A rock formed by consolidation of sediments deposited in layers, for example sandstone, siltstone and limestone.
Share component	An entitlement to water specified on an access licence, expressed as a unit share or for specific purpose licences a volume in megalitres (e.g. local water utility, major water utility and domestic and stock).
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.

[4] As defined in 'Strategic Regional Land Use Plans' ((Department of Planning and Infrastructure, 2012)

Unconfined aquifer	A groundwater system usually near the ground surface, which is in connection with atmospheric pressure and whose upper level is represented by the water table.
Unconsolidated sediment	Particles of gravel, sand, silt or clay that are not bound or hardened by mineral cement, pressure, or thermal alteration of the grains.
Unsaturated zone	Area above the water table where soil spaces, pores, fractures and voids are not completely filled with water.
Water balance	A calculation of all water entering and leaving a system.
Water resource plan	[5]A plan made under the *Commonwealth Water Act 2007* that outlines how a particular area of the Murray–Darling Basin's water resources will be managed to be consistent with the Murray–Darling Basin Plan. These plans set out the water sharing rules and arrangements relating to issues such as annual limits on water take, environmental water, managing water during extreme events and strategies to achieve water quality standards and manage risks.
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*' (DPI Water, 2015)

1 Introduction

The Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008 (WSP 2008) started in July 2008 for a period of 10 years up to June 2018. In June 2018, the Natural Resources Commission reviewed the WSP 2008 and recommended it for replacement in July 2020. Water sharing plans align with state-based water resource management policies and build on the existing water planning and management frameworks that have been established in NSW.

The Great Artesian Basin (GAB) is Australia's largest groundwater basin, spreading across 1.7 million square kilometres of New South Wales (NSW), Queensland, South Australia and Northern Territory, or approximately 22% of Australia. The GAB underlies 207,592 square kilometres of New South Wales.

The GAB in NSW includes a part of the larger Surat and Eromanga geological basins that were deposited in the Jurassic and Cretaceous periods (210 to 65 Million years ago). These geological basins were formed on older geological basins such as the Bowen and Gunnedah Basins and older basement rocks.

The GAB is comprised of sedimentary rock layers that form aquifers and aquitards containing groundwater that is mostly under artesian conditions. These groundwater sources support towns and industries across the western regions of NSW including pastoral, opal mining and spa baths. It also supports the irrigation industry in the recharge areas.

The NSW GAB is managed as five groundwater sources (Figure 1). These five groundwater sources are the Eastern Recharge, the Southern Recharge, the Surat, the Warrego and the Central Groundwater Sources.

This report provides up to date information of the status of the groundwater to stakeholders and the public. It describes the location, climate and physical attributes of the WSP 2008 area, and explains the GAB Groundwater Sources' geological and hydrogeological context, environmental assets, groundwater quality and management. It also presents the status of these groundwater sources including groundwater rights, accounts, dealings, take and groundwater behaviour.

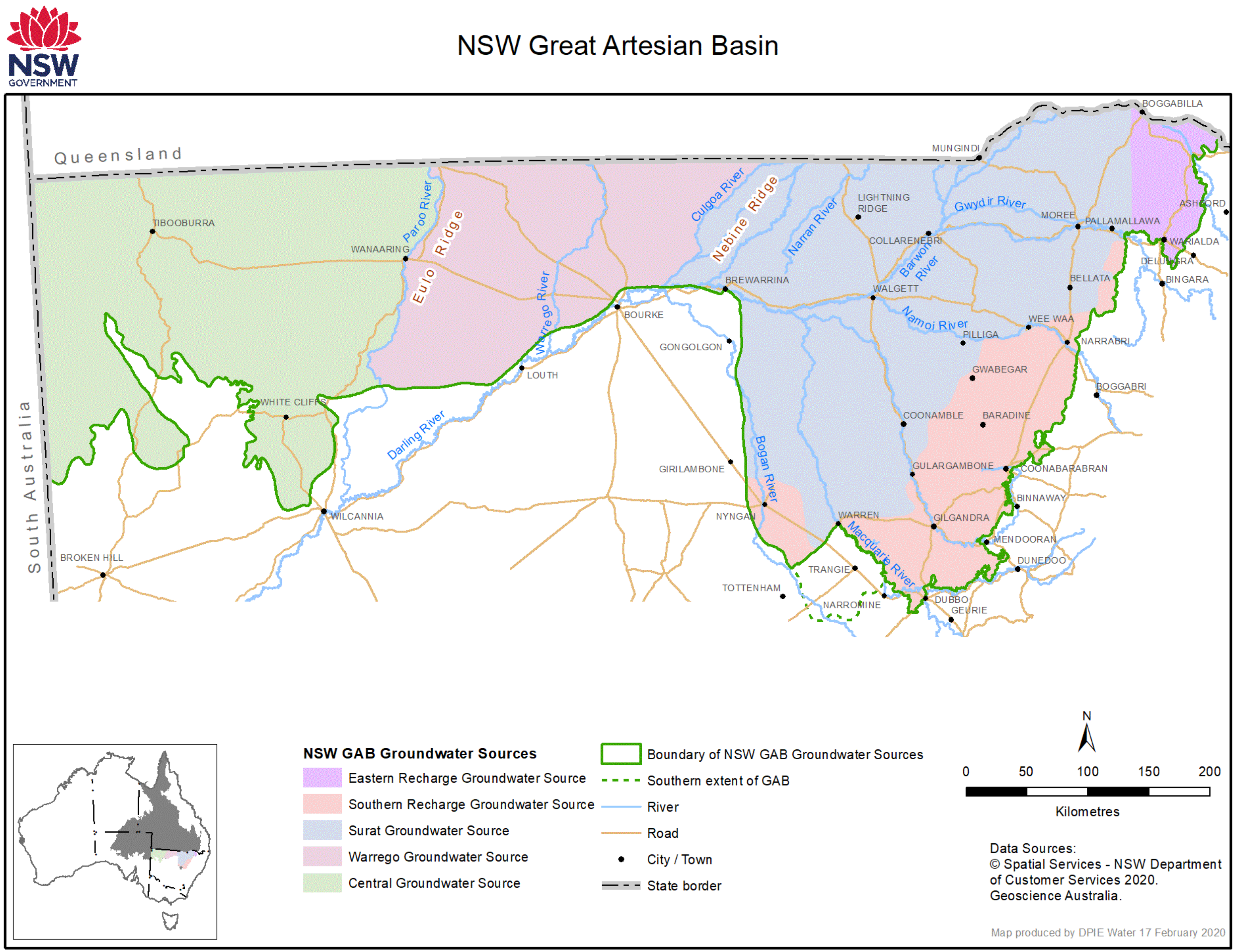

Figure 1 NSW Great Artesian Basin Groundwater Sources

2 History of Groundwater Management

2.1 Early groundwater management

The *Water Act 1912* (*WA1912*) 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 *WA1912*, 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 *WA1912* 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 & O'Keefe, 1997 Unpublished).

From 1984, all new high yield bores and wells (greater than 20 megalitres) 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 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 (WMA2000)*. The *WMA2000* 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 *WMA2000* 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 *WMA2000* also sets up the framework for developing statutory plans to manage water.

Water sharing plans are the principal 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 inland groundwater sharing plans commenced between 2006 and 2008 across six large alluvial groundwater systems in the Murray-Darling Basin and the NSW GAB.

Since then, 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 *WA1912* 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 *WMA2000* and other relevant legislative frameworks.

2.3 History of groundwater management in the NSW GAB Groundwater Sources

The groundwater development for pastoral use in the NSW GAB started in late 1870s immediately after the discovery of artesian groundwater at Kallara station west of Bourke. With the introduction of the *Public Watering Places Act 1884*, the NSW Government invited tenders for the construction of artesian bores on some of the far western stock routes. The groundwater development was further promoted by the *Artesian Wells Act 1897*, which enabled groups of settlers to obtain government assistance to construct an artesian bore to serve their collective properties and the water being distributed to them by open drains (Williamson W. H., 2012).

The *Water Act 1912 (WA1912)* superseded the former acts and required that a licence be obtained before any water bore or well be drilled, altered or deepened deeper than 30 m in the NSW GAB. The *WA1912* was amended in 1955 so that the licence requirement applied to all water bores across NSW regardless of depth (Williamson W. H., 2012). Since 1965, all new artesian bore licences have permitted water distribution from the bore only through closed pipeline system (Williamson W. H., 1984).

From early 1960s, the bore licences were issued without volumetric entitlement or restriction for productive uses. The first interim volumetric groundwater policy for the NSW GAB was introduced in 1983. Under this interim policy, the entitlements were issued for properties in the recharge areas based on the irrigation area and capped to a maximum entitlement of 486 ML/year. Where possible all unrestricted licences were issued with the volumetric entitlements based on the groundwater use. Because of the unsuitability of artesian water due to high sodium ion concentration, its use for irrigation was not encouraged under this policy.

An embargo on additional licence applications for bores accessing water from NSW GAB for irrigation, recreational and industrial use was placed on 17 December 1999 and subsequently amended on 15 November 2005 to exempt applications for major projects seeking access to water savings generated under the Great Artesian Basin Sustainable Initiative (GABSI). This embargo remained in place until the commencement of the Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008 on 1 July 2008.

3 Regional Setting

3.1 Topography and hydrology

The WSP 2008 area falls into the Murray Darling Basin (MDB) and Lake Eyre drainage catchments. About 25% of the NSW GAB Groundwater Sources fall into the Lake Eyre catchment. All major rivers within the WSP 2008 area are located within the MDB catchment.

The elevation across the WSP 2008 area decreases from east to west. The elevation ranges from over 1,200 m Australian Height Datum (AHD) in the Warrumbungle Range to about 50 m AHD on the state border with South Australia in the west of the WSP 2008 area (Figure 2). The peak of Warrumbungle Ranges is a dominant topographical feature within the WSP 2008 area.

The WSP 2008 area is also dominated by wide flood plains with elevation less than 200 m AHD and tributaries into Barwon-Darling River. These being the flood plains of the Barwon–Darling, Culgoa, Namoi, Gwydir, Macquarie, Bogan, Castlereagh, Warrego and Paroo River systems.

The Barwon River starts at an elevation of 200 m AHD at the confluence of the Macintyre and Weir Rivers, and flows for approximately 700 km over a low gradient to an elevation of 110 m at its confluence with Culgoa River (MDBA, 2017). Downstream of the Culgoa confluence, the Barwon River becomes the Darling River, and flows another 900 km to the Menindee Lakes.

The Namoi River above Keepit dam starts at elevations over 1,000 m AHD in the Great Dividing Range to the south east of Tamworth. The Namoi River flow is regulated downstream of Keepit Dam. The Namoi River joins with the Barwon River at Walgett.

The Gwydir River begins at an elevation of 1,200 m AHD near Uralla and the flow is regulated downstream of the Copeton dam. 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. Both water courses confluence with the Barwon River upstream of Collarenebri.

The Macquarie River originates south of Bathurst in the Great Dividing Range and flows in the north westerly direction into Macquarie Marshes, and joins the Barwon River downstream of Walgett. The Macquarie River flow is regulated downstream of the Burrendong dam.

From its headwaters near Harvey Ranges, south west of Dubbo, the Bogan River flows parallel to Macquarie River before joining with Barwon River between Bourke and Brewarrina.

The Castlereagh River starts in the Warrumbungle Ranges near Coonabarabran, and flows south west, then north-west for 549 km to its confluence with the Macquarie River. It runs parallel to Barwon River at the lower end of the river reach. Here the lower flood plain carries flows from the Barwon River through to the Castlereagh River during major floods.

The Warrego River starts at an elevation about 600 m AHD near Carnarvon Range in Queensland and flows southwards to the flood plains of north western New South Wales where it meets the Darling River downstream of Bourke near Louth. The Warrego flows intermittently and generally ends in large swamps and storages near Louth. In wet years, waters of the Warrego River system flow through Cuttaburra Creek to the lower reaches of the Paroo River (MDBA, 2017).

The Paroo River is an ephemeral river, flowing mainly when heavy rains fall in its northern catchment. Mostly, the river is a series of waterholes, lakes and wetlands. In wet years, the Paroo's floodwaters typically end at the Paroo overflow lakes on the floodplains south of Wanaaring. Only in exceptionally wet years will the Paroo join the Darling River, which occurred only four times between 1900 and 2010 (MDBA, 2017).

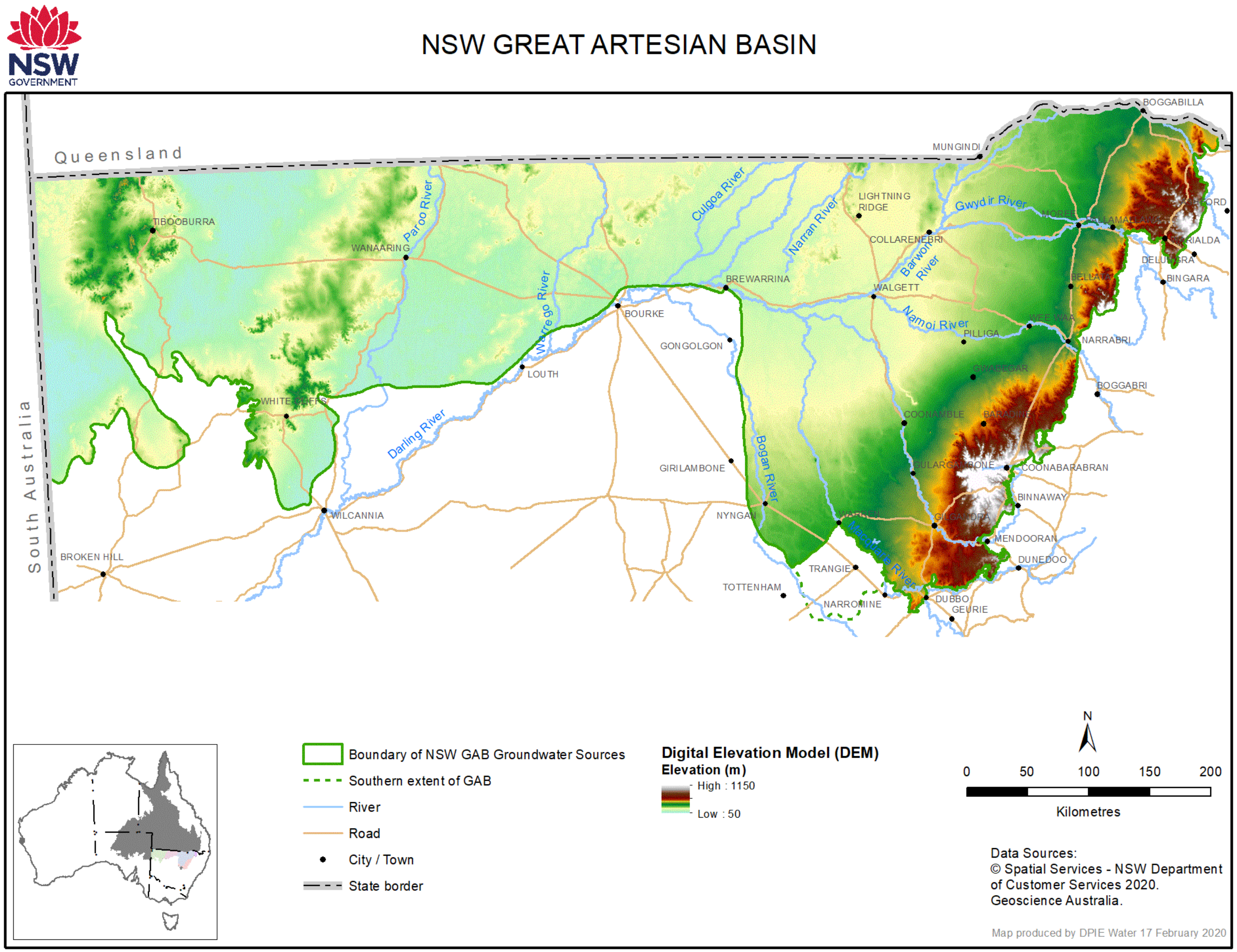

Figure 2 [7]Topography and elevation of the WSP 2008 area

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[7] Data source: 1 second SRTM Level 2 Derived Digital Surface Model v1.0 (Gallant, Dowling, Read, Wilson, & Tickle, 2009)

3.2 Climate

The climate in the central and western part of the WSP 2008 area is influenced by its low-lying topography and distance from the coast. Figure 3 shows that the eastern fringe experiences the highest rainfall totals in the area, whilst the central and western parts are very dry. Average annual rainfall gradually decreases westward from approximately 750 mm at Coonabarabran in the south east and 620 mm at Pallamallawa in the east to 185 mm in the west at Tibooburra. Although rainfall can vary considerably between years, rainfall across the WSP 2008 area tends to be summer dominant whilst more than double the rainfall occurs in each month in the east compared to the west (Figure 5).

The WSP 2008 area experiences arid to semi-arid climate characterised by warm to hot summers and mild winters. At the higher elevations in the south east near Coonabarabran, temperatures vary from a winter average minimum of 0° Celsius (C) to a summer average maximum to 32°C. In the far west near Tibooburra, the temperatures range from winter average minimum of around 7°C to a summer average maximum of 35°C.

Climate change modelling (OEH, 2014) projects the maximum temperatures to increase in the near future (2020–2039) by 0.3-1.0°C and 1.8-2.7°C in the far future (2060-2079). The rainfall is projected to decrease in spring and increase in summer and autumn.

Figure 4 shows that evaporation has a strong gradient increasing from east to west. Yearly evaporation varies from around 1,600 mm in the east to over 3,150 mm in the west. Annual evaporation significantly exceeds the annual rainfall across the WSP 2008 area.

Evaporation is seasonal throughout the year. The average daily evaporation rates at Moree Airport vary from 10 mm/day in summer months to about 3 mm/day in winter months (Figure 6).

Residual rainfall graph has been constructed from daily rainfall data sourced from the Bureau of Meteorology (Bureau of Meteorology, 2020). The residual rainfall mass graph plots the cumulative difference from the monthly average rainfall and provides a visual representation of the rainfall history in an area. A falling trend indicates a period of lower than average rainfall, a rising trend showing periods of above average rainfall.

Figure 7 shows the residual rainfall mass graph of average monthly rainfall from 1970 to 2019 at Wanaaring Post Office and Pallamallawa Post Office. It shows a below average rainfall trend during the millennium drought from 2001 to 2009, followed by an above average spike over the 2010 to 2012 period then below average trend to 2019.

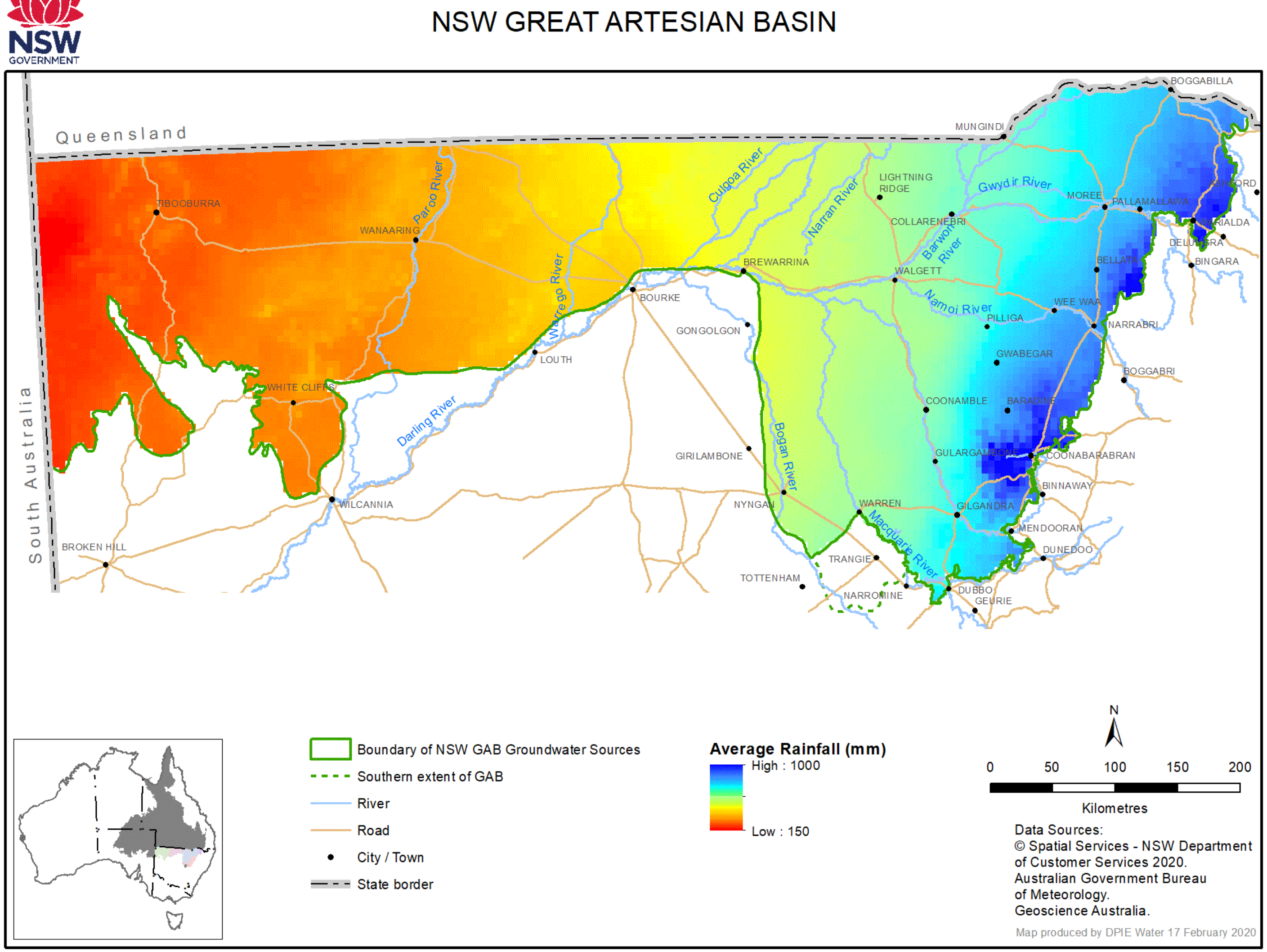

Figure 3 [8]Average annual rainfall of the WSP 2008 area

[8] 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 (Bureau of Meteorology, 2008).

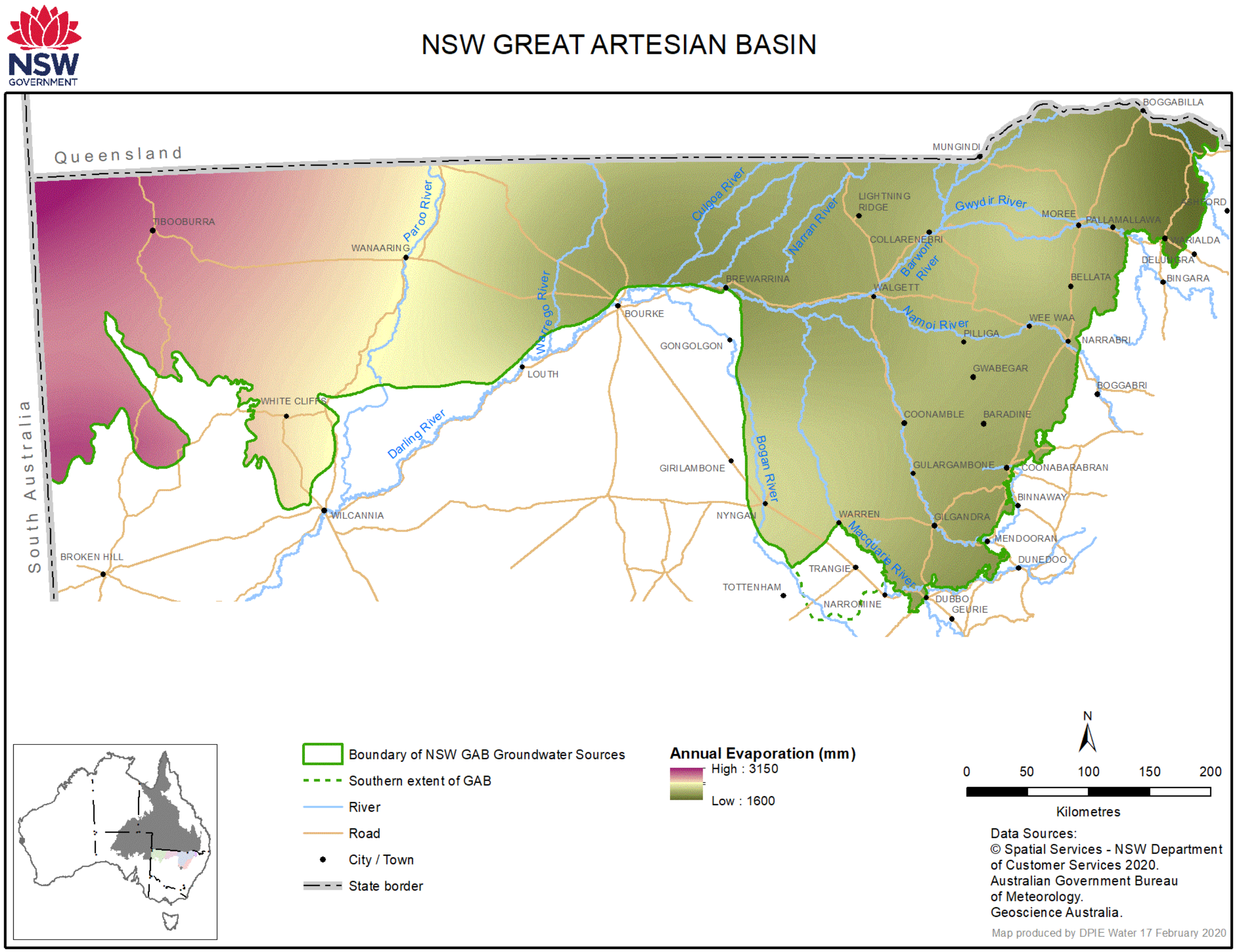

Figure 4 [9]Average annual evaporation of the WSP 2008 area

[9] The average evaporation period 1976 - 2005 displayed in this map is the standardised average conditions gridded data set available from the Bureau of Meteorology (Bureau of Meteorology, 2008).

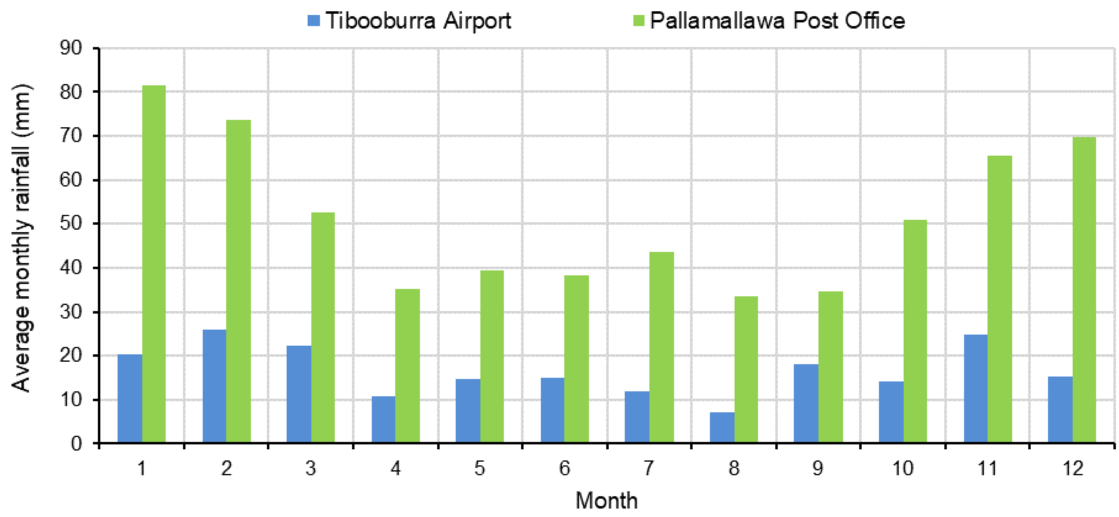

Figure 5 Average monthly rainfall for Tibooburra Airport and Pallamallawa Post Office

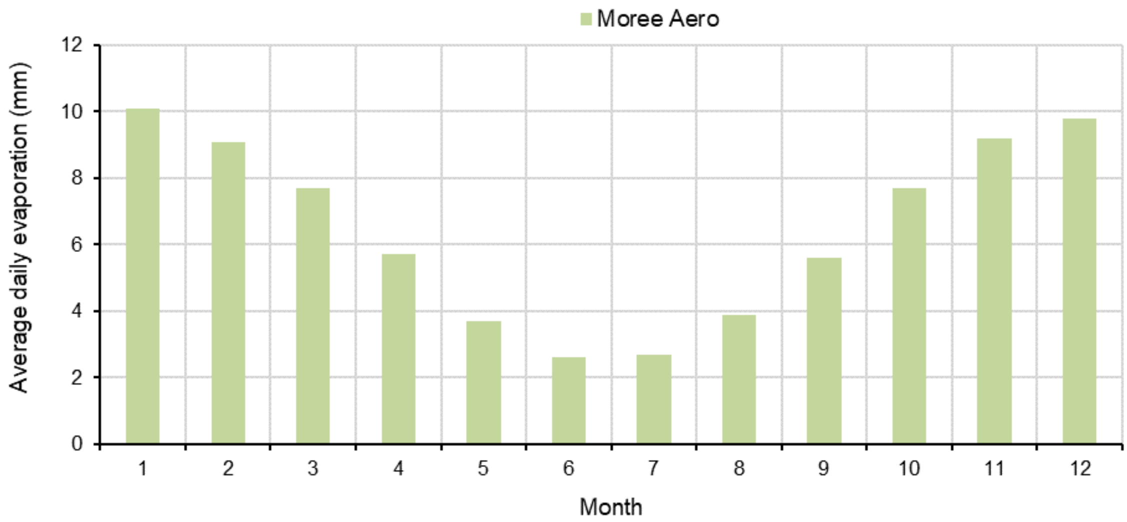

Figure 6 Average daily evaporation rate for Moree Airport

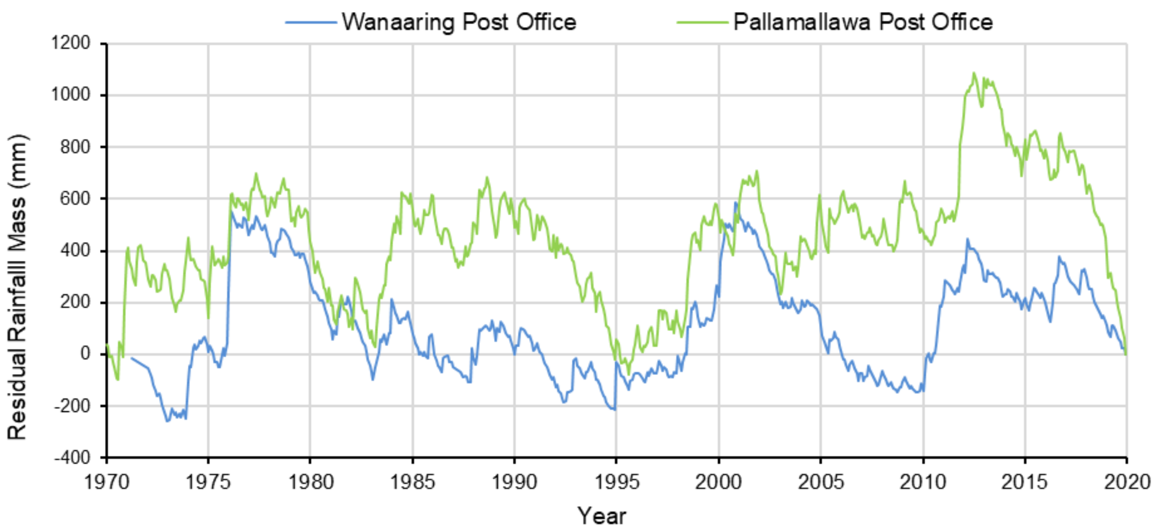

Figure 7 Wanaaring and Pallamallawa residual rainfall mass graph 1970 - 2019

3.3 Land use

The predominant land use in the WSP 2008 area is low intensity grazing on pastoral leases. Additional activities which occur in the WSP 2008 area include dryland farming, irrigated agriculture, forestry and mining. Figure 8 shows land use information across the WSP 2008 area based on the Australian Bureau of Agricultural and Resource Economics and Sciences 2010/2011 land use data (Smart, 2016).

The Barkindji, Bigambul, Budjiti, Euahlayi, Kambuwal, Guwamu/Kooma, Kamilaroi/Gomeroi, Kwiambul, Maljangapa, Murrawarri, Ngarabal, Ngemba, Wailwan and Wiradjuri people were the original inhabitants in the WSP 2008 area. The springs and associated wetlands of the WSP 2008 area were a source of sustenance for the Aboriginal nations of these lands, often serving as clan meeting places, and have an important place in the Dreaming. The groundwater that feed these springs originates from the aquifers of the GAB groundwater sources.

In the late 1860s with the arrival of the pioneering pastoralists, Aboriginal people were displaced as the landscapes were transformed for grazing and agricultural purposes. The early European settlers were seeking landscapes for grazing sheep and cattle and for other forms of agriculture. Large stations became established in the area, and the introduction of riverboats increased the number of people moving to the area.

Today the area is made up of large pastoral stations, which occupy all the leasehold land within the WSP 2008 area aside from, the scattering of localities, and national parks or nature reserves. There are areas within the WSP 2008 area that remain under native vegetation and some of these are protected as national park or nature reserves. The Paroo River is protected through an inter-governmental agreement between NSW and Queensland. Similarly, the terminal Narran Lake, at the end of the Narran River system is a RAMSAR protected wetland.

The Ramsar listed Macquarie wetlands and a part of Gwydir wetlands also fall in the WSP 2008 area and are protected in the Macquarie Marshes Nature Reserve and State Conservation Area and the Gwydir State Conservation Area respectively.

Pilliga Forest, the largest native forest in inland NSW, is located between Coonabarabran and Narrabri. The Pilliga West State Conservation Area and Pilliga and Pilliga West National Parks are within the WSP 2008 area.

Agriculture is the largest user of NSW GAB groundwater resources. Much of the irrigated land use overlying these water sources, however, relies on water from other water sources in the same geographic area, particularly the reliable good quality water from the alluvial groundwater sources and the river water sources.

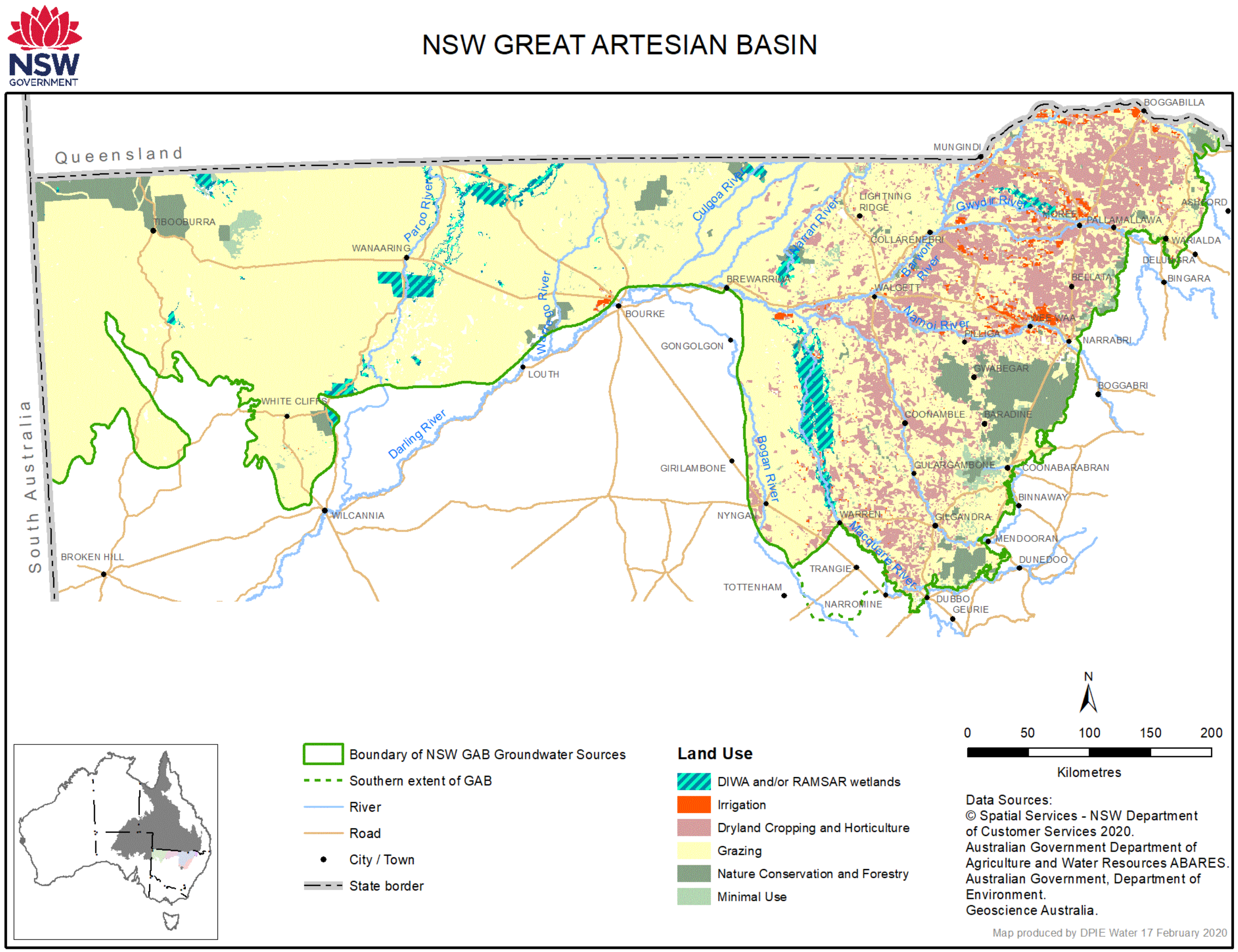

Figure 8 [10]Land use map of the WSP 2008 area (Smart, 2016)

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[10] User guide for land use of Australia 2010 - 2011 (Smart, 2016)

4 Geology

The surface geology of the NSW GAB area is made up of five main geological sequences including; the Cenozoic unconsolidated sediments, the Cenozoic extrusive volcanics, the Mesozoic Great Artesian Basin (GAB), and Palaeozoic and Proterozoic fold belt rocks (Figure 9).

The main peak near Coonabarabran and topographic high near Warialda are formed by Cenozoic extrusive volcanic rocks of basalts that were erupted during widespread volcanic activity throughout the eastern part of the state over the last sixty-five million years.

The Cenozoic unconsolidated sediments that overlie Mesozoic rocks cover most of the area. These are mainly flood plain and marshy environment deposits with occasional interlayers of low to medium energy fluvial deposits (Watkins & Meakin, 1996). They were deposited on the eroded and weathered surface of the Rolling Downs Group (Ransley & Smerdon, 2012).

The NSW GAB groundwater sources are part of the larger Surat and Eromanga geological basins that were deposited in the Jurassic and Cretaceous periods of Mesozoic era. These geological basins sit atop older geological basins, the Bowen and Gunnedah Basins, and other basement rocks. The sediments of the Surat Basin inter-finger with sediments of the Eromanga Basin (Cresswell & Smerdon, 2012) across the buried Nebine and Eulo Ridges (Figure 1). The sediments of both basins consist of sandstone, mudstone, siltstones, shale and coal.

The Surat Basin extends southwards from Queensland into NSW where it is referred to as the Coonamble Embayment. In NSW, the Surat Basin unconformably overlies the Lachlan Fold Belt in the west, the New England Fold Belt in the east and Gunnedah - Bowen Basin in its centre.

The Eromanga Basin extends from central Queensland into north western NSW and north eastern South Australia. The Eromanga Basin in NSW unconformably overlies the Lachlan Fold Belt in the east, the Kanmantoo Fold Belt and the Adelaide Fold Belt in the west. On the southern margin, the Eromanga Basin in NSW forms the Bulloo Embayment in the east and Lake Frome Embayment in the west which is separated by the Tibooburra Ridge (Ransley, Radke, & Kellett, 2012).

The depositional history and tectonic evolution of Surat and Eromanga geological basins are similar (Ransley, Radke, & Kellett, 2012), with the rate of subsidence and deposition influenced by structures inherited from older underlying basins and basement rocks. The Cenozoic era uplift of the eastern highlands and tilting of the basins westwards are linked to the commencement of artesian conditions and through flow in these two basins.

The late Palaeozoic Gunnedah Basin is a sedimentary coal basin that occurs only at depth and it does not outcrop at the surface within the WSP 2008 area.

The basement fold belts are mostly buried under the NSW GAB. Minor outcrops of Proterozoic Adelaide Fold Belt and early Palaeozoic Kanmantoo Fold Belt are found near and south west of Tibooburra. The Proterozoic Adelaide Fold Belt is the oldest among the buried fold belts and it comprises strongly deformed and metamorphosed sedimentary and igneous rocks. The Early Palaeozoic Kanmantoo Fold Belt consists of deformed metasediments. The Palaeozoic Lachlan Fold Belt and New England Fold Belt comprise sedimentary rocks, metasediments and metavolcanics.

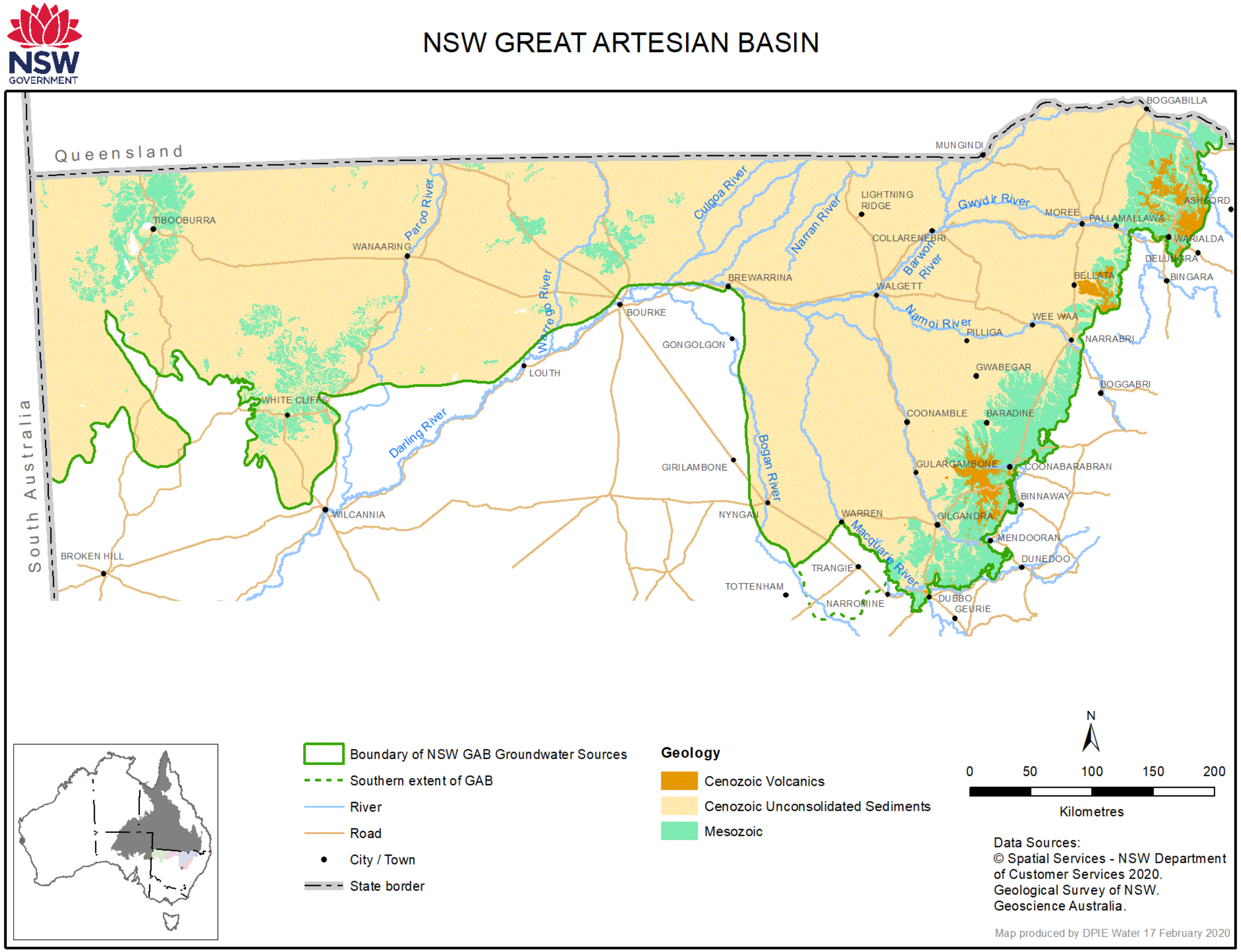

Figure 9 Geology of the WSP 2008 area

5 Hydrogeology

The aquifers within the NSW GAB groundwater sources are comprised of predominantly sandstones, confined by aquitards of both fluvial and marine siltstones, mudstones and shale. Figure 10 shows the stratigraphic sequence of the geological basins (Ransley, Radke, & O'Brien, 2012) that form the GAB.

The Pilliga Sandstone in the Surat Basin, its equivalent in the Eromanga Basin, the Hooray Sandstone and the Hutton Sandstone contain significant aquifers. The Mooga Sandstone aquifers whilst still geographically extensive are not as high yielding as the Pilliga and Hooray Sandstones.

The Rolling Downs Group acts as confining layer over the deep aquifers and it is comprised of a very thick aquitards of mudstones, siltstones and shale. The upper part of the Rolling Downs Group has minor semi-confined aquifers (Cresswell & Smerdon, 2012).

The hydrogeological cross sections in Figure 12, Figure 13 and Figure 14 illustrate the major aquifer forming units, aquitards and the basement rocks across the NSW GAB. These hydrogeological cross sections are based on the information of water bores (Figure 11) and the elevation of base of hydro stratigraphic unit surfaces (Geoscience Australia, Canberra, 2013). Major aquifer forming units in NSW GAB, the Mooga Sandstone, Pilliga Sandstone and Hooray Sandstone are collectively referred as Hooray – Pilliga Sandstone equivalents in the hydrogeological cross sections.

5.1 Eastern Recharge Groundwater Source

The Eastern Recharge Groundwater Source (Figure 1) is bounded by outcrops of New England Fold Belt rocks to the east and south, Moonie-Goondiwindi thrust fault to the west and Queensland border to the north. The alluvial groundwater sources of the NSW Border Rivers overlie the Eastern Recharge Groundwater Source along its northern boundary. The Eastern Recharge Groundwater Source overlies the New England Fold Belt.

The thickness of the Eastern Recharge Groundwater Source increases westward up to about 380 m. Recharge to this groundwater source occurs directly through exposed out crops of Pilliga Sandstone and overlying strata where there is a potential for downward leakage. The recharge takes place mainly as a diffuse rainfall recharge and to a lesser extent from overlying alluvium. The groundwater flow direction is from east to west and north-west.

Most bores in this groundwater source are sub artesian (non-flowing). A few artesian (flowing) bores are confined to the north western part of this groundwater source. In this area, upward leakage of GAB groundwater discharges into the overlying Border Rivers alluvium and its tributaries.

The aquifers are found predominantly in Pilliga Sandstone and to a lesser extent in Hutton Sandstone at depths between 60 m and 380 m. The upper Mooga Sandstone is absent in this groundwater source.

The artesian bores yield up to 4 L/s as free flow of water with salinity levels up to 1000 mg/L. The artesian head (groundwater level) varies from 0.5 m to 24 m above ground level. The temperature of artesian groundwater varies between 24ºC and 29ºC.

The groundwater is primarily used for stock, domestic and irrigation purposes. The low salinity and low sodium content of the groundwater make it suitable for irrigation where sufficient yields can be obtained. High yielding aquifers capable of large-scale irrigation have been developed near Croppa Creek and North Star with bores yielding up to 100 L/s in this area.

5.2 Southern Recharge Groundwater Source

The Southern Recharge Groundwater Source (Figure 1) is bounded by outcrops of Gunnedah - Oxley Basins to the east, the Surat Groundwater Source to the west and Lower Macquarie groundwater sources to the south. The Southern Recharge Groundwater Source overlies the Lachlan Fold Belt in the west and the Gunnedah Basin in the east. It in turn underlies the Warrumbungle Basalt Groundwater Source and parts of Lower Namoi, Upper Namoi, Upper Macquarie and Castlereagh alluvial groundwater sources.

The Southern Recharge Groundwater Source increases in thickness northward and westward, being up to 300 m thick in its north-west portion. Recharge to the Southern Recharge Groundwater Source occurs directly through exposed out crops of Pilliga Sandstone and via overlying strata. The recharge takes place as diffuse rainfall recharge as well as leakage from overlying alluvium and rivers. The groundwater flows from the east to a westerly direction in this groundwater source.

Most bores are sub artesian (non-flowing) bores with an exception of a few artesian (flowing) bores that are located near the boundary with the Surat Groundwater Source. The aquifers within the Pilliga Sandstone range in depths between 50 m and 300 m.

The artesian bores yield up to 3 L/s free flow of water with salinity levels up to 900 mg/L. The artesian head varies from 0.5 m to 4 m above ground level. The temperature of artesian groundwater varies between 24ºC and 28ºC.

The groundwater is used for stock, domestic, industrial, irrigation and town-water supply purposes. The low sodium content and low salinity of this groundwater make it suitable for irrigation. Moderate scale groundwater irrigation occurs near Narromine, Collie, Gilgandra and Narrabri with the bores yielding up to 50 L/s.

5.3 Surat Groundwater Source

The Surat Groundwater Source (Figure 1) is bounded by the Culgoa River and the Warrego Groundwater Source to the northwest, the Eastern Recharge Groundwater Source to the east, the Southern Recharge Groundwater Source to the south, sub crops of the Lachlan Fold Belt rocks to the southwest and the Queensland border to the north. The southern edge of the buried Nebine Ridge (Figure 1) approximately aligns to the western boundary of this groundwater source. The Surat Groundwater Source overlies the Gunnedah Basin in the east and the Lachlan Fold Belt in the west. It underlies the NSW GAB Surat shallow, Lower Gwydir alluvial and the western portion of Lower Namoi alluvial groundwater sources.

The thickness of the Surat Groundwater Source is up to about 1250 m. Within the Surat Groundwater Source, through flow from the Eastern and Southern Recharge Groundwater Sources drives groundwater flow toward west and north-west direction (Figure 15). This flow meets the south west flowing groundwater from Queensland in the north west of the Surat Groundwater Source and flows westward over Nebine ridge (Smerdon, et al., 2012).

The artesian conditions exist over most of this groundwater source. The artesian aquifers are found in sandstones of various formations at depths between 200 m and 1250 m.

The Pilliga Sandstone aquifers are at depths between 400 m to 1250 m and bores can flow up to 45 L/s unrestricted. Salinity levels range from 500 mg/L to 1300 mg/L. The artesian head of the Pilliga Sandstone aquifers varies from 10 m to 52 m above ground level. High pressure and large free flowing bores are in the eastern, central and northern part of this groundwater source as the GAB sediments deepen in that direction. As the GAB sediments thin out over the Nebine Ridge on the western side of this groundwater source, the pressure and free flow from the artesian bores are relatively small in that region. The temperature of groundwater in these aquifers varies between 35ºC and 58ºC.

The Mooga Sandstone aquifers are at depths between 220 m and 350 m and are mostly in artesian (flowing) condition. These aquifers produce up to 20 L/s of unrestricted flow with salinity levels ranging from 500 mg/L to 2,000 mg/L. The artesian head of the Mooga Sandstone aquifers varies from a few metres to 20 m above ground level. The temperature of groundwater varies between 25ºC and 30 ºC.

In the southern most extent of Surat Groundwater Source, the Mooga Sandstone is indistinguishable from other sandstone lenses grouped in the Keelindi Beds (Radke, Kellett, Ransley, & Bell, 2012). The shallow aquifers found in minor sandstones of the Keelindi Beds, the Drildool Beds and the Rolling Downs Group are sub artesian and can often produce low yields of saline water.

The groundwater is primarily used for pastoral, domestic, town water supply, spa bath industry and opal mining purposes. The high sodium content of the groundwater makes it unsuitable for irrigation.

5.4 Warrego Groundwater Source

The Warrego Groundwater Source (Figure 1) is bounded by the Paroo River to the west, the Culgoa River and Surat Groundwater Source to the east, Queensland border to the north and sub crops of Lachlan Fold Belt rocks to the south. The Warrego Groundwater Source overlies the Lachlan Fold Belt and underlies NSW GAB Warrego Shallow and Darling Alluvial Groundwater Sources.

The thickness of the Warrego Groundwater Source extends up to about 750 m. South flowing groundwater from Queensland converges with that flowing west across the Nebine Ridge from the Surat Groundwater Source (Figure 15) and continues in a south western direction (Smerdon, et al., 2012).

Artesian conditions exist over most of this groundwater source from the deeper aquifers. Shallow bores, less than 150 m, usually yield sub artesian supplies.

The bores targeting the Hooray Sandstone aquifers are mainly located in the north and eastern part of this groundwater source. These sandstone aquifers occur at depths between 400 m and 750 m and currently produce up to 55 L/s of unrestricted artesian flow. Salinity levels range from 500 mg/L to 2,000 mg/L. The artesian head of the Hooray Sandstone aquifers varies from 20 m to 50 m above ground level. The temperature of groundwater in these aquifers varies between 35ºC and 48 ºC.

Upward groundwater leakage from the Hooray Sandstone aquifers discharges to the surface as springs (Ransley, et al., 2012) through polygonal faulting as well as regional faulting in the Rolling Downs Group. The springs are concentrated in three almost linear clusters (Pickard, 1992). These are Hungerford – Fords Bridge, Fords Bridge – Enngonia, and north west of Weilmoringle. The linear arrangements of the springs suggest that they occur along geological structures.

Mooga Sandstone aquifers are at depths between 200 m and 350 m and yield artesian unrestricted flows of up to 15 L/s. Salinity levels in these aquifers range from 1000 mg/L to 3,500 mg/L. The temperature of groundwater varies between 25ºC and 30 ºC.

The shallow aquifers found in the Rolling Downs Group at depths between 80 m and 150 m are sub artesian and the groundwater is typically saline.

Groundwater within this groundwater source is primarily used for pastoral, domestic and town water supply purposes. The high sodium content of the groundwater makes it unsuitable for irrigation.

5.5 Central Groundwater Source

The Central Groundwater Source (Figure 1) is bounded by the Paroo River and the Warrego Groundwater Source to the east, sub crops of Lachlan, Kanmantoo & Adelaide Fold Belts to the south, Queensland border to the north and South Australia border to the west. The boundary between Central and Warrego Groundwater Sources approximately coincides with the southern extent of buried Eulo Ridge (Figure 1). The Central Groundwater Source overlies the Lachlan, Kanmantoo and Adelaide Fold Belts and underlies the NSW GAB Central Shallow and Darling Alluvial Groundwater Sources.

The thickness of the Central Groundwater Source is up to 900 m. The south flowing groundwater from Queensland converges with the southwest flowing groundwater from the Warrego Groundwater Source across the Eulo Ridge (Figure 15) and flows in a south to south west direction (Smerdon, et al., 2012).

Artesian conditions occur only in a few areas in the north central, south east and south west part of this groundwater source where the Hooray Sandstones are found at depths between 400 m and 900 m. These sandstone aquifers produce up to 35 L/s free flow of water with salinity levels ranging from 900 mg/L to 2,000 mg/L. The artesian head of these aquifers varies from a few metres to 30 m above ground level. The temperature of groundwater in these aquifers varies between 58ºC and 74 ºC.

The Mooga Sandstone aquifers occasionally found at depths between 200 m and 400 m are mostly sub artesian and occasionally produce low artesian flow of brackish water. The temperature of groundwater varies between 25ºC and 33ºC.

The shallow aquifers in the Rolling Downs Group are found at depths between 80 m and 150 m and are sub artesian and saline.

The groundwater is primarily used for pastoral and domestic water supply purposes. The high sodium and salinity content of the groundwater makes it unsuitable for irrigation.

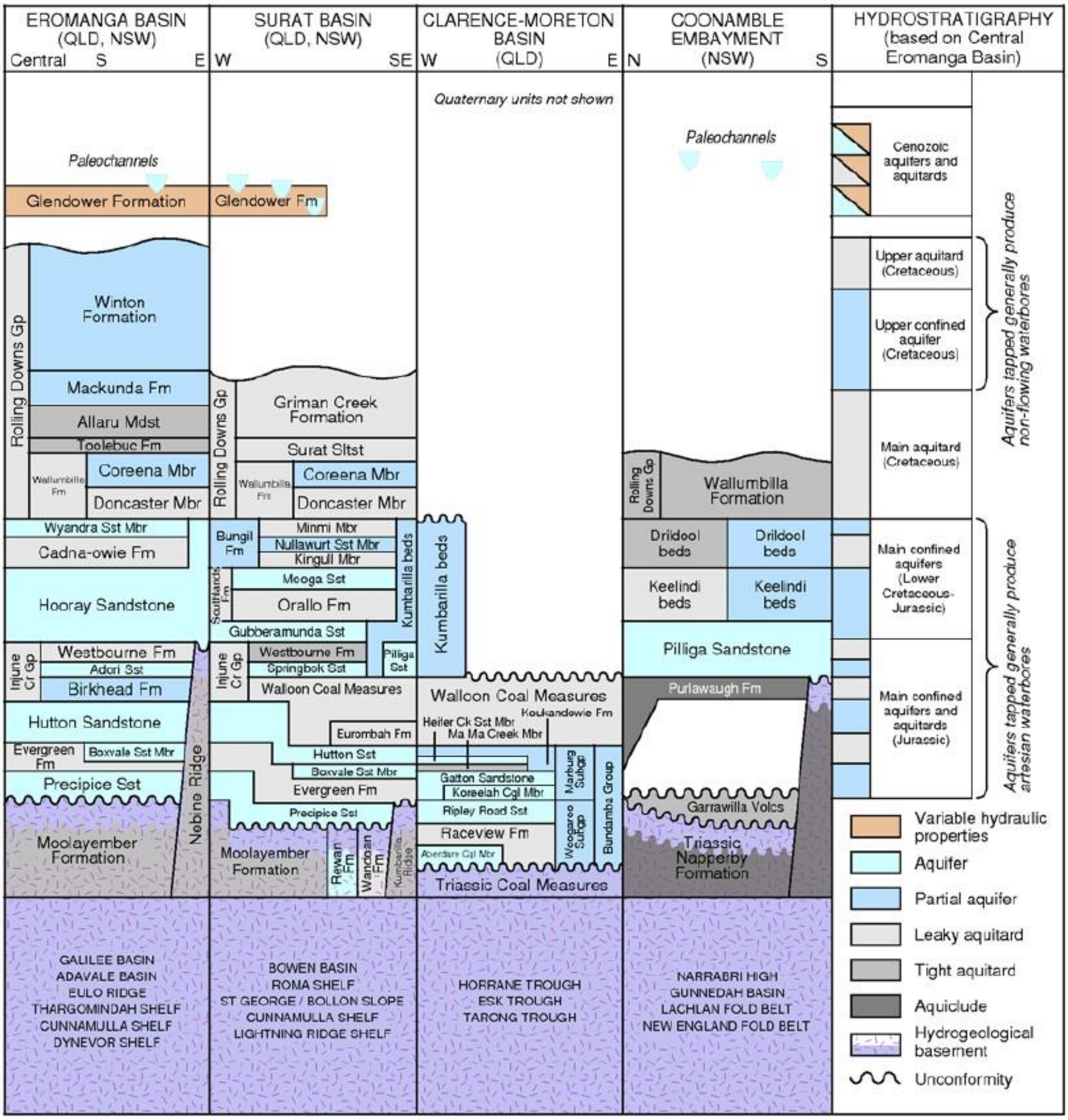

Figure 10 Stratigraphic sequence of geological basins (Ransley, Radke, & O'Brien, 2012)

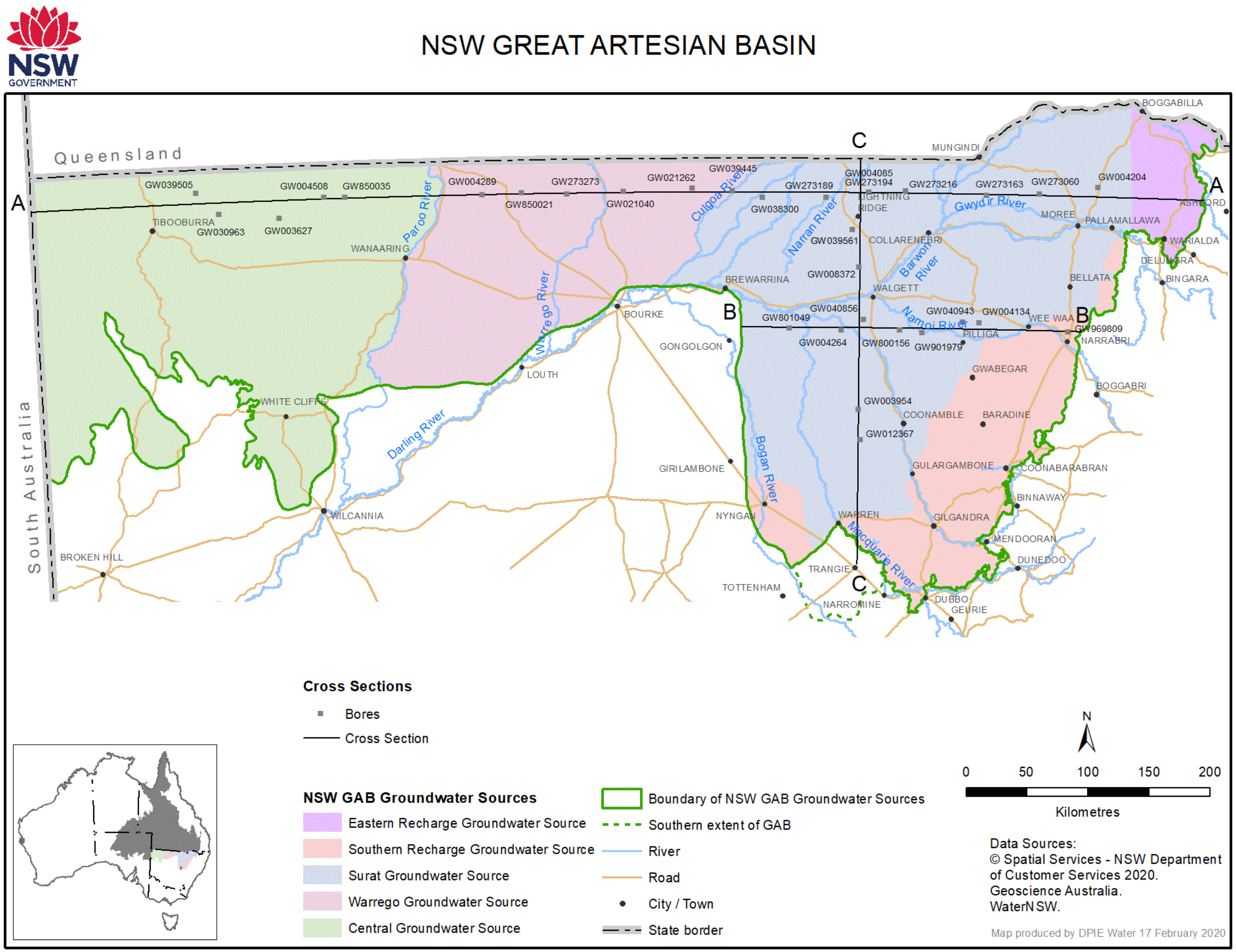

Figure 11 Location of cross sections

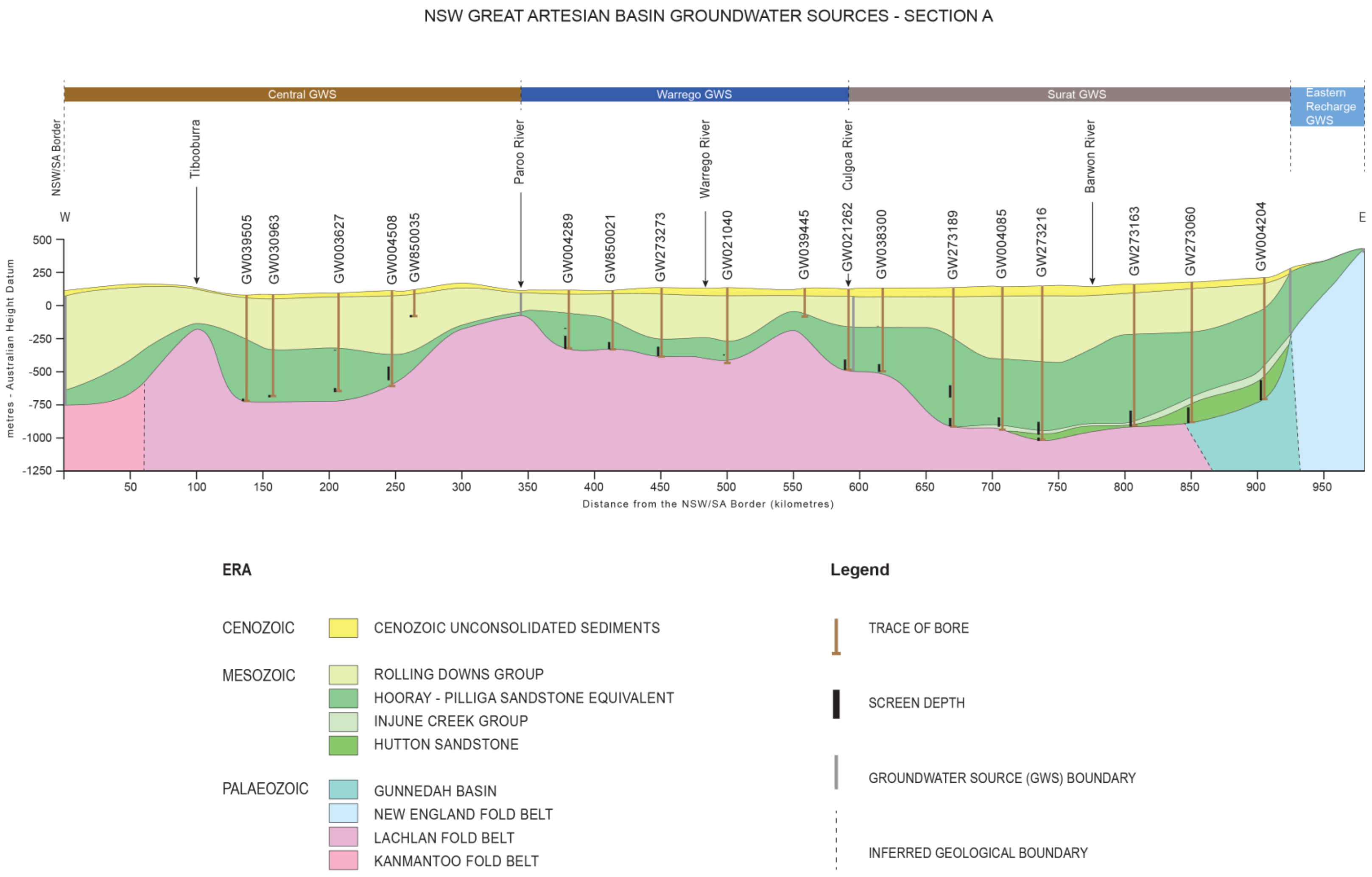

Figure 12 Cross section A along the 29°15' S parallel line

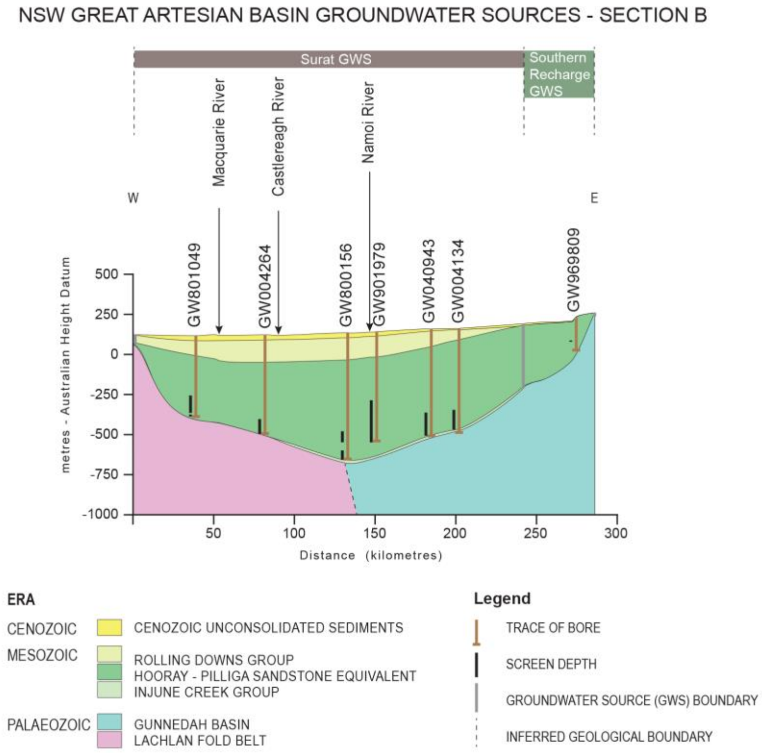

Figure 13 Cross section B along the 30°15' S parallel line

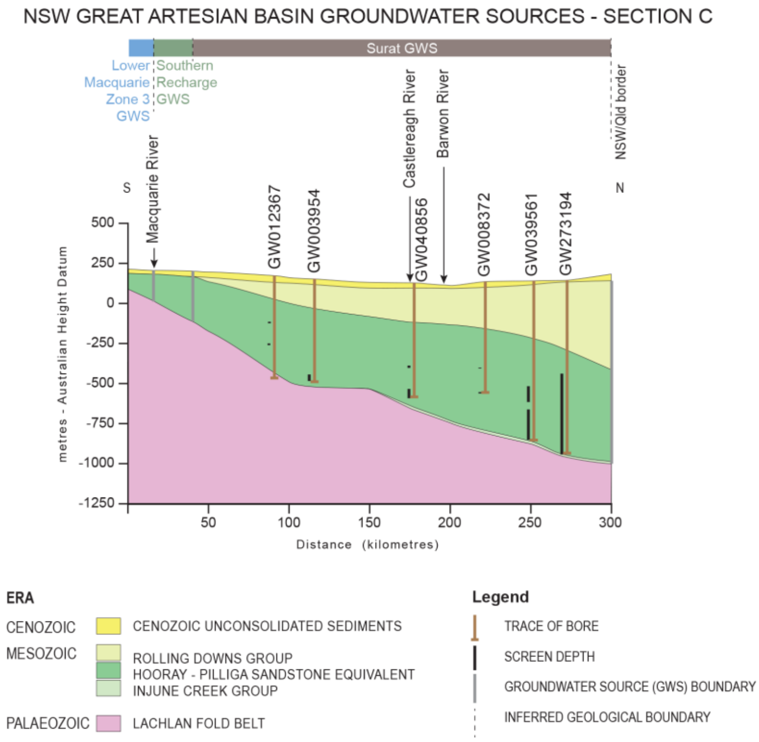

Figure 14 Cross section C along the 148°00' meridian line

NSW Great Artesian Basin

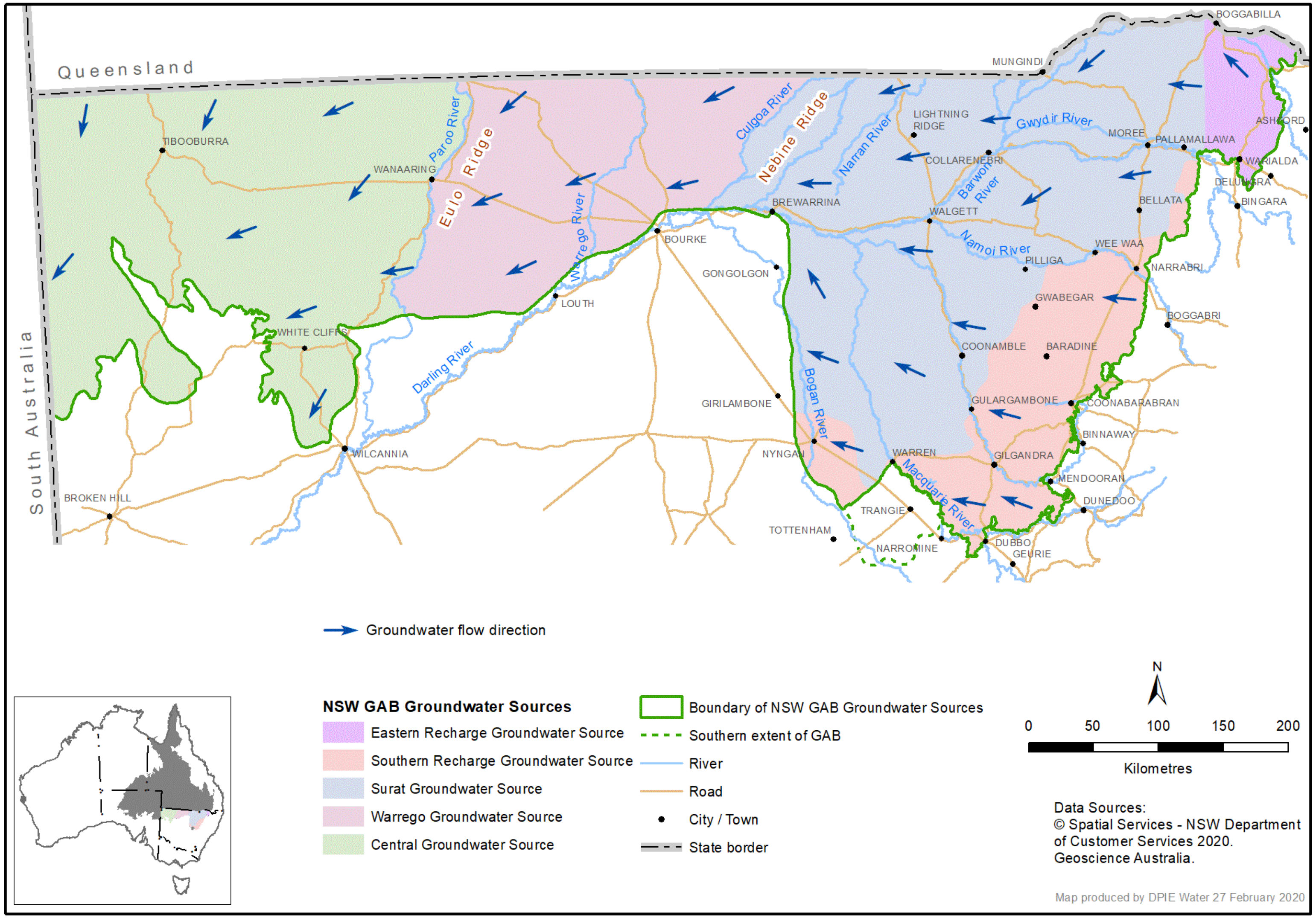

Figure 15 Groundwater flow direction

6 Groundwater dependent ecosystems

Groundwater dependent ecosystems (GDE) 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*' (DPI Water, 2016).

The artesian conditions found in the NSW GAB area support, in addition to GDEs expected to be found in the landscape, a number of artesian springs, which are a unique feature of the GAB.

6.1 High probability groundwater dependent (vegetation) ecosystems

The former NSW Department of Industry Water developed a method for the identification of high probability groundwater dependent vegetation ecosystems (DPI Water, 2016) and associated ecological value (Dabovic, Raine, Dobbs, & Byrne, In prep). This process has identified many high probability vegetation GDE and their ecological values in the NSW GAB area.

This mapping exercise shows the Eastern Recharge and Southern Recharge Groundwater Sources support significant GDE of ecological value including wetlands, springs, vegetation and base flow ecosystems. The high probability groundwater dependent vegetation ecosystems' ecological value in these two recharge areas (Figure 16) is mainly classified as low to very high.

The Eastern Recharge and Southern Recharge Groundwater Sources areas are dominated by the vegetation GDE communities of River Red Gum woodland wetlands, Lignum wetlands, freshwater wetlands, Black Box woodlands, Coolabah-River Coolabah-Lignum woodland wetlands and chenopod shrublands, Bladder Salt Bush, Poplar Box woodlands, Gidgee chenopod woodlands, Leopard Wood woodlands, permanent and shallow wetlands. These communities are characterised by having endangered ecological communities, Directory of important wetlands in Australia (DIWA)/Ramsar wetlands, extensive connected riparian corridors and basin target vegetation species (MDBA, 2014) of Black Box, Lignum and River Red Gums. The riparian communities provide vital habitat to nesting species and contribute to ecosystem function of instream ecosystems.

Generally, the high probability GDE communities with high ecological value have large vegetation patches, are highly connected (such as riparian corridors) and have a moderate number of threatened species present especially in the wetland areas.

6.2 High priority groundwater dependent (springs) ecosystems

Thirty-five springs were identified as geothermal springs (Figure 17) in the WSP 2008. Since that time, additional GAB spring characterisation has been undertaken by the QLD Herbarium (Queensland Herbarium, 2015) and by DPIE Water between 2017 and 2019 (DPIE Water, 2020). Fifty-one unique spring 'complex' names (at 379 spring vents locations) are identified.

Figure 18 shows the location of all springs that will be identified as high priority GDEs in the Water Sharing Plan for the NSW GAB Groundwater Sources 2020 (WSP 2020). These springs include 23 springs in the recharge areas and all the geothermal springs that were identified in the fifty-one unique spring complexes.

The GAB springs in NSW have watered megafauna dating back to 36-30,000 years, support endemic ecosystems and continue to sustain wetlands of international importance (Ramsar site) today. The GAB spring formations at Peery Spring Complex are one of the rarest landforms in Australia and one of the largest active complexes in the NSW GAB (Trueman, et al., 2005; NSW Department of Environment and Conservation, 2006; Fillios, et al., 2010).

The GAB springs have unique characteristics related to their chemistry, flow and wetland isolation. The nature and persistence of these surface water expressions through glacial and arid periods has provided a wetlands habitat refuge for relictual species. As a result, remarkable concentration of endemics exists, and has also evolved in these isolated communities throughout the geological epoch (Commonwealth of Australia, 2014).

GAB springs are a matter of national and international environmental significance. They support endangered ecological communities protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).*

Two high priority GDEs, Coolabah Spring west of the Surat Groundwater Source and Wee Wattah Spring southwest of Warrego Groundwater Source fall just outside the boundary of the NSW GAB groundwater sources. The location of these two springs needs further investigation regarding their source aquifer. Whilst they may be geographically outside the GAB, they may be fed by discharge form the GAB into the adjacent rock strata.

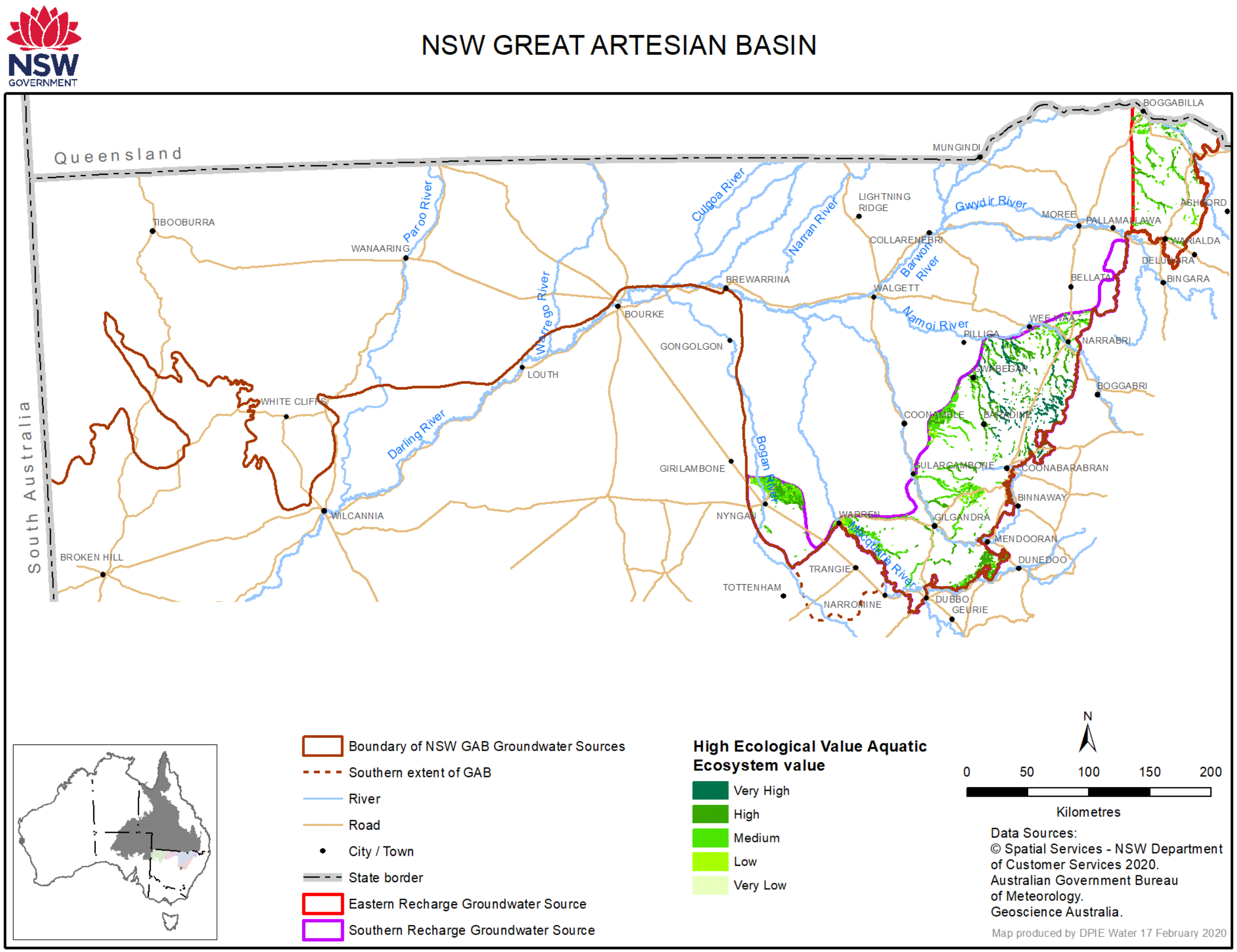

Figure 16 Ecological value for high probability groundwater dependent vegetation ecosystems

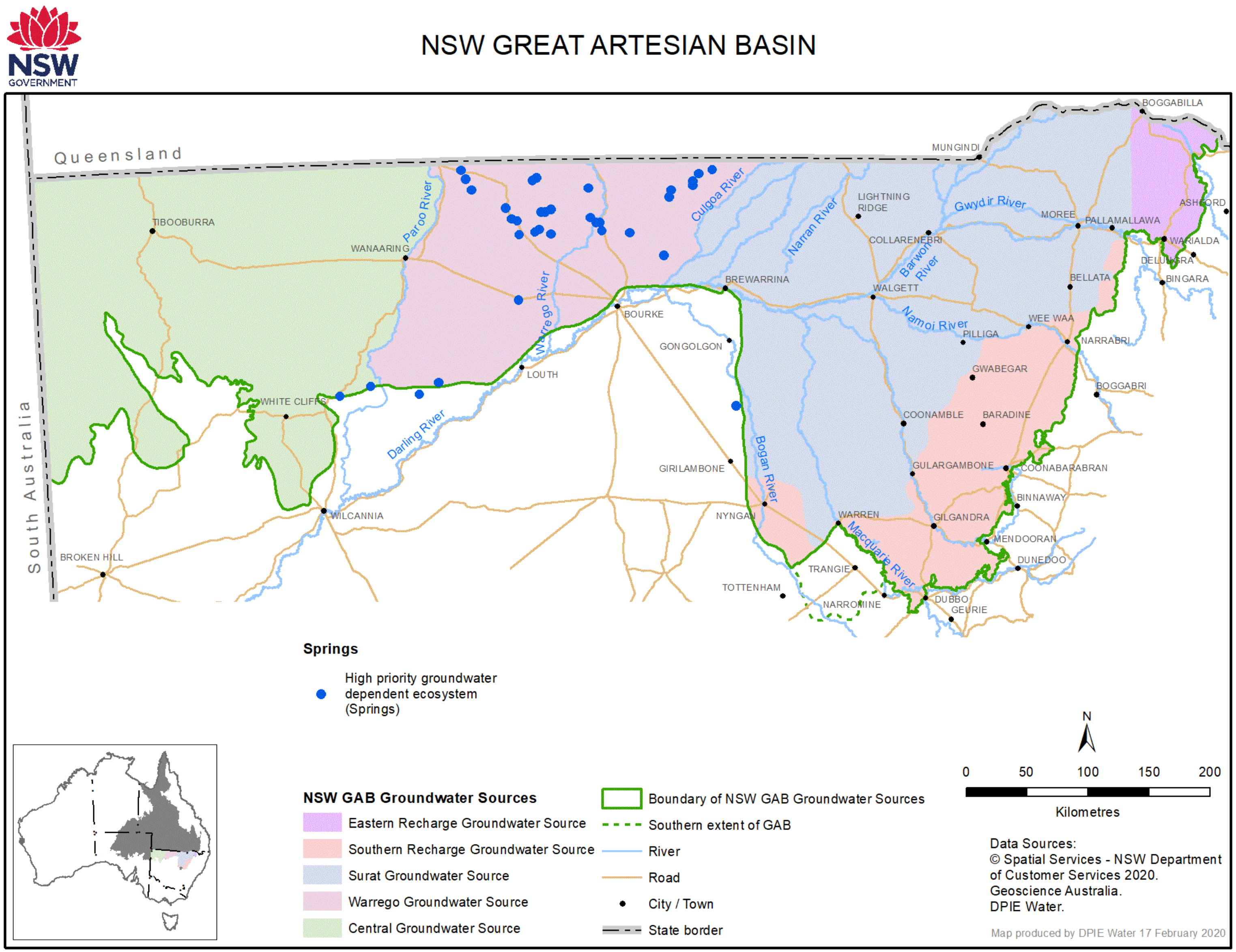

Figure 17 Location of high priority groundwater dependent ecosystems (geothermal springs) in the WSP 2008 area

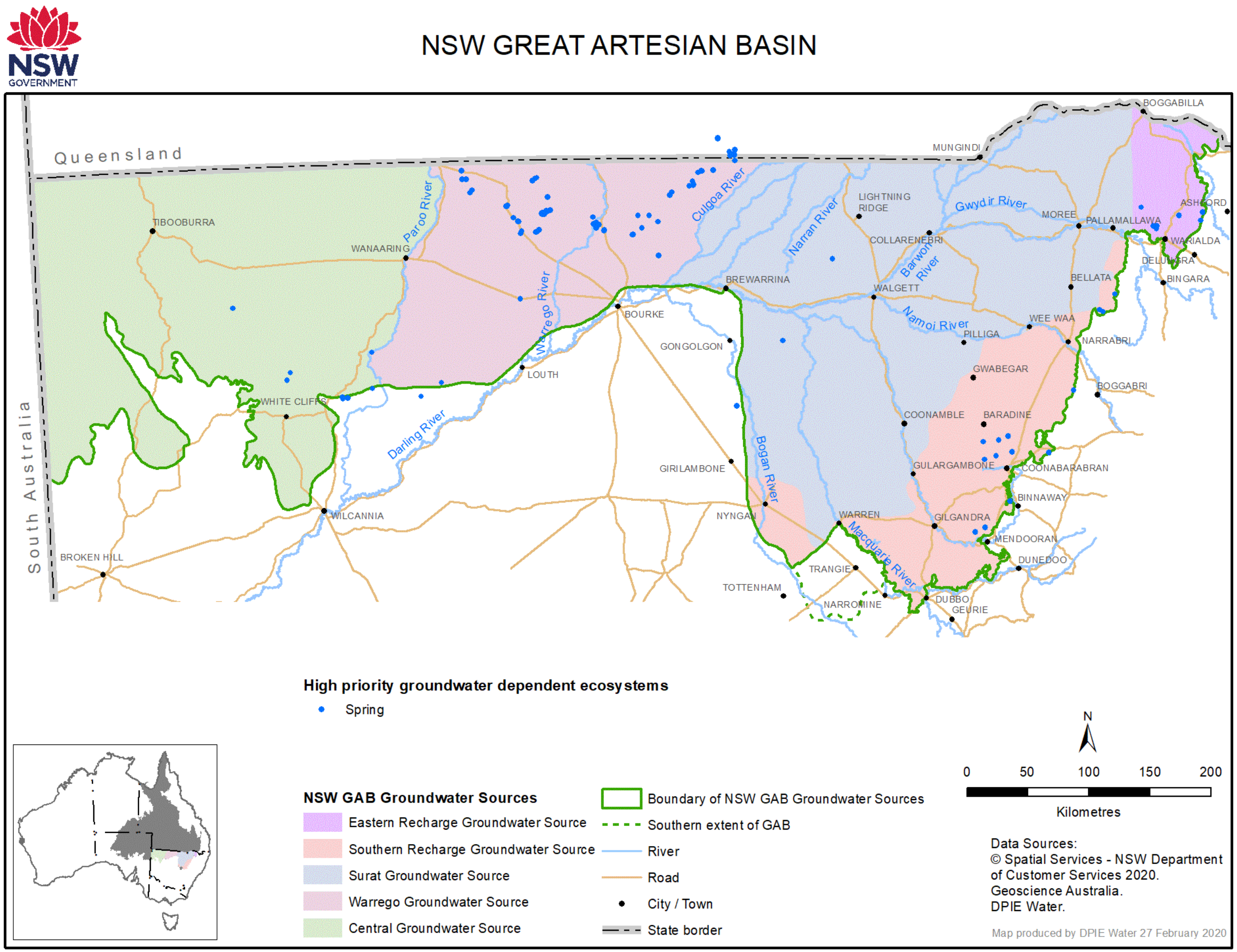

Figure 18 Location of high priority groundwater dependent ecosystems (springs) in the WSP 2020 area

7 Groundwater quality

7.1 Groundwater chemistry

Following the infiltration of rainfall in the recharge areas in the east, the evolutionary path of groundwater generally begins as low salinity, slightly acidic groundwater. In the recharge areas, the dissolution of clay and carbonate minerals increases alkalinity levels and the concentration of calcium (Ca), magnesium (Mg) and sodium (Na) cations in the groundwater to calcium – magnesium-bicarbonate-chloride (Ca-Mg-HCO_3-Cl) dominant type groundwater (Cresswell, et al., 2012).

As the groundwater flows from recharge areas to the Surat, Warrego and Central Groundwater Sources, exchange of sodium from the aquifer matrix for calcium and magnesium in the groundwater increases the sodium concentration in the groundwater (Herczeg, Togerson, Chivas, & Habermehl, 1991). As a consequence of this elevated sodium relative to that of calcium and magnesium, the groundwater becomes too sodic for irrigation and also exceeds the Australian drinking water quality guidelines (NHMRC, NRMC, 2011) aesthetic values for sodium in most areas in the Surat, Warrego and Central Groundwater Sources even though the overall salinity is low.

The sodium absorption ratio is an irrigation water quality parameter used in the management of irrigated soils and is based on the concentration of sodium ion relative to concentration of calcium and magnesium ions in the water. Figure 19 shows the sodium absorption ratio values (Feitz, Ransley, & Owens, 2015) of groundwater in the Hooray – Pilliga Sandstone aquifers.

With the removal of calcium and magnesium from the groundwater by exchange with sodium in clay minerals within the aquifer matrix, hydrogen ions (H+) are released, further promoting carbonate dissolution (Radke, Ferguson, Cresswell, Ransley, & Habermehl, 2000). As a consequence of these processes the groundwater evolves towards elevated sodium (Na) and bicarbonate (HCO_3) concentrations and become sodium-bicarbonate-chloride (Na-HCO_3-Cl) dominant type in the artesian aquifers in particular in the Jurassic - Lower Cretaceous aquifers (i.e. Hooray - Pilliga Sandstone equivalent aquifers such as Hutton, Hooray, Pilliga and Mooga Sandstones).

The type of groundwater in the Upper Cretaceous (Rolling Downs Group) sub artesian aquifers significantly differs from the type of water in Jurassic - Lower Cretaceous artesian aquifers. It has high concentration of sodium and chloride (Cl) ions and becomes sodium-chloride (Na-Cl) and sodium-chloride-bicarbonate (Na-Cl- HCO_3) dominant type groundwater. The dominance of sodium-chloride values is attributed to poorly flushing out characteristics of these mainly isolated and lenticular shaped aquifers (Cresswell, et al., 2012).

7.2 Salinity, pH and temperature

The salinity of groundwater as indicated by total dissolved solids, ranges between 500 mg/L and 1,500 mg/L in the most widely exploited confined artesian aquifers of the Hooray – Pilliga Sandstone equivalent sequence. Groundwater in the Rolling Downs Group sub artesian aquifers can have high salinities in excess of 5,000 mg/L throughout the groundwater sources. In the discharge areas of Warrego and Central Groundwater Sources near springs, the salinity level of the deeper sandstones increases above 3,000 mg/L due to intermixing with upper aquifers. The salinity variance within the individual hydrogeological unit is described in hydrogeology section 5 of this report.

The pH values of groundwater in the Hooray – Pilliga Sandstone equivalent aquifers generally fall between 6.5 and 8.5. The pH values gradually increase with the groundwater flow from the recharge groundwater sources into the Surat, Warrego and Central Groundwater Sources. The recharge groundwater sources are dominated by near neutral to weakly alkaline (pH < 7.5) groundwater. Alkaline groundwater conditions (pH > 7.5) exist in the Surat, Warrego and Central Groundwater Sources.

A relationship exists between temperature of the groundwater and the depth of aquifers. In the Eastern and Southern Recharge Groundwater Sources where aquifers are at relatively shallow depth, the groundwater is cooler. In the Surat, Warrego and Central Groundwater Sources, the groundwater is hotter with the increasing depth of aquifers. Significant temperature difference up to 16°C is observed between the Central Groundwater Source that falls entirely into the Eromanga geological basin and the Surat Groundwater Source that falls into the Surat geological basin. The highest groundwater temperature of 74°C is observed in the Central Groundwater Source. A brief description of temperature in each groundwater sources is provided in section 5.

Figure 20, Figure 21 and Figure 22 illustrate the groundwater salinity, pH levels and temperature of groundwater (Feitz, Ransley, & Owens, 2015) respectively in the Hooray – Pilliga Sandstone equivalent aquifers.

7.3 Fluoride

Fluoride concentration values in a few parts of the NSW GAB groundwater sources are high, with values up to 10 mg/L and more, which is higher than the acceptable limit of 1.5 mg/L recommended by the Australian drinking water guidelines (NHMRC, NRMC, 2011).

High fluoride concentrations in the artesian groundwater have been attributed to groundwater being in contact with igneous hydrogeological basement rocks (Habermehl, Lau, Mackenzie, & Wellman, 1996). Fluoride in excess of 10 mg/L is observed in artesian waters along the boundary between Warrego and Central Groundwater Sources where the Eulo granite ridge is in contact with the groundwater sources. Figure 23 shows the fluoride levels (Feitz, Ransley, & Owens, 2015) of groundwater in the Hooray - Pilliga Sandstone equivalent aquifers.

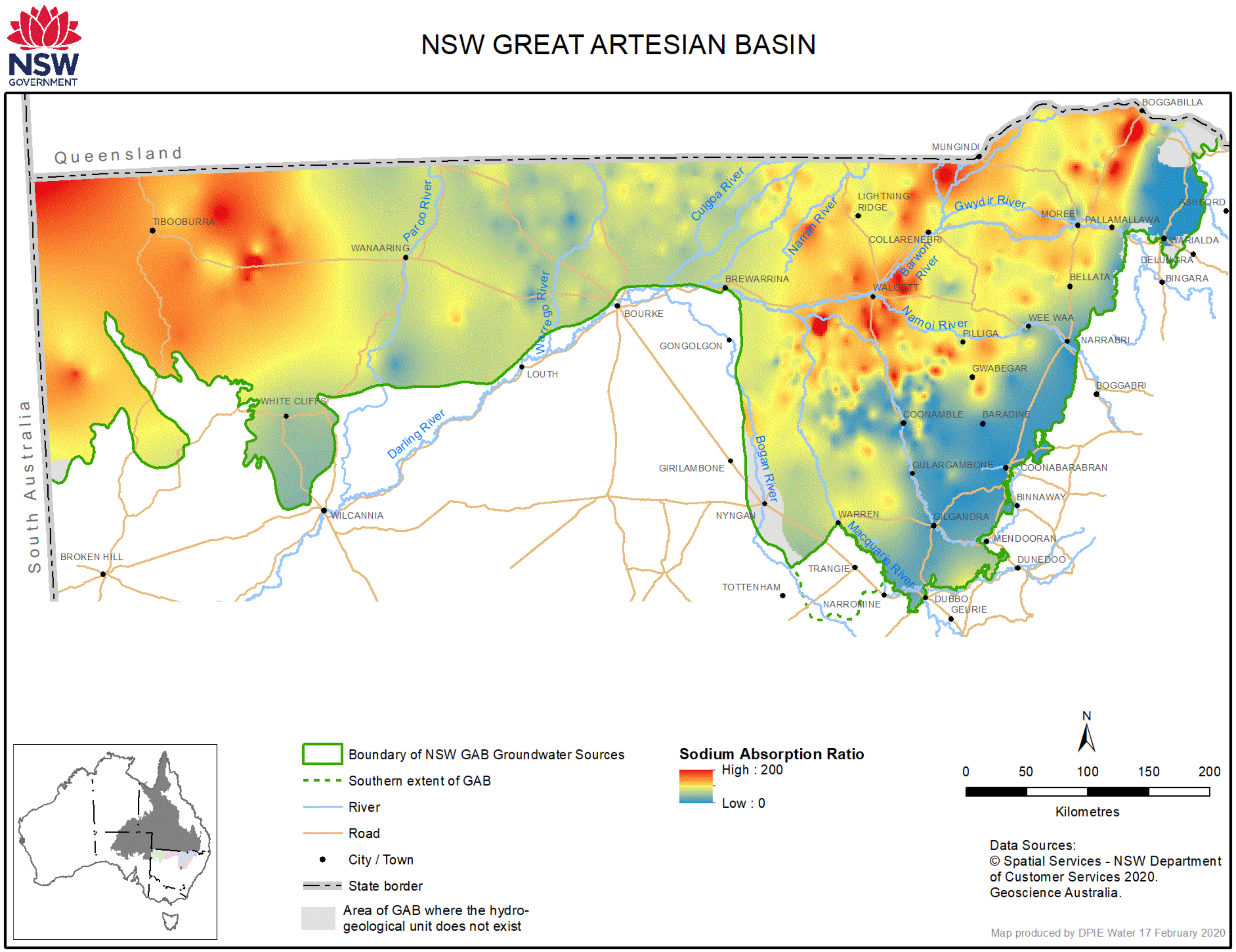

Figure 19 [11]Sodium absorption ratio values of groundwater in the Hooray – Pilliga Sandstone aquifers

[11] Data source: http://pid.geoscience.gov.au/dataset/ga/81695 (Feitz, Ransley, & Owens, 2015)

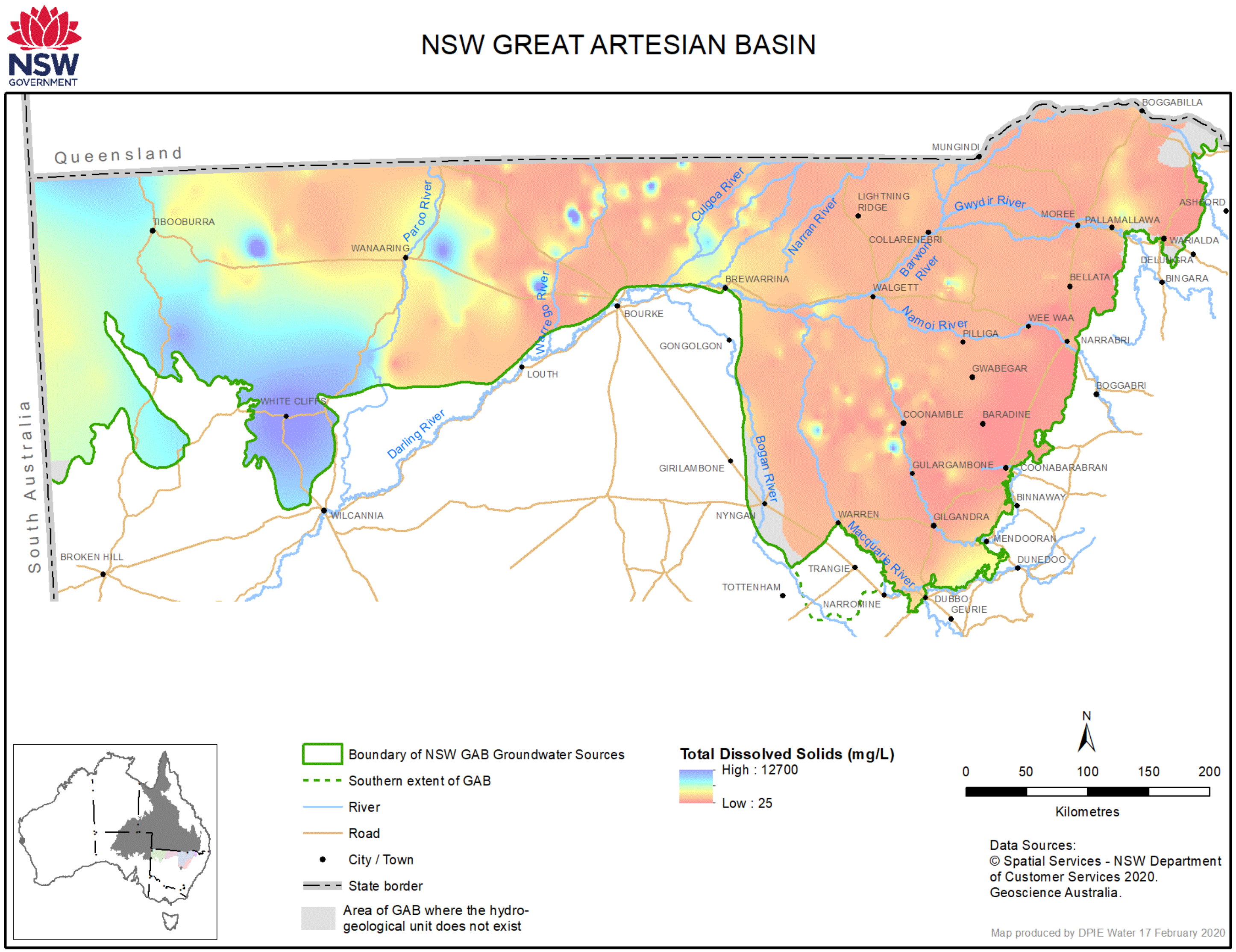

Figure 20 [12]**Total dissolved solids values of groundwater in the Hooray – Pilliga Sandstone aquifers**

[12] Data source: http://pid.geoscience.gov.au/dataset/ga/81693 (Feitz, Ransley, & Owens, 2015)

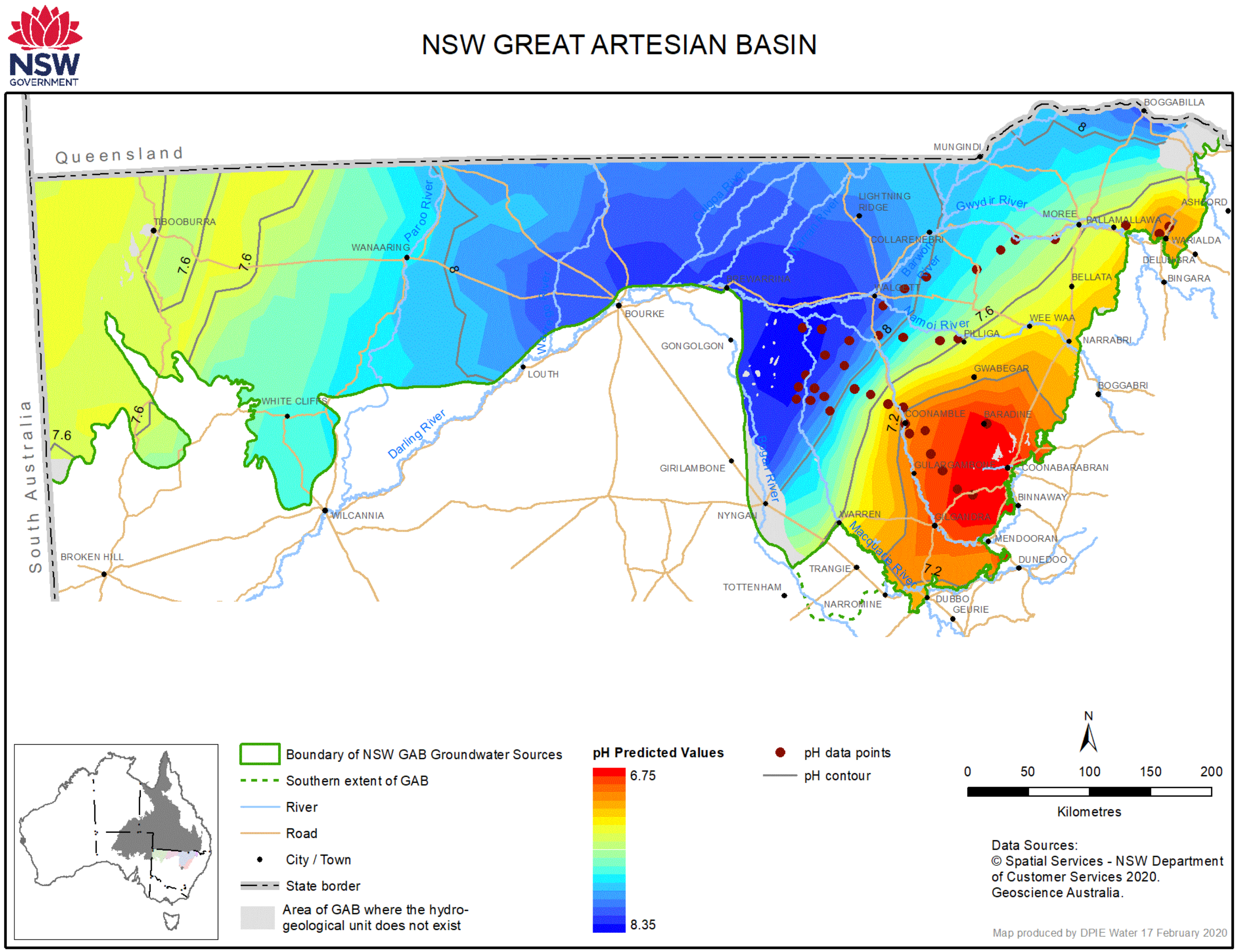

Figure 21 [13]**pH values of groundwater in the Hooray – Pilliga Sandstone aquifers**

[13] Data source: http://pid.geoscience.gov.au/dataset/ga/81696 (Feitz, Ransley, & Owens, 2015)

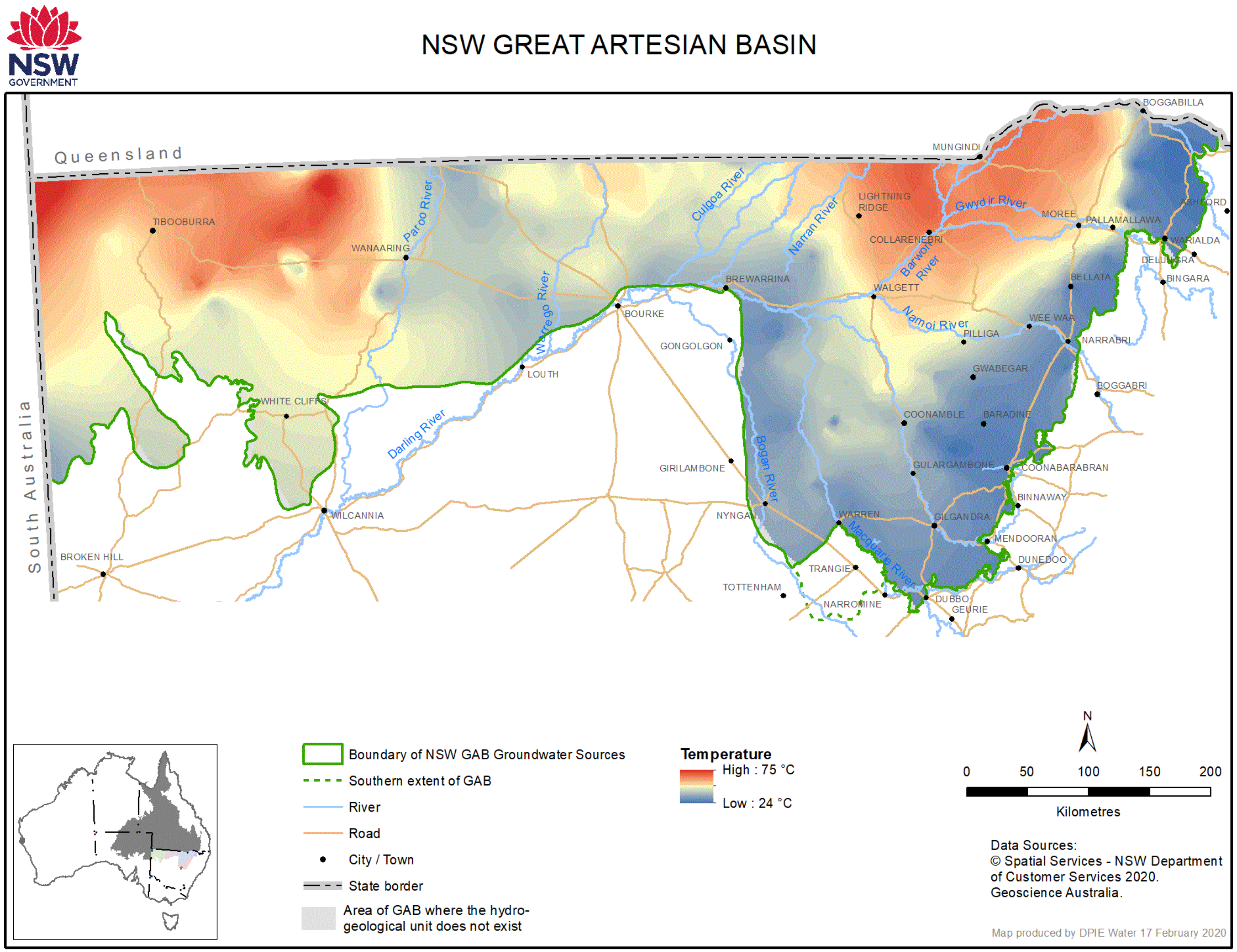

Figure 22 [14]**Temperature of groundwater in the Hooray – Pilliga Sandstone aquifers**

[14] Data source: http://pid.geoscience.gov.au/dataset/ga/76929 (Geoscience Australia, 2013)

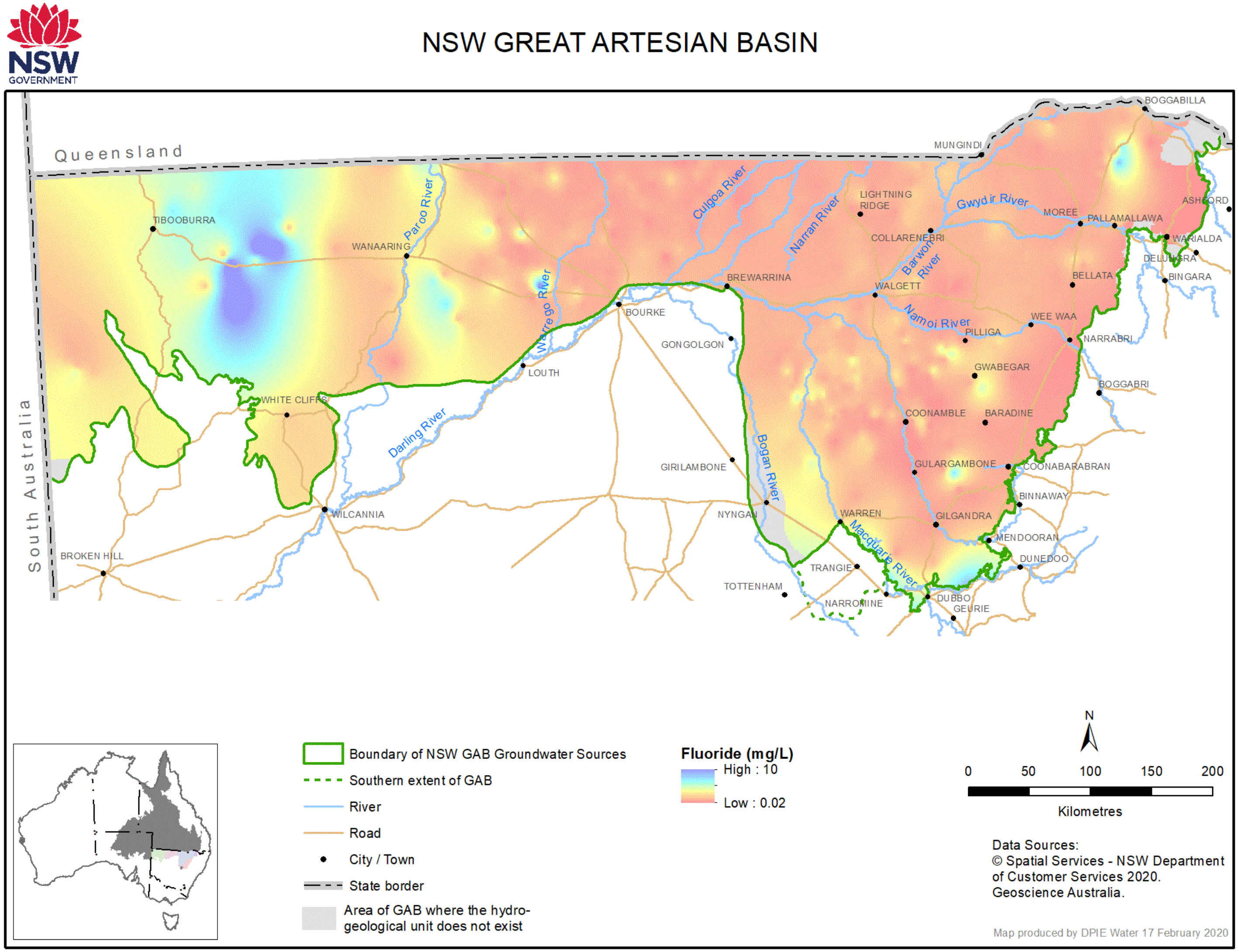

Figure 23 [15]Fluoride values of groundwater in the Hooray – Pilliga Sandstone aquifers

[15] Data source: http://pid.geoscience.gov.au/dataset/ga/81701 (Feitz, Ransley, & Owens, 2015)

8 Groundwater Management

The Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008 (WSP 2008) commenced on 1 July 2008 for 10 years. The [16]WSP 2008 sets the framework for management of the Eastern Recharge, Southern Recharge, Surat, Warrego and Central Groundwater Sources. It sets rules for water sharing among extractive uses and the environment, granting access licences, access licence dealings, operation of water allocation accounts and water supply work approvals.

The WSP 2008 was extended for two more years until 30th June 2020 and will be replaced by the Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2020 (WSP 2020) on 1st July 2020.

The WSP 2008 applies to groundwater contained in all rocks of Jurassic and Cretaceous age at depths greater than 60 m below ground level within the geographic extent of the Surat, Warrego and Central Groundwater Sources. The WSP 2008 also applies to all rocks of Jurassic, Cretaceous and Cenozoic age and unconsolidated sediments within the geographic extent of Eastern Recharge and Southern Groundwater Sources.

The WSP 2008 excludes all groundwater sources that overlie and underlie the NSW GAB Groundwater Sources, which are covered by other water sharing plans. The WSP 2008 also excludes about 3,592 square kilometres of the GAB that is within the area managed under the Water Sharing Plan for the Lower Macquarie groundwater sources 2019. Table 1 shows the area of each NSW GAB Groundwater Source.

Table 1 Area of NSW GAB Groundwater Sources

Groundwater Source	Area (km^2)
Eastern Recharge	6,131
Southern Recharge	23,602
Surat	73,833
Warrego	35,821
Central	64,613
Total	204,000*

***** The NSW GAB covers 207,592 square kilometres in NSW, which includes 3,592 square kilometres in the Lower Macquarie groundwater sources.

The NSW GAB Groundwater Sources sit over and adjacent to the fractured rock management units of Lachlan Fold Belt, Kanmantoo Fold Belt, Adelaide Fold Belt and New England Fold Belt, and porous rock management unit of the Gunnedah Basin.

The NSW GAB Groundwater Sources underlie many groundwater sources. These include the alluvial groundwater sources of the Border Rivers, Darling, Gwydir, Namoi, Castlereagh and Macquarie catchments; the Warrumbungle Basalt and the groundwater sources managed by the Water Sharing Plan for the NSW GAB Shallow Groundwater Sources 2011.

[16] http://www.legislation.nsw.gov.au/viewtop/inforce/subordleg+202+2008+cd+0+N/

8.1 Access rights

Three categories of water access licences are held in the NSW GAB Groundwater Sources. These are aquifer access licences, local water utility access licences and domestic and stock access licences.

All take of water for industries such as irrigation, mining and tourism are required to hold aquifer access licences to account for their take of water. The share components of aquifer access licences are issued for a specified number of unit shares in each groundwater source.

The local water utility access licence is held by local government for town water supply purposes. Eight shire councils in NSW are reliant on groundwater from the GAB groundwater sources for their town water supply. The combined population of these shires that is reliant on this resource is approximately 60,000.

The domestic and stock access licence is held by a community group and used for domestic and stock purposes. The share components of the local water utility, and domestic and stock access licences are for a specified volume of groundwater.

The stock and domestic use from a bore under the basic landholder rights, does not require nomination of the bore to an access licence. However, an approval is required to construct the bore to exercise the basic landholder rights.

Table 2 provides information on the details of groundwater access licences in each groundwater source.

Figure 24 shows the location of production bores that are nominated by access licences to extract groundwater

Table 2 Access licence share components in the NSW GAB Groundwater Sources

Groundwater Source	Aquifer (unit shares)	Local Water Utility (ML/yr)	Domestic & Stock (ML/yr)	Total** (ML/yr)
Eastern Recharge	34,974	-	32	35,006
Southern Recharge	24,462	3,066	-	27,528
Surat	5,527	3,393	-	8,920
Warrego	406	252	-	658
Central	43	25	-	68

* * Total expressed in ML/yr based on a unit shares assumed to be to 1 ML/yr.

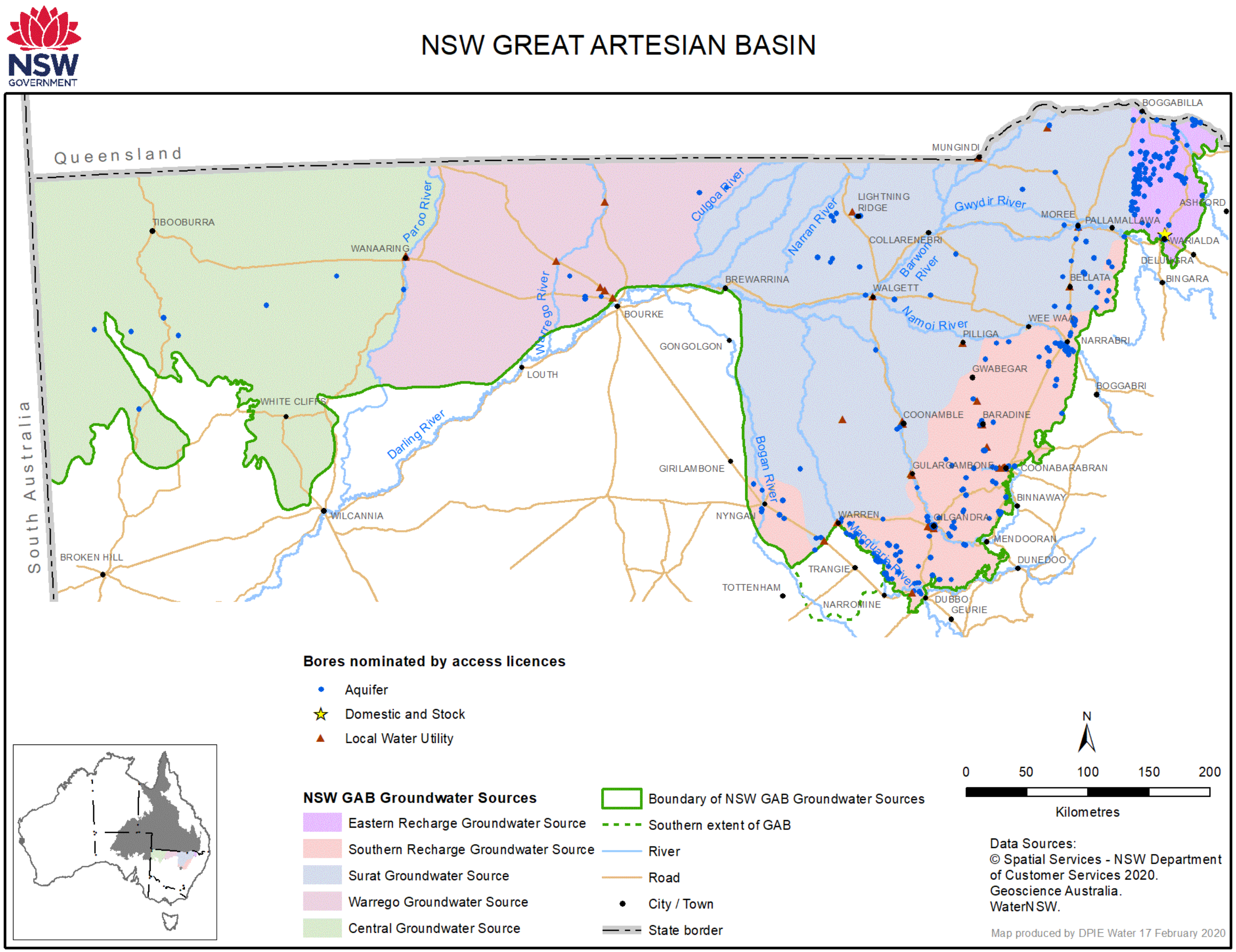

Figure 24 Distribution of bores nominated by access licence categories

8.2 Basic landholder rights

Basic landholder rights (BLR) include domestic and stock rights and native title rights. At the commencement of the WSP 2008, the total water requirement for domestic and stock rights was estimated to be 52,300 ML/yr. These estimates were based on broad scale stocking rate and stock and domestic consumption rates applied over the area of each groundwater source whilst not considering the number of properties and its reliance on alternative water sources.

No native title rights existed at the commencement of the WSP 2008, however a native title determination for the Barkandji Traditional Owners #8 (Part A, National Native Title Tribunal references NCD2015/001) currently exists.

The water requirements for domestic and stock rights were re-estimated (Klohn Crippen Berger, 2019) for the draft Water Sharing plan for the NSW GAB Groundwater Sources 2020 (WSP 2020). These estimates are based on the stock and domestic demand for the rural properties that are outside the irrigated cropping land whilst discounting the water demand for the properties that have reliance on rivers and overlying groundwater sources. In these estimates, the domestic use requirement is based the water consumption of each household in the rural properties. As a result, the water requirement estimates for domestic use is considerably higher than that of the WSP 2008 estimates for the Southern Recharge Groundwater Source where large number of small rural properties are common. Whereas the water requirement estimate for the Warrego Groundwater Source is significantly lower than that of the WSP 2008 estimate because a fewer number of rural properties that are large in size over that groundwater source.

About 7,842 water supply bores access groundwater for domestic and stock rights. Table 3 shows the distribution of these bores and the estimated water requirement for each of the groundwater sources in the WSP 2008 and the draft WSP 2020. The estimate of take in excess of BLR requirements of properties being supplied is also provided in Table 3.

Table 3 Number of bores and the estimated water requirements for domestic and stock rights

Groundwater Source	Number of Bores	[17]Water Requirement for WSP 2008 (ML/yr)	[18]Water Requirement for WSP 2020 (ML/yr)	Estimated take in excess of BLR requirements of properties being supplied (ML/yr)
Eastern Recharge	1,064	2,000	3,200	-
Southern Recharge	3,888	3,000	13,500	60
Surat	1,433	28,100	20,400	15,000
Warrego	683	14,300	3,600	4,320
Central	774	4,900	3,800	2,420
Total	7,842	52,300	44,500	21,800

[17] As estimated in the “Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008”
[18] Rounded estimate from the “Estimation of Basic Landholder Rights Requirements and Abstraction for the NSW Great Artesian Basin Groundwater Sources” (Klohn Crippen Berger, 2019)

The estimated volume in excess of the BLR requirements provided in Table 3 is based on preliminary work done by KCB consultancy (Klohn Crippen Berger, 2019) with additional data and analysis sourced from recent bore surveys.

Whilst there has been considerable investment in efficient water delivery systems for domestic and stock use, there is still an estimated 21,800 ML/yr taken from BLR bores in excess of the stock and domestic requirements of the properties being supplied. This wastage of water from uncontrolled artesian flow or the distribution of water through extensive open bore drains for the delivery of stock and domestic supplies are a legacy of past practices that were previously endorsed by government. The capping and piping of these schemes has been a significant investment from both government and private landholders to improve the efficiency of this infrastructure and reduce the wastage of the GAB resources (refer Section 9).

8.3 Extraction limits

The WSP 2008 sets rules for sharing groundwater resources among extractive uses and the environment. It sets annual extraction limit for each groundwater source to ensure that secure long-term access to water is available for the environment and extractive uses. Extraction in a groundwater source is managed to the long-term average annual extraction limit (LTAAEL) set by the water sharing plan.

As part of development of the draft WSP 2020, the extraction limits have been reviewed using the latest knowledge and information acquired on the GAB in the last decade.

8.3.1 Eastern Recharge and Southern Recharge Groundwater Sources

The basis for water sharing for the Eastern Recharge and Southern Recharge Groundwater Sources is the long-term net annual recharge volumes. Seventy percent of this volume is set as LTAAEL available for extractive uses for these two groundwater sources.

In 2019, the NSW Department of Planning, Industry and Environment (DPIE) engaged Klohn Crippen Berger Ltd (KCB) consultancy to conduct a literature review of published recharge mechanisms and collate existing estimates of recharge for the GAB, focusing on the Eastern Recharge and Southern Recharge Groundwater Sources. On completion of the literature review, KCB re estimated the long-term annual recharge volumes for these two groundwater sources (Klohn Crippen Berger, 2019) using the recharge rates obtained from the saturated zone chloride mass balance method of the GAB Water Resources Assessment by CSIRO (Smerdon, et al., 2012).

Sixty percent of these long-term annual recharge estimates are assigned as through flow component from these two groundwater sources to the adjacent groundwater sources and the remaining 40% of the estimated recharge is assigned as long-term net annual recharge volume for these groundwater sources. The LTAAEL for these two recharge groundwater sources for the WSP 2020 is revised using the re estimated long-term net annual recharge volumes.

Table 4 shows the LTAAEL for the Eastern Recharge and Southern Recharge Groundwater Sources in the WSP 2008 and the draft WSP 2020.

Table 4 LTAAEL for the Eastern Recharge and Southern Recharge Groundwater Sources

Groundwater Source	[19] WSP 2008 - LTAAEL (ML/yr)	[20] WSP 2020 - LTAAEL (ML/yr)
Eastern Recharge	13,300	16,200
Southern Recharge	29,680	38,700

8.3.2 Surat, Warrego and Central Groundwater Sources

8.3.2.1 Water sharing plan 2008

The basis for water sharing in the WSP 2008 for the Surat, Warrego and Central Groundwater Sources is the volume of water that was being taken associated with the entitlements, infrastructure and management rules in place in 1990. The WSP 2008 adopts this volume as that associated with the groundwater pressures being experienced in 1990. The WSP 2008 refers this volume as the sustainable pressure estimate equivalent (SPEE).

The SPEE volumes for the WSP 2008 were based on broad scale extraction volumes applied to artesian bores in each groundwater source with the data available at that time. The flow rate and flow status at the bore head for each individual artesian bore, and water demand for the property where the artesian bore is located were not considered in the estimation.

The SPEE volume, the water savings through the Cap and Pipe the Bores program since 1990 and the increased extraction between 1990 and 2008 are all components of the LTAAEL for these three groundwater sources. The LTAAEL has progressively decreased as a portion of the savings made under the Cap and Pipe the Bores program is preserved as planned environmental water and no longer available to be taken under the extraction limit. The remaining smaller portion of the savings, i.e. 30% of savings since 1999, are attributed to the extraction limit. Table 5 shows the LTAAEL and its components as at 31st December 2019 for the WSP 2008.

Table 5 LTAAEL and its components as at 31st December 2019 for the WSP 2008

Groundwater Source	SPEE (ML/yr) I.e. Estimated groundwater take in 1990	Increased extraction between 1990 and 2008 (ML/yr)	Savings attributed to the Planned Environmental Water (ML/yr)	LTAAEL at 31st December 2019 (ML/yr)
Surat	75,000	8,414	41,643	41,771
Warrego	22,400	96	12,035	10,461
Central	7,900	115	5,268	2,747

8.3.2.2 Draft water sharing plan 2020

DPIE has re estimated the volume that was being taken in 1990 based on existing and new data collected on the pressure and flow characteristics of individual bores from the two recent bore

[19] As described in the “Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008”
[20] As estimated in the “Southern and Eastern Recharge Groundwater Sources. Literature Review and Recommended Recharge Rates” (Klohn Crippen Berger, 2019)

surveys (refer section 9.3). Table 6 shows the revised estimates of the 1990 volume as well as the estimated volume being taken in 2019 from the water supply bores in these groundwater sources.

Table 6 Estimates of volume being taken in 1990 and 2019 from the Surat, Warrego and Central Groundwater Sources (assuming take at 100% entitlement)

Groundwater Source	Groundwater take in 1990 (ML/yr)	Groundwater take in 2019 (ML/yr)
Surat	60,729	39,706
Warrego	18,717	12,014
Central	9,844	5,851

An alternative approach to setting the LTAAEL for each of these three groundwater sources is being proposed in the draft WSP 2020. The approach is to preserve the intent of the WSP 2008 by providing for the level of extraction authorised in 2008 and continue to permit a portion of the water saved through water efficiency schemes to be available under the extraction limit. The proposed LTAAEL will include the revised BLR requirement for the draft WSP 2020 (refer Section 8.2), the entitlements authorised in 2008 and the portion of the water savings already attributed to the each of these water sources under the WSP 2008.

The draft WSP 2020 also accounts for water that is taken in excess of the BLR requirements that is being lost via inefficient bores and reticulation systems under the LTAAEL. This volume represents potential future savings that could be made under capping and piping the bores programs.

The draft WSP 2020 proposes to continue preserving 70% of future water savings as planned environmental water which results in a progressive decrease in the LTAAEL as savings are made. The draft WSP 2020 allows the remaining 30% of future savings to be accounted for under the extraction limit.

Table 7 shows the proposed LTAAEL at 1st July 2020 for the draft WSP 2020 and the components that contribute to it for these three groundwater sources.

Table 7 Proposed LTAAEL as at 1st July 2020 in the draft WSP 2020

Groundwater Source	Revised BLR requirement for the WSP 2020 ML/yr	Entitlements authorised at start of the WSP 2008 ML/yr	Savings already attributed from previous Cap and Pipe programs ML/yr	# LTAAEL for the WSP 2020 ML/yr
Surat	20,400	7,645	15,401	43,446
Warrego	3,600	558	4,658	8,816
Central	3,800	68	1,325	5,193

This does not include the volume of water lost via inefficient reticulation system

8.4 Available water determination

At the start of each water year, an available water determination (AWD) is made which sets the allocation of groundwater for the different categories of access licences. The WSP 2008 requires that in each groundwater source, if the average extraction for the preceding five years exceeds the long term annual average extraction limit by 10% or greater in any water year then the water made available to aquifer access licences in 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 WSP 2008's extraction limit.

The AWDs for local water utility, domestic and stock access licences have been set as 100% of their share components every year.

The AWD for aquifer access licences has remained at 1 ML/Unit share for the Southern Recharge, Surat, Warrego and Central Groundwater Sources.

For the Eastern Recharge Groundwater Source, with the exception of an AWD of 0.8 ML/Unit share in 2008-09 and 2009-10 water years, 0.5 ML/Unit share in 2018-19 water year and 0.32 ML/Unit share in 2019-20 water year, the AWD for aquifer access licences remained 1 ML/Unit share for the rest of water years.

Figure 25 to Figure 29 show the annual water allocations for each category of licences in each groundwater source since commencement of the WSP 2008.

For the Eastern Recharge Groundwater Source, the water allocation for domestic and stock access licence is 32 ML/yr since 2011-12 water year, which is three magnitudes smaller than the water allocation to aquifer access licences. Therefore, the water allocation for domestic and stock licence is not clearly visible in Figure 25 due its scale.

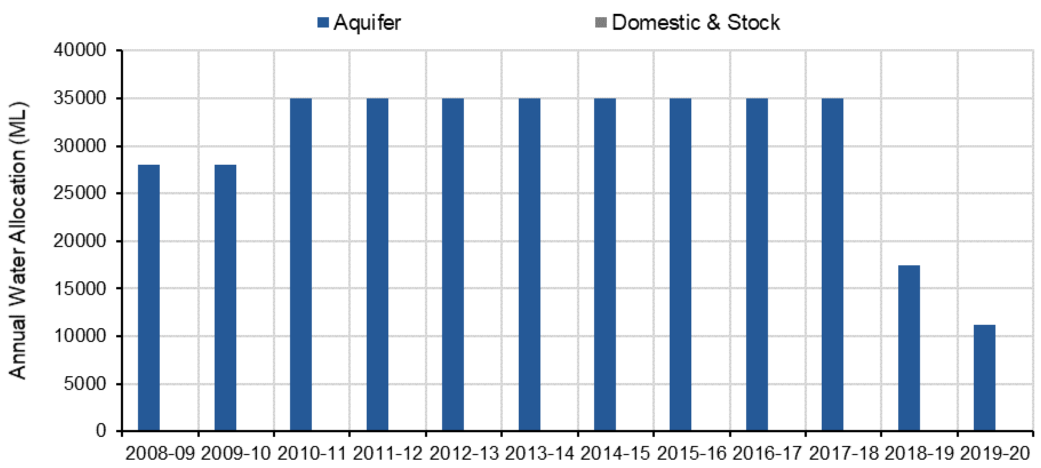

Figure 25 Annual water allocation for each category of access licence in the Eastern Recharge Groundwater Source

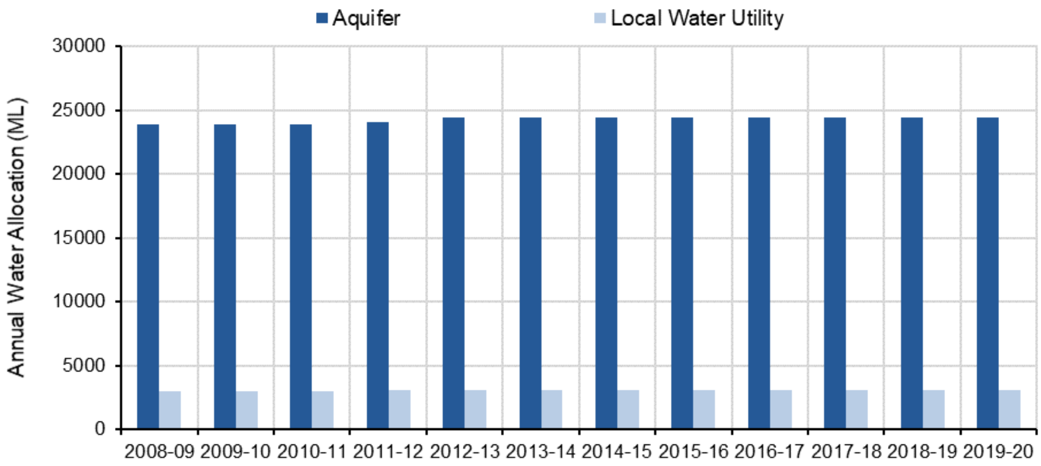

Figure 26 Annual water allocation for each category of access licence in the Southern Recharge Groundwater Source

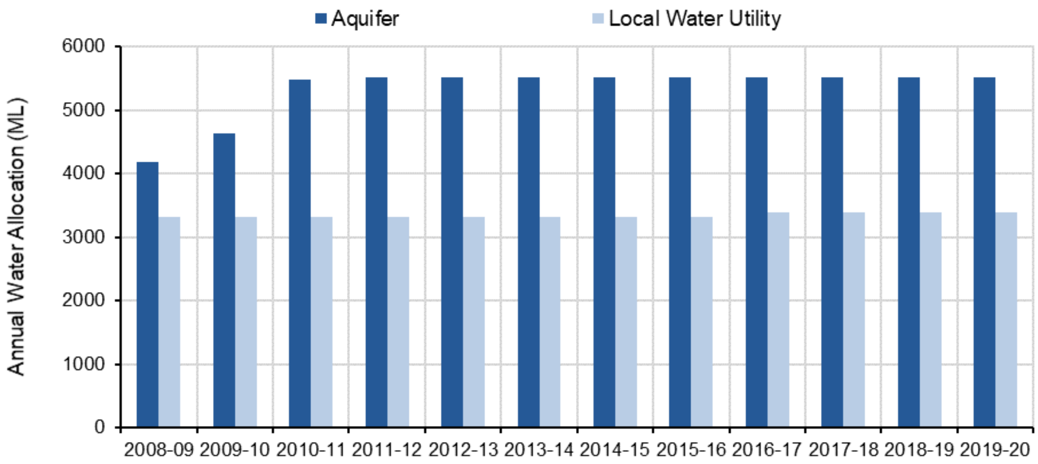

Figure 27 Annual water allocation for the Surat Groundwater Source

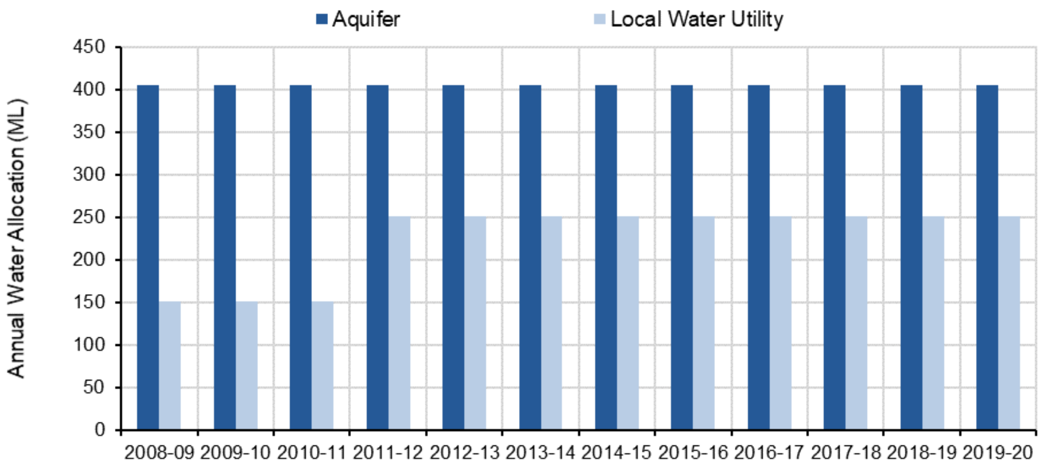

Figure 28 Annual water allocation for each category of access licence in the Warrego Groundwater Source

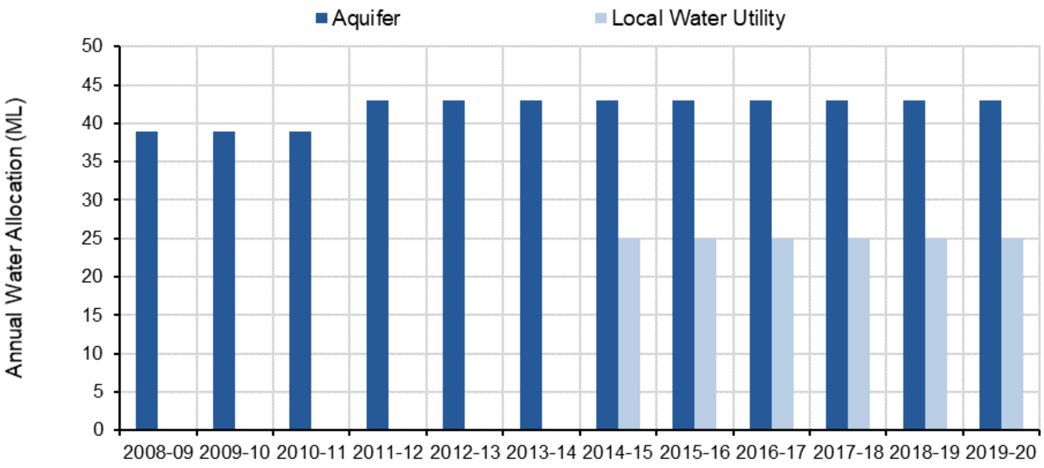

Figure 29 Annual water allocation for each category of access licence in the Central Groundwater Source

8.5 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 WSP 2008 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 0.6 ML/Unit share.

The maximum amount of water that can be debited from an account in any one water year (i.e. account take limit) in these groundwater sources cannot exceed 1.3 ML/Unit share component plus any allocation transferred in, and minus any allocation transferred out.

Figure 30 to Figure 34 show the volumes held in water accounts for access licences in each groundwater source since 2008-09 water year. Noteworthy in Figure 30 for Eastern Recharge Groundwater Source are the diminishing account water and account water available for extraction in the last two water years due to reduced AWDs and increased groundwater take.

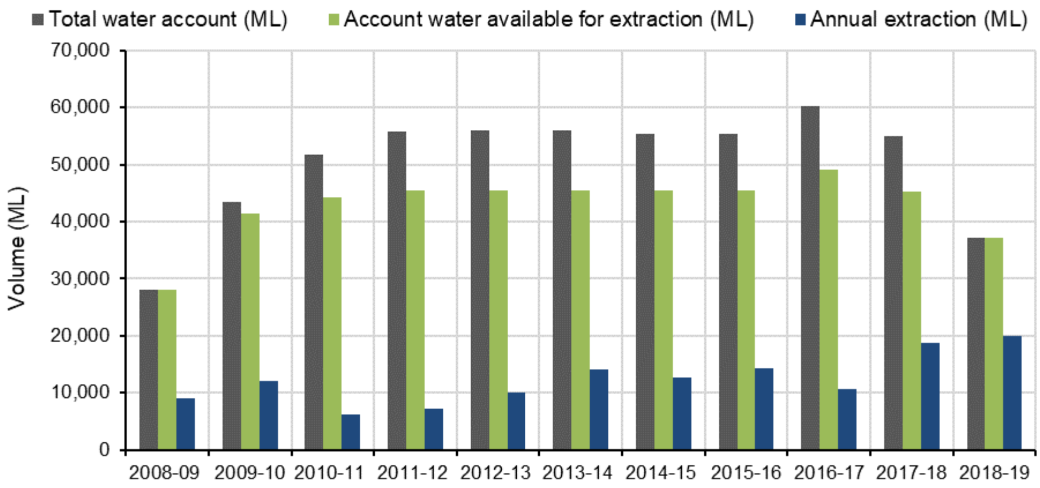

Figure 30 Water accounts for the Eastern Recharge Groundwater Source

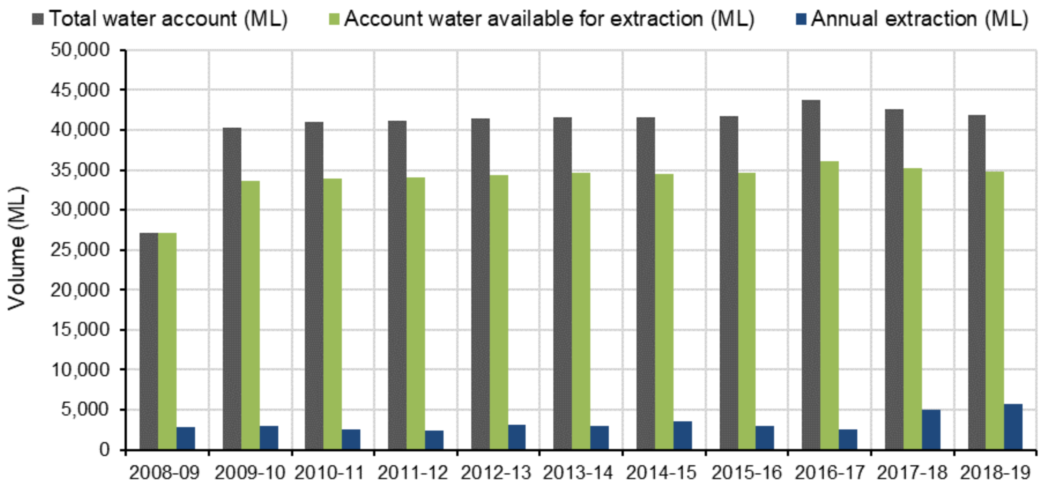

Figure 31 Water accounts for the Southern Recharge Groundwater Source

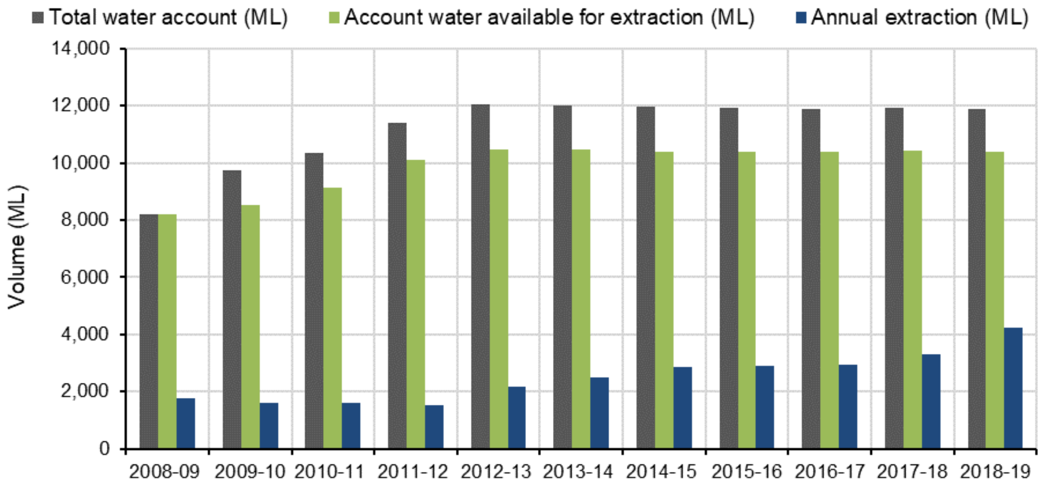

Figure 32 Water accounts for the Surat Groundwater Source

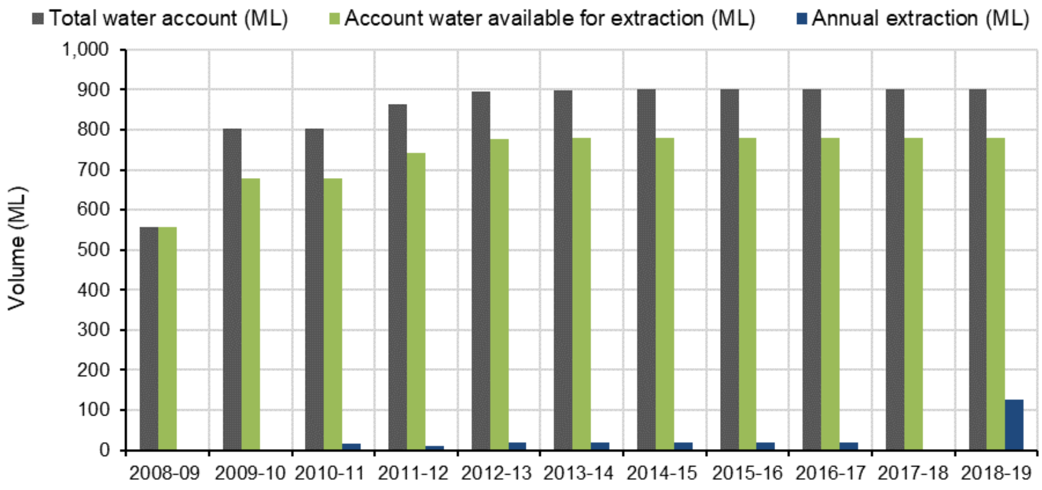

Figure 33 Water accounts for the Warrego Groundwater Source

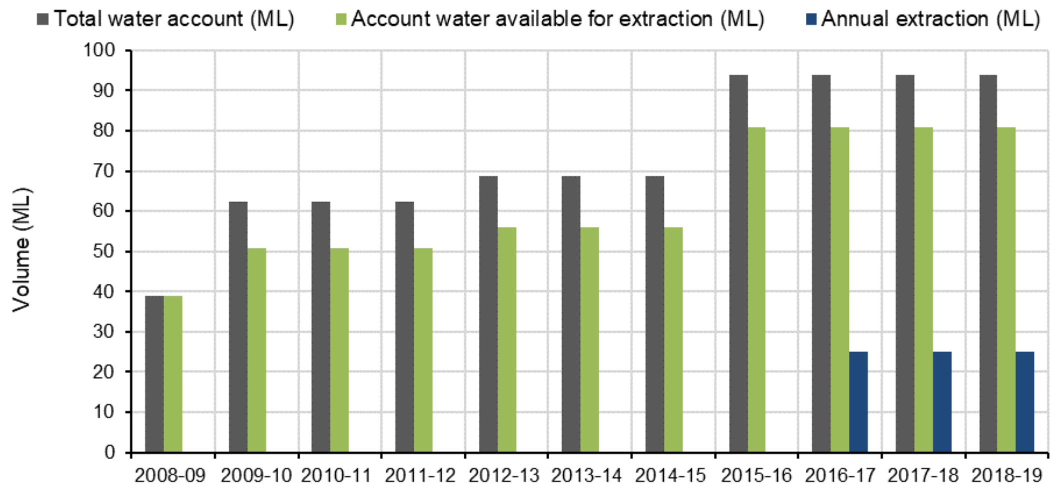

Figure 34 Water accounts for the Central Groundwater Source

8.6 Groundwater take

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

The groundwater take has been metered in all production bores that are nominated by access licences, since commencement of the WSP 2008. Prior to this, metering of the groundwater extraction was sporadic and partial in the Southern Recharge and Surat Groundwater Sources, whereas the extraction in Warrego and Central Groundwater Sources was not metered at all. The Eastern Recharge Groundwater Source has reliable long-term history of extraction since 1998-99 water year.

The use for basic landholder rights is not metered in the NSW GAB Groundwater Sources.

Approximately 383 production bores nominated by access licences, are in the NSW GAB Groundwater Sources. Table 8 shows the distribution of production bores by access licence categories in each groundwater source. Figure 24 shows the spatial distribution of these production bores and its categories.

Table 8 Distribution of production bores nominated by access licence categories

Groundwater Source	Aquifer	Local water utility	Domestic and stock	Total
Eastern Recharge	113	-	2	115
Southern Recharge	164	19	-	183
Surat	55	13	-	68
Warrego	6	3	-	9
Central	8	-	-	8

Figure 35, Figure 36 and Figure 37 show the comparison of annual metered take with the WSP 2008 LTAAEL for the Eastern Recharge, Southern Recharge and Surat Groundwater Sources respectively. Figure 38 shows the spatial distribution of average annual extraction volumes from the production bores since commencement of the WSP 2008.

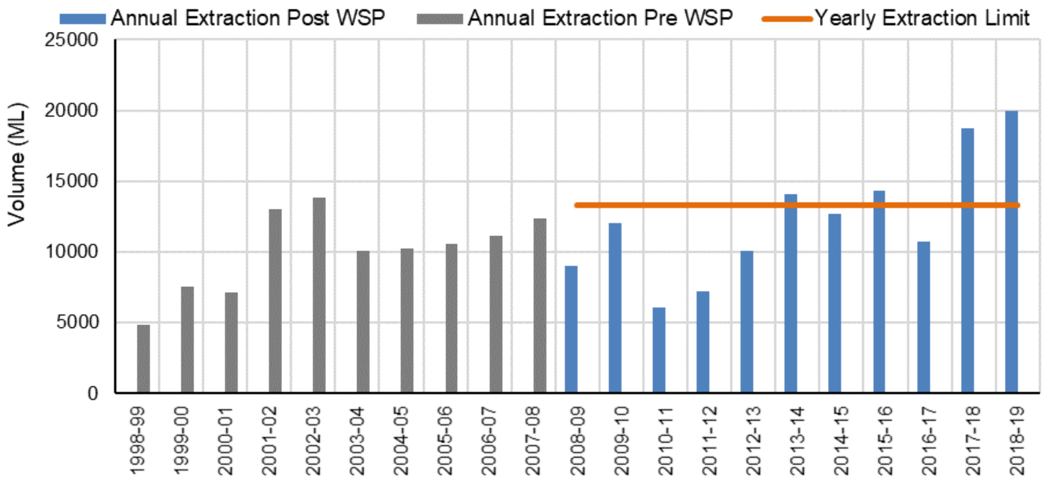

Figure 35 Annual extraction for the Eastern Recharge Groundwater Source

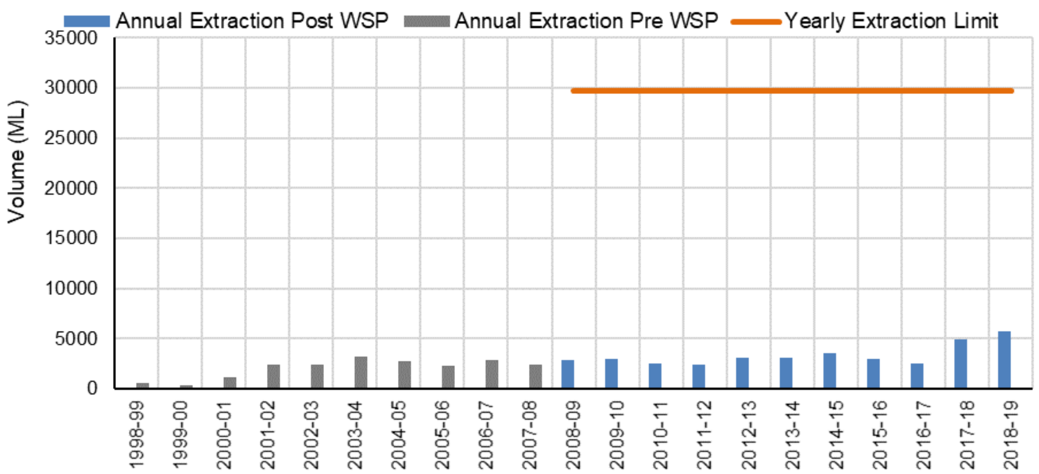

Figure 36 Annual extraction for the Southern Recharge Groundwater Source

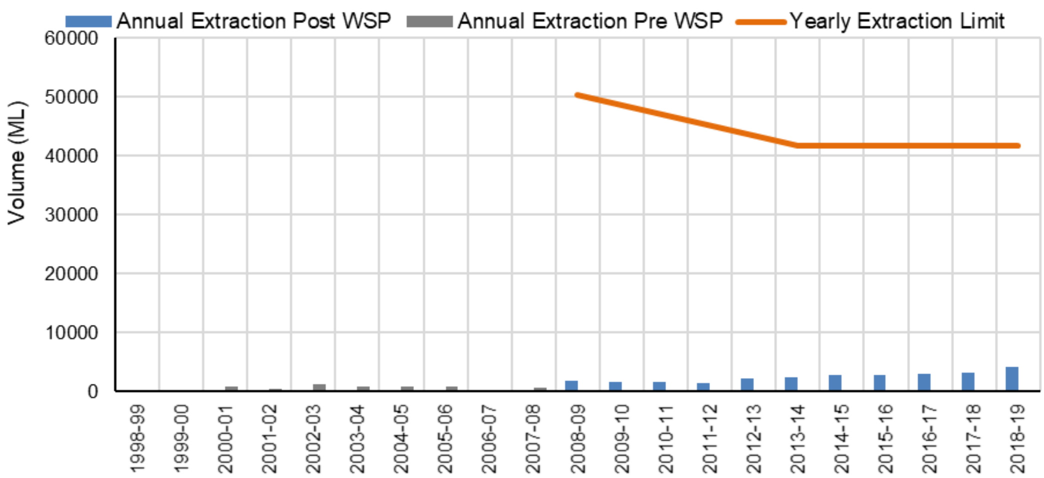

Figure 37 Annual extraction for the Surat Groundwater Source

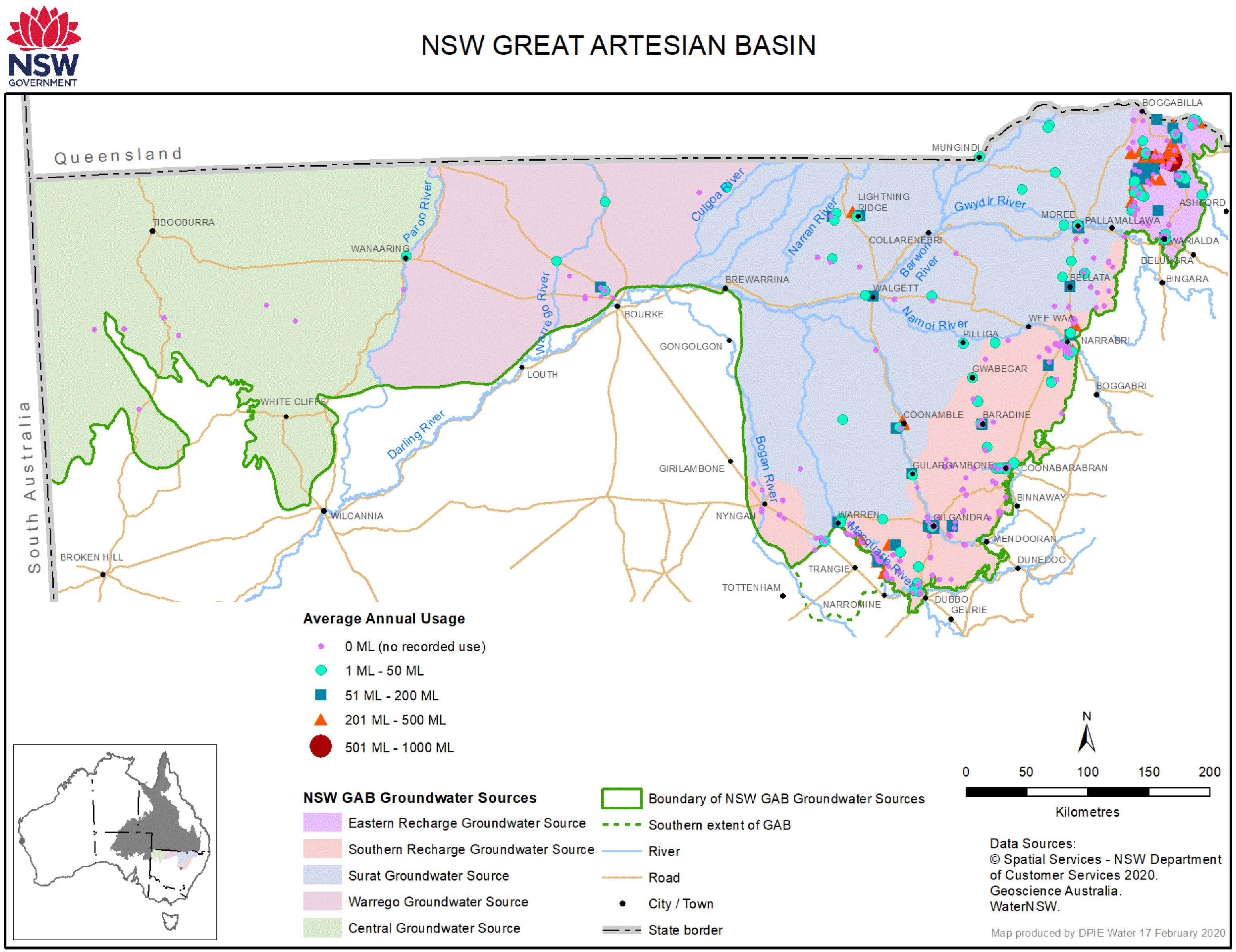

Figure 38 Average metered extraction from the production bores since 2008-09 water year

Annual metered groundwater take exceeded the LTAAEL for the Eastern Recharge Groundwater Source for a number of years since commencement of the WSP 2008.

The annual metered groundwater take for Warrego Groundwater Source since 2010-11 water year had been under 18 ML except for 2018-19 water year when it peaked to 127 ML. The annual metered groundwater take for Central Groundwater Source remained 25 ML since 2016-17 water year. The annual metered groundwater take for the Warrego and Central Groundwater Sources are two magnitudes smaller than their LTAAELs. Therefore, comparison of the groundwater take against yearly extraction limit for these two groundwater sources is not shown due to its scale difference.

8.7 Groundwater Dealings

Under the *WMA2000*, dealings are permitted in access licences, shares, account water and the nomination of water supply works.

Dealings that can result in a change in the potential volume that can be extracted from a location and have the potential to cause third party impacts are subject to a hydrogeological assessment. It may be approved subject to conditions being placed on the nominated approvals, such as a bore extraction limit, to minimise potential impact on neighbouring bores. All dealings are assessed in accordance with the water management principles of the *WMA2000*, the principles in the "*Access Licence Dealing Principles Order 2004*" and the access licence dealings rules established by the water sharing plan.

The most common dealings are assignment of water allocation (71T), assignment of share (71Q), licence transfer (71M) and nomination of work (71W).

Dealings that result in the interstate transfer of access licences (71U) or the interstate assignment of water allocation (71V) are prohibited until an agreement is reached with relevant State governments.

8.7.1 Permanent dealings

The popular permanent dealings are assignment of shares (71Q), transfer of access licences (71M) and nomination of works (71W).

8.7.1.1 Assignment of share (71Q) dealings

There have been no 71Q dealings in the Surat, Warrego and Central Groundwater Sources so far. Table 9 shows the summary of 71Q dealings in the Eastern Recharge and Southern Recharge Groundwater Sources. The average price paid for a unit share is $777 in the Eastern Recharge Groundwater Source and $368 in the Southern Recharge Groundwater Source.

Table 9 Summary of assignment of share (71Q) dealings

Groundwater Source	Dealings	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
Eastern Recharge	Number	-	-	2	2	-	-	-
	Unit Shares	-	-	1,286	886	-	-	-
Southern Recharge	Number	1	1	-	2	-	1	3
	Unit Shares	30	1,000	-	26	-	128	280

8.7.1.2 Transfer of access licences (71M) dealings

The 71M dealings are a change in ownership only and therefore have no potential for additional third-party impacts. Until now, no 71M dealings took place in the Central Groundwater Source. Table 10 provides the summary of 71M dealings for the remaining four groundwater sources.

Table 10 Summary of transfer of access licences (71M) dealings

Groundwater Source	Eastern Recharge		Southern Recharge		Surat		Warrego	
Water Year	**No of Dealings**	**Unit Shares**	**No of Dealings**	**Unit shares**	**No of Dealings**	**Unit Shares**	**No of Dealings**	**Unit Shares**
2008-09	1	486	1	120	4	1260	-	-
2009-10	4	1,758	5	1,249	2	49	-	-
2010-11	6	3,617	2	34	4	187	-	-
2011-12	-	-	6	603	-	-	1	5
2012-13	2	510	7	2,047	-	-	-	-
2013-14	-	-	7	1,974	3	101	-	-
2014-15	7	3,043	7	1,493	1	100	-	-
2015-16	11	7,197	5	875	4	193	1	40
2016-17	4	1,512	4	967	3	127	1	5
2017-18	5	2,176	8	732	2	86	-	-
2018-19	2	786	10	2,078	3	664	-	-

8.7.2 Temporary dealings

The groundwater allocation assignment (71T) dealings between access licences are temporary dealings for a water year. There was no 71T dealings reported in the Central Groundwater Source. In Surat Groundwater Source, only two 71T dealings totalling 169 ML were reported in 2010-11 water year. Only three 71T dealings totalling 260 ML were reported in the Warrego Groundwater Source in 2018-19 water year.

A number of 71T dealings were reported in the Eastern Recharge Groundwater Source since 2014-15 water year and in the Southern Recharge Groundwater Source since 2012-13 water year.

Figure 39 and Figure 40 show the statistics of 71T dealings in the Eastern Recharge and Southern Recharge Groundwater Sources respectively. The price per megalitre value for a number of water allocation assignments worth $1/ML or less in these two groundwater sources is not shown in these figures. All five dealings in 2014-15 water year for the Eastern Recharge Groundwater Source are water allocation assignments worth $1/ML in value or less.

Significant increase in water allocation assignments and number of 71T dealings in 2018-19 water year for the Eastern Recharge Groundwater Source are attributed to the necessity of topping up the water accounts that were credited with less water allocation as a result of reduced AWD of 0.5 ML/Unit share for aquifer access licences in that water year.

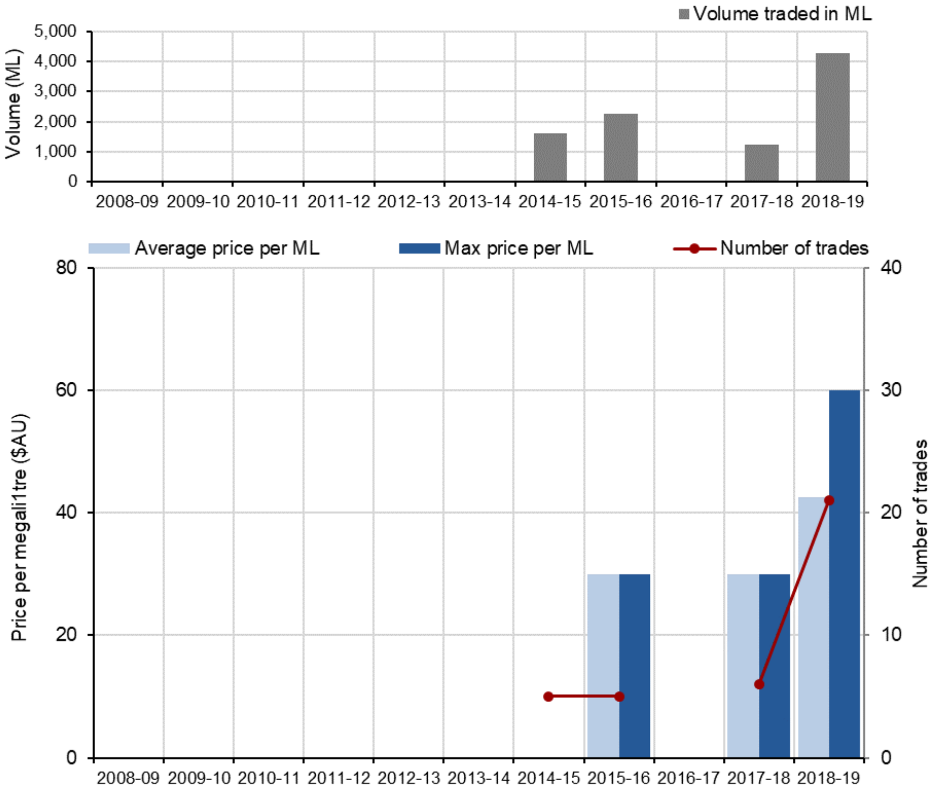

Figure 39 Statistics of 71T dealings in the Eastern Recharge Groundwater Source

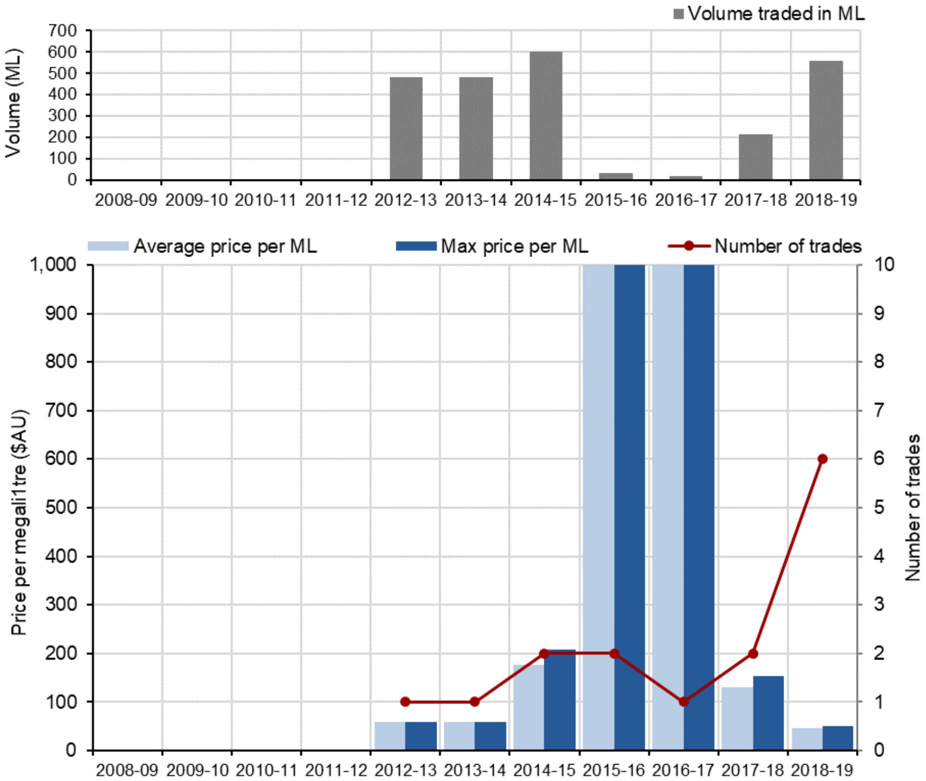

Figure 40 Statistics of 71T dealings in the Southern Recharge Groundwater Sources

9 Cap and Pipe the Bores Program

9.1 Overview

Over 8,500 water supply bores have been drilled in NSW GAB groundwater sources since commencement of exploration of groundwater in GAB in late 1870s. Approximately 8,200 water supply bores do currently exist in the NSW GAB. The distribution of water supply bores across each groundwater source and their artesian condition are provided in Table 11 and Figure 41.

Table 11 Distribution of water supply bores and their artesian condition

Groundwater Source	Artesian (flowing)	Sub Artesian (non-flowing)	Total
Eastern Recharge	10	1,164	1,174
Southern Recharge	11	4,048	4,059
Surat	391	1,100	1,491
Warrego	229	464	693
Central	46	736	782
Total	687	7,512	8,199

On completion of drilling, 1,360 bores produced artesian (flowing) water supply, but about 520 bores ceased to flow at some stage after the drilling. About 200 artesian bores have now been plugged and six artesian bores are deemed as abandoned. Figure 42 shows the current status of the bores that were artesian (flowing) at the time of completion of drilling.

Many bores drilled before mid-last century were allowed to flow unrestricted. The water was distributed through open bore drains to a number of properties for pastoral use. The practice of distributing artesian water through open drains is inefficient. The volume of water flowing from the bores was much greater than that required for use by the pastoral industry. The consequent decline of pressure in the aquifers led many artesian bores and springs to cease flowing across the GAB. Combination of pressure decline and proliferation of water bores over the last 140 years led to reduced discharge from the artesian bores, though the use of water increased over this time.

In NSW, an initial program of rehabilitating unrestricted bores was in place between 1952 and 1971 (Williamson W. H., 2012). The Cap and Pipe the Bores program was introduced in 1990 by the NSW Government to address the wastage of water and improve land management across the GAB. The program achieved this by providing grants to landholders to rehabilitate failing bores and replace inefficient bore drains with efficient water supply systems. Between 1999 and 2016, Cap and Pipe the Bores program in NSW had been implemented through the Great Artesian Basin Sustainability Initiative (GABSI). The final fourth phase of GABSI ended in 2016. Since 2017, the bores are being capped and piped through the Interim Great Artesian Basin Infrastructure Investment Program (IGABIIP) until 2019.

For reporting purpose, the artesian bores in the NSW GAB are grouped into three broad categories of bores namely unrestricted, unregulated and regulated. The unrestricted bores flow uncontrollably into bore drains as there is no infrastructure to control the bores. Flow from the unregulated bores is either not controlled or partially controlled due to logistics involving bore integrity and delivery of water. Groundwater flow from the regulated bores is controlled and delivered to properties via watertight pipe system.

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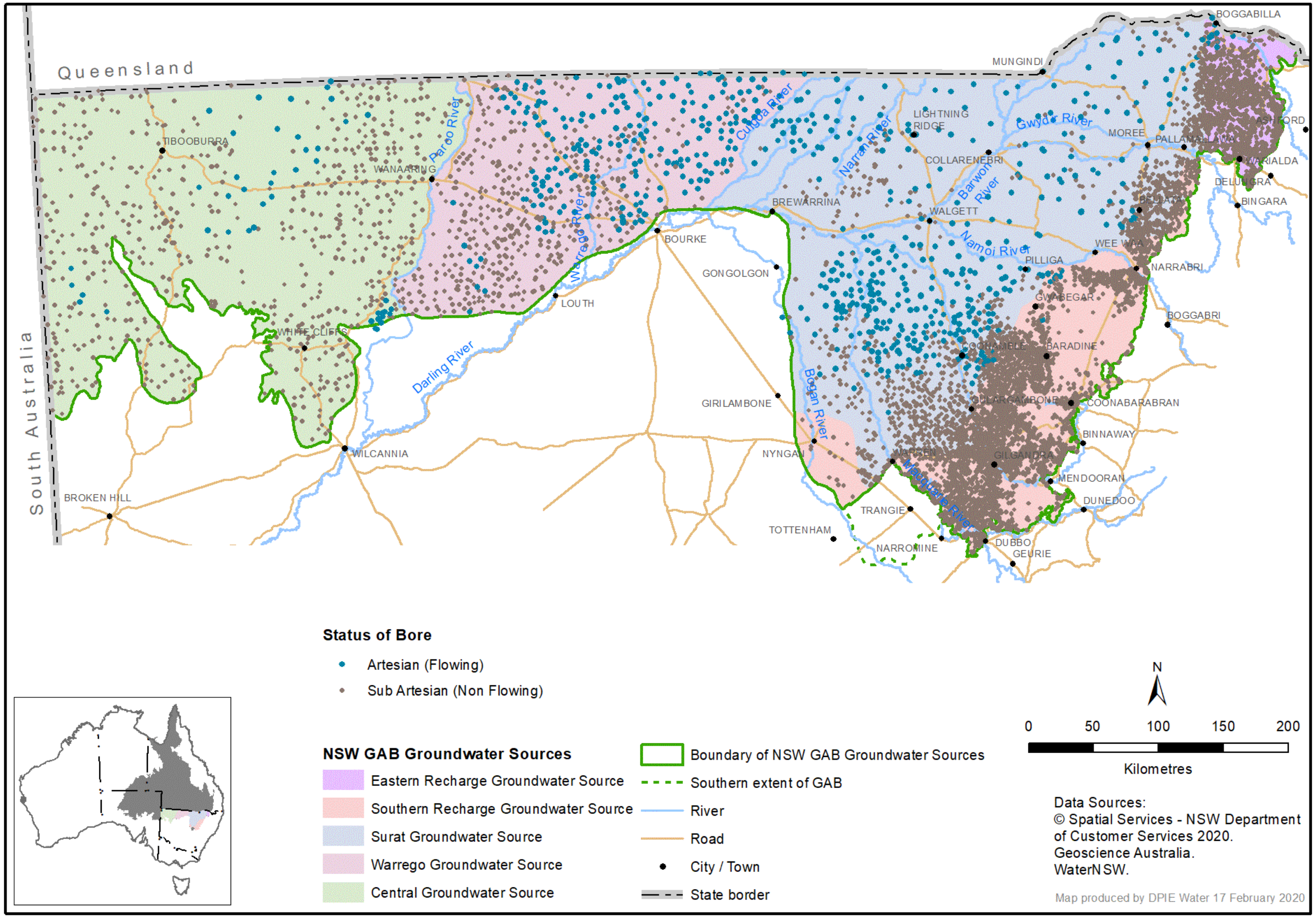

Figure 41 Current artesian status of the water supply bores

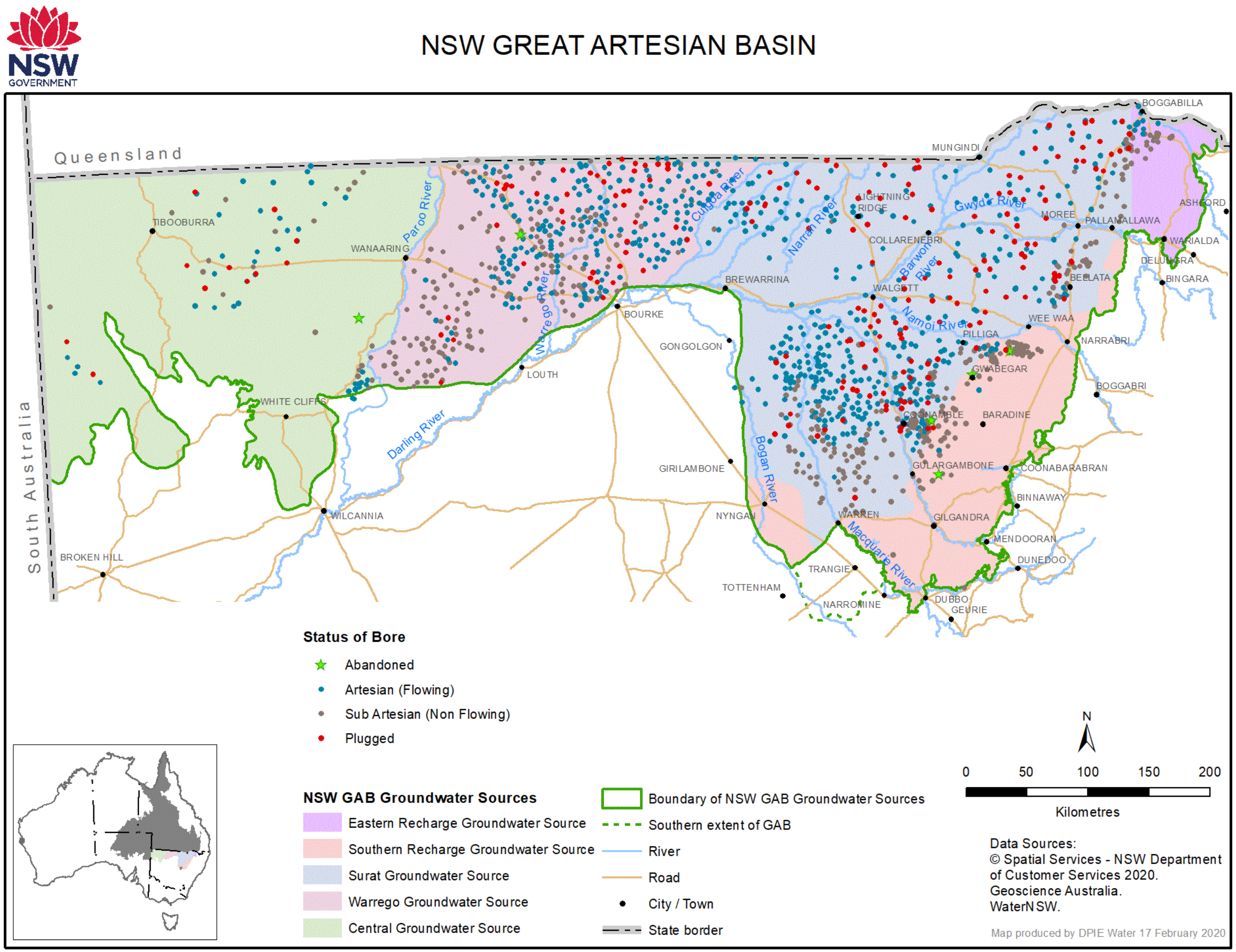

Figure 42 Current status of bores that flowed on completion of drilling

Figure 43 shows the total estimated groundwater discharge volume and proliferation of artesian bores over the last 140 years. Figure 44 shows the estimated discharge volumes for each category of artesian bores.

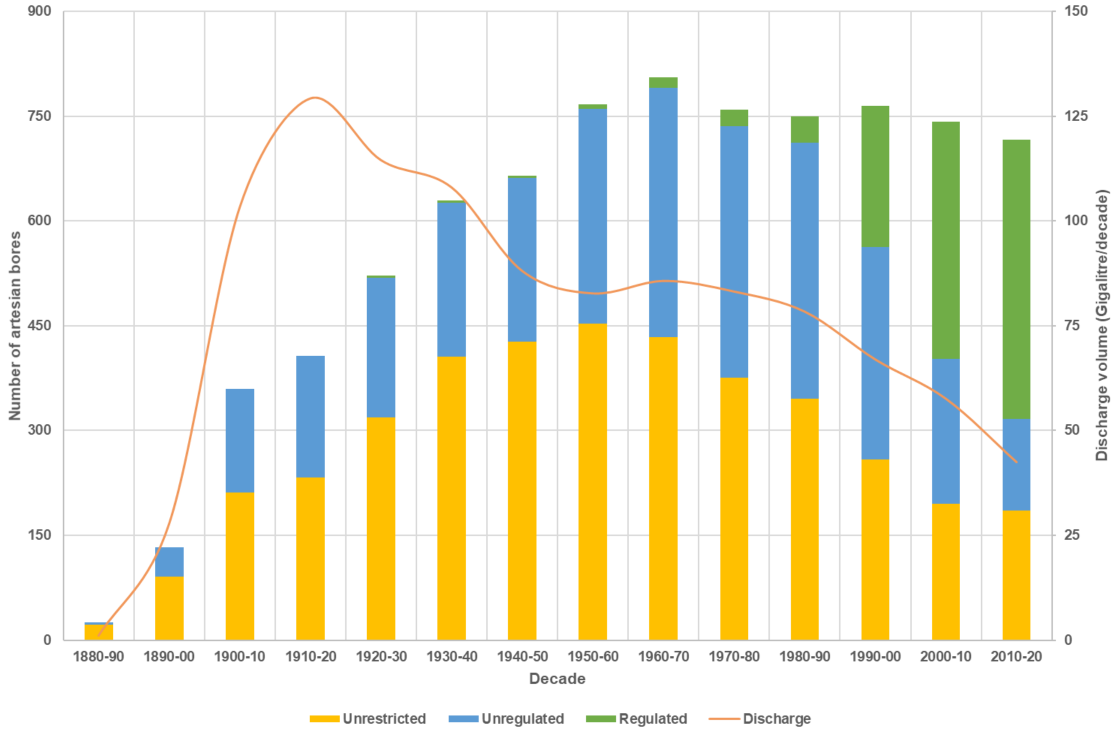

Figure 43 Total discharge and proliferation of artesian bores

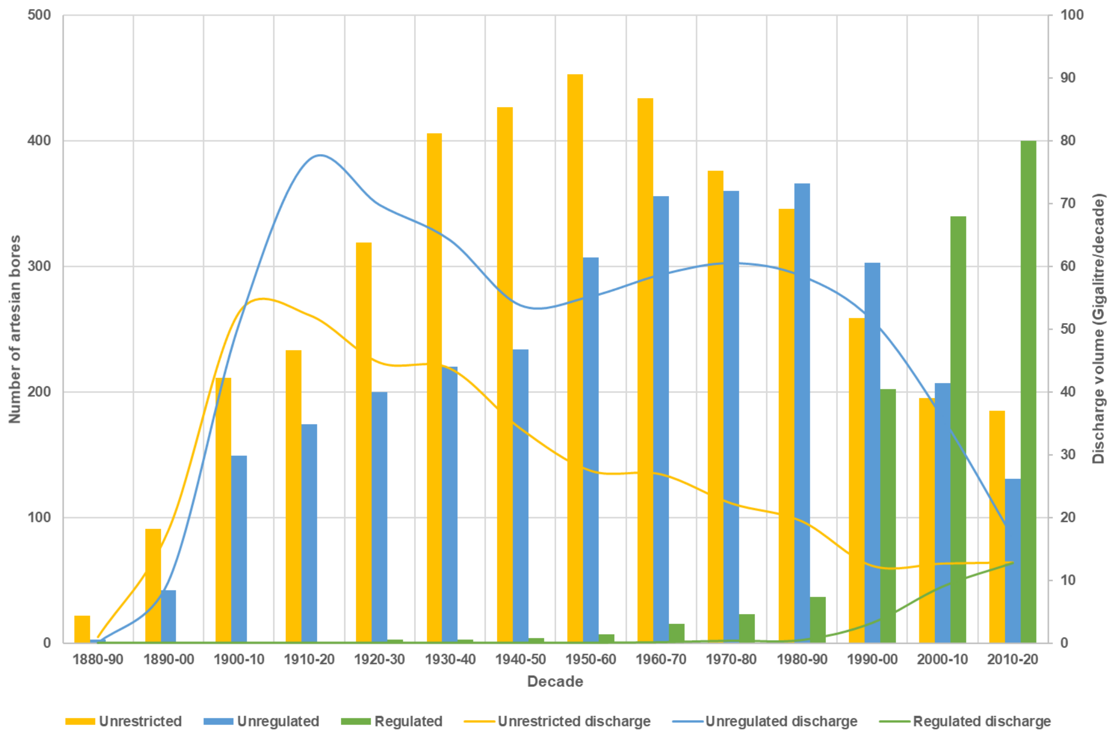

Figure 44 Discharge and proliferation of each category of artesian bores

9.2 Achievements

Cap and Pipe the Bores program has resulted in an estimated 80,328 ML/yr of water savings through the reduction of water extraction. It has replaced 9,963 km of earthen bore drains with piped systems to provide reliable permanent water supply to 4.2 million hectares of land, an area greater than that previously watered by the bore drain network. The control of large number of unrestricted flowing bores has restored artesian pressure in the aquifers which in turn improved access to the artesian water. The piped systems not only improve water efficiency but also deliver better quality water to the properties.

Cap and Pipe the Bores program has been implemented in the Surat, Warrego and Central Groundwater Sources only. Figure 45 shows the areas where the program was implemented and the bores that have been plugged through the program.

Table 12 summarises the achievements in each phase of the Cap and Pipe the Bores program up to 2019. The number of bores controlled in (Table 12) includes bores that have been plugged, reconditioned and capped.

Table 12 Achievements up to year 2019 in each phase of Cap and Pipe the Bores program

Program	Number of bores controlled	Bore drains deleted (km)	Piping installed (km)	Water savings (ML/yr)
Pre GABSI (prior to July 1999)	86	1,391	2,812	9,051
GABSI – Phase 1 (1999 - 2004)	111	3,409	6,285	26,093
GABSI – Phase 2 (2004 - 2009)	117	3,036	5,256	25,075
GABSI – Phase 3 (2009 – 2014)	74	2,051	3,451	15,991
GABSI – Phase 4 (2014 – 2016)	9	62	77	3,254
IGABIIP (2017 – 2019)	4	14	14	864
Total	401	9,963	17,895	80,328

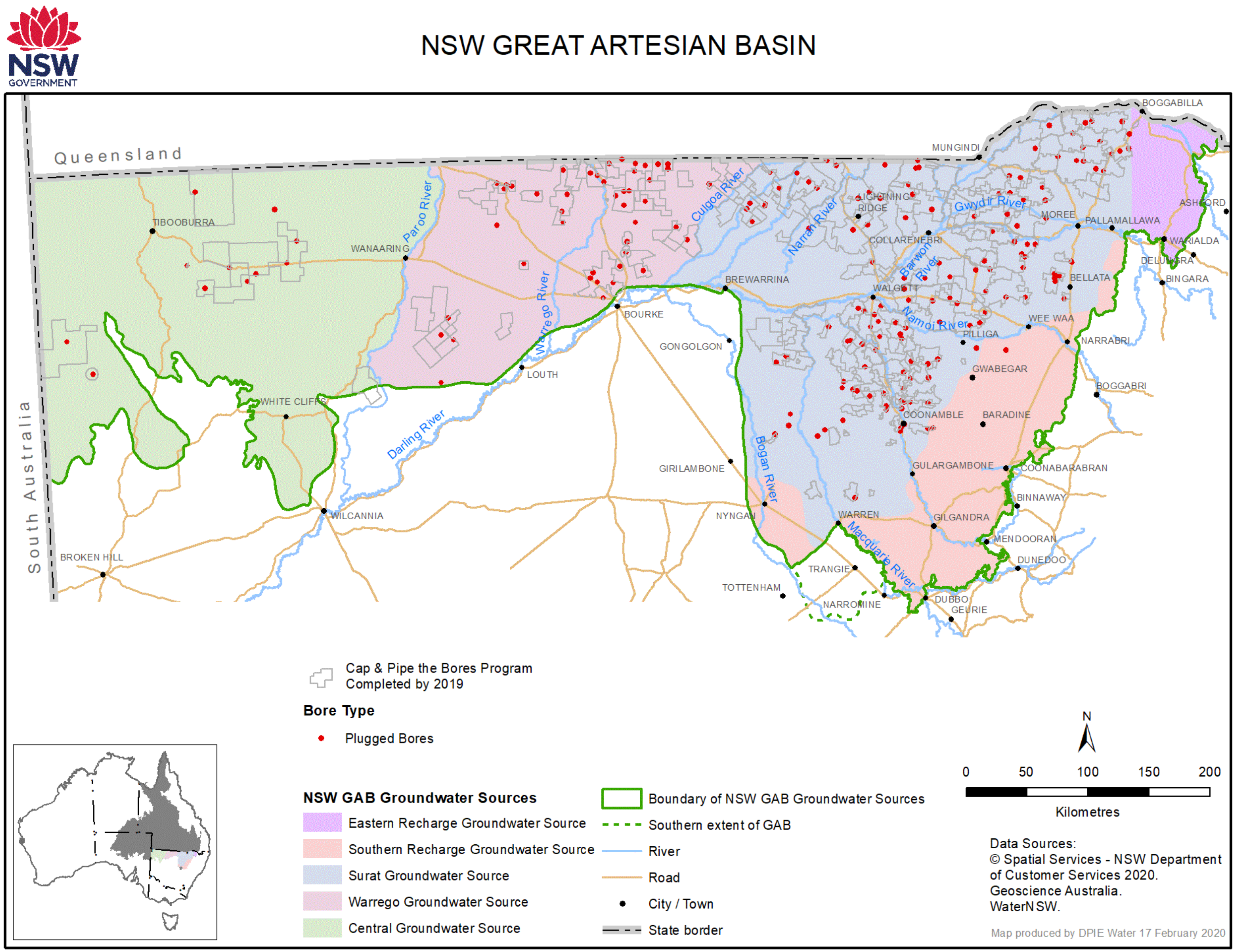

Figure 45 Artesian bores that have been plugged in the NSW GAB

Table 13 shows the total achievements of the program up to 2019 in these three groundwater sources.

Table 13 Achievements of Cap and Pipe the Bores program up to year 2019 in each groundwater source

Achievement	Surat	Warrego	Central	Total
Number of bores controlled	272	101	28	401
Bore drains deleted (km)	9,154	726	83	9,963
Piping installed (km)	15,982	1,430	483	17,895
Water Savings (ML/yr)	57,043	16,693	6,593	80,328

9.3 Bore survey program

Implementation of Cap & Pipe programs over the last three decades has resulted in pressure increases within the NSW GAB. This has led to a situation where a few bores which previously ceased flowing, recommenced flowing in some areas. Many artesian bores are ageing and the structural integrity of a number of bores is compromised. This can result in cross aquifer contamination and water wastage through leaking head works. Consequently, water wastage and salinity issues across the NSW GAB become emerging issue that requires attention through future water efficiency infrastructure programs.

To facilitate the future water efficiency infrastructure projects, DPIE carried out two phases of bore survey program in 2018 and 2019 across the NSW GAB to gather information on the condition of ageing artesian bores and the bores that are expected to recommence flowing. During the first phase of the survey in 2018, 226 bores were visited and during the second phase in 2019, 432 bores were visited.

Artesian bore head condition of about 390 bores still needs to be verified through the third phase of the bore survey that is planned in 2020.

During the bore survey, the information collected were condition of the bore, pressure, water level, flow, temperature, water quality and condition of water distribution system. As part of the bore survey, the landholders were interviewed about the condition of the bore and previous history of any flow conditions, and photographs of bore head and water distribution system were taken. Water samples from 12 artesian bores that are located near to springs were also collected for isotope analysis to determine the relationship of groundwater to the spring water.

On completion of each phase of bore survey, DPIE sent the survey results of the bores to the respective landholders who participated in the survey program.

The status of 658 bores has been updated using the information collected from the completed survey program. DPIE estimates that about 179 unrestricted bores, 109 unregulated bores and 399 regulated bores are in NSW GAB. Table 14 shows the distribution of the artesian bore categories in each GAB groundwater source and Figure 46 shows the spatial distribution of the same in the NSW GAB.

Table 14 Distribution of artesian bore categories in each NSW GAB Groundwater Source

Groundwater Source	Unrestricted	Unregulated	Regulated
Eastern Recharge	-	-	10
Southern Recharge	5	-	6
Surat	84	64	243
Warrego	78	41	110
Central	12	4	30
Total	179	109	399

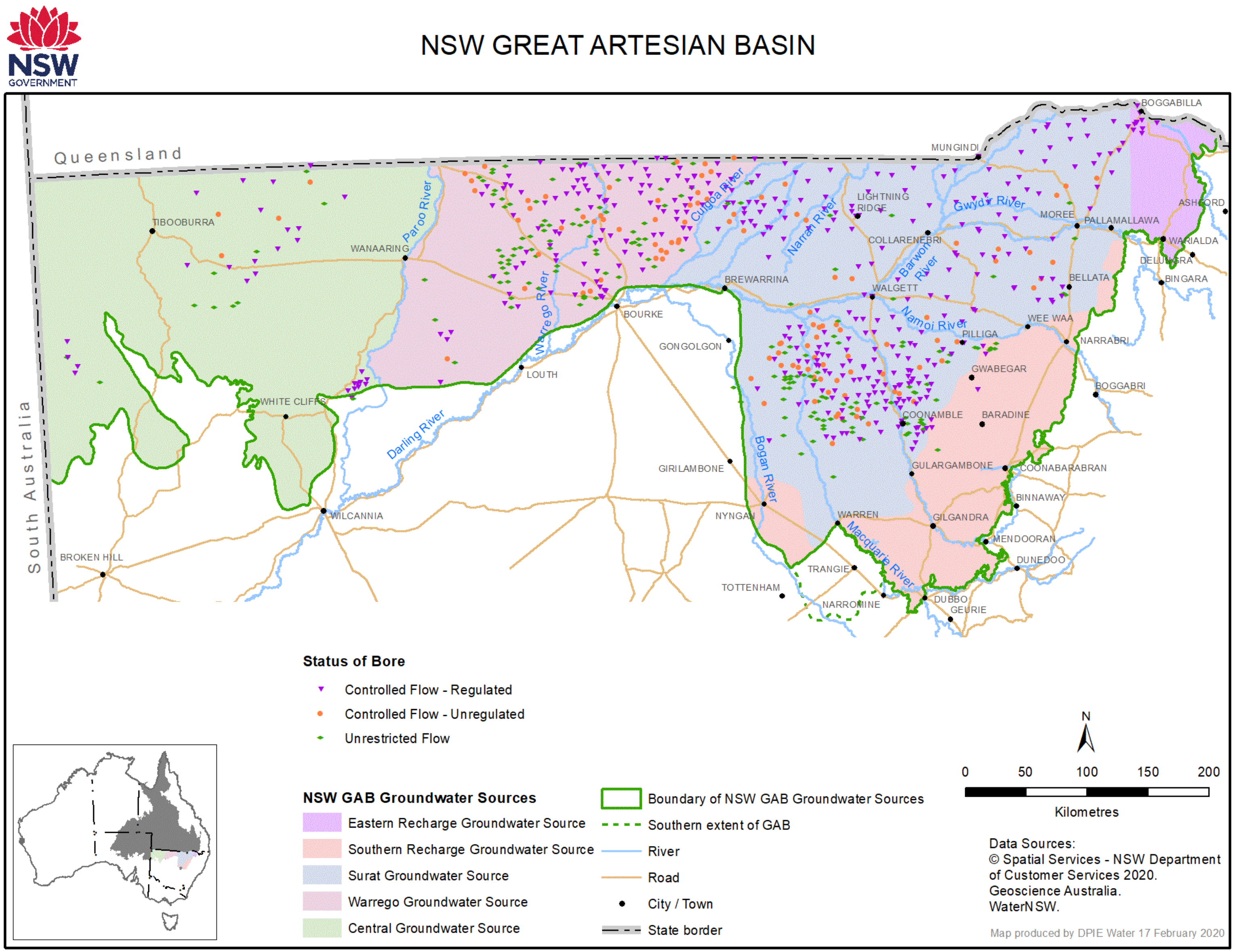

Figure 46 Status of artesian flow at the bore head

10 Groundwater Monitoring

WaterNSW 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 47 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 47 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 level 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 47 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 NSW GAB, WaterNSW monitors groundwater level, artesian pressure, artesian flow, temperature and to a lesser extent, general water quality in 210 pipes at 123 sites (Figure 48). The monitoring network currently includes 29 bores equipped with data loggers that record information continuously. These are all telemetered, so continuous real time data are available at WaterNSW web site (http://realtimedata.waternsw.com.au/water.stm).

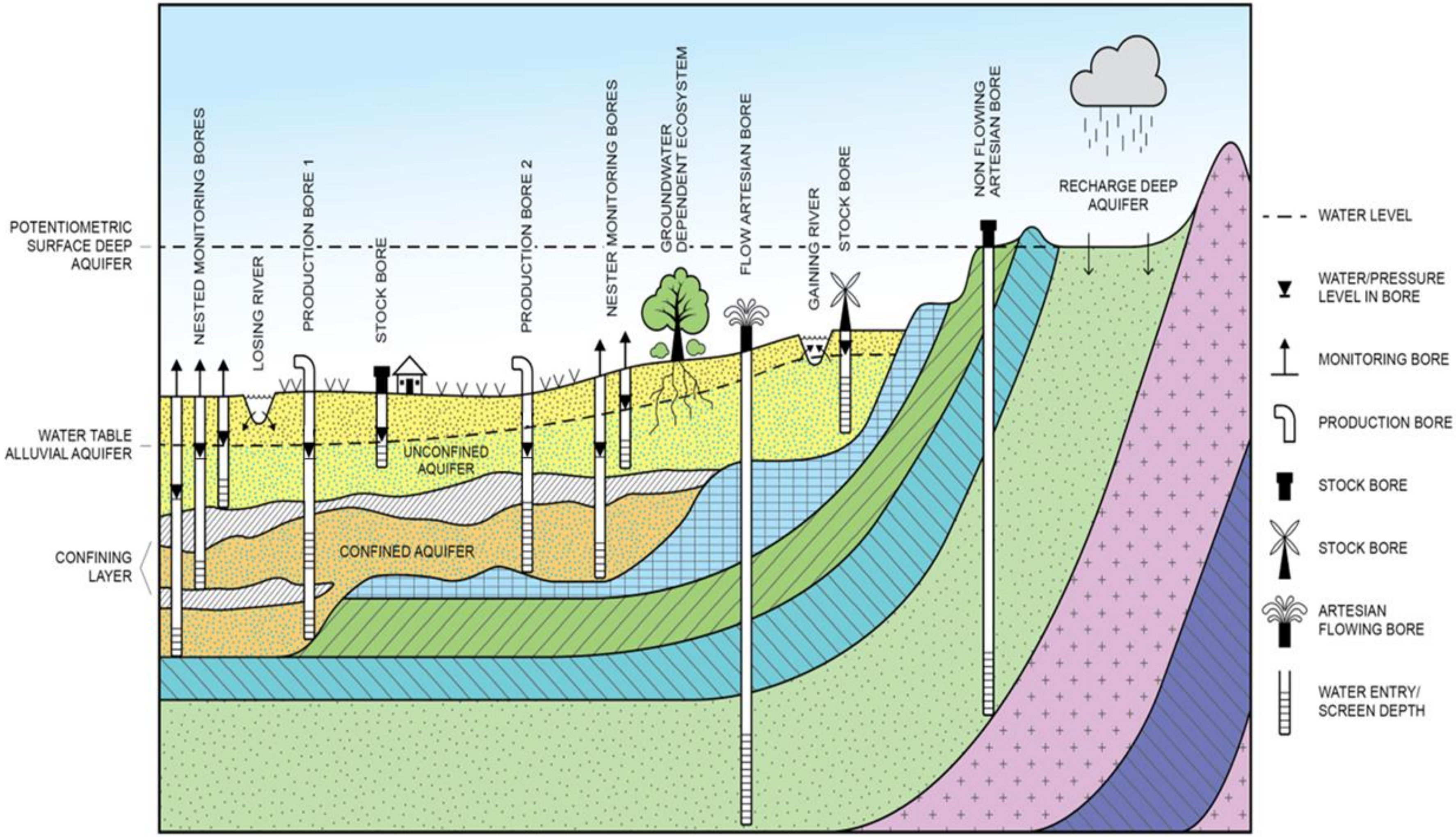

Figure 47 Schematic diagram of different types of aquifers

10.1 Groundwater Level

The groundwater level is monitored in 90 pipes at 57 sites in the Eastern & Southern Recharge Groundwater Sources. The monitoring includes real time groundwater level recording at 16 sites. At a few monitoring sites, there are two or more pipes monitoring aquifers at different depths. The depth monitored by each pipe corresponds to the median depth interval at which the casing is slotted to allow groundwater entry into the pipe.

10.2 Artesian pressure, flow and temperature

Measurement of groundwater pressure, flow and temperature in the NSW GAB groundwater sources started in the early 1900s. Over 300 flowing private bores have been monitored for artesian pressure in the last 120 years. The monitoring discontinued in many bores as they were either deemed unsuitable for monitoring due to deteriorating structural condition of the bores or were decommissioned under the Cap & Pipe the Bores program.

Currently, artesian pressure, flow and temperature are monitored in 66 private bores. This monitoring includes real time recording of the data at 13 bores.

The artesian pressure values are dependent on the temperature and salinity of the groundwater. As these values vary across these groundwater sources, the pressure values have to be corrected to equivalent freshwater head at 25°C for flow direction analysis. As such, the raw pressure value measured at bore head cannot be used to infer groundwater flow directions and rates. The flow directions discussed earlier in Section 5 is based on the potentiometric pressure surface derived from the corrected equivalent freshwater hydraulic head values.

The artesian flow rate in a bore is a function of artesian pressure of the aquifer and bore efficiency that relates to losses due to friction inside the bore casing and inter-aquifer leakage. As such, the measured flow rate is not appropriate to be used to infer pressure gain and losses in the groundwater sources. Hence, the analysis of artesian flow rates is not provided in this report, but the general description of artesian flow in each groundwater sources is provided in section 5.

10.3 Groundwater quality

There is no routine monitoring of groundwater quality in the NSW GAB groundwater sources in the last 20 years other than ad hoc sampling of electrical conductivity (EC) of the artesian water of a few bores. The real time EC of the flowing artesian bores is also monitored at 13 artesian bore sites. Water quality information of a number of bores in the NSW GAB were collected in 2018 and 2019 through the two phases of bore survey.

CSIRO Great Artesian Basin Water Resource Assessment (2012) reviewed the historical records of basic water quality information available in the WaterNSW water databases along with the data available from industries and other participating Great Artesian Basin States and Territory. A summary of the assessment’s findings and an extract of water quality information relevant to the NSW GAB from the data compiled to make the “Hydrogeological Atlas of Great Artesian Basin” (Ransley, et al., 2015) are provided in section 7 of this report.

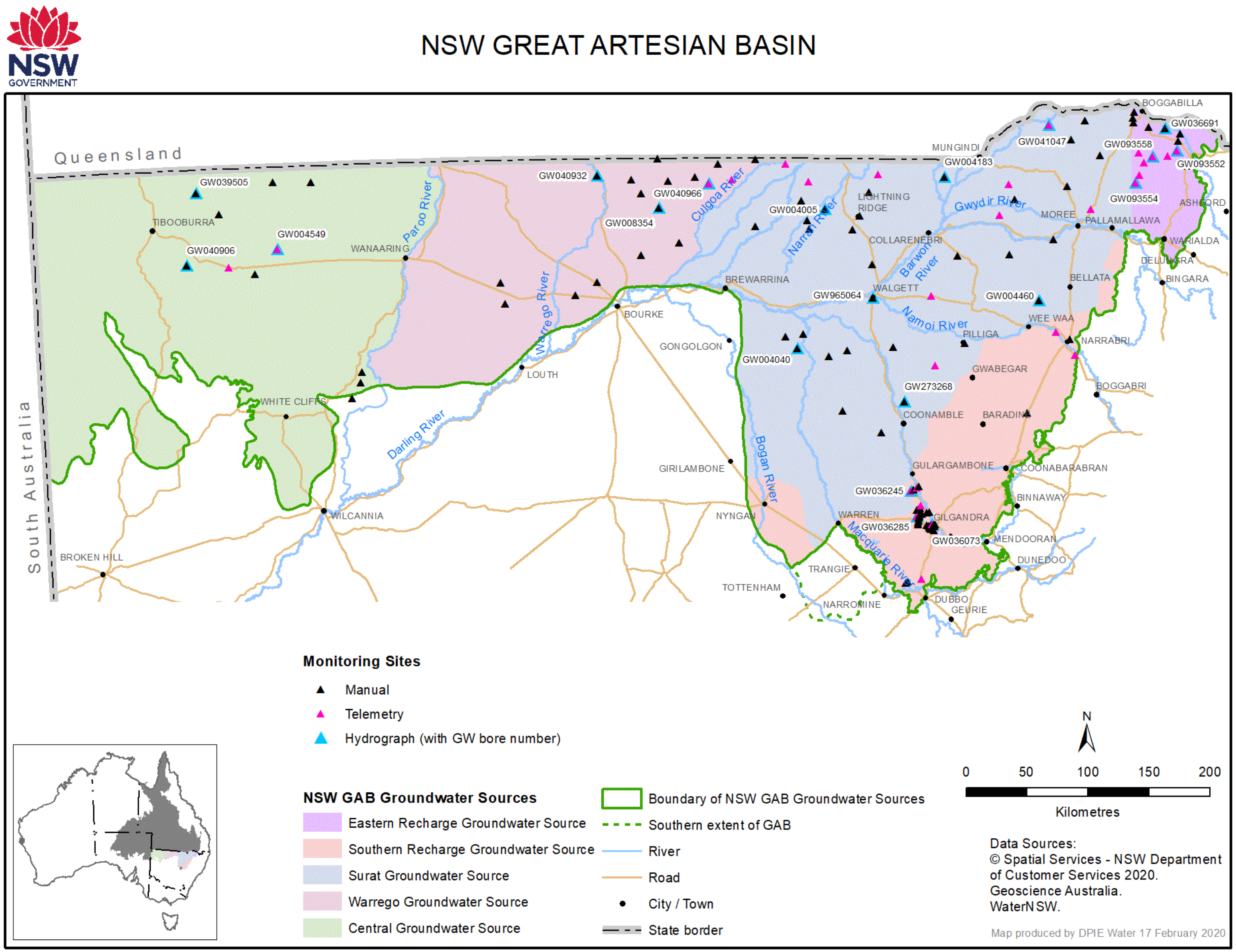

Figure 48 Location of Monitoring Sites

11 Groundwater Behaviour

11.1 Introduction

The reference condition to which long term trends are compared is the ‘pre-GABSI’ water level. In the NSW GAB Groundwater Sources, the ‘pre-GABSI’ is defined as the average recovered water level experienced in year 1990 circa. Changes in groundwater levels in the NSW GAB Groundwater Sources are discussed in the following sections presenting data from hydrographs.

11.2 Hydrographs

A hydrograph (Figure 49) is a plot of groundwater level or pressure head from a monitoring bore over time. 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 49 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.

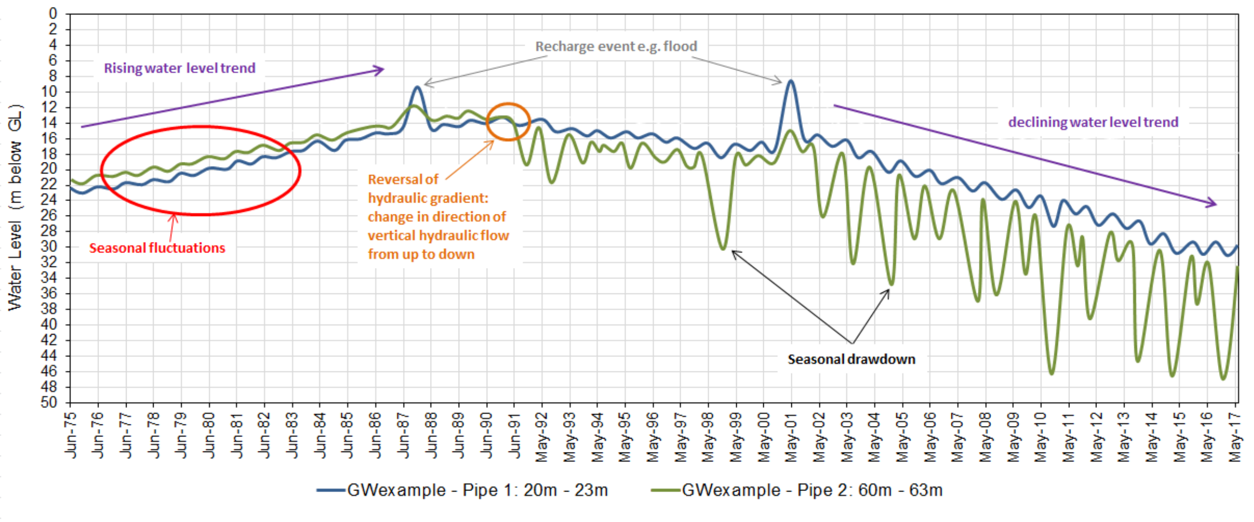

Figure 49 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate

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.

11.3 Review of groundwater levels

The hydrographs of bores illustrate the groundwater level variations over time from the median depth indicated by the pipe's slots. The location of the bores in NSW GAB for which the hydrographs are provided is shown in Figure 48. In the hydrographs, the groundwater level below ground is expressed as a positive value in metres whereas artesian head above ground is expressed as a negative value in metres.

The hydrographs of artesian bores assume that the pressure measurement is taken at ground level for the bores for which the measurement points are not surveyed to Australian height datum (AHD). The elevation of ground level for such bores is taken from NSW digital elevation model.

Where an artesian bore with a long history of monitoring is plugged and a replacement bore is drilled near that location to access the same aquifers, the hydrograph shows the groundwater levels of both the replacement bore and the plugged bore.

All private artesian bores monitored for pressure are slotted against multiple aquifers. The shut off pressure measured at the bore head represents the resultant pressure of all the slotted aquifers combined. The measured artesian pressure is not corrected for temperature and density of the water as these hydrographs are provided for illustrative purposes and not used for flow analysis.

11.3.1 Eastern Recharge Groundwater Source

Bores GW093552, GW093554 and GW093558 are located in an area where there is an intensive groundwater irrigation activity. The hydrographs (Figure 50 to Figure 52) show that the groundwater level drops down to about 25 m during the irrigation season in some locations, but recovers well during the non-pumping season. However, the recovered water level shows a declining trend in the last five water years.

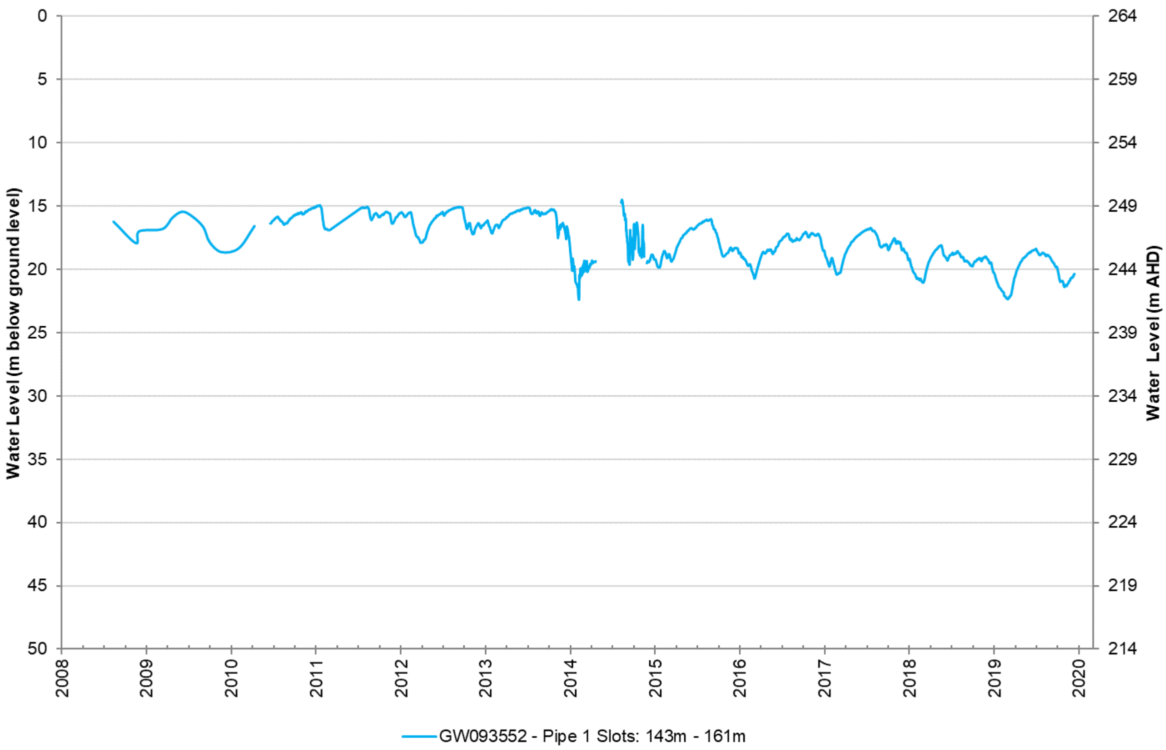

Figure 50 Hydrograph of bore GW093552 - Eastern Recharge Groundwater Source

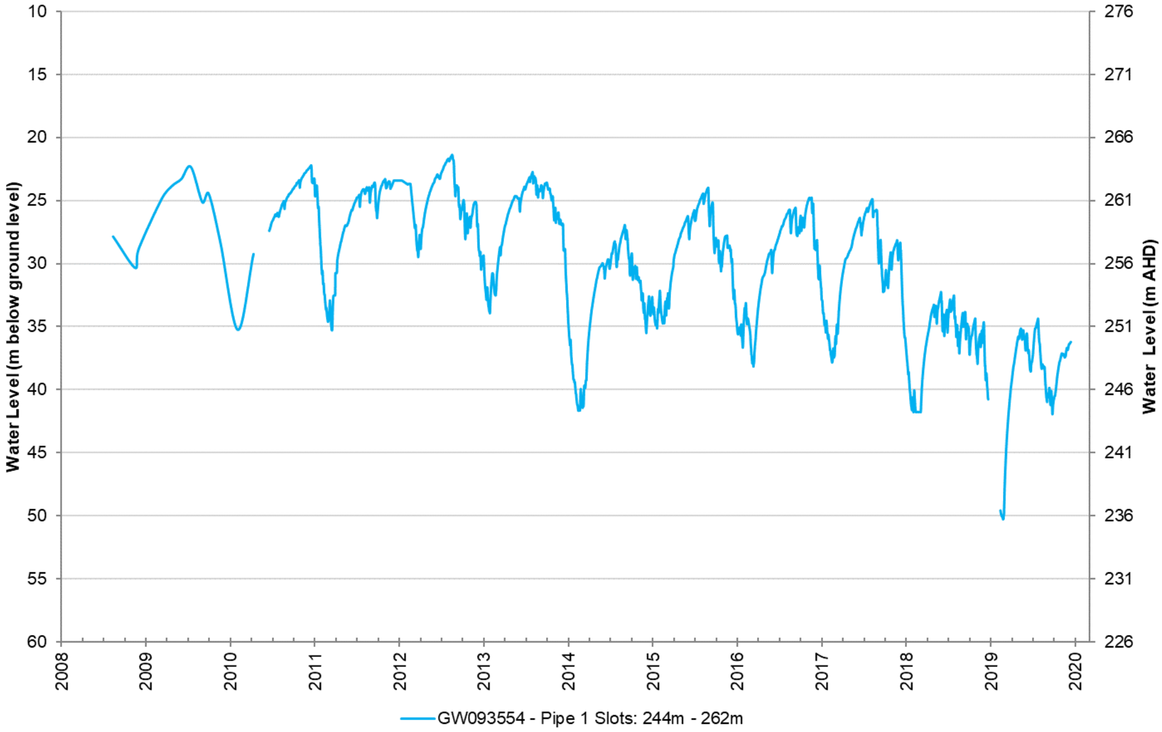

Figure 51 Hydrograph of bore GW093554 - Eastern Recharge Groundwater Source

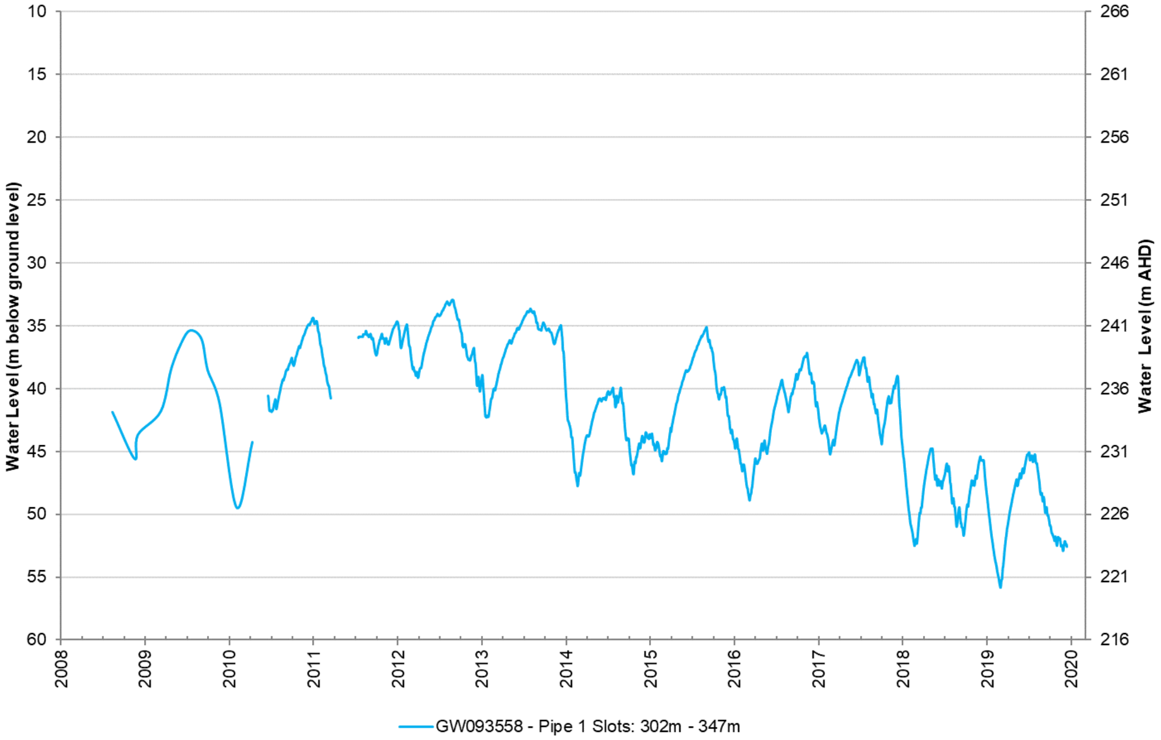

Figure 52 Hydrograph of bore GW093558 - Eastern Recharge Groundwater Source

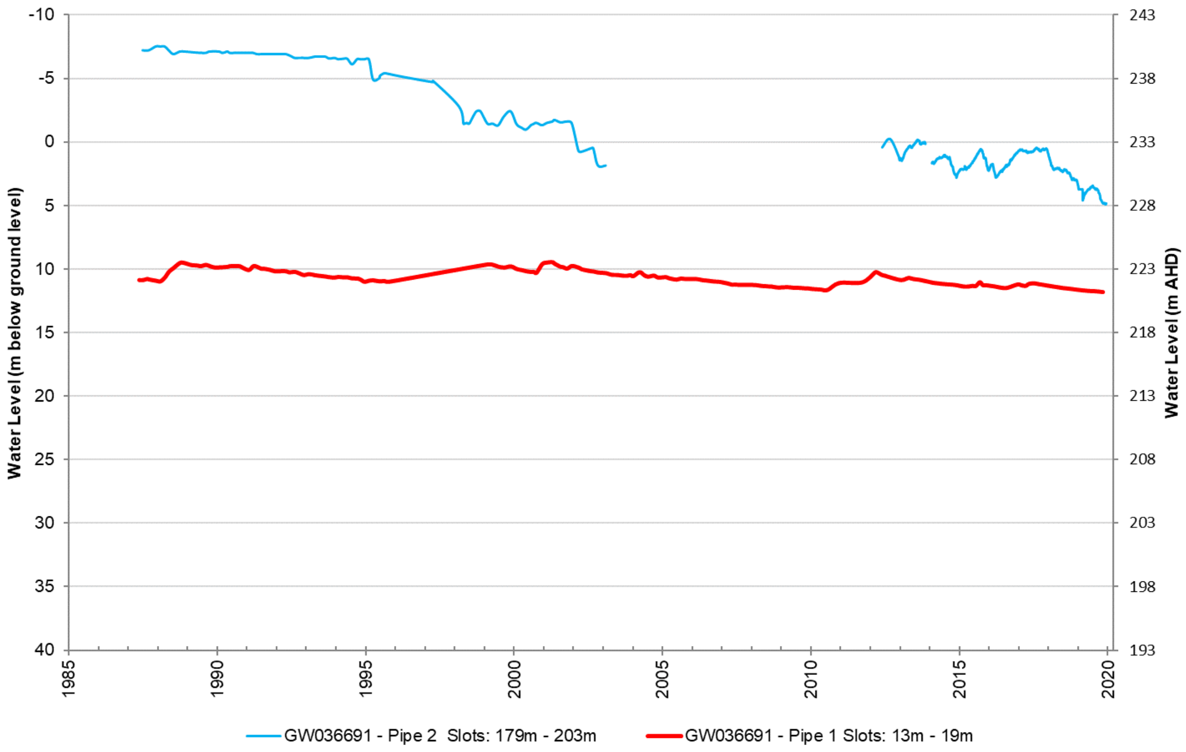

Figure 53 Hydrograph of bore GW036691 - Eastern Recharge Groundwater Source

Bore GW036691 is located near Ottleys Creek. The shallow pipe, pipe 1, is completed in the Ottleys Creek alluvium and the deeper pipe, pipe 2, is in the underlying Eastern Recharge Groundwater Source. The hydrograph (Figure 53) shows a potential head difference for upward leakage from the Eastern Recharge Groundwater Source to the overlying Ottleys Creek alluvium. It also shows a steady decline of artesian head in pipe 2 over the time due to significant groundwater extraction in the Eastern Recharge Groundwater Source.

11.3.2 Southern Recharge Groundwater Source

Bore GW036073 is the only monitoring bore in Southern Recharge Groundwater Source which is located near a bore linked to an access licence used for a relatively high level of groundwater extraction. The hydrograph (Figure 54) shows seasonal pumping stresses caused by the nearby bore used for Gilgandra town water supply.

Bore GW36285 has two pipes and it is located about 7 km east of the south western boundary of Surat Groundwater Source. The pipe 1 is slotted against the shallow aquifer of no economic importance in unconsolidated sediments whereas the pipe 2 is slotted against sandstone aquifers where there is no significant groundwater extraction taking place other than for basic landholder rights use. The hydrograph (Figure 55) shows gentle rising and declining trends in pipe 1 and pipe 2, respectively.

Bore GW036245 is located about 4 km east of the south western boundary of Surat Groundwater Source in Armatree. The hydrograph (Figure 56) shows minor fluctuation of groundwater level due to seasonal climatic variations.

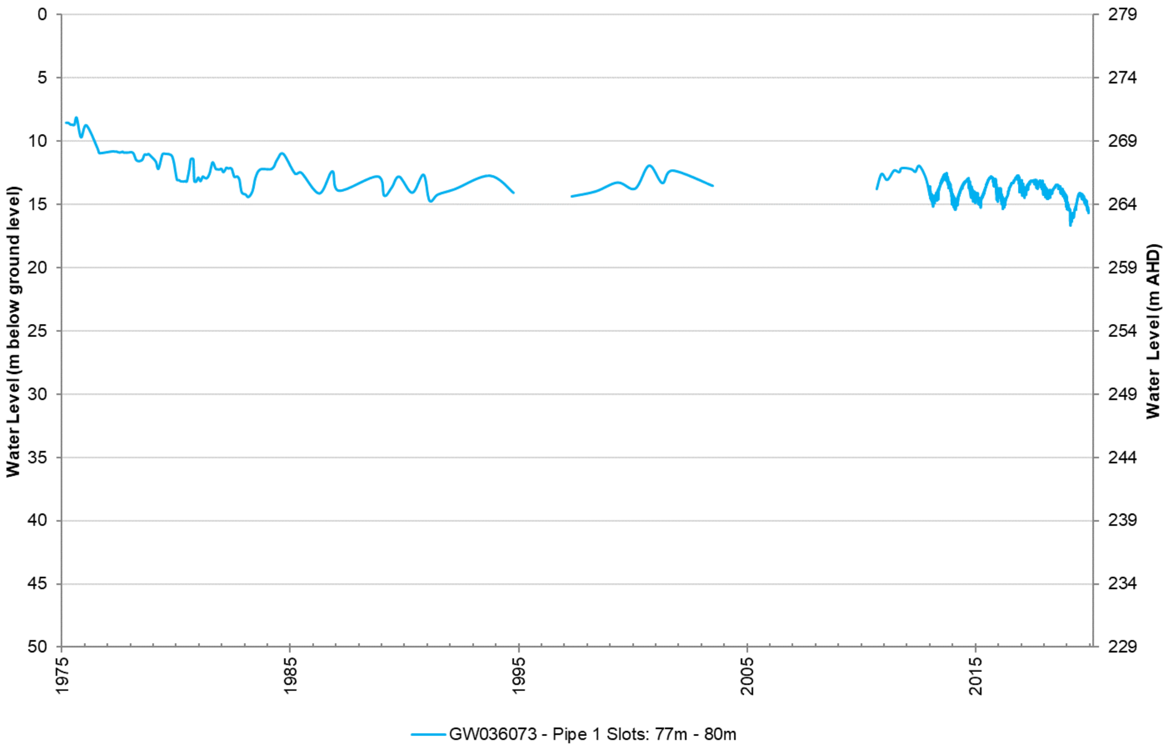

Figure 54 Hydrograph of bore GW036073 - Southern Recharge Groundwater Source

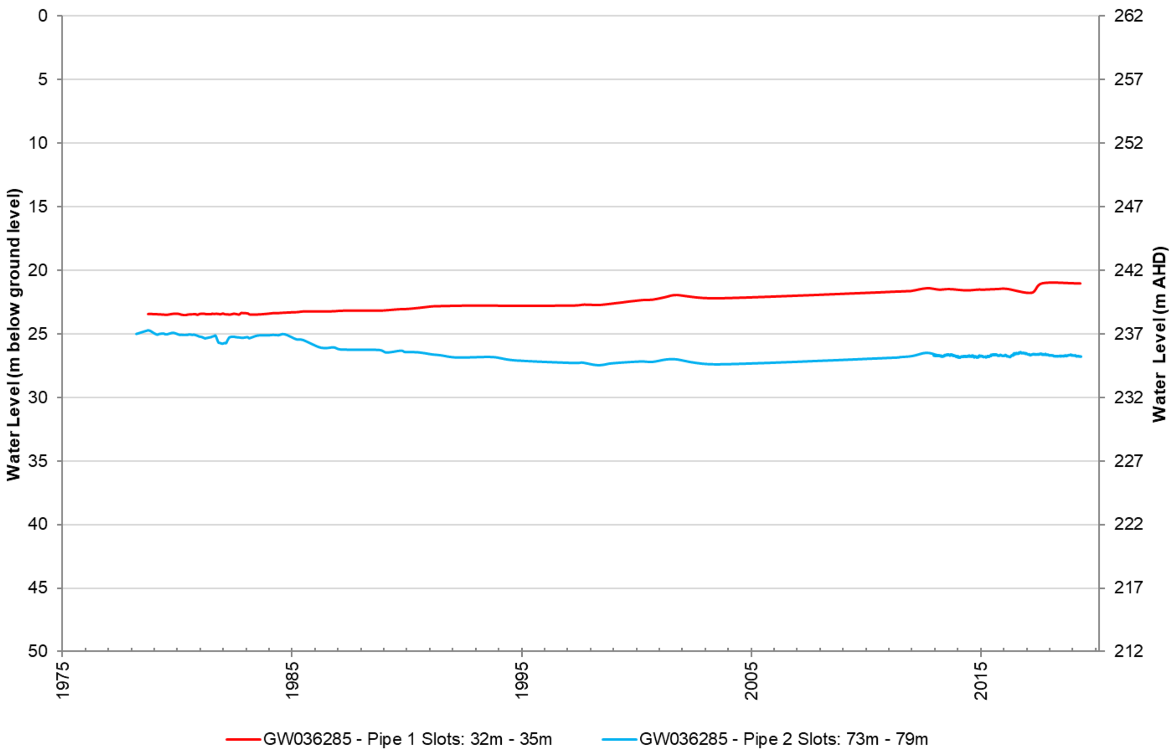

Figure 55 Hydrograph of bore GW036285 - Southern Recharge Groundwater Source

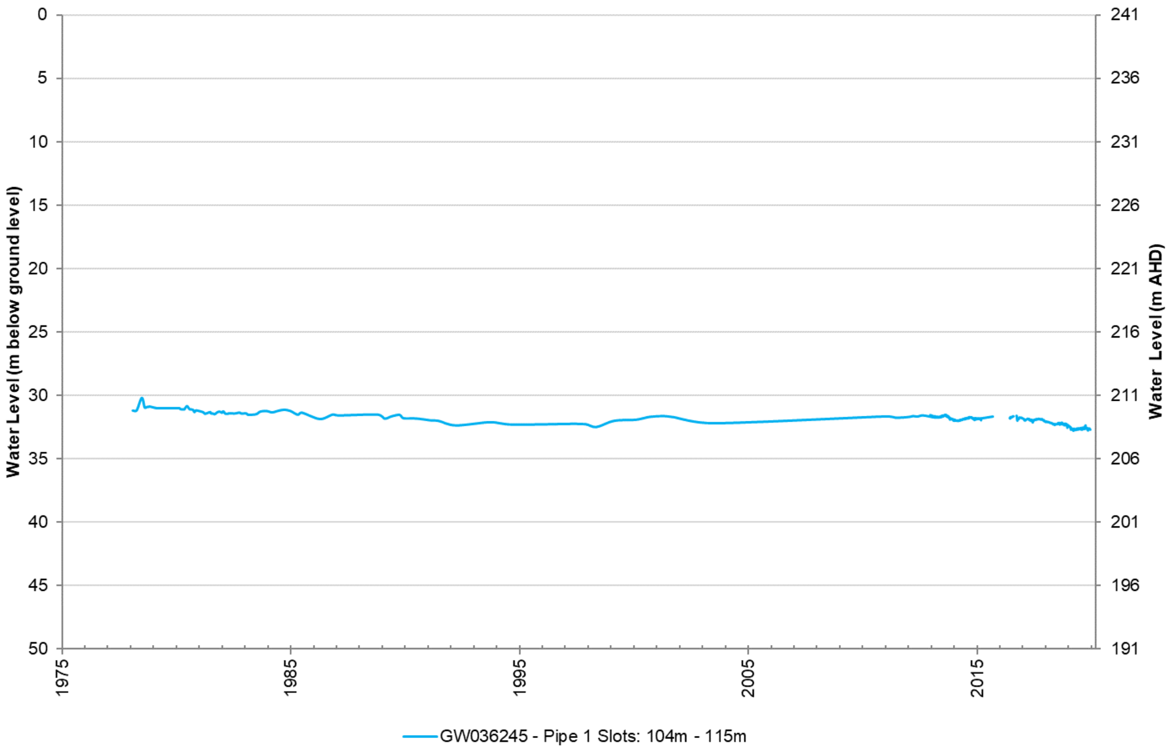

Figure 56 Hydrograph of bore GW036245 - Southern Recharge Groundwater Source

11.3.3 Surat Groundwater Source

The Surat Groundwater Source is large in size; hence hydrographs of seven bores (Figure 57 to Figure 63) are presented to show the artesian pressure recovery in this water source.

The hydrograph (Figure 57) of bore GW273268 (Whittonbri No 2) and bore GW001654 (Whittonbri) shows that in the last three decades the artesian head rose by about 12 m and currently the artesian head is about 6 m above the pre 1930's head. The plugging of bore GW001654 and two other unrestricted flowing bores within 5 km radius of this location contributed to the artesian pressure recovery in this area.

The hydrograph (Figure 58) of bore GW004040 (Brewon No 2) shows that the declining artesian head is reversed with a gentle rise of artesian head. The rise is attributed to capping and rehabilitation of an unrestricted flowing bore GW004044 (Brigalow) that is located about 11 km away from the bore GW004040.

The artesian head (Figure 59) in bore GW004005 (Bangate No 2) rose by about 12 m in the last three decades. After replacement of the gate valve at the bore head in 1997 and subsequent rehabilitation of the bore in early 2000s, the flow form the bore is now controlled. The reduced wastage of water after the rehabilitation of the bore contributed to the pressure recovery in this area.

The artesian head (Figure 60) in bore GW004183 (Eulalie) rose by more about 10 m in the last three decades. This bore was relined in 2002 with new head works. The rise in groundwater level is attributed to plugging of 6 unrestricted flowing bores within 30 km of this monitoring bore.

The hydrograph (Figure 61) of bores GW041047 (Boomi East No 2) and GW004024 (Boomi) shows that the artesian head recovered by 7 m in the last three decades. The rapid recovery of the artesian head since 2006 is attributed to plugging of four unrestricted flowing bores within 25 km radius of bore GW041047.

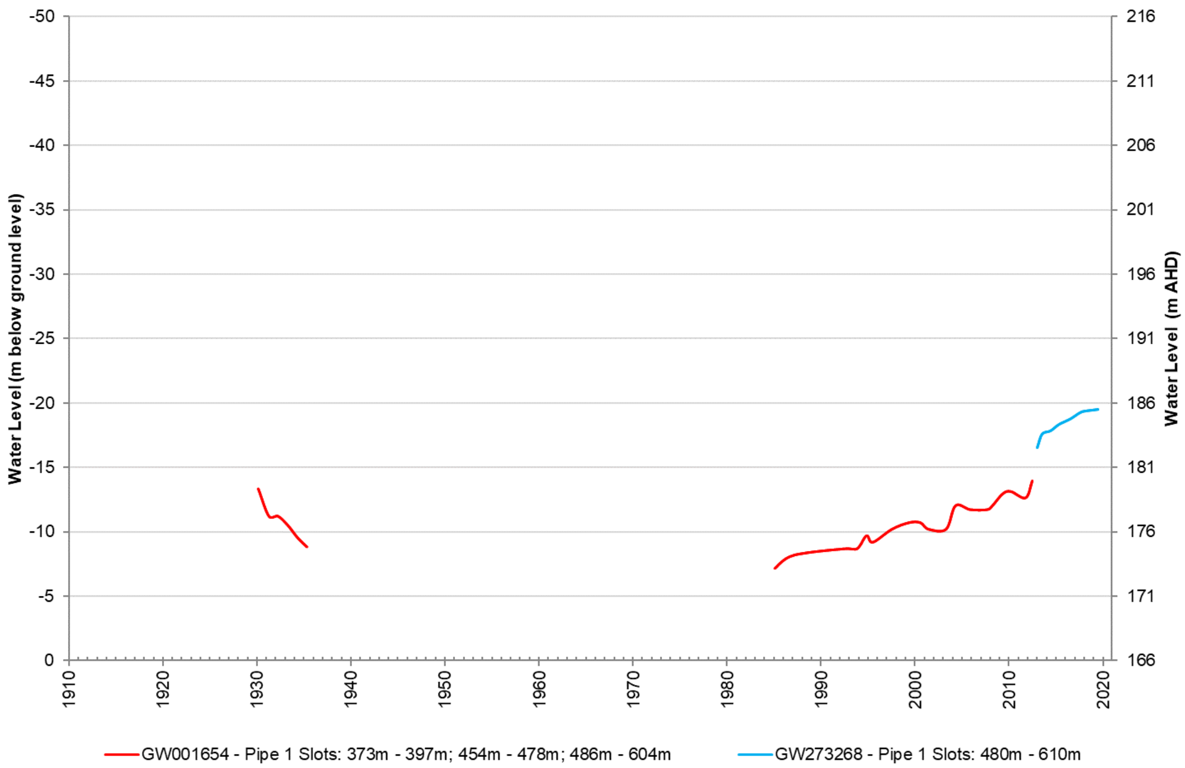

Figure 57 Hydrograph of bores GW001654 (Whittonbri - Plugged) and GW273268 (Whittonbri No 2) - Surat Groundwater Source

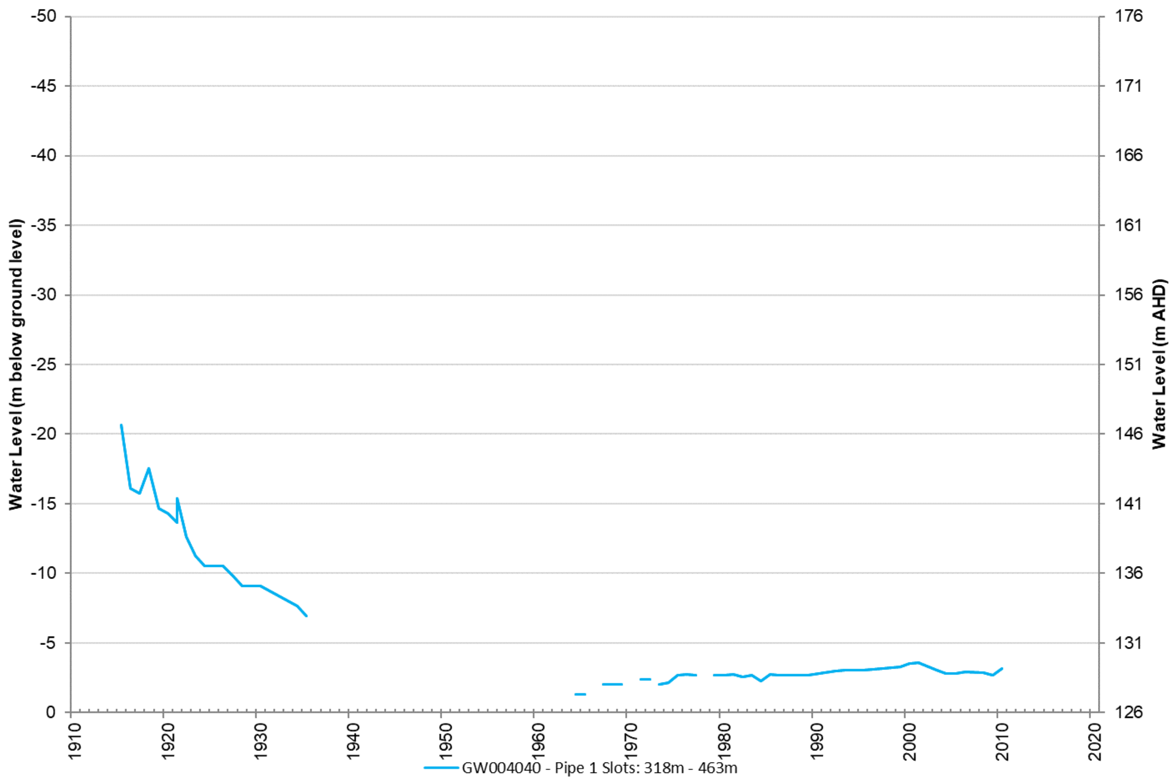

Figure 58 Hydrograph of bore GW004040 (Brewon No 2) - Surat Groundwater Source

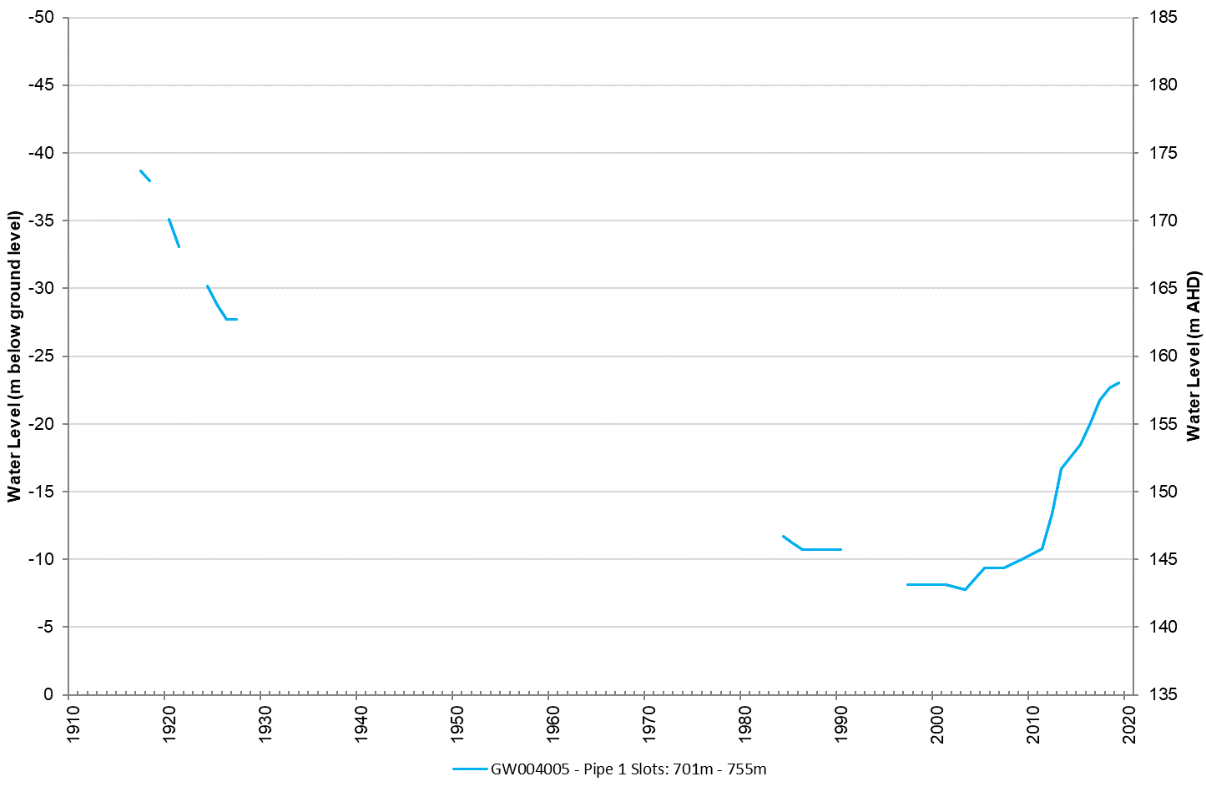

Figure 59 Hydrograph of bore GW004005 (Bangate No 2) - Surat Groundwater Source

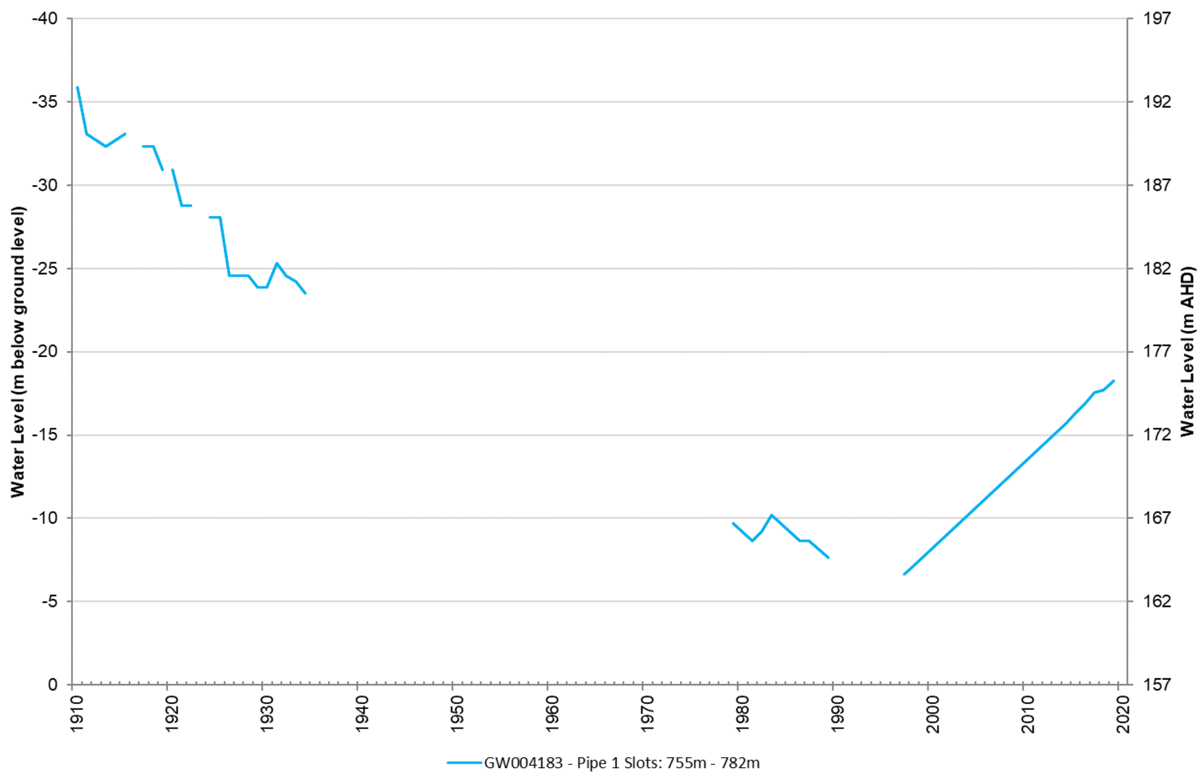

Figure 60 Hydrograph of bore GW004183 (Eulalie) - Surat Groundwater Source

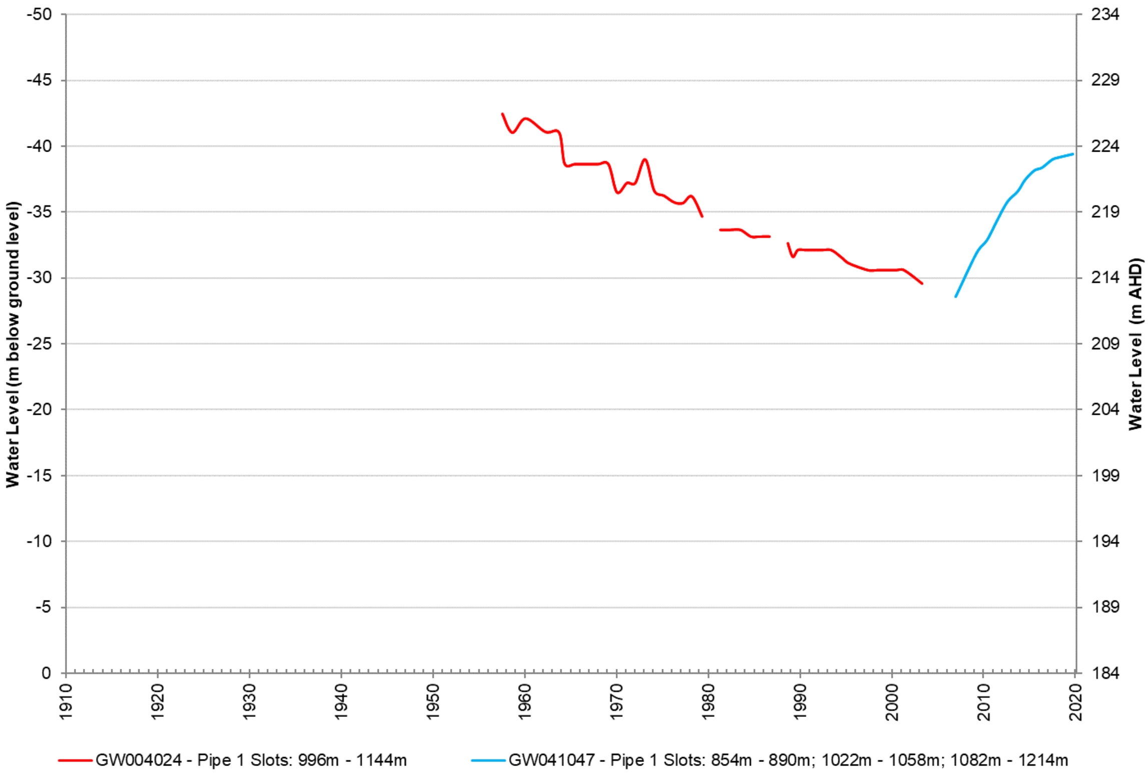

Figure 61 Hydrograph of bores GW004024 (Boomi - Plugged) and GW041047 (Boomi East No 2) - Surat Groundwater Source

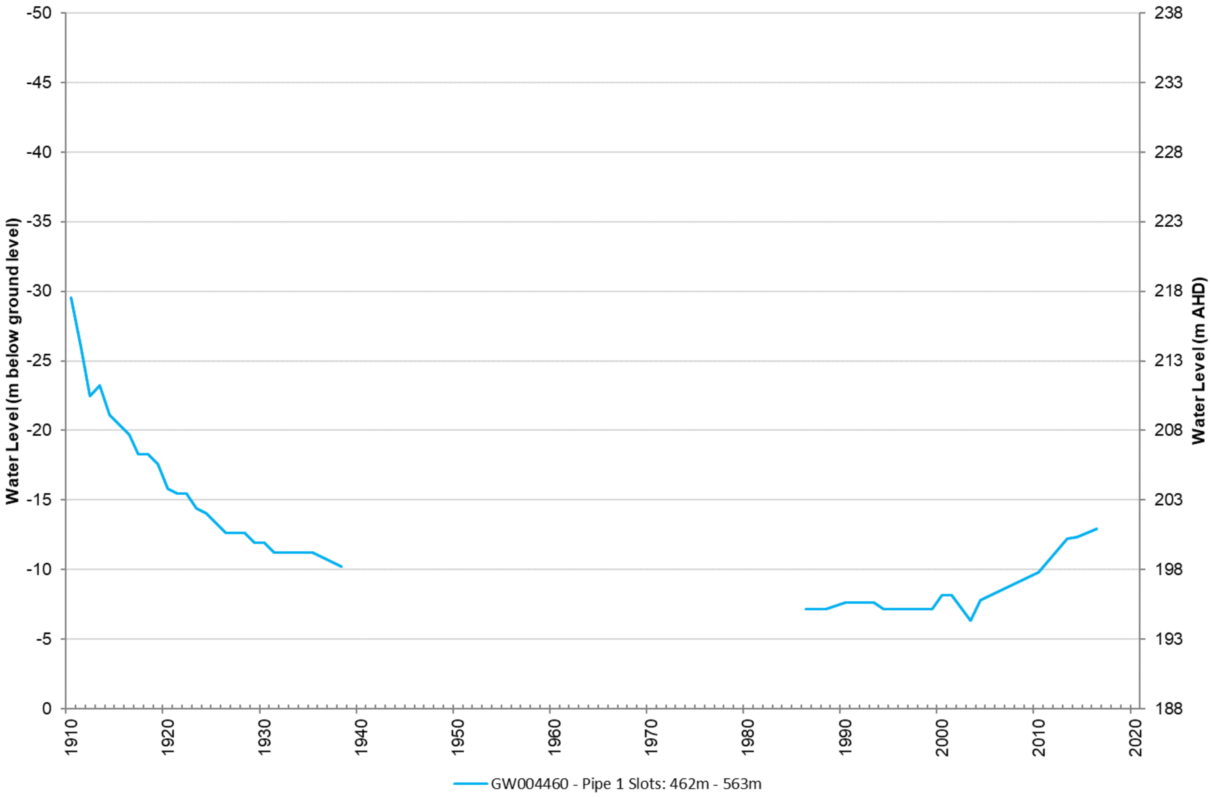

Figure 62 Hydrograph of bore GW004460 (Roma) - Surat Groundwater Source

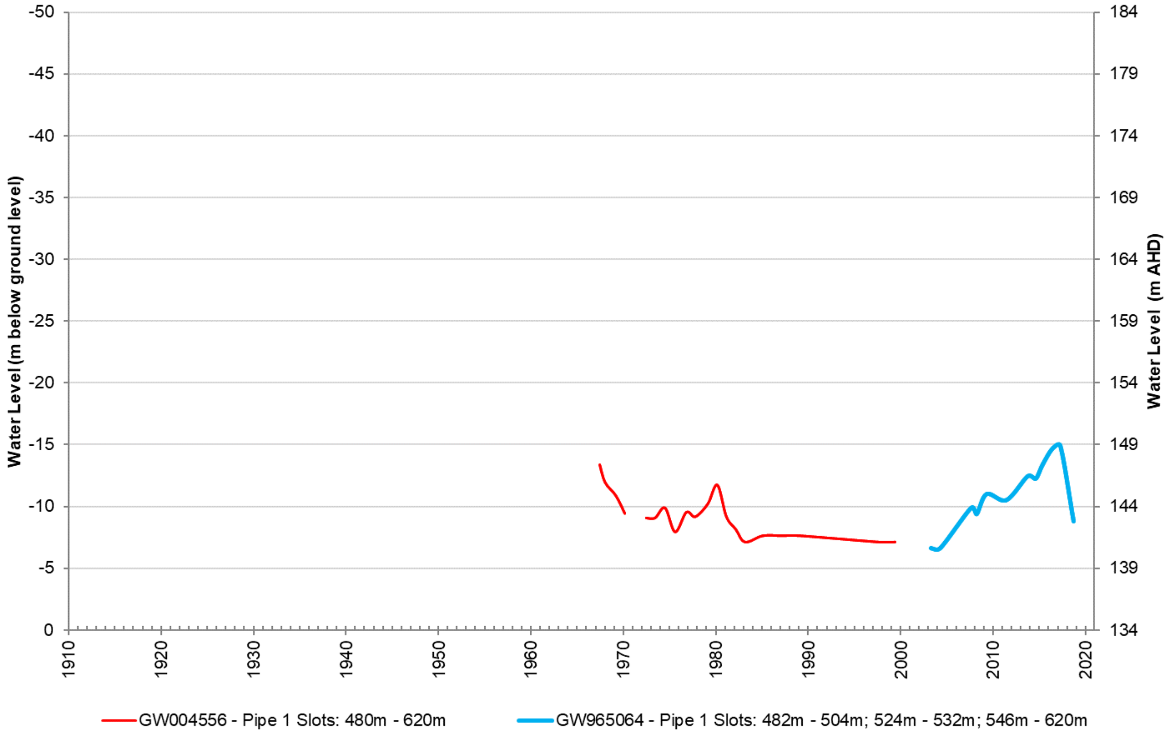

Figure 63 Hydrograph of bores GW004556 (Walgett TWS - Plugged) and GW965064 (Ulumbie No 2) - Surat Groundwater Source

The artesian head (Figure 62) in bore GW004460 (Roma) that is located about 16 km west of boundary with Southern Recharge Groundwater Source, recovered by about 5 m in the last three decades. Slow and steady recovery of pressure is attributed to plugging of 5 unrestricted flowing bores within 25 km of the bore GW004460.

The hydrograph (Figure 63) of bores GW965064 (Ulumbie No 2) and (Walgett TWS) shows that the artesian head recovered by about 7 m in the last three decades to pre 1965 level. The pressure recovery is attributed to the plugging of six flowing bores within 25 km of the bore GW965064. However, due to drought related intensive extraction from the bore for town water supply, the water level dropped by about 6 m in the last two years.

11.3.4 Warrego Groundwater Source

The hydrograph (Figure 64) of bores GW040966 (Orana) and GW004609 (Weilmoringle No 2) shows the artesian head recovered by about 8 m in 13 years. Only a single bore GW004609 is plugged in this area.

The hydrograph (Figure 65) of bore GW040932 (Belalie No 8) shows that the artesian head recovered by over 4 m in the last 15 years. The slow recovery of groundwater level is attributed to the plugging of four unrestricted low flowing bores and capping of two bores within 25 km radius of the bore GW040932.

The hydrograph (Figure 66) of bore GW008354 (Oswald) shows that the artesian head recovered by over 16 m in the last three decades. The fluctuation in the artesian head prior to 1980 is related to alterations to the casings done in 1970s. The artesian head recovery is attributed to the plugging of a bore and rehabilitation of another bore within 20 km radius of the bore GW008354.

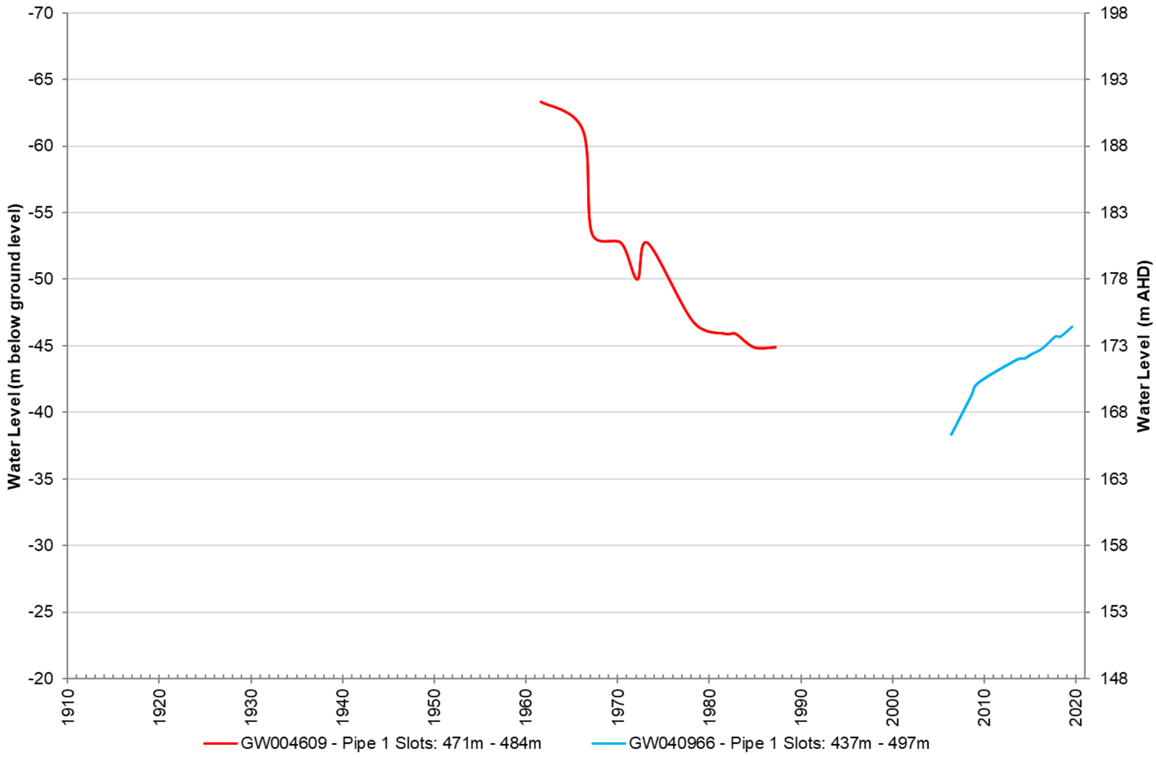

Figure 64 Hydrograph of bores GW004609 (Weilmoringle No 2 - Plugged) and GW040966 (Orana) - Warrego Groundwater Source

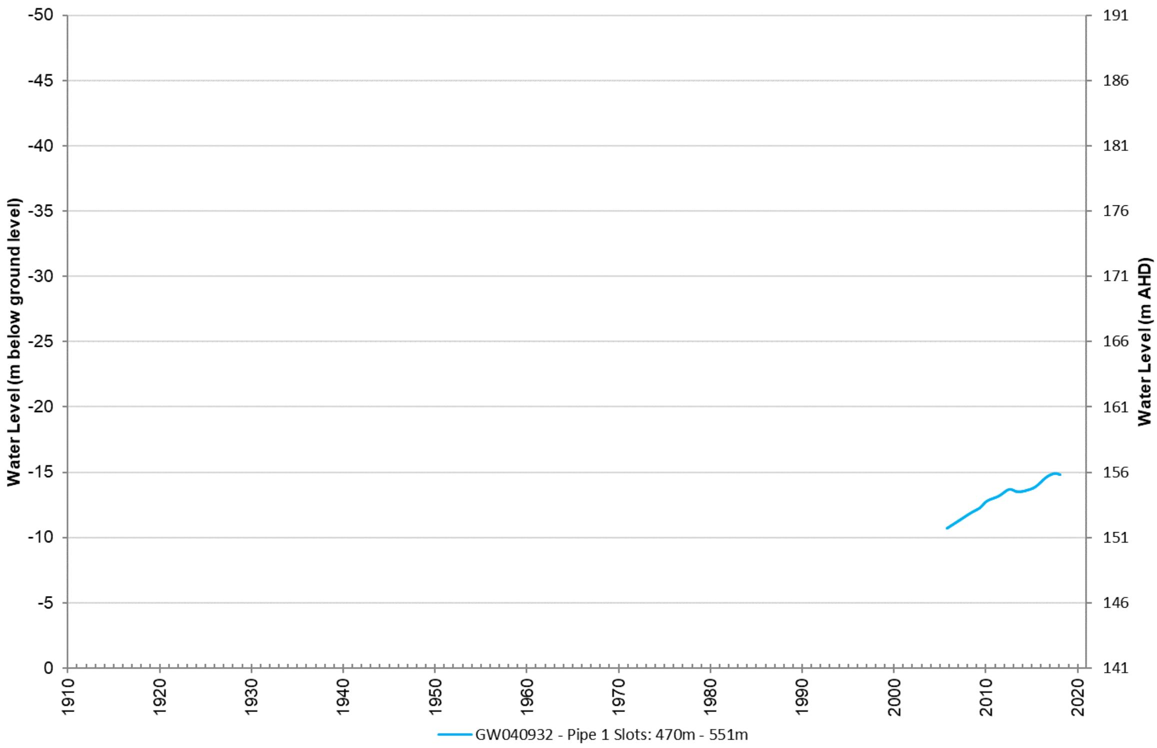

Figure 65 Hydrograph of bore GW040932 (Belalie No 8) - Warrego Groundwater Source

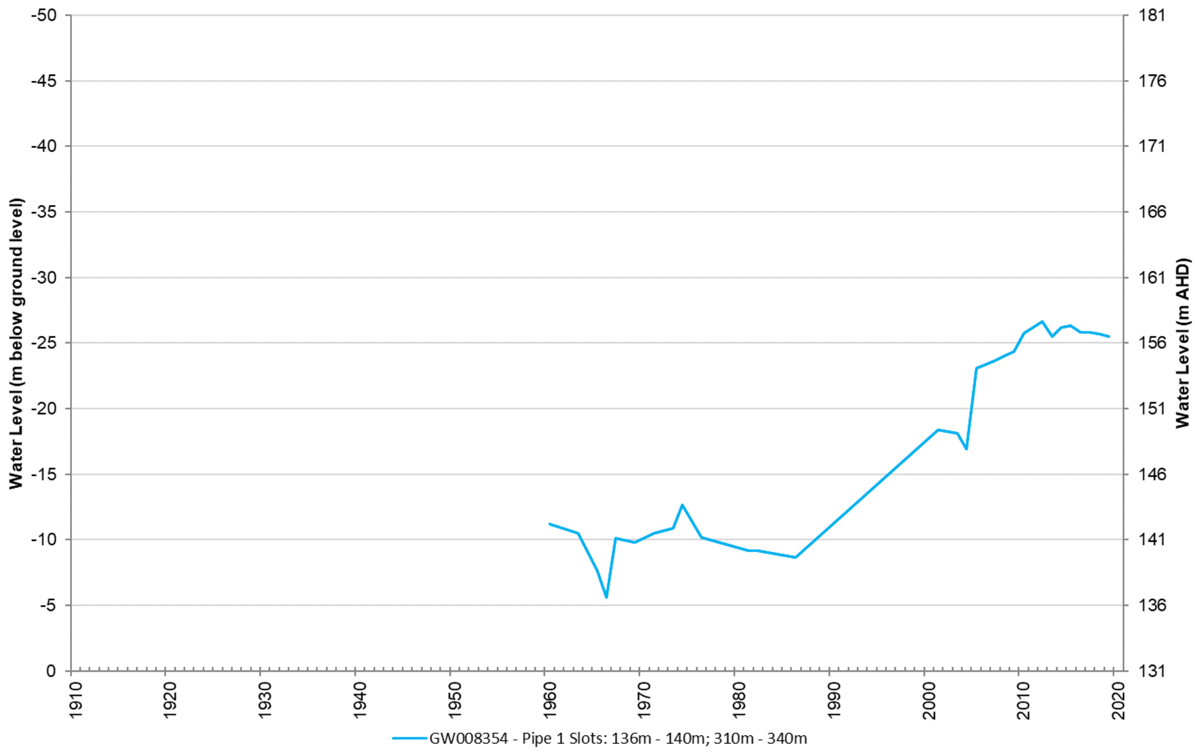

Figure 66 Hydrograph of bore GW008354 (Oswald) - Warrego Groundwater Source

11.3.5 Central Groundwater Source

The hydrograph (Figure 67) of bores GW040906 (Tineroo No 2) and GW004515 (Tineroo) shows that the artesian head recovered by about 4 m in the last two decades. The artesian head recovery is attributed to the elimination of wastage of water by plugging of the leaking bore GW004515.

The hydrograph (Figure 68) of bore GW039505 (Caryapunda No 2) shows that the artesian head is stable in the last decade. This bore replaced an unrestricted flowing bore that was plugged in mid 1990s.

The hydrograph (Figure 69) of bore GW004549 (Urisino No 4) shows slight rise in the artesian head followed by gentle decline after early 1980s. The rise in the artesian head is due to reconditioning and capping of this unrestricted flowing bore in early 1960s. The current water level is about 0.5 m below the level experienced in early 1960s.

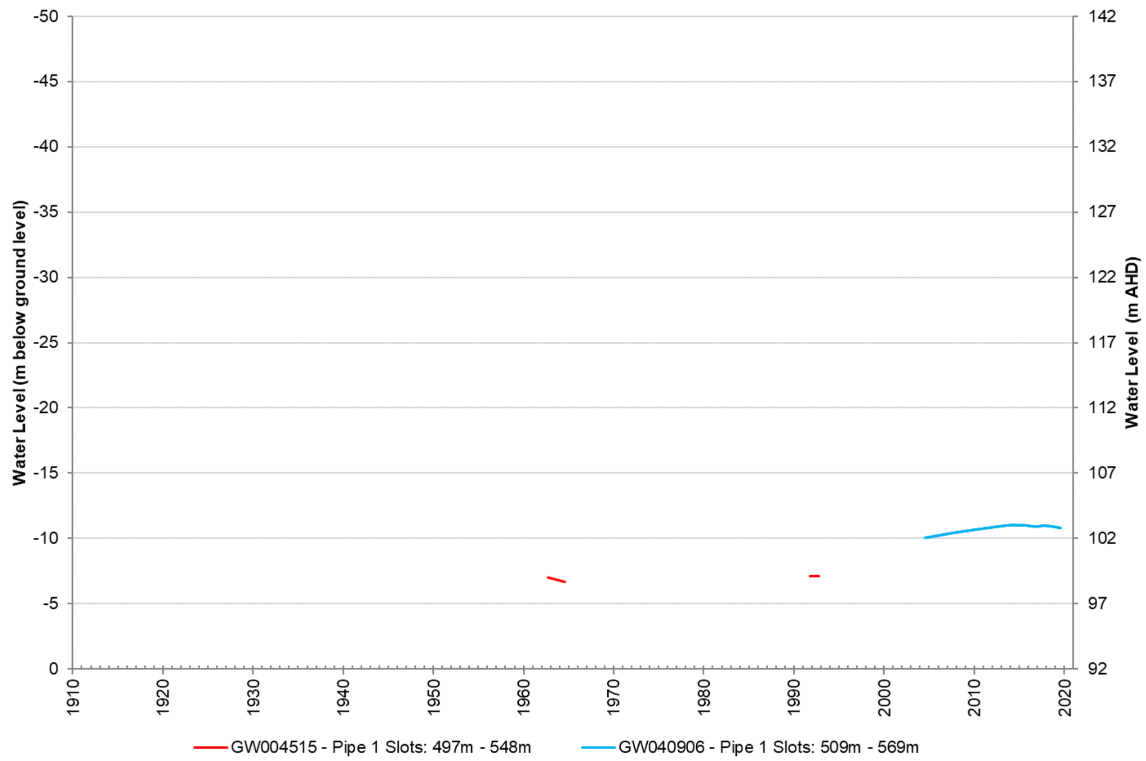

Figure 67 Hydrograph of bores GW004515 (Tineroo - Plugged) and GW040906 (Tineroo No 2) - Central Groundwater Source

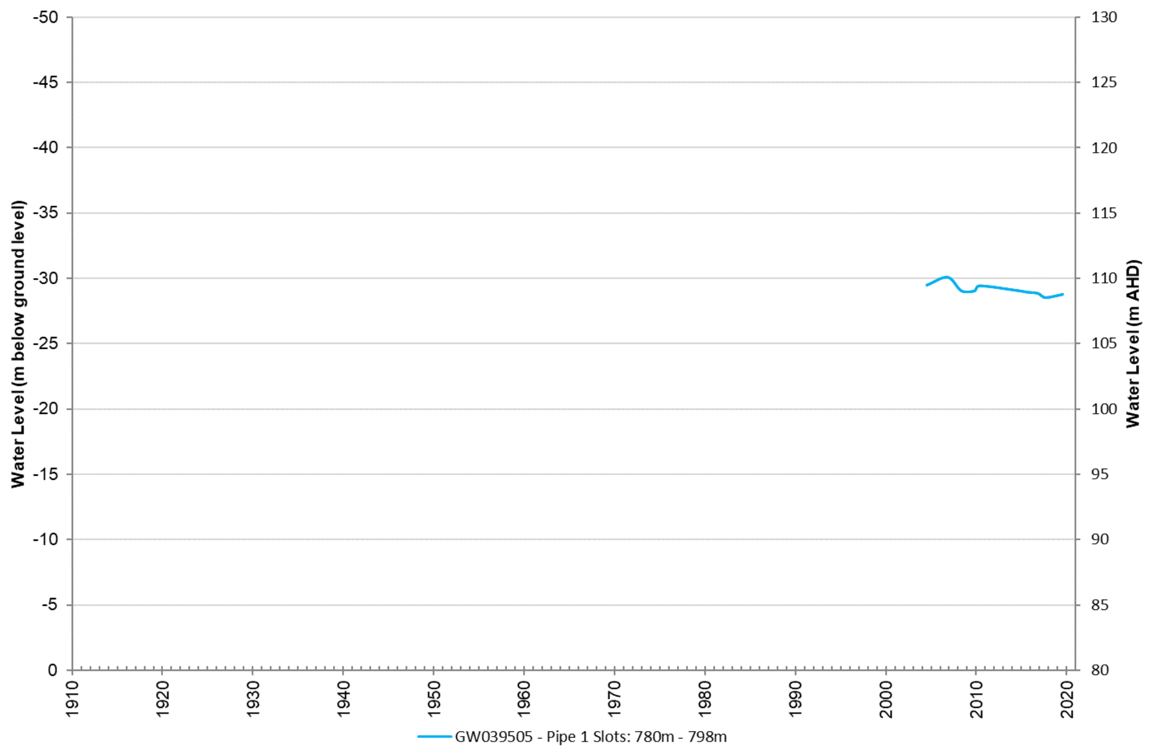

Figure 68 Hydrograph of bore GW039505 (Caryapunda No 2) - Central Groundwater Source

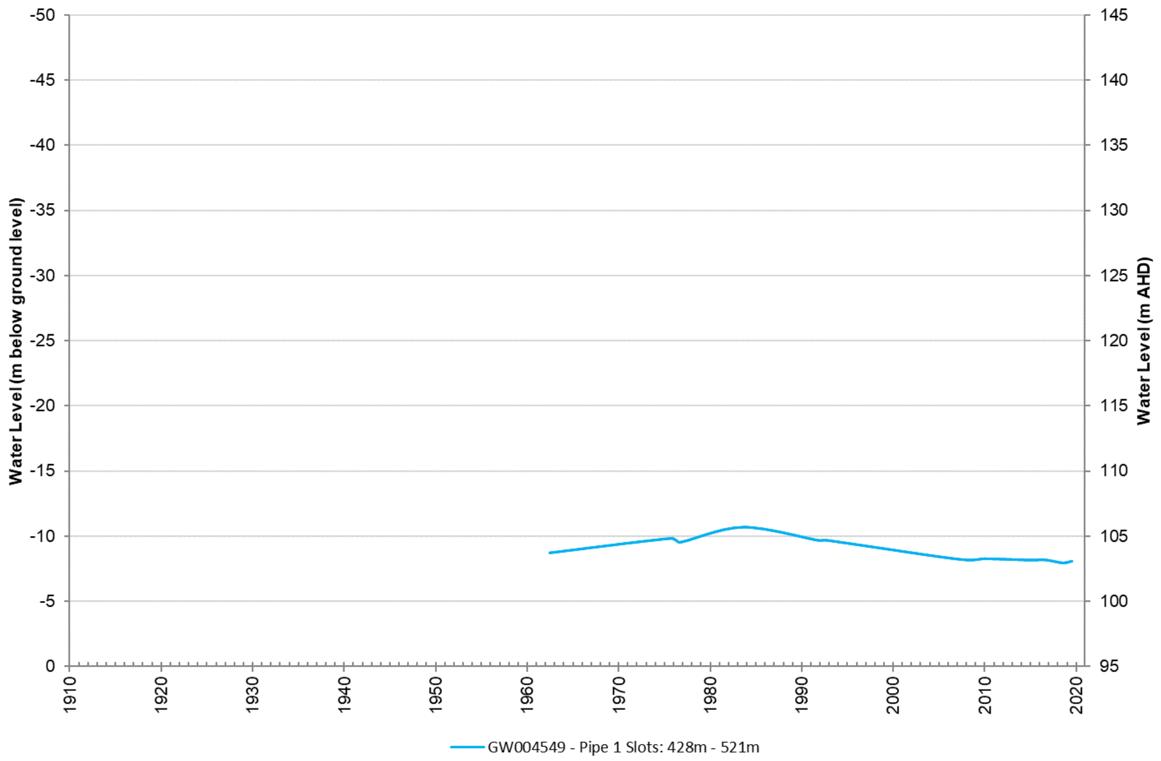

Figure 69 Hydrograph of bore GW004549 (Urisino No 4) - Central Groundwater Source

11.4 Pressure recovery

Increases in artesian bore pressure are being observed in many areas as a result of capping and piping the bores. Significant artesian pressure increase is noticed in the areas where many unrestricted bores are now controlled (Figure 45). About 70% of the bores controlled to date were in the Surat Groundwater Source (Table 13) where many unrestricted high flow bores existed prior to the implementation of the program.

Signs of pressure recovery and reversal of declining pressure are seen in large areas of the Surat Groundwater Source. The area of pressure recovery is smaller in the Warrego and Central Groundwater Sources in comparison to the Surat Groundwater Source. In the Central Groundwater Source, the pressure decline slowed and shows early signs of recovery.

Hydrographs of bores (refer Section 11.3) show that the rate of pressure recovery appears to be higher in the Surat Groundwater Source than in the Warrego and Central Groundwater Sources. The pressure increase over 120 kPa (~ 12 m head) in the last three decades is noticed in areas north of Coonamble in the Surat Groundwater Source.

In 2018, Klohn Crippen Berger Ltd (KCB) on behalf of NSW government undertook a desktop study (Klohn Crippen Berger, 2018) to inform artesian bore integrity risk assessment for the NSW GAB. This study was focused on the bores and potentiometric surface of Hooray – Pilliga Sandstone equivalent aquifers in the Surat, Warrego and Central Groundwater Sources. It produced potentiometric surface maps for a number of years including the projected future pressures across the NSW GAB. Figure 70, Figure 71 and Figure 72 show the potentiometric surface maps for years 1990, 2018 and 2033 respectively. These maps reiterate the rapid pressure rise in the Surat Groundwater Source.

Consequent to increases in artesian bore pressure, several bores that previously ceased to flow, recommenced flowing and the flow increased in many unrestricted bores that are yet to be capped. The study (Klohn Crippen Berger, 2018) identified a risk of 46 sub artesian bores recommence flowing by year 2033, if there is no intervention to cap and pipe the bores with unrestrictive flow by year 2033. Figure 73 shows the spatial distribution of 46 sub artesian bores that will be in transition from sub artesian to artesian by 2033.

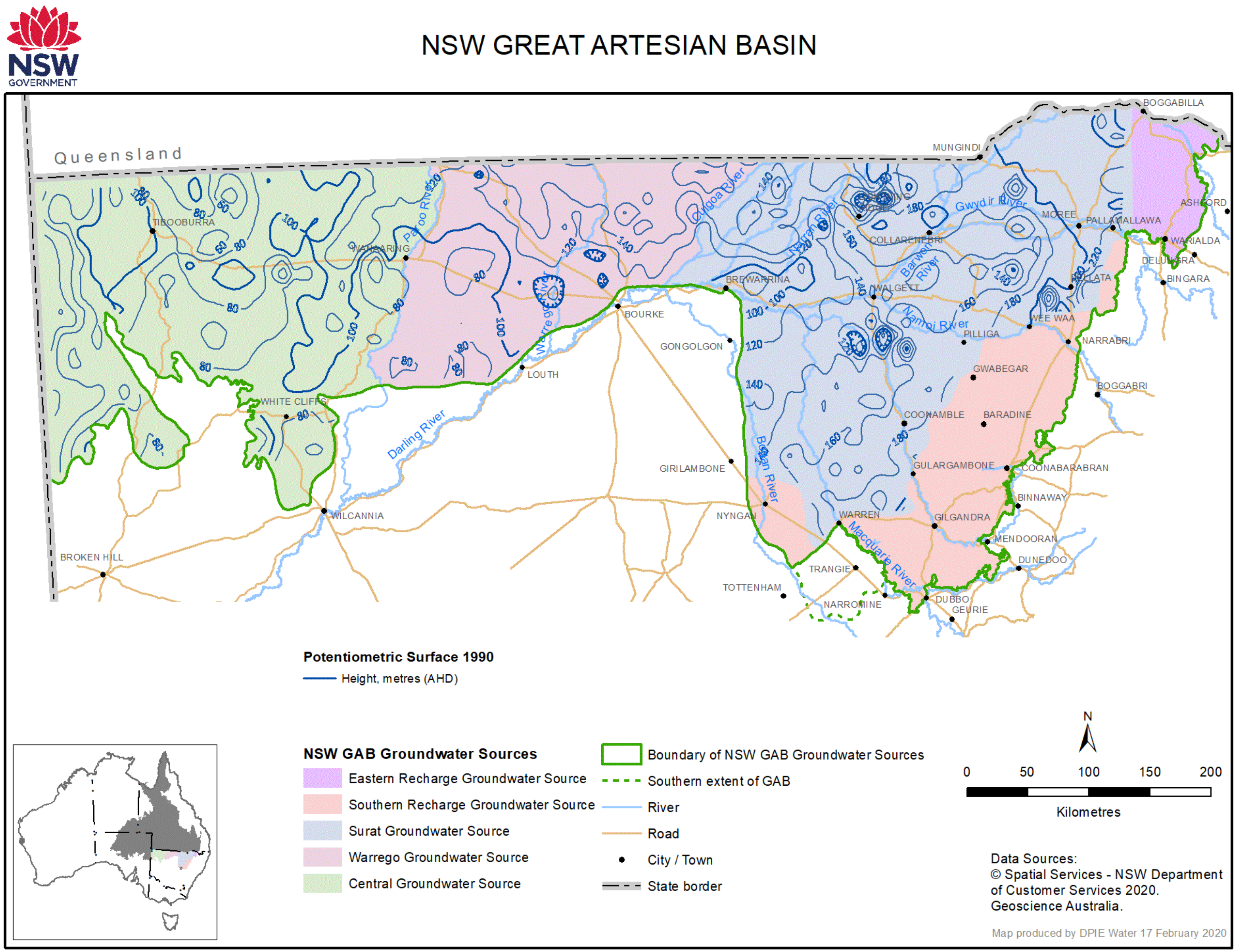

Figure 70 Potentiometric surface map for year 1990 based on field and modelled data

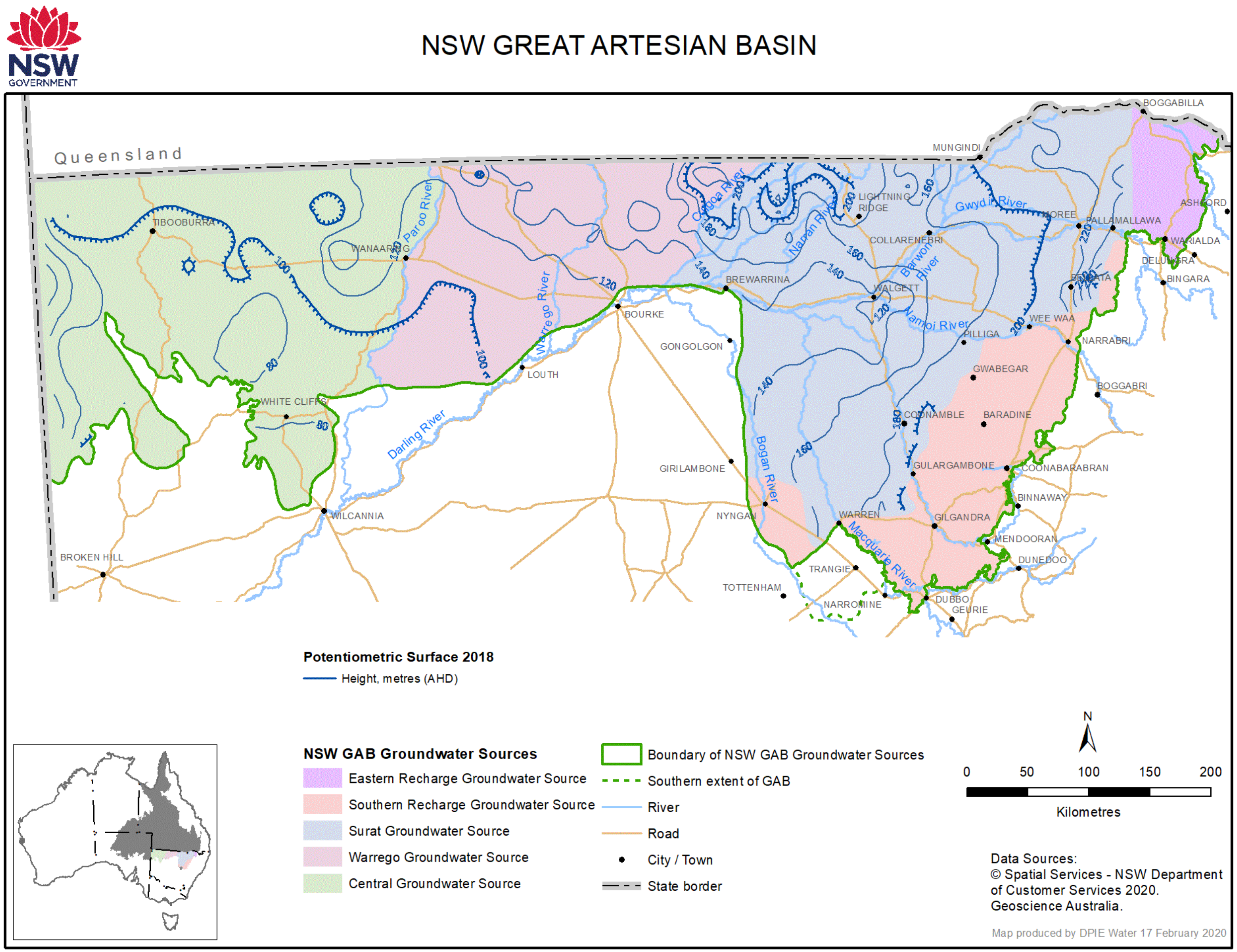

Figure 71 Potentiometric surface map for year 2018 based on field and modelled data

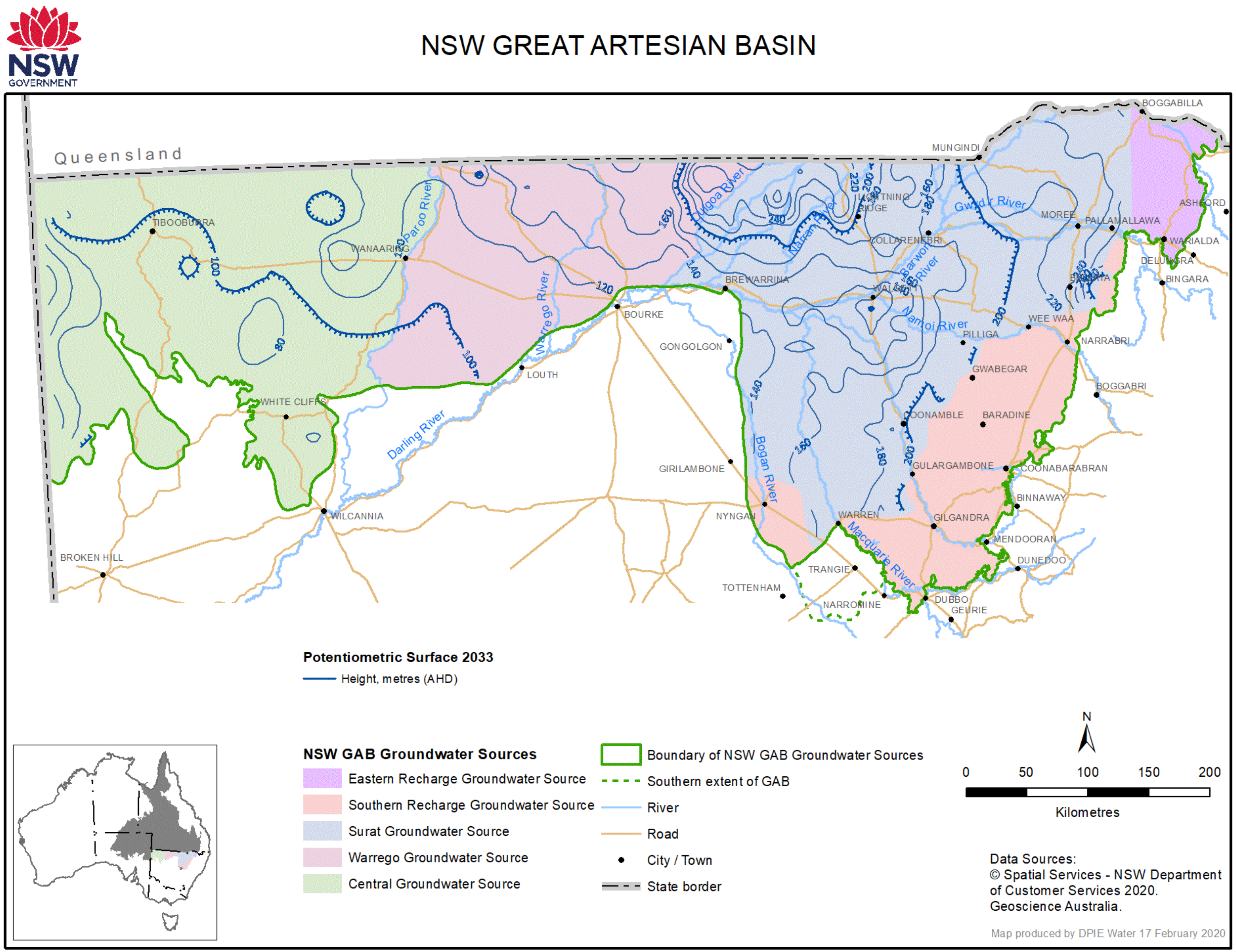

Figure 72 Potentiometric surface map for year 2033 based on modelled data

NSW GREAT ARTESIAN BASIN

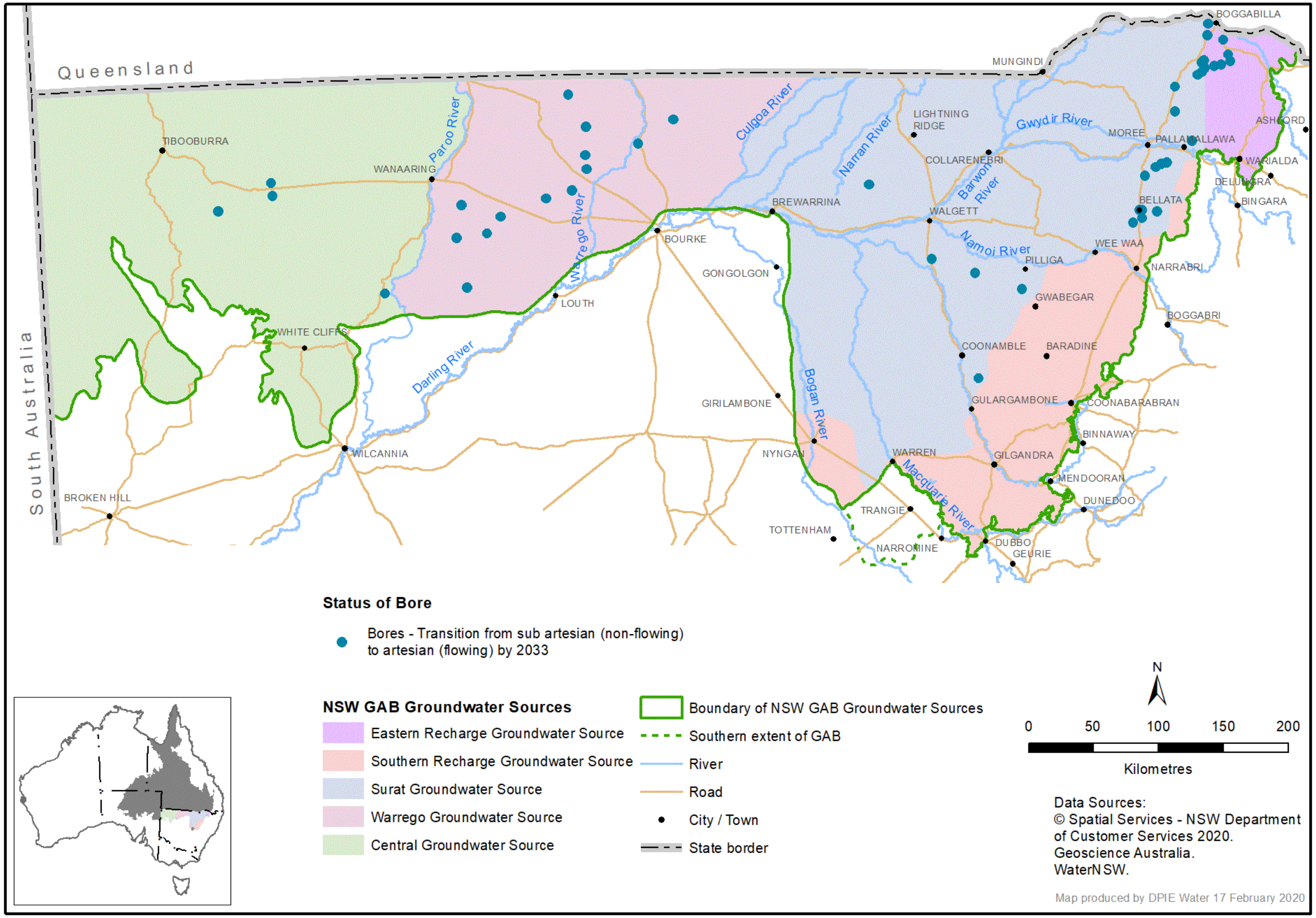

Figure 73 Location of bores that will be in transition from sub artesian to artesian by year 2033

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