Department of Planning and Environment

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Groundwater resource description

Water sharing plan for the Greater Metropolitan Region Groundwater Sources

June 2022

Acknowledgement of Country

The Department of Planning and Environment acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders, past, present, and emerging through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

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Glossary

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

Alluvial aquifer	A groundwater system whose geological matrix is composed of unconsolidated gravel, sand, silt, or clay transported and deposited by rivers and streams.
Alluvium	Unconsolidated sediments deposited by rivers or streams consisting of gravel, sand, silt, or clay, and found in terraces, valleys, alluvial fans, and floodplains.
Aquifer	Under the *Water Management Act 2000* an aquifer is a geological structure or formation, or an artificial landfill that is permeated with water or is capable of being permeated with water. More generally, the term aquifer is commonly understood to mean a groundwater system that can yield useful volumes of groundwater. For the purposes of groundwater management in NSW the term ‘aquifer’ has the same meaning as ‘groundwater system’ and includes low yielding and saline systems.
Anabranch	Stable multi-thread channels that are intermediate between single thread and braided channels characterised by vegetation or otherwise stable alluvial islands that divide flows at discharges up to nearly bank-full.
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 a salinity between 3,000 and 7,000 mg/L total dissolved solids.
Cenozoic	The Cenozoic Era spans from 66 million years ago to present.
Confined aquifer	An aquifer which is bounded above and below by impermeable layers. Confined aquifers are typically under pressure so that when the aquifer is penetrated by a bore, the groundwater rises above the top of the confined 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.

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

Dual porosity	Where a groundwater system has two types of porosity; primary porosity resulting from the voids between the constituent particles forming the rock mass, and secondary porosity resulting from dissolution, faulting, and jointing of the rock mass.
Electrical conductivity (EC)	Ability of a substance to conduct an electrical current. Used as a measure of the concentration of dissolved ions (salts) in water (i.e., water salinity). Measured in micro-Siemens per centimetre (μS/cm) or deci-Siemens per metre (dS/m) at 25^{o} C. 1 dS/m = 1000 μS/cm.
Environmental Value	[2]Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety, or health and which require protection from the effects of contamination, waste discharges and deposits.
Fractured rock	Rocks with fractures, joints, bedding planes and cavities in the rock mass.
Geological sequence	A sequence of rocks or sediments occurring in chronological order.
Groundwater	Water that occurs beneath the ground surface in the saturated zone.
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.

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

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

Groundwater system	Any type of saturated sequence of rocks or sediments that is in hydraulic connection. The characteristics can range from low yielding and high salinity water to high yielding and low salinity water.
Hydraulic conductivity	The capacity of a porous medium to transmit water. Measured in meters/day.
Hydraulic connection	A path or conduit allowing fluids to be connected. The degree to which a groundwater system can respond hydraulically to changes in hydraulic head.
Hydraulic head	The height of a water column above a defined point, usually expressed in metres.
Hydrogeology	The branch of geology that relates to the occurrence, distribution, and processes of groundwater.
Hydrograph	A plot of water data over time.
Kriging	A method of interpolation using a weighted average of neighbouring samples to estimate an 'unknown' value at a given location to create surfaces.
Long term average annual extraction limit (LTAAEL)	The long term average volume of water (expressed in megalitres per year) in a water source available to be lawfully extracted or otherwise taken.
Igneous rock	Rocks which have solidified from a molten magma or lava mass.
Infiltration	The movement of water from the land surface into the ground.
Ion	A charged particle, atom or molecule 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).

[4] As defined by Strategic Regional Land Use Plans

Unassigned water	Exists where current water requirements (including licensed volumes and water to meet basic landholder rights) are less than the extraction limit for a water source.
Unconfined aquifer	A groundwater system usually near the ground surface, which is in connection with atmospheric pressure and whose upper level is represented by the water table.
Unconsolidated sediment	Particles of gravel, sand, silt, or clay that are not bound or hardened by mineral cement, pressure, or thermal alteration of the grains.
Unsaturated zone	Area above the water table where soil spaces, pores, fractures, and voids are not completely filled with water.
Water balance	A calculation of all water entering and leaving a system.
Water sharing plan	[5]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] As defined in '*Macro water sharing plans – the approach for groundwater*' (NSW Office of Water, 2011)

1. Introduction

The NSW government is reviewing the Water Sharing Plan for the Greater Metropolitan Region which was implemented in 2011. That plan sets the rules for sharing groundwater between the environment and for extraction. It divided the region into 13 groundwater sources. As part of the review of the plan, five of these groundwater sources are proposed to be combined with adjacent, hydrogeologically similar groundwater sources within the plan area. The new water sharing plan proposes to manage the region's resources as 10 separate groundwater sources as described in this report.

The 10 proposed groundwater sources are classified as coastal sands, alluvium, porous rock, and fractured rock aquifer types. The water sharing plan covers an area of 32,500 km^2 from Broken Bay in the north, to Shoalhaven Heads in the south, and Lithgow and Goulburn to the west and is shown in Figure 1. It incorporates groundwater in all rock types, alluvial and coastal sands within the area of the plan.

The 10 proposed groundwater sources are:

- Botany Sands Groundwater Source.
- Hawkesbury Alluvium Groundwater Source.
- Lachlan Fold Belt Greater Metropolitan Groundwater Source.
- Maroota Tertiary Sands Groundwater Source.
- Metropolitan Coastal Sands Groundwater Source.
- Sydney Basin Central Groundwater Source.
- Sydney Basin Nepean Groundwater Source.
- Sydney Basin North Groundwater Source.
- Sydney Basin South Groundwater Source.
- Sydney Basin West Groundwater Source.

The proposed Lachlan Fold Belt Greater Metropolitan Groundwater Source is a combination of the Goulburn Fractured Rock and the Coxs River Fractured Rock groundwater sources. The proposed Sydney Basin West Groundwater Source is a combination of the Sydney Basin Blue Mountains, Sydney Basin Coxs River and Sydney Basin Richmond groundwater sources.

This report describes the location, climate and physical attributes of the groundwater sources and explains their geological and hydrogeological context, environmental assets, groundwater quality and management. It also presents information on the current level of groundwater licences and estimates of take under legislative rights and exemptions.

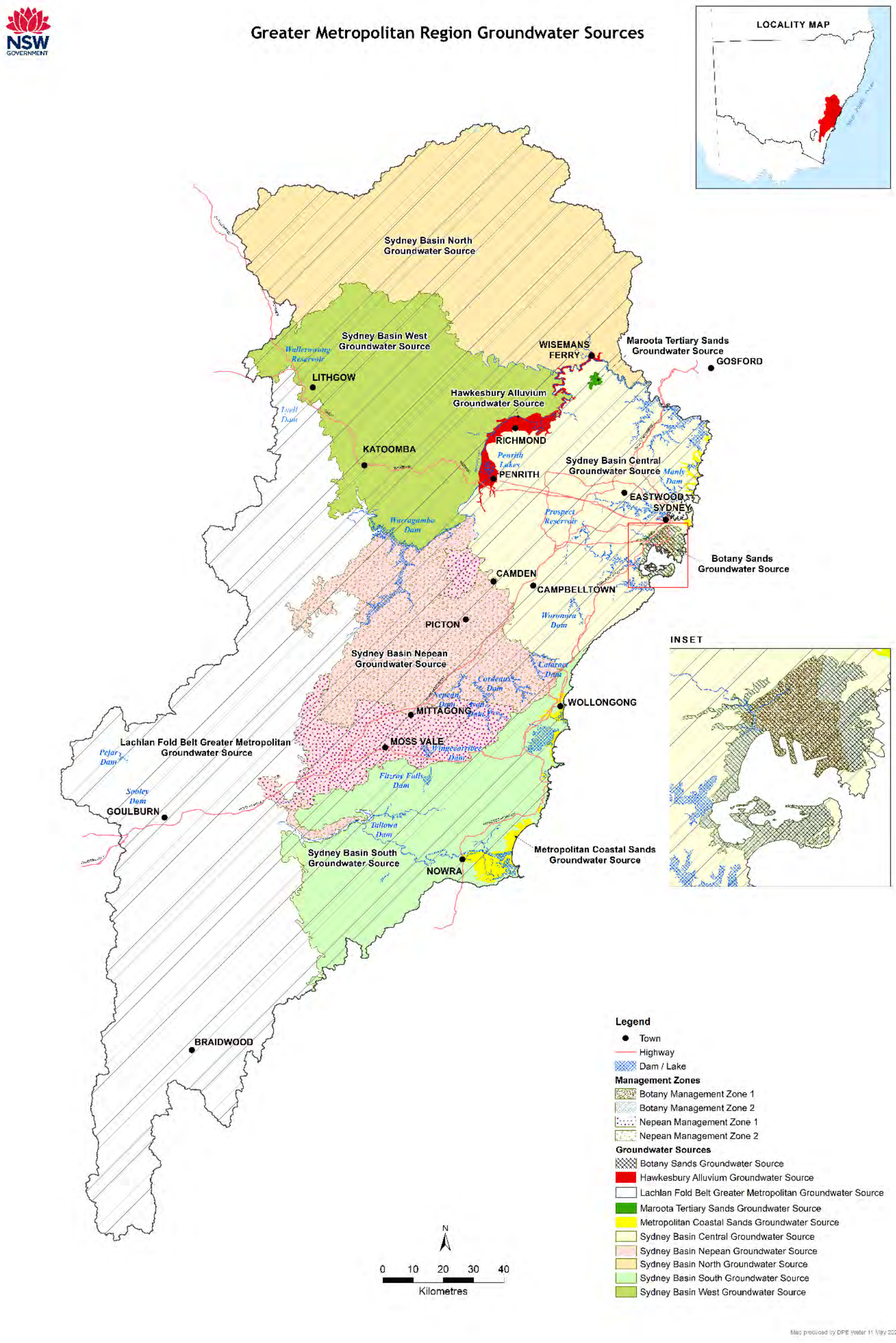

Figure 1 Location map of the water sharing plan for the Greater Metropolitan Region groundwater sources (proposed)

2. History of groundwater management

2.1 Early groundwater management

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

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

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

Acknowledging that groundwater was a finite resource, from 1972 to 1983 new irrigation licences were issued based on the size of the area being irrigated. These licences had to be renewed every 5 years, but still had no volumetric limit on extraction (Gates et al, 1997).

From 1984, all new high yield bores and wells (with extraction greater than 20 ML/year), except for those in the Great Artesian Basin, were given a volumetric entitlement. Older 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 manage development more effectively in those groundwater systems where the resource was fully committed and to encourage the use of groundwater where it was underutilised.

Prior to the water sharing plan, groundwater entitlements were granted based on the need and the demonstrated capacity of a bore. Bore licences were issued for a particular purpose and were divided into ‘perpetual’ or ‘renewable’. These terms described the licence period and whether the entitlement was less than 20 ML/year, or greater, respectively. Where irrigation was the intended purpose, maximum entitlements were assessed on the basis of 6 megalitres per hectare per year up to a property limit of 486ML/year. Entitlements for industrial/commercial were also volumetric and were given on the need basis.

2.2 NSW water reforms

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

By the late 1990s, NSW had embarked on a major program of water policy reforms. This included the development of the NSW State Groundwater Policy Framework Document, the NSW Groundwater Quality Protection Policy, and an assessment of risk to the State's groundwater systems from over-extraction and/or contamination. In 1998, the NSW State Groundwater Quality Protection Policy was released, designed to protect groundwater resources and the ecosystems to which they are connected against pollution The NSW State Groundwater Dependent Ecosystems Policy was released in 2002.

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

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

Water sharing plans are the principal tool for managing the State's water resources including groundwater. These 10 year plans manage groundwater resources at the 'water source' scale, define the long term average annual extraction limit (LTAAEL), establish rules for sharing groundwater between users and the environment, establish basic landholder rights and set rules for water trading.

Priority for developing water sharing plans was based on the groundwater systems identified by the risk assessment as being at highest risk. The first groundwater sharing plans started in 2004 and included a number of basalt, coastal sands, and sandstone groundwater sources on the coast. The first plans inland commenced between 2006 and 2008 across 6 large alluvial groundwater systems in the Murray-Darling Basin.

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

In 2011, the 'NSW Policy for Managing Access to Buried Groundwater Sources' was released. This Policy established a framework for managing access to water in groundwater sources that are fully or partly buried.

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

2.3 Greater metropolitan region

Except for groundwater extraction restrictions associated with contamination in the Botany Sands there was no formal groundwater sharing arrangements or restrictions for the Greater Metropolitan Region until the implementation of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. Prior to 2011, for some of the other water sources (now incorporated into Greater Metropolitan Region groundwater sources), interim groundwater management plans or management options had been developed through local water management committees. Substantial work had been completed for the Wollondilly-Nepean and Blue Mountains-Richmond districts as well as the Coxs River catchment before the water sharing plan was developed.

Applications for groundwater entitlements were assessed on the need or the demonstrated capacity of bores by a pumping test if the requested volume was over 20 ML/year. For dewatering and mining applications, the application was considered in context of the proposed dewatering or mining operation.

2.3.1 Coastal sands

The groundwater resources of the Botany Sands were managed under the *Water Act 1912* as Groundwater Management Area 018 until the Water Sharing Plan for the Greater Metropolitan Region 2011 commenced. The focus of groundwater management was around limiting access to groundwater where substantial contamination associated with historic industrial areas was identified.

Two embargoes were gazetted for the Botany Sands, the first in August 2003 and the second in June 2007. These embargoes were progressive extensions of restrictions put in place since 1996 to manage groundwater access in the vicinity of pollution plumes. In 1996 what was to become the 'Groundwater Extraction Exclusion Area' was established, initially aligning with pollution plumes, and later expanded to provide a buffer around contaminated locations. Directions under section 117A(3) of the *Water Act 1912* to cease using groundwater and disable pumping equipment were issued to licensees in that vicinity. An embargo on the application for new licences in the western half of the coastal sands north of Botany Bay was established under section 113A of the *Water Act 1912* in August 2003.

The following year, a Temporary Water Restriction Order under Section 323 of the *Water Management Act 2000* (those powers later transferred to Section 324) was gazetted that prevented access to groundwater for all purposes other than industrial, recreational, commercial uses or for monitoring. There were 4 management zones established under the order particularly to protect domestic users who could unknowingly become exposed to contaminated groundwater.

In 2007, 4 years after the first embargo, new applications for entitlement in the remainder of the groundwater source was embargoed to prevent over allocation. Following administrative adjustments to the *Water Management Act 2000*, the Temporary Water Restriction Order was remade under Section 324 of the Act in February 2018 for a period of 8 years. The order simplified the application of the restrictions by re-establishing the extraction exclusion area as Area 1 and consolidating the remaining portion as Area 2 (see Figure 1).

Groundwater development within the Metropolitan Coastal Sands groundwater source is relatively low in comparison with the Botany Sands. Although the Metropolitan Coastal Sands were broadly identified as Groundwater Management Area 067 through the macro planning process, specific management of those groundwater systems were not previously prioritised due to the low level of development.

2.3.2 Alluvium

The Hawkesbury Alluvium was managed as Groundwater Management Area 068 under the *Water Act 1912* until the commencement of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. Groundwater entitlements were granted based on the need and the demonstrated capacity of bores.

Prior to the 2011 water sharing plan, the groundwater resources in Maroota Tertiary Sands were managed as Groundwater Management Area 027 (Maroota Alluvium and Sandstone) under the *Water Act 1912*. Impacts of extractive industries on groundwater users and the environment including groundwater dependent ecosystems have been the main concern in this area.

The Sydney Region Environmental Plan No 9 – Extractive Industry (No 2) 1995, defined the areas set aside for extractive industry operations around the broader Sydney region that included the Maroota Sands. This area was defined according to lot boundaries and extended across the geological boundary between the Tertiary alluvial deposit and the surrounding Hawkesbury Sandstone. It included special requirements for the Maroota area in which the local council was vested with the authority to control any adverse impact on the groundwater resource and users as well as to conserve environmentally sensitive and significant areas. The provisions of that plan relating to the Maroota area are now included in the State Environmental Planning Policy (Resources and Energy) 2021. The 2 councils which have jurisdiction in the Maroota area are required to protect groundwater systems and users, as well as the environmentally sensitive features around the locality, such as threatened species, populations, and ecological communities. Both the Hills Shire Council and Hornsby Shire Council have regulated extractive industry under their Development Control Plans (DCPs) and include provisions for environmental protection within those DCPs through a limit to extraction at a depth that is 2 m above the high groundwater level (Hornsby Shire Council) or the wet weather high groundwater level (The Hills Shire Council).

2.3.3 Sydney Basin

The Sydney Basin porous rock groundwater resources were managed under the *Water Act 1912* until the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 commenced. Groundwater entitlements were granted based on the need and the demonstrated capacity of a bore.

The groundwater management areas (GWMAs) that covered the Sydney Basin groundwater resources were GWMA 603 (Sydney Basin Central), GWMA 606 (Sydney Basin Blue Mountains), GWMA 607 (Sydney Basin Nepean), GWMA 609 (Sydney Basin Coxs River), GWMA 614 (Sydney Basin Richmond), GWMA 615 (Sydney Basin North) and GWMA 616 (Sydney Basin

South). These 7 GWMAs were the basis of the 7 porous rock groundwater sources defined under the 2011 water sharing plan.

A draft Blue Mountain – Richmond Interim Groundwater Management Plan was released after community consultations in 1999 as an unpublished document describing how groundwater was to be managed. This plan was a combination of management responsibilities, actions, objectives, and rules. However, it was not progressed further prior to the commencement of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. Restrictions on domestic groundwater use were placed in part of the GWMA 606 Sydney Basin Blue Mountains in response to extreme drought conditions in 2007 and 2009. The orders were gazetted under section 323 (for the first orders) and section 324 (for the last order) of the *Water Management Act 2000* to bring the use of bores into line with Level 1 mains water supply restrictions. The orders applied to 'all aquifers or parts of aquifers underlying the land within the area of Blue Mountains City Council'.

A draft interim groundwater management plan was developed in 1999 for the Southern Highlands region for 'Wollondilly-Nepean aquifers' within the current Sydney Basin Nepean and Sydney Basin South water sources. It also included Lachlan Fold Belt aquifers in addition to Hawkesbury Sandstones and basalts, east of the Wollondilly River. The plan was a holistic document that examined the groundwater catchment in its entirety and included a groundwater allocation plan and recognised the need for groundwater quality protection and that of groundwater dependent ecosystems. The interim groundwater management plan was not finalised prior to the commencement of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011.

An embargo on applications for entitlement (under s113A of the *Water Act 1912*) for 5 parishes of Bong Bong, Berrima, Mittagong, Sutton Forest, and Yarrunga in the Southern Highlands was gazetted in May 2004 (with some exceptions including town or village water supplies and up to 10 ML/year for research, teaching and Aboriginal cultural purposes) in response to high concentrations of bores and rapid growth in licence applications in the area. Subsequently, the escalating demand for groundwater moved into neighbouring parishes. To preserve the level of entitlement and recognising the potential requirement from a borefield in the area to supply drought relief for Sydney, a second embargo was gazetted in December 2005 to cover 7 more parishes. In June 2007 a third embargo increased the embargoed areas to include another 7 parishes to manage continuing increased groundwater demand.

The water sharing plan incorporated these embargoed areas into the Nepean Management Zone 1, a subdivision within the Sydney Basin Nepean Groundwater Source. The remaining area of the groundwater sources is the Nepean Management Zone 2 (see Figure 1). These management zones were continued from the earlier embargoes to maintain trade restrictions around the parishes of high groundwater demand to prevent widespread impacts.

In 2001, the Minister for Natural Resources established the Coxs River Water Management Committee to develop a water sharing plan for the Coxs River surface water and groundwater sources. A draft water sharing plan was prepared in July 2004 but was not finalised before the commencement of the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011.

2.3.4 Fractured rock

The Lachlan Fold Belt fractured rocks were separated into GWMA 816 (Coxs River Fractured Rock) and GWMA 820 (Goulburn Fractured Rock). These 2 GWMAs became the 2 fractured rock groundwater sources when the Water Sharing Plan for the Greater Metropolitan Region 2011 commenced.

3. Regional setting

3.1 Topography

The Greater Metropolitan Region water sharing plan area covers approximately 32,500 km^2, comprising the Shoalhaven River catchment, the Hawkesbury-Nepean catchment and the Illawarra and metropolitan Sydney catchments (Figure 2 and Figure 3). A large part of the area is made up of elevated plateau and ridges that have been modified by erosion and dissected by major river valleys. In many places the river valleys have been categorised as wild and scenic gorges (Allen, 2016) as they are relatively undisturbed from their original natural condition.

Topographically, locations along the Great Dividing Range reach elevations greater than 1,000 m and the gorges formed by the major rivers can be deep. For example, the Shoalhaven River, Corang River and Endrick River have created gorges upstream of the Mongarlowe River confluence that reach 300 to 500 m deep (Allen, 2016). Broader valleys have been created by the Coxs River (within the Blue Mountains National Park), the Grose River and the Capertee River in the western and north-western parts of the water sharing plan area. The main rivers ultimately descend to near sea level, either uniquely or as combined flows with tributary sources, having generally lower gradient estuarine reaches.

Greater Sydney’s water supply catchment area covers 16,000 km^2 to the west and also to the southwest of Sydney, extending from Lithgow to Goulburn. It includes large areas of 2 major river systems, the Hawkesbury-Nepean, and the Shoalhaven, as well as part of the smaller Woronora River catchment. In total the area incorporates 11 major dams and reservoirs.

The Warragamba Dam on the Warragamba River is Australia’s largest urban water storage. It is upstream of Nepean River confluence southwest of Penrith and covers an area of approximately 75 km^2 and used for Sydney’s water supply. Other catchment dams that form part of the complex network of dams and storages to supply Sydney’s water are the Wingecarribee Dam located southwest of Wollongong; the Tallowa Dam on the Shoalhaven River that provides water to the Illawarra region and the Southern Highlands; the Nepean, Avon, Cordeaux, and Cataract Dams that capture and store water from the Upper Nepean River catchment and the Woronora Dam supplies water to communities in the Sutherland Shire and the northern suburbs of Wollongong.

Prospect Reservoir in western Sydney, is a smaller water storage dam with a catchment area of approximately 10 km^2 and an area of approximately 5 km^2. The reservoir receives water from other catchment dams and is used as a distribution point for parts of the Sydney water supply.

The Penrith Lakes system, which is used for recreational purposes and includes environmental habitats, is located by the Nepean River further downstream of the Warragamba Dam and covers an area of approximately 20 km^2.

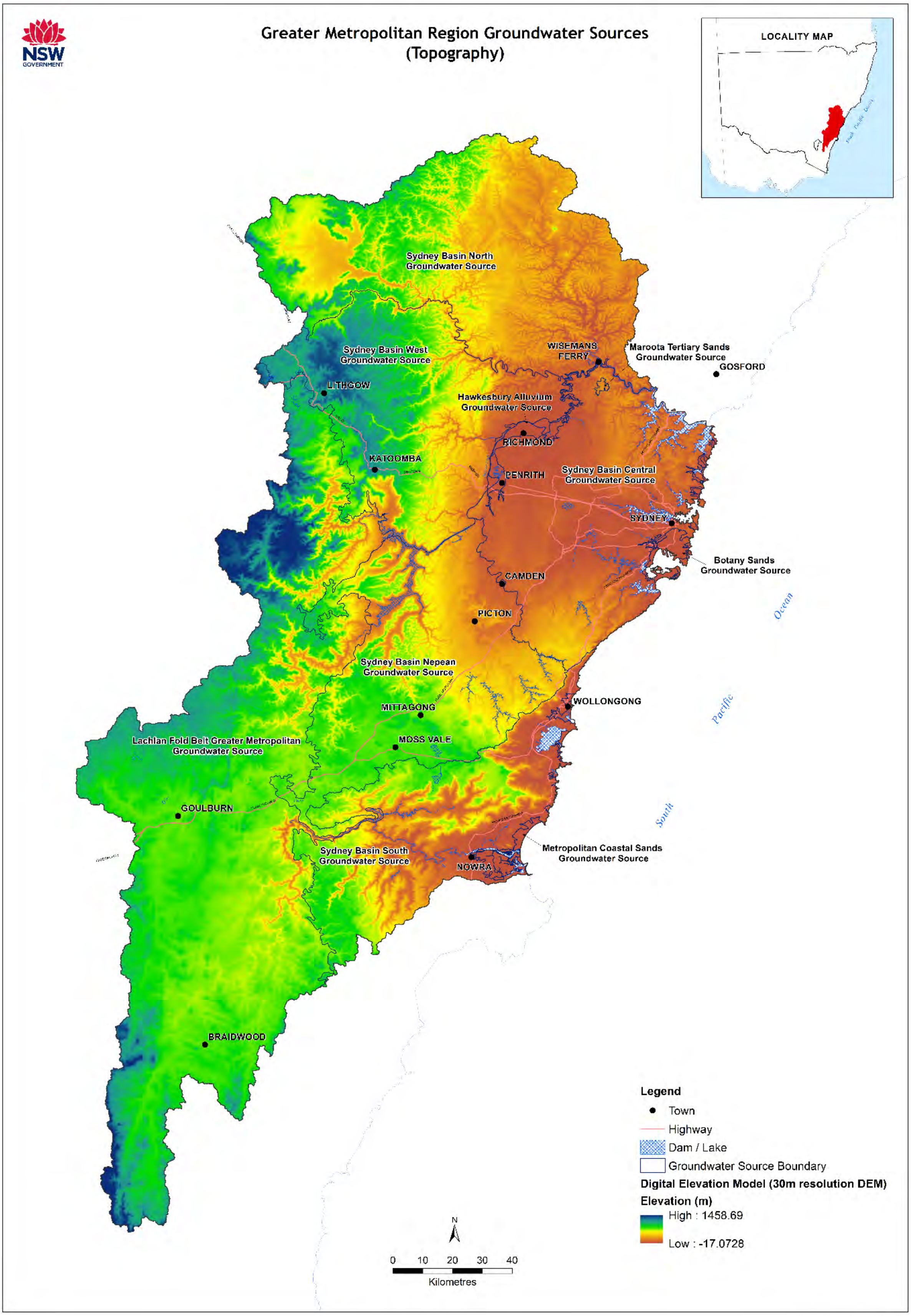

Figure 2 Topography and elevation

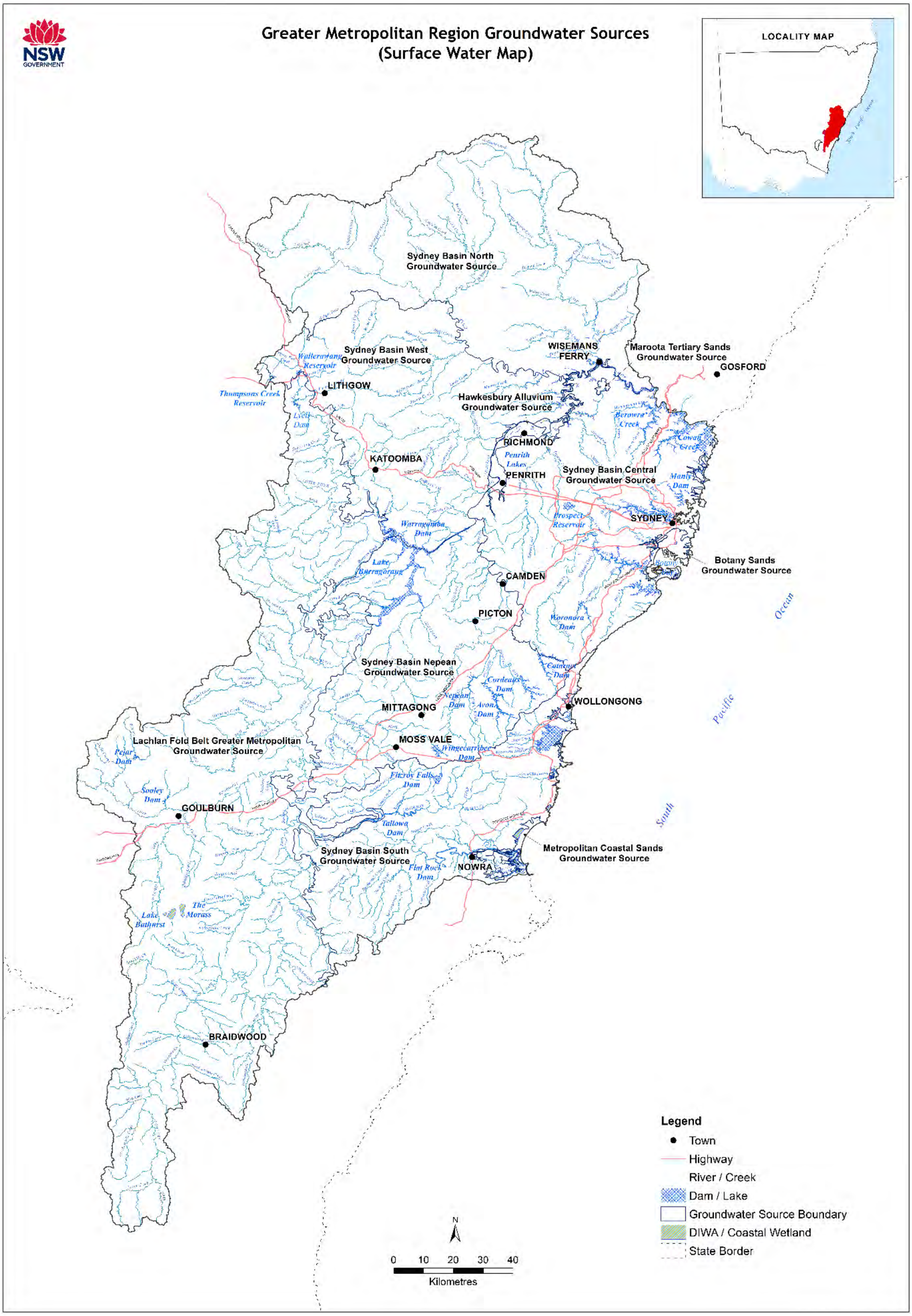

Figure 3 Surface water map

3.2 Climate

The water sharing plan area has a temperate climate which means that temperatures are on average relatively moderate and not characterised by extremes of hot and cold or significant changes between summer and winter. The mean monthly temperatures for June, July and August are below 10 °C and for December to February are around 20 °C, but parts of the region are characterised by hot summers, particularly along the coast and at lower elevations, grading to warm summers at higher elevations. The long-term (1900 to 2012) mean precipitation is 951 mm/year, but there is considerable inter-annual variability. The area does not have a dry season, but the temporal pattern indicates summer dominant rainfall with December to March averaging 90 to 120 mm/month, while July to October averages about 60 mm/month (https://www.bioregionalassessments.gov.au/assessments/11-context-statement-sydney-basin-bioregion/1123-climate).

Rainfall is the most relevant climate parameter with regard to groundwater systems, as it represents a major recharge input to aquifers, however evaporation losses can also be substantial.

3.2.1 Rainfall

Figure 4 presents a map of the average annual rainfall. The spatial distribution of rainfall varies significantly, with rainfall generally decreasing with distance from the coast, but increasing with elevation. It highlights the higher rainfall areas along the coast and in the upland areas associated with the Blue Mountains and the Southern Highlands between Wollongong, Nowra, and Berrima. Mean annual rainfall varies from 610 mm/year in the north-west of the region to 1530 mm to the north of Nowra.

In the Shoalhaven River catchment, rainfall generally increases from the southwest (Windellama near Goulburn) to the northeast (Robertson near Moss Vale) — average annual rainfall increasing from 700 to 2,400 mm (Allen, 2016).

In the Hawkesbury-Nepean catchment, rainfall generally decreases from near the coast (particularly near the Illawarra escarpment to inland locations (in the Capertee Valley) — average annual rainfall reducing from 1,600 to 700 mm (Allen, 2016).

In the Illawarra catchments, rainfall generally decreases from west to east, however in the metropolitan catchments rainfall generally increases from west to east (Allen, 2016). Typical average annual rainfall in the Illawarra reduces from 2,300 mm (Jamberoo near Nowra) to 1,200 mm at Albion Park (south of Wollongong). In the metropolitan catchments, the average annual rainfall typically ranges from 900 mm (near Campbelltown) to 1,500 mm (near Darkes Forest between Sydney and Wollongong).

Average monthly rainfall bar chart from 1997 – 2021 (Figure 5) shows a mainly summer dominated rainfall but the 6 month period from October to March has relatively higher rainfall compared to the period from April to September. Residual mass graphs (Figure 6) shows the broader weather trend for the same period

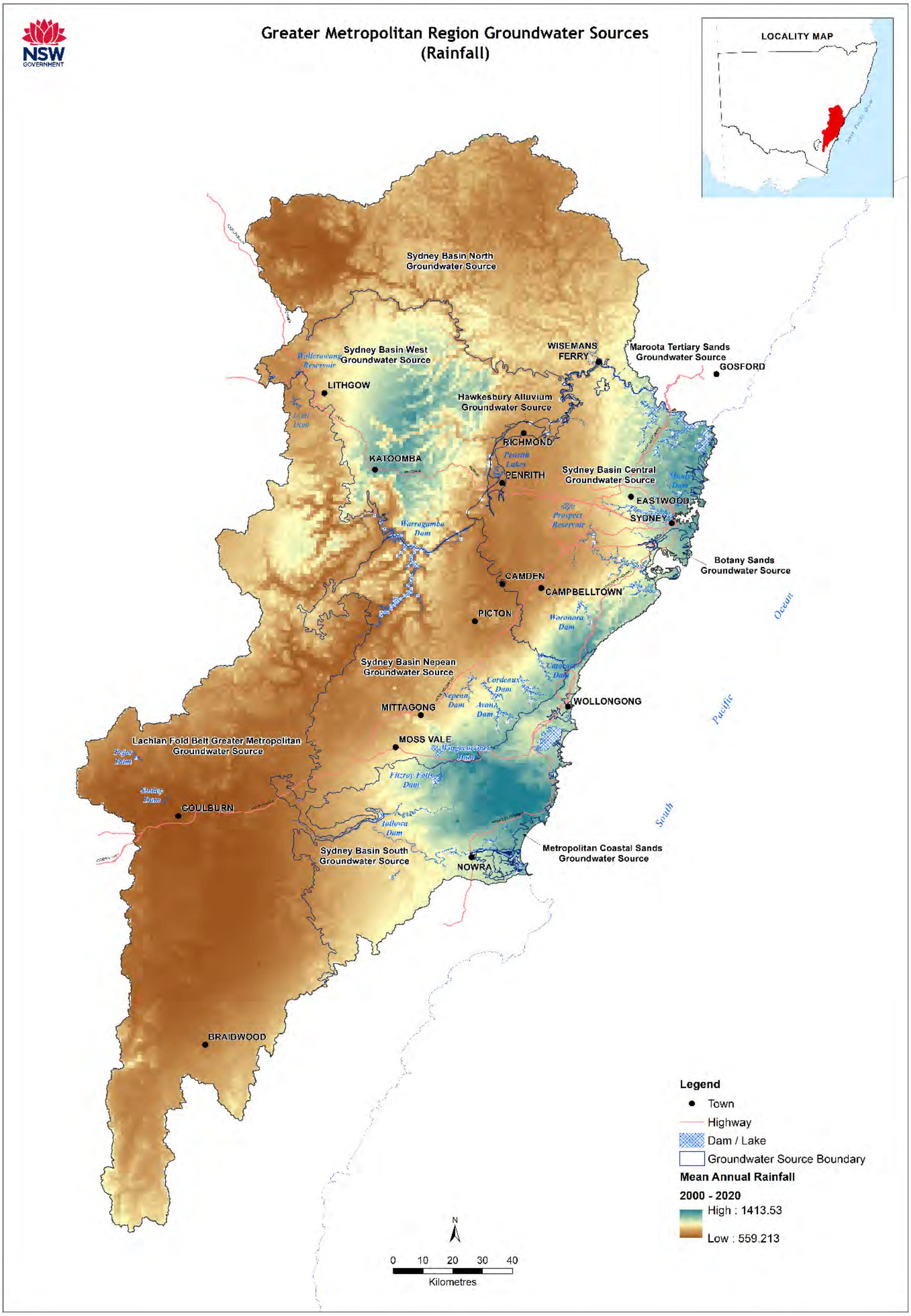

Figure 4 Average annual rainfall

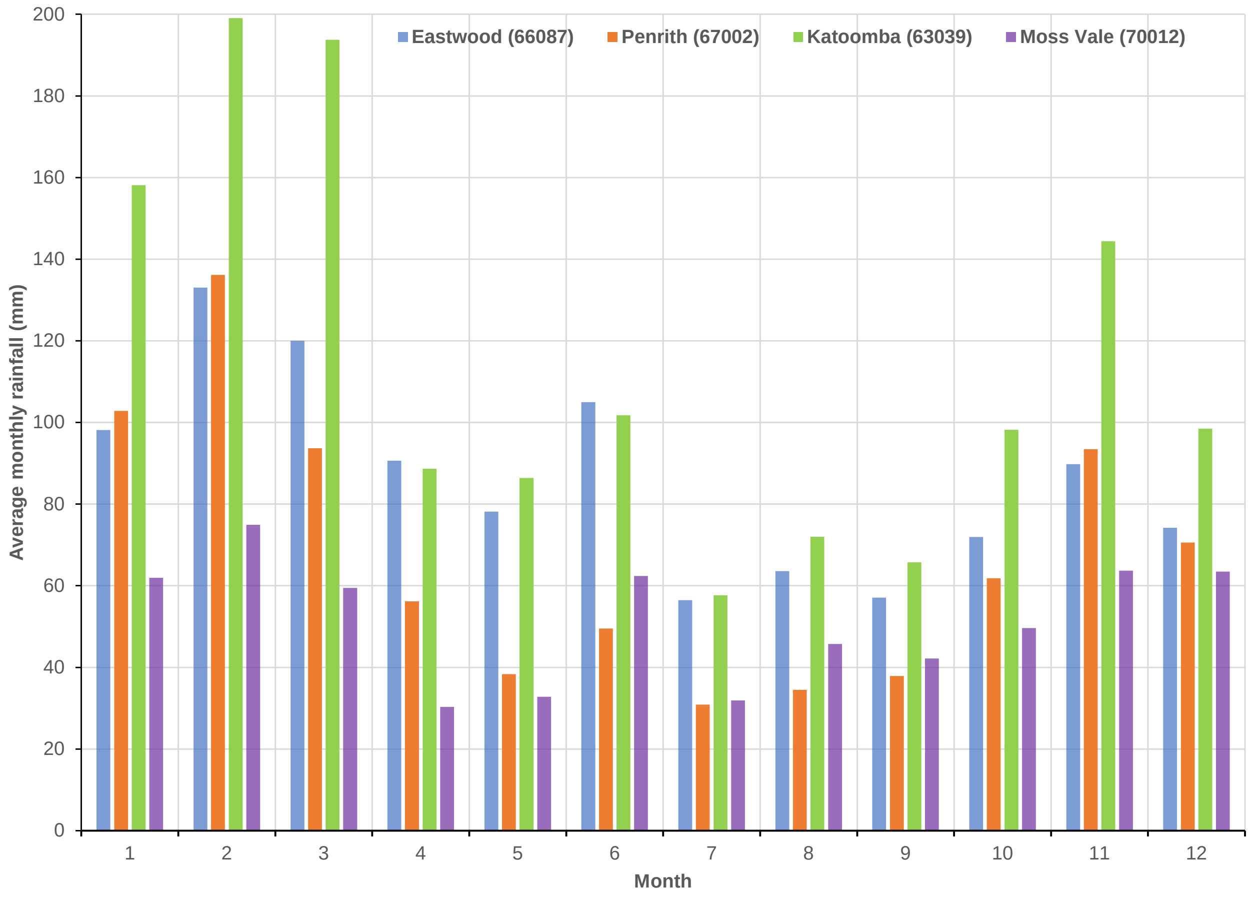

Figure 5 Average monthly rainfall (BOM) 1997 – 2021

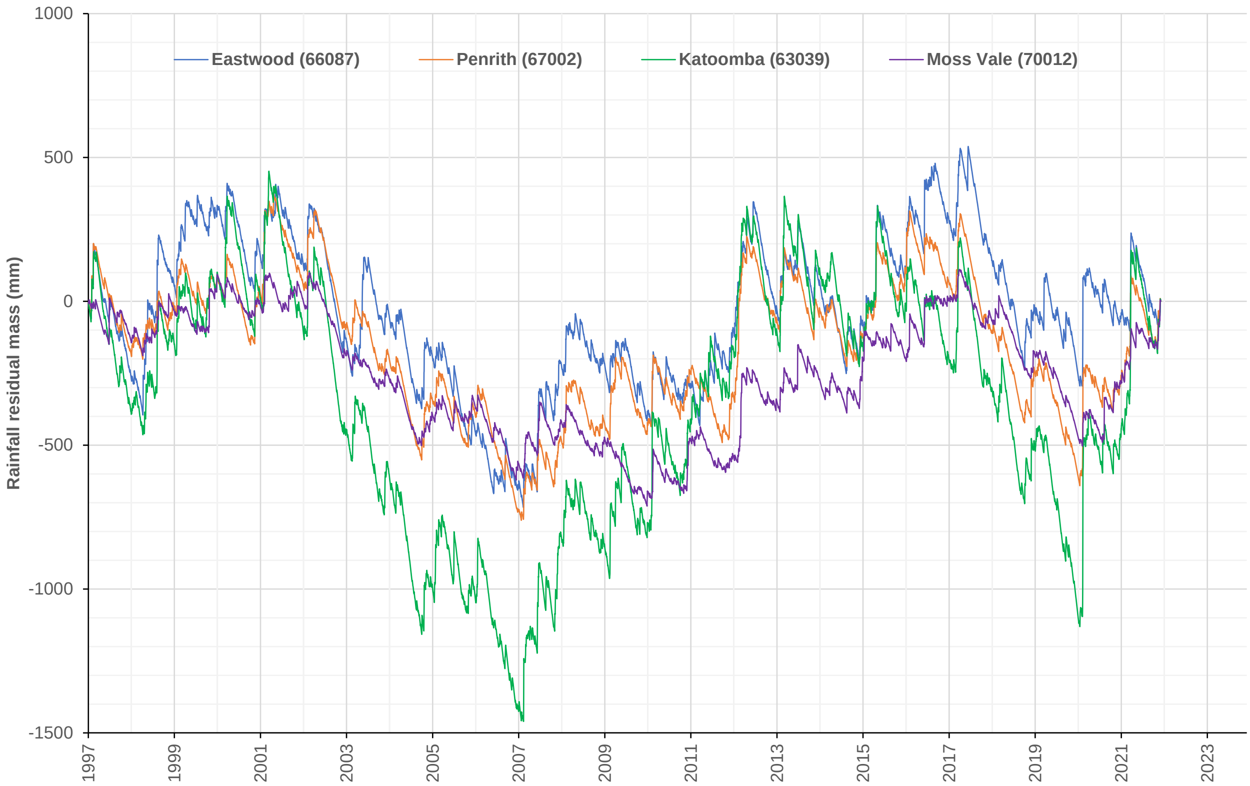

Figure 6 Rainfall residual mass graphs (BOM) 1997 – 2021

3.2.2 Evaporation

Only a limited number of weather stations across the water sharing plan area have long-term evaporation data. Evaporation is expected to be high, and possibly exceed the average daily value over summer months, whereas during winter the rate would likely be considerably less. Other factors, such as relative humidity, wind speed, wind direction and temperature can all vary substantially over days or weeks throughout the year, and these would also have an influence on the daily evaporation rate.

The spatial distribution of average annual evaporation is shown in Figure 7. Monthly average evaporation bar charts for 1997 – 2021 (Figure 8) shows that higher rates of evaporation occurred during the 6 month period from October to March.

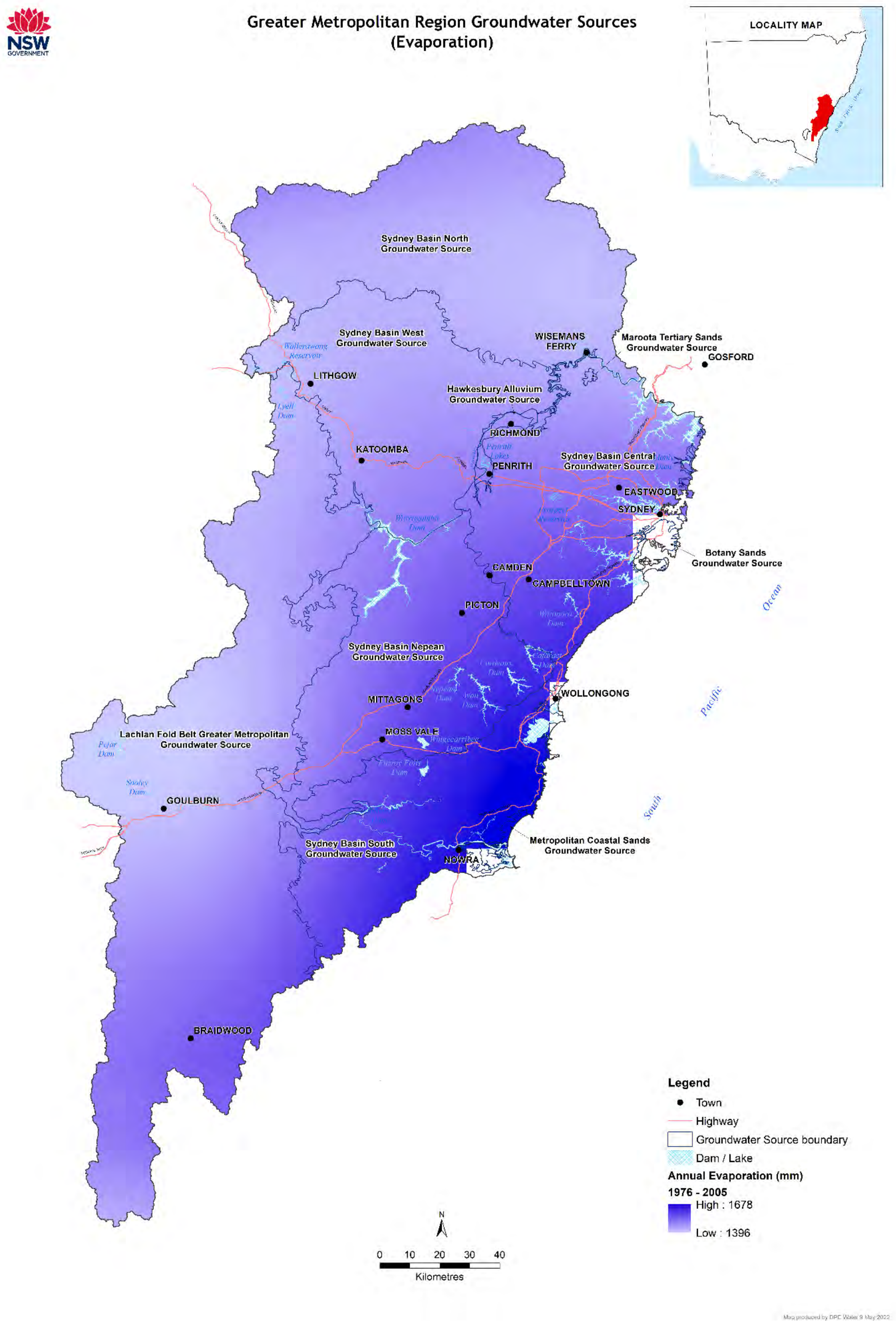

Figure 7 Average annual evaporation (BOM)

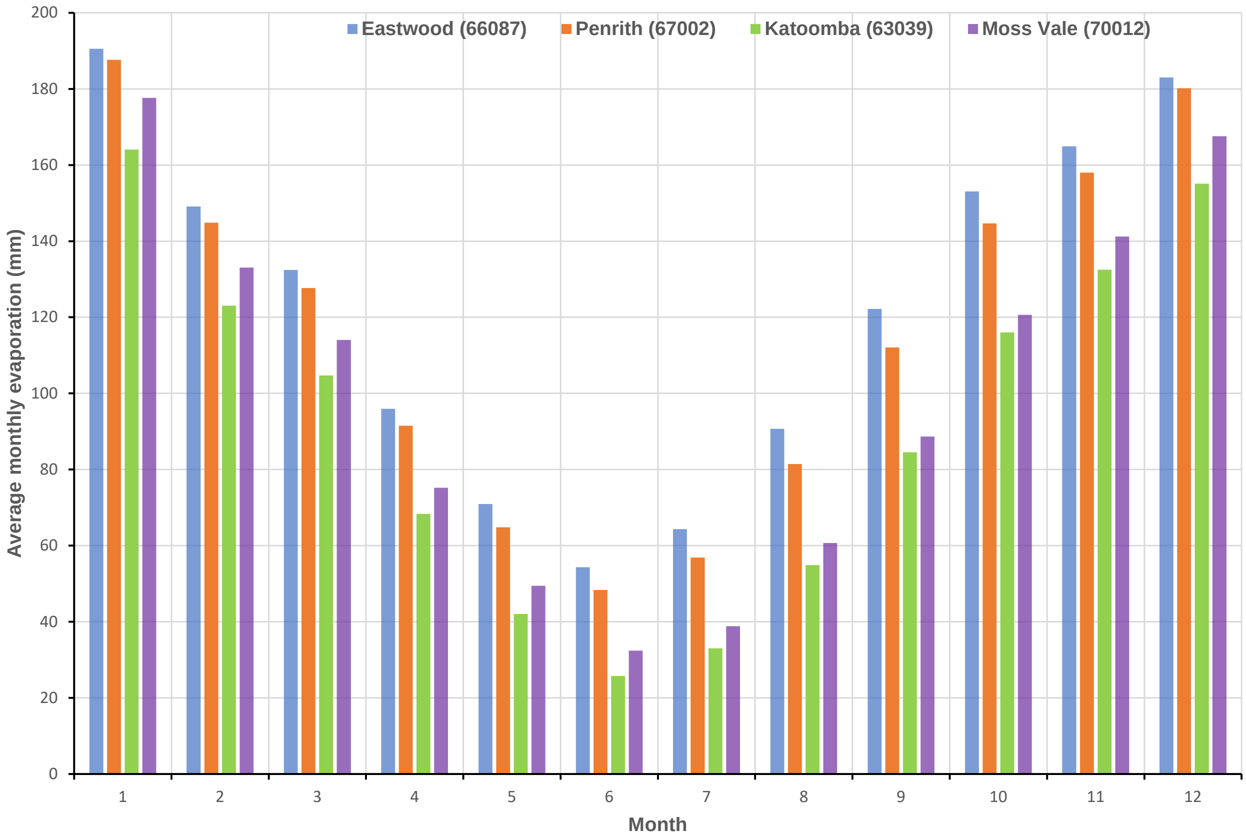

Figure 8 Average monthly evaporation (BOM) 1997 - 2021

3.3 Land use

The region prior to white settlement included country of 5 indigenous nations. Country of Yuin and Tharawal included the Shoalhaven River, with Tharawal occupying the lower reaches of the river. The country of Tharawal also included lands of the Illawarra and north to Botany Bay. The Eora country spanned the coast north of Tharawal country to about the Parramatta River and west to the eastern boundary of the Hawkesbury River catchment. The Hawkesbury River catchment was largely Dharug country, with the exception of the Wollondilly River, which was Gundungurra country, which may have also included the Shoalhaven River around Kingpin Mountain.

A number of national parks within the water sharing plan area are managed in partnership with Aboriginal peoples whose traditional owners and clans are represented across the region by 12 statutory Local Aboriginal Land Councils.

Blue Mountains National Park, Kanangra Boyd National Park and Wollemi National Park in the catchment of the Nepean and Hawkesbury Rivers were declared in 1959, 1969 and 1979 respectively. In 1993, 35,000 hectares of the Blue Mountains National Park were declared wilderness. Three years later 125,000 hectares of Kanangra Boyd National Park were declared wilderness, and in 1999, 361,000 hectares of Wollemi National Park were declared wilderness. Morton National Park, Bungonia State Recreation Area and Budawang National Park lying in the Shoalhaven River catchment were declared in 1967, 1974 and 1977 respectively. In 1996, 68,000 hectares of Morton and Budawang National Parks were declared wilderness. Between 1956 and 1980 over 10,000 hectares of the escarpment and plateau in the Illawarra were gazetted as National Park, Nature Reserve, or State Conservation Area.

Apart from the metropolitan Sydney, the main land use is for national parks (Figure 9) to the north and west and also to the south of the water sharing plan area. The other land uses includes nature reserves, state forests/plantations, native vegetation, rural residential, urban, extractive industries (quarries, mines), commercial and light industrial uses, agriculture, transport corridors and conservation areas. The water sharing plan area also covers areas of important rural economy where agriculture is a significant land use. Irrigation is used for market gardens, turf farming, orchards, and nurseries. Biodiversity corridors and community use areas for sportsgrounds, parklands, reserves, and golf courses also cover a notable area. The Blue Mountains and surrounds consist of significant natural features (geological, geomorphological, and scenic), natural areas such as bushland, wetlands, escarpments, and water courses and also areas declared for critical habitat under the Threatened Species Act.

WaterNSW water catchments cover an area of 16,000 km^2 which is about 50% of the plan area. These water catchment areas are mainly in 4 groundwater source areas; Lachlan Fold Belt Greater Metropolitan, Sydney Basin South, Sydney Basin Nepean, and Sydney Basin West. The main land use categories are 35.9% livestock grazing, 28.7% nature conservation lands in national parks and 15.7% crown lands and reserves and the rest of the area is covered by intense agriculture, cropping mining, forestry plantation, and urban and rural residential use. (https://www.waternsw.com.au/water-quality/science/catchment/landuse).

The population is concentrated mainly within the area of Greater Sydney, with smaller concentrations in Wollongong, Nowra, and Southern Highlands towns. To the south of Botany Bay, the area surrounded by Kurnell Peninsula currently host various industrial activities, sand extraction operations and a sewage treatment plant. In the past, land uses north of Botany Bay included petrochemical operations, paper manufacturing, tanneries, automotive industries, pharmaceutical businesses, and gelatine production, some of which remain. Industry coupled with urban development has led to extensive modification of land use.

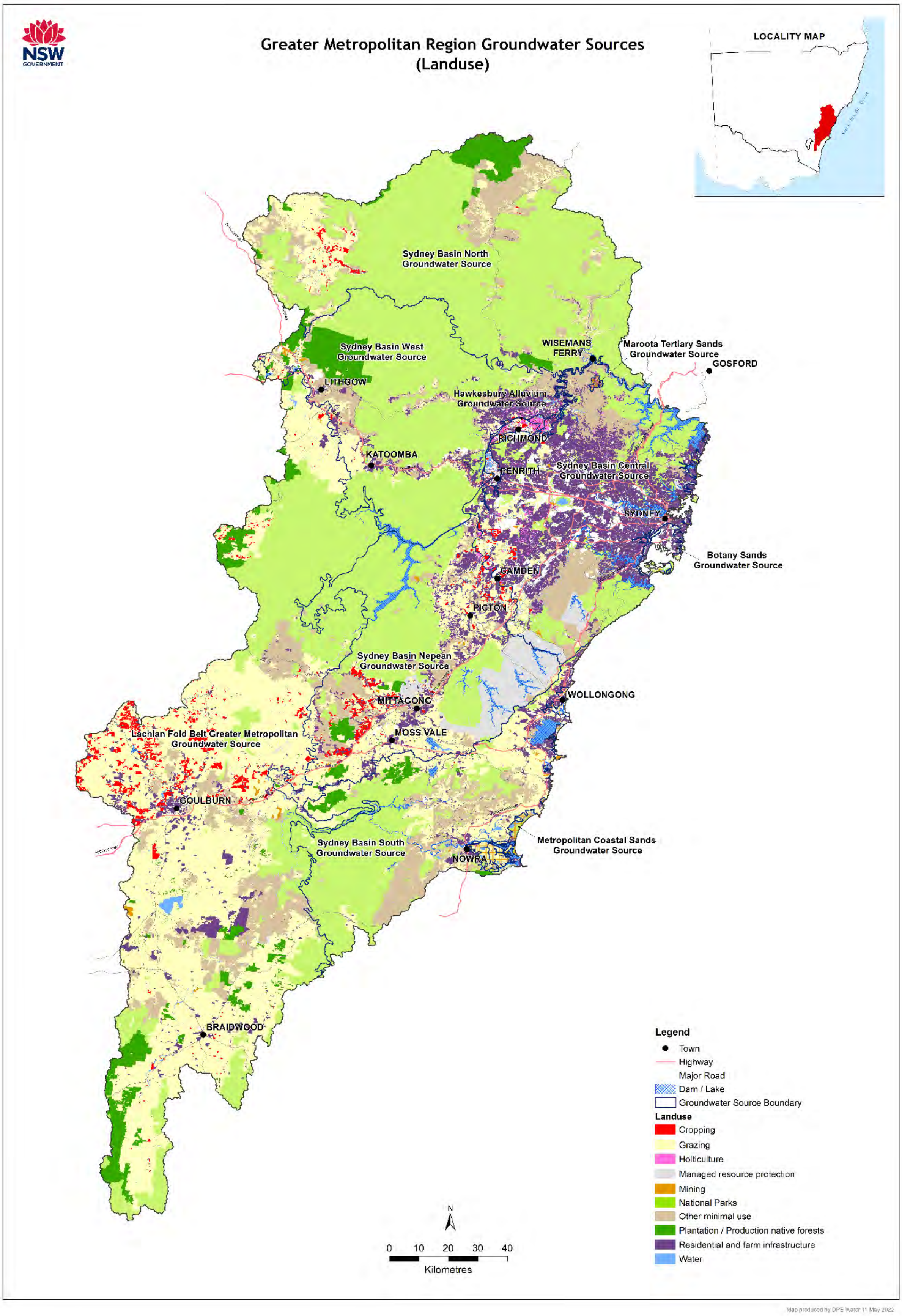

Figure 9 Land use (source: https://datasets.seed.nsw.gov.au)

4. Geology

The Greater Metropolitan Region water sharing plan area overlies parts of two different geological provinces named the Lachlan Fold Belt and the Sydney Basin. The older Lachlan Fold Belt province includes rocks ranging from Palaeozoic (Ordovician: 485 to 444 million years) to Cainozoic (Tertiary: 66 to 2 million years) and sediments from early Cainozoic (2 million years) to present (Tertiary to Quaternary). The geology map of the water sharing plan area is shown in Figure 10.

The younger and more elevated Sydney Basin sequence sits above the underlying Lachlan Fold Belt basement and comprises mainly of consolidated sedimentary rocks (Figure 11). The Sydney Basin rocks are typically from late Palaeozoic (Permian: 299 to 252 million years) to early Mesozoic (Triassic: 252 to 201 million years), and these are also shrouded by Cainozoic sediments (Tertiary and Quaternary).

The Lachlan Fold Belt rocks are exposed along the western side of the water sharing plan area and underlie the younger and more elevated rocks of the Sydney Basin and the outcropping lithologies range from early Palaeozoic to mid to late Palaeozoic (Ordovician to Carboniferous). As a result of the repeated deformation and abundant mineralisation sources, the Lachlan Fold Belt contains favourable targets for various mining projects

The Sydney Basin is the southern extent of the more extensive sedimentary basin province that extends from the east coast south of Sydney, northwest into the Gunnedah Basin and then north to the Bowen Basin in Queensland. Along the southern and western boundary, the Sydney Basin sediments unconformably overlies the Lachlan Fold Belt rocks. The deposition of the basin sediments commenced in the Permian in marine environments, transitioning to non-marine deposits within which economic coal measures were formed. At the end of the Permian, this changed to alluvial fan and fluvial deposition. The Permian coal seams are a major commodity within the area that are mined in both the Southern and Western Coalfields. The younger Triassic sediments are important for various extractive industries such as for building products.

The Permian units comprise sedimentary rocks (sandstone, limestone, conglomerate, shale) with interbedded volcanic beds (latite) and volcaniclastic layers (tuff). Within the water sharing plan area these are broadly subdivided into the Shoalhaven Group and the Illawarra Coal Measures. The Sydney Subgroup in the southeast of the plan area includes all of the economic coal seams (Tongarra Coal, Wongawilli Coal, Balgownie Coal and Bulli Coal) and is the focus of underground mining. Within the Illawarra Coal Measures, the economic seams are interbedded with sandstone and claystone layers in the south and west, whereas further north there is an increased presence of tuffaceous units.

The Permian Illawarra Coal Measures are directly overlain by the Triassic Narrabeen Group across most of the basin (and plan area). The exception to this is along the southwest margin where the Narrabeen Group is absent, and the coal measures are directly overlain by the younger Hawkesbury Sandstone. The Hawkesbury Sandstone comprises a substantial sedimentary sequence in the south and the north. The formation thins out from east to west and is poorly represented, and even absent, in the westernmost parts of the Sydney Basin province within the water sharing plan area.

Igneous rocks of Jurassic age include the Gingenbullen Dolerite in the south and the Prospect Picrite near Prospect Reservoir. Other unnamed igneous intrusive and extrusive rocks are mapped as isolated features throughout the water sharing plan area. Various igneous rocks (dolerite, teschenite, monchiquite) of Cretaceous age have also been found in the south-eastern part of the water sharing plan area and also other igneous rocks (dolerite, basalt) have been mapped as isolated features.

The unconsolidated sediments present in the water sharing plan area are of Cainozoic Era (Tertiary and Quaternary). These deposits occur in settings where there is a supply of source material that has been accumulated over time along the water courses or the coastline. The fluviatile action of major rivers and streams has resulted in alluvial deposits throughout the Greater Metropolitan Region. Longshore drift up the NSW coast, and then accumulation of sand by wind action has created aeolian deposits of varying extents within the water sharing plan area. Tertiary and Quaternary alluvial deposits formed by the fluvial action of rivers and streams generally comprise sand, silt, clay, or gravel in various proportions (e.g., as found along the Nepean and Hawkesbury rivers floodplains).

Quaternary coastal sands groundwater systems are typically comprised of aeolian (windblown) sands deposited in embayments along the shoreline. Where the depositional environment was favourable, the coastal sands can extend further inland particularly where broad erosional depressions were formed in the weathered underlying rock (e.g., the Botany Sands). Peats, clays, and silts may be incorporated within the sands where there have been periodic inputs of transported sediment or vegetative material from water courses or swamps.

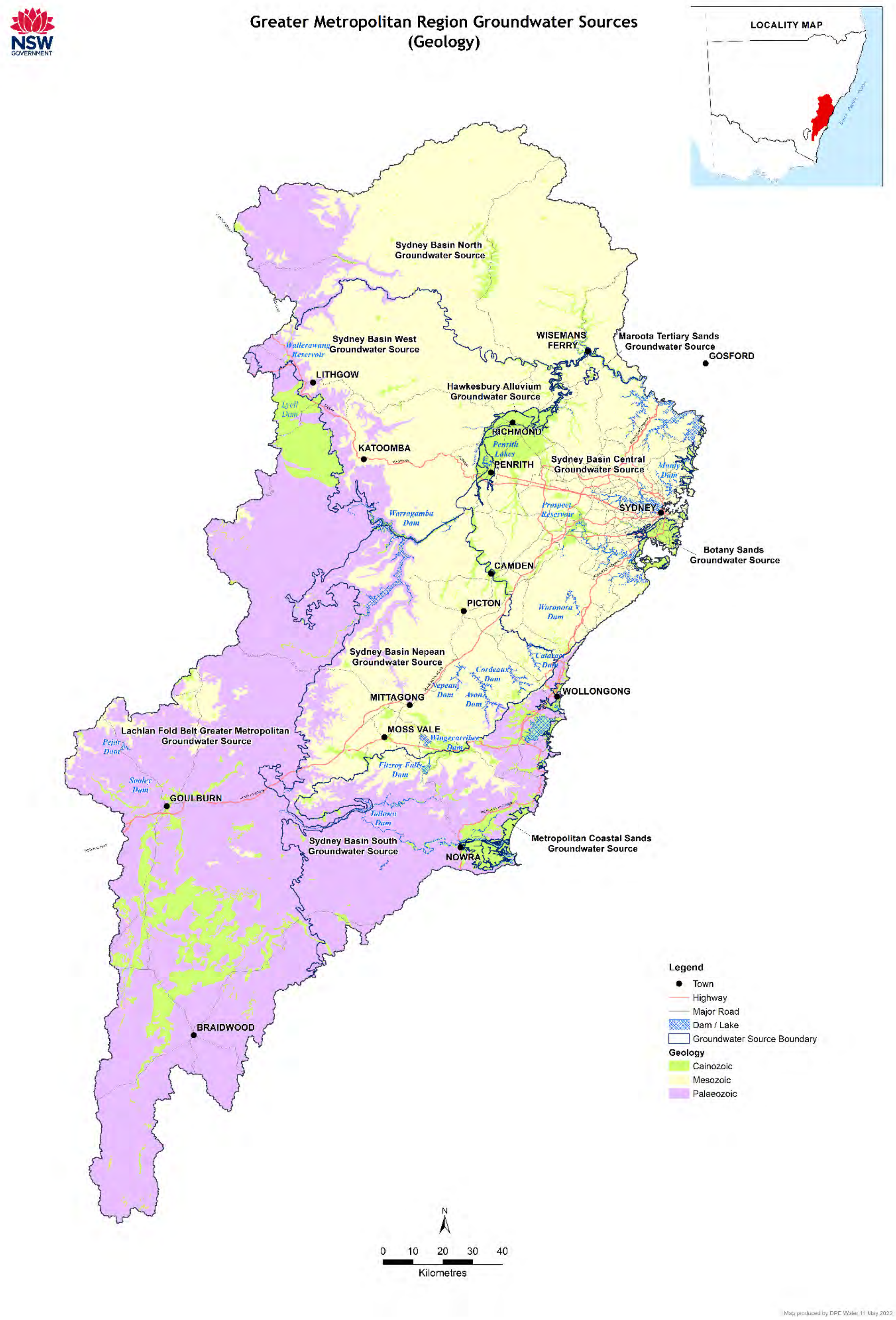

Figure 10 Geology

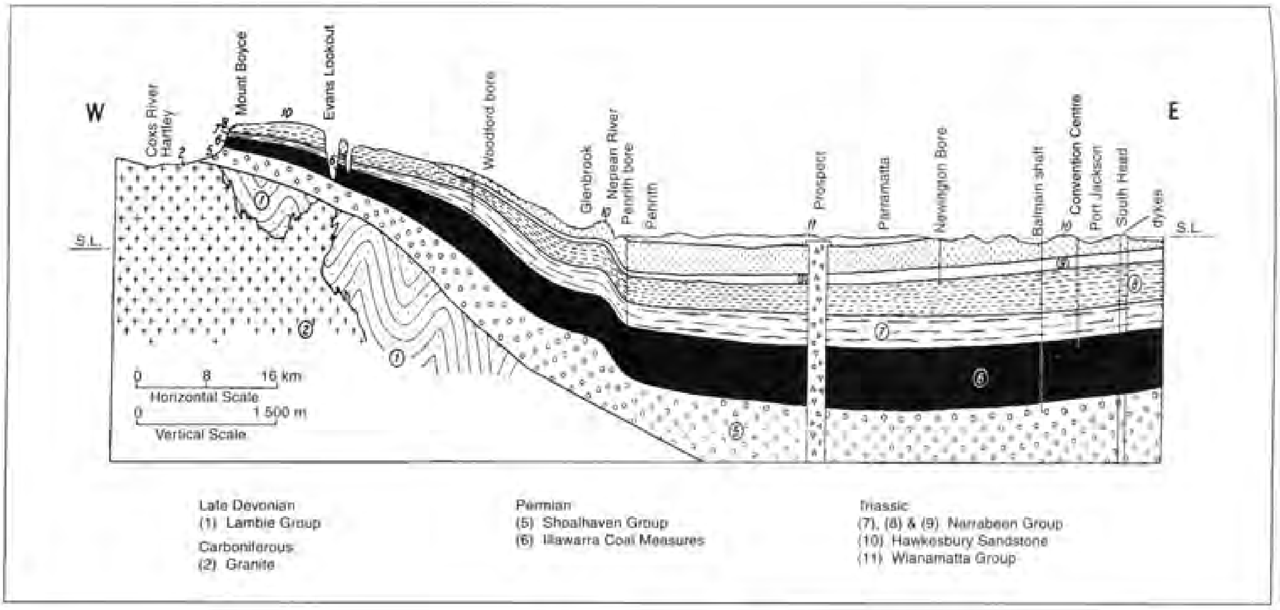

Figure 11 Geological cross section from Hartley to Sydney (Branagan and Packham, 2000)

5. Hydrogeology

5.1 Regional context

The 10 proposed groundwater sources in the Sydney Metropolitan Region Water Sharing Plan can be categorised into 4 groups; fractured rocks, porous rocks, alluvium, and coastal sands. The porous and fractured rock water sources typically include a number of aquifers or groundwater systems in different locations and at different depths. These water sources are themselves also layered over each other. The basal layers are the fractured rock groundwater sources which are overlain by the younger porous rocks that are in turn overlain by the alluvium, or coastal sands.

The basement rocks in the region are those of the Lachlan Fold Belt which are the oldest geologies in the region. Generally fractured rock aquifers have limited potential to have useful yields, however at some locations higher yields can be obtained from the fractured bedrock within various structural settings such as alongside lineaments and faults.

The Sydney Basin is a Permian-Triassic sedimentary rock sequence which includes important aquifers within the Hawkesbury Sandstone and Narrabeen Group. Upper Triassic Wianamatta Group consists of minor aquifers (sandstones) and aquitards (shales) while the Lower Triassic Narrabeen Group consists of minor sandstone aquifers. Water quality of Wianamatta shales is generally poor. The Permian Coal measures (Illawarra and Shoalhaven Groups) also consist of typically minor aquifers often with poor water quality.

The Hawkesbury Sandstone occurs across the entire Sydney Basin, extending from the Southern Highlands to the north, and to the lower Blue Mountains in the west. It is the dominant aquifer with unconfined and perched aquifers as well as semi-confined aquifers separated by relatively impermeable claystone layers.

Alluvial deposits occur along the valleys, creeks and floodplains of the Nepean, Hawkesbury, Georges, and Shoalhaven rivers. These deposits are generally shallow unconfined aquifers that are responsive to rainfall and streamflow. Water movement in these deposits occurs as intergranular flow through the preferential pathways provided by interconnected, higher permeability sand and gravel lenses. Unlike other minor occurrence of alluvium, deposits along the Lower Nepean and Hawkesbury rivers floodplains are significant enough to recognised as a separate groundwater source. The Maroota Tertiary Sands consist of gravel, sand and clay deposited within 2 ancient channels incised in older Hawkesbury Sandstone, and occurs east-northeast of the Hawkesbury alluvium deposits.

The Botany Sands and the Metropolitan Coastal Sands are the 2 main groups of coastal sands. Whilst the Botany Sands is a broad area of unconsolidated sediments having a saturated thickness typically in the order of 20 m, the Metropolitan Coastal Sands comprises much smaller and thinner discrete deposits along the coastal areas between the Hawkesbury River and the Shoalhaven River.

5.2 Fractured rock groundwater sources

5.2.1 Lachlan Fold Belt Greater Metropolitan Groundwater Source

The Lachlan Fold Belt province fractured rocks are present beneath the overlying Sydney Basin porous rock, coastal sand, and alluvium groundwater sources and extends to the coastline. Geological cross sections would show the stacked aquifer arrangement of the Sydney Basin above older Devonian and Carboniferous rocks of the Lachlan Fold Belt (see Figure 11). However, the Lachlan Fold Belt sequence is present only at a substantial depth under the Sydney Basin porous rocks, particularly towards the coast. The proposed Lachlan Fold Belt Greater Metropolitan Groundwater Source is the amalgamation of the previous Goulburn Fractured Rock and the Coxs River Fractured Rock groundwater sources that were included in the 2011 water sharing plan.

The water source extends across the entire water sharing plan area. It outcrops over an area of approximately 10,053.3 km^2 which is about 30% of its total extent. In the southern part of the outcropped area around Goulburn, most of the groundwater found within these rocks is suitable for some domestic, agricultural, and limited industrial uses with an average salinity of 625 mg/L total dissolved solids (TDS) where the average bore depth and yield are around 50 metres below ground level (mbgl) and 1.5 litres per second (L/s) respectively. Higher bore yields up to 16 L/s have also been recorded. The borehole logs, screen intervals and water level data indicate that the bores are generally intersecting a deeper semi-confined aquifer. The bore depths are from few metres to approximately 200 mbgl and the median water level of bores at the time of construction is 14 mbgl. High salinity groundwater does underlie some areas near Goulburn. Although groundwater yield in bores may be reasonable, the water quality may limit its potential uses. Bore distribution is well spread out, but there is some concentration around major townships like Goulburn.

Further north in the Coxs River area the average yield of a bore is about 0.7 L/s. The groundwater is generally fresh, and the average salinity is about 250 mg/L TDS. The bores are up to 135 m deep and the median water level of bores at the time of construction is 9 mbgl.

5.3 Porous rock groundwater sources

The porous rock groundwater sources consist of sequences of major and minor aquifer systems of the Wianamatta Group, Narrabeen Group, Hawkesbury Sandstone, and Permian Coal Measures. The Wianamatta Group shales and Permian Coal Measures often have poor groundwater quality and also low yields. The Hawkesbury Sandstone is the dominant aquifer that occurs across most of the Sydney Basin in the water sharing plan area and typically has dual porosity with preferential flow dominated by secondary porosity (fractures). The Hawkesbury Sandstone is layered and consists of medium to coarse grained sands while the underlying Narrabeen Group consists of interbedded fine to coarse grained sands and silts. Sandstone beds are separated by low permeable shales and siltstones that significantly affect groundwater flow.

The Sydney Basin porous rocks have been split into 5 groundwater sources as proposed (order from north to south)

- Sydney Basin North Groundwater Source
- Sydney Basin West Groundwater Source (amalgamating Sydney Basin Coxs River, Sydney Basin Blue Mountains and Sydney Basin Richmond groundwater sources that were included in the 2011 water sharing plan)
- Sydney Basin Central Groundwater Source
- Sydney Basin Nepean Groundwater Source
- Sydney Basin South Groundwater Source.

Within the Sydney Basin water sources, bore depths are variable, ranging from 20 to 200 m with most bores less than 60 m deep. Groundwater salinity in several areas, may limit its potential uses.

5.3.1 Sydney Basin North Groundwater Source

The water source is bounded by the main arm of the Colo and Hawkesbury River to the south, Kulnura – Mangrove Mountain Groundwater Sources to the east, the Hunter Range to the north and Great Dividing Range to the west and covers an area of 5,413.9 km^2.

Permian and Palaeozoic rocks and Triassic Hawkesbury Sandstone outcrops in the eastern half of the water source while Narrabeen Group, Shoalhaven Group and Illawarra Coal Measures are outcropping in the western half including some volcanic rocks; Tertiary basalt, and dolerites. There is also irregular and limited Quaternary alluvium along drainage lines.

As much of this groundwater source is covered by national park, the bore distribution is more concentrated in the western and northern areas. The average depth and yield of bores are around 50 mbgl and 1.9 L/s respectively. The average salinity is about 950 mg/L TDS. The bore depths are from few meters to approximately 200 mbgl and the median water level of bores at the time of construction is 17 mbgl. The targeted aquifer for water supply is sandstone which is interbedded with shales.

5.3.2 Sydney Basin West Groundwater Source

The water source is bounded by its geological boundary with the proposed Lachlan Fold Belt Greater Metropolitan Groundwater Source to the west and the southwest, the Wolgan River to the north-west, Colo River to the north, Lake Burragorang and the Nepean River to the south and the Hawkesbury River to east. It covers an area of 3,761.1 km^2.

In the northern part of the water source, much of the area is covered by national parks with bore distribution constrained to the eastern area of Kurrajong and Grose Vale. Bore yields are generally low but groundwater is fresh. Average bore depth and average yield are about 125 m and 2.2 L/s respectively. The average salinity is about 475 mg/L TDS. Domestic use (house and garden) dominates the groundwater use while some groundwater is used for the bottled water industry.

The geology is predominantly sedimentary sandstones (Hawkesbury Sandstone and underlying Narrabeen Group), which are the main aquifers in the water source. Other minor aquifers include localised basalts and alluvium. The groundwater flow direction is locally controlled by dissecting valleys. As valleys intersect the watertable, groundwater discharge will occur locally changing the flow direction into the valleys. Water level decline can occur during prolong dry periods. Groundwater discharges along escarpment margins and support important environment sensitive vegetation communities and also sustains number of surface water systems as baseflow.

The western part of the groundwater source consists of Triassic sandstones and siltstones and also Permian layered rocks of Illawarra coal measures and underlying interbedded sandstones and siltstones. The area is topographically elevated and receives relatively higher annual rainfall (see Figure 5). It is bounded on one side by deep escarpments that hosts important groundwater dependent ecosystems. Both the Narrabeen Group and Illawarra Coal Measures contain fractures that control groundwater flow. The majority of bores are located in these sediments which are the primary source of groundwater. The groundwater system operates under unconfined, perched, or confined conditions. The main groundwater discharge from the sandstone groundwater systems in both the Triassic and Permian units is likely to be to the east in the lower lying areas. Bores are fairly evenly distributed. Average bore depth and average yield are about 70 m and 1.2 L/s respectively. The average salinity is about 1,035 mg/L TDS .

In the southern part of the water source, a large proportion is covered by national parks, therefore the bore distribution is concentrated in areas associated with the towns of Leura, Katoomba, and Wentworth. The geology is predominantly sedimentary sandstone (Hawkesbury Sandstone and underlying Narrabeen Group) and siltstone formations with intervening coal seams. The groundwater occurs in both fractured zones and porous layers throughout the sandstone units. Because of the reliance on continued rainfall recharge, water level declines can be expected during dry periods. The area is characterised by the unique relationship between groundwater beneath the plateaus, the surrounding deeply incised valleys, and distinct environmentally sensitive vegetation communities. There is considerable contribution to the overall stream flow from the natural groundwater discharge. Groundwater discharging from the high sandstone terrain forms the baseflow of streams that rise on the plateau. The shallow aquifer is often exposed on, or just above the cliff faces, which assists in the formation of hanging swamps and hanging valley dependent ecosystems. Average bore depth and average yield are about 60 m and 2.1 L/s respectively. The average salinity is about 450 mg/L TDS. Groundwater uses are for domestic (house and garden), livestock watering, industrial, commercial, irrigation, horticultural and recreation.

5.3.3 Sydney Basin Central Groundwater Source

The water source is bounded by the main arm of the Hawkesbury River to the north and the Nepean River to the west and south covering an area of 3,831.4 km^2.

The Sydney Basin Central Groundwater Source is, for the most part, topographically low-lying within a broad structural depression. It is predominantly capped by low permeability shale units of the Wianamatta Group. The area receives relatively less rainfall compared to water sources in the west. The land use over the groundwater source is predominantly urban.

Bores are evenly distributed across the area. Average bore depth and average yield are about 50 m and 1.6 L/s respectively. The targeted aquifer for water supply is sandstone which is interbedded with shales. Median water level of bores at the time of construction is 29 mbgl. The average salinity is about 1,485 mg/L TDS.

5.3.4 Sydney Basin Nepean Groundwater Source

The water source covers an area of 3,949.3 km^2 and is bounded by Lake Burragorang to the north, Nepean River and Cataract River to the east, and the Illawarra Range to the south. National parks cover much of the north-western portion of the groundwater source and the bore distribution is concentrated to the north-east around Camden and the south-western areas around Moss Vale. The area has some similarities with the groundwater sources across the Blue Mountains and Newnes Plateau to the northwest although it is largely hydraulically isolated from those to the northwest.

The geology consists predominantly of sedimentary sandstone (medium to coarse grained) and siltstone formations with intervening coal seams. Tertiary basalts outcrop as caps overlying the sandstone in the elevated highland areas. The Hawkesbury Sandstone, which underlies a large proportion of the area is capable of producing high yields of good quality groundwater. In some areas, where the Wianamatta Group that mainly consists of shales and siltstones overlies the Hawkesbury Sandstone, pumping induced downward leakage between units can lead to intrusion of saline groundwater from the overlying shale into the sandstone. Groundwater sustains many of the GDEs located on the highlands and swamps and contribute to river and creek baseflow in the lower catchment.

The depth to water table can be down to about 50 mbgl depending on the location in the landscape. Basalt caps (fractured) overlying sandstone are locally important for small supplies and can have shallower water tables down to about 15 mbgl. Average bore depth and average yield are about 90 m and 3.2 L/s respectively. The average salinity is about 250 mg/L TDS.

5.3.5 Sydney Basin South Groundwater Source

The water source is bounded by the Illawarra Range to the north, the Turpentine Range to the south and east, and the geological boundary of the Lachlan Fold Belt Greater Metropolitan Groundwater Source to the west. It covers an area of 3,081.7 km2. It is largely positioned below the sandstone escarpment contiguous with the Sydney Basin Nepean Groundwater Source and is located in the southern part of the Southern Coal Field.

The water source consists mostly of Permian Shoalhaven Group and also Illawarra Coal Measures, Hawkesbury Sandstone and occasional volcanics. The Illawarra Coal Measures have confined aquifer systems while the Hawkesbury Sandstone has unconfined and semi-confined aquifers with low yields and good water quality. Similar to the Sydney Basin Central Groundwater Source, this groundwater source is predominantly of low topographic relief and similar rainfall.

The bore distribution is mainly limited to the northern half of this area with national parks covering much of the southern part. Average bore depth and average yield are about 60 m and 1.4 L/s respectively. Median water level of bores at the time of construction is 13 mbgl. The average salinity is about 208 mg/L TDS.

Different management pressures apply across this groundwater source compared to the others, with urbanisation and extractive industries (both coal mining and quarrying) being significant.

5.4 Alluvial groundwater sources

Alluvial deposits (sand, gravel, silt, and clay) occur along most of the rivers and creeks in the water sharing plan area. However, most of them are not extensive and therefore not managed as separate water sources due to their limited extent. Within the water sharing plan these small alluvial deposits are not differentiated from the underlying groundwater source.

The more extensive Quaternary alluvial deposits of current and ancient Lower Nepean and Hawkesbury rivers floodplains are defined as an alluvial groundwater source. In addition, the Maroota Sands, located east-northeast of the Hawkesbury Alluvium Groundwater Source and within the bounds of Sydney Basin Central Groundwater Source area, has an alluvial origin and is managed as a separate alluvial water source in the water sharing plan.

5.4.1 Hawkesbury Alluvium Groundwater Source

The groundwater source comprises of alluvial deposits of the Lower Nepean and Hawkesbury rivers floodplains, extending downstream of the Warragamba Dam to the township of Spencer, and covers an area of 153.4 km^2 and approximately 37 km in length. The alluvial deposits are broadest in the Windsor to Wilberforce area.

The groundwater source consists of unconsolidated sedimentary units of the Quaternary age and overlie Triassic sandstones (Figure 12). The alluvium thickness varies from 10 - 30 m. The upper catchment part of the water source (southern) consists of reasonably thick sand and gravel aquifers up to about 30 m with low salinity groundwater, while further downstream (northern) the sand layers are thinner and water quality becomes marginal and suitable for stock watering.

The groundwater flow in the alluvium is more localised than the main regional groundwater flow system within the underlying Hawkesbury Sandstone. The alluvial water source is predominantly unconfined and hydraulically connected to the Hawkesbury/Nepean River. Groundwater levels are typically at or near the river water levels and contribute to the river baseflow particularly around upper and central parts of the water source. Yields of bores are typically in the range of 1 – 5 L/s. Groundwater salinity is generally low except for areas where the basal alluvium is in contact with the underlying shale or adjacent Tertiary sediments. The groundwater recharge is from rainfall and its interaction with the river. There is also likely to be some upward vertical leakage from the underlying Hawkesbury Sandstone. Groundwater salinity in several areas may limit its potential uses.

A large proportion of the licensed bores have been constructed in the northern areas of the water source along the thinner alluvial deposits associated with meanders of the Hawkesbury River. Groundwater is used predominantly for irrigation and limited garden and commercial use. The average groundwater salinity of bores is about 1,025 mg/L TDS.

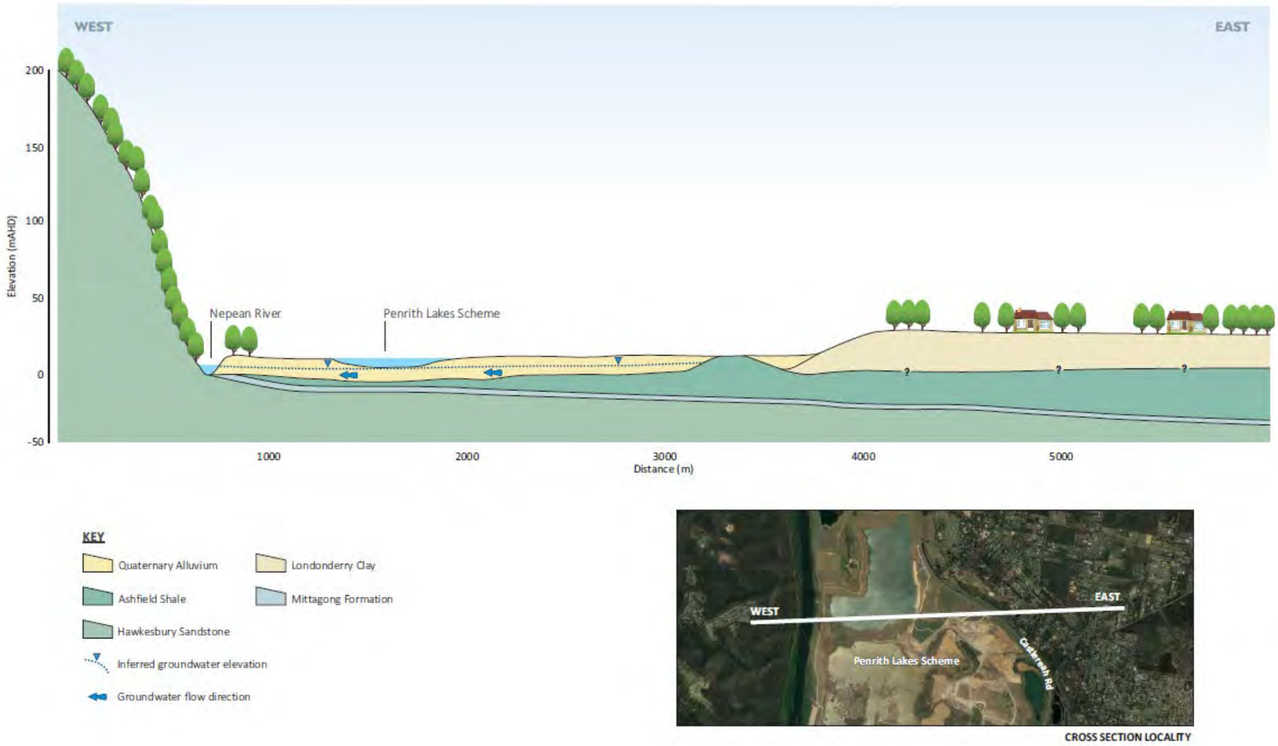

Figure 12 Hawkesbury Alluvium conceptual cross section (Source: groundwater status report EMM 2021)

5.4.2 Maroota Tertiary Sands Groundwater Source

The groundwater source consists of sand deposits, which are up to a maximum thickness of approximately 40 m and the underlying Sydney Basin sediments within the approximately 11.5 km^2 area across the Maroota plateau, 5 to 6 kilometres from Wiseman's Ferry.

The sand deposits that form the groundwater source are underlain by the Sydney Basin sequence (Figure 13). The Tertiary deposits consist of sequence of gravel, sand, clayey sands, and clay deposited within 2 ancient river channels incised in the older Hawkesbury Sandstone. It is difficult to distinguish the Tertiary sands from weathered friable Hawkesbury Sandstone as the hydrogeological characteristics are also similar. The unconsolidated local shallow groundwater system consists of Maroota Sands and weathered friable Hawkesbury Sandstone.

The shallow aquifer system is generally unconfined and forms the locally significant groundwater resource. Water levels are generally deep. There is limited saturated sediments in the more elevated portions of the sand deposit. Perched water occasionally occurs above the saturated zone of the shallow aquifer on shallow clay or sandy clay horizons.

Yields are typically low (0.1 to 2.5 L/s) and water quality is generally good with salinity less than 1,000 mg/L TDS (average from licensed bores is 128 mg/L TDS). It is used for irrigation, stock, domestic, and industrial purposes such as quarrying activities with numerous quarries being established. Springs can occur at the interface between the colluvial sands and the underlying Hawkesbury Sandstone which is the deeper aquifer system.

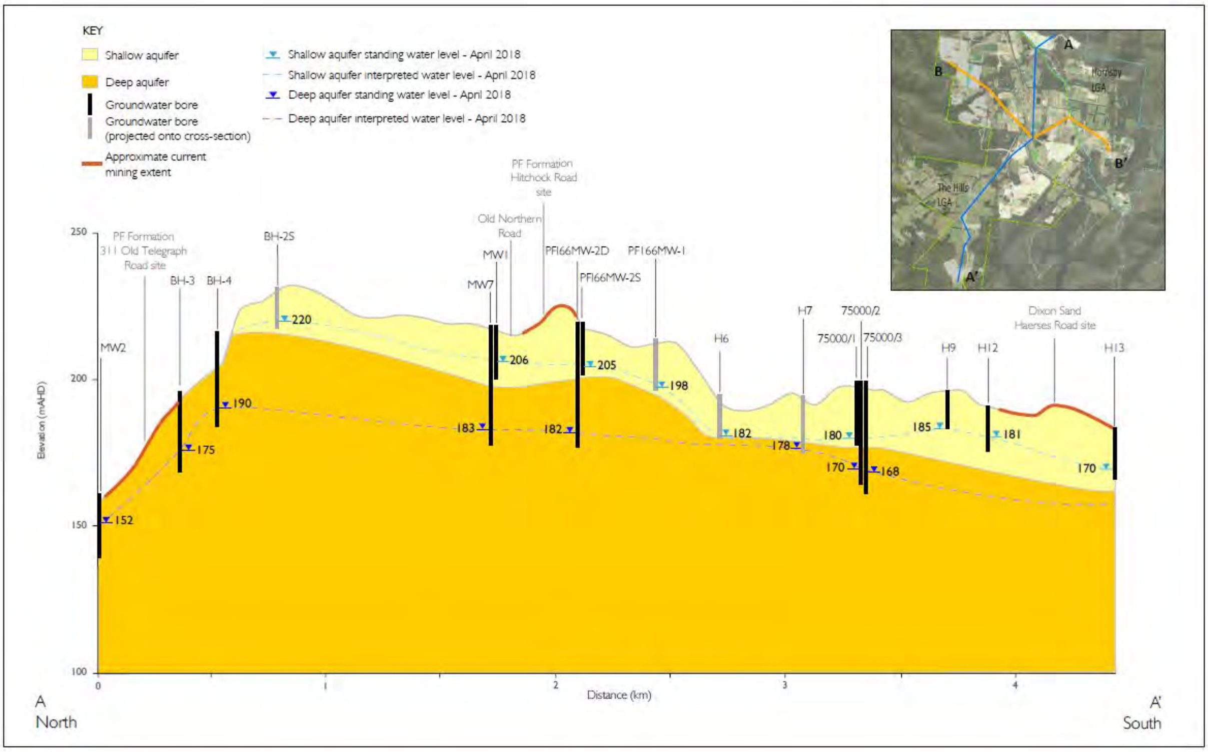

Figure 13 Maroota Tertiary Sands north-south hydrogeological cross section (Source: Maroota extractive industry groundwater study, EMM, 2018)

5.5 Coastal sands groundwater sources

There are 2 coastal sands groundwater sources in the Greater Metropolitan Region water sharing plan; the Botany Sands and the Metropolitan Coastal Sands. The coastal sands consist primarily of aeolian and beach sands that are underlain by Triassic shales and sandstones. Hydraulic interactions between coastal sands and the deeper groundwater systems are not well understood. The Botany Sands Groundwater Source covers a broad area of unconsolidated sediments with a saturated thickness typically in the order of 20 m. The Metropolitan Coastal Sands Groundwater Source comprises much smaller and thinner discrete deposits. A number of hydrogeological investigations had been carried out for urban development projects in the Botany Sands Groundwater Source. Similar extensive investigations have not been carried out in the Metropolitan Coastal Sands Groundwater

Source, but these deposits are expected to have similar groundwater characteristics to the Botany Sands.

5.5.1 Botany Sands Groundwater Source

The groundwater source includes all unconsolidated sediments contained in the topographic depression of Botany Basin (Figure 14), which occupies the coastal areas surrounding Botany Bay. The groundwater source consists primarily of aeolian sand deposits covering an area of 94.8 km^2 and has uniformly graded, well-sorted, clean, and poorly cemented fine- to medium-grained quartz sands. These sand beds are underlain by clay and clay-rich quartz sand lenses and a basal unit consisting of fluvial and aeolian medium-grained sands. The infilled basin has a mean thickness of about 20 m, with up to 53 m deep in paleochannels incised in the basement rocks.

The aquifer system is mostly unconfined with the exception of semi-confined areas underlying discontinuous bands, beds and lenses of clay, silt, peat. Groundwater recharge is primarily from rainfall, with other contributions from irrigation and expected leakage from service mains. There may also be some discharge from the underlying bedrock units into the sands. Groundwater flow follows the topographic gradient towards Botany Bay.

The groundwater is mostly low in salinity and high-yielding and has been an important source of water supply for Sydney's industry and community for many years. The yields of water bores are typically in the range of 0.5 to 41 L/s. Groundwater salinity is typically fresh to slightly brackish (30 – 1,500 mg/L TDS). Groundwater salinity in areas with reclaimed sediments and man-made fill is typically saline. Average bore depth and average yield are about 9 m and 1.7 L/s respectively.

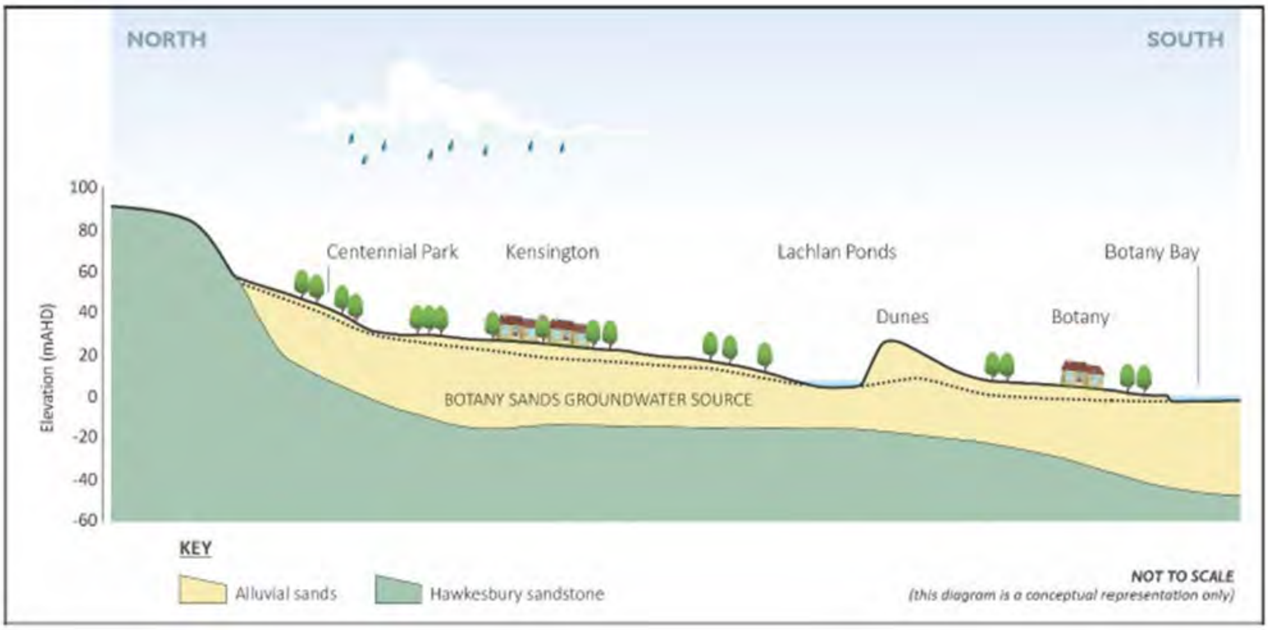

Figure 14 Botany Sands conceptual cross section (Source: groundwater status report, EMM 2021)

5.5.2 Metropolitan Coastal Sands Groundwater Source

The water source consists of aeolian and beach sands and alluvial quaternary sand deposits along the coast, extending from the Hawkesbury River in the north to Crookhaven River in the south, excluding the area covered by the Botany Sands Groundwater Source. It covers an area of 165.7 km^2. The sand deposits are typically small and isolated beach deposits. The largest of these coastal sand deposits within the groundwater source is situated along the Shoalhaven River where it meets the Tasman Sea and extends north along Seven Mile Beach. The groundwater source is expected to have similar groundwater systems and natural characteristics as the Botany Sands Groundwater Source.

Groundwater extraction is largely associated with shallow (<6 m depth) domestic spear points, along with a few larger high-yielding works that draw water for recreational purposes.

The water source typically does not support extracting large volumes and is more commonly accessed for domestic supplies and limited recreational watering. Average bore depth and average yield are about 18 m and 1.3 L/s respectively. Groundwater is typically of good quality and the average salinity of bores is about 517 mg/L TDS.

5.6 Connection with surface water

Most of the water courses in the water sharing plan area are considered to be gaining streams where groundwater is contributing to the river or creek baseflow. Connection between the groundwater and surface water systems (see Figure 3) is controlled by the degree of fracturing in rocks extending to the riverbed or surface water features in the fractured rock area as well as within the porous rock groundwater sources that have significant secondary porosity. Where the base of the permeable weathered profile intersects with surface water features is also locally important to the hydraulic connection between groundwater and surface water.

The alluvial aquifers such as the Hawkesbury Alluvium have connection to the river system via the coarser floodplain sediments close to the river.

Groundwater flow within elevated areas, having high rainfall, is expected to be discharging as springs providing some baseflow along the upper catchments particularly in the north, west and south of the water sharing plan area. Rivers and creeks are generally considered disconnected for management purposes from groundwater in the eastern areas of the water sharing plan where they flow through topographically lower lying plain or flat areas.

While the surface water and groundwater connectivity to a varying degree is acknowledged in most water sources, the groundwater pumping impact on the river flow is considered 'subdued and/or delayed'. Most of the groundwater systems are considered to be "less highly connected" as described in the groundwater macro-planning method report. Therefore, the groundwater sources in the water sharing plan area are managed independently from surface water except for the Hawkesbury Alluvium which is considered as a connected system.

For the Hawkesbury Alluvium Groundwater Source, in addition to the rules specified in Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011, bores shallower than 30 m from the ground surface in the Upper Hawkesbury area are subjected to the water management access rules specified in Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources 2011.

6 Groundwater dependent ecosystems

Groundwater dependent vegetation and wetland ecosystems within the area of the Greater Metropolitan Region water sharing plan have been identified and classified as having ecological value categories ranging from very high to very low (Figure 15). Coastal wetlands and rainforest communities are also protected under the coastal SEPP (State Environmental Protection Policy) along with various other endangered ecological communities. Other communities which are assigned as endangered ecological communities include upland swamps, swamp meadows, and Newnes Plateau swamp woodlands.

Within the Sydney Basin Central Groundwater Source area, very high and high ecological values are dominated by coastal rainforests, upland swamps and heathlands, swamp mahogany-paperbark forested wetlands, red gum river flat forested wetlands, swamp oak forested wetlands, turpentine woodland forests, coastal alluvial bangalay forest, freshwater wetlands, coastal saline wetlands, and mangrove forests.

Within the Sydney Basin North Groundwater Source area, the dominant vegetation communities with very high and high ecological value include river oak forest, apple-red gum forests, temperate rainforests, turpentine woodlands, heathy forests, sand swamp woodlands.

In the proposed Sydney Basin West Groundwater Source area, the HEVAE values of high and very high are dominated by Newnes Plateau swamp woodlands, creek-flat swamp mahogany paperbark forest, riparian grey myrtle, swamp oak forests, turpentine forests and sandstone riparian scrub forests. Also, within this water source area the Blue Mountains are dominated by rainforest, grey myrtle riparian forest, turpentine moist forest, blue mountains swamp and mallee heaths, Newnes Plateau swamps, river oak and riparian scrub communities. In the Coxs River catchment area the groundwater source area is dominated by swamp meadow complexes, fringing swamp woodlands, Newnes Plateau shrub swamps and woodlands.

In the Sydney Basin Nepean Groundwater Source area, the very high and high ecological value communities are dominated by upland swamps, freshwater wetlands, swamp meadow complexes, turpentine gully forests, Nattai and Woronora Plateau woodlands, red gum, and river oak forests.

The Botany Sands Groundwater Source area is dominated by estuarine wetlands, littoral rainforest, coastal swamps, swamp oak-mangrove forests and saltmarsh.

The Hawkesbury Alluvium Groundwater Source area is dominated by communities of swamp mahogany-paperbark and riparian red gum forests, rainforest, freshwater wetlands.

The Maroota Tertiary Sands Groundwater Source area is dominated by swamp paperbark communities.

The Metropolitan Coastal Sands Groundwater Source area is dominated by coachwood rainforest, freshwater wetlands, alluvial bangalay forest, swamp oak forest, mangrove forest, estuarine wetlands, and swamp mahogany swamp forests.

There are also karst cave groundwater dependent ecosystems (GDEs) present which provide habitat for very high ecological value communities. The most well-known of these is the Jenolan Caves complex within the proposed Lachlan Fold Belt Greater Metropolitan Groundwater Source.

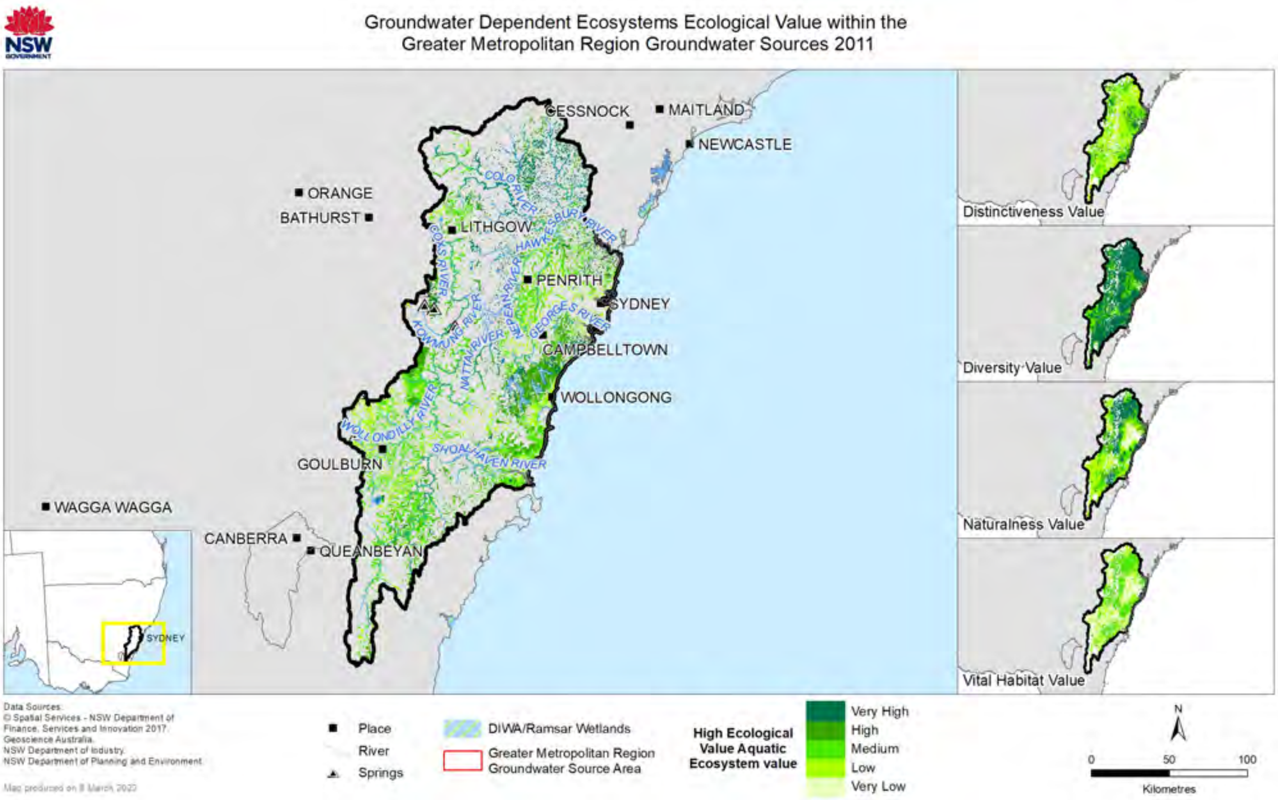

Figure 15 Ecological value for high probability groundwater dependent vegetation ecosystems

7. Groundwater quality

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

One measure of quality most relevant to the end use is the level of salt present in groundwater, or groundwater salinity. This is determined by measuring the electrical conductivity (EC) and is generally reported in micro-Siemens per centimetre (µS/cm) or as milligrams per litre (mg/L) of total dissolved solids (TDS).

In NSW, groundwater salinity levels can range from that of rainwater (<250 µS/cm or 150 mg/L TDS) to greater than that of sea water (~60,000 µS/cm or 36,000 mg/L TDS). Groundwater with salinity suitable for a range of productive uses, is generally found in the large unconsolidated alluvial systems associated with the major westward draining rivers.

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

7.1 Porous rocks

Groundwater quality within the Hawkesbury Sandstone varies from fresh to slightly saline and from slightly acidic to slightly alkaline, as well as being high in iron (SCA, 2005). Water quality within the upper sections of the buried Hawkesbury Sandstone is often poorer than the lower sections where leakage from the overlying shale formations can occur. In areas around Camden, the sandstone groundwater is commonly acidic with some pH values recorded below 5 (AGL, 2013).

A centrally-located accumulation of saline water (exceeding 3,000 mg/L of TDS) exists beneath the Cumberland Basin, corresponding to a pattern where groundwater flows radially from elevated recharge areas around the fringes of the down warped region and is constrained by limited discharge locations (Russell et al., 2009). The regolith aquifers in the western Sydney area have groundwater with generally low salinities (<1,000 mg/L TDS), particularly following heavy rainfall when the salinity can be similar to that in the nearby semi-perennial streams (McNally, 2009).

Analyses of water quality in an oil and gas exploration bore located to the north of the Wallacia investigation area (south-western Sydney) show that salinity increases with depth in the Narrabeen Group and Illawarra Coal Measures (Parsons Brinckerhoff, 2009). Groundwater quality of the coal seams in the Illawarra Coal Measures is generally poor, with moderately saline groundwater, mostly between 5,000 and 10,000 mg/L TDS (AGL, 2013).

Groundwater salinity of Triassic age shale units (Wianamatta Group) in the Southern Highlands is generally considerably less (typically <3,000 mg/L TDS) than that in the Sydney area (mainly >5,000 mg/L TDS). This is attributed to the higher elevation of the former, caused by regional and intermediate deformation and uplift, which contributes to greater flushing of accumulated salts from the rock matrix (Russell et al., 2009).

The Ashfield and Bringelly shales (Late Triassic Wianamatta Group), though primarily aquitards, do include scattered zones of fracture porosity within the weathered bedrock and groundwater is generally saline, typically in the range of 5,000 to 50,000 mg/L TDS (McNally, 2009). The Ashfield and Bringelly Shales are associated with surface salting in parts of western Sydney. At some locations, where the Ashfield Shale overlies or is immediately up gradient of the Hawkesbury Sandstone, saline groundwater from this aquitard contributes to the higher salinities observed in the upper part of the sandstone (Webb et al., 2009). At the same time, upward flow, and migration of brackish/saline groundwater from the underlying Narrabeen Group may be contributing to brackish conditions of the deeper Hawkesbury Sandstone on the eastern side of the Lapstone Structural Complex (Webb et al., 2009).

7.2 Alluvium

In the Hawkesbury Alluvium, groundwater is generally fresh close to the river in the floodplain, however, groundwater salinity can increase adjacent to Tertiary sediment deposits and locations near where shale abuts the water source as those units typically have brackish to saline groundwater (Woolley, 1987). Groundwater in the alluvium is slightly acidic to neutral, and fresh to slightly brackish, i.e., generally less than 1,500 mg/L TDS (EMM 2020). In the southern part of the alluvium, where there is shallow groundwater located close to the Nepean River and where there are green open spaces that allow rainfall recharge, groundwater quality is typically fresher. In the central and northern parts of the alluvium, where there is tidal influence, the better quality groundwater tends to be away from the Hawkesbury River. Water types are dominated by sodium, chloride, and to a lesser extent bicarbonate and magnesium (Parsons Brinckerhoff 2008). There is also potential for groundwater contamination in localised areas associated with industrial land use.

Groundwater salinity on average in the Maroota Tertiary Sands are generally low compared to underlying Hawkesbury Sandstone. Licensed bores have groundwater salinity between 50 – 250 mg/L TDS with an average of 128 mg/L TDS. Both sodium and chloride concentrations are also low in Maroota Sands, however calcium concentrations are notably higher. Nitrate concentrations in both Maroota Sands and Hawkesbury Sands are generally elevated.

7.3 Coastal sands

In the Botany Sands Groundwater Source, water quality is highly variable from fairly fresh (80 – 360 mg/L TDS) in recharge areas to saline groundwater in near shore areas (57,000 mg/L TDS), (DLWC, 2000). Groundwater quality in those areas with reclaimed sediments and man-made fill is typically saline. Since the land use changes in the past, the groundwater quality has deteriorated due to poor sanitation, poor quality stormwater, and inappropriate land uses but primarily the influence from industry and their historically poor waste disposal practices. Sand extraction and landfilling activities have also contributed to degraded groundwater quality in the northern and southern areas of the water source. Groundwater pH is variable (3.9 – 8.9) however it is slightly acidic where it is associated with peaty sediments (DLWC, 2000).

Groundwater quality in Metropolitan Coastal Sands is also highly variable. The changes arise from natural variations in aquifer conditions. Groundwater is vulnerable to contamination due to the permeable nature of sediments and in places where land uses associated with urbanisation and industrial activities can pose a risk of contamination. Licensed bores have groundwater salinity between 90 – 2,000 mg/L TDS.

7.4 Fractured rocks

Groundwater quality within the Lachlan Fold Belt varies significantly based on rock type, fracture density, aquifer/bore depth, and recharge. Salinity can range from fresh to saline. Generally fresh water occurs in recharge areas, but quality deteriorates further down the groundwater flow path. Groundwater salinity in northern part of the water source in Coxs River catchment fractured rock area (average 250 mg/L TDS) is generally low compared to southern part of the water source in the Goulburn area (average 625 mg/L TDS). Licensed bores have shown that in the Goulburn area have salinity levels up to 2,600 mg/L TDS while licensed bores in Coxs River catchment have salinity levels up to 570 mg/L TDS.

8. Groundwater management

The Water Sharing Plan for Great Metropolitan Region Groundwater Sources 2011 divided the groundwater resources into 13 water sources. The revised water sharing plan proposes to reduce this to 10 by amalgamating some water sources as listed below.

- Botany Sands Groundwater Source
- Hawkesbury Alluvium Groundwater Source
- Lachlan Fold Belt Greater Metropolitan Groundwater Source (amalgamation of Goulburn Fractured Rock and Coxs River Fractured Rock groundwater sources)
- Maroota Tertiary Sands Groundwater Source
- Metropolitan Coastal Sands Groundwater Source
- Sydney Basin Central Groundwater Source
- Sydney Basin Nepean Groundwater Source
- Sydney Basin North Groundwater Source
- Sydney Basin South Groundwater Source
- Sydney Basin West Groundwater Source (amalgamation of Sydney Basin Blue Mountains, Sydney Basin Richmond, and Sydney Basin Coxs River groundwater sources)

Botany Sands Groundwater Source and the Sydney Basin Nepean Groundwater Source are divided into 2 management zones each for groundwater trading (dealings) purposes.

8.1 Access rights and extraction limits

Groundwater access licenses for the 10 proposed groundwater sources in the WSP area are shown in Table 1. The share components of aquifer access licences are issued for a specified number of unit shares. There are no local water utility (LWU) access licences as such but there are 2 water access licences for town water supply held by Upper Lachlan Shire Council for town water supply purposes.

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

Table 1 lists the LTAAEL for the individual groundwater sources. The estimated requirement of 19,973 ML/year for basic landholder rights across all water sources in the WSP is included in the LTAAEL.

Groundwater extraction from the Greater Metropolitan Region is not currently metered. Table 1 presents the average annual extraction for the last 3 years for each water source where approval holders have reported their metered extraction. These volumes of reported usage are not indicative of the total volume extracted.

Under the NSW Non-urban water metering policy (2020) all water supply bores within the Greater Metropolitan Region that are required to install a meter must do so by 1 December 2023. The approval holder will then be required to self-report their meter reading monthly to WaterNSW. Approval holders of bores that are not required to have a meter installed will need to keep records of their extraction within 24 hours after each day water is taken and provide this information annually within 28 days after 30 June each year. Whether a bore is required to be metered is based on the bore diameter and the number of bores on the licence. This is detailed in the NSW Non-Urban Water Metering Policy, 2020.

This metered groundwater extraction data is required to ensure groundwater extraction remains within the plan limits. To manage any growth in extraction above the LTAAEL, water sharing plans set a trigger for complying with the extraction limit. A growth in extraction response is triggered if average annual extraction over 5 preceding water years exceeds the LTAAEL by more than 5 percent. Then the available water determination made for aquifer access licences for the following year, should be reduced by an amount that is necessary to return subsequent water extraction to LTAAEL.

Table 1 Access licence share components , LTAAEL and average measured extraction in the WSP area

Aquifer type	Groundwater source	LTAAEL (ML/year) 2011	LTAAEL (ML/year) 2022	Aquifer access shares (unit shares)	Aquifer access town water supply (unit shares)	3 year average annual extraction* (ML/year) (2018/19 – 2020/21)
Fractured rock	Lachlan Fold Belt Greater Metropolitan (previously Goulburn Fractured Rock)	53,074	133,949	7,791	100	83
Fractured rock	Lachlan Fold Belt Greater Metropolitan (previously Coxs River Fractured Rock)	7,005				
Porous rock	Sydney Basin North	19,682	25,297	1,027	-	13

Aquifer type	Groundwater source	LTAAEL (ML/year) 2011	LTAAEL (ML/year) 2022	Aquifer access shares (unit shares)	Aquifer access town water supply (unit shares)	3 year average annual extraction* (ML/year) (2018/19 – 2020/21)
Porous rock	Sydney Basin West (previously Blue Mountains)	7,039	36,045	26,706	-	16,796
Porous rock	Sydney Basin West (previously Coxs River)	17,108				
Porous rock	Sydney Basin West (previously Richmond)	21,103				
Porous rock	Sydney Basin Central	45,915	31,859	4,029	-	10
Porous rock	Sydney Basin Nepean	99,568	64,785	31,446	-	1,119
Porous rock	Sydney Basin South	69,892	30,584	4,444	-	31
Alluvium	Hawkesbury Alluvium	2,456	5,103	1,172	-	1
Alluvium	Maroota Tertiary Sands	645	1,364	179	-	23
Coastal sands	Botany Sands	14,684	16,411	8,120	-	929
Coastal sands	Metropolitan Sands	27,206	11,407	1,069	-	179
Total		**385,377**	**356,804**	**85,983**	**100**	**19,184**

*These volumes are self-reported by licence holders and are not indicative of the total volume of pumping.

8.2 Available water determination

An available water determination is made at the start of each water year which sets the allocation of groundwater for the different categories of access licences. Whilst there is limited metered groundwater extractions data across the water sharing plan area, entitlements in each of the groundwater sources is less than the extraction limit. Therefore, all authorised extraction under licences would not result in the water sharing plan extraction limit compliance rules to be exceeded that would require a subsequent reduction in allocation. Since the commencement of the 2011 water sharing plan, allocations have been made available at 100 per cent access for all water sources, i.e., 1 ML per share.

8.3 Groundwater accounts

The water account management rules are specified in 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.

Individual access licence account management rules for all groundwater sources in the Greater Metropolitan Region, except for the Botany Sands, the Hawkesbury Alluvium and the Maroota Tertiary Sands groundwater sources are allowed to carryover up to 0.1 ML per unit share of the access licence share component remaining in the water allocation account from one water year to the next. In Botany Sands, Hawkesbury Alluvium and Maroota Tertiary Sands groundwater sources, water allocations remaining in the water allocation account for an access licence cannot be carried over from one water year to the next.

The maximum amount of water that can be debited from aquifer access licence accounts in any one water year (i.e., account take limit) is equal to the sum of water allocations accrued to the water allocation plus any allocation transferred in, and minus any allocation transferred out.

8.4 Groundwater take

Groundwater is taken and used in the water sharing plan area for productive purposes such as irrigation and industry as well as for stock and domestic use (basic landholder rights). Groundwater use is influenced by climate, access to surface water or as is the case in many Greater Metropolitan Region groundwater sources, access to reticulated supplies. Reliance on groundwater increases in drier years and when there is reduced access to surface water. Figure 16 shows the distribution of water supply bores across the 10 proposed groundwater sources in the water sharing plan area.

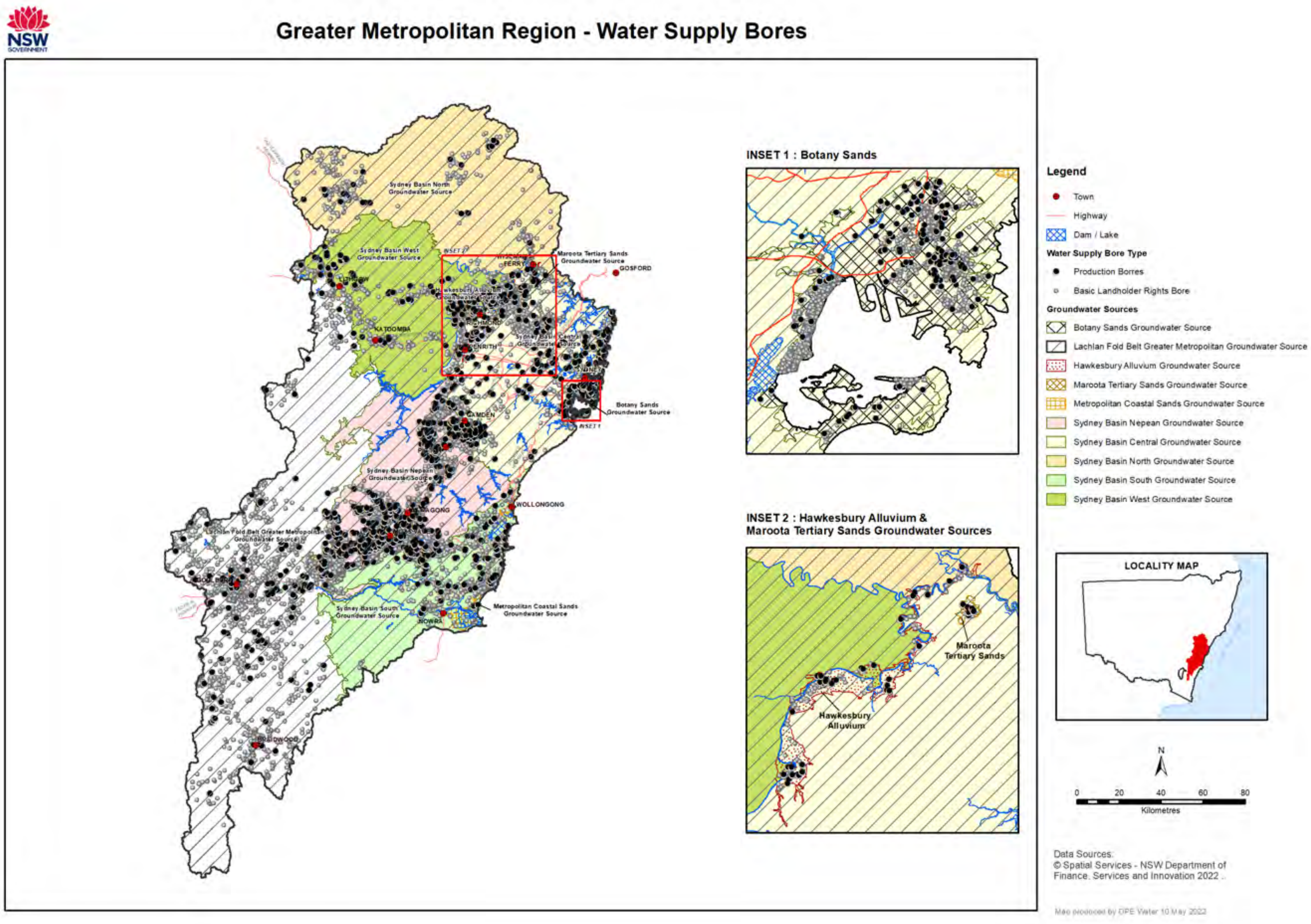

Figure 16 Registerd bores in the water sharing plan area

There are approximately 11,487 registered bores (March 2022) in the water sharing plan area (Table 2), the majority are exclusively for stock and domestic purposes (i.e., basic landholder rights) while others have a range of purposes including dewatering (approximately 200) and irrigation (approximately 500). The majority of dewatering licences (approximately 115) are in the Sydney Basin Central Groundwater Source while the majority of irrigation bores (approximately 225) are in the Sydney Basin Nepean Groundwater Source.

Table 2 Number of water supply bores in the WSP area

Water source	Basic rights	Production bores	Total
Botany Sands	1,868	230	2,098
Hawkesbury Alluvium	126	50	176
Lachlan Fold Belt Greater Metropolitan*	1,559	173	1,732
Maroota Tertiary Sands	6	13	19
Metropolitan Sands	256	79	335
Sydney Basin Central	1,289	339	1,628
Sydney Basin Nepean	2,365	490	2,855
Sydney Basin North	309	34	343
Sydney Basin South	844	102	946
Sydney Basin West**	1,227	128	1,355
Total	9,849	1,638	11,487

*The proposed Lachlan Fold Belt Greater Metropolitan Groundwater Source includes the Goulburn Fractured Rock and Coxs River Fractured Rock groundwater sources

**The proposed Sydney Basin West Groundwater Source includes the Sydney Basin Blue Mountains, Sydney Basin Richmond, and Sydney Basin Coxs River groundwater sources

8.5 Groundwater dealings

Under the *Water Management Act 2000*, dealings are permitted in access licences, shares, account water and the nomination of supply works. Access licence dealings in these groundwater sources are subject to the provisions of the Act, the Regulations, the access licence dealing principles and the access licence dealing rules. All types of dealing are permitted only within a groundwater source.

There are certain trade restrictions in Botany Sands and Sydney Basin Nepean groundwater sources as given below.

8.5.1 Permanent dealings

Dealings for groundwater licences can be made under sections 71M (licence transfer), 71N (term licence transfer), 71P (subdivision/consolidation) and 71Q (assignment of shares) and 71W (nomination of works) of the *Water Management Act 2000*. Dealings to convert the licence purpose to another category (71O) and assign share component to another water source (71R) are not permitted.

There are dealing restrictions between management zones in the Botany Sands and also in the Sydney Basin Nepean groundwater sources. In the Botany Sands, 71Q dealings are not permitted from Management Zone 2 to Management Zone 1. In the Sydney Basin Nepean, 71Q dealings are not permitted from Management Zone 2 to Management Zone 1 (see Figure 1) if the dealing exceeds the total access share component at the commencement of the water sharing plan in 2011.

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

Table 3 shows the statistics for dealings that result in a change in the potential volume that can be extracted from a location since commencement of the water sharing plan in 2011. 71M dealings are not considered as these are change of ownership only and therefore have no potential for additional third party impacts.

Table 3 Number of permanent dealings over the past 3 years (71M dealings not included)

Water source	2018-2019	2019-2020	2020-2021
Botany Sands	1 (2 unit shares)	1 (7 unit shares)	0
Hawkesbury Alluvium	0	0	0
Lachlan Fold Belt Great Metropolitan*	0	2 (72 unit shares)	0
Maroota Tertiary Sands	0	0	0
Metropolitan Sands	0	0	0

Water source	2018-2019	2019-2020	2020-2021
Sydney Basin Central	0	0	1 (3 unit shares)
Sydney Basin Nepean	0	2 (10 unit shares)	0
Sydney Basin North	0	0	0
Sydney Basin South	1 (15 unit shares)	1 (12 unit shares)	0
Sydney Basin West**	0	0	0
Total	2 (17 unit shares)	6 (130 unit shares)	1 (3 unit shares)

*The proposed Lachlan Fold Belt Greater Metropolitan Groundwater Source includes the Goulburn Fractured Rock and Coxs River Fractured Rock groundwater sources

**The proposed Sydney Basin West Groundwater Source includes the Sydney Basin Blue Mountains, Sydney Basin Richmond, and Sydney Basin Coxs River groundwater sources

8.5.2 Temporary dealings

Generally, the most common type of dealings between groundwater licences are allocation assignments (temporary trades) made under section 71T of the *Water Management Act 2000*. These are permitted between water access licences linked to metered bores only.

There are dealing restrictions between management zones in the Botany Sands and also in the Sydney Basin Nepean groundwater sources. In the Botany Sands, 71T dealings are not permitted from Management Zone 2 to Management Zone 1. In the Sydney Basin Nepean, 71T dealings are not permitted from Management Zone 2 to Management Zone 1 if the sum of water allocations credited to the water allocation accounts of all access licences of that water year exceeds the total access share component at the commencement of the water sharing plan in 2011. Table 4 shows 71T dealings during the last 3 years.

There are no 71T dealing restrictions in other water sources.

Table 4 Number of temporary trade 71T dealings over the past 3 years

Water source	2018-2019	2019-2020	2020-2021
Botany Sands	0	1 (7 ML)	0
Hawkesbury Alluvium	0	0	0
Lachlan Fold Belt Great Metropolitan*	8 (420 ML)	7 (390 ML)	0

Water source	2018-2019	2019-2020	2020-2021
Maroota Tertiary Sands	0	0	0
Metropolitan Sands	0	0	1 (10 ML)
Sydney Basin Central	0	1 (10 ML)	2 (5 ML)
Sydney Basin Nepean	1 (8 ML)	0	2 (50 ML)
Sydney Basin North	0	0	0
Sydney Basin South	0	1 (12 ML)	0
Sydney Basin West**	0	1 (1,000 ML)	1 (1,500 ML)
Total	**9 (428 ML)**	**11 (1,419 ML)**	**6 (1,565)**

*The proposed Lachlan Fold Belt Greater Metropolitan Groundwater Source includes the Goulburn Fractured Rock and Coxs River Fractured Rock groundwater sources

**The proposed Sydney Basin West Groundwater Source includes the Sydney Basin Blue Mountains, Sydney Basin Richmond, and Sydney Basin Coxs River groundwater sources

9. 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 17 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 17 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 across multiple water bearing zones within an aquifer.

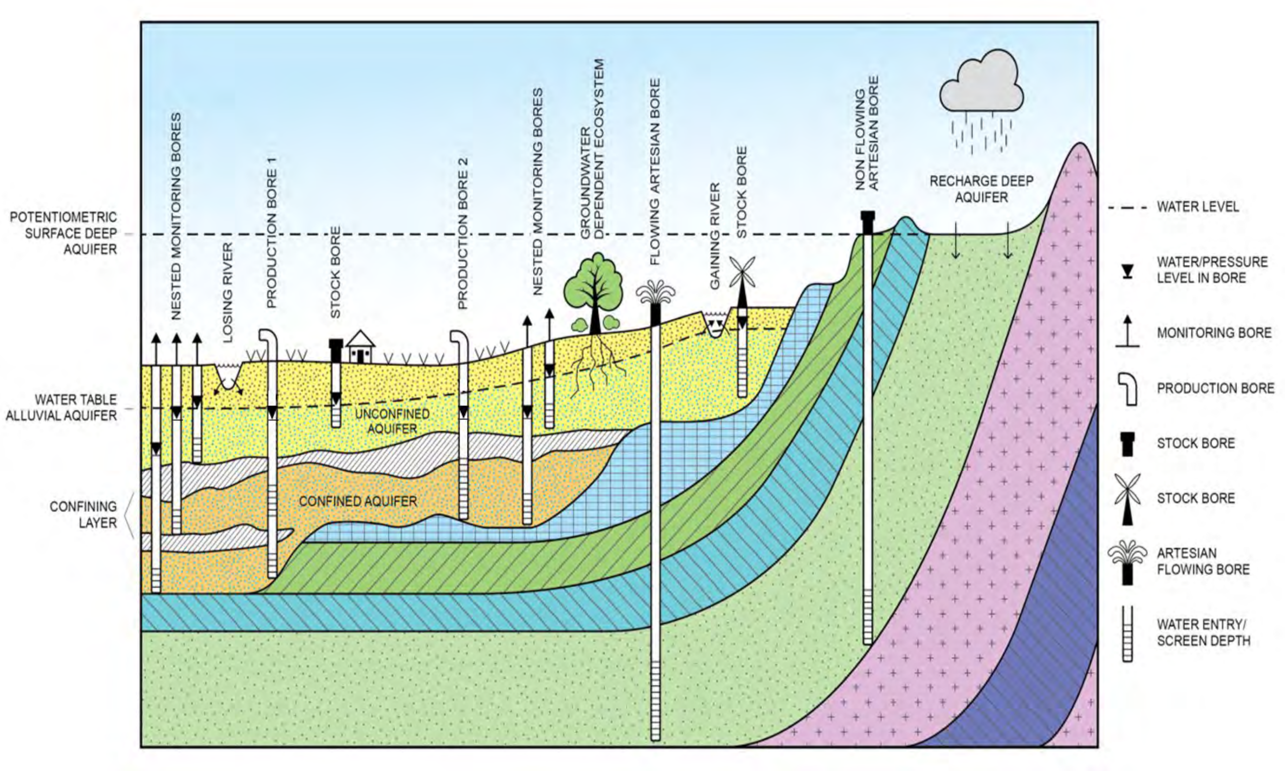

Figure 17 Schematic diagram of different types of aquifers

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 17 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.

Groundwater monitoring is carried out at 69 monitoring sites across the water sharing plan area and have data loggers installed with some also fitted with telemetry (Figure 18). The distribution of monitoring bores are focussed on areas where historic groundwater development demands or particular management issues were apparent. The manual irregular measurement of groundwater levels has been ongoing within the plan area for many decades, however monitoring using automatic loggers and recorders has only been occurring since the end of 1997. Manual records of groundwater levels are archived within the corporate database.

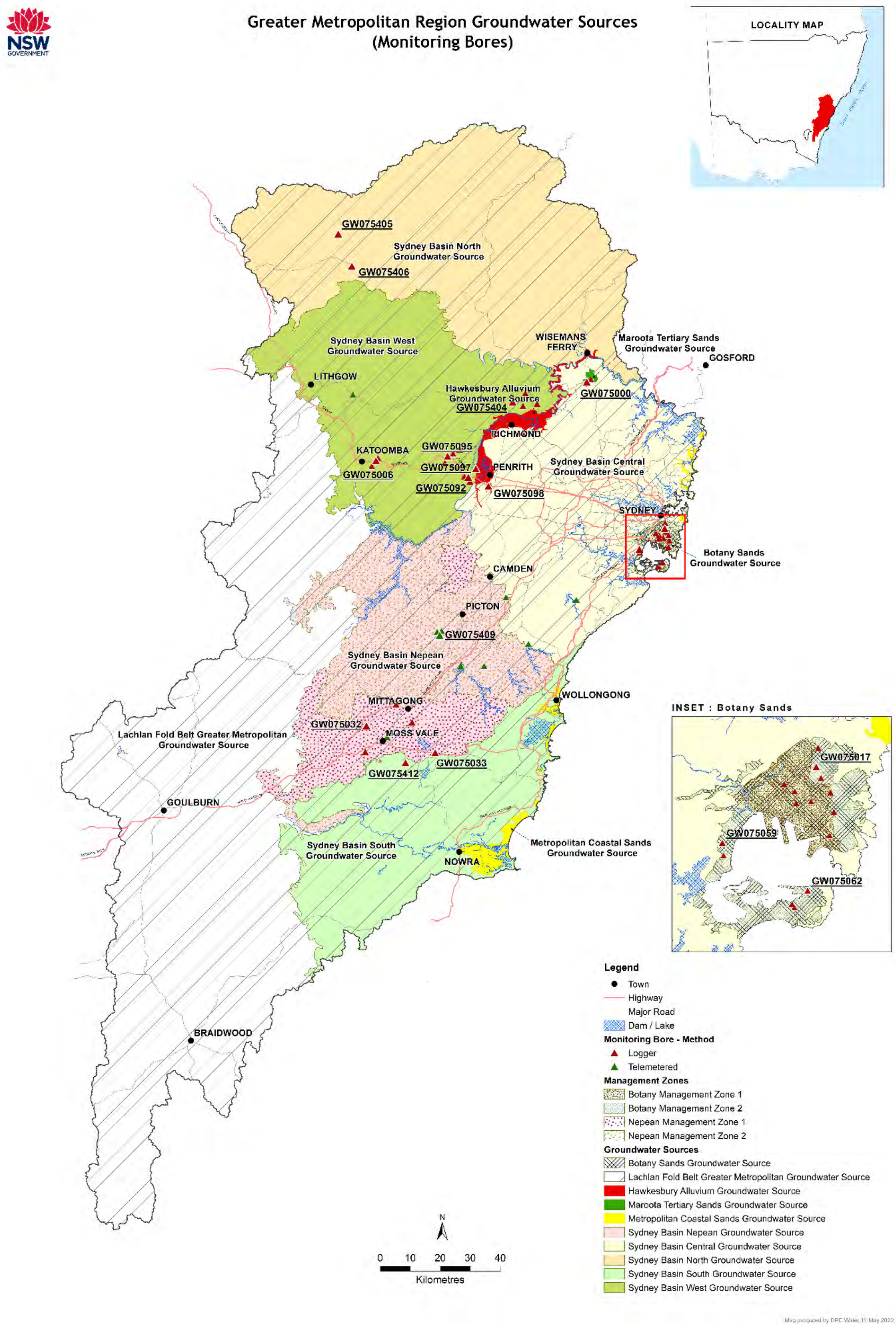

Figure 18 Location map of monitoring bores

10. Groundwater behaviour in the water sharing plan area

10.1 Hydrographs

A hydrograph is a plot of groundwater level or pressure from a monitoring bore over time (Figure 19). 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 19 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.

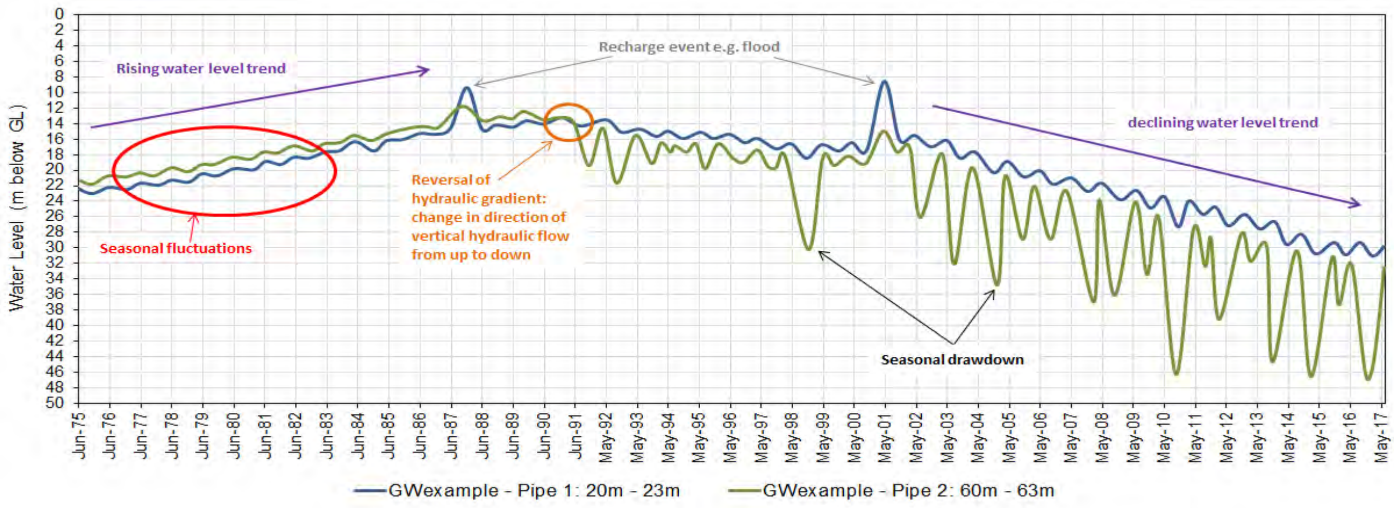

Figure 19 Example of a groundwater hydrograph identifying trends in groundwater responses to pumping and climate

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

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

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

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

10.2 Review of groundwater level data

The regional monitoring bore network is irregularly distributed across the plan area, having been established to gather data in locations where past groundwater demand or specific management issues prompted the necessary investigations. Therefore, not all of the groundwater sources within the water sharing plan area have monitoring bores installed. Furthermore, because some monitoring locations were installed for particular purposes (for example, the shallow bores at Thirlmere Lakes), they may not be entirely representative of the broader groundwater source as a whole. The depth to water shown in hydrographs below is also dependent on the topography at each monitoring bore location. Monitoring with automatic loggers started in 1997 and the monitoring network was expanded with more sites after 2007.

10.2.1 Botany Sands Groundwater Source

All of the regional monitoring bores consists of a single pipe at each site, measuring the shallow groundwater levels in the unconsolidated sediments. Generally, water levels are steady with no apparent declining trend (Figure 20, Figure 21 and Figure 22). Some of the bores in the water source show a groundwater level fluctuation between 1 and 2 m. This would be representative of natural water table changes, with higher levels corresponding to periods of increased recharge (wet seasonal conditions) and lower levels reflecting reduced recharge (drought or dry seasonal conditions).

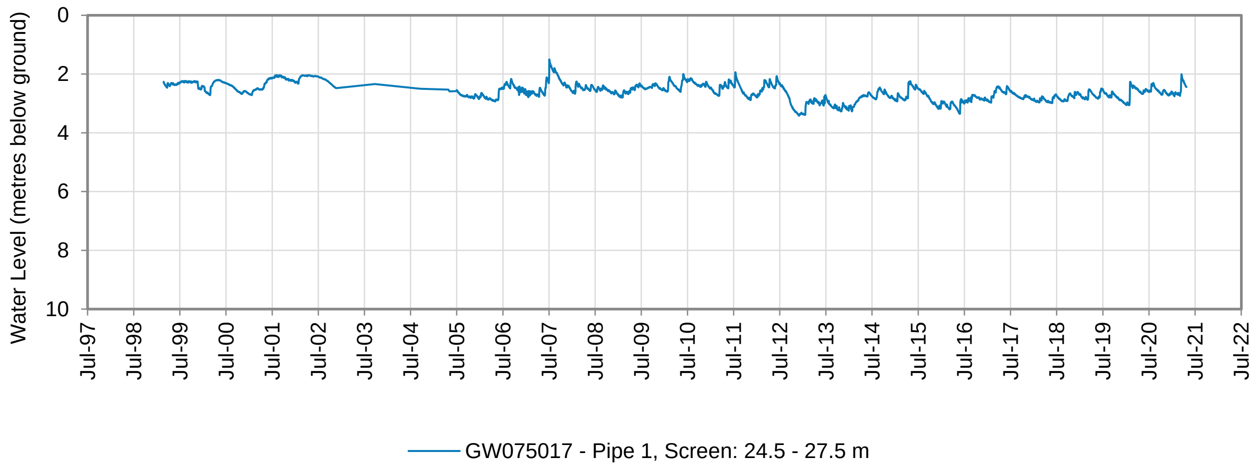

Figure 20 GW075017 – Australian Golf Course, Kensington

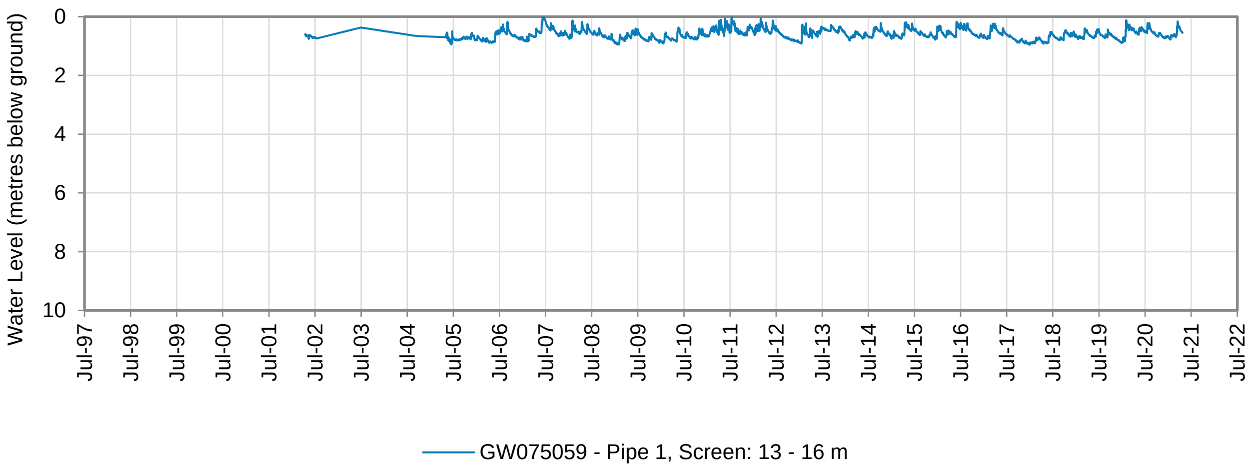

Figure 21 GW075059 – Scarborough Park, Monterey

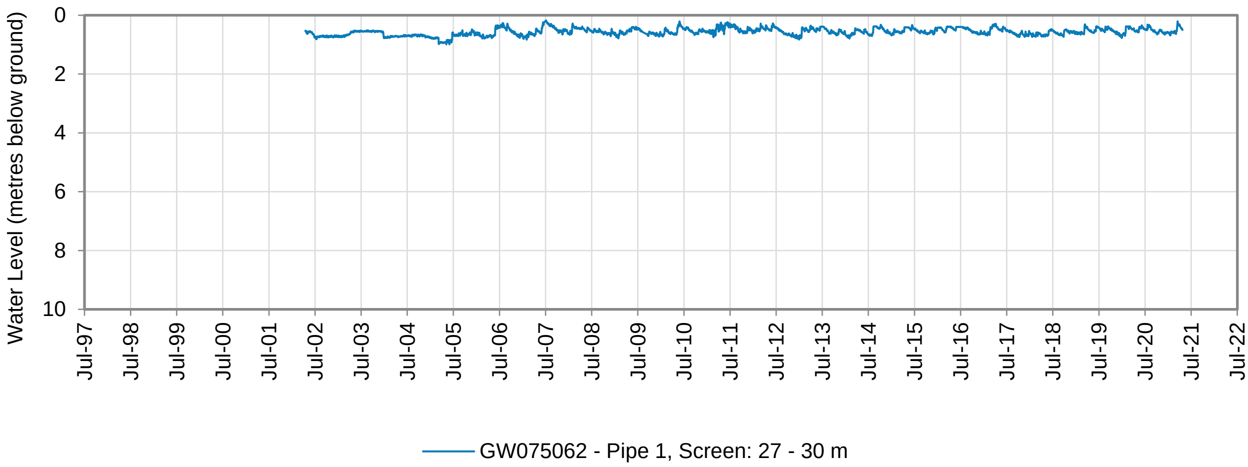

Figure 22 GW075062 – Marton Park, Kurnell

10.2.2 Hawkesbury Alluvium Groundwater Source

The monitoring bore sites site GW075097 (Figure 23) comprises three pipes; the shallowest pipe monitors the unconsolidated sediments on the western floodplain of the Nepean River while the other 2 pipes monitor the underlying shallow and deep Hawkesbury Sandstone groundwater systems in relative isolation (the deepest, pipe 3, is not shown due to unreliable data). The range in groundwater levels change within the alluvium at this site is up to about 2 m. The record for this bore is generally representative of the natural groundwater level variations in the alluvium. The reason for spikes in water levels shown in hydrograph is unclear in pipe 2 where the monitoring bore is screened against the shallower Hawkesbury Sandstone.

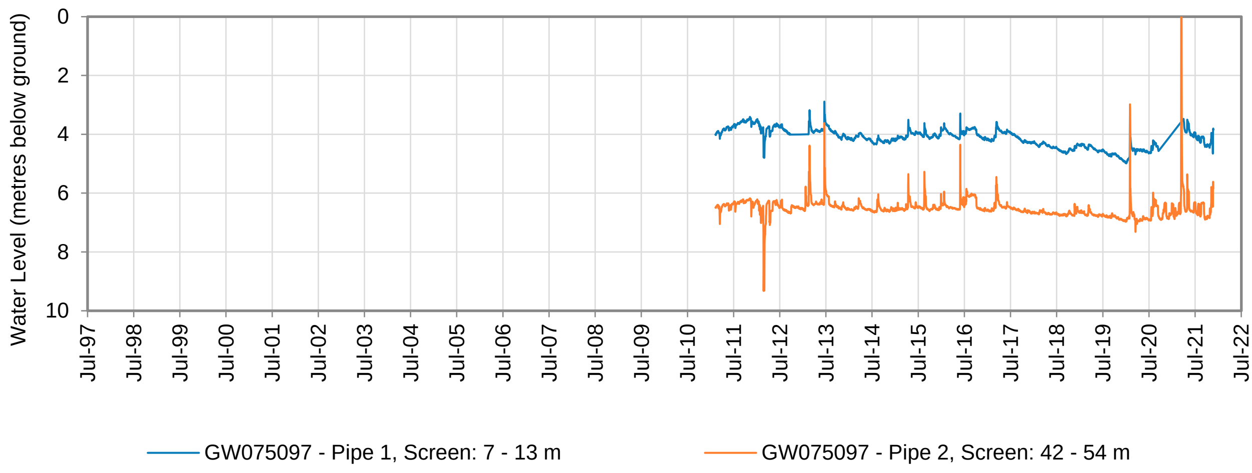

Figure 23 GW075097 Wedmore Reserve, Emu Heights

10.2.3 Maroota Tertiary Sands Groundwater Source

The monitoring bore GW075000 (Figure 24) is screened against the uppermost Maroota Sands in the shallowest pipe, other 2 pipes are screened against the underlying Hawkesbury Sandstone. The monitoring bores screened in the Maroota Sands show a range of groundwater levels change from 4.4 m to 8.7 m. This is likely to be due to active pumping from excavations near the monitoring bores.

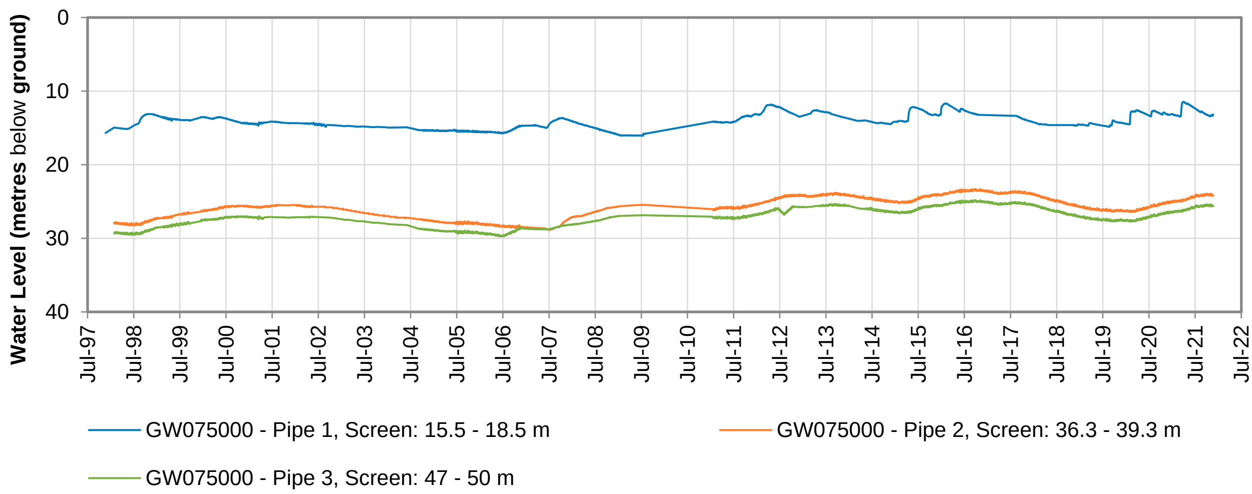

Figure 24 GW075000 Haerses Road, Maroota

10.2.4 Sydney Basin West Groundwater Source

10.2.4.1 Blue Mountains area

In the upper Blue Mountains, the regional monitoring bore network is distributed across the plateau between Leura and Wentworth Falls within the urbanised corridor along the Great Western Highway and monitor the shallow and deeper groundwater systems in the Narrabeen Group sandstones. Generally, water levels are steady in both shallow and deep sandstone aquifers (GW075006, Figure 25).

In the lower Blue Mountains, the regional monitoring bore network extends over a larger area but is still limited to the more urbanised areas of the plateau. Most of the bores in this network were completed as multiple pipe installations at different levels within the Hawkesbury Sandstone groundwater systems in relative isolation. Two bores (GW075092 and GW075095) monitor shallow, intermediate and deep groundwater systems (Figure 26 and Figure 27). Water levels are generally steady with no apparent declining or rising trend.

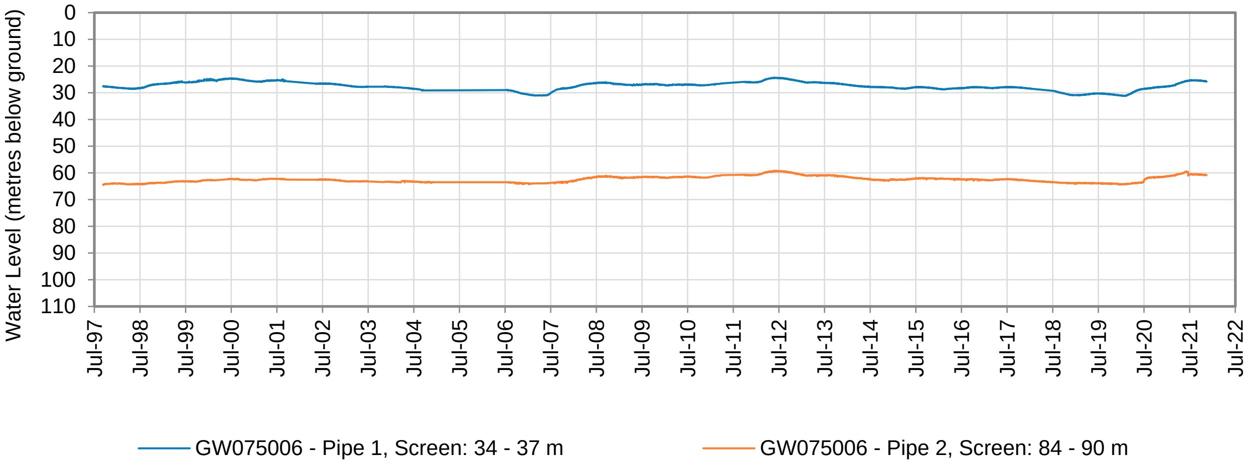

Figure 25 GW075006 Sinclair Crescent, Wentworth Falls

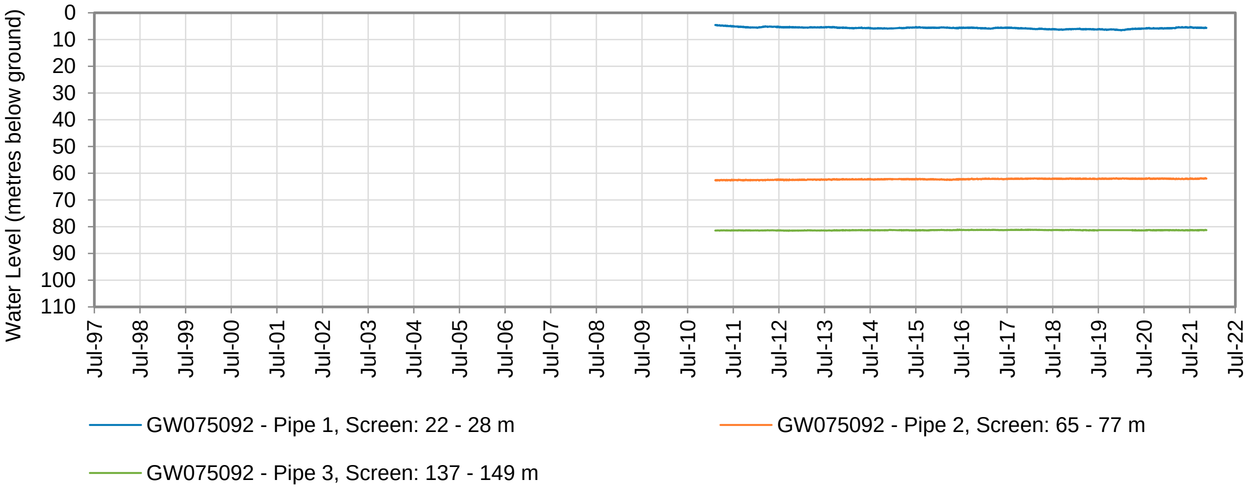

Figure 26 GW075092 Knapsack Park, Glenbrook

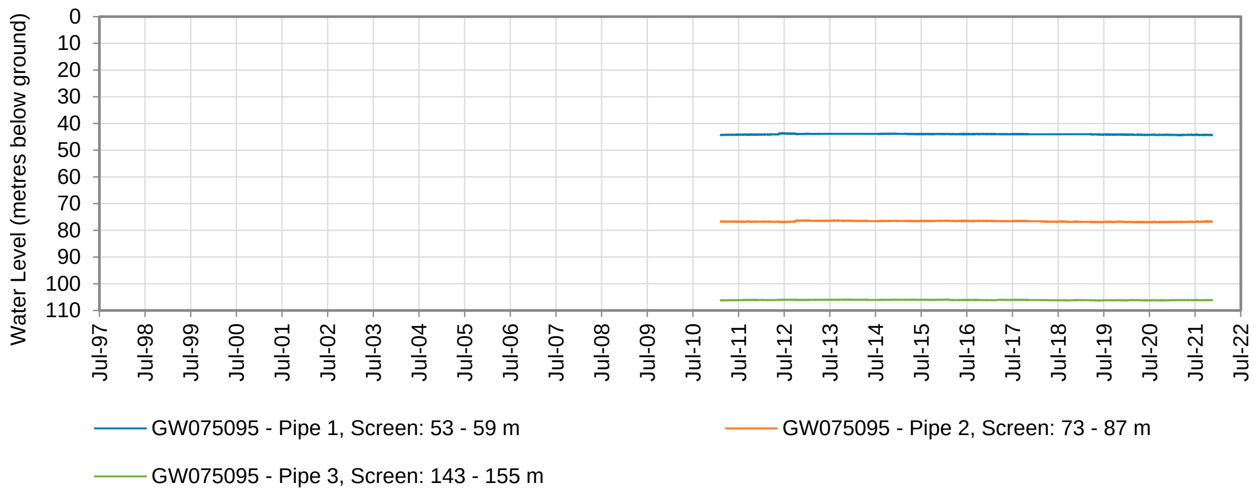

Figure 27 GW075095 Lomatia Park, Springwood

10.2.4.2 Richmond area

The monitoring bore sites are distributed along the elevated sandstone ridges at Wilberforce, Glossodia, Freemans Reach and East Kurrajong. Monitoring bore GW075404 (Figure 28) at Glossodia is designed to monitor the shallow and deep Hawkesbury Sandstone groundwater systems. The water levels in the deeper sandstone aquifer (pipe 2) show a declining trend of about 12 m between 2014 and 2020.

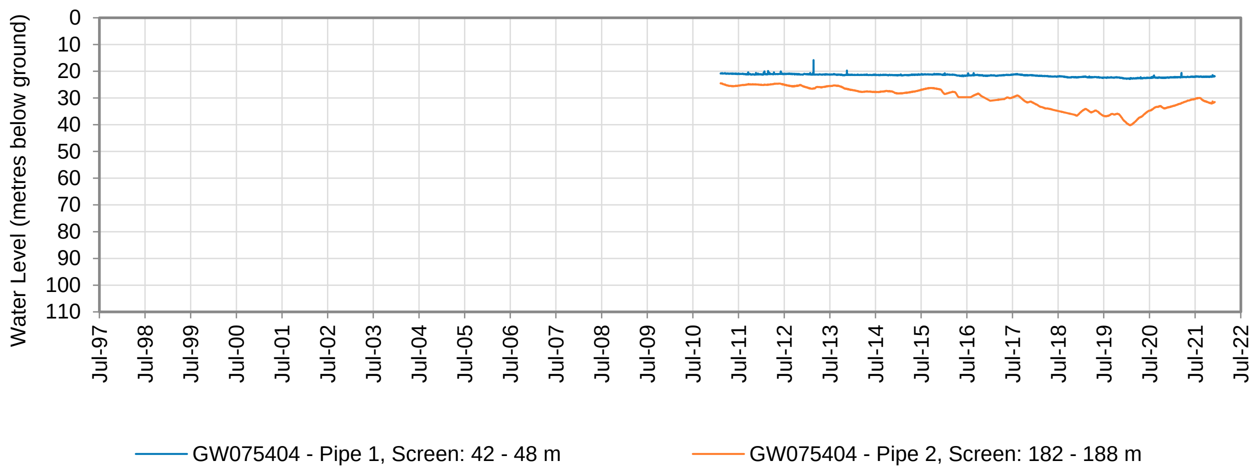

Figure 28 GW075404 Woodbury Reserve, Glossodia

10.2.5 Sydney Basin Central Groundwater Source

The regional monitoring bore site (GW075098, Figure 29) at Glenmore Park at the western part of the water source. The site comprises three separate pipes designed to monitor groundwater levels; the shallowest pipe 1 in the Wianamatta Group while the other 2 deeper pipes in the underlying Hawkesbury Sandstone and they are in relative isolation. Water levels are generally steady.

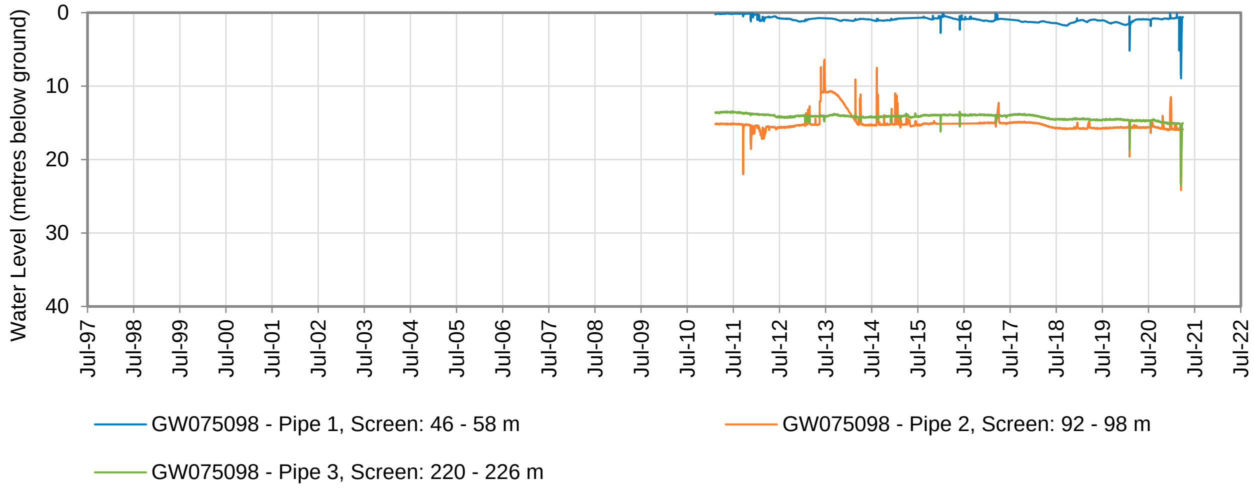

Figure 29 GW075098 Surveyors Creek Softball Fields, Glenmore Park

10.2.6 Sydney Basin Nepean Groundwater Source

The monitoring bores in this groundwater source are located next to water supply infrastructure, on council land or within national parks. GW0075032 (Figure 30) is located at the southwestern end of the water source while GW075033 (Figure 31) is located at the south eastern edge targeting Hawkesbury Sandstone at different depths in the Southern Highlands. GW075409 (Figure 32) is located within Thirlmere Lakes National Park and monitors both shallow (unconsolidated) and deep (Hawkesbury Sandstone) groundwater systems.

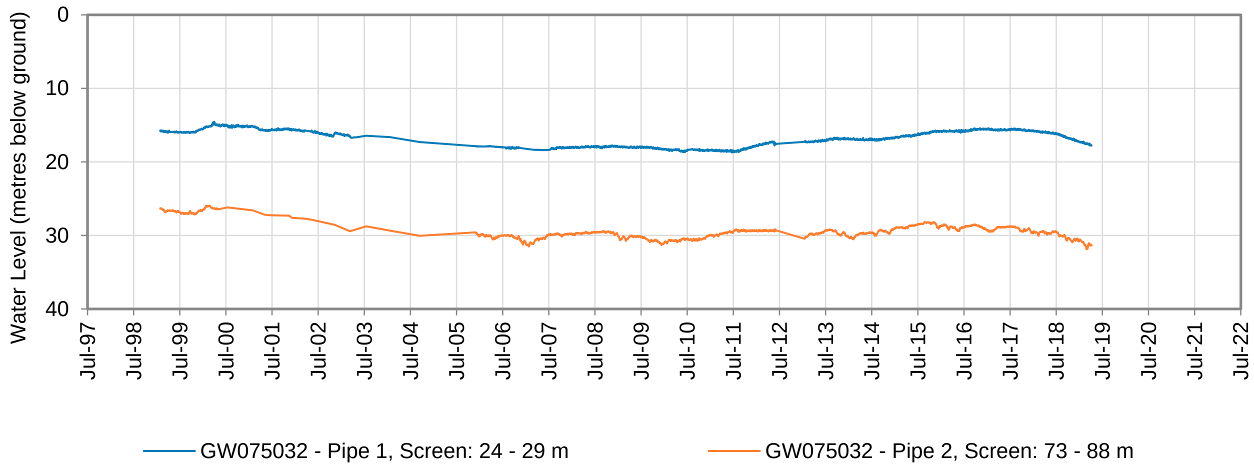

Figure 30 GW075032 Sewage treatment plant, Berrima

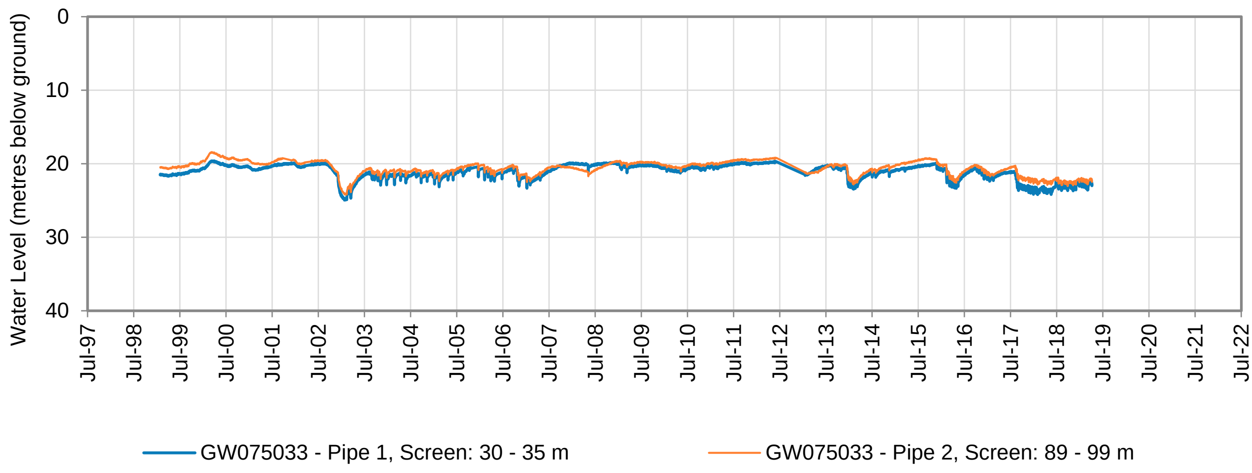

Figure 31 GW075033 Pumping station, Burrawang

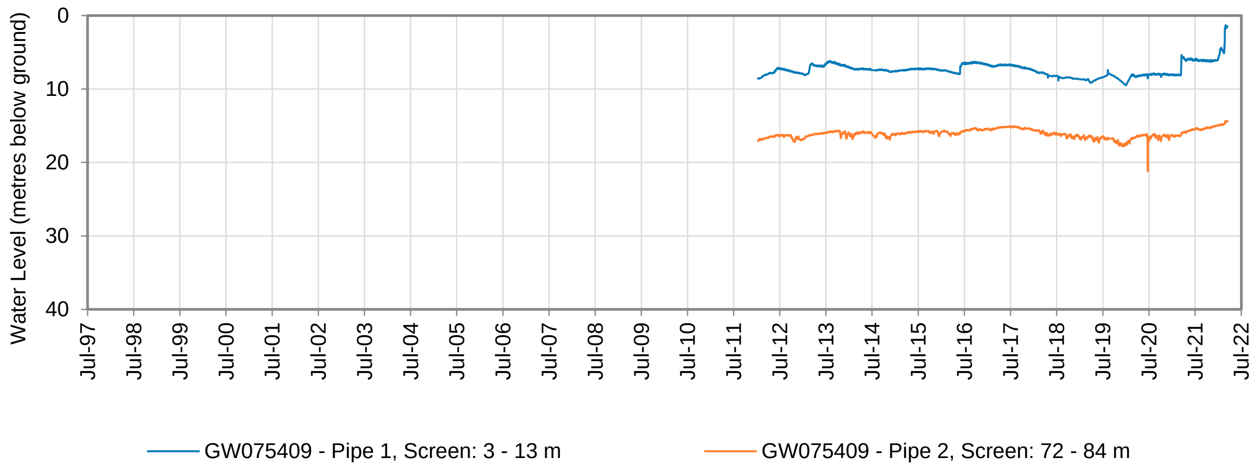

Figure 32 GW075409 Lake Couridjah, Thirlmere Lakes

10.2.7 Sydney Basin North Groundwater Source

GW075405 (Figure 33) monitors both shallow groundwater system in unconsolidated sediments and also a deeper groundwater system in the underlying sandstones in relative isolation and water level fluctuations are over one meter. Water level behaviour in both groundwater systems are similar. GW075406 (Figure 34) monitors the deep groundwater system within the Berry Siltstone and the range of water level fluctuation is small (0.8 m). Groundwater levels are steady at both sites.

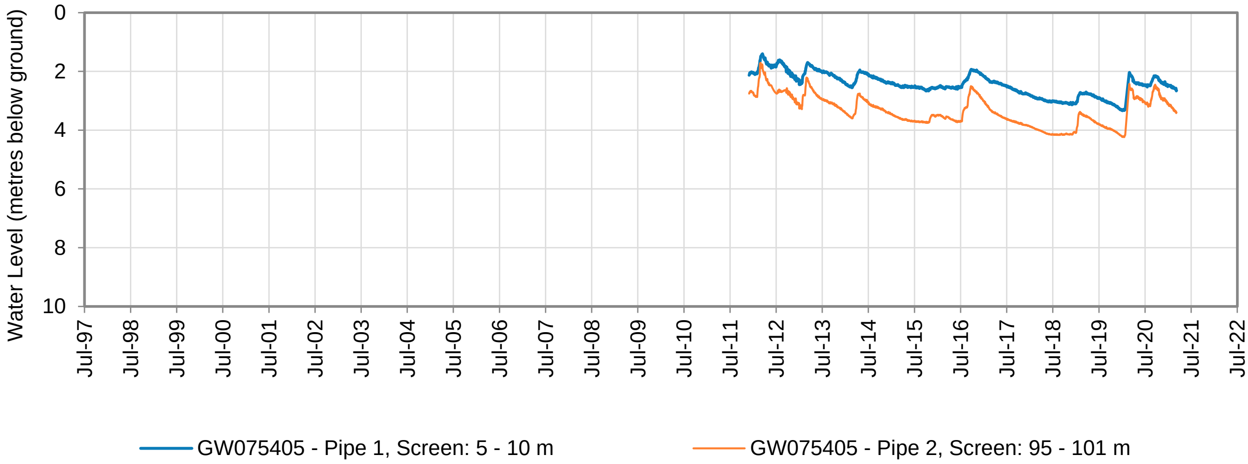

Figure 33 GW075405 Upper Nile Road, Glen Alice

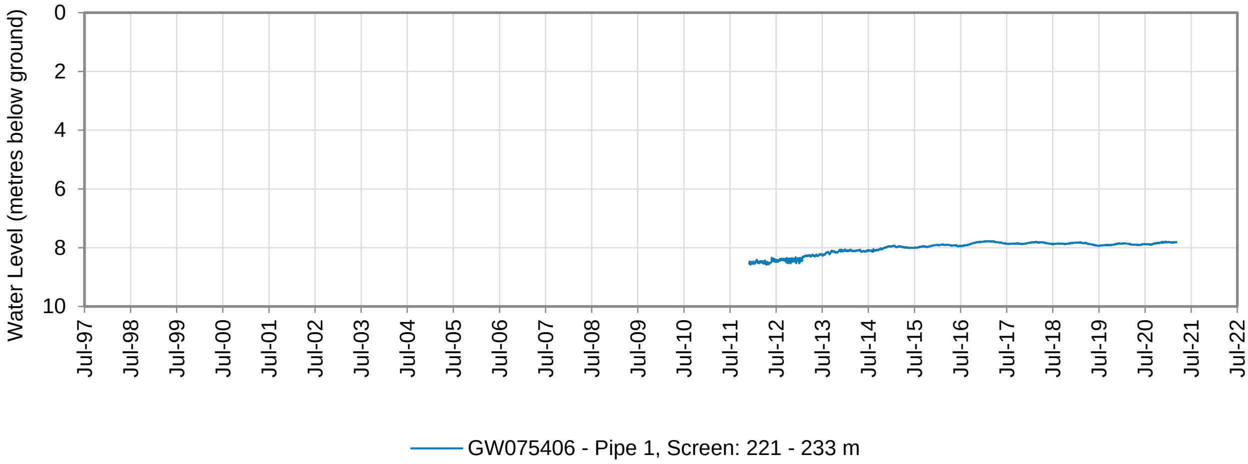

Figure 34 GW075406 Campground, Glen Davis

10.2.8 Sydney Basin South Groundwater Source

GW075412 (Figure 35) is located above the sandstone escarpment at Fitzroy Falls positioned close to the catchment boundary and water level fluctuation is nearly 2m.

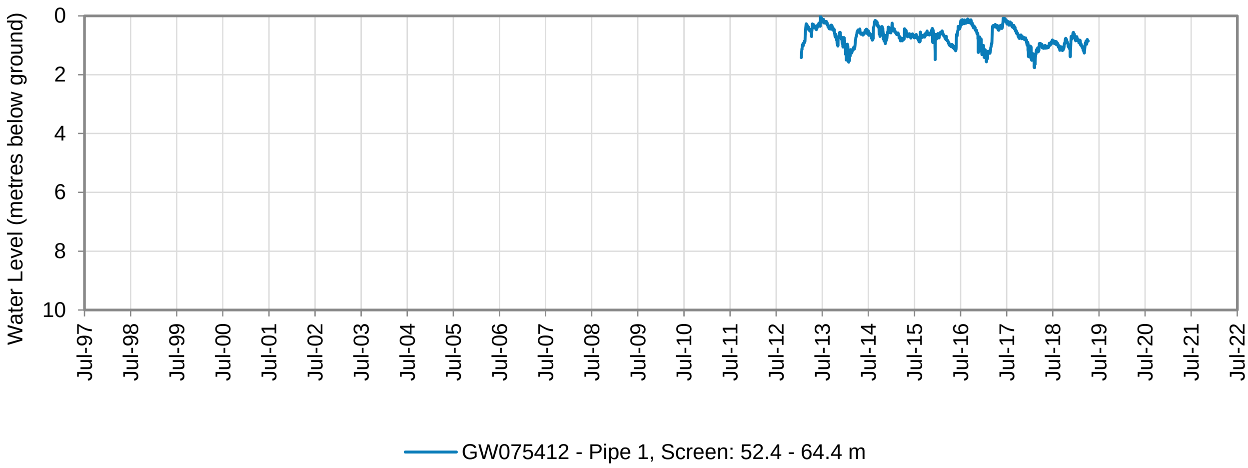

Figure 35 GW075412 Redhills Road, Fitzroy Falls

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