APPENDIX U

GROUNDWATER IMPACT ASSESSMENT

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REPORT ON

Groundwater Impact Assessment

Dalswinton Quarry

FOR

Rosebrook Sand and Gravel Pty Ltd

30 April 2021

Project No.: 4047

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Groundwater Impact Assessment – Dalswinton Quarry

Prepared for

Rosebrook Sand and Gravel Pty Ltd

1. Introduction

Rosebrook Sand and Gravel Pty Ltd (RSG) propose to expand their existing sand and gravel quarry operation at Dalswinton Quarry (the Project), located approximately 8 km south of Denman, New South Wales (NSW) (Figure 1.1).

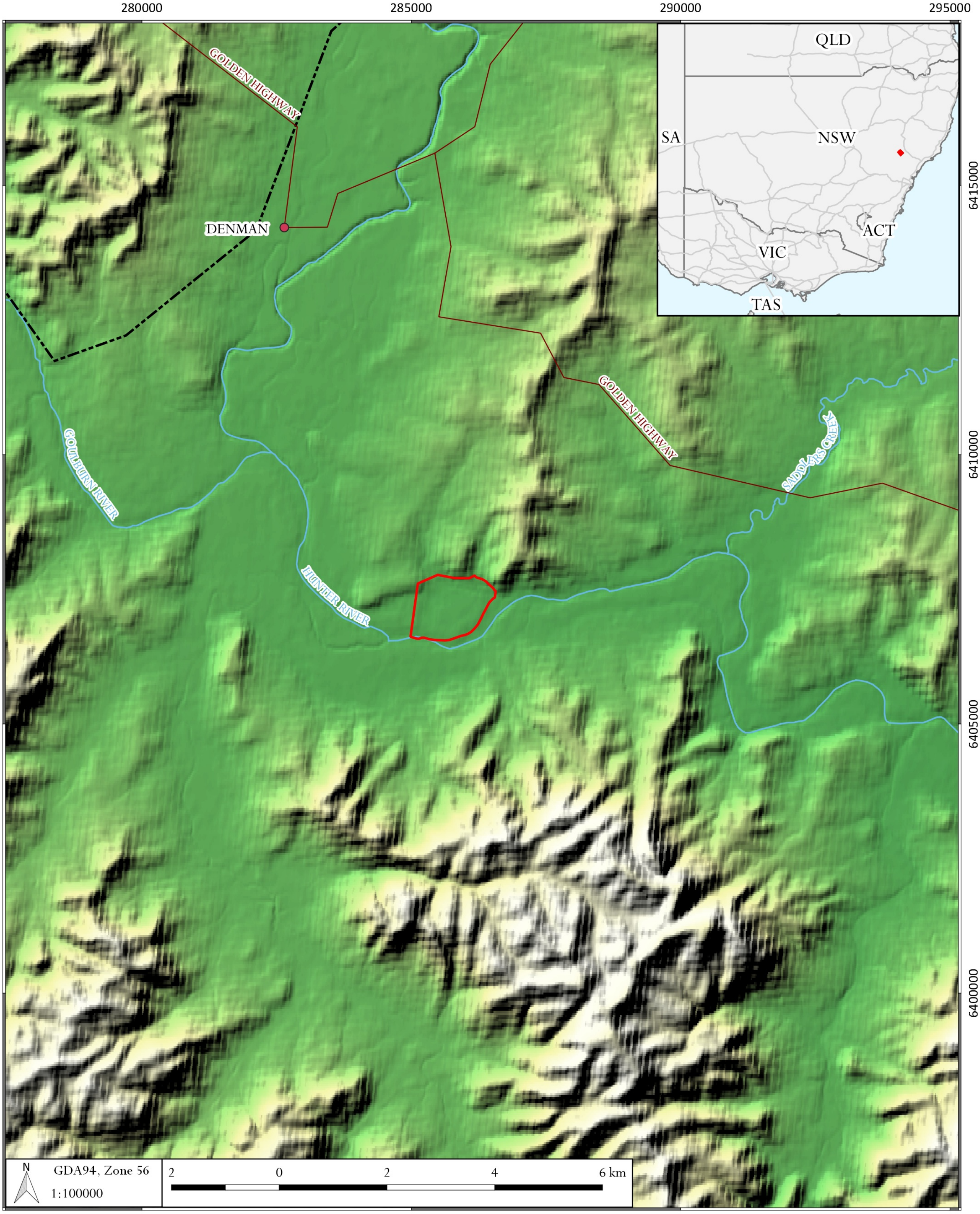
The planned expansion will involve the quarrying of unconsolidated Quaternary alluvium and the reworking of previously quarried material to recover fine aggregate that was previously discarded. The operation will have a maximum production capacity of 500,000 tonnes per annum, equating to approximately 15 to 20 million tonnes of material over an expected 25 years of Project life.

This report describes the hydrogeological regime of the site and surrounding area and provides a groundwater impact assessment of the Project. The work has been undertaken by **hydrogeologist.com.au** at the request of HDB Town Planning and Design (HDB), who are managing the Project approvals. The groundwater impact assessment has been guided by the requirements of the NSW Department of Planning and Environment Secretary's Environmental Assessment Requirements (SEARs) for the Project, which were issued on the 14th August 2018.

1.1. Project description

The Project will comprise of the following components:

- a maximum production capacity of 500,000 tonnes per annum;
- a proposed disturbance footprint of about 89 hectares (ha) in total, which is comprised of approximately 50 ha of previously mined land that will be reworked (Work Area 1), and 39 ha of unmined land (Work Area 2);
- a single pit targeting alluvium that will be excavated to the depth of bedrock;
- a processing area within the disturbance footprint comprising the processing plant, stockpiling area, weighbridge, site offices, amenities, workshop, and ancillary facilities;
- a water treatment plant for thickening tailings;
- use of an existing water storage area for the supply of processing water; and
- progressive rehabilitation of the mined area, with the final landform surface post-rehabilitation to be 2 m above the median flow in the Hunter River.



LEGEND

- Project area
- Railway
- Road
- Major watercourse
- Town

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Dalswinton Quarry - Groundwater Assessment (4047)

Project location

FIGURE No.
1.1

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2. Scope of work

The scope of work required a groundwater impact assessment to address the SEARs and to enable the preparation of an Environmental Impact Statement (EIS) for the Project. The SEARs issued for the Project detailed the following specific issues to be addressed in the groundwater impact assessment:

- identification of any licensing requirements or other approvals under the *Water Act 1912* and/or *Water Management Act 2000* (see Section 3.3);
- demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP) (see Section 8.3);
- a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo (see Section 8.3);
- a detailed assessment of any need to maintain an adequate buffer between excavations and the highest predicted or recorded regional groundwater table (see Section 4 and Section 8.3);
- an assessment of the likely impacts on the quality and quantity of existing surface and ground water resources including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives (see Section 8);
- an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users (see Section 8); and
- a detailed description of the proposed water management system, water monitoring program and other measures to mitigate surface and groundwater impacts (see Section 9).

This report addresses the scope of work required by the SEARs. To address the specific issues detailed in the SEARs, **hydrogeologist.com.au** has:

- completed a desktop review of publicly available information and reports;
- established a groundwater dataset for bores within and surrounding the Project area, where these bores are listed in the WaterNSW database;
- reviewed the geology of the area based on public domain reports and information available from Geoscience Australia and Geological Survey of NSW (GSNSW);
- developed a conceptual model of the groundwater regime for the purpose of defining any impact on the alluvial aquifer;
- developed a numerical flow model of the groundwater system and calibrated this to available groundwater and surface water data to identify any potential for impact to the alluvial aquifer; and
- simulated the effect of the Project on the groundwater regime using the numerical model.

3. Regulatory framework and engagement

3.1. Secretary's Environmental Assessment Requirements

Under the NSW *Environmental Planning and Assessment Act (1979)* and the NSW *Environmental Planning and Assessment Regulation (2000)*, the NSW Planning Secretary issued Environmental Assessment Requirements (SEARs) that are required to be addressed as part of the Project.

The SEARs for the Project (Application SSD 9094) were provided by the NSW Department of Planning and Environment on 14 August 2018. Input into the SEARs was received from the NSW Environment Protection Authority (EPA), GSNSW, Hunter New England Population Health (HNEPH), NSW Department of Industry, Muswellbrook Shire Council, NSW Office of Environment and Heritage (OEH), NSW Rural Fire Service and NSW Department of Transport. The sections below summarise the intent of the legislation, policy and guidelines listed in the SEARs and how they relate to the Project.

3.2. Water Act

The *Water Act 1912* regulates water sources in NSW, including rivers, lakes and groundwater aquifers. However, the *Water Management Act 2000* has replaced the *Water Act 1912* in relation to alluvial aquifers in NSW, and therefore is not applicable to the Project.

3.3. Water Management Act

The *Water Management Act 2000* (WM Act) aims to provide for the sustainable and integrated management of water resources in NSW, while balancing competing environmental, social and economic considerations. Under the WM Act, water sharing plans (WSPs) have been developed. The aim of a WSP is maintain the health of river and groundwater systems, while also providing equitable access for water users and the opportunity to trade water.

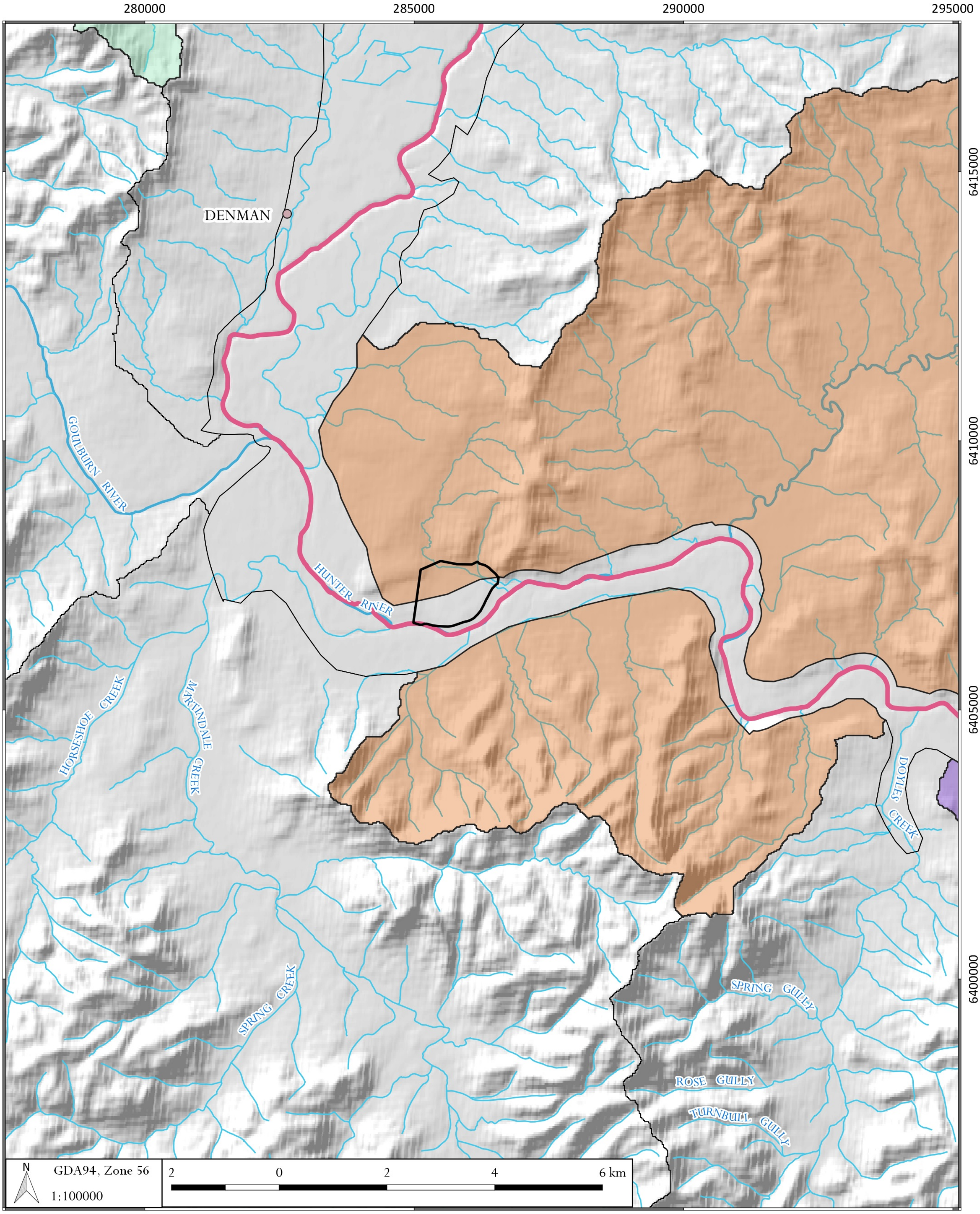
The Project area covers two WSPs, namely:

- Hunter Regulated River Water Source WSP; and
- Hunter Unregulated and Alluvial Water Sources WSP.

Figure 3.1 shows the location of the Project in relation to the areas covered by the relevant WSPs and associated management zones. Water access licences currently held by RSG in each WSP are listed in Table 3-1.

Table 3-1 Water licences held by RSG

Water Sharing Plan	Water Source	Licence	Entitlement
Hunter Unregulated and Alluvial Water Sources	Jerrys Management Zone of the Jerrys Water Source	20WA212819	20 ML/year
Hunter Regulated River Water Source	Hunter Regulated River Source (Zone 1B – Hunter River from Goulburn River Junction to Glennies Creek Junction)	20WA201001	



LEGEND

WSP for the Hunter Regulated River Water Source

WSP for the Hunter Unregulated and Alluvial Water Sources

Appletree Flat management zone

Jerrys management zone

Wybong management zone

Project area

Town

Major watercourse

Minor watercourse

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Water sharing plans - Water management areas

FIGURE No.

3.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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3.3.1. Hunter Regulated River Water Source Water Sharing Plan

The WSP for the Hunter Regulated River Water Source covers the regulated Hunter River from below the Glenbawn and Glennies Creek Dams to the tidal limit of the Hunter River estuary. The southern extent of the Project area falls within this WSP, and is specifically covered by Management Zone 1B, which encompasses the section of the Hunter River from the Goulburn River Junction to the Glennies Creek Junction.

3.3.2. Hunter Unregulated and Alluvial Water Sources Water Sharing Plan

The rules of the Hunter Unregulated and Alluvial Water Sources WSP apply to all surface waters located within the management zone, as well as the alluvial groundwater that is highly connected to the surface waters. The northern extent of the Project is located within this WSP and is specifically covered by the Jerrys Management Zone of the Jerrys Water Source.

3.4. Aquifer interference policy

The NSW Aquifer Interference Policy (AIP) provides a framework for the assessment of impacts of the extraction of water for proposed developments. Groundwater sources are divided into “highly productive” and “less productive” categories based on salinity and aquifer yield as shown in Table 3-2. The alluvium along the Hunter River is considered to generally fall within the “highly productive” category.

Table 3-2 NSW Aquifer Interference Policy – salinity and aquifer yield criteria

Criteria		Salinity (Total dissolved solids)	
		Less than 1,500 mg/L	More than 1,500 mg/L
Aquifer yield	More than 5 L/s	Highly productive	Less productive
	Less than 5 L/s	Less productive	

The AIP also specifies minimal impact considerations for both “highly productive” and “less productive” aquifers within each WSP. These comprise thresholds for water table and groundwater pressure drawdown, and changes in groundwater and surface water quality. A summary of the AIP minimal impact considerations is included as part of the project potential impacts assessment in Section 8.

3.5. Office of Water Guidelines for Controlled Activities

This guideline sets out the approval requirements for activities along waterfront land. As the proposed Project is considered a State Significant Development, the Project falls into an Exemption category.

3.6. NSW State Groundwater Policy Framework Document

The Policy Framework document sets out the overarching context of the various policies used to sustainably manage the state’s groundwater resources. These include the NSW State Groundwater Quality Protection Policy which aims to prevent the pollution and contamination of groundwater, and the NSW State Groundwater Policy which aims to achieve the efficient, equitable and sustainable use of the state’s groundwater.

3.7. EPA Guidelines for the Assessment and Management of Groundwater Contamination

This guideline outlines the framework for assessing and managing contaminated groundwater in NSW.

4. Site description

The Project site is an irregular parcel of land located adjacent to the northern bank of the Hunter River, approximately 8 km south of Denman in the Hunter Valley, NSW (Figure 1.1). The Project is located on Lot 72 DP1199484 within the Muswellbrook Shire Council local government area. The site covers an area of about 144 ha, of which 50 ha is approved for disturbance under the current Development Application (DA 410/1995), with an additional 39 ha proposed for disturbance (the Project). The southern boundary of the Project is formed by the Hunter River, and the northern, eastern and western boundaries by agricultural activities.

Quarrying has occurred at the site since 1986. Initial works consisted of a small-scale gravel operation on the south-eastern side of the site, which operated from 1986 to 1995. Since then, operations have focussed on the western side of the site. Along with the current quarry operations, a processing plant, site office and other ancillary infrastructure are located nearby. A proposed water treatment plant will be located close to the processing plant and will remove excess water from the tailings prior to deposition in the tailings dam. The eastern side of the site is currently vacant.

Quarrying activities, as well as historical agricultural activities at the site, have resulted in much of the site consisting of a heavily disturbed environment. Vegetation across the site is generally negligible, with only a few scattered trees present. However, several mature clusters of vegetation are present along the banks of the Hunter River.

It is important to note that the existing and approved quarry has historically, and currently intersects the groundwater table within the Quaternary alluvium as part of normal operations. The current quarry forms a window into the groundwater table and there is currently no need to maintain a buffer between the quarry excavation and the groundwater table. There is licensing in place to deal with the take of water (evaporation from the groundwater table window). The proposed development would be carried out in a similar manner to the existing operation, therefore there is no need for a buffer between the quarry excavation and the groundwater table.

4.1. Climate

The climate of the region is temperate and is characterised by hot summers and mild dry winters. A long-term Bureau of Meteorology (BOM) weather station is located in proximity to the Project at Denman (Station No. 61016), which is located approximately 7.5 km north-west of the site and has a continuous climate record from January 1889 to the present. The location of the weather station is shown in Figure 1.1.

The BoM data has been compared to an interpolated site-specific dataset obtained from the Scientific Information for Land Owners (SILO) service (32 27'S 150 42'E). The data is a patched point data set, meaning that missing or suspect values are ‘patched’ with interpolated data. Table 4-1 shows the average monthly rainfall from the SILO data as well as the BoM weather station, for data covering the period from 1889 to 2019.

Table 4-1 Average monthly climate data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average
Rainfall (mm)													
SILO data	70.7	63.6	55.2	39.5	36.1	44.5	38.8	34.8	40.5	48.5	57.9	65.6	595.6
BOM Site 61016	72.9	65.6	55.8	39.3	35.8	42.6	37.8	33.8	38.9	48.9	55.7	65.2	592.4
Evapotranspiration (mm)													
SILO data	132.9	111.7	96.6	63.0	33.9	22.3	26.5	48.3	76.6	103.5	117.4	130.6	963.3

Recent rainfall years have been put into historical context using the Cumulative Rainfall Departure (CRD) method. This method is a summation of the monthly departure of rainfall from the long-term average monthly rainfall. A rising trend in the CRD plot indicates periods of above average rainfall, whilst a falling slope indicates periods when rainfall is below average. Figure 4.1 presents the CRD graph for the region using BoM daily rainfall data.

The CRD graph indicates that the region has experienced distinct cycles of above average and below average rainfall. The CRD graph indicates that since 1995 the site experienced a general trend of above average rainfall that lasted until 2017, with below average rainfall seen from 2017 to the present.

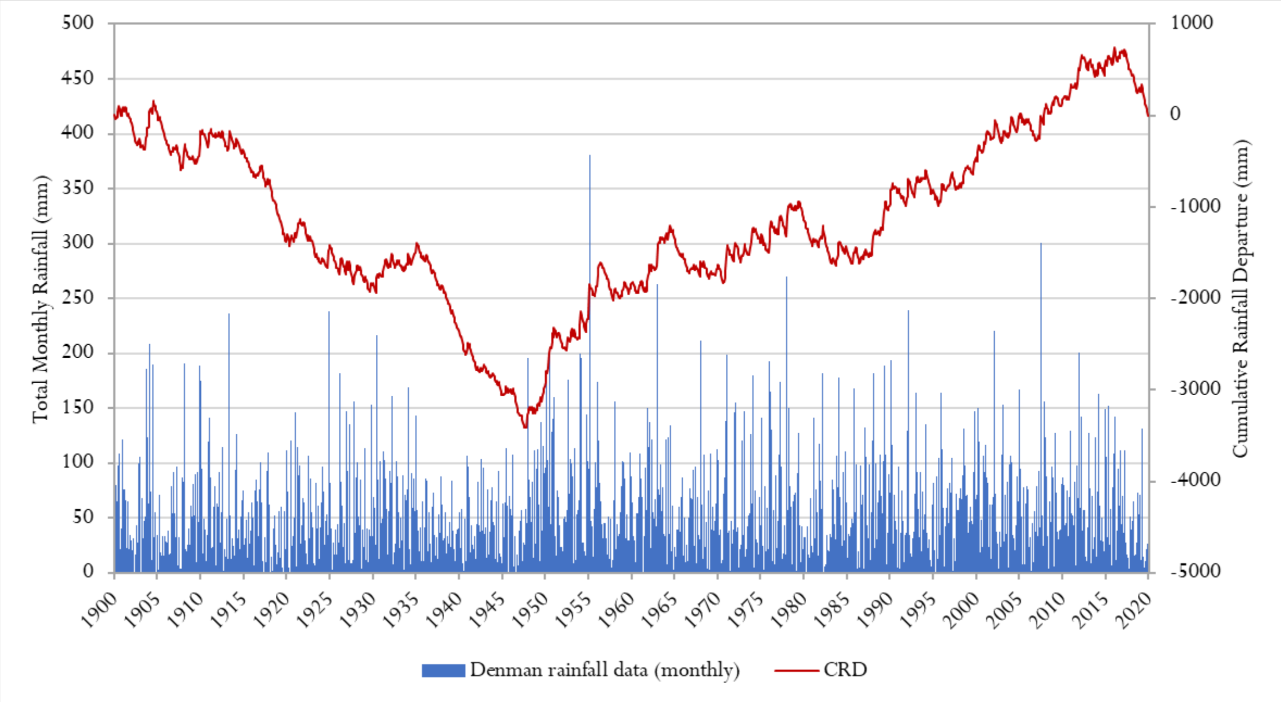


Figure 4.1 Cumulative rainfall departure

The SILO dataset also provides monthly pan evaporation and calculated evapotranspiration rates using the Morton actual evapotranspiration over land formulation, as shown in Figure 4.2. The bimodal plot indicates that higher rainfall, evaporation and evapotranspiration occur during the summer months. During the mid-year winter months, evaporation and evapotranspiration are at their lowest.

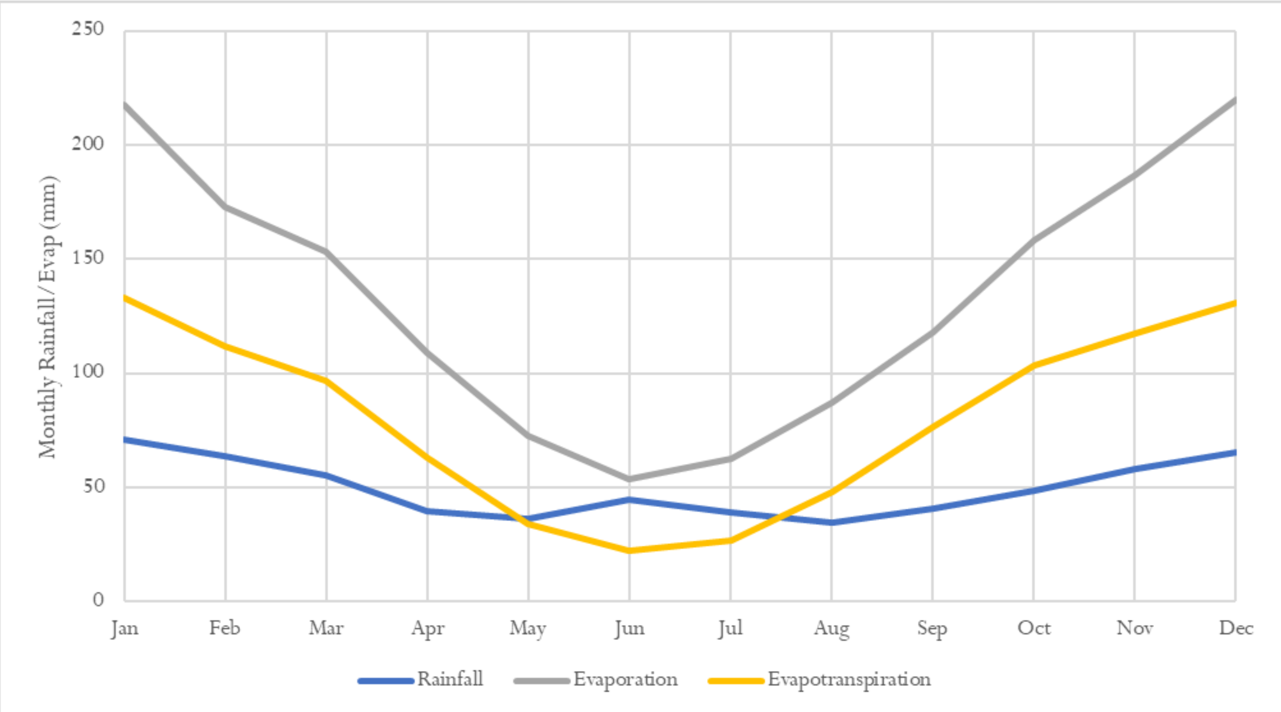


Figure 4.2 SILO average monthly rainfall, evaporation and evapotranspiration

4.2. Terrain and drainage

The Project site is located within the Hunter River catchment. Figure 4.3 shows the terrain of the Project site and its surrounds. Much of the site is located within the alluvial floodplain of the Hunter River. Towards the northern boundary of the Project, the terrain gradually rises as the alluvium thins, and consolidated sedimentary and igneous rocks outcrop to the north of the Project. The topographic elevation is approximately 88 m above the Australian Height Datum (AHD) along the banks of the Hunter River, rising to approximately 120 mAHD along the northern side of the Project.

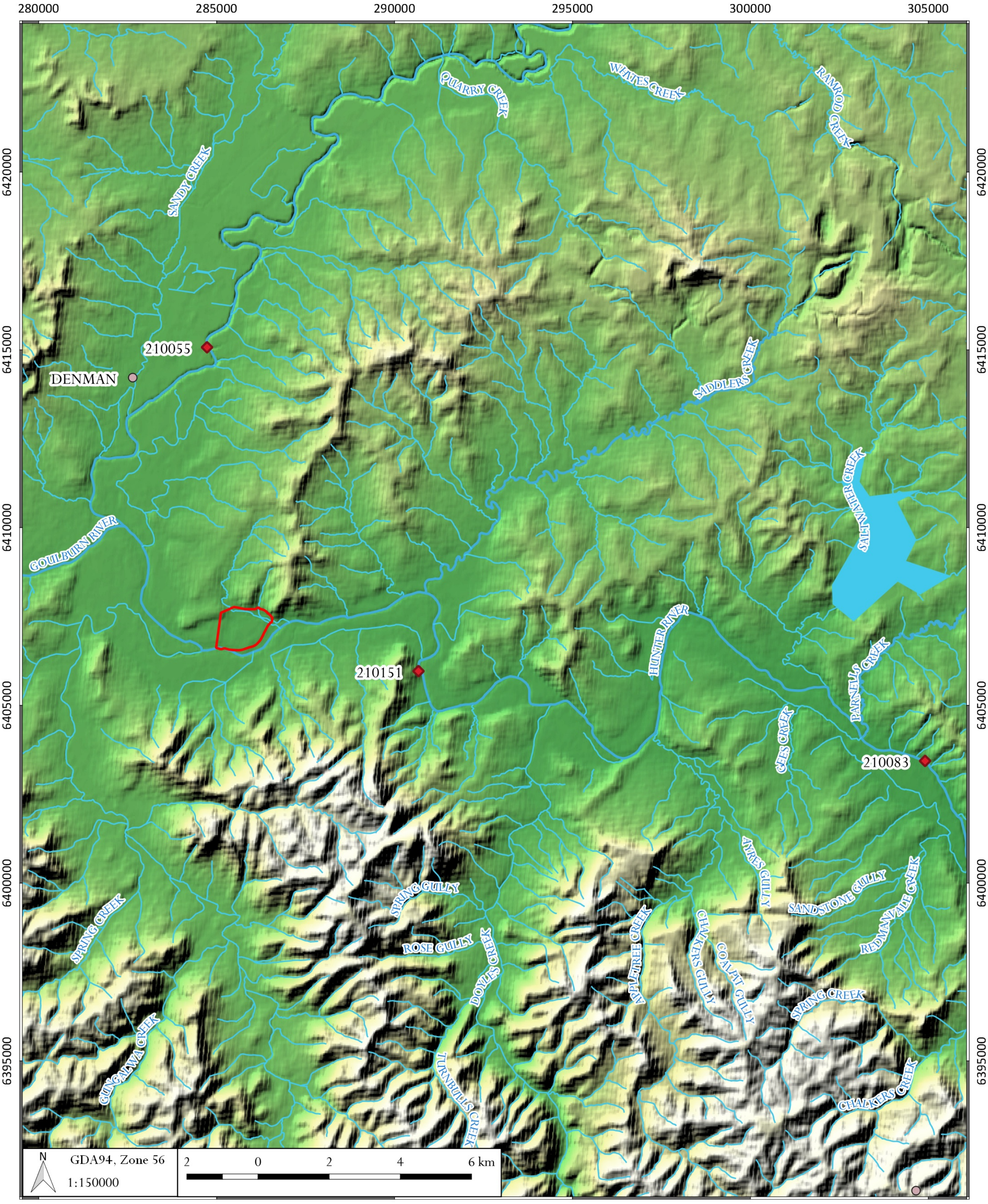
The main drainage feature associated with the Project site is the Hunter River, which forms the southern border of the Project site. The Hunter River is a perennial watercourse (i.e., permanently flowing), and flows in an easterly direction at the site. Minor drainage features at the site are limited to ephemeral creeks on the northern boundary of the site that flow during and shortly after heavy rainfall events, and discharge to the Hunter River east of the Project area.

4.2.1. Hunter River flow

Three river gauging stations are located near the Project:

- The Downstream Saddlers Creek gauge (GS 210151) is located approximately 8 km downstream of the Project. The initial catchment area for the gauge station was 99 km^2, however this has been reduced due to mining activity within the catchment. Data has been collected at the site since 2015.
- The Denman gauge (GS 210055) is located approximately 13 km upstream of the Project and has a catchment area of 4,530 km^2. Data has been collected at the site from 1908.
- The Liddell gauge (GS 210083) is located approximately 29 km downstream of the Project and has a catchment area of 13,400 km^2. Data has been collected at the site since 1969.

The location of the river gauging stations in relation to the Project are shown below in Figure 4.3.



LEGEND

Elevation (mAHD)

- 0
- 100
- 200
- 300
- 400
- 500
- 600

- Project area
- Major watercourse
- Minor watercourse
- Town
- River gauging station

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Terrain and drainage

FIGURE No.
4.3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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Figure 4.4 shows the flow-duration relationship for the recorded Hunter River flows at the river gauging stations. The median flow varies between the gauging stations, ranging from a median of 333 ML/day at the Denman gauge, 234 ML/day at the Liddell gauge, to 142 ML/day at the gauge downstream of Saddlers Creek. The lower median flow seen at the downstream Saddlers Creek gauge may reflect the smaller time period the gauge covers in comparison to the Denman and Liddell gauges.

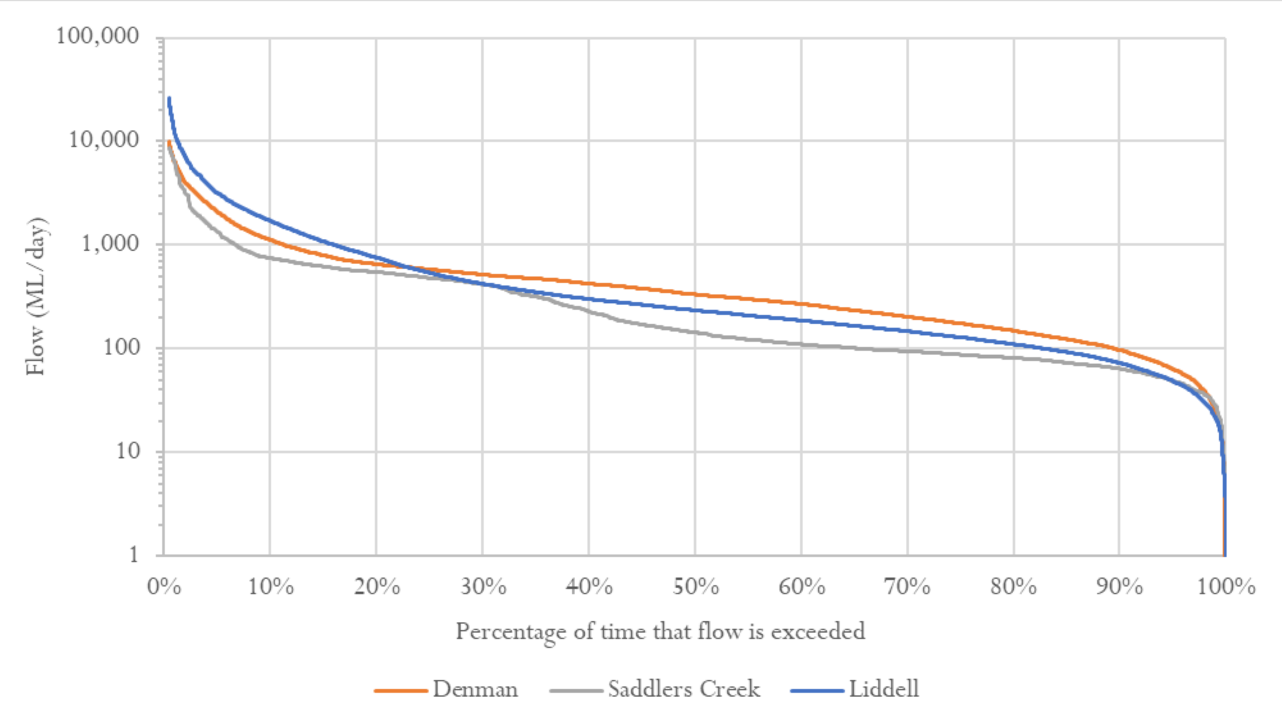


Figure 4.4 Flow-duration relationship for the Hunter River

5. Hydrogeological regime

The hydrogeological setting at the Project site and surrounding area was based on numerous data sources. The available information was used to conceptualise the geology associated with the Project and the surrounding area, and to develop the numerical groundwater model. The available data included:

- geology logs and information for existing groundwater bores from the WaterNSW monitoring database and the National Groundwater Information System (NGIS);
- publicly available geological maps and reports; and
- publicly available geological and hydrogeological reports for the region, including groundwater assessments reports for the Drayton and HVO mines, as well as the Maxwell and Spur Hill coal projects.

5.1. Geological setting

The Project is located within the Sydney Basin, which is comprised of Permian-aged sedimentary sequences. Near the Project area, the sedimentary sequence is present as the Jerrys Plains Subgroup of the Whittingham Coal Measures, which outcrops to the north of the Project area. At the surface, the Permian strata are covered with a layer of weathered bedrock (regolith). Along the Hunter River, unconsolidated Quaternary-aged alluvium overlies the Permian strata.

Figure 5.1 shows the regional surface geology in the vicinity of the project, based on the seamless geology map published by the GSNSW (Colquhoun *et al.*, 2019). This geological map is a compilation of existing 1:100,000 and 1:250,000 scale published maps.

The Project itself is located completely within the Hunter River alluvium, which is the targeted resource of the Project. The alluvium is contained within the floodplain that surrounds the Hunter River, and comprises of basal coarse sands and gravels, which are overlain by silts and clays. The alluvium is thickest in the centre (up to 20 m thick) as it runs along the course of the Hunter River and thins away from the Hunter River. The basal coarse sands and gravels are highly permeable, resulting in the alluvium where the basal sediments are present being considered a "highly productive" groundwater source. As the alluvium thins away from the Hunter River, the basal coarse sands and gravels disappear, and the alluvium is composed of only silts and clays. In these areas, the alluvium is generally unsaturated, and is therefore considered to be a "less productive" groundwater source.

A review of the lithological logs for the holes drilled within the extent of the planned Project area indicates that the alluvium is generally composed of sand and gravel, ranging from 8 m to 14 m in depth from north to south. A line of bores drilled across the northern boundary of the Project illustrates the "pinching" of the coarser sands and gravels, as the thickness of the coarser sands and gravels decreases from 10 m to absent over a distance of 30 m.

The underlying Permian strata consists of interbedded sandstone and siltstone, with minor shale and coal. Where the Permian strata outcrops at the surface it has been weathered to form a regolith. The depth of the regolith ranges from 1 m to 16 m in the vicinity of the Project, with an average depth of 5 m (Wilford *et al*., 2018).

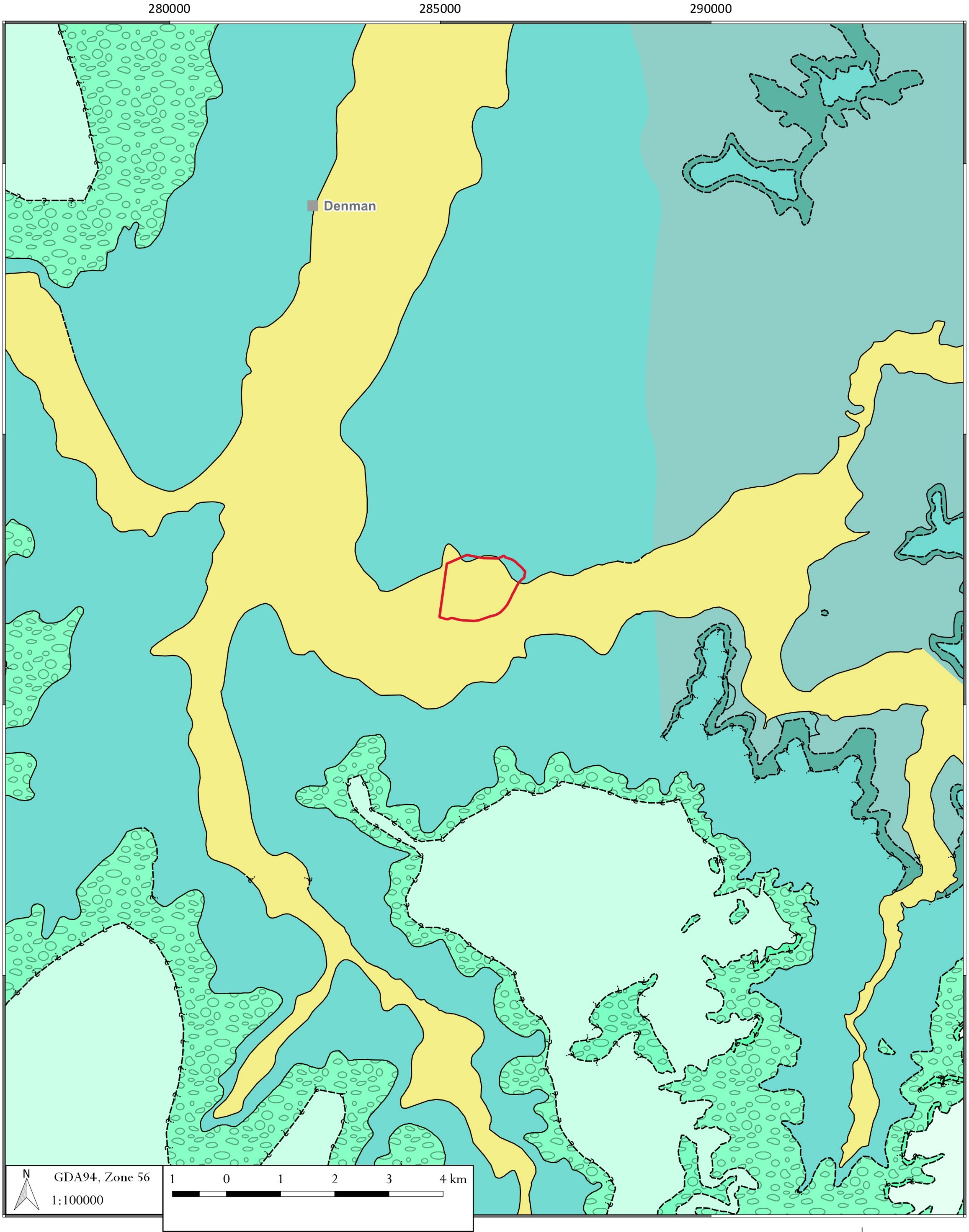
5.2. Groundwater occurrence and use

Within the region, the Hunter River alluvium comprises the main aquifer used for water supply purposes. This aquifer generally yields sufficient groundwater for agricultural and irrigation purposes, except on the margins of the alluvium where the sediments are thin or unsaturated, that is "less productive".

The underlying Permian bedrock is considered to be a porous rock aquifer of low resource potential. The coal seams are typically more permeable than the sandstone and siltstone due to flow through fractures associated with joints and cleats in the coal (HydroSimulations, 2019).

Within the alluvium, groundwater flows along the course of the Hunter River, reflecting that the Hunter River is the primary control on groundwater recharge and discharge, and hence on groundwater flow directions and heads, in the Hunter River alluvium.

Groundwater is considered to flow between the alluvium and the underlying Permian strata, however this is likely to be limited due to the lower permeability of the Permian bedrock. Groundwater flows through the Permian strata in a southerly direction that reflects the local topography, and is discharged through the alluvium and creeks and by evapotranspiration at significantly slower rates than the alluvium.



LEGEND **Geology**

- Alluvium
- Newcastle Coal Measures
- Widden Brook Conglomerate
- Banks Wall Sandstone
- Jerry Plains Subgroup/Wittingham Coal Measures
- Watts Sandstone/Illawara Coal Measures

- Project area
- Town

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Surface geology

FIGURE No.
5.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.

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5.2.1. Hunter River alluvium

Groundwater levels within the Hunter River alluvium in the vicinity of the Project range from 0.6 m (GW012984) to 21 m (GW065521) below ground, and groundwater elevations range between 102.6 mAHD (GW023481) and 72.9 mAHD (GW065521). The location of these bores is shown in Figure 5.3. This indicates that groundwater flow within the alluvium generally follows the direction of surface water flow, in a south to easterly direction.

An excellent groundwater level record is available from government monitoring bore GW040959, which is screened within the Hunter River alluvium. Groundwater measurements at GW040959 date back to 2006 and reflect nearly 14 years of continuous daily measurements. The hydrograph for this monitoring bore is shown below in Figure 5.2, and shows that the groundwater in the alluvium fluctuates by 3 m over the monitoring period. The groundwater levels are relatively stable over time (Figure 5.2), despite periods of above and below average rainfall as illustrated by the CRD. This indicates that there is a degree of recharge to the alluvium from the Hunter River, which has regulated flow.

However, comparison of the groundwater levels to rainfall indicates that the groundwater levels in the alluvium are highly responsive to rainfall events, suggesting that rainfall is also a source of recharge.

Additionally, comparison of the groundwater levels in GW040959 with the water levels in the Hunter River at the closest gauging station (GS 210055, located upstream at Denman) shows a correlation between flow spikes in the Hunter River and increased groundwater levels. This is strong evidence of groundwater connectivity between the Hunter River and the alluvium.

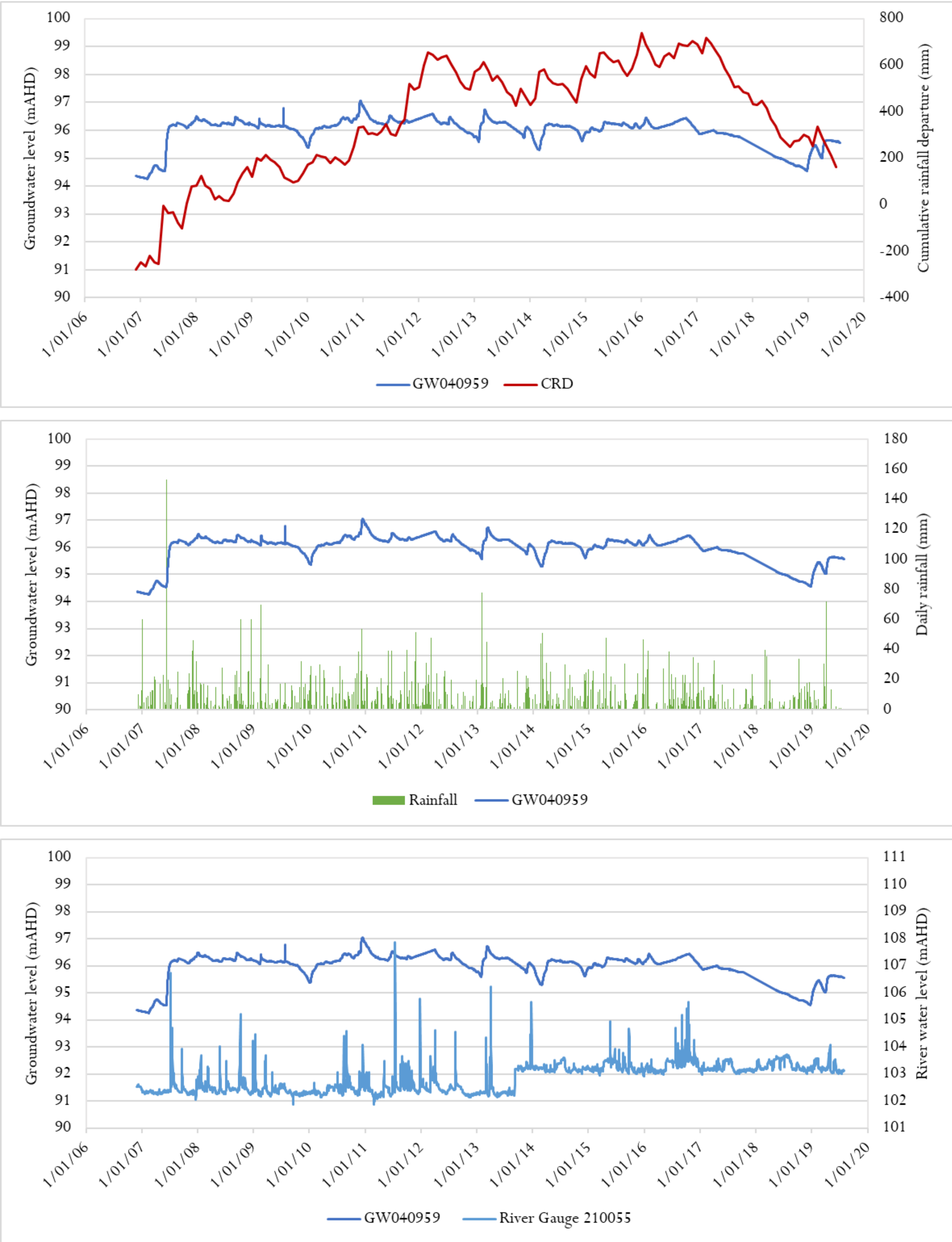
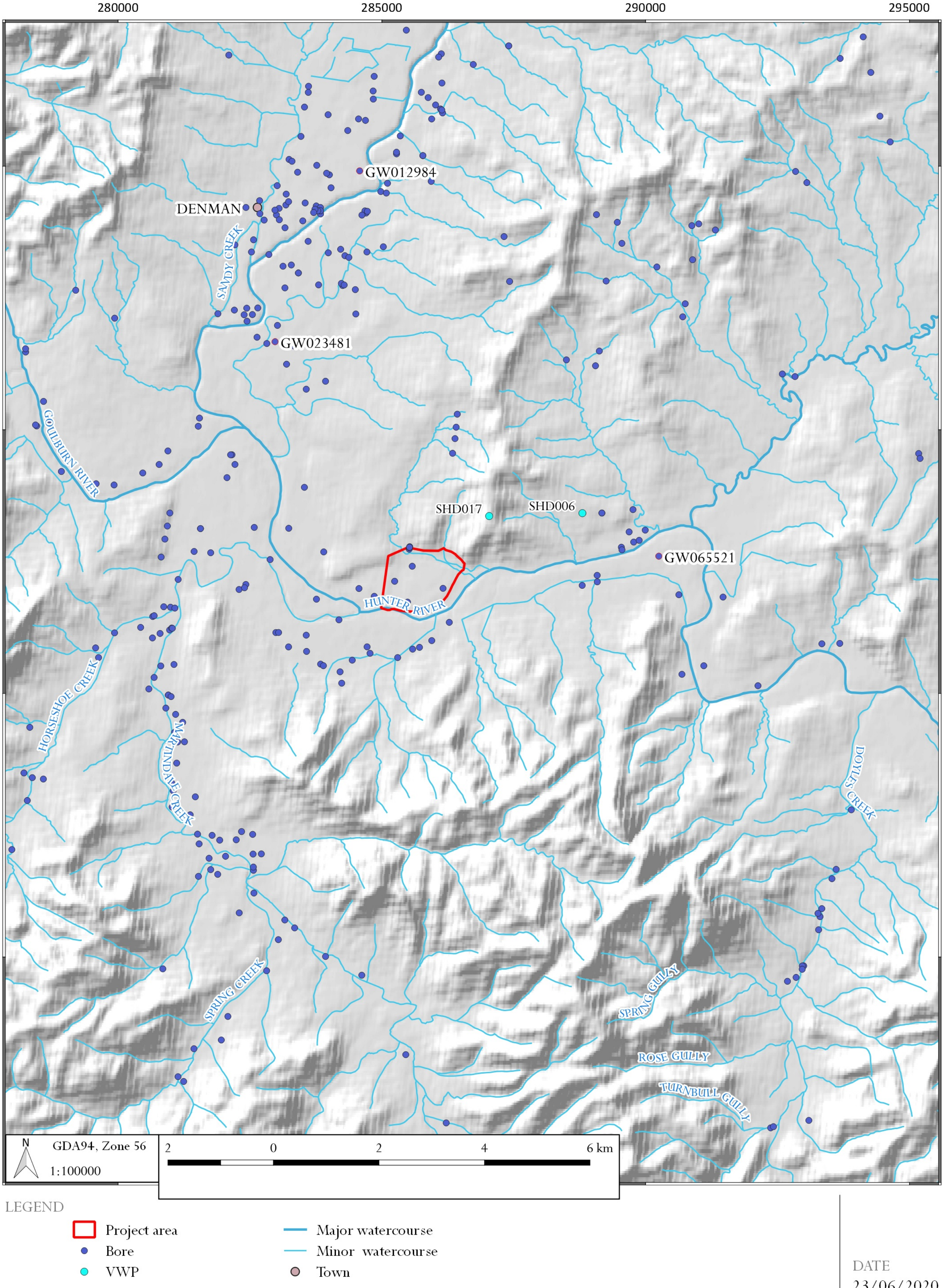


Figure 5.2 GW040959 hydrograph - Hunter River alluvium



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Bore locations

FIGURE No.
5.3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
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5.2.2. Permian strata

The Permian-aged Whittingham Coal Measures underlie the Project area and comprise interbedded sandstone, siltstone with minor beds of shale and coal. Groundwater within the Permian strata is primarily associated with coal seams due to their secondary porosity from fractures and cleats in the coal. The sandstones and siltstones generally have a low permeability, and due to the stratified nature of the stratigraphy have a very low vertical hydraulic conductivity.

Through a data sharing agreement, the groundwater levels for two (VWP) vibrating wire piezometers (SHD006 and SHD017) installed at the Spur Hill Project (owned by Malabar Coal) were made available to **hydrogeologist.com.au**. The location of the VWPs is shown above in Figure 5.3.

The shallowest VWP installed in SHD006 was at 65 m, in the Whybrow Seam Overburden of the Whittingham Coal Measures. Monitoring data for this VWP was available from September 2013 until March 2020. The hydrograph for SHD006 (Figure 5.4) shows a general trend of declining groundwater levels in the Permian strata. However, comparison of the groundwater levels to rainfall indicates that the groundwater levels in the Permian strata are responsive to high rainfall events, suggesting that the Permian strata receives recharge in some form from rainfall events.

Additionally, comparison of the groundwater levels at SHD006 with the water levels in the Hunter River at the closest gauging station (GS 210151, located downstream of Saddlers Creek) shows a correlation between flow spikes in the Hunter River and increased groundwater levels. This suggests that there is some level of groundwater connectivity between the Hunter River and the underlying Permian strata.

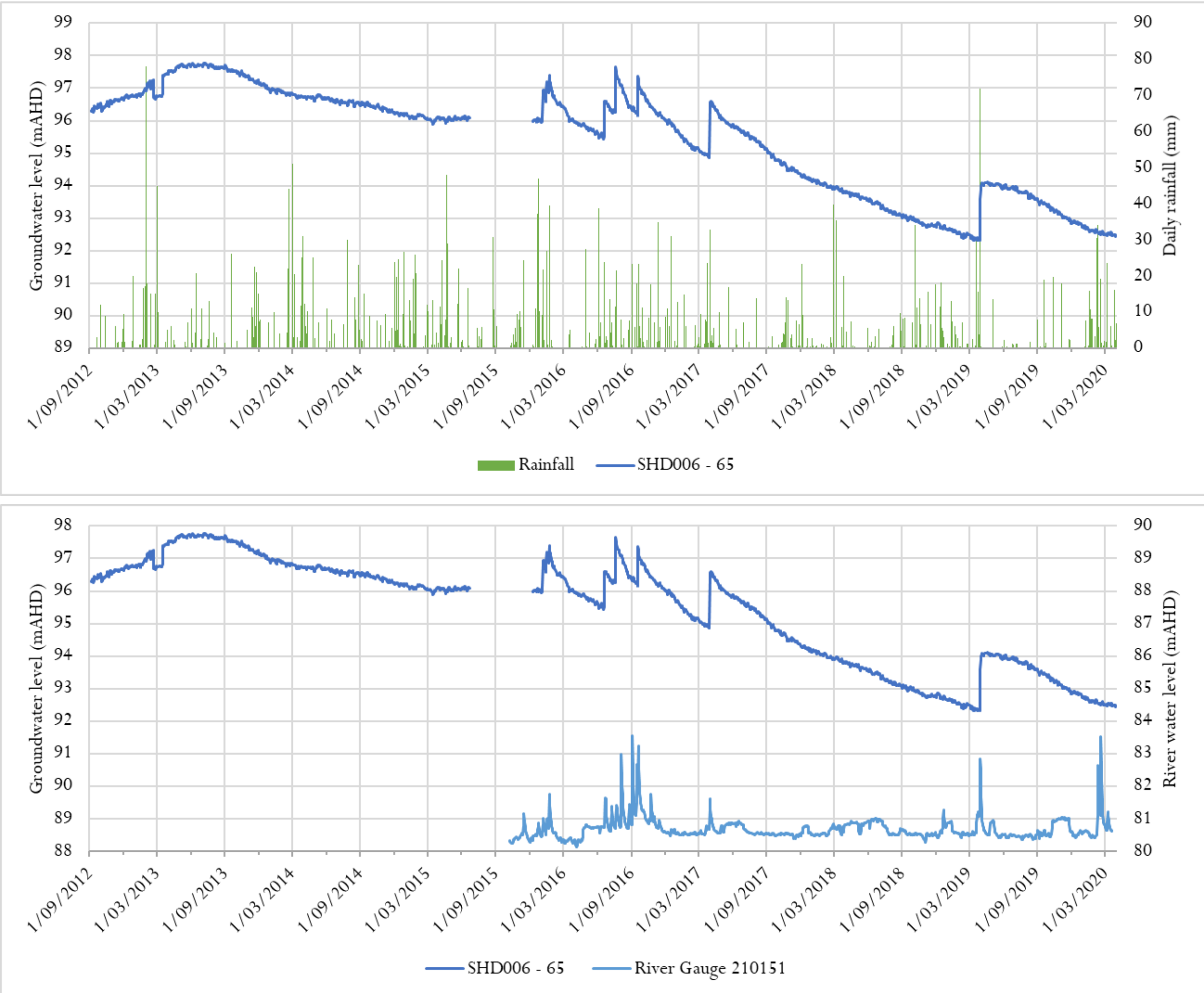


Figure 5.4 Hydrograph - Permian strata

The shallowest VWP installed in SHD017 was at 175 m, in the Newcastle Coal Measures. Monitoring data for this bore is available from 2013 to present. The heads in the bore slowly decrease over a period of 12 months after monitoring begins, starting at 175 mAHD, before slowly stabilising at 95 mAHD. Head levels at this VWP have remained consistently at around 95 mAHD for a period of approximately three years from mid-2017 until the present (2020). Due to the depth of the interval screened, the data for this bore is considered to be too deep to be of relevance in this assessment.

5.2.3. Groundwater use

Information on registered bores within the vicinity of the Project was obtained from the WaterNSW database (WaterNSW, n.d.) and the Australian Groundwater Explorer database (Bureau of Meteorology, n.d.). A search of these databases indicated that there were 116 registered bores within 5 km of the Project area. The registered purpose of these bores is summarised below in Table 5-1, with the location of the bores shown in Figure 5.3. Details of the registered bores are listed in Appendix A.

Table 5-1 Groundwater use

Purpose	Number	Location
Irrigation	58	Within, or close to, the mapped extent of the alluvium
Water supply	16	Within the mapped extent of the alluvium, except for 3 bores drilled to the north of the Project, which are close to minor creeks
Stock and domestic	9	Outside the extent of the alluvium, although in proximity to minor creeks
Monitoring	9	In proximity to the edge of the Hunter River alluvium
Exploration	4	Within the extent of the Project
Unknown	20	Within, or close to, the extent of the alluvium
Total	**116**	

5.2.4. Groundwater dependant ecosystems

The nearest high-priority groundwater dependent ecosystem (GDE) listed in the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Source 2009 is the Wappinguy Spring, located near Merriwa (as shown in Figure 5.5). However, as this site is located over 40 km to the north-west, the Project poses no risks to any known high-priority GDEs.

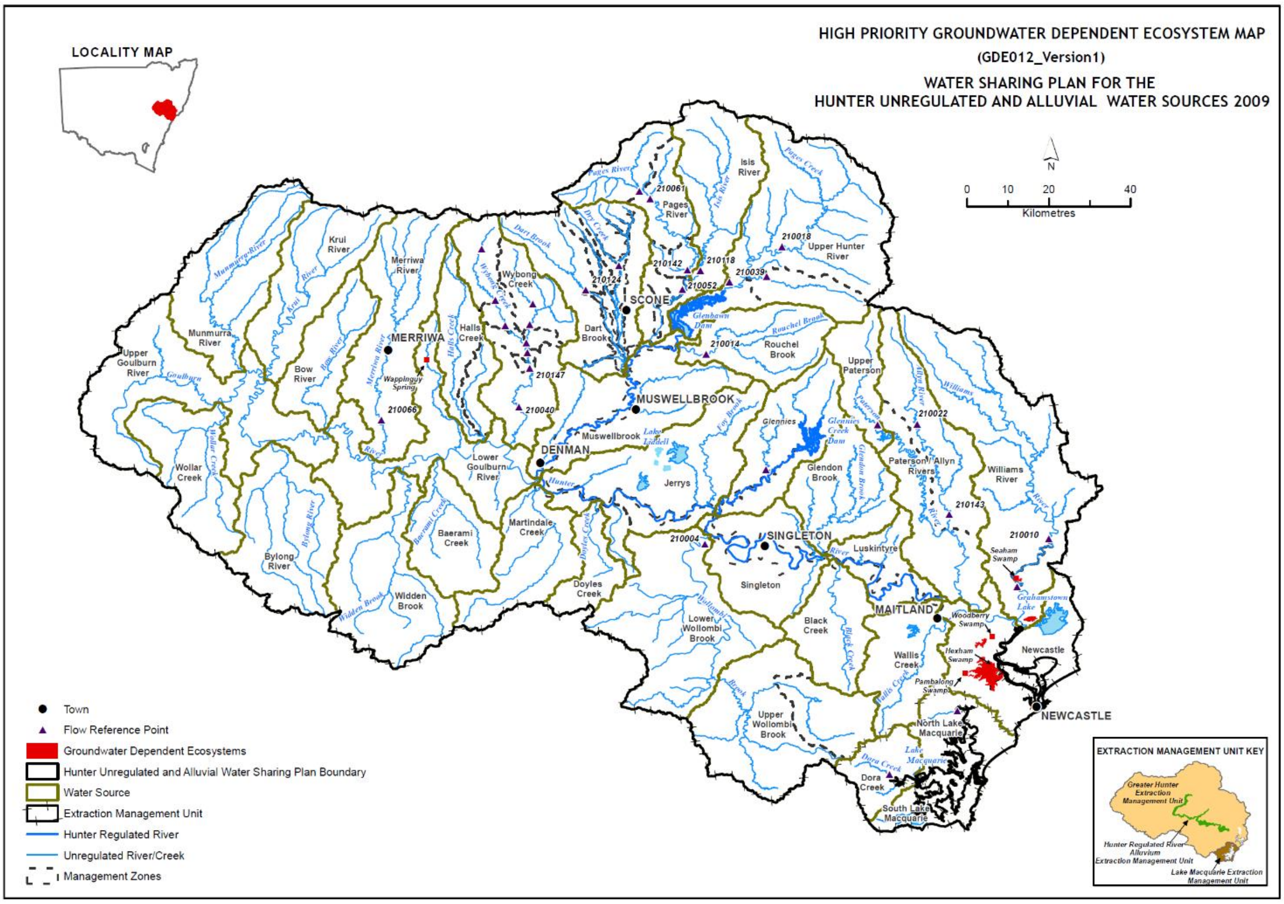
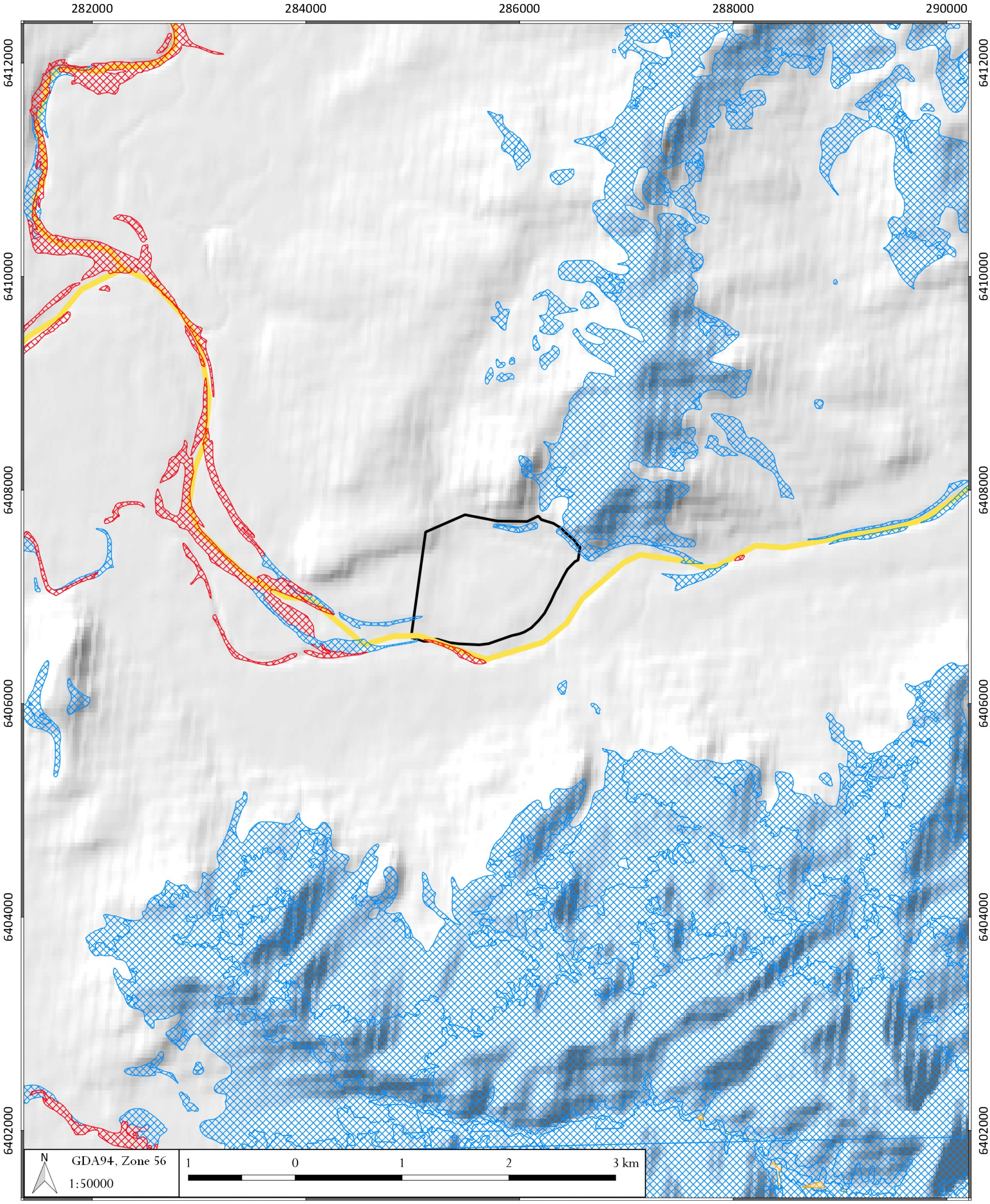


Figure 5.5 High-priority GDEs listed in the Hunter Unregulated and Alluvial WSP

The National Atlas of Groundwater Dependent Ecosystems (GDE Atlas) comprises maps that show the location of GDEs across Australia (Bureau of Meteorology, 2019). Information in the GDE Atlas includes GDEs identified in previous studies, as well as potential GDEs identified through spatial analysis. GDEs mapped in the Atlas are mapped as one of the following classifications:

- High potential groundwater dependent ecosystem;
- Moderate potential groundwater dependent ecosystem; and
- Low potential groundwater dependent ecosystem.

Figure 5.6 shows a map of the potential GDEs as listed in the GDE Atlas for the Project area and surrounds. The Hunter River (which runs along the southern boundary of the Project area) is identified as a known aquatic GDE, however there are no other areas of high or moderate GDE potential within the Project area. Small areas of low GDE potential are located towards the northern boundary of the Project extent, and in the south-western corner of the Project area. These areas align with areas of vegetation that can be observed in satellite images of the area, which aligns with their classification in the GDE Atlas as areas of woodland.



LEGEND

Terrestrial groundwater dependent ecosystem

- High potential GDE - from regional studies
- Low potential GDE - from regional studies
- Moderate potential GDE - from regional studies

Aquatic groundwater dependent ecosystem

- River

Project area

DATE
17/06/2020

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Dalswinton Quarry - Groundwater Assessment (4047)

Groundwater dependent ecosystems

FIGURE No.
5.6

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.
\\hydro-nas\Data\4000_Projects\4047_HDB_Dalswinton Quarry GIA\3_GIS\Workspaces\AC_05_01_4047_GDEs.qgz

5.3. Groundwater quality

Within a 5 km radius of the Project, 33 registered groundwater bores had a total of 55 salinity readings. The earliest salinity measurement was taken in 1965, while the most recent measurement dated from 2013. With the exception of GW029659 (which is installed in Permian strata), all the salinity measurements are associated with alluvium. The salinity measurements in the alluvium range from 8 µS/cm to 6,700 µS/cm, with a median value of 1,225 µS/cm. The salinity measurement in the Permian strata was 3,940 µS/cm.

Generally, the salinity in the alluvium is lowest towards the centre of the Hunter River alluvium, where the groundwater is in closer contact with the Hunter River. Towards the edges of the alluvium, the salinity readings increase. There does not appear to be any correlation between the time of year at which the measurement was taken and the salinity, indicating that the salinity levels are not affected by rainfall.

This conclusion is supported by the observations of Kellett *et al.*, (1989), which concluded that geology is the dominant control on the chemistry of the upper Hunter Valley groundwater, and that background salinity values originated from the Permian strata.

Figure 5.7 shows a plot of the salinity measurements over time. Readings taken in the alluvium are shown in blue, while the salinity measurement from the Permian strata is shown in red.

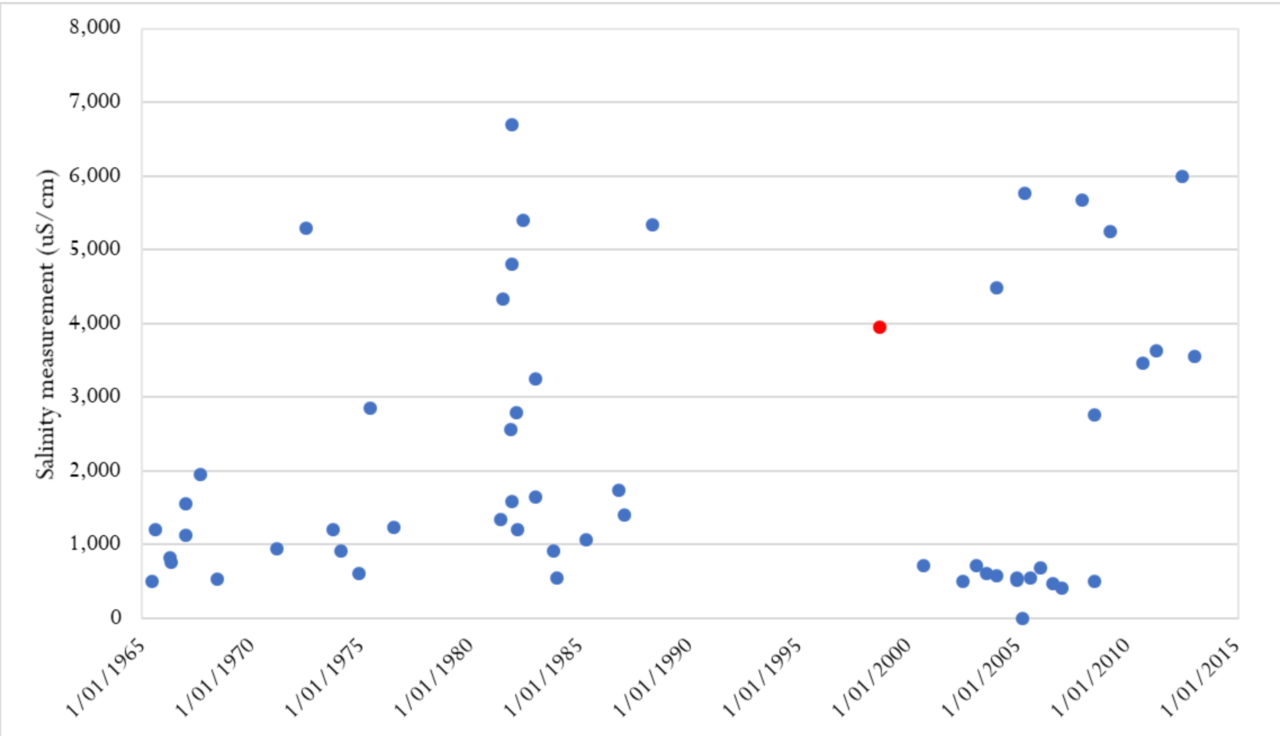

Figure 5.7 Groundwater quality data

6. Groundwater conceptualisation

This section describes the processes that control and influence the storage and movement of groundwater through the hydrogeological system. The groundwater regime in the Project area consists of three hydrostratigraphic units, including:

- alluvium associated with the Hunter River;
- shallow weathered bedrock (regolith); and
- deeper, fresh Permian strata.

Table 6-1 summarises the dominant lithology and aquifer category for each hydrostratigraphic unit.

Table 6-1 Hydrostratigraphic summary

Formation	Dominant lithology	Aquifer type/category
Hunter River alluvium	Sands and gravels	High yield aquifer
Regolith (weathered Permian)	Sandstone/siltstone	Poor yield aquifer
Permian strata	Sandstone/siltstone	Poor yield aquifer to aquitard

Recharge to the groundwater system is primarily from direct rainfall, with additional recharge into the alluvium due to seepage from the Hunter River and the underlying Permian strata. Due to the higher permeability and storage of the alluvium, a larger volume of groundwater recharge occurs to the alluvium compared to the regolith and bedrock. Within the regolith, lower levels of recharge are expected in the topographically higher or steeper areas, due to a greater amount of surface runoff occurring in those areas after rainfall. Conversely, topographically lower or flatter areas of regolith are expected to have greater levels of recharge due to a lower amount of surface runoff. Irrigation, while present in the Hunter Valley, is not considered to be a significant factor in recharge for the purpose of this conceptualisation.

Although groundwater levels are sustained by recharge, they are controlled largely by surface topography, surface water levels, and aquifer hydraulic conductivity. A groundwater high is seen beneath the ridge to the north of the Project area and a hydraulic gradient occurs towards the lower lying alluvial lands adjacent to the Hunter River. Groundwater flows from this high towards the lower head of the Hunter River.

As groundwater flow occurs from these elevated areas, it discharges to the Hunter River where the groundwater head is above the river level. Evaporation and/or evapotranspiration through vegetation are other discharge mechanisms and take place where the water table is within a few metres of ground surface.

Discharge from the Hunter River alluvium is expected to be primarily from groundwater usage and evaporation and/or evapotranspiration if the water table is within a few metres of ground surface. Discharge from the regolith and Permian strata is expected to consist of seepage to the alluvium, as well as evaporation and/or evapotranspiration where the water table is close to the surface.

On a regional scale, extraction from the Hunter River alluvium occurs via irrigation and stock/domestic bores. However, relatively minimal extraction of groundwater from the Hunter River alluvium occurs within the immediate vicinity of the Project.

7. Numerical modelling

The objective of the groundwater modelling was to produce a model that suitable represented the current understanding of the groundwater environment and predict changes in the groundwater conditions due to the development of the Project.

The design, construction and calibration of the model was tailored to meet these objectives. It is considered that the model objectives have been addressed and it is considered fit for purpose. The objectives of the modelling, based on the Australian modelling guidelines (Barnett *et al*., 2012), were to:

- simulate measured groundwater levels at each observation bore;
- simulate groundwater drawdown during quarrying;
- predict any changes to surface flows and other groundwater users due to the Project; and
- identify areas of potential risk where groundwater impact mitigation/control measures may be necessary.

This section provides a summary of the design and development of the numerical groundwater model.

7.1. Model development

7.1.1. Software

MODFLOW-USG (Panday et al., 2015), based on the U.S. Geological Survey MODFLOW-2005 groundwater modelling code, was used as the modelling code. MODFLOW-USG simulates groundwater flow using a generalised control volume finite-difference approach, which allows non-orthogonally structured grids to be used for groundwater flow simulations (Panday *et al*., 2013). The MODFLOW-USG input mesh (or grid) was constructed using AlgoMesh (Merrick, 2016).

The model calibration and parameter sensitivity analysis was undertaken using PEST (Doherty, 2019a, 2019b) and BeoPEST (Doherty, 2012).

7.1.2. Hydrogeological domains

The model domain extends for approximately 11 km from east to west, and 8 km from north to south, covering an area of approximately 57 km^2. The extent of the model domain is relatively large in comparison to the size of the Project in order to cover the extent of the alluvium in the vicinity of the Project, and to ensure boundary conditions do not influence the model predictions.

A polygonal mesh was created to cover the model domain and was refined around the planned extent of mining within the Project area, as well as surface streams, the boundary of the alluvium, and observation points (groundwater bores). Each layer within the model contains 12,694 nodes. The extent of the model mesh, illustrating the refinement around the various spatial definition features, is shown below in Figure 7.1.

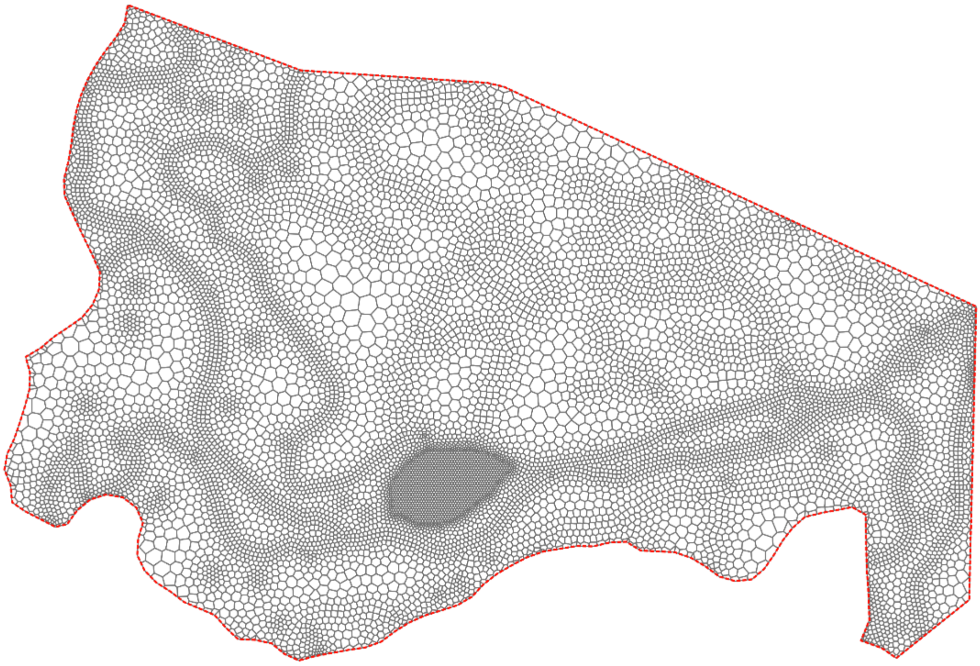

Figure 7.1 Model mesh

The model represented the key hydrostratigraphic units as two layers. The top layer (Layer 1) represents the alluvium and regolith across the model domain, with the base layer (Layer 2) representing the underlying Permian strata to a depth of 50 m below the base of Layer 1. The numerical model was built around the conceptual understanding summarised in Section 6.

Layer 1 was split into two 'zones' to delineate the extent of the alluvium and regolith. The extent of each zone is shown below in Figure 7.2. The number of nodes, as well as the thickness, for each zone is shown below in Table 7-1. Layer 2 was assigned a consistent zone number across the whole layer.

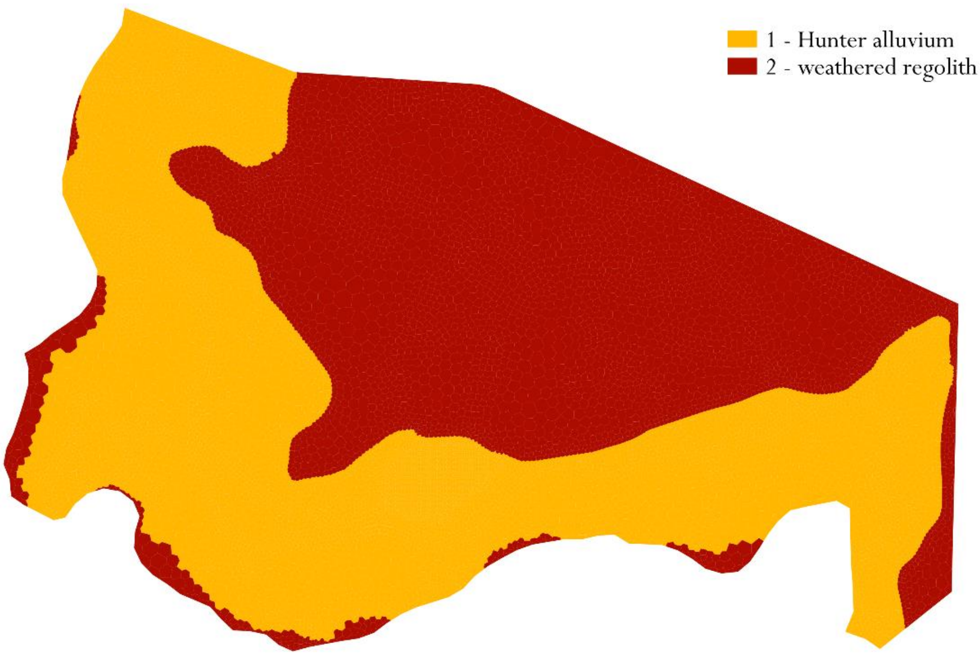

Figure 7.2 Zones applied to Layer 1

Table 7-1 Zone thickness and node count

Layer	Zone	Description	# Nodes	Thickness (m)		
				Minimum	Average	Maximum
1	1	Hunter River alluvium	8480	2.16	9.84	19.58
1	2	Weathered regolith	4214	2.03	6.47	17.15
2	3	Permian strata	12694	50	50	50

The initial hydraulic properties assigned to each layer and zone in the numerical model are shown below in Table 7-2. The initial hydraulic parameters were based on publicly available hydrogeological information for projects located within the vicinity of the Project (AGE Consultants, 2017, 2015; HydroSimulations, 2019, 2013).

Table 7-2 Initial hydraulic properties

Layer	Zone	Description	Kx (m/d)	Kz (m/d)	Ss (m^{-1})	Sy
1	1	Hunter River alluvium	5	1.5	0.000002	0.5
1	2	Weathered regolith	0.1	0.01	0.000002	0.05
2	3	Permian strata	0.001	0.00005	0.000002	0.001

7.1.3. Temporal discretisation and output control

Time steps were applied to the numerical model. The length of the stress periods and the time steps associated with them are detailed below in Table 7-3. Each stress period has a variable-length time step with a minimum time step of 0.1 of a day and a maximum time step length of half the stress period length.

Table 7-3 Temporal discretisation – calibration and predictions

Stress period	Stress period length	Dates	Modelling phase
1	-	Pre-2020	Calibration
1 - 25	1 year	01/01/2020 - 31/12/2045	Prediction - mining

7.1.4. Boundaries

'No-flow' boundary conditions were applied to the northern boundary of the model, where the regional groundwater flow system is perpendicular to the model boundary, and the southern boundary of the model, along the southern edge of the alluvial aquifer. Model boundaries that cut across the alluvial aquifer were given general head boundaries which enabled upstream inflow and downstream outflow from the alluvial aquifer. There was no cross-boundary flow applied to the numerical model.

Figure 7.3 illustrates where the various boundary conditions were applied to the numerical model.

Figure 7.3 Model boundary conditions

7.1.5. Surface drainage

Zone numbers were applied to the numerical model to represent the surface drainage across the model extent. The surface drainage included the Hunter River (Zone 1), Goulburn River (Zone 2), Martindale Creek (Zone 3) and Saddlers Creek (Zone 4). Minor, ephemeral drainage was also modelled (Zone 5). The location of the rivers and creeks across the model extent is shown below in Figure 7.4.

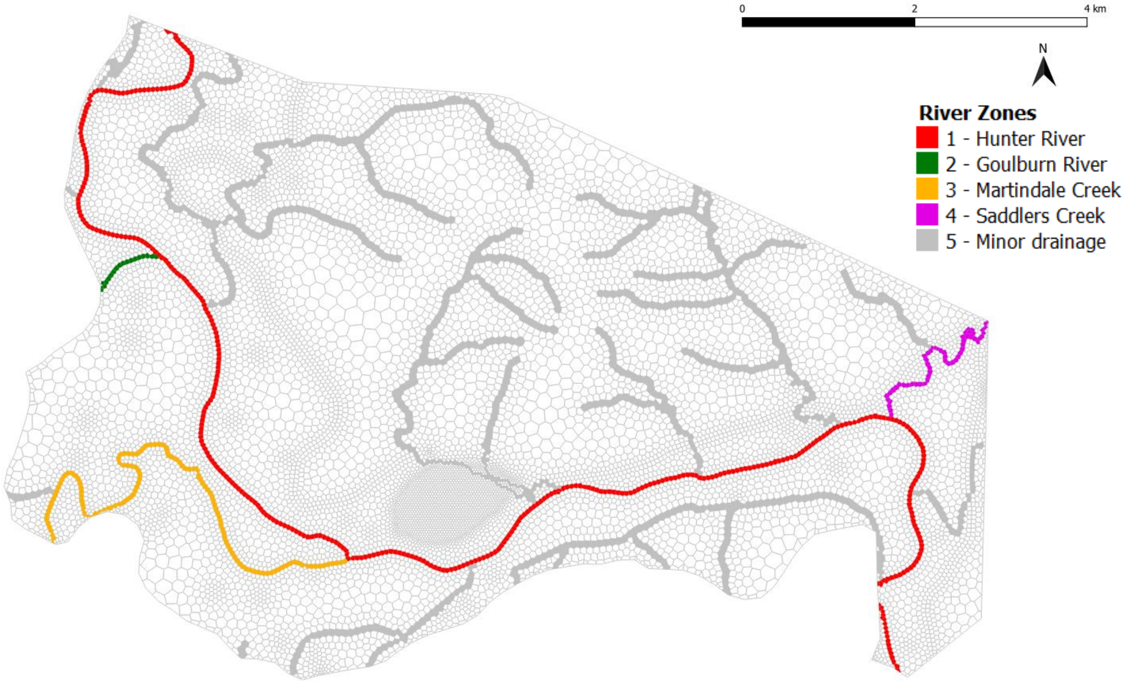

Figure 7.4 Surficial drainage zones

The rivers and creeks were modelled using the MODFLOW River (RIV) package. The parameters used in model for the RIV package are listed below in Table 7-4.

Table 7-4 River package parameters

Zone	Description	# Cells	Bed Kz (m/d)	Channel width (m)	Incision depth (m)	Bed thickness (m)	Water depth (m)
1	Hunter River	394	15.0	10.0	7.1	5.0	1.0
2	Goulburn River	19	15.0	10.0	7.1	5.0	1.0
3	Martindale Creek	136	15.0	10.0	7.1	5.0	0.1
4	Saddlers Creek	58	0.1	5.0	0.5	1.0	0.0
5	Minor drainage	946	0.1	1.0	0.5	1.0	0.0

Steady-state river stage elevations on the Hunter River were based on the long-term average from gauging stations at Denman (GS 210055) and Liddell (GS 210083). For the transient simulation, river stage levels were varied monthly based on the historical monthly average levels from the gauging stations.

7.1.6. Recharge

An annual rainfall of 612.59 mm/year was applied to the numerical model, based on the annual average rainfall between 1995 and 2019 from the SILO climate dataset discussed in Section 4.1. Recharge was applied to the numerical model using the MODFLOW Recharge (RCH) package.

The rainfall recharge to the top layer of the model was assigned as shown in Table 7-5. The regolith was split into two recharge zones - a zone representing the colluvium in the lower-lying areas of the model domain, and a second zone representing the regolith in areas of steeper slopes and ridges in the northern section of the model domain. This was to represent the higher amount of rainfall runoff seen in the steeper areas of the model domain, resulting in lower levels of recharge to groundwater in these areas. The various recharge zones are illustrated in Figure 7.5

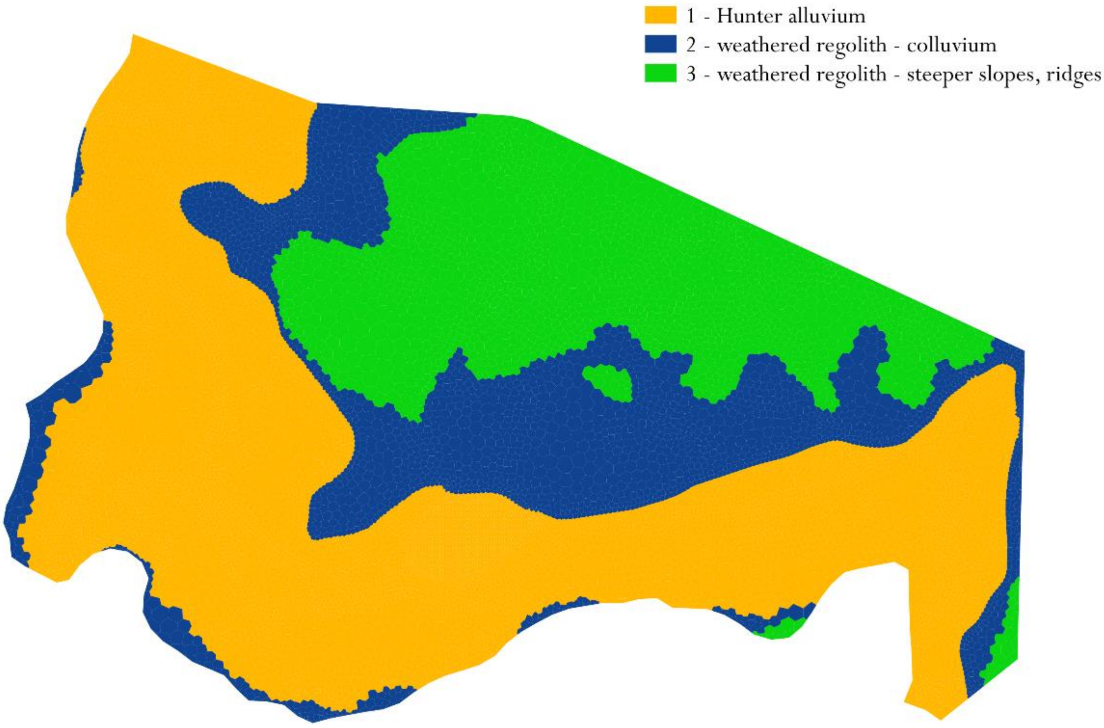

Figure 7.5 Rainfall recharge zones

Table 7-5 Recharge factors

Zone	Description	Recharge factor
1	Hunter River alluvium	0.0900
2	Weathered regolith - colluvium	0.0550
3	Weathered regolith - steeper slopes, ridges	0.0060

7.1.7. Evapotranspiration

An annual evapotranspiration rate of 950 mm/year was applied to the numerical model, based on the annual Morton's actual evapotranspiration from the SILO climate dataset discussed in Section 4.1. Evapotranspiration was applied to the numerical model using the MODFLOW Evapotranspiration (EVT) package.

Evapotranspiration was applied to Layer 1 of the numerical model, with the alluvium and regolith represented as separate zones. The factors used in the EVT package are shown below in Table 7-6. The EVT rate factor was applied at the water table at the top of Layer 1 and decreased linearly as the water table height drops below the surface until it equals zero at the extinction depth. The extinction depth represents the depth where below evapotranspiration will not occur.

Table 7-6 Evapotranspiration factors

Zone	Description	EVT rate factor	Extinction depth (m)
1	Hunter River alluvium	0.95	1.5
2	Weathered regolith	0.73	2.5

7.1.8. Extraction due to quarrying

In the vicinity of the Project, there is no significant groundwater abstraction apart from small-scale stock and domestic use. Therefore, abstraction from water supply bores has not been represented within the numerical model.

The extent of the quarrying area within the Project was divided into 25 equal areal sections, to represent the annual production over the projected 25-year life of the Project. During the transient stress periods representing the life of the quarry operations, each areal section was removed from Layer 1, representing the quarrying (removal) of the alluvial material. Groundwater extraction due to mining was simulated through an increased amount of evaporation in the area being mined, and was calculated as part of the EVT package discussed in Section 7.1.7.

7.2. Model calibration

The groundwater model was calibrated to replicate steady state conditions (1930 to 2015). The calibration was based upon existing groundwater levels at bores located within the model domain, that were considered representative. The groundwater bores used in the calibration are listed in Table 7-7, along with their date of drilling and the standing groundwater level (head) measured at that time.

Table 7-7 Observation points used as calibration target points

Bore ID	Easting	Northing	Elevation (SRTM)	Elevation (model)	Drill date	Measured head (mAHD)
GW010053	283897	6407685	101.02	101.04	1/06/1952	92.62
GW013353	283234	6408133	100.36	100.38	1/10/1955	91.86
GW016838	281138	6407163	104.04	104.06	1/12/1958	102.24
GW018743	285582	6405842	96.36	96.57	1/09/1960	89.06
GW018790	284855	6406843	98.45	98.44	1/01/1960	89.95
GW018791	284565	6406991	100.49	100.58	*Unknown*	92.29
GW019602	282063	6409094	103.84	103.87	1/09/1962	94.04
GW019611	281561	6408128	102.65	102.81	1/01/1962	95.75
GW019615	281440	6407694	102.62	102.87	*Unknown*	95.72
GW022035	283838	6405558	98.29	98.27	1/01/1950	90.69
GW022037	284238	6405196	107.74	108.71	1/01/1930	106.84
GW022046	282420	6407068	99.17	99.13	1/10/1964	96.47
GW022047	282396	6407006	99.07	99.10	1/01/1964	95.07
GW022048	282292	6406973	99.48	99.38	1/01/1964	95.18
GW022515	284207	6405411	98.63	98.60	1/03/1965	90.83
GW023481	282974	6411672	104.46	104.43	1/03/1966	102.66
GW023487	283342	6411587	104.70	104.67	1/04/1966	96.90
GW023488	282632	6411757	104.22	104.25	1/04/1966	98.42
GW024076	283891	6405528	98.29	98.31	1/07/1965	90.39
GW024213	283565	6406106	100.13	100.13	1/08/1965	90.33
GW025617	283041	6406157	97.68	97.64	1/11/1957	88.88
GW027188	285944	6406003	97.49	97.50	1/01/1937	87.69
GW027189	286277	6406350	97.89	97.78	1/01/1954	88.09
GW029656	289759	6408488	102.30	102.64	1/01/2015	99.30
GW029707	284186	6406397	97.03	99.05	1/09/1968	87.63
GW034337	282132	6409527	103.69	103.74	1/01/1966	94.89

Bore ID	Easting	Northing	Elevation (SRTM)	Elevation (model)	Drill date	Measured head (mAHD)
GW035250	285298	6405681	96.93	96.92	*Unknown*	89.63
GW037927	283530	6408910	101.83	101.50	1/01/1934	99.13
GW045158	289876	6407905	91.38	91.30	1/02/1976	79.18
GW045160	289550	6407725	92.15	92.60	1/04/1973	81.75
GW045161	289685	6408064	92.52	92.48	1/01/1930	82.12
GW051328	283931	6410922	104.78	104.44	1/10/1980	95.78
GW053347	291466	6406829	93.68	93.67	1/08/1981	82.68
GW053349	291101	6405527	90.00	89.99	*Unknown*	80.00
GW053410	283565	6410771	102.57	102.62	27/10/1980	94.57
GW053444	288796	6407050	93.17	93.81	1/01/1982	85.87
GW053533	285712	6405875	95.99	96.35	1/01/1982	86.99
GW057804	289082	6407118	91.18	91.18	1/11/1982	83.18
GW057805	289080	6407241	92.55	92.62	1/11/1982	84.55
GW057826	282881	6407540	96.29	97.42	1/12/1983	89.79
GW059332	282818	6411637	103.16	103.65	1/07/1983	95.36
GW065521	290248	6407605	93.83	93.93	1/01/1965	72.83
GW202524	285517	6407737	*Unknown*	98.96	23/08/2012	91.86
GW202526	285521	6407764	*Unknown*	100.53	23/08/2012	93.33
GW202528	285526	6407783	*Unknown*	100.53	23/08/2012	92.23
GW271034	289990	6408086	95.62	91.36	3/04/2008	87.62

After the initial calibration run, eight bores were removed from the calibration dataset, due to the large residuals seen between the measured and modelled heads for each bore. These bores are listed below in Table 7-8.

Table 7-8 Observation points removed from the calibration targets dataset

Bore ID	Measured head (mAHD)	Modelled head (mAHD)	Residual (m)
GW022037	106.840	94.945	11.895
GW037927	99.130	93.266	5.864
GW045158	79.180	81.938	-2.757
GW051328	95.780	110.167	-14.387
GW053410	94.570	106.593	-12.023
GW065521	72.830	95.703	-22.873
GW202528	92.227	109.706	-17.479
GW029656	99.300	106.436	-7.136

The steady state calibration achieved a 7.6 % scaled root mean square (SRMS) error, which is within acceptable limits (i.e. 10%), as recommended in Barnett *et al*. (2012). The model calibration is therefore considered to be valid, with the calibration statistics shown in Table 7-9 below.

Table 7-9 Model calibration – calibration statistics

Calibration measure	Value	Unit
Number of observations	38	
Range of measured heads	22.66	m
Sum of squared residuals	173.89	m^2
Mean sum of residuals	1.72	m
Scaled mean sum of residuals	7.59	%
Root mean squared error	2.14	m
Scaled root mean squared error	9.44	%

A scatterplot of model calibration results is shown in Figure 7.6, which shows the observed and modelled heads for each bore in the calibration target dataset (as listed in Table 7-7). A good correlation between the measured and observed heads is seen, with the measured and observed heads for groundwater bores removed from the calibration dataset (as listed in Table 7-8) also shown. The residuals (difference between the measured and observed heads) are also listed for each bore in Table 7-10.

The calibrated hydraulic properties assigned to the numerical model are listed below in Table 7-11.

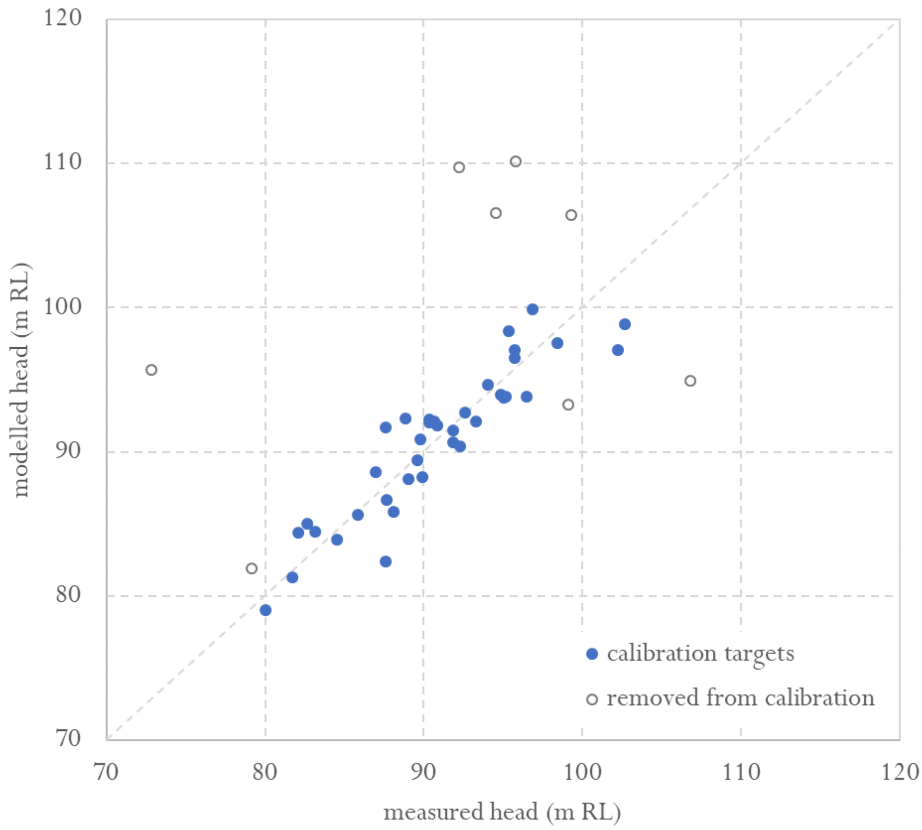

Figure 7.6 Observed and modelled heads

Table 7-10 Model calibration – steady state calibration – head residuals

Bore ID	Measured head (m RL)	Modelled head (m RL)	Residual (m)
GW010053	92.620	92.713	-0.093
GW013353	91.860	90.650	1.210
GW016838	102.240	97.062	5.178
GW018743	89.060	88.105	0.955
GW018790	89.950	88.213	1.737
GW018791	92.290	90.397	1.893
GW019602	94.040	94.651	-0.611
GW019611	95.750	96.506	-0.756
GW019615	95.720	97.081	-1.361
GW022035	90.690	92.088	-1.398
GW022046	96.470	93.846	2.624
GW022047	95.070	93.743	1.327
GW022048	95.180	93.792	1.388
GW022515	90.830	91.803	-0.973
GW023481	102.660	98.857	3.803
GW023487	96.900	99.902	-3.002
GW023488	98.420	97.572	0.848
GW024076	90.390	92.065	-1.675
GW024213	90.330	92.270	-1.940
GW025617	88.880	92.340	-3.460
GW027188	87.690	86.663	1.027
GW027189	88.090	85.864	2.226
GW029707	87.630	91.695	-4.065
GW034337	94.890	93.969	0.921
GW035250	89.630	89.438	0.192
GW045160	81.750	81.319	0.431
GW045161	82.120	84.381	-2.261
GW053347	82.680	84.988	-2.308
GW053349	80.000	79.034	0.966
GW053444	85.870	85.602	0.268
GW053533	86.990	88.579	-1.589
GW057804	83.180	84.430	-1.250
GW057805	84.550	83.908	0.642
GW057826	89.790	90.894	-1.104
GW059332	95.360	98.390	-3.030
GW202524	91.864	91.501	0.363
GW202526	93.327	92.076	1.251
GW271034	87.620	82.381	5.239

Table 7-11 Calibrated hydraulic properties

Layer	Zone	Description	Kx (m/d)	Kz (m/d)	Ss (m-1)	Sy (-)
1	1	Hunter River alluvium	12.829	1.283×10^{-1}	2.00×10^{-6}	5.00×10^{-2}
1	2	Weathered regolith	1.650	1.650×10^{-2}	2.00×10^{-6}	1.00×10^{-2}
2	3	Permian strata	0.010	1.000×10^{-5}	2.00×10^{-6}	1.00×10^{-3}

7.3. Predictive modelling

The potential impacts of the Project were assessed by making a comparison between the baseline and modelled predictions (with the Project simulated as outlined in Section 0). This allows for the simulated impact of the Project on the hydrogeological environment to be isolated from other model processes.

Two predictive model scenarios were run:

- a baseline scenario that excludes the Project (i.e., a 'no-quarrying' scenario); and
- a quarrying scenario with the Project in operation.

7.3.1. Baseline scenario

The water balance for the baseline scenario is presented in Table 7-12, averaged over the duration of the model period of 25 years. The mass balance error was 0.00%, indicating that the model is stable and achieves an accurate numerical result.

Table 7-12 Predictive mass balance - baseline scenario

	Inflow (ML/day)	Outflow (ML/day)
Recharge (RCH)	5.82	-
Evapotranspiration (EVT)	-	0.36
Rivers (RIV)	2.99	8.05
Regional groundwater flow (GHB)	-	0.40
Total	8.81	8.81
% Error	0.00%	

The water balance indicates that recharge to the groundwater system within the model averages 5.8 ML/day, with approximately 8.05 ML/day discharged via the Hunter River. The model predicted 0.36 ML/day lost to evapotranspiration in areas where the water table is within 1.5 m to 2.5 m of the surface (i.e., above the depth at which evapotranspiration no longer occurs).

7.3.2. Mining scenario

The water balance for the mining scenario is presented in Table 7-13, averaged over the duration of the model period of 25 years. The mass balance error was 0.00%, indicating that the model is stable and achieves an accurate numerical result.

Table 7-13 Predictive mass balance - quarrying scenario

	Inflow (ML/day)	Outflow (ML/day)
Recharge (RCH)	5.82	-
Evapotranspiration (EVT)	-	0.40
Rivers (RIV)	2.99	8.01
Regional groundwater flow (GHB)	-	0.40
Total	8.81	8.81
% Error	0.00%	

The water balance indicates little to no change in recharge, surface water discharge and regional groundwater flow between the baseline and mining scenario model runs. A difference between the baseline and quarrying scenarios was seen for evapotranspiration, which increased by 11% between the scenarios (equating to an average increase of 0.04 ML/day). The increase in evapotranspiration is due to quarrying increasing the area where the water table is within 1.5 to 2.5 m of the surface.

7.4. Sensitivity analysis

A sensitivity analysis was undertaken to demonstrate the response of the model to variation in uncertain input parameters. The objective of the sensitivity analysis was to review the input parameters in terms of their influence on the predicted results. The parameters considered most likely to affect the model predictions were hydraulic conductivity, evapotranspiration, rainfall and storage. The following scenarios were assessed in the sensitivity analysis:

- ±50% change in the horizontal hydraulic conductivity of the Hunter River alluvium;
- -80% and +100% change in the storage of the Hunter River alluvium;
- ±50% change in the average yearly evapotranspiration across the model domain; and
- ±50% change in the average yearly rainfall across the model domain.

Figure 7.7 and Figure 7.8 summarise the difference to the mass balance in response to the changed model parameters. The analysis showed that the model is most sensitive to changes in evapotranspiration, and to a lesser extent, recharge. Changes to the hydraulic and storage properties of the model showed no sensitivity to those parameters.

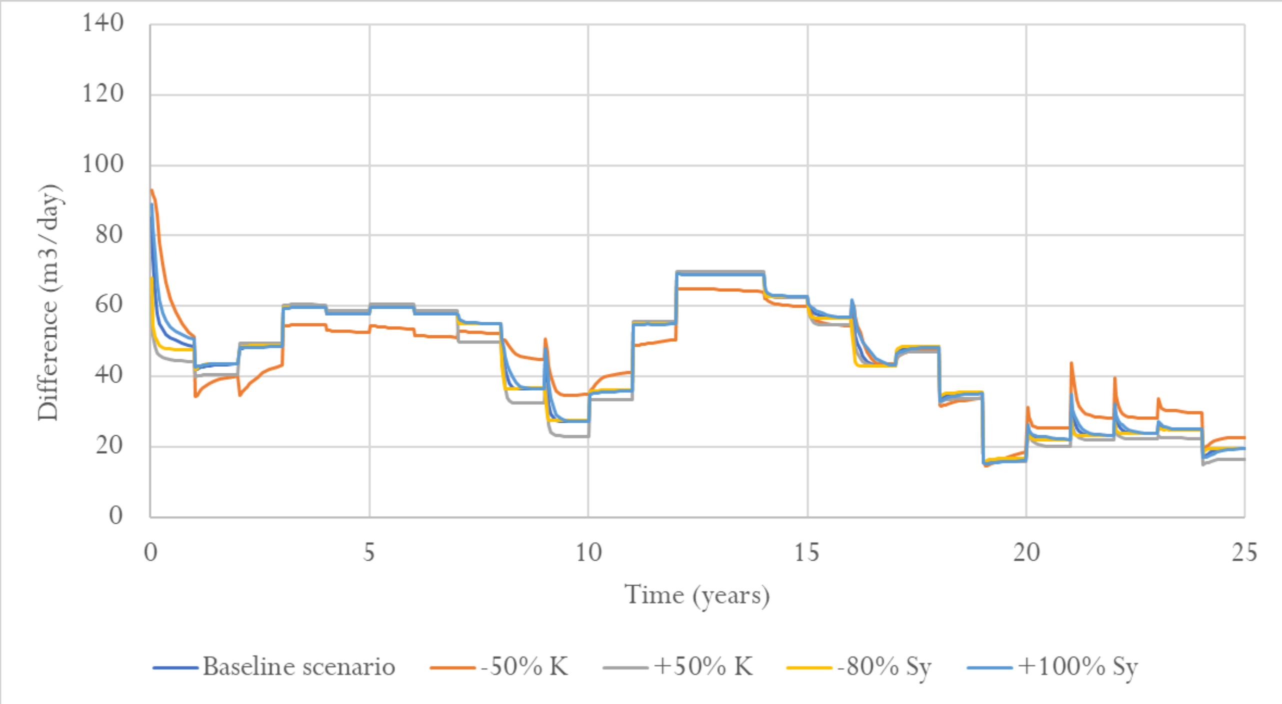

Figure 7.7 Sensitivity to change of hydraulic and storage properties

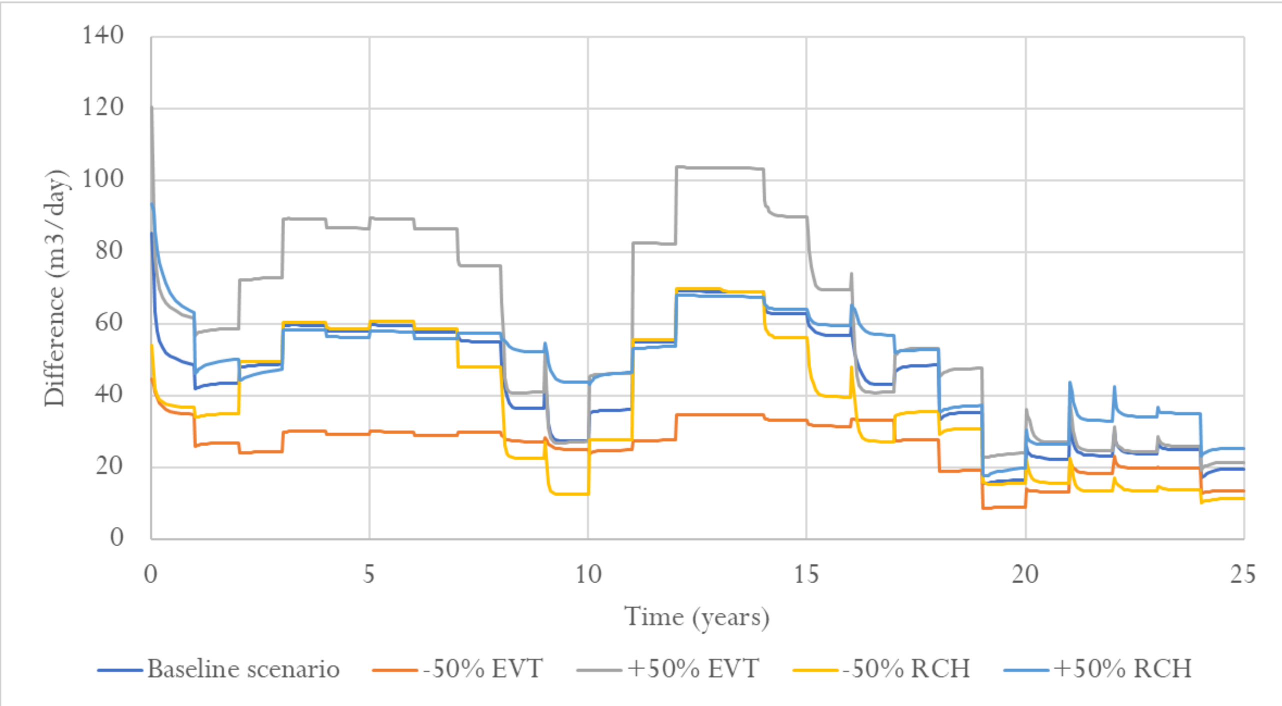

Figure 7.8 Sensitivity to change of evapotranspiration and recharge rates

8. Groundwater impact assessment

This section of the report describes the numerical model predictions and impacts of the Project, including:

- drawdown levels in the alluvium;
- change in alluvial water resource availability;
- water licensing requirements;
- impact on supplies from private bores; and
- potential impacts to groundwater dependent ecosystems.

8.1. Impacts on groundwater levels

The maximum combined drawdown (reduction in groundwater level) over the life of the Project is presented in Figure 8.1. The predicted maximum drawdown is 1.7 m, with an average predicted drawdown of 0.4 m over the Project area.

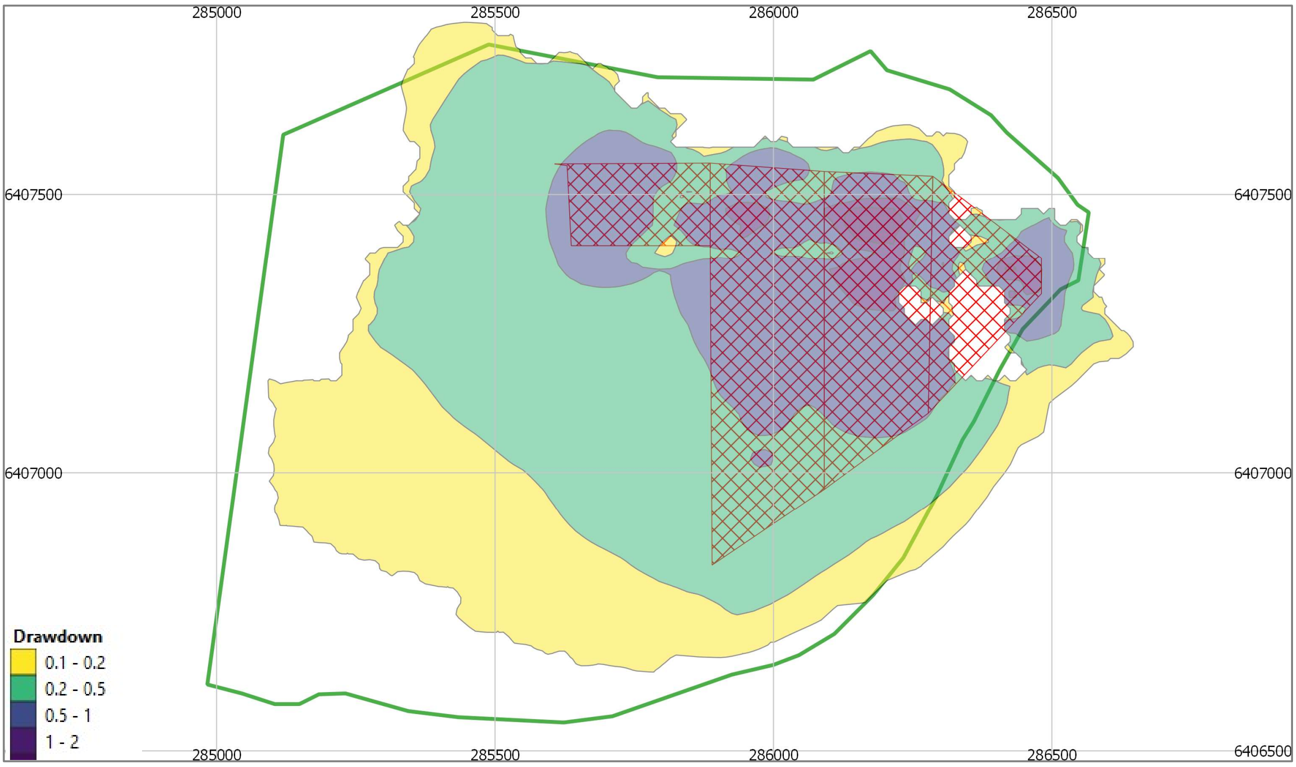

Figure 8.1 Maximum combined drawdown

Generally, the drawdown is limited to within the extent of the Project area, with the greatest amount of drawdown associated with the area of quarrying modelled for that time step. This is demonstrated in Figure 8.2, which illustrates the predicted drawdown after 5 years of quarrying. The outline of the Project extent is shown in green, with the quarrying area for the Year 5 period shown in red. The image illustrates that the maximum drawdown after Year 5 of quarrying is 0.5 m, which is centred over the quarrying area.

If process water recovered by the water treatment plant is used for activities such as dust suppression, this may act as additional recharge to the alluvium and offset some of the predicted groundwater take from evapotranspiration. This would slightly reduce the predicted drawdown within the Project area.

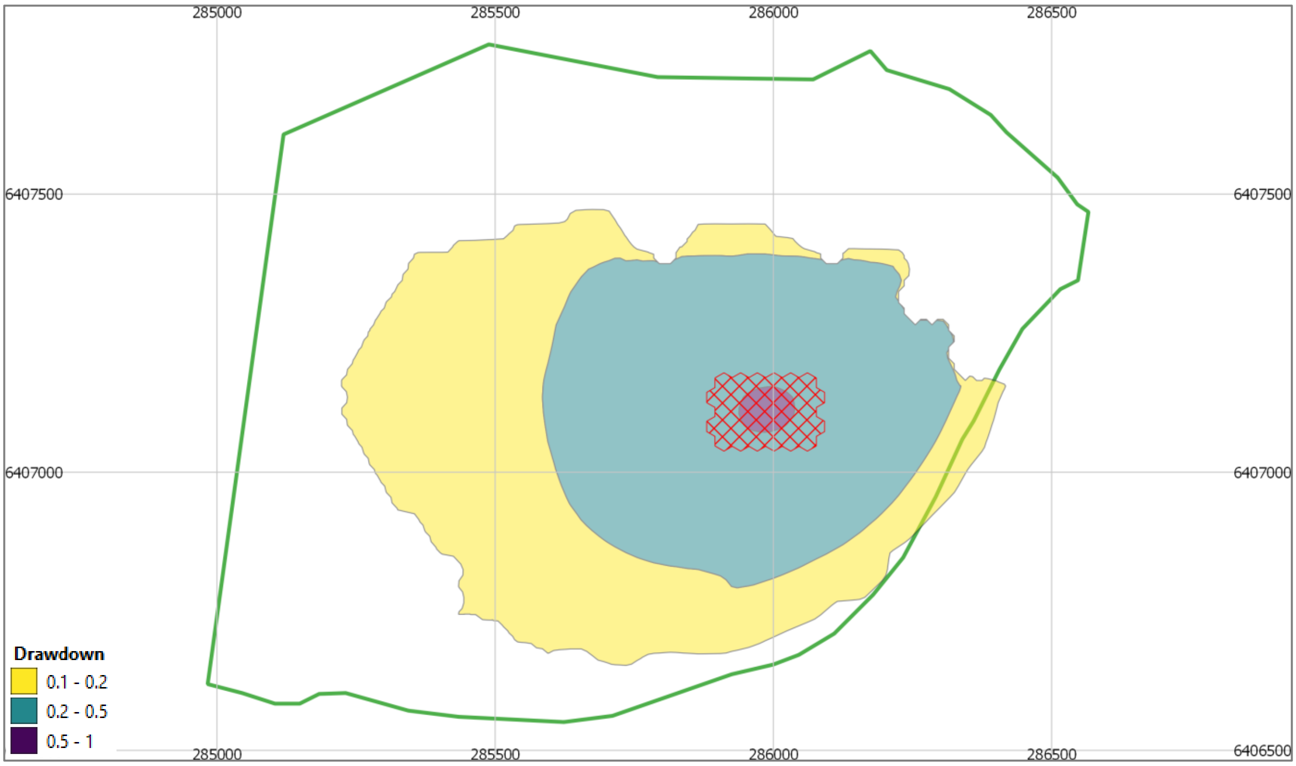

Figure 8.2 Drawdown after 5 years

8.2. Predicted take of water from the alluvium

The predicted take of groundwater from the alluvium was assessed by comparing the results of the two predictive modelling scenarios (see in Section 7.3). The difference in the water budget of the baseline and quarrying scenarios was due solely to an increase in evaporation and equates to 14.6 ML/year extracted from the groundwater alluvium.

8.3. Water licensing

The Project will require a predicted 14.6 ML/year of groundwater to be obtained from an appropriately authorised and reliable water supply. As RSG is currently licensed to extract 20 ML/year under the WSP for the Hunter Unregulated and Alluvial Water Sources, no changes or additional water licences would be required as the Project will be able to operate in accordance with the requirements of the WSP for the Hunter Unregulated and Alluvial Water Sources.

The current quarry operation does not operate with a buffer in place above the groundwater table, and as such intersects the groundwater table as part of normal quarrying activities. The Project as proposed is expected to operate in a similar manner. As RSG is currently licensed for any water take from intersecting the groundwater table, no buffer between quarrying and the groundwater table is required.

8.4. Drawdown at private bores

As the modelled drawdown is limited to the extent of the Project area, there are no predicted impacts at third party, or private bores. The drawdown is limited to four monitoring bores at the northern boundary of the Project (GW202524, GW202426, GW202427 and GW202428). The predicted drawdown for all these bores is expected to be less than 0.5 m (Figure 8.3).

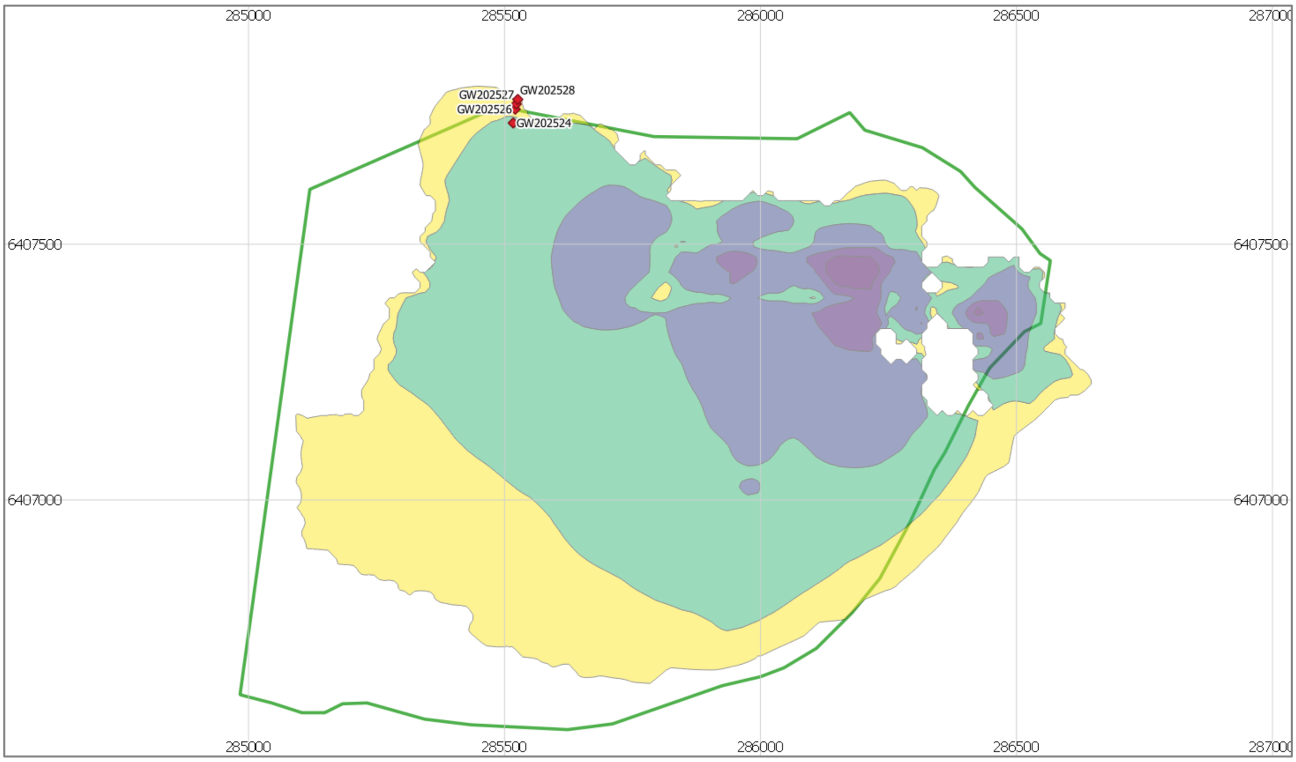

Figure 8.3 Groundwater bores intersected by drawdown

8.5. Impact on groundwater dependent ecosystems

A review of the maximum combined drawdown shows that the modelled drawdown extent does not significantly intersect the low-potential GDEs located in the northern portion of the Project area (see Section 5.2.4). This is illustrated below in Figure 8.4. Where drawdown is predicted to encroach on the low-potential GDEs, the temporal nature of the drawdown would suggest recovery as the quarry location moves away from the GDEs or on the cessation of quarrying. As such, there is no risk of the Project development to any GDE sites.

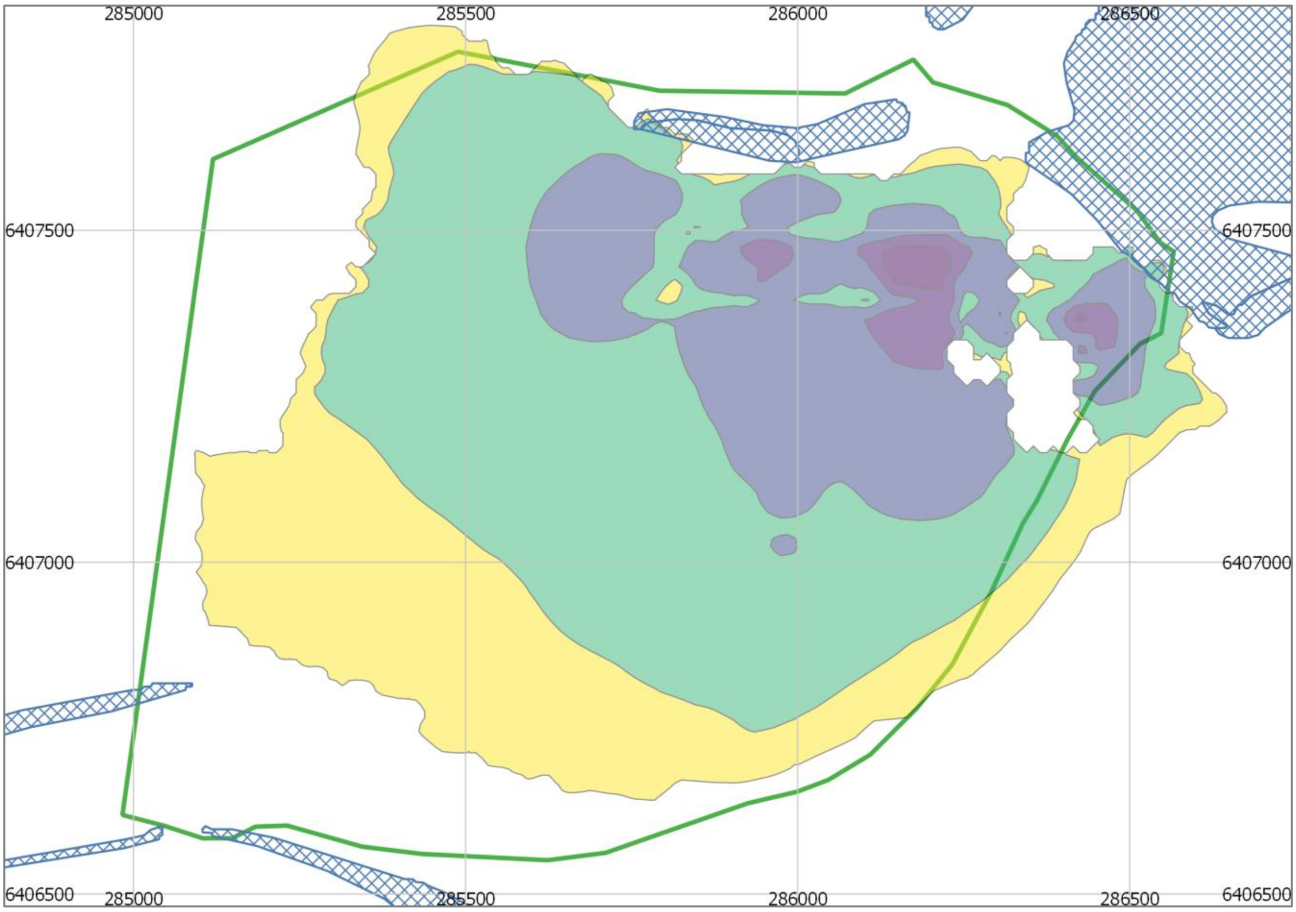

Figure 8.4 Comparison of GDE potential and drawdown extent

8.6. Post-mining equilibrium

As drawdown is associated with an increase in evaporation induced by the quarrying process, groundwater levels are expected to return to the conditions modelled in the baseline scenario (Section 7.3.1) once quarrying ceases and the landform is rehabilitated at closure.

8.7. Potential impacts on groundwater quality

As the only modelled groundwater extraction is due to increased levels of evaporation, there are no expected impacts on groundwater quality. No discharge is expected to occur, and as such, there is no potential for degradation to groundwater quality.

8.8. Minimal impact conditions

The minimal impact conditions listed in the NSW Aquifer Interference Policy (AIP) that are relevant to the Project are listed below in Table 8-1. Table 8-1 also summarises the predicted impact of the Project on these conditions.

As the predicted impacts of the Project are less than the Level 1 minimal impact considerations for highly productive alluvial groundwater sources, the impacts of the Project are considered acceptable under the terms of the AIP.

Table 8-1 Project impacts under the AIP

Impact condition	Level 1 considerations	Project impact
Water Table	Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any high priority GDE or high priority culturally significant site listed in the schedule of the relevant WSP.	No high priority GDE or culturally significant sites listed in the WSP for the Hunter Unregulated and Alluvial Water Sources are within the projected drawdown extent of the Project.
Water Pressure	A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work.	As no water supply works are located within the projected drawdown extent of the Project, no pressure head declines will be seen.
Water Quality	Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity; and	No change to the groundwater quality is predicted.
	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; and	No change to the groundwater salinity is predicted.
	No mining activity to be below the natural ground surface within 200 m laterally from the top of the high bank or 100 m vertically beneath a highly connected surface water source that is define as a "reliable water supply"; and	No quarrying activities will occur within 200 m of the high bank of the Hunter River, or occur to a depth of greater than 100 m.
	Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 m laterally from the top of high bank and 100 m vertically beneath a highly connected surface water supply that is defined as a "reliable water supply".	Quarrying activity outside 200 m of the high bank of the Hunter River, and at a depth of greater than 100 m will not remove more than 10% cumulatively of the alluvial material.

9. Proposed groundwater monitoring program

hydrogeologist.com.au recommends that RSG installs monitoring bores both upstream and downstream of the Project area. The installation of monitoring bores would allow natural groundwater level fluctuations (such as responses to rainfall) to be distinguished from potential groundwater level impacts due to the Project. Ongoing monitoring of groundwater levels can also be used to assess the extent and depth of drawdown against the numerical model predictions.

In addition, **hydrogeologist.com.au** recommends that RSG conducts groundwater quality sampling of both the monitoring bores and any groundwater present within the quarry pit in order to detect any changes in groundwater quality during and post quarrying. Sampling should be conducted on a quarterly basis, and include physio-chemical indicators (pH, electrical conductivity, and total dissolved solids) as well as major ions (calcium, fluoride, magnesium, potassium, sodium, chloride and sulfate). In the unlikely event that a decrease in water quality is seen, additional testing of dissolved and total metals and metalloids may be required.

hydrogeologist.com.au considers that the Project has a negligible risk to the groundwater environment, and as such no mitigation measures are required to prevent or minimise groundwater impacts.

10. Conclusions

hydrogeologist.com.au has completed a groundwater impact assessment for the Dalswinton Quarry, located near Denman, NSW.

A review of publicly available data and literature was conducted. A numerical groundwater model was developed to represent the local geology and hydrogeological conditions, as described in Sections 5 and 6. The numerical model covered a large domain in comparison to the extent of the project in order to comprehensively model the extent of the alluvium in the vicinity of the project, and to provide enough data to ensure a reasonable outcome from the modelling.

The key conclusions from the groundwater assessment are:

- The model predicts that groundwater will be extracted associated with the Project, due solely to an increase in evaporation induced by the removal of alluvium during quarrying. The model predicts a take of 14.6 ML/year from the groundwater alluvium. This volume of water is within the licensed entitlement (20 ML/year) held by RSG.
- As the predicted take of groundwater is within the licensed entitlement held by RSG, the Project will be able to operate in accordance with the WSP for the Hunter Unregulated and Alluvial Water Sources.
- Due to the predicted low impact of the Project, there is no need to maintain a buffer between any excavations and the highest predicted or recorded regional groundwater table. This approach is consistent with the historical and current quarrying methods.
- The Project is not predicted to impact on the quality and quantity of the existing groundwater resources. No water discharge is expected to occur at the site.
- No impacts on aquifers, watercourses, riparian land, water-related infrastructure, and other water users is expected to occur as a result of the Project.
- As the Project is expected to have no impacts on groundwater, the only recommended water management strategy is monitoring.
- **hydrogeologist.com.au** recommends the installation of upstream and downstream monitoring bores and regular groundwater quality sampling as a water monitoring program.

11. References

AGE Consultants, 2017. HVO South Modification 5 Groundwater Study.

AGE Consultants, 2015. Drayton South Coal Project EIS - Groundwater Impact Assessment.

Barnett, B., Hunt, R.J., Townley, L.R., Peeters, L., 2012. Australian groundwater modelling guidelines (No. Waterlines Report Series No. 82). National Water Commission, Canberra, ACT, Australia.

Bureau of Meteorology, 2019. GDE Atlas Home [WWW Document]. URL http://www.bom.gov.au/water/groundwater/gde/ (accessed 8.5.19).

Bureau of Meteorology, n.d. Australian Groundwater Explorer [WWW Document]. URL http://www.bom.gov.au/water/groundwater/explorer/map.shtml

Colquhoun, G.P., Hughes, K.S., Deyssing, L., Ballard, J.C., Phillips, G., Troedson, A.L., Folkes, C.B., Fitzherbert, J.A., 2019. Dataset | NSW Seamless Geology.

Doherty, J., 2019a. PEST - Model-Independent Parameter Estimation; user manual Part I: PEST, SENSAN and Global Optimisers.

Doherty, J., 2019b. PEST - Model-Independent Parameter Estimation; User manual Part II: PEST Utility Support Software.

Doherty, J., 2012. Windows BEOPEST.

HydroSimulations, 2019. Maxwell Project: Groundwater Assessment (No. HS2018/44).

HydroSimulations, 2013. Spur Hill Underground Coking Coal Project: Gateway Application Preliminary Groundwater Assessment (No. HC2013/14).

Merrick, D., 2016. AlgoMesh User Guide.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., Hughes, J.D., 2015. MODFLOW-USG. U.S. Geological Survey. https://doi.org/10.5066/f7r20zfj

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., Hughes, J.D., 2013. MODFLOW–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation (No. Chapter 45 of Section A, Groundwater Book 6, Modeling Techniques), Techniques and Methods 6-A45. U.S. Geological Survey, Reston, Virginia, USA.

WaterNSW, n.d. Dataset | Real-time data.

Wilford, J., Searle, R., Thomas, M., Grundy, M., 2018. Dataset | Soil and Landscape Grid National Soil Attribute Maps - Depth of Regolith (3" resolution) - Release 2. v6.

Appendix A Summary of Registered Bores

RN / Name	Easting	Northing	Drilled date	Purpose	Status
GW005309	283020	6411981	1/08/1956	Irrigation	Unknown
GW007624	282580	6408150	1/06/1948	Irrigation	Functional
GW008053	280795	6406139	1/03/1948	Unknown	Unknown
GW008061	281028	6406236	1/05/1948	Unknown	Unknown
GW008074	281071	6404265	1/05/1948	Unknown	Unknown
GW008087	280682	6405304	1/07/1948	Unknown	Proposed
GW008261	280808	6405523	1/11/1951	Unknown	Unknown
GW008273	280951	6404971	1/03/1952	Irrigation	Unknown
GW008276	281089	6404604	1/02/1952	Irrigation	Unknown
GW008284	280951	6404971	1/05/1952	Irrigation	Unknown
GW008299	281110	6403680	1/06/1952	Water Supply	Functional
GW008350	280583	6405086	1/05/1953	Irrigation	Decommissioned
GW010053	283897	6407685	1/06/1952	Irrigation	Unknown
GW013353	283234	6408133	1/10/1955	Irrigation	Unknown
GW016142	281519	6410068	1/08/1950	Unknown	Unknown
GW016838	281138	6407163	1/12/1958	Irrigation	Unknown
GW017374	280904	6404723	1/01/1959	Irrigation	Unknown
GW018743	285582	6405842	1/09/1960	Irrigation	Unknown
GW018790	284855	6406843	1/01/1960	Irrigation	Functional
GW018791	284565	6406991		Unknown	Unknown
GW018897	284505	6412198	1/01/1961	Unknown	Unknown
GW019602	282063	6409094	1/09/1962	Water Supply	Functional
GW019611	281561	6408128	1/01/1962	Unknown	Unknown
GW019615	281440	6407694		Irrigation	Non-functional
GW020073	281223	6404453	1/01/1962	Irrigation	Unknown
GW020173	282158	6409527	1/01/1962	Unknown	Functional
GW021850	280467	6409182	1/08/1964	Irrigation	Unknown
GW021851	280777	6409343	1/08/1964	Irrigation	Unknown
GW022035	283838	6405558	1/01/1950	Irrigation	Unknown
GW022037	284238	6405196	1/01/1930	Irrigation	Unknown
GW022046	282420	6407068	1/10/1964	Irrigation	Unknown
GW022047	282396	6407006	1/01/1964	Unknown	Unknown
GW022048	282292	6406973	1/01/1964	Water Supply	Decommissioned

RN / Name	Easting	Northing	Drilled date	Purpose	Status
GW022515	284207	6405411	1/03/1965	Unknown	Functional
GW023481	282974	6411672	1/03/1966	Unknown	Unknown
GW023487	283342	6411587	1/04/1966	Irrigation	Unknown
GW023488	282632	6411757	1/04/1966	Irrigation	Unknown
GW024076	283891	6405528	1/07/1965	Irrigation	Unknown
GW024213	283565	6406106	1/08/1965	Irrigation	Functional
GW024499	282550	6402328	1/01/1965	Water Supply	Unknown
GW024712	281754	6407670	1/01/1948	Unknown	Unknown
GW025616	283759	6406789	1/01/1954	Unknown	Unknown
GW025617	283041	6406157	1/01/1957	Irrigation	Non-functional
GW025750	283230	6405883	1/03/1965	Irrigation	Functional
GW026550	282989	6406156	1/06/1965	Irrigation	Non-functional
GW027188	285944	6406003	1/01/1937	Irrigation	Unknown
GW027189	286277	6406350	1/01/1954	Unknown	Functional
GW029644	289048	6411215	1/01/1920	Water Supply	Unknown
GW029650	286339	6409556	1/04/1957	Stock and Domestic	Unknown
GW029651	286385	6409834	1/04/1957	Stock and Domestic	Unknown
GW029652	286407	6410050	1/04/1957	Stock and Domestic	Unknown
GW029653	286428	6410297	1/04/1957	Stock and Domestic	Unknown
GW029656	289759	6408488	1/01/1915	Stock and Domestic	Unknown
GW029657	288497	6411327	1/01/1966	Water Supply	Unknown
GW029659	289121	6411494	1/01/1936	Water Supply	Functional
GW029707	284186	6406397	1/09/1968	Irrigation	Functional
GW031824	281258	6404084	1/04/1968	Irrigation	Unknown
GW031825	281127	6404081	1/04/1968	Irrigation	Unknown
GW034337	282132	6409527	1/01/1966	Irrigation	Unknown
GW035250	285298	6405681		Irrigation	Unknown
GW037412	281004	6404941		Irrigation	Unknown
GW037794	284098	6411665		Irrigation	Non-functional
GW037882	283571	6405798	1/01/1965	Irrigation	Unknown
GW037927	283530	6408910	1/01/1934	Irrigation	Unknown
GW039428	285575	6407413	1/06/1989	Exploration	Abandoned
GW039429	285485	6406733	1/06/1989	Exploration	Abandoned
GW039430	286158	6406994	1/06/1989	Exploration	Abandoned
GW039432	285241	6407129	1/06/1989	Exploration	Abandoned
GW040959	280945.1	6409604	24/03/2005	Monitoring	Unknown
GW045158	289876	6407905	1/02/1976	Water Supply	Unknown
GW045159	289772	6407872	1/05/1974	Water Supply	Proposed
GW045160	289550	6407725	1/04/1973	Water Supply	Abandoned
GW045161	289685	6408064	1/01/1930	Water Supply	Removed
GW051328	283931	6410922	1/10/1980	Stock and Domestic	Unknown
GW053090	281561	6408128	1/03/1981	Irrigation	Unknown

RN / Name	Easting	Northing	Drilled date	Purpose	Status
GW053117	284719	6405885	1/10/1981	Irrigation	Functional
GW053347	291466	6406829	1/08/1981	Irrigation	Functional
GW053349	291101	6405527		Irrigation	Functional
GW053410	283565	6410771	27/10/1980	Irrigation	Unknown
GW053430	280886	6407928	1/01/1945	Irrigation	Functional
GW053431	280980	6408423	1/01/1977	Irrigation	Functional
GW053432	280933	6408176	1/09/1981	Irrigation	Functional
GW053433	280815	6407588	1/01/1962	Irrigation	Functional
GW053444	288796	6407050	1/01/1982	Irrigation	Unknown
GW053533	285712	6405875	1/01/1982	Irrigation	Unknown
GW057804	289082	6407118	1/11/1982	Irrigation	Functional
GW057805	289080	6407241	1/11/1982	Irrigation	Functional
GW057826	282881	6407540	1/12/1983	Irrigation	Unknown
GW059332	282818	6411637	1/07/1983	Irrigation	Unknown
GW060426	282214	6409344		Unknown	Functional
GW060488	289539	6407774		Irrigation	Decommissioned
GW065046	284437	6405632	1/01/1950	Irrigation	Unknown
GW065047	284774	6405763	1/01/1950	Irrigation	Unknown
GW065521	290248	6407604	1/01/1965	Irrigation	Unknown
GW066015	280976	6406204	1/08/1992	Water Supply	Functional
GW071278	283192	6411245	1/12/1990	Irrigation	Functional
GW078336	281542	6410223		Unknown	Unknown
GW078448	280993	6406636	1/01/1996	Water Supply	Functional
GW078449	280683	6406475		Water Supply	Functional
GW078462	280426	6406254	1/01/1982	Stock and Domestic	Functional
GW078519	290629	6406873		Stock and Domestic	Unknown
GW078520	290686	6405364		Stock and Domestic	Unknown
GW078763	281058	6405551	14/09/1999	Irrigation	Unknown
GW080211	281015	6406242		Irrigation	Unknown
GW200175	280650	6406054	10/11/2004	Unknown	Unknown
GW200177	280655	6406461	1/12/2004	Unknown	Unknown
GW201202	280865	6406645	20/03/2012	Water Supply	Functional
GW202524	285517	6407737	23/08/2012	Monitoring	Functional
GW202525	285517	6407755	23/08/2012	Monitoring	Abandoned
GW202526	285521	6407764	23/08/2012	Monitoring	Functional
GW202527	285523	6407774	23/08/2012	Monitoring	Functional
GW202528	285526	6407783	23/08/2012	Monitoring	Functional
GW202960	281075	6406620	1/06/1972	Water Supply	Functional
GW203975	289168.8	6408423	20/11/2014	Monitoring	Proposed
GW203976	289168.8	6408423	18/11/2014	Monitoring	Proposed
GW271034	289990	6408086	3/04/2008	Monitoring	Unknown

Note: Coordinates are in GDA94, Zone 56