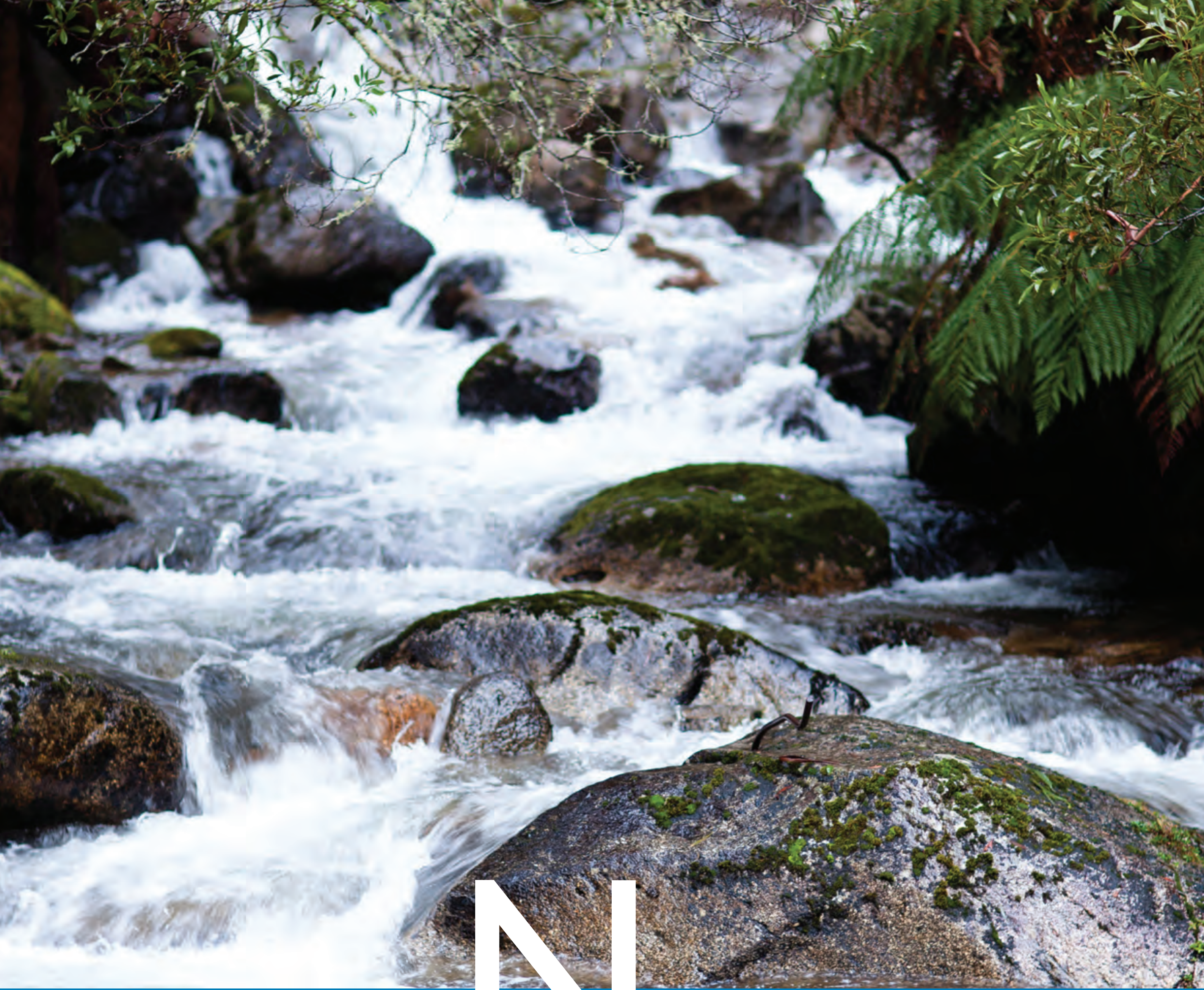
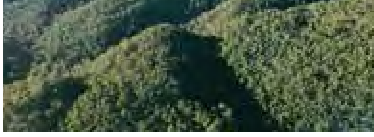


APPENDIX N

GROUNDWATER ASSESSMENT



Groundwater assessment

Exploratory Works for Snowy 2.0

Prepared for Snowy Hydro Limited
July 2017

snowy 2.0

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Prepared for Snowy Hydro Limited | 13 July 2018

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Groundwater assessment

Final

Report Groundwater Assessment | Prepared for Snowy Hydro Limited | 13 July 2018

Prepared by	Sean Cassidy, Doug Weatherill	Approved by	John Ross, Liz Webb
Position	Senior Hydrogeologist, Associate Groundwater Modeller	Position	Senior Principal Hydrogeologist, Director
Signature		Signature	
Date	13 July 2018	Date	13 July 2018

This report has been prepared in accordance with the brief provided by the client and has relied upon the information collected at the time and under the conditions specified in the report. All findings, conclusions or recommendations contained in the report are based on the aforementioned circumstances. The report is for the use of the client and no responsibility will be taken for its use by other parties. The client may, at its discretion, use the report to inform regulators and the public.

Document Control

Version	Date	Prepared by	Reviewed by
1	13 April 2018	Sean Cassidy, Doug Weatherill	John Ross

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Executive Summary

ES1 Assessment overview

Snowy Hydro Limited (Snowy Hydro) proposes to develop Snowy 2.0, a large scale pumped hydro-electric storage and generation project which would increase hydro-electric capacity within the existing Snowy Mountains Hydro-electric Scheme (Snowy Scheme). This would be achieved by establishing a new underground hydro-electric power station that would increase the generation capacity of the Snowy Scheme by almost 50%, providing an additional 2,000 megawatts (MW) generating capacity, and providing approximately 350 gigawatt hours (GWh) of storage available to the National Electricity Market (NEM) at any one time, which is critical to ensuring system security as Australia transitions to a decarbonised NEM. Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and hydro-electric power station.

Snowy 2.0 has been declared to be Critical State Significant Infrastructure (CSSI) by the NSW Minister for Planning under the provisions of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) and is defined in Clause 9 of Schedule 5 of the State Environmental Planning Policy (State and Regional Development) 2011 (SRD SEPP). Separate applications and environmental impact statements (EIS) for different phases of Snowy 2.0 are being submitted under Part 5, Division 5.2 of the EP&A Act. The application for Exploratory Works is the first application for Snowy 2.0.

The purpose of Exploratory Works for Snowy 2.0 is primarily to gain a greater understanding of the conditions at the proposed location of the power station, approximately 850 metres (m) below ground level. Understanding factors such as rock conditions (including stress conditions) and ground temperature is essential to inform decisions about the precise location of the power station cavern and confirm the cavern construction methods.

Exploratory Works comprises:

- an exploratory tunnel to the site of the underground power station for Snowy 2.0;
- horizontal and other test drilling, investigations and analysis in situ at the proposed cavern location and associated areas, and around the portal construction pad, access roads and excavated rock management areas all within the disturbance footprint;
- a portal construction pad for the exploratory tunnel;
- an accommodation camp for the Exploratory Works construction workforce;
- road works and upgrades providing access and haulage routes during Exploratory Works;
- barge access infrastructure, to enable access and transport by barge on Talbingo reservoir;
- excavated rock management, including subaqueous placement within Talbingo Reservoir;
- services infrastructure such as diesel-generated power, water and communications; and
- post-construction revegetation and rehabilitation, management and monitoring.

This Groundwater Assessment supports the EIS for Exploratory Works. It documents the groundwater assessment methods and results, the initiatives built into the project design to avoid and minimise associated impacts to groundwater, and the mitigation and management measures proposed to address residual impacts not able to be avoided.

Ecological effects are also discussed briefly in this report and are thoroughly assessed in the *Snowy 2.0 Exploratory Works Biodiversity Development Assessment* (EMM 2018a). Historic mining activities and associated contamination are also referenced briefly in this report and are comprehensively assessed in the *Snowy 2.0 Exploratory Works Phase 1 Contamination Assessment* (EMM 2018b). Surface water aspects are broadly covered in this assessment and are assessed in detail in the *Snowy 2.0 Exploratory Works Surface Water Assessment* (EMM 2018c).

ES2 Water resources

The surface water and groundwater sources near Exploratory Works area are subject to water sharing plans and therefore most aspects of project water management are regulated under the *Water Management Act 2000*. However, licensing of monitoring bores is regulated under the *Water Act 1912*.

The surface water resources are managed under the *Water Sharing Plan for the Murrumbidgee unregulated and alluvial water source 2012* (unregulated WSP). The Exploratory Works are within the unregulated Upper Tumut Water Source.

The groundwater resources of Exploratory Works area are primarily regulated by the *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011*, and are within the Lachlan Fold Belt Murray Darling Basin (MDB) Groundwater Source. A small portion of the project area is within the *Water Sharing Plan for the South Coast Groundwater Sources 2016*, specifically the Lachlan Fold Belt Coast Groundwater Source.

Exploratory Works project area is traversed by several drainage lines all of which ultimately drain via the Yarrangobilly River to Talbingo Reservoir.

The distinct groundwater units within the Exploratory Works project area are defined as:

- localised unconsolidated shallow Quaternary gravels episodically recharged through rainfall/flooding events
- shallow groundwater associated with weathered fractured rock (between 5 and 30 metres below ground level); and
- deep groundwater associated with deeper fractured rock (ie the Ravine Beds).

The Ravine Beds are the main groundwater bearing unit to be intercepted by the project. Groundwater within the Ravine Beds has a marginally brackish water quality and is generally considered to have a low permeability.

Streams in the area are all considered 'gaining' streams with groundwater providing stream baseflow. Recharge to the groundwater system is via rainfall infiltration. Lateral groundwater flow dominates with regional flow influenced by the regional topography (ie incised streams to the north-west) and the general dip of the strata to the west.

ES3 Tunnelling methods and water management

The exploratory tunnel will be constructed using drill and blast techniques. Snowy Hydro will progressively line the exploratory tunnel with shotcrete to limit groundwater inflows as tunnelling progresses.

The water management objectives are to minimise disturbance to water resources; runoff will be diverted from undisturbed areas, collected and reused, and releases minimised. This will be achieved via a series of water dams and stormwater basins. Water supply for tunnelling components of the Exploratory Works will be fully self-contained by using:

- rainfall-runoff stored in the disturbance area water dams;
- groundwater collected in the underground tunnel sump (where groundwater inflow to underground workings will be captured); and
- supply from within the Unregulated Upper Tumut Water Source, specifically the Talbingo Reservoir.

The volume of groundwater required to be licensed for the Exploratory Works is defined as the groundwater inflow to the tunnel.

Based on the maximum plausible impact scenario simulated by the numerical groundwater model, the predicted peak annual groundwater take for Exploratory Works required for licensing is 340 ML/yr. There is sufficient groundwater entitlement available within the Lachlan Fold Belt MDB Fractured Rock Groundwater Source to secure the predicted take for Exploratory Works. The NSW Government has periodically released additional entitlements within this water source via controlled allocation releases. Snowy Hydro has consulted with the NSW Department of Industries Water (formerly Crown Lands and Water Division) (DoI Water) and local water traders and have identified a clear pathway for how the remaining licence volume will be secured so that all water taken is adequately licensed. It is understood that another controlled allocation release within this groundwater source is likely to occur in the latter half of 2018.

ES4 Monitoring network

A comprehensive water monitoring network has been designed and implemented to establish pre-construction baseline data for the project. The groundwater monitoring network includes 20 conventional groundwater monitoring bores at 11 nested sites, 11 vibrating wire piezometers (VWPs), and four shallow drive point piezometers located within and around the Exploratory Works project area. The network has been developed in consultation with the local DoI Water hydrogeologists and assessment officers.

A diverse range of hydraulic tests have provided site-specific information on the hydraulic properties of the groundwater systems, including rising and falling head tests (slug tests) and constant rate pumping tests.

There are no identified high-priority groundwater dependent ecosystems (GDEs) within the project area. However, Yarrangobilly Caves is a High Priority GDE listed within the Lachlan Fold Belt MDB (Fractured Rock Groundwater source) WSP within the groundwater model domain and is located approximately 8 km north of the Exploratory Works project area.

ES5 Assessment and findings

Numerical groundwater flow modelling was used in this assessment to predict changes in groundwater and surface water resources.

Assessment of the project has been undertaken in reference to the requirements of the *Water Management Act 2000* and attendant regulations, the NSW Aquifer Interference Policy and relevant water sharing plans.

Groundwater modelling predicted localised water table drawdown in the vicinity of the exploratory tunnel alignment. This drawdown is primarily around the portal where the exploratory tunnel intercepts shallow geological material that is more permeable than the deeper competent rock mass in which the majority of the tunnel will be constructed. Drawdown does not extend beyond 2 km laterally and therefore no drawdown impact is predicted at the high-priority GDE identified in the project area, the Yarrangobilly Caves.

Only minor impacts to the baseflow contribution to the Yarrangobilly River and associated tributaries are expected. A base case and maximum plausible impact scenario has been modelled, predicting baseflow reductions of 0.14% (4 ML/yr) (base case scenario) and 0.18% (14 ML/yr) (maximum plausible impact scenario) arising from the construction of the exploratory tunnel at the end of the construction period. Baseflow losses are predicted to increase post construction until a new equilibrium is reached for which the steady state model predicted losses of 0.67% (19 ML/yr) (base case) and 2.29% (178 ML/yr) (maximum plausible impact).

ES6 Mitigation, avoidance, management and monitoring

An overarching and adaptive Water Management Plan (WMP) will be prepared for Exploratory Works in consultation with NSW Government agencies to support construction activities.

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1 Introduction

1.1 The project

Snowy Hydro Limited (Snowy Hydro) proposes to develop Snowy 2.0, a large scale pumped hydro-electric storage and generation project which would increase hydro-electric capacity within the existing Snowy Mountains Hydro-electric Scheme (Snowy Scheme). This would be achieved by establishing a new underground hydro-electric power station that would increase the generation capacity of the Snowy Scheme by almost 50%, providing an additional 2,000 megawatts (MW) generating capacity, and providing approximately 350,000 megawatt hours (MWh) of storage available to the National Electricity Market (NEM) at any one time, which is critical to ensuring system security as Australia transitions to a decarbonised NEM. Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and hydro-electric power station.

Snowy 2.0 has been declared to be State significant infrastructure and critical State significant infrastructure (CSSI) by the NSW Minister for Planning under the provisions of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) and is defined in Clause 9 of Schedule 5 of the *State Environmental Planning Policy (State and Regional Development) 2011* (SRD SEPP). Separate applications and environmental impact statements (EIS) for different phases of Snowy 2.0 are being submitted under Part 5, Division 5.2 of the EP&A Act. This technical assessment has been prepared to support an EIS for Exploratory Works to undertake investigative works to gather important technical and environmental information for the main Snowy 2.0 project. The main project will be subject of a separate application and EIS next year.

The purpose of Exploratory Works for Snowy 2.0 is primarily to gain a greater understanding of the conditions at the proposed location of the power station, approximately 850 metres (m) below ground level. Understanding factors such as rock conditions (such as stress conditions) and ground temperature is essential to inform decisions about the precise location of the power station cavern and confirm the cavern construction methods.

Exploratory Works comprises:

- an exploratory tunnel to the site of the underground power station for Snowy 2.0;
- horizontal and other test drilling, investigations and analysis in situ at the proposed cavern location and associated areas, and around the portal construction pad, access roads and excavated rock management areas all within the disturbance footprint;
- a portal construction pad for the exploratory tunnel;
- an accommodation camp for the Exploratory Works construction workforce;
- road works and upgrades providing access and haulage routes during Exploratory Works;
- barge access infrastructure, to enable access and transport by barge on Talbingo reservoir;
- excavated rock management, including subaqueous placement within Talbingo Reservoir;
- services infrastructure such as diesel-generated power, water and communications; and
- post-construction revegetation and rehabilitation, management and monitoring.

1.2 Purpose of this report

This Groundwater Assessment supports the EIS for Exploratory Works. It documents the groundwater assessment methods and results, the initiatives built into the project design to avoid and minimise associated impacts, to groundwater, and the mitigation and management measures proposed to address any residual impacts not able to be avoided.

1.3 Location of Exploratory Works

Snowy 2.0 and Exploratory Works are within the Australian Alps, in southern NSW. The regional location of Exploratory Works is shown on Figure 1.1. Snowy 2.0 is within both the Snowy Valleys and Snowy Monaro Regional local government areas (LGAs), however Exploratory Works is entirely within the Snowy Valleys LGA. The majority of Snowy 2.0 and Exploratory Works are within Kosciuszko National Park (KNP). The area in which Exploratory Works will be undertaken is referred to herein as the project area, and includes all of the surface and subsurface elements further discussed in Section 2.1.

Exploratory Works is predominantly in the Ravine region of the KNP. This region is between Talbingo Reservoir to the north-west and the Snowy Mountains Highway to the east, which connects Adaminaby and Cooma in the south-east to Talbingo and Tumut to the north-west of the KNP. Talbingo Reservoir is an existing reservoir that forms part of the Snowy Scheme. The reservoir, approximately 50 kilometres (km) north-west of Adaminaby and approximately 30 km east-north-east of Tumbarumba, is popular for recreational activities such as boating, fishing, water skiing and canoeing.

The nearest large towns to Exploratory Works are Cooma and Tumut. Cooma is approximately one hour and forty five minutes drive (95 km) south-east of Lobs Hole. Tumut is approximately half an hour (45 km) north of Talbingo. There are several communities and townships near the project area including Talbingo, Tumbarumba, Batlow, Cabramurra and Adaminaby. Talbingo and Cabramurra were built for the original Snowy Scheme workers and their families. Adaminaby was relocated to alongside the Snowy Mountains Highway from its original location (now known as Old Adaminaby) in 1957 due to the construction of Lake Eucumbene. Talbingo and Adaminaby provide a base for users of the Selwyn Snow Resort in winter. Cabramurra was modernised and rebuilt in the early 1970s and is owned and operated by Snowy Hydro. It is still used to accommodate Snowy Scheme employees and contractors. Properties within Talbingo are now predominantly privately owned. Snowy Hydro now only owns 21 properties within the town.

Other attractions and places of interest in the vicinity of the project area include Selwyn Snow Resort, the Yarrangobilly Caves complex and Kiandra. Kiandra has special significance as the first place in Australia where recreational skiing was undertaken and is also an old gold rush town.

The project area is shown on Figure 1.2 and comprises:

- **Lobs Hole:** Lobs Hole will accommodate the excavated rock emplacement areas, an accommodation camp as well as associated infrastructure, roads and laydown areas close to the portal of the exploratory tunnel and portal construction pad at a site east of the Yarrangobilly River;

- **Talbingo Reservoir:** installation of barge access infrastructure near the existing Talbingo Spillway, at the northern end of the Talbingo Reservoir, and also at Middle Bay, at the southern end of the reservoir, near the Lobs Hole facilities, and installation of a submarine cable from the Tumut 3 power station to Middle Bay, providing communications to the portal construction pad and accommodation camp. A program of subaqueous rock placement is also proposed;

- **Mine Trail Road** will be upgraded and extended to allow the transport of excavated rock from the exploratory tunnel to sites at Lobs Hole that will be used to manage excavated material, as well as for the transport of machinery and construction equipment and for the use of general construction traffic; and

- several sections of **Lobs Hole Ravine Road** will be upgraded in a manner that protects the identified environmental constraints present near the current alignment.

The project is described in more detail in Chapter 2.

1.4 Proponent

Snowy Hydro is the proponent for Exploratory Works. Snowy Hydro is an integrated energy business – generating energy, providing price risk management products for wholesale customers and delivering energy to homes and businesses. Snowy Hydro is the fourth largest energy retailer in the NEM and is Australia's leading provider of peak, renewable energy.

1.5 Assessment guidelines and requirements

This Groundwater Assessment has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for Exploratory Works, issued first on 17 May 2018 and revised on 20 June 2018, as well as relevant governmental assessment requirements, guidelines and policies, and in consultation with the relevant government agencies.

The SEARs must be addressed in the EIS. Table 1.1 lists the matters relevant to this assessment and where they are addressed in this report.

Table 1.1 Relevant matters raised in SEARs

Requirement	Section addressed
An assessment of the impacts of the project on the quantity and quality of the region's surface water resources, including Yarrangobilly River, Wallaces Creek, and Talbingo Reservoir, having regard to NSW Water Quality Objectives	Section 9.4.1 and Section 11
An assessment of the impacts of the project on groundwater aquifers and groundwater dependent ecosystems having regard to the NSW Aquifer Inference Policy and relevant Water Sharing Plans	Section 9, Section 10 and Section 11.2

To inform preparation of the SEARs, the Department of Planning and Environment (DPE) invited relevant government agencies to advise on matters to be addressed in the EIS. These matters were taken into account by the Secretary for DPE when preparing the SEARs.

1.5.1 Other relevant reports

This Groundwater Assessment has been prepared with reference to other technical reports that were prepared as part of the Exploratory Works EIS. The other relevant reports referenced in this Groundwater Assessment are listed below.

- Biodiversity development assessment (EMM 2018a) – Appendix F of the EIS

- Phase 1 contamination assessment (EMM 2018b) – Appendix J of the EIS

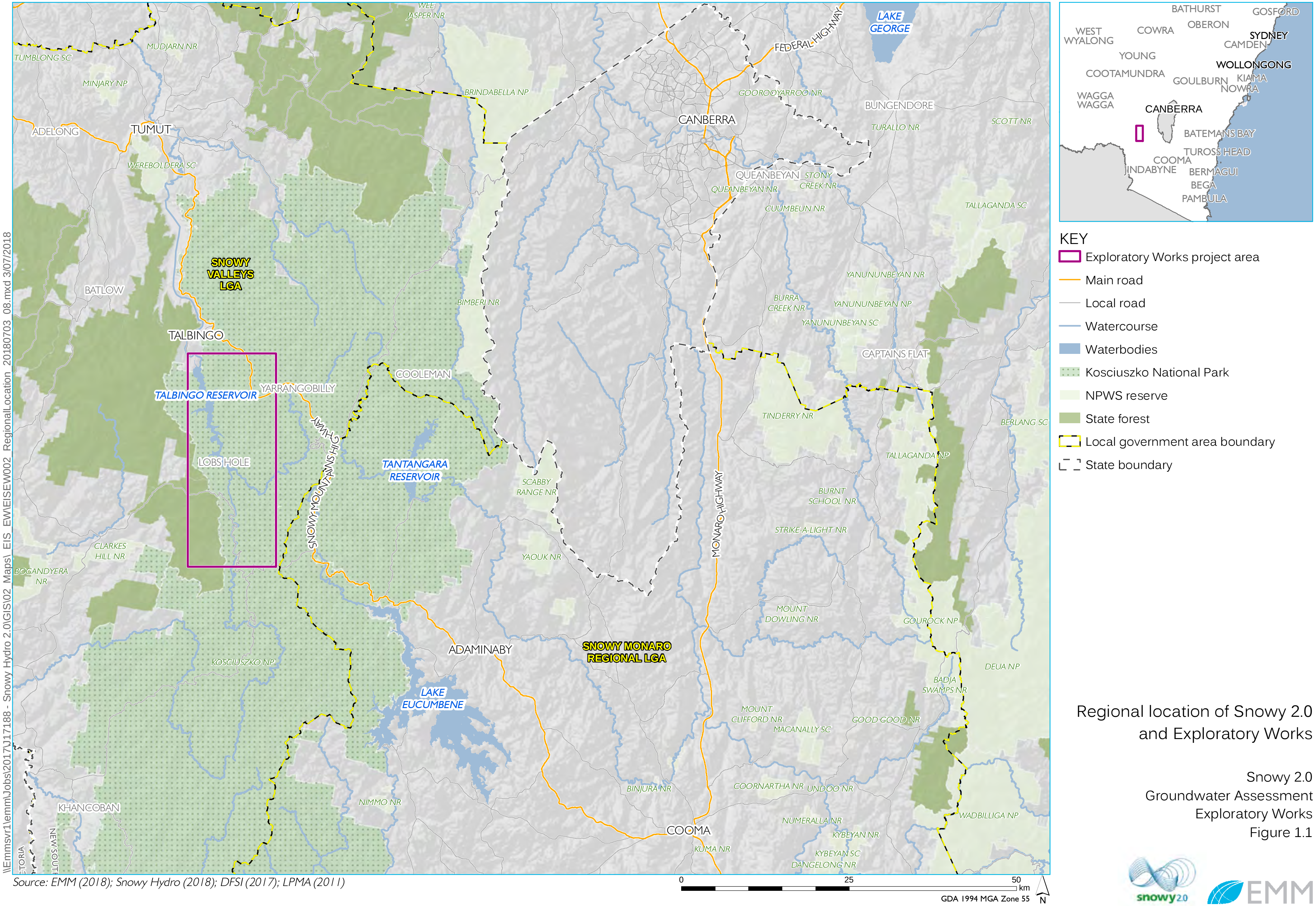
- Surface water assessment (EMM 2018c) – Appendix M of the EIS

1.5.2 Key terms

A comprehensive glossary of terms is included at the back of this report. Commonly used terms are defined in Table 1.2 for ease of reference.

Table 1.2 Key terms

Term	Definition and description
Drawdown	Refers both to the lowering of the water level in a bore, and the lowering of the water table. The change in the groundwater head (level) as measured in a bore reflects the pressure of the natural groundwater in the aquifer at the depth where the bore is open/screened. Drawdown refers to the change (lowering) in the groundwater level over time. Note that adjacent monitoring bores with different screen depths would be subject to different drawdown.
Model domain or groundwater model domain	The area that has been included in the groundwater model. This extends beyond the project area and is defined by hydrogeological or other boundaries such as catchment divides.
Potentiometric surface/ level	An imaginary surface representing the static head of groundwater and defined by the level to which water will rise in a bore. In an unconfined groundwater system, this will generally be the same as the water table. If a bore is installed and screened below the water table, the groundwater level in the bore will rise up to the height of the potentiometric surface at the depth of the bore screens.
Sediment dam	Temporary structures that are constructed and used during construction of the surface infrastructure area to prevent sediment-laden runoff entering the local catchment. Water from dams will be released to the local catchment (as they are designed to do) once sediment is settled and separated. Once construction of the infrastructure area is finished, sediment dams will generally be decommissioned and will not remain part of the operations phase water management system.
Stormwater basin	Structures designed to collect and temporarily store water that falls within the surface infrastructure area during large rainfall events. These basins will contain mainly clean run-off water in high rainfall events, and water that enters them will have limited, if any, direct contact with waste rock.
Sump	An underground water storage where water is pumped to/from, or collects. For the project, the sump is where water from various parts of the tunnel is collected. This water is then pumped to the surface for temporary storage and treatment.
Volume of licensable water	The volume of water required to be licensed for the project is defined as the groundwater inflow to the sump.
Water table	The depth, or level, below which the ground is fully saturated with groundwater.



Source: EMM (2018); Snowy Hydro (2018); DFSI (2017); LPMA (2011)

KEY
- Exploratory Works project area
- Main road
- Local road
- Watercourse
- Waterbodies
- Kosciuszko National Park
- NPWS reserve
- State forest
- Local government area boundary
- State boundary

Regional location of Snowy 2.0 and Exploratory Works

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 1.1

Source: EMM (2018); Snowy Hydro (2018); SMEC (2018); Robert Bird (2018); DFSI (2017); LPMA (2011)

0 2.5 5 km

N

GDA 1994 MGA Zone 55

Exploratory Works project area

KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Local road
- Major watercourse
- On land rock management
- Subaqueous excavated rock placement
- Disturbance footprint
- Avoidance footprint

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 1.2

snowy 2.0 EMM

2 Project description

2.1 Overview

Exploratory Works comprises construction associated with geotechnical exploration for the underground power station for Snowy 2.0. The Exploratory Works elements are shown on Figure 2.1 and involve:

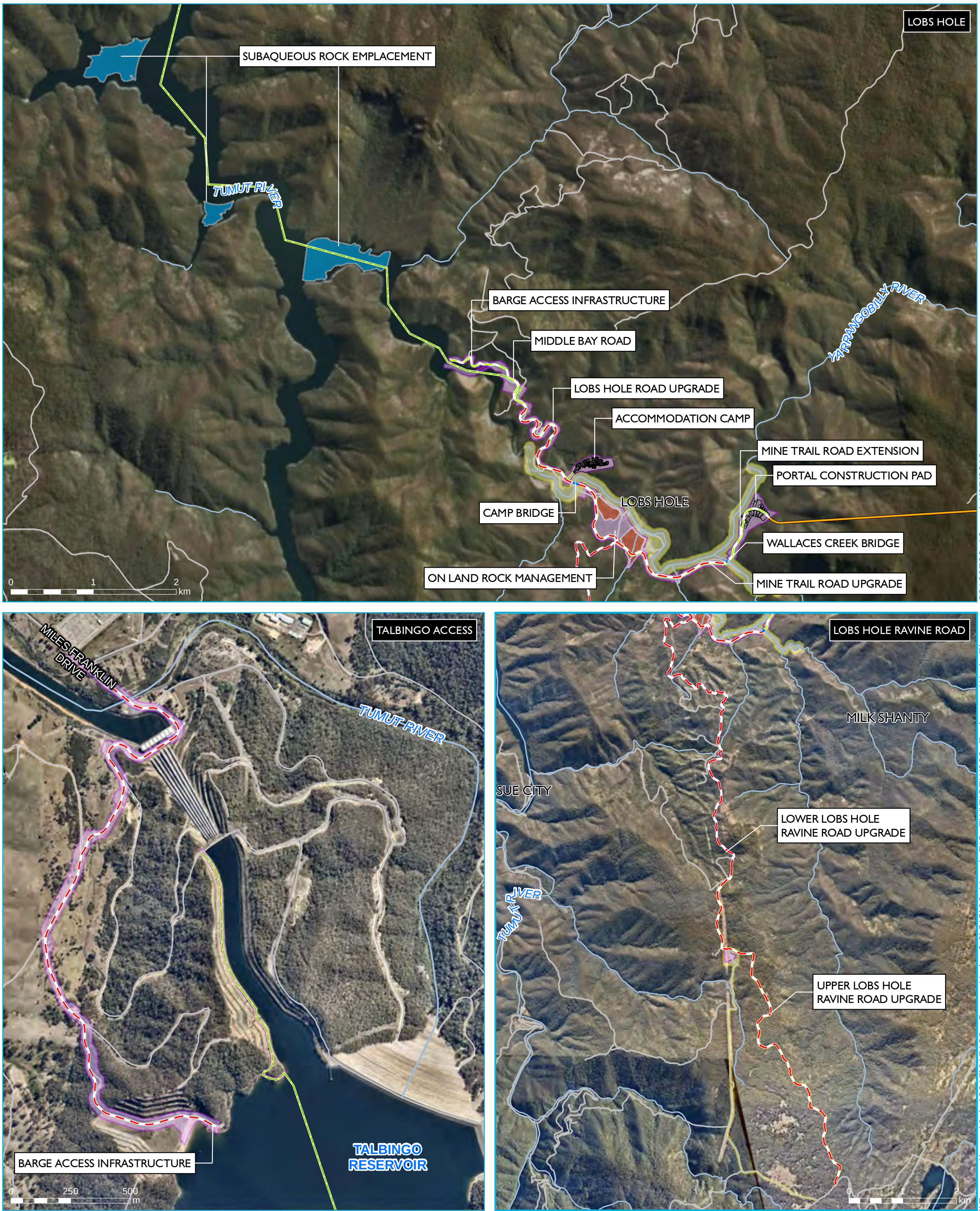
- establishment of an exploratory tunnel to the site of the underground power station for Snowy 2.0;
- horizontal and other test drilling, investigations and analysis in situ at the proposed cavern location and associated areas, and around the portal construction pad, access roads and excavated rock management areas all within the disturbance footprint;
- establishment of a portal construction pad for the exploratory tunnel;
- establishment of an accommodation camp for the Exploratory Works construction workforce;
- road works and upgrades providing access and haulage routes during Exploratory Works;
- establishment of barge access infrastructure, to enable access and transport by barge on Talbingo reservoir;
- excavated rock management, including subaqueous placement within Talbingo Reservoir;
- establishment of services infrastructure such as diesel-generated power, water and communications; and
- post-construction revegetation and rehabilitation, management and monitoring.

2.2 Exploratory tunnel

An exploratory tunnel of approximately 3.1 km is proposed to provide early access to the location of the largest cavern for the underground power station. This will enable exploratory drilling and help optimise the location of the cavern which, in turn, will optimise the design of Snowy 2.0.

The exploratory tunnel is proposed in the north-east section of Lobs Hole and will extend in an east-west direction with the portal construction pad to be outside the western end of the tunnel at a site east of the Yarrangobilly River, as shown on Figure 2.2.

The location of the proposed exploratory tunnel and portal construction pad is shown in Figure 2.2. The exploratory tunnel will be excavated by drill and blast methods and have an 8 x 8 m D-Shaped cross section, as shown on Figure 2.3.



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Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); Robert Bird (2018); DFSI (2017); LPMA (2011)

GDA 1994 MGA Zone 55

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KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Permanent bridge
- Portal construction pad and accommodation camp conceptual layout
- Communications cable
- Local road or track
- Watercourse
- On land rock management
- Subaqueous rock emplacement area
- Disturbance footprint
- Avoidance footprint

Exploratory Works elements

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.1

The drill and blast excavation process will be repeated cyclically throughout the tunnelling works, involving:

- marking up and drilling blast holes in a predetermined pattern in the working face of the tunnel;
- loading the blast holes with explosives, attaching detonators and connecting the holes into a blast sequence, and detonating the blast;
- ventilating the tunnel to remove blast fumes and dust;
- removing blasted rock;
- scaling and wash down of the tunnel roof and walls to remove loosened pieces of rock;
- geological mapping of the exposed rock faces and classification of the conditions to determine suitable ground support systems for installation;
- installing ground support; and
- advancing construction ventilation ducting and other utilities including power, water, compressed air and communications.

The exploratory tunnel will be shotcrete-lined with permanent anchor support, and incorporate a groundwater management system. The exploratory tunnel shape and dimensions are designed to allow two-lane traffic for the removal of excavated material, along with additional space for ventilation and drainage of groundwater inflows. Groundwater intersected during tunnelling will be contained and transferred to the portal for treatment and management. Areas identified during forward probing with the potential for high groundwater flows may require management through a detailed grouting program or similar.

The tunnel portal will be established at the western end of the exploratory tunnel and provide access and utilities to the exploratory tunnel during construction. The portal will house power, communications, ventilation and water infrastructure. The portal will also provide a safe and stable entrance to the exploratory tunnel.

It is anticipated that the exploratory tunnel will be adapted for multiple functions during construction of the subsequent stages of the Snowy 2.0 project. The exploratory tunnel will also eventually be utilized to form the main access tunnel (MAT) to the underground power station during the operational phase of Snowy 2.0, should it proceed.

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KEY

- Access road upgrade
- Access road extension
- Portal construction pad conceptual layout
- Exploratory tunnel
- Permanent bridge
- Communications cable
- Watercourse
- Contour (10m)
- Contour (100m)
- Disturbance footprint
- Avoidance footprint

Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); Robert Bird (2018); SMEC (2018); DFSI (2017)

0 0.5 1 km
GDA 1994 MGA Zone 55
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Exploratory tunnel location

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.2

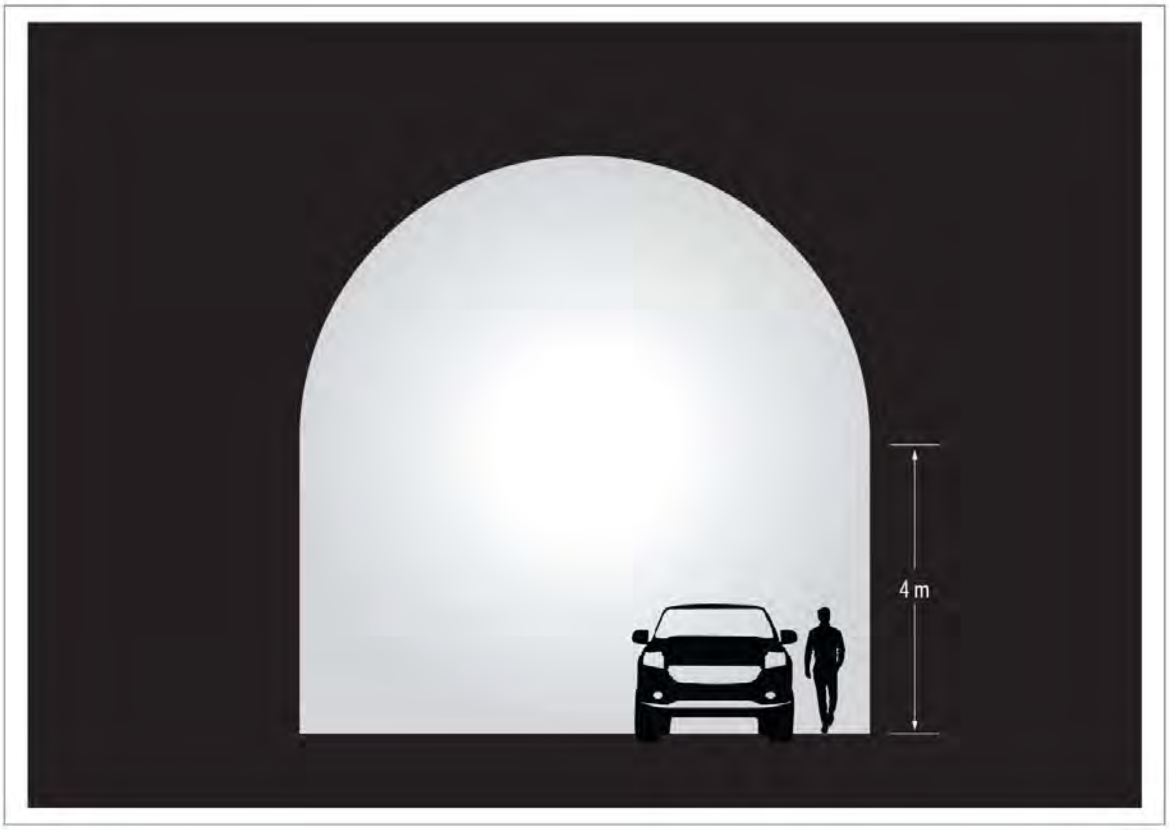
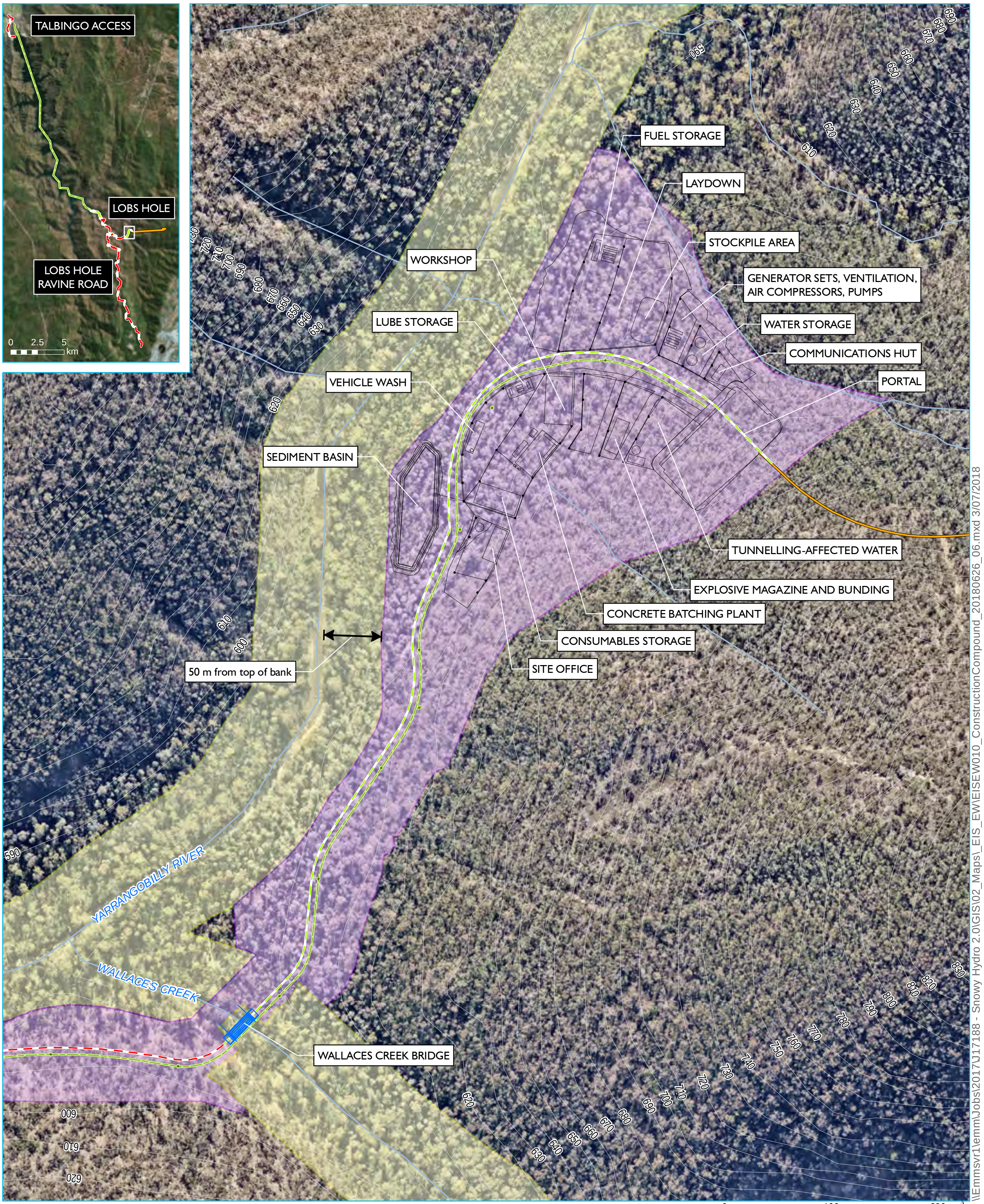


Figure 2.3 Exploratory tunnel indicative cross section

2.3 Portal construction pad

A portal construction pad for the exploratory tunnel will provide a secure area for construction activities. Infrastructure at the portal construction pad, shown in Figure 2.4, will primarily support tunnelling activities and include a concrete batching plant and associated stockpiles, site offices, maintenance workshops, construction support infrastructure, car parking, equipment laydown areas. Stockpile areas will allow for around two to three months supply of concrete aggregate and sand for the concrete batching plant to ensure that the construction schedule for the proposed access road works do not interfere with the exploratory tunnel excavation schedule. A temporary excavated rock stockpile area is also required to stockpile material excavated during tunnel construction prior to its transfer to the larger excavated material emplacement areas.

The portal construction pad will be at the western end of the exploratory tunnel. The portal construction pad will be excavated to provide a level construction area with a near vertical face for the construction of the portal and tunnelling. The area required for the portal construction pad is approximately 100,000 m^2.



Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); Robert Bird (2018); DFSI (2017)

0 100 200 m
GDA 1994 MGA Zone 55
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KEY

- Access road upgrade
- Access road extension
- Permanent bridge
- Portal construction pad conceptual layout
- Exploratory tunnel
- Communications cable
- Watercourse
- Contour (10m)
- Disturbance footprint
- Avoidance footprint

Conceptual layout – portal construction pad

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.4

2.4 Excavated rock management

It is estimated that approximately 750,000 m^3 of bulked materials will be excavated, mostly from the exploratory tunnel and portal construction pad with additional quantities from road upgrade works. Subject to geochemical testing of the rock material, excavated rock will be placed either on land or subaqueously within Talbingo Reservoir.

2.4.1 On land placement

Excavated materials will be placed in one of two rock emplacement areas at Lobs Hole as shown on Figure 2.5.

The strategy for excavated rock management is for excavated material to be emplaced at two areas with the final placement of excavated material to be determined at a later date.

Consultation with NPWS throughout the design process has identified an opportunity for the eastern emplacement area to form a permanent landform that enables greater recreational use of Lobs Hole following the completion of Snowy 2.0’s construction. It is envisaged that the excavated rock emplacement area will provide, in the long-term, a relatively flat final landform suitable for camping and basic recreational facilities to be confirmed in consultation with NPWS.

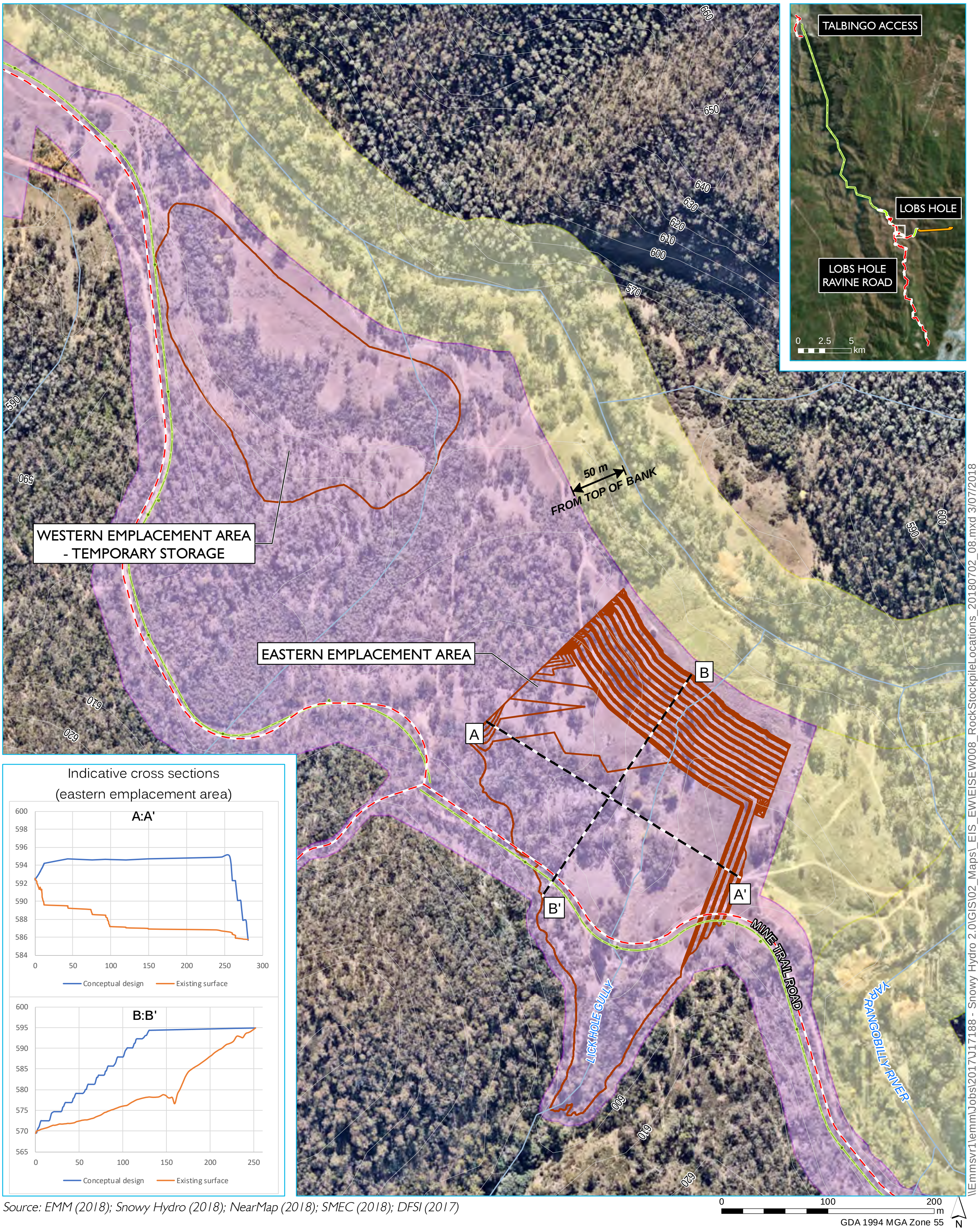
The eastern emplacement area has a capacity of up to 600,000 m^3 of material. It will be approximately 25 m maximum depth and will be benched down to the northern edge of the emplacement which is setback 50 m from the Yarrangobilly River.

The western emplacement area will be used to store excavated material should it not be able to be placed within the eastern emplacement area. It is envisaged this emplacement area will be used to store excavated materials suitable for re-use within the construction of Exploratory Works or for use by NPWS in KNP maintenance activities. All remaining material placed in this emplacement area will be removed following the completion of Exploratory Works.

The guiding principles for the design, construction method and management of emplacement areas undertaken for Exploratory Works have been as follows:

- reducing potential for acid rock drainage from the excavated rock emplacement area entering the Yarrangobilly River or forming groundwater recharge;
- avoid known environmental constraints; and
- manage existing surface water flows from Lick Hole Gully.

The design and management of the emplacement areas have not yet been finalised due to the need for further investigations to determine the likely geochemical characteristics of the excavated material. Following further investigation and prior to construction of Exploratory Works a management plan will be prepared and implemented.



Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); DFSI (2017)

KEY

- Cross-section
- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- On land rock management
- Watercourse
- Contour (10m)
- Disturbance footprint
- Avoidance footprint

Conceptual layout – excavated material emplacement areas

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.5

2.4.2 Subaqueous placement

An initial program for the placement of excavated rock within Talbingo Reservoir also forms part of Exploratory Works. The program will be implemented in an appropriate section of Talbingo Reservoir in accordance with a detailed management plan based on an engineering method informed through the materials' geochemistry and reservoir's characteristics. The purpose of the program is to confirm the suitability of the emplacement method for future excavated rock material from the construction of Snowy 2.0, should it proceed.

The rock for subaqueous placement will be taken from the excavated rock emplacement areas as described above. Testing of the rock would be conducted during excavation to assess geochemical properties. Any rock assessed as unsuitable for subaqueous placement based on the prior geochemical and leachability testing would be separately stockpiled and not used in the program. Suitable (ie non-reactive material) would be transported and loaded to barge, for placement at the deposition area. Suitable placement locations have been identified for Exploratory Works and are shown indicatively on Figure 2.6.

All placement within the reservoir would occur within silt curtains and would be subject to a detailed monitoring regime including survey monitoring of pre-placement and post-placement bathymetry, local and remote background water quality monitoring during placement with a structured management response to monitoring results in the event of an exceedance of established triggers. The management, mitigation and monitoring measures would be refined following the ongoing investigations.

2.5 Accommodation camp

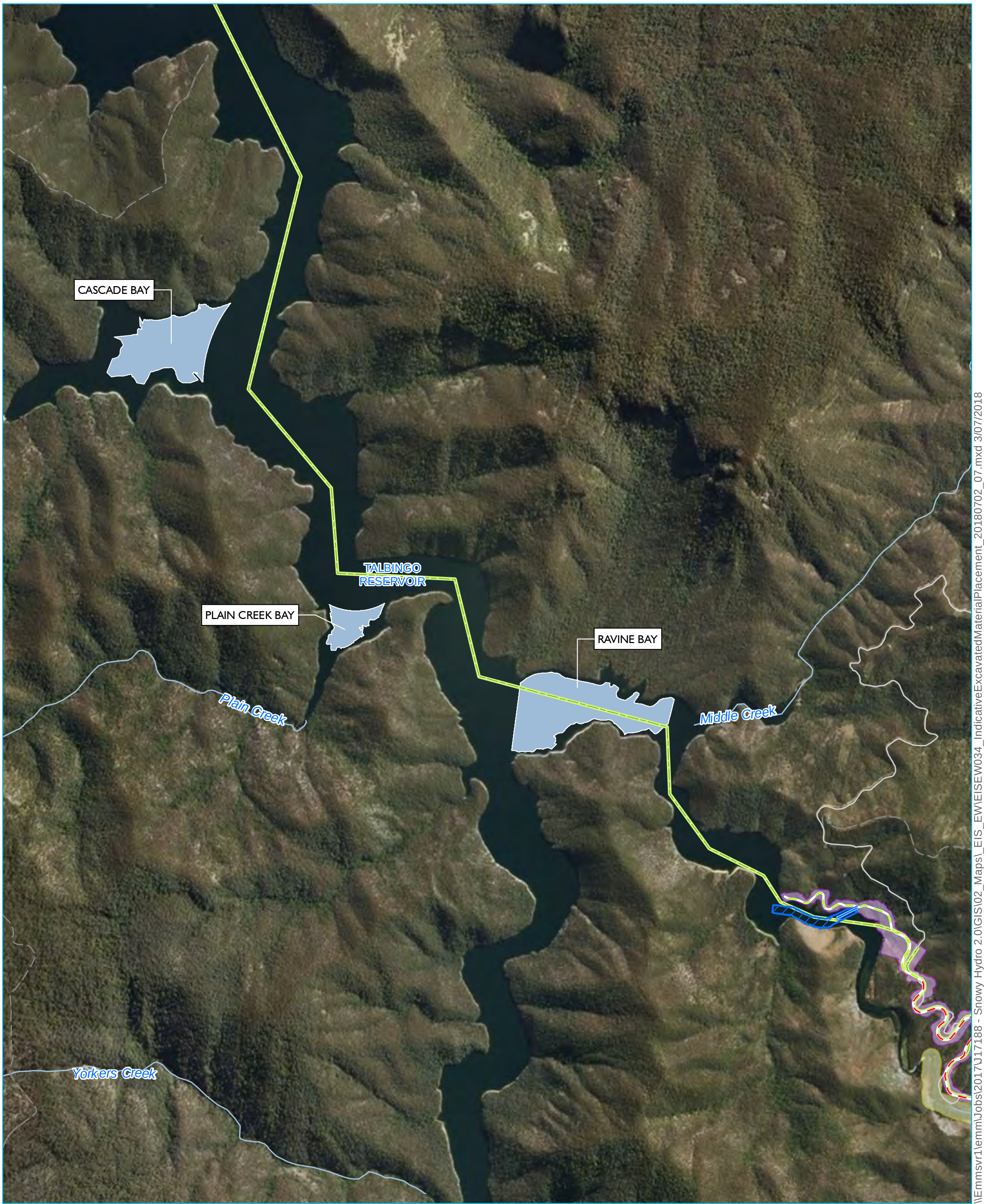
An accommodation camp is proposed to provide accommodation and supporting services for workers in close proximity to the exploratory tunnel. The accommodation camp layout is shown on Figure 2.7 and includes ensuite rooms surrounding central facilities including a kitchen, tavern, gym, admin office, laundry, maintenance building, sewage and water treatment plants and parking that will service the Exploratory Works workforce. The accommodation camp access road will connect to the north side of Lobs Hole Road at Lobs Hole. The conceptual layout of the accommodation camp is shown on Figure 2.7.

2.6 Road and access provisions

Existing road and access will need to be upgraded to a suitable standard to:

- provide for the transport of excavated rock material between the exploratory tunnel and the excavated rock emplacement areas;
- accommodate the transport of oversized loads as required; and
- facilitate the safe movement of plant, equipment, materials and construction staff to the portal construction pad.

Given the topographic constraints of the area, the standard of the existing roads and the environmental values associated with KNP, the option of barging larger and oversized loads to the site is available. This is discussed further at Section 2.7.

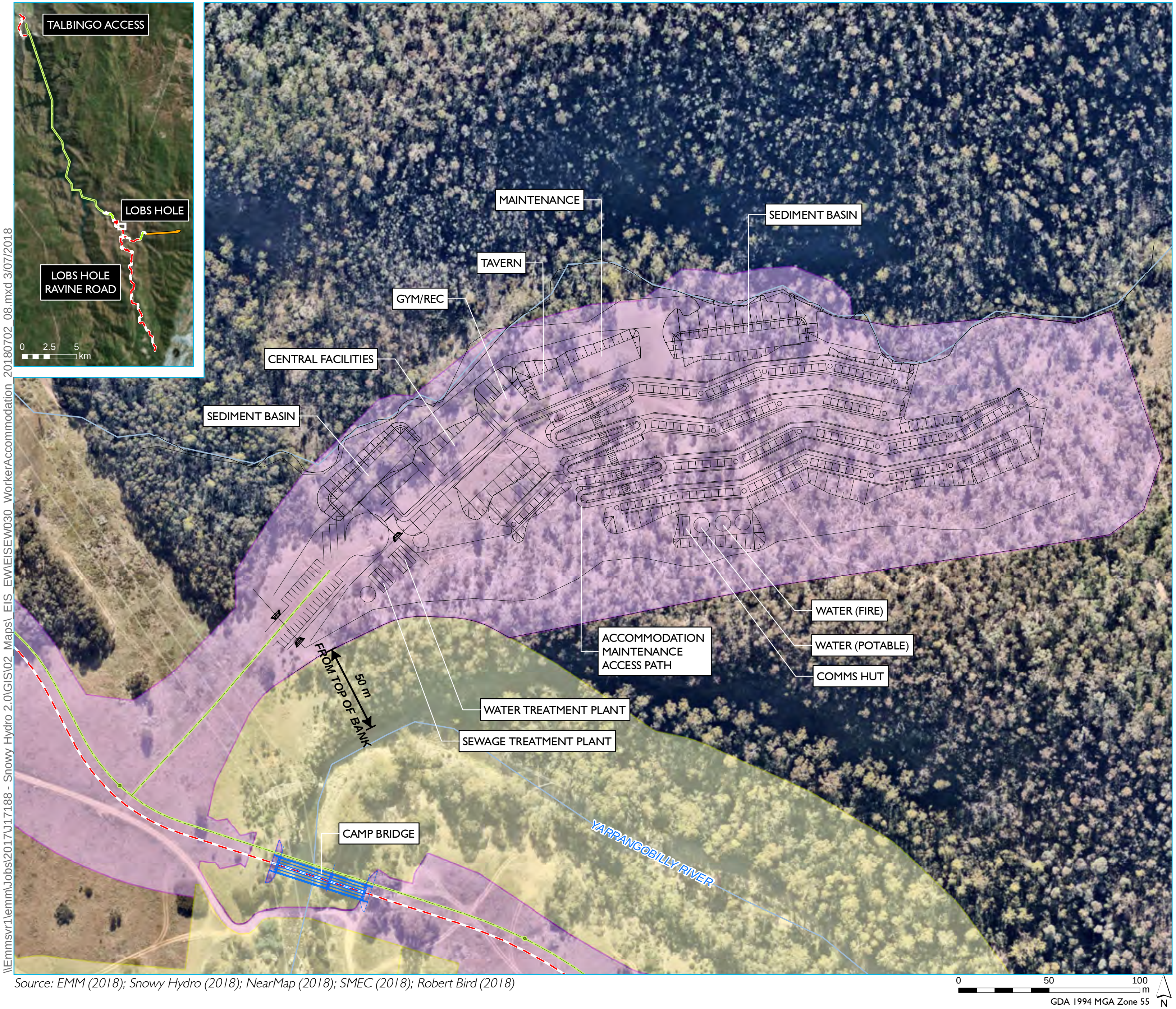


Source: EMM (2018); Snowy Hydro (2018); ESRI (2018); SMEC (2018); DFSI (2018); GA (2017); LPMA (2011)

KEY
- Access road upgrade
- Access road extension
- Communications cable
- Subaqueous rock emplacement
- Major watercourse
- Local road
- Track
- Middle Bay barge access
- Disturbance area - barge infrastructure
- Disturbance footprint
- Avoidance footprint

Subaqueous excavated rock placement

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.6



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Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); Robert Bird (2018)

Conceptual layout – accommodation camp

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.7

2.6.1 Access road works

The access road upgrades will be designed based on access for a truck and dog trailer. The proposed road works are shown in Figure 2.8 and described in Table 2.1. It is expected that the majority of materials and equipment will travel along the Snowy Mountains Highway, Link Road and Lobs Hole Ravine Road, with some required to travel on Miles Franklin Drive via Talbingo to Talbingo Dam Wall and be transferred via a barge to site. The primary haul routes for construction material on site are provided in Figure 2.9. Where existing roads are replaced by new access roads or road upgrades, the existing roads will be removed and rehabilitated in line with the rehabilitation strategy for Exploratory Works.

Table 2.1 Access road works summary

Roadwork area	Overview
Upper Lobs Hole Ravine Road upgrade	Minor upgrades to 7.5 km section of existing road. Only single lane access will be provided. No cut and fill earthworks or vegetation clearing will be undertaken.
Lower Lobs Hole Ravine Road upgrade	Upgrades to 6 km section of existing road involving cut and fill earthworks in some sections. Only single lane access will be provided.
Lobs Hole Road upgrade	Upgrade to 7.3 km section of existing road providing two-way access.
Mine Trail Road upgrade	Upgrade to 2.2 km section of existing track to two-way access.
Mine Trail Road extension	Establishment of a new two-way road providing access to the exploratory tunnel portal.
Middle Bay Road	Establishment of a new two-way road to the proposed Middle Bay barge ramp.
Spillway Road	Upgrade of a 3 km section of existing road to provide two-way access to the proposed Spillway barge ramp.

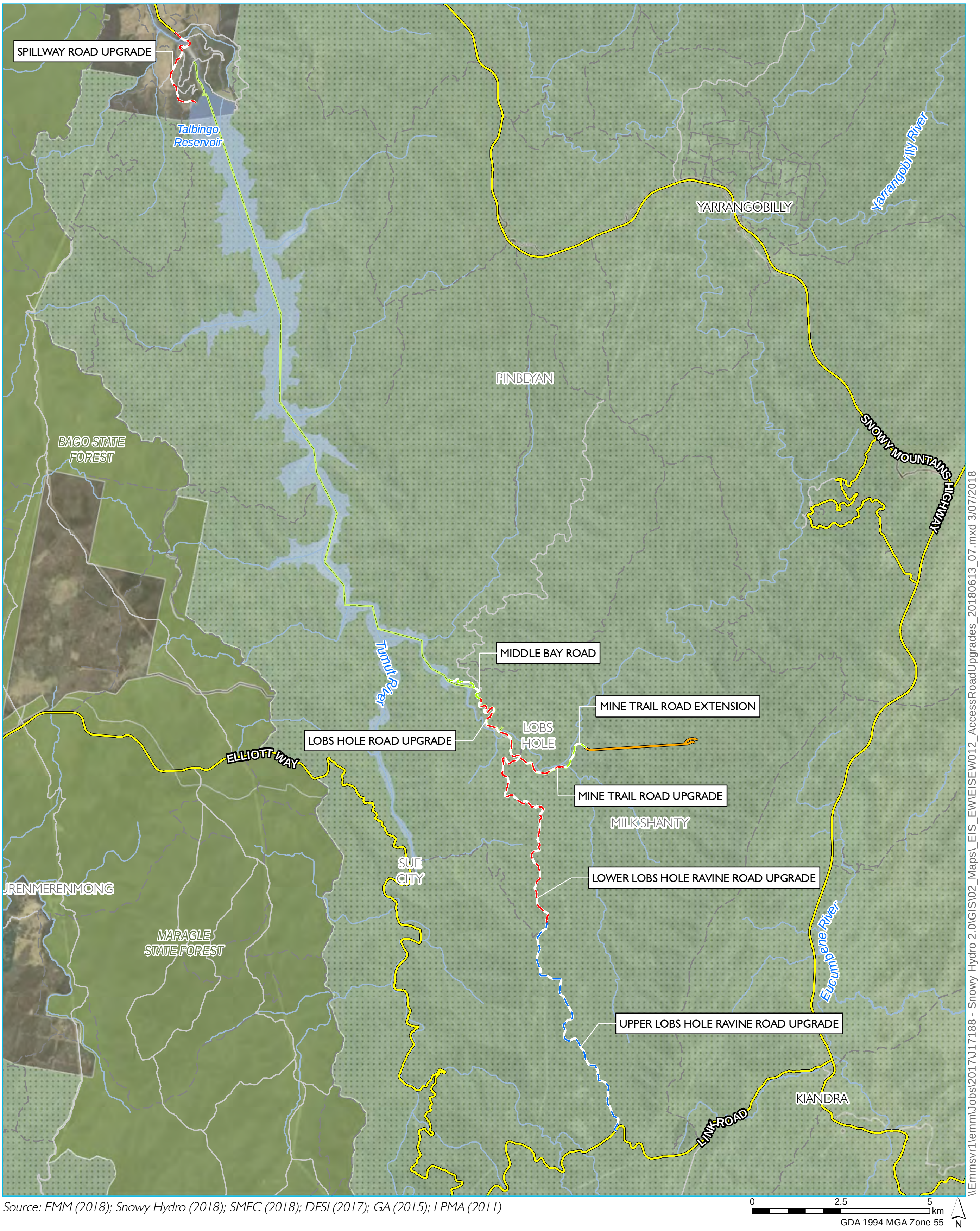
While no cut and fill earthworks or vegetation clearing is proposed along Upper Lobs Hole Ravine Road, a laydown area is proposed within and adjacent to the existing transmission line easement. This area will be used to store materials required for the road works to the lower section of Lobs Hole Ravine Road.

2.6.2 Watercourse crossings

Bridge construction will be required at two locations as described in Table 2.2. The locations of these bridge works are shown in Figure 2.9.

Table 2.2 Watercourse crossing summary

Bridge works area	Overview
Camp bridge	An existing crossing on Yarrangobilly River will be used as a temporary crossing while a new permanent bridge is built as part of Lobs Hole Road upgrade. The existing crossing will require the crossing level to be raised with rocks to facilitate vehicle passage. The rocks used to raise the crossing level will be removed and the crossing no longer used once the permanent bridge has been constructed. The new bridge (Camp Bridge) will be a permanent crossing and used for both Exploratory Works and Snowy 2.0 main works, should it proceed.
Wallaces Creek bridge	Establishment of a new permanent bridge at Wallaces Creek as part of the Mine Trail Road extension. Establishment of this bridge will require an initial temporary pre-fabricated 'Bailey bridge' to be constructed, which will be removed before the end of Exploratory Works.



Source: EMM (2018); Snowy Hydro (2018); SMEC (2018); DFSI (2017); GA (2015); LPMA (2011)

KEY

- Access road upgrade - without widening
- Access road upgrade - with widening
- Access road extension
- Exploratory tunnel
- Communications cable
- Main road
- Local road
- Vehicular track
- Perennial watercourse
- Scheme storage
- Kosciuszko National Park
- State forest

Access road upgrades and establishment

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.8

snowy 2.0 EMM

Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); Robert Bird (2018); DFSI (2017)

KEY

- Access road upgrade
- Access road extension
- Permanent bridge
- Exploratory tunnel
- Portal construction pad and accommodation camp conceptual layout
- Communications cable
- Excavated rock haul route
- Watercourse
- On land rock management
- Middle Bay barge access
- Disturbance footprint
- Avoidance footprint

Excavated material haul route

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.9

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The design for permanent bridges at both crossings will consist of steel girders with a composite deck. This is the most common type of permanent bridge constructed in and around the existing Snowy Scheme. Lightweight steel girders are easy to transport and will therefore allow for efficiencies in the construction schedule and permit the use of smaller-scale lifting equipment at the construction site.

2.7 Barge access infrastructure

To provide an alternative to road access, a barge option is proposed, not only for bulky and heavy equipments but for materials and also in case of emergency. During Exploratory Works, barges will be loaded at the northern barge ramp (Talbingo barge ramp), travel about 18 km along Talbingo Reservoir and be unloaded at the southern barge ramp (Middle Bay barge ramp) before returning to the north. Some loads may also be transported in the reverse direction.

Barge access infrastructure will comprise two dedicated barge ramps at Middle Bay and Talbingo Spillway, with a slope of approximately 1 vertical to 10 horizontal (1V: 10H) at each location. A navigation channel is also required adjacent to the Middle Bay barge ramp. Construction will involve:

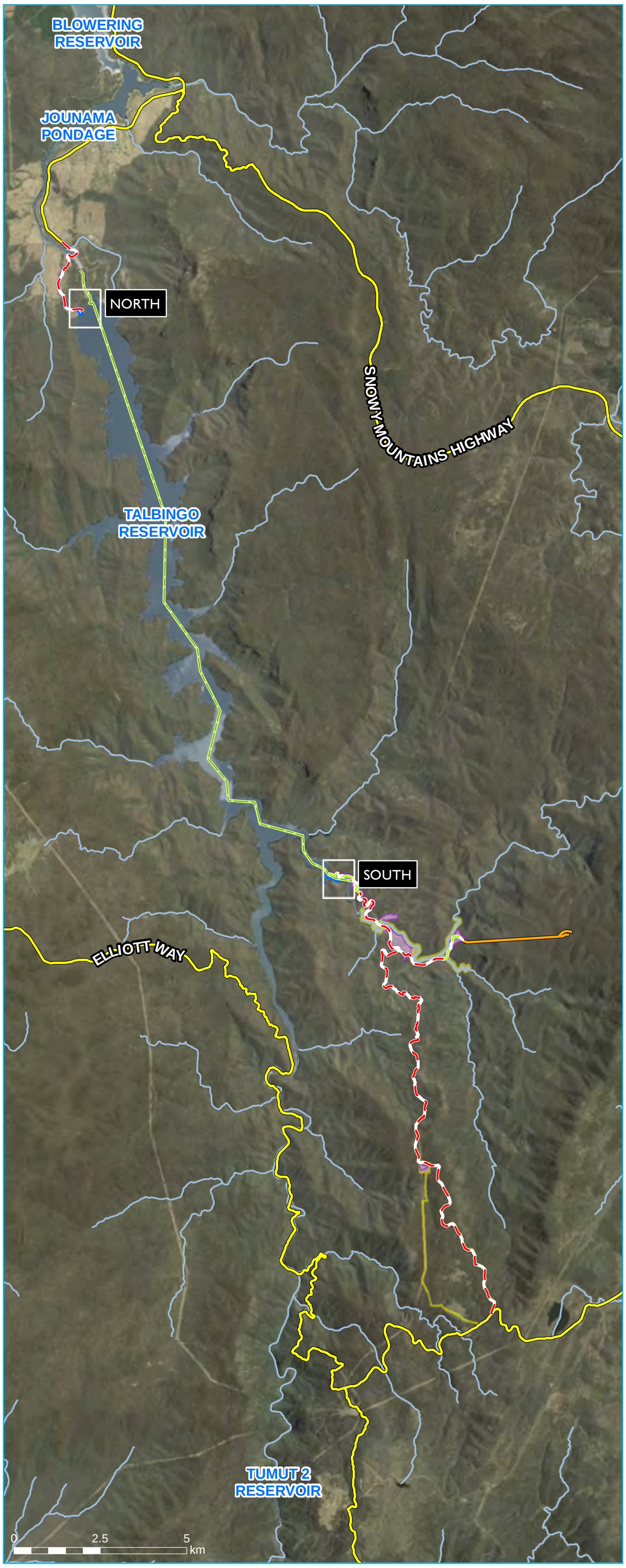
- geophysical and geotechnical investigation of the barge access area to inform detailed design;
- site establishment and excavation of barge access area;
- installation of precast concrete panels at the ramp location;
- installation of bollards for mooring lines;
- removal of trees and debris to establish a navigation channel allowing barge access; and
- minor dredging to allow barge access at the reservoir minimum operating level.

To facilitate construction, laydown areas are proposed adjacent to the Middle Bay barge ramp and adjacent to the water inlet pipeline. Laydown will also be used within the footprint of the Talbingo barge ramp.

Dredged material will be placed as part of the subaqueous placement program or within one of the designated on land rock emplacement areas. The infrastructure proposed for the Talbingo Spillway barge ramp and Middle Bay barge ramp is provided in Figure 2.10.

2.8 Services and infrastructure

Exploratory Works will require additional power and communication infrastructure. Water services are also needed and include a water services pipeline and water and waste water (sewage) treatment facilities. A summary of services required is provided at Table 2.3.



Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); DFSI (2017); LPMA (2011)

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KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Local road or track
- Perennial watercourse
- Middle Bay barge access
- Disturbance area - barge infrastructure
- Laydown area
- Disturbance footprint
- Avoidance footprint

Barge access locations

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 2.10

snowy 2.0 EMM

Table 2.3 Summary of services and infrastructure

Services infrastructure	Description
Power	Power will be provided at the portal construction pad and accommodation camp by diesel generators, with fuel storage provided at the portal construction pad.
Communication	Communication will be provided via fibre optic link. The fibre optic service has been designed to incorporate a submarine cable from Tumut 3 power station across Talbingo Reservoir to Middle Bay, and then via a buried conduit within the access roads to the accommodation camp and the portal construction pad.
Water and waste water (sewage)	A water services pipeline is proposed for the supply and discharge of water for Exploratory Works which will pump water between Talbingo Reservoir and the exploratory tunnel portal, portal construction pad and accommodation camp.
	A package water treatment plant is proposed at the accommodation camp to provide potable water to the accommodation camp and portal construction pad facilities and will be treated to a standard that complies with the Australian Drinking Water Guidelines. The accommodation camp water supply will be pumped via the water pipeline from Talbingo Reservoir at Middle Bay.
	A package waste water (sewage) treatment plant (STP) is proposed at the accommodation camp for Exploratory Works waste water. The STP will produce effluent quality comparable to standard for inland treatment facilities in the region (eg Cabramurra). Following treatment waste water will be discharged to Talbingo reservoir via the water services pipeline connecting the accommodation camp to Talbingo Reservoir.
	Waste water from the exploratory tunnel and concrete batching plant will be either re-used on site or sent to the waste water treatment plant for treatment prior to discharge.

2.9 Construction and schedule

2.9.1 Geotechnical investigation

To assist the design development for the portal construction pad, accommodation camp, Middle Bay Road, Spillway Road, and Lobs Hole Ravine Road, further survey of ground conditions is required. A program of geotechnical investigations including geophysical survey, construction of test pits, and borehole drilling within the disturbance footprint, will be undertaken as part of construction activities. Excavation of test pits in areas where information on relatively shallow subsurface profiles is required, or where bulk sampling is required for laboratory testing. Borehole drilling is required to facilitate the detailed design of cuttings, bridge foundations, retaining wall foundations, and drainage structures.

2.9.2 Construction activities

A disturbance footprint has been identified for Exploratory Works. The extent of the disturbance footprint is shown on Figure 2.1 and shows the area required for construction, including the buildings and structures, portal construction pad, road widening and bridges, laydown areas, and rock emplacement areas. Typical construction activities that will occur within the footprint are summarised in Table 2.4.

Table 2.4 Construction activities

Activity	Typical method
Geophysical and geotechnical investigation	Geophysical surveys will generally involve: • laying a geophone cable at the required location and establishing seismic holes; • blasting of explosives within seismic holes; and • in-reservoir geophysics surveys will use an air gun as the seismic source. Geotechnical surveys will generally involve: • establishing a drill pad including clearing and setup of environmental controls where required; • drilling a borehole to required depth using a tracked or truck mounted drill rig; and • installing piezometers where required for future monitoring program. Geophysical and geotechnical investigation within Talbingo Reservoir will be carried out using barges and subject to environmental controls.
Site establishment for portal construction pad, accommodation camp, rock placement areas and laydown areas	Site establishment will generally involve: • identifying and flagging areas that are to be avoided during the Exploratory Works period; • clearing of vegetation within the disturbance footprint, typically using chainsaws, bulldozers and excavators; • civil earthworks to create a stable and level area suitable for establishment. This will involve a cut and fill approach where required to minimise the requirement for imported material; • installing site drainage, soil erosion and other permanent environmental controls where required; • surface finishing, compacting only existing material where possible, or importing additional material. Where suitable, this material will be sourced locally (eg from upgrade works to Lobs Hole Ravine Road); and • set up and commissioning of supporting infrastructure, including survey marks.
Road works	Upgrades of existing tracks (no widening) will generally involve: • identifying and flagging areas that are to be avoided during the Exploratory Works period; and • removing high points, infilling scours, levelling of rutting, and compacting surfaces. Extension or widening of existing tracks will generally involve: • identifying and flagging areas that are to be avoided during the Exploratory Works period; • installing site drainage, soil erosion and other permanent environmental controls where required; • clearing and earthworks within the disturbance footprint; and • placing road pavement material on the roadway.
Bridge works	Establishment of permanent bridges will generally involve: • installing erosion and sedimentation controls around watercourses and installing scour protection as required; • establishing temporary diversions within the watercourse where required, including work to maintain fish passage; • establishing temporary bridges to facilitate permanent bridge construction; • constructing permanent bridges including piling, establishment of abutments and piers; and • removal and rehabilitation of temporary bridges and diversions.
Barge access works	Establishment of barge access infrastructure will generally involve: • installing sediment controls; • excavating and dredging of barge ramp area and navigation channel; • installing precast concrete planks and bollards; and • set up and commissioning of supporting infrastructure.

Table 2.4 Construction activities

Activity	Typical method
Exploratory tunnel construction	The drill and blast excavation process will be repeated cyclically throughout the tunnelling works, involving: • marking up and drilling blast holes in a predetermined pattern in the working face of the tunnel; • loading the blast holes with explosives, attaching detonators and connecting the holes into a blast sequence, and detonating the blast; • ventilating the tunnel to remove blast fumes and dust; • removing blasted rock; • scaling and wash down of the tunnel roof and walls to remove loosened pieces of rock; • geological mapping of the exposed rock faces and classification of the conditions to determine suitable ground support systems for installation; • installing ground support; and • advancing construction ventilation ducting and other utilities including power, water, compressed air and communications.

2.9.3 Ancillary construction areas

Ancillary facilities and laydown areas have been identified within the conceptual layout for the portal construction pad and accommodation camp. A number of other indicative construction and laydown areas have also been identified to support Exploratory Works. A summary of these sites are:

- Upper Lobs Hole Ravine Road laydown area;
- rock emplacement area laydown, storage and ancillary uses;
- barge access infrastructure laydown areas at Talbingo and Middle Bay; and
- other minor laydown areas as needed during site establishment of watercourse crossings.

All laydown areas are within the disturbance footprint identified for Exploratory Works.

In addition, an area near Camp Bridge has been identified to be used for a plant nursery and organic stockpile area.

2.9.4 Construction workforce requirements

i Staffing levels

It is currently expected that workforce for Exploratory Works will be approximately 200 people in total at peak construction. Workers are anticipated to work a 'swing' shift, for example two weeks on and one week off. These workers will be accommodated within the accommodation camp at Lobs Hole when rostered on.

The majority of the workforce will work on a fly-in fly-out and drive-in drive-out basis. It is expected that the majority of workers will fly in and out of either Cooma Airport or Canberra Airport and then travel to site via bus.

During construction of the accommodation camp, workers will be accommodated at Cabramurra. Some workers may also be accommodated at Snowy Hydro existing accommodation units at Talbingo during construction of the Talbingo barge ramp. No accommodation will be required outside of Cabramurra, the construction accommodation camp or Talbingo for the Exploratory Works workforce.

ii Hours of operation

It is expected that construction of the exploratory tunnel and haulage of rock material between the tunnel and excavated rock stockpile locations at Lobs Hole will be 24 hours a day, seven days a week for the duration of the tunnel drilling and blasting operation. Other construction activities, including the establishment works, road and infrastructure works, will normally work a 12 hour day, seven days a week.

The transport of materials along the haul route from Snowy Mountains Highway, Link Road and Upper Lobs Hole Ravine Road will only occur during day time hours (except during emergency), to avoid impacts to threatened species (Smoky Mouse). Transport by barge will be 24 hours a day, seven days a week.

iii Timing and staging

Exploratory Works are expected to take about 34 months, with the exploratory tunnel expected to be completed by late 2021.

It is expected that the construction works will be completed largely in parallel. However, road and access works are expected to be completed within the first six months from commencement. The proposed staging of construction activities are highlighted in Figure 2.11.

Figure 2.11 Indicative timing of Exploratory Works elements

2.10 Site rehabilitation

All Exploratory Works align with components of the main works for Snowy 2.0. However, should Snowy 2.0 not be approved or not progress, the project area will need to be rehabilitated, and project elements decommissioned in consultation with NPWS. Anticipated rehabilitation activities are summarised in Table 2.5.

Table 2.5 Planned Exploratory Works rehabilitation activities

Exploratory Works element	Indicative rehabilitation activities
Exploratory tunnel	Tunnel to remain open, and allowed to flood in lower portion provided groundwater impacts are negated.
Exploratory tunnel portal area	Permanent portal facade to be constructed, portal to be sealed from entry.
Portal construction pad and associated infrastructure	To be demobilised and all infrastructure removed. Site to be revegetated and returned to "original state".
Excavated rock emplacement areas	Emplaced excavated rock in the western emplacement area to be removed offsite and area to be revegetated and returned to "original state". The eastern emplacement area could remain in-situ and the landform rehabilitated as agreed with NPWS.
Accommodation camp	To be demobilised and all infrastructure removed. Site to be revegetated and returned to "original state".
Road access works	No remediation required as works are to be designed to be permanent.
Barge access infrastructure	No remediation works required as wharf and loading ramps are designed as permanent. Wharf can be removed if desired.
Services and infrastructure	To be demobilised and all infrastructure removed. Site to be revegetated and returned to "original state".

2.11 Decommissioning

Should Snowy 2.0 not proceed following the commencement or completion of Exploratory Works, elements constructed are able to be decommissioned and areas rehabilitated. Given works are within KNP, Snow Hydro will liaise closely with NPWS to determine the extent of decommissioning and types of rehabilitation to be undertaken. This approach will be taken to ensure that decommissioning allows for integration with future planned recreational use of these areas and to maintain the values of KNP.

2.12 Key aspects relevant to groundwater

The key objectives of the groundwater assessment are to:

- identify and assess potential impacts on groundwater from the construction of Exploratory Works;
- satisfy the SEARs and other relevant agency requirements pertinent to the groundwater assessment; and
- inform the wider community about Exploratory Works project and its potential impacts on the local and regional water environments.

To achieve these objectives, the groundwater assessment:

- assesses the existing hydrogeological environment using a risk-based approach, and establishment and assessment of baseline conditions within Exploratory Works area and the broader regional setting;
- identifies and quantifies the potential risks and impacts of Exploratory Works on the groundwater resource, and on the water users for both environmental and extractive;
- proposes mitigation and management measures, and monitoring requirements for groundwater; and
- discusses water licensing requirements in accordance with the relevant legislation, statutory plans and policies.

3 Project setting

3.1 General site description

The location of Exploratory Works is provided in Chapter 1. Given the complexity of the local and regional hydrogeology, this assessment relies on data collected across an extensive area (30 km x 15 km), covering areas of interest conceptualised to interact with the local Exploratory Works project area. These areas broadly include: the Yarrangobilly Caves, all major rivers and creeks (including Yarrangobilly River), the Long Plain Fault and geological domains central and to the east of Exploratory Works project area.

3.1.1 Topography

Exploratory Works project area is within a steeply incised ravine, along the western fringe of the Long Plains fault escarpment. Elevations typically range from around 550 to 1,400 metres Australian Height Datum (AHD) (Figure 3.1). Most of the project area is characterised by deep gorges and steep sloping ridges, the product of incision from watercourse flow and historic glaciation.

3.1.2 Meteorology

The broader Snowy 2.0 project area has an oceanic/humid continental climate, characterised by cool summers and chilly, very damp and sometimes snowy winters. January is typically the driest month. Table 3.1 summarises average climate data specific to Exploratory Works project area, using rainfall data from the Bureau of Meteorology (BoM) weather station at Cabramurra SMHEA AWS (station 072161), which began recording in 1996, and mean pan evaporation measurements from the Eucumbene Dam weather station. The relevance and appropriateness of the Cabramurra SMHEA AWS has been well considered. The weather station is located at the top of the groundwater flow divide, local to Exploratory Works, contributing recharge to the local groundwater source.

The data in Table 3.1 shows the temperature range from an average maximum of 21.4°C in January to an average minimum of -0.9°C in July.

Table 3.1 Local climate data

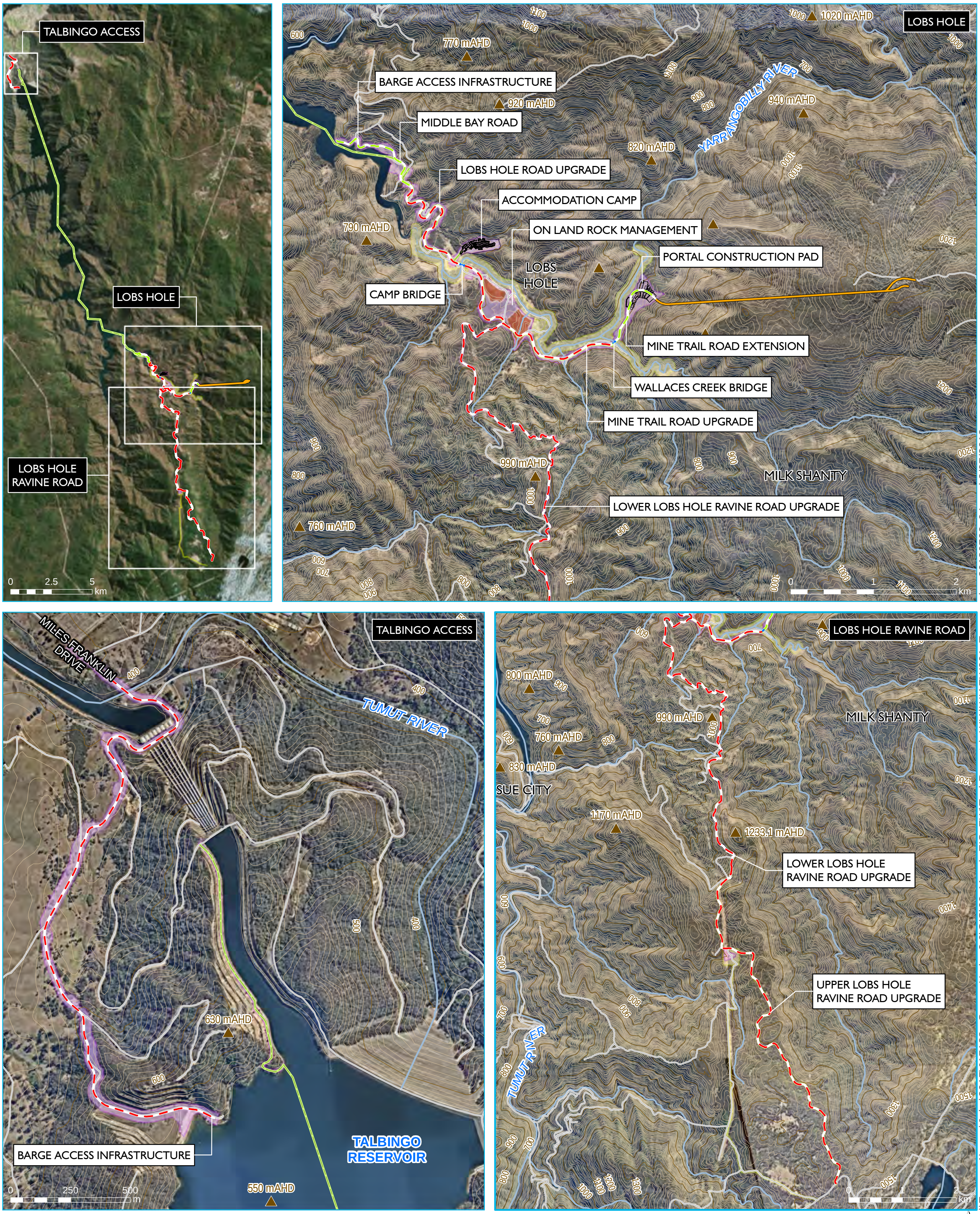
Parameter		Measurement	Month
Mean temperature at Cabramurra SMHEA AWS BoM station 072161			
Maximum	Annual	12.6°C	-
	Highest monthly	21.4°C	January
	Lowest monthly	5.1°C	July
Minimum	Annual	5.1°C	-
	Highest monthly	11.5°C	January
	Lowest monthly	-0.9°C	July
Mean rainfall at Cabramurra SMHEA AWS BoM station 072161			
Annual		1,178 mm	-
Highest monthly		130 mm	August
Lowest monthly		63 mm	January

Table 3.1 Local climate data

Parameter	Measurement	Month
Mean pan evaporation at Eucumbene Dam		
Annual	1,268 mm	-
Highest monthly	205	January
Lowest monthly	30	June

Figure 3.2 compares mean monthly evaporation and rainfall from the Eucumbene Dam and Cabramurra stations, respectively. Rainfall is relatively consistent throughout the year, although obvious seasonal fluctuations occur in line with winter and summer months. A soil moisture deficit is likely from November to April when evaporation typically exceeds rainfall. The long-term regional average annual rainfall for the assessment area is about 988 mm and is slightly lower than that observed at the Cabramurra station; this approximation is based on an area-weighting of three nearby BoM climate stations (including 072161, 072141 and 071000).

The numerical groundwater model used area-weighted data from these three nearby BoM climate stations covering a much broader area to better represent the climate of the numerical groundwater model's larger study area (Section 7.1) As a result, climatic statistics, including averages referenced in the various technical reports within the EIS will vary slightly as the average most applicable to the study that is being referenced will be adopted. Some studies, such as the groundwater assessment, regional averaging of several stations is considered most appropriate, whereas studies that are more localised (such as *Snowy 2.0 Exploratory Works Noise and Vibration Impact Assessment*) may require more localised data to be considered.



Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); Robert Bird (2018); DFSI (2017); LPMA (2011)

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KEY

- Access road upgrade
- Access road extension
- Permanent bridge
- Exploratory tunnel
- Portal construction pad and accommodation camp conceptual layout
- Communications cable
- On land rock management
- Disturbance footprint
- Avoidance footprint
- Local road or track
- Watercourse
- Spot height (trig station)
- Contour (100m)
- Contour (10m)

Topography

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 3.1

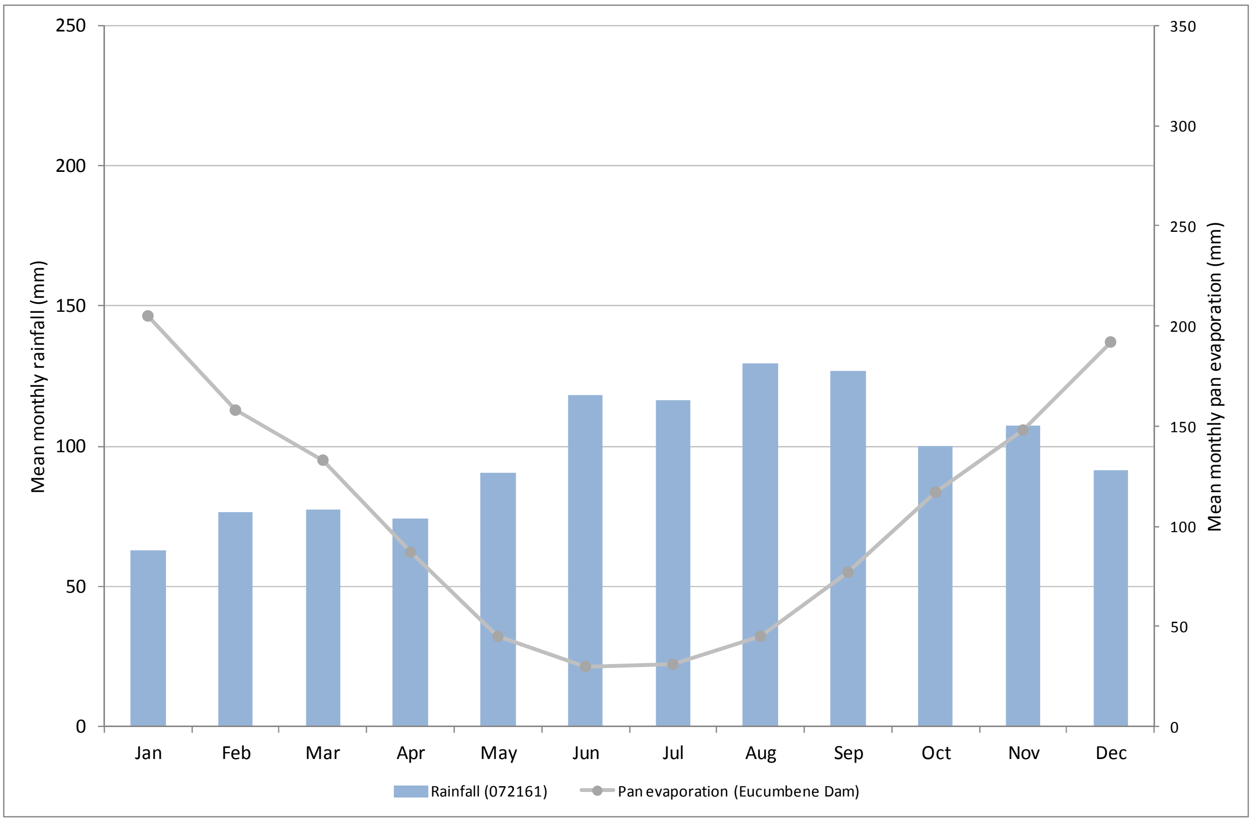


Figure 3.2 Mean monthly rainfall and evaporation

i Cumulative deviation rainfall

The long-term annual cumulative deviation from the mean (CDFM) of rainfall at Cabramurra (from 1996 to 2018) is plotted in Figure 3.3.

The CDFM plot is made by subtracting the mean annual rainfall (calculated from the whole dataset) from the actual annual rainfall observed in each particular year. Periods of below average rainfall plot as a downward trend while periods of above average rainfall plot as an upward trend. These deficits and excess in rainfall can also correspond to falling and rising groundwater levels respectively.

The CDFM plot for Cabramurra shows that, based on the 22 years from 1996 to 2018, monthly rainfall in recent years is above average.

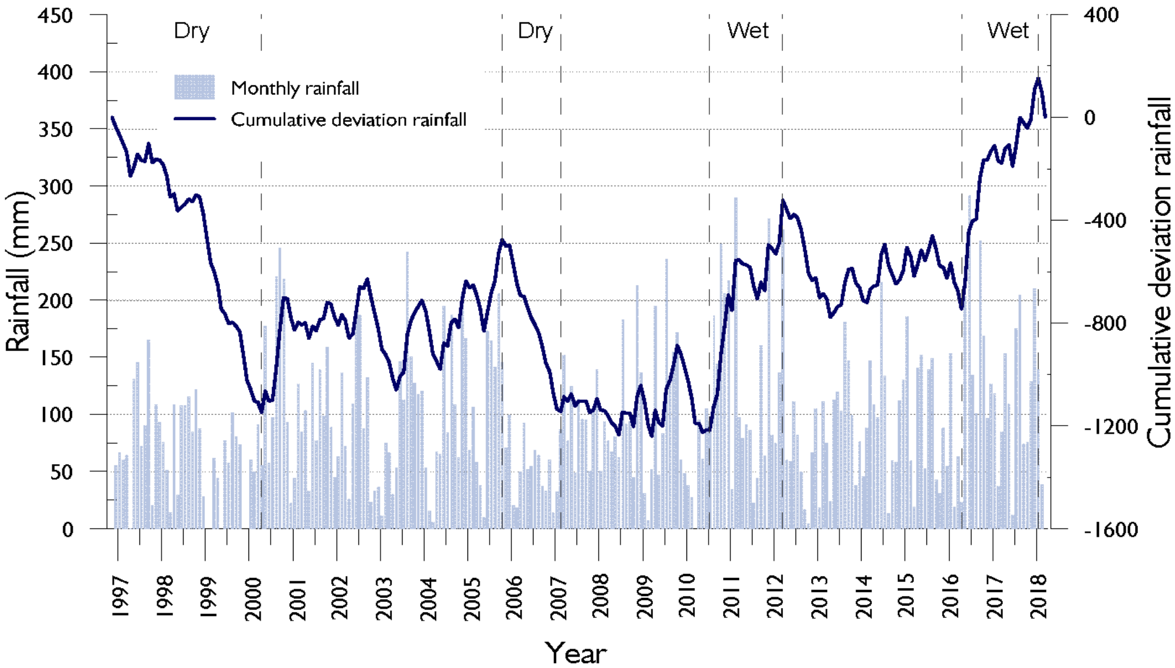


Figure 3.3 Monthly cumulative deviation from the mean of rainfall (1996 2018)

3.1.3 Water resources

Exploratory Works project area is within the Murrumbidgee River catchment, one of the state's larger surface water catchments (84,000 km^2) bordered by the Great Dividing Range to the east, the Murray Catchment to the south, and to the north (well beyond the project area), the Lachlan Catchment.

The surface water resources within Exploratory Works area are within the Unregulated Upper Tumut Water Source within the *Water Sharing Plan for the Murrumbidgee unregulated and alluvial water source 2012* (unregulated WSP).

The groundwater resources of Exploratory Works area are primarily regulated by the *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011*, and are within the Lachlan Fold Belt Murray Darling Basin (MDB) Groundwater Source. A small portion of the project area is within the *Water Sharing Plan for the South Coast Groundwater Sources 2016*, specifically the Lachlan Fold Belt Coast Groundwater Source.

A detailed description of the water resources is provided in Chapter 6. Figure 3.4 provides an overview of the relevant surface water and groundwater resources pertinent to Exploratory Works project area.

3.1.4 Soils and geology

i Soils

The soils of the Australian Alps Bioregion reflect the extreme climatic gradient across the ranges. The lowlands consist mainly of texture contrast soils, grading to uniform, organic soils and peats at the highest elevations (NPWS 2003). The soils of the South Eastern Highlands Bioregion vary significantly in relation to altitude, temperature and rainfall.

ii Regional geological setting

The geology of the broader assessment area comprises Ordovician to Devonian granites, volcanics, and metamorphosed sedimentary sequences that have formed faulted, stepped ranges at the point where the South Eastern Highlands (part of the Lachlan Fold Belt (LFB)) in NSW transition west into Victoria (NPWS 2003). More recent Tertiary volcanic activity produced basalts and, in the Pleistocene, the cold climate superimposed glacial features on the landscape (NPWS 2003). The Australian Alps Bioregion was the only part of the mainland to have been affected by Pleistocene glaciation and contains a variety of unique glacial and periglacial landforms above 1,100 m altitude (NPWS 2003).

The geology of Exploratory Works area comprises a complex series of metamorphosed Ordovician to Devonian sandstones, shales and volcanic rocks intruded by numerous granite bodies and deformed by four episodes of folding, faulting and uplift.

Shallow and outcropping Ordovician to Devonian units are regionally extensively weathered, consisting, consisting of a mixture of colluviums, regolith and weathered basement rocks. Tertiary aged basalts also exist within this weathered zone and form some of the ridgelines to the east of the project area.

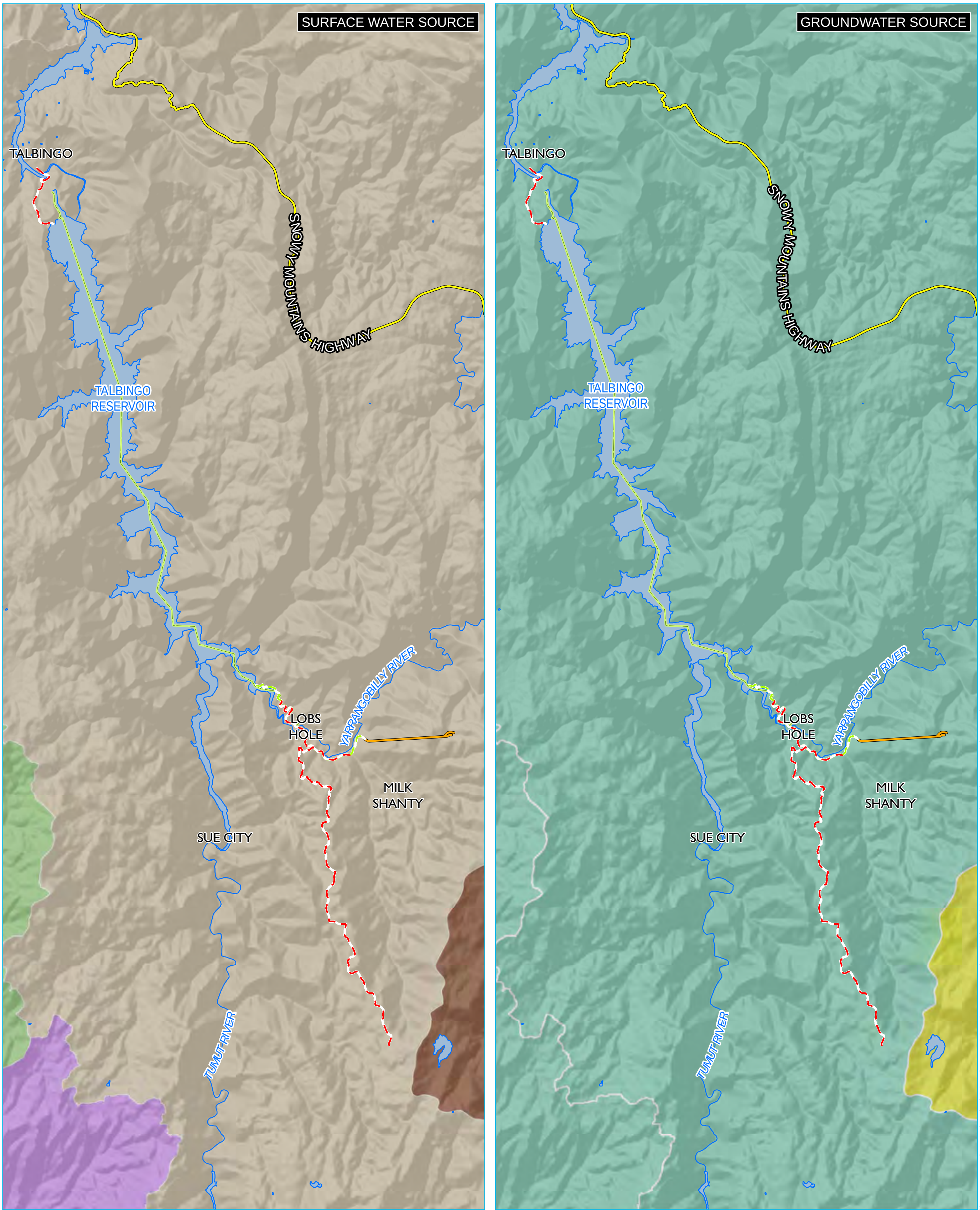
The Late Silurian Ravine Beds geological unit is likely to be intersected by the exploratory tunnel excavation; this unit consists of limestone, sandstone, siltstone and shale.

3.1.5 Hydrology

Existing surface water features in proximity to Exploratory Works are shown in Figure 3.6.

Exploratory Works will be adjacent to the lower reach of the Yarrangobilly River within the catchment of the Murrumbidgee River. The Yarrangobilly River is a major watercourse within Exploratory Works project area that flows into the Talbingo Reservoir, approximately 1.5 km downstream of Exploratory Works project area. The Yarrangobilly River catchment is wholly within the KNP and is characterised by a range of subalpine grasslands and woodlands and montane dry sclerophyll forests.

Other watercourses within proximity to Exploratory Works include Stable Creek, Wallaces Creek and Cave Gully. All of these watercourses are tributaries to the Yarrangobilly River.



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Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); GA (2015); DPI (2013); LPMA (2011)

KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Watercourse
- Waterbody

Surface water source

- Lake Eucumbene Water Source
- Maragle Water Source
- Tooma Water Source
- Upper Tumut Water Source

Groundwater source

- Lachlan Fold Belt Coast
- Lachlan Fold Belt MDB

Water sources

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 3.4

KEY

Exploratory tunnel

Access road upgrade

Access road extension

Communications cable

Perennial watercourse

Long Plain Fault (interpreted)

Geology (1:250,000)

w - Water

Quaternary

Qa - Alluvium

Tertiary

Tbm - Basalt

Cainozoic

Cz - Unknown (undifferentiated)

Devonian

Dls1 - Byron Range Group (undifferentiated)

Dlv2 - Boraig Group (unnamed)

Dlv3 - Black Range Group (Mountain Creek Volcanics)

gah3 - Free Damper Suite (Free Dampier Adamellite)

gah4 - Free Damper Suite (Pennyweight Adamellite)

glp2 - Tumut Granites (Lobs Hole Adamellite)

glp3 - Bogong Suite (Bogong Granite)

Silurian

Sc2 - Unknown (Tumut Ponds Sepentinite)

Smf2 - Unknown (Jackalass Slate)

Ss2 - Bredbo Group (Ravine Beds/Yarrangobilly Limestone)

Sv5 - Young Suite (Goobarragandra Volcanics)

Sv6 - Unknown (Blowering Formation)

Sv7 - Unknown (Kings Cross Formation)

ggb29 - Tom Groggin Suite (Rough Creek Tonalite)

ggb9 - Tom Groggin Suite (Green Hills Granodiorite)

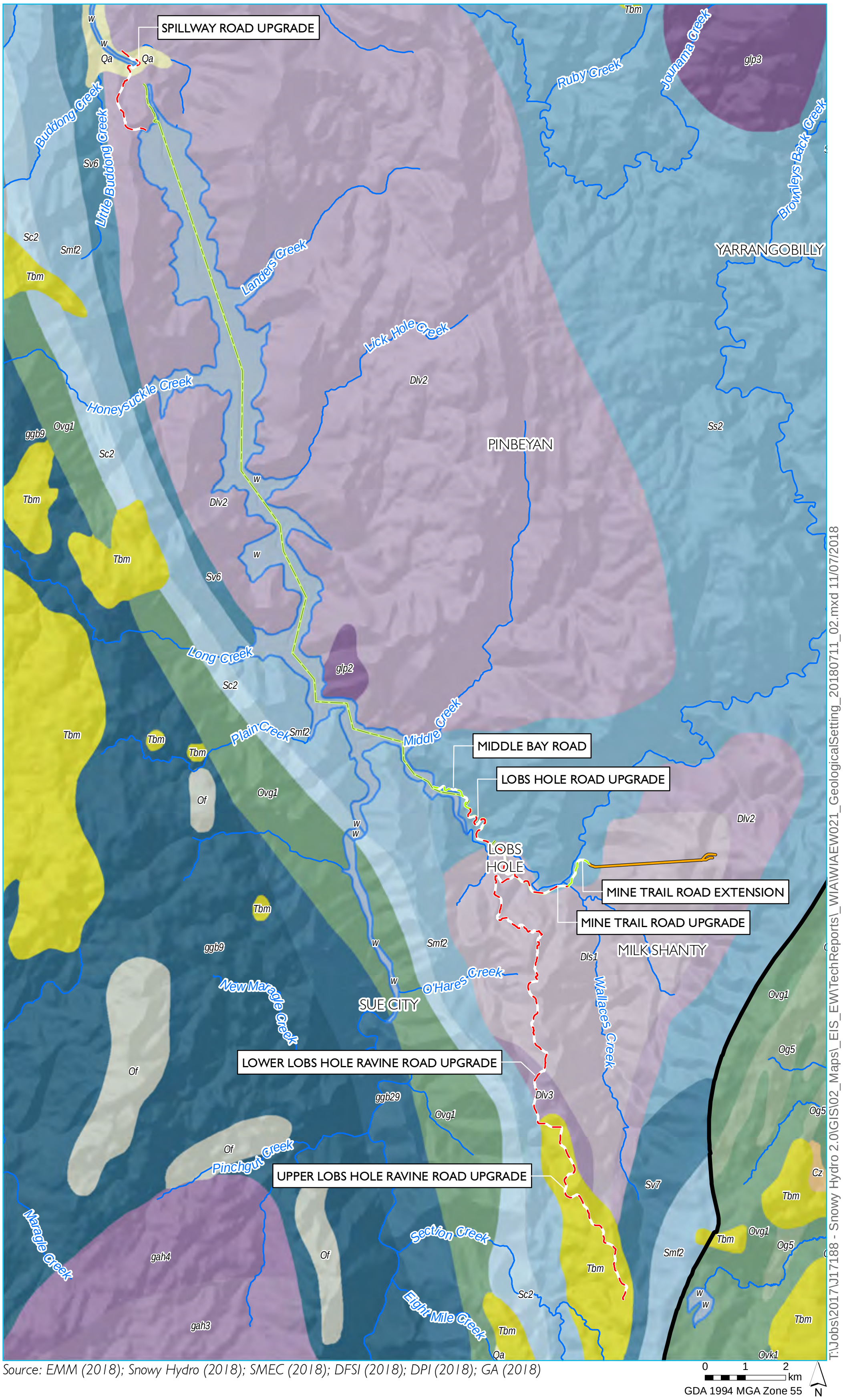
Ordovician

Of - Adaminaby Group (Adaminaby Group)

Og5 - Unknown (Shaw Hill Gabbro)

Ovg1 - Unknown (Gooandra Volcanics)

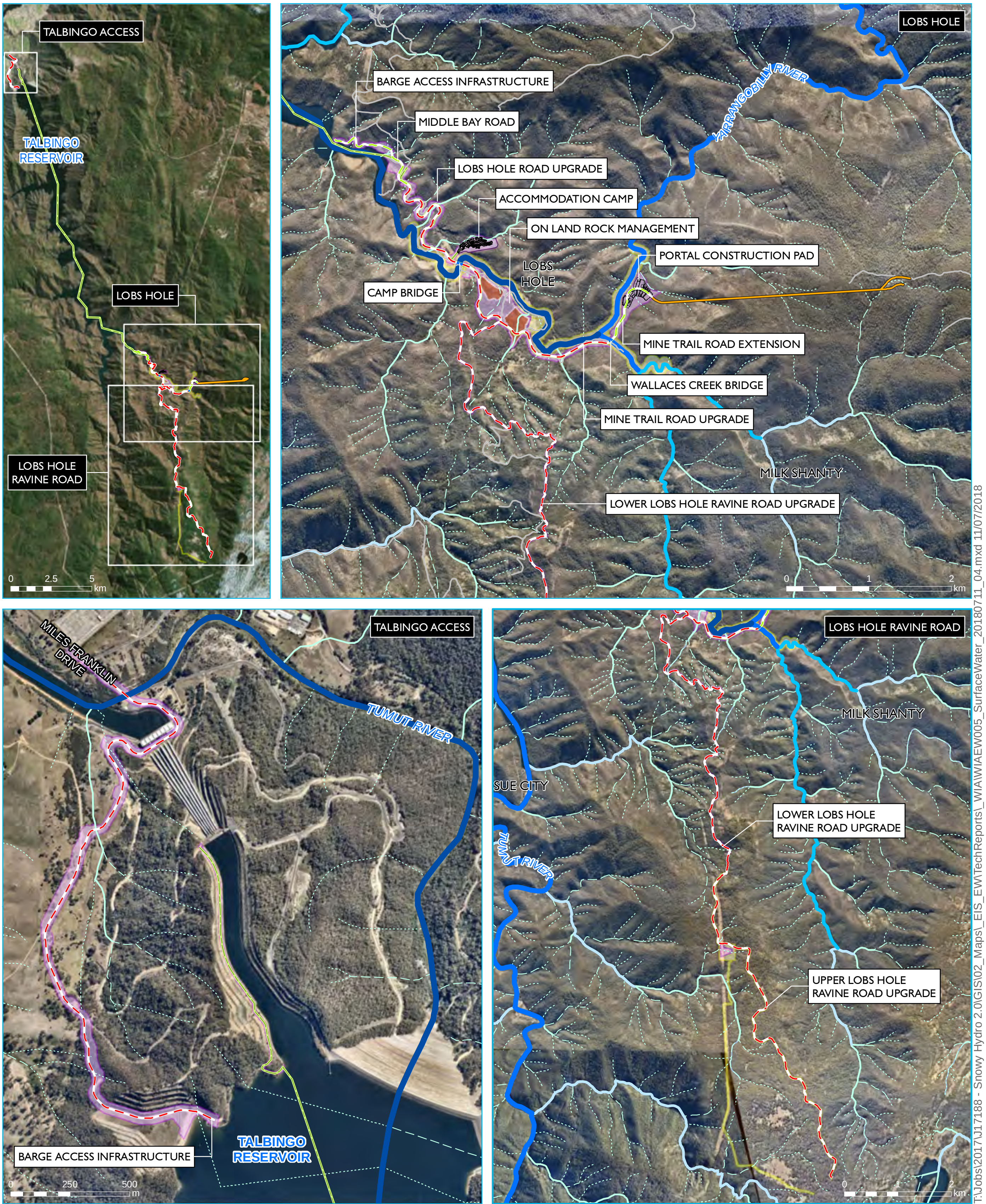
Ovk1 - Kiandra Group (unnamed)



Source: EMM (2018); Snowy Hydro (2018); SMEC (2018); DFSI (2018); DPI (2018); GA (2018)

Exploratory Works - geological setting

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 3.5



Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); SMEC (2018); Robert Bird (2018); DFSI (2017); LPMA (2011)

GDA 1994 MGA Zone 55

N

KEY

- Exploratory tunnel
- Portal construction pad and accommodation camp conceptual layout
- Access road upgrade
- Access road extension
- Permanent bridge
- Communications cable
- Local road or track
- On land rock management
- Disturbance footprint
- Avoidance footprint

Strahler stream order

- 1st order
- 2nd order
- 3rd order
- 4th order
- 5th order
- 6th order
- 7th order

Hydrology

Snowy 2.0
Gro undwater Assessment
Exploratory Works
Figure 3.6

snowy 2.0 EMM

4 Regulatory and policy context and assessment

The primary water related statutes that apply to the project are the *NSW Water Management Act 2000* (WMA 2000), *NSW Water Act 1912 (*WA 1912*), Protection of the Environment Operations Act 1997* (POEO Act), and their attendant regulations (including water sharing plans under the WMA 2000). Projects that intercept groundwater also need to consider the NSW Aquifer Interference Policy (AIP) (NOW 2012b) which requires projects to hold licences that account for the volume of water intercepted and consider changes in water quality and water levels against sensitive receptors in accordance with prescribed minimal impact criteria.

4.1 Water Act 1912

The WA 1912 is gradually being repealed and replaced by the WMA 2000 as water sharing plans (WSPs) are developed for water sources across NSW, and as new regulations are made. Some aspects of the WA 1912 are still operational across all of NSW, such as licences for all monitoring bores greater than 40 m in depth. This is the only commitment under the WA 1912 required for Exploratory Works.

4.2 Water Management Act 2000

The WMA 2000 is based on the principles of ecologically sustainable development and the need to share and manage water resources for future generations. The WMA 2000 recognises that water management decisions must consider: economic, environmental, social, cultural and heritage factors. The WMA 2000 recognises that sustainable and efficient use of water delivers economic and social benefits to the state of NSW.

The WMA 2000 provides for water sharing between different water users, including environmental, basic rights or existing water access licence (WAL) holders and provides security for licence holders. The licensing provisions of the WMA 2000 apply to those areas where a WSP has commenced.

4.3 Water Sharing Plans

WSPs are statutory documents that apply to one or more water sources. They contain the rules for sharing and managing water resources within water source areas. WSPs describe the basis for water sharing, and document the water available and how it is shared between environmental, extractive, and other uses. The WSPs then outline the water available for extractive uses within different categories, such as: local water utilities, domestic and stock, basic rights, and access licences.

The water sharing plans and water sources relevant for Exploratory Works are:

- *Water Sharing Plan for the Murrumbidgee unregulated and alluvial water source 2012* (unregulated WSP) and the water source of relevance for Exploratory Works is the Upper Tumut Surface Water Source.
- *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011* and the water source is Lachlan Fold Belt MDB Groundwater Source.
- *Water Sharing Plan for the South Coast Groundwater Sources 2016* and the water source is the Lachlan Fold Belt Coast Groundwater Source.

4.3.1 Environmental water

Planned environmental water is water prescribed under the rules of a water sharing plan to protect the aquifer and groundwater dependent ecosystems (GDEs) (for groundwater) or the river and streams systems and associated ecosystems (surface water).

For groundwater, environmental water typically is defined as 100% of the storage volume within the aquifers plus a proportion of the annual recharge volume. The environmental water volume, a combination of *Not High Environmental Value* and *High Environmental Value*, set aside in the Lachlan Fold Belt MDB and Lachlan Fold Belt Coast groundwater sources (as per the Water Sharing Plans) is estimated to be 3,727,236 ML/yr and 680,000 ML/yr respectively.

4.3.2 Water availability and licences

The groundwater availability and licences for the NSW MDB Fractured Rock and Coast groundwater sources are shown in Figure 4.1 and Figure 4.2 respectively. These figures demonstrate that the volume of licences within these water sources represent a very small percentage of the overall availability of water. There are, therefore very large volumes of water unassigned within these water sources available to be granted via controlled allocation releases to new proponents. The information used to generate these figures was sourced from the relevant groundwater source WSPs, and from a recent search of the NSW Water Register (DoI 2017a).

The surface water available for extractive uses within the Unregulated Upper Tumut Water Source is shown in Table 4.1. The dominant users of water from the Unregulated Upper Tumut Water Source is local water utilities, with town water supply over the past three water years (ie 2015/16 to 2017/18) reporting usage of between 12.25 ML/year and 67.5 ML/year. It is noted that the town water supply usage remains significantly below the total annual share component for town water supply of 153 ML/year.

The Snowy Scheme operating and water accounting principles are reflected in the Snowy Water Licence, which prescribes the basic rights and obligations. This is discussed further in Section 4.7.

DoI Water has outlined requirements for Snowy Hydro to model their peak predicted annual groundwater take for Exploratory Works. The predicted volumetric take will require a water access licence as per the NSW Aquifer Interference Policy (NSW DPI 2012).

4.3.3 Other plan rules

The WSPs also establish the rules for granting licences, managing water allocations and accounting for water, trading entitlements and water allocations, and in the case of groundwater, rules for managing the effects of water extraction between users, and between users and dependent environmental assets.

In summary:

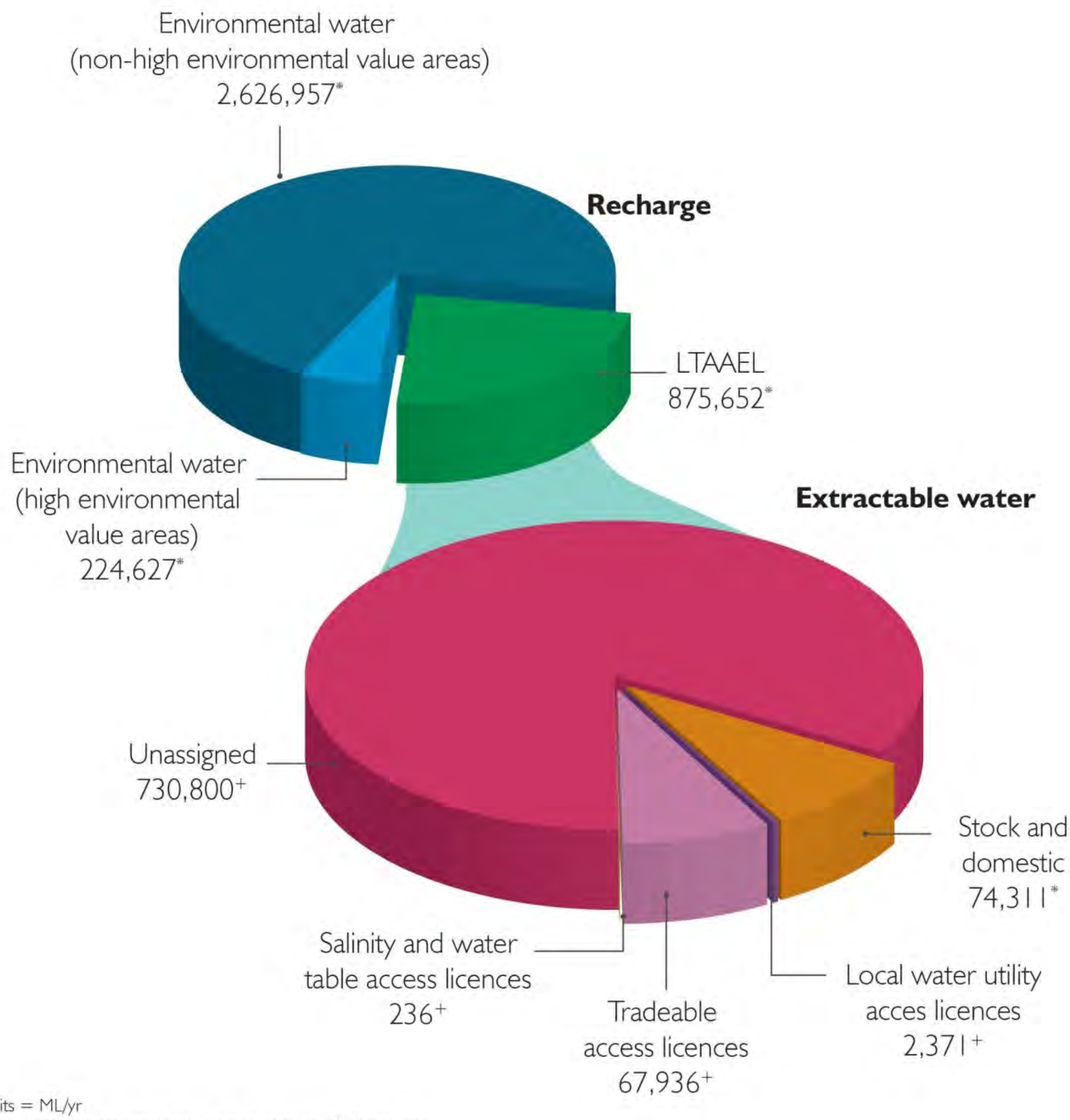
- unassigned water entitlement is available in both the Lachlan Fold Belt MDB Fractured Rock and Coast Groundwater Sources, and this can be granted by the NSW Government via controlled allocation releases;
- water trading is restricted to within individual water sources and cannot be traded across water source boundaries; and

- water trading in all relevant water sources that result in conversions of an access licence of one category to another category is prohibited except where permitted under the Minister's Access Licence Dealing Principles.

Snowy Hydro will comply with the rules in both WSPs. Snowy Hydro will apply for the estimated peak groundwater inflow volume (340 ML in Year 3) to account for the take of groundwater from this groundwater source, and connected systems, as per the requirements of the Aquifer Interference Policy.

Dealings (trades) of groundwater licence volumes may also be undertaken in accordance with the rules and principles in the WSP to secure the required licence volume.

Snowy Hydro has therefore identified a clear pathway to secure the required licence in the relevant groundwater sources. Snowy Hydro will participate in future controlled allocation orders as facilitated by DoI Water, and have also commenced investigation of options for trade within the existing market for both surface and groundwater.



Units = ML/yr
Where available, volumes have been updated to 2018 numbers
Source of data:
* 2011 volumes from the Water Sharing Plan
+ 2018 volumes from DPI Water Register (DoI Water 2018)

Figure 4.1 Lachlan Fold Belt MDB Fractured Rock Groundwater Source provisions (ML/yr)

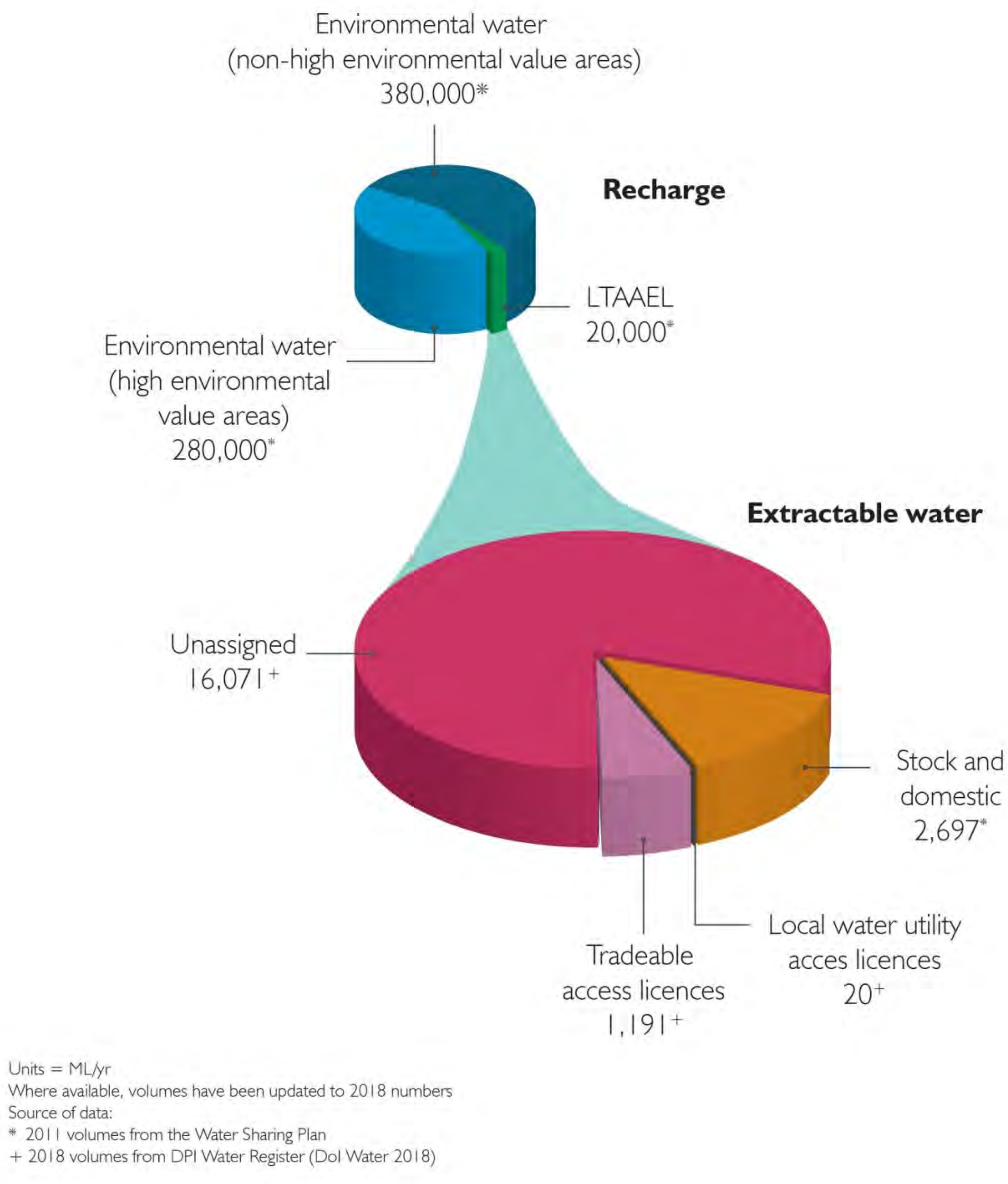


Figure 4.2 Lachlan Fold Belt MDB Coast Groundwater Source provisions (ML/yr)

Table 4.1 Water rights in the Unregulated Upper Tumut Water Source, within the WSP for the Murrumbidgee Unregulated and Alluvial Water Sources 2012

Unregualted Upper Tumut Water Source	Unit	Upper Tumut
Basic landholder rights		
Domestic and stock	ML/day	nd
Native title	ML/yr	0
Harvestable rights		nd
Water access licences		
Domestic and stock licences	ML/yr	7
Local water utility licences	ML/yr	153
Unregulated river access licences (tradeable)	Unit shares	45

Notes: nd - volume not defined based on an entire water source.

4.3.4 Controlled allocation (groundwater)

Share components for an Aquifer Access Licence can be granted by the NSW Government where the right to apply for the licence has been acquired in accordance with a controlled allocation order made under Section 65 of the WMA 2000. Section 65 (1) provides that:

> The Minister may, by order published in the Gazette, declare that the right to apply for an access licence for a specified water management area or water source is to be acquired by auction, tender or other means specified in the order.

There have been three controlled allocation releases made within the groundwater sources surrounding the project area; details are provided in Table 4.2. The outcomes of the most recent release (5 May 2017) have not yet been made available.

Table 4.2 Controlled allocation release

Controlled allocation order	Water source	Units made available	Quantity of shares issued	Price paid per unit share ($)	Total price paid ($)
31 May 2013	Lachlan Fold Belt MDB Groundwater Source	36,375	4	900	3600
			300	800	240,000
4 September 2014	Lachlan Fold Belt MDB Groundwater Source	5,114	-	-	-
5 May 2017	Lachlan Fold Belt MDB Groundwater Source	37,723	NA	NA	NA
	Lachlan Fold Belt Coast Groundwater Source	2,000	NA	NA	NA

4.3.5 NSW Aquifer Interference Policy

The dictionary to the WMA 2000 (under Section 91) defines an 'aquifer interference activity' as an activity involving any of the following:

- penetration of an aquifer;
- interference with water in an aquifer;
- obstruction of the flow of water in an aquifer;
- taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations; or
- disposal of water taken from an aquifer in the course of carrying our mining or any other activity prescribed in the regulations.

Section 91 (3) of the WMA 2000 relates to aquifer interference approvals. The requirement to obtain an aquifer interference approval under Section 91 is triggered only when a proclamation has been made under Section 88A that the particular type of approval is required. To date, no proclamation has been made specifying that an aquifer interference approval is required in any part of NSW. This is expected to remain the case for Exploratory Works.

In the meantime, the AIP sets the policy with respect to aquifer interference. The policy explains the role and requirements of the Minister in determining applications for aquifer interference activities. There is a series of seven fact sheets relating to the AIP. Six of these factsheets are relevant to this assessment and have been considered with the policy itself.

The AIP specifically refers to 'take' that is 'required to allow for the effective and safe operation of an activity, for example dewatering to allow mining' (p.3), regardless of whether the take is required to be used. The take, use, and incidental interception of groundwater requires a licence. The AIP states that, unless specifically exempt, a WAL is required under the WMA 2000 where any act by a person carrying out an aquifer interference activity causes:

- the removal of water from a water source;
- the movement of water from one part of an aquifer to another part of an aquifer; and
- the movement of water from one water source to another water source, such as:
    - from an aquifer to an adjacent aquifer; or
    - from an aquifer to a river/lake; or
    - from a river/lake to an aquifer.

The AIP defines water sources as being either 'highly productive' or 'less productive' based on levels of salinity and average yields from bores; the mapped distribution of the highly productive and less productive groundwater sources in NSW are included in NOW (2012c). The AIP then further defines water sources by their lithological character, being one of: alluvium, coastal sand, porous rock, or fractured rock.

For each category of water source the AIP identifies thresholds for minimal impact considerations. These thresholds relate to impacts on the water table, water pressure and water quality, and are ranked as being either ‘level 1 minimal impact’ or ‘level 2 exceeding minimal impact’. The definition of 'minimal impact' is outlined in a series of tables which demonstrate how the criteria are applied for different types of water sources and for different sensitive receptors (ie other users and ecosystems). The aspects applicable for the project have been reproduced in Table 4.3.

If the impact of an activity is assessed as being Level 1: minimal impact then the project is considered to have impacts that are acceptable. Where the predicted impacts exceed the Level 1 thresholds by no more than the accuracy of the model, then this is considered as having impacts within the range of acceptability and extra monitoring or mitigation or remediation will be required during operations.

Where the predicted impacts an activity is assessed as being ‘Level 2’ or ‘greater than minimal impact’, additional studies are required to fully understand the predicted impacts. If the assessment shows that the predicted impacts, although greater than ’minimal’, do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered to be acceptable.

Where impacts are predicted to be ‘greater than minimal impact’ and the long-term viability of the water-dependent asset is compromised the impact is subject to make good provisions.

AIP Fact Sheet 4 (NOW 2013b) outlines how a minimal impact is to be considered. It describes how the minimal impact criteria are applied to both a water supply work and a GDE defined in a water sharing plan (Figure 4.4). This fact sheet also defines the term ‘make good provisions' as the requirement to ensure that third parties with water supply works have access to an equivalent supply of water through enhanced infrastructure or other means, for example deepening an existing bore, compensation for extra pumping costs or constructing a new pipeline or bore.

Table 4.3 Minimal impact criteria for ‘highly productive’ fractured rock water source

Impact level	Water table	Water pressure	Water quality
Level 1 impact (ie less than minimal)	1. 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: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. A maximum of a 2 m decline cumulatively at any water supply work.	1. A cumulative pressure head decline of not more than a 2 m decline, at any water supply work.	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.

Table 4.3 Minimal impact criteria for 'highly productive' fractured rock water source

Impact level	Water table	Water pressure	Water quality
Level 2 impact (ie greater than minimal)	2. If more than 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan then appropriate studies (including the hydrogeology, ecological condition and cultural function) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long-term viability of the dependent ecosystem or significant site. If more than a 2 m decline cumulatively at any water supply work then make good provisions should apply.	2. If the predicted pressure head decline is greater than requirement 1 above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long-term viability of the affected water supply works unless make good provisions apply.	2. If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.

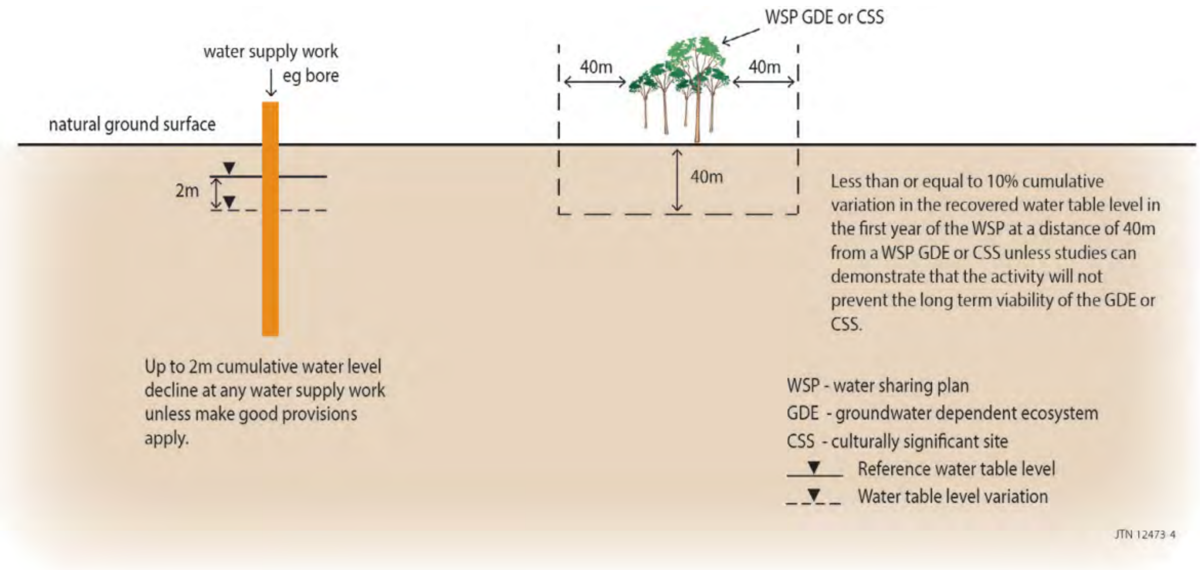


Figure 4.3 Fractured rock groundwater source minimal impact considerations

The AIP requires that two years of baseline groundwater data be collected and incorporated into an impact assessment before lodging a development application for an activity.

The broader Snowy 2.0 project has an extensive monitoring network, developed in consultation with DoI Water (and former departments), that includes 20 conventional groundwater monitoring bores at 11 nested locations, 15 vibrating wire piezometer (VWP) sensors at five locations and four shallow drive point piezometer installations, with groundwater monitoring commencing in January 2018. The baseline monitoring program is discussed in Section 5. Exploratory Works will have less than the recommended two years of baseline data, which has been discussed with DoI Water through the consultation process.

4.4 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act* (1999) (EPBC Act) provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities, and heritage places, which are defined as matters of national environmental significance.

A referral was lodged with the Commonwealth Department of Environment and Energy (DEE) for Exploratory Works. Supporting preliminary studies concluded that Exploratory Works is unlikely to have a 'significant impact' on water resources and listed threatened species. This view was supported by DEE with the Minister for Environment declaring that Exploratory Works did not require an approval under the EPBC provided the works carried out incorporated particular management measures prescribed by DEE. None of these measures relate to groundwater.

4.5 NSW Protection of the Environment Operations Act 1997

The *Protection of the Environment Operations Act 1997* (PoEO Act) is the key piece of environment protection legislation administered by the NSW Environment Protection Authority (EPA). The PoEO Act enables the government to set protection of the environment policies that provide environmental standards, goals, protocols, and guidelines. It also establishes a licensing regime for pollution generating activities in NSW. Under section 48, an environment protection licence (EPL) is required for 'scheduled activities', which include tunnelling and waste water treatment. Accordingly, an EPL for Exploratory Works will be issued and be consistent with the approval, should it be granted by the NSW Minister for Planning. The PoEO Act also includes a duty to notify relevant authorities of pollution incidents where material harm to the environment is caused or threatened.

4.6 Snowy Hydro Corporatisation Act 1997

The NSW *Snowy Hydro Corporatisation Act 1997* (SHC Act) came into effect on 28 June 2002. The Act enabled the corporatisation of the former Commonwealth Snowy Mountains Hydro-Electric Authority to Snowy Hydro, and entitled Snowy Hydro to a number of key operating instruments to enable the continued operation of the existing Snowy Scheme.

Part 4 and 5 of the SHC Act relates to water. Part 4 sets out the terms and timing for the Snowy Water Inquiry which was to examine environmental issues arising in rivers and streams from the operations of the Snowy Scheme. Part 5 established the entitlement of Snowy Hydro to the Snowy Water Licence and prescribes the basic rights and obligations that are to be contained in the licence.

The Snowy Water Licence embodies the operating and accounting principles of the Snowy Scheme. The Snowy Water Licence confers the following rights on Snowy Hydro:

- to collect all water from the rivers, streams and lakes within the Snowy Water Catchment;
- to divert that water;
- to store that water;

- to use that water to generate electricity and for purposes that are incidental or related to the generation of electricity; and
- to release that water from storage.

Snowy Hydro's rights are subject to the rights of certain other occupiers to take and use water (eg local councils). In addition to these rights, the Snowy Water Licence also sets out Snowy Hydro's water related obligations, in particular, release obligations.

Exploratory Works will have no impact on downstream water users (see Section 9.4). No amendments to the Snowy Water Licence will be required for Exploratory Works.

4.7 Relevant NSW plans, policies and guidelines

Apart from the AIP, a number of other guidelines and policies relevant to the groundwater assessment are discussed in the following sections.

4.7.1 Risk assessment guidelines for groundwater dependent ecosystems

The risk assessment guidelines for groundwater dependent ecosystems (2012) (GDE Risk Assessment Guidelines) are the NSW requirements for assessment and management of GDEs under the WMA 2000. The dictionary to the Lachlan Fold Belt MDB Fractured Rock and Coast Groundwater sources provides that:

> groundwater dependent ecosystems include ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater.

The GDE Risk Assessment Guidelines provide that GDEs:

> explicitly include any ecosystem that uses groundwater at any time or for any duration in order to maintain its composition and condition.

An ecosystem's dependence on groundwater can be variable, ranging from partial and infrequent dependence, ie seasonal or episodic (facultative), to total continual dependence (entire/obligate) (Figure 4.4).

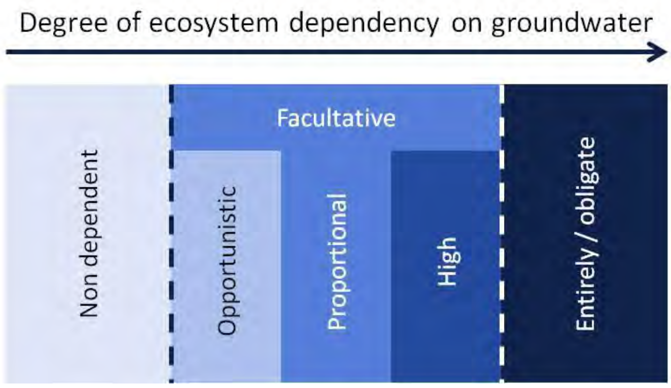


Figure 4.4 Groundwater dependent ecosystem level of dependence on groundwater

A GDE assessment for Exploratory Works considered variations in available water and ecosystem types with assessment methods based on the GDE Risk Assessment guidelines. There are no High Priority GDEs designated by the AIP within the project area. Yarrangobilly Caves, approximately 8 km north, is the only High Priority GDE listed within the Lachlan Fold Belt MDB (Fractured Rock Groundwater source) WSP within the groundwater model domain.

Potential impacts from Exploratory Works (and Snowy 2.0, should it proceed) has been the subject of specific consultation between Snowy Hydro and NPWS. Yarrangobilly Caves has been studied, and monitored, as part of this groundwater assessment, and there are no impacts predicted to occur at Yarrangobilly Caves as a result of Exploratory Works. Yarrangobilly Caves is discussed in more detail in Section 6.10.2.

Three plant community types (PCTs) within the Exploratory Works project area were identified as potential GDEs. These PCTs include:

- PCT 285 Broad-leaved Sally grass – sedge woodland on valley flats and swamps;
- PCT 296 Brittle Gum peppermint open forest of the Woomargama to Tumut region; and
- PCT 302 Riparian Blakeley’s Red Gum Woodland Broad-leaved Sally woodland, tea-tree, bottlebrush, wattle shrubland wetland.

The relationship of the PCTs are discussed in detail within the Biodiversity Development Assessment Report (EMM 2018). These potential GDEs are not predicted to be impacted from Exploratory Works.

4.7.2 State Groundwater Policy Framework Document

The NSW State Groundwater Policy Framework Document (DLWC 1997) aims to manage the groundwater resources of the state so they can sustain environmental, social, and economic outcomes for the people of NSW. The policy will be considered in resource management decisions made in NSW.

The document is a framework for the following three policies:

- NSW State Groundwater Quantity Management Policy (2001 (unpublished));
- NSW State Groundwater Quality Protection Policy (DLWC 1998); and
- NSW State Groundwater Dependent Ecosystem Policy (DLWC 2002).

This policy establishes the overarching principles for the management of groundwater in NSW, which still remains valid 21 years after its inception. The principles of sustainability across the three environmental, social, and economic aspects are still referenced in modern water policies released by the NSW Government.

The exploratory tunnel design, operation, and rapid rehabilitation and applied mitigation strategies will considerably minimise groundwater inflow and overall groundwater impacts. The design of the tunnel will closely follow the NSW State Groundwater Policy Framework Document objectives of achieving beneficial environmental, social, and economic outcomes for the state of NSW.

4.7.3 State Groundwater Dependent Ecosystems Policy

The NSW State Groundwater Dependent Ecosystems Policy (DLWC 2002) was used with the more recent GDE Risk Assessment Guidelines (NOW 2012d) to assess ecosystems in the project area that potentially rely on groundwater. There are five principles within the NSW State Groundwater Dependent Ecosystems Policy; these are summarised in Table 4.3 with commentary on how the principle has been applied to Exploratory Works.

Table 4.4 State GDE Policy principles

Principle	Exploratory Works assessment
Principle one The scientific, ecological, aesthetic and economic values of GDEs, and how threats to them may be avoided, should be identified and actions taken to ensure protection of the most vulnerable and valuable ecosystems.	The one high priority GDE (as per the Lachlan Fold Belt MDB Water Sharing Plan) is Yarrangobilly Caves, and this system has been specifically assessed. No impacts are predicted to this high priority GDE (Section 9.4.1).
Principle Two Groundwater extractions should be managed within the sustainable yield of the groundwater system, to maintain and/or restore ecological processes and biodiversity of their dependent ecosystems.	Modelling predicts peak inflow to the tunnel, for a maximum plausible impact scenario, of 340 ML/yr (Section 9.5.3). There is sufficient water entitlement available within the Lachlan Fold Belt MDB Fractured Rock Groundwater Source to secure the predicted water take for the project.
Principle Three Priority should be given to ensure sufficient groundwater of suitable quality is available when it is needed for: ● protecting known or likely GDEs; and ● GDEs that are under immediate or high degree of threat from groundwater related activities.	No impacts to water quality are predicted for Yarrangobilly Caves, or the water table in the area around the GDE as a result of Exploratory Works (Section 9.4.1).
Principle Four The Precautionary Principle should be applied to protect GDEs where scientific knowledge is lacking. Adaptive management systems and research to improve understanding is essential to their management.	The GDE, ecology and water studies for the project are rigorous and are ongoing. Adaptive management is proposed for terrestrial ecosystems as required.
Principle Five Planning, approval, and management of developments and land use activities should aim to minimise adverse impacts on GDEs by: ● maintaining natural patterns of groundwater flow and not disrupting groundwater levels that are critical for GDEs; ● not polluting or causing adverse changes in groundwater quality; and ● rehabilitating degraded groundwater systems where practical.	Modelling carried out for this assessment predicts no impacts on the one high priority GDE, Yarrangobilly Caves, in the study area. Three PCTS were identified as potential GDEs. These are discussed in detail within the Biodiversity Development Assessment Report (EMM 2018). No impacts on these potential GDEs are predicted from Exploratory Works (Section 9.4.1).

4.8 Relevant Commonwealth policy and guidelines

4.8.1 Australian Groundwater Modelling Guidelines

The Australian Groundwater Modelling Guidelines, National Water Commission (NWC) (Barnett et al. 2012) provide a consistent and sound approach for the development of groundwater flow models in Australia. The guidelines 'propose a point of reference and not a rigid standard' and provide direction on scope and approaches while acknowledging that techniques are continually evolving and innovation is to be encouraged. The guidelines provide a confidence-based classification system that defines three different classes of model:

- class 1 – low confidence in model predictions, suitable for use in low value resource or low risk developments;
- class 2 – high confidence in model predictions, suitable for use in high value resources or projects with medium to high risk developments; and
- class 3 – high confidence in model predictions, suitable for use in high value resources and projects such as regional sustainable yield assessments.

The guidelines provide information on the data requirements for each model class, such as spatial distribution of bores and temporal groundwater level data. Groundwater resource assessments at major development sites generally require the use of a class 2 model. The onerous data requirements to achieve a class 3 model (ie reliable metered extraction and the duration of the prediction to be not more than three times the calibration data period) mean that for most major projects in NSW a full class 3 model is practically unattainable.

The numerical groundwater model developed to predict potential impacts of the project is best described as a class 1 model, however many elements of the model meet the characteristics of a class 2 model. DoI Water were consulted during the development of the numerical groundwater model. The numerical model has been prepared in accordance with the Australian Groundwater Modelling Guidelines and peer reviewed using the structure of the 'review checklist'. A pre-eminent hydrogeologist, Hugh Middlemis, was engaged to peer review the numerical model.

The model was deemed by the peer reviewer to be fit for purpose and, in several aspects, conservative. The peer review report (HydroGeoLogic 2017) is included in Appendix B.

4.8.2 Australian and New Zealand Guidelines for Fresh and Marine Water Quality

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council (ANZECC & ARMCANZ) 2000 describe the water quality objectives for marine and freshwater environments, aquatic ecosystems, primary industries, and recreational water.

The guidelines should be considered when setting water quality objectives for natural and semi-natural water resources in Australia and New Zealand sustaining current or likely future environmental values (uses). They also set out a framework for the application of water quality trigger levels.

The guidelines are a generic reference and should be used accordingly, ie only as a default reference. It is recommended to collect and use site-specific baseline data to establish baseline conditions and develop trigger levels. Project impacts should be assessed using site-specific baseline data and not the generic guidelines, where sufficient (typically > 24 months) baseline data allows.

4.8.3 National Water Quality Management Strategy Guidelines for Groundwater Quality Protection in Australia

The National Water Quality Management Strategy Guidelines for Groundwater Quality Protection in Australia (NWQMS 2013) provides a risk-based management framework to protect and enhance groundwater quality for the maintenance of specified environmental values. The framework involves the identification of specific beneficial uses and values for the major groundwater systems, and a number of protection strategies that can emerge to protect each aquifer, including monitoring for all aquifers.

The guidelines, including defined environmental values and water quality objectives, have been referenced in Section 5.2.

5 Baseline monitoring program

Surface water and groundwater monitoring are essential components in characterising the project area's baseline, hydrogeological and hydrologic environments. Baseline water level and water quality field data collected from the various groundwater systems and watercourses has been used to determine the overall water chemistry, flow paths, recharge and discharge characteristics, and groundwater–surface water connectivity. Field data have been an important input to validate the hydrogeological and hydraulic conceptual and numerical models.

A comprehensive water monitoring network has been designed and used to establish a baseline dataset for Exploratory Works, incorporating spatial and temporal variations. Details of the groundwater monitoring network are presented in Section 5. A detailed overview of the surface water monitoring network has been provided in the *Exploratory Works Surface Water Assessment* (EMM 2018c).

5.1 Groundwater monitoring network

EMM designed and implemented a dedicated project groundwater monitoring network to investigate hydrogeological conditions in the broader Snowy 2.0 project area (including Exploratory Works) (Appendix A). The network was developed in consultation with DoI Water (then CLAWD).

The groundwater monitoring network within the Exploratory Works project area includes conventional groundwater monitoring bores and vibrating wire piezometers (VWPs). Monitoring bores and VWPs are positioned to provide spatial coverage, investigate the major hydrogeological environments, and monitor potentially sensitive features. Specifically, the groundwater monitoring network was designed to:

- identify and characterise water bearing units in the project area, with particular focus on characterising groundwater flow and quality;
- provide spatial representation and flux of pressure heads across the project area to investigate potential vertical hydraulic gradients and connectivity between water bearing units;
- investigate the potential for surface water–groundwater interaction; and
- monitor potential sensitive features, including Yarrangobilly River and potential groundwater dependent ecosystems.

5.2 Monitoring bores

5.2.1 Installation

Highland Drilling Limited (drilling contractor), under the supervision of EMM hydrogeologists, completed all of the project groundwater monitoring bore drilling and installation in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC 2012). All drilling was undertaken using open hole rotary down hole hammer drilling techniques, with clean water for the drilling fluid.

The groundwater monitoring bores were installed as nested sites designed to target shallow groundwater and deeper groundwater. Where appropriate, overlying water bearing zones were isolated to provide accurate representation of water quality and pressure at depth.

During drilling, the supervising hydrogeologist completed:

- geological assessment at 1 m intervals, based on visual inspection of drill cuttings or drill core, and production of bore log;
- recording of water interceptions and airlift yields at each water bearing zone intersected;
- measurement of water quality for all major water bearing zones intersected. This typically involved measurement of field physio-chemical parameters and selected samples undergoing more detailed laboratory analysis; and
- specific design of each monitoring installation.

Monitoring bore licences were obtained from DoI Water (formally CLAWD) before drilling works began. Form A: Particulars of Completed Works forms (drilling completion forms) were submitted to DoI Water following monitoring bore installation (Appendix A).

Water used and produced during drilling was managed in accordance with the Snowy 2.0 Review of Environmental Factors (REF) (SHL 2018a). Water for drilling was sourced from licensed supply in the Snowy Hydro village of Cabramurra. There were no instances of uncontrolled release of water; water was discharged only when it met the water quality limits specified in the REF. All drilling scraps, drilling fluids and water that did not comply with REF limits was contained in above-ground tanks and disposed of at a licensed waste facility.

5.2.2 Monitoring bore details

The groundwater monitoring network installation occurred between January 2018 and April 2018 (Appendix A). The network consists of:

- 20 groundwater monitoring bores at 11 locations. Often multiple monitoring bores are installed next to one another at the same location; this is called a nested location. Each bore at a nested location is installed to a different depth monitoring a different zone within the groundwater systems. Nested sites provide information on the vertical hydraulic gradients and inferred vertical connectivity at that location.
- 4 shallow drive point piezometers. These narrow diameter installations target shallow groundwater within unconsolidated, boggy soils. The shallow installations provide information on groundwater level fluctuations within mapped alpine bogs.

Table 5.1 and Figure 5.1 show details and locations of the groundwater monitoring bores. Monitoring bores that are within the Exploratory Works project area are highlighted in blue.

Summary bore logs are included in Appendix A.

Table 5.1 Groundwater monitoring bores overview

Bore ID	Ground level (mAHD)	Total depth (mgbl)	Screen interval (mbgl)	Monitored formation	Lithology	Licence number
Project groundwater monitoring bores						
TMB01A	581.2	15	11-14	Boraig Group	Ignimbrite	40BL192707
TMB01B	581.8	72	63-69	Ravine Formation	Siltstone	
TMB02A	1469.6	15	11-14	Gooandra Volcanics	Basalt	
TMB02B	1472.3	200	191-197	Gooandra Volcanics	Chloritic schist	
TMB03A	1477.7	34	29.5-32.5	Gooandra Volcanics	Basalt	
TMB03B	1477.6	150	141-147	Gooandra Volcanics	Chloritic schist	
TMB03C	1478	250	237-249	Gooandra Volcanics	Chloritic schist	
TMB04	1345.8	200	191-197	Gooandra Volcanics	Chloritic schist	
TMB05A	601.7	19	12-18	Ravine Formation	Weathered siltstone	
TMB05B	601.7	77	68-74	Ravine Formation	Siltstone	
MB01B	1464.4	7.5	5.3-6.8	Tertiary Basalt	Basalt	
MB01C	1464	53	45-51	Gooandra Volcanics	Chloritic schist	
MB02	1386.7	150	141-147	Gooandra Volcanics	Chloritic schist	
MB03	1373	100	92-98	Gooandra Volcanics	Chloritic schist	
MB04A	1330	30	23-29	Gooandra Volcanics	Basalt	
MB04B	1330	102.5	93.5-99.5	Gooandra Volcanics	Chloritic schist	
MB06A	1145.4	14	9-12	Boraig Group	Ignimbrite	
MB06B	1145.5	72	64-70	Boraig Group	Ignimbrite	
MB07A	1265	15	10-13	Tantangara Formation	Weathered siltstone	
MB07B	1265	60	51-57	Tantangara Formation	Sandstone	

5.3 Cave monitoring

Following consultation with DoI Water and NPWS regarding the adequacy of the groundwater monitoring network, arrangements were made by Snowy Hydro to install groundwater level monitoring equipment at Yarrangobilly Caves.

Groundwater level monitoring also occurs at Ravine Cave of Yarrangobilly Caves (YC05). A pressure transducer data logger is submerged within a cave pool, located approximately 100 m from the bank of the Yarrangobilly River. The purpose of the installation is to capture baseline cave pool fluctuations in response to recharge. The location of YC05 is shown on Figure 5.1.

5.4 Hydraulic testing

A diverse range of hydraulic tests have been conducted to provide site-specific information on the hydraulic properties of the various groundwater systems. The tests completed include rising and falling head tests (slug tests), a constant rate pumping test and Theis recovery tests (Appendix A). The locations of the various tests are shown on Figure 5.1.

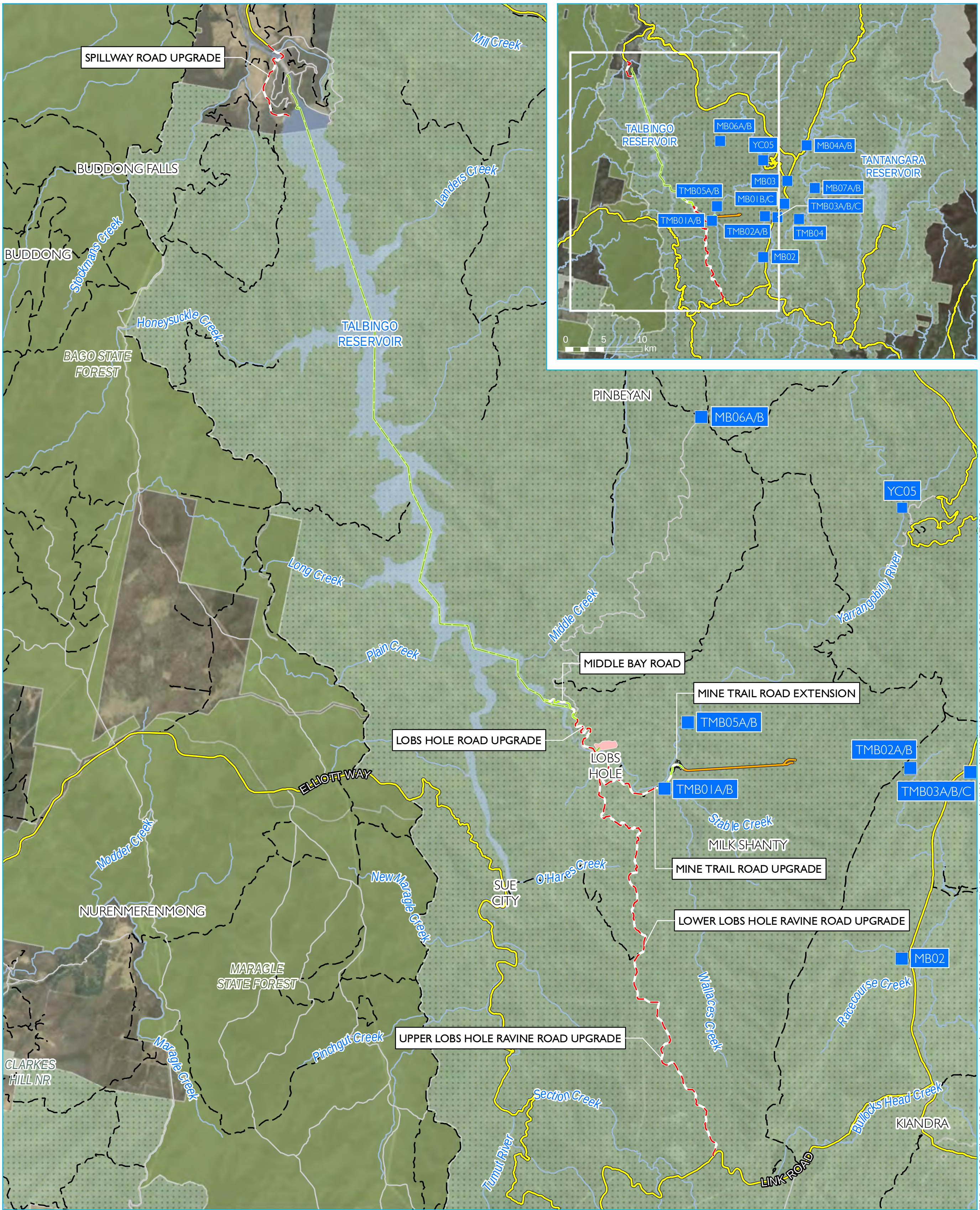
5.4.1 Slug testing

Slug tests provided an indication of the hydraulic parameters of the formation in the immediate vicinity of the screened interval of a monitoring bore. Slug tests were carried out at all 20 project groundwater monitoring bores. This involved installing an electronic water level logger in the bore, displacing water in the bore using a slug (a solid bailer), and recording the water level change over time. The results provide an indication of the rock's bulk hydraulic conductivity, or rate of groundwater flow, in the immediate vicinity of the screened interval.

5.4.2 Pumping tests

Pumping tests involve pumping water from a test bore at a suitable constant rate and for enough time for a significant drawdown response in nearby monitoring bores. Pumping tests are a direct and reliable method to obtain estimates of groundwater system hydraulic properties, including storativity, transmissivity, horizontal and vertical hydraulic conductivity. Pumping tests also provide information on the extent and sustainability of the aquifer and the degree of connection with nearby surface water sources, where present.

One pumping test was conducted at TMB03C. This consisted of four consecutive 3-hour constant rate tests followed immediately by monitored Theis recovery tests. The groundwater level observations from the test and monitoring bores have been assessed using the computer-based 'AQTESOLVE' algorithm for confined groundwater systems (Appendix A). Additional pumping tests have been undertaken for the broader Snowy 2.0 project and are ongoing.



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Source: EMM (2018); Snowy Hydro (2018); SMEC (2018); DFSI (2017); LPMA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 55 N

KEY

- Groundwater monitoring bore
- Access road upgrade
- Access road extension
- Exploratory tunnel
- Portal construction pad and accommodation camp conceptual layout
- Communications cable
- Main road
- Local road
- Vehicular track
- Perennial watercourse
- Portal construction pad and accommodation camp conceptual area
- Scheme storage
- Kosciuszko National Park
- Other NPWS reserve
- State forest

Groundwater monitoring locations

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 5.1

snowy 2.0 EMM

5.5 Groundwater level monitoring

Groundwater level monitoring began in January 2018 in bores MB01B/C following installation and has expanded to include all 20 monitoring bores as these have been progressively drilled and constructed (Appendix A).

Solinst pressure transducers and data loggers are installed in all the project groundwater monitoring bores and monitor groundwater levels every six hours. When the loggers were downloaded, manual groundwater level measurements were also recorded to calibrate the logger data. A barometric data logger installed above the water table at both TMB01A and TMB02A records changes in atmospheric pressure. Data from this logger is used to correct for the effects of changing barometric pressure and barometric efficiency on groundwater levels.

5.6 Groundwater quality monitoring

An initial round of groundwater quality monitoring was completed following each monitoring bore installation. Groundwater quality monitoring was then conducted at a monthly frequency (access pending), and will continue until Exploratory Works approval at this frequency. Monitoring will then continue as agreed in the conditions of approval and in accordance with the Construction Water Management Plan that will then prepared in consultation with relevant agencies establishing construction monitoring commitments (see Section 11.2).

The groundwater sampling method used across the monitoring network has been selected based best practice, logistics, and on the hydraulic conductivity of the screened formations. Dedicated low flow double valve pumps have been installed in each the screen section of each monitoring bores. During sampling, water quality parameters (including pH, temperature and electrical conductivity (EC)) are measured during purging and pumping to monitor water quality changes, and to indicate representative groundwater suitable for sampling and analysis.

Water quality samples were collected in laboratory provided sample bottles, with appropriate preservation. Samples undergoing dissolved metal analysis were filtered through a 0.45 µm filter in the field before collection in nitric acid preserved plastic sample bottles. Samples were stored on ice and sent to the laboratory under appropriate chain-of-custody protocols.

Groundwater samples are analysed by ALS for either the standard or comprehensive suite of analytes shown in Table 5.2.

Table 5.2 Analytical suite

Suite	Analytes
Physicochemical properties	Field parameters (pH, EC, redox potential, DO, temperature) EC, TDS, TSS
Major ions	calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity
Dissolved metals	arsenic, cadmium, chromium, copper, fluoride, lead, magnesium, nickel, zinc
Nutrients	ammonia as N, nitrite as N, nitrate as N, reactive phosphorous, phosphorous, total phosphorus

Field and laboratory QA/QC procedures are used to establish accurate, reliable and precise results. QA/QC procedures included: analysis of unstable parameters in the field, calibration of equipment, submitting laboratory samples within holding times, collection of blind duplicate samples, keeping samples chilled and wearing gloves during sampling.

5.6.1 Groundwater quality assessment criteria

The methodology and criteria for ecological water quality assessment in Australia are presented in the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000).

The guidelines present assessment criteria (referred to as 'trigger values') for a range of organic and inorganic chemicals, which are applicable to both protection of aquatic ecology, and suitability for primary industries. While the guidelines are not specifically 'groundwater criteria', they apply at the point of use or exposure and are therefore relevant where an aquatic ecosystem is partially or wholly dependent on groundwater, or where groundwater supply supports primary industry.

5.7 Ecology surveys

Extensive ecology surveys and assessments have been completed for Exploratory Works project; the details and results of the field surveys are in the *Snowy 2.0 Exploratory Works Biodiversity Development Assessment* (EMM 2018d). The ecology survey considered threatened species as well as mapping the baseline vegetation and habitat for Exploratory Works project area.

There are no listed high priority terrestrial or aquatic GDEs within the Fractured Rock or Coast groundwater sources. However, there are three PCTs that are potential GDEs (Section 4.7.1). No impacts to these potential GDEs are expected to occur from Exploratory Works.

Despite this, shallow monitoring and water quality sampling is occurring across the Exploratory Works area to capture potential changes in levels and quality.

5.8 Landholder bore review

A review for registered groundwater and surface water users was completed on the DoI Water online water database (DoI Water 2018). A review of groundwater and surface water licence entitlement has also been completed in the respective water sources. Based on both reviews, there are no groundwater extraction bores or licences within the Exploratory Works project area or within a 20 km search around the project area boundary.

6 Groundwater

6.1 Regional geological setting

Exploratory Works are within the south-east portion of the Lachlan Orogen (Fold Belt) of NSW. The Lachlan Orogen comprises a suite of Ordovician (485 million years (Ma)) to Devonian (359 Ma) sedimentary, igneous and metamorphic rocks that have developed during multiple orogenic periods associated with extensive faulting forming major geotectonic structures through the area (see Section 6.2.2).

The majority of the rock units in the Exploratory Works project area are Palaeozoic in age with the exception of isolated occurrences of Tertiary basalt (Wyborn and Owen 1990). The relative ages of the strata are not always sequential due to offsets along faults and folding.

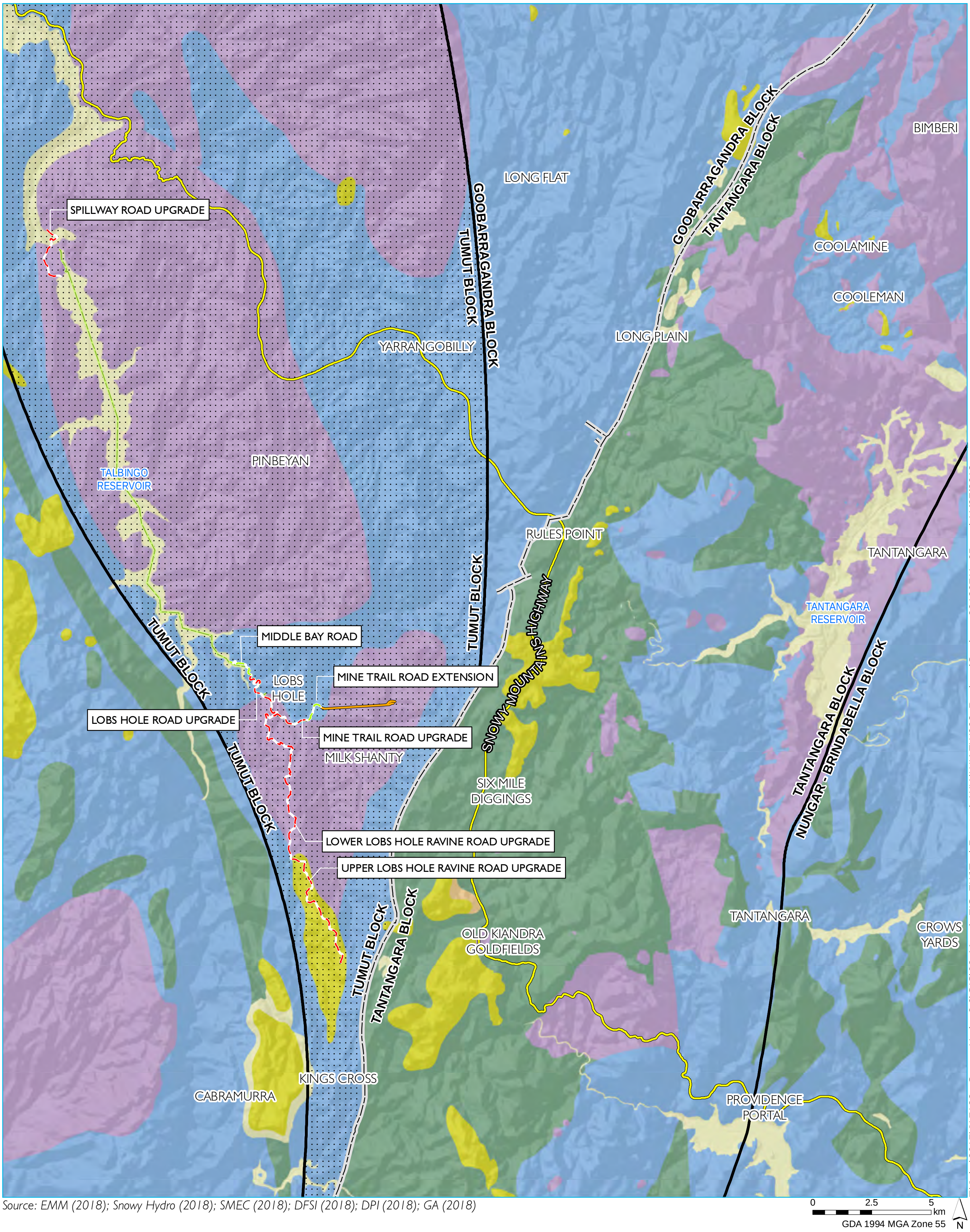
Two distinct geological terrains ('Incised Ravine Area' and the 'Plateau Area') are within the broader Snowy 2.0 project area, separated by an escarpment caused by movement on the Long Plain Fault (see Figure 6.1). The Exploratory Works project area is wholly situated on the western side of this fault structure, in the Incised Ravine Area.

6.2 Local geological setting

The Exploratory Works project area is within a geologic domain referred to as the 'Ravine Incised Area' (or Tumut Block), immediately west of the Long Plains Fault (Figure 6.2). The area is dominated by sedimentary and igneous rock of Silurian to Devonian age. The Silurian aged Ravine Beds, composed of stratified altered siltstone, sandstone and limestone, provide the structural framework and topographic control for this area. The Ravine Beds are overlain in areas, typically along the escarpment, by younger volcanic rock (Boraig Group and Byron Range Group) deposited during the Devonian period.

The Yarrangobilly Caves, a karstic limestone, is approximately 8 km north of the Exploratory Works project area. The caves are stratigraphically interpreted to be at the base of the Ravine Beds and will not be intercepted by the Exploratory Tunnel, as demonstrated through geotechnical drilling.

Younger Quaternary colluvium has been observed along the river terrace of the Yarrangobilly River (Appendix A). The unit is composed of subordinate river gravels and boulders with an estimated thickness of between 3 m and 4 m.



Source: *EMM (2018); Snowy Hydro (2018); SMEC (2018); DFSI (2018); DPI (2018); GA (2018)*

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KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Long Plain Fault (interpreted)
- Ravine Incised Area
- Geological domain boundary

Geology (250k) by period

- Cainozoic
- Quaternary
- Tertiary
- Devonian
- Silurian
- Ordovician

Regional geology and Snowy 2.0 geological terrains

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 6.1

KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Perennial watercourse
- Long Plain Fault (interpreted)

Geology (1:250,000)

- *w* - Water

Quaternary

- *Qa* - Alluvium

Tertiary

- *Tbm* - Basalt

Cainozoic

- *Cz* - Unknown (undifferentiated)

Devonian

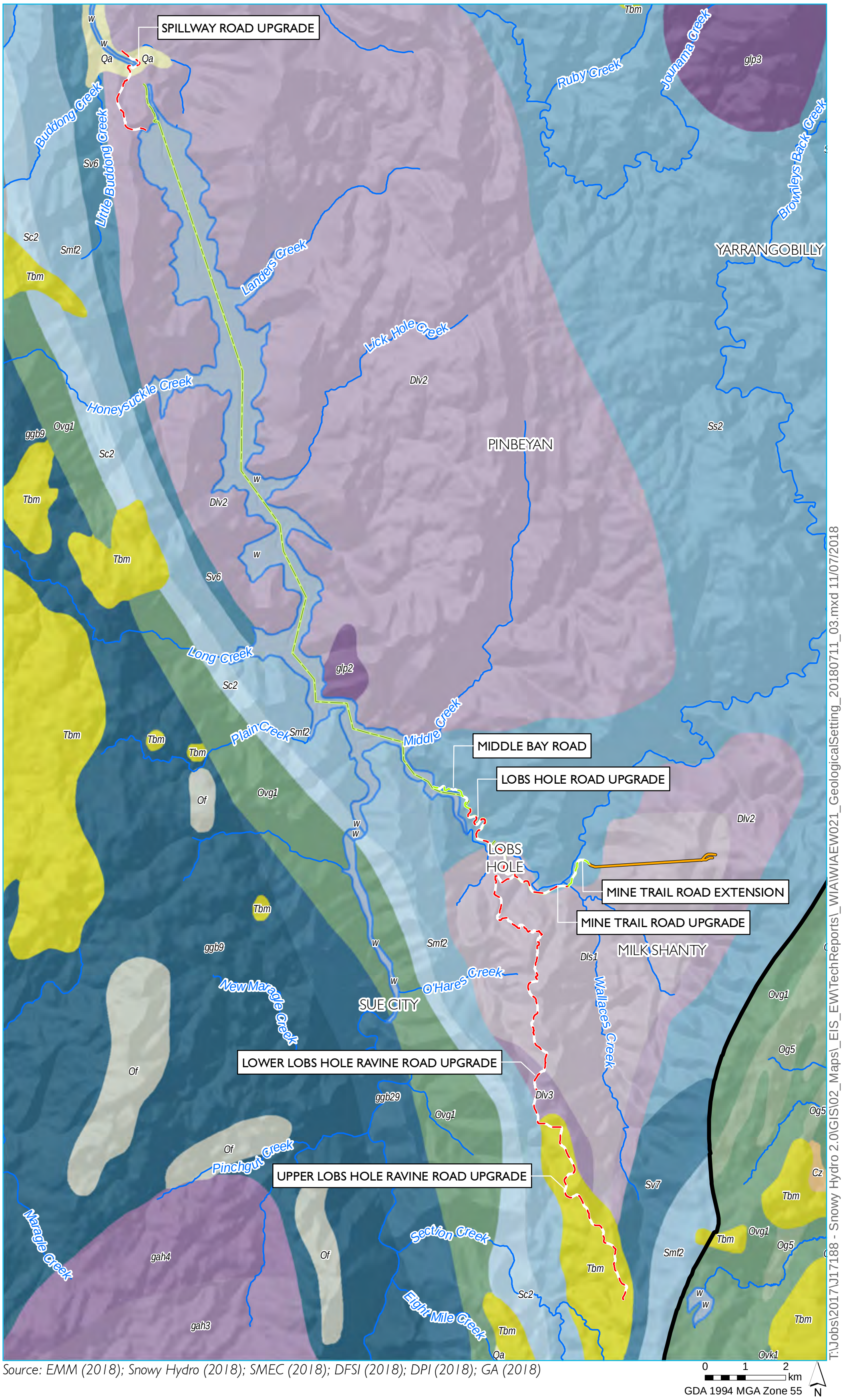
- *Dls1* - Byron Range Group (undifferentiated)
- *Dlv2* - Boraig Group (unnamed)
- *Dlv3* - Black Range Group (Mountain Creek Volcanics)
- *gah3* - Free Damper Suite (Free Dampier Adamellite)
- *gah4* - Free Damper Suite (Pennyweight Adamellite)
- *glp2* - Tumut Granites (Lobs Hole Adamellite)
- *glp3* - Bogong Suite (Bogong Granite)

Silurian

- *Sc2* - Unknown (Tumut Ponds Sepentinite)
- *Smf2* - Unknown (Jackalass Slate)
- *Ss2* - Bredbo Group (Ravine Beds/Yarrangobilly Limestone)
- *Sv5* - Young Suite (Goobarragandra Volcanics)
- *Sv6* - Unknown (Blowering Formation)
- *Sv7* - Unknown (Kings Cross Formation)
- *ggb29* - Tom Groggin Suite (Rough Creek Tonalite)
- *ggb9* - Tom Groggin Suite (Green Hills Granodiorite)

Ordovician

- *Of* - Adaminaby Group (Adaminaby Group)
- *Og5* - Unknown (Shaw Hill Gabbro)
- *Ovg1* - Unknown (Gooandra Volcanics)
- *Ovk1* - Kiandra Group (unnamed)



Source: EMM (2018); Snowy Hydro (2018); SMEC (2018); DFSI (2018); DPI (2018); GA (2018)

Local geology - Ravine Incised Area (Exploratory Works)

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 3.5

6.2.1 Stratigraphy

The stratigraphy relevant to the exploratory tunnel component of the Exploratory Works project area is shown in Table 6.1.

Table 6.1 Exploratory Works (Exploratory Tunnel) project area stratigraphy

Age	Group	Formation	Symbol	Rock type
Tertiary		Tertiary Basalt	Tb	Alkali olivine basalt
Devonian	Byron Range		Dls1	Siltstone, quartzite, shale, sandstone conglomerate
	Boraig		Dlv2	Rhyolite, rhyodacite, lapilli tuff, feldspathic sandstone
	Black Range	Mountain Creek Volcanics	Dlv3	Rhyolite, rhyodacite, tuff, feldspathic sandstone
Silurian	Bredbo	Ravine Beds	Ss2	Shallow marine shelf deposits: shale, slate, siltstone, conglomerate
		Yarrangobilly Limestone	Ss2	Karstic limestone
	Young Suite	Goobarragandra Volcanics	Sug	Dacite ignimbrite, tuff, intrusive porphyry
		Jacklass Slate	Smf2	Sandstone, siltstone and shale

6.2.2 Geological structure

The broader Snowy 2.0 project area intercepts two major structural blocks (Figure 6.1). The two blocks, the dominantly Silurian Tumut Block in the west and the dominantly Ordovician Tantangara Block in the east, are separated by the regional Long Plain Fault.

There are four main faults or fault groups relevant to the Snowy 2.0 project area. These include:

- Long Plain Fault;
- Kiandra Fault;
- Boggy Plain Fault; and
- Cenozoic Faults.

The only significant fault structure of relevance to the Exploratory Works project area is the Long Plain Fault.

i Long Plain Fault

The north-northeast trending Long Plain Fault extends over a distance of 200 km from the Upper Murray River to west of the Brindabella Ranges near Canberra. The fault is understood to have a horizontal shear zone at the Exploratory Works project area of between 300 m and 350 m (Jacobs 2017).

ii Folding

Folding is well developed across the Exploratory Works project area and is a consequence of the significant tectonic activity and east-west compression across the Tumut and Tantangara geological blocks.

The Silurian Ravine Beds are reported to have undergone moderate folding and some faulting, particularly along Yarrangobilly River. Bedding dips at 25-50 degrees to the east near Yarrangobilly River and to the west near Talbingo Reservoir, forming a synclinal structure (Wyborn and Owen 1990).

6.3 Hydrogeological units

The groundwater units within the Exploratory Works project area are defined as:

- localised unconsolidated shallow Quaternary gravels episodically recharged through rainfall/flooding events;
- shallow groundwater associated with weathered fractured rock (between 5 and 30 metres below ground level); and
- deep groundwater associated with deeper fractured rock (ie the Ravine Beds)

6.4 Hydraulic conductivity

Hydraulic testing from bores within the Exploratory Works project area has allowed an assessment to be made of horizontal hydraulic conductivity (K) within the weathered and deeper fractured rock profiles of the Byron Range Group and Ravine Beds geologic units.

There is an exponential decrease in K with depth due to increasing overburden pressure, and this is typical of most fractured rock groundwater sources. This decrease in K is evident in the results of the slug testing at two nearby nested monitoring sites (TMB01 and TMB05 – refer to Figure 5.2).

A summary of the range of K values derived for each hydrogeological unit from the various hydraulic tests is shown in Table 6.1. The heterogeneous nature of fractured rock groundwater systems is reflected by the wide range of measured K values, and this is typical of fractured rock environments. The hydrogeological units relevant to Exploratory Works have been highlighted in blue.

Table 6.2 Hydraulic conductivity for hydrogeological units in the Snowy 2.0 project area

Hydrogeological unit	Hydraulic conductivity (k) (m/day)	Project area
Tertiary Basalt	8.7 - 14.7	Broader Snowy 2.0
Gooandra Volcanics (weathered)	0.004 - 0.116	Broader Snowy 2.0
Gooandra Volcanics (competent fractured rock)	0.005 - 41.9	Broader Snowy 2.0
Tantangara Formation (weathered)	42.7 - 72.4	Broader Snowy 2.0
Tantangara Formation (competent fractured rock)	0.013	Broader Snowy 2.0
Ravine Beds (weathered)	0.03 - 0.17	Exploratory Works
Ravine Beds (competent fractured rock)	0.00034	Exploratory Works
Boraig Group (Rhyolite)	3.08 - 3.59	Exploratory Works

6.5 Groundwater recharge and discharge

There are thought to be two primary sources of groundwater recharge to the conceptualised groundwater systems, these include:

- Rainfall recharge (dominant recharge source) is estimated to be up to 10% within the Ravine region. This recharge estimate is considered appropriate given the unconsolidated, fractured and leaky aquifer nature of overlying colluvial sediments and basaltic ridge caps.
- Direct leakage from rivers and storages (secondary recharge source) is likely to occur in some areas, particularly adjacent to the Yarrangobilly River and adjoining tributaries where the water level in the storage is elevated above the regional groundwater table.

Given the prominence of groundwater springs across the Ravine incised area (ie the Exploratory Works project area), it is likely that the water table is locally elevated within this area. The shallow water table is likely to be contributing to local drainage lines and larger creek systems. However, during periods of extended drought and seasonal fluxes associated with wet and dry seasons, hydraulic gradients may be reversed, prompting surface water systems to discharge to a reduced groundwater table.

The volume of recharge from rainfall is the dominant source of recharge, with recharge from surface water expected to be very low in comparison. This is due to the small area of surface water bodies compared to the overall area of land, and the conceptualisation that streams are mostly gaining (ie groundwater is discharging to streams), as discussed in Section 6.6

Various analytical methods have been used to assess rainfall recharge rates to the groundwater system within the Ravine region, including baseflow index calculations and chloride mass balance techniques.

The baseflow index of the Yarrangobilly River has been calculated to be approximately 25% of average streamflow. Assuming a catchment area of 271.6 km^2 and a rainfall rate of 972 mm/yr (based on the SILO model maintained by the Dept Science, Information Technology and Innovation), a groundwater recharge rate of 101.8 mm/yr is estimated, or approximately 11% of rainfall. Using the baseflow 'fixed-block' filter method on the Yarrangobilly River estimates a groundwater recharge rate of approximately 274 mm/yr or approximately 28% of rainfall. The chloride mass balance method suggests groundwater recharge estimates range from less than 7% within the Ravine region. As such, for the Ravine region, rainfall recharge is estimated to be approximately 10% of annual rainfall.

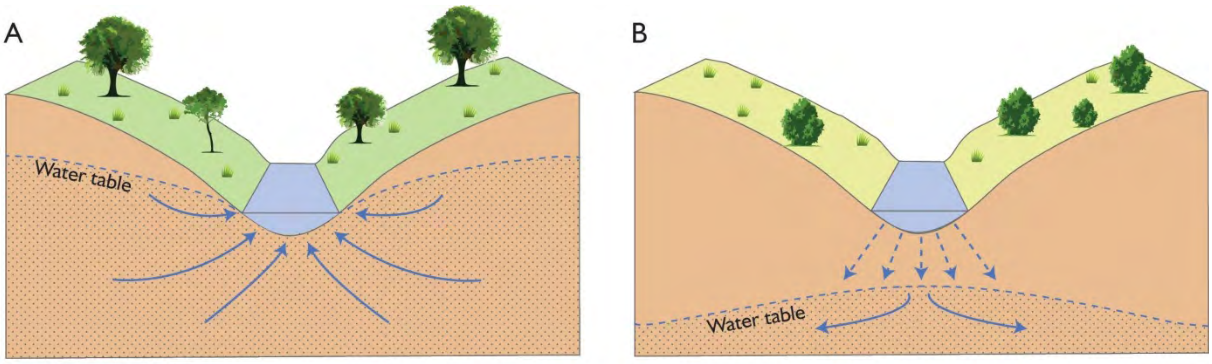
The discharge area from the conceptualised groundwater systems in the Exploratory Works project area is likely to be the Talbingo Reservoir. Locally, the Yarrangobilly River as well as other smaller local drainage lines are also likely to gain locally from shallow groundwater persisting within colluvium or the shallow Ravine Beds.

Evapotranspiration is expected to be a significant groundwater discharge mechanism in areas where the water table is shallow (ie adjacent to creek and river alignments).

6.6 Baseflow

Baseflow is the component of streamflow that is sourced from groundwater and released from groundwater storage during low streamflow conditions. Baseflow steadily decreases following high rainfall and high surface runoff. This decrease with time is often termed the groundwater recession (Domenico & Schwartz 1990).

As shown in Figure 6.4A, where the base of a stream is lower in elevation than the surrounding water table, the stream can gain water from groundwater inflow (ie baseflow); this condition is referred to as a 'gaining' stream. Conversely, as shown in Figure 6.4B, where the water table is lower in elevation than the base of a stream, the stream can lose water to the underlying water table; this condition is referred to as a 'losing' stream. The relationship between surface water and groundwater can change along the course of a stream channel, and can also change over time. Surface water and groundwater connectivity depends on hydraulic gradients (the slope of the water table), stream bed and aquifer hydraulic conductivity.



Adapted from Fetter (1994)

Figure 6.3 Gaining (right) and losing (left) streams

If groundwater is extracted from a groundwater system that is connected to the water table (unconfined or semi-confined), the water table will be lowered. If this extraction occurs in an area where there are gaining streams it is likely the amount of baseflow will decrease over time depending on the rate of extraction (ie an intercepted proportion of baseflow would be captured). The degree of influence on the water table and intercepted baseflow therefore depends on the properties of the groundwater system, connectivity between the groundwater and stream, and the rate and amount of extraction.

The groundwater level in the Exploratory Works project area is typically higher than stream stages; hence, the streams in the area are predominantly gaining streams.

Groundwater baseflow has been analysed by separating baseflow from total stream flow using the local-minimum method (Wahl & Wahl 1995). The baseflow results are area-averages for an entire catchment. The baseflow analysis indicates that annual baseflow to drainage channels is estimated to be between 10% and 30% of annual rainfall.

6.7 Groundwater levels and flow

Groundwater flow in the deep fractured rock groundwater system occurs primarily through secondary porosity (fractures), bedding planes and joints.

The regional groundwater flow direction in the main hydrogeological unit within the Exploratory Works project area, the Ravine Beds, is influenced by the location of major hydraulic boundaries in the landscape, including:

- topography;
- recharge areas, particularly north of the project area boundary at elevated areas where the Ravine Beds outcrop with limited vegetation cover;

- discharge areas, typically associated with lower or steep topographic gradients, such as cliff escarpments or Talbingo Reservoir; and
- stratigraphic dip of the geological units.

The main groundwater flow direction in the Ravine Beds is regionally from areas of higher elevation in the east towards the west; this is consistent with the regional topography and stratigraphic dip (Wyborn & Owen 1990). Regional groundwater elevations and flow directions across the deeper fractured rock systems within the broader Snowy 2.0 project area are shown on Figure 6.5.

Groundwater levels (hydraulic head) near Exploratory Works are currently monitored at two nested monitoring sites (TMB01 and TMB05) adjacent to the proposed exploratory tunnel. Groundwater levels have shown little fluctuation since monitoring commenced in mid-March 2018. Vertical hydraulic head gradients (directed downwards) are evident at the nested monitoring sites indicating a leaky aquifer rainfall recharge system between weathered and deeper fractured rock.

The Quaternary colluvium observed on the river terraces of the Yarrangobilly River during drilling is considered to episodically recharge via rainfall and flooding events. Currently this unit is not monitored; however, Snowy Hydro is committed to installing shallow monitoring bores into this localised groundwater system in late 2018 prior to commencement of tunnel works to better characterise and obtain baseline shallow groundwater data.

6.8 Vertical head gradients

The vertical hydraulic head differences between different groundwater units are variable, reflecting recharge areas, cliff escarpment discharge, and local groundwater systems within the various geological units. Groundwater level monitoring data indicates that downward trending vertical gradients are typically present within the Exploratory Works project area, consistent with areas of recharge.

6.9 Groundwater quality

Groundwater quality results collected between February 2018 and June 2018 are presented as an average for each monitoring site located within the Exploratory Works (Table 6.2).

The groundwater quality results are comparable and typical for the different target formations across the larger Snowy 2.0 project area. Within the Exploratory Works area, pH is slightly alkaline, averaging 7.5, while salinity is observed to be marginal (780 µS/cm).

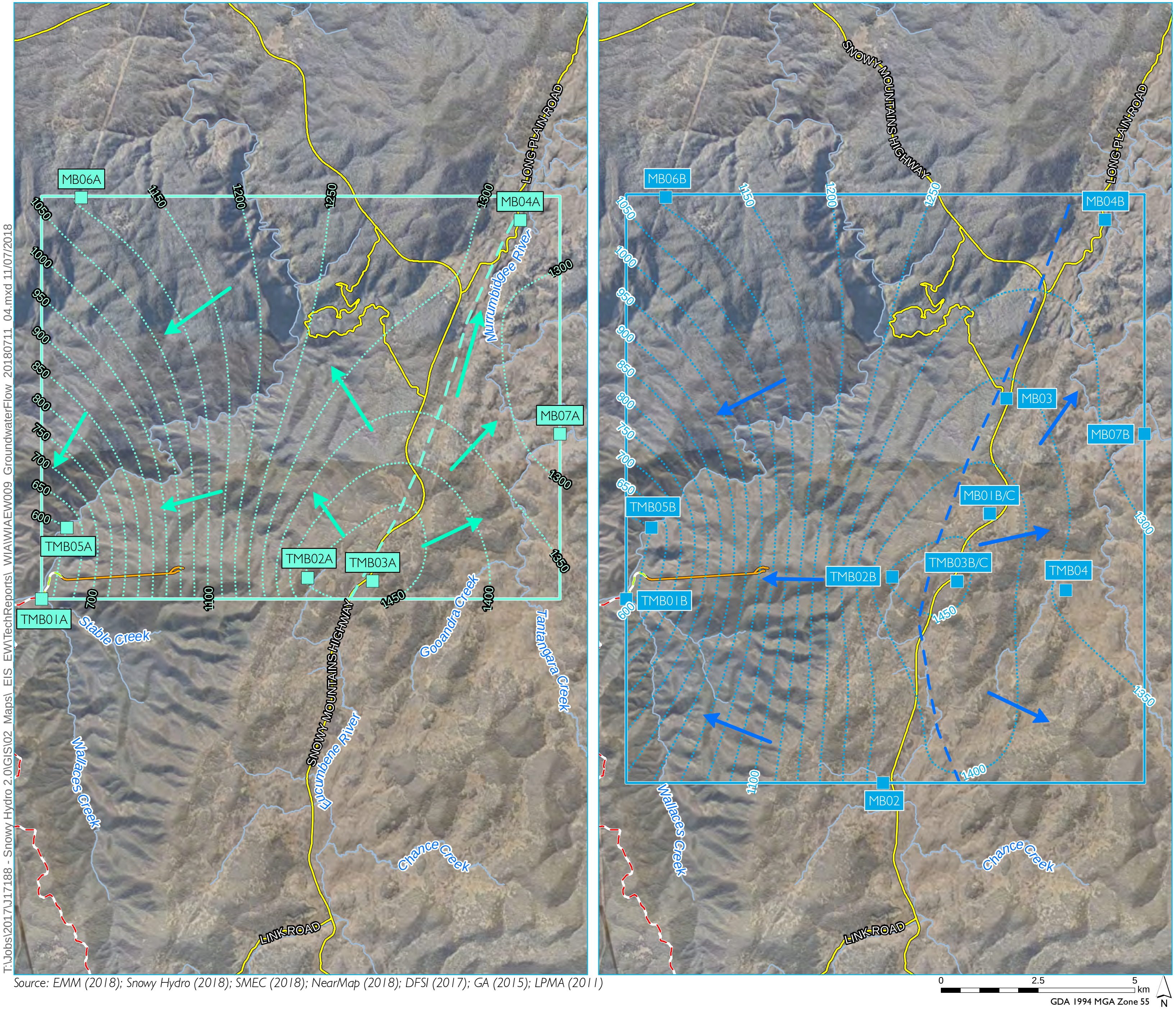
The dominant hydrochemical water type in the Ravine Beds (within the Exploratory Works project area) is Ca-Na-SO_4-$CaCO_3$. The strong sodium component in the Ravine Beds (siltstone) is likely the result of the original marine deposition of these sedimentary rock types.

Concentrations of most dissolved metals are typically low, with many measurements below detection limits. This is typical of groundwaters with reasonably neutral pH and in alpine areas where the groundwater is readily recharged via rainfall and snow melt.

Table 6.3 Mean groundwater quality results (February 2018 – June 2018)

Analyte	Units	ANZECC/ ARMCANZ 99% protection	TMB05A	TMB05B	TMB01A	TMB01B
Formation			Ravine Beds (w)	Ravine Beds	Boraig Group	Ravine Beds
Field analytes						
pH[4]	-	6.5-7.5	8.18	9.18	7.62	7.37
EC[1]	µS/cm	30-350	948	613	470	1,050
Temperature	°C	-	18.2	18.8	16.3	19.0
Dissolved oxygen	mg/L	-	1.70	2.88	3.09	6.57
Laboratory analytes						
TDS[2]	mg/L	-	627	484	1530	765
Major ions						
Calcium	mg/L	-	35	6	11	21
Chloride	mg/L	-	9	10	21	63
Magnesium	mg/L	-	8	4	6	13
Sodium	mg/L	-	148	142	99	248
Potassium	mg/L	-	11	8	4	9
Sulfate	mg/L	-	348	22	4	4
Fluoride	mg/L	-	1.1	1.5	1.8	3.0
Alkalinity						
Bicarbonate as $CaCO_3$	mg/L	-	117	198	267	572
Carbonate as $CaCO_3$	mg/L	-	<1	128	<1	<1
Hydroxide as $CaCO_3$	mg/L	-	<1	<1	<1	<1
Total as $CaCO_3$	mg/L	-	117	326	267	572
Total metals						
Arsenic	mg/L	-	0.01	0.011	0.006	0.023
Cadmium	mg/L	0.00006	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (III+VI)	mg/L	-	0.003	0.013	<0.001	<0.001
Copper	mg/L	0.001	0.004	0.003	<0.001	0.002
Mercury	mg/L	0.00006	<0.0001	<0.0001	<0.0001	<0.0001
Nickel	mg/L	0.008	0.001	0.003	0.002	0.008
Zinc	mg/L	0.0024	0.007	0.012	0.006	0.128
Lead	mg/L	0.001	<0.001	<0.001	<0.001	<0.001
Nutrients						
Ammonia as N	mg/L	-	300	80	40	<10
Kjeldahl Nitrogen Total	mg/L	-	0.6	0.3	2.6	0.1
Nitrate (as N)	mg/L	-	0.03	0.20	18.5	0.04
Nitrite (as N)	mg/L	-	<0.01	<0.01	<0.01	<0.01
Nitrogen (Total)	mg/L	2.5	600	500	21,100	100
Phosphorus	mg/L	-	0.66	0.03	0.48	0.01

Notes: 1. EC = electrical conductivity; 2. TDS = total dissolved solids; 3. (w) = weathered;
4. arithmetic mean was calculated for pH; and
5. values less than the limit of recording were treated as half the LOR when calculating mean values.



Source: EMM (2018); Snowy Hydro (2018); SMEC (2018); NearMap (2018); DFSI (2017); GA (2015); LPMA (2011)

Fractured rock groundwater levels and flow direction – Snowy 2.0 project area

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 6.4

6.10 Groundwater use

6.10.1 Extractive water users and water-related assets

There are no registered groundwater users within the Exploratory Works project area or within a 20 km search around the project area boundary.

6.10.2 Ecosystems that potentially rely on groundwater

Ecosystems that could rely on either the surface or subsurface expression of groundwater within or surrounding the Exploratory Works project area are those associated with:

- creeks where deep groundwater is discharging and provides baseflow, including Yarrangobilly River and some drainage lines in the northern and western areas of the project;
- shallow (perched) groundwater systems;
- springs associated with the steep escarpment across the eastern extent of the Exploratory Works project area; and
- terrestrial vegetation overlying shallow groundwater (within the vegetation's root zone).

These ecosystems have been classified into three categories according to their dependence on groundwater: non-dependent, facultative, and entirely/obligate (Figure 4.4).

An assessment of ecosystem groundwater reliance is described in the *Snowy 2.0 Exploratory Works Biodiversity Development Assessment* (EMM 2018d). A summary is provided below.

Ecosystems that rely on groundwater are important environmental assets and typically occur where groundwater is at or near the land surface. NSW WSPs include schedules with lists of high priority groundwater dependent ecosystems (GDEs), which are required to be assessed using the minimal impact criteria outlined in the Aquifer Interference Policy.

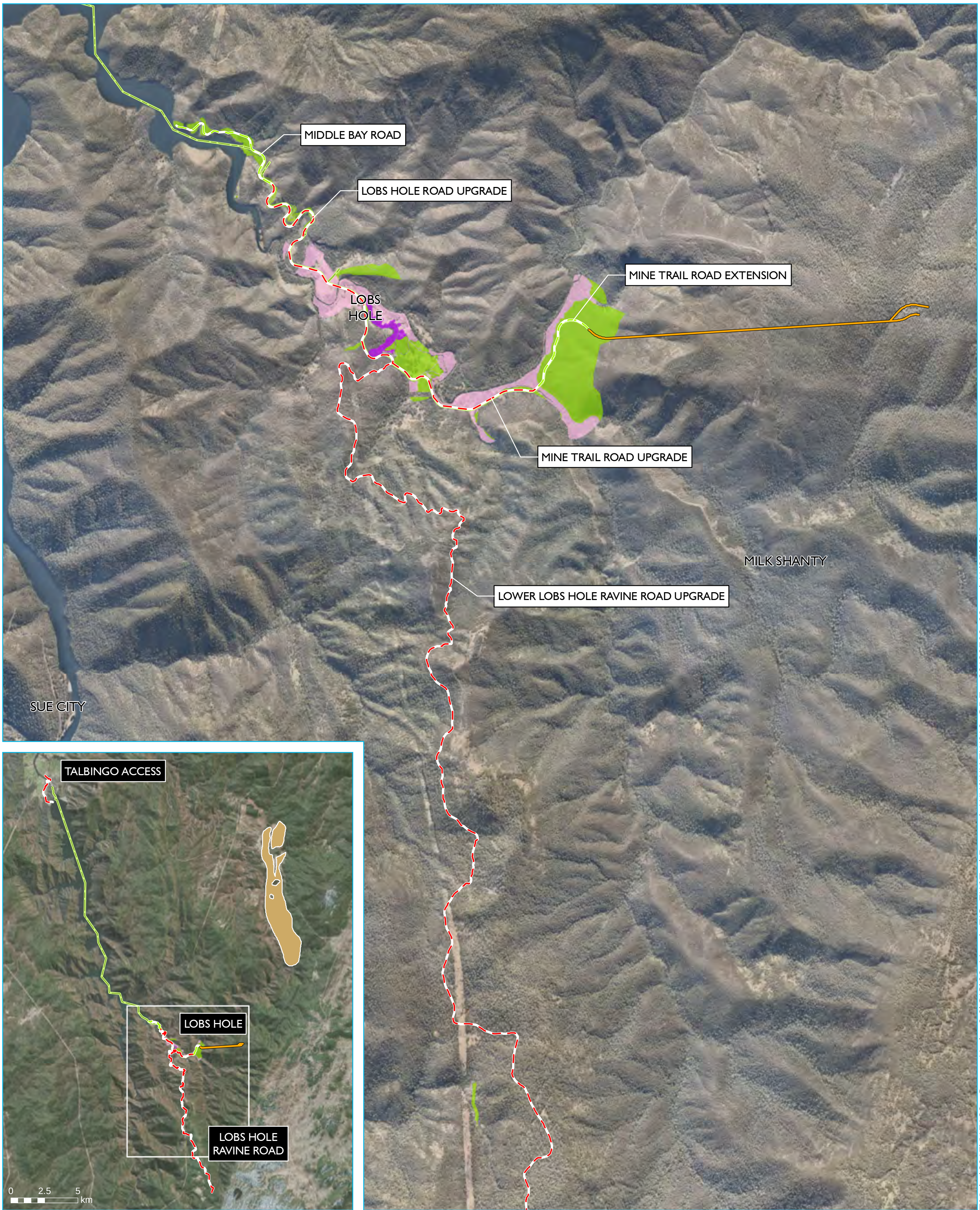
The Yarrangobilly Caves are listed as the only high priority GDE in the Fractured Rock WSP within a 50 km radius of the Exploratory Works project area. The Yarrangobilly Caves are an important limestone karst feature approximately 8 km north of the Exploratory Works project area, formed over time via dissolution processes.

The Yarrangobilly Caves have an 'entirely/obligate' dependence on groundwater. Their formation over time and current structure is maintained by groundwater levels, flow and quality.

Terrestrial vegetation overlies shallow groundwater (0-5 mbgl) across most of the Exploratory Works project area, with higher vegetation density occupying riparian corridors adjacent the Yarrangobilly River and adjoining tributaries, such as Stable Creek and Wallaces Creek. Three of the native vegetation types in the *Snowy 2.0 Exploratory Works Biodiversity Development Assessment* (EMM 2018d) study area occur where groundwater is less than 5 m deep and, therefore, have potential to access groundwater sporadically at these locations. These terrestrial plant community types (PCTs) include:

- PCT 285 Broad-leaved Sally grass – sedge woodland on valley flats and swamps;
- PCT 296 Brittle Gum peppermint open forest of the Woomargama to Tumut region; and
- PCT 302 Riparian Blakeley's Red Gum Woodland Broad-leaved Sally woodland, tea-tree, bottlebrush, wattle shrubland wetland.

None of these terrestrial ecosystems described above have a facultative (highly dependent) dependence or are entirely dependent on groundwater.



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Source: EMM (2018); Snowy Hydro (2018); DFSI (2017); GA (2015); LPMA (2011)

0 1 2 km
GDA 1994 MGA Zone 55
N

KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Yarrangobilly Caves - High Priority GDE

Plant community types

- PCT 285 - Broad-leaved Sally grass - sedge woodland on valley flats and swamps in the NSW South Western Slopes Bioregion and adjoining South Eastern Highlands Bioregion
- PCT 296 - Brittle Gum - peppermint open forest of the Woomargama to Tumut region, NSW South Western Slopes Bioregion
- PCT 302 - Riparian Blakely's Red Gum - Broad-leaved Sally woodland - tea-tree - bottlebrush - wattle shrubland wetland of the NSW South Western Slopes Bioregion and South Eastern Highlands Bioregion

Ecosystems that potentially rely on groundwater

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 6.5

7 Site conceptual model

7.1 Introduction

The hydrological conceptual model has been developed using data from the hydrological environment described in the previous sections. The model provides a schematic illustration of the various interacting components of the hydrological cycle. It includes the groundwater systems, surface water systems, flow paths, recharge and discharge mechanisms, and the interaction between these various hydrological components and geological units. It forms the basis for the numerical groundwater flow model.

The conceptual model is shown in Figure 7.1.

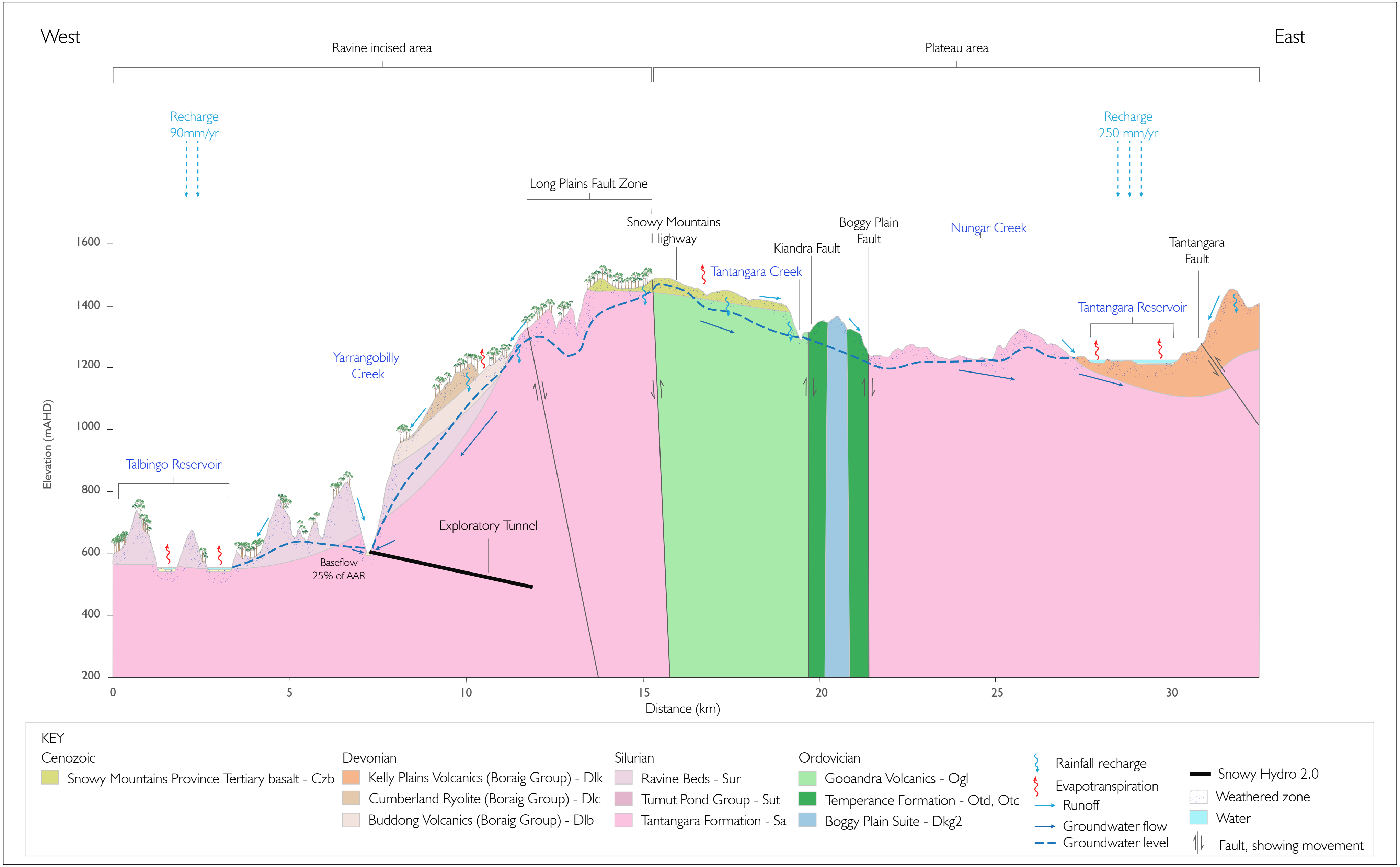
7.2 Conceptual model components

- Rainfall, evaporation and evapotranspiration:
  - high average annual rainfall (approximately 1,150 mm/yr);
  - evaporation exceeds rainfall, on average, from November to April (pan evaporation 1,712 mm/yr); and
  - transpiration from vegetation, with deeper extinction depths existing within the Ravine region reflective of deeper rooted species.
- Drainage lines:
  - most drainage lines in the Exploratory Works project area are confined valley settings with occasional flood terraces; and
  - upper reaches have low flow energy.
- Surface water use:
  - Talbingo Reservoir for pumped hydro storage and water release.
- Geological setting:
  - negligible alluvium present across the Exploratory Works project area, minor colluviums present along the Yarrangobilly River floodplain terrace;
  - surface geology is dominated by Devonian to Silurian sedimentary units, comprising younger lava flows along steep escarpments within the Ravine incised area, giving way to older reef derived carbonates closer to the incised valley floors;
  - the Ravine Beds and Tumut Pond Group are the primary geological units to be intercepted by the exploratory tunnel;
  - stratigraphy regionally dips to the west, toward Talbingo Reservoir at 15-20 degrees; and

- a major regional fault structure (Long Plain Fault) runs relatively north-south parallel to the eastern boundary of the Exploratory Works project area, separating the Tumut Block (sedimentary units) from the Tantangara Block (volcanic units).

- Groundwater systems:
  - shallow colluvium is likely to recharge during high rainfall and corresponding flooding events;
  - weathered siltstone (Ravine Beds) and rhyolite (Boraig Group) are thought to be low permeability (unless localised fractures are intercepted), and groundwater quality is fresh; and
  - the deeper Ravine Beds have a lower horizontal hydraulic conductivity than shallower groundwater systems, likely primarily due to increased overburden pressure.
- Recharge:
  - rainfall recharge is modelled at about 10% of annual rainfall within the Ravine region; and
  - recharge to the Ravine Beds is mostly from direct rainfall on outcrop, with minor contributions from the Yarrangobilly River.
- Groundwater discharge:
  - drainage to surface water (baseflow) – the largest discharge component (Figure 6.3);
  - evaporation from the water table, where it is shallow;
  - transpiration from overlying ecosystems;
  - seepage/springs and evaporation along escarpments (Figure 7.1); and
  - regional groundwater throughflow in the Ravine Beds toward Talbingo Reservoir in the west.
- Groundwater flow:
  - a relatively horizontal bedding structure means lateral flow dominates across the Exploratory Works project area, with minimal downward flow between layers;
  - groundwater flow within the colluvium (when saturated) is via primary porosity, and within the deeper Ravine Beds and Boraig Group occurs via secondary porosity (ie fractures, joints and bedding planes); and
  - regional flow influenced by stratigraphic dip and topography, generally towards the west.
- Groundwater levels:
  - stable hydraulic heads regionally;
  - groundwater elevations are typically higher than nearby rivers (including Yarrangobilly River); and
  - given the absence of nearby groundwater users, groundwater levels are only likely to fluctuate due to short and long-term climatic drivers.

- Vertical gradients and connectivity:
    - minor downward trending gradients observed between shallow weathered and deeper, competent rock within the Ravine Beds and overlying Boraig Group;
    - steep vertical gradients along the Long Plain Fault escarpment and seepage face, where discharge is conceptualised to occur; and
    - when saturated, the shallow colluvium is considered to recharge the underlying Ravine Beds.
- Surface water/groundwater interaction:
    - all streams in the Exploratory Works project area are classified as gaining streams with groundwater providing baseflow to streams; and
    - leakage from Yarrangobilly River to the Ravine Beds is likely upstream of the Exploratory Works project area.
- Ecosystems that potentially rely on surface and/or groundwater:
    - there are no high priority GDEs identified within the project area, the closest one is the Yarrangobilly Caves, a limestone karst system, 8 km north of the exploratory tunnel;
    - ecosystems may rely on surface expressions of groundwater at springs and creeks, where baseflow contribution is significant; and
    - vegetation root zones may rely on shallow groundwater (<5 mbgl) near some creeks.
- Exploratory Works / water interaction:
    - groundwater inflows to the exploratory tunnel during tunnelling will be removed to allow tunnel progression to continue, and then recycled and reused for tunnelling, surface construction operations; and
    - rainfall onto the infrastructure area (disturbed area) is harvested and stored in a series of sediment dams, stormwater and detention basins for use in construction operations of the surface infrastructure area.



Conceptual cross-section

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 7.1

8 Numerical groundwater flow model

A regional numerical groundwater flow model, referred to as SH1.0, was developed for the Exploratory Works groundwater assessment. The model has been developed with data available to date, which included:

- surface geological maps;
- initial hydraulic head measurements from recently installed monitoring wells; and
- hydraulic conductivity estimates from slug tests from bores within the broader Snowy 2.0 project area and from published literature.

Further in-situ characterisation of hydraulic properties is planned, and includes: pumping tests at multiple sites with observations down a profile to identify horizontal and vertical hydraulic conductivity/connectivity as well as storage properties); and ongoing monitoring across the network of recently installed wells, to inform seasonal and longer-term trends.

The model was prepared in accordance with the *Australian Groundwater Modelling Guidelines* (AGMG) (Barnett et al. 2012). The current model (SH1.0) meets many of the criteria outlined in the AGMG for a Class 2 model, with the remaining criteria conforming to Class 1. The primary limitations of the model relate to the water level dataset and length of monitoring available to inform the conceptualisation and calibration.

EMM, on Snowy Hydro's behalf, held preliminary discussions with DoI Water in March 2018 to discuss the proposed numerical model. Model build (including platform, extent and boundary conditions) as well as available data collected from the groundwater and surface water monitoring network was outlined and an approach to steady state and transient modelling was agreed.

The model design and calibration are summarised in the following sections, with model results, including uncertainty analysis, discussed in Chapter 9.

The model has been independently peer reviewed by Hugh Middlemis of Hydrogeologic Pty Ltd. The peer reviewer deemed that the model objectives were satisfied, the model calibration satisfactory, the model predictions conform to best practice, and that the model is fit for purpose. The peer review report is included in Appendix B.

8.1 Model objectives

The modelling objectives were to quantify potential impacts on the groundwater system resulting from construction and continued operation of the exploratory tunnel. Specifically, the outcomes required were predictions of water table drawdown, tunnel inflows and water balances. The numerical model was not designed to simulate water quality changes.

The Exploratory Works represent the first stage of Snowy 2.0.It is noted that the numerical model (SH1.0) was set up and designed to provide a platform that can be adapted to produce subsequent predictions of impacts of the greater Snowy 2.0 project over time. Hence, the domain for SH 1.0 is much larger than would be required to predict impacts of the Exploratory Works only, as it is sufficiently large to encompass the footprint of all groundwater-affecting infrastructure anticipated for Snowy 2.0 and the maximum potential extent of associated groundwater impacts. As further monitoring and testing data become available, they will be used to refine and update the current conceptual and numerical models.

8.2 Design

8.2.1 Modelling software

The model was built using the Groundwater Vistas 7 (ESI 2017) graphical user interface (GUI) because of its highly flexible input, output and data processing options when compared with other commercially available GUIs. The model runs in the MODFLOW-USG (HGL 2017) numerical groundwater flow modelling code. MODFLOW-USG enables use of an "unstructured grid" rather than the regular rectangular grid of rows, columns and layers required for all previous versions of MODFLOW. This enables much greater flexibility in representing detailed geometry associated with hydrostratigraphy or other hydrogeological features (such as the simulated rivers and tunnel). Additional spatial refinement can be employed around features requiring it, without the requirement for additional rows, columns or layers to be continued across the whole model domain.

8.2.2 Model extent

The south-west corner of the model domain has coordinates of E621,500 m, N6,032,000 m (MGA Zone 55), and extends 30 km to the east and 15 km to the north. The model domain, presented in Figure 8.1, is sufficiently large to encompass exploratory tunnel, Yarrangobilly Caves, all major rivers and creeks as well as the footprint of anticipated groundwater-affecting infrastructure associated with the between the Talbingo and Tantangara Reservoirs associated with Snowy 2.0, should it proceed.

8.2.3 Spatial discretisation

The spatial grid employed to discretise the model domain is shown in Figure 8.1. The model has a regional cell size of 200 m by 200 m. A "quadtree mesh" provides local refinement around the modelled surface water features and the exploratory tunnel. Quadtree refinement splits regional model cells into smaller cells with dimensions reduced by a factor of 2^{n-1}. The level "n" of refinement is selected by the user. The SH1.0 model employs quadtree refinement of order 3 along the paths of modelled rivers and creeks and around the edges of Talbingo and Tantangara Reservoirs. This reduces cell sizes around these features to 50 m by 50 m. Along the alignment of the exploratory tunnel quadtree refinement of order 5 is employed such that cells are reduced to 12.5 m by 12.5 m, enabling representation of the anticipated large depressurisation gradients into the rock mass moving away from the tunnel walls.

Twenty-five model layers are used to represent the hydrostratigraphy, exploratory tunnel and anticipated hydraulic gradients. The basis for the model layer structure is outlined in Table 8.1. The uppermost three layers are used to represent the more permeable weathered geology and, where present, Tertiary basalt. Below these the majority of model layers are primarily horizontal set at intervals of 100 mAHD. Where such layers intersect the upper three layers they either thin or "pinch out" completely. "Pinching out" occurs wherever a cell has a thickness less than 0.5 m and the node is deactivated. Layers are forced to be continuous across pinched out nodes, such that hydraulic connections are maintained. Furthermore, where layers are steeply dipping or pinched out, nodes sharing at least a 20 % overlap are connected.

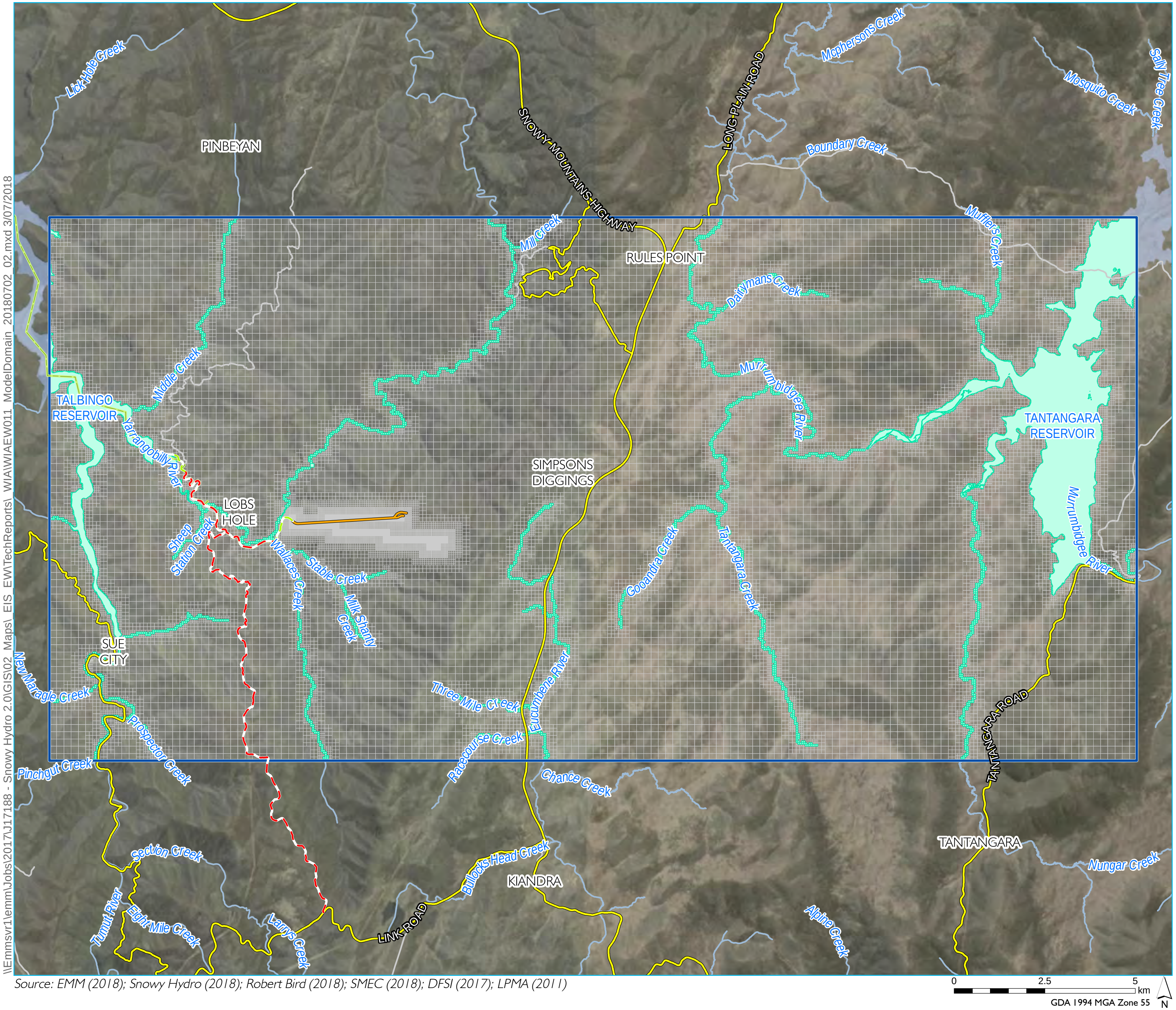
Nine model layers are used to provide spatial detail above and below the exploratory tunnel. The central one of these, model layer 19, is defined to have its base located 1.5 m below the tunnel floor and be 12 m thick. These nine tunnel-based layers are active only for a rectangular portion of the model domain within 1 km of the minimum and maximum eastings and northings of the exploratory tunnel. Outside this area the nine tunnel-based layers are pinched out.

The 25 model layers, regional and quadtree meshes and pinching out of discontinuous model layers yields a total 1,289,325 nodes. East-west cross sections through the model domain are presented in Figure 8.2 to illustrate the geometrical structure and discretisation of the model.

Table 8.1 Description of model layers

Model layer	Features represented	Nominal layer top (mAHD)*	Nominal layer bottom (mAHD)*	Thickness (m)
1	Colluvium, tertiary basalt and weathered surface geology	LiDAR topography	25 m below topography	25
2	Intermediate weathered zone	25 m below topography	50 m below topography	25
3	Intermediate weathered zone	50 m below topography	100 m below topography	50
4	"Deep" rock: Ravine Beds, Tumut Pond Group, Gooandra Volcanics, Temperance Fm, Boggy Plain Adamellite, Bolton Beds, Tantangara Fm, Nungar Beds	1600	1500	100*
5		1500	1400	100*
6		1400	1300	100*
7		1300	1200	100*
8		1200	1100	100*
9		1100	1000	100*
10		1000	900	100*
11		900	800	100*
12		800	700	100*
13		700	600	100*
14		600	44 m above tunnel layer	variable
15		44 m above tunnel layer	29 m above tunnel layer	15*
16		29 m above tunnel layer	17 m above tunnel layer	12*
17		17 m above tunnel layer	7 m above tunnel layer	10*
18		7 m above tunnel layer	Tunnel layer	7*
19	Exploratory tunnel	10.5 m above tunnel floor	1.5 m below tunnel floor	12*
20	"Deep" rock: Ravine Beds, Tumut Pond Group, Gooandra Volcanics, Temperance Fm, Boggy Plain Adamellite, Bolton Beds, Tantangara Fm, Nungar Beds	Tunnel layer	7 m below tunnel layer	7*
21		7 m below tunnel layer	17 m below tunnel layer	10*
22		17 m below tunnel layer	29 m below tunnel layer	12*
23		29 m below tunnel layer	44 m below tunnel layer	15*
24		44 m below tunnel layer	500	variable
25		500	400	100

Note: ** where not deflected by proximity to topography or tunnel layer or, for layers based on tunnel geometry, pinched out where more than 1 km from the tunnel alignment.*



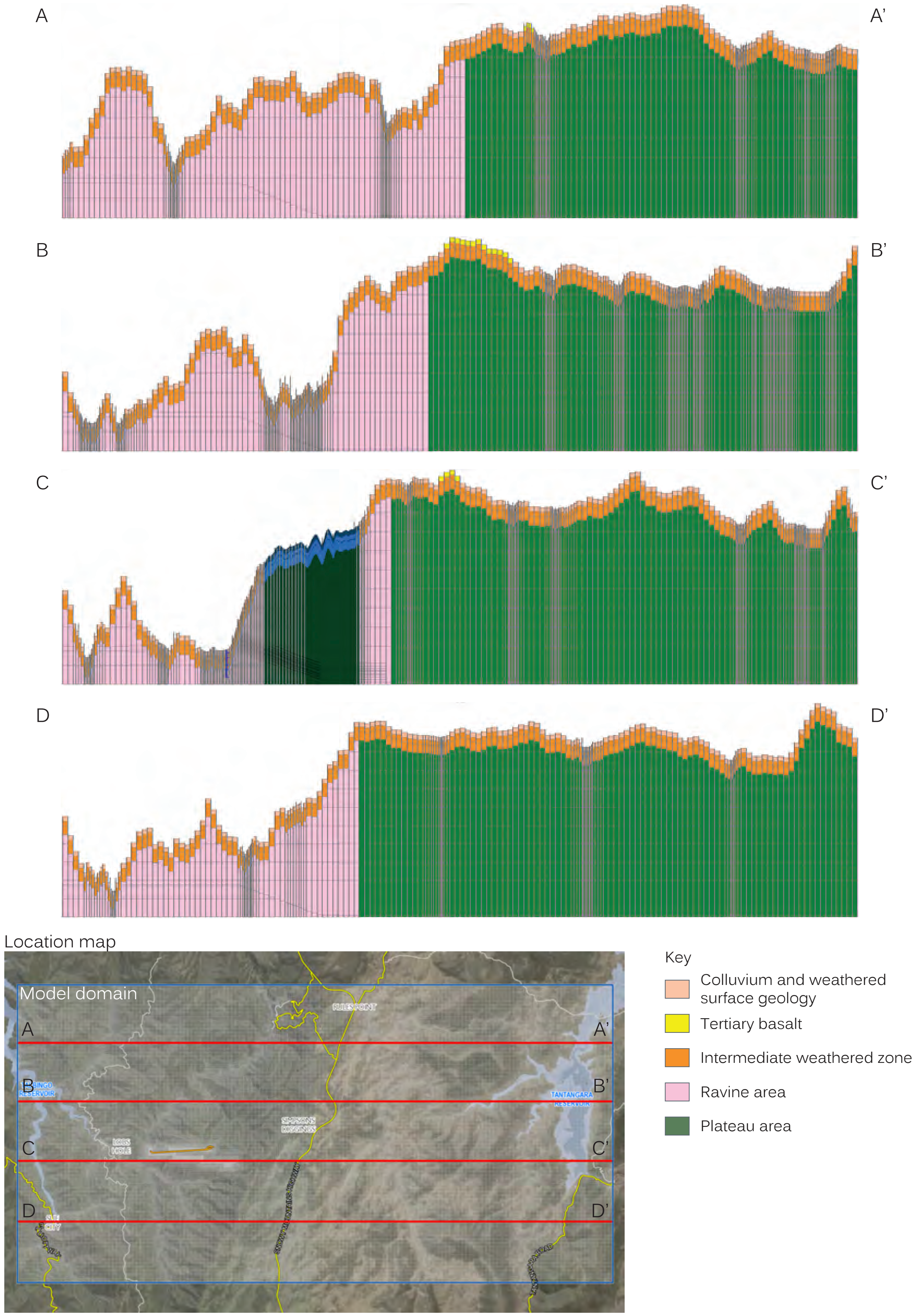
Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Local road
- Perennial watercourse
- Scheme storage
- Model domain
- Model grid
- Model reservoirs and river boundary condition

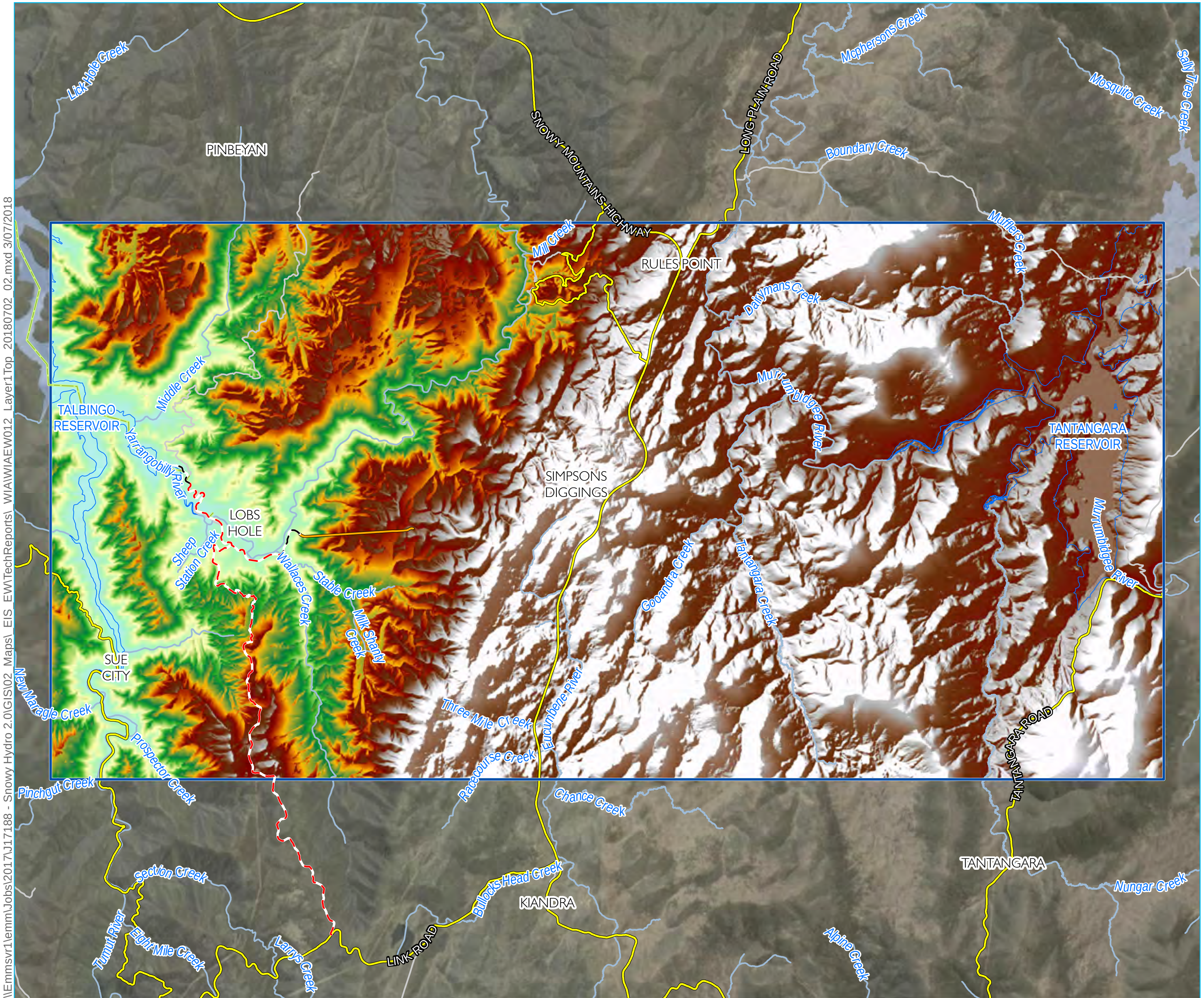
SH1.0 model domain, grid and boundary conditions

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.1



West-east cross-sections through model layers and grid structure

Snowy 2.0
Groundwter Assessment
Exploratory Works
Figure 8.2



KEY
- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Local road
- Perennial watercourse
- Scheme storage
- Model domain
- Model reservoirs

Top elevation of model layer 1 (m AHD)
High : 1709.7
Low : 541.647

Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

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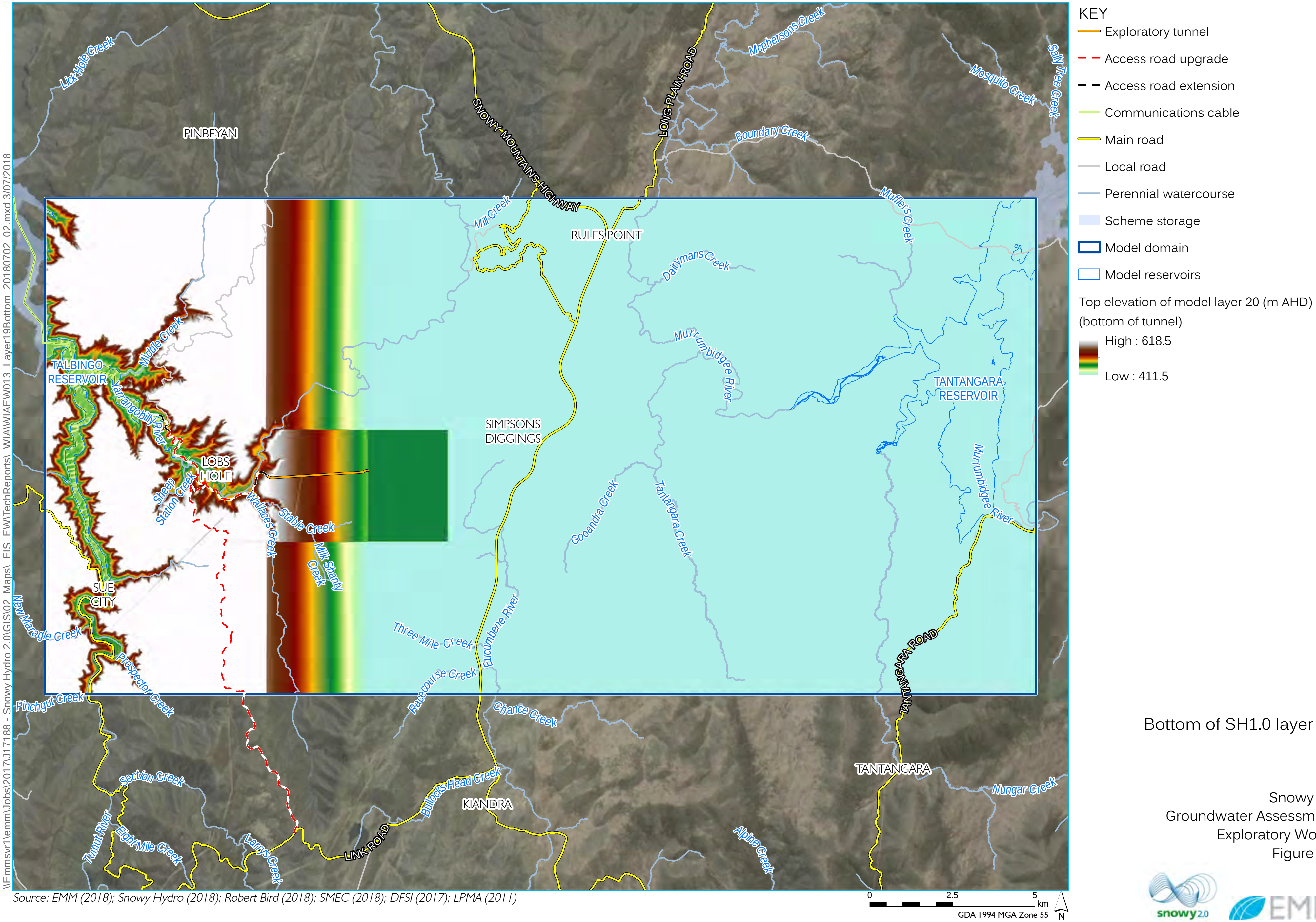
Top of SH1.0 layer 1
(topography)

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.3

snowy2.0 EMM



Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

Bottom of SH1.0 layer 19

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.4

snowy2.0 EMM

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8.2.4 Boundary conditions

Regional hydraulic head data, beyond the monitoring bores recently constructed for Snowy 2.0, were not available to suitably inform hydraulic heads or gradients near the model edges. Hence, a conservative approach of assigning no flow boundary conditions around the model domain in all layers was adopted. In this way drawdown induced by depressurisation of the exploratory tunnel is not incorrectly buffered by model-edge boundary conditions.

i Surface water features

The MODFLOW river (RIV) package was used to represent the Talbingo Reservoir, Tantangara Reservoir and all major named surface water features within the model domain.

River boundary condition cells representing the Talbingo and Tantangara reservoirs (cells typically measuring 200 m by 200 m) were assigned a conductance of 4000 m^2/d. Stage was set at 541 mAHD for Talbingo and 1,215 mAHD for Tantangara. For each reservoir the “river” bottom elevation was set 5 m below stage.

Major rivers and creeks were assigned stage equal to topography and a conductance of 250 m^2/d. River bottom elevations were set 3 m below stage in each cell.

Smaller springs and drainage lines were not represented explicitly in the model. However, modelled evapotranspiration (see next section) removes groundwater in regions where the modelled water table is near ground surface.

Modelled surface water features are illustrated in Figure 8.1.

ii Rainfall recharge and evapotranspiration

The Exploratory Works area is characterised by steeply dipping topography and incised drainage lines and is largely covered with trees. Conversely, the plateau area has low relief, marshes and only small stands of tree coverage. These two very different systems are expected to respond differently to rainfall and, hence, were assigned as different recharge zones. A third recharge zone was defined in the plateau area where Tertiary basalt outcrop is mapped. It is likely the highly permeable nature of this basalt will allow greater infiltration of rainfall than the surrounding geology. Model cells assigned as river boundary conditions were assigned zero rainfall recharge. Rainfall recharge was applied to the model as follows:

1. Ravine: a recharge rate of 90 mm/yr is applied across this zone and represents approximately 10 % of annual rainfall.

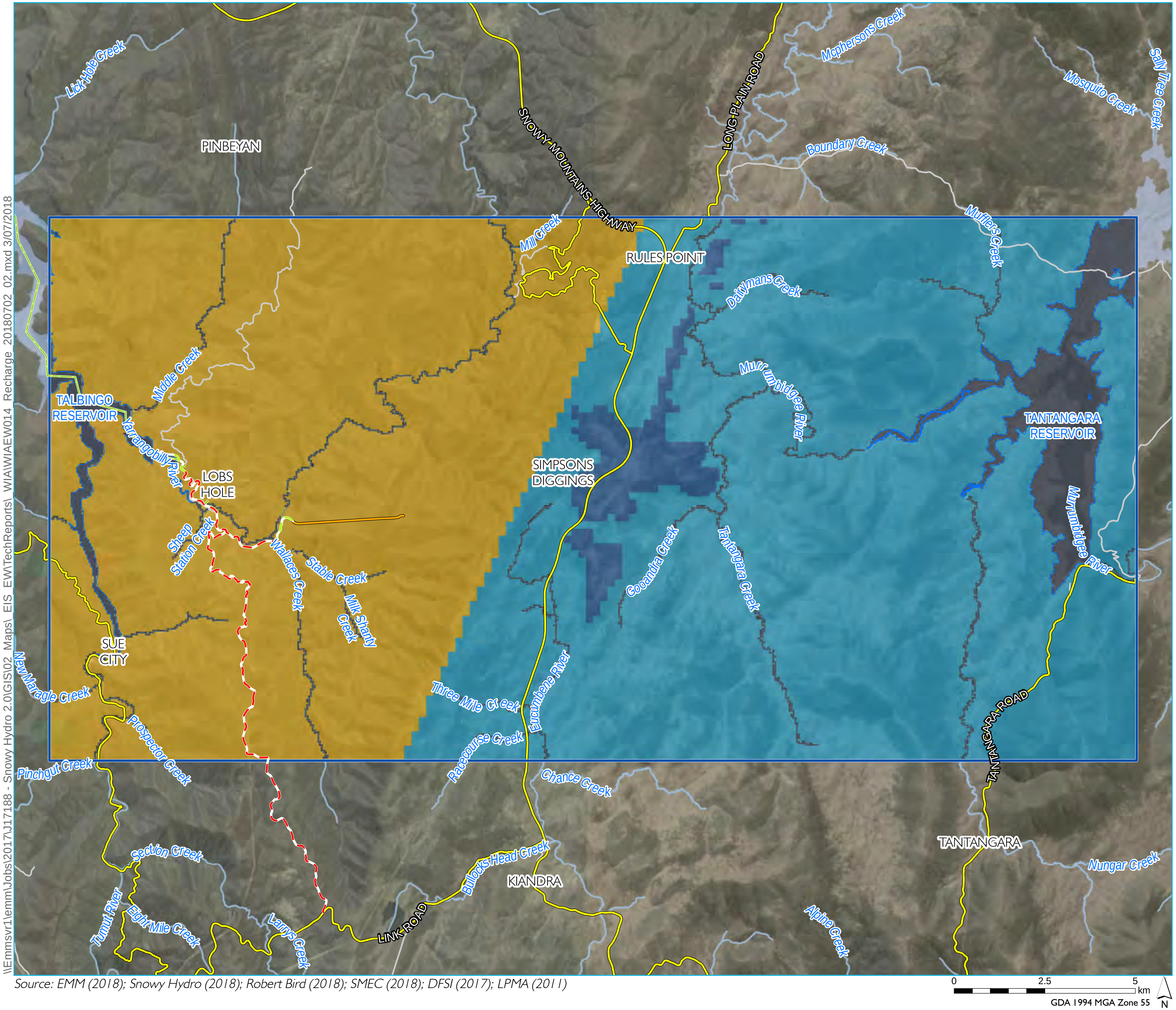
2. Plateau: a recharge rate of 250 mm/yr is applied across this zone and represents approximately 25 % of annual rainfall.

3. Tertiary basalt outcrop: a recharge rate of 300 mm/yr is applied across this zone and represents approximately 30 % of annual rainfall.

4. Modelled surface water features: a recharge rate of 0 mm/yr is applied.

The MODFLOW evapotranspiration (EVT) package is used to simulate evapotranspiration from groundwater (not total evapotranspiration that includes evaporation and transpiration from surface and soil water sources). A uniform maximum evapotranspiration rate of 1,300 mm/yr is applied across the model, except for modelled surface water features which are assigned zero evapotranspiration. The Ravine and Plateau zones used for recharge are used to assign two different evapotranspiration extinction depths (if the water table is deeper than the extinction depth then no evapotranspiration is simulated). In the Ravine area a depth of 5 m is assigned due to the coverage of large trees with likely ability to access water from this depth.

The distribution of modelled rainfall recharge and evapotranspiration is illustrated in Figure 8.5.



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Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

Modelled rainfall recharge and evapotranspiration

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.5

8.3 Calibration

8.3.1 Approach

Snowy Hydro holds extensive groundwater information relating to the existing scheme, and this was reviewed and utilised where possible for the Exploratory Works assessment. However, there are limitations to the data, primarily due to the complex and distinct nature of the local geology and its influence on groundwater movement.

Data available for calibration of the numerical groundwater flow model were constrained to single (ie non-transient) hydraulic head values at recently installed monitoring bores plus river flow gauging data (available over a duration of several decades). This, combined with the lack of any evidence to suggest the groundwater system is in a long term state of change, led to the adoption of calibration in steady state only as an appropriate means for project assessment.

Sixteen of the twenty monitoring locations in the groundwater monitoring network are within the model domain for SH 1.0, providing a total of sixteen hydraulic head calibration targets. Time series data, and a greater coverage of monitoring locations, will be available for recalibration of the model for subsequent groundwater modelling of the full Snowy 2.0 project.

The hydraulic properties of the model were assigned using zones based on the conceptualisation of the system as being split into;

- into a more permeable shallow system overlying the deeper fractured rock system with low permeability; and
- into the Ravine catchment, west of Long Plain fault, dominated by sedimentary geology and the plateau region, east of the Long Plain fault, dominated by volcanic geology.

Storage properties were assigned using two layer-based zones. Layer one was assigned higher (confined and unconfined) storage property values, consistent with being weathered and under less geostatic pressure than deeper layers, and layers two to twenty five were assigned lower values.

Calibration was carried out using a combination of manual and automated (using PEST, (Doherty 2010)) parameter adjustment to reduce residuals between modelled and measured hydraulic heads. The parameters calibrated were hydraulic conductivity assigned to the zones mentioned above and the recharge assigned to the three zones. Recharge flux was constrained to be consistent with estimates from chloride mass balance analysis across the entire groundwater monitoring network as well as two baseflow analysis techniques applied to gauged data for the Yarrangobilly River. Storage parameter values could not be calibrated and were based on published ranges for similar geological media due to the calibration being undertaken in steady state and transient data not available.

8.3.2 Performance and results

The modelled watertable, representing present day pre-exploratory tunnel construction, is presented in Figure 8.6. The modelled water table replicates the conceptualisation of being a damped version of topography, with high elevation on the plateau declining steeply west of the Long Plain Fault in the Ravine area, with localised drainage from ridges towards creeks and rivers. The model produces the regional groundwater divide, approximately co-linear with Long Plain Fault, with groundwater flowing west towards Talbingo Reservoir and east towards Tantangara Reservoir. Modelled hydraulic heads are consistent with both reservoirs acting as regional groundwater discharge features.

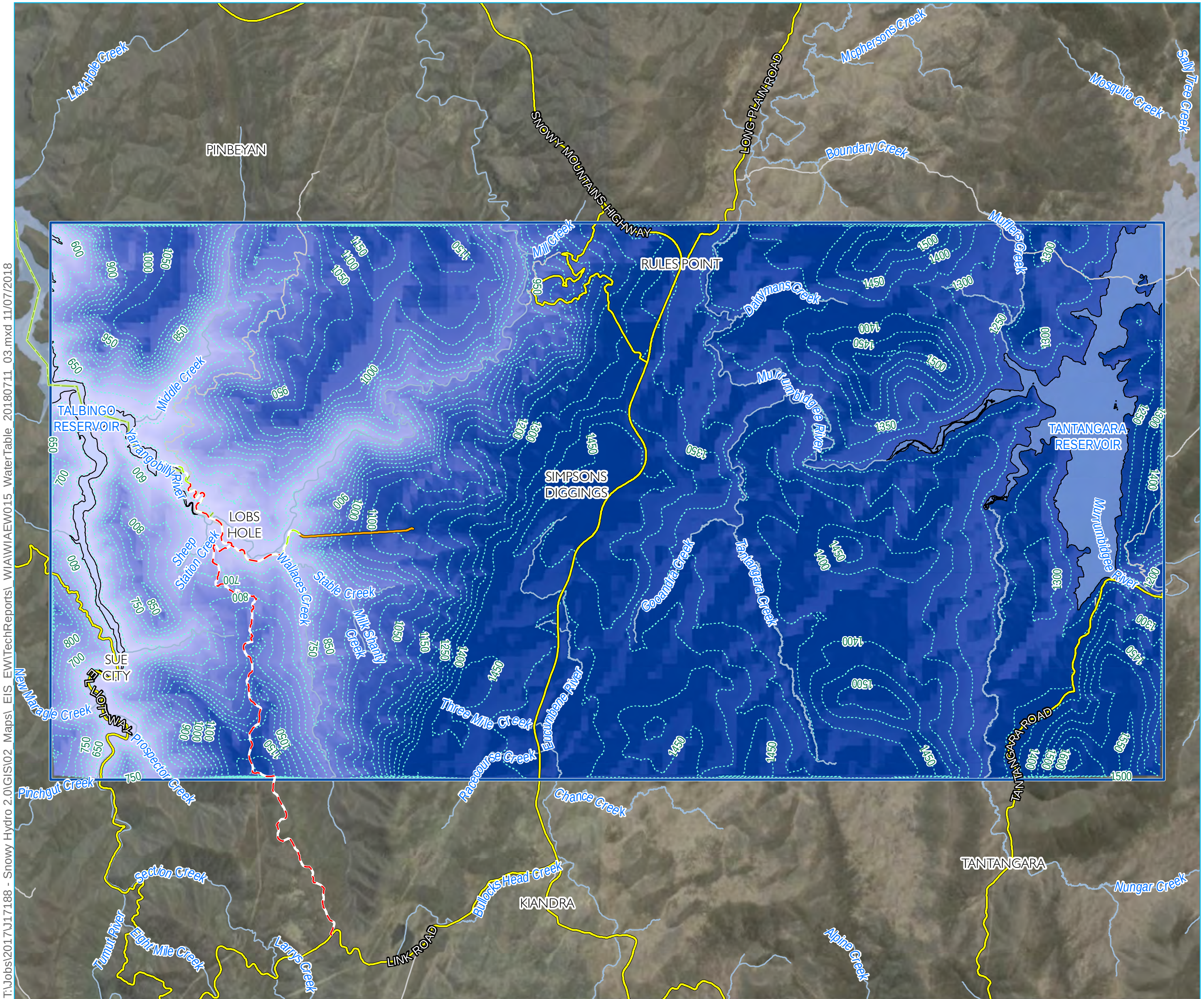
It was noted, during calibration, that the elevated groundwater levels observed at a number of bores on the plateau near Long Plain Fault and Tertiary basalt outcrop were difficult to replicate in the numerical model. The steeply dipping watertable west of the fault causes groundwater to flow in that direction, effectively pulling down the water table around the fault and associated groundwater divide. Without applying rainfall recharge and/or hydraulic conductivity values outside the ranges consistent with the conceptualisation, it was not possible to replicate the local high water table associated with these locations. The hydraulic nature of the Long Plain Fault continues to be investigated, but the numerical groundwater flow model suggests it may act as a barrier to groundwater flow, separating the Ravine and Plateau areas hydraulically, to some degree. Even though this conceptualisation is not fully understood, the impacts will likely be localised, and therefore it is unlikely to have a significant effect on the overall regional impacts of the larger Snowy 2.0 project from either a volumetric inflow or propagation of depressurisation/drawdown effects.

Measured hydraulic head targets and corresponding modelled head and residuals are tabulated in Table 8.2. The model produces a Root Mean Squared (RMS) error of 9.72 m which, combined with a range in observations of 890.13 m, equates to a Scaled Root Mean Squared (SRMS) error of 1.09 %. This is well inside the often targeted 5 % (for example, Barnett et al. (2012)).

A scatter plot of modelled versus measured hydraulic head is presented in Figure 8.7. These can be seen to lie close to the line of best fit (ie a line with slope of 1, upon which modelled head equals measured head). No significant bias is evident across the dataset which suggests the model matches heads equally well across the range of observations.

Table 8.2 Measured and modelled hydraulic head targets

Well name	Easting (m)	Northing (m)	Model layer	Measured head (m AHD)	Modelled head (m AHD)	Residual (m)
TMB01A	627698	6038041	1	576.00	582.94	-6.94
TMB01B	627698	6038041	3	575.60	586.80	-11.20
TMB02A	634554	6038586.4	1	1463.80	1456.39	7.41
TMB02B	634548.5	6038606.6	7	1465.07	1452.97	12.10
TMB03A	636224.2	6038504.3	2	1465.73	1469.81	-4.08
TMB03B	636215.2	6038505.1	6	1459.82	1469.91	-10.10
TMB03C	636220.7	6038495.1	7	1455.76	1469.56	-13.80
TMB04	639018.2	6038261.2	8	1328.58	1335.78	-7.20
TMB05A	628352	6039882	1	598.50	602.53	-4.03
TMB05B	628352	6039882	3	598.40	612.88	-14.48
MB01B	637059.5	6040238	1	1460.80	1460.16	0.64
MB01C	637065.7	6040245.3	2	1442.40	1459.98	-17.58
MB02	634310.5	6033304.1	7	1380.55	1384.34	-3.79
MB03	637491	6043212.7	3	1367.19	1356.06	11.12
MB07A	641051	6042294.1	1	1256.05	1262.87	-6.82



Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

Modelled present day steady state water table

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.6

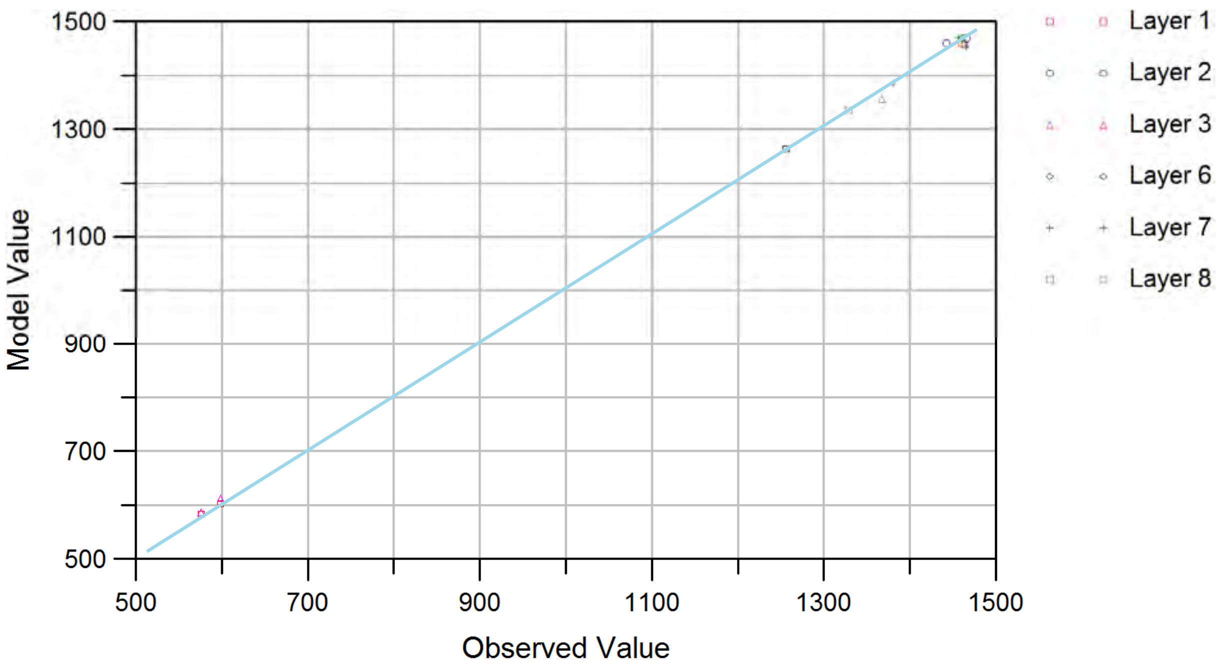


Figure 8.7 Scatter plot of modelled versus measured hydraulic head

The modelled steady state present day water balance is provided in Table 8.3. Modelled inflow and outflow components balance almost exactly, producing a water balance error of 0.0%. Consistent with the conceptualisation of the system, rainfall recharge provides by far the greatest inflow to the model domain. Relatively small contributions to the groundwater system occur from surface water leakage, however these are minor in comparison to groundwater outflow to modelled surface water features (baseflow). Net modelled baseflow (outflow minus inflow) is approximately 18,000 ML/yr. This volume is significantly lower than the modelled volume of over 57,000 ML/yr attributed to evapotranspiration.

Fixed block method analysis of gauge data from the Yarrangobilly River, scaled down for the proportion of the catchment within the model domain, yielded an estimated baseflow from within the model domain of around 38,000 ML/yr. Flow Duration Curve (FDC) analysis estimated around 14,000 ML/yr. In comparison, modelled net baseflow to the Yarrangobilly River and its tributaries from the calibrated model is 2,799 ML/yr. It is worth noting that only the major creeks and rivers were simulated. It is likely that smaller tributaries to these, that are not modelled explicitly, contribute to interpreted baseflow in the Yarrangobilly River. Where the modelled water table is near, or at, ground surface in the vicinity of such features the model will simulate this discharge as evapotranspiration.

During calibration it was noted that the horizontal hydraulic conductivity of model layer 1 appeared to have strong influence over the distribution of modelled outflow between baseflow and evapotranspiration. Results from ongoing field testing and monitoring will provide information to further constrain the properties and dynamics of the shallow groundwater system and its interaction with surface water bodies in the Exploratory Works project area.

Table 8.3 Modelled present day steady state water balance

Component	In (ML/yr)	Out (ML/yr)
Rainfall recharge	75,477	-
Surface water leakage	6,331	24,150
Evapotranspiration	-	57,657
TOTAL	**81,808**	**81,807**

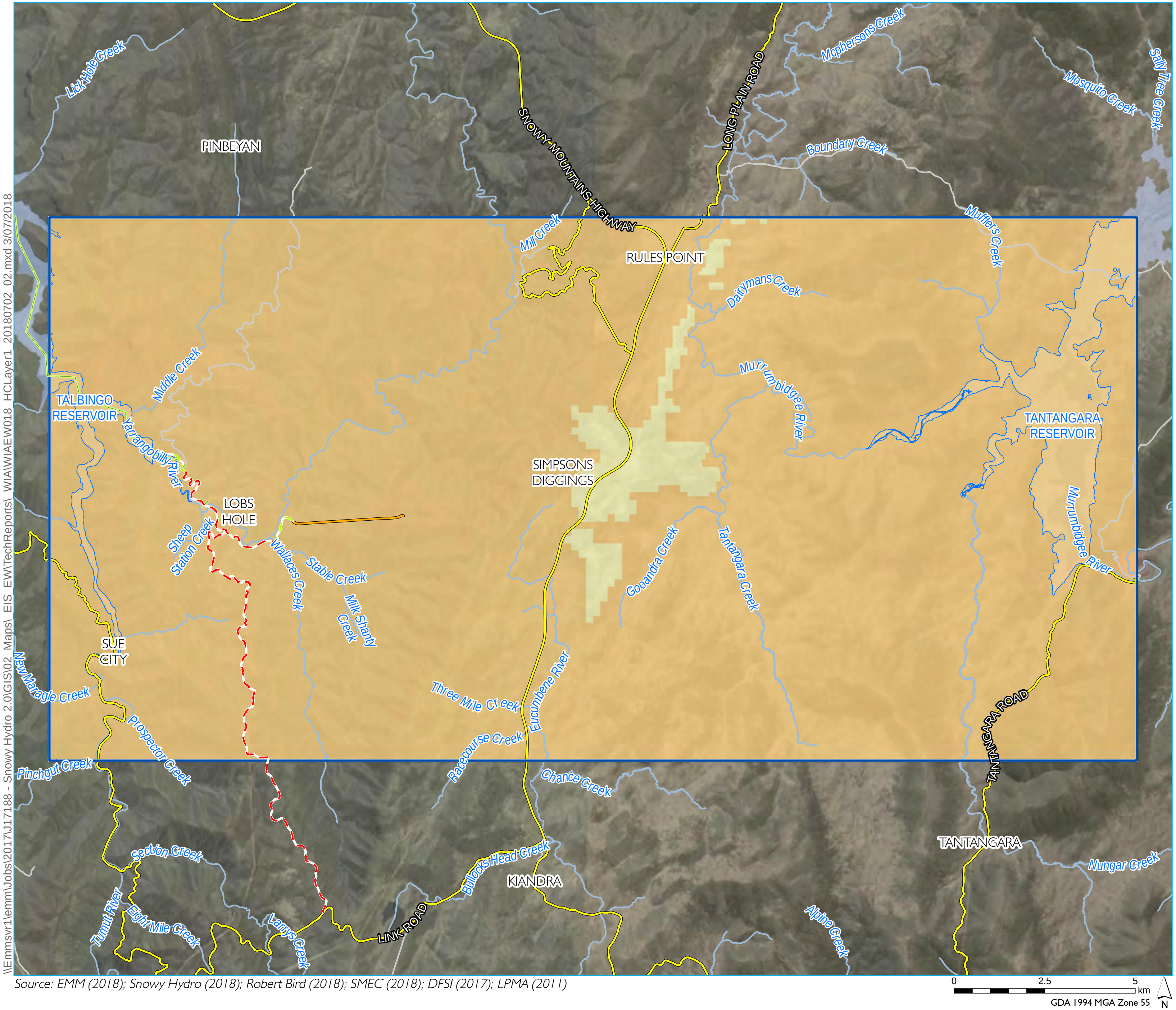
8.3.3 Calibrated aquifer parameter values

Calibrated aquifer parameter values are tabulated in Table 8.4 and presented in Figure 8.8 and Figure 8.9. The intermediate weathered zone is applied uniformly across model layers two and three and, hence, is not presented in a figure.

Calibrated values are consistent with the conceptual model. However, data available at the time of model construction and calibration do not provide a dataset that can be adopted for identifying vertical hydraulic conductivity both within and between shallow and deep units. Further, because a steady state calibration only was required for the Exploratory Works assessment the parameter values for specific storage (Ss) and specific yield (Sy) could not be calibrated and are not required, as they do not impact steady state groundwater flow. The adopted values are based on published literature values (Domenico & Schwartz 1990) for similar geological media and have been selected to likely be conservative, particularly for the rock at hundreds of metres depth, with regard to their impact on tunnel inflows.

Table 8.4 Calibrated aquifer parameter values

Zone	Layer(s)	Kh (m/d)	Kv (m/d)	Ss (1/m)	Sy (-)
Colluvium and weathered surface geology	1	0.1	0.01	5×10^{-5}	0.05
Tertiary basalt	1	1	0.1	5×10^{-5}	0.05
Intermediate weathering	2 and 3	0.01	0.005	5×10^{-6}	0.01
"Deep" rock in Ravine area: Ravine Beds, Tumut Pond Group	4 to 25	0.0001	0.0003	5×10^{-6}	0.01
"Deep" rock in plateau area: Gooandra Volcanics, Temperance Fm, Boggy Plain Adamellite, Bolton Beds, Tantangara Fm, Nungar Beds	4 to 25	0.0001	0.001	5×10^{-6}	0.01



KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Local road
- Perennial watercourse
- Scheme storage
- Model domain
- Model reservoirs

Modelled hydraulic conductivity in layer 1

- 0.1 Kh (m/d), 0.01 Kv (m/d)
- 1 Kh (m/d), 0.1 Kv (m/d)

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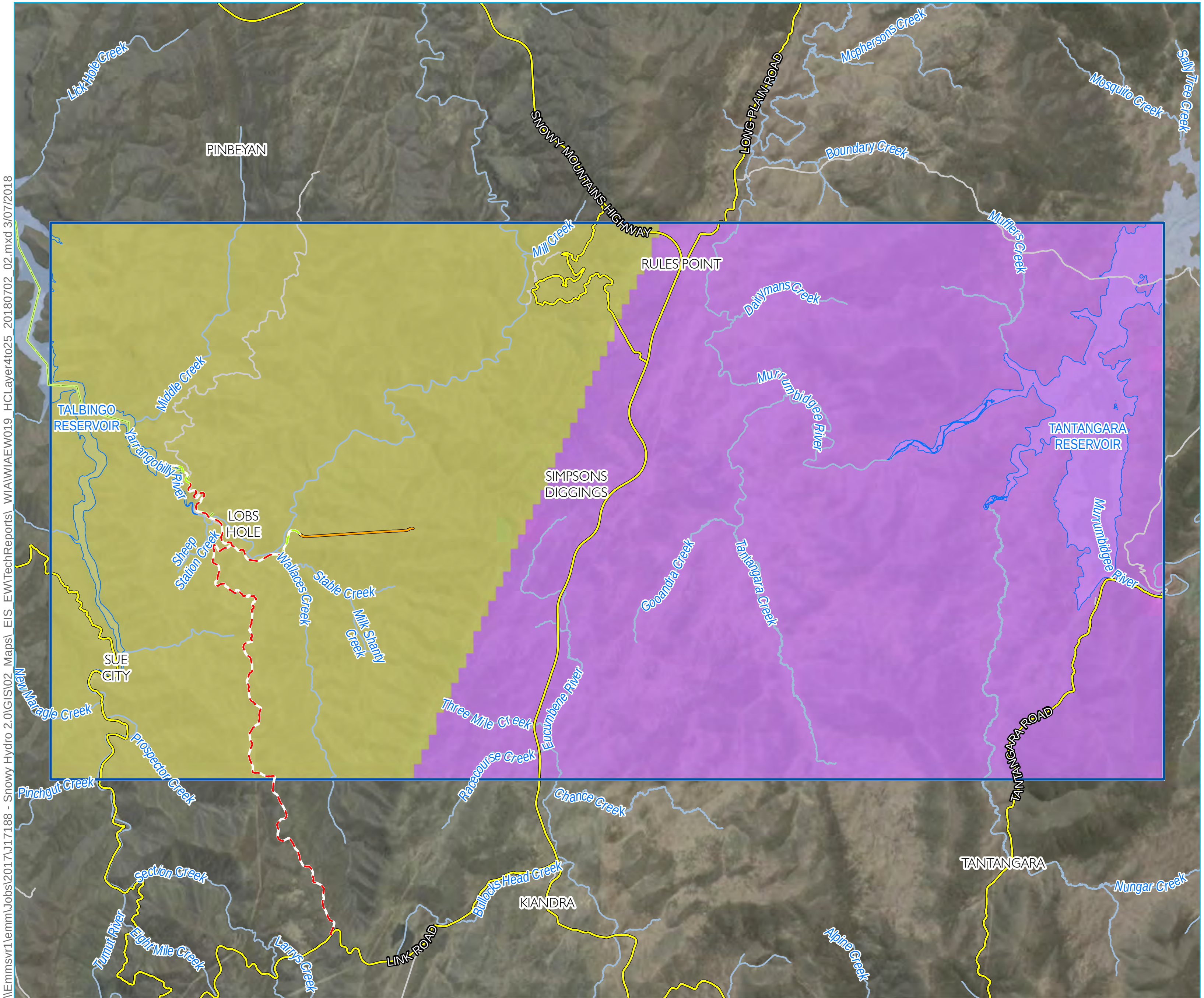
Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

Modelled hydraulic conductivity in layer 1

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.8

snowy2.0 EMM



Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Local road
- Perennial watercourse
- Scheme storage
- Model domain
- Model reservoirs

Modelled hydraulic conductivity in layers 4 to 25

- 0.0001 Kh (m/d), 0.001 Kv (m/d)
- 0.0001 Kh (m/d), 0.0003 Kv (m/d)

Modelled hydraulic conductivity in layers 4 to 25

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.9

8.4 Scenario modelling

To meet the model objectives, in regard to both exploratory tunnel inflows and environmental impacts, two predictive scenarios were produced, which are:

- a steady state simulation was produced to predict maximum impacts on baseflow to the Yarrangobilly River and drawdown at the water table across the model domain; and
- a transient simulation. This was undertaken because an aquifer access licence will be required for the maximum annual tunnel inflow, which will occur during tunnelling, a transient simulation was also constructed to identify likely tunnel inflow during tunnelling, not just after the groundwater system has re-equilibrated.

8.4.1 Representation of tunnel

The exploratory tunnel footprint and floor elevation were used to define the location and stage of MODFLOW drain (DRN) boundary conditions (Figure 8.10). Drains were primarily assigned in model layer 19, the "tunnel layer", which was based on tunnel geometry. However, where layer 19 comes within 100 m of the ground surface it thins and, eventually, pinches out. Drain boundary conditions were assigned to model cells in which the drain stage elevation occurs. Therefore, near the exploratory tunnel portal, where the tunnel is shallowest it is simulated in model layers up to, and including, model layer 1. This only occurs for the first 300 m of tunnel, beyond which the tunnel floor is at a depth greater than 100 m and drains are simulated in model layer 19.

In the steady state model (used to predict for maximum water table drawdown and baseflow impacts) the drain boundary conditions are active for the single steady state stress period. The timing of excavation is irrelevant in this case, as the model aims to predict the maximum impacts that will develop ever, whether during or long after construction of the tunnel.

In the transient model, 26 monthly stress periods, each with 30 time steps, were employed to simulate the construction of the tunnel over time. This was based on the construction timeline and an average drill and blast advance rate of 4 m/d specified in the exploratory tunnel design. Within each stress period, drain boundary conditions were activated in the cells corresponding to the exploratory tunnel chainage to be excavated that month. Once activated, drain boundary conditions were kept active to simulate ongoing depressurisation of the rock mass associated with the unlined construction planned for the exploratory tunnel. All drain boundary conditions were assigned conductance of 10,000 m^2/d. Model results were checked to ensure this depressurised the tunnel to the drain stage set equal to the designed tunnel floor elevation.

8.5 Predictive uncertainty analysis

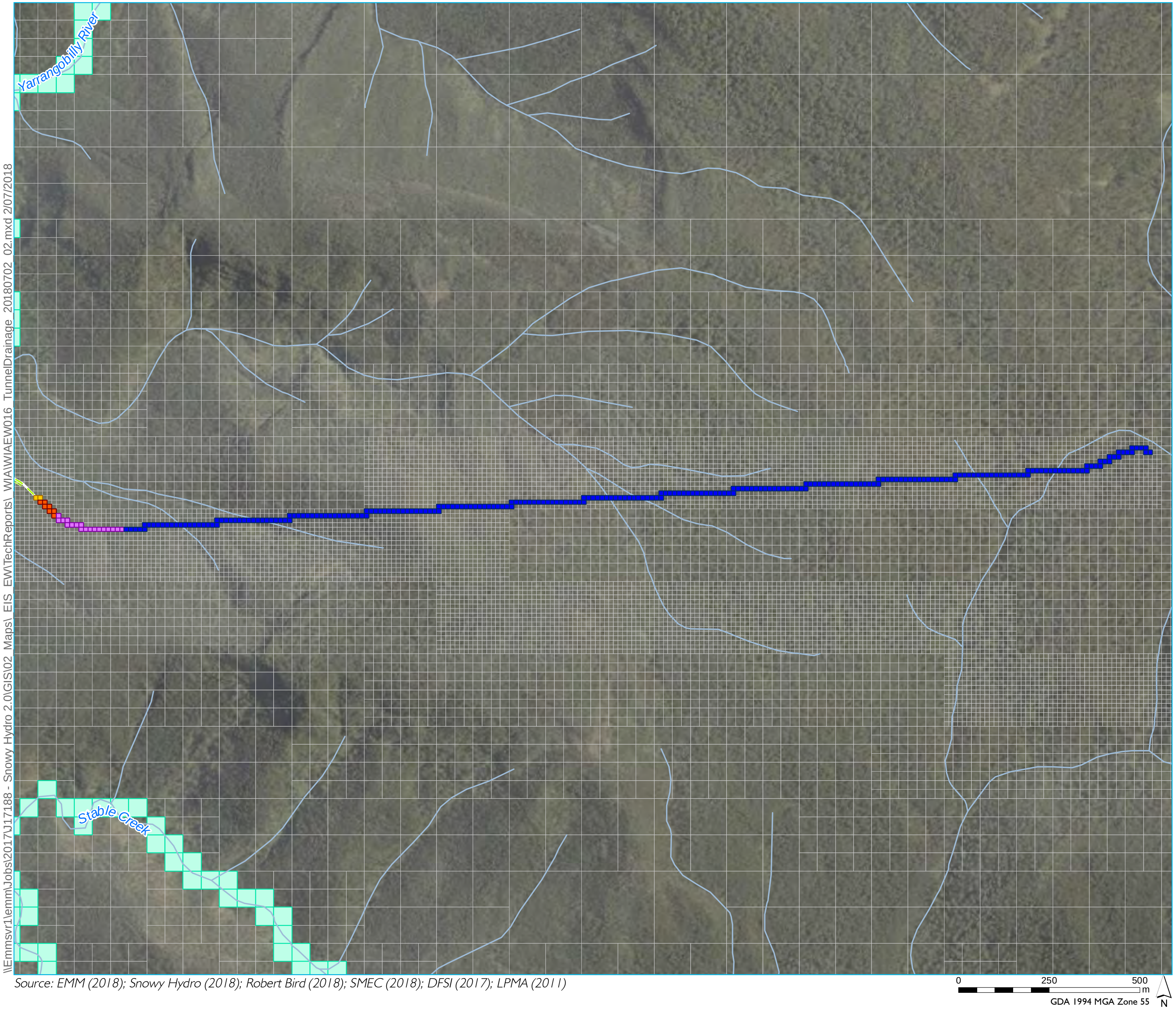
The *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012) states that groundwater model "results presented to decision-makers should include estimates of uncertainty." The approach adopted for the Early Works model (SH1.0) was to select, consistent with the current hydrogeological conceptualisation, the parameter values that would create the maximum tunnel inflows and environmental impacts (drawdown and reduction in baseflow). These were combined to create the "maximum plausible impact" realisation.

Table 8.5 presents the adopted "maximum plausible impact" parameter values along with the calibrated base case parameter values. This realisation was used in both steady state and transient predictive models to provide estimates of uncertainty associated with the base case predictions.

Additional and a more detailed uncertainty analysis is proposed for the greater Snowy 2.0 project numerical model.

Table 8.5 Uncertainty analysis parameter values

Zone	Base case				Maximum plausible impact			
	Kh (m/d)	Kv (m/d)	Ss (1/m)	Sy (-)	Kh (m/d)	Kv (m/d)	Ss (1/m)	Sy (-)
Colluvium and weathered surface geology	0.1	0.01	5×10^{-5}	0.05	1	0.1	5×10^{-4}	0.1
Tertiary basalt	1	0.1	5×10^{-5}	0.05	1	0.1	5×10^{-4}	0.1
Intermediate weathering	0.01	0.005	5×10^{-6}	0.01	0.1	0.05	5×10^{-5}	0.02
"Deep" rock in Ravine area: Ravine Beds, Tumut Pond Group	0.0001	0.0003	5×10^{-6}	0.01	0.001	0.0003	5×10^{-5}	0.02
"Deep" rock in plateau area: Gooandra Volcanics, Temperance Fm, Boggy Plain Adamellite, Bolton Beds, Tantangara Fm, Nungar Beds	0.0001	0.001	5×10^{-6}	0.01	0.0001	0.001	5×10^{-5}	0.02



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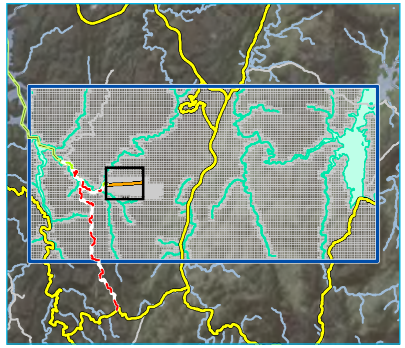


KEY

- Exploratory tunnel
- Access road upgrade
- Access road extension
- Communications cable
- Main road
- Local road
- Watercourse
- Model domain
- Model grid
- Model reservoirs and river boundary condition

Modelled drain layer

- 1
- 2
- 3
- 19

Source: EMM (2018); Snowy Hydro (2018); Robert Bird (2018); SMEC (2018); DFSI (2017); LPMA (2011)

Exploratory tunnel drain boundary conditions

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 8.10

9 Potential groundwater impacts

This chapter outlines the results of the impact assessment for construction-related impacts to groundwater resources and water users.

The likelihood of a potential impact occurring and the corresponding consequence of the potential impact is defined in Table 11.2. Management and mitigation measures relating to each of the identified potential impacts is shown in Table 11.3.

9.1 Assessment criteria

The assessment of project-related impacts to water resources and water users considers the requirements of the *WMA 2000*, the relevant water sharing plans and the NSW Aquifer Interference Policy 2012 (the AIP).

The project has been assessed in detail against the minimal harm thresholds defined in the AIP. The AIP divides groundwater sources into 'highly productive' or 'less productive' based on the yield (>5 L/s for highly productive) and water quality (<1,500 mg/L total dissolved solids for highly productive). Thresholds are set in the AIP for the different groundwater sources for the different minimal impact considerations.

Based on DoI Water's mapped areas of groundwater productivity in NSW (NOW 2012b), the project is considered to be within 'less productive' fractured rock source. The applicable minimal harm considerations are shown in Table 4.3.

9.2 Exploratory tunnel inflow

Figure 9.1 presents predicted inflow to the exploratory tunnel. The upper graph shows predicted monthly average inflow over the estimated 26 months of construction as well for steady state (ie long term, after the system has re-equilibrated). Tunnel inflow is generally predicted to increase during construction as a longer length of tunnel is open to inflows. A slight deviation from this trend occurs in the first few months. These have greater inflows due to tunnelling (and simulated drainage) through weathered shallow material that is more permeable than the rock hosting the majority of the tunnel.

An exception is also seen in the last month, for which inflow is predicted to decline slightly. This is an artefact of tunnelling advancing slightly less distance in this month than previous months. Given that the greatest inflows from an area occur when it is first depressurised, by depressurising a lesser chainage of tunnel in this final construction month the monthly average predicted inflow is somewhat reduced.

The lower graph in Figure 9.1 illustrates the average monthly inflow per kilometre of tunnel constructed to date. As discussed above, the first few hundred metres of tunnel produce greater inflows due to the simulated higher hydraulic conductivity of the weathered material in the upper 100 m of the profile. Predicted tunnel inflows are consistent with those observed across the existing Scheme. It is worth noting the prediction of no tunnel inflow for first month of the maximum plausible impact scenario. This realisation of parameter values produces a steady state present day watertable (ie prior to construction of the exploratory tunnel) that is below the lowest tunnel floor elevation excavated in the first month and, hence, no water is removed by the drain boundary conditions.

Table 9.2 presents predicted annualised tunnel inflows, commencing with the first month of tunnel excavation and drainage. For both the base case and maximum plausible impact scenario, the maximum annualised rate occurs for year 3 of construction, but it should be noted that this is calculated by extrapolating predicted inflow for only two months (after which construction is complete and inflow will begin to decline towards steady state values).

Table 9.1 Predicted tunnel inflow

Scenario	Max. monthly inflow (L/s)[1]	Steady state inflow (L/s)	Max. monthly inflow per constructed length (L/s/km)[2]	Steady state inflow per constructed length (L/s/km)
Base case	5.2	3.3	8.5	1.1
Maximum plausible impact	10.8	6.8	3.6	2.2

Notes: 1. L/s = litres per second; and

2. L/s/km = litres per second per kilometre.

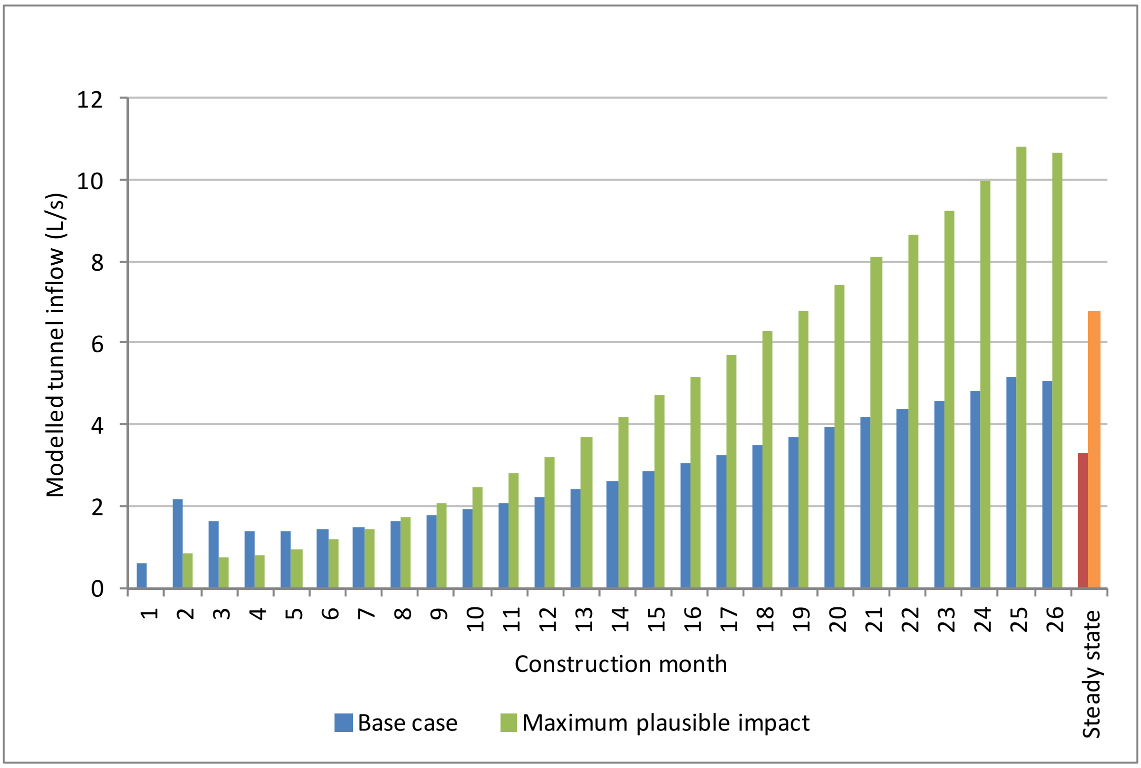
Table 9.2 Predicted annual exploratory tunnel inflow

Scenario	Year 1 inflow (ML)[1]	Year 2 inflow (ML)	Year 3 inflow (ML)*	Steady state inflow (ML/yr)[2]
Base case	52	114	161	104
Maximum plausible impact	48	210	340	214

Notes: 1. ML = megalitres; and

2. ML/yr = megalitres per year.

**extrapolated from only 2 months of construction/drainage*



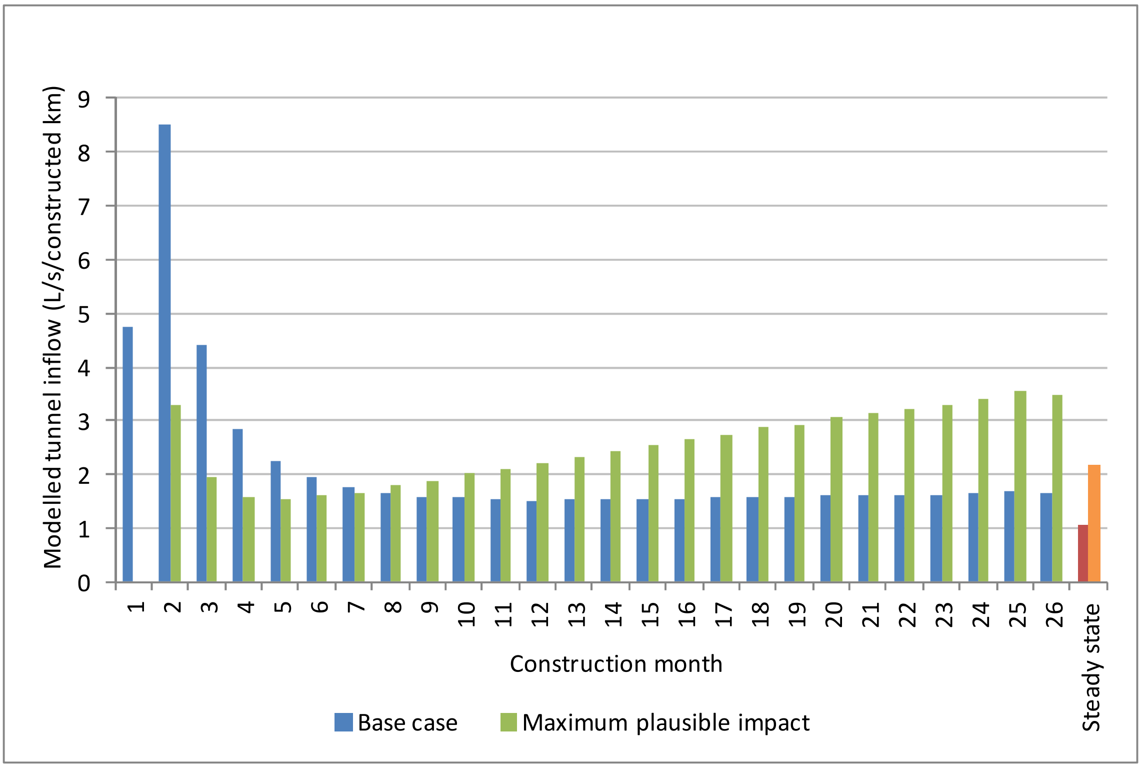


Figure 9.1 Predicted exploratory tunnel inflows

9.3 Groundwater levels

Inspection of model results confirmed the drain boundary conditions depressurised the tunnel to the floor elevation. Figure 9.2 presents predicted biannual depressurisation profiles every 500 m along the exploratory tunnel alignment. As expected, drawdown is experienced earlier at lesser chainage values, due to the progression of excavation away from the exploratory tunnel portal (chainage of 0 m). Although drawdown occurs later at greater chainage, it also reaches greater values due to a) higher initial hydraulic head; and b) drawdown to a lower tunnel floor design elevation.

Profiles at all six locations demonstrate a large gradient between the exploratory tunnel and the surrounding rock, with very little drawdown propagating to near ground surface.

Predicted steady state drawdown of the water table is presented in Figure 9.3. Predicted drawdown, for both the base case and maximum plausible impact scenario, reaches a maximum of over 30 m in the immediate vicinity of the tunnel. However, water table drawdown of 2 m (the level referenced in the AIP) does not extend further than 2 km from the exploratory tunnel alignment. The largest drawdown occurs where the exploratory tunnel is in the simulated weathered portion of the profile, that extends to a chainage of 300 m. Beyond chainage of 300 m the model simulates rock with low hydraulic conductivity and drawdown above the majority of the exploratory tunnel alignment is constrained by this.

Given this outcome, hydraulic testing and further characterisation of the groundwater system in the regions of shallow competent rock coverage above the broader project tunnel alignment would provide valuable information to constrain predictions. A network of shallow monitoring bores will be installed across the proposed Exploratory Works surface infrastructure area in late 2018 to characterise the shallow rock profile (see Section 10.3)

Drawdown results are presented in Figure 9.3 for both the base case and maximum plausible impact scenarios. To accommodate increased hydraulic conductivity values in the maximum plausible impact scenario, steady state starting water levels automatically adjusted to a lower level compared to the base case scenario. This explains the irregular shape of drawdown predicted in the maximum plausible impact scenario.

The drawdown results, combined with results from a virtual monitoring bore simulated in the model at the location of a cave pool in River Cave (see Section 5.1), part of the Yarrangobilly Caves, confirm that no drawdown impact is predicted to reach the Yarrangobilly Caves – which are 8 km north of the Exploratory Tunnel and critically, distant from the maximum drawdown impact of 2 m extending to a distance of 2 km from the Exploratory Tunnel. This is the only identified high priority GDE in the study area and, hence, no impacts on GDEs are predicted as a result of Exploratory Works.

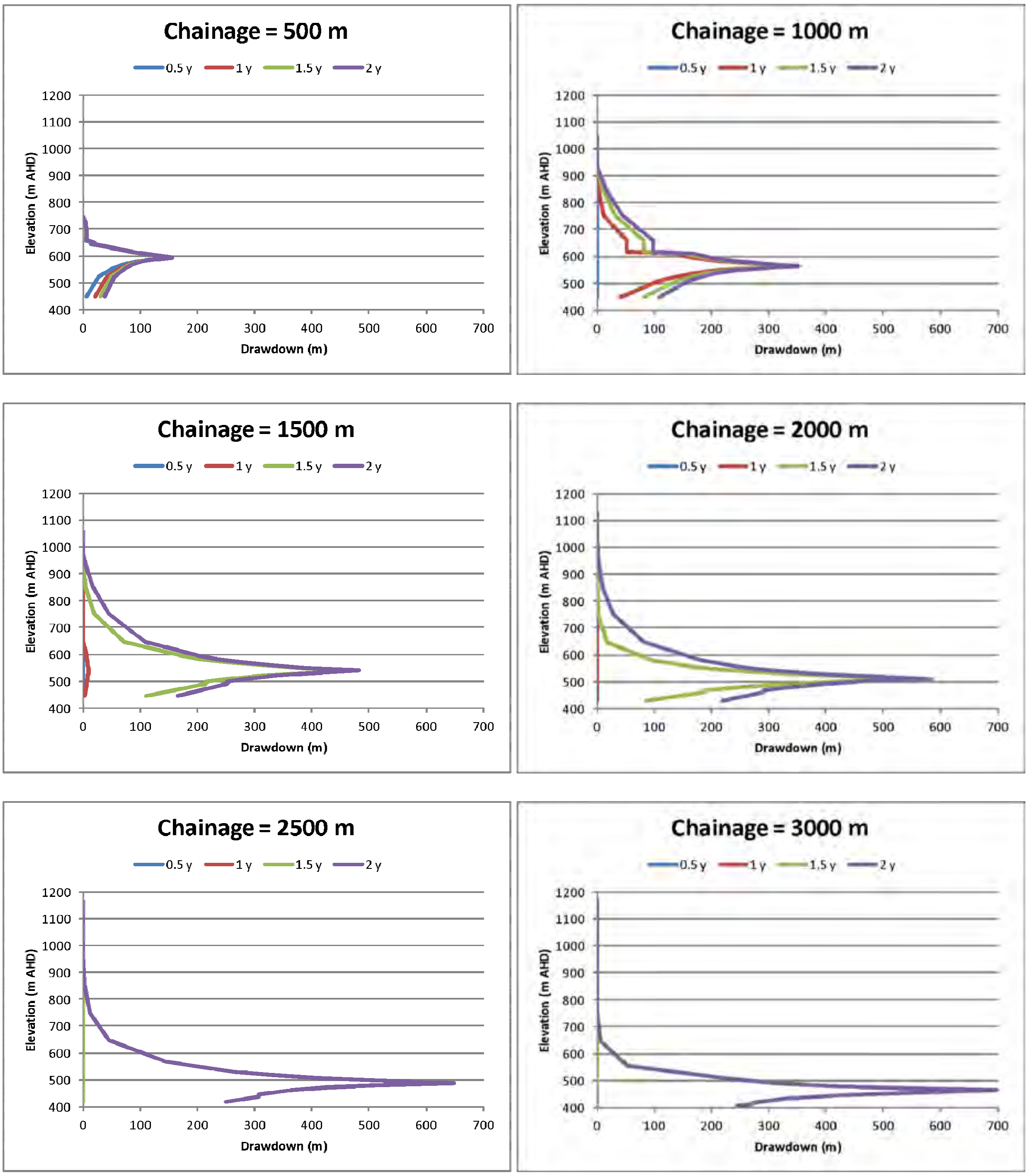
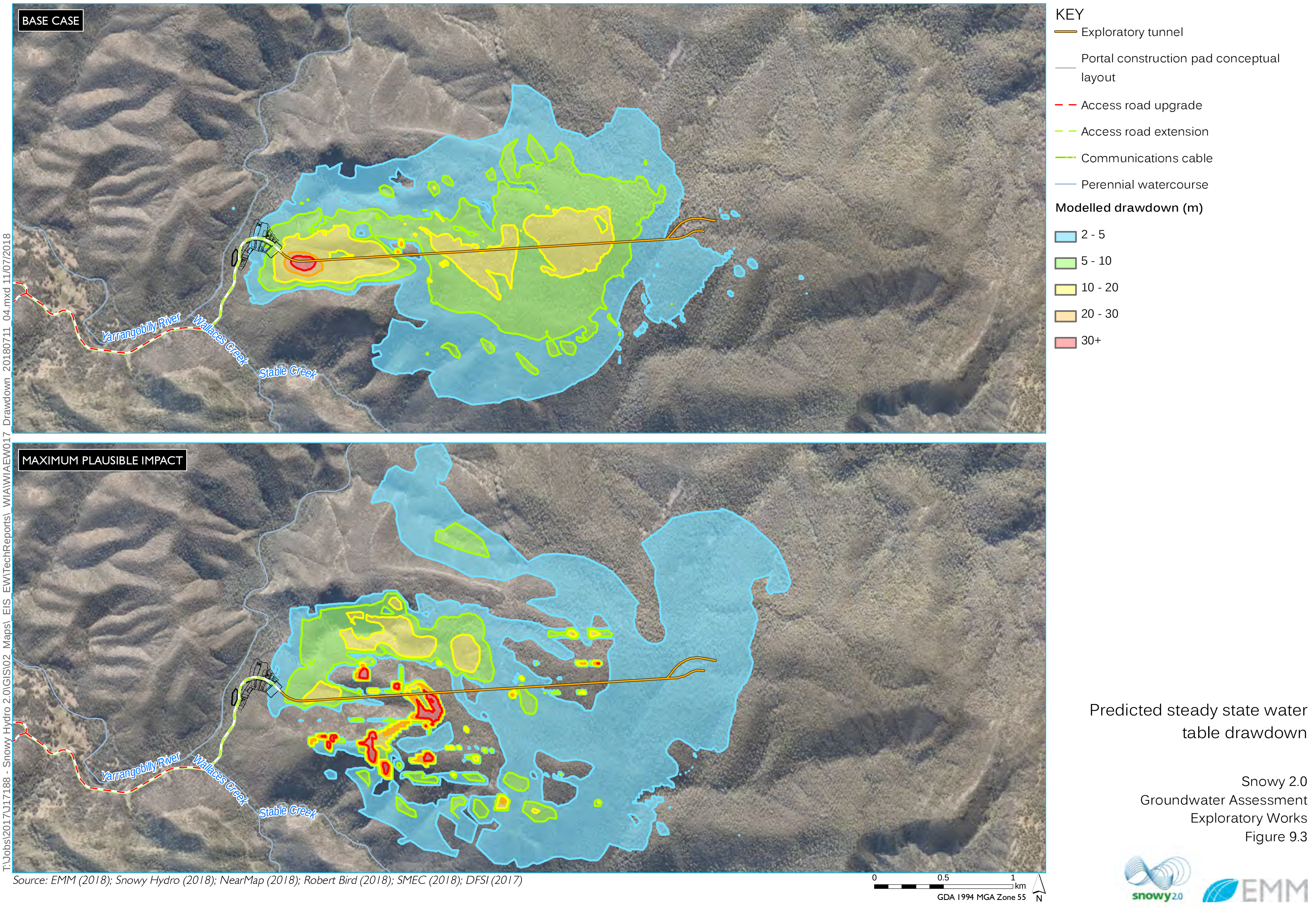


Figure 9.2 Predicted drawdown adjacent the exploratory tunnel



Source: EMM (2018); Snowy Hydro (2018); NearMap (2018); Robert Bird (2018); SMEC (2018); DFSI (2017)

Predicted steady state water table drawdown

Snowy 2.0
Groundwater Assessment
Exploratory Works
Figure 9.3

9.4 Water balance

The predicted transient water balance for the entire model domain is presented in Figure 9.4. Whilst non-zero, predicted drainage into the exploratory tunnel is minor when considered on the scale of the modelled water balance of the model domain. Further, on this scale, no significant change in components of the modelled water balance is evident.

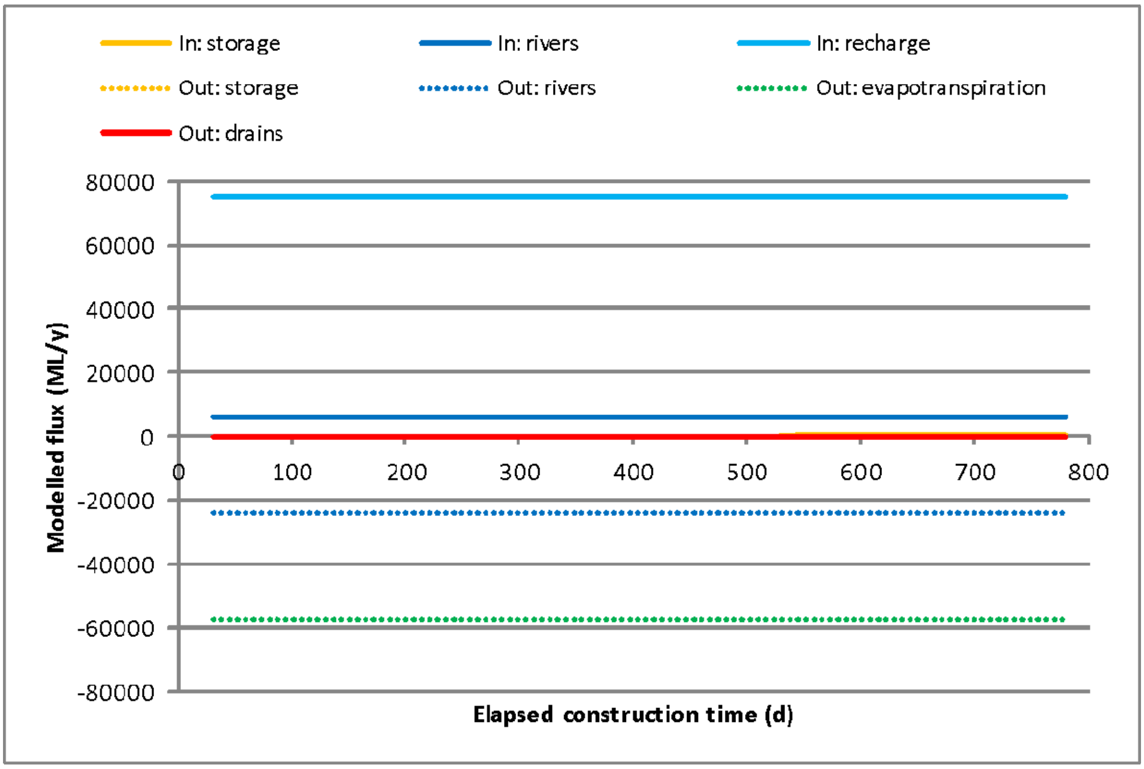


Figure 9.4 Predicted transient water balance

9.4.1 Surface water

The surface water feature closest to the proposed exploratory tunnel, and therefore most likely to experience impacts from its construction, is the Yarrangobilly River, directly adjacent to the tunnel portal. Modelled baseflow to the Yarrangobilly River, along with its tributaries Wallaces Creek, Stable Creek, Milk Shanty Creek and Mill Creek, is presented in Table 9.3. As mentioned in Section 8.3, modelled present day steady state baseflow is sensitive to horizontal hydraulic conductivity in model layer 1. Given the early stage of the groundwater investigation and monitoring in the project area, there are little data to constrain local-scale surface water-groundwater interactions. Hence, absolute modelled baseflow volumes are not considered to be well constrained. Therefore, impacts have been presented for the base case and maximum plausible impact scenario as both absolute modelled values and percentage change.

In both cases the maximum reduction in baseflow does not occur during construction, but develops once the system has reached a new equilibrium. The base case and maximum plausible impact scenarios predict baseflow reduction of 0.67% (19 ML/yr) and 2.29% (178 ML/yr) respectively. The corresponding predicted steady state tunnel inflows are 104 ML/yr and 214 ML/yr, with the remaining difference attributed to a localised reduction in evapotranspiration primarily around the portal and first few hundred metres of tunnel.

Table 9.3 Modelled baseflow to Yarrangobilly River

Time	Base case		Maximum plausible impact	
	Baseflow (ML/yr)	Change	Baseflow (ML/yr)	Change (%)
Present day steady state	2,799	n/a	7,774	n/a
1 year into construction	2,798	-0.05%	7,765	-0.11%
End of construction	2,795	-0.14%	7,760	-0.18%
Post construction steady state	2,781	-0.67%	7,596	-2.29%

9.5 Groundwater quality

The following sections provide a summary of potential groundwater-related impacts arising from project activities. The potential, likelihood and consequence have all been considered in Section 11. Mitigating management measures have also been proposed in Section 11.

9.5.1 Material stockpiling

The majority of the surface infrastructure area will be established on a shallow colluvial deposit. The colluvium was observed to be unsaturated during monitoring bore drilling (TMB01A and TMB01B). However, the unit is thought to episodically recharge during rainfall events, providing a source of groundwater to opportunistic GDEs down-gradient of the infrastructure area. The colluvium is also likely to provide limited recharge to the deeper Ravine Beds.

The potential for groundwater contamination is greatest adjacent to excavated rock emplacement areas (see Figure 2.6), given the areas proximity to the highly porous, unconsolidated colluvium. This area will not be disturbed as part of Exploratory Works.

9.5.2 Blasting

The drill and blast techniques proposed for the construction of the exploratory tunnel not only have the potential to increase the hydraulic connection between surface water and groundwater resources, but the chemicals used in this process (ammonium nitrate) have the potential, although minor, to affect groundwater quality within the Ravine Beds.

A risk assessment, detailing risk likelihood and consequence for this potential impact has been outlined in Table 11.4.

9.5.3 Storage and transportation of chemicals, fuels

The construction of the accommodation camp and the construction compound will require storage of hydrocarbons, oils and solvents. There are inherent risks to surface water and groundwater risks associated with the transportation and storage of organic compounds within the Exploratory Works project area, including contaminant leaching and direct spills within perennial losing streams and their catchments.

A risk assessment, detailing risk likelihood and consequence for this potential impact has been outlined in Table 11.4. Mitigating management measures designed to reduce the overall potential of environmental impact relating to this activity has been presented in Table 11.5.

9.6 Predicted impact on groundwater users

The predicted potential effects on sensitive receptors, as defined in Section 6.10, are described below. In summary:

- High priority ecosystems that rely on groundwater (GDEs listed in a water sharing plan):
  - there are **no predicted impacts** to GDEs as a result of the project.
- Ecosystems that potentially rely on groundwater:
  - potentially GDEs are considered to have facultative (opportunistic) dependency on groundwater. Where water table drawdown is predicted to occur, the ecosystems are expected to be able to adapt and, therefore, influence would be minimal. As per the *Significant impact guidelines* (DoE 2013), this impact is considered **insignificant**.
- Watercourses such as creeks and drainage lines that receive baseflow:
  - baseflow reduction is expected to occur in most drainage lines near the project. The rate of reduction is not constant over time. The maximum rate of reduction is expected to be a minor proportion of the total baseflow. The impact on baseflow reduction has been assessed in the *Snowy 2.0 Exploratory Works Surface Water Assessment* and is expected to be minimal on surface water uses during a range of climatic conditions. As per the *Significant impact guidelines* (DoE 2013), this impact is considered **insignificant**.

There are no registered groundwater extraction users within or within 20 km of the Exploratory Works project area. As such, there are **no impacts predicted** to occur on landholder bores.

10 Water licences

10.1 NSW Water legislation and policies for licensing water

Snowy Hydro is required to licence groundwater in accordance with the AIP, the WMA 2000, and the relevant statutory WSPs. This includes water taken for use as well as water intercepted and managed as a result of tunnelling activities. Sufficient share components and WALs must be held to account for the peak annual volume of water intercepted from all water sources (directly or indirectly) as a result of the project activities.

The AIP specifies the project licence requirement needs to consider adjacent and overlying water sources. Should the project cause water to inflow and subsequently capture an adjacent water source, a licence for that volume is required from that adjacent water source. The numerical groundwater model predicts the total volume of water intercepted during tunnelling and the ultimate sources of that water.

10.2 Modelled water inflows

10.2.1 Inflow to exploratory tunnel

The transient numerical modelling for the exploratory tunnel predicts that inflows in Year 3 will be the peak at 161 ML for the base case and 340 ML for the maximum plausible impact. These values are conservative and based on an assumption of no lining or remedial grouting of the tunnel to restrict inflows (excluding shotcreting). These values compare reasonably well with the steady state model estimates of tunnel inflows of 104 ML/yr (base case) and 214 ML/yr (maximum plausible impact).

10.2.2 Source of water

The predicted transient water balance for the entire model domain is presented in Figure 9.4 which shows that rainfall recharge, evapotranspiration and discharges that contribute to stream baseflow are the most significant regional components of the groundwater budget. Whilst non-zero, predicted drainage into the exploratory tunnel is minor (Section 10.2.1) when considered on the scale of the modelled water balance across the model domain.

The source of the water reporting to the exploratory tunnel is predominantly groundwater sourced from the *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011*; specifically the Lachlan Fold Belt Murray Darling Basin (MDB) Groundwater Source.

Licences and sufficient share components will be sought via the upcoming controlled allocation release within the water source, which is understood to be scheduled for late 2018. Investigations into purchasing water in the market have also commenced.

10.2.3 Intercepted baseflow (Yarrangobilly River and adjoining tributaries)

The base case and maximum plausible impact scenarios predict baseflow reductions to the Yarrangobilly River of 0.14% (4 ML/yr) and 0.18% (14 ML/yr) respectively arising from the construction of the exploratory tunnel at the end of the construction period (refer to Table 9.3). Baseflow reduction is predicted to increase post construction until a new equilibrium is reached for which the steady state model predicts losses of 0.67% (19 ML/yr) and 2.29% (178 ML/yr) respectively for the base case and maximum plausible impact scenarios.

These percentage changes are based on a steady state modelled (present day) baseflow contribution to the Yarrangobilly River of 2,799 ML/yr for the base case and 7,774 ML/yr for the maximum plausible impact case. On the basis of other empirical assessments these baseflow predictions are low, and stream continue to gain from groundwater, therefore the likely actual percentage change in baseflow to the river will be even lower than these modelled percentages.

These small baseflow losses into the depressurised deep groundwater system do not report directly to the tunnel, but are required to be licensed as per the AIP. The volumes are very small components of the groundwater budget and are a negligible component of the surface water budget.

10.2.4 NSW approach to licensing intercepted baseflow

The sustainable limit for extraction has been defined for each water source in each WSP across NSW. This considers acceptable levels of regional impact for both groundwater and surface water users, including reduction of baseflow to streams regionally. Long-term average annual extraction limits (LTAAEL) set for individual surface and groundwater systems within the WSPs take into account potential reduction of baseflow should 100% of the LTAAEL be extracted.

DoI Water has advised that Snowy Hydro will be required to determine the ultimate source of tunnel inflow and licence accordingly: Section 60 I (2) of the WMA 2000. In a gaining stream scenario (which is the scenario for Exploratory Works) this source is the deep groundwater.

The project will therefore licence:

- intercepted groundwater as groundwater;
- intercepted baseflow to gaining streams as groundwater and
- losses from surface water to groundwater (ie losing stream) as surface water.

10.3 Required licence volumes

The groundwater licence volumes that Snowy Hydro needs to acquire for Exploratory Works are recommended to be 340 ML/yr plus 14 ML/yr, ie 354 ML/yr, to cater for the maximum plausible impact scenario predicted by the transient model at the end of the construction program. This will be acquired via a controlled allocation purchase from DoI Water when additional water is released for the Lachlan Fold Belt MDB Fractured Rock Groundwater Source.

As the predicted baseflow reduction volumes (14 ML/yr for maximum plausible) are minor compared to the overall baseflow contribution (7,774 ML/yr for maximum plausible), it is assumed that all streams will remain gaining and continue to receive baseflow contributions from groundwater. As such, no loss from surface water systems are predicted and no additional surface water licences are required.

11 Monitoring, mitigation and management

11.1 Risk assessment and management framework

An evaluation of project activities and potential impacts to groundwater, surface water and GDEs associated with these activities has been completed. The project activities are discussed in Section 2, with potential groundwater impacts arising from the project activities discussed later in Section 9. A risk assessment matrix has been used (Table 11.1) to quantify the level of environmental risk based on the following:

- the likelihood of a potential impact occurring; and
- the consequence of a potential impact.

The definition of likelihood and the consequences are detailed in Table 11.2 and Table 11.3, respectively.

Table 11.1 Risk assessment matrix

Likelihood	Consequences				
	1 insignificant	2 minor	3 moderate	4 major	5 severe
A almost certain	medium	significant	high	high	extreme
B likely	medium	medium	significant	high	extreme
C moderate	low	medium	Significant	high	high
D unlikely	low	low	medium	significant	high
E rare	low	low	low	medium	significant

Table 11.2 Classification of likelihood for construction activities

Level	Categorisation of likelihood	Description
A	almost certain	is expected to occur during Exploratory Works, >90% probability
B	likely	will probably occur during Exploratory Works, ~50% probability
C	moderate	might occur at some time during Exploratory Works, ~25% probability
D	unlikely	could occur at some time during Exploratory Works, ~10% probability
E	rare	only occur in exceptional circumstances, <1% probability

Table 11.3 Classification of consequence

Level	Categorisation of consequence	Description
1	insignificant	no significant change in flow volumes, water levels or water quality
2	minor	minor short term and reversible change in flow volumes, water levels or water quality
3	moderate	moderate, minor breaches of environmental statutes or changes to flow volumes, water levels or water quality
4	major	major, ongoing breaches of environmental statutes with major changes to flow volumes, water levels or water quality
5	severe	shutdown of Exploratory Works due to environmental breach causing severe changes to flow volumes, water levels or water quality that may be irreversible

Risks will be managed as follows, based on the risk rating in Table 11.1:

- Low: no additional management measures required.
- Medium: routine monitoring and management measures to be implemented.
- Significant: specific monitoring and management measures to be implemented.
- High: further specific additional management measures required to reduce risk as far as possible.
- Extreme: unacceptable risk–further specific additional management measures (including redesign) required to reduce risk.

11.2 Risk evaluation

The risks of potential impacts caused by Exploratory Works activities, assuming no controls are in place are summarised in Table 11.4. Potential impacts identified as having a medium or above risk classification may be downgraded if appropriate controls and management measures are implemented and maintained. The commitments to the implementation of management measures and residual risk levels are provided in Table 11.5.

Table 11.4 Assessment of unmitigated potential impacts

Component	Potential impact	Receptor	Risk analysis (likelihood and consequence)			
			Low	Medium	Significant	High
Earthworks	spills of hydrocarbons leaching/running into groundwater/ephemeral creeks	surface water/ groundwater		C 2		
Blasting	change in water quality (due to presence of ammonium nitrate)	groundwater		C 2		
	increased hydraulic connection between surface and groundwater resources	surface water/ groundwater		D 3		

Table 11.4 Assessment of unmitigated potential impacts

Component	Potential impact	Receptor	Risk analysis (likelihood and consequence)			
			Low	Medium	Significant	High
Material stockpiling / emplacement	leaching or mobilised contaminants	surface water/shallow groundwater		B 2		
Excavations	local depressurisation of groundwater resources	Groundwater			B 3	
	altering the local groundwater flow system	Groundwater			C 3	
	reducing baseflow to possibly connected waterways	Groundwater	D 1			
	decreased baseflow to possible GDEs reliant on surface expression of groundwater	GDEs	D 1			
	decreased groundwater availability to possible GDEs reliant on the subsurface presence of groundwater	GDEs		D 3		
Surface infrastructure	decreased groundwater recharge	groundwater	D 1			
Fuels and chemical storage and refuelling	spills of hydrocarbons that leach downwards or are mobilised	surface water/ groundwater		D 3		
Transportation/ storage of hydrocarbons, solvents, oils	waste spills that mobilise in ephemeral creek lines or underground in storage	surface water/ groundwater		D 3		

11.3 Environmental management measures

Water management for the project combines site surface water management, management of groundwater inflow, and the correct transportation and storage of chemical compounds. The key to successful water management for this project will be the separation and control of water from different sources and of different water qualities. In addition, a water monitoring program to assess impacts and ensure the functioning of the site water management system will be implemented. The site water management strategy and infrastructure will be designed to ensure that Exploratory Works has a negligible impact on the quality of surface runoff and potential receiving environments.

11.3.1 Water management

A water management system will be designed to:

- segregate different water sources and different water qualities, (ie raw water from the groundwater inflows, sediment-laden water);
- capture and contain waste water and prevent discharge to receiving water environments;
- ensure unused abstracted groundwater is contained rather than discharged to the surface;

- capture and segregate runoff from the following locations:
  - processing area;
  - excavated rock emplacement areas;
  - topsoil and subsoil stockpiles; and
  - other disturbed areas (ie roads).
- divert clean runoff away from areas disturbed by project activities to minimise the volume of affected water;
- manage sediment laden water in accordance with an erosion and sediment control plan that would be part of the water management plan, which will include the capture and treatment of sediment laden water in sediment dams;
- reuse and recycle water in tunnelling operations;
- include contingency measures to accommodate either a surplus or deficit of site water;
- monitoring and evaluation of the system including reporting and development of performance criteria; and
- communicate with key stakeholders as agreed in WMP (ie DoI Water, NSW EPA).

11.3.2 Residual risk levels and environmental management measures

Specific management measures to address the requirements relating to water and the potential impacts identified in Table 11.4 have been outlined in Table 11.5. In addition, the residual risk associated with each potential impact has been recalculated.

As seen in Table 11.5 the control measure(s) focus on lowering the likelihood of an impact occurring, typically the consequence will remain unchanged, except where the risk control measure applied directly reduces the impact/consequence (eg silt fences on the surface, shotcreting of the exploratory tunnel).

Table 11.5 Groundwater management measures

Component	Potential impact	Control measure	Risk analysis (likelihood and consequence)			
			Low	Medium	Significant	High
Vegetation clearing	erosion and sedimentation of disturbed areas including surrounding waterways	installation of silt fences, bund walls and geo mats/geo fabrics vegetation clearing will occur immediately before construction works progressive revegetation	E 3			
Earthworks	spills of hydrocarbons leaching/running into groundwater/ creeks	implementation of spill kits on site and training of personnel in their use handling of chemicals will be as per manufacturer's instructions	E 3			

Table 11.5 Groundwater management measures

Component	Potential impact	Control measure	Risk analysis (likelihood and consequence)			
			Low	Medium	Significant	High
Culvert and drainage works	disruption to flow and increased turbulence	installation of silt fences and geo mats/geo fabrics windrows on contours to reduce slope length and surface flow velocities		D 3		
	creek bed and bank scouring	installation of silt fences and geo mats/geo fabrics	E 3			
	direct impact on streambeds through excavation works	installation of silt fences and geo mats/geo fabrics		D 3		
Blasting	change in water quality (due to presence of ammonium nitrate)	groundwater quality monitoring as early warning mechanism		C 2		
	increased hydraulic connection between surface and groundwater resources	groundwater level monitoring to detect fluxes		D 3		
Material stockpiling / emplacement	leaching or mobilised contaminants	installation of silt fences and bund walls construction and ongoing maintenance of an infiltration drain downgradient to capture and abstract contaminated waste water possible treatment with liquid lime to neutralise lower pH spoil as per the acid sulfate soils procedure installation of shallow groundwater monitoring network down-up gradient of stockpiling area to monitor quality	E 3			
Excavations	local depressurisation of groundwater resources	shotcreting areas of groundwater inflow to prevent further ingress groundwater level monitoring as early warning mechanism	E 3			
	altering the local groundwater flow system	shotcreting areas of groundwater inflow to prevent further ingress groundwater level monitoring as early warning mechanism	E 3			

Table 11.5 Groundwater management measures

Component	Potential impact	Control measure	Risk analysis (likelihood and consequence)			
			Low	Medium	Significant	High
	reducing baseflow to possibly connected waterways	regular review of streamflow gauge data and surface water quality results as early warning mechanism annual monitoring of mapped opportunistic GDEs groundwater level monitoring as early warning mechanism	E 2			
	decreased groundwater availability to possible GDEs reliant on the subsurface presence of groundwater	annual assessment of *Brittle Gum Peppermint Open Forest, White Box Yellow Box Blakeley's Red Gum Woodland, and Broad-leaved Sally grass-sedge, woodland and wetland* ecosystem health using the RARC guidelines and RCE method groundwater level monitoring as early warning mechanism	E 3			
Surface infrastructure	localised flooding	construct drainage channels, bunds and sediment dams to rainfall events equal to design rainfall events (EMM2018a)	E 2			
	increased surface runoff	construct drainage channels, bunds and sediment dams to rainfall events equal to design rainfall events (EMM2018a)	E 2			
	decreased/increased groundwater recharge	groundwater quality monitoring as early warning mechanism clean and dirty runoff will be separated, with dirty runoff stored on site	E 3			
Fuels and chemical storage and refuelling	spills of hydrocarbons that leach downwards or are mobilised	designated spill kits will be located across site and at refuelling areas storage and handling of chemicals will be as per manufacturer's instructions at surface, refuelling will be undertaken away from waterways in designated, impermeable areas below ground, refuelling will be undertaken in dry, enclosed, bunded areas		E 4		

Following the implementation of control and mitigation management measures the residual risk of the potential impacts to the various receptors have reduced in all cases. All risks initially characterised as either significant or high have been downgraded to either medium or low and are therefore considered to pose low to negligible risks to local water resources.

11.4 Management Plans

A water management plan (WMP) will be developed for the project to support construction activities, assuming Exploratory Works is approved. The WMP will be a sub-plan of the environmental management system. The WMP will document the proposed mitigation and management measures for the approved project, and will include the surface and groundwater monitoring program, reporting requirements, spill management and response, water quality trigger levels, corrective actions, contingencies, and responsibilities for all management measures.

The WMP will be prepared in consultation with DoI Water, EPA, WaterNSW, and the local council, and would consider concerns raised during the exhibition and approvals process for the project.

The WMP will include details of the surface water and groundwater monitoring program, which will incorporate and update the existing monitoring network, monitoring frequencies and water quality constituents, and physical water take and pumping volumes between water storage structures. Reporting frameworks for the above will be prepared in accordance with licensing and agency requirements. Trigger levels for water quality parameters will be developed as part of the WMP to assist in early identification of water quality trends. The monitoring program will be prepared in accordance with the approved project's environment protection licence (EPL), once enacted. Further details on the monitoring program are included in Section 11.5.

The WMP will also provide a program for reviewing and updating the numerical groundwater model as more data and information become available; this program would include reporting requirements.

11.5 Monitoring and thresholds

The baseline water monitoring network is comprehensive, allowing for quality data collection as the project advances. The network has been developed with ongoing consultation with DoI Water. The water monitoring network is positioned to provide spatial coverage across the project area and beyond, investigate the major hydrological and hydrogeological environments, and monitor potentially sensitive features.

The baseline groundwater monitoring network consists of 20 groundwater monitoring bores at 11 nested and single locations.

Baseline data will continue to be collected from this network throughout the life of the Exploratory Works project. Expansion of the network may be considered once the project starts construction and then operation, and may expand to include aspects such as:

- installation of a network of shallow groundwater monitoring bores adjacent to the proposed stockpiling area;
- shallow groundwater monitoring next to the proposed stockpiling area;
- water quality monitoring of water dams and sediment basins;
- water metering and recording of pumped volumes to/ from the exploratory tunnel sump; and

- monitoring quality and metering the volume of water releases to Talbingo Reservoir from the WTP (if required).

The suite of water quality analytes (ie constituents) to be sampled and the frequency of sampling will be reviewed and updated in the WMP developed for the Exploratory Works. Data loggers that currently monitor water levels will continue to operate. The ongoing development and expansion of the monitoring network will occur in consultation with DoI Water and WaterNSW.

11.6 Groundwater model validation

The groundwater model predictions would be validated by installing custom-designed groundwater monitoring sites at selected virtual piezometers used in the model. Should sites be unsuitable (ie access restrictions), then the model will be re-run with additional virtual piezometers in accessible sites. The model can be regularly validated. Significant deviations from the predicted impacts will be investigated. Reporting on this is proposed annually. Model recalibration will be considered every two years (based on analysis of predicted versus actual impacts), and done as required.

12 Summary and conclusions

A groundwater assessment has been carried out for the Exploratory Works.

The Exploratory Works comprise:

- establishment of an exploratory tunnel to the site of the underground power station for Snowy 2.0;
- establishment of a portal construction pad;
- excavated rock management, including subaqueous rock placement;
- establishment of an accommodation camp;
- road establishment and upgrades providing access and haulage routes during Exploratory Works;
- establishment of barge access infrastructure, including dredging, to enable access and transport by barge on Talbingo reservoir; and
- establishment of services infrastructure such as diesel-generated power, water and communications.

Modelling predicted localised water table drawdown in the vicinity of the tunnel alignment, primarily around the portal where the exploratory tunnel intercepts shallow geological material that is more permeable than the deeper competent rock mass in which the majority of the tunnel will be constructed.

There are no identified High Priority GDEs within the project area. Yarrangobilly Caves was the only High Priority GDE listed within the Lachlan Fold Belt MDB (Fractured Rock Groundwater source) WSP within the groundwater model domain, approximately 8 km north of the Exploratory Works project area. Modelling predicts no impacts on the Yarrangobilly Caves with a maximum lateral drawdown extent of 2 km predicted.

Only minor impacts to baseflow to the Yarrangobilly River and associated tributaries are expected, with the base case and maximum plausible impact scenarios predicting baseflow reductions of 0.14% (4 ML/yr) and 0.18% (14 ML/yr) respectively arising from the construction of the exploratory tunnel at the end of the construction period. Losses are predicted to increase post construction until a new equilibrium is reached for which the steady state model predicts losses of 0.67% (19 ML/yr) and 2.29% (178 ML/yr) respectively for the base case and maximum plausible impact scenarios.

The groundwater licence volumes that Snowy Hydro needs to acquire for Exploratory Works are recommended to be 340 ML/yr plus 14 ML/yr (ie 354 ML/yr) to cater for the maximum plausible impact scenario predicted by the transient model at the end of the construction program. This should be acquired via a controlled allocation purchase from DoI Water when additional water is released for the Lachlan Fold Belt MDB Fractured Rock Groundwater Source.

No additional surface water licence is required as a result of the changes in baseflow being sourced from groundwater, and included in the groundwater licence requirement.

An overarching and adaptive Water Management Plan (WMP) will be prepared for Exploratory Works in consultation with NSW Government agencies.

The groundwater assessment forms part of an ongoing assessment of the broader Snowy 2.0 project, should it proceed, for which further site-based groundwater testing and monitoring is continuing to be carried out. These will further inform and refine the conceptual and numerical hydrogeological models of the project area.

A detailed list of all mitigations is provided in this report. Table 12.1 distils these measures and provides a summary for Chapter 6 of the Exploratory Works EIS.

Table 12.1 Summary of water related mitigation measures (Source Chapter 6 of the Exploratory Works EIS)

Impact	Ref #	Environmental management measures
Stormwater management and erosion and sediment control from construction areas	WAT01[1]	Erosion and Sediment Control Plans will be prepared for all construction sites. The plans will consider local soil characteristics, clean water management and the proposed construction methods.
	WAT02[1]	The following controls will be applied to the design of the clean water management system: • Where possible, all clean water will be diverted around or through water management areas. Runoff from clean water areas that cannot be diverted must be accounted for in the design of water management systems. • All clean water drainage will be designed and constructed to convey the 1% AEP peak flow and will have adequate scour protection. • Where possible, diversions will seek to avoid materially increasing flow rates in adjoining watercourses. • Where possible, the diversion of drainage lines or watercourses using contour drains will be avoided.
	WAT03[1]	Where construction areas are not constrained by terrain, sedimentation dams will be constructed in accordance with the methods recommended in Managing Urban Stormwater: Soils and Construction: Volume 1 (Landcom, 2004) and Volume 2D (DECC, 2008). Construction of sedimentation dams in steep terrain will be avoided.
	WAT04[1]	A stormwater management plan for the accommodation camp will be prepared as part of the detailed design and will consider the design measures identified in Section 5.4 of the EIS. Collectively, the stormwater controls will be sized and configured to achieve the following pollution load reductions (as calculated using the MUSIC water quality model): • 85% reduction in post development mean annual load of total suspended solids; • 60% reduction in the post development mean annual load of total phosphorous; and • 45% reduction in the post development mean annual load of total nitrogen.
	WAT05[1]	A stormwater management plan for portal construction pad will be prepared as part of the detailed design and will consider the design measures identified in Section 5.4 of the EIS. Key controls include: • Activities that have the potential to contaminate stormwater runoff will be isolated from the stormwater system through the use of covering (ie by a building or roof) and bunding. • A stormwater management system will manage runoff from the portal construction pad. The system will include a 2,500 m3 water management basin. Captured water in the basin will be harvested for use in construction activities. • The stormwater management system will be designed to contain any leak, spill or fire water runoff from the portal construction pad.

Table 12.1 Summary of water related mitigation measures (Source Chapter 6 of the Exploratory Works EIS)

Impact	Ref #	Environmental management measures
Process water management	WAT06[1]	A process water system will be designed and implemented to manage any potentially contaminated water that may be produced by construction activities. The process water system will: • be separated from the stormwater system to avoid uncontrolled overflows associated with stormwater ingress; • incorporate a water treatment plant that will treat water to a suitable quality for its proposed use in construction activities or discharge to Talbingo Reservoir (if required); and • have the ability to extract water from the portal construction pad's water management basin.
	WAT07[1]	A waste water treatment plant will be designed and implemented to treat all waste water produced by the Exploratory Works. The plant will treat waste water to the water quality specifications provided in Section 5.4 of the EIS or as specified by an EPL.
Flood risks	WAT08[1]	Camp and Wallaces Bridges will be designed in accordance with AustRoads bridge design standards which require the: • bridge deck soffit to be located above the 1% AEP flood level; • bridge structure to be designed to withstand a 0.05% AEP event; and • abutments to be protected by appropriately designed scour protection.
	WAT9[1]	The western emplacement will be designed to prevent the risk of emplacement material being entrained in flood waters during a 0.2% AEP event.
	WAT10[1]	Flood emergency procedures will be prepared and implemented as part of the Emergency Response Plan.
Spills of hydrocarbons leaching/running into groundwater/ creeks	WAT11[1]	• Procedures to address spills, leaks and tunnel washing will be developed and implemented as part of the CEMP. • The portal construction pad's stormwater management system will be designed to contain any leak, spill or fire water runoff from the portal construction pad.
Impacts on surface and groundwater	WAT12	A Surface and Groundwater Monitoring Program will be developed and implemented to monitor the effectiveness of water quality controls and compliance with licence conditions. The program will: • establish monitoring locations to provide suitable baseline and detection monitoring of surface and groundwater parameters; • monitor groundwater inflows in the tunnel and groundwater levels as well as groundwater quality during construction; and • set out annual monitoring requirements for Yarrangobilly Caves and PCTs potentially reliant on groundwater.
	WAT13	Areas of groundwater inflow will be shotcreted to prevent further ingress

Notes: 1. Refer to the Exploratory Works – surface water assessment (EMM, 2018)

References

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List of units

Unit	Description
$	Australian dollar
%	percent
°C	degrees Celsius
µm	micrometre
µS/cm	microsiemens per centimetre
L/s	litres per second
km	kilometre
km^2	square kilometres
m	metres
m/d	metres per day
mAHD	metres Australian Height Datum
mbgl	metres below ground level
mg/L	milligrams per litre
ML	megalitres
ML/day	megalitres per day
ML/yr	megalitres per year
mm/year	millimetres per year
pH	pH, unit of acidity and alkalinity

Abbreviations

Abbreviation	Description
AHD	Australian height datum
ALS	Australian Laboratory Services
AIP	Aquifer Interference Policy 2012
ANZECC and ARMCANZ	Australian and New Zealand guidelines for fresh and marine water quality
BoM	Bureau of Meteorology
BTEXN	Benzene, toluene, ethyl-benzene, and xylene
BTEXN	benzene, toluene, ethyl-benzene, xylene and naphthalene
CDFM	Cumulative deviation from the mean
CWMP	Construction water management plan
DECC	Department of Environment and Climate Change NSW
DECCW	Department of Environment, Climate Change, and Water NSW
DEHP	Department of Environment and Heritage Protection (QLD)
DIPNR	Department of Infrastructure, Planning and Natural Resources NSW
DLWC	Department of Land and Water Conservation NSW
DNR	Natural Resources Department NSW
DO	Dissolved oxygen
DoI Water	Department of Industries Water
DWE	Department of Water and Energy NSW
EC	Electrical conductivity
EIS	Environmental Impact Statement
EP&A Act	Environmental Planning and Assessment Act
EPA	Environment Protection Authority
EPBC Act	Environment Protection and Biodiversity Conservation Act
EPL	Environment protection licence
GDE	Groundwater dependent ecosystem
K	Hydraulic conductivity
Kh	Horizontal hydraulic conductivity
Kv	Vertical hydraulic conductivity
LGA	Local government area
LPI	Land and Property Information NSW
LTAAEL	Long-term average annual extraction limit
N	Nitrogen
NATA	National Association of Testing Authorities
NHMRC	National Health and Medical Research Council
NOW	NSW Office of Water, now DPI Water
NSW	New South Wales
NUDLC	National Uniform Drillers Licensing Committee
NWC	National Water Commission
NWQMS	National Water Quality Management Strategy

Abbreviation	Description
OEH	Office of Environment and Heritage
OWMP	Operation water management plan
POEO Act	*Protection of the Environment Operations Act 1997*
QA/QC	Quality assurance/quality control
REF	Review of Environmental Factors
SEARs	Secretary’s environmental assessment requirements
SEPP	State Environmental Planning Policy
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
VRC	Vegetated riparian corridors
VWP	Vibrating wire piezometer
WA 1912	*Water Act 1912*
WAL	Water access licence
WMA 2000	*Water Management Act 2000*
WMP	Water management plan
WRC	Water Resources Council NSW
WSP	Water sharing plan
WTP	Water treatment plant

Glossary of terms

Acidity	Base neutralising capacity.
Alkalinity	Acid neutralising capacity.
Alluvium	Unconsolidated sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on riverbeds, floodplains, and alluvial fans.
Alluvial aquifer	Permeable zones that store and produce groundwater from unconsolidated alluvial sediments. Shallow alluvial aquifers are generally unconfined aquifers.
Anion	An ion with a negative charge.
Anthropogenic	Occurring because of, or influenced by, human activity.
Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.
Baseflow	The part of stream discharge that originates from groundwater seeping into the stream.
Bore	A structure drilled below the surface to obtain or monitor water from an aquifer or series of aquifers.
Borehole	A hole in the ground drilled by a drill rig for constructing a bore.
Boundary	A lateral discontinuity or change in the formation resulting in a significant change in hydraulic conductivity, storativity or recharge.
Cation	An ion with a positive charge – usually metal ions when disassociated and dissolved in water.
Confined formation	An aquifer that is overlain by low permeability strata. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Concentration	The amount or mass of a substance present in a given volume or mass of sample, usually expressed as microgram per litre (water sample) or micrograms per kilogram (sediment sample).
Conceptual model	A simplified and idealised representation (usually graphical) of the physical hydrogeologic and/or hydrologic setting and the hydrogeological understanding of the essential flow processes of the system. This includes the identification and description of the geologic and hydrologic framework, media type, hydraulic properties, sources and sinks, and important aquifer flow and surface-groundwater interaction processes.
Confining layer	Low permeability strata that may be saturated but will not allow water to move through it under natural hydraulic gradients.
Contamination	Contamination is the presence of a non-natural compound in soil or water, or unwanted compound in chemicals or other mixtures.
Cross bedded	Characteristic bedding structure produced by the migration of bedforms with inclined depositional surfaces.
Discharge	The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.
Discharge area	An area in which there are upward or lateral components of flow in an aquifer.
Drawdown	The change in the groundwater head (level) as measured in a bore or at the water table. The groundwater level reflects the pressure of the groundwater at the depth the bore is open/screened. Drawdown refers to the change (lowering) in the groundwater level over time. Note that nearby monitoring bores with different screen depths would be subject to different drawdown.
Electrical conductivity (EC)	A measure of a fluid's ability to conduct an electrical current and an estimation of the total ions dissolved. It is often used as a measure of water salinity.

Elevation	The height above a given level, often sea level (Australian Height Datum)
Fault	A fracture in rock along which there has been an observable amount of displacement. Faults are rarely single planar units; normally they occur as parallel to sub-parallel sets of planes along which movement has taken place to a greater or lesser extent. Such sets are called fault or fracture zones.
Fracture	Breakage in a rock or mineral along a direction or directions that are not cleavage or fissility directions.
Fractured rock aquifer	These occur in sedimentary, igneous and metamorphosed rocks that have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding planes, fractures and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary rock aquifers.
Groundwater	The water contained in interconnected pores or fractures located below the water table in the saturated zone.
Groundwater dependent (or potentially dependent) ecosystems (GDEs)	Groundwater dependent ecosystems are communities of plants, animals and other organisms whose extent and life processes depend (or partially depend) on groundwater.
Groundwater flow	The movement of water through openings in sediment and rock within the zone of saturation.
Groundwater system	A system that is hydrogeologically more similar than different in regard to geological province, hydraulic characteristics and water quality, and may consist of one or more geological formations.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).
Hydraulic gradient	The change in total hydraulic head with a change in distance in a given direction.
Hydraulic head	A specific measurement of water pressure above a datum. It is usually measured as a water surface elevation, expressed in units of length. In an aquifer, it can be calculated from the depth to water in a monitoring bore. The hydraulic head can be used to determine a hydraulic gradient between two or more points.
Hydrochemistry	Chemical characterisation of water (both surface water and groundwater).
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.
Hydrology	The study of the occurrence, distribution, and chemistry of all surface waters.
Igneous	A rock that has solidified from molten or partially molten material (ie volcanic)
Infiltration	The downward flow of water from the land surface into and through the upper soil layers.
Interbedded	Deposited between units.
Major ions	Constituents commonly present in concentrations exceeding 10 milligram per litre. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulfate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.
MicroSiemens per centimetre (µS/cm)	A measure of water salinity commonly referred to as EC (see also electrical conductivity). Most commonly measured in the field with calibrated water quality meter.
Monitoring bore	A non-pumping bore, which is generally small in diameter and used to measure the elevation of the water table and/or water quality. Bores generally have a short well screen against a single aquifer through which groundwater can enter.

Numerical model	A model of groundwater flow in which the aquifer is described by numerical equations (with specified values for boundary conditions) that are usually solved in a computer program. In this approach, the continuous differential terms in the governing hydraulic flow equation are replaced by finite quantities. Computational power is used to solve the resulting algebraic equations by matrix arithmetic. In this way, problems with complex geometry, dynamic response effects and spatial and temporal variability may be solved accurately. It must be used in cases where the essential aquifer features form a complex system (ie high complexity models).
Outcrop	The area where a particular rock unit or formation occurs at surface.
Overburden	The rock units that are above a particular rock unit. Usually used in reference to the rock above the particular target mining unit (ie the seam).
Permeability	The property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. It is a measure of the relative ease of fluid flow under unequal pressure. The hydraulic conductivity is the permeability of a material for water at the prevailing temperature.
Permeability test	An aquifer test performed in a laboratory on a sample of aquifer rock (core) to determine the permeability. Liquid or gas is allowed to flow through at different rates and the inflow and outflow pressures are measured.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
pH	Potential of hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; and provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).
Porosity	The proportion of open space within an aquifer, comprised of intergranular space, pores, vesicles and fractures.
Precipitation	(1) in meteorology and hydrology, rain, snow and other forms of water falling from the sky (2) the formation of a suspension of an insoluble compound by mixing two solutions. Positive values of saturation index (SI) indicate supersaturation and the tendency of the water to precipitate that mineral.
Pumping test	An aquifer test made by pumping a bore for a period of time and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the bore and the hydraulic characteristics of the aquifer.
Quaternary	The most recent geological period extending from about 2.5 million years ago to the present day.
Reach	An uninterrupted length of a stream, creek, or river.
Recharge	The process that replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water reaching the water table or exposed aquifers. The addition of water to an aquifer.
Recharge area	A geographic area that directly receives infiltrated water from surface and in which there are downward components of hydraulic head in the aquifer. Recharge generally moves downward from the water table into the deeper parts of an aquifer then moves laterally and vertically to recharge other parts of the aquifer or deeper aquifer zones.
Recovery	The difference between the observed water level during the recovery period after pumping stopped and the water level measured immediately before pumping stopped.
Residence time	The time that groundwater spends in storage before moving to a different part of the hydrological cycle (ie it could be argued it is a rate of replenishment).
Salinity	The concentration of dissolved salts in water, usually expressed in electrical conductivity as total dissolved solids.

Salinity classification (Australia Water Resources s Council 1988)	Fresh water quality – water with a salinity <800 µS/cm. Marginal water quality – water that is more saline than freshwater and generally waters between 800 and 1,600 µS/cm. Brackish quality – water that is more saline than freshwater and generally waters between 1,600 and 4,800 µS/cm. Slightly saline quality – water that is more saline than brackish water and generally waters with a salinity between 4,800 and 10,000 µS/cm. Moderately saline quality – water that is more saline than brackish water and generally waters between 10,000 and 20,000 µS/cm. Saline quality – water that is almost as saline as seawater and generally waters with a salinity greater than 20,000 µS/cm. Seawater quality – water that is generally around 55,000 µS/cm.
Saturated zone	The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric pressure.
Screen	A type of bore lining or casing of special construction, with apertures designed to permit the flow of water into a bore while preventing the entry of aquifer or filter pack material.
Semi-confined formation	An aquifer overlain by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the leaky confining layer – also known as a leaky artesian or leaky confined aquifer.
Slug test	An aquifer test made either by pouring a small instantaneous charge of water into a well or by withdrawing a slug of water from the well.
Specific storage	Relating to the volume of water that is released from an aquifer following a unit change in the hydraulic head. Specific storage normally relates to confined aquifers.
Specific yield	The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Specific yield generally relates to unconfined aquifers. Gravity drainage may take many months to occur.
Standing water level (SWL)	The height to which groundwater rises in a bore after it is drilled and completed, and after a period of pumping when levels return to natural atmospheric or confined pressure levels.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to specific yield.
Stratigraphy	The depositional order of sedimentary rocks in layers.
Surface water–groundwater interaction	This occurs in two ways: (1) streams gain water from groundwater through the streambed when the elevation of the water table next to the streambed is greater than the water level in the stream; and (2) streams lose water to groundwater through streambeds when the elevation of the water table is lower than the water level in the stream.
Tertiary	a geological time period of the Cenozoic era c. 65–1.6 million years ago.
Total Dissolved Solids (TDS)	A measure of the salinity of water, usually expressed in milligrams per litre (mg/L). See also EC.
Transmissivity	The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Unconfined formation	Also known as a water table aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of an unconfined aquifer.
Unconformity	A break in the stratigraphic record, representing a period of no deposition
Unsaturated zone	The rock, soil, sediments, or regolith between the land surface and water table. It includes the root zone, intermediate zone and capillary fringe.

Water quality	Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Water quality data	Chemical, biological, and physical measurements or observations of the characteristics of surface and ground waters, atmospheric deposition, potable water, treated effluents, and waste water and of the immediate environment in which the water exists.
Water table	The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water.