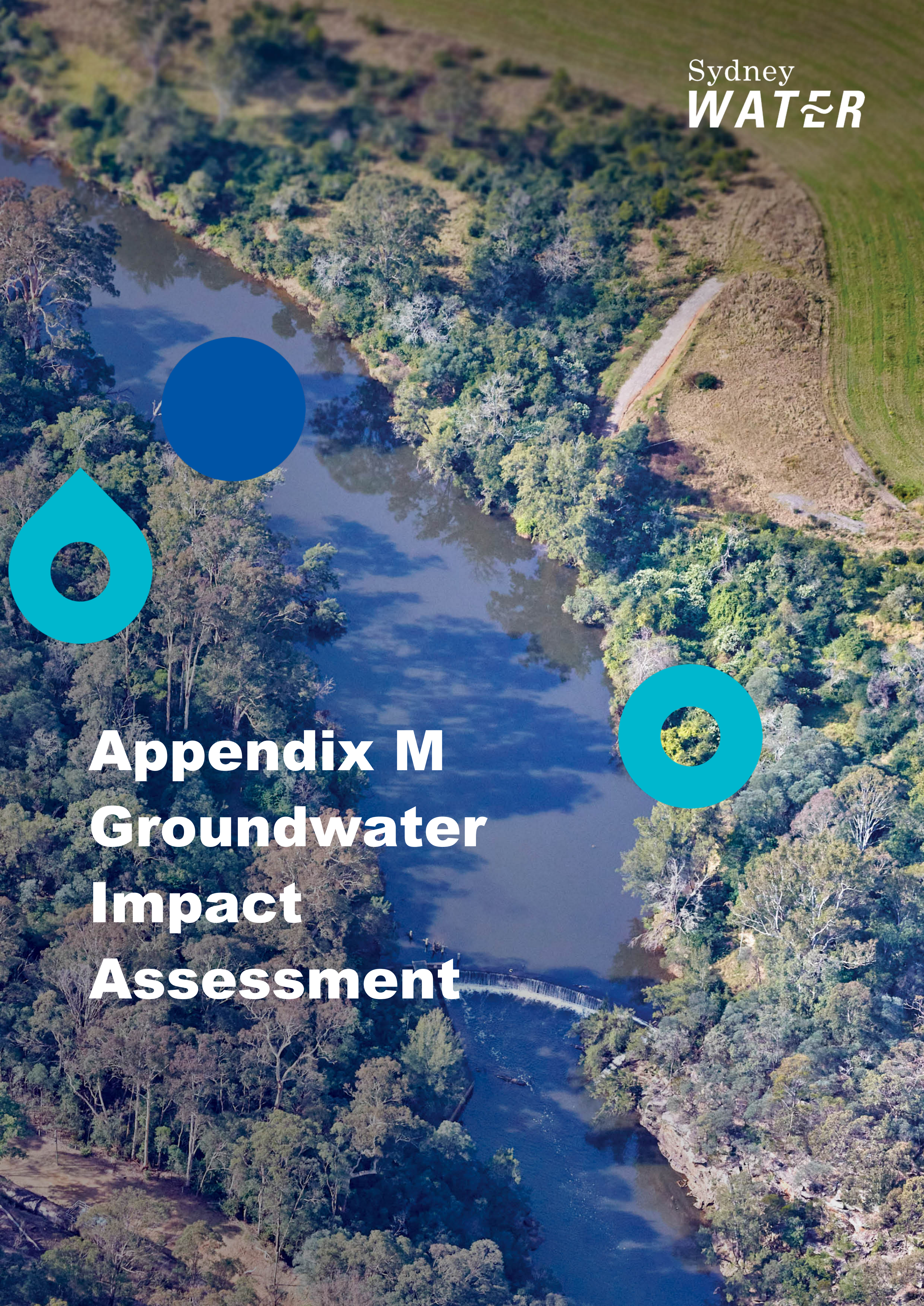

Sydney WATER

Appendix M Groundwater Impact Assessment

Upper South Creek Advanced Water Recycling Centre

Groundwater Impact Assessment

FINAL

Executive Summary

The objective of the Groundwater Impact Assessment is to identify and address potential impacts to groundwater impacts associated with the construction and operational phases of the Upper South Creek Advanced Water Recycling Centre (AWRC), treated water pipelines, brine pipeline and all ancillary infrastructure (the project). It also aims to provide guidance on ways of mitigating and managing the potential impacts to avoid environmental degradation.

Based on a review of available background information on groundwater conditions across the desktop assessment area, along with an assessment of the existing environmental setting, two principal groundwater systems have been identified and are relevant to this assessment, these are:

- Unconfined to semi-confined groundwater systems associated with Quaternary alluvial deposits, most prevalent in areas surrounding the rivers and streams that intersect the project.
- Unconfined to semi-confined groundwater systems within the bedrock formations (Wianamatta Group formations overlying Hawkesbury Sandstone).

Five key hydrostratigraphic units are identified within the desktop assessment area. Each hydrostratigraphic unit is comprised of geological formations, which have grouped together based on their hydrogeological properties, including the nature and connectivity or the void spacing (porosity and hydraulic conductivity) and transmission / storage properties. The hydrostratigraphic units (in descending stratigraphic order) that have been defined within the desktop assessment area include:

1) Unconsolidated Quaternary alluvial aquifer.
2) Unconsolidated residual / regolith soils associated with weathered Triassic Bringelly Shale.
3) Upper Wianamatta Group (Triassic Bringelly Shale), weathered zone with fractures.
4) Lower Wianamatta Group (Triassic Bringelly Shale, Minchinbury Sandstone and Ashfield Shale), widely spaced fractures.
5) Triassic Hawkesbury Sandstone.

Both alluvial and porous/fractured rock aquifers intersected by the project are categorised as “less productive groundwater sources” as defined by the NSW Aquifer Interference Policy criteria based on the relatively low number of registered supply bores, expected low yields and poor water quality (high salinity).

Several groundwater dependent ecosystems have been identified across the project with a high level of interaction with groundwater. There are currently large volumes of unallocated groundwater in the Water Sharing Plan associated with the desktop assessment area. The desktop assessment area covers the Advanced Water Recycling Centre (AWRC) site and pipeline alignments (treated water pipeline, brine pipeline and environmental flows pipeline) as well as a wider 2 km impact assessment (buffer) area around the project features.

Construction of the proposed AWRC and pipelines has the potential to impact the groundwater systems in a number of ways, including:

- Induced drawdown of groundwater from required construction dewatering activities, reducing the availability of groundwater for Groundwater Dependent Ecosystems and surrounding groundwater users.

- Seepage and/or unintentional return of drilling fluid via groundwater to the surface via preferential pathways (e.g. fault lines, fractures, or loose materials) during Horizontal Directional Drilling construction (frac-outs).
- Mobilisation and migration of contaminated groundwater or acid sulfate soil leachate (resulting from drawdown), altering pH and water quality, and causing potential soil contamination and possible downstream ecological impacts.
- Discharges of wastewater from any required dewatering activities may mobilise sediments and contaminants and increasing the turbidity and reducing the water quality in receiving waters.
- Release of alkaline concrete wash water, which may cause localised soil, surface water or groundwater contamination and possible downstream ecological impacts.
- Interception of aquifers during excavation, leading to increased hydraulic connection between otherwise disconnected aquifers and/or lateral migration of groundwater along pipeline backfill material. Affecting water qualities, hydraulic gradients, and flow regimes in the groundwater systems.
- Disruption of surface water and groundwater connectivity.

Operation of the proposed AWRC and pipelines has the potential to impact the groundwater systems in several ways:

- Induced drawdowns from any underdrainage systems employed for underground structure floatation management, reducing the availability of groundwater for GDEs and surrounding groundwater users.
- Groundwater quality impacts from infiltrating contaminated runoff from the operation of vehicles and machinery at the AWRC, chemical spills and overflow/leakages of untreated or partially treated wastewater to the groundwater systems.
- Groundwater seepage via preferential pathways (e.g. fault lines, fractures, or loose materials) after HDD construction.
- Leakage of water from pipelines during operation resulting in localised increases to groundwater levels and degradation in groundwater quality. Water transmitted through the treated water and environmental flows pipelines will be predominately fresh and unlikely to cause direct significant impacts to groundwater quality. Water transmitted through the brine pipeline will have much higher total dissolved solids and any leaks/bursts occurring across this pipeline has the potential to cause direct localised degradation of groundwater quality and/or groundwater dependent ecosystems.
- Increased groundwater recharge from stormwater irrigation at the AWRC site, leading to increased water levels of saline aquifer.

To minimise impacts to groundwater systems, a range of mitigation measures would be implemented during the detailed design, construction and operational phases of the project. These include:

- Design and construction of trench/shaft support systems that minimise groundwater drawdowns (e.g. sheet piling), particularly in areas with coarse-grained soils with higher hydraulic conductivity and storage properties.
- Where feasible, “key” the trenchless launch and reception shafts into underlying material with relatively low permeability (e.g. competent bedrock) to reduce the amount of groundwater that may enter through the floor.

- Adopting a staged approach to dewatering through dewatering in discrete, areas aligned closely with the construction schedule.
- Developing and implementing an approach to manage extracted groundwater. Depending on extracted groundwater quality, treatment may be required to meet the applicable water quality criteria, prior to discharge (e.g. to a receiving surface water body).
- Install permanent vertical cut-offs within the trench to prevent the lateral migration of groundwater along the alignment of the pipelines. In the residual / regolith soils associated with weathered Bringelly Shale, which is expected to have relatively low permeability, these trench cut-offs may be located at spacings of several hundred metres. In alluvial soils, or at river crossings, trench cut-off spacing should be significantly smaller e.g. every ten metres. Horizontal trench cut-offs should also be considered where the perched aquifers are encountered, to prevent lateral migration and dewatering of the system. Maintenance of the perched layers may also be achieved through backfilling to prevent vertical migration.

The majority of these groundwater impacts would be constrained to a short period of time during construction and are not expected to impact the long-term viability of the affected ecosystems or groundwater resources.

The degree or severity of any impact during construction is largely based on the duration of dewatering and disruption of groundwater connection to any potential GDEs in the vicinity where a disruption occurs. Other factors include the depth to the groundwater table which influences the extent of dewatering required and the hydraulic characteristics of the intersected ground material.

A groundwater quantity (i.e. levels and dewatering volumes) and quality monitoring program is recommended. Monitoring should incorporate pre-construction monitoring of groundwater conditions to form a baseline dataset to which the construction and operational monitoring data could be compared against. The baseline dataset would assist in developing site-specific action levels and responding to any identified impacts during construction and operation.

Based on the available information and the analyses conducted in this impact assessment, with the successful implementation of the proposed mitigation measures the impacts to groundwater systems across the project are expected to be of low significance overall, with a minor contribution to any foreseen cumulative groundwater impacts from other identified projects in the vicinity.

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Document title	Groundwater Impact Assessment	**File reference:** as above
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Issue Document Verification with Document ✓

Glossary and Abbreviations

Term	Abbreviation	Definition
Advanced Water Recycling Centre	AWRC	Proposed centre for treatment of the wastewater prior to reuse applications or discharge, which includes liquids treatment, advanced water treatment, solids treatment, odour treatment, and residuals management
Ancillary infrastructure	-	This is permanent infrastructure to support operation of the AWRC and may include a range of infrastructure such as access roads and provision of utilities such as power.
Australian Height Datum	AHD	A common reference level used in Australia which is approximately equivalent to the height above sea level in metres.
Brine pipeline	-	A pipeline to transport brine (salty/concentrated wastewater). Brine water is a by-product of reverse osmosis in the wastewater treatment process.
Construction Environmental Management Plan	CEMP	A CEMP describes how activities undertaken during the construction phase of development will be managed to avoid or mitigate environmental or nuisance impacts, and how those environmental management requirements will be implemented.
Critical State Significant Infrastructure	CSSI	Critical State significant infrastructure projects are high priority infrastructure projects that are essential to the State for economic, social or environmental reasons.
Desktop assessment area	-	The area defined for footprint-related specialist desktop assessments.
Drawdown		Reduction in hydraulic head in an aquifer due to an applied stress (e.g. pumping from a well)
Electrical Conductivity	EC	The ability of a material to conduct an electric current. In groundwater studies, electrical conductivity is used as an indicator of water quality, as it relates to the concentration of charged particles in water. Electrical conductivity provides an indication of the amount of total dissolved solids and the amount of salts in the water.
Environmental Impact Statement	EIS	An Environmental Impact Statement is a publicly available document that provides information on a project, including its environmental impacts and mitigation measures, and is used to inform development consent decisions

Term	Abbreviation	Definition
Environmental flows	-	Environmental flows refer to water released from a dam or weir to sustain healthy rivers. Some of the Sydney Water wastewater treatment and water recycling facilities also release treated wastewater into creeks and rivers. This can help improve conditions for native fish, frogs, birds, plants and other animals. It can also reduce the likelihood of algal blooms and enhance recreational uses. Environmental Flows from the AWRC may be used, supplement or replace flows that would have been released from Warragamba Dam.
Environmental Values	EVs	Environmental Values for water are the qualities that make it suitable for supporting aquatic ecosystems and human water uses. These qualities need to be protected from the effects of habitat alteration, waste releases, contaminated run-off and changed flows to ensure healthy aquatic ecosystems and waterways that are safe for community use.
Highly treated water	-	What wastewater becomes after it has been treated. We treat wastewater so clean water can be safely returned to the environment or re-used. We filter the water and disinfect it with chlorine or ultraviolet light (UV). This kills any remaining microorganisms. We force the water at high pressure through reverse osmosis membranes to remove even smaller bacteria and particles. This is the finest level of filtration.
Hydraulic Conductivity		The measure of how easily water can pass through a porous material. High values indicate permeable material through which water can pass easily and low values indicate a less permeable material. Hydraulic conductivity is dependent upon the intrinsic permeability of the material, the degree of saturation and the fluid properties (i.e. density and viscosity).
Hydrostratigraphic unit		A general grouping of geologic materials that form a distinct hydrologic unit with respect to the flow and behaviour of groundwater.
Impact assessment area	-	The area within which project impacts may occur. This will be larger than the actual impact area to give some flexibility with regards to exacts construction locations. This may be refined as the infrastructure reference design progresses.
Impact area	-	This refers to the actual area impacted by construction and operation. Sydney Water has indicated an expected impact corridor of 25 metres either side along the pipeline alignments.

Term	Abbreviation	Definition
Porosity		A measure of the void spaces within a material, presented as a fraction of the volume of void spaces over the total volume (between 0 and 1 or a percentage between 0% and 100%)
Project	-	The construction and operation of the Upper South Creek Advance Water Recycling Centre (AWRC), pipelines and all ancillary infrastructure. Construction of the AWRC is subject to environmental approval and has been identified as critical infrastructure. There are many stages and we are at the very early planning. Detailed construction staging will be established by the detailed design contractor. Noting that the timelines aren't finalised, it's expected that construction will start in mid-2022.
Radius of influence		The maximum distance from an applied stress at which the drawdowns can be detected.
Secretary's Environmental Assessment Requirements	SEARs	These are issued by the Secretary of the NSW Department of Planning and Environment for projects declared by the Minister of Planning as Critical State Significant Infrastructure. These SEARS provide the technical requirements for the impact assessment of each potential key issue, including the desired performance outcome, requirement and current guidelines.
Service area	-	The intention is to treat wastewater from Western Sydney Airport, Western Sydney Aerotropolis Growth Area (WSAGA) and South West Growth Area (SWGA). Additional areas may be transferred over time, pending growth distribution and servicing efficiency analysis. Sydney Water is currently planning for the major wastewater pipelines and other infrastructure required to transfer wastewater from these servicing areas to the AWRC site for treatment.
Temporary ancillary facilities	-	These are temporary facilities to support construction including: • Access roads • Construction compounds • Laydown areas • Parking • Site offices and amenities.

Term	Abbreviation	Definition
Treated water pipeline	-	The pipelines that will convey the treated effluent water to the receiving environment. The pipelines will transport water from the AWRC to the discharge points at the Nepean and Warragamba Rivers. These pipelines will range in size from about 0.6 m to 1.5 m in diameter and will generally consist of steel, glass reinforced plastic and polyethylene pipe materials.
Upper South Creek	USC	The catchment in which the AWRC will be located. South Creek discharges to the Nepean River which flows directly into the Hawkesbury River and then discharges out to the Pacific Ocean
Wastewater	-	The used water from baths, showers and washing machines ('greywater') and toilets ('blackwater') and enters into the sewerage system. About 99% of this is water with the remaining 1% composed of the components added to water during the previous use.
Water Quality Objectives	WQO	Water Quality Objectives are long-term goals for water quality management. They are measures, levels or narrative statements of indicators of water quality that protect EVs. They define what the water quality should be to protect the EVs—after consideration of the socio-economic assessment of protecting the water quality.

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1 Introduction

1.1 Background

The Groundwater Impact Assessment has been undertaken to support the Environmental Impact Statement (EIS) for the Upper South Creek Advanced Water Recycling Centre (AWRC) along with its ancillary infrastructure (henceforth referred to as “the project”). The AWRC will be located in Kemps Creek, NSW, with pipelines traversing Western Sydney from the Nepean River in the West to Cabramatta in the East (**Figure 1-1**).

This report provides a review of the existing groundwater conditions and potential project impacts during the construction and operation phases. It also provides recommended mitigation measures to minimise any identified residual impacts.

The project is State Significant Infrastructure (SSI) and the Secretary of the Department of Planning, Industry and Environment has issued project specific environmental assessment requirements (SEARs). This report addresses the project specific SEARs relating to groundwater (see **Section 1.4**).

Potential adverse impacts to receiving surface waters are addressed in the Surface Water Impact Assessment report (Aurecon Arup, 2021).

1.2 Project Overview

Sydney Water is planning to build and operate new wastewater infrastructure to service the South West and Western Sydney Aerotropolis Growth Areas. The proposed development will include a wastewater treatment plant in Western Sydney, known as the Upper South Creek Advanced Water Recycling Centre. Together, this Water Recycling Centre and the associated treated water and brine pipeline, will be known as the ‘project’. An overview of the location of the proposed infrastructure is provided in **Figure 1-1**. Further details of each component of the project are provided in chapter 6.

1.2.1 Advanced Water Recycling Centre (AWRC)

A wastewater treatment plant with the capacity to treat up to 50 ML of wastewater per day, with ultimate capacity of up to 100 ML per day

The AWRC would produce:

- High-quality treated water suitable for a range of uses including recycling and environmental flows.
- Renewable energy, including through the capturing of heat for cogeneration.
- Biosolids suitable for beneficial reuse.
- Brine, as a by-product of reverse osmosis treatment.

1.2.2 Treated water pipelines

The treated water pipelines refer to:

- A pipeline about 17 km long from the Advanced Water Recycling Centre to the Nepean River at Wallacia Weir, for the release of treated water.

- Infrastructure from the Advanced Water Recycling Centre to South Creek to release excess treated water and wet weather flows.
- A pipeline about five kilometres long from the main treated water pipeline at Wallacia to a location between the Warragamba Dam and Warragamba Weir, to release high-quality treated water to the Warragamba River as environmental flows.

1.2.3 Brine pipeline

The Brine pipeline refers to:

- A pipeline about 24 km long that transfers brine from the Advanced Water Recycling Centre to Lansdowne, in south-west Sydney, where it connects to Sydney Water's existing Malabar wastewater network.

Sydney Water is planning to deliver the project in stages, with Stage 1 comprising:

- Building and operating the Advanced Water Recycling Centre to treat an average dry weather flow of up to 50 ML per day.
- Building all pipelines to their ultimate capacity, but only operating them to transport and release volumes produced by the Stage 1 Advanced Water Recycling Centre.

The timing and scale of future stages will be phased to respond to drivers including population growth rate and the most efficient way for Sydney Water to optimise its wastewater systems.

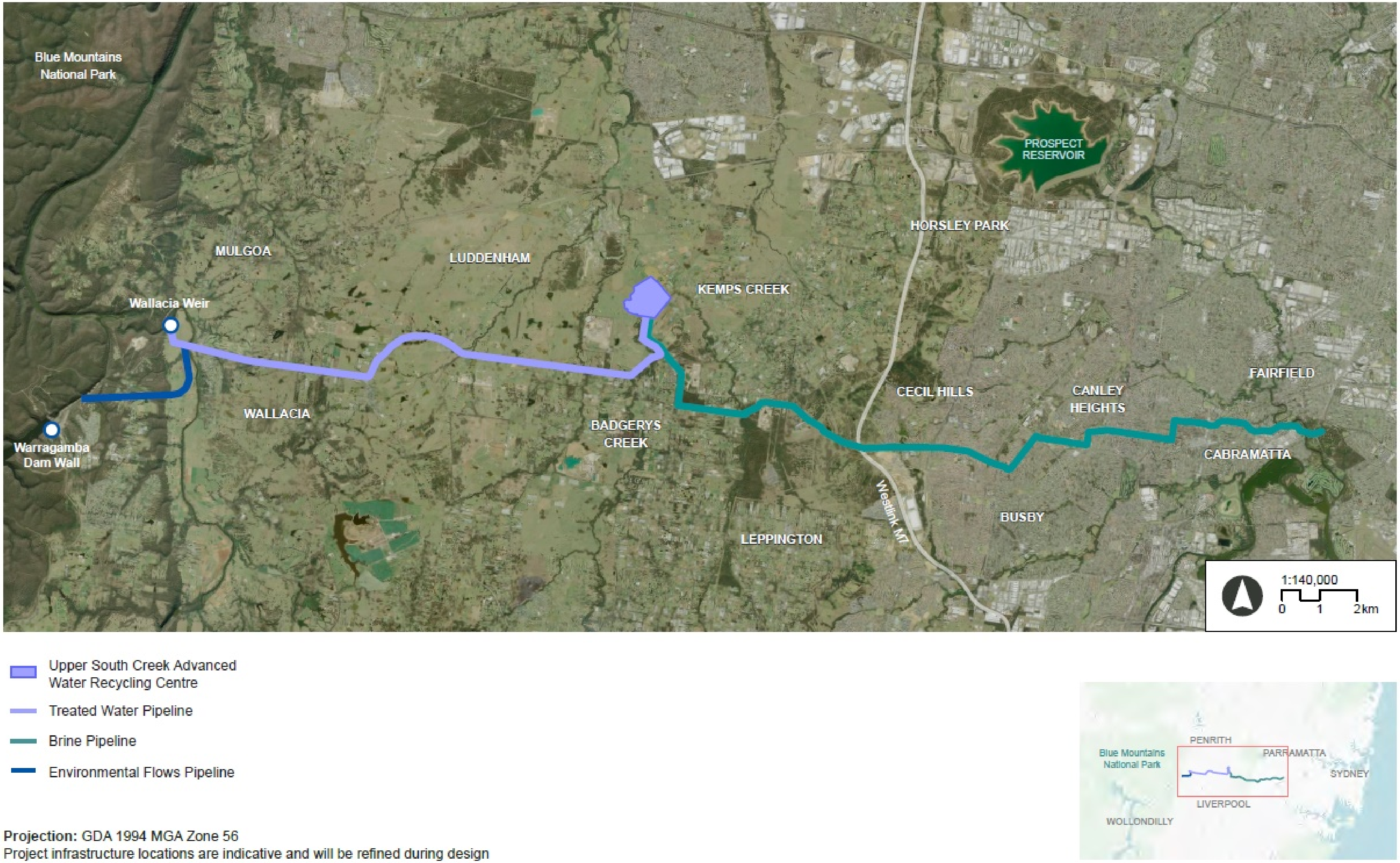


Figure 1-1 USC AWRC Project Overview

1.3 Study Objectives

The objective of the *Groundwater Impact Assessment* is to assess and address potential groundwater impacts associated with the construction and operational phases of the project. It also aims to provide guidance on ways of mitigating and managing the potential sources of impacts to avoid environmental degradation.

A reference design for the Project has been developed which informs the various impact assessments. Several studies have been undertaken in parallel to cover various aspects relating to the potential water environment impacts. These studies and the extent of each study's considerations are indicated in **Figure 1-2**.

Surface Water Impact Assessment	Hydrodynamic and Water Quality Impact Assessment	Flood Assessment	Groundwater Impact Assessment	Ecohydraulic and Geomorphology Assessment	Aquatic and Riparian Ecosystem Assessment
• Construction and operational impacts related to local runoff and stormwater management at the AWRC site as well as along the pipeline routes	• Treated water releases and impacts on the chemistry and water quality of the Warragamba and Nepean rivers and South Creek	• Assessment of potential impacts on local and downstream flooding regimes associated with discharge infrastructure and landform changes, and temporary construction activies along pipelines	• Construction and operational impacts to local and regional groundwater sources related to proposed activities at the AWRC site as well as along the pipeline routes	• Potential impacts to ecohydrology and geomorphology of the Warragamba and Nepean rivers and Wianamatta-South Creek	• Potential impacts associated with the proposed works on riparian and aquatic flora and fauna

Figure 1-2 Specific water cycle impacts addressed by each study in this EIS

1.4 Secretary environmental assessment requirements (SEARs)

The project is State Significant Infrastructure (SSI) and the Secretary of the Department of Planning, Industry and Environment has issued project specific environmental assessment requirements (SEARs). These SEARs provide the technical requirements for the impact assessment of each potential key issue, including the desired performance outcome, requirement and current guidelines.

The scope of work undertaken to address groundwater related matters for each component of the issued SEARs is summarised in **Table 1-1**.

Table 1-1 Groundwater related project specific SEARS and associated scope of works

Requirement (groundwater specific assessment requirements in addition to the general requirements)	Scope of work undertaken to address	Location addressed in report
1. Water Describe background conditions for any water resource likely to be affected by the development, including:		
a) existing surface and groundwater	Description of the receiving hydrogeological environment (including a hydrogeological conceptual model). Surface water conditions are described in the *Surface Water Impact Assessment* report.	Section 4.3 Section 4.5
c) Water Quality Objectives (as endorsed by the NSW Government) including groundwater as appropriate that represent the community's uses and values for the receiving waters.	Applicable groundwater quality objectives are stated. WQO's related to surface water are provided in the *Surface Water Impact Assessment* report.	Section 2.2
d) indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.	Applicable groundwater quality objectives are stated. WQO's related to surface water are provided in the *Surface Water Impact Assessment* report.	Section 2.2
2. Assess the impacts of the development on water quality, including:		

Requirement (groundwater specific assessment requirements in addition to the general requirements)	Scope of work undertaken to address	Location addressed in report
a) the nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction.	Available groundwater quality data within the desktop assessment area (defined in Section 3.2) has been collated and compared against applicable legislation, WQ objectives and trigger values. The potential changes to the to the receiving hydrogeological environment during the construction and operational phases of the project (AWRC and pipelines) entering South Creek and the local creeks along the pipeline have been assessed using groundwater numerical modelling (AWRC site) and analytical modelling (pipelines). Where impacts to the receiving hydrogeological environment have been identified, mitigation measures have been proposed. The proposed mitigation measures have been assessed for both the operational and construction phases of the project.	Section 9.1 Section 9.2
b) Identification of proposed monitoring of water quality	Recommendations for future monitoring to establish a pre-construction baseline, in addition to monitoring during the project construction and operation phases are provided.	Section 11
3. Assess the impact of the development on hydrology, including:		
a) water balance including quantity, quality and source.	Water-take / discharge activities associated with potential dewatering requirements during construction and operation have been included in this assessment. Stormwater discharge and both an operations water balance as well as an environmental water balance for the AWRC site have been developed in the *Surface Water Impact Assessment* report. The primary treated water discharge location will be to the Nepean River and potential associated impacts have been assessed and are documented in the *Hydrodynamic and Water Quality Impact Assessment* report.	Section 9.1 Section 9.2

Requirement (groundwater specific assessment requirements in addition to the general requirements)	Scope of work undertaken to address	Location addressed in report
c) effects to downstream water-dependent fauna and flora including groundwater dependent ecosystems.	Potential changes to the receiving hydrogeological environment have been assessed and compared to existing conditions. Impacts to Groundwater Dependent Ecosystems (GDEs) are included in this assessment and also documented in the Aquatic Ecology Impact Assessment.	Section 4.8 Section 7.2 Section 8
g) identification of proposed monitoring of hydrological attributes.	The proposed monitoring during the project construction and operation phases has been included where relevant to groundwater. Other monitoring recommendations will align with the programmes proposed in the other water studies.	Section 10
4. Map		
c) groundwater	Features relevant to the existing hydrogeological environment (including a hydrogeological conceptual model) have been mapped.	Section 4.5 Section 5
d) groundwater dependent ecosystems	GDE’s have been mapped in this assessment and the *Aquatic Ecology Impact Assessment* report.	Section 4.8
7. Consult/coordinate with the Department of Planning, Industry and Environment (and Planning Partnership Office) in respect to environmental impacts on the South Creek catchment and the Wianamatta South Creek program. This includes:		

Requirement (groundwater specific assessment requirements in addition to the general requirements)	Scope of work undertaken to address	Location addressed in report
c) assess the potential impacts on the quantity and quality of surface and groundwater resources along South Creek, including the implications of dry and wet weather flows from the project.	Potential groundwater related impacts associated with development along South Creek have been identified and assessed. Mitigation measures to prevent, minimise and / or contain these impacts are included. Potential impacts associated with site-runoff on the quantity and quality of surface water resources along South Creek have been assessed in the *Surface Water Impact Assessment* report. Dry and wet weather treated effluent discharges have been assessed in the Hydrodynamic and Water Quality Impact Assessment, Aquatic Ecology Impact Assessment and Ecohydraulic and Geomorphology Impact Assessment reports.	Section 8.1.1 Section 8.1.2 Section 9.1 Section 9.2
d) details about how the project will be designed, operated and maintained to ensure post-development flows do not exceed pre-development flows into and through the Pipelines Corridor and additional surface and groundwater entering the Pipelines Corridor must be prevented.	Potential operational impacts from groundwater entering the Pipelines Corridor has been assessed and mitigation measures developed. An assessment of pre-development and post-development surface flows has been documented in the *Surface Water Impact Assessment and Flood Impact Assessment* reports.	Section 9.1 Section 9.2

2 Legislation, policy and guidelines

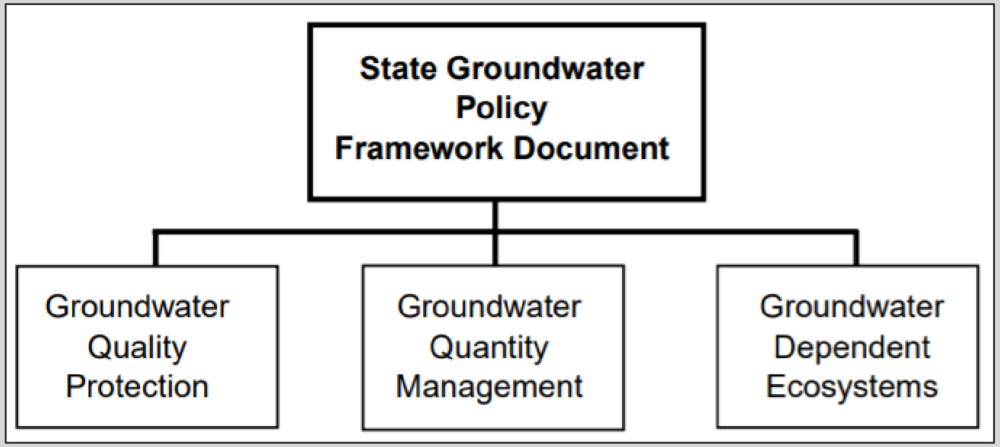
2.1 General legislation, policy and guidelines

This section summarises the current legislative requirements and guidelines relevant to groundwater considerations for the project.

Table 2-1 Legislation and policy context

Legislation/Policy	Brief description and intent	Relevance to project
Water Act 1912, **Water Management Act 2000** **Water Management Regulation 2018**	The objects of the Water Management Act 2000 are to provide for the sustainable and integrated management of the water sources of the state for the benefit of both present and future generations. In NSW, the regulator and policy maker for water resource management is the NSW Department of Planning, Industry and Environment – Water (DPIE Water). The department develops natural resource management policy frameworks, strategies and plans related to water management. DPI Water is accountable for water sharing plans (WSPs), which define the rules for sharing the water resources of each regulated river valley between consumptive users and the environment. WSPs are made under the Water Management Act 2000. In accordance with section 5.23(1) of the EPA act the following approvals which may have otherwise been required to undertake the project would not be required: • Water use approval under section 89 of the WM Act • Water management work approval (including a water supply works approval) under section 90 of the WM Act • Activity approval (other than an aquifer interference approval) under section 91 of the WM Act.	Consideration of the project against the objects, water management principles and the applicability of access licence dealing principles under the Water Management Act, 2000. The project is located within an existing Water Sharing Plan (discussed below) for which the Water Management Act applies. An aquifer interference approval under section 91 of the WM Act is required.

Legislation/Policy	Brief description and intent	Relevance to project
Water Sharing Plan	The project is located within the existing Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. The Water Sharing Plan area covers approximately 32,500 km^2, spanning from the Hawkesbury River catchment in the north, Shoalhaven River catchment in the south/south-west and Lithgow/Goulburn in the west. The plan covers 13 distinct groundwater sources, the project is located within the "Sydney Basin Central" groundwater source. Within the Sydney Basin Central groundwater sources, there are currently 171 aquifer access licences, with a total licensed volume of 3,629.5 ML/year. The long-term average annual extraction limit for the Sydney Basin Central groundwater source is 45,915 ML/year, which approximates to 20% of the total estimated annual aquifer recharge rate of 229,223 ML/year for the area (NSW Office of Water, 2011). Therefore, there are currently large volumes of unallocated groundwater in the desktop assessment area.	As more than 3 ML/year of groundwater is anticipated to be extracted for the Sydney Basin Central Groundwater Source, a Water Access Licence, under the Water Management Act 2000, must be sought through the Natural Resource Access Regulator (NRAR). The water access licence would specify the allocated shares in the Water Sharing Plan and the allowable groundwater extraction rates, timing and location(s). The water access licence would specify the allocated shares in the Water Sharing Plan and the allowable groundwater extraction rates, timing and location(s).
The NSW State Groundwater Policy Framework (Department of Land & Water Conservation (DLWC), 1998)	The NSW State Groundwater Policy Framework was established to manage groundwater resources in NSW so that they can sustain environmental, social and economic uses for the people of NSW, so as to: • Slow and halt or reverse any degradation of groundwater resources. • Ensure long term sustainability of the systems ecological support characteristics. • Maintain the full range of beneficial uses of these resources. • Maximise economic benefit to the Region, State and Nation. The framework includes a set of three component policies, providing principles concerning the management of groundwater dependent ecosystems, groundwater quantity and groundwater quality. The policy relationships are shown in **Figure 2-1.** Each of these component policies are discussed in further detail in subsequent rows below.	The policy identifies management tools to achieve groundwater protection, some of which are relevant to the development of the project, including groundwater quality protection, groundwater quantity management and protection of groundwater dependent ecosystems.

Legislation/Policy	Brief description and intent	Relevance to project
	 **Figure 2-1 NSW State Groundwater Policy Framework and component policy relationships.**	

Legislation/Policy	Brief description and intent	Relevance to project
NSW Groundwater Quality Protection Policy (DLWC, 1998)	The NSW Groundwater Quality Protection Policy adopts the principles outlined in the NSW State Groundwater Policy Framework Document in relation to groundwater quality protection, and specifically the following management principles: • All groundwater systems should be managed so that the most sensitive identified beneficial use (or environmental value) is maintained. • Town water supplies should be afforded special protection against contamination. • Groundwater pollution should be prevented so that future remediation is not required. • For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the resource. • A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters. • Groundwater dependent ecosystems will be afforded protection. • Groundwater quality protection should be integrated with the management of groundwater quantity. • The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource. • Where possible and practical, environmentally degraded areas should be rehabilitated, and their ecosystem support functions restored.	The policy identifies management tools to achieve groundwater protection, some of which are relevant to the development of the project, including the use of groundwater management plans, groundwater vulnerability mapping and groundwater monitoring. The project may also impact on groundwater dependent ecosystems which are afforded special protection under the NSW Groundwater Protection Policy. The policy is relevant to the project in governing how groundwater quality impacts are assessed in relation to surrounding groundwater dependent ecosystems and groundwater users. Groundwater beneficial use categories are defined in the policy based on ranges of background concentrations of Total Dissolved Solids (TDS) (a measure of salinity) in the groundwater source (detailed in Section 2.2.1). The overriding principle is that groundwater quality should be maintained within its beneficial use category. The potential impacts to groundwater dependent ecosystems have also been assessed in the *Aquatic and Riparian Ecosystem Impact Assessment* report.
NSW Groundwater Quantity Protection Policy (DLWC, 1998)	The NSW Groundwater Quantity Protection Policy adopts the principles outlined in the NSW State Groundwater Policy Framework Document in relation to groundwater quantity protection, and specifically the following management principles: • Total use of groundwater in a water source or zone will be managed within the sustainable yield, so that groundwater is available for future generations, and dependent ecological processes remain viable. • Significant groundwater dependent ecosystems must be identified and protected.	This policy details the various mechanisms available for sustainable groundwater resource management, recognising the variety of aquifer types and behaviours and the need for flexible management, whilst safeguarding dependent ecosystems and reducing interference effects between users.

Legislation/Policy	Brief description and intent	Relevance to project
	• Total licensed entitlements will not exceed 125% of the sustainable yield in currently over-allocated groundwater sources or zones. • Groundwater access must be managed in such a way that it does not cause unacceptable local impacts. • Artificial recharge of groundwater will be strictly controlled. • Landholders overlying an aquifer will have basic right to access groundwater for domestic and stock purposes. • Access to groundwater will be managed according to an established priority of use. • All rights (excepting basic rights) to access and extract groundwater must be licensed and metered. • In systems that are not subject to a licence embargo or a Ministerial order, groundwater access licences will be issued on the basis of demonstrated need, within the sustainable yield. • Groundwater access licence holders have resource stewardship obligations and are required to abide by the conditions of their licence. • Permanent and temporary transfer of groundwater access will be permitted within sustainable yield constraints, if the transfer does not cause unacceptable impacts on other users, water quality or dependent ecosystems. Inter-aquifer transfers will not be permitted. • Within environmental and interference constraints, the management of groundwater access should provide business flexibility for existing users through carryover and borrowing provisions on annual entitlements. • Approvals must be obtained before any groundwater access licence can be activated at a particular location. • All activities or works that intersect an aquifer and are not for the primary purpose of extracting groundwater, need an aquifer interference approval.	The policy is relevant to the project in governing how groundwater level/availability impacts are assessed in relation to surrounding groundwater dependent ecosystems and groundwater users.

Legislation/Policy	Brief description and intent	Relevance to project
NSW Groundwater Dependent Ecosystems Policy (Department of Land & Water Conservation, 2002)	Groundwater Dependent Ecosystems (GDEs) refer to both terrestrial and aquatic ecosystems that require access to groundwater to meet all or some of their water requirements for their ecological processes and ecosystem services. The GDE Policy adopts principles outlined in the NSW State Groundwater Policy Framework Document and provides a framework the management of GDEs in NSW, including: • The scientific, ecological, aesthetic and economic values of GDEs, and how threats to them may be avoided, should be identified and action taken to ensure that the most vulnerable and the most valuable ecosystems are protected. • Groundwater extraction should be managed within sustainable yield of aquifer systems, so that the ecological processes and biodiversity of their dependent ecosystems area maintained and/or restored. Management may involve establishment of threshold levels that are critical for ecosystem health, and controls on extraction in the proximity of groundwater dependent ecosystems. • Priority should be given to ensuring that sufficient groundwater of suitable quality is available at the time when it is needed, for: • Protecting ecosystems which are known to be, or are most likely to be, groundwater dependent. • For the GDEs which are under an immediate or high degree of threat from groundwater-related activities. • Where scientific knowledge is lacking, the Precautionary Principle should be applied to protect GDEs. The development of adaptive management systems and research to improve understanding of these ecosystems is essential to their management. • Planning, approval and management of development and land use activities should aim to minimise adverse impacts on GDEs by. • Maintaining, where possible, natural patterns of groundwater flow and not disruption groundwater levels that are critical for ecosystems. • Not polluting or causing adverse changes in groundwater quality. • Rehabilitating degraded groundwater systems where practical.	The policy contains management principles and methods to protect GDEs that may be relevant if these ecosystems are encountered during the development and /or operation of the AWRC. The policy is relevant to the project in governing how groundwater impacts are assessed in relation to surrounding groundwater dependent ecosystems. The potential impacts to groundwater dependent ecosystems has also been assessed in the *Aquatic* and *Riparian Ecosystem Impact Assessment* report.

Legislation/Policy	Brief description and intent	Relevance to project
NSW Aquifer Interference Policy (2012)	The NSW Aquifer Interference Policy (NSW DPI, 2012) outlines the requirements to minimise impacts to a groundwater system (minimal impact considerations for water table, water pressure and water quality), with consideration for high priority groundwater dependent ecosystems (GDE), high priority culturally significant sites and existing groundwater users (as identified in the Water Sharing Plan. The aquifer interference conditions that apply to the project, in relation to the location of any high priority GDE or high priority culturally significant site, are outlined in **Sections 2.2** and **2.3** below. Groundwater sources have been divided into "highly productive" and "less productive". Highly productive groundwater is defined in this Policy as a groundwater source that is declared in the Regulations and is based on the following criteria: • Has total dissolved solids of less than 1,500 mg/L. And, • Contains water supply works that can yield water at a rate greater than 5 L/sec.	There may be localised areas/geologies where groundwater conditions could potentially be within the criteria of the "highly productive" groundwater source category (e.g. within the Hawkesbury Sandstone), however the vast majority of the desktop assessment area is within a "less productive groundwater source" as defined by the Aquifer Interference Policy based on the relatively low number of registered supply bores, expected low yields, poor water quality (high salinity) and outcomes of other groundwater investigations within the same groundwater source area (detailed in Section 3.2 and Section 4). For the purposes of this assessment, the "less productive" category has been applied to both alluvial and porous/fractured rock groundwater within the Sydney Basin Central groundwater source area. Therefore the relevant minimal impact considerations are applicable (outlined in **Sections 2.2** and **2.3**). If these cannot be met, then appropriate studies will need to demonstrate that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. Otherwise, remedial provisions must be applied.

Legislation/Policy	Brief description and intent	Relevance to project
National Water Quality Management Strategy	The National Water Quality Management Strategy (NWQMS) provides a nationally consistent approach to water quality management and the information and tools to help water resource managers, planning and management agencies, regulatory agencies and community groups manage and protect their water resources. The main policy objective of the NWQMS is to achieve sustainable use of water resources, by protecting and enhancing their quality, while maintaining economic and social development.	Construction and operational phases of the project have the potential to impact water quality within groundwater systems and within the adjacent surface water bodies. As such, construction and operational phases should integrate water quality management strategies (consistent with NWQMS) such that the environmental values of the sensitive receiving environments are not adversely impacted. These should be included in the construction and operational EMPs.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018)	The Water Quality Guidelines provide authoritative guidance on the management of water quality for natural and semi-natural water resources in Australia and New Zealand. The 2018 revision of the Water Quality Guidelines is presented as an online platform, to improve usability and facilitate updates as new information becomes available. Where site-specific guideline values are not present, the ANZG's give directions to default guideline values (DGVs) for a range of stressors relevant to different community values, such as aquatic ecosystems, human health and primary industries.	The guidelines do not provide guideline values for toxicants in groundwaters, however, the Water Quality Guidelines generally applies to the quality of both surface water and of groundwater, since the community values which they protect relate to above-ground groundwater uses (e.g. irrigation, drinking water, farm animal or fish production and maintenance of aquatic ecosystems). For example, where groundwater fauna (e.g. stygofauna) need to be protected, Default Guideline Values (DGVs) for surface water ecosystem protection could be applied in the absence of any site-specific data that indicate the DGVs will be under- or over-protective. As regional physical and chemical stressor default guideline values are not yet provided for the project's ecoregion and local jurisdictions have not yet derived finer scale guideline values, these guidelines direct back to the regional DGVs provided in the ANZECC & ARMCANZ (2000) guidelines (see below).

Legislation/Policy	Brief description and intent	Relevance to project
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000)	The ANZECC Water Quality Guidelines provide a framework for conserving ambient water quality in rivers, lakes, estuaries and marine waters and list a range of environmental values assigned to that waterbody. The ANZECC Water Quality Guidelines provide recommended trigger values for various levels of protection which have been considered when describing the existing water quality and key indicators of concern. The level of protection applied in this assessment when assessing ambient water quality is for slightly to moderately disturbed ecosystems.	The ANZECC Water Quality Guidelines provide recommended trigger values for various levels of protection which have been considered when describing the existing water quality and key indicators of concern. The level of protection applied in this assessment when assessing ambient water quality is for slightly disturbed ecosystems in NSW Lowland Rivers.
National Environment Protection (Assessment of Site Contamination) Measure (2013)	The National Environment Protection (Assessment of Site Contamination) Measure (1999) (NEPC, as amended 2013) (NEPM, 2013) exists to establish a nationally consistent approach to the assessment of site contamination to ensure sound environmental management practices by the community, which includes regulators, site assessors, environmental auditors, landowners, developers and industry. The primary purpose of the NEPM is to provide a framework for the efficient and effective national approach to the assessment of site contamination to promote the protection of human health and the environment. The NEPM provides guidance on investigation levels of specific contaminants, including groundwater quality screening criteria for fresh waters, marine waters and drinking water.	The NEPM is relevant to the assessment of groundwater quality during future monitoring, as the framework and investigation levels can be used to evaluate the potential risks to human health and ecosystems from groundwater contamination. The selection and use of the groundwater investigations levels should be considered in the context of the hydrogeological conceptual model, along with relevant human/ecological exposure pathways and risk to groundwater resources.
Protection of the Environment Operations Act (1997)	The Protection of the Environment Operations Act (POEO), 1997 is a piece of legislation administered by the Environment Protection Authority (EPA) and provides a licensing arrangement to reduce pollution and protect the environment. Licences can be granted under the POEO Act for activities that may impact on the environment (e.g. discharge of extracted groundwater to a natural watercourse). The licenses specify the conditions under which those activities must be carried out, which may include monitoring requirements, compliance certification, mandatory environmental audits, pollution studies etc.	The project includes activities under which Environmental Protection Licence(s) (EPL) under the POEO Act would be required during both construction (scheduled development work) and operation (scheduled activity). For example, the discharge of extracted groundwater to a receiving surface water body such as creek, river or stream.

2.2 Groundwater Quality Objectives

2.2.1 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy's minimal impact considerations for groundwater quality have been included in this assessment.

Groundwater sources in the NSW Aquifer Interference Policy have been divided into "highly productive" and "less productive". Highly productive groundwater is defined in this Policy as a groundwater source that is declared in the Regulations and is based on the following criteria:

- Has total dissolved solids of less than 1,500 mg/L. And,
- Contains water supply works that can yield water at a rate greater than 5 L/sec.

There may be localised areas/geologies where groundwater conditions could potentially be within the criteria of the "highly productive" groundwater source category (e.g. within the Hawkesbury Sandstone), however the vast majority of the desktop assessment area is within a "less productive groundwater source" as defined by the Aquifer Interference Policy based on the relatively low number of registered supply bores, expected low yields, poor water quality (high salinity) and outcomes of other groundwater investigations within the same groundwater source area.

For the purposes of this assessment, the "less productive" category has been applied to both alluvial and porous/fractured rock groundwater within the Sydney Basin Central groundwater source area.

The minimal impact considerations for groundwater quality under the Aquifer Interference Policy for "less productive" groundwater sources are presented in Table 2-2. If these conditions are not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the River Condition Index category of the highly connected surface water source (for alluvial groundwater sources) will not be reduced at the nearest point to the activity and/or change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.

Table 2-2 Minimal water quality impact considerations for Aquifer Interference Activities – NSW Water

Groundwater System	Water Quality
Alluvial Water Sources	Any change in groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m of the activity And No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity.
Porous and Fractured-Rock Water Sources	Any change in groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m of the activity.

The beneficial use category of a groundwater source refers to a general categorisation of groundwater uses based on water quality, dependent upon groundwater salinity and the presence/absence of contamination. The beneficial use categories are defined in the NSW Groundwater Protection Policy (outlined in **Table 2-1**). The salinity thresholds for each beneficial use category and the associated groundwater uses are outlined in **Table 2-3** below. An overriding principle of the NSW Groundwater Protection Policy is that groundwater quality should be maintained within its beneficial use category, which is reflected in the NSW minimal impact considerations for groundwater quality under the Aquifer Interference Policy outlined above. The natural distribution of water quality will vary spatially across a groundwater system, an overview of the expected beneficial use categories across the desktop assessment area is provided in **Section 4.5.6**.

Table 2-3 Beneficial uses of groundwater (based on salinity)

Beneficial uses of groundwater – based on salinity ranges				
Total Dissolved Solids (mg/L)	**0 – 1,200**	**1,201 – 3,000**	**3,001 – 10,000**	**> 10,000**
Electrical Conductivity (µS/cm)	**0 – 1,791**	**1,792 – 4,478**	**4,479 – 14,925**	**> 14,925**
Beneficial use category	**A**	**B**	**C**	**D**
Aquatic ecosystem protection	P	P	P	P
Irrigation	P	P		
Stock drinking water	P	P	P	
Recreation and aesthetics	P	P	P	P
Raw drinking water	P			
Industrial water	P	P	P	P
Cultural and spiritual	P	P	P	P

2.2.2 Project Waterway Objectives

In addition to the above, to assess the potential impacts of the project in relation to water quality in the receiving hydrogeological environment, waterway objectives have been identified in accordance with the project specific environmental assessment requirements (SEARs). The SEARS relating to waterway objectives are further detailed in **Section 1.4.** These waterway objectives relate to surface water and are detailed in the *Surface Water Impact Assessment* report.

The ANZECC/ARMCANZ (2000) Water Quality Guidelines outline linkages to groundwater, which remain applicable under the ANZG (2018) Water Quality Guidelines as groundwater is an essential water resource for many aquatic, riparian and terrestrial ecosystems. The ANZG 2018 guidelines state:

“Generally, the Water Quality Guidelines should apply to the quality of both surface water and of groundwater, since the community values which they protect relate to above-ground uses (e.g. irrigation, drinking water, farm animal or fish production and maintenance of aquatic ecosystems). Hence, groundwater should be managed in such a way that when it comes to the surface, whether from natural seepages or from bores, it will not cause the established water quality objectives for these waters to be exceeded, nor compromise their designated community values. In addition to this, underground aquatic ecosystems and any novel fauna also need to be protected. Relatively little is still known of the lifecycles and environmental requirements of groundwater communities.

Where potentially high conservation values are identified, the groundwater upon which the communities depend should be afforded the highest level of protection, at least until further knowledge is gained. Basing groundwater quality objectives on data from groundwater reference condition locations is recommended to achieve this protection. It is important to note that different biological, physical and chemical conditions and processes operate in groundwater compared with surface waters, and these can affect the fate and transport of many chemicals. This may have implications for the application of guideline values and overall management of groundwater quality.”

2.2.2.1 Nepean River, Warragamba River and Wianamatta-South Creek

The objectives are specific to this project and were developed in accordance with the *Risk-based Framework for Considering Waterway Health Outcomes in Strategic Land-use Planning Decisions* (OEH, 2017). The numerical criteria are sourced from existing guidelines and objectives. Predicted impacts from the Project will be assessed against the waterway objectives.

The Risk Based Framework defines waterway objectives as consisting of:

- community’s environmental values and uses of the water
- indicator(s) and corresponding numerical criteria to assess whether the waterway will support a particular environmental value or use.

The values and uses adopted for the Nepean and Warragamba Rivers and South Creek are:

- aquatic ecology
- recreation and aesthetics
- primary industries
- drinking water (Nepean River only).

Management goals and numerical criteria for each of these values have been informed by the following guidelines:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000 and ANZG 2018)
- Guidelines for managing risks in recreational water (NHMRC, 2008)
- Australian Drinking Water Guidelines 2011, Version 3.5 Updated August 2018 (NHMRC, NRMMC 2011)
- Regulating nutrients from STPs in Lower Hawkesbury Nepean River catchment (EPA 2019)
- Draft Wianamatta-South Creek Waterway Health Objectives (DPIE, 2020)

The Department of Planning, Industry and Environment (DPIE) has developed draft water quality and flow objectives as part of the precinct planning work for the Aerotropolis. These draft objectives include performance criteria that have been included in our objectives for South Creek.

A list of the waterway objectives and adopted numerical criteria/metrics for the Nepean and Warragamba Rivers and Wianamatta-South Creek are provided in the *Surface Water Impact Assessment* report.

These have been used as to compare against baseline groundwater quality and will be used during construction to monitor discharges to the environment.

2.2.2.2 Georges River catchment

A large section of the brine pipeline will be in the Georges River catchment. The environmental values and numerical criteria applicable for lowland rivers in this catchment have been sourced from the NSW Water Quality and River Flow Objectives (NSW DEC, 2006).

A list of the waterway objectives and adopted numerical criteria/metrics for the Georges River catchment are provided in the *Surface Water Impact Assessment* report.

2.3 Groundwater Level/Availability Criteria

The potential impacts of the project in relation to groundwater levels and availability in the receiving hydrogeological environment are assessed against the Level 1 minimal impact considerations defined in the NSW Aquifer Interference Policy with consideration to the location of any high priority GDE, high priority culturally significant site and existing groundwater users. The Level 1 minimal groundwater level/ availability impact considerations for “less productive” groundwater sources are outlined in **Table 2-4**.

It is noted that minimal impact considerations for water pressure are also presented in the NSW Aquifer Interference Policy, however these are not applicable due to the nature of the groundwater sources within the desktop area. Unconfined to semi-confined conditions are expected in the groundwater systems intersected by the project (described in Section 4), therefore only the water table criteria is considered relevant regarding groundwater level/availability.

Where the predicted impacts are greater than the Level 1 minimal groundwater level/availability impact considerations, a more detailed impact assessment is required. If the assessment demonstrates that the predicted impacts do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered acceptable.

Table 2-4 Minimal water table impact considerations for Aquifer Interference Activities – NSW Water

Groundwater System	Water Table
Alluvial Water Sources & Porous and Fractured-Rock Water Sources	Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 m from any; high priority GDE, or high priority culturally significant site listed in the relevant water sharing plan Or A maximum of a 2m decline cumulatively at any water supply work unless make good provisions should apply.

At the time of this investigation, no long-term groundwater hydrographs were available within the desktop assessment area to determine the cumulative variation of the groundwater table. A natural seasonal variation of 1.0 m for the water table in the alluvial and the porous fractured rock water sources has been assumed as a conservative approach to assessing the potential impacts from project activities. Accordingly, the drawdown threshold for predicted impact assessment has been taken as 0.1 m (i.e. 10% of 1.0 m). This assumed seasonal variation should be reviewed against groundwater level monitoring data collected during future stages of the project to verify this assumption or refine the drawdown impact criteria.

A review of the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 Schedule 4* indicated that there are no high priority GDEs within the desktop assessment area. To meet the SEARs, potential impacts to other GDEs (identified in Section 4.8) have been assessed using the Aquifer Interference Policy criteria as a conservative approach.

3 Assessment Methodology

3.1 Site Walkover and Inspection

A walkover of the proposed AWRC site was conducted on the 20th of April 2020. The visit focused on visual inspection of the site including the condition and geomorphology of South Creek and Kemps Creek, topography, soil and flood plain.

In addition, a site visit of the proposed environmental flows pipeline alignment was conducted on 22nd September 2020 with the purpose of measuring groundwater levels in existing registered bores in close proximity to the pipeline corridor to close data gaps and determine the current groundwater conditions within the area. No direct groundwater measurements were able to be obtained during this site visit due to pump manifolds on the registered bores preventing access for the water level meter. However, interviews with the landowners were carried out, providing a general understanding of groundwater conditions (albeit anecdotal). The information provided by the landowners is described in **Section 4.7**.

3.2 Desktop Assessment

- The desktop assessment has been prepared using a combination of variable scale publicly available datasets, and information / datasets specific to the Project. The information summarised within this desktop assessment specifically focuses on information relevant to characterisation of hydrogeological conditions within and around the desktop assessment area, including:
- Topography, soil and geology – relevant to groundwater recharge and hydraulics.
- Local and regional climatic conditions – relevant to groundwater recharge.
- Local aquifers intercepted by the project – relevant to groundwater storage and availability.
- Existing groundwater users/extraction within and around the desktop assessment area.
- The presence of Groundwater Dependent Ecosystems (GDEs) in the desktop assessment area and vicinity.
- Groundwater levels and local/regional groundwater flow directions.
- Groundwater quality, including potential sources of groundwater contamination.

The desktop assessment area covers the Advanced Water Recycling Centre (AWRC) site and pipeline alignments (treated water pipeline, brine pipeline and environmental flows pipeline) as well as a wider 2 km impact assessment (buffer) area around the project features. The buffer area has been included to examine hydrogeological systems at a sub-regional scale and assess a wide extent of potential groundwater impacts and to allow for uncertainty within the current pipeline alignment and changes that may need to occur during detailed design. The buffer does not necessarily cover the full extents of the associated aquifers but has been selected to encapsulate the full extent to which the potential impacts are expected to propagate.

Previous Investigations

A number of historic investigations have been undertaken in the desktop assessment area. Reports containing information on subsurface and groundwater conditions are summarised in **Table 3-1**.

Table 3-1 Sources of Information – Previous Investigations and Reports

Document Title	Author	Date Published
University of Sydney Preliminary Site Investigation, Badgerys Creek, NSW	JBS & G	2018
Heritage Assessment Historic Period Resources, University of Sydney Western Sydney Lands Badgerys Creek Farm Centre, Elizabeth Drive, Badgerys Creek	CRM	2019
Badgerys Creek Development – Elizabeth Drive Geotechnical Investigation	Pells Sullivan and Meynink	2018
M12 Motorway Environmental Impact Statement – Appendix N: Groundwater quality and hydrology assessment report	RMS	2019
Western Sydney Airport Environmental Impact Statement – Appendix L3: Groundwater assessment	GHD	2015
Environmental Impact Statement – Geology, Soils and Water: Proposal for a Second Sydney Airport at Badgerys Creek or Holsworthy Military Area	PPK	1999

3.3 Modelling Methodologies

3.3.1 Pipeline Analytical Modelling

To assess potential groundwater impacts during pipeline construction, likely groundwater inflow rates and the extents of induced groundwater drawdowns were calculated using analytical equations derived from Darcy's law. Darcy's law describes fluid flow through porous media, which is controlled by hydraulic conductivity (the ability of a material to transmit fluid through pore spaces) and hydraulic gradient (head difference between two points over the length of the flow path).

As groundwater conditions are expected to vary across the extent of the pipelines, the reference design alignment was divided into discrete sections based on "Hydrogeological Landscapes" (described in **Section 4.5**) to provide realistic inputs to the analytical calculations. For each section, reference design features and expected hydrogeological properties were collated to form the basis of the analytical calculations.

In accordance with the hydrogeological conceptual model developed in this assessment (described in **Section 5**), the following analytical equations were applied:

- Radius of influence (i.e. extent of induced groundwater drawdowns) calculated using Sichardt's formula (Sichardt, 1930) for unconfined aquifers:

$$R_o = C \times s\sqrt{K}$$

Where:

R_o = Radius of influence (m)

C = Radial/linear flow conversion factor = 2000 for linear flow into trenches (dimensionless)

s = Maximum drawdown (m)

K = Hydraulic conductivity (m/d)

- Total discharge from a single row of partially penetrating well points in an unconfined aquifer midway between two equidistant and parallel line sources (Mansur & Kaufman, 1962). This analytical scenario is applicable to total groundwater inflow into a linear trench:

$$Q = \left[\left(0.73 + 0.27\frac{(H - h_w)}{H}\right)\frac{Kx}{R_0}(H^2 - h_w^2)\right]$$

Where:

Q = Total discharge from the well points (m^3/d)

H = Height of the water table at the radius of influence (m)

h_w = Height of the water table at well point (m)

K = Hydraulic conductivity (m/d)

x = Length of trench (m)

R_o = Radius of influence = calculated from Sichardt's formula above (m)

The results from these analytical calculations provide an understanding of the potential groundwater impacts and the amount of dewatering that may be required during construction of the pipelines. The results were then assessed against the groundwater level/availability criteria outlined in **Section 2.3** with consideration to the location of surrounding groundwater users and groundwater dependent ecosystems.

Analytical calculations and assumptions are provided in **Appendix B** and results are discussed in **Section 7.2**. Understanding model assumptions is crucial in interpreting the results. Worthy of note is the assumption that the analytical model is in equilibrium / steady state. This assumes that pumping has continued for a period where the zone of influence has intercepted sufficient recharge to equal the amount being pumped. This is unlikely for this project because the excavation of the trenches for the pipe will be undertaken as a moving system aimed at minimising exposure time, progressing at the assumed daily pipe lay rates provided in **Section 7.2** (and summarised in **Table 7-13**).

The progressive excavation will introduce non-steady state or transient conditions where the pumped water will be released mainly from storage. This phenomenon is not considered in the adopted analytical model. The potential effects of aquifer storage characteristics were checked using the principle of superposition to Cooper-Jacob's approximation of the Theis nonequilibrium equation using the Aquiworx wellfield tool, with pumping wells at 1 m spacing for a one-day pumping period. The checks were tested using average values of the parameters provided in **Section 7.2** and **Appendix B**. As expected, the results indicate that the Mansur & Kaufman solution generally overestimates the radius of influence and underestimates the expected volume of water to be pumped. In general, for the same drawdown, low storage capacity aquifers such as fractured rocks produce less amount of water from storage with rapid propagation of drawdown compared to high storage capacity aquifers such as alluvial aquifers. After cessation of dewatering as the excavation progresses, the water table is expected to recover to original levels rapidly. The water table is therefore expected to be depressed for very short periods. These factors should be considered in interpreting the modelling results provided in **Section 7.2**.

3.3.2 AWRC Numerical Modelling

Potential groundwater impacts at the AWRC were assessed using a numerical groundwater model to simulate the existing and future behaviour of the groundwater systems at the site. Specifically, groundwater flow responses and potential impacts in response to construction dewatering during construction of the AWRC were evaluated.

The application of a computer based numerical model provides a powerful tool for the prediction of flow in a complex spatially and temporally varying environment. This approach applies a system of mathematical equations derived from Darcy's Law for flow of water through porous media to simulate flow in the aquifer.

Groundwater numerical modelling can overcome the difficulties inherent in the assessment of hydrogeological systems using classical analytical methods, which assume aquifer homogeneity and are more applicable to the interpretation of localised aquifer response. With a computer numerical model, it is possible to simulate complex conditions by introducing variations in aquifer transmissivity or hydraulic loads. This is accomplished by discretising the modelled area into a number of blocks each representing a volume of aquifer with constant hydraulic parameters. The accuracy of model predictions depends on the knowledge of all parameters having an impact on the groundwater regime, both in the area of interest as well as in more distant areas.

The development of a model also facilitates sensitivity analysis which provide a means of understanding the dominant parameters and mechanisms operating within a hydrogeological system.

Groundwater modelling for the AWRC was undertaken using MODFLOW-USG, with the aid of Groundwater Vistas pre- and post-processing environment. MODFLOW-USG is a groundwater flow simulation computer code developed by the United States Geological Survey (USGS).

The following predictive model scenarios were assessed:

- Scenario 1: Construction Phase modelling

This scenario relates to construction dewatering for the bioreactors which would penetrate below the water table. Only Stage 1 has been assessed. Since this is located closer to South Creek than the proposed future stages' works, it is considered that this represents the worst-case scenario of impact to the environmental values of the creek.

- Scenario 2: Operational Phase modelling

These scenarios were used to simulate the predicted impacts of the listed conditions and events:

  - partial blockage of groundwater due to the AWRC bioreactors which have with foundations below the groundwater table;
  - impermeable surfaces across the AWRC site on the local water balance due to the reduction in recharge; and
  - maintenance dewatering regimes at the bioreactors.

Full details of the AWRC numerical modelling approach, including model build, model calibration, sensitivity analysis and the outcomes of predictive modelling and the associated impact assessment is provided in **Appendix A**.

3.4 Impact assessment

The impact assessment for construction and operation of the project incorporated quantitative and qualitative methods to assess the potential impacts pre- and post-mitigation attributable to the activities and the physical changes proposed by the project.

Proposed activities associated with the project development, construction and operation have been reviewed to identify those activities with the potential to lead to a disturbance or a change in the groundwater systems. These activities are indicated in **Section 6.1** for the construction phase and **Section 6.2** for the operational phase of the project.

Pipelines

The pipeline infrastructure will primarily be below ground and therefore potential impacts to groundwater associated with the pipelines are expected, predominately associated with the construction phase where dewatering would be required. Potential groundwater impacts associated with the construction of the trenched pipeline sections have been quantitatively assessed using analytical calculations (further detailed in **Section 8**).

Due to the nature of trenchless pipeline construction techniques, groundwater impacts are inherently mitigated (e.g. through the use of shaft supports, headwall and seal assembly within each shaft etc). Therefore, the conditions and underlying assumptions in the quantitative analytical calculations are not applicable to the trenchless pipeline sections and potential groundwater impacts associated with the construction of trenchless pipeline sections and operation of the pipelines have been qualitatively assessed.

AWRC Site

Significant below ground changes are expected to occur during the construction phase of the AWRC site, these changes will mostly remain in place during the operational phase as well. Given these expected changes a more detailed numerical groundwater modelling has been developed to quantify the potential impacts.

As the AWRC will be constructed in stages, the initial modelling and assessment focused on the Stage 1 footprint, however the models were subsequently expanded to represent the ultimate footprint associated with potential future stages and assess the resultant impacts.

An overview of the methodology adopted for numerical groundwater modelling, which was used to inform AWRC groundwater impact assessments is described in **Section 3.3.2** with further details of the model provided in **Appendix A**.

3.4.1 Impact Significance

The significance of any potential project impact on the local groundwater systems has been determined by considering the sensitivity of the environment related to the assessed criteria (outlined in **Sections 2.2** and **2.3**) as well as the magnitude of the expected change. The resultant matrix of significance is shown in **Table 3-2**.

Table 3-2 Matrix of impact significance

Magnitude of Impact	Sensitivity of Environmental Values		
	High	Moderate	Low
High	Major	High	Moderate
Moderate	High	Moderate	Low
Low	Moderate	Low	Negligible

The *Sensitivity of Environmental Values* evaluation is influence by the following criteria:

- Condition of the environmental value, i.e. how far is it understood to have already been changed from its original natural form or state?
- How unique or rare is the condition or value or it’s dependant ecological receptors?
- How sensitive are the dependant receptors to changes?

- How to the results compare against the identified groundwater level/availability and quality criteria?

The *Magnitude of Impact* evaluation is influence by the following criteria:

- If a qualitative assessment has been conducted, how do the results compare to the pre-development conditions?
- How to the results compare against the identified groundwater level/availability and quality criteria?
- For quantitative assessments the following is considered:
  - Expected duration of impact: Temporary vs. long-lasting/permanent.
  - Expected extent of impact: Local vs. regional/widespread.
  - Estimated degree of change from pre-development conditions.

4 Existing Environment

4.1 Climate

The Department of Environment and Science (DES) provides an enhanced climate database SILO (Scientific Information for Land Owners) that holds Australian climate data from 1889. The interpolated climate data is stored on a regular 0.05° latitude x 0.05° longitude grid, which is approximately 5 km x 5 km. This database was used to obtained long-term geostatistically determined climate records at 150.75ºE, 33.85ºS near geographical centre of the AWRC groundwater model domain (Appendix A) for the period 1 January 1900 to 30 April 2020 (119 years). This is considered representative for the entire desktop assessment area for the purposes of this assessment. Figure 4-1 and Figure 4-2 display the annual rainfall and pan evaporation at the site, respectively.

Table 5-1 provides annual rainfall and evaporation statistics generated for the site over the 119-year period. **Table 4-2** indicates average monthly maximum and minimum temperature, rainfall, pan evaporation and potential evapotranspiration. The monthly statistics of rainfall and evaporation is shown in **Figure 4-3**.

From **Table 4-2** it is evident that the site receives relatively uniform rainfall with no distinct dry or wet seasonal variation. On average most of the rainfall (456 mm or 61%) is received between November and April. The least rainfall (124 mm or 17%) falls between July and September.

The mean annual evaporation (1,456 mm) exceeds annual rainfall (746 mm) by a factor of 2 (**Table 4-1**) and is greater than rainfall on average for all months of the year (**Table 4-2**). However, the upper quartile for rainfall in May, June and July exceeds the upper quartile value for evaporation in the same winter months (**Figure 4-3**). This indicates that large wet seasons do occur periodically at the site, and when they occur such events produce rainfall that exceeds exceed the evaporation rate and this occurs during the cold winter months.

It is expected that groundwater recharge and water levels will increase during wetter months with lower evaporation rates (e.g. May, June and July). During drier months with higher evaporation rates, (e.g. January to April and August to December), groundwater recharge and water levels are expected to decrease.

Annual rainfall at the site is highly variable with historical rainfall ranging from 314 mm to 1,725 mm with a standard deviation of 235 mm.

Another way to assess these long-term cycles is to examine a plot of cumulative residuals of monthly rainfall from mean monthly rainfall, and monthly rainfall. Such plots provide an indication of the state of the groundwater storage where groundwater storage is most strongly influenced by rainfall recharge and where there is no immediately adjacent groundwater discharge site that might otherwise act as a control on maximum groundwater elevations, which is the case for the desktop assessment area.

Figure 4-4 provides a plot of cumulative residuals of monthly rainfall from mean monthly rainfall for the site, and this indicates drought conditions which is expected to correlate with a decline in groundwater storage since 1990 to present times.

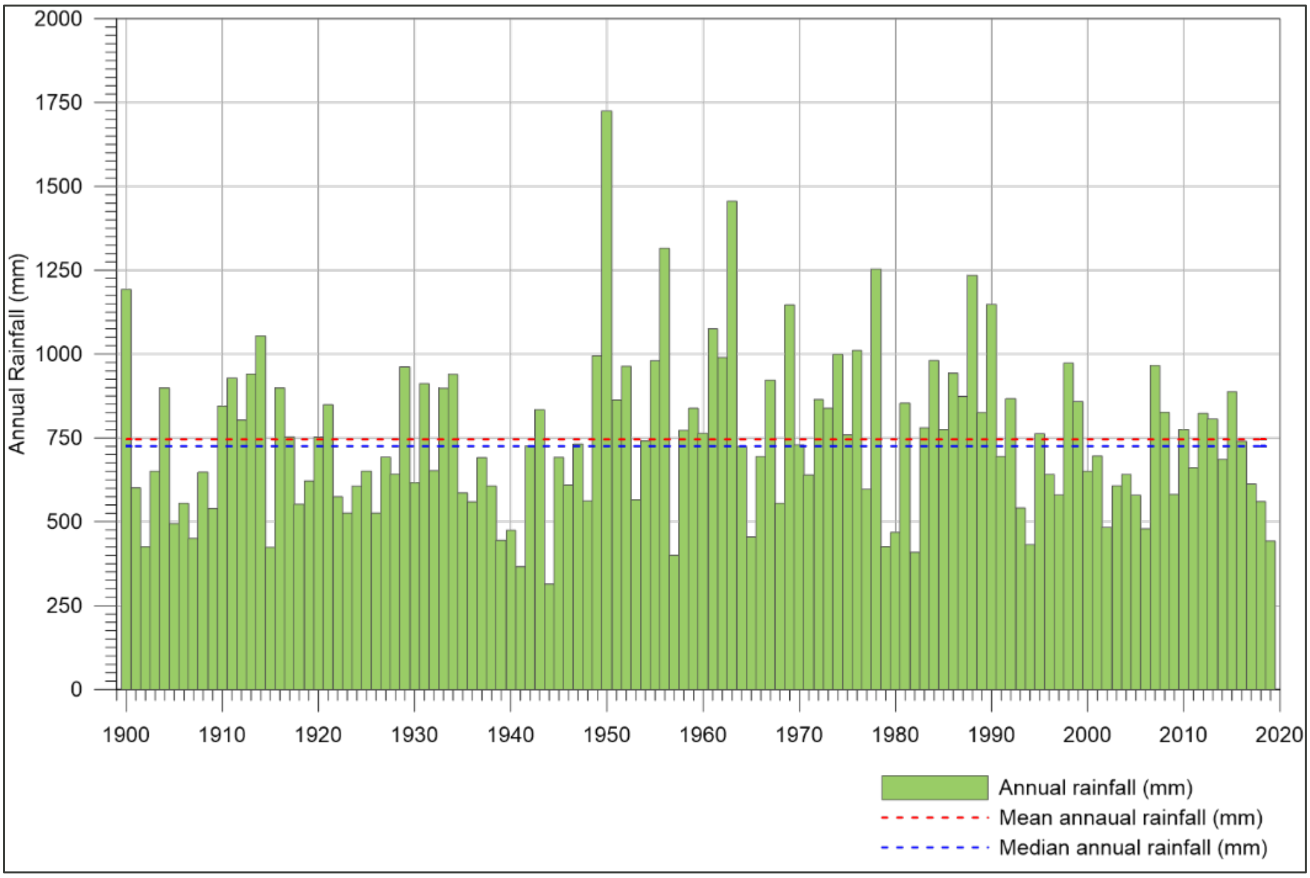


Figure 4-1 Historical annual rainfall (SILO climate data 1900 to 2019)

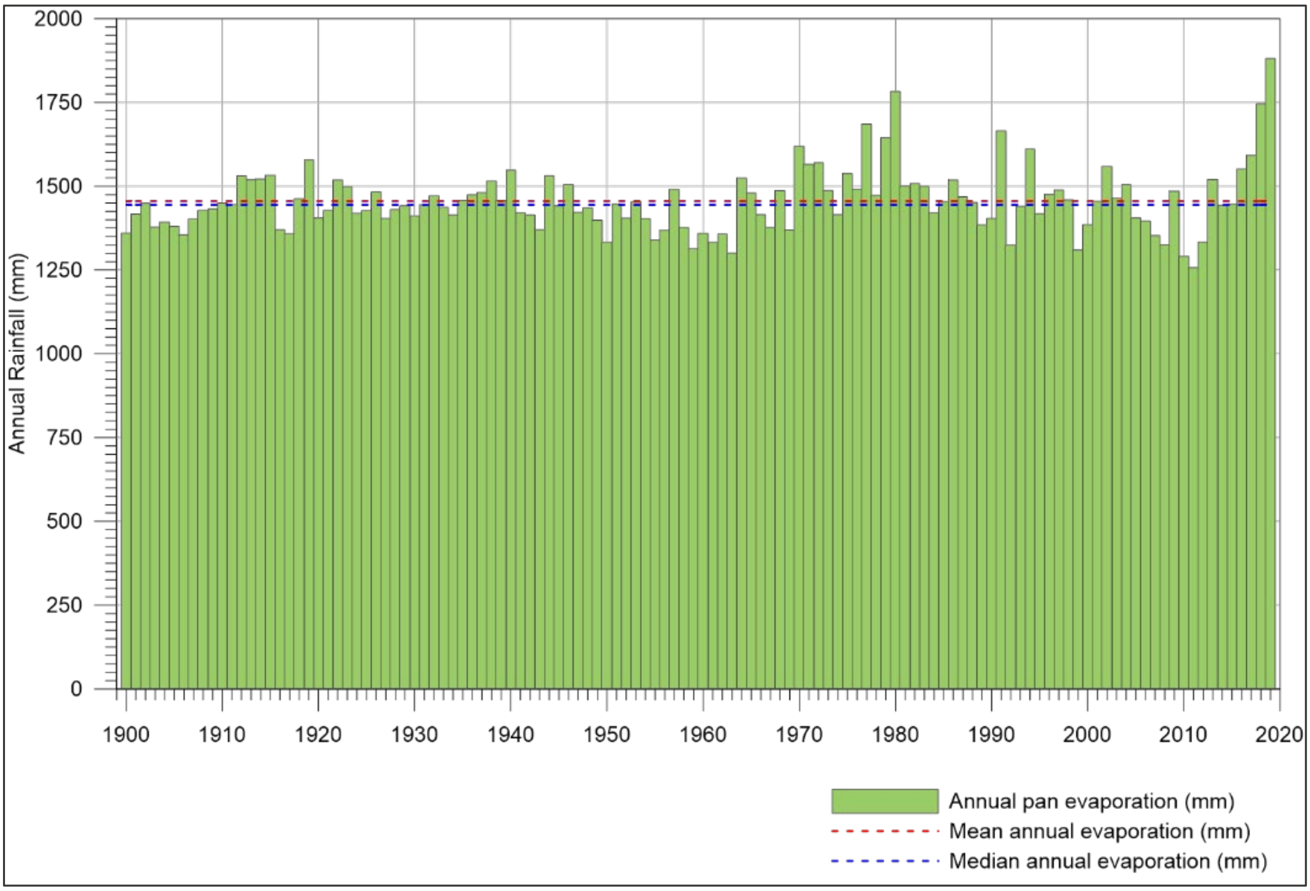


Figure 4-2 Historical annual evaporation (SILO climate data 1900 to 2019)

Table 4-1 Annual rainfall and evaporation statistics

Statistic	Annual Rainfall (mm)	Annual Pan Evaporation (mm)	FAO-56 Potential Evapotranspiration (mm)
Mean	746	1,456	1,227
Minimum	314 (year 1944)	1,257 (year 2011)	N/A
Median	725	1,445	N/A
Maximum	1,725 (year 1950)	1,881 (year 2019)	N/A

Table 4-2 Average monthly climate data

Month	Ambient Temperature (°C)		Rainfall (mm)	Pan evaporation (mm)	FAO-56 Potential Evapotranspiration (mm)
	Minimum	Maximum			
Jan	17.4	29.2	84.2	185.7	156.4
Feb	17.4	28.7	86.7	147.1	126.4
Mar	15.8	27.0	82.5	135.1	114.1
Apr	12.2	24.0	63.8	98.1	82.2
May	8.6	20.5	53.8	68.0	59.9
Jun	6.2	17.6	58.8	57.0	45.3
Jul	4.7	17.3	45.1	62.2	51.3
Aug	5.5	19.0	40.1	87.2	70.4
Sep	8.2	22.0	38.4	113.9	94.8
Oct	11.1	24.4	53.7	144.1	125.3
Nov	13.8	26.4	67.3	166.6	140.8
Dec	16.0	28.6	71.3	190.7	159.7

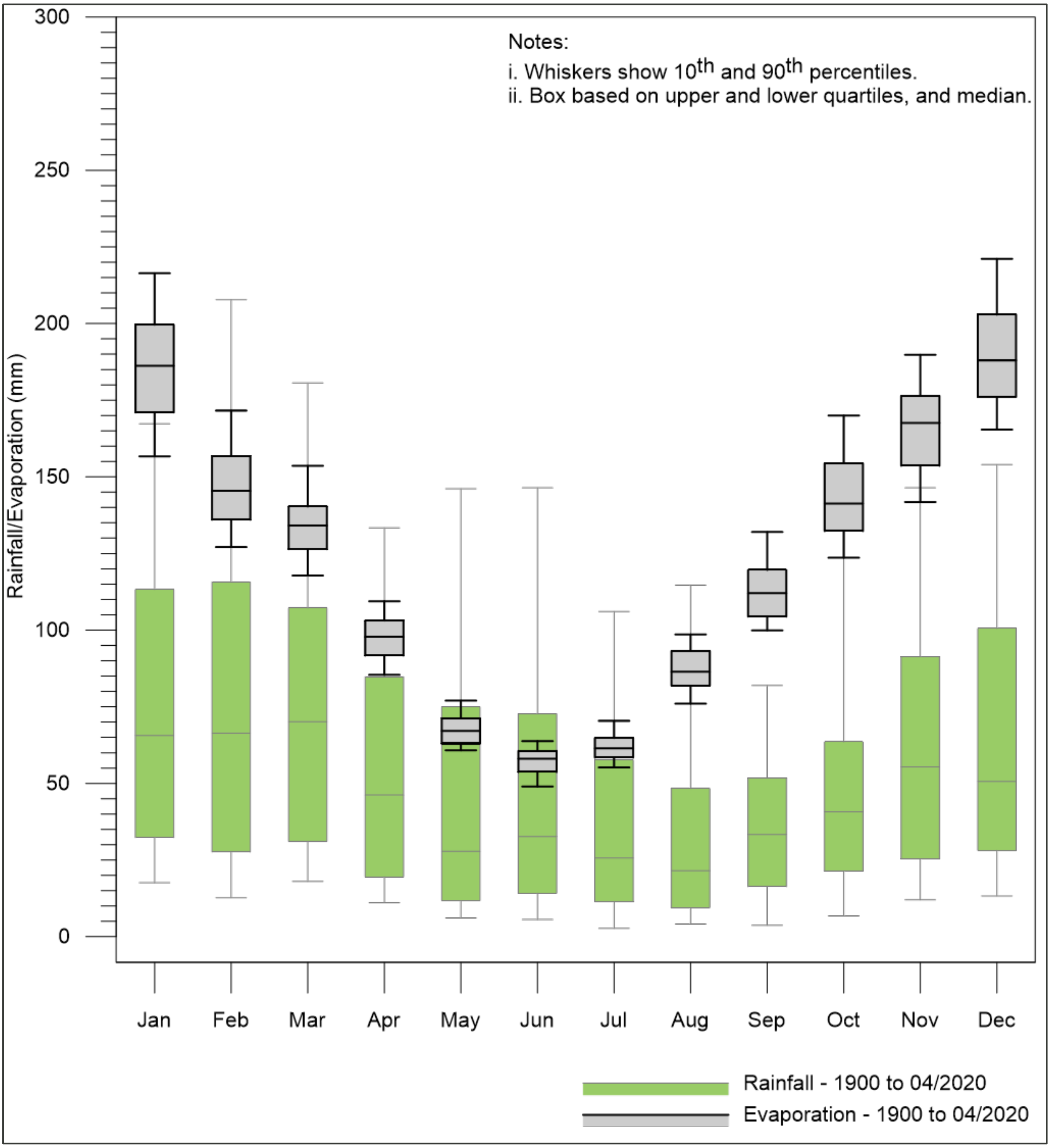


Figure 4-3 Monthly rainfall and evaporation statistics based on SILO (1900 to 2020)

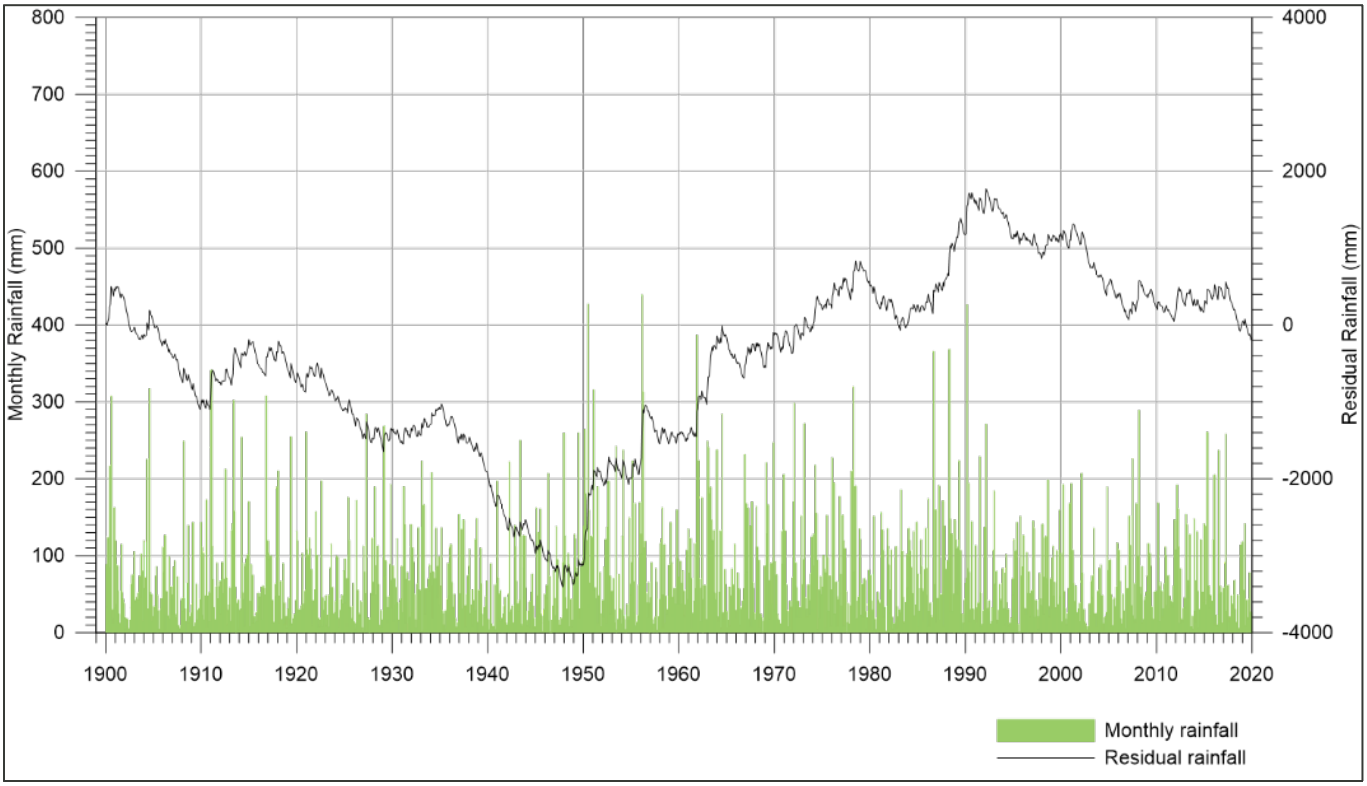


Figure 4-4 Monthly rainfall plus cumulative residuals from mean monthly rainfall - SILO (1900 to 2020)

4.1.1 Climate change

Consideration of potential climate change is a crucial factor in assessing the future water resources, as it has the potential to influence the general environmental water balance as well as groundwater availability, soil and water salinity and water quality. The NSW Office of Environment and Heritage (OEH) has published several documents detailing the expected effects of climate change on water resources. Study results documented in a 2015 report, "*Climate change impacts on surface runoff and recharge to groundwater*" (OEH, 2015), have been used to assess expected local climatic changes.

There are two models of climate data in use in Australia which are applicable to this desktop assessment area. The national model, CSIRO, and a local model, the NSW and ACT Regional Climate Model (NARCliM). The CSIRO data is not as granular as NARCliM, which uses downscaled regional climate models (RCM's) derived from IPCC's Global Climate Models (GCM) to project their findings across three time periods.

Utilising NARCliM, the OEH study predicted near future (2020-2039) and far future (2060-2079) changes to rainfall, runoff and recharge to groundwater. **Table 4-3** presents a summary of the statistical analysis for Metropolitan Sydney.

Table 4-3 Percent changes to multi-model mean annual rainfall, surface runoff and recharge

	Percentage change in near future (2020-2039)			Percent change in far future (2060-2079)		
State planning region	**Rainfall**	**Runoff**	**Recharge**	**Rainfall**	**Runoff**	**Recharge**
Metropolitan Sydney	0.4	4.0	-5.0	8.1	17.6	12.5

The results of this model for the Hawkesbury catchment are presented in **Table 4-4**. In summary, the study predicted that changes in near future, were likely to be a reduction in the rainfall and recharge to the groundwater and increase in the surface runoff, while in far future, the model predicted an increase in all three parameters (rainfall, surface runoff and recharge to the groundwater).

Table 4-4 Percentage change in rainfall, runoff and groundwater recharge for the Hawkesbury catchment

	Percentage change in near future (2020-2039)			Percent change in far future (2060-2079)		
State planning region	**Rainfall**	**Runoff**	**Recharge**	**Rainfall**	**Runoff**	**Recharge**
Hawkesbury Nepean Catchment	-0.1	0.9	-9.3	6.1	13.4	5.6

4.2 Topography

Light detection and ranging (LiDAR) data with +/- 1 m resolution has been used to define the physiographic context of the project. Results from LiDAR mapping are presented in **Figure 4-6**, **Figure 4-7** and **Figure 4-8** as topographic elevation maps. The following sections discuss the topography for the AWRC and each of the USC AWRC pipelines, including the treated water pipeline, environmental flows pipeline and brine pipeline.

4.2.1 Advanced water recycling centre

The AWRC is located within a regional alluvial plain associated with Badgery's Creek, South Creek and Kemps Creek watercourses. The topography in this area is predominately flat, with a gentle slope towards the north. Elevations across the AWRC generally range between about 35 to 40 mAHD.

4.2.2 Treated water pipeline

The treated water pipeline follows undulating, gently sloping terrain from the low-lying areas around the Nepean River in Wallacia (35 mAHD) in the east to South Creek/Kemps Creek (40-45 mAHD) with some areas of higher elevation (90 mAHD) around The Northern Road, Luddenham.

4.2.3 Environmental flows pipeline

The environmental flows pipeline traverses south from Silverdale Road along a plateau adjacent to the Nepean River valley before turning west towards the Warragamba River downstream of the Warragamba Dam. The pipeline route encounters a steep north-south aligned ridge along the westward route with the surface elevations increasing from about 61 mAHD to about 153 mAHD within a distance of about 300 m equating to a slope of about 31%.

The proposed construction methodology for the environmental flows pipeline along the westward route is via horizontal directional drilling (HDD) cutting through east side of the ridge line at about 66 mAHD and exiting on the west side of the ridge line at an elevation of about 34 mAHD adjacent to the Warragamba River for discharge.

The complete elevation profile for the environmental flows pipeline along its approximate 4.4 km length is illustrated in **Figure 4-5**. The orientation and direction of this cross-section is indicated by the "Environmental Flows Pipeline" illustrated in **Figure 4-6**.

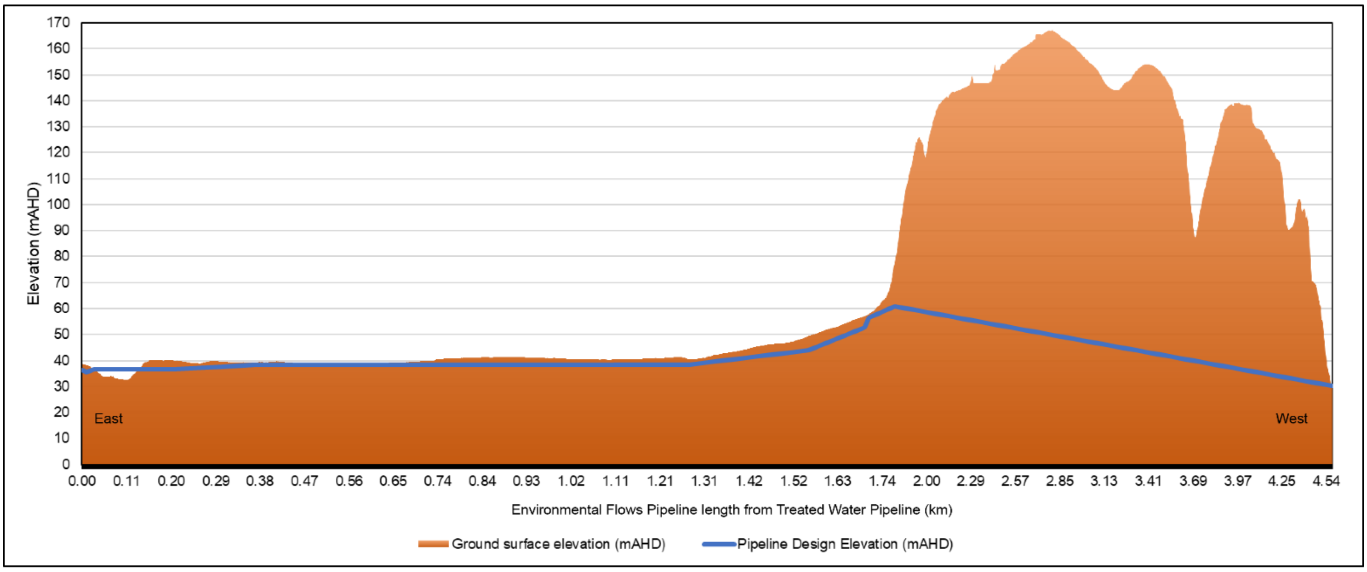


Figure 4-5 Elevation profile along the environmental flows pipeline

4.2.4 Brine pipeline

East of the AWRC, along the brine pipeline, the alignment follows gently undulating, sloping topographies, rising from about 40 mAHD, reaching a high point at Cecil Hills at approximately 80 mAHD before sloping down towards Prospect Creek and the Georges River in Fairfield at approximately 10 mAHD.

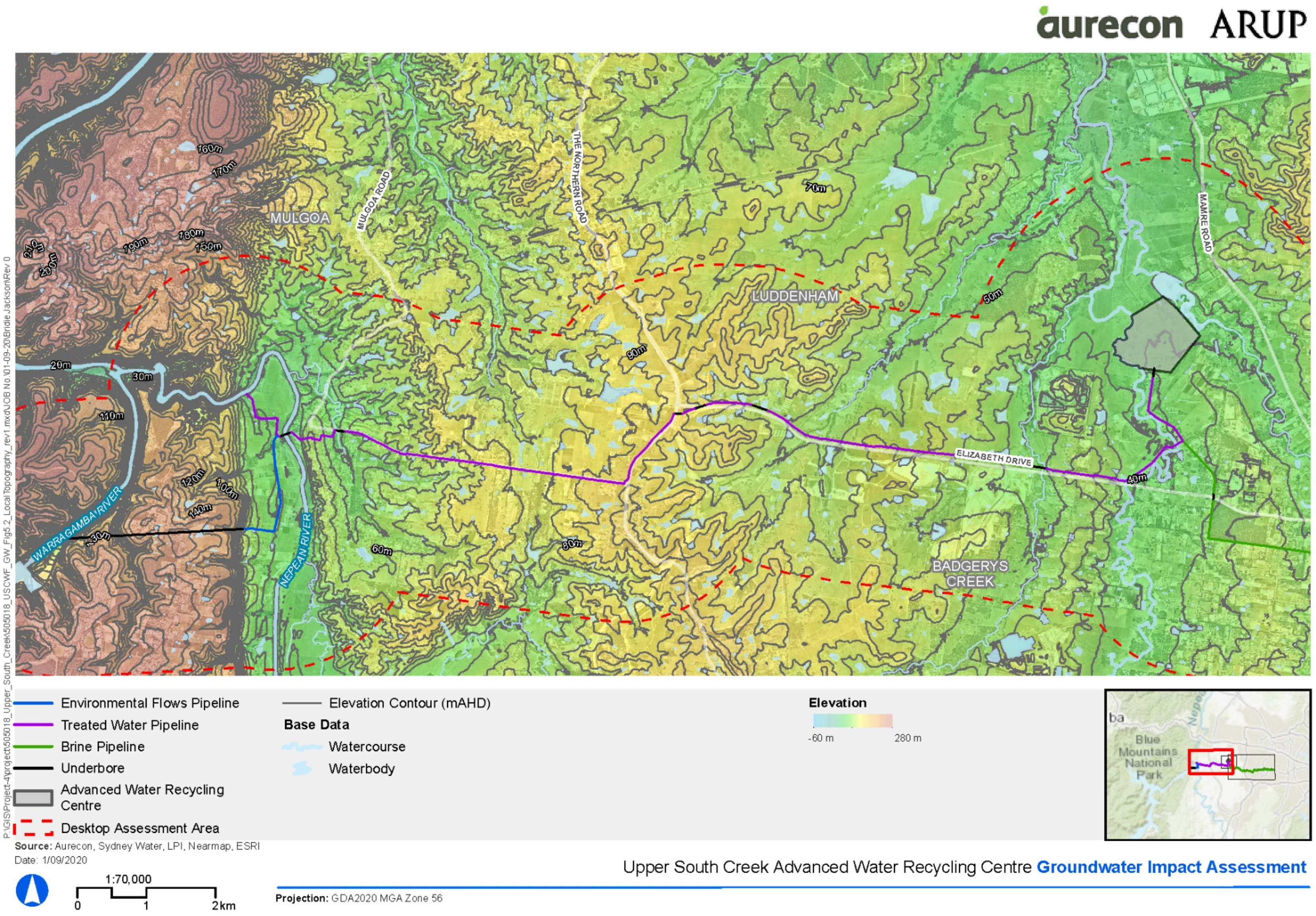


Figure 4-6 Local Topography – Treated Water / Environmental Flow Pipelines

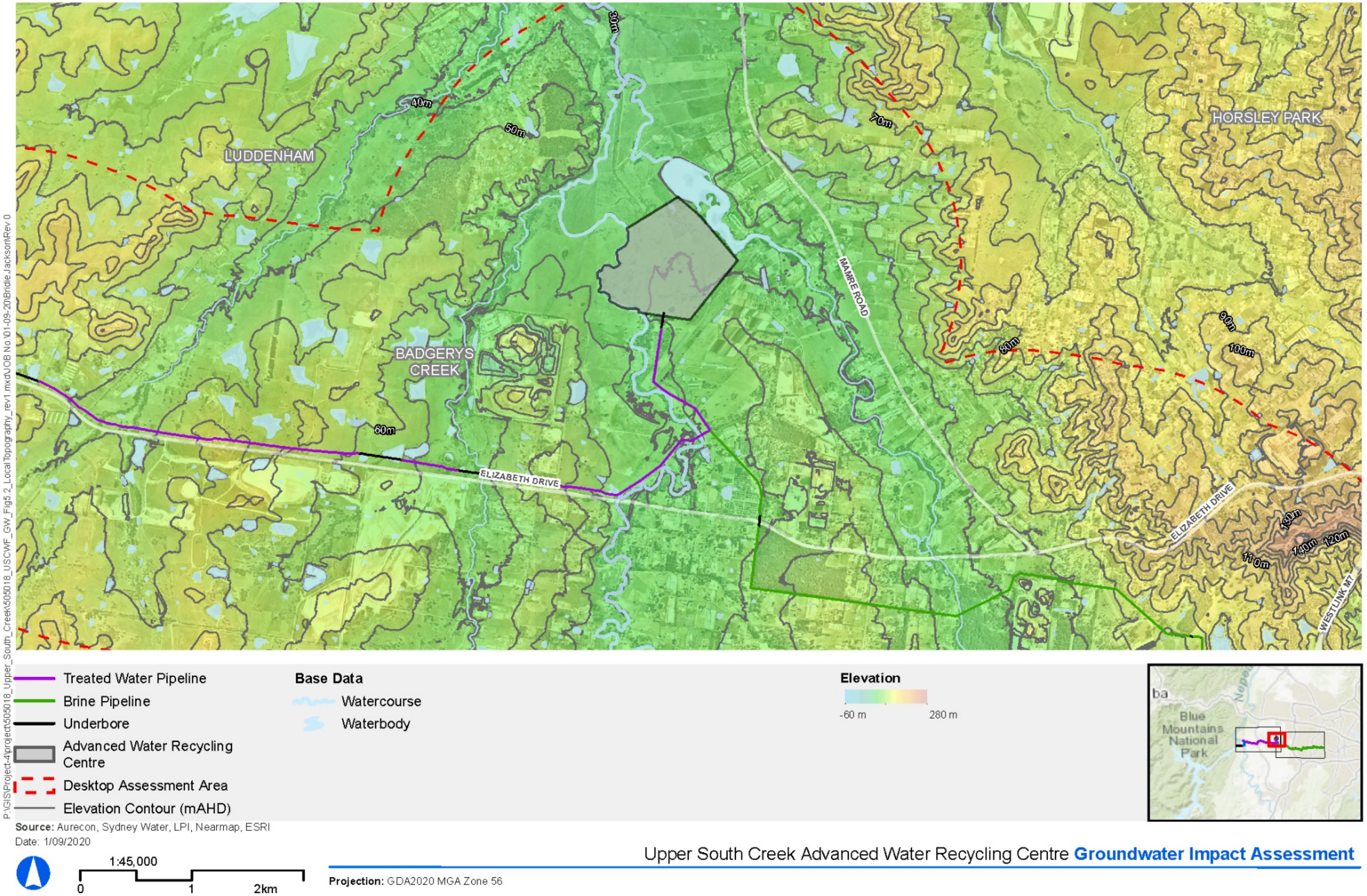


Figure 4-7 Local Topography – The AWRC

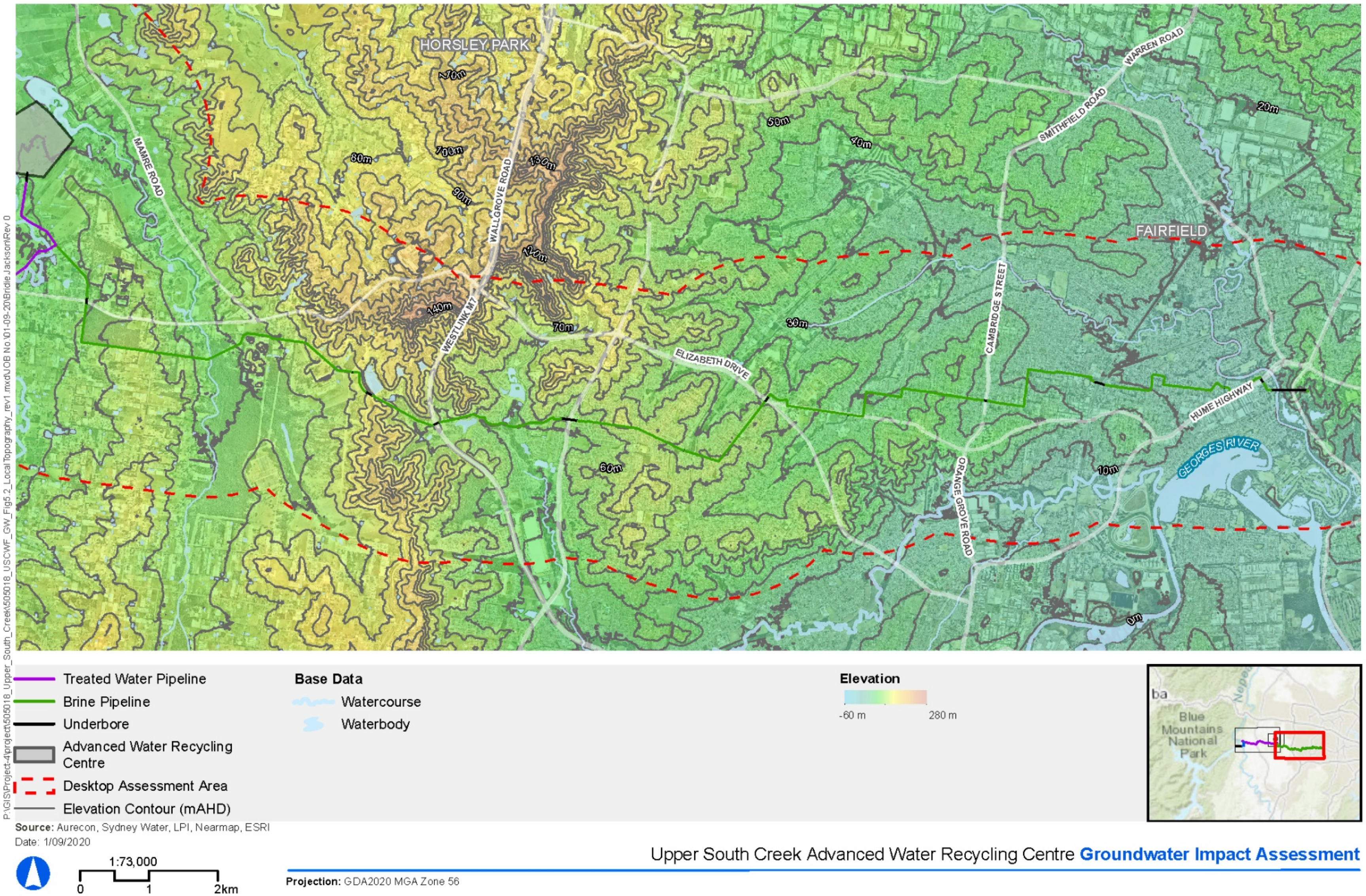


Figure 4-8 Local Topography – Brine Pipeline

4.3 Drainage and Hydrology

The hydrology of the site is described in detail in the *Surface Water Impact Assessment* report (Aurecon Arup, 2021). A brief summary of features pertinent to the groundwater impact assessment is provided below for context to the discussions in this report.

4.3.1 Catchments

Most of the desktop assessment area including the AWRC, treated water pipelines and the western portion of the brine pipeline is located in the Hawkesbury-Nepean catchment. A smaller portion of the desktop assessment area, including the eastern portion of the brine pipeline, is located within the Georges River catchment.

The catchments and sub-catchment boundaries for the AWRC site are illustrated in **Figure 4-9**.

The principal waterways intersected by the pipelines from west to east include:

- Hawkesbury Nepean catchment:
  - Nepean River
  - Jerrys Creek (tributary to Nepean River)
  - Baines Creek (tributary to Nepean River)
  - Warragamba River (tributary to Nepean River)
  - Megarritys Creek (tributary to Warragamba River)
  - South Creek (tributary to Hawkesbury River)
  - Badgerys Creek (tributary to South Creek)
  - Kemps Creek (tributary to South Creek)
  - Cosgrove Creek (tributary to South Creek)
  - Oaky Creek (tributary to Cosgrove Creek)
- Georges River catchment:
  - Prospect Creek (tributary to Georges River)
  - Green Valley Creek (tributary to Prospect Creek)
  - Hinchinbrook Creek (tributary to Cabramatta Creek)

The Hawkesbury-Nepean catchment provides drinking water, agricultural and fisheries produce, recreational opportunities and tourism resources for Metropolitan area of Sydney and is one of the largest coastal basins in NSW with an area of 21,400 km^2 (NSW DPI, 2017). Over its 470 km flowing length, it originates from the headwaters of the Nepean River in Goulburn before joining the Hawkesbury River in the west of Sydney and draining to Broken Bay.

The Georges River catchment has an area of 960 km^2 and the Georges River itself extends approximately 60 km south-west of Sydney. It is one of the most highly urbanised catchments in Australia. It includes parts of 14 local government areas and covers a significant portion of the Greater Metropolitan Region (Georges Riverkeeper, n.d.). The Georges River, having come together from such widespread sources as Wollongong and Wollondilly in the south and Blacktown in the north, initially flows northward until Chipping Norton where it bends and ultimately flows eastwards into Botany Bay.

While almost half the Hawkesbury-Nepean Catchment is protected in national parks and water catchment reserves, the AWRC lies within the Badgerys Creek, South Creek and Kemps Creek sub-catchments which have been extensively modified and disturbed by agriculture, increasing urbanisation and associated land clearing. Specifically, the AWRC is located within a floodplain bordered by Kemps Creek to the northeast and South Creek to the southwest. Surface water flow would be consistent with the topography, outward toward both creeks.

The hydrology of both the Georges River and local Lower Hawkesbury-Nepean catchment have been significantly altered due to increasing impervious surfaces which has in turn altered the geomorphology and ecology of the watercourses.

Additional flows within the Lower Hawkesbury-Nepean catchment are derived from a number of major Sewage Treatment Plants (STPs) which discharge treated effluent (HNCMA, 2007). The Hawkesbury River is the ultimate downstream receiving environment and is located about 29 kilometres from the project at the closest point.

Some local drainage ditches also exist within the AWRC site, most prominently observed in a generally straight line from northeast to southwest. Any remaining discharge should percolate through the soil into groundwater. The creeks and their associated ecosystems are the environmental receptors for potential impacts from the AWRC development.

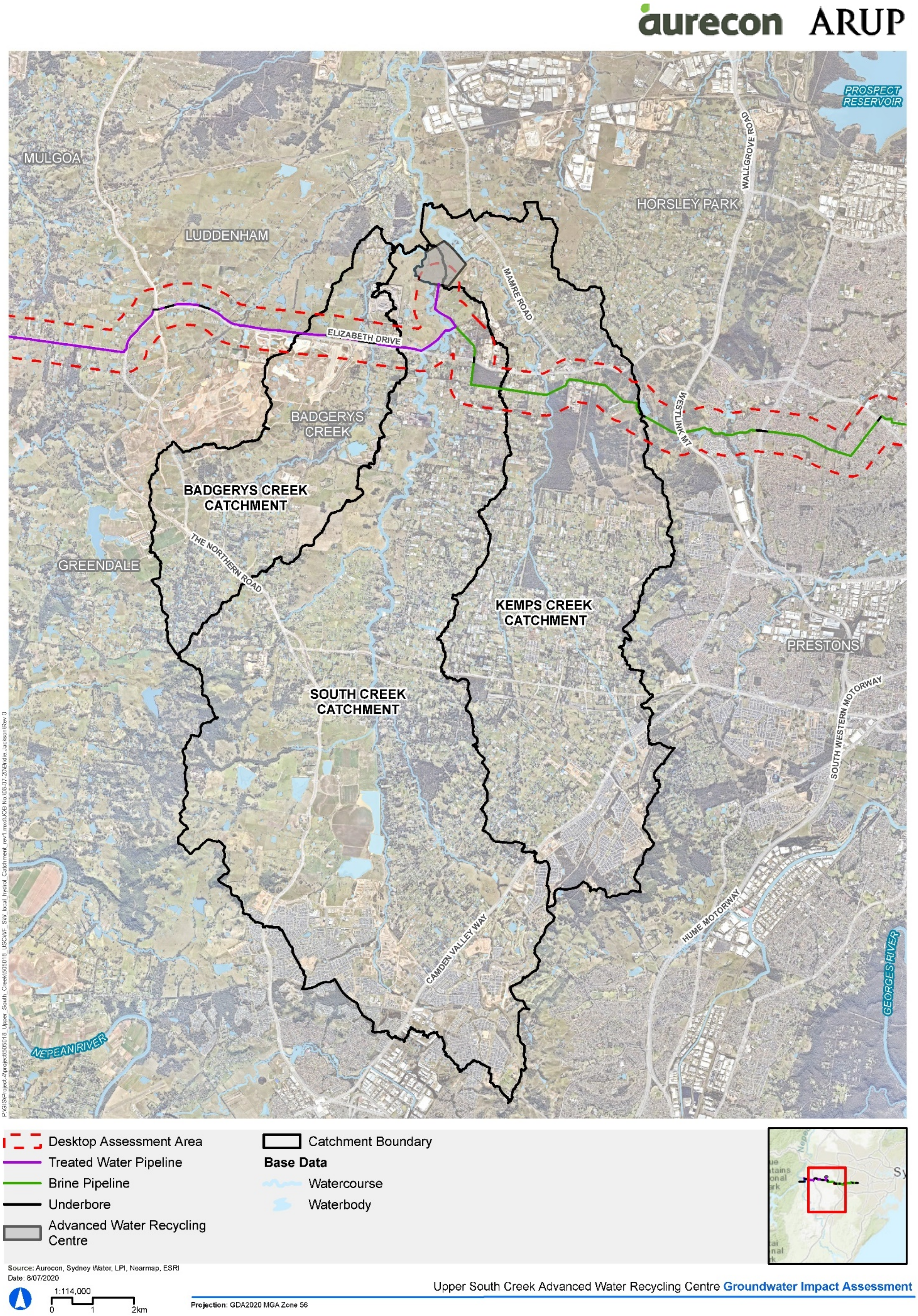


Figure 4-9 Drainage & Hydrology – Key sub-catchments relevant to the AWRC site

South Creek Sub-Catchment

South Creek sub-catchment covers an area of approximately 490 km^2, forming part of the Hawkesbury Nepean catchment and a tributary of the Hawkesbury-Nepean River. It rises around Oran Park, flowing generally north, where it is joined by other tributaries such as Badgerys Creek and Kemps Creek before reaching its confluence with the Hawkesbury River, near Windsor. The creek generally flows from south to north, descending approximately 94 m over its 70 km course.

The confluence of Kemps Creek and Badgerys Creek into South Creek is about three kilometres north of Elizabeth Drive.

Kemps Creek Sub-Catchment

Kemps Creek is a tributary of South Creek and is a fourth order stream which flows into the Hawkesbury-Nepean River. The creek originates about two kilometres east of Catherine Fields and flows for about 17 km through the suburbs of Rossmore, Bringelly, Austral and Kemps Creek before entering South Creek north of Elizabeth Drive.

The Kemps Creek sub-catchment is known to experience flooding and associated drainage problems due to limited hydraulic capacity in the creek channels, filling activities on the floodplain and inadequate hydraulic capacity at culverts and bridges. As a result of drainage problems, considerable earthworks have been conducted to control water including construction of dams to store water, construction of channels or banks to divert flow of water and enlarging the creek channel to reduce flood levels (Liverpool City Council, 2003). Land use within the Kemps Creek sub-catchment largely includes agriculture (grazing, market gardens, poultry), residential, commercial and extractive industry.

Badgerys Creek Sub-catchment

Badgerys Creek has a catchment area of approximately 28 km^2 and has its headwaters in the vicinity of Findley Road, Bringelly, approximately 10 km upstream of the AWRC. It flows generally in a north to north-east direction. The creek then forms the south-eastern boundary of the Western Sydney Airport as far as Elizabeth Drive. It then passes the Elizabeth Drive landfill site, operated by SUEZ Environment. It then continues to flow until its confluence with South Creek at nearly 500 m (at the closest point) downstream of the AWRC.

4.3.2 Interconnection between surface water and groundwater systems

Interactions between surface water and groundwater system occurs through either the river leaking into the underlying groundwater system or vice versa, depending on the relative levels of the water levels in the two systems and the permeability of the riverbed material.

For hydraulically connected systems, rivers may lose water to the underlying aquifer when the water level in the river is higher than the water level in the aquifer. In this case the river is considered as a losing stream. If the groundwater table is higher than the water level in the creek the aquifer discharges water to the river. When this occurs, it is referred to as a gaining stream and the discharge is referred to as baseflow.

A river may comprise multiple gaining and losing reaches. No studies to date have been carried for South Creek which identify gaining and losing reaches for this creek. Information on observed baseflow was obtained from the water balance modelling of South Creek catchment undertaken by Cooperative Research Centre (CRC) for Irrigation Futures (2009). The model used by CRC comprised sub-catchments of South Creek which discretised at selected stream gauges as shown in **Figure 4-10**.

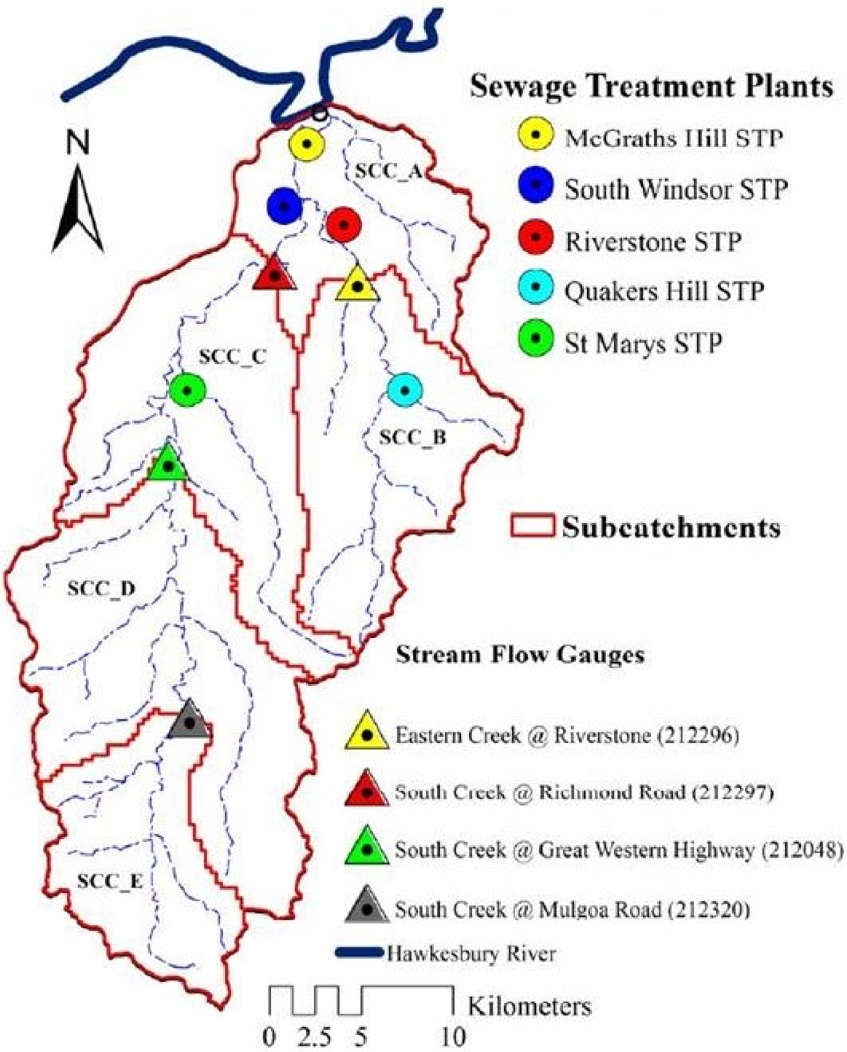


Figure 4-10 The South Creek catchment and its sub-catchments (CRC, 2009)

The simulated annual and monthly runoff volumes determined by CRC for Irrigation Futures (2009) are provided in **Figure 4-11** and **Figure 4-12**, respectively.

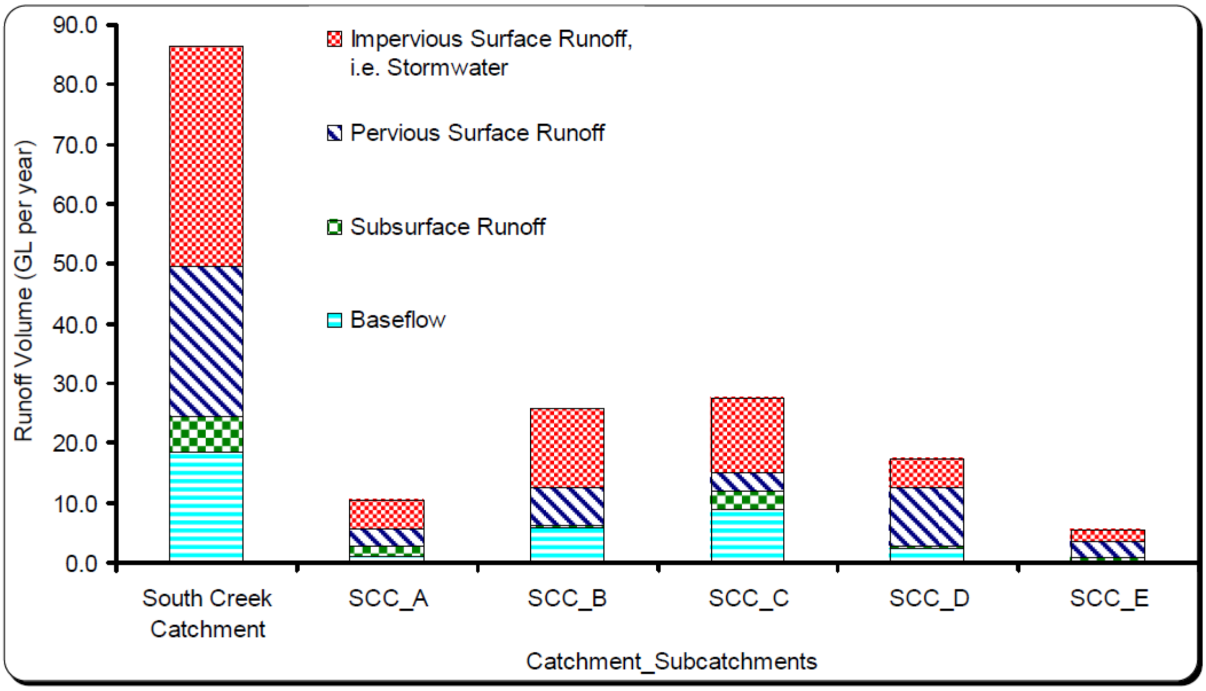


Figure 4-11 Average annual rainfall runoff volumes in the South Creek catchment (GL/year) (CRC, 2009)

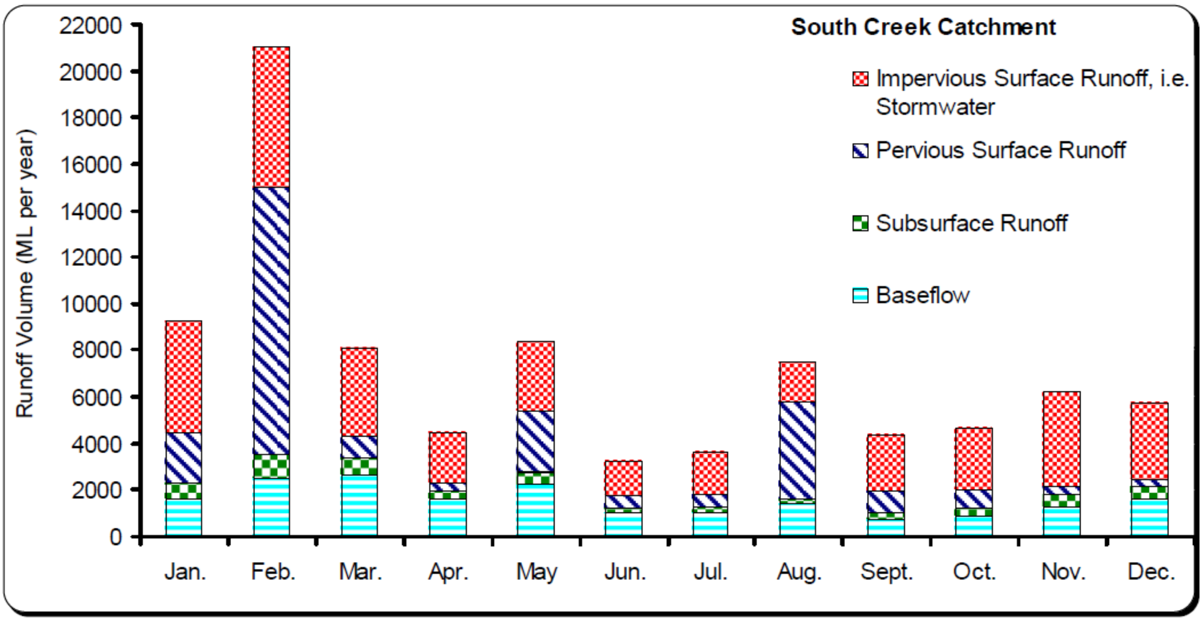


Figure 4-12 Average monthly rainfall runoff volumes in the South Creek catchment (ML/month) (CRC, 2009)

The AWRC is in catchment SCC_D shown in **Figure 4-10** and the simulated annual and monthly runoff volumes for this catchment in are of direct relevance to the AWRC numerical groundwater model (**Appendix A**).

The total annual modelled and calibrated baseflow at Great Western Highway Gauge 212048 is 2.5 GL/year (or 6,926 m^3/d). The total length of major creeks discharging at this streamflow gauge is 63.9 km. Assuming uniform contribution from these creeks, this baseflow equates to 0.108 $m^3/d/m$. The total length of major creeks within the ARWC groundwater model domain is 37.0 km, and this translates to approximately 4,007 m^3/d (maximum) as baseflow being generated annually within the AWRC model domain. However, in reality rivers could comprise alternating gaining and losing reaches depending on a number of factors including local hydrogeological conditions, the characteristics of the riverbed material and the elevation of the riverbed relative to local groundwater level. It is expected that gaining reaches of the creek would likely be in the lowland sections. Observed groundwater levels at AWRC during the project fieldwork, as well as those from nearby studies were all higher than the observed water levels in the adjacent creeks (South Creek and Kemps Creek). The reaches of the creeks in these areas are therefore gaining river segments.

4.4 Regional Geology

The project is located within the Permo-Triassic Sydney Basin. The Sydney Basin is characterised by sub-horizontal sedimentary deposits, which mainly comprise sandstone with interbedded shale layers deposited unconformably on a basement of the Lachlan fold belt (Haworth, R.J., 2003). Surface outcrops of geological units associated with the desktop assessment area has been determined from a review of the NSW Seamless Geology dataset (Department of Regional NSW, 2020) and are presented in **Figure 4-13**, **Figure 4-14** and **Figure 4-15**.

A depositional and descriptive summary of the geological units (in order of age: most recent to oldest) that occur within the desktop assessment area is presented in **Table 4-5**. Further details of each identified stratigraphic unit are provided in the following sections.

The regional geology is the physical setting of groundwater systems in the desktop assessment area, therefore the information presented in this section has been used to form the basis of the hydrogeological conceptual model (outlined in **Section 5**) and the subsequent impact assessment.

Table 4-5 Relevant geological units within the desktop assessment area

Age	Stratigraphic unit	Deposition environment	Description
Anthropocene	Anthropogenic Fill	Sub-aerial	Highly variable fill materials (includes topsoil, embankments, road pavements, landscaped areas etc.)
Quaternary	Alluvial Sediments/Deposits	Non-marine rivers, creeks and streams	Loose, unconsolidated fine to medium grained sand, silt and clay.
Triassic	Bringelly Shale	Swampy alluvial plain with streams flowing from the west.	Variable sedimentary rock types. Black and grey shales and sandstones with small scale bedding.
	Minchinbury Sandstone	Shoreline marine environment	Fine to medium grained quartz sandstone with calcite and volcanic lenses.

Age	Stratigraphic unit	Deposition environment	Description
	Ashfield Shale	Low energy marine environment	Black mudstones and grey shales with small scale bedding.
	Hawkesbury Sandstone	Braided alluvial channel fill	Medium to coarse-grained quartz sandstone with minor shale and laminate lenses. Sandstones are either massive or cross-bedded sheet facies with vertical or sub-vertical joint sets. The combination of bedding planes and widely spaced joints gives sandstone outcrops a distinctive blocky appearance.

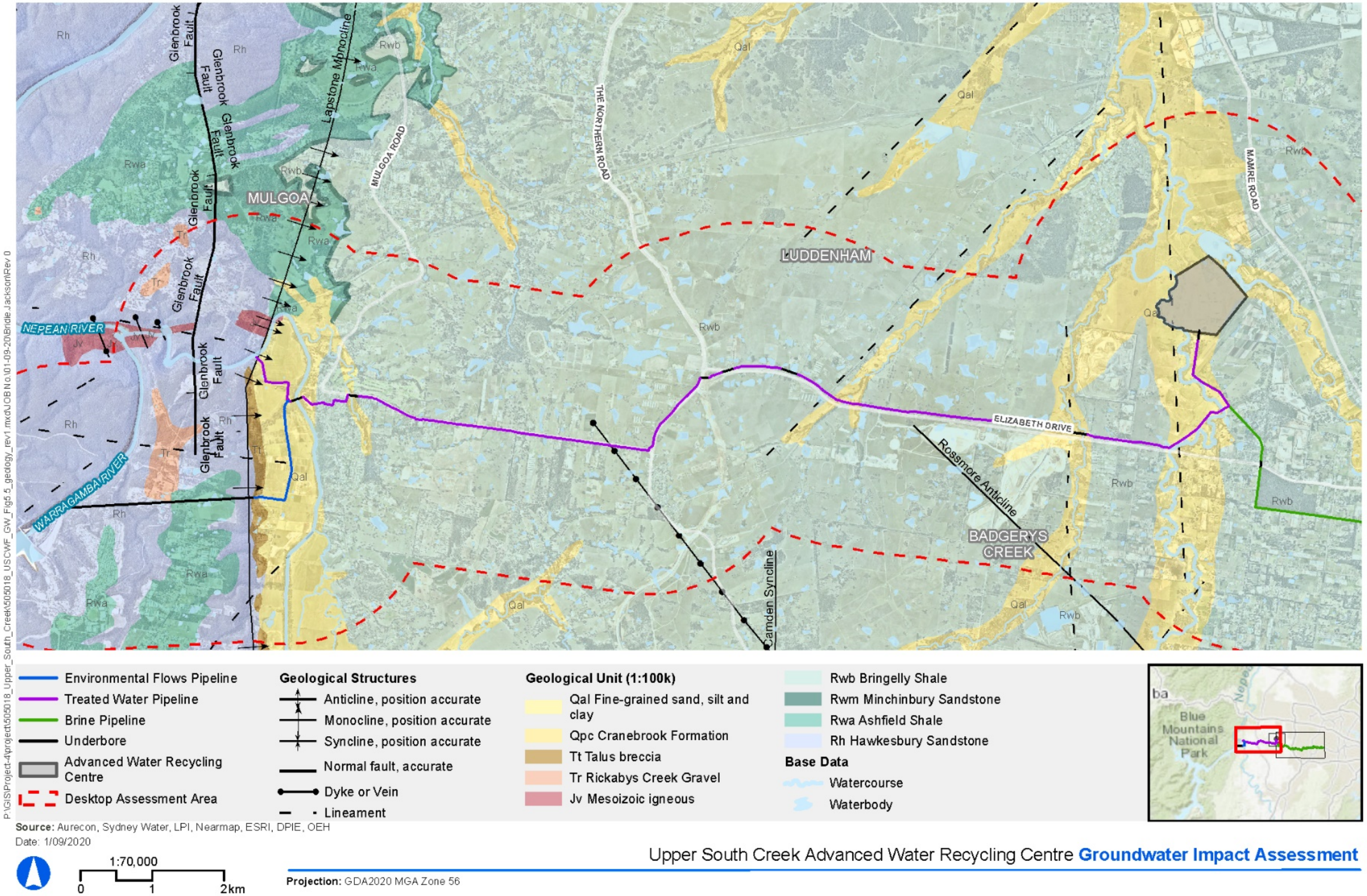


Figure 4-13 Regional Surface Geology – Treated Water / Environmental Flow Pipelines

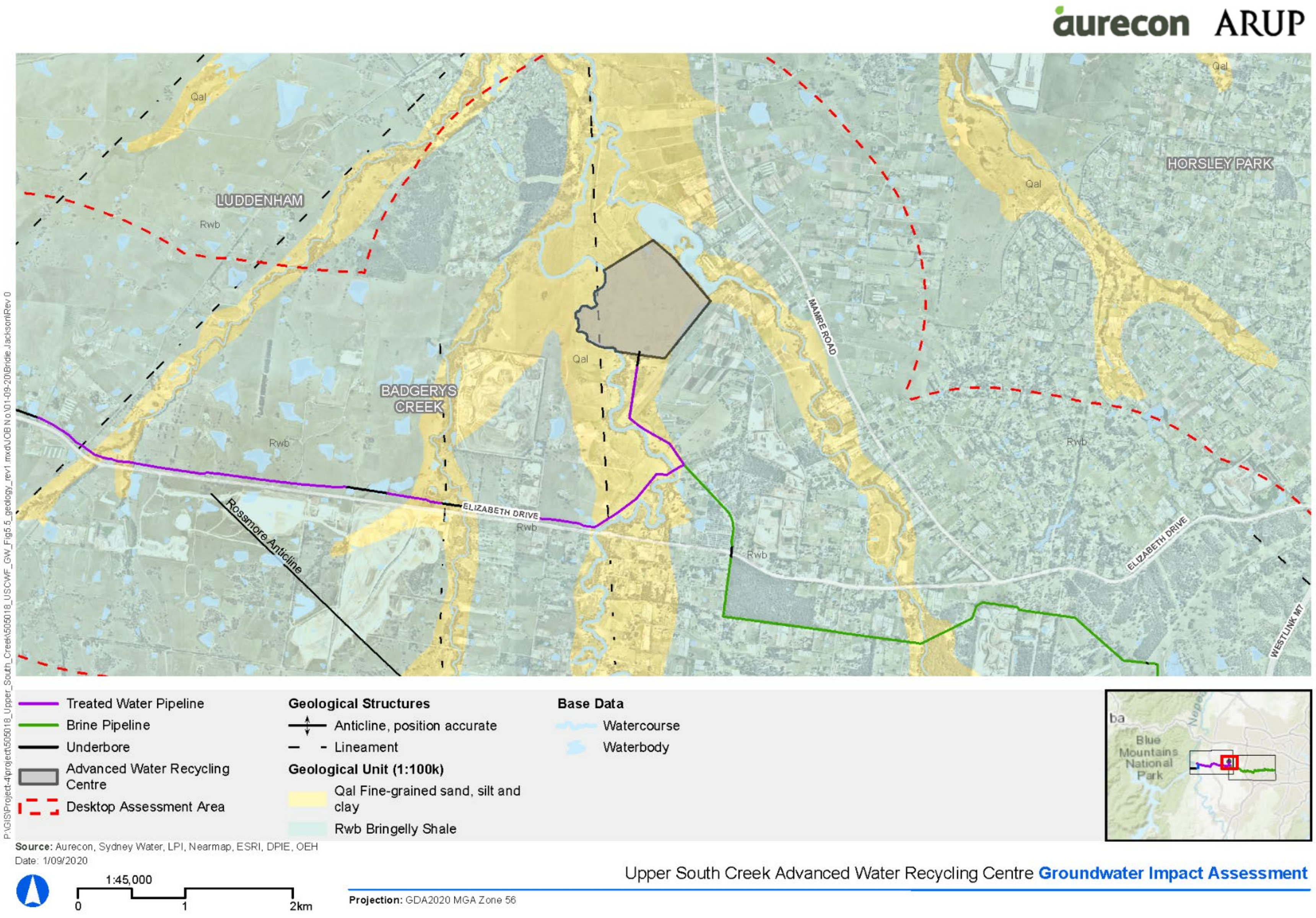


Figure 4-14 Regional Surface Geology – AWRC site

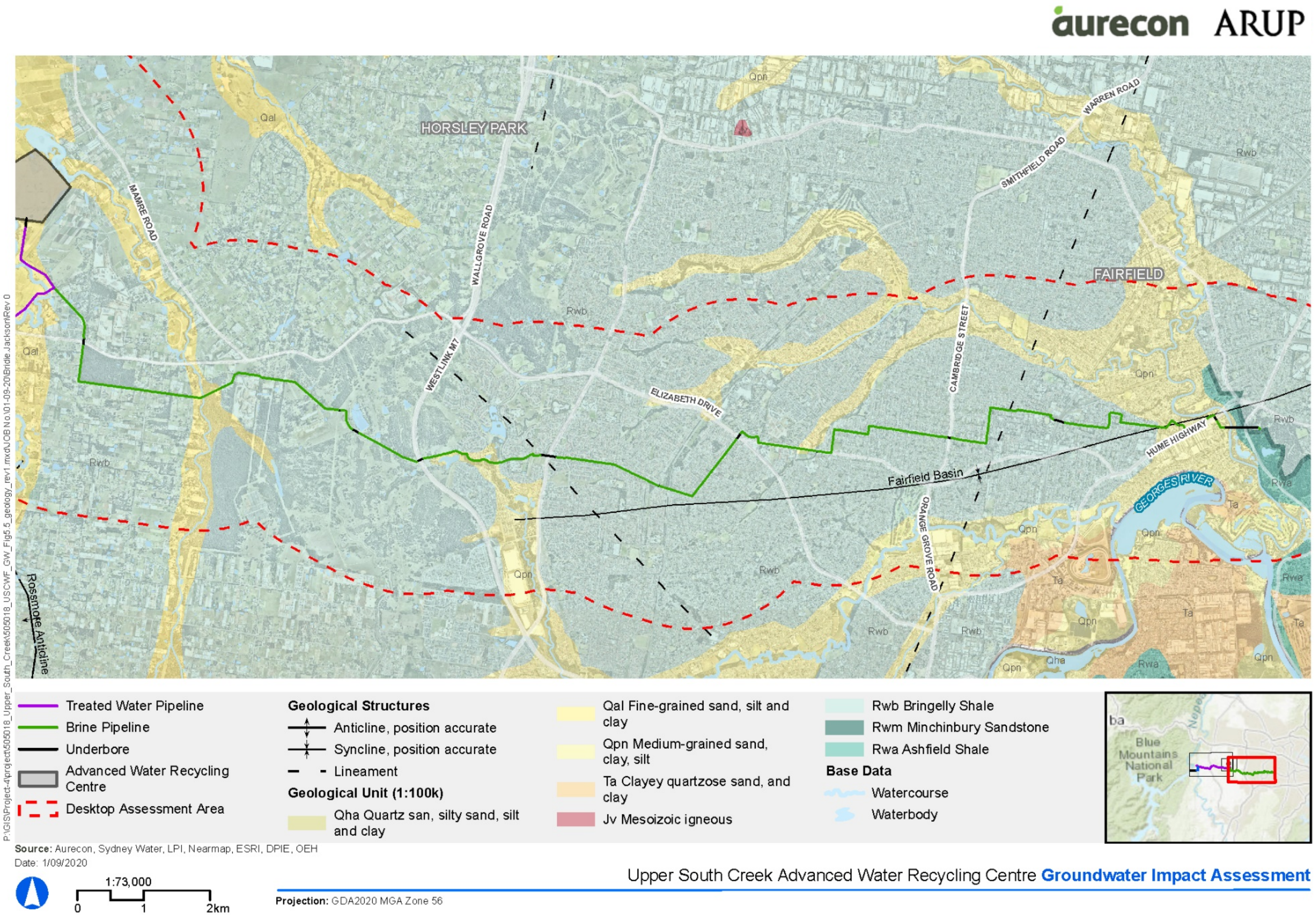


Figure 4-15 Regional Surface Geology – Brine Pipeline

4.4.1 Quaternary deposits

Anthropogenic Fill

Artificial ground (anthropogenic deposits of fill material) is likely to be present as a thin layer across the desktop assessment area, associated with pavement construction, landscaping and building foundations. Deeper fill deposits may be present in areas mapped as "disturbed terrain" in the east around Prestons and Liverpool.

Quaternary Alluvium

Quaternary alluvium is commonly encountered in areas adjacent to and within floodplains of rivers and streams throughout the desktop assessment area, including Nepean River, Badgerys Creek, South Creek, Kemps Creek, Cabramatta Creek, Clear Paddock Creek, Georges River and Prospect Creek.

Areas where alluvium is presented are associated incisions in the underlying bedrock formed by river/stream erosion, later infilled with sediments as a result of changes in potential energy associated with sea level fluctuations.

Alluvial deposits in the desktop assessment area comprise fine-grained sand, silt and clay. The extents of alluvial deposits are based on the available 1:100,000 scale geological mapping. Based on this mapping, the total width of the alluvium deposits around the rivers/streams are as follows:

- Nepean River: 900 metres
- Cosgroves Creek: 300 metres
- Badgerys Creek: 600 metres
- South Creek: 850 metres
- Kemps Creek: 450 metres
- Cabramatta Creek: 1,500 metres

A larger area of alluvial deposition is present at the confluence between Kemps Creek, South Creek and Badgerys Creek, with a width of approximately 1,600 m edge to edge.

4.4.2 Triassic sediments

The Wianamatta Group (Late-Triassic)

The Wianamatta Group was deposited in the Triassic Age during a single regressive period following the subsidence of the Hawkesbury Sandstone alluvial plain. The deposition of sedimentary rock types occurred continuously during the period in connection with a large river delta, with vertical accumulation of sediments and a shoreline progressing from west to east.

Deposition of the Wianamatta Group began with a basal unit of offshore low energy marine muds/clays (Ashfield Shale), which then became a shoreline/beach sand deposit (Minchinbury Sandstone) and finally became marshy alluvial plain deposits across the delta (Bringelly Shale).

The Wianamatta Group is up to 300 m thick and typically expressed as a shale with sporadic thin lithic sandstone beds. The Wianamatta Group represents the last phase of sedimentation directly related to the tectonic development of the Sydney Basin (O'Neill & Danis, 2013). The following sections discuss the geological features of each unit associated with the Wianamatta Group within the desktop assessment area.

Bringelly Shale

Bringelly Shale is the most prevalent surface outcropping geological formation across the desktop assessment area and comprises variable sedimentary rock types, including shale, carbonaceous claystone, claystone, laminate, fine to medium grained lithic sandstone, rare coal and tuff. Bringelly Shale is the upper member of the Wianamatta Group.

The variable rock types arise from the alluvial plain depositional environment, which included swampy organic rich sediments, overbank alluvial clays, channel sands and lake deposits.

The average thickness of the Bringelly Shale formation is approximately 60 m (Lovering, 1954) and is often deeply weathered to depths up to 10 metres. Weathering of the Bringelly Shale typically forms clays and silty clays of medium to high plasticity (and low permeability).

Minchinbury Sandstone

The Minchinbury Sandstone is a relatively thin stratigraphic unit that lies between the Bringelly Shale and Ashfield Shale formations within the Wianamatta Group. The unit comprises fine to medium grained quartz lithic sandstone with calcite and volcanic lenses. The high quantities of quartzite and limited amount of felspar in the Minchinbury Sandstone differentiate it from the sandstones that occur within the Bringelly Shale.

The unit ranges in vertical thickness between 1.5 and 6 m and is less than 3 m thick in most areas (Lovering, 1954).

Ashfield Shale

Ashfield Shale occurs below in the Minchinbury Sandstone, forming the basal unit of the Wianamatta Group. The unit comprises black claystone, siltstone, mudstone and grey shales with interbedded ironstone bands. Small-scale bedding is prevalent, with thin alternating layers of siltstone and sandstone that is sometime carbonaceous with variable silt and clay particles throughout.

Hawkesbury Sandstone (Triassic)

The Hawkesbury Sandstone formation is the predominant bedrock in the Sydney Basin. It occurs below the Ashfield Shale and Minchinbury Sandstone formations (Wianamatta group) across the Sydney area. It is associated with the Narrabeen Group; a prograding sequence of alluvial deposits that characterised the Late Permian to Middle Triassic. The Hawkesbury Sandstone is up to 250 m thick and is typically expressed as coarse quartz-rich sandstone with very minor shale and laminite lenses. Sediments that comprise the Hawkesbury Sandstone may be associated with erosion of Upper Devonian Quartzites belonging to the Lachlan Fold Belt (O’Neill & Danis, 2013).

4.4.3 Intrusions and structural elements

Triassic sediments in the Sydney Basin are highly fractured and faulted due to transpressional tectonic stresses resulting from the Hunter-Bowen Orogeny (HBO) in the Late Triassic. Subsequent transtension volcanic activity in the Jurassic period resulted in the intrusion of syenitic volcanics into the Hawkesbury Sandstone and other Permian and Triassic formations (including dykes, sills and laccoliths) throughout the Sydney region (O’Neill & Danis, 2013; Cook and Ross, 2009). Passive margin development, extension, and uplift following the Jurassic period resulted in opening of fractures because of both tectonic and erosional stress release.

Post Jurassic extension created a topographic depression resulting in the Sydney Basin. The basin persisted into the late Quaternary Period when sea level fluctuation conditions favoured the persistence of sedimentary deposition over erosion (Hatley, 2004).

Major faults and shear zones affecting the Triassic units are principally aligned along a NW-SE direction because of the prevailing tectonic stresses which formed them. They include high angle displacement faults, low angle thrusts and bedding shear zones.

The mapped surface outcrop of the geological units and associated intrusions and structural are shown on Figure 4-13, Figure 4-14 and Figure 4-15 and include:

- Luddenham Dyke: A basaltic dyke with a NW-SE orientation, intersecting Park Rd, Wallacia.
- Narellan Lineament: Aligning with the overall linearity of South Creek, suggesting that the creek may be structurally controlled. There are also a number of north-east trending tributaries into the Narellan Lineament, (e.g. Cosgrove Creek) with align with regional faulting trends.
- Rossmore Anticline: This feature forms a structural high point of the Wianamatta Group. Geological bedding dips in the vicinity of the Rossmore Anticline are likely and are expected to dip to the west on the western side of this structure.

4.4.4 Acid Sulfate Soils and Rock

Acid Sulfate Soils (ASS) refer to soils containing sulfides. When the sulfides contained in ASS are exposed to oxygen, such as from groundwater drawdown and/or excavation, sulfuric acid can be generated, which may result in a number of detrimental effects on groundwater dependant ecosystems, underground structures and receiving water bodies, including:

- Sulfuric acid causing leaching/mobilisation of metals from otherwise stable soil matrices, increasing the concentration of heavy metals in the groundwater to potentially toxic levels.
- Reduced durability of underground structures, such as steel and concrete, through corrosion.
- Degradation of soil quality in affected areas, preventing vegetation growth.

Acid sulfate rock (ASR) can also occur within some geological units such as marine sedimentary units, coal measures and igneous rock with sulfide and pyrite mineralisation. All ASR contains appreciable iron sulfide that when disturbed and specifically crushed, presents a risk of environmental and durability impacts for road structures when in contact with water and atmospheric oxygen. ASR presents a risk for fresh rock when excavated and not weathered rock that has been exposed to weathering process and leaching of pyrite over time.

A review of the Office of Environment and Heritage NSW Acid Sulfate Soils Risk Maps (OEH, 2015) check with contaminated land, indicates that the majority of the desktop assessment area is not located within an area of potential acid sulfate soils (potential ASS). The exception is some potential ASS risk areas are present around Georges River and Prospect Creek in the eastern portion of the desktop assessment area (refer to **Figure 4-16**), including:

- A high potential for occurrence of ASS along the brine pipeline for bottom sediments and surrounding embankments where Hume Hwy intersects Prospect Creek.
- A high potential for occurrence of ASS for bottom sediments in the George Rivers near Moorebank, and a low probability for occurrence of ASS along the sides of the Georges River.

- Areas surrounding the Georges River in Chipping Norton and Milperra, where a mixture of ASS probability zones are present, including disturbed terrain, high probability ASS, high probability bottom sediments, and low probability for ASS.

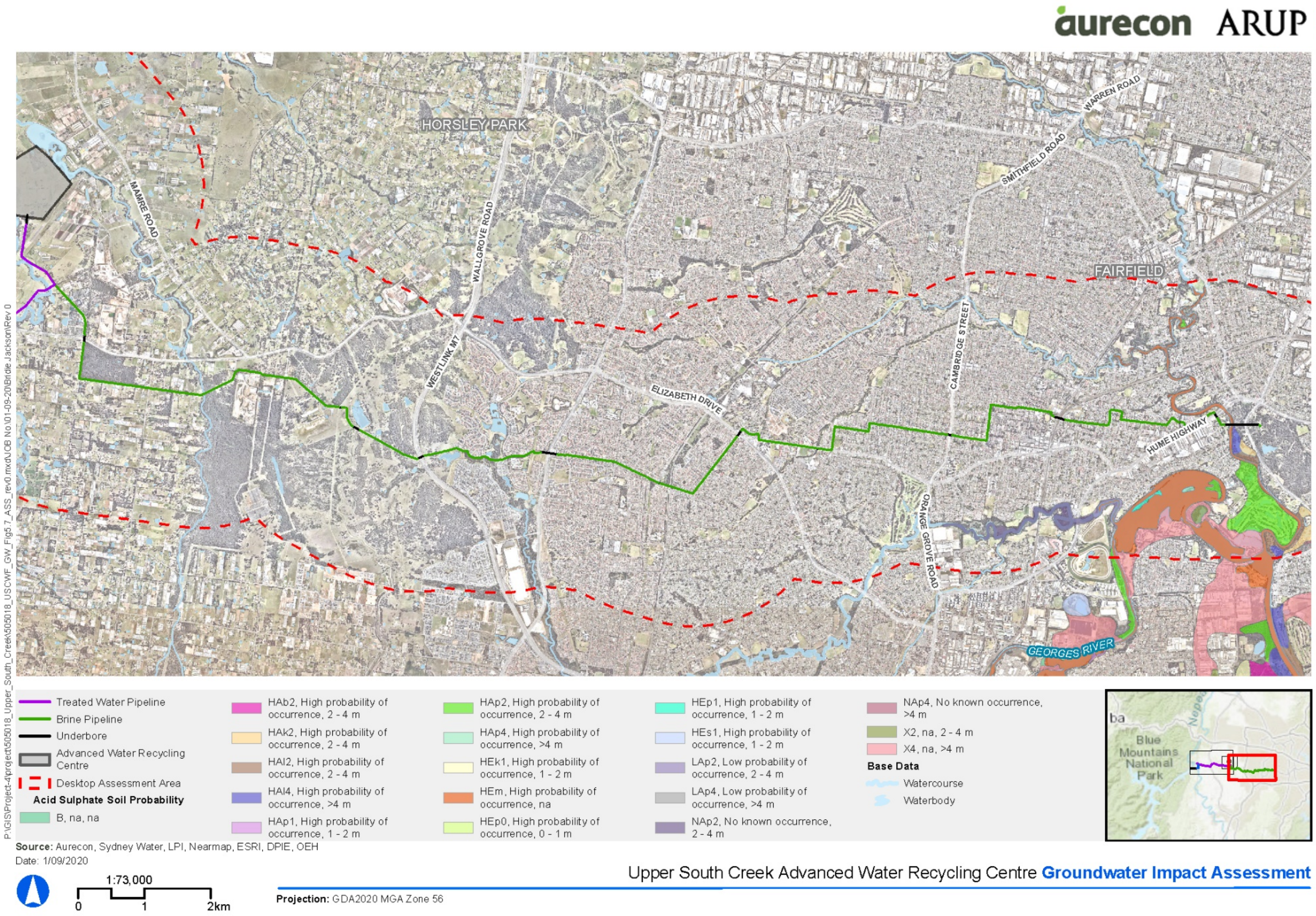


Figure 4-16 Distribution of Acid Sulfate Soils Risk – Brine Pipeline

4.5 Catchment hydrogeology

4.5.1 Hydrostratigraphy

Based on the regional geology and information gathered from available data sources, two main groundwater systems are identified across the desktop assessment area, including:

- Unconfined to semi-confined groundwater systems associated with Quaternary alluvial deposits, most prevalent in areas surrounding the rivers and streams that intersect the project.
- Unconfined to semi-confined groundwater systems within the bedrock formations (Wianamatta Group formations overlying Hawkesbury Sandstone).

4.5.2 Aquifers

Alluvial Groundwater Systems

Quaternary alluvium in the desktop assessment area is most prevalent in areas surrounding the rivers and streams that intersect the project, including Nepean River, Badgerys Creek, South Creek, Kemps Creek, Cabramatta Creek, Clear Paddock Creek, Georges River and Prospect Creek.

These areas are associated with infilled incisions in the underlying bedrock formed by river/stream erosion. Alluvial deposits comprise fine-grained sand, silt and clay and are expected to be relatively thin (i.e. between 2.5 to 7.0 m in vertical thickness) based on previous investigations in the region (M12 Motorway EIS, Appendix N).

Based on the geological mapping presented in **Section 4.4**, the width of the alluvium deposits around the rivers/streams are approximately 900 m for the Nepean River, 300 m for Cosgroves Creek, 600 m for Badgerys Creek, 850 m for South Creek, 450 m for Kemps Creek and 1,500 m for Cabramatta Creek. A larger area of alluvial deposition is present at the intersection between Kemps Creek, South Creek and Badgerys Creek, with a width of approximately 1,600 m. Larger vertical thicknesses of the alluvial deposits are expected to occur in these areas.

These deposits form predominately unconfined aquifers that are likely connected to the associated rivers/streams and responsive to rainfall. The presence of clays in the alluvial deposits may form localised aquitards leading to semi-confined groundwater conditions in some areas.

Bedrock Groundwater Systems

The bedrock groundwater systems expected to be intercepted by the project in the desktop assessment area are characterised as unconfined to semi-confined dual porosity (granular and fractured) bedrock systems. Several distinct hydrostratigraphic units are expected to be present, including Bringelly Shale, Minchinbury Sandstone and Ashfield Shale of the Wianamatta Group, overlying Hawkesbury Sandstone (in stratigraphic order).

The hydrostratigraphic units present within the bedrock groundwater systems are summarised as:

- Residual / regolith soils associated with weathered Bringelly Shale. Comprising floodplain alluvial soils, weathered shale and saprolite.
- Upper aquifer within the Wianamatta Group, weathered/fractured Bringelly Shale, with typical vertical thicknesses ranging between 3 to 10 m. Fractures formed by weathering of the Bringelly Shale are typically filled with clays and silty clays of medium to high plasticity and low permeability where this is encountered.

- Lower aquifer within the Wianamatta Group, occurring at the base of weathering, comprising fine-grained mudstone/shale. Some degree of widely spaced fracturing may be present allowing some groundwater flow, however in unfractured areas the shale will be effectively impermeable.
- Hawkesbury Sandstone aquifer, strongly influenced by secondary porosity, with groundwater flow occurring mostly through fractures along joints and/or shear zones. Rock defect characteristics within this hydrostratigraphic unit are influenced by depth and in-situ stress conditions, in addition to regional structural features.

4.5.3 Hydrogeological Properties

The hydrogeological properties presented in the subsequent sections have been used to characterise the groundwater systems and the mechanics of groundwater movement in the desktop assessment area. This forms a key component of the hydrogeological conceptual model (outlined in **Section 5**).

Porosity

- Porosity is defined as the total void space of geological materials. Consolidated bedrock materials often have distinct primary and secondary porosities (also known as ‘dual porosity). The primary porosity is the original porosity of the rock when it was formed, and secondary porosity is the void space caused by subsequent fracturing.

Porosity in geologic materials provide space for groundwater storage. However, in geologic materials there are regions where void spaces exist but do not have the ability to transmit groundwater. Not all pores are connected, therefore, when discussing groundwater flow an important property is “effective porosity” which is the total interconnected void space. Effective porosity is a measure of aquifers ability to store and release groundwater, therefore, dictates an aquifer’s response to stresses such as rainfall events and construction dewatering.

- Available data relating to storage properties in the desktop assessment area is scarce, therefore the following literature values have been derived to estimate the porosity of the identified geological materials (Morris and Johnson, 1967).

- Unconsolidated sedimentary materials associated with the Quaternary alluvial and residual/regolith soils:
  - Fine-grained sands = 26% to 53%
  - Silts = 34% to 61%
  - Clays = 34% to 57%
- Sedimentary rocks associated with the bedrock groundwater systems:
  - Shale = 1% to 10%
  - Claystone = 41% to 45%
  - Siltstone = 21% to 41%
  - Sandstone = 14% to 49%

Hydraulic Conductivity

In general, the hydraulic conductivity of shallow unconsolidated materials associated with alluvial deposits and residual soils is comparatively higher than the hydraulic conductivity of deeper consolidated rocks present in the Wianamatta Group and Hawkesbury Sandstone.

Hydraulic tests carried out in the quaternary alluvial materials during previous investigations in the region indicate that hydraulic conductivities range between 0.017 to 0.14 m/day (WSA EIS – Appendix L3; M12 EIS – Appendix N). Hydraulic tests carried out in the quaternary alluvial materials at the AWRC site indicate that hydraulic conductivities range between 0.01 to 1.29 m/day (Aurecon Arup, 2020). Lower hydraulic conductivities occur in areas with an increased presence of clay deposits and weathered shale, and higher hydraulic conductivities occur in areas with an increased presence of sands and gravels.

Hydraulic tests carried out in the residual soils and weathered Wianamatta Group shales at the AWRC indicate that hydraulic conductivities range between 0.05 to 0.48 m/day (Aurecon Arup, 2020). Hydraulic conductivities within the Upper Wianamatta Group are expected to be highly variable, ranging between 10^{-5} and 0.01 m/day (Bradd et al., 2012). The higher end is associated with open fractures occurring in the upper weathered zone.

The Lower Wianamatta Group is expected to have lower hydraulic conductivities due to less frequent occurrence of fractures, ranging between 0.001 and 10^{-8} m/day (Bradd et al., 2012). The lower end reflects the intrinsic impermeability of unfractured shale. Vertical hydraulic conductivities within the Wianamatta Group shales are expected to be two to three orders of magnitude lower than horizontal hydraulic conductivities, due to the horizontal bedding planes that are present throughout the geological units.

The hydraulic conductivity of the Hawkesbury Sandstone is related to the rock defect characteristics, which are influenced by the depth and in-situ stress conditions as well as the presence of regional structural features. Conductivities in the Hawkesbury Sandstone are expected to range between 0.01 to 0.5 m/day (Tammetta & Hewitt, 2004), reflecting the difference between deep and near surface conditions.

Storage Properties

Storage properties represent the ability of an aquifer to store and release groundwater. These properties dictate the aquifer's response to stresses such as rainfall events and construction dewatering.

Two main properties that dictate the amount of storage within an aquifer and the amount of groundwater able to be released from storage from an aquifer are:

- Specific Yield (S_y): Relates to unconfined aquifers. Defined as the volume of water released from storage per unit of water table drawdown. Generally equivalent to the effective porosity of an aquifer.
- Storativity (S): Relates to confined aquifers. Defines as the volume of water released from storage per unit decrease in hydraulic head.

Available data relating to storage properties in the desktop assessment area is scarce, therefore literature values have been derived to estimate the storage properties of the identified geological materials (Morris and Johnson, 1967; Hazel, 2009).

- Unconsolidated sedimentary materials associated with the unconfined Quaternary alluvial aquifer and residual/regolith soils:
  - Specific Yield (Sy) = 0.06 (clays) to 0.33 (fine-grained sand).
- Sedimentary rocks associated with the bedrock groundwater systems.
  - Storativity (S) = 0.00005 (shales) to 0.001 (sandstone).

4.5.4 Hydrostratigraphic Units

Based on the information presented in previous sections, five main hydrostratigraphic units are identified in the desktop assessment area. These units are general groupings of geological formations based on their hydrogeological properties, including the nature and connectivity or the void spacing (porosity and hydraulic conductivity) and transmission / storage properties. The hydrostratigraphic units (in stratigraphic order) are defined as:

1) Unconsolidated Quaternary alluvial aquifer.
2) Unconsolidated residual / regolith soils associated with weathered Triassic Bringelly Shale.
3) Upper Wianamatta Group (Triassic Bringelly Shale), weathered zone with fractures.
4) Lower Wianamatta Group (Triassic Bringelly Shale, Minchinbury Sandstone and Ashfield Shale), widely spaced fractures.
5) Triassic Hawkesbury Sandstone.

A summary of the hydrostratigraphic units and their estimated hydrogeological properties is provided in **Table 4-6** below.

Table 4-6 Overview of identified hydrostratigraphic units within the desktop assessment area.

Hydrostratigraphic Unit	Approximate thickness (m)	Porosity (%)	Hydraulic Conductivity (m/day)	Storage Properties (unitless)
Quaternary alluvial aquifer	2.5 – 9.0	26% – 57%	0.017 – 1.287	Specific Yield (S_y) = 0.06 (clays) to 0.33 (fine-grained sand)
Residual / regolith soils associated with weathered Bringelly Shale	1 - 5	26% - 45%	0.05 – 0.484	Specific Yield (S_y) = 0.06 (clays) to 0.33 (fine-grained sand)
Upper Wianamatta Group (Bringelly Shale), weathered zone with fractures	10	1% - 45%	0.01 – 1 x 10^{-5}	Storativity (S) = 0.00005 (shales) to 0.001 (sandstone)
Lower Wianamatta Group (Bringelly Shale, Minchinbury Sandstone and Ashfield Shale), widely spaced fractures.	120	1% – 10%	0.001 – 1 x 10^{-8}	Storativity (S) = 0.00005 (shales)
Hawkesbury Sandstone	250	14% - 49%	0.01 – 0.5	Storativity (S) = 0.00005 (shales) to 0.001 (sandstone)

4.5.5 Secondary Hydrogeological Structures

Aquifer characteristics of hydraulic conductivity and storativity reflect both primary and secondary features. Primary features reflect the composition of the skeletal material comprising the aquifer; while the secondary features reflect elements that develop after the initial formation of the strata (e.g. faults and dykes).

Faults and dykes can have variable flow properties and features may act as either flow barriers, conduits or just zones of high storage. Where significant clays are present in fault zones or dykes, they are more likely to act as barriers to flow.

Secondary features relevant to the aquifers in the impact assessment area comprise the following:

- Fracturing due to faulting or erosional unloading that creates defects in the aquifer material (such as jointing or parting of bedding).
  - Extensive faulting can often create an extensive network of broken material that exhibits elevated values of hydraulic conductivity.
  - Enhanced weathering can occur along these defects such that clays develop, which reduce the overall hydraulic conductivity of the material (Pells et al., 2019).
- Deformation associated with igneous intrusions, such as the Luddenham Dyke. These features can often impede the lateral flow of groundwater across the intrusion but may have enhanced hydraulic conductivity within the interior of the intrusion.

4.5.6 Hydrogeological Landscape Mapping

The Hydrogeological Landscape (HGL) units spatially define and characterise discrete areas of similar character, including salt accumulation, salt stores, saline manifestations and pathways for salt mobilisation. The terms 'hydrogeological' and 'landscapes' reflect the importance of lithology, bedrock structure, regolith (including soils), landforms, climate (including rainfall, seasonality, evaporation) and vegetation on recharge, groundwater flow or movement, storage and discharge of a particular hydrological system. The combination of these factors provides a structure for understanding how salinity manifests in the landscape, the differences in salinity development, and the impacts (land salinity/ salt load/ water electrical conductivity) in the landscape (DPIE, 2011a) (DPIE, 2011b).

A review of hydrogeological landscape (HGLs) mapping presented in Figure 4-17, Figure 4-18 and Figure 4-19, indicates the project intersects nine main HGLs. Table 4-7 summarises the nine HGLs and their definitive characteristics as described in the associated landscape information reports. The most prominent HGL within the desktop assessment area is the Upper South Creek (and Upper South Creek Variant A) HGL, which is intersected by the Treated Water pipeline east of Luddenham, the AWRC and brine pipeline in the vicinity of Kemps Creek and between Cecil Hills and Prospect Creek in Lansdowne.

Table 4-7 Summary descriptions of HGLs relevant to the desktop assessment area

Hydrogeological Landscape	Relevance to project feature(s)	Description
Hawkesbury	Intersected by E-Flows pipeline, in elevated areas between Warragamba River and Nepean River.	The Hawkesbury HGL is characterised by plateau, scarps, benches and hills on sandstones from the Triassic Hawkesbury Sandstone and Narrabeen Group as well as minor outbreaks of Tertiary Basalt and Jurassic Volcanics. Unconsolidated colluvial sediments and talus derived from Triassic sedimentary rocks have been deposited on the slopes and valley floors across this HGL. Groundwater flow to be intercepted by the project facilities for this HGL relates to the upper systems which are expected to be predominantly unconfined along structural features (bedding, joints, faults etc.) in the fractured bedrock and through connected pore spaces in the sandstones. Depth to water table is typically deep (>8 mBGL). Land salinity is low, groundwater is generally fresh (EC less than 0.8 dS/m or 800 µS/cm) which equates to the beneficial use category “A” (refer to **Table 2-3**).
Mid-Nepean River	Intersected by E-Flows and Treated Water pipelines in low-lying areas west of the Nepean River.	The Mid-Nepean River HGL is characterised by floodplains and gentle rises on the active floodplain of the Nepean River, comprising unconsolidated alluvial sediments of fine-grained sands, silts and clays of the Quaternary period derived from the surrounding Wianamatta Group rocks and Hawkesbury Sandstone. Groundwater flow is unconfined through unconsolidated alluvial sediments. Localised perching of water tables may occur above clay lenses during wetter periods. Depth to water table is typically shallow to intermediate (0-8 mBGL) with seasonal variation. Land salinity is low, groundwater is generally fresh (EC between 0.8-1.6 dS/m or 800-1600 µS/cm) which equates to the beneficial use category “A” (refer to **Table 2-3**).
Mulgoa	Intersected by Treated Water pipeline in Wallacia, east of the Nepean River and again in the vicinity of Elizabeth Dr in Luddenham.	The Mulgoa HGL is characterised by hillslopes and benches on Triassic shale and sandstones (Bringelly Shale and Ashfield Shale) overlain by unconsolidated colluvial and alluvial gravels, sands and silts deposited on lower slopes and along streams. Groundwater flow is unconfined to semi-confined through unconsolidated alluvial/colluvial sediments and along structural features (bedding, joints, faults etc) in the fractured bedrock. Localised perching of water tables occurs above clay lenses during wetter periods. In the fractured rock, groundwater predominantly moves laterally through the shale layers (although vertical movement through fracturing does occur) and vertically through interbedded sandstone and sandstone fracturing. Depth to water table is intermediate (2-8 mBGL) with seasonal variation. Land salinity is moderate, groundwater is generally brackish (EC between 1.6-4.8 dS/m or 1,600-4,800 µS/cm) which equates to the beneficial use category “B” (refer to **Table 2-3**).

Hydrogeological Landscape	Relevance to project feature(s)	Description
Greendale	Intersected by Treated Water pipeline between Park Rd in Wallacia and Elizabeth Dr in Luddenham.	The Greendale HGL is characterised by low rises, gently sloping plains and ponded drainage lines on Triassic Wianamatta Group rocks (predominately Bringelly Shale) overlain by unconsolidated sediments of sands, silts and clays of the Quaternary period. Groundwater flow is unconfined to semi-confined through unconsolidated alluvial/colluvial sediments and along structural features (bedding, joints, faults etc) in the fractured bedrock. Localised perching of water tables occurs above clay lenses during wetter periods. In the fractured rock, groundwater predominantly moves laterally through the shale layers (although vertical movement through fracturing does occur) and vertically through interbedded sandstone and sandstone fracturing. Depth to water table is intermediate (2-8 mBGL) with seasonal variation. Land salinity is moderate, groundwater is generally brackish (EC between 1.6-4.8 dS/m or 1,600-4,800 µS/cm) which equates to the beneficial use category "B" (refer to **Table 2-3**).
Upper South Creek	Intersected by Treated Water pipeline east of Luddenham, the AWRC site and brine pipeline in the vicinity of Kemps Creek	The Upper South Creek HGL is characterised by low, undulating hills with colluvial/ alluvial foot slopes and plains (often ponding) and drainage lines on Triassic Wianamatta Group rocks (predominately Bringelly Shale). Groundwater flow is unconfined along structural features (bedding, joints, faults etc) in the fractured bedrock, predominantly moving laterally through the shale layers (although vertical movement through fracturing does occur) and vertically through interbedded sandstone and sandstone fracturing. Lateral flow occurs through alluvial sediments on slopes and plains. Localised perching of water tables may occur above clay lenses during wetter periods. Depth to water table is intermediate (2-6 mBGL). Land salinity is high, groundwater is generally saline (EC greater than 4.8 dS/m or 4,800 µS/cm) which equates to the beneficial use category "C" (refer to **Table 2-3**).
Mount Vernon	Intersected by the Brine pipeline in Cecil Park	The Mount Vernon HGL is characterised by steep low hills on Triassic Wianamatta Group rocks (predominately Bringelly Shale). Alluvial sands and gravel are present along current streams. Groundwater flow is unconfined along structural features (bedding, joints, faults etc) in the fractured bedrock, predominantly moving laterally through the shale layers (although vertical movement through fracturing does occur) and vertically through interbedded sandstone and sandstone fracturing. Lateral flow occurs through alluvial sediments on slopes and plains. Localised perching of water tables may occur above clay lenses during wetter periods. Depth to water table is intermediate (2-6 mBGL). Land salinity is moderate, groundwater is generally brackish (EC between 0.8-1.6 dS/m or 800-1600 µS/cm) which equates to the beneficial use category "A" (refer to **Table 2-3**).

Hydrogeological Landscape	Relevance to project feature(s)	Description
Denham Court	Intersected by the Brine pipeline in Cecil Hills	The Denham Court HGL is characterised by steep low hills on Triassic Wianamatta Group rocks (predominately Bringelly Shale). Quaternary alluvial soils (fine-grained sands, gravels, silts and clays) are present along drainage lines. Groundwater flow is unconfined along structural features (bedding, joints, faults etc) in the fractured bedrock, predominantly moving laterally through the shale layers (although vertical movement through fracturing does occur) and vertically through interbedded sandstone and sandstone fracturing. Lateral flow occurs through alluvial sediments on slopes and plains. Depth to water table is intermediate (2-6 mBGL). Land salinity is moderate, groundwater is generally fresh (EC less than 0.8 dS/m or 800 µS/cm) which equates to the beneficial use category “A” (refer to **Table 2-3**).
Upper South Creek variant A	Intersected by the Brine pipeline between Cecil Hills and Prospect Creek in Lansdowne	The Upper South Creek Variant A HGL is characterised by low, undulating hills with colluvial/ alluvial foot slopes and plains (often ponding) and drainage lines on Triassic Wianamatta Group rocks (predominately Bringelly Shale). Groundwater flow is unconfined along structural features (bedding, joints, faults etc) in the fractured bedrock, predominantly moving laterally through the shale layers (although vertical movement through fracturing does occur) and vertically through interbedded sandstone and sandstone fracturing. Lateral flow occurs through alluvial sediments on slopes and plains. Depth to water table is intermediate (2-6 mBGL). Land salinity is high, groundwater is generally brackish to saline (EC between 1.6-4.8 dS/m or 1,600-4,800 µS/cm) which equates to the beneficial use category “B” (refer to **Table 2-3**).
Moorebank	Intersected by the Brine pipeline east of Prospect Creek	The Moorebank HGL is characterised by alluvial deposits associated with the Georges River, including broad, flat alluvial plains intersected by present day drainage channels (e.g. Prospect Creek). Unconsolidated materials comprise Neogene alluvial sediments (sands and clays) overlying small areas of Triassic Hawkesbury Sandstone and Wianamatta Group shales (predominately Ashfield Shale). Groundwater flow is unconfined through unconsolidated alluvial sediments. Localised perching of water tables may occur above clay lenses during wetter periods. Unconfined to semi-confined flow also occurs along structural features (bedding, joints, faults etc) in the fractured bedrock. Depth to water table is shallow to intermediate (0-8 mBGL) with seasonal variation. Land salinity is moderate, groundwater is generally fresh (EC between 0.8-1.6 dS/m or 800-1,600 µS/cm) which equates to the beneficial use category “A” (refer to **Table 2-3**).

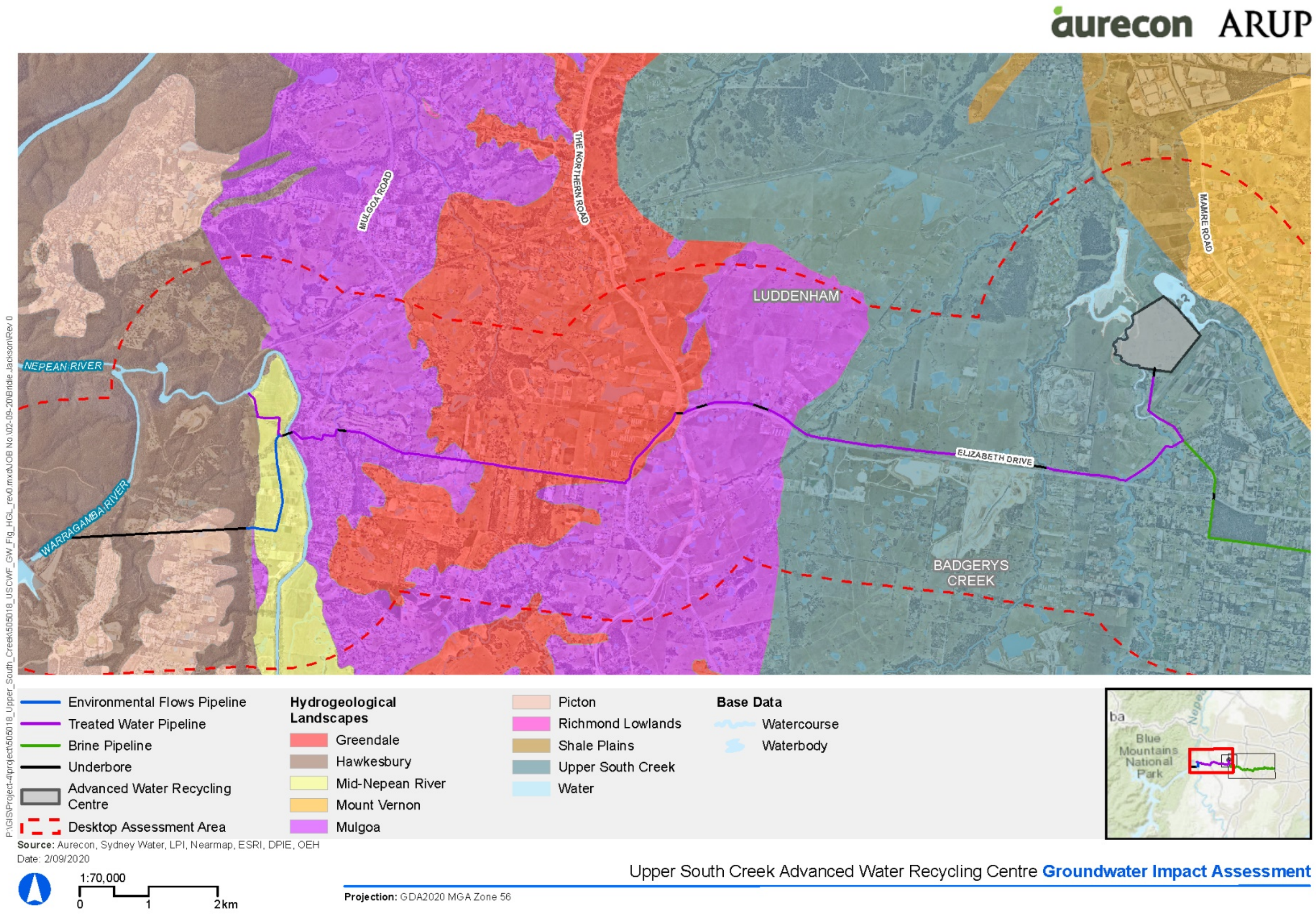


Figure 4-17 Hydrogeological Landscapes – Treated Water / Environmental Flow Pipelines

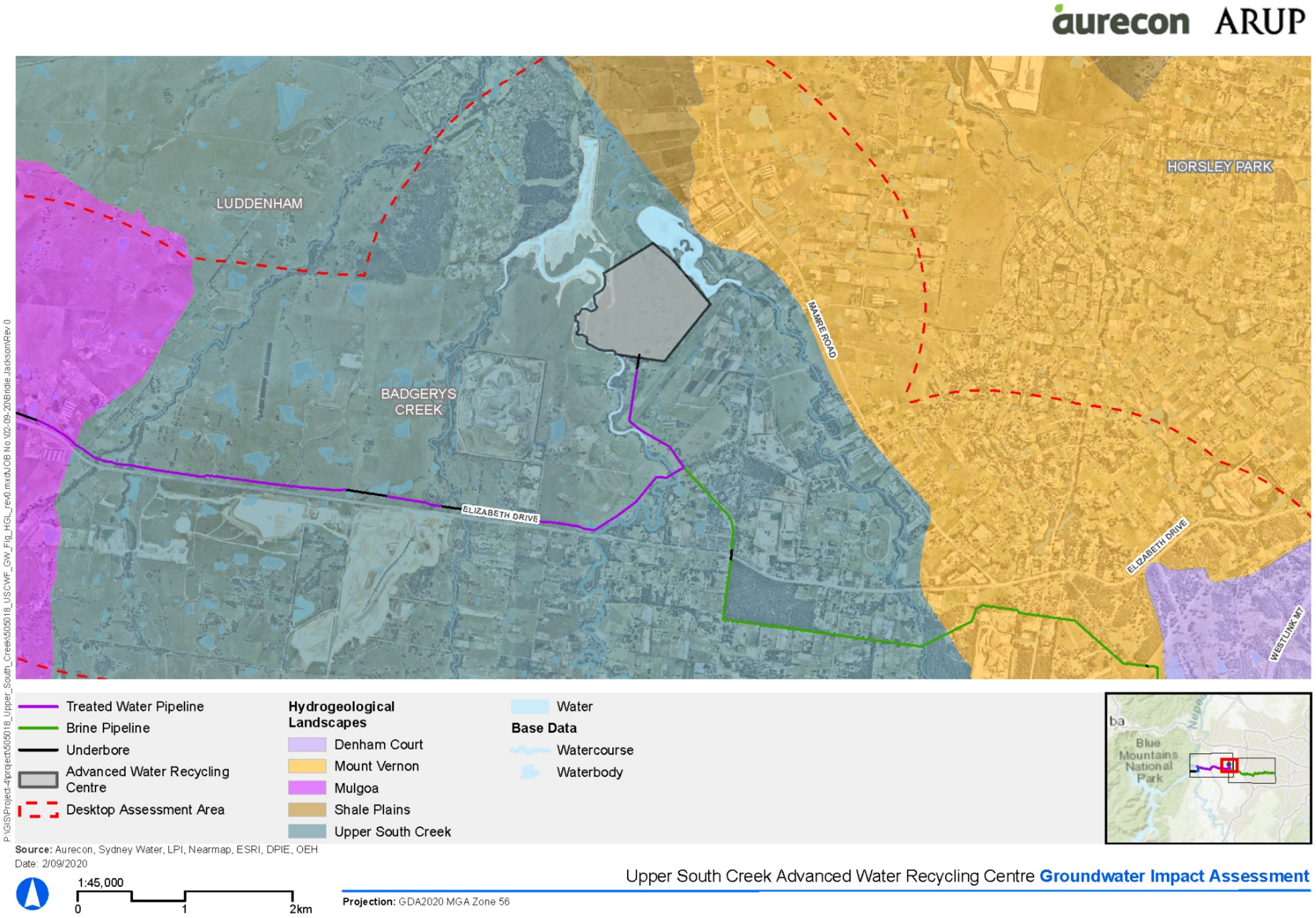


Figure 4-18 Hydrogeological Landscapes – The AWRC

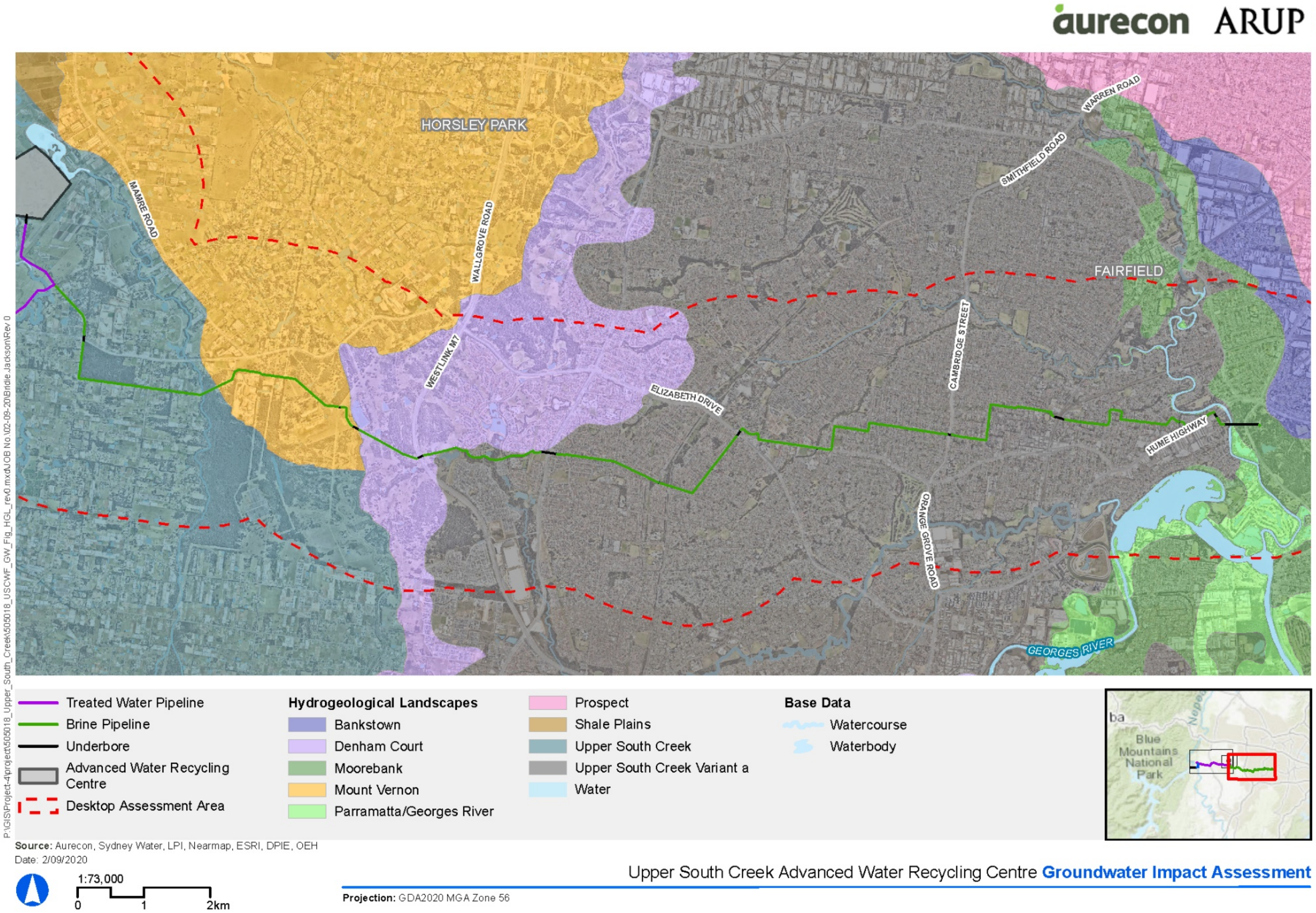


Figure 4-19 Hydrogeological Landscapes – Brine Pipeline

4.6 Groundwater chemistry

Groundwater chemistry can be defined both in terms of major ions and by minor and trace elements. Minor and trace elements, along with man-made chemicals can be present at elevated concentrations in areas that have been modified by human activity, and where elevated can form toxicants / stressors to aquatic ecosystems.

The major and trace element chemistry of groundwater is controlled by a number of environmental factors that include climate, geology, biochemistry, hydrological conditions, composition of precipitation, and anthropogenic influences. Other principles and processes controlling hydrochemistry of natural waters include thermodynamics, equilibrium, chemical kinetics, solubility, and interface reactions.

As groundwater moves through a system it typically undergoes a geochemical evolution that is defined by increasing salinity as the concentrations of major ions increase through dissolution of rocks. Major ion concentrations typically to shift from bicarbonate (HCO_3) type, to sulfate (SO_4^{2-}) type / mixed type, to chloride (Cl-) type with increasing age (Chebotarev, 1955). These changes occur as the water moves from shallow zones of active flushing through intermediate zones and deeper zones where the flow rates are slower and water is of greater age and reflect changes expected in large sedimentary basins. It should be noted however that this typical geochemical evolution can be influenced by local driving factors including geochemical composition of rocks, and proximity to the coastline.

The ionic composition of groundwater is used to classify it into ionic types based on the dominant dissolved cation and anion. Previous groundwater investigations in the region indicate the dominant groundwater type is sodium chloride, as indicated in **Figure 4-20** (RMS, 2019). These investigations reported Total Dissolved Solids (TDS) results in groundwater between 2,650 to 19,500 mg/L. These results correspond with the brackish to saline groundwater expected across the majority of the desktop assessment area.

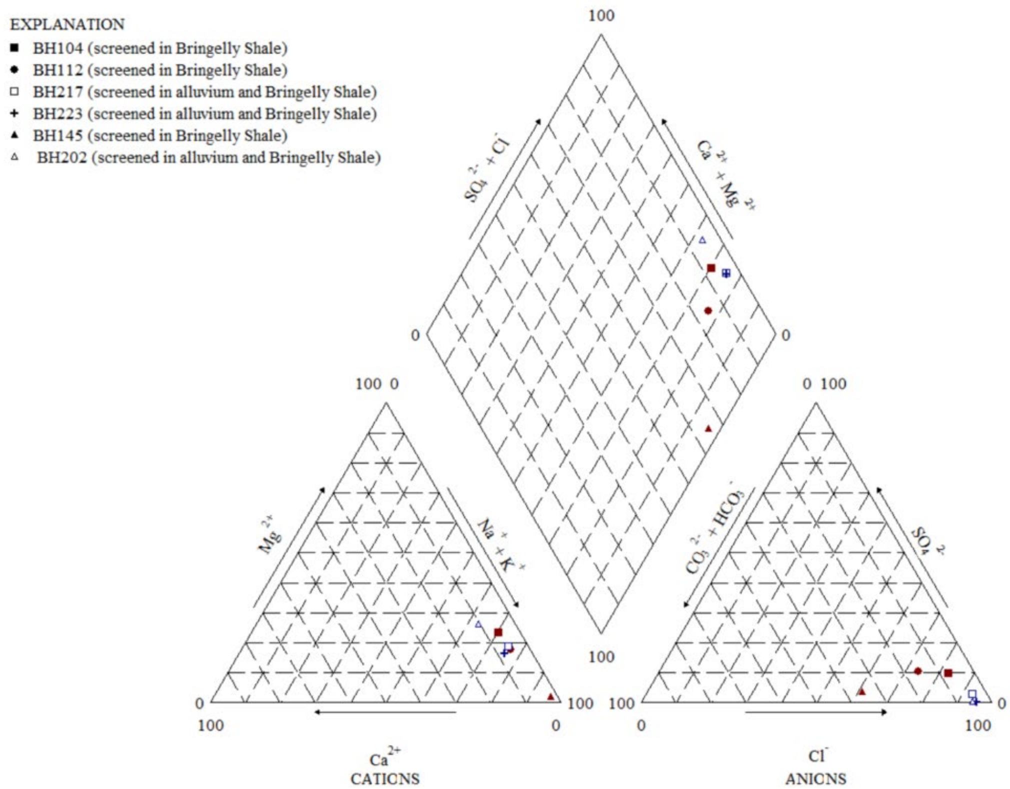


Figure 4-20 Piper Plot for M12 Motorway Groundwater Monitoring Bores (RMS, 2019)

Electrical conductivity ranges for Mulgoa, Greendale, Upper South Creek and Upper South Creek Variant A HGLs (described in Section 4.5.6), have maximum values that exceed the project waterway objectives criteria of 125 – 2200 µS/m.

The groundwater across the majority of the desktop assessment area is of relatively poor quality and has low potential for beneficial use for agricultural and potable purposes. Salinity, metals and nutrients in the groundwater may require management during construction and operation, particularly in relation to the potential impacts to surface water bodies and GDEs present in the impact assessment area.

4.6.1 Groundwater Contamination

The potential presence of contamination is described in detail in the *Soils and Contamination Impact Assessment* report (Aurecon Arup, 2021). A brief summary of features pertinent to the groundwater impact assessment is provided below for context to the discussions in this report.

Groundwater toxicants may be present in the desktop assessment area, associated with anthropogenic influences such as widespread agricultural land use, areas of disturbed terrain, landfilling etc. Exceedances of the adopted project waterway objectives have been reported for heavy metals (copper, arsenic, nickel and zinc), speciated nitrogen (nitrogen and ammonia), sodium and TDS have been identified in previous investigations in the region (RMS, 2019).

Contaminated sites notified to the NSW EPA

Under Section 60 of the *Contaminated Land Management Act 1997* (CLM Act), a person whose activities have contaminated land, or a landowner whose land has been contaminated, is required to notify the EPA if certain conditions are met. For example, if contaminant levels are above current or approved land use criteria and people have been (or will foreseeably be) exposed to the contamination, the EPA is to be notified.

A review of contaminated sites within the desktop assessment area has been undertaken to assess the potential presence of groundwater contamination at the locations. The risk of project activities inducing contaminant mobilisation / migration and the associated impacts have been assessed in **Section 7.3.2**.

If this occurs, it is likely that extracted groundwater would contain contaminants and would therefore require management / treatment prior to discharge / disposal.

The EPA maintains a register of sites of which it has been notified under Section 60 of the CLM Act. The register identifies sites of which the EPA is aware in its regulatory role and is not a list of all contaminated sites in NSW.

A search of the NSW EPA public register (notified sites and the contaminated land record) of contaminated sites was undertaken on the 25 March 2020. The results identified a number of records for addresses within 500 m of the pipeline alignments and within 2 km of the AWRC site have been summarised in **Table 4-8**.

Table 4-8 EPA notified contaminated sites within the desktop assessment area.

Contaminated Land Record	Site Location	Site Description	Approximate distance from project feature
Caltex Service Station	3019-3035 The Northern Rd, Luddenham	Service Station	115 m from treated water pipeline

Contaminated Land Record	Site Location	Site Description	Approximate distance from project feature
BP-Branded Service Station Bonnyrigg	451 North Liverpool Rd, Bonnyrigg	Service Station	10 m from brine pipeline
Metro (Formerly United & AP SAVER) Service Station Bonnyrigg	709 Cabramatta Rd W, Bonnyrigg	Service Station	10 m from brine pipeline
Caltex Service Station Cabramatta	168 John St, Cabramatta	Service Station	10 m from brine pipeline
Mobil Service Station	44 Hume Hwy, Lansvale	Service Station	7 m from brine pipeline
Coles Express Lansvale	99 Hume Hwy, Lansvale, Canley Vale	Service Station	40 m from brine pipeline
Caltex (former Mobil) Lansvale Service Station	141 Hume Hwy, Lansvale	Service Station	200 m from brine pipeline
BP Lansvale	115-119 Hume Hwy, Cabramatta West	Service Station	50 m from brine pipeline
Former Mobil Service Station	96 Canley Vale Rd, Canley Vale	Service Station	190 m from brine pipeline
Former Caltex Canley Heights	368 Canley Vale Rd, Canley Heights	Service Station	160 m from brine pipeline
Caltex Service Station	1163 Mamre Road, Kemps Creek	Service Station	1.1 km east of the AWRC site
United Petroleum petrol station	1465-1467 Elizabeth Drive, Kemps Creek	Service Station	1.2 km south-east of the AWRC site
BP Petrol Station	Lot 5 / 1443 Elizabeth Drive, Kemps Creek	Service Station	1.3 km southeast of the AWRC site

Most of the notified sites are listed as not requiring regulation under the CLM Act. However, the Caltex on 141 Hume Hwy was formerly regulated for contamination under the CLM Act.

The risks of the EPA notified sites impacting the alignment areas are generally considered to be low due to management class and/or distance from the pipeline options. Metro Service Station Bonnyrigg is considered to be moderate risk due to known contamination and distance from pipeline options.

In addition, an active landfill (SUEZ Kemps Creek Resource Recovery Park) is located approximately 800 m south-west of the AWRC site. Groundwater monitoring data from this site has not been made publicly available through the Environment Protection License, however, the site is not notified to the EPA as a contaminated site. Contaminants of concern associated with landfill sites include ground gases (methane, carbon dioxide, hydrogen sulfide etc) and leachate (acidic water, nitrogen, phosphorous and heavy metals).

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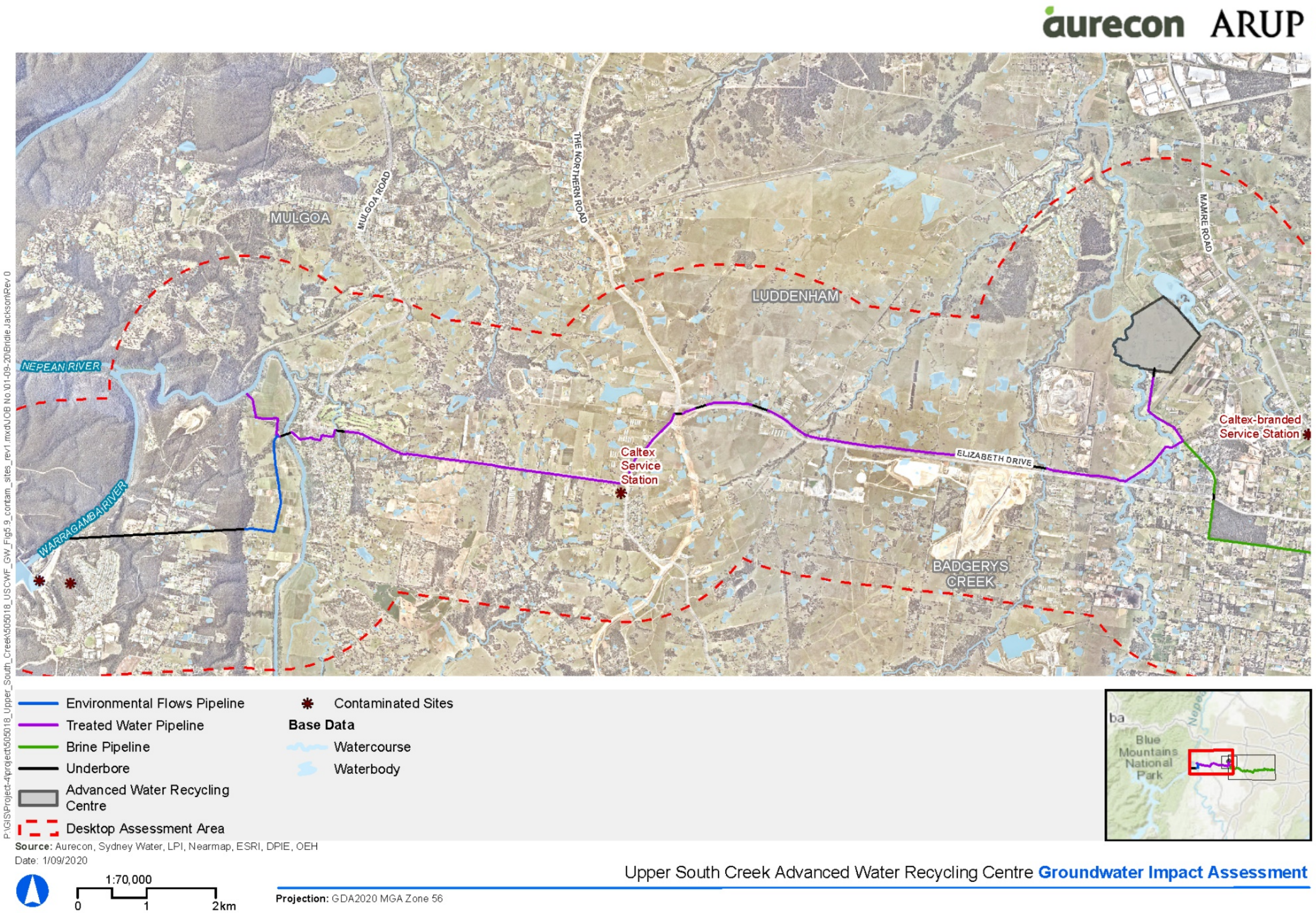


Figure 4-21 Contaminated sites notified to the EPA – Treated Water / Environmental Flow Pipelines

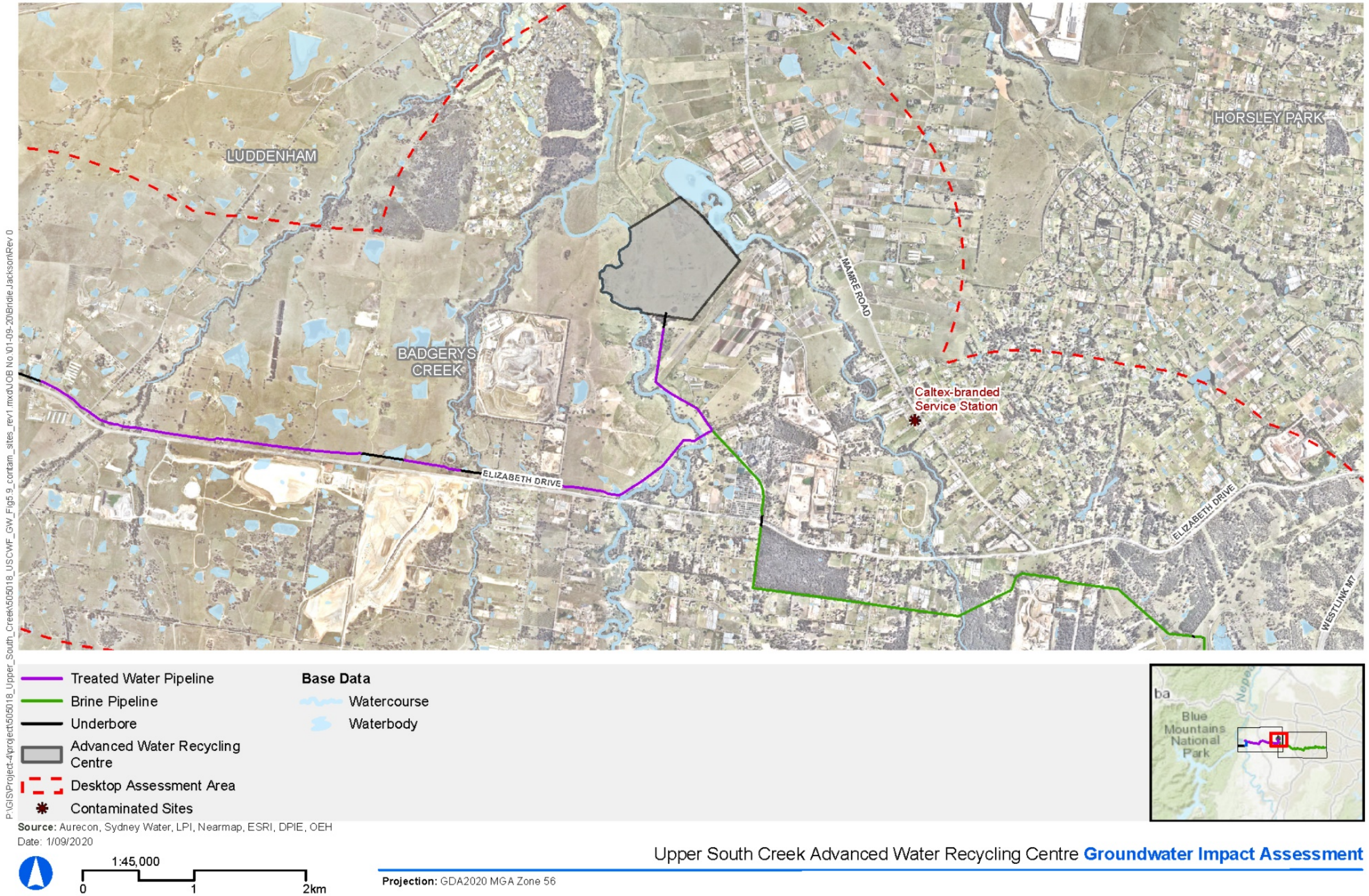


Figure 4-22 Contaminated sites notified to the EPA – AWRC site

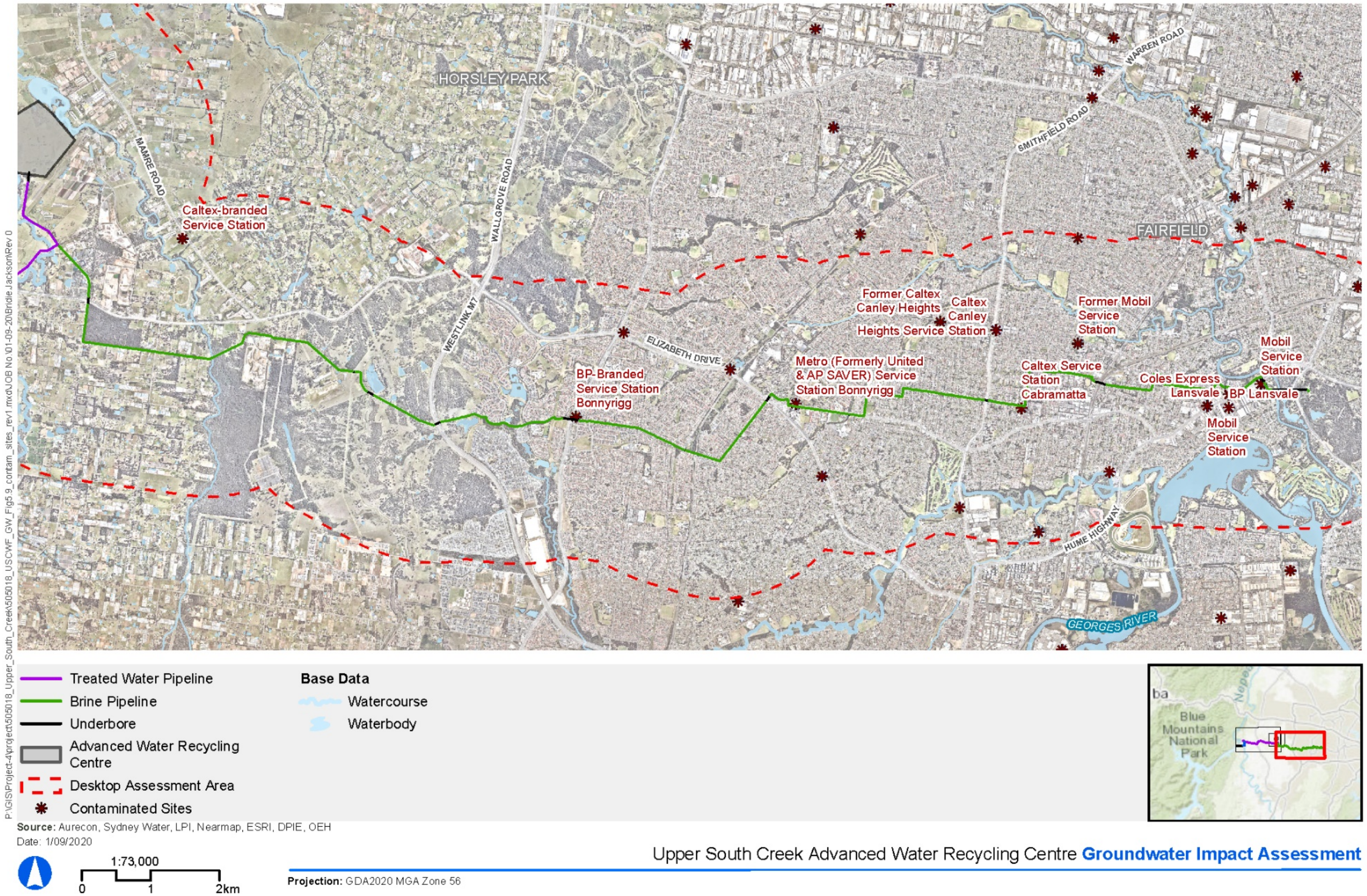


Figure 4-23 Contaminated sites notified to the EPA – Brine Pipeline

4.6.2 Groundwater salinity

Salinity occurrence in the region is associated with historical evaporation of inland seas, prevailing winds carrying ocean salt and the weathering of rocks. Salt infiltrates into the saturated zone where it gets left behind by natural evaporation processes and therefore concentrates. Salinity is therefore associated with drainage systems or low lying/flat grounds with shallow water tables where there is high potential for the ground to become waterlogged.

Groundwater quality is expected to vary across the desktop assessment area. Groundwater is expected to be brackish to saline across a significant portion of desktop assessment area (e.g. Upper South Creek Hydrogeological Landscape), with some small areas of fresh water (e.g. in the Hawkesbury and Mid-Nepean Hydrogeological Landscapes). An overview of the varying groundwater quality reported in each Hydrogeological Landscape intersected by the project can be found in **Section 4.5.6**

Historic investigations on groundwater in the Wianamatta Group (Bringelly Shale, Minchinbury Sandstone and Ashfield Shale) have reported total dissolved solids (an indicator of salinity) between 5,000 and 26,000 mg/l (PPK, 1999; McNally, 2004). The high salinities reported in the Wianamatta Group are suggested to be a result of the marine depositional environment in which they were formed, in addition to windblown aerosols accumulating in the subsoils (McNally, 2004).

Groundwater salinity in the Hawkesbury Sandstone is variable, ranging from fresh to brackish in the upper aquifers and freshening with depth. The increased salinity in the upper Hawkesbury Sandstone is attributed to leakage of saline groundwater from the overlying Ashfield Shale (Hawkes et al., 2009; McLean & Ross, 2009). Salinity in Hawkesbury Sandstone is generally fresh where it is not overlain by the Ashfield Shale. 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 (Webb et al., 2009). The high salinity of groundwater within the Bringelly and Ashfield Shales can be attributed to connate water within the formations reflecting their marine origin.

It is expected that groundwater quality in the local flow systems is comparatively fresher than that of the Bringelly and Ashfield Shales and underlying intermediate and regional flow systems (outlined in **Section 4.7**). Within the alluvial groundwater systems, it is possible that localised lenses of fresh groundwater overly saline groundwater. Salt is more likely to accumulate in areas with slow groundwater flow and low hydraulic gradients.

Electrical conductivity ranges for Mulgoa, Greendale, Upper South Creek and Upper South Creek Variant A have maximum values that exceed the project waterway objectives criteria of 125-2200 µS/m.

There is potential for saline conditions to be present in shallow soils across the desktop assessment area. Surface water quality data from June 2018 in Kemps Creek and South Creek alongside the AWRC site reported electrical conductivities of 1,889 and 2,640 µs/cm respectively, indicating brackish conditions in surface water (Aurecon Arup, 2021).

A review of the Map of Salinity Potential in Western Sydney (Department of Infrastructure, Planning and Natural Resources, 2002) is presented in **Figure 4-24**, **Figure 4-25** and **Figure 4-26**, indicating a variable salinity risk across the project. Areas to the west around Warragamba and Wallacia have a very low to moderate salinity risk, while all other areas are within moderate to high salinity risk areas, with some areas of known salinity. Areas with high salinity potential include the low-lying areas around Cosgrove Creek and along Kemps Creek.

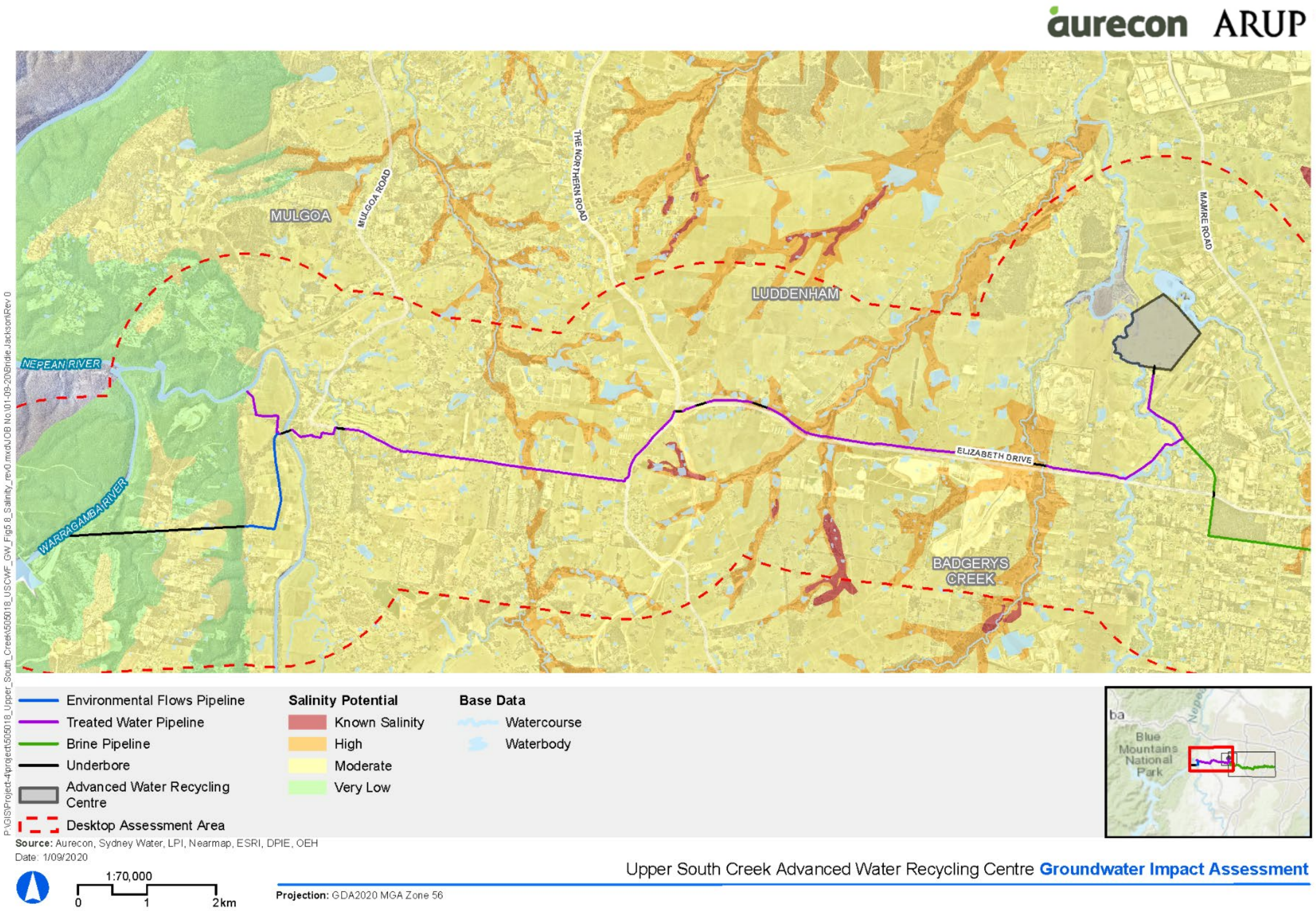


Figure 4-24 Distribution of Salinity Risk– Treated Water / Environmental Flow Pipelines

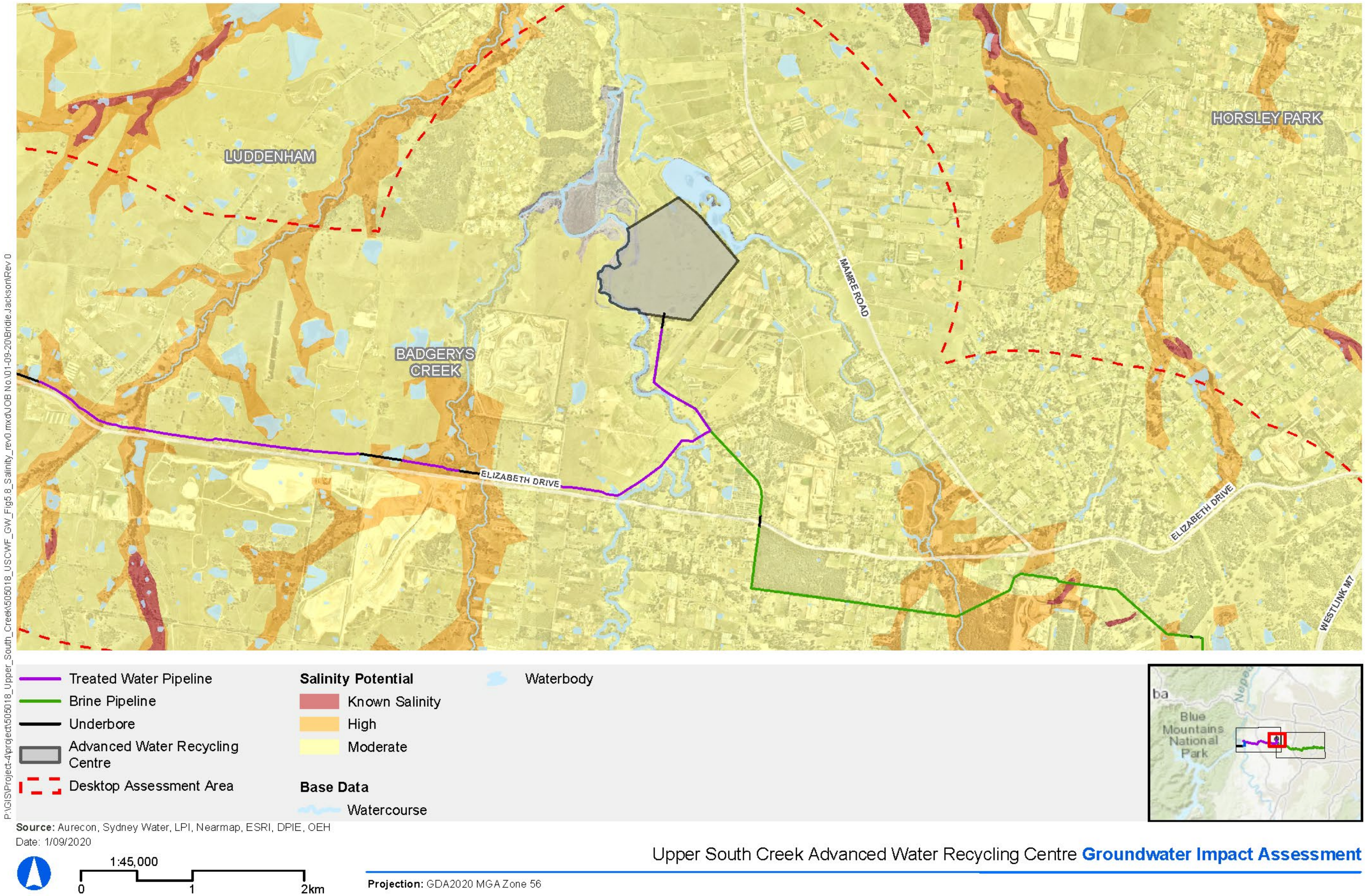
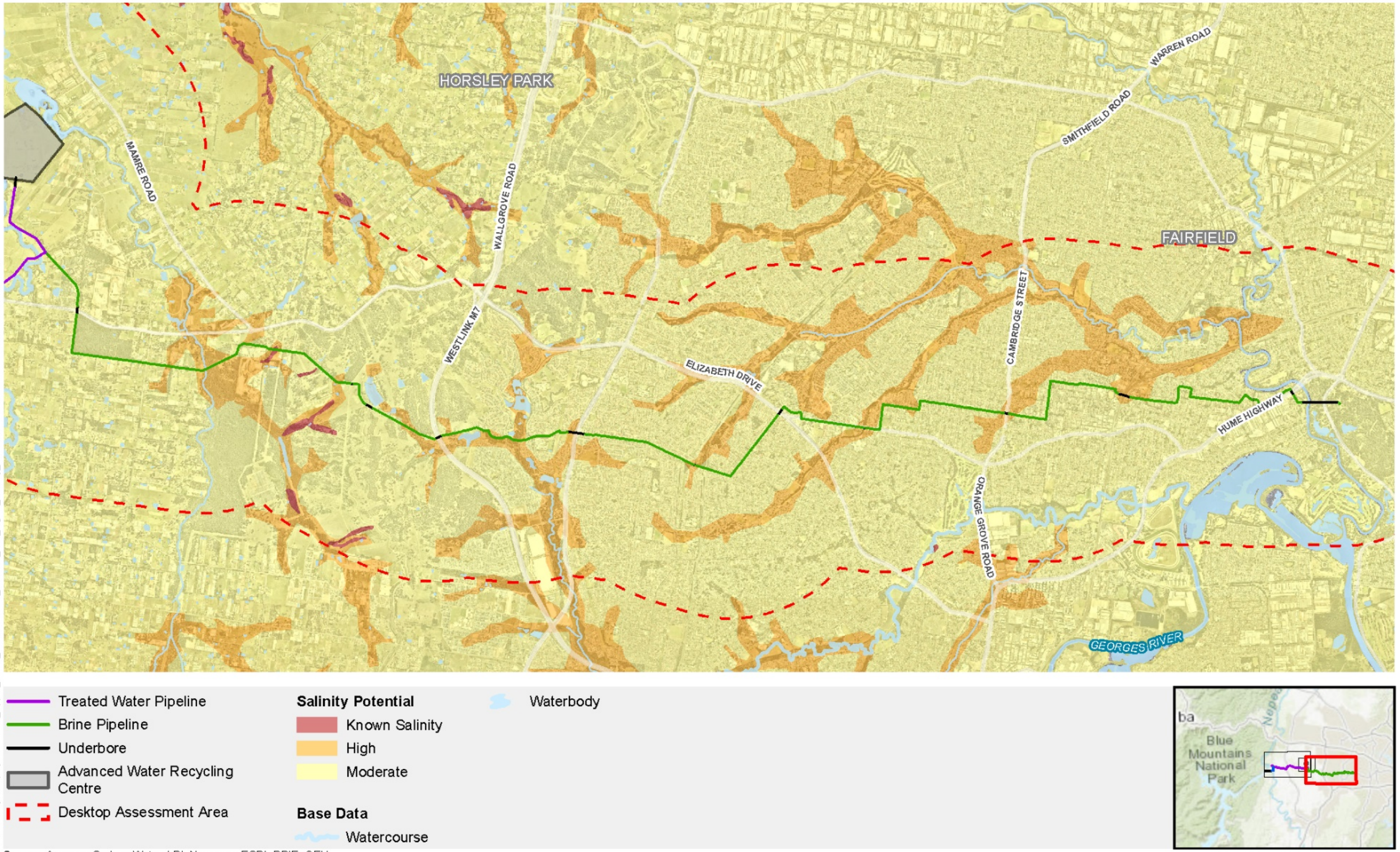


Figure 4-25 Distribution of Salinity Risk – The AWRC



Source: Aurecon, Sydney Water, LPI, Nearmap, ESRI, DPIE, OEH
Date: 1/09/2020

1:73,000
0 1 2km

Projection: GDA2020 MGA Zone 56

Upper South Creek Advanced Water Recycling Centre **Groundwater Impact Assessment**

Figure 4-26 Distribution of Salinity Risk – Brine Pipeline

4.7 Groundwater Levels and Flow

Topography is most important driving force for groundwater flow in groundwater systems. Flow occurs because hydraulic head decreases from a high-elevation recharge area (high hydraulic head) to a low elevation discharge area (low hydraulic head). The topographic setting across the project is outlined in **Section 4.2**.

In sedimentary basins different orders of flow systems can exist, including local, intermediate, regional flow systems. The type of groundwater flow system depends on topographic variations, aquifer permeability, heterogeneity and anisotropy and recharge.

In the desktop assessment area, local scale flows are expected in the alluvial groundwater systems. The shallower alluvial groundwater systems are generally present in areas adjacent to mapped waterways, including Nepean River, Badgerys Creek, South Creek, Kemps Creek, Cabramatta Creek, Clear Paddock Creek, Georges River and Prospect Creek, which intersect the project (see **Section 4.4**).

The direction of local groundwater flow is likely to be controlled by the proximity to local surface water bodies and areas of higher permeability soils. Shallow groundwater through unconsolidated and surface material flows (i.e. alluvial groundwater systems) tend to be much faster relative to consolidated rocks in the Wianamatta Group (Stammers, 2012; Bradd et al., 2012).

Intermediate and regional flow directions are expected in the underlying bedrock aquifers (Wianamatta Group formations and Hawkesbury Sandstone). Intermediate and regional groundwater flow direction is expected to be generally consistent with the topography.

Waters recharging a flow system may be discharged at local topographic depressions for local flow systems or at regional / intermediate discharge areas at the base of catchments / sub-catchments respectively. Where local relief is minimal, regional systems may prevail. Conversely where topography is pronounced, local systems may dominate groundwater flow.

Groundwater elevation data taken across the central portion of the desktop assessment area in August 2018 as part of the M12 EIS are illustrated in **Figure 4-27**, indicating the following intermediate/regional groundwater flow directions:

- From west to east, groundwater elevations range from 90 mAHD in Luddenham to 35 mAHD in the vicinity of the AWRC site, indicating intermediate/regional groundwater flow is in an easterly direction between these areas.
- Continuing from west to east, groundwater elevations range from 35 mAHD in the vicinity of the AWRC to 112 mAHD in Cecil Park, indicating intermediate/regional groundwater flow is in a westerly direction between these areas.
- Therefore, groundwater levels and flow appear to converge towards the low-lying areas in the vicinity of Badgerys Creek, South Creek, Kemps Creek and the AWRC site, which is consistent with local topographical observations (outlined in **Section 4.2**). Hydraulic gradients in this central area are relatively low, in comparison to surrounding gradients from the east and west.

Beyond the extents of the M12 EIS groundwater elevation data, the following intermediate/regional groundwater flow directions are expected, in sympathy with local topographic observations:

- Generally, east to west between Luddenham and the Nepean River;
- Generally, west to east between Cecil Park and Cabramatta, tending south-east towards Georges River.

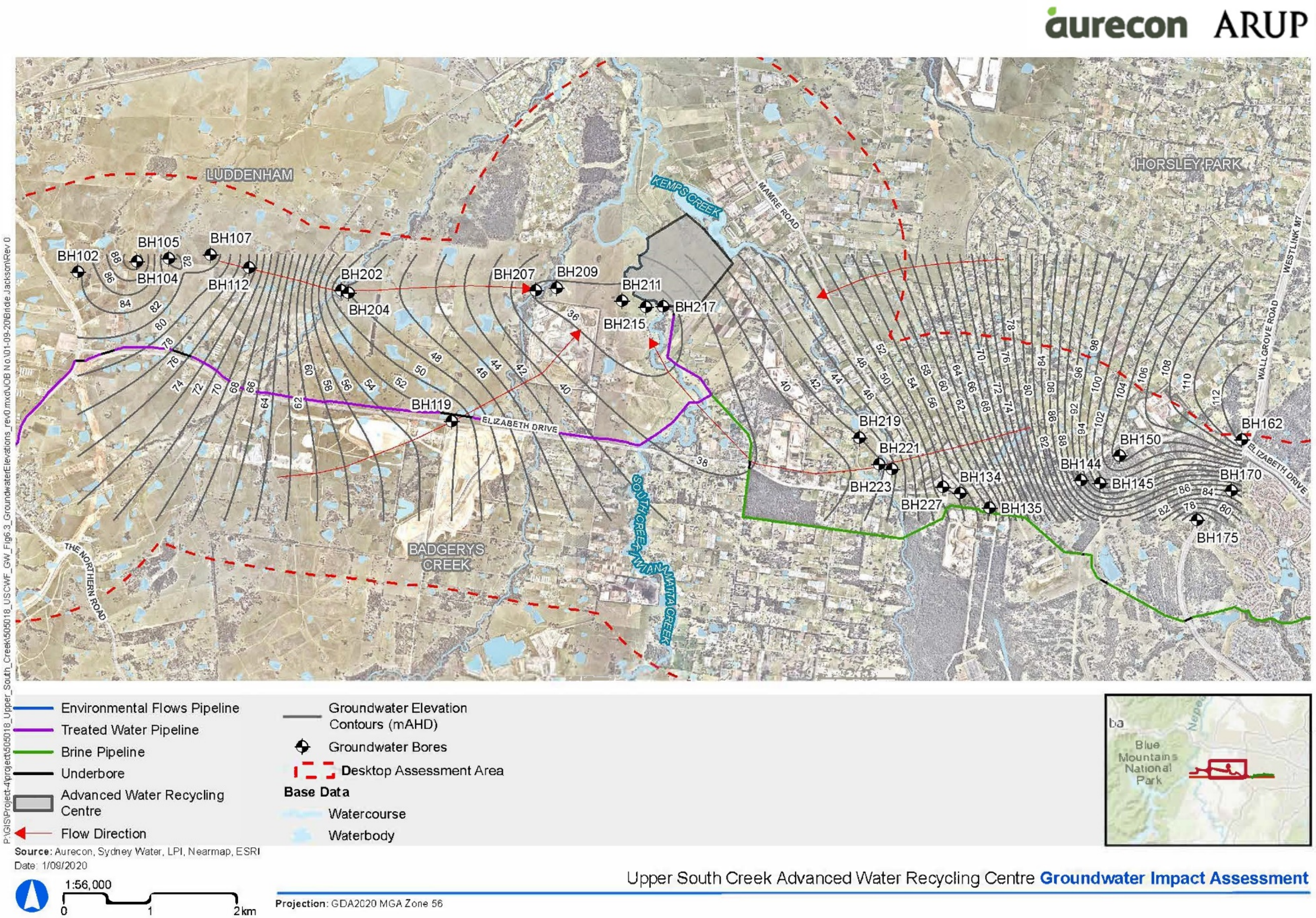


Figure 4-27 M12 EIS August 2018: Groundwater Elevations – Intermediate/Regional Groundwater Flow

As outlined in **Section 4.2**, part of the environmental flows pipeline involves a proposed horizontal directional drilling (HDD) section through a steep ridge between the Nepean River valley and the Warragamba River. Attempts were made to measure groundwater levels in registered water supply bores along this ridge in close proximity to the proposed HDD alignment. Direct measurements were unable to be collected (discussed in **Section 3.1)** however anecdotal information about the registered bores from interviews with landowners was gathered and is summarised below.

Table 4-9 Registered groundwater bore information in the vicinity of the environmental flows pipeline

Well ID	Easting	Northing	Distance from proposed alignment	Bore Type	Surface Elevation (mAHD)	Approximate groundwater elevation (mAHD)	Total Bore Depth (mbgl)	Approximate yield (L/s)
GW072366	280175	6248743	35 m north	Water supply	151.1	-23 *	178.4	<1 *
GW101239	279882	6247603	1 km south	Water supply	164.5	34.5 *	180	>4 *

* Denotes anecdotal information gathered from landowners. All other data is sourced from the Bureau of Meteorology (BoM) National Groundwater Information System (NGIS) (see **Section 4.9** for more details regarding NGIS data).

When considered alongside the topography and elevation profile of the environmental flows pipeline, this information indicates there is no significant aquifer present at the depth and location of the proposed HDD alignment and groundwater is unlikely to be encountered.

4.8 Groundwater Dependent Ecosystems (GDEs)

Groundwater Dependent Ecosystems (GDEs) are ecological communities that rely upon groundwater, either entirely or in part, for their health or survival. The level of dependence or interaction with the groundwater can be variable, ranging from partial dependence (e.g. seasonal or episodic) to total dependence (continuous).

The potential impacts to GDEs are described in detail in the *Aquatic and Riparian Ecosystem Impact Assessment* report. A brief summary of GDEs pertinent to the groundwater impact assessment is provided below for context to the discussions in this report.

A review of the Bureau of Meteorology's GDE Atlas (BOM, 2020) indicates that a number of GDE's are present within the desktop assessment area. GDEs can be characterised as Terrestrial, Aquatic or Subterranean. Aquatic ecosystems rely on the surface expression of groundwater, including surface water ecosystems which may have a groundwater component, such as rivers, wetlands and springs. Terrestrial ecosystems rely on the subsurface presence of groundwater, this includes all vegetation ecosystems. Subterranean ecosystems include cave and aquifer ecosystems (BOM, 2020).

A review of the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 Schedule 4* indicated that there are no high priority GDEs within the desktop assessment area. To meet the SEARs, potential impacts to all identified GDEs have been assessed.

There is no data for subterranean GDEs in the proposal area. The approximate location of each aquatic and terrestrial GDE is illustrated on **Figure 4-29**, **Figure 4-28** and **Figure 4-30** and are summarised in **Table 4-10**.

Table 4-10 Groundwater Dependant Ecosystems (GDEs) within the desktop assessment area.

GDE Name	GDE Type	Location	Level of Groundwater Interaction
South Creek	Aquatic - River	South Creek	High
Nepean River	Aquatic – River + Wetland	Nepean River	Low, moderate and high
Warragamba River	Aquatic – River + Wetland	Warragamba River	Low, moderate and high
Cumberland River Flat Forest	Terrestrial - Vegetation	Appears throughout entire desktop assessment area, most prevalent along banks of surface water bodies.	Moderate to high
Castlereagh Ironbark Forest	Terrestrial - Vegetation	Kemps Creek (suburb) along Elizabeth Drive	Low to moderate
Castlereagh Scribbly Gum Woodland	Terrestrial - Vegetation	Kemps Creek (suburb) along Elizabeth Drive	Low to moderate
Castlereagh Shale-Gravel Transition	Terrestrial - Vegetation	Throughout Kemps Creek (suburb)	High
Castlereagh Swamp Woodland	Terrestrial - Vegetation	Throughout Kemps Creek (suburb)	High
Coastal Sandstone Ridgetop Woodland	Terrestrial - Vegetation	Along banks of Warragamba River.	Moderate
Cumberland Shale Hills Woodlands	Terrestrial - Vegetation	Appears throughout areas between Wallacia and Kemps Creek	Low, moderate and high
Cumberland Shale Plains Woodlands	Terrestrial - Vegetation	Appears throughout entire desktop assessment area.	Low, moderate and high
Cumberland Shale Sandstone Transition	Terrestrial - Vegetation	Wallacia, along the banks of Nepean River and Baines Creek	Moderate to high
Hinterland Sandstone Gully Forest	Terrestrial - Vegetation	Wallacia, along the banks of Nepean River and Warragamba River	High

GDE Name	GDE Type	Location	Level of Groundwater Interaction
Southern Highlands Basalt Forest	Terrestrial - Vegetation	Wallacia, along the banks of Nepean River and Warragamba River	High
Sydney Hinterland Transition Woodland	Terrestrial - Vegetation	Wallacia, in vegetated areas west of the Nepean River and along the banks of Warragamba River.	High

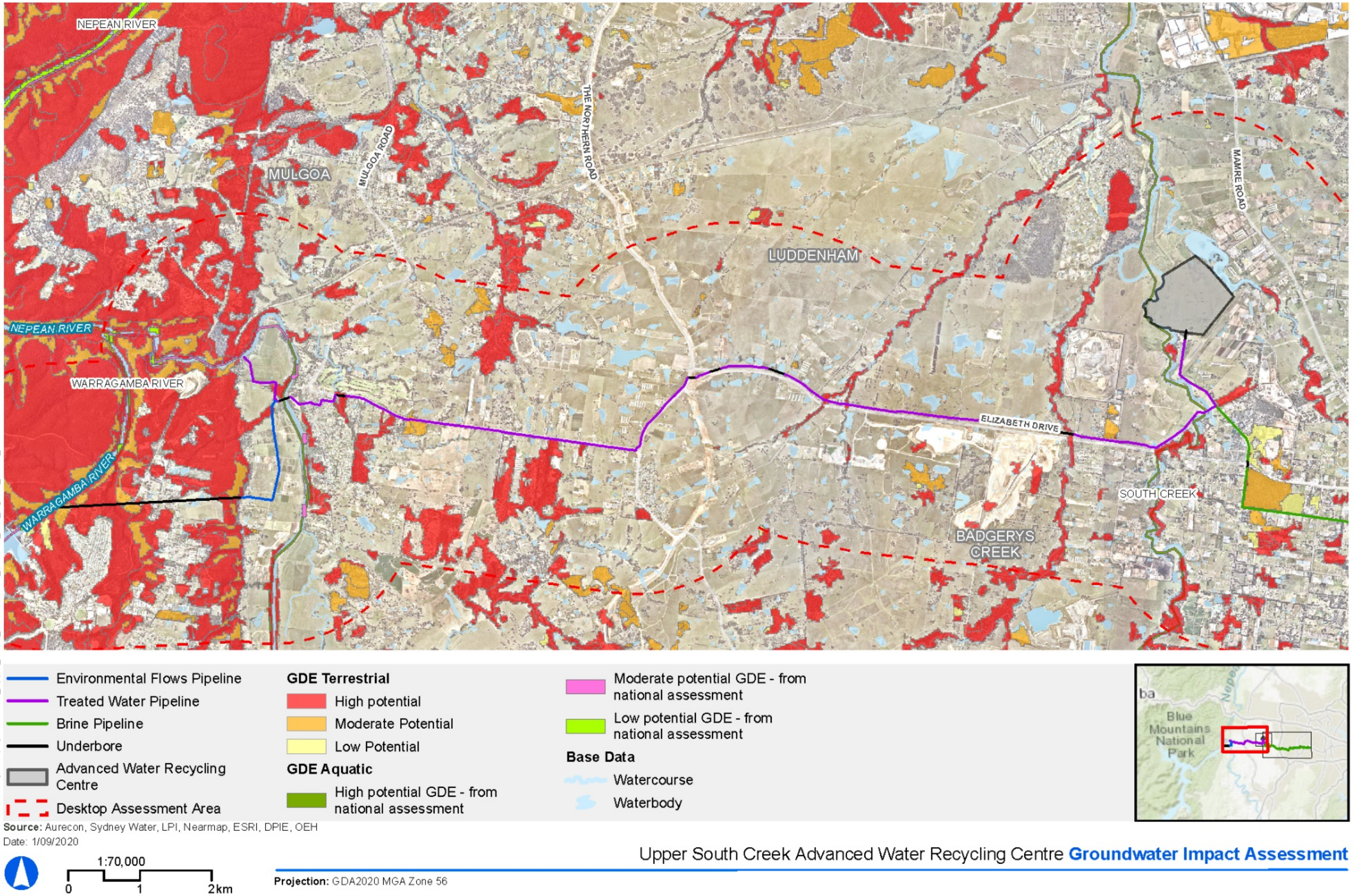


Figure 4-28 Groundwater Dependent Ecosystems (GDEs) – Treated Water / Environmental Flow Pipelines

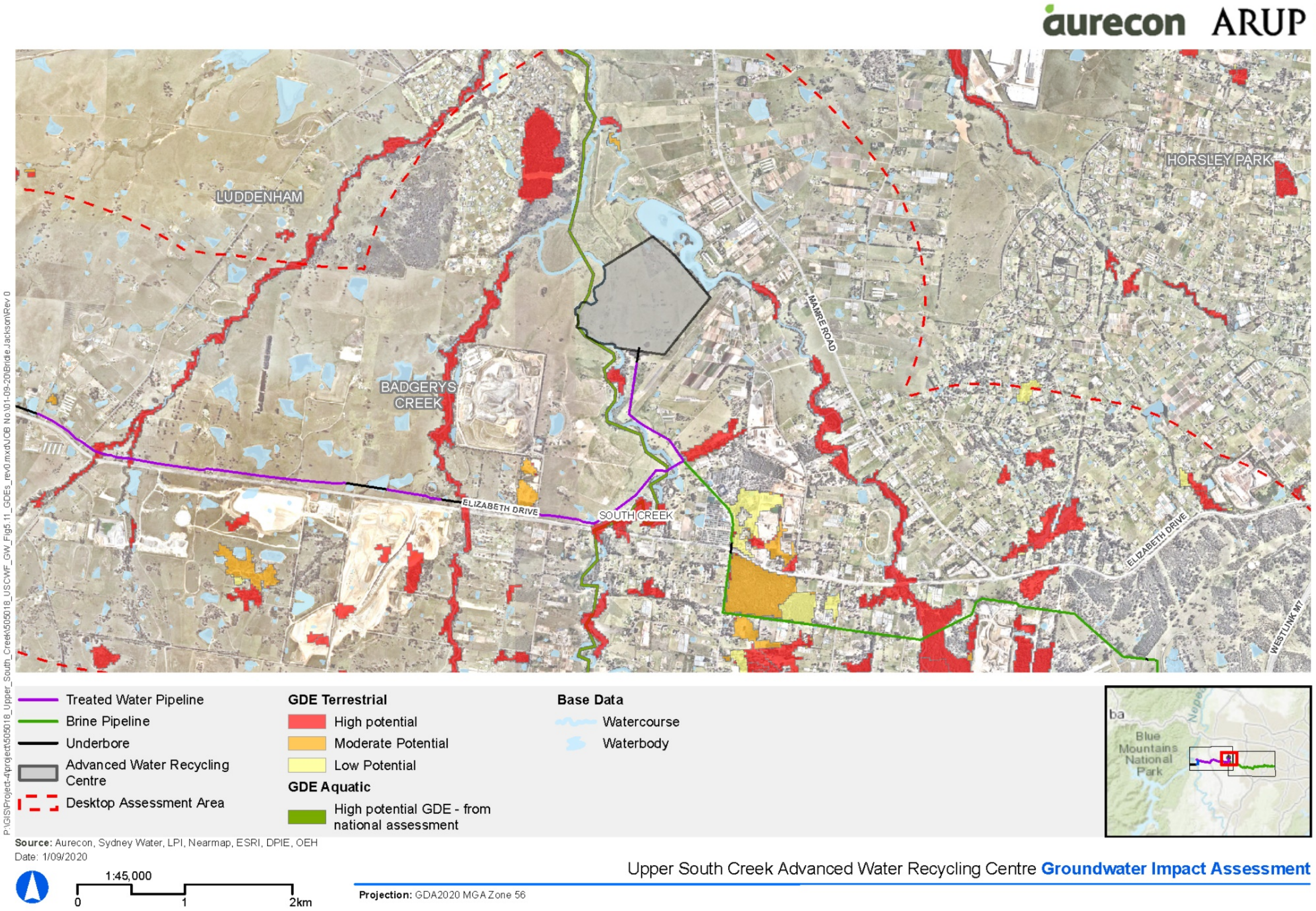


Figure 4-29 Groundwater Dependent Ecosystems (GDEs) – The AWRC

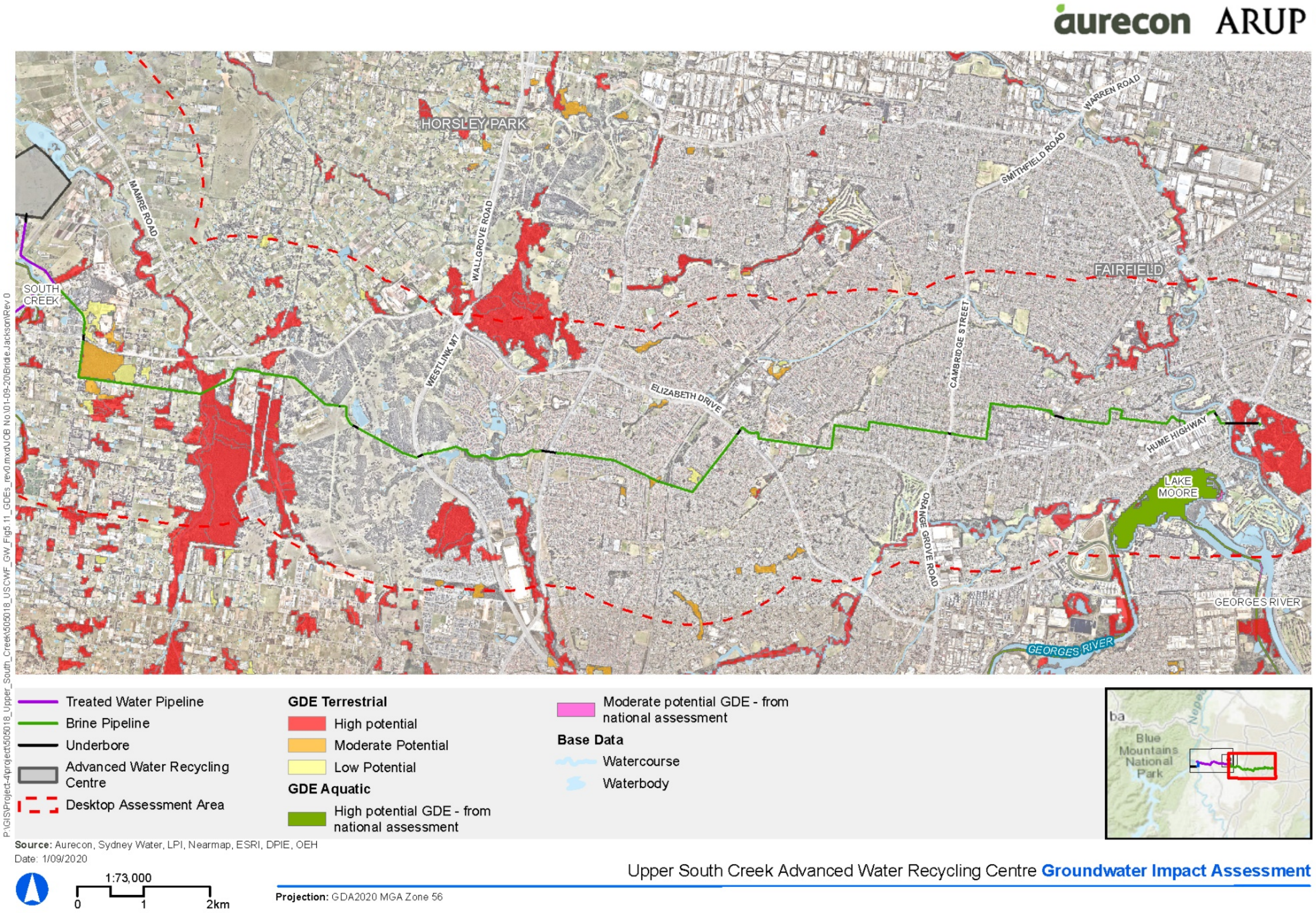


Figure 4-30 Groundwater Dependent Ecosystems (GDEs) – Brine Pipeline

4.9 Regional groundwater users and Water Sharing Plans

The project is located within the "Sydney Basin Central" groundwater source which is covered under the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011*. Within the Sydney Basin Central groundwater sources, there are currently 171 aquifer access licenses, with a total licensed extraction volume of 3,629.5 ML/year. The long-term average annual extraction limit for the Sydney Basin Central groundwater source is 45,915 ML/year, which approximates to 20% of the total estimated annual aquifer recharge rate of 229,223 ML/year for the area (NSW Office of Water, 2011) Therefore, there are currently large volumes of unallocated groundwater in the desktop assessment area.

Both alluvial and porous/fractured rock aquifers intersected by the project are within a "less productive groundwater source" category as defined by the NSW Aquifer Interference Policy criteria based on the relatively low number of registered supply bores, expected low yields and poor water quality (high salinity).

Review of access data available through the Bureau of Meteorology (BoM) National Groundwater Information System (NGIS) indicated a number of registered groundwater bores that lie within the desktop assessment area. No groundwater level information from the NGIS is available for these bores. The locations of the registered groundwater bores are illustrated in **Figure 4-31**, **Figure 4-32** and **Figure 4-33**.

A summary of the registered groundwater bores within the desktop assessment area is provided in **Table 4-11**.

Table 4-11 Summary of registered bores within the desktop assessment area.

Groundwater Bore Type	Impact assessment areas		
	The AWRC site (2 km buffer)	Brine pipeline (2 km buffer)	Treated water pipeline and environmental flows (2 km buffer)
Commercial and industrial	1	1	1
Stock and domestic	0	0	1
Monitoring	19	67	5
Irrigation	0	4	0
Exploration	1	0	0
Unknown	0	0	0
Water Supply	0	1	2
Total	21	73	9

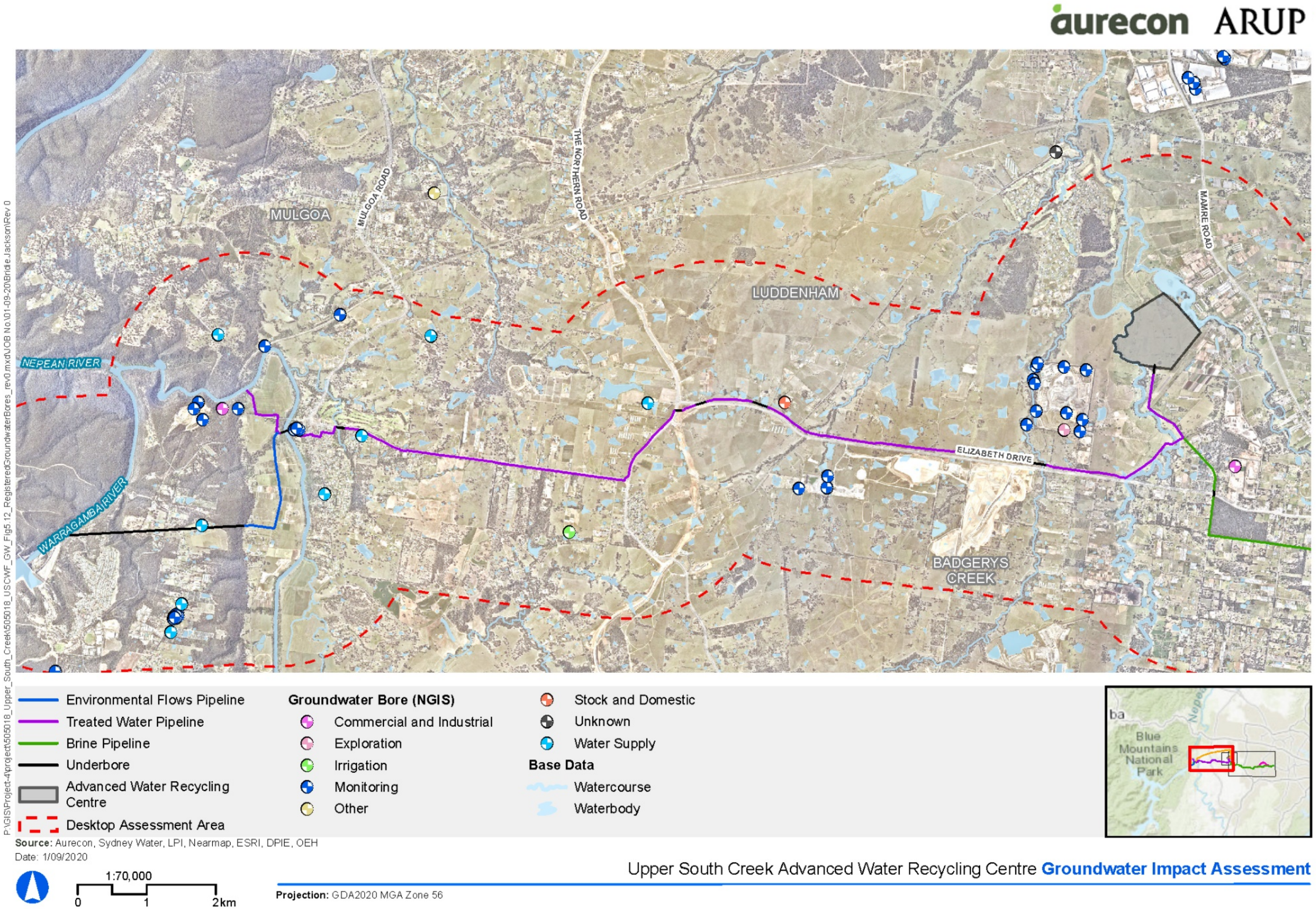


Figure 4-31 Registered Groundwater Bores – Treated Water / Environmental Flow Pipelines

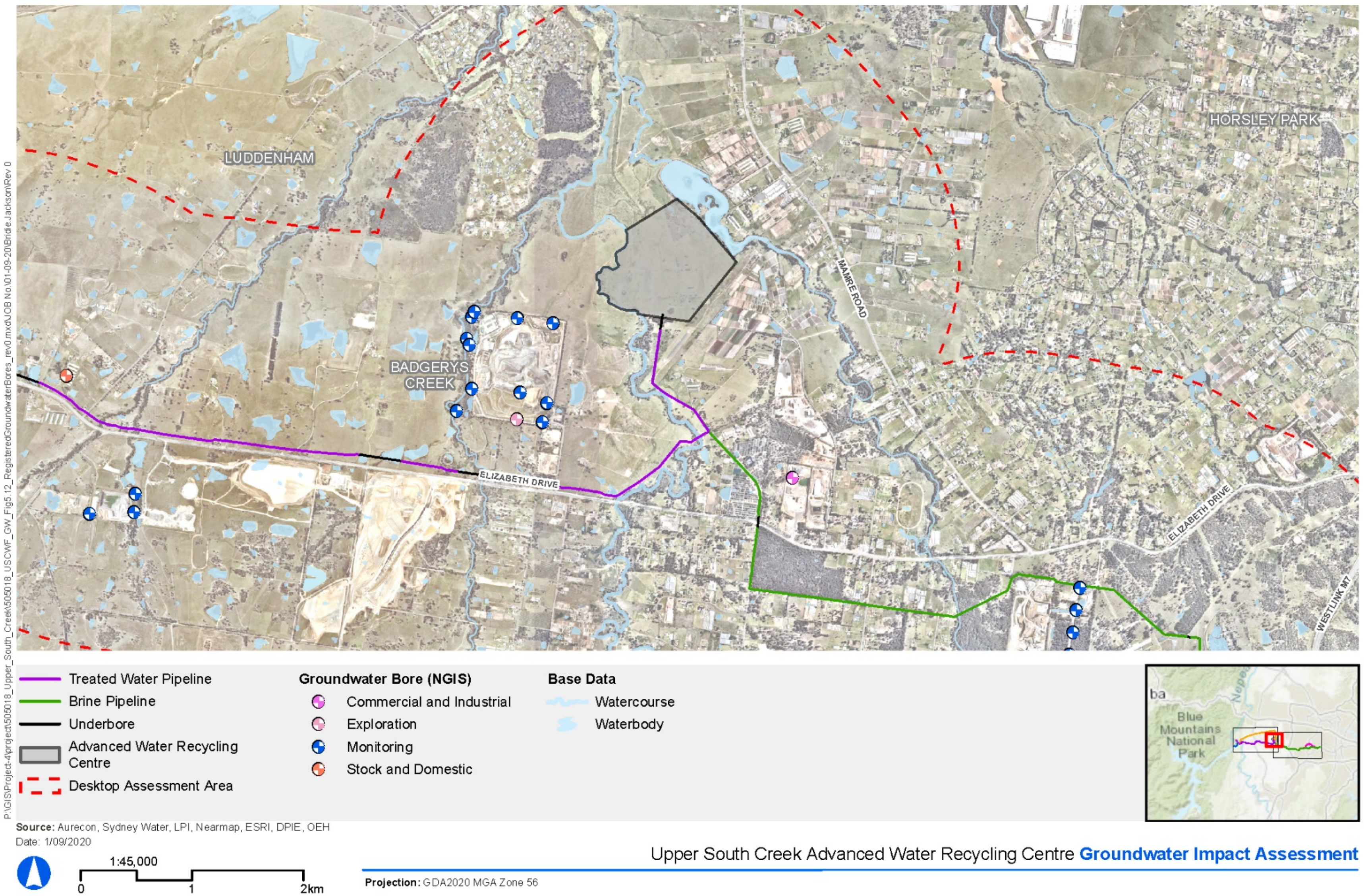


Figure 4-32 Registered Groundwater Bores – The AWRC

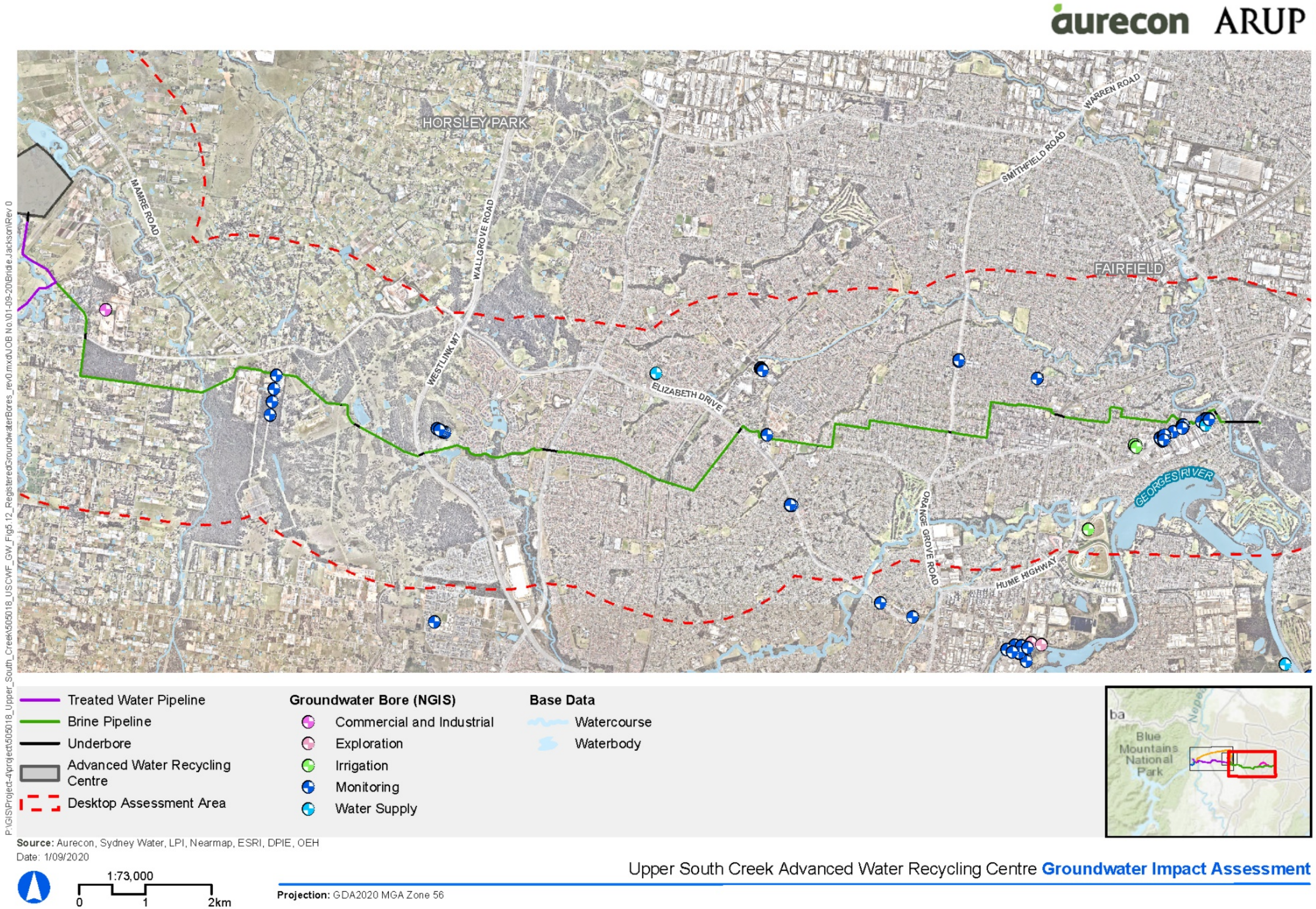


Figure 4-33 Registered Groundwater Bores – Brine Pipeline

5 Hydrogeological Conceptual Model

The following sections describe the hydrogeological conceptual model (HCM) for the desktop assessment area. The HCM is a simplified representation of the natural system, identifying the most important geological units and hydrogeological processes (the hydrogeologic framework) and hydrological processes (the hydrologic system), which control fluid (groundwater in this case) flow and contaminant transport of consequence (if present) at a specific site, based upon available data and understanding of the system mechanics.

HCMs are generally accompanied by pictorial, diagrammatic and/or tabular interpretations and representations of site hydrogeologic conditions as well as corresponding flow/transport dynamics.

In this section, conceptual cross-sections illustrating key hydrological / hydrogeological processes encountered in the environments across the desktop assessment area are presented. In principle the HCM answers the following key questions which are addressed by the methodology in **Section 4**:

- Groundwater flow direction (and contaminants if present), where is it coming from and where is it going? This is assessed based on monitored groundwater levels or conceptually based on geomorphology/topography (**Section 4.7**).
- The type of porous media containing groundwater. This is characterized in terms of porosity and permeability of the geologic material which can be either primary or secondary (**Section 4.5.3**).
- How much of groundwater (and contaminant) is there, and how fast is it flowing? This is quantified based on aquifer hydraulic parameters such as hydraulic conductivity, and storage coefficients of the aquifer units (**Section 4.5.3**).
- Description of climate (Hydrometeorology) and hydrologic budget and stresses (**Section 4.1**). Type and nature of recharge sources? Nature and type of groundwater-surface water interactions?
- Description of regional and site-specific hydrostratigraphic units (**Section 4.5**) based on the nature and connectivity of the openings (void space) in the geologic material, which determine transmission and storage properties. The void space is characterized by porosity and permeability.
- Groundwater flow system boundary locations including hydraulic features such as groundwater divides and physical features such as bodies of surface water and relatively impermeable rock?
- How did the groundwater system behave in the past, and how will it change in the future based on both natural and anthropogenic influences? This is covered in the Groundwater Modelling Report in **Appendix A**.

Figure 5-1 and Figure 5-2 show conceptual cross-sections for the trenched and trenchless pipelines, respectively. Figure 5-3 show the conceptual cross-section for the AWRC site.

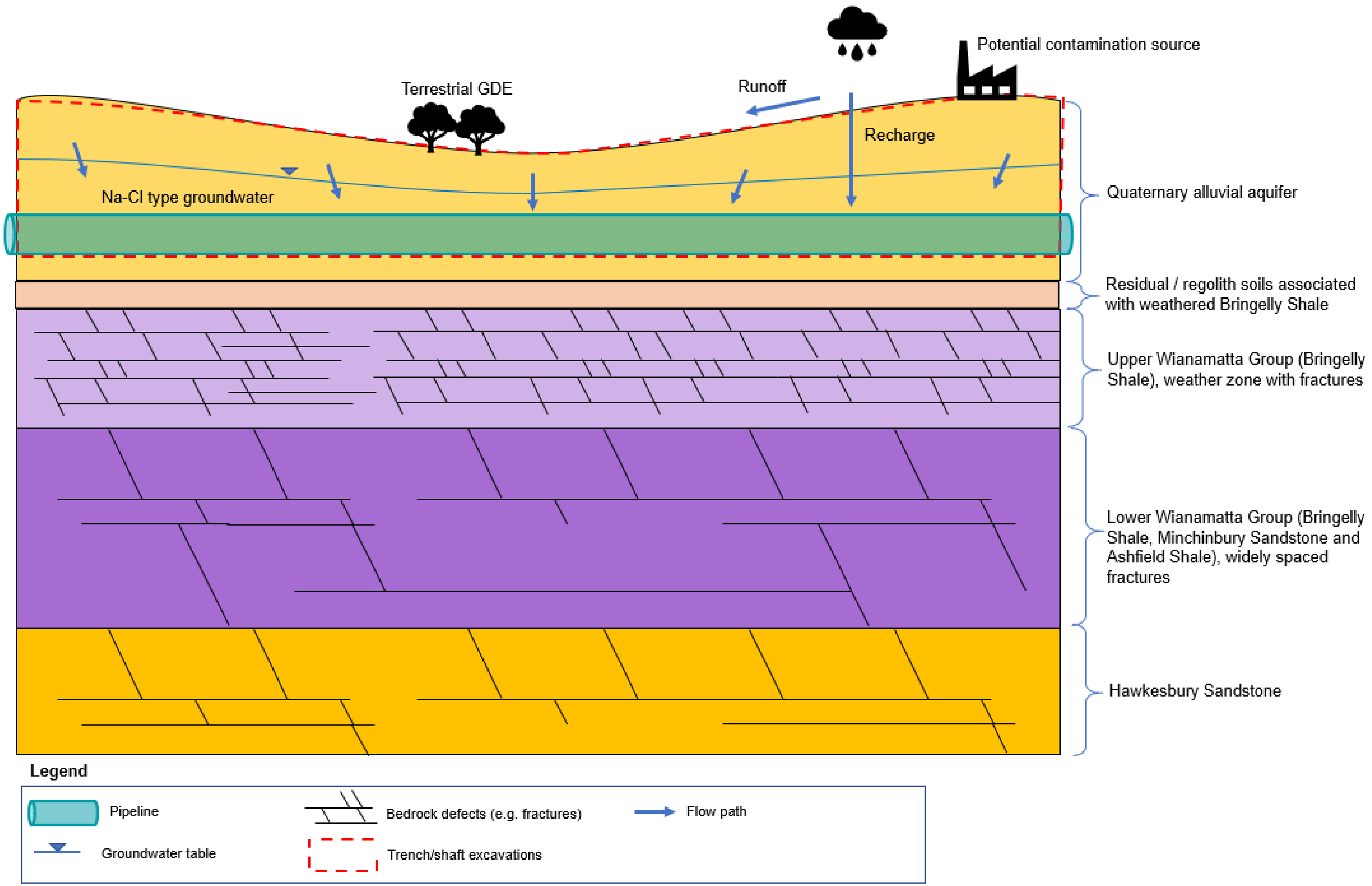


Figure 5-1 Trenched Pipeline – Hydrogeological Conceptual Model Overview

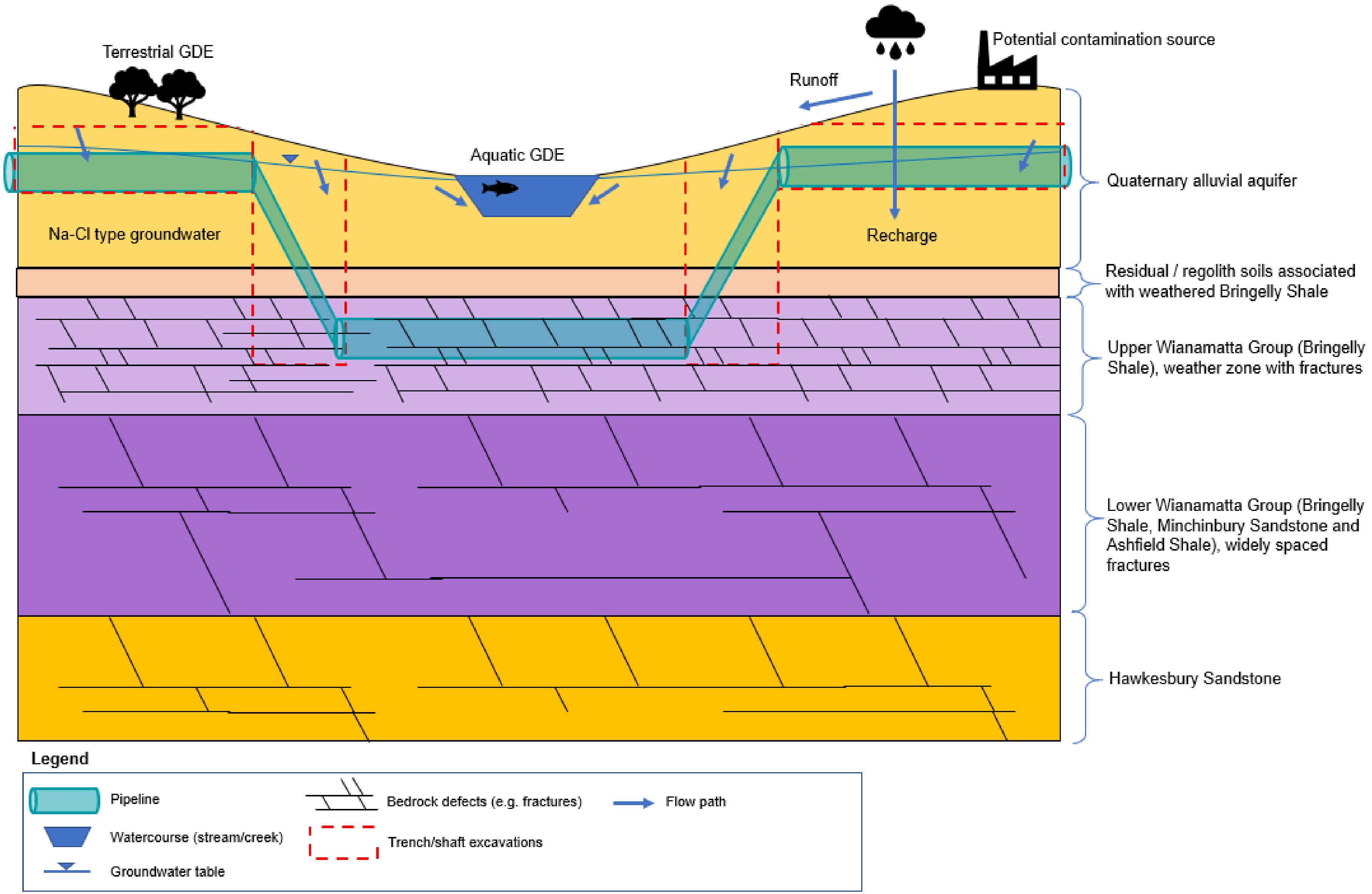
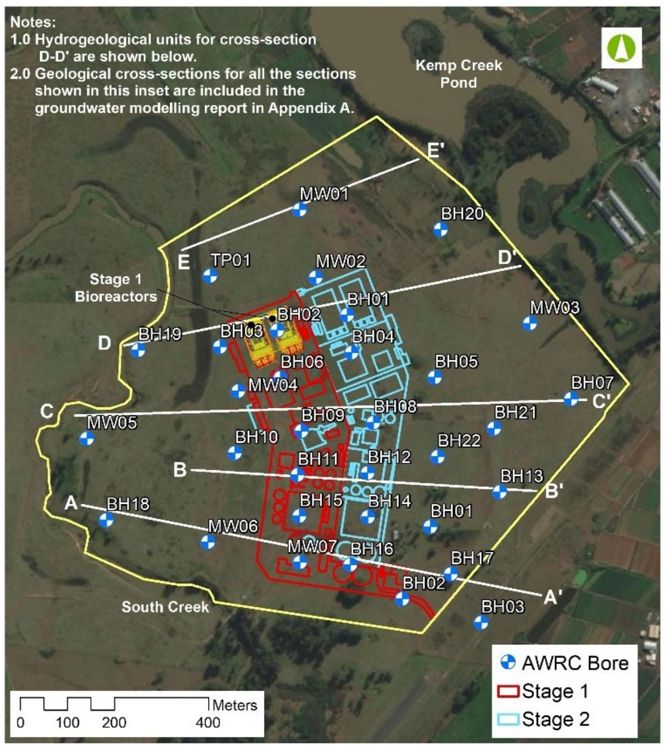
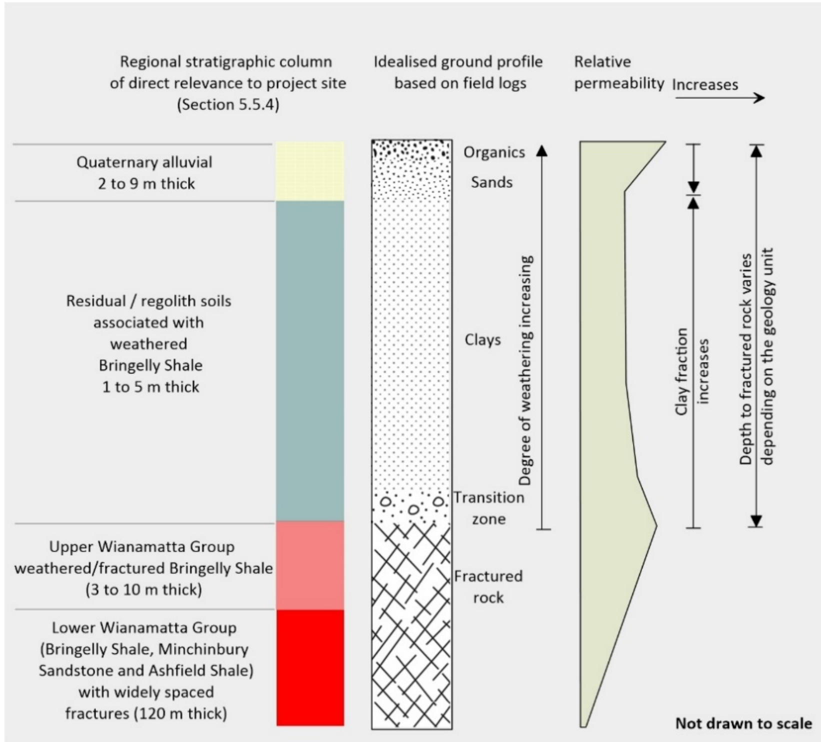


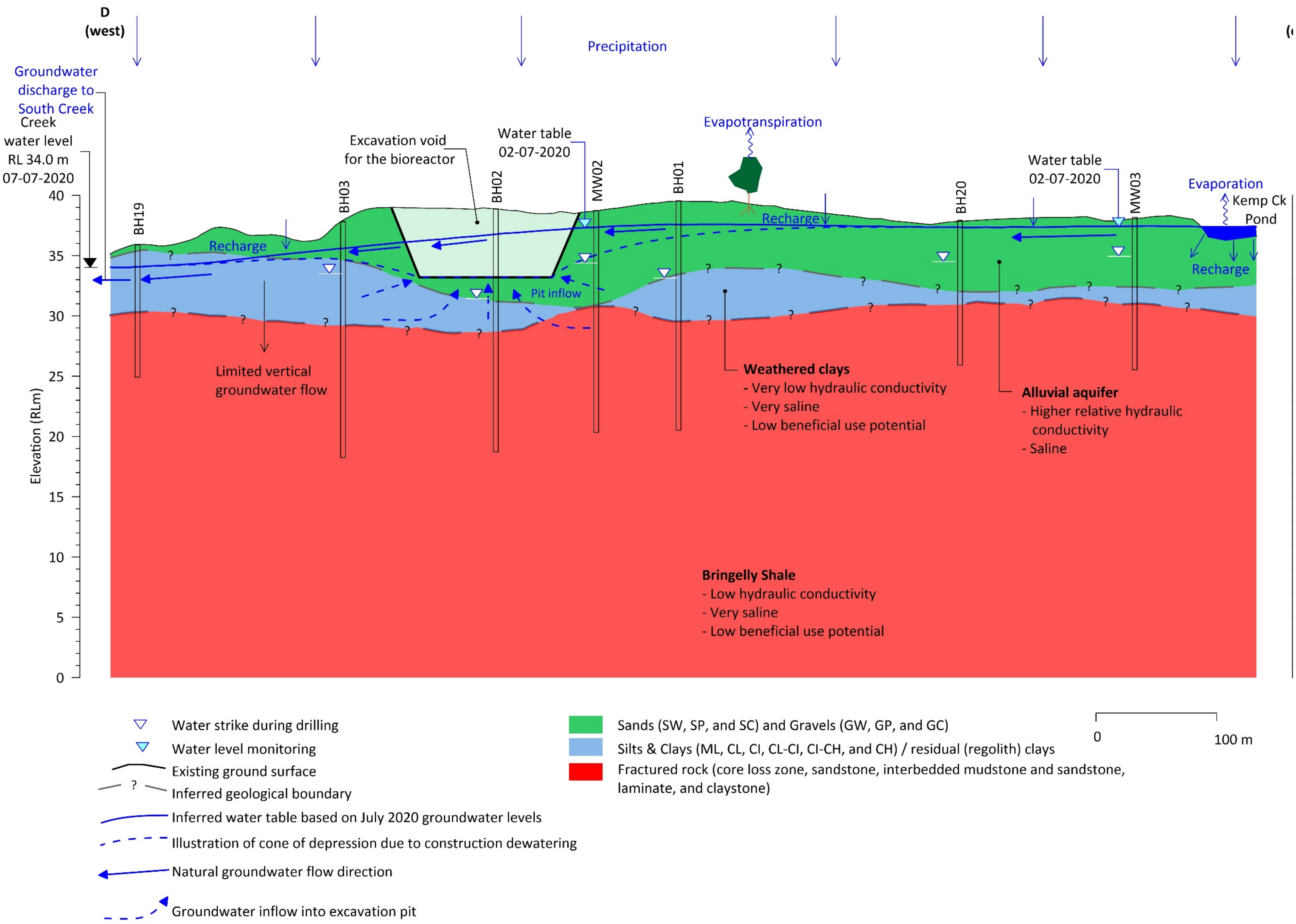
Figure 5-2 Trenchless Pipeline – Hydrogeological Conceptual Model Overview



(a)



(c)



(b)

Figure 5-3 (a) AWRC site cross-section location map (b) AWRC site conceptual Hydrogeological profile of D-D' showing simplified lithology and groundwater flow direction (c) Idealised subsurface profile of the AWRC site

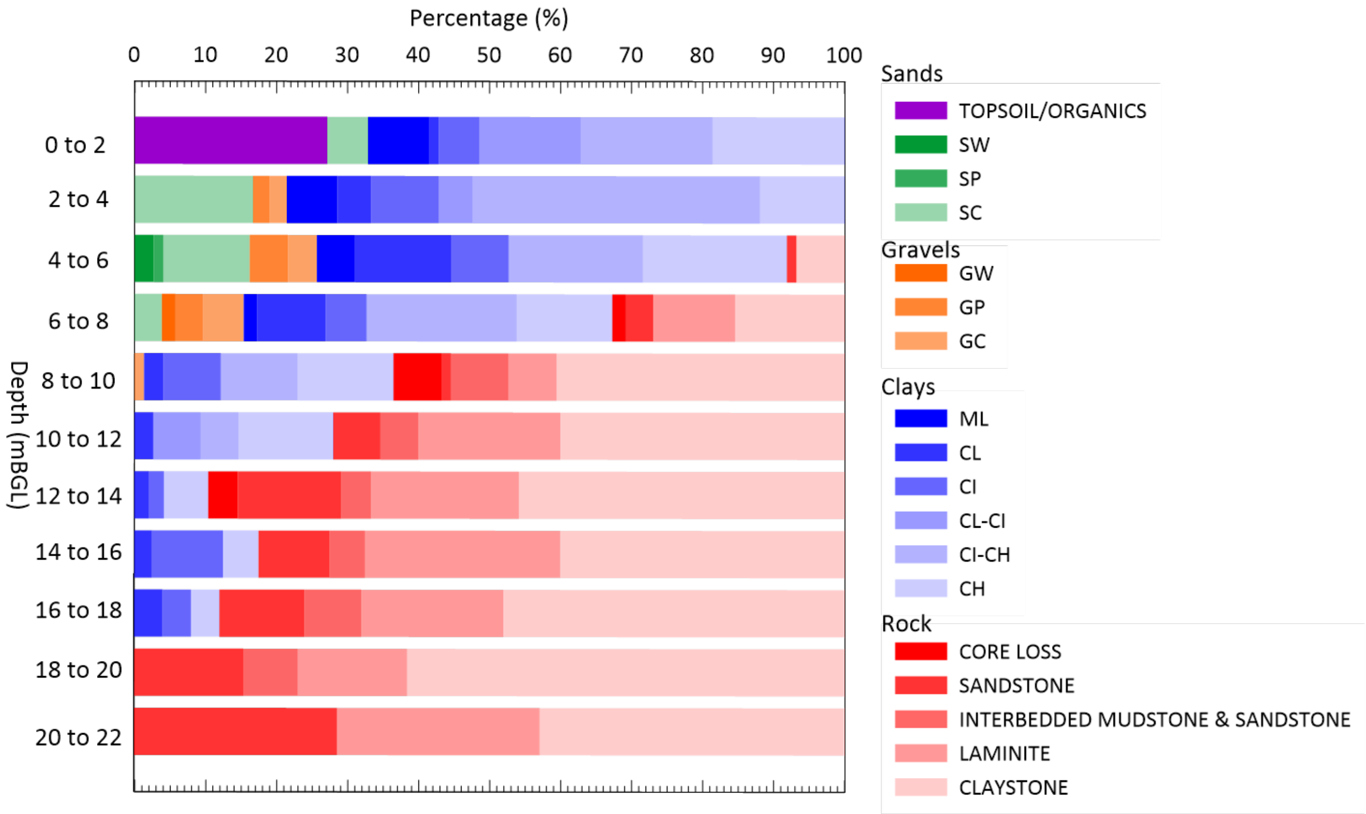


Figure 5-4 Graphical illustration of the stratigraphy encountered at the proposed AWRC site

6 Project Features

6.1 Construction Phase

6.1.1 AWRC Site

The key construction phase activities for the proposed AWRC site include the following:

- Establishment site runoff control
- Establishment of bench. The detailed approach to this has not been finalised but a typical methodology would involve:
  - Grubbing
  - Removal and stockpiling of 200-300 mm of topsoil for re-use later (following chemical and geotechnical testing for suitability). An area of approximately 115,000 m^2 will need to be stripped equating to a topsoil volume around 34,500 m^3
  - Geotechnical investigation identified the underlying 200 mm of material below the topsoil is unsuitable for construction and is to be removed and disposed offsite
  - Stormwater management (e.g. installation of appropriate erosion and sediment controls)
  - A water tank will be required for dust suppression
  - Cut and fill to bench levels with import of quality engineered fill as required and removal of any excess / poor quality material if it cannot be re-used on site elsewhere for landscaping purposes
  - Filling performed in layers of up to about 300 mm, which is compacted before the next layer is added. The fill depth on this site will generally increase from southeast to northwest up to a depth of about 2.5 m

- Excavation for construction of below surface infrastructure, including targeted dewatering of surficial local aquifer systems to required depths.
- Installation of subfloor drainage, foundations and underground infrastructure.

6.1.2 Pipelines

Key construction phase activities associated with the installation of the pipelines will include the following:

- Excavation (trench, shafts and/or pits) for construction of below surface infrastructure, including targeted dewatering of surficial local aquifer systems to required depths.
- Installation of foundations and underground infrastructure.
- Installation of aboveground civil, mechanical and electrical plant and equipment.

Different construction methods are proposed along the pipeline routes. In general, the pipelines will be constructed using standard trenching methods Trenchless methodologies will be will be used at most watercourse or infrastructure intersections with the pipeline occur.

Trenchless sections completed using HDD generally involve the activities listed above, in addition to the following:

- Mobilising the drill equipment and installing measures to manage groundwater if required.
- Inject a bentonite-based drilling fluid to lubricate the drill head and flush the drilled hole. Remove drill cuttings to be contained, collected and recycled/disposed.
- As the HDD bore and drill head advances, a casing pipe and the pipeline is inserted while grouting the annulus.

Trenchless sections completed using microtunneling / pipe-jacking generally involve the activities listed above, in addition to the following:

- Establish launch and reception shafts, install jacking frame and headwalls.
- Mobilising the drill equipment and installing within the launch pit, including measures to manage groundwater if required.
- Remove drilling fluids and cuttings via vacuum extraction.
- Once the jacking pipe reaches the reception shaft, the pipeline is inserted, and annulus is grouted.

6.2 Operational Phase

6.2.1 AWRC Site

The primary activities that could lead to groundwater impacts associated with the operational phase of the project all relate to site stormwater management practices as well as potential underdrainage systems for underground structure flotation management.

The key operational phase activities for the proposed AWRC site include the following:

- On and off-site irrigation
- Pumped underdrainage systems
- Storage and use of chemicals and contaminants

6.2.2 Pipelines

During standard operating conditions limited activities will be conducted directly relating to the operation of the pipelines. However, maintenance activities or breakdowns leading to potential impacts to local groundwater systems are:

- Pipe leaks/bursts

7 Analysis Results

A combination of qualitative and quantitative analyses were conducted to assess the potential and degree of impacts associated with the following key activities or physical changes:

- AWRC site
  - Construction phase
- Construction dewatering and groundwater management
  - Operational phase
- Underdrainage systems employed for underground structure flotation management
- Pipelines
  - Construction phase
- Construction dewatering and groundwater management
  - Operational phase
- Groundwater seepage after trenchless pipeline construction
- Pipe leaks/bursts
- Other key considerations
  - Acid sulfate soils
  - Mobilisation and migration of contaminants

7.1 AWRC Site

7.1.1 Construction phase

Potential impact assessed in this section: Induced drawdowns from required dewatering activities, reducing the availability of groundwater for GDEs and surrounding groundwater users.

Temporary groundwater impacts could potentially arise from dewatering which will be required to provide a stable platform for the construction of underground structures (e.g. the bioreactors). The potential impacts from construction dewatering have been assessed using predictive numerical modelling scenarios, which are detailed in **Appendix A** and summarised below. The focus of the predictive modelling is on bioreactors as they have deep foundations which will penetrate below the existing groundwater table.

A comparison of pre-development groundwater levels and maximum predicted construction dewatering groundwater levels (i.e. just before cessation of bioreactor dewatering) is shown in **Figure 7-2** below.

During construction of the AWRC, high initial inflow would occur and would stabilise at about 115 m^3/day (i.e. 75 m^3/d and 40 m^3/d, respectively for the eastern and western bioreactors). The construction period comprises 492 days. Total pumped volume over 492 days construction period has been estimated to be about 57ML, with approximately 50ML pumped within the first 365 days of the construction.

The extent of influence due to construction dewatering can be interpreted to be similar to the extent of the cone of depression and is described in terms of the radial distance from the area where dewatering is being implemented to the point where there is zero drawdown. The modelling results indicate that the extent of influence due to AWRC Stage 1 construction dewatering will be about 325 m from the central part of the bioreactor site as shown **Figure 7-2**. The extent of influence due to construction dewatering associated with future stages of the AWRC has not been modelled as part of this study. Since the designs for Stage 1 and the current future stages are expected to be similar, it is expected that it will also be around 325 m. Based on these modelling results, the impact of construction dewatering is expected to be of local extent, which will be contained within the extent of the footprint of the proposed AWRC site. Beyond this extent, the groundwater flow pattern is unimpacted. **Figure 7-2** compares simulated groundwater level contours representative of current conditions and groundwater level contours due to simulated construction dewatering.

The creeks were discretised into segments referred to as the river reaches. Discretising the river into reaches provide the modelling software a way of summarising water mass balances at specific areas. For this study, creek segments were discretised at approximately 400 m to 500 m lengths. Reach 10 and Reach 11 are directly adjacent to AWRC site. An inspection of the simulated water balances for the modelled river reaches shows that a small section of South Creek (approximately 650 m length) will be impacted, with a slight reduction in baseflow to the creek in this area during construction reducing from an average of about 79 m^3/d to 74 m^3/d over Reach 10 and Reach 11. This represents a baseflow reduction of approximately 6% during construction (full details are provided in **Appendix A**).

The degree of impact is dependent on the distance between the dewatering and the creek (reducing with distance). In terms of foundation design, the degree of impact increases with depth below current ground surface.

This groundwater impact could affect the aquatic ecosystems (South Creek) with a high level of interaction with groundwater near the proposed AWRC site shown in **Figure 4-29**, in particular areas in Reach 10 and Reach 11 (**Figure 7-2**). Climate change influences during future stages are not expected to exacerbate the impact, as the reduction in baseflow will be negligible in comparison to the predicted increase in surface water runoff. The predicted groundwater drawdowns are within the range of acceptability defined by the NSW Aquifer Interference Policy (outlined in **Section 2.3**) are not expected to prevent the long-term viability of surrounding water-related assets and are considered acceptable.

The potential impacts of the solar panels during is a reduction in the permeable surface and groundwater recharge, this has not been directly modelled in the construction phase, but has been captured in the long-term modelling (see **Section 7.1.2**).