Water assessment

Snowy 2.0 Main Works EIS

Prepared for Snowy Hydro Limited
September 2019

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Snowy 2.0 Main Works EIS

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Executive Summary

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). Snowy 2.0 is the largest committed renewable energy project in Australia and is critical to underpinning system security and reliability as Australia transitions to a decarbonised economy. Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground.

Snowy 2.0 has been declared to be State significant infrastructure (SSI) and critical State significant infrastructure (CSSI) by the former NSW Minister for Planning under Part 5 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) and is defined as CSSI in clause 9 of Schedule 5 of the *State Environmental Planning Policy (State and Regional Development) 2011* (SRD SEPP). CSSI is infrastructure that is deemed by the NSW Minister to be essential for the State for economic, environmental or social reasons. An application for CSSI must be accompanied by an environmental impact statement (EIS).

Separate applications are being submitted by Snowy Hydro for different stages of Snowy 2.0 under Part 5, Division 5.2 of the EP&A Act. This includes the preceding first stage of Snowy 2.0, Exploratory Works for Snowy 2.0 (the Exploratory Works) and the stage subject of this current application, Snowy 2.0 Main Works (the Main Works). In addition, an application under Part 5, Division 5.2 of the EP&A Act is also being submitted by Snowy Hydro for a segment factory that will make tunnel segments for both the Exploratory Works and Main Works stages of Snowy 2.0.

ES1 Water resources

The surface water and groundwater sources near Snowy 2.0 Main Works 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 NSW Aquifer Interference Policy (AIP) establishes the criteria for assessment of projects that intercept groundwater and how the project needs to be licensed. The water assessment has been undertaken in accordance with the AIP.

Surface water resources within the project area comprise the Murrumbidgee Catchment and the Snowy River Catchment. There are four surface water sources within the project area that are managed within two separate water sharing plans:

- Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012:
  - Upper Tumut Water Source;
  - Tantangara Water Source;
  - Murrumbidgee Zone 1 Water Source;
- Water Sharing Plan for the Snowy Genoa Unregulated and Alluvial Water Sources 2016:
  - Eucumbene Water Source.

The groundwater resources for the project are all within the Lachlan Fold Belt (LFB). There are two water sources within the project area that are managed under two separate water sharing plans:

- Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011:

- Lachlan Fold Belt Murray Darling Basin (LFB MDB) Groundwater Source;

- Water Sharing Plan for the South Coast Groundwater Source 2016:

  - Lachlan Fold Belt South Coast Groundwater Source.

ES2 Baseline monitoring program

A comprehensive water monitoring network has been designed and implemented to establish pre-construction baseline data for the project. The water monitoring network has been designed to ensure that the project can be adequately assessed against the AIP and has been designed and developed in accordance with the guidelines for the Development of Monitoring and Modelling Plan (DPI Water 2014).

The groundwater monitoring network includes conventional groundwater monitoring bores, vibrating wire piezometers, test production and water supply bores, and shallow drive point piezometers. The network covers 83 locations across the project area, many of which include dual installations or contain multiple sensors. The surface water monitoring network includes 16 streamflow gauging locations and 30 surface water quality monitoring locations. Surface water monitoring targets areas upstream and downstream of the proposed project in major creeks and rivers intercepted by the project. Both the groundwater and surface water monitoring networks have been developed in consultation with DPIE hydrogeologists, hydrologists and assessment officers.

A diverse range of field investigations have been undertaken to develop the conceptual model understanding, including hydraulic testing, geochemical investigations, geophysical investigations, geomorphological studies and ecological studies.

The extent, duration and frequency of baseline monitoring, for which this water assessment has been based on, is considered fit-for-purpose. Additional data will be required at key locations to further understand and monitor potential project impacts at a more local scale and to verify model predictions and provide recalibration targets over time.

ES3 Assessment and findings

Numerical modelling has been used in this assessment to predict potential changes in groundwater and surface water resources. Groundwater flow into the tunnel is expected to occur primarily as a function of secondary porosity (ie via fractures and along bedding planes). The model assumed a bulk conservative hydraulic conductivity for each rock type and cannot simulate individual fractures because the locations and conductivity of individual fractures are not known until the tunnel intersects them. Attempts to 'constrain' the model to simulate unknown geological occurrences (ie fractures interspersed with low hydraulic conductivity zones) or design elements, is not in-line with the Australian Groundwater Modelling Guidelines (Barnett et al 2012) and this has therefore not been undertaken.

The modelling results are therefore conservative for two reasons:

- modelling does not consider actual design, management or mitigating activities (ie pre-grouting and segmental lining). During construction the discrete fractures that yield excess water will be grouted and will reduce the actual overall tunnel inflow volume; and

- hydraulic parameters within the numerical model for the Gooandra Volcanics and the Kellys Plain Volcanics are conservative and assume significant connection to the watertable based on pumping test data. However, in reality the entire unit may not behave like this, with some parts expected to be much less permeable.

Therefore, the model predictions of tunnel inflow, baseflow reduction and watertable drawdown are likely to be over estimating project impacts. The results of this conservative model approach need to be considered within this overall context to accurately assess the project on its true merits.

Groundwater modelling predicts localised watertable drawdown in the vicinity of the project throughout construction and operation. Watertable drawdown, once the project has advanced into year 5 of construction and into operations, is predicted to extend approximately 1.5 km north and south of the proposed project in the plateau area, east of the Snowy Mountains Highway. Watertable drawdown across the ravine area (west of the Snowy Mountains Highway) is less extensive and restricted to less than 100 m from the project.

Based on the model, watertable drawdown is predicted to have effects on terrestrial, aquatic and subterranean groundwater dependant ecosystems (GDEs), and groundwater available for baseflow to rivers and creeks. The modelled reduction in baseflow is predicted to have greatest effect to Gooandra Creek and the upper reaches of Eucumbene River, and represents a small area of the project and a small percentage of these stream lengths (5% of the Gooandra Creek length and 2% of the Eucumbene stream lengths are affected). The predicted effects will be localised to the area directly overlying the drawdown zone, and are not predicted to significantly affect downstream reaches of these watercourses. Furthermore, the project is not predicted to impact the Yarrangobilly Caves or any groundwater/ surface water user.

Instream works and disturbance of waterfront land have the potential to affect the flood regime within the Yarrangobilly River (including Lobs Hole), Kellys Plain Creek, and Rock Forest. The flooding assessment identified that increases in flood water level would be limited to locations in the immediate vicinity of the project works. No increase in flood risk to private property was identified. No change to total flood runoff will occur. Talbingo and Tantangara reservoirs will receive the same volumes of flood water that they would in the absence of the project.

Infrastructure will unavoidably need to be constructed on flood prone land in the ravine area, particularly around Lobs Hole. This includes temporary infrastructure (eg associated with construction phase works, such as the western and eastern emplacement areas) and permanent infrastructure (eg Camp Bridge, Wallaces Bridge and paved access roads). Project infrastructure placed on flood prone land will be designed to be flood resistant.

ES4 Mitigation and management

An approach to managing predicted impacts to water resources has been proposed as part of the accepted tender design. Proposed environmental management measures have been summarised briefly in the water assessment and described in detail in Annexure D.

Management and mitigation reflects the requirements of guidelines, policy and legislation and outlines the residual impacts of the project against key aspects of water resource functioning (ie surface water quantity, groundwater quality etc).

Mitigation and management options will potentially significantly reduce the inflow tunnel volumes. Peer reviewed referenced journal articles on inflow reductions from grouting and lining in other fractured rock tunnel environments are quoted as being reduced to less than 20% of the original pre-mitigated inflow volume (Wannenmacher et al. 2019).

ES5 Water licensing and overall take

The volume of groundwater required to be licensed for the Snowy 2.0 Main Works is defined in accordance with the AIP for interception activities, plus the direct take for construction and potable supply. The licence requirements for tunnel inflows are separated into direct take (ie tunnel inflow) and then also needs to include the effects on overlying water sources – which includes reduced availability of groundwater to provide baseflow (ie baseflow reduction to streams). This baseflow reduction is a stream impact, but is licensed from the source, which is groundwater. Due to the time lag, the water is removed from the water source once, but licensed twice to account for secondary impacts that occur years after the initial inflow occurs. Top-up process water and potable supply will be provided via bores into the LFB MDB groundwater source and these estimates are included in the required licences.

The peak inflow, impacts and takes are considered for each groundwater source, and for each component that requires licensing in Table ES1. The overall licence peak take is 3,729 ML in the LFB MDB groundwater source, and 1,722 ML in the LFB South Coast Groundwater Source.

Table ES1 Licence take breakdown by source

	LFB MDB groundwater source			**LFB South Coast Groundwater Source**		
Measure	**Direct tunnel inflow**	**Reduced baseflow to streams**	**Potable and process top-up**	**Direct tunnel inflow**	**Reduced baseflow to streams**	**Potable and process top-up**
Maximum take / interception / process	3,529 ML in construction year 5	1,665 ML in operational year 4	345 ML in operational year 1	1,000 ML in first year of operations	840 ML post year 20 of operations	1,722 ML post year 20 of operations
Peak water source volume for licensing	3,729 ML (first year of operation)			1,722 ML (post year 20 of operation – ie steady state operation)		

Notes: the peak licence volume is not the sum of the three components due to the difference in timing on individual peak take.

There is sufficient groundwater entitlement available within both groundwater sources to secure the respective predicted take for the project.

The NSW Government has periodically released additional entitlements within this water source via controlled allocation, with the next controlled allocation scheduled for 8 October 2019 (DPIE 2019). Snowy Hydro will apply for the required licences at this time and this therefore provides the clear pathway for how the remaining licence volume will be secured so that all water taken is adequately licensed.

It is noted that the numerical groundwater model is conservative and with the inclusion of design mitigation options and a potential refinement of the hydraulic parameters adopted for the Gooandra and Kellys Plain Volcanics, the inflow volumes required for licensing may be reduced.

Table of Contents

Annexures

Tables

Figures

Part A

Project context

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). Snowy 2.0 is the largest committed renewable energy project in Australia and is critical to underpinning system security and reliability as Australia transitions to a decarbonised economy. Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground.

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The first stage of Snowy 2.0, the Exploratory Works, includes an exploratory tunnel and portal and other exploratory and construction activities primarily in the Lobs Hole area of the Kosciuszko National Park (KNP). The Exploratory Works were approved by the former NSW Minister for Planning on 7 February 2019 as a separate project application to DPIE (SSI 9208).

This water assessment has been prepared to accompany an application and supporting EIS for the second phase of Snowy 2.0, which is to be known as the **Snowy 2.0 Main Works**. As the title suggests, this phase of the project covers the major construction elements of Snowy 2.0, including permanent infrastructure (such as the underground power station, power waterways, access tunnels, chambers and shafts), temporary construction infrastructure (such as construction adits, construction compounds and accommodation), management and storage of extracted rock material and establishing supporting infrastructure (such as road upgrades and extensions, water and sewage treatment infrastructure, and the provision of construction power). The Snowy 2.0 Main Works also include the operation of Snowy 2.0.

Snowy 2.0 Main Works is shown in Figure 1.1 in the regional context. If approved, the Snowy 2.0 Main Works would commence before completion of Exploratory Works.

The Snowy 2.0 Main Works do not include the transmission works proposed by TransGrid (TransGrid 2018) that provide connection between the cableyard and the NEM. These transmission works will provide the ability for Snowy 2.0 (and other generators) to efficiently and reliably transmit additional renewable energy to major load centres during periods of peak demand, as well as enable a supply of renewable energy to pump water from Talbingo Reservoir to Tantangara Reservoir during periods of low demand. While the upgrade works to the wider transmission network and connection between the cableyard and the network form part of the CSSI declaration for Snowy 2.0 and Transmission Project, they do not form part of this application and will be subject to separate application and approval processes, managed by TransGrid. This project is known as the HumeLink and is part of AEMO's Integrated System Plan.

With respect to the provisions of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), on 30 October 2018 Snowy Hydro referred the Snowy 2.0 Main Works to the Commonwealth Department of the Environment and Energy (DoEE) and, on a precautionary basis, nominated that the Snowy 2.0 Main Works has potential to have a significant impact on Matters of National Environmental Significance (MNES) and the environment generally.

On 5 December 2018, the Snowy 2.0 Main Works were deemed a controlled action by the Assistant Secretary of the DoEE. It was also determined that potential impacts of the project will be assessed by accredited assessment under Part 5, Division 5.2 of the EP&A Act. This accredited process will enable the NSW Department of Planning, Industry and Environment (DPIE) to manage the assessment of the Snowy 2.0 Main Works, including the issuing of the assessment requirements for the EIS. Once the assessment has been completed, the Commonwealth Minister for the Environment will make a determination under the EPBC Act.

1.2 Project location

The Snowy 2.0 Main Works are within the Australian Alps, in southern NSW, about mid-way between Canberra and Albury. Snowy 2.0 Main Works is within both the Snowy Valleys and Snowy Monaro Regional local government areas (LGAs).

The nearest large towns to Snowy 2.0 Main Works are Cooma and Tumut. Cooma is located about 50 kilometres (km) south-east of the project area (or 70 km by road from Providence Portal at the southern edge of the project area), and Tumut is located about 35 km north-west of the project areas (or 45 km by road from Tumut 3 power station at the northern edge of the project area). Other townships near the project area include Talbingo, Cabramurra, Adaminaby and Tumbarumba. Talbingo and Cabramurra were built for the original Snowy Scheme workers and their families, while Adaminaby was relocated in 1957 to make way for the establishment of Lake Eucumbene.

The location of the Snowy 2.0 Main Works with respect to the region is shown in Figure 1.1.

The pumped hydro-electric scheme elements of the Snowy 2.0 Main Works are mostly underground between the southern ends of Tantangara and Talbingo reservoirs, a straight-line distance of 27 km. Surface works will also occur at locations on and between the two reservoirs. Key locations for surface works include:

- **Tantangara Reservoir** - at a full supply level (FSL) of about 1,229 metres (m) to Australian Height Datum (AHD), Tantangara Reservoir will be the upper reservoir for Snowy 2.0 and include the headrace tunnel and intake structure. The site will also be used for a temporary construction compound, accommodation camp and other temporary ancillary activities;

- **Marica** - this site will be used primarily for construction including construction of vertical shafts to the underground power station (ventilation shaft) and headrace tunnel (surge shaft), and a temporary accommodation camp;

- **Lobs Hole** - the site will be used primarily for construction but will also become the main entrance to the power station during operation. Lobs Hole will provide access to the Exploratory Works tunnel, which will be refitted to become the main access tunnel (MAT), as well as the location of the emergency egress, cable and ventilation tunnel (ECVT), portal, associated services and accommodation camp; and

- **Talbingo Reservoir** - at a FSL of about 546 m AHD, Talbingo Reservoir will be the lower reservoir for Snowy 2.0 and will include the tailrace tunnel and water intake structure. The site will also be used for temporary construction compounds and other temporary ancillary activities.

Works will also be required within the two reservoirs for the placement of excavated rock and surplus cut material. Supporting infrastructure will include establishing or upgrading access tracks and roads and electricity connections to construction sites.

Most of the proposed pumped hydro-electric and temporary construction elements and most of the supporting infrastructure for the Snowy 2.0 Main Works are located within the boundaries of KNP, although the disturbance footprint for the project during construction is less than 0.25% of the total KNP area. Some of the supporting infrastructure and construction sites and activities (including sections of road upgrade, power and communications infrastructure) extends beyond the national park boundaries. These sections of infrastructure are primarily located to the east and south of Tantangara Reservoir. One temporary construction site is located beyond the national park along the Snowy Mountains Highway about 3 km east of Providence Portal (referred to as Rock Forest).

The project is described in more detail in Chapter 2.

1.3 Project area

A project area for the Snowy 2.0 Main Works has been identified that includes the elements of the project, including all construction and operational elements. The project area is shown in Figure 1.2. Key features of the project area are:

- the water bodies of Tantangara and Talbingo reservoirs, covering areas of 19.4 square kilometres (km^2) and 21.2 km^2 respectively. The reservoirs provide the water to be utilised in the pumped hydro-electric scheme;
- major watercourses including the Yarrangobilly, Eucumbene and Murrumbidgee rivers and some of their tributaries;
- KNP, within which the majority of the project area is located. Within the project area, KNP is characterised by two key zones: upper slopes and inverted treelines in the west of the project area (referred to as the ‘ravine’) and associated subalpine treeless flats and valleys in the east of the project area (referred to as the ‘plateau’); and
- farm land south-east of KNP at Rock Forest.

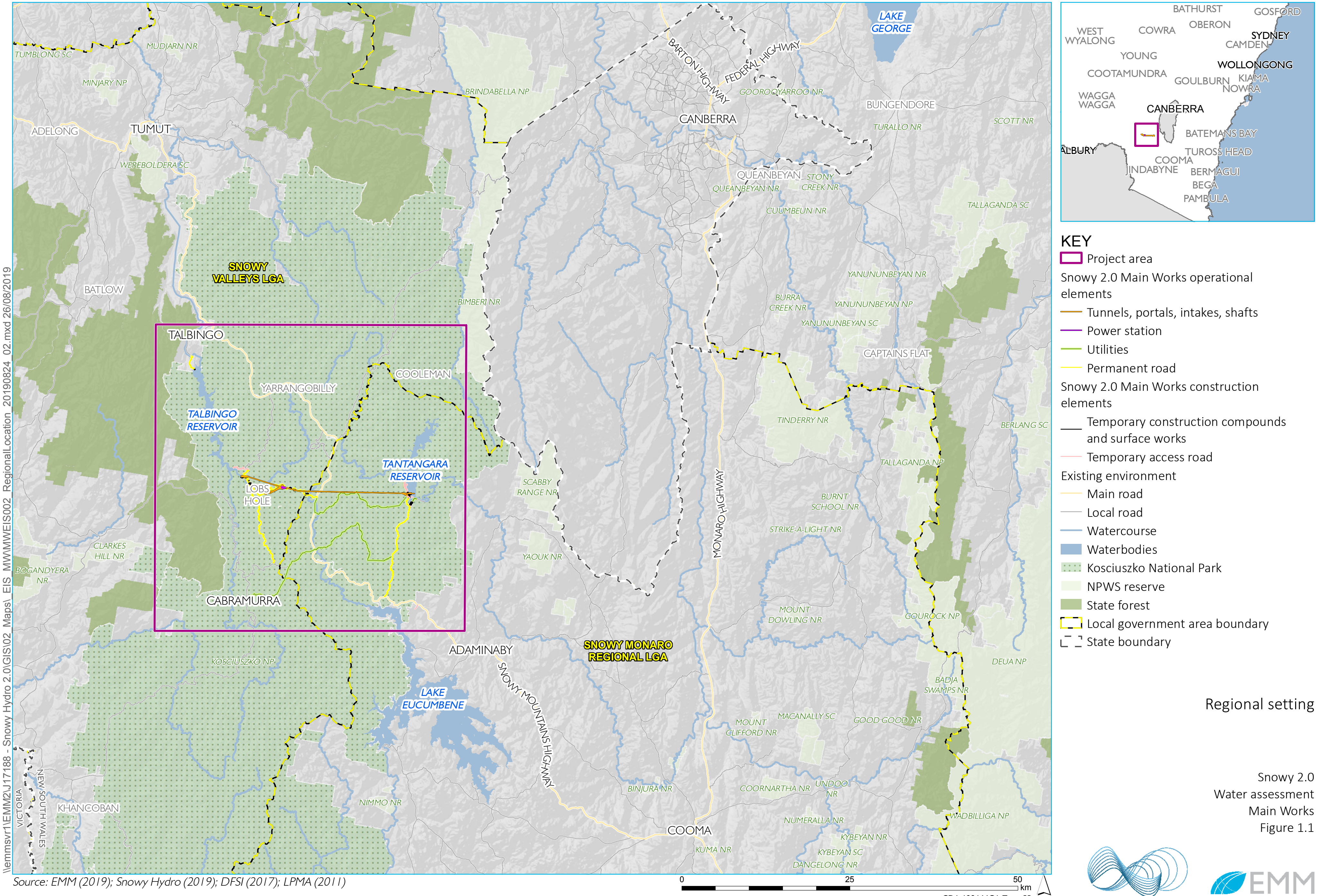
The project area is interspersed with built infrastructure including recreational sites and facilities, main roads as well as unsealed access tracks, hiking trails, farm land, electricity infrastructure, and infrastructure associated with the Snowy Scheme.

1.3.1 Study area

Each technical assessment (as discussed in Section 1.5) focused on a particular study area that was relevant to the subject matter. For example, the study area for the water modelling is larger than that examined in the flooding assessment. The study area for each technical assessment associated with the overall water assessment is described in Table 1.1.

Table 1.1 Defined study areas for each water-related technical assessment

Technical assessment	Study area
Water balance	The surface infrastructure area (Annexure D) and the underground components (Annexure D).
Flooding	The surface infrastructure area (Annexure C) and the surrounding Tantangara Creek, Gooandra Creek, Eucumbene Creek, Nungar Creek and Yarrangobilly River catchments.
Numerical groundwater model	The groundwater model domain (refer Section 10)



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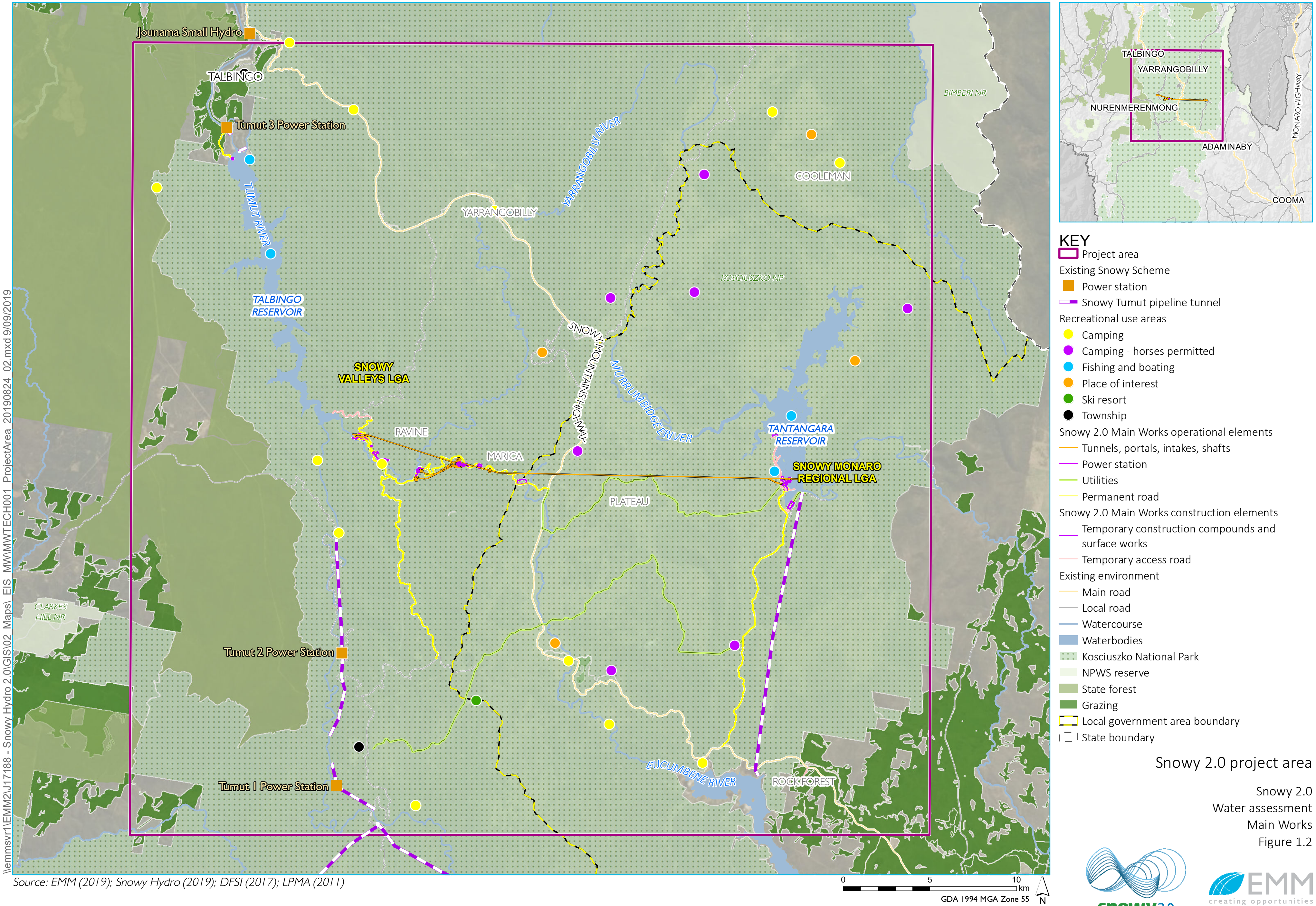
Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

Regional setting

Snowy 2.0
Water assessment
Main Works
Figure 1.1

snowy 2.0

EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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Snowy 2.0 project area

Snowy 2.0
Water assessment
Main Works
Figure 1.2

1.4 Proponent

Snowy Hydro is the proponent for the Snowy 2.0 Main 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 Purpose of this report

This water assessment supports the EIS for the Snowy 2.0 Main Works. The key objectives of the water assessment are to:

- outline the proposed site water management arrangements for the project;
- assess the existing surface water and groundwater related environments and baseline conditions within the project and surrounding area;
- assess the regulatory environment (with respect to water resources) within which the project will operate;
- quantify the requirements of the project for water access licences to satisfy project demands, and specify arrangements for acquiring them;
- identify and quantify the potential impacts of the project on the current surface water and groundwater resources, and on water users both environmental and extractive (including cumulative effects) in accordance with the AIP;
- specify mitigation and management measures, and monitoring requirements for surface water and groundwater;
- satisfy the Secretary's Environmental Assessment Requirements (SEARs) relevant to groundwater and surface water impacts; and
- inform the wider community about the project and its potential impacts on the local and regional water environments.

This assessment covers all issues relating to site water management, groundwater and surface water and their related environmental and other users. For surface water, this includes issues relating to river waters, geomorphology, and flooding. Ecological effects are referred to in this report but are discussed in detail in the Snowy 2.0 Biodiversity Assessment Report.

The water assessment consists of four supporting technical annexures and each annexure has a number of supporting technical reports or data sets, termed attachments. The document structure for the water assessment is shown in Figure 1.3 and the purpose of the water assessment and each annexure is described below.

- The water characterisation report (Annexure A to the water assessment):
  - describes the available data, monitoring programs and field surveys that inform the water assessment; and
  - describes the existing surface water and groundwater environment and presents a conceptual model of the water cycle within the project area, including the interaction between surface water and groundwater.

- The modelling report (Annexure B) presents:
  - the numerical groundwater and surface water modelling undertaken to describe the potential impacts of the underground elements of the project on groundwater head and drawdown;
  - groundwater inflow rates to the various tunnels and excavations; and
  - the baseflow component of streamflow and overall streamflow statistics within the project area.
- The flood risk assessment (Annexure C):
  - describes the existing flood characteristics of the key watercourses where catchments or flowpaths may be subject to change as a result of project surface works; and
  - models the predicted impacts of construction and operational elements of the project.
- The water management report (Annexure D):
  - describes the proposed water management system, including management measures;
  - characterises all discharge in terms of location, volume, frequency and water quality;
  - describes works on waterfront land; and
  - provides estimates of water take to supply construction activities.

Several independent subconsultant water-related technical studies were undertaken to inform the project, namely:

- Geomorphological assessment (Flow and Loam Environmental, 2019);
- Geophysical investigation (SMEC, 2019a);
- Sediment Coring Report – Talbingo Reservoir (Royal Haskoning DHV) (RHDHV, 2019a);
- Independent peer review of modelling (Middlemis, 2019);
- Flooding assessment (GRC Hydro, 2019); and
- Reservoir modelling and subaqueous excavated rock placement assessment (RHDHV, 2019b).

The technical studies have been carried out in accordance with the SEARs and agency requirements and with reference to leading practice guidelines, legislation and policies.

The structure of the technical reports and assessments which support the overall water assessment are shown in Figure 1.3.

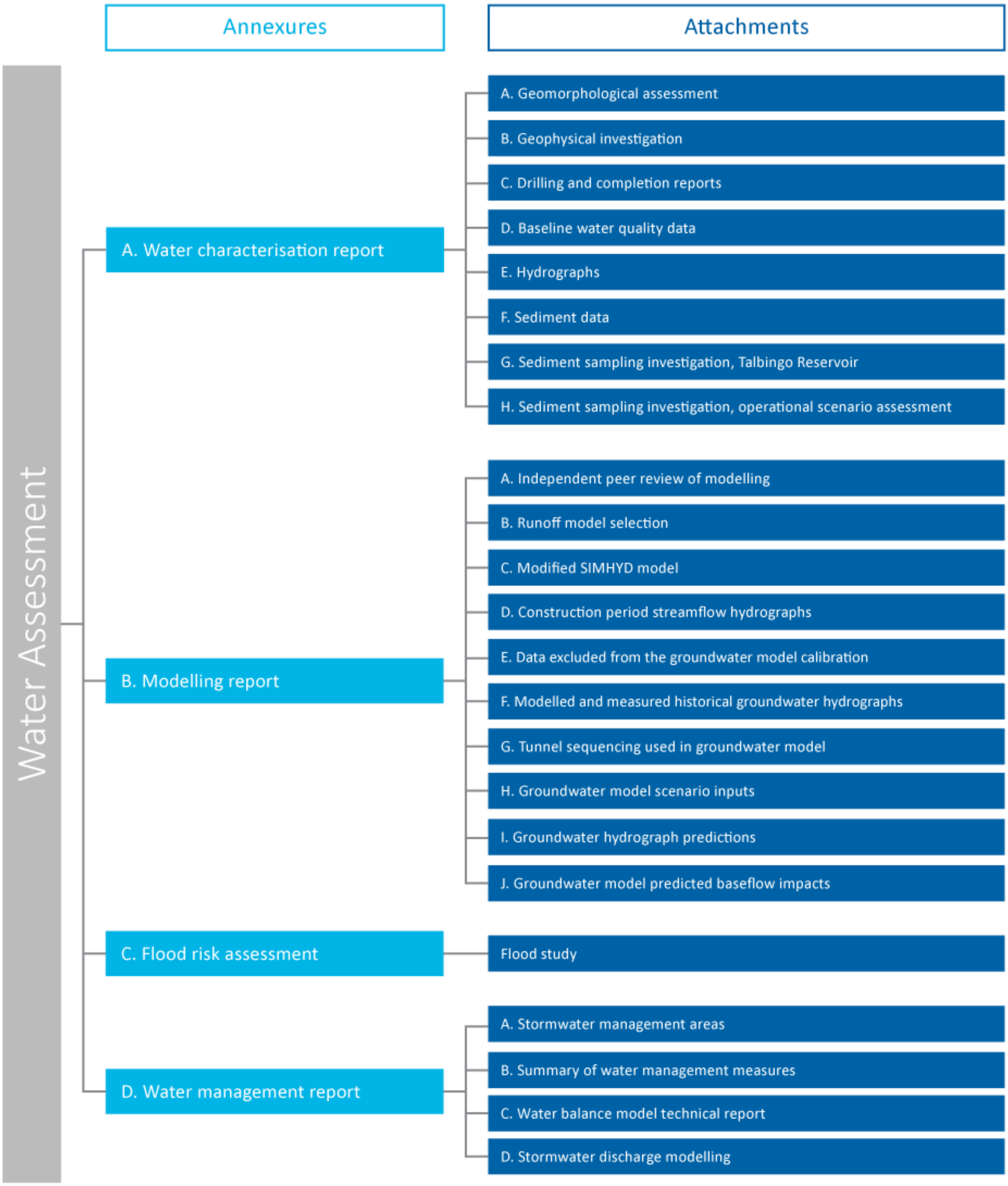


Figure 1.3 Water assessment structure

1.6 Assessment guidelines and requirements

This water assessment has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for the Snowy 2.0 Main Works, issued on 31 July 2019, 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 1.2 lists the matters relevant to this assessment and where they are addressed in this report.

Table 1.2 Relevant matters raised in SEARs

WA SEARs ID	Requirement	Section addressed
1	A detailed site water balance for the project, including the water take from each surface and groundwater source.	A summary of the site water balance is presented in Section 11.3 and described in detail in Annexure D. Calculated water take for each groundwater and surface water source is provided in Section 14.
2	An assessment of the impacts of the project on: • the quantity and quality of the region's surface and groundwater resources, including Yarrangobilly River, Wallaces Creek, and the Tantangara and Talbingo Reservoirs; • hydrological flows on site, including any potential flooding impacts; • key water features on site, including potential impacts on riparian land and the Tantangara and Talbingo Reservoirs; and • water-related infrastructure, basic landholder rights and the entitlements of water users.	A summary of potential impacts has been provided in Section 10 and 11. Detailed descriptions of impacts are provided in Annexure B, Annexure C and Annexure D.
3	A description of the likely changes to the hydrological regime of the existing water storages of the Snowy Hydro Scheme up to the authorised full supply level, and any associated biodiversity impacts.	Provided in the Reservoir modelling and subaqueous excavated rock placement assessment (Annexure A, Attachment H of the WA)) and the biodiversity development assessment report (Appendix M.1 of the EIS).
4	A strategy to manage the emplacement of spoil in the Tantangara and Talbingo Reservoirs and enhance any new landforms created.	The Rehabilitation Strategy provides a strategy for the emplacement and management of spoil emplacement. Water-related impacts arising from spoil emplacement has been discussed in Section 10 and Section 11.
5	An assessment of biodiversity impacts of the project on terrestrial, aquatic and groundwater-dependent ecosystems, including listed Commonwealth and State threatened species and communities and listed Commonwealth migratory species	A summary of potential impacts has been provided in Section 10.4 and 10.8. Detailed descriptions of impacts are provided in EIS Appendix M.1 and M.2.

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

1.7 Related projects

There are three other projects related to the Snowy 2.0 Main Works, they are:

- Snowy 2.0 Exploratory Works (SSI-9208) – a Snowy Hydro project with Minister's approval;
- Snowy 2.0 Transmission Connect Project (SSI-9717) – a project proposed by TransGrid; and
- Snowy 2.0 – Segment Factory (SSI-10034) – a project proposed by Snowy Hydro.

While these projects form part of the CSSI declaration for Snowy 2.0 and the Transmission Project, they do not form part of Snowy Hydro's application for the Snowy 2.0 Main Works. These related projects are subject to separate application and approval processes. Staged submission and separate approval is appropriate for a project of this magnitude, due to its complexity and funding and procurement processes. However, cumulative impacts have been considered in this report where relevant.

1.8 Other relevant reports

This water assessment has been prepared with reference to other technical reports that have been prepared as part of the Snowy 2.0 Main Works EIS. The other relevant reports referenced in this water assessment are:

- Aquatic ecology assessment (Cardno 2019) – Appended to the EIS;
- Biodiversity development assessment (EMM 2019) – Appended to the EIS;
- Contamination assessment (EMM 2019) – Appended to the EIS;
- Excavated rock placement assessment summary - Appendix L of the EIS; and
- Soils and land assessment (EMM 2019) – Appended to the EIS.

1.9 Key terms

A glossary of terms is included at the end of this report. Commonly used terms are defined in Table 1.3 for ease of reference.

Table 1.3 Key terms

Terms	Definition and description
Baseflow	Baseflow is the component of streamflow that is sourced from groundwater and released from groundwater storage during low streamflow conditions. Baseflow generally steadily decreases following high rainfall and high surface runoff.
Cumulative impacts	Impacts from existing and future approved projects that may have an impact in combination with the predicted impacts from the project. These projects may already exist, be under construction, are confirmed, or are at various stages of the development application process.

Table 1.3 Key terms

Terms	Definition and description
Drawdown	The change in the groundwater head (level) as measured in a bore or at the watertable. The groundwater level reflects the pressure of the groundwater at the depth/elevation the bore is open/screened. Drawdown refers to the change (lowering) in the groundwater level over time.
Model domain or groundwater model domain	The area that has been included in the numerical groundwater model. This extends beyond the project area and is defined by hydrogeological or other boundaries.
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 sediment dams will be transferred via a water treatment plant and then released to the environment in accordance with water quality objectives and discharge criteria. Once construction of the infrastructure area is finished, sediment dams will generally be decommissioned and will not remain part of the operational phase water management system.
Sump	A water storage where water is pumped to/from or where water collects. For the project, a sump is where water from various parts of the subsurface excavation is collected and either reused for further construction purposes or pumped to surface and temporarily stored in sediment dams.
Watertable	The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water.

2 Project description

This section provides a summary of the Snowy 2.0 Main Works project. It outlines the functional infrastructure required to operate Snowy 2.0, as well as the key construction elements and activities required to build it. A more comprehensive detailed description of the project is provided in Chapter 2 (Project description) of the EIS, which has been used as the basis of this technical assessment.

2.1 Overview of Snowy 2.0

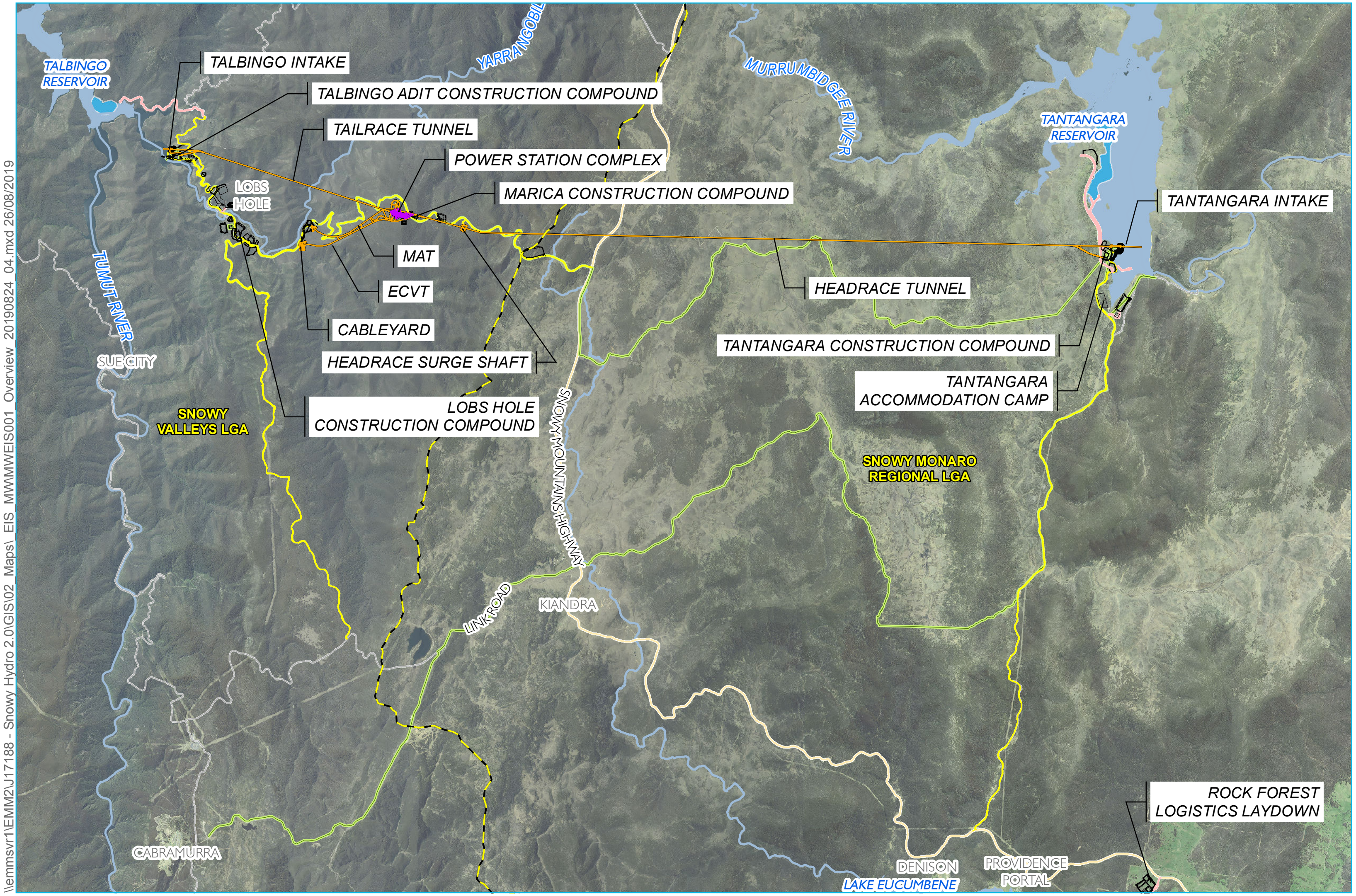
Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground. An overview of Snowy 2.0 is shown in, Table 2.1 and the key project elements of Snowy 2.0 are summarised in Figure 2.1.

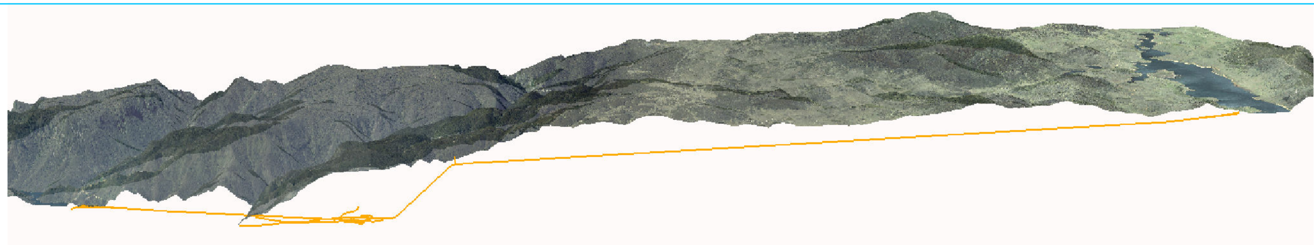
Table 2.1 Overview of the Snowy 2.0 Main Works

Project element	Summary of the project
Project area	The project area is the broader region within which Snowy 2.0 will be built and operated, and the extent within which direct impacts from the Snowy 2.0 Main Works are anticipated.
Permanent infrastructure	Snowy 2.0 infrastructure to be built and operated for the life of the assets include the: intake and gate structures and surface buildings at Tantangara and Talbingo reservoirs; power waterway tunnels primarily comprising the headrace tunnel, headrace surge structure, inclined pressure tunnel, pressure pipelines, tailrace surge tank and tailrace tunnel; underground power station complex comprising the machine hall, transformer hall, ventilation shaft and minor connecting tunnels; access tunnels (and tunnel portals) to the underground power station comprising the main access tunnel (MAT) and emergency egress, communication, and ventilation tunnel (ECVT); establishment of a portal building and helipad at the MAT portal; communication, water and power supply including the continued use of the Lobs Hole substation; cable yard adjacent to the ECVT portal to facilitate the connection of Snowy 2.0 to the NEM; access roads and permanent bridge structures needed for the operation and maintenance of Snowy 2.0 infrastructure; and fish control structures on Tantangara Creek and near the Tantangara Reservoir wall.
Temporary infrastructure	Temporary infrastructure required during the construction phase of the Snowy 2.0 Main Works are: construction compounds, laydown, ancillary facilities and helipads; accommodation camps for construction workforce; construction portals and adits to facilitate tunnelling activities; barge launch ramps; water and wastewater management infrastructure (treatment plants and pipelines); communication and power supply; and temporary access roads.
Disturbance area	The disturbance area is the extent of construction works required to build Snowy 2.0. The maximum disturbance area is about 1,680 hectares (ha), less than 0.25% of the total area of KNP. Parts of the disturbance area will be rehabilitated and landformed and other parts will be retained permanently for operation (operational footprint).
Operational footprint	The operational footprint is the area required for permanent infrastructure to operate Snowy 2.0. The maximum operational footprint is about 99 ha. This is 0.01% of the total area of KNP.

Table 2.1 Overview of the Snowy 2.0 Main Works

Project element	Summary of the project
Tunnelling and excavation method	The primary tunnelling method for the power waterway is by tunnel boring machine (TBM), with portals and adits constructed using drill and blast methods. Excavation for other underground caverns, chambers and shafts will be via combinations of drill and blast, blind sink, and/or raise bore techniques.
Excavated rock management	Excavated rock will be generated as a result of tunnelling activities and earthworks. The material produced through these activities will be stockpiled and either reused by the contractor (or NPWS), placed permanently within Tantangara or Talbingo reservoirs, used in final land forming and rehabilitation of construction pads in Lobs Hole, or transported offsite.
Construction water and wastewater management	Water supply for construction will be from the two existing reservoirs (Talbingo and Tantangara) and reticulated via buried pipelines (along access roads). Raw water will be treated as necessary wherever potable water is required (eg at accommodation camps). Water to be discharged (comprising process water, wastewater and stormwater) will be treated before discharge to the two existing reservoirs (Talbingo and Tantangara) as follows: treated process water will be reused onsite where possible to reduce the amount of discharge to reservoirs, however excess treated water will be discharged to the reservoirs; collected sewage will be treated at sewage treatment plants to meet the specified discharge limits before discharge and/or disposal; and stormwater will be captured and reused where possible.
Rehabilitation	Rehabilitation of areas disturbed during construction including reshaping to natural appearing landforms or returning to pre-disturbance condition, as agreed with NPWS and determined by the rehabilitation strategy. This includes construction areas at Lobs Hole which comprise surplus cut materials that are required for the construction. Areas to be used by Snowy Hydro in the long-term may be re-shaped and rehabilitated to maintain access and operational capabilities (eg intakes and portal entrances).
Construction workforce	The construction workforce for the project is expected to peak at around 2,000 personnel.
Operational life	The operational life of the project is estimated to be 100 years.
Operational workforce	The operational workforce is expected to be 8-16 staff, with fluctuations of additional workforce required during major maintenance activities.
Hours of operation	Construction of Snowy 2.0 will be 24/7 and 365 days per year. Operation of Snowy 2.0 will be 24/7 and 365 days per year.
Capital investment value	Estimated to be $4.6 billion.





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KEY

Existing environment

- Main road
- Local road
- Watercourse
- Waterbodies
- Local government area boundary

Snowy 2.0 Main Works operational elements

- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements

- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement area

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 55
N

Snowy 2.0 project elements

Snowy 2.0
Water assessment
Main Works
Figure 2.1

2.2 Construction of Snowy 2.0

A number of construction activities will be carried out concurrently, and across a number of different sites. Specific details on these activities as well as an indicative schedule of construction activities is provided in Chapter 2 (Project description) of the EIS. This section summarises the key construction elements of the project.

Table 2.1 provides an overview of the construction elements, their purpose and location within the project area.

Table 2.1 Snowy 2.0 construction elements

Construction element	Purpose	Location
Construction sites	Due to the remoteness of Snowy 2.0, construction sites are generally needed to: • provide ancillary facilities such as concrete batching plants, mixing plants and on-site manufacturing; • store machinery, equipment and materials to be used in construction; • provide access to underground construction sites; and • provide onsite accommodation for the construction workforce.	Each construction site needed for Snowy 2.0 is shown in Figures 2.2 to Figure 2.6.
Substations and power connection	One substation is required to provide permanent power to Snowy 2.0, located at Lobs Hole. This substation is proposed as a modification to the Exploratory Works with a capacity of 80 mega volt amp (MVA). It will continue to be used for the Snowy 2.0 Main Works, however requires the establishment of further power supply cables to provide power to the work sites and TBM at Tantangara, as well as Talbingo, in particular to power the TBMs via the MAT, ECVT, Talbingo and Tantangara portals.	The supporting high voltage cable route mostly follows access roads to each of the work sites, using a combination of aerial and buried arrangements.
Communications system	Communications infrastructure will connect infrastructure at Tantangara and Talbingo reservoirs to the existing communications system at the Tumut 3 power station (via the submarine communications cable in Talbingo Reservoir established during Exploratory Works) and to Snowy Hydro's existing communications infrastructure at Cabramurra.	The cable will be trenched and buried in conduits within access roads. Crossing of watercourses and other environmentally sensitive areas will be carried out in a manner that minimises environmental impacts where possible, such as bridging or underboring.
Water and wastewater servicing	Drinking water will be provided via water treatment plants located at accommodation camps. Water for treatment will be sourced from either the nearest reservoir or groundwater via bores. There are three main wastewater streams that require some form of treatment before discharging to the environment, including: • tunnel seepage and construction wastewater (process water); • domestic sewer (wastewater); and • construction site stormwater (stormwater).	Utility pipelines generally follow access roads. Water treatment plants (drinking water) will be needed for the accommodation camps and will be located in proximity. Wastewater treatment plants will similarly be located near accommodation camps. Process water treatment plants will be at construction compounds and adits where needed to manage tunnel seepage and water during construction.
Temporary and permanent access roads	Access road works are required to: • provide for the transport of excavated material between the tunnel portals and the excavated rock emplacement areas;	The access road upgrades and establishment requirements across the project area are shown on Figure 2.1. Main access and haulage to site will be via Snowy Mountains Highway, Link Road and

Table 2.1 Snowy 2.0 construction elements

Construction element	Purpose	Location
	• accommodate the transport of oversized loads as required; and • facilitate the safe movement of plant, equipment, materials and construction workers into and out of construction sites. The access road upgrades and establishment requirements are shown in Figure 2.2 to Figure 2.6. These roads will be used throughout construction including use of deliveries to and from site and the external road network. Some additional temporary roads will also be required within the footprint to reach excavation fronts such as various elevations of the intakes excavation or higher benches along the permanent roads.	Lobs Hole Ravine Road (for access to Lobs Hole), and via Snowy Mountains Highway and Tantangara Road (for access to Tantangara Reservoir).
Excavated rock management	Approximately 9 million m^3 (unbulked) of excavated material will be generated by construction and will require management. The strategy for management of excavated rock will aim to maximise beneficial reuse of materials for construction activities. Beneficial reuse of excavated material may include use for road base, construction pad establishment, selected fill and tunnel backfill and rock armour as part of site establishment for construction. Excess excavated material that cannot be reused during construction will be disposed of within Talbingo and Tantangara reservoirs, used in permanent rehabilitation of construction pads to be left in situ at Lobs Hole, or transported for on-land disposal if required.	Placement areas are shown in Figure 2.2 and Figure 2.6.
Barge launch facilities	Barge launch facilities on Talbingo Reservoir will have already been established during Exploratory Works for the placement of the submarine communications cable, and will continue to be used for the Snowy 2.0 Main Works for construction associated with the Talbingo intake structure. The Snowy 2.0 Main Works will require the establishment of barge launch facilities on Tantangara Reservoir to enable these similar works (removal of the intake plug).	Barge launch sites are shown in Figure 2.2 and Figure 2.6.
Construction workforce	The construction workforce will be accommodated entirely on site, typically with a FIFO/DIDO roster. Private vehicles will generally not be permitted and the workforce bused to and from site.	Access to site will be via Snowy Mountains Highway

The key areas of construction are shown in Figure 2.2 and described below:

- Talbingo Reservoir – Talbingo Reservoir provides the lower reservoir for the pumped hydro-electric project and will include the tailrace tunnel and water intake structure. The site will also be used for temporary construction compounds and other temporary ancillary activities;
- Lobs Hole – this site will be used primarily for construction (including construction of the MAT and ECVT portals and tunnels to the underground power station and the headrace tunnel (and headrace tunnel surge shaft), underground tailrace surge shaft and a temporary accommodation camp);

- Marica – the site will be used primarily for construction to excavate the ventilation shaft to the underground power station as well as for the excavation and construction of the headrace surge shaft;

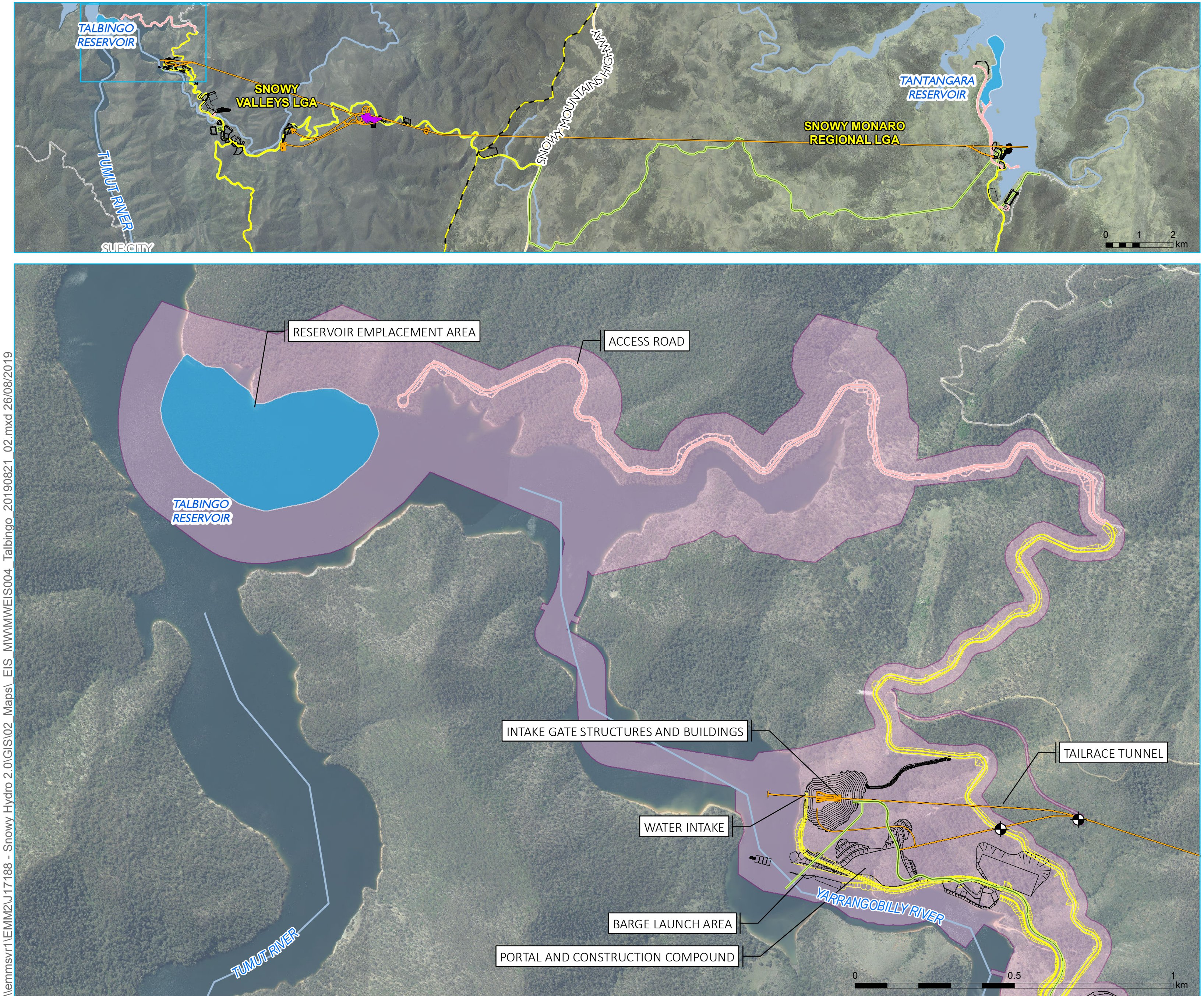
- Plateau – the land area between Snowy Mountains Highway and Tantangara Reservoir is referred to as the plateau. The plateau area will be used to access and construct a utility corridor and construct a fish weir on Tantangara Creek;

- Tantangara Reservoir – Tantangara Reservoir will be the upper reservoir for the pumped hydro-electric project and include the headrace tunnel and intake structure. The site will also be used for a temporary construction compound, accommodation camp and other temporary ancillary activities; and

- Rock Forest – the site to be used temporarily for logistics and staging during construction. It is located beyond the KNP along the Snowy Mountains Highway about 3 km east of Providence Portal.

During the construction phase, all work sites will be restricted access and closed to the public. This includes existing road access to Lobs Hole via Lobs Hole Ravine Road. Restrictions to water-based access and activities will also be implemented for public safety and to allow safe construction of the intakes within the reservoirs. Access to Tantangara Reservoir via Tantangara Road will be strictly subject to compliance with the safety requirements established for the project.

A key construction element for the project is the excavation and tunnelling for underground infrastructure including the power station, power waterway (headrace and tailrace tunnels) and associated shafts. The primary methods of excavation are shown in Figure 2.7 with further detail on construction methods provided at Appendix D of the EIS.



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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KEY

Existing environment
- Main road
- Local road
- Watercourse
- Waterbodies
- Local government area boundary

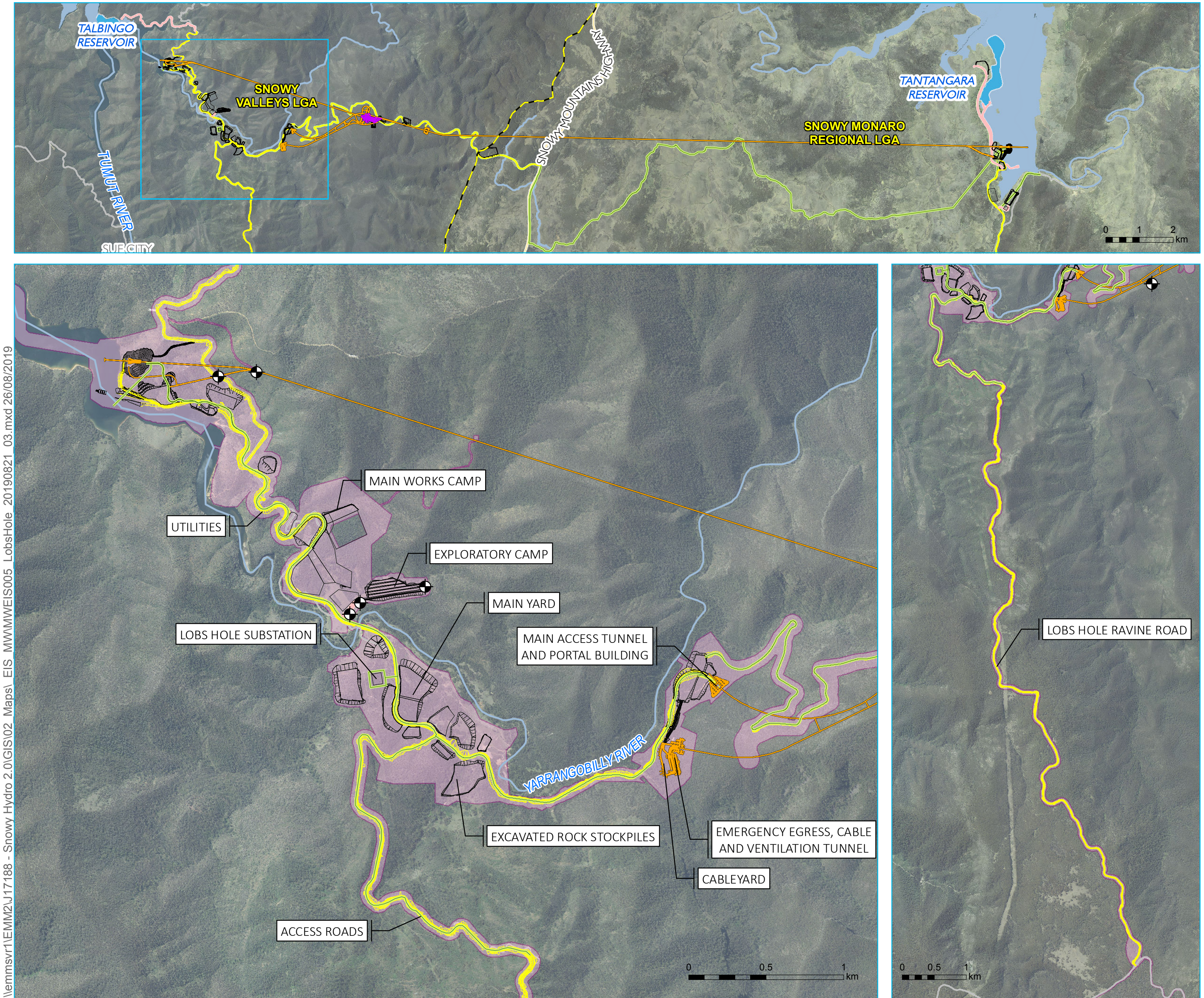
Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Geotechnical investigation
- Indicative rock emplacement area
- Disturbance area*

Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during detailed design.

Talbingo Reservoir - project elements, purpose and description

Snowy 2.0
Water assessment
Main Works
Figure 2.2



KEY

Existing environment
- Main road
- Local road
- Watercourse
- Waterbodies
- Local government area boundary

Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Geotechnical investigation
- Indicative rock emplacement area
- Disturbance area*

Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during detailed design.

Lobs Hole - project elements, purpose and description

Snowy 2.0
Water assessment
Main Works
Figure 2.3

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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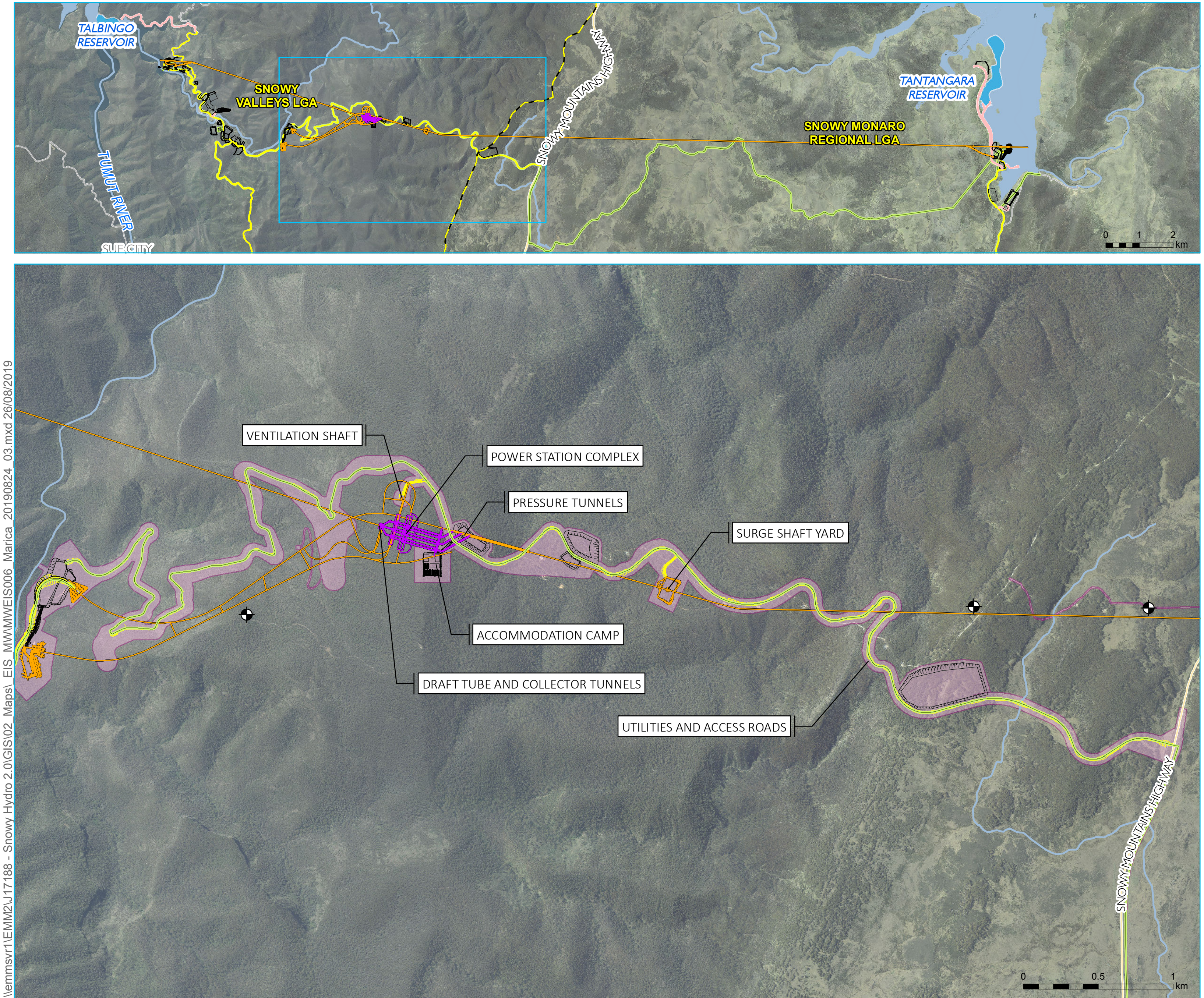

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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

GDA 1994 MGA Zone 55

N

KEY

Existing environment

- Main road
- Local road
- Watercourse
- Waterbodies
- Local government area boundary

Snowy 2.0 Main Works operational elements

- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements

- Temporary construction compounds and surface works
- Temporary access road
- Geotechnical investigation
- Indicative rock emplacement area
- Disturbance area*

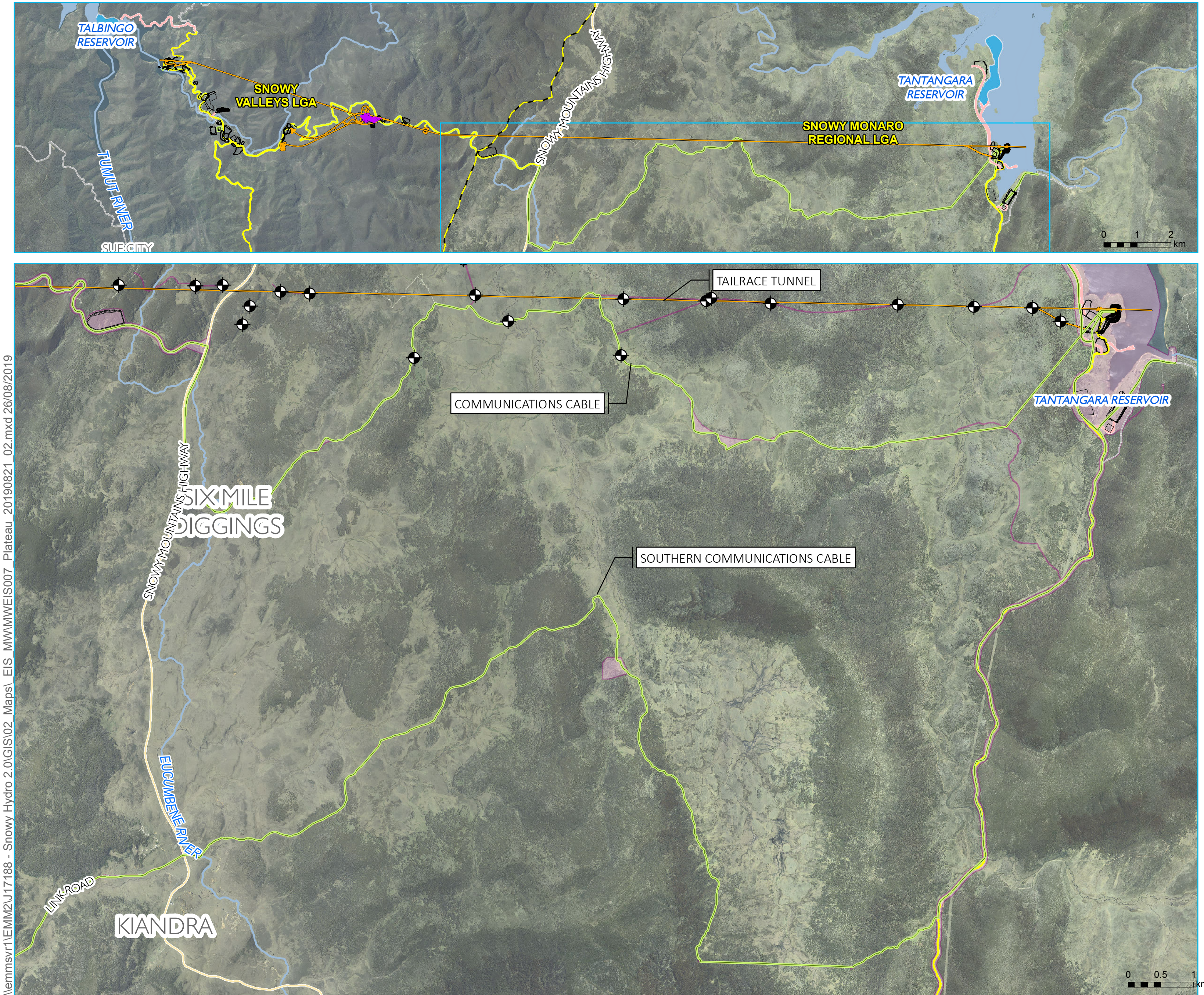
Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during detailed design.

Marica - project elements, purpose and description

Snowy 2.0
Water assessment
Main Works
Figure 2.4

snowy 2.0

EMM creating opportunities



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

GDA 1994 MGA Zone 55

N

KEY

Existing environment
- Main road
- Local road
- Watercourse
- Waterbodies
- Local government area boundary

Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Geotechnical investigation
- Indicative rock emplacement area
- Disturbance area*

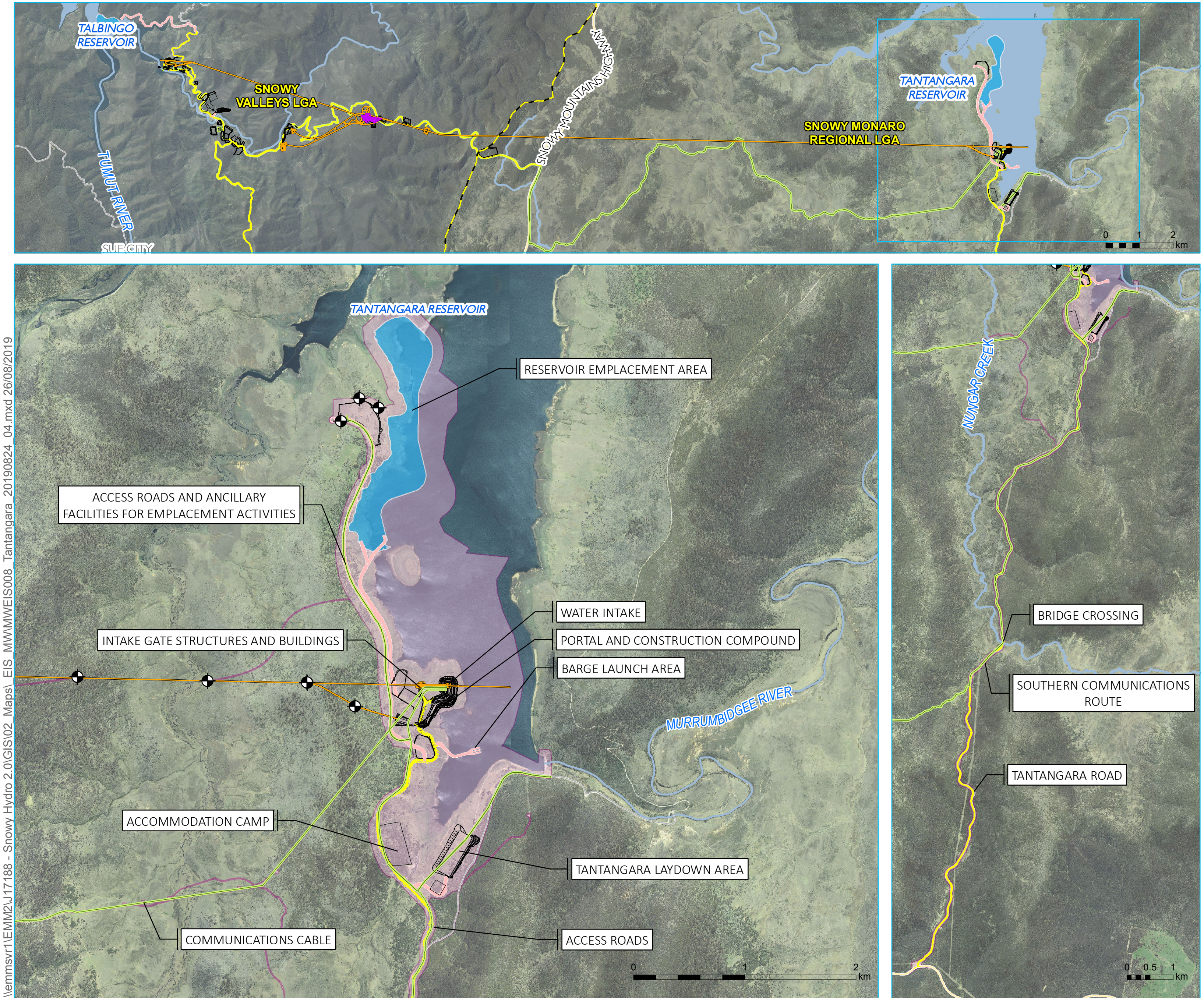
Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during detailed design.

Plateau - project elements, purpose and description

Snowy 2.0
Water assessment
Main Works
Figure 2.5

snowy 2.0

EMM creating opportunities



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

GDA 1994 MGA Zone 55

KEY

Existing environment
- Main road
- Local road
- Watercourse
- Waterbodies
- Local government area boundary

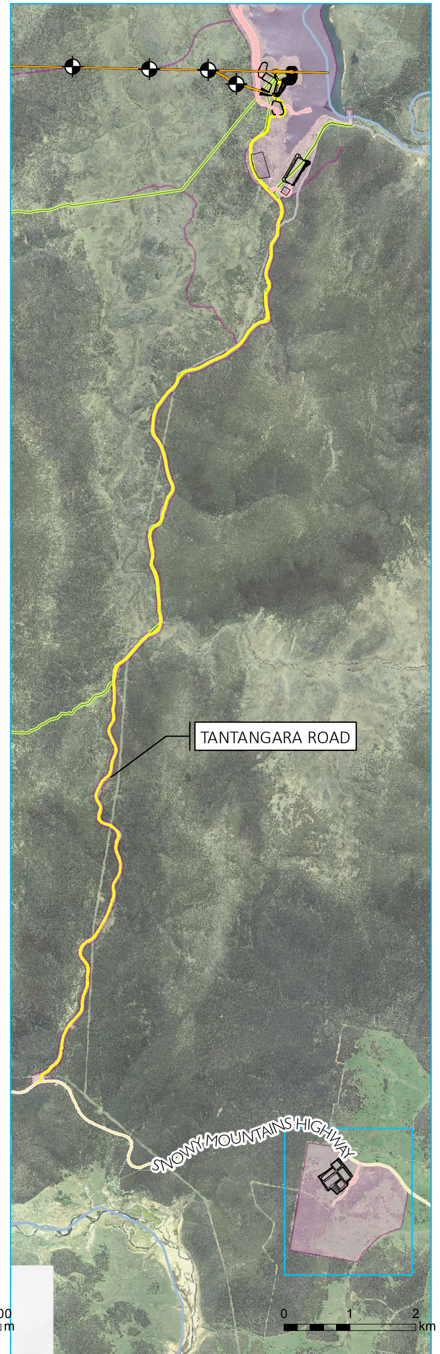
Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Geotechnical investigation
- Indicative rock emplacement area
- Disturbance area*

Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during detailed design.

Tantangara Reservoir - project elements, purpose and description

Snowy 2.0
Water assessment
Main Works
Figure 2.6



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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KEY

Existing environment

Main road

Local road

Watercourse

Snowy 2.0 operational elements

Tunnels, portals, intakes, shafts

Utilities

Permanent road

Snowy 2.0 contruction elements

Temporary construction compounds and surface works

Temporary access road

Geotechnical investigation

Disturbance area*

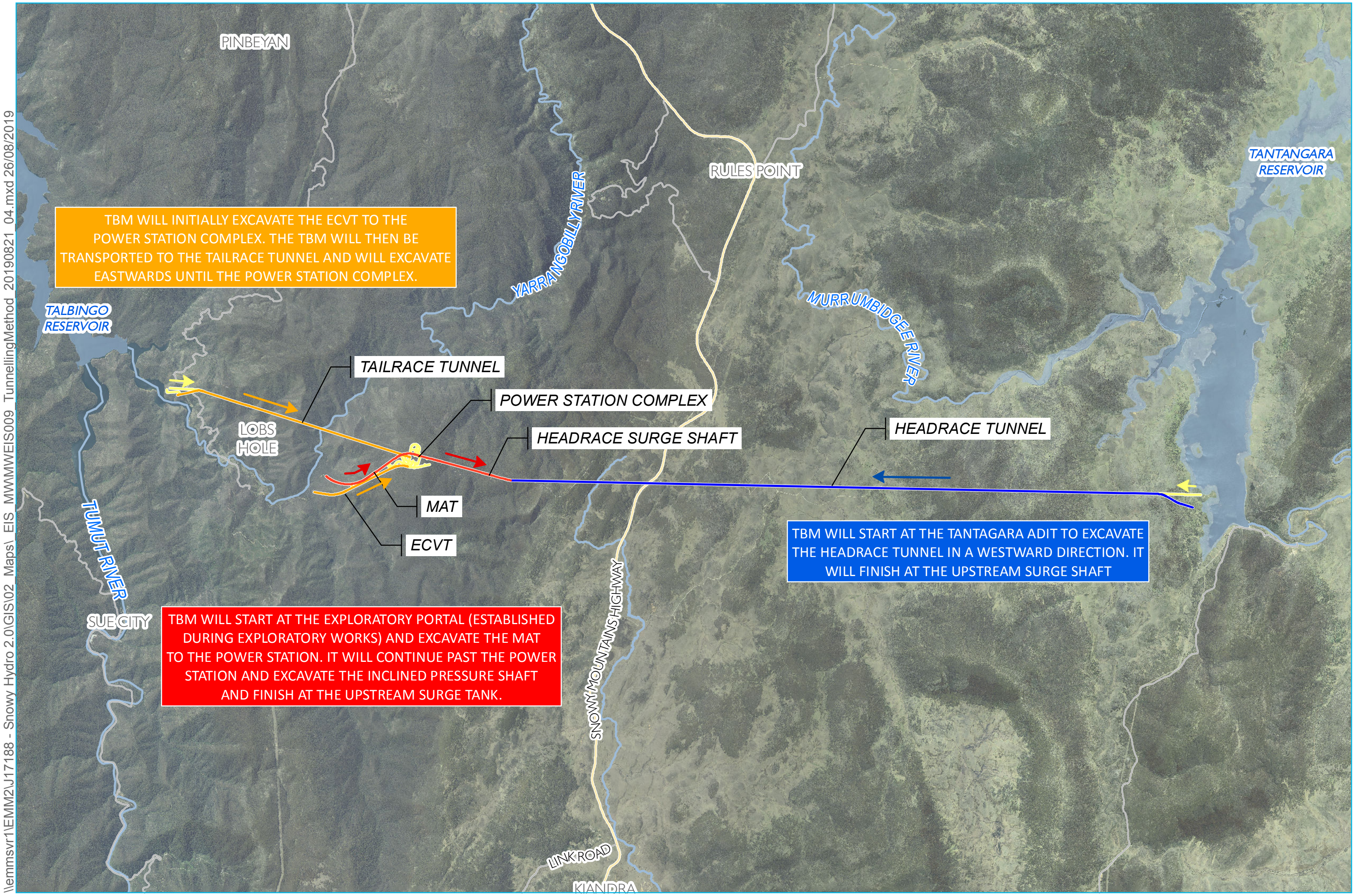
Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during detailed design.

Rock Forest - project elements, purpose and description

Snowy 2.0
Water assessment
Main Works
Figure 2.7

snowy 2.0

EMM creating opportunities



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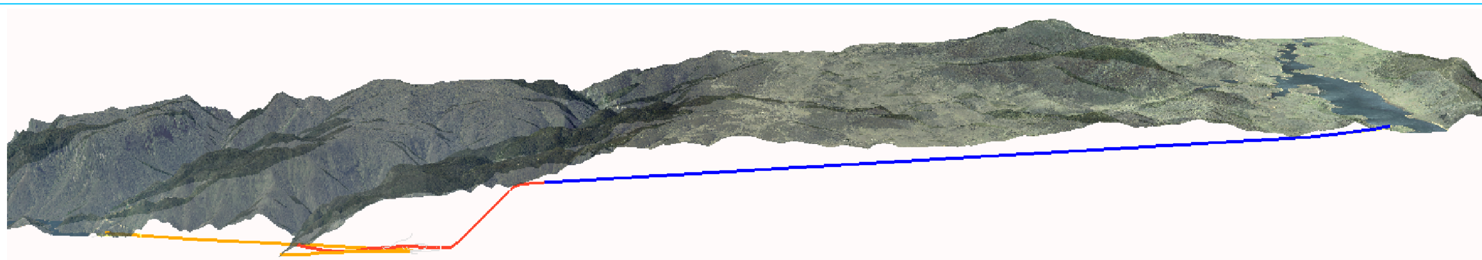
KEY

Tunnelling method

- Drill and blast
- TBM 1
- TBM 2
- TBM 3
- Tunnelling direction

Existing environment

- Main road
- Local road
- Watercourse
- Waterbodies



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km

GDA 1994 MGA Zone 55

N

Primary excavation methods – drill and blast and tunnel boring machine

Snowy 2.0
Water assessment
Main Works
Figure 2.8

2.3 Operation of Snowy 2.0

2.3.1 Scheme operation and reservoir management

Snowy 2.0 would operate within the northern Snowy-Tumut Development, connecting the existing Tantangara and Talbingo reservoirs.

Tantangara Reservoir currently has the following operational functions within the Snowy Scheme:

- collecting releases from the Murrumbidgee River and the Goodradigbee River Aqueduct;
- providing a means for storage and diversion of water to Lake Eucumbene via the Murrumbidgee-Eucumbene Tunnel; and
- providing environmental releases through the Tantangara Reservoir river outlet gates to the Murrumbidgee River.

Talbingo Reservoir currently has the following operational functions:

- collecting releases from Tumut 2 power station;
- collecting releases from the Yarrangobilly and Tumut rivers;
- acting as head storage for water pumped up from Jounama Pondage; and
- acting as head storage for generation at Tumut 3 power station.

Due to its historic relationship to both the upstream Tumut 2 Power Station and downstream Tumut 3 Power Station, Talbingo Reservoir has had more operational functions than Tantangara Reservoir in the current Snowy Scheme.

Following the commencement of the operation of Snowy 2.0, both Tantangara and Talbingo reservoirs will have increased operational functions. Tantangara Reservoir will have the additional operational functions of acting as a head storage for generation from the Snowy 2.0 power station and also acting as a storage for water pumped up from Talbingo Reservoir. Talbingo Reservoir will have the additional operational function of acting as a tail storage from Snowy 2.0 generation.

As a result of the operation of Snowy 2.0, the water level in Tantangara Reservoir will be more variable than historically. Notwithstanding this, operations will not affect release obligations under the Snowy Water Licence nor will it involve any change to the currently imposed FSLs. No additional land will be affected by inundation of the reservoirs through Snowy 2.0 operations. Water storages will continue to be held wholly within the footprint of the existing FSLs.

2.3.2 Permanent access

Permanent access to Snowy 2.0 infrastructure will be required. During operation, a number of service roads established during construction will be used to access surface infrastructure including the power station's ventilation shaft, water intake structures and gates, and the headrace tunnel surge shaft. Permanent access tunnels (the MAT and ECVT) will be used to enter and exit the power station. For some roads, permanent access by Snowy Hydro will require restricted public access arrangements.

2.3.3 Maintenance requirements

Maintenance activities required for Snowy 2.0 will be integrated with the maintenance of the existing Snowy Scheme. Maintenance activities that will be required include:

- maintenance of equipment and systems within the power station complex, intake structures, gates and control buildings;
- maintenance of access roads (vegetation clearing, pavement works, snow clearing);
- dewatering of the tailrace and headrace tunnel (estimated at once every 15 to 50 years, or as required); and
- maintenance of electricity infrastructure (cables, cable yard, cable tunnel).

2.4 Rehabilitation and final land use

A Rehabilitation Strategy has been prepared for Snowy 2.0 Main Works and appended to the EIS.

It is proposed that all areas not retained for permanent infrastructure will be revegetated and rehabilitated. At Lobs Hole, final landform design and planning has been undertaken to identify opportunities for the reuse of excavated material in rehabilitation to provide landforms which complement the surrounding topography in the KNP.

Given that most of the Snowy 2.0 Main Works is within the boundaries of the KNP, Snowy Hydro will liaise closely with NPWS to determine the extent of decommissioning of temporary construction facilities and rehabilitation activities to be undertaken following the construction.

3 Project setting

3.1 Topography

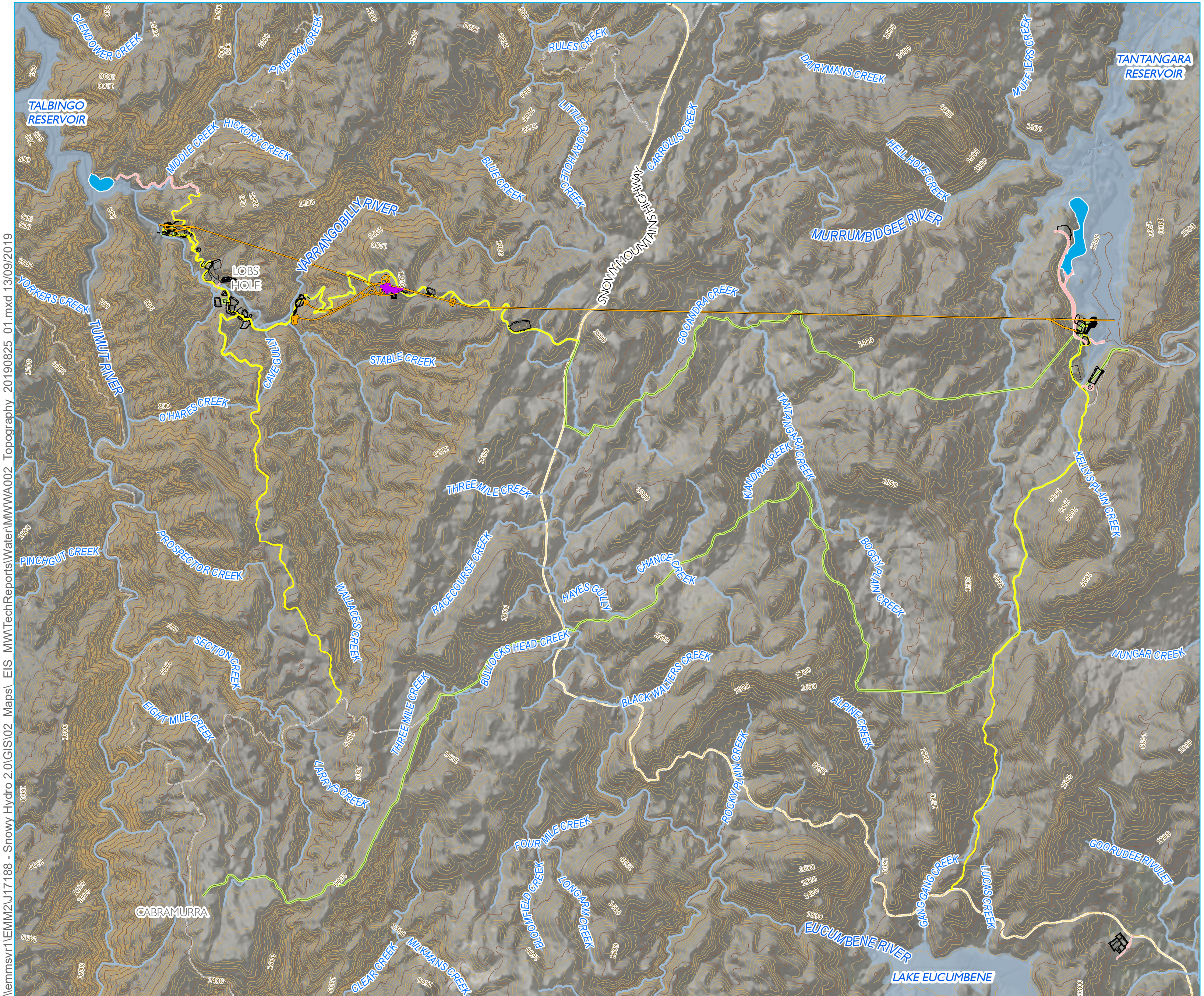
The Snowy 2.0 Main Works project spans the NSW Western Slopes, South Eastern Highlands and Australian Alps Interim Biogeographic Regionalisation for Australia (IBRA) regions. The geomorphic history of the project area is complex and has resulted in a landscape of disrupted drainage patterns, swampy basins and erosion surfaces (Snowy Hydro 2017). This complexity is seen in the diverse landforms present in the area, ranging from valleys to mountain ranges. The alpine area is dominated by granites that have formed faulted stepped ranges at the point where the South Eastern Highlands in NSW turn west into Victoria. More recent volcanic activity produced basalts in the north, which are characterised by flat-topped hills. The sedimentary rocks of the Byadbo country have eroded into steep-sided valleys and ridges, while the limestone landscapes of Cooleman Plain and Yarrangobilly are pocketed with sinkholes and caverns (NPWS 2006). Moreover, during the Pleistocene, the cold climate superimposed glacial features on the landscape, adding to the diverse topography (NPWS 2017).

Elevations across the Snowy 2.0 Main Works project area range from 545 m AHD at the Yarrangobilly River interface with Talbingo Reservoir in the west to 1,524 m AHD at Gooandra Hill to the east. For the most part, the project area can be broken into two distinctive terrains; the incised ravine area and the plateau (Figure 3.1). The ravine area; located mostly to the west of the Snowy Mountains Highway, is characterised by deep gorges and steep sloping ridges, the product of incision from river flow, historic glaciation and structural movement. The plateau area; located to the east of the Snowy Mountains Highway and spanning the area between the highway and Tantangara Reservoir, is typical of elevated alpine environments, dominated by low energy streams, gentle rolling hills and mostly flat floodplains.

3.2 Climate

The project area has an alpine climate that is characterised by cool summers and cold, damp, and snowy winters. The highest and most consistent precipitation occurs in winter to early spring, with precipitation amounts increasing with elevation. Summer and autumn are generally drier and experience greater variation in monthly rainfall. Summer rainfall is generally of higher intensity and of shorter duration than in winter.

Climate data for the project area has been sourced from regional Bureau of Meteorology (BoM) and Snowy Hydro rainfall gauges, as well as climate maps produced by BoM. A summary of climate data for the ravine and plateau areas is provided in Table 3.1. A more detailed description of the project area climate, including additional data used in the technical studies (Annexures A to D), is provided in the water characterisation report (Annexure A). It is noted that precipitation comprises rainfall and snowfall, however, the term rainfall has been used throughout the water assessment to maintain consistency with other sections of the EIS.



KEY

Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement area

Existing environment
- Main road
- Local road
- Watercourse
- Contour (100 m)
- Contour (20 m)
- Waterbodies

0 2.5 5 km

GDA 1994 MGA Zone 55

Topography

Snowy 2.0
Water assessment
Main Works
Figure 3.1

Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

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Table 3.1 Climate summary

	Ravine area	Plateau area
Temperature[1]		
Mean annual maximum	21.3 °C	12.6 °C
Mean annual minimum	9.1 °C	5.1 °C
Annual rainfall[2]		
Highest	1,315 mm/year	1,902 mm/year
Median	878 mm/year	1,158 mm/year
Lowest	382 mm/year	525 mm/year
Mean Class A pan evaporation[3]		
Annual	1,256 mm/year	
Lowest monthly	27 mm/month	
Highest monthly	206 mm/month	

Notes: 1. Representative temperature for the ravine and plateau have been sourced from Snowy Hydro operated Talbingo gauge and BoM operated Cabramurra SMHEA AWS (72161) gauge.

2. Representative rainfall for the ravine and plateau areas have been sourced from Snowy Hydro operated Ravine gauge and BoM operated Yarrangobilly Caves (72141) gauge.

3. Representative pan evaporation sourced from Climate Atlas maps (BoM website).

The 10th, 50th and 90th percentile monthly rainfall have been calculated by BoM from the Yarrangobilly Caves (72142) gauge records and are presented in Figure 3.2. Mean monthly pan evaporation sourced from the BoM website are also shown in Figure 3.2. The trends shown in Figure 3.2 indicate that a soil moisture deficit is likely to occur from December to March, when monthly evaporation exceeds the 90th percentile rainfall.

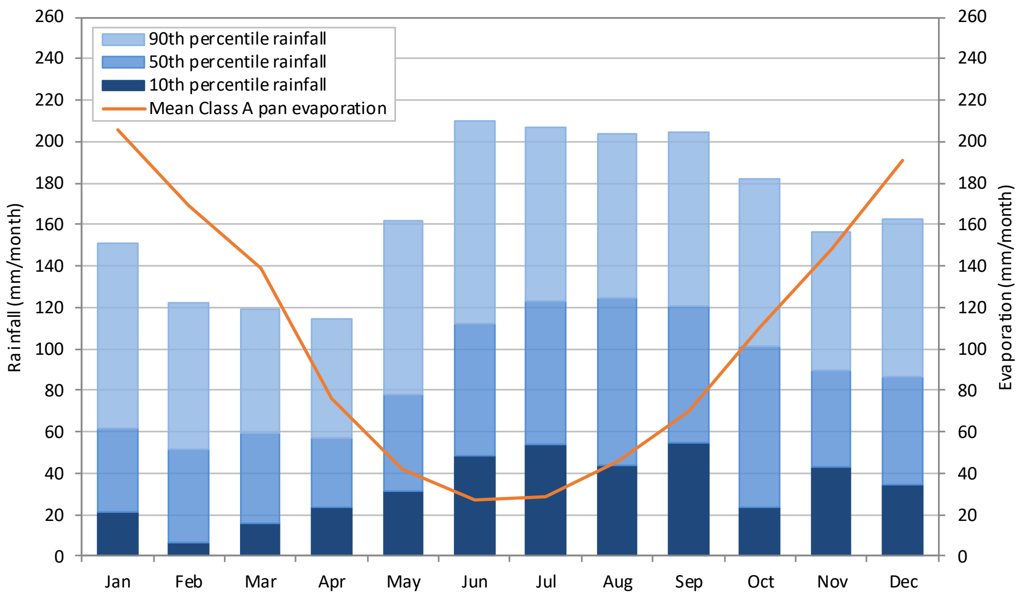


Figure 3.2 Monthly rainfall variability (BoM: 72141) and mean monthly pan evaporation

3.3 Recent rainfall

Monthly rainfall totals recorded at Yarrangobilly Caves (BoM station 72141) from 1999 to March 2019 are shown in Figure 3.3. The deviation of rainfall totals over the previous 12-month period have been calculated and compared to annualised monthly average rainfall to identify and characterise periods of extended dry and wet conditions. A positive value relates to wetter than average conditions while a negative value relates to drier than average conditions. These deficits and excess in rainfall can also correspond to long-term groundwater level and streamflow trends. The trends in Figure 3.3 indicate that:

- Below average rainfall occurred between mid-2002 to late 2003, mid-2004 to early 2005, mid-2006 to late 2010, early 2013 to mid-2016 and mid-2017 to mid-2019. The most significant below average rainfall conditions occurred between mid-2006 and late 2010.
- Above average rainfall occurred between 1999 and mid-2002, April 2005 to May 2006, late 2010 to early 2013 and mid-2016 to mid-2017.

It is noted that data collected for this EIS during 2018 and early 2019 was collected during drier than average conditions.

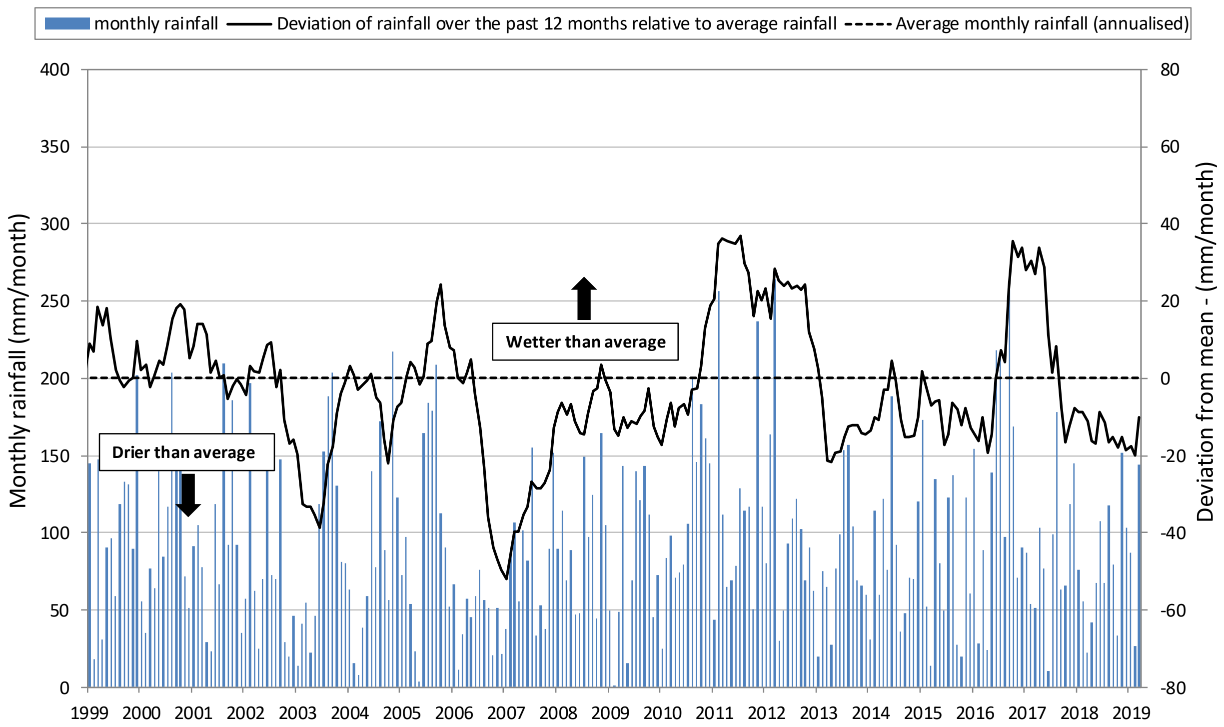


Figure 3.3 Yarrangobilly Caves (BoM: 72141) rainfall over the 1999 to 2019 period

3.4 Soils and geology

The project area is located within the south-eastern portion of the Lachlan Fold Belt (LFB) of NSW (Stuart-Smith 1991). The LFB comprises a suite of Ordovician to Devonian sedimentary, igneous and metamorphic rocks that have developed during multiple orogenic periods. These orogenic periods are associated with extensive faulting and have formed major structural features throughout the area (Wyborn et al 1990).

Volcanic activity associated with periods of uplift during the Tertiary period also resulted in the formation of basalts which form some of the ridgelines to the east of the project area.

Shallow and outcropping Ordovician to Devonian rocks are regionally extensively weathered, consisting of a mixture of colluviums, regolith, and weathered basement rocks.

The geology between Talbingo and Tantangara reservoirs is structurally deformed with numerous folds and several major faults associated with the north-south trending Long Plain Fault (LPF) zone. The project intercepts two major structural blocks (see Figure 3.4). These two structural blocks form distinct geological terrains; the dominantly Silurian Tumut Block in the west (the incised ravine area), and the dominantly Ordovician Tantangara Block in the east (the plateau). The terrains are separated by an escarpment caused by movement on the LPF (see Figure 3.4).

There are eight karst areas in KNP, all of which are developed in Silurian or Devonian limestones (NPWS 2006). These include Yarrangobilly Caves, a known groundwater dependent ecosystem (GDE) and karst area, and Coolemans Plain karst area; both are recognised in the KNP Plan of Management (DEC 2014) for their cultural and natural significance.

The geology of the project area is discussed in further detail in Section 6 and shown in Figure 3.4 for context. The stratigraphy of geological units relevant to the project area are presented in Table 3.2. A conceptual block diagram showing the geology and terrains in the project area is presented in Figure 3.5.

This complex geology, in association with topography, has resulted in a diverse soil landscape. Soils vary significantly in relation to altitude, temperature and rainfall. The soils reflect the extreme climatic gradient across the ranges and a relatively large range of soil types is found over a comparatively small area. Main soil orders within the project area include Kandosols, Tenosols, Dermosols, Vertosols, Ferrosols, Organosols, Hydrosols and Rudosols (Appendix N.2 of the EIS). The alpine soils support unique flora and fauna, with uniform organic soils and peats found at the highest elevations (NPWS 2003).

Table 3.2 Project area stratigraphy

Age	Formation	Description
Tertiary	Tertiary basalt	Alkali olivine basalt deposited during uplift periods. Occurs as capping on some low hills on the plateau.
Devonian	Kellys Plain Volcanics	Dacite ignimbrite, rhyodacite ignimbrite, tuff, agglomerate and rhyolite porphyritic monzogranite. Occurring in the eastern section of the of the plateau, the unit unconformably overlies the Tantangara and Peppercorn Formations.
	Boggy Plain Suite	I-type granitoids; even grained texture, mostly granodiorites and quartz monzogabbros, biotite monzogranite commonly containing hornblende. Shallow crustal – continental I-type deposits. Occurs in the eastern section of the plateau.
	Byron Range Group	Quartzite, siltstone, sandstone, shale, conglomerate and nodular limestone. Occurs in the central area of the ravine.
	Boraig Group	Rhyolite, rhyodacite, tuff, lapilli tuff, feldspathic sandstone, granophyre deposited in shield building volcanic complexes. Terrestrial – extrusive volcanic deposits.

Table 3.2 Project area stratigraphy

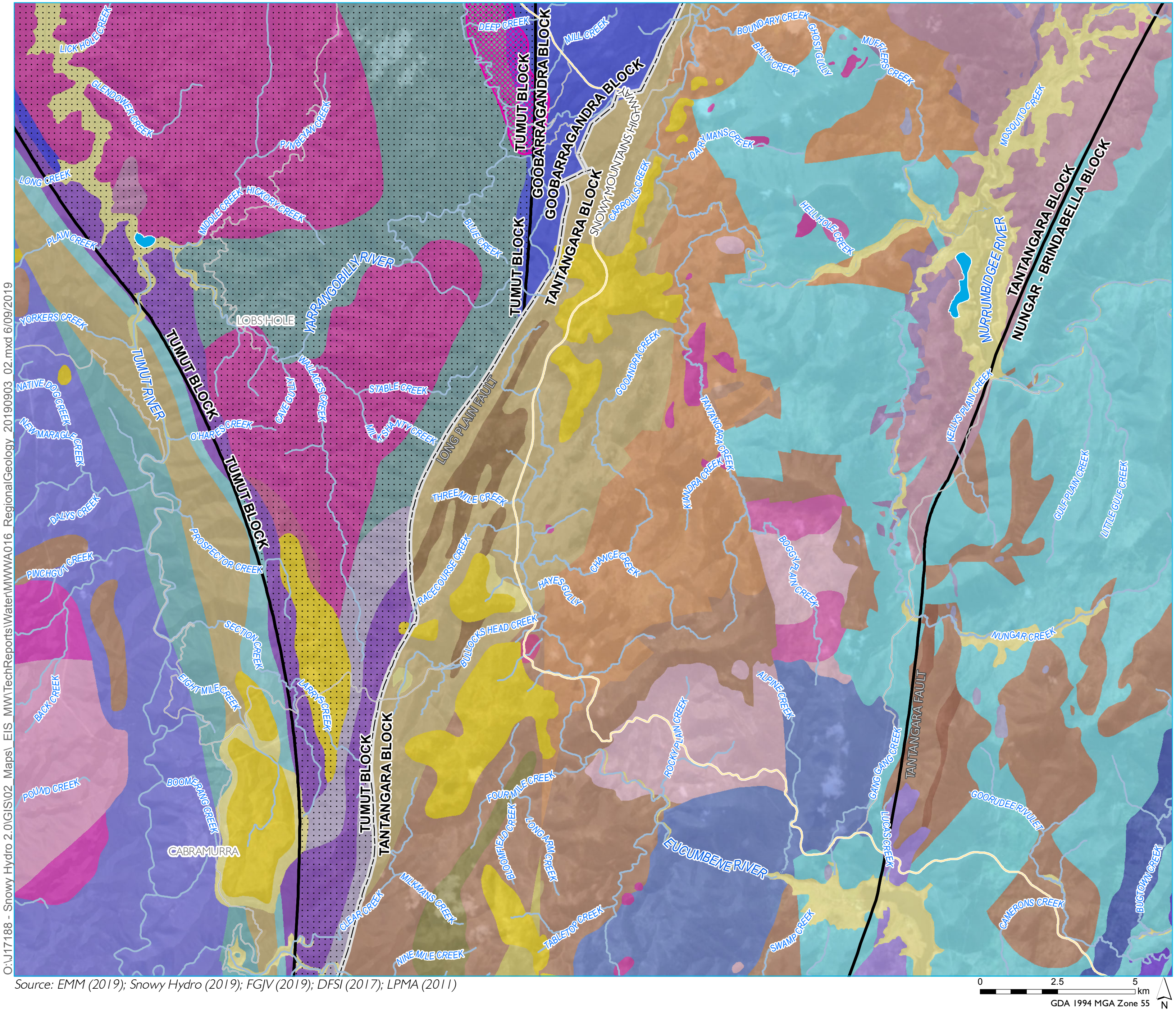
Age	Formation	Description
Silurian	Peppercorn Formation	Basal conglomerate, overlain by sandstone, siltstone and cleaved shale, with minor limestone lenses. Shallow marine shelf deposit. Occurs north of the headrace tunnel alignment.
	Tantangara Formation	Sedimentary turbidite sequence; sandstone, siltstone and shale; quartzite. Deep marine, siliciclastic deposits. Occurs in the eastern section of the plateau, adjacent to Tantangara Reservoir.
	Ravine Beds	Shale, slate siltstone and conglomerate. Shallow marine – shelf deposits. Occurs extensively throughout the ravine.
Ordovician	Temperance Formation	Sandstone, siltstone and shale with interbedded basaltic tuff, chert, feldspathic arenite and minor agglomerate. Some monzonite, hornblendite, lamprophyre and quartz monzonite. Deep marine volcaniclastic deposits. Occurs throughout much of the eastern section of the plateau.
	Shaw Hill Gabbro	Gabbro, diorite, metabasic intrusive rock and pyroxenite. Shallow crustal-continental deposits. Occurs in the western section of the plateau, adjacent to the LPF.
	Gooandra Volcanics	Metabasalt, basalt breccia (emplaced as pillow lavas), amphibolite, chloritic schists, feldspathic sandstone; aphyric and feldspar-phyric basalt, basaltic lava breccia, rhyolite, shale; fine grained feldspathic siltstone and shale. Typically, deep marine-extrusive volcanic deposits. Occurs throughout the western section of the plateau.

3.5 Water resources

3.5.1 Surface water management units

The project area lies predominantly within the Murrumbidgee River catchment and within a minor area within the Snowy River Catchment. The Murrumbidgee River is a mostly a regulated system and has 14 dams and eight large weirs, designed to support primarily environmental receivers, power generation and irrigation. The Murrumbidgee Catchment drains to the Murray River and forms part of the Murray Darling Basin. The upper section of the Murrumbidgee River (upstream of Burrinjuck Dam), is considered unregulated for purposes of water management and licensing. Tantangara Dam is located in the upper reaches of the Murrumbidgee River. The Snowy River catchment is unregulated and drains to the east with four major dams associated with the Snowy Mountains hydro-electric scheme.

The surface water resource catchments disturbed by the project are therefore managed under two separate water sharing plans (WSP). The *Water Sharing Plan for the Murrumbidgee unregulated and alluvial water source 2012* (unregulated Murrumbidgee WSP) and the *Water Sharing Plan for the Snowy Genoa Unregulated and Alluvial Water Sources 2016* (unregulated Snowy WSP).



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Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

KEY

- Long Plain Fault (interpreted)
- Geological domain boundary
- Yarrangobilly Caves complex
- Ravine Incised Area
- Indicative rock emplacement area

Existing environment
- Main road
- Local road
- Watercourse

Quaternary
- Quaternary

Devonian
- Boggy Plain Adamellite
- Coolamine Igneous Complex
- Crack Hardy Point Monzodiorite
- Free Dampier Adamellite
- Hell Hole Creek Adamellite
- Kellys Plain Volcanics
- Lobs Hole Adamellite
- Mountain Creek Volcanics
- Pennyweight Adamellite
- Undifferentiated

Ordovician
- Bolton Beds
- Geordies Spur Gabbro
- Gooandra Volcanics
- Shaw Hill Gabbro
- Temperance Formation
- Warbisco Shale
- Undifferentiated

Silurian
- Blowering Formation
- Bugtown Tonalite
- Gang Gang Adamellite
- Goobarragandra Volcanics
- Green Hills Granodiorite
- Jackalass Slate
- Kings Cross Formation
- Lucas Creek Granite
- McLaughlins Flat Granodiorite
- Peppercorn Formation
- Ravine Beds/Yarrangobilly Limestone
- Rough Creek Tonalite
- Tantangara Formation
- Tumut Ponds Sepentinite
- Undifferentiated

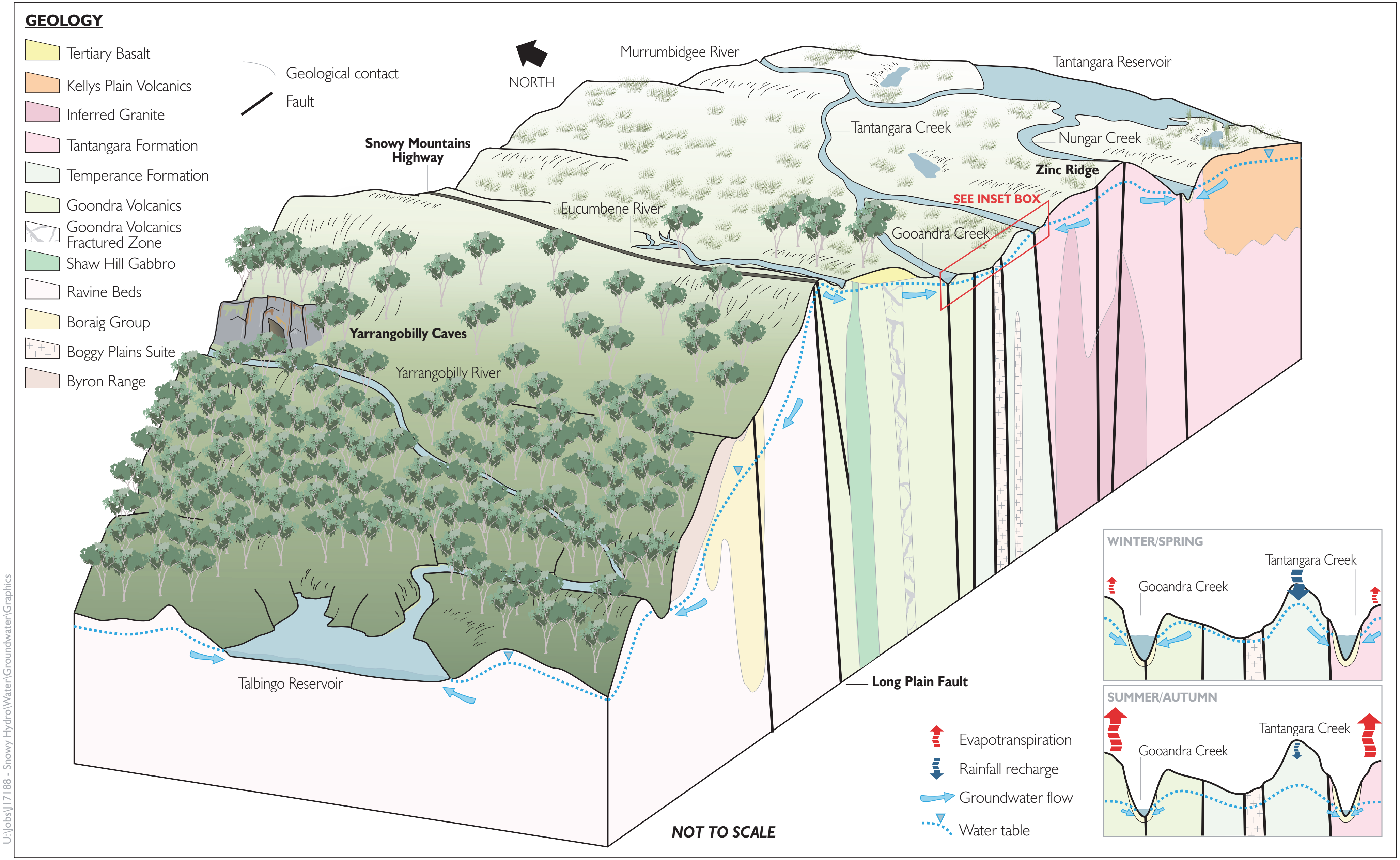
Tertiary
- Tertiary

Regional geology and Snowy 2.0 geological terrains

Snowy 2.0
Water assessment
Main Works
Figure 3.4

snowy 2.0

EMM
creating opportunities



EMM creating opportunities

snowy2.0

Snowy 2.0 conceptual geological block diagram

Snowy 2.0
Water Assessment
Figure 3.5

The unregulated Murrumbidgee WSP comprises the Murrumbidgee River catchment and the adjoining Billabong Creek catchment and contains 39 unregulated surface water sources and six alluvial groundwater sources, covering an area of approximately 84,000 km^2.

The unregulated Snowy WSP comprises the Snowy River Catchment and the adjoining Genoa River catchment and contains 25 unregulated surface water sources (which include both the surface water and alluvial groundwater beneath them), covering an area of approximately 10,077 km^2.

The water sources within the project area are the:

- Upper Tumut water source (unregulated Murrumbidgee WSP);
- Lake Eucumbene water source (unregulated Snowy WSP);
- Tantangara water source (unregulated Murrumbidgee WSP); and
- Murrumbidgee Zone 1 water source (unregulated Snowy WSP).

The unregulated Murrumbidgee WSP can be divided into three main extraction management units (EMU) defined by extraction related to long-term average annual extraction limits, these are:

- *Unregulated Murrumbidgee above Burrinjuck Dam EMU* (which contains the Tantangara water source and Murrumbidgee Zone 1 water source);
- *Unregulated Murrumbidgee below Burrinjuck Dam to Gogeldrie EMU* (which contains the Upper Tumut water source below Burrinjuck Dam); and
- the Billabong Creek catchment.

The unregulated Snowy WSP can also be divided into three main EMUs defined by extraction related to long-term average annual extraction limits, these are:

- *Alpine Rivers EMU* (which contains the Lake Eucumbene water source);
- *Lower NSW Snowy River EMU*; and
- the Genoa River catchment.

Table 3.3 provides a summary of the WSPs, EMUs and water sources applicable to the project.

Table 3.3 Water sharing plans and water sources within the project area

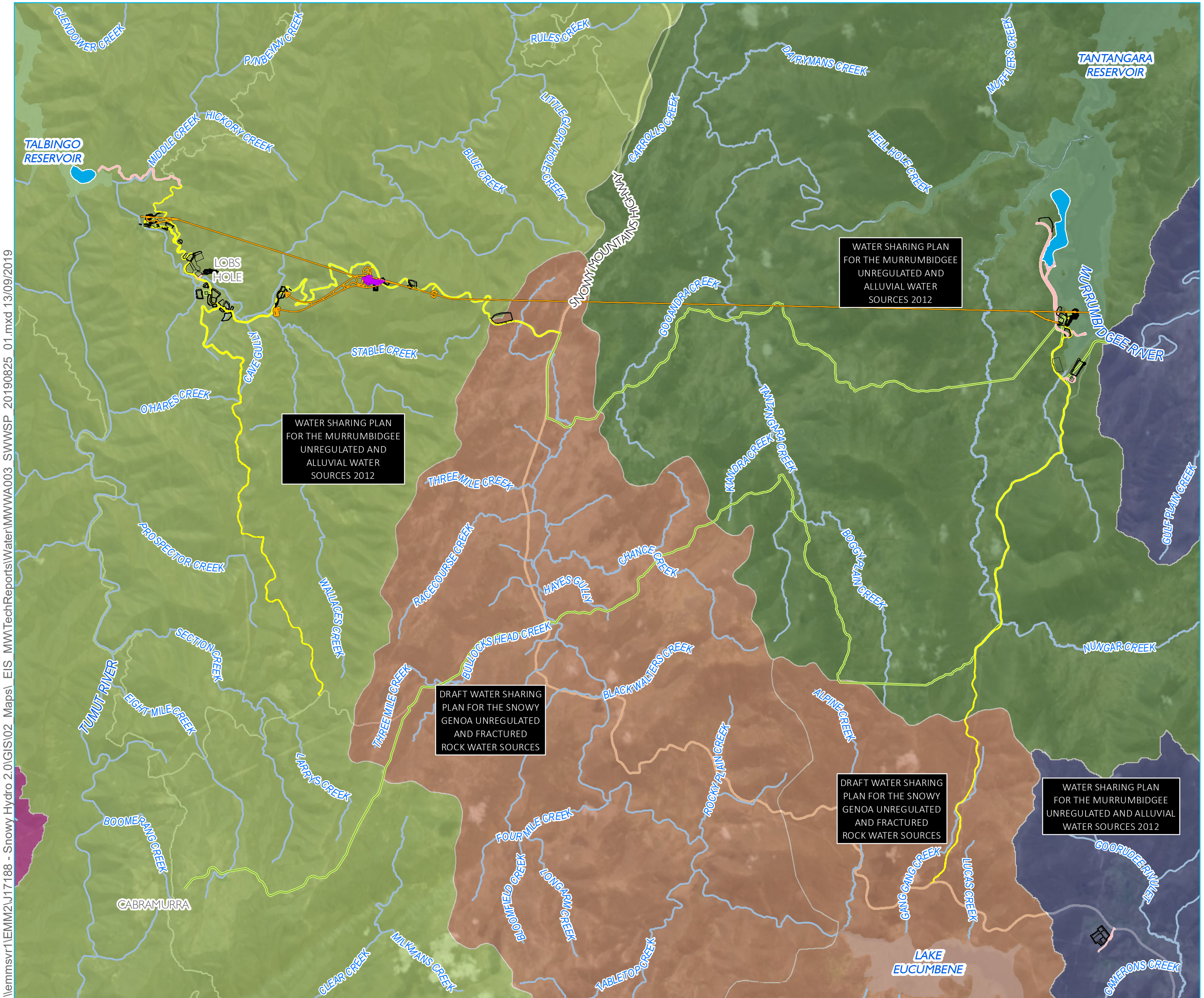
Water sharing plan	Extraction management unit (applicable to the project)	Water sources applicable to the project
Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012	*Unregulated Murrumbidgee above Burrinjuck Dam EMU*	Tantangara water source Murrumbidgee Zone 1 water source
	Unregulated Murrumbidgee Below Burrinjuck Dam to Gogeldrie EMU	Upper Tumut water source
Water Sharing Plan for the Snowy Genoa Unregulated and Alluvial Water Sources 2016	*Alpine Rivers EMU*	Lake Eucumbene water source

Figure 3.6 shows the location of the surface water sources and EMUs intercepted by the project.

3.5.2 Groundwater management units

The groundwater resources of the project are primarily regulated by the *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011* and are within the LFB Murray Darling Basin (MDB) Groundwater Source. There are two Management Zones within this water source and the one applicable to the project is the LFB MDB (other) Management Zone.

A small portion of the project area is within the *Water Sharing Plan for the South Coast Groundwater Sources 2016*, specifically the LFB South Coast Groundwater Source.



KEY

Surface water source
- Lake Eucumbene Water Source
- Murrumbidgee I Water Source
- Tantangara Water Source
- Upper Tumut Water Source
- Tooma Water Source

Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement area

Existing environment
- Main road
- Local road
- Watercourse
- Waterbodies

Surface water sources

Snowy 2.0
Water assessment
Main Works
Figure 3.6

Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

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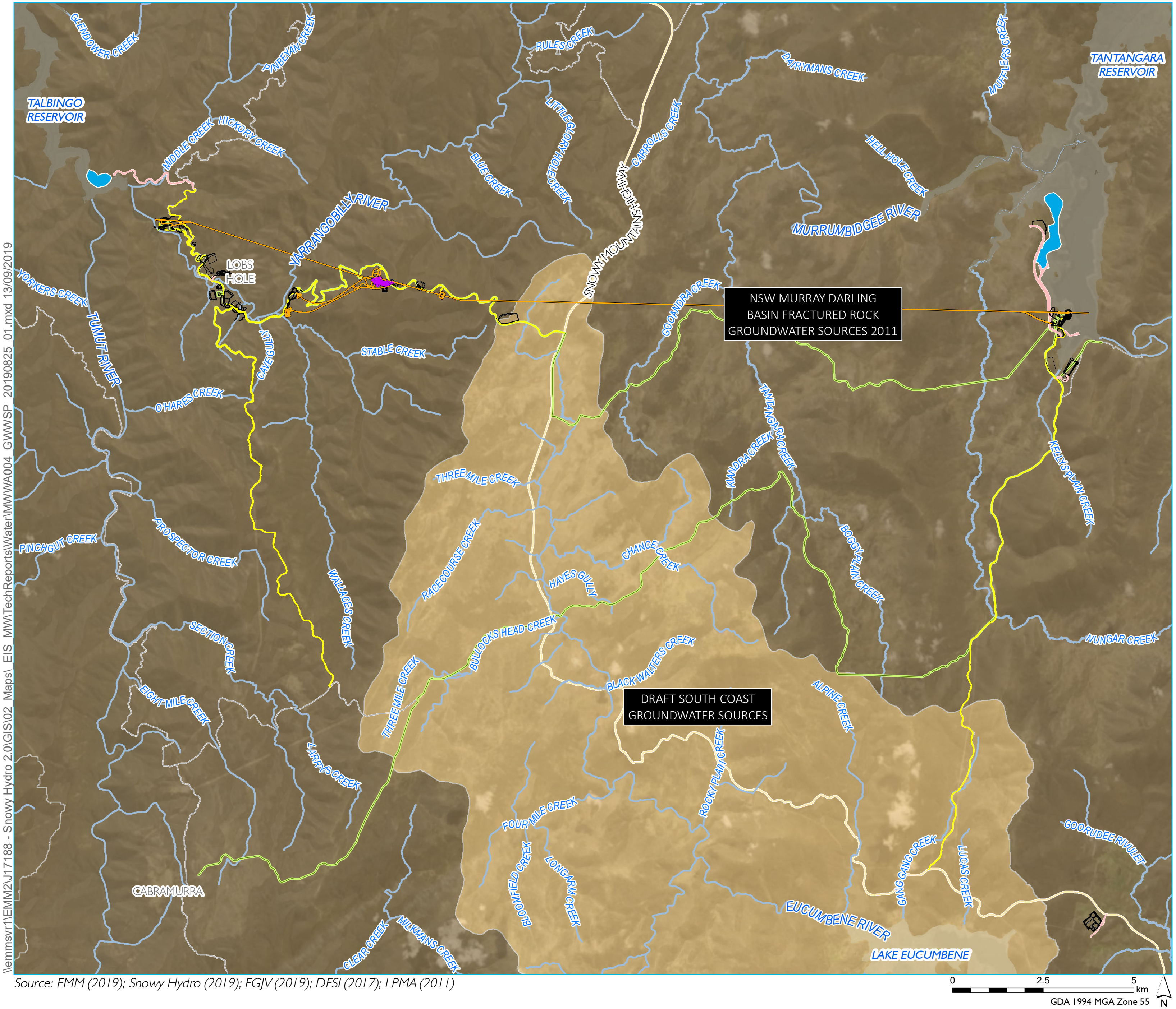

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Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

KEY

Water sharing plan
- Lachlan Fold Belt - South Coast Groundwater Sources
- Lachlan Fold Belt - NSW Murray Darling Basin Fractured Rock Groundwater Sources

Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement area

Existing environment
- Main road
- Local road
- Watercourse
- Waterbodies

Groundwater sources

Snowy 2.0
Water assessment
Main Works
Figure 3.7

snowy 2.0

EMM creating opportunities

3.5.3 Surface water

Most of the project area is located between Talbingo and Tantangara reservoirs, within the catchments of the Yarrangobilly, Eucumbene and Murrumbidgee rivers. Watercourses across the project area vary according to soil type, geology, topography and climate, and range from small ephemeral watercourses to regional rivers with perennial flow regimes.

The plateau area is located within the upper reaches of the Murrumbidgee and Eucumbene River catchments, wholly within KNP. Both the Murrumbidgee and Eucumbene rivers flow into reservoirs that form part of the Snowy hydro-electric scheme. There are no flow diversions upstream of the reservoirs (in the vicinity of the project area).

As defined above, the ravine area is located between Talbingo Reservoir (to the west) and the LPF (to the east). The Yarrangobilly River is the major regional watercourse that flows into Talbingo Reservoir, downstream of Lobs Hole. The Yarrangobilly River catchment area is 271 km^2 and is wholly within KNP.

Rock Forest is in the headwaters of the Goorudee Rivulet catchment, outside of KNP. The property is characterised by rolling topography and is traversed by Camerons Creek, a fourth order watercourse with a 12.2 km^2 catchment area, and an unnamed third order watercourse with a 1.9 km^2 catchment area.

Further characterisation of the surface water environment is provided in the water characterisation report (Annexure A).

3.5.4 Groundwater

As defined above, most of the project area is located between Talbingo and Tantangara reservoirs, within the Tumut (ravine) and Tantangara (plateau) structural blocks. The two structural blocks are separated by the north-south trending LPF, forming distinct geological terrains and associated groundwater systems.

The groundwater units within the project area are defined as:

- a localised highly permeable shallow groundwater system associated with the thin basalt caps present across the plateau area;
- a low permeability fractured rock groundwater system associated with the weathered and oxidised shallow component of the geology across the plateau area; and
- a low permeability regional fractured rock groundwater system associated with the volcanic and metasedimentary rock across the plateau and ravine areas.

In addition, localised groundwater systems are associated with unconsolidated Quaternary alluvium and colluvium deposited in major creeks and river valleys, and in depressions across the plateau and ravine areas.

The fractured rock volcanic and metasedimentary rock is the main hydrogeological unit in the project area. The unit is accessed by various environmental users, including alpine bog/fen vegetation, deep rooted Eucalypt species and gaining creeks and rivers. There are no recorded landholder bores located within the project area. Groundwater within the fractured rock unit is generally fresh and low yielding.

The volcanics intercepted by the project across the western plateau area have been extensively deformed through structural movement resulting in enhanced secondary porosity and vertical connection.

The metasedimentary units located across the remainder of the plateau area (closer to Tantangara Reservoir) and within the ravine area are more massive with reduced permeabilities.

Reported yields from test production and operational production bores (owned by Snowy Hydro) generally vary between 0.5 and 4 L/s (see Annexure A).

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*), NSW Protection of the Environment Operations Act 1997* (POEO Act), the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (*EPBC Act), and their attendant regulations (including WSPs 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 at sensitive receptors in accordance with prescribed minimal impact criteria.

4.1 NSW Water Act 1912

The WA 1912 is gradually being repealed and replaced by the WMA 2000 as 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 the requirement to hold a licence for all monitoring bores greater than 40 m in depth. This is the only obligation under the WA 1912 for the Snowy 2.0 Main Works.

4.2 NSW 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.

4.2.1 Water Sharing Plans

WSPs are statutory documents that apply to one or more water sources. They contain the rules for sustainably sharing and managing water resources within water source areas. WSPs outline the vision, objectives and strategies for achieving sustainable water sharing, and describe the basis for water sharing. WSPs document the water available and how it is shared between environmental, extractive, and other uses. WSPs also outline the water available for extractive uses within different categories (at the time the plan commenced), such as: local water utilities, domestic and stock, basic rights, and access licences. WSPs establish trading rules and mandatory licence conditions that apply to licence holders within each water source.

The NSW Water Register is an online and real-time database that contains up to date information on licence volumes within different licence categories which may change over time.

The WSPs, associated water sources, available water, basic rights and licence shares as outlined in the WSPs applicable to the Snowy 2.0 Main Works are outlined in Table 4.1.

Table 4.1 Available water, basic rights and licence shares - groundwater

WSP	***WSP for the South Coast Groundwater Sources 2016***	***WSP for the NSW MDB Fractured Rock Groundwater Sources 2011***	***WSP for the Murrumbidgee Unregulated and Alluvial water source 2012***			***WSP for the Snowy Genoa Unregulated and Alluvial Water Sources 2016***
Water source	**LFB South Coast Groundwater Source**	**LFB MDB Groundwater Source**	**Upper Tumut water source (unregulated surface water)**	**Tantangara water source (unregulated surface water)**	**Murrumbidgee Zone 1 water source**	**Eucumbene River water source (unregulated surface water)**
Recharge (ML/yr)						
Not High Environmental Value	400,000	3,502,609	NA	NA	NA	NA
High Environmental Value	280,000	224,627				
Environmental water (ML/yr)						
Not High Environmental Value (95% for Coast, 75% for MDB)	380,000	2,626,957				
High Environmental Value (100%)	280,000	224,627				
Long term average annual extraction limit (LTAAEL)	20,000 (3% of total annual recharge)	875,652 (23% of total annual recharge)				
Requirements for water (ML/yr)						
Basic Landholder Rights (at time plan Gazetted)						
Domestic and Stock rights	2,697	74,311	10	5	218	37.6
Native title	0	0	0	0	0	0
Access licences (as per the NSW Water Register on 20 August 2019)						
Domestic and stock	0	0	7	0	653.5	10.5
Domestic and stock (town water supply			153		2,134	
Aquifer (town water supply)	21.5	467				
Local water utility	20	3,371	153	0	0	0

Table 4.1 Available water, basic rights and licence shares - groundwater

WSP	***WSP for the South Coast Groundwater Sources 2016***	***WSP for the NSW MDB Fractured Rock Groundwater Sources 2011***	***WSP for the Murrumbidgee Unregulated and Alluvial water source 2012***			***WSP for the Snowy Genoa Unregulated and Alluvial Water Sources 2016***
Water source	**LFB South Coast Groundwater Source**	**LFB MDB Groundwater Source**	**Upper Tumut water source (unregulated surface water)**	**Tantangara water source (unregulated surface water)**	**Murrumbidgee Zone 1 water source**	**Eucumbene River water source (unregulated surface water)**
Local water utility (domestic and commercial)		50				
Share components of aquifer access licences	1,210.5	67,257	0	0		0
Unregulated river			45		1,752.5	68.5
Unregulated river (Snowy 2.0 Project)			227			
Salinity and watertable management access licences	NA	236	NA	NA		NA
Total requirements for water	NA	74,889	205	5		116.6
Total measured and recorded water usage in 2018/19	**14.5**	**5,333**	**0**	**0**	**362.4**	**0**
Unassigned water - available (LTAAEL minus total requirements for water)	**16,051**	**729,960**	**0**	**0**	**0**	**0**

Notes: ML/yr = megalitres per year

One share component is equivalent to 1ML (unless a reduced available water determination is made for the water source).

NA = not applicable

Neither the LFB MDB groundwater source nor the LFB South Coast groundwater source is fully allocated. The LFB MDB groundwater source is approximately 17% allocated, with an additional 729,960 shares (one share component is equivalent to 1 ML) of water available for release. The LFB South Coast groundwater source is approximately 20% allocated, with an additional 16,051 shares of water still available for release.

The release of these additional licence shares is made available via controlled allocation approximately every 12-18 months. The volumes historically allocated have been relatively minor, with 304 ML in 2013, none in 2014, and the results of the 2017 yet to be made public. Prices ranged between $650 and $900 per share component. This water is applied for and purchased directly from the NSW Government and the next release via controlled allocated has been announced for 8 October 2019. More details are provided in Section 4.2.1iv.

Under the AIP, the project will need to hold a licence to the equivalent volume of the water extracted each year. When submitting an EIS for a project, there needs to be a demonstrated pathway for the peak water demand to be obtained from the source in which it originates. The numerical groundwater model (Section 10) demonstrates that water inflow that reports to the tunnel during construction and operation will be sourced from the LFB MDB and LFB South Coast groundwater sources. The pathway for these share components to be obtained is therefore via the controlled allocation process scheduled for 8 October 2019. Snowy Hydro will therefore apply for the required peak inflow demand under the upcoming controlled allocation process.

Surface water licences are not required for the project due to exemptions (ie sediment dams) or due to the source of the water ultimately being from groundwater (ie reduced baseflow contribution is sourced from groundwater).

i Environmental water

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

For groundwater, environmental water is typically defined as 100% of the storage volume plus a proportion of the annual recharge volume. The recharge component of the environmental water volume comprises, a combination of *Not High Environmental Value*, and *High Environmental Value Areas*. The *Not High Environmental Value* proportion of recharge reserved for the environment is 75% of recharge for the LFB MDB and 95% of the recharge for the LFB South Coast groundwater sources. The *High Environmental Value* is equivalent to 100% of recharge in these areas for both water sources.

The total volume of annual recharge reserved for the environmental water as per the WSPs, is reported as 3,727,236 ML/yr for the LFB MDB (76% of average annual recharge reserved) and 680,000 ML/yr for the LFB South Coast groundwater sources (97% of the average annual recharge).

4.2.2 Water availability and licences

i Groundwater

The groundwater availability and licences for the LFB MDB Fractured Rock and South 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. The groundwater source is generally not highly productive and groundwater abstraction within the Silurian and Ordovician geological units is generally for stock and domestic purposes. The actual measured and recorded groundwater usage for the 2018/19 water year is minimal at 14.5 ML (or 0.4% of the LTAAEL) for the LFB South Coast groundwater source, and 5,333 ML (3.6% of the LTAAEL) for the LFB MDB groundwater source. Therefore, there are very large volumes of water unassigned within these water sources available to be granted.

Share components for a WAL 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.

Four orders have been made over recent years (2013, 2014, 2017 and 2018), with 304 ML being allocated in 2013, none in 2014, and the results of the orders in 2017 and 2018 are yet to be made public. Prices for water ranged between $650 and $900 per share component (ie per ML). The 2017 controlled allocation order was gazetted on

5 May 2017, and in the LFB MDB groundwater source there were 37,723 shares released at $650/share, and in the LFB South Coast groundwater source there were 2,000 shares released at $500 per share.

Published results from previous controlled allocation releases are provided in Table 4.2.

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	LFB MDB Groundwater Source	36,375	4	900	3600
			300	800	240,000
4 September 2014	LFB MDB Groundwater Source	5,114	-	-	-
5 May 2017	LFB MDB Groundwater Source	37,723	NA	650	NA
	LFB Coast Groundwater Source	2,000	NA	500	NA

The NSW Government have announced on their website that the next controlled allocation release is scheduled to commence on 8 October 2019 (DPIE 2019), and this is the pathway that Snowy Hydro will undertake to secure remaining groundwater licences required for the project.

ii Surface water

The surface water available for extractive uses within the unregulated surface water sources is shown in Table 4.1. There are minimal requirements for water in these water sources, mainly due to the fact that most are within KNP and therefore the demand to extractive water supply purposes is extremely limited.

The requirements for water from the identified water sources is very small in volume, and therefore the available volume for trade is also very limited (see Table 4.3). Trading of the water from existing users to offset potential project water impacts would effectively 'sterilise' this water from being used productively within these water sources, and in some cases insufficient water exists on the trading market to purchase to offset these impacts.

Table 4.3 Surface water sources and water available for trade

Water source	Requirements for water (ML)	Available water for trade (ML)
Upper Tumut water source	635	45
Murrumbidgee Zone 1 water source	4,758	1,752
Tantangara water source	5	0
Eucumbene River water source	116.6	68.5

Snowy Hydro have access to a Specific Purpose Access Licence for 227 ML to take water from the Upper Tumut water source to account for the take of surface water from Talbingo water storage for the purposes of the Snowy 2.0 Exploratory Works. The impact of this volumetric take was assessed as minimal in the approved Exploratory Works EIS.

Water trading is currently restricted to within individual water sources within the rules of the individual WSPs. However, prior to the plans being gazetted, trading of water was not restricted to water source boundaries, and since the WSPs have commenced there has been debate and interest in trading across water source boundaries for some areas where the water sources are particularly small, or the available trading market is limited in number.

To comply with the Murray Darling Basin Plan (2012), then NSW Government is developing Water Resource Plans for all water resource areas in the Basin. These Water Resource Plans need to be developed in conjunction and in accordance with the WMA 2000 and the existing legislative WSPs. In order for this to occur amendments to existing WSPs are being proposed.

The *Murrumbidgee Surface Water Resource Plan* proposes amendments to trading rules in the WSP, and specifically a note in Part 10 Subclause 72 of the *DRAFT WSP for the Murrumbidgee Unregulated River Water Sources 2012 (amended 2019)* states that:

> Minister's Note. The Department of Industry – Water is considering an option to allow limited conversion of regulated river (high security) access licences to access licences in connected upstream unregulated river water sources. This would enable some additional water to be taken in upstream areas without affecting water availability in the downstream storage/s, but may need to be subject to an assessment of potential local impacts of any such trade on the environment and access to water by other water users, and may be limited in scope. This is a new concept that is yet to be discussed with stakeholders (including the Murrumbidgee Stakeholder Advisory Panel). As such, no provisions to facilitate it have been included within this draft amended plan, other than an amendment provision within Part 12. If pursued, new provisions will need to be incorporated into the Plan. More information will be prepared for additional stakeholder consultation before this issue is formally considered, however early stakeholder feedback on the concept is welcome.

Snowy Hydro currently only require the take of a very minimal volume of surface water for operational purposes for Exploratory Works and they have a 227 ML Specific Purpose Access Licence to cover this. At this stage it is not anticipated that Snowy Hydro will require additional surface water licences due to exemptions within the WMA 2000 and the Water Management (General) Regulation.

Snowy Hydro therefore propose to either take water under their existing Specific Purpose Access Licence and/or trade surface water from downstream users to offset impacts in upstream unregulated catchments in accordance with the above proposed amendment to the WSP, should additional volumetric licence volumed be required. This provides the pathway for securing the required water licences for the project.

In summary:

- WSPs and water sources relevant for the project have been identified and assessed;
- Snowy Hydro has identified a clear pathway to secure the required licence in the relevant groundwater sources;
- for groundwater, Snowy Hydro will participate in future controlled allocation orders as facilitated by DPIE Water and consider the trading market within the respective water sources;
- the volumes required to be licenced for groundwater have been determined in accordance with the AIP, the WMA 2000 and the respective WSP; and
- the volumes required have been calculated using conservative numerical models and are presented in detail in Section 12.

4.2.3 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 the Snowy 2.0 Main 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. The aquifer interference assessment framework is included (and completed) in Section 16.

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 will 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 watertable, 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).

Based on mapped areas of groundwater productivity in NSW (NOW 2012), the project is considered to be within a 'less productive' fractured rock source. The applicable minimal impact considerations are shown 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 impact of 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 WSP. 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 4.4 Minimal impact criteria for 'less productive' porous and fractured rock water sources

Watertable	Water pressure	Water quality
1. Less than or equal to 10% cumulative variation in the watertable, 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.
2. If more than 10% cumulative variation in the watertable, 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 if appropriate studies 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.

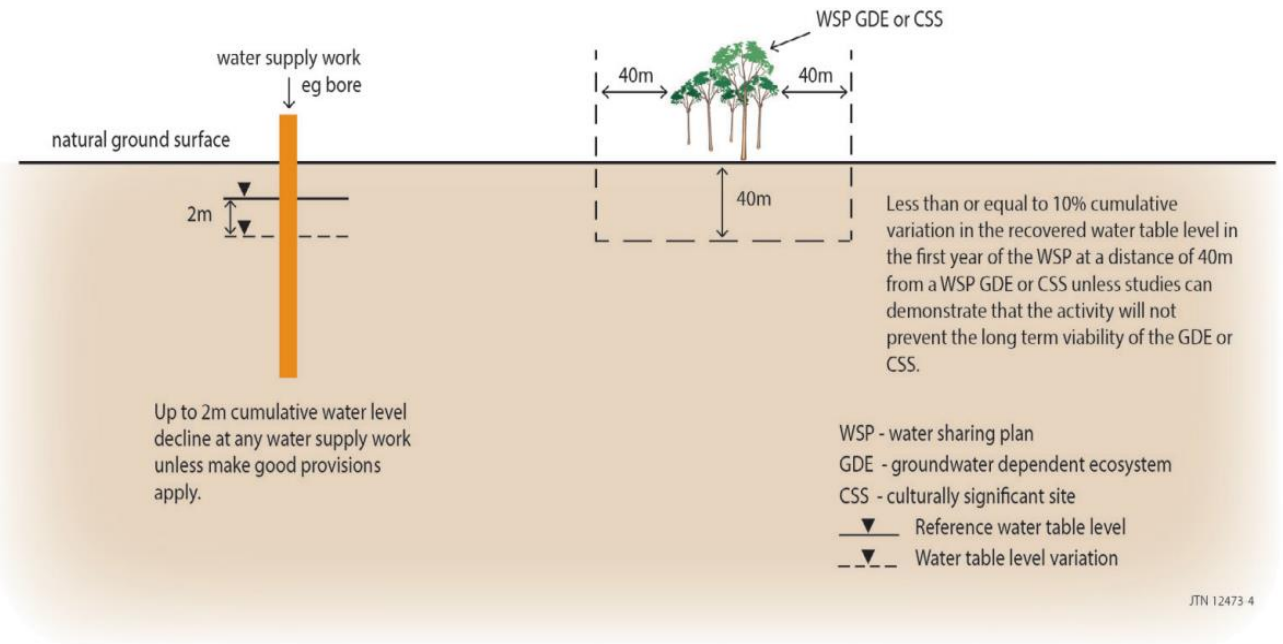


Figure 4.1 Fractured rock groundwater source minimal impact considerations

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 project has an extensive groundwater monitoring network, developed in consultation with DPIE Water (and its predecessors), that includes:

- 48 conventional groundwater monitoring bores at 39 nested locations;
- 10 test production bores;
- Four shallow driver point piezometers;
- 12 shallow swamp monitoring bores; and
- 23 VWPs with 59 sensors at 23 locations.

The baseline monitoring program commenced in September 2017 and is ongoing. The project therefore has 2 years of baseline monitoring and is discussed further in the water characterisation report (Annexure A).

4.3 NSW Protection of the Environment Operations Act 1997

The 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 47 and 48 of the POEO Act, an environment protection licence (EPL) is required for 'scheduled development work' and 'scheduled activities' respectively, which include electricity generation and wastewater treatment. Accordingly, an EPL for Snowy 2.0 Main Works will be applied for. In accordance with section 5.24 of the EP&A Act, and EPL cannot be refused if it is necessary for carrying out approved SSI and is to 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.

4.4 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.

On 30 October 2018, Snowy Hydro submitted to the Commonwealth Department of the Environment and Energy a referral for a proposed action under the EPBC Act for Snowy 2.0 Main Works (EPBC 2018/8322). This referral considered impacts to matters of MNES and the environment generally and detailed that Snowy 2.0 would potentially have a significant impact on MNES, including national heritage places, listed threatened species and ecological communities and listed migratory species. The referral also identified that Snowy 2.0 would potentially have a significant impact on the environment, as defined under the EPBC Act.

Due to the potential impacts of the Snowy 2.0 Main Works on MNES and the environment, an accredited assessment process was sought under section 87(4) of the EPBC Act, where the Commonwealth accredits the assessment process under Division 5.2 of the EP&A Act. On 5 December 2018, the Assistant Secretary of the Commonwealth Department of the Environment and Energy provided notification of its referral decision and designated proponent, determining that the Snowy 2.0 Main Works action was a controlled action and is to be assessed by accredited assessment process under Part 5, Division 5.2 of the EP&A Act.

As part of the accredited assessment process, DEE's assessment requirements have been included in the SEARs.

4.5 Snowy Hydro Corporatisation Act 1997

The NSW *Snowy Hydro Corporatisation Act 1997* (SHC Act) came into effect on 28 June 2002. The SHC 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 and, in particular, release obligations.

4.6 Relevant NSW plans, policies and guidelines

Several other guidelines and policies relevant to the water assessment are discussed in the following sections.

4.6.1 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 more than twenty 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 project and applied mitigation strategies will considerably minimise groundwater inflow and overall groundwater impacts (see Section 15). The design of the project will closely follow the NSW State Groundwater Policy Framework Document objectives of achieving beneficial environmental, social, and economic outcomes for the state of NSW.

4.6.2 Risk assessment guidelines for groundwater dependent ecosystems

The risk assessment guidelines for GDEs (2012) (GDE Risk Assessment Guidelines) are the NSW requirements for assessment and management of GDEs under the WMA 2000. The dictionary to the LFB 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) (see Figure 4.2).

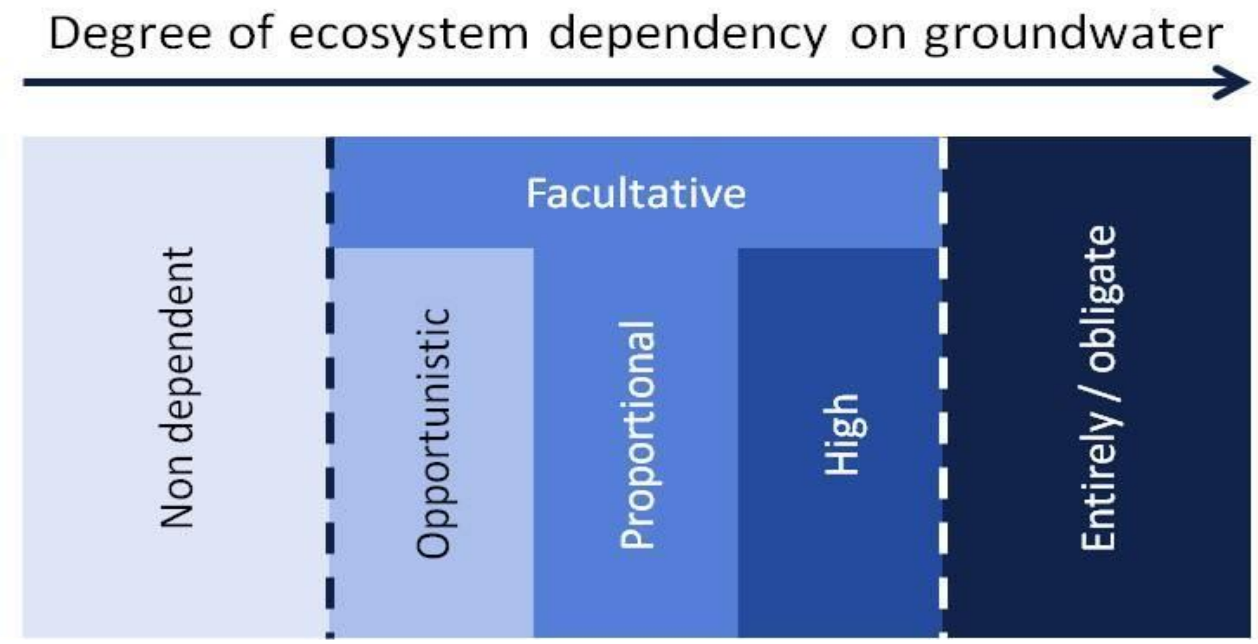


Figure 4.2 Ecosystem level of dependence on groundwater

A GDE risk assessment has been completed for the project in accordance with the GDE Risk Assessment Guidelines. The assessment has been detailed in the Snowy 2.0 Main Works Biodiversity development assessment and summarised below.

The process for identification, assessment and risk mitigation (where required) has been documented in Figure 4.3.

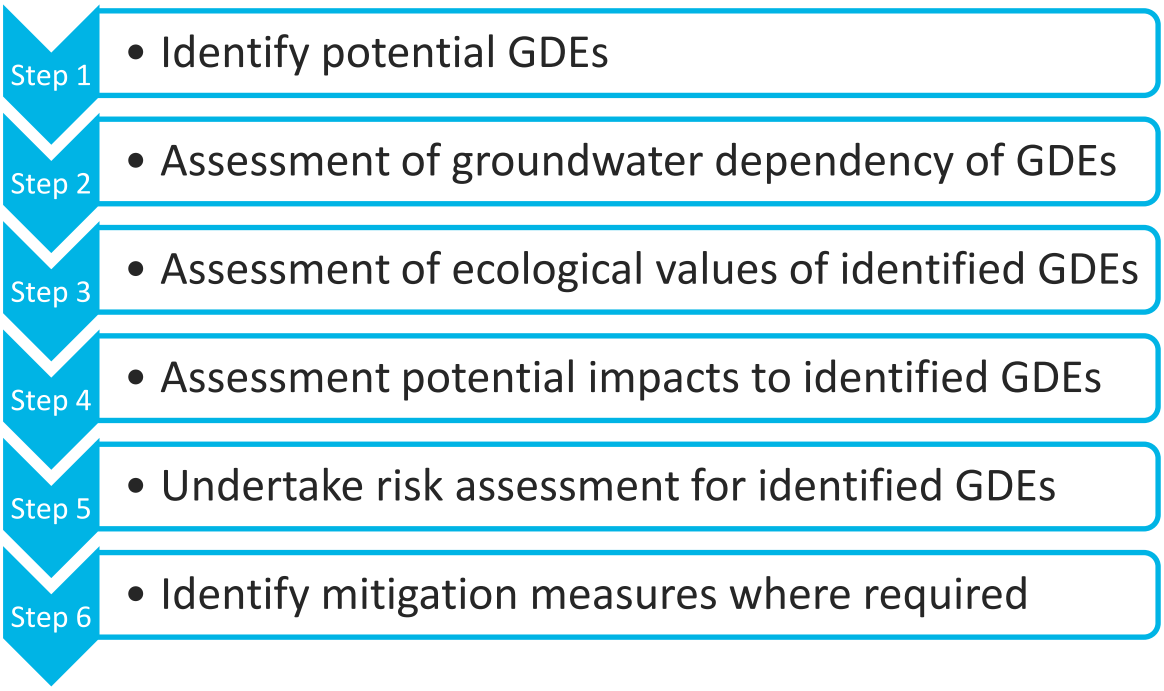


Figure 4.3 GDE risk assessment

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

- watercourses where groundwater is discharging and provides baseflow. This includes the Yarrangobilly River and some drainage lines in the northern and western areas of the project area;
- springs associated with the steep escarpment across the eastern extent of the project area;
- terrestrial vegetation overlying shallow groundwater (within the vegetation root zone); and
- subterranean ecosystems that are dependent on water held in aquifers (eg stygofauna) or inundated caves.

These ecosystems have been classified into three categories according to their dependence on groundwater:

- non-dependent;
- facultative:
  - opportunistic;
  - proportional;
  - highly dependent; and
- entirely dependent/obligate.

Considerations in evaluating plant community types (PCTs) and their potential dependency on groundwater included:

- the physiology of plant species that occur in the community and the likely dependence on groundwater availability;
- the PCTs location in the landscape; and
- if the rooting depth of vegetation would be able to take up groundwater based on likely depth of the aquifer and soil characteristics.

Access to groundwater is dependent on a number of factors with the core factor being the depth to the watertable. As terrestrial vegetation communities are composed of a range of vegetation types with a range of rooting depths and strategies, there is a relationship between groundwater depth and the types and composition of the vegetation that is able to access it (Serov et al 2012).

4.6.3 Guidelines for controlled activities on waterfront land

Under the WMA 2000, proponents are required to assess the impact of proposed controlled activities to find out whether no more than minimal harm will occur to waterfront land (NRAR 2018). Waterfront land includes the bed and bank of a river, lake or estuary, and all land within 40 m of the highest bank of the river, lake or estuary. If controlled activities are proposed within this corridor, then an approval must be obtained from the Natural Resources Access Regulator (NRAR).

The Snowy 2.0 Main Works are categorised as CSSI under Part 5, Division 5.2 of the EP&A Act 1979. As such, should approval be granted, a controlled activity approval will not be required to undertake work on waterfront land as stated in section 5.23(1)(g) of the EP&A Act.

4.6.4 State Rivers and Estuary Policy

The NSW State Rivers and Estuary Policy (1993) encourages sustainable management of the state's rivers, estuaries, and wetlands to halt or reduce:

- declining water quality;
- loss of riparian vegetation;
- damage to river banks and channels;
- declining natural productivity;
- loss of biological diversity; and
- declining natural flood mitigation.

The project commitments have been assessed against this policy and component policies and each of the above listed objectives has been specifically considered. In summary, the water management report (Annexure D) and the flood risk assessment (Annexure C) has concluded that:

- water quality effects regionally (project scale) are moderate with some localised effects potentially significant;
- riparian vegetation effects regionally (project scale) are insignificant, with some very localised effects to be considered moderate to low based on adoption of mitigation and management measures during tunnel construction;
- effects to regional and project scale surface water resources are insignificant;
- effects to regional and project scale biodiversity are insignificant; and
- flooding effects will be negligible and a full flood study for the project has been conducted.

4.6.5 Wetlands Policy

The NSW Wetlands Policy (DECCW 2010) provides for the protection, ecologically sustainable use and management of NSW wetlands.

A wetland is defined as areas of land that are wet by surface and/or groundwater for a sufficient period that plants and animals adapt to and depend on that moisture for at least part of their life cycle. Wetlands can be permanent or ephemeral. The policy contains 12 guiding principles focused on conservation, water and land management, sustainability, prioritisation of significant wetlands, recognition of wetlands' cultural significance, climate change, protection, and reporting.

The project has referenced the 2010 NSW Wetlands Policy in the Biodiversity development assessment, and has concluded that no *Directory of Important Wetlands in Australia* (Environment Australia 2001), mapped wetlands or Ramsar wetlands (Australian Wetland Database 2019) are located in the vicinity of the Snowy 2.0 Main Works project area.

4.6.6 Floodplain Development Manual

The NSW Floodplain Development Manual is a document published in 2005 by the NSW Government. The document details flood prone land policy which has the primary objective of reducing the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods. At the same time, the policy recognises the benefits from occupation and development of flood prone land.

4.6.7 Erosion and Sediment Control Guidelines

The following NSW government guidelines have been referred to when developing erosion and sediment control strategies for the project:

- Managing Urban Stormwater: Soils and Construction – Volume 1 (DECC 2004);
- Managing Urban Stormwater: Soils and Construction – Volume 2C – Unsealed roads (DECC 2008a); and
- Managing Urban Stormwater: Soils and Construction – Volume 2D – Main road construction (DECC 2008b).

4.6.8 Bunding and Spill Management Guidelines

The following NSW Government guidelines detail best practice storage, handling and spill management procedures for liquid chemicals:

- Liquid Chemical Storage, Handling and Spill Management: Review of Best Practice Regulation (DEC 2005); and
- Storing and Handling Liquids: Environmental Protection: Participant's Manual (DEC 2007).

4.7 Relevant Commonwealth policy and guidelines

4.7.1 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. DPIE 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 2019) is included in Annexure C of the modelling report (Annexure B).

4.7.2 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 (EVs) (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.

Further revisions to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality were made in 2018 with the release of a web-based guideline (ANZG 2018). The revised default guideline values for chemical contaminants/toxicants that are relevant to the project area are consistent with ANZECC/ARMCANZ (2000). Physical and chemical stressors have not yet been released for the ecoregion that contains the project area. Hence, the ANZECC/ARMCANZ (2000) guidelines have been applied to establish water quality objectives and environmental values for the project.

4.7.3 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 EVs. The framework involves the identification of specific beneficial uses and values for the major groundwater systems, and several protection strategies that can emerge to protect each aquifer, including monitoring for all aquifers.

The guidelines, including defined EVs and water quality objectives, have been referenced in Section 3 of the Water Characterisation Report (Annexure A).

4.7.4 Australian Rainfall and Runoff

The Australian Rainfall and Runoff (ARR 2016) (Commonwealth of Australia 2016) is the national guideline to estimate design flood volumes and velocities in Australia. It provides robust estimates of flood risks to avoid development in high risk areas and sound design of infrastructure in flood-prone areas and has been referenced as part of the flood risk assessment (Annexure C).

5 Baseline monitoring program

Surface water and groundwater monitoring are essential components in characterising the baseline conditions of the environment in the project area. 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 has been an important input to validate the groundwater and surface water conceptual and numerical models.

A comprehensive water monitoring network was designed and used to establish a baseline dataset for Snowy 2.0 Main Works, incorporating spatial and temporal variations. Data collection to inform the water assessment commenced in June 2017 and is ongoing. The data collection program includes surface water and groundwater monitoring and several field surveys. The monitoring network was developed in consultation with the NSW Department of Planning, Industry and Environment Water (formerly NSW Department of Industry Water). The network was also designed in accordance with the NSW Guidelines for Monitoring and Modelling Plans (NSW DPI Water 2014) which then ensures that the assessment can be undertaken in accordance with the NSW Aquifer Interference Policy (NSW DPI Water 2012). A detailed overview of the baseline monitoring program, available data and interpretation is provided in the water characterisation report (Annexure A).

5.1 Groundwater monitoring network

EMM designed and implemented a dedicated project groundwater monitoring network to investigate groundwater conditions in the project area (Annexure A). The network was developed in consultation with DPIE Water.

The groundwater monitoring network within the project area includes conventional groundwater monitoring bores, test production bores, vibrating wire piezometers (VWPs) and shallow drive points/auger holes. Monitoring bores, VWPs and drive points/auger holes are positioned to provide spatial coverage, investigate the major geologies and groundwater 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 focus on characterising groundwater flow and quality;
- identify and characterise the different geological units in the project area with a focus on charactering their groundwater flow and quality;
- establish baseline groundwater;
- 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
- understand and monitor potential sensitive features, including surface watercourses and water levels in potential groundwater dependent ecosystems (GDEs).

The groundwater monitoring network includes both background (regional) monitoring locations and targeted monitoring locations along the alignment of the key proposed project features.

The network was completed over four drilling campaigns. Bore completion and pumping test reports document the results of each campaign. These are available in Attachment D of the water characterisation report (see Annexure A).

The groundwater monitoring network consists of:

- Forty-eight groundwater monitoring bores at 39 locations (see Table 5.1). At some locations multiple monitoring bores are installed next to one another to varying depths (nested bores). Nested bores are installed at different depths to target different horizons within the groundwater system. Groundwater level and water quality data are collected from each of these monitoring bores to provide information on vertical hydraulic gradients and vertical connectivity at that location.

- Eight test production bores used to assess indicative groundwater yields and quality at the proposed tunnel depth (see Table 5.1). Nested monitoring bores and VWPs accompany test production bores and were used to estimate horizontal and vertical hydraulic conductivities of tested geological units. Following testing, test production bores have been used as additional monitoring bores to collect groundwater levels and quality.

- Two production bores at Lobs Hole which are used as water supply sources for Exploratory Works construction (see Table 5.1).

- Four shallow drive point piezometers and 12 swamp monitoring bores (see Table 5.1). These narrow diameter installations (20 mm to 40 mm) target shallow groundwater within unconsolidated, boggy soils. The shallow installations provide information on groundwater level fluctuations within select alpine bogs and fens.

- Twenty-three VWPs with 59 sensors at 23 locations (see Table 5.2). These sensors monitor groundwater pressures within the very deep (up to 993.9 m below ground level (BGL)) portions of the fractured rock groundwater system, generally just above the invert of the proposed subsurface engineered structures (ie tunnels, power station cavern, etc). The VWPs monitor hydrostatic pressure (or groundwater levels).

The groundwater data collection commenced in September 2017, and the monitoring network in the ravine area has been fully operational since April 2018. Infill drilling across the plateau area was completed between October 2018 and March 2019. Test production bores were installed progressively after February 2018. The drive point piezometers were installed in February 2018, with the remainder of works installed in late January 2019.

The location of monitoring bores within the ravine area are shown in Figure 5.1 and within the plateau area in Figure 5.2.

Table 5.1 Summary of groundwater monitoring bores

Target formation	Bore ID	Ground level (m AHD)[1]	Total depth (m BGL)	Screen interval (m BGL)	Target lithology
Conventional monitoring bores					
Boggy Plain Suite	SMB02	1,335	195.0	182.0–194.0	Sandstone
Boraig Group	BH5105	1,199	108.2	97.0–109.0	Ignimbrite
	BH7104	584	92.2	80.2–89.2	Ignimbrite
	MB06A	1,145	14.0	9.0–12.0	Weathered volcanic
	MB06B	1,145	72.0	64.0–70.0	Volcanic
	TMB01A	581	14.0	11.0–14.0	Ignimbrite
Gooandra Volcanics	BH3110	1,346	178.9	165.9–177.9	Diorite
	MB01C	1,464	52.0	45.0–51.0	Basalt
	MB02	1,387	150.0	141.0–147.0	Chloritic schist

Table 5.1 Summary of groundwater monitoring bores

Target formation	Bore ID	Ground level (m AHD)[1]	Total depth (m BGL)	Screen interval (m BGL)	Target lithology
	MB03	1,373	101.0	92.0–98.0	Chloritic schist
	MB11A	1,485	7.5	17.0–23.0	Weathered basalt
	SMB04	1,342	180.0	170.0–179.0	Chloritic schist
	SMB05	1,342	50.0	40.0–49.0	Basalt
	TMB02A	1,470	15.0	11.0–14.0	Weathered basalt
	TMB02B	1,472	200.0	191.0–197.0	Chloritic schist
	TMB03A	1,478	34.0	29.5–32.5	Weathered basalt
	TMB03B	1,478	150.0	141.0–147.0	Chloritic schist
	TMB04	1,346	200.0	191.0–197.0	Basalt
Kellys Plain Volcanics	BH1115	1,231	55.0	42.0–51.0	Dacite
	BH1116	1,234	93.1	80.5–89.5	Dacite
	BH1117	1,241	65.0	51.9–60.9	Dacite
	BH2101	1,314	169.9	154.6–166.6	Siltstone
Ravine Beds East	MB12B	1,331	180.0	149.0–179.0	Siltstone
	MB12A	1,330	36.0	26.0–35.0	Weathered siltstone
Ravine Beds West	BH7106	613	154.1	141.1–153.1	Siltstone
	BH8101	610	68.4	53.4–65.4	Siltstone
	BH8102	608	68.6	53.6–65.6	Siltstone
	BH8105	621	58.9	43.9–55.9	Siltstone
	BH8108	629	60.0	45.0–57.0	Siltstone
	RSMB1	561	30.0	27.0–30.0	Siltsone/sandstone
	RSMB2	570	30.0	27.0–30.0	Siltsone/sandstone
	RSMB3	593	30.0	27.0–30.0	Siltsone/sandstone
	TMB01B	582	72.0	63.0–69.0	Siltstone
	TMB05A	603	21.0	12.0–18.0	Weathered Siltstone
	TMB05B	603	77.0	68.0–74.0	Siltstone
Tantangara Formation	BH2103	1,264	103.3	94.3–100.3	Sandstone
	BH3101	1,418	85.6	76.6–82.6	Sandstone
	MB08A	1,435	30.0	20.0–29.0	Weathered siltstone
	MB08B	1,436	298.0	277.0–297.0	Sandstone
Temperance Formation	BH3102	1,383	91.0	82.0–88.0	Sandstone
	MB04A	1,330	30.0	23.0–29.0	Basalt
	MB04B	1,330	102.5	93.5–99.5	Chloritic schist
	MB07A	1,265	15.0	10.0–13.0	Weathered siltstone

Table 5.1 Summary of groundwater monitoring bores

Target formation	Bore ID	Ground level (m AHD)[1]	Total depth (m BGL)	Screen interval (m BGL)	Target lithology
	MB07B	1,265	60.0	51.0–57.0	Sandstone
	MB13A	1,382	60.0	50.0–59.0	Weathered siltstone
	MB13B	1,382	190.0	169.0–189.0	Siltstone
Temperance Formation /Boggy Plain Suite	SMB03	1,335	50.0	40.0–49.0	Sandstone
Tertiary basalt	MB01B	1,464	7.5	5.3–6.8	Basalt
Test production bores					
Boggy Plain Suite	PB03	1,336	215.0	200.0–215.0	Granite
Gooandra Volcanics	PB04	1,341	200.0	185.0–200.0	Chloritic schist
	TMB03C	1,478	250.0	237.0–249.0	Chloritic schist
Kellys Plain Volcanics	PB01	1,231	60.0	30.0–60.0	Dacite
Ravine Beds East	PB09	1,330	300.0	200.0–300.0	Siltstone
Ravine Beds West	PB05	614	100.0	50.0–100.0	Siltstone
Tantangara Formation	PB06	1,436	318.0	298.0–318.0	Sandstone
Temperance Formation	PB10	1,382	230.0	210.0–230.0	Chloritic schist
Production bores					
Ravine Beds West[3]	EWPB1	563	96.0	36.0–42.0, 54.0–60.0, 90.0–96.0	Siltstone/sandstone
	EWPB3	560	60.0	24.0–42.0, 48.0–54.0	Siltstone/sandstone
Drive point piezometers and narrow diameter piezometers					
Bullocks Hill Bog[2]	BP1	1,366	1.8	1.5–1.8	Alluvium/colluvium
	BP2	1,364	1.8	1.5–1.8	Alluvium/colluvium
	BP3	1,364	1.8	1.5–1.8	Alluvium/colluvium
	BP4	1,363	1.8	1.5–1.8	Alluvium/colluvium
	BH01	1,351	0.4	0.2–0.4	Alluvium/colluvium
	BH02	1,352	0.9	0.6–0.9	Alluvium/colluvium
	BH03	1,350	0.7	0.5–0.7	Alluvium/colluvium
Gooandra Hill Bog[2]	GH01	1,456	1.0	0.5–1.0	Alluvium/colluvium
	GH02	1,456	0.9	0.5–0.9	Alluvium/colluvium
	GH03	1,455	0.6	0.3–0.6	Alluvium/colluvium
Nungar Creek Bog/Fen[2]	NC01	1,237	0.8	0.5–0.8	Alluvium/colluvium
	NC02	1,237	1.1	0.8–1.1	Alluvium/colluvium
	NC03	1,237	1.0	0.7–1.0	Alluvium/colluvium

Table 5.1 Summary of groundwater monitoring bores

Target formation	Bore ID	Ground level (m AHD)[1]	Total depth (m BGL)	Screen interval (m BGL)	Target lithology
Tantangara Creek Bog[2]	TC01	1,324	1.0	0.6–1.0	Alluvium/colluvium
	TC02	1,322	1.1	0.7–1.1	Alluvium/colluvium
	TC03	1,321	0.8	0.5–0.8	Alluvium/colluvium

Notes: 1. m AHD = metres Australian Height Datum.
2. Interpreted surficial formation.
3. monitoring bores used for production only, no testing completed.

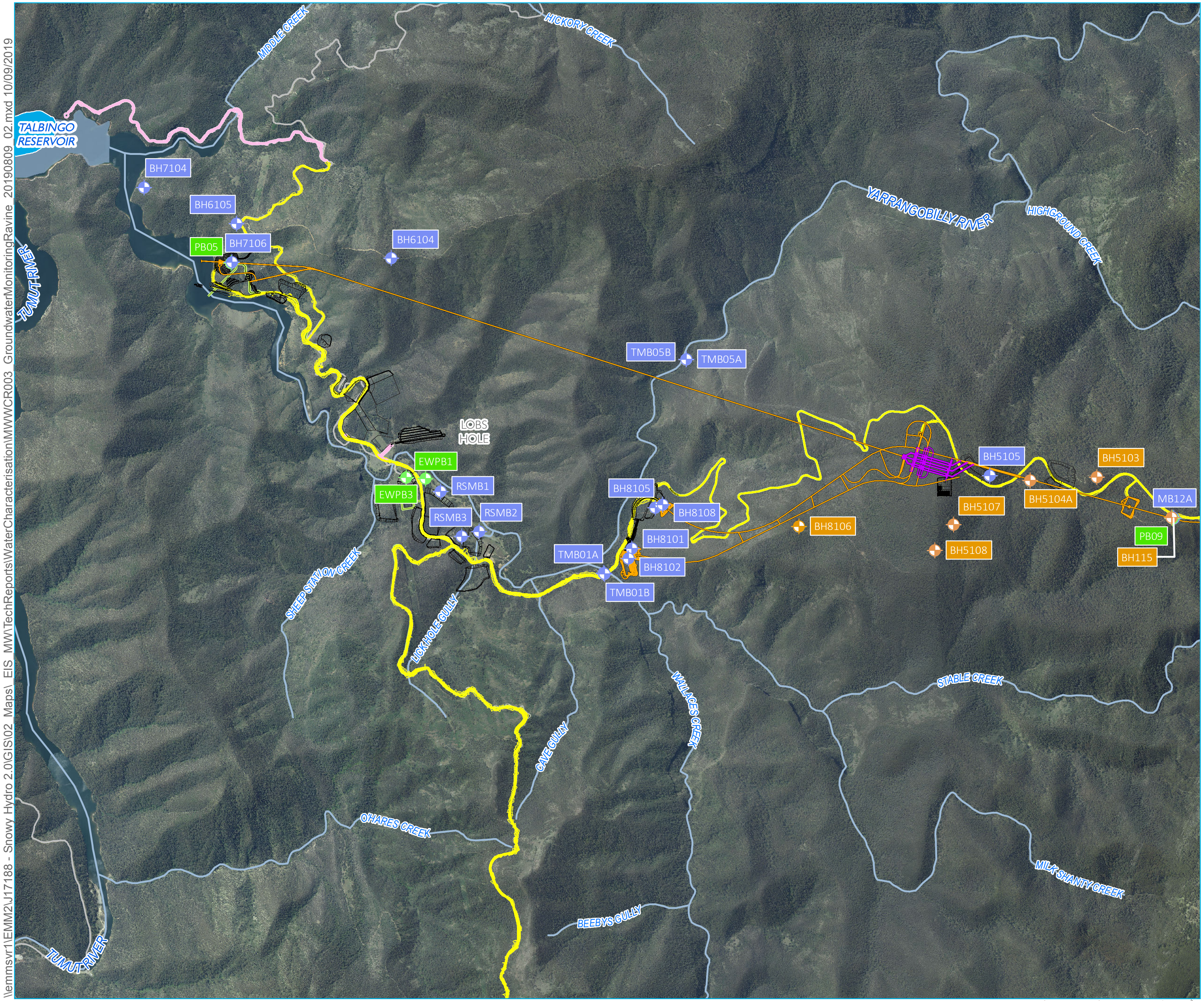
Table 5.2 Summary of Vibrating Wire Piezometers (VWPs)

Target formation	Site ID	Ground level (m AHD)	Borehole angle (°)[1]	Borehole length (m)	Vertical depth (m BGL)	Vertical sensor depth (m BGL)	Target lithology
Gooandra Volcanics	BH3108	1,368.5	90	998.8	998.0	620.0, 342.0, 250.0	Schist
	BH3111	1,501.5	90	406.4	406.4	354.6, 252.5, 120.5	Metasiltstone, Metasandstone
	BH4101	1,479.0	69	1176.1	1100.2	883.9, 729.6, 542.5	Metarhyolite
	BH4102	1,459.8	62	605.1	534.3	455.6, 374.3, 246.3	Gneiss, Phyllite
	BH4103	1,470.5	75	401.9	388.2	335.6, 232.2, 139.5	Metatuff, Tuff, Gneiss
Ravine Beds East	BH4104	1,484.1	77	941.0	916.9	628.4, 506.6	Siltstone
	BH5101A	1,389.8	81	1036.6	1023.8	248.0	Siltstone
	BH5102	1,328.9	87	951.5	950.2	818.8, 619.1, 419.4	Siltstone with Interbedded Mudstone/Sandstone
	BH5103	1,272.1	90	882.0	882.0	765.0, 562.0, 352.0	Tuff, Conglomerate, Interbedded Conglomerate and Sandstone
	BH5104A	1,187.0	82	856.3	848.0	673.3, 475.3, 376.3	Sandstone, Siltstone
	BH5107	1,162.5	90	774.4	774.4	737.5, 554.5, 381.4	Interbedded Siltstone and Sandstone
	BH5108	1,140.8	90	764.0	764.0	666.0, 431.0, 380.3	Siltstone
	BH5110	1,196.1	64	856.3	769.6	687.5, 435.4, 267.3	Sandstone, Conglomerate, Interbedded Siltstone and Sandstone
	BH5111	1,351.0	90	271.9	271.9	232.4, 180.7, 116.5	Interbedded Siltstone and Sandstone, Siltstone

Table 5.2 Summary of Vibrating Wire Piezometers (VWPs)

Target formation	Site ID	Ground level (m AHD)	Borehole angle (°)[1]	Borehole length (m)	Vertical depth (m BGL)	Vertical sensor depth (m BGL)	Target lithology
	BH5114	1,287.1	61	601.9	526.4	491.9, 359.0, 208.5	Siltstone
	BH5115	1,329.7	90	789.0	789.0	292.0, 192.0	Siltstone
	BH8106	1,096.3	90	673.0	673.0	669.0, 431.0	Sandstone/Interbedded Siltstone and Sandstone
Ravine Beds West	BH6103	601.5	61	251.5	220.0	218.7, 131.2	Interbedded Siltstone and Sandstone
Tantangara Formation	BH2102	1,245.6	69	155.2	144.8	107.2, 41.8	Interbedded Metasiltstone and Metasandstone
	BH3104	1,436.2	90	339.0	339.0	287.0, 174.0, 72.9	Sandstone, Siltstone
	BH3113	1,334.4	90	233.9	233.9	184.8, 94.9	Interbedded Metasandstone and Metasiltstone
Temperance Formation/Boggy Plain Suite	BH3106	1,335.4	79	256.8	252.1	194.3, 150.1	Pyroxenite, Diorite
Temperance Formation/Gooandra Volcanics	BH3107A	1,324.6	79	241.4	237.0	200.2, 133.5	Interbedded Siltstone and Sandstone

Notes: 1. ° indicates degrees (bore inclination from horizontal).



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KEY

Groundwater monitoring network
- Monitoring bore
- Production bore
- VWP

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Indicative rock emplacement area
- Permanent road

Snowy 2.0 construction elements
- Temporary construction compounds and surface works
- Temporary access road

Existing environment
- Local road
- Watercourse
- Waterbodies
- State boundary

Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

0 0.5 1 km

GDA 1994 MGA Zone 55

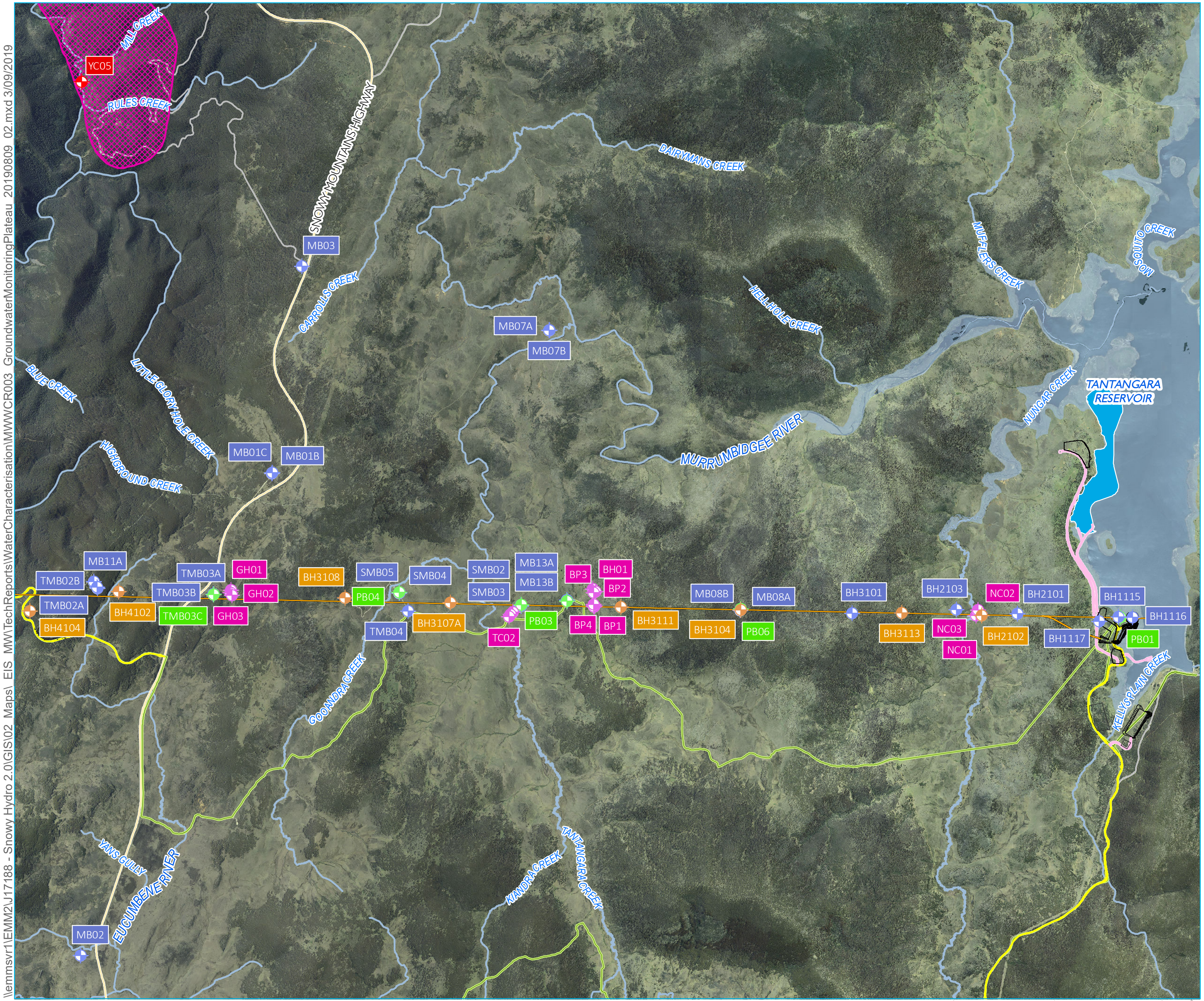
N

Groundwater monitoring locations - ravine

Snowy 2.0
Water Assessment
Main Works
Figure 5.1

snowy 2.0

EMM creating opportunities



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Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

0 1.5 3 km

GDA 1994 MGA Zone 55

N

KEY

Cave monitoring

Groundwater monitoring network

- Monitoring bore
- Production bore
- Swamp piezometer
- VWP

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Utilities
- Permanent road

Snowy 2.0 construction elements

- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement area

Existing environment

- Main road
- Local road
- Watercourse
- Waterbodies
- Yarrangobilly Caves complex

Groundwater monitoring locations - plateau

Snowy 2.0
Water assessment
Main Works
Figure 5.2

5.1.1 Hydraulic testing

Hydraulic tests provide site-specific information on the hydraulic properties of the various groundwater systems. Hydraulic testing included the following:

- pumping tests;
- drill stem tests (DST);
- rising/falling head (slug) tests; and
- packer tests.

i Pumping tests

Pumping tests generally involve pumping water from a large diameter production bore for a period of time such that a drawdown response is observed in nearby monitoring bores. Pumping tests generally are a direct and reliable method to obtain estimates of aquifer hydraulic properties, including storativity, transmissivity, and horizontal and vertical hydraulic conductivity. Data collected during pumping tests can also be used to assess the extent and sustainability of the aquifer and the degree of connection with nearby surface water sources, where present.

Pumping tests were undertaken at seven locations across the project area (PB01, PB03, PB04, PB05, PB09, PB10, TMB03C). The tests consisted of constant rate tests (of up to 72 hours duration) followed by 24-hour recovery monitoring. Groundwater level observations from the test and monitoring bores have been assessed using computer based 'AQTESOLV' and 'MLU' algorithms for confined groundwater systems.

ii Drill stem tests

DSTs can be used to estimate the horizontal hydraulic conductivity across an isolated section of a borehole. The test section is isolated using pneumatic or hydraulic inflatable packers that encase a wireline tool. Both the packer and wireline tool are lowered into the drill string which is set at the test depth. The wireline tool is fitted with a series of valves that control the release of fluid and air.

Compressed air is used to push down the groundwater level in the drill string creating a displacement. When the desired displacement is achieved, the compressed air is released, and the test zone allowed to return to equilibrium. The aquifer response after the air is released is measured using an automated pressure transducer data logger and the aquifer response is used to calculate the horizontal hydraulic conductivity of the test section.

iii Rising and falling head tests (slug tests)

Slug testing has been completed in conventional groundwater monitoring bores and is used to estimate the bulk hydraulic conductivity in the immediate vicinity of the screened interval.

Slug testing involves displacing water in the bore (using a slug, eg solid bailer) and measuring the change in groundwater level within the bore (using an automated pressure transducer data logger). When the groundwater level increases (falling head test) or decreases (rising head test) as a result of lowering or removing the slug in the bore, the change in water level is captured by the data logger and the aquifer response used to calculate horizontal hydraulic conductivity.

iv Packer tests

Packer testing (also known as Lugeon testing) is an in-situ method of testing the average hydraulic conductivity of a rock mass over a selected depth interval. The formation is tested by inflating pneumatic or hydraulic packers and injecting water at a constant pressure into the isolated section of the borehole.

Packer testing is typically completed in five stages, gradually increasing then decreasing injection pressure and averaging the flow and pressure at each stage to estimate average hydraulic conductivity. Results are expressed in Lugeon units which is the conductivity required to inject 1 litre of water per metre of the test interval under a constant pressure.

5.1.2 Groundwater level monitoring

Project specific groundwater level monitoring commenced in September 2017, following the construction of BH1115, BH1116, and BH1117 (adjacent to Tantangara Reservoir). The groundwater level monitoring network has been progressively expanded as new monitoring bores and VWPs have been installed (see Table 5.1 and Table 5.2).

Groundwater levels are monitored via automated pressure transducer data loggers (installed in monitoring bores) and VWP pressure sensors, with data recorded at six-hourly intervals.

Total pressures recorded at the pressure transducer data loggers are compensated for atmospheric pressure changes using barometric loggers installed at PB01, TMB03C, TMB01A and YC05. The barometric loggers provide sufficient spatial coverage at different elevations to capture barometric fluctuations across the project area. All data loggers and VWP sensors are downloaded monthly and groundwater levels are verified with manual groundwater level measurements taken during each groundwater quality sampling event.

A summary of groundwater level monitoring for the monitoring and production bores is provided in Figure 5.3. A summary of groundwater level monitoring for VWPs and drive point/narrow piezometers is provided in Figure 5.4.

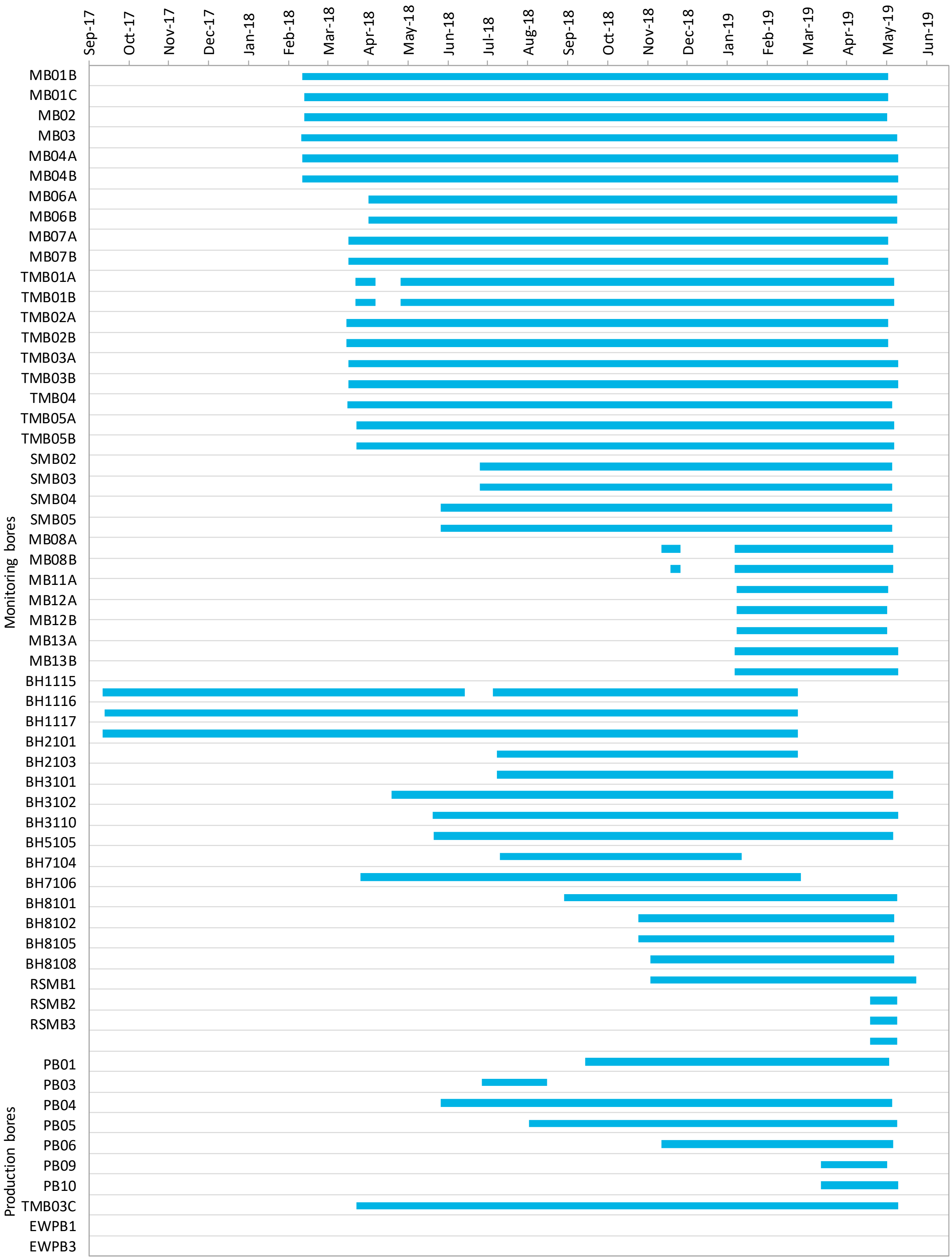


Figure 5.3 Conventional monitoring bores – groundwater monitoring overview

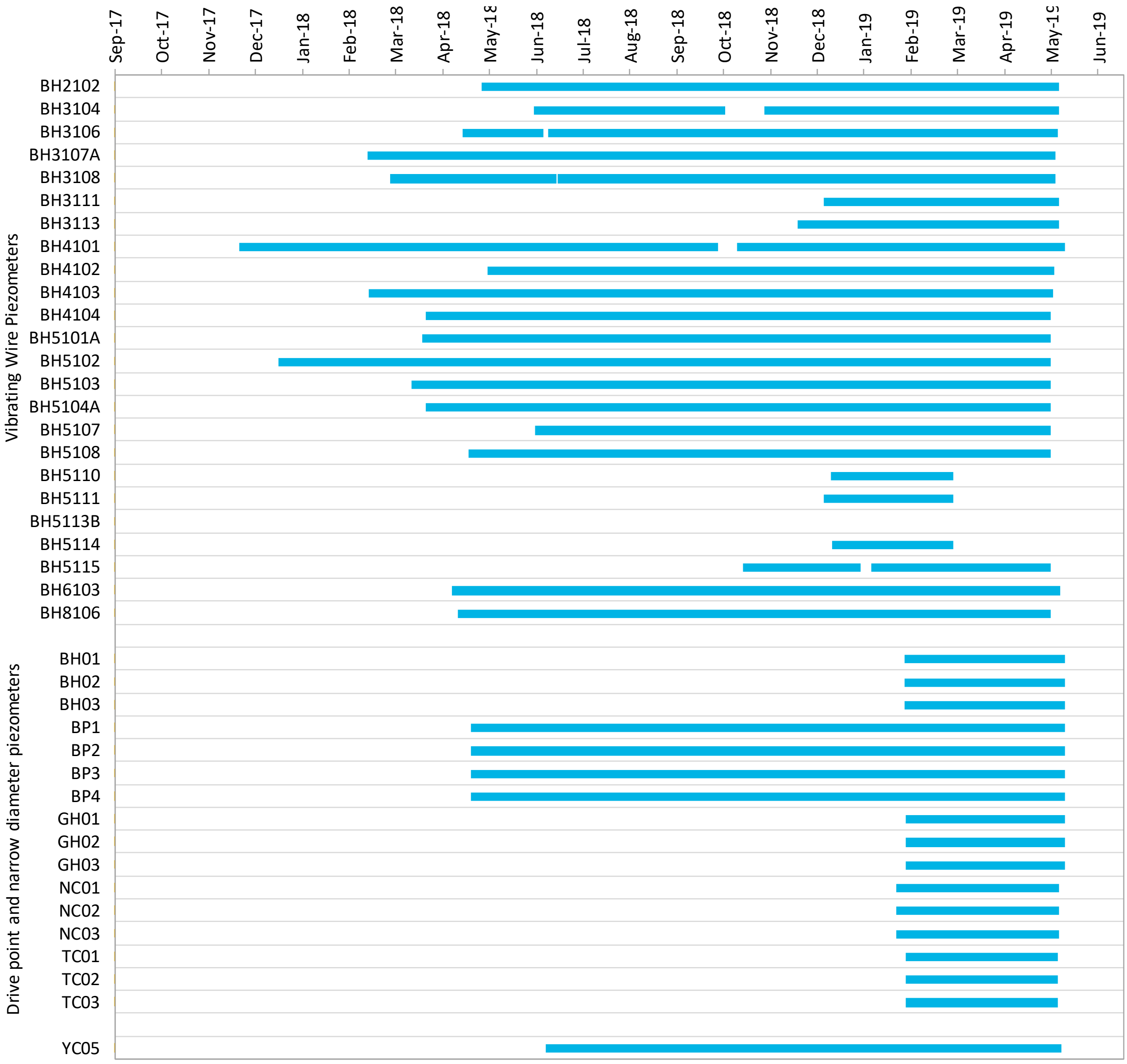


Figure 5.4 Vibrating Wire Piezometers – groundwater monitoring overview

5.1.3 Groundwater quality monitoring

A baseline groundwater quality monitoring program commenced in February 2018 following the installation of MB01 and was expanded as new bores were completed.

Groundwater sampling is undertaken at a monthly frequency (access dependent) in conjunction with surface water sampling in accordance with *AS/NZS 5667.11:1998 Australian Standard for Water Quality Sampling*. Dedicated sampling pumps (Solinst™ double-valve pumps) are installed in 36 conventional groundwater monitoring bores and are used to collect groundwater samples using low-flow sampling methods. Details regarding the sampling methodology is provided in the water characterisation report (Annexure A).

The sampling and analysis methods and monitoring analytes for the groundwater monitoring program are described in Table 5.3. A record of monitoring events is shown in Figure 5.5.

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.

Table 5.3 Groundwater analysis methods and parameters

Category	Monitoring analytes	Analysis method
Physico-chemical properties	pH, electrical conductivity, total dissolved solids, dissolved oxygen, temperature, redox potential	Measured in situ using a portable water quality meter
	alkalinity (bicarbonate, carbonate, hydroxide and total as $CaCO_3$)	Analysis undertaken by a NATA certified laboratory
Major ions	calcium, chloride, magnesium, sodium, potassium, sulphate	
Inorganics	cyanide, fluoride	
Nutrients	total nitrogen, ammonia, oxidised nitrogen and total kjeldahl nitrogen	
	total phosphorus and reactive phosphorous	
Metals (field filtered)	Al, As, Ag, B, Ba, Be, Cd, Cr (total), Co, Cu, Fe, Hg, Mn, Ni, Pb, Se, V and Zn	

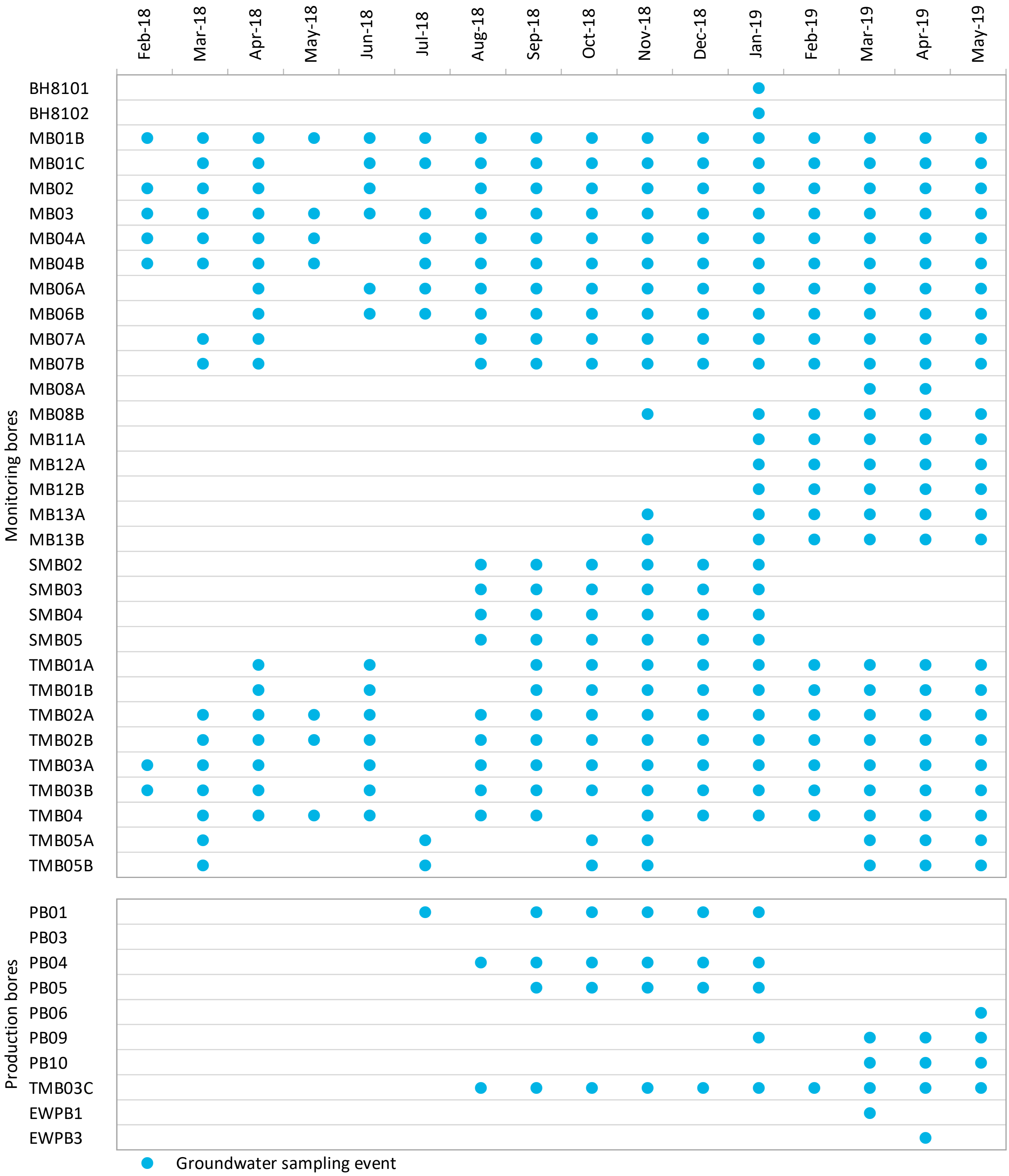


Figure 5.5 Groundwater quality sampling overview

5.2 Yarrangobilly Caves

5.2.1 Monitoring network

Water level monitoring at Yarrangobilly Caves commenced in June 2018. Water level data is measured within a cave pool at Ravine Cave (YC05), via a stilling well which has been equipped with an automated pressure transducer data logger. The purpose of the installation is to capture baseline cave pool fluctuations in response to recharge and "flushing" events. The data logger is programmed to measure hydrostatic pressure at 15-minute intervals. The Yarrangobilly Caves water level monitoring location is shown in Figure 5.2.

Water quality monitoring at Yarrangobilly Caves commenced in July 2018. The water quality monitoring network at Yarrangobilly Caves comprises the following:

- two springs discharging downstream of the cave system, adjacent to the Yarrangobilly River (YC01 and YC02);
- two minor watercourses (YC03 and YC04);
- a cave pool, within Ravine Cave (YC05); and
- a site on Yarrangobilly River downstream of the cave system.

The water quality monitoring suite for the Yarrangobilly Caves monitoring sites is consistent with the analytes listed in Table 5.3. The water quality monitoring record for monitoring sites at Yarrangobilly Caves is shown in Figure 5.6.

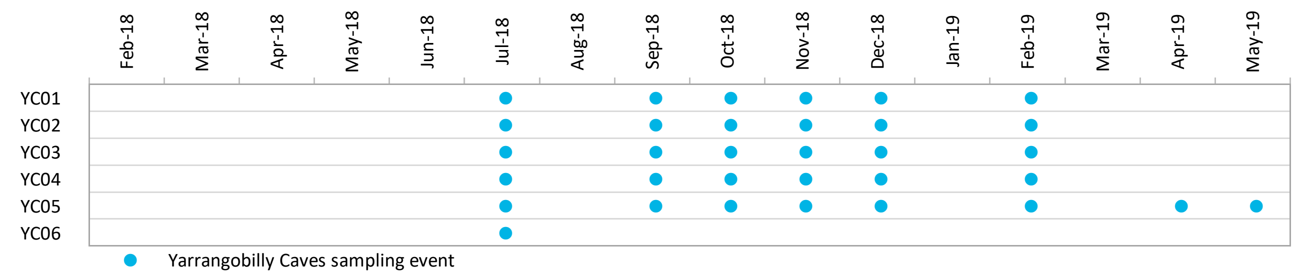


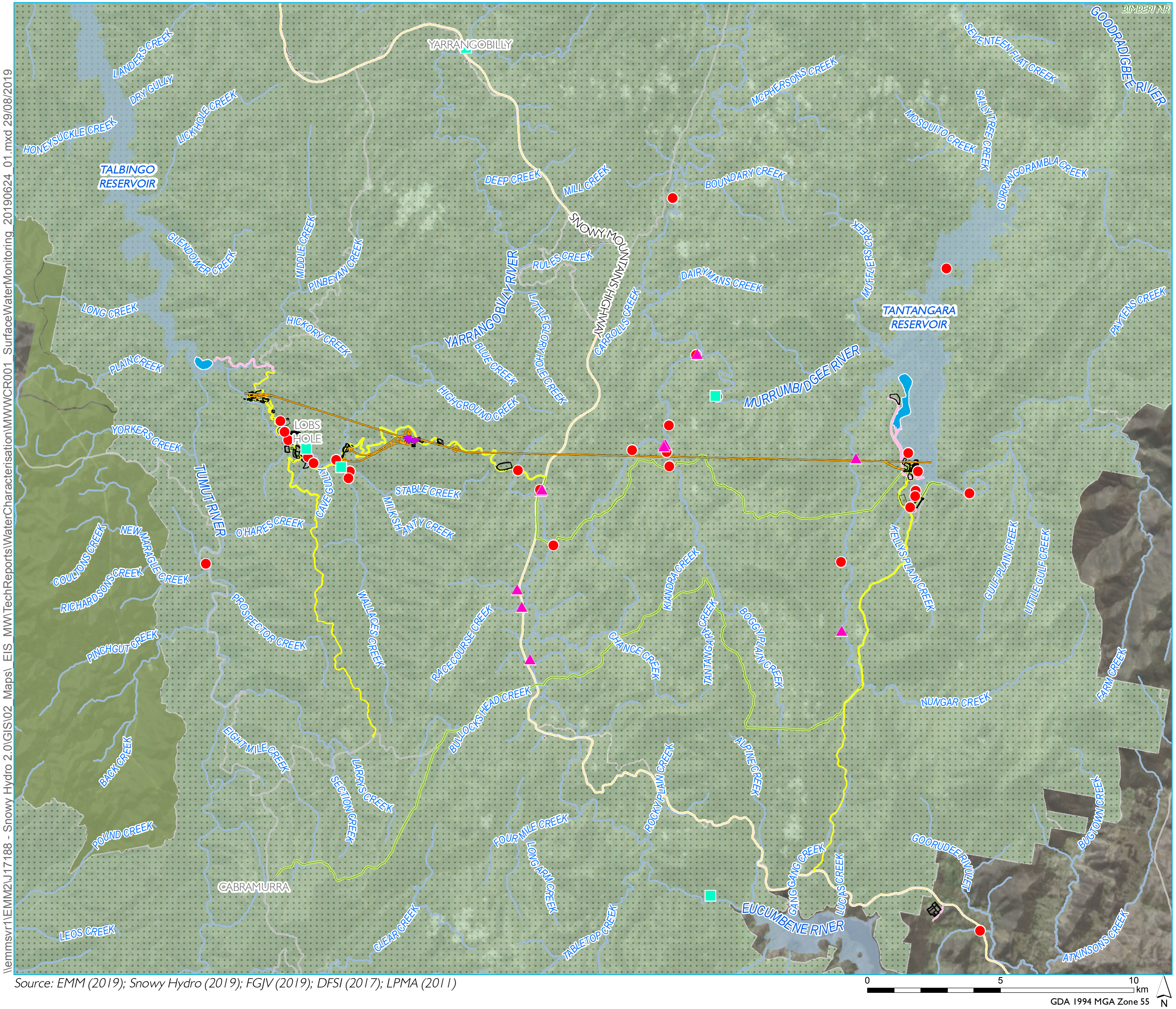
Figure 5.6 Yarrangobilly Caves water quality sampling overview

5.3 Surface water monitoring

5.3.1 Monitoring network

Long-term surface water quality and streamflow monitoring has been conducted across the project area, providing over 40 years of baseline data (1978-2019, inclusive). In addition to the historical monitoring sites, new in situ monitoring of streamflow occurred across the plateau area for the project. The project surface water monitoring network consists of 16 streamflow gauging locations and 30 water quality monitoring locations (Figure 5.7) (Annexure A). No new permanent stream gauging stations have been installed for the Snowy 2.0 Main Works. The new monitoring locations were developed in consultation with DPIE Water to:

- create spatial representation across the project area, including upstream and downstream locations, and different land use scenarios;
- characterise major watercourses (ie larger stream orders) and streams that will be undermined; and
- examine the potential for surface water–groundwater interaction.



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Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

KEY

- Flow monitoring network
- Gauging station
- Surface water monitoring location

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 construction elements

- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement area

Existing environment

- Main road
- Local road
- Watercourse
- Waterbodies
- Kosciuszko National Park
- NPWS reserve
- State forest
- State boundary

Surface water monitoring locations

Snowy 2.0
Water assessment
Main Works
Figure 5.7

5.3.2 Streamflow data

i Plateau

Streamflow data is available from Snowy Hydro operated stream gauges located on the Eucumbene and Murrumbidgee rivers. Both gauges have long-term records (see Table 5.4). In situ measurements of streamflow were taken at 11 sites, most within plateau watercourses from October 2018, using a handheld propeller flow meter (see Table 5.4). Velocity measurements were taken using a grid sampling approach across the channel at regular depths and distances from the bank. The resulting velocity data was integrated to provide a total flow estimate.

Table 5.4 Summary of streamflow data – plateau

Site ID	Catchment	Location	Number of measurements
Snowy Hydro operated stream gauges			
Eucumbene River at Providence 2 (222522)	Eucumbene River	Eucumbene River upstream of Eucumbene Dam	Continuous
Murrumbidgee River above Tantangara Reservoir (410535)	Murrumbidgee River	Murrumbidgee River downstream of Tantangara Creek confluence	Continuous
In situ streamflow measurement locations			
Site 0	Nungar Creek	Nungar Creek upstream of Tantangara Reservoir	3
Site 1	Nungar Creek	Nungar Creek midway along watercourse	4
Site 2	Eucumbene River	Eucumbene River at Garden Gully confluence	5
Site 3	Murrumbidgee River	Gooandra Creek upstream of Tantangara Creek confluence	4
Site 4	Murrumbidgee River	Tantangara Creek upstream of Gooandra Creek confluence	4
Site 5	Murrumbidgee River	Tantangara Creek downstream of Gooandra Creek confluence	4
Site 6	Murrumbidgee River	Tantangara Creek at Murrumbidgee River confluence	5
Site 7	Eucumbene River	Racecourse Creek upstream of Snowy Mountains Highway	5
Site 8	Eucumbene River	Three Mile Creek upstream of Snowy Mountains Highway	5
Site 9	Eucumbene River	Unnamed watercourse downstream of Snowy Mountains Highway	5
Site 10	Eucumbene River	Eucumbene River upstream of Snowy Mountains Highway	5
Murrumbidgee River gauge (410535)	Murrumbidgee River	Murrumbidgee River downstream of Tantangara Creek confluence	2

ii Ravine

Streamflow data is available from three Snowy Hydro operated stream gauges in the Yarrangobilly River Catchment. Gauge locations are indicated in Figure 5.7. All gauges have long-term and continuous monitoring records (see Table 5.5).

Table 5.5 Summary of streamflow data – ravine

Site ID	Catchment	Location	Number of measurements
Yarrangobilly River at Ravine (410574)	Yarrangobilly River	Yarrangobilly River, upstream of Lobs Hole Mine	Continuous
Wallaces Creek (410507)	Yarrangobilly River	Wallaces Creek, upstream of Yarrangobilly River confluence	Continuous
Brownleys Back Creek (600577)	Yarrangobilly River	Brownleys Back Creek, upstream of Yarrangobilly River confluence	Continuous

5.3.3 Water quality monitoring

A project specific baseline surface water quality monitoring program commenced in February 2018 and is ongoing. Monitoring locations for the ravine and plateau areas are indicated in Figure 5.7. A summary of the baseline surface water quality monitoring locations and number of samples collected for the project is provided in Table 5.6.

Table 5.6 Surface water quality baseline monitoring locations

ID	Location	Comments[1]
Yarrangobilly River		
LH_SW_004	Upstream of Wallaces Creek confluence	13 samples collected
LH_SW_006	Upstream of Talbingo Reservoir	13 samples collected
LH_SW_007	Adjacent to remnant mine workings	14 samples collected
PN_SW_001	Upper Yarrangobilly River near Snowy Mountains Highway	16 samples collected
Wallaces and Stable Creeks		
LH_SW_001	Stable Creek, upstream of Wallaces Creek confluence	2 samples collected[2]
LH_SW_002	Wallaces Creek, upstream of Stable Creek confluence	4 samples collected[3]
LH_SW_003	Wallaces Creek, downstream of Stable Creek confluence	13 samples collected
Tumut River		
TalS_SW_001	Tumut River, upstream of Talbingo Reservoir	13 samples collected
Lick Hole Gully		
LH_SW_005	Lick Hole Gully	7 samples collected
Minor watercourses - ravine		
LH_SW_008	Watercourse 3	3 sample collected, generally dry in summer and autumn
LH_SW_009	Watercourse 2	7 samples collected, generally dry in summer and autumn
Murrumbidgee River		
PL_SW_005	Downstream of Tantangara Creek confluence	10 samples collected
PN_SW_002	Upper Murrumbidgee River	15 samples collected

Table 5.6 Surface water quality baseline monitoring locations

ID	Location	Comments[1]
TanS_SW_002	Downstream of Tantangara Reservoir	14 samples collected
Eucumbene River		
PL_SW_003	At Snowy Mountains Highway	15 samples collected
PL_SW_006	Upstream of Snowy Mountains Highway	8 samples collected
PL_SW_007	Downstream of Snowy Mountains Highway	9 samples collected
Tantangara Creek		
PL_SW_002	Upstream of Gooandra Creek confluence	14 samples collected
PL_SW_004	Upstream of confluence with Murrumbidgee River	5 samples collected[4]
PL_SW_009	Downstream of Gooandra Creek confluence	9 samples collected
Gooandra Creek		
PL_SW_001	Approx. 1.5 km upstream of Eucumbene River confluence	14 samples collected
Nungar Creek		
TanR_SW_001	Nungar Creek upstream of Tantangara Reservoir	11 samples collected
Kellys Plain Creek		
TanS_SW_001	Kellys Plain Creek at southern end of Tantangara Reservoir	15 samples collected
Minor watercourses - plateau		
PL_SW_008	1st order watercourse that drains to Tantangara Creek	9 samples collected
TanN_SW_001	Mosquito Creek upstream of Tantangara Reservoir	12 samples collected
TanS_SW_003	2nd order watercourse at southern end of Tantangara Reservoir	8 samples collected
TanS_SW_004	2nd order watercourse at southern end of Tantangara Reservoir	9 samples collected
TanS_SW_005	1st order watercourse that drains to Kellys Plain Creek	1 sample collected, generally dry[5]
TanS_SW_006	2nd order watercourse that drains to Kellys Plain Creek	3 samples collected, generally dry
Camerons Creek (Rock Forest)		
TRL_SW_001	Downstream of Rock Forest project area	5 samples collected

Notes: 1. The stated number of samples collected refers to samples collected in the February 2018 to May 2019 period.
2. Sampling at this location was discontinued in June 2018 following a review of the initial monitoring program.
3. Sampling at this location was discontinued in July 2018 following a review of the initial monitoring program.
4. Sampling at this location was discontinued in August 2018 following review of the initial monitoring program.
5. Sampling at this location was discontinued in February 2019 following review of the initial monitoring program.

Generally, monitoring was conducted monthly, predominantly during baseflow conditions. Monitoring during wet weather conditions was undertaken in Lobs Hole in March and early May 2019. Figure 5.8 shows the monitoring timeline at each location. Wet weather samples and monitoring locations that were dry at the time of sampling are also identified.

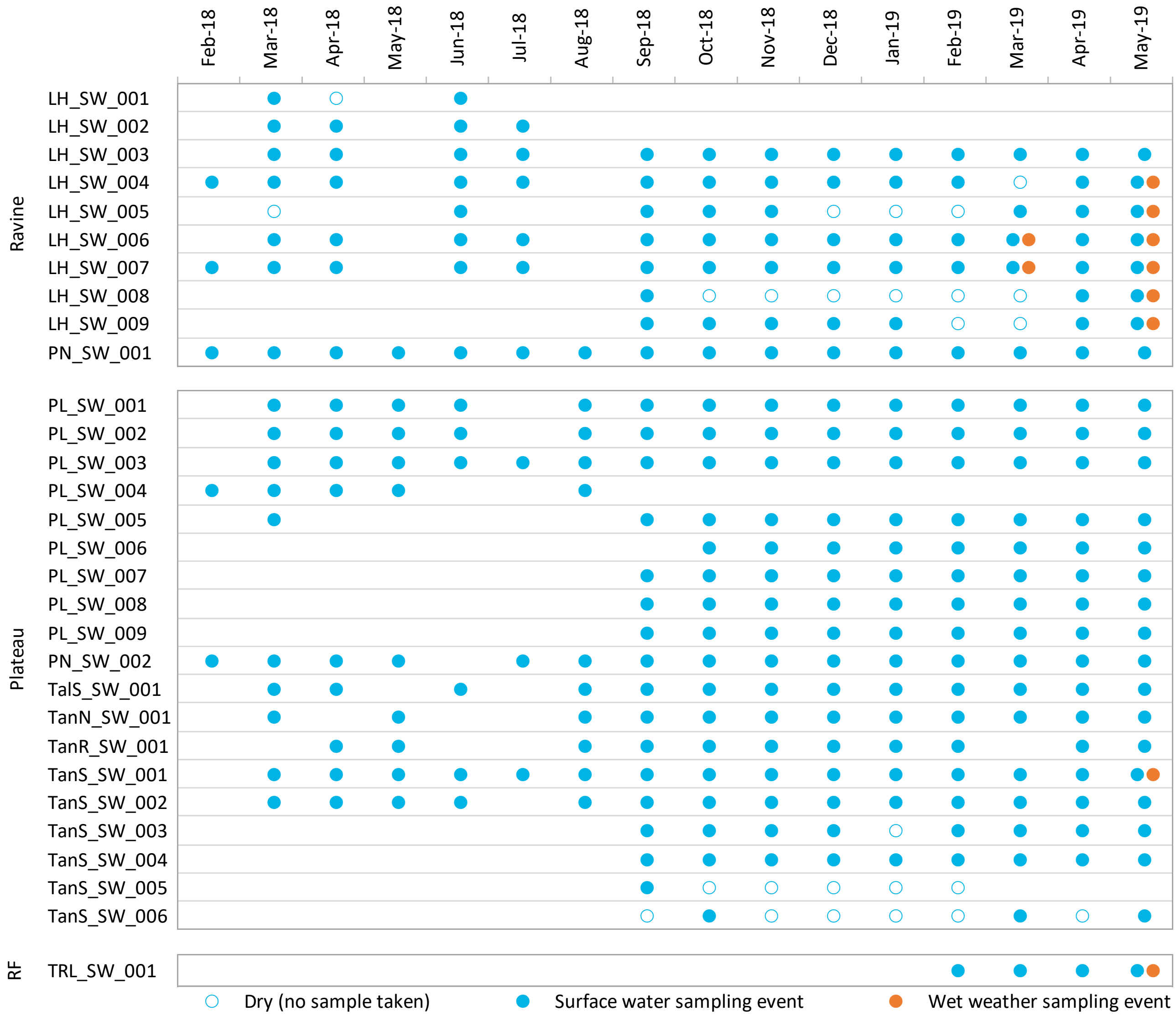


Figure 5.8 Water quality monitoring timeline – watercourse

Table 5.7 describes the analytes and analysis methods applied to the surface water monitoring program.

Table 5.7 Analysis methods and parameters

Category	Monitoring analytes	Analysis method
Physico-chemical properties	pH, electrical conductivity, turbidity, dissolved oxygen, temperature, oxidation reduction (redox) potential	Measured in situ using a portable water quality meter
	total suspended solids, total alkalinity, total hardness	Analysis undertaken by a NATA certified laboratory
Nutrients	total nitrogen, ammonia, oxidised nitrogen and total kjeldahl nitrogen	
	total phosphorus and reactive phosphorus	
	total organic carbon, dissolved organic carbon	

Table 5.7 Analysis methods and parameters

Category	Monitoring analytes	Analysis method
Inorganics	cyanide	
Metals (field filtered)	Al, As, Ag, B, Ba, Be, Cd, Cr (total), Co, Cu, Fe, Hg, Mn, Ni, Pb, Se, V and Zn	

5.3.4 Geomorphology assessment

A geomorphic characterisation assessment was undertaken by Flow and Loam Environmental (2019). The objective of the assessment was to characterise the channel zone and floodplains within the following assessment areas:

- Plateau area – major watercourses within 1 km to the north and south of the proposed headrace tunnel alignment;
- Marica area – select watercourses in proximity to proposed surface works; and
- Lobs Hole – Yarrangobilly River and tributaries in proximity to proposed surface works.

The assessment used the River Styles framework (Brierley and Fryirs 2005) and included the following components:

- desktop assessment including interpretation of aerial imagery, LiDAR, geology and soils spatial data sets; and
- field surveys including visual assessment of exposed sediment profiles, near surface soil profiling (based on sediment spear penetration) and interpretation of the assemblage of geomorphic units.

A summary of the assessment outcomes is provided in Annexure A. The technical report prepared by Flow and Loam Environmental is provided in Attachment A of Annexure A.

5.4 Ecology surveys

5.4.1 Overview

A comprehensive biodiversity assessment has been completed by EMM to identify the presence of terrestrial and aquatic biodiversity values within the project area, identify appropriate avoidance and mitigation measures to reduce residual impacts and assess the significance of residual impacts. Terrestrial biodiversity impact assessments have been undertaken by EMM while Cardno completed the aquatic biodiversity impact assessments.

The NSW *Biodiversity Conservation Act 2016* (BC Act) is the primary legislation responsible for the conservation of biodiversity in NSW and sets a framework for how the biodiversity assessments need to be completed for the project. The BC Act, together with the NSW *Biodiversity Conservation Regulation 2017*, establish the Biodiversity Offsets Scheme (BOS), which then introduces the biodiversity assessment method (BAM) (NPWS 2017). EMM has designed and implemented biodiversity surveys, analysis and impact assessments for the project in line with the BC Act and BAM.

The biodiversity assessments have also addressed matters of national environmental significance (MNES) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

For full details on seasonal terrestrial and aquatic biodiversity surveys, methods and results refer to the biodiversity development assessment report (EIS Appendix M.1).

5.4.2 Field surveys and results

i Terrestrial

A preliminary assessment of the area was undertaken between August 2017 and October 2017. Additional mapping was undertaken in February and March 2018 due to the inclusion of additional survey areas. This preliminary assessment included detailed vegetation mapping and habitat assessments. Revision and refinement of this preliminary vegetation mapping was undertaken in November and December 2018, in response to additional plots being undertaken and review of the PCTs across the Snowy 2.0 survey area.

Site investigations, including determination of vegetation communities using the methods described in the biodiversity development assessment report, identified the presence of 22 PCTs within the Snowy 2.0 Main Works disturbance footprint. The total project footprint supports 985.06 ha of native vegetation communities including grassy woodlands, grasslands, dry sclerophyll forests, wet sclerophyll forests, alpine complex and very minor areas of freshwater wetlands with montane bogs and fens. Dominant vegetation communities are grassy woodlands including PCT 1224 – Sub-alpine dry grasslands and heathlands of valley slopes, southern South Eastern Highlands Bioregion and Australian Alps Bioregion and PCT 1196 - Snow Gum - Mountain Gum shrubby open forest of montane areas, South Eastern Highlands Bioregion and Australian Alps Bioregion.

The degree of groundwater dependence for most plant communities is influenced by climate and seasonality of rainfall. Groundwater dependency can therefore range from total reliance (ie obligate) to a proportional, opportunistic reliance, and in some cases are classified as groundwater dependent in certain environments.

The following sections provide a summary of the PCTs that have been identified as being groundwater dependent (to varying degrees). Figure 5.9 describes the mapped PCTs in the context of their level of groundwater dependency across the project area.

Further detail of the terrestrial ecology assessments is provided in the biodiversity development assessment report (EIS Appendix M.1).

a Plateau

The following PCTs have an been identified as GDEs:

- PCT 303 - Black Sally grassy low woodland in valleys in the upper slopes sub-region of the NSW South Western Slopes Bioregion and western South Eastern Highlands Bioregion;
- PCT 637– Alpine and sub-alpine peatlands, damp herbfields and fens, South Eastern Highlands Bioregion and Australian Alps Bioregion;
- PCT 679 - Black Sallee - Snow Gum low woodland of montane valleys, South Eastern Highlands Bioregion and Australian Alps Bioregion;
- PCT 765 – Carex – Juncus sedgeland/wet grassland of the South Eastern Highlands Bioregion; and
- PCT 1225 – Sub-alpine grasslands of valley floors, southern South Eastern Highlands Bioregion and Australian Alps Bioregion.

These PCTs were assessed as entirely/obligate and/or having facultative-opportunistic dependencies on groundwater:

- entirely/obligate: more than 50% of the PCT is mapped in areas with groundwater at 0.5 m BGL or less, or more than 75% of the PCT is mapped in areas with groundwater at 2 m BGL or less; and

- facultative-opportunistic: more than 50% of the PCT is mapped in areas with groundwater at 5 m BGL or less, but less than 75% of the PCT is mapped in areas with groundwater at 5 m BGL and/or less than 50% of the PCT is mapped in areas with groundwater at 2 m BGL.

Table 5.8 demonstrates the PCT occurrence with groundwater in the plateau area.

Table 5.8 Occurrence of entirely/obligate and facultative-opportunistic GDEs on the plateau

PCT[2] name	Community occurrence within modelled groundwater levels			Entirely/obligate GDEs occurring in areas where groundwater is ≤ 2 mBGL[1]	Entirely/obligate GDEs occurring in areas where groundwater is ≤ 5 mBGL[1]	GDE type
	0–0.5 m BGL[1]	0.5–2 m BGL[1]	2–5 m BGL[1]			
PCT 303	32%	18%	30%	50%	80%	Facultative-opportunistic
PCT 637	69%	16%	12%	86%	98%	Entirely/obligate
PCT 679	58%	11%	26%	69%	95%	Facultative-opportunistic
PCT 765	17%	81%	2%	98%	100%	Entirely/obligate
PCT 1225	50%	46%	4%	96%	100%	Entirely/obligate

Notes: 1. m BGL – metres below ground level; and
2. PCT – plant community type.

b Ravine

Four PCTs have been identified as facultative-proportional and/or facultative-opportunistic GDEs:

- 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 299 - Riparian Ribbon Gum - Robertsons Peppermint - Apple Box riverine very tall open forest of the NSW South Western Slopes Bioregion and South Eastern Highlands Bioregion;
- PCT 300 - Ribbon Gum - Narrow-leaved (Robertsons) Peppermint montane fern - grass tall open forest on deep clay loam soils in the upper NSW South Western Slopes Bioregion and western Kosciuszko escarpment; and
- 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.

The following PCTs were assessed as having facultative-proportional/opportunistic dependencies on groundwater:

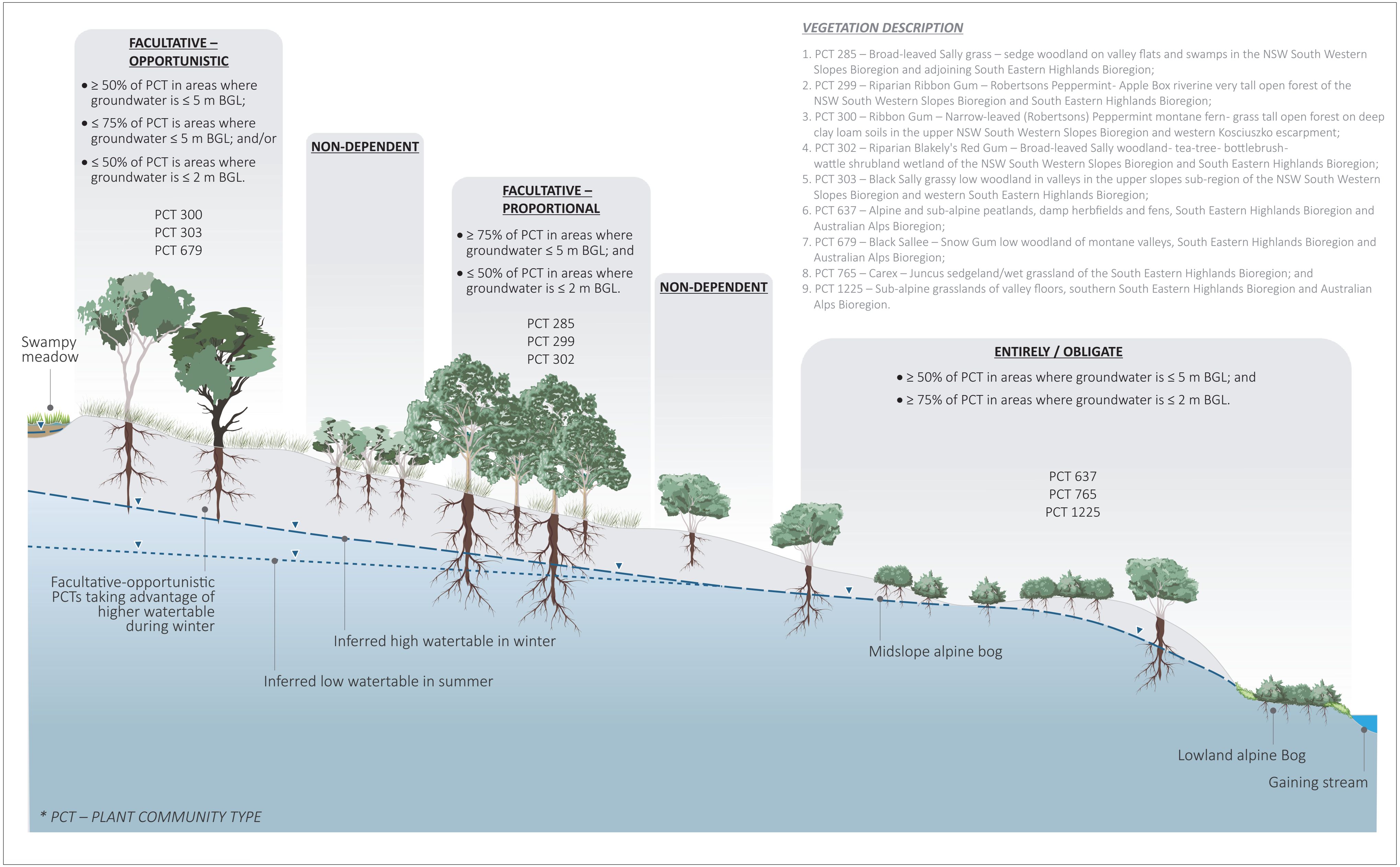
- facultative-proportional: more than 75% of the PCT is mapped in areas with groundwater at 5 m BGL or less, but less than 50% of the PCT is mapped in areas with groundwater at 2 m BGL or less; and
- facultative-opportunistic: more than 50% of the PCT is mapped in areas with groundwater at 5 m BGL or less, but less than 75% of the PCT is mapped in areas with groundwater at 5 m BGL and/or less than 50% of the PCT is mapped in areas with groundwater at 2 m BGL.

Table 5.9 demonstrates PCT occurrence with groundwater in the ravine area.

Table 5.9 Occurrence of facultative-proportional/opportunistic GDEs in the ravine

PCT[2] name	Community occurrence within modelled groundwater levels			Entirely/obligate GDEs occurring in areas where groundwater is ≤ 2 m BGL[1]	Entirely/obligate GDEs occurring in areas where groundwater is ≤ 5 m BGL[1]	GDE type
	0–0.5 m BGL[1]	0.5–2 m BGL[1]	2–5 m BGL[1]			
PCT 285	11%	14%	67%	25%	92%	Facultative-proportional
PCT 299	27%	19%	35%	46%	81%	Facultative-proportional
PCT 300	17%	8%	27%	25%	52%	Facultative-opportunistic
PCT 302	4%	16%	69%	20%	89%	Facultative-proportional

Notes: 1. mBGL – metres below ground level; and
2. PCT – plant community type.



Conceptual diagram for Terrestrial GDEs

Snowy 2.0

Water Assessment

Figure 5.9

ii Aquatic

The aquatic ecology assessment focused on the reservoirs and catchments that have been considered in relation to potential impacts (both direct and indirect) from Snowy 2.0 Main Works and/or nearby reference areas. At a broad-scale, the study area includes the project area, Talbingo and Tantangara Reservoirs and the broader areas associated with the Tumut River, Murrumbidgee River, Snowy River and upper Murray Catchments and sub-catchments (i.e. major tributaries). These divisions were based on ecological and physical criteria, primarily geographic context, hydrological connectivity (ie the presence of artificial and natural barriers to the movement of aquatic biota), aquatic habitat types (eg still versus flowing water) and the known distribution of key species. This helped conceptualise and discriminate the different ecological attributes that may be affected by Snowy 2.0 and thereby facilitate the impact assessment.

Targeted field surveys were undertaken to inform aspects of the aquatic ecology assessment and to characterise the aquatic flora and fauna within the study area, with a focus on locations expected to be directly disturbed by Snowy 2.0 Main Works. Boat-based electrofishing surveys were done in Talbingo Reservoir in February 2018 and surveys of fish and aquatic habitat in the Yarrangobilly River catchment in January/February and May of 2018 were also undertaken.

Further details of field surveys and method are discussed in EIS Appendix M.1 and M.2

iii Subterranean

A stygofauna assessment was undertaken by Macquarie University (2019) at 16 sites located within 2 km of the project alignment. These include existing monitoring bores installed within fractured rock aquifers (subsurface phreatic aquifer ecosystems – 11 sites) at various depths, as well as colluvial aquifers associated with the alpine bogs and fens (baseflow stream hyporheic ecosystems – 5 sites).

Sampling was undertaken by pumping water from groundwater bores, with 100 L of water collected or 2 hours of pumping (whichever came first). For groundwater bores in which pumps were not installed, groundwater was sampled by dragging plankton nets (50-µm mesh) through the water to collect any fauna, or by lowering a bailer into the bore to collect 10 L of water. All samples collected were sieved through a 50-µm mesh sieve. The contents of the sieve were carefully transferred to sample jars and preserved.

Preserved samples were analysed in the laboratory and all invertebrates removed, identified and enumerated. All specimens collected were identified to the lowest practicable level using morphological traits and keys. Each specimen was classified based on the likelihood of it being an obligate groundwater organism. eDNA (environmental DNA) analysis of groundwater samples was also undertaken on groundwater collected from 11 groundwater bores (ie not including piezometers in alpine bogs and fens).

A total of five specimens, likely to be obligate stygofauna representatives, were collected from one of the 11 fractured rock sites (TMB02A), and two of the five alpine bog and fen sites sampled (GH01, GH02). Species collected from TMB02A are unique to fractured rock aquifers of the Gooandra Volcanics, while species observed in GH01 and GH02 are unique to the alpine bogs and fens.

While other stygobiotic species were observed in other monitoring bores, it was considered difficult to determine their affinity with groundwater due to the wide variety of habitats in which they occur.

Limited stygofauna studies have been undertaken within fractured rock aquifers of the region. Hence, there is limited data for comparison. The stygofauna found on the plateau are like those encountered in other fractured rock systems in NSW.

6 Groundwater

6.1 Overview

This chapter describes the local geological and hydrogeological setting, including groundwater levels and flow, hydraulic properties, groundwater quality characteristics and surface water-groundwater interaction of the hydrogeological units in the project area. The hydrogeology of the plateau and ravine are materially different and are therefore described separately.

An overall appreciation of the recharge, discharge and flow patterns, and corresponding shallow and deep water levels along the tunnel alignment is provided.

EVs and Water Quality Objectives (WQOs) for groundwater are based on the *National Water Quality Management Strategy Guidelines for Groundwater Quality Protection in Australia (NWQMS 2013)*. EVs are particular values, or uses, of the water resource that are important for a healthy ecosystem or for public benefit, welfare, safety or health, and which require protection from the effects of contamination, waste discharges and deposits (ANZECC and ARMCANZ 2000). EVs for groundwater include aquatic ecosystems, primary industries, recreation and aesthetic values, drinking water, industrial water and cultural and spiritual values. As groundwater provides baseflow to many watercourses within the project area, the primary EV for groundwater is aquatic ecosystems. The following default WQO values have been applied to characterise the groundwater quality:

- physical and chemical stressors – default trigger values for upland rivers in South Eastern Australia that are reported in ANZECC/ARMCANZ (2000); and
- toxicant trigger values for the protection of 99% of freshwater aquatic species that are provided in ANZECC/ARMCANZ (2000).

Characterisation of water quality in relation to WQOs for plateau groundwater is provided in Section6.3.1iii and for ravine groundwater in Section6.3.2iii.

6.2 Local geological setting

6.2.1 Plateau

The plateau is located within a geologic domain referred to as the Tantangara Block which extends from the Tantangara Fault in the east to the LPF in the west (see Figure 3.4). This area has been significantly deformed through faulting, intrusion and volcanism.

The geological units within the plateau area generally grade from youngest to oldest in an east to west direction (ie from Tantangara Reservoir to the Snowy Mountains Highway), reflecting the compression and tilt placed on the structural block. Igneous intrusions within the plateau include the Ordovician Shaw Hill Gabbro, Devonian Boggy Plain Suite and Tertiary basalt. The structural controls placed on the geological domain have prompted a dominant north-south strike and a steeply dipping structural block which dips between 90 to 80 degrees on its axis.

Surficial deposits, comprising shallow alluvium and colluvium, occupy the floodplains and valley margins of the major watercourses across the plateau.

6.2.2 Ravine

The ravine is located within a geologic domain referred to as the Tumut Block which extends west of the LPF (see Figure 3.4) to the east of Talbingo Reservoir. The area is dominated by Silurian to Devonian sedimentary and igneous rocks. The Silurian 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 in the Devonian during a period of explosive felsic volcanism. The Ravine Beds can be separated into two discrete sub units by the LPF: Ravine Beds East and Ravine Beds West.

The major watercourses, including the Yarrangobilly River, Wallaces Creek and Stable Creek are supported and flanked by extensive colluvium.

6.3 Hydrogeological characterisation

6.3.1 Plateau

i Groundwater levels and flow

Groundwater levels within the plateau are influenced by the relief and generally mirror the topography. Groundwater levels are above the creeks and therefore groundwater provides baseflow to streams (gaining streams).

Along the proposed headrace tunnel transect, groundwater levels vary from approximately 1,470 m AHD in the elevated areas adjacent to the LPF in the west, to approximately 1,170 m AHD in the lower elevated area near Tantangara Creek. Overall, groundwater levels observed along the proposed tunnel alignment indicate that groundwater flow direction is generally west to east from the LPF.

Groundwater levels within monitoring bores and VWPs have generally shown fluctuations of less than 10 m during the monitoring period. Groundwater levels within the Gooandra Volcanics, Tertiary basalt, Tantangara Formation, Temperance Formation, Boraig Group, Kellys Plain Volcanics and Boggy Plain Suite generally show a moderate to strong response to rainfall events.

Vertical leakage within the Gooandra Volcanics, Tantangara Formation and Temperance Formation is variable and potentially complex with the direction of vertical leakage (ie upwards versus downwards) varying with location and depth within these units.

Differences between groundwater levels within the Tertiary basalt and underlying Gooandra Volcanics suggests that the Tertiary basalt aquifer is a perched aquifer.

Further detail regarding groundwater levels and flow within the plateau area is provided in Section 9.2.1 of the water characterisation report (Annexure A).

ii Hydraulic properties

Hydraulic properties within the plateau are summarised as follows:

- estimated horizontal hydraulic conductivity in the Gooandra Volcanics are generally higher when compared to the other geological units (see Figure 6.1);
- pumping tests conducted at bores installed within the Gooandra Volcanics and Kellys Plain Volcanics demonstrated vertical hydraulic connection between shallow and deeper horizons within these geological units;

- pumping tests conducted at bores installed within the Temperance Formation and Boggy Plain Suite demonstrated no apparent vertical hydraulic connection between shallow and deeper horizons within these geological units; and
- horizontal hydraulic conductivity is generally decreasing with increasing depth in all the geological units tested.

Further detail is provided in Section 9.2.2 of the water characterisation report (Annexure A).

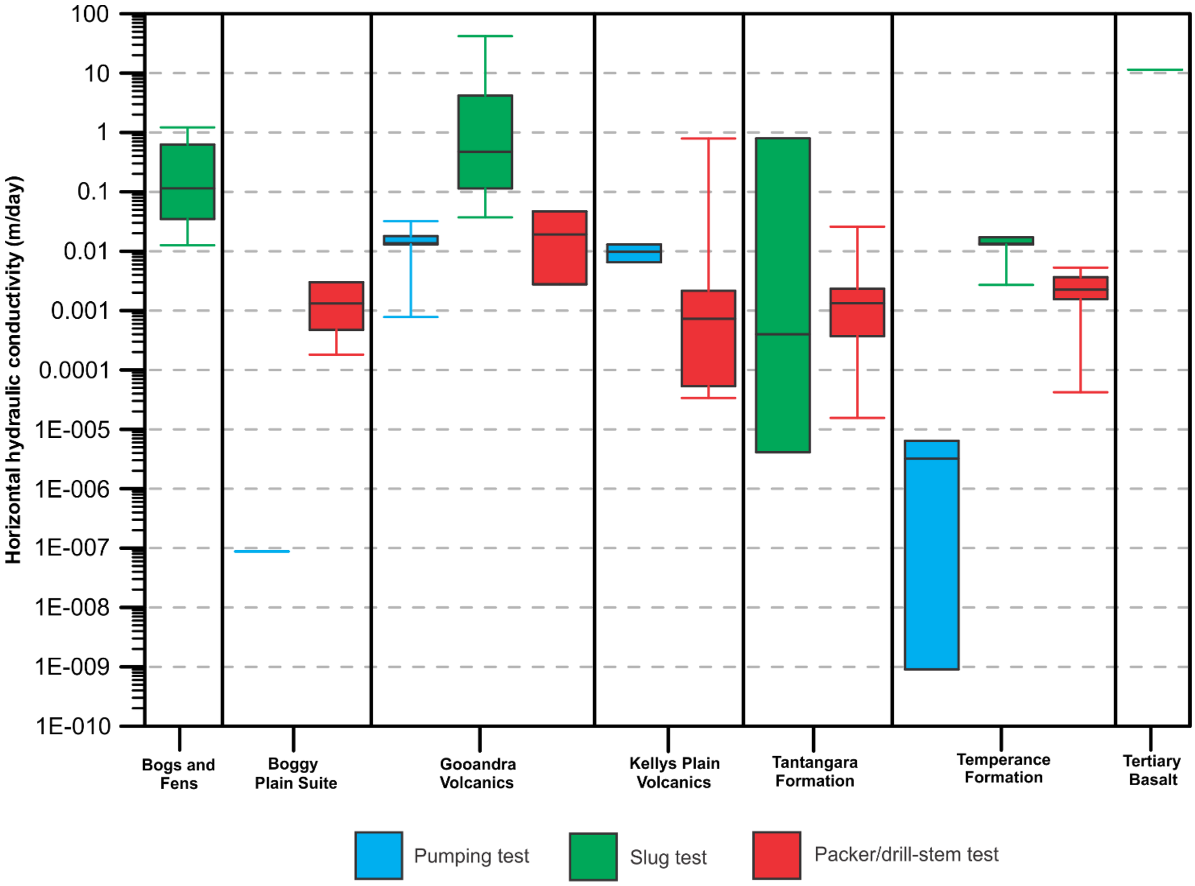


Figure 6.1 Plateau area estimated horizontal hydraulic conductivity ranges – Box and Whisker plot (Note: whiskers represent the minimum and maximum and the box represents the 75th and 25th percentiles of the data).

iii Aquifer chemistry

To assist with the characterisation of aquifer chemistry within the plateau, statistical and graphical interpretation of the water quality data was undertaken including Piper diagrams, box and whisker plots, Stiff diagrams, pie charts of major ion concentrations and trends over time.

This section summarises the main interpretation of the above, further detail is provided in Section 9.2.3 of the water characterisation report (Annexure A).

Box and whisker plots of major ions for each of the geological units within the plateau are shown in Figure 6.2 and are summarised as follows:

- pH within the different geological units across the plateau ranges from 3.5 to 13.0. pH is generally lowest in the bogs and fens and highest within the Kellys Plain Volcanics;
- total dissolved solids (TDS) range from 14 mg/L (Gooandra Volcanics) to 1,610 mg/L (Temperance Formation);
- calcium, magnesium, chloride, sodium and sulphate are generally less than 100 mg/L in all geological units; and
- bicarbonate concentrations in all geological units are generally higher than other major ions with a maximum of 205 mg/L in the Temperance Formation.

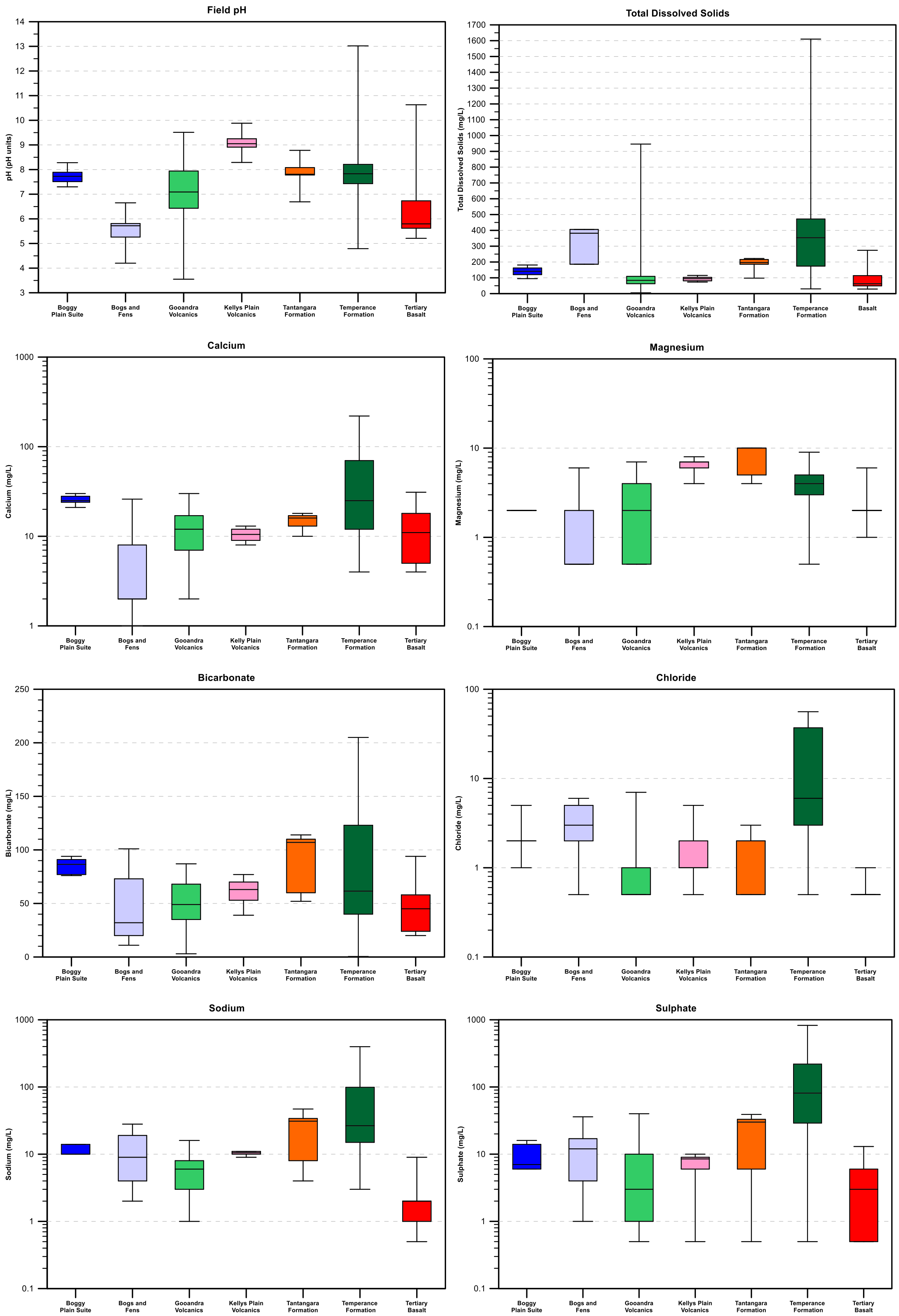


Figure 6.2 Plateau area selected groundwater quality analytes – Box and Whisker plots

Key findings from Stiff plots and pie charts are summarised as follows:

- similarities between Stiff patterns and chemical composition of groundwater within the Boggy Plain Suite and Temperance Formation indicate that these geological units may be in hydraulic connection across some areas of the plateau;

- all monitoring bores screened across Gooandra Volcanics have narrow Stiff patterns which suggests that the groundwater has low residence times and/or has undergone limited interaction with the rock material;

- similarities between Stiff patterns and the chemical composition of monitoring bores within the Gooandra Volcanics suggests that groundwater may be largely interconnected, and is supported the high degree of fracturing which has been observed within this geological unit;

- monitoring bores screened across Kellys Plain Volcanics and Tertiary basalt have narrow Stiff pattern which suggests that the groundwater within these geological units has a short residence times and/or has undergone limited interaction with the rock material;

- deeper monitoring bores within the Tantangara Formation have broader Stiff patterns and higher proportions of sodium compared to shallow monitoring bores indicating that deeper groundwater within the Tantangara Formation has longer residence times/or has greater interaction with the rock material when compared to shallower groundwater; and

- monitoring bores screened across the Temperance Formation show a broad range in Stiff pattern and chemical composition suggesting that there is a high degree of heterogeneity within the Temperance Formation both spatially and with depth.

The following is a summary of baseline water chemistry in comparison with the WQOs:

- samples collected from all plateau aquifers exceeded dissolved oxygen, ammonia, oxidised nitrogen, total nitrogen and copper WQOs; and

- total or reactive phosphorus and several metals including aluminium, arsenic, boron, chromium, cobalt, copper, iron, lead, vanadium and zinc WQOs were exceeded in samples collected from the Boggy Plain Suite, Gooandra Volcanics, Tantangara Formation, Temperance Formation, Tertiary basalt and bogs and fens.

iv Surface water-groundwater interaction

Groundwater levels are above the creeks across the area and therefore groundwater systems provide baseflow to streams (gaining streams).

To assess the dependence of bogs and fens on groundwater, water levels in the bog and fen piezometers have been compared to groundwater levels within nearby monitoring bores (see Figure 6.3).

At all four monitored bog and fen locations, groundwater levels in nearby monitoring bores (up to 400 m from the bog /fen) have been significantly higher (ie 8 m to 23 m) than the water level within the bog and fen. These differences imply a local upward hydraulic gradient (and upward leakage) from the shallow groundwater system to the bogs and fens. The bogs and fens are likely proportionally reliant on the regional groundwater system, receiving groundwater contributions either from adjacent seeps and springs or upward seepage (as described above) as well as receiving water from rainfall, snowfall and runoff.

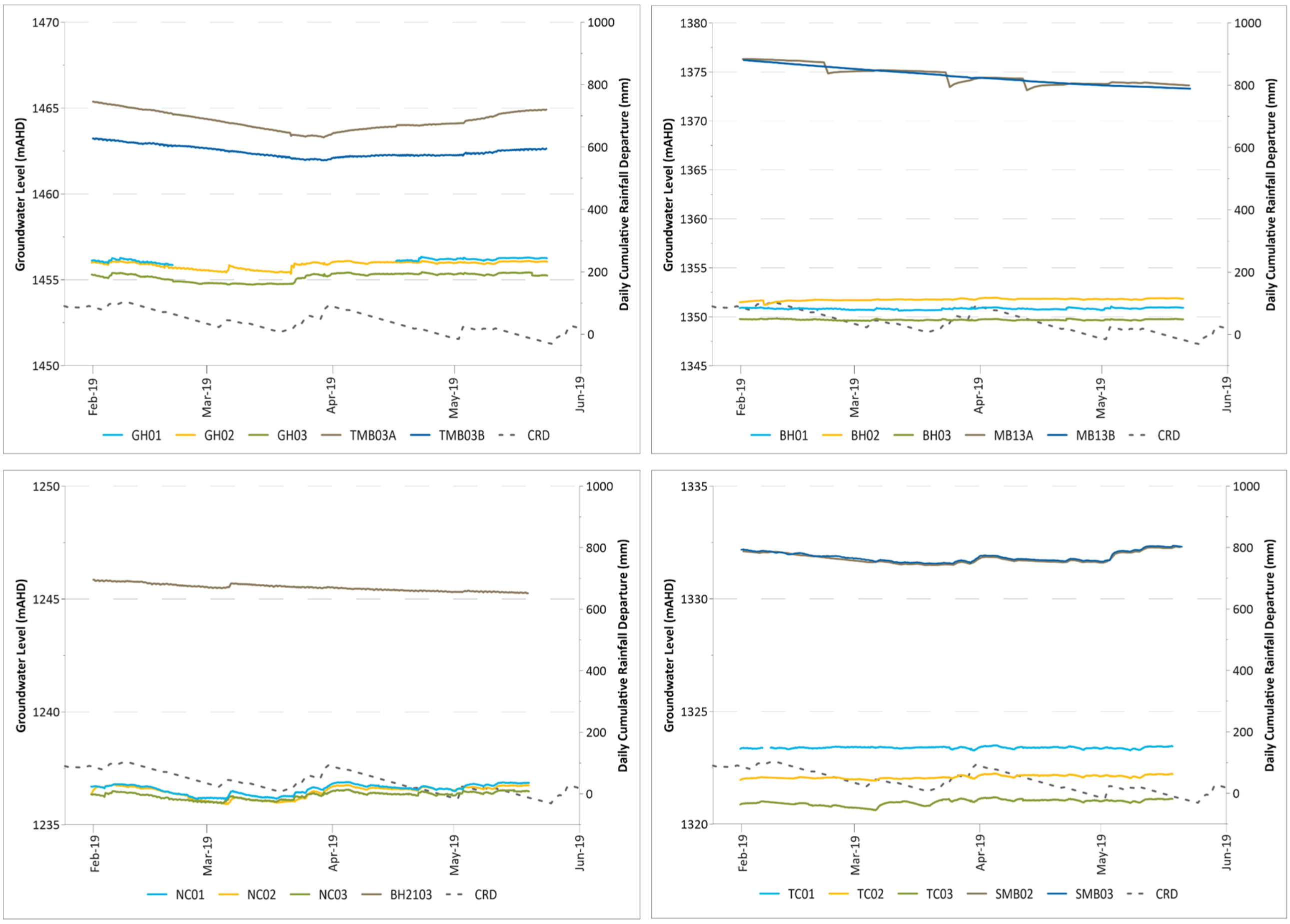


Figure 6.3 Bog and fen water levels versus nearby monitoring bore water levels

6.3.2 Ravine

i Groundwater levels and flow

Groundwater levels within the ravine are influenced by the steep relief that exists across the area and generally mirrors the topography. In monitored locations within the project area, groundwater levels are above creeks and streams, therefore suggesting creeks and streams are gaining systems.

Along the proposed headrace tunnel transect, groundwater levels within the Ravine Beds vary from approximately 1,325 m AHD in the topographically elevated terrain adjacent to the LPF in the east, to approximately 570 m AHD in the topographically lower terrain near Lobs Hole. Groundwater flow direction is generally from east to west, with the LPF area acting as a groundwater divide between the ravine and plateau areas.

Groundwater levels within monitoring bores and VWPs have generally shown fluctuations of less than 10 m during the monitoring period. Groundwater levels within the ravine do not typically show an obvious response to rainfall events or flow events within the Yarrangobilly River.

Vertical leakage within the Ravine Beds is downwards with groundwater in the upper horizons of the unit recharging the deeper horizons.

Nested monitoring bores within the Boraig Group have similar groundwater elevation and trends which suggests that the top 70 m or so of Boraig Group sediments are hydraulically connected.

Groundwater levels within the Ravine Beds and Boraig Group show similar elevations and trends at one nested location (TMB01A/TMB02B) which suggests that there may be some degree of hydraulic connection between the Boraig Group and Ravine Beds at this location.

Further discussion on groundwater levels and flow within the ravine area is provided in Section 9.3.1 of the water characterisation report (Annexure A).

ii Hydraulic properties

Hydraulic properties within the ravine are summarised as follows:

- estimated horizontal hydraulic conductivity in the Ravine Beds West are generally higher when compared to the Ravine Beds East (see Figure 6.4);
- a pumping test conducted within the Ravine Beds West demonstrated a low to moderate degree of vertical hydraulic connection between shallow and deeper horizons within this geological unit; and
- horizontal hydraulic conductivity generally decreases with increasing depth in all the geological units tested.

Further detail regarding hydraulic properties in the ravine area is provided in Section 9.3.2 of the water characterisation report (Annexure A).

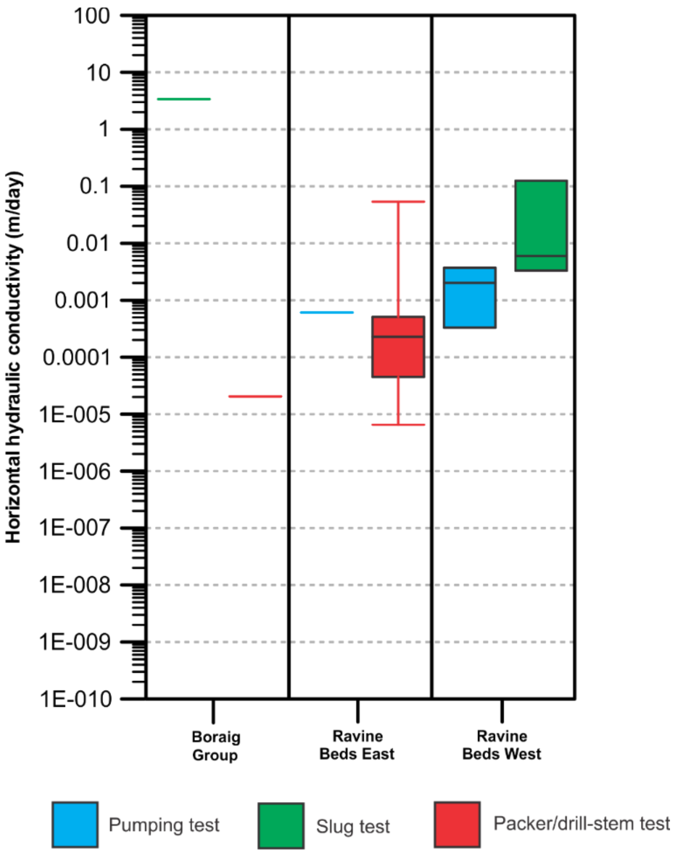


Figure 6.4 Ravine area estimated horizontal hydraulic conductivity – Box and Whisker plot (Note: whiskers represent the minimum and maximum and the box represents the 75th and 25th percentiles of the data).

iii Aquifer chemistry

To assist with the characterisation of aquifer chemistry in the ravine area, statistical and graphical interpretation of the water quality data was undertaken including Piper diagrams, box and whisker plots, Stiff diagrams, pie charts of major ion concentrations and trends over time.

This section summarises the interpretation of the above, with further detail provided in Section 9.3.3 of the water characterisation report (Annexure A).

Box and whisker plots of major ions for each of the geological units within the ravine are shown in Figure 6.5 and are summarised as follows:

- pH within the different geological units across the ravine ranges from 4.7 to 8.1. pH is generally highest in the Ravine Beds West when compared to the other monitored geological units;
- TDS is fresh and ranges from 52 mg/L (Boraig Group) to 1,540 mg/L (Ravine Beds West);
- calcium, magnesium, chloride, sodium and sulphate are generally less than 100 mg/L in all geological units; and
- bicarbonate concentrations in all geological units are generally higher than other major ions with a maximum of 1,170 mg/L in the Ravine Beds West.

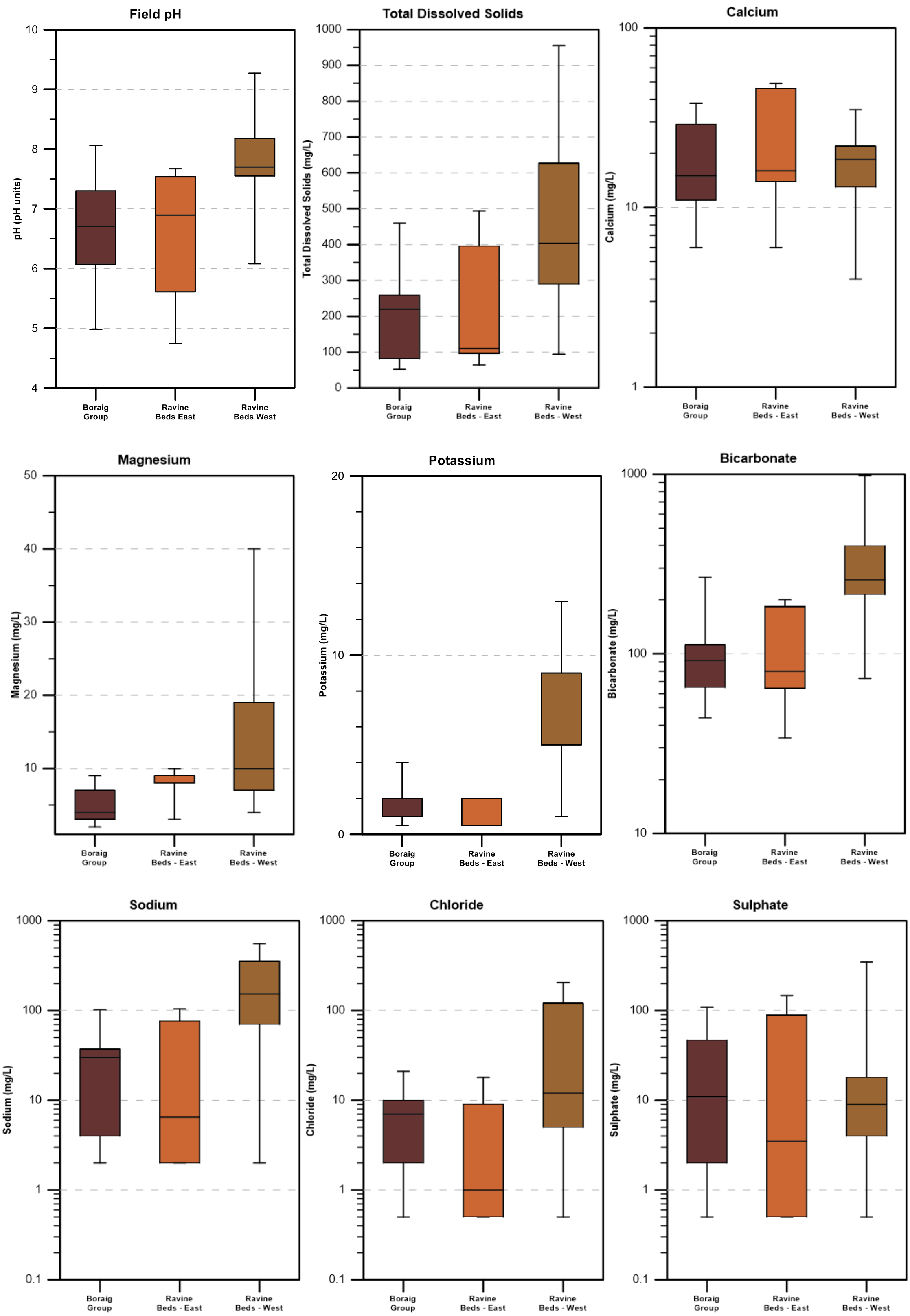


Figure 6.5 Ravine area selected groundwater quality analytes – Box and Whisker plots

Key findings from Stiff plots and pie charts are summarised as follows:

- differences in Stiff patterns and chemical composition between nested monitoring bores within the Ravine Beds East suggests that there is heterogeneity within this geological unit with depth;
- monitoring bores within the Ravine Beds West show a broad range in Stiff pattern and chemical composition suggesting that there is a high degree of heterogeneity within the Ravine Beds West both spatially and with depth; and
- deeper monitoring bores along the proposed tunnel alignment within the Ravine Beds West have noticeably higher concentrations of chloride and broader Stiff patterns than shallower bores which suggests that deeper groundwater has longer residence times and/or has undergone greater interaction with the rock material when compared to the shallower bores.

The following is a summary of ravine baseline water chemistry in comparison with the WQOs:

- samples collected from all bores exceeded dissolved oxygen, electrical conductivity, ammonia, oxidised nitrogen, arsenic, copper and zinc WQOs; and
- total nitrogen, total or reactive phosphorus and several metals including aluminium, boron, chromium, cobalt, iron, nickel and zinc were exceeded in samples collected from bores in other geological units.

7 Watercourses

7.1 Overview

This section describes the physical setting, hydrologic processes, streamflow regimes and water quality characteristics of watercourses in the project area. Watercourses across the project area vary according to soil type, geology, topography, elevation and climate and range from small ephemeral watercourses to regional rivers with perennial flow regimes. Groundwater provides baseflow to streams across the project area and therefore all streams are considered to eb ‘gaining’ systems (ie receive water from the adjacent groundwater sources).

Watercourses in the plateau are categorised as high conservation systems. To assist in the characterisation of water quality, water quality results have been compared to the following default values which are based on the NSW Water Quality and River Flow Objectives (DECCW 2006):

- physical and chemical stressors – default trigger values for upland rivers in South Eastern Australia that are reported in ANZECC/ARMCANZ (2000); and
- toxicant trigger values for the protection of 99% of freshwater aquatic species that are provided in ANZECC/ARMCANZ (2000).

River flow objectives are used by the NSW Government in the management of environmental flows and set out aspects of flow considered to be critical for the protection or restoration of river health, ecology and biodiversity (DECCW 2006). The following flow categories are defined within the NSW river flow objectives:

- Very low flows: flows below the level naturally exceeded on 95% of all days with flow;
- Low flows: flows below the level naturally exceeded on 80% of all days with flow; and
- High flows: flows that are greater than the level naturally exceeded on 30% of all days with flow.

Characterisation of water quality for the plateau watercourses is provided in Section 7.2.3 and for the ravine watercourses in Section 7.3.3. The river flow objectives have been used in the impact assessment (Section 11).

7.2 Plateau

7.2.1 Physical setting

The stream order, catchment area and flow regime of key watercourses that are discussed further in this section are described in Table 7.1. It is noted that Nungar and Kellys Plain creeks are described as tributaries of the Murrumbidgee River, but flow directly into Tantangara Reservoir.

Table 7.1 Watercourse characteristics – plateau

Watercourse name	Stream order[1]	Catchment area	Flow regime[2]
Eucumbene River catchment			
Eucumbene River (upper reach[3])	4th order watercourse	20 km^2	Perennial
Eucumbene River (at Lake Eucumbene)	6th order watercourse	184 km^2	Perennial
Murrumbidgee River catchment			

Table 7.1 Watercourse characteristics – plateau

Watercourse name	Stream order[1]	Catchment area	Flow regime[2]
Murrumbidgee River (at Tantangara Reservoir)	6th order watercourse	221 km^2	Perennial
Tantangara Creek	5th order watercourse	77 km^2	Perennial
Gooandra Creek	4th order watercourse	14 km^2	Perennial
Gooandra Creek Tributary 1	3rd order watercourse	2.5 km^2	Perennial
Gooandra Creek Tributary 2	3rd order watercourse	2.6 km^2	Perennial
Nungar Creek (at Tantangara Reservoir)	5th order watercourse	83 km^2	Perennial
Kellys Plain Creek (at Tantangara Reservoir)	4th order watercourse	9 km^2	Perennial

Notes: 1. Stream order has been established using the Strahler system of ordering watercourses using information provided on a 1:25,000 topographic map.
2. Flow regimes for ungauged watercourses have been estimated based on site observations.
3. Refers to river reach above Racecourse Creek confluence.

i Watercourse characterisation

A geomorphic characterisation assessment of the watercourses in the plateau was undertaken by Flow and Loam Environmental. The full geomorphic characterisation report is provided in Attachment A of the water characterisation report (Annexure A).

The following points summarise the geomorphic characterisation:

- headwater streams of the western plateau between Eucumbene River and Tantangara Creek have varying dependence on groundwater and can be classified as either (1) swampy meadows, (2) steep headwater streams, or (3) laterally unconfined valley setting watercourses with a discontinuous channel:
  - swampy meadows are characterised by having no continuous channel and no mechanism for fluvial transport or sorting of sediments;
  - steep headwater streams occur in the upper catchment and are often steep and short in length. At most locations surveyed, groundwater discharge from the adjoining shallow groundwater system occurs in the middle to lower portions of the reach length;
  - laterally unconfined watercourses are typically characterised as broad treeless depressions extending upslope from larger watercourses.
- trunk streams of the western plateau between Eucumbene River and Tantangara Creek are groundwater dependent and are classified as either (1) confined valley setting watercourses, or (2) unconfined and partly confined valley setting watercourses:
  - confined valley watercourses are often incised into the underlying geology and are interpreted to be gaining streams with groundwater discharge occurring along the reach length and from tributaries. A typical profile of a confined valley setting watercourse showing surface and groundwater interactions is shown in Figure 7.1; and
  - unconfined valley watercourses are characterised by a meandering channel through a floodplain and are interpreted to be gaining streams with groundwater discharge occurring along the reach length

and from tributaries. A typical profile of an unconfined valley setting watercourse showing surface and groundwater interactions is shown in Figure 7.2.

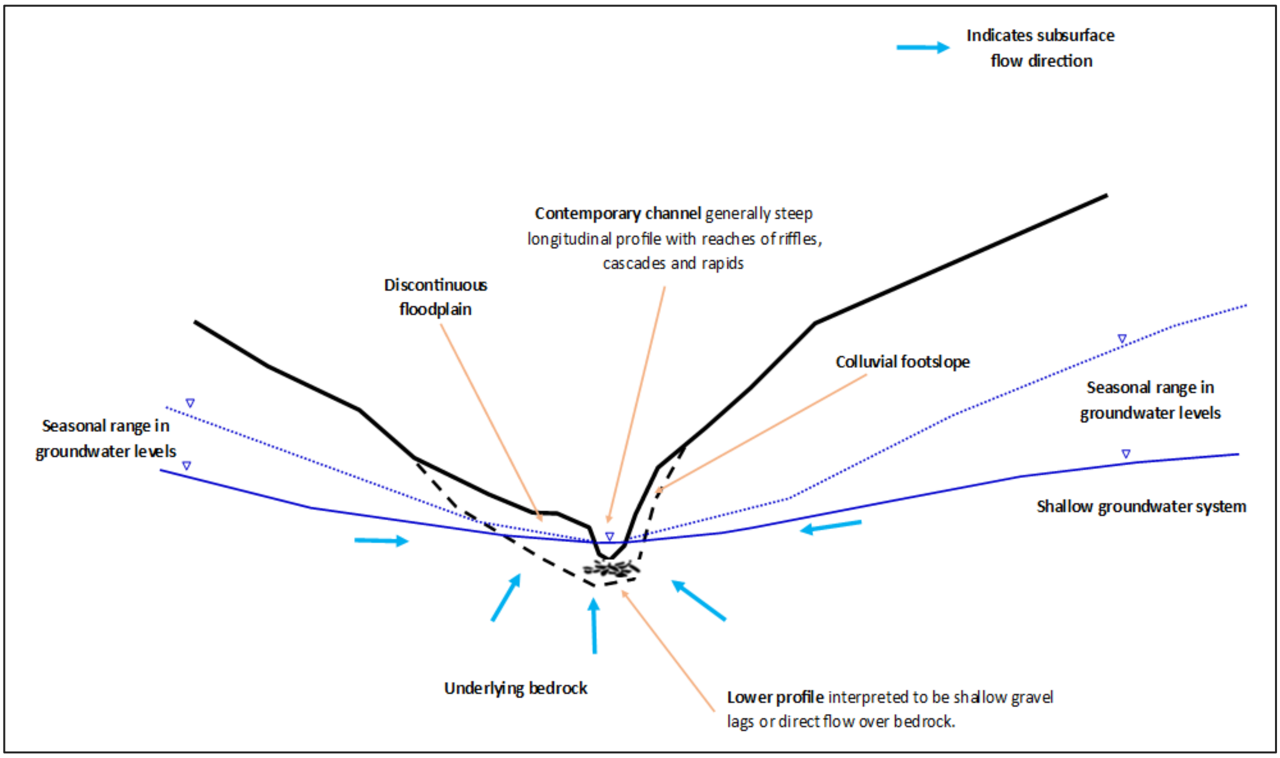


Figure 7.1 Typical profile of a watercourse in a confined valley setting showing surface and groundwater interaction (adapted from Flow and Loam Environmental 2019)

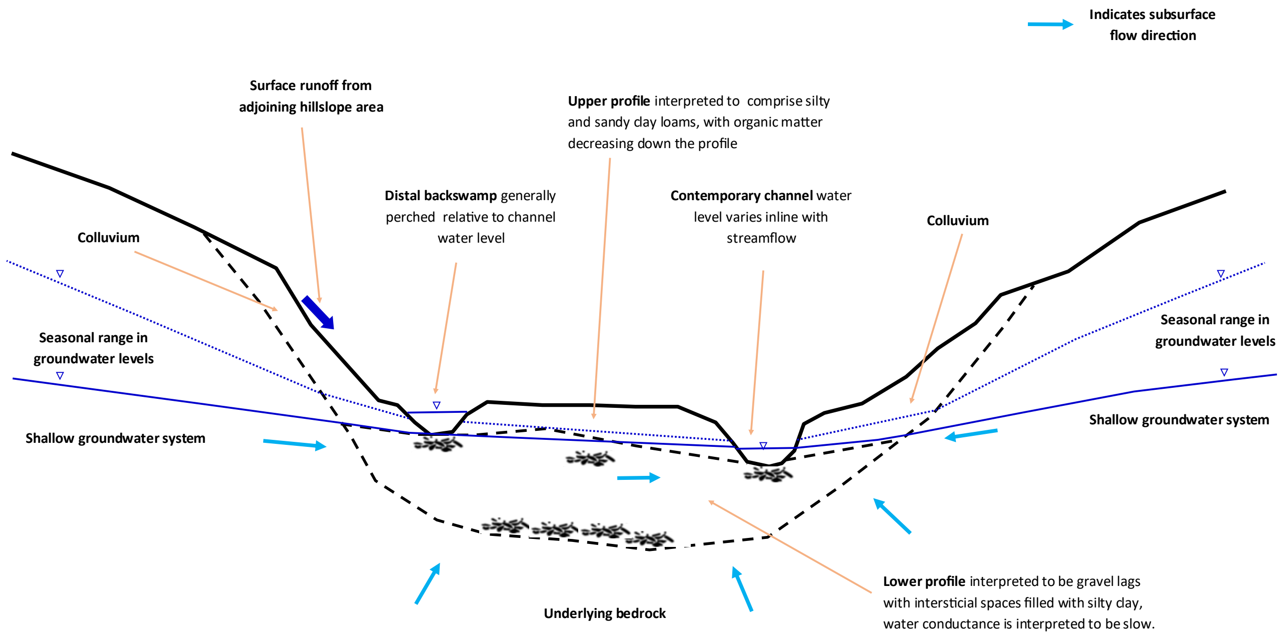


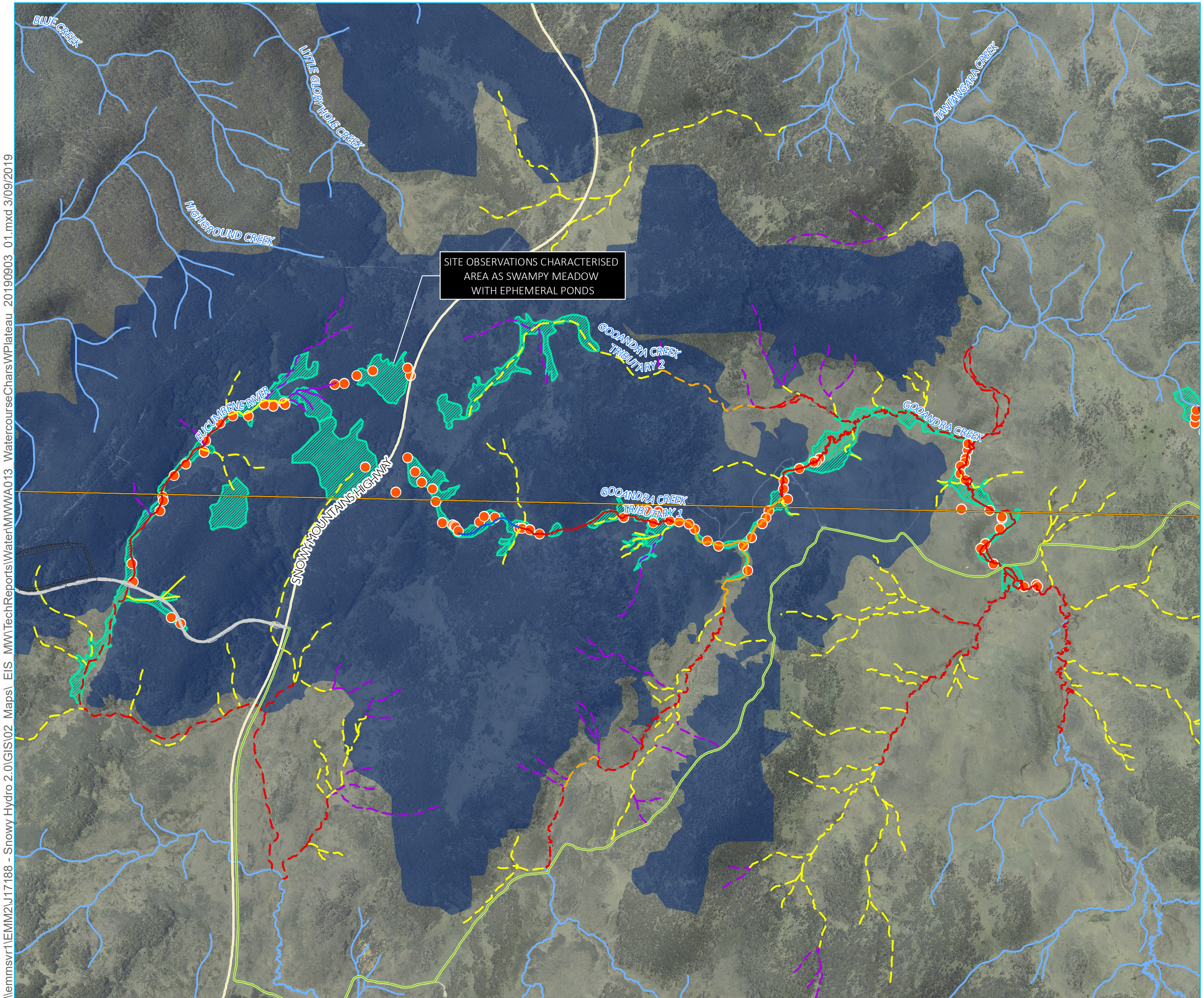
Figure 7.2 **Typical profile of an unconfined watercourse showing surface and groundwater interaction (adapted from Flow and Loam Environmental 2019)**

Watercourse characteristics across the plateau are shown in Figure 7.3.

ii Groundwater discharge characteristics

Groundwater discharge as springs along the headrace tunnel alignment between the Eucumbene River and Tantangara Creek have been categorised into one of the following three types:

1. Contact/hillslope springs: springs displaying visible flow, typically on hillslopes;
2. Lowland seeps: visible seeps into sediment storage (ie floodplains); and
3. Alpine bogs: boggy, wet ground, typically in depressions in the landscape.



Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

0 1 2 km

GDA 1994 MGA Zone 55

N

KEY

- Geomorphology field assessment location
- Approximate groundwater drawdown extent
- Interpreted sediment storage
- Watercourse

Surveyed watercourse

- Confined valley setting
- Partly unconfined valley setting
- Steep headwater stream
- Swampy meadow
- Unconfined valley setting, discontinuous channel

Inferred watercourse category

- Watercourse
- Confined valley setting
- Partly and unconfined valley setting
- Steep headwater stream
- Unconfined valley setting, discontinuous channel

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Utilities
- Permanent road

Snowy 2.0 construction elements

- Temporary construction compounds and surface works

Existing environment

- Main road

Watercourse characteristics
- western plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 7.3

7.2.2 Hydrology

This section summarises the hydrology of the plateau area, further detailed discussion is provided in Section 7.2.2 of the water characterisation report (Annexure A).

i Hydrologic processes

The majority of annual groundwater recharge and streamflow occurs in winter and early spring due to higher soil moisture levels and snowmelt influences during these seasons.

Streamflow in watercourses occurs due to the following processes:

- Quickflow – refers to surface water runoff that occurs following intense or prolonged periods of rainfall. Quickflow will rapidly enter receiving watercourses, resulting in a period of elevated streamflow.
- Interflow – refers to the lateral movement of water through the unsaturated zone that returns to surface. In the plateau, it is expected that subsurface flow along the soil-bedrock contact zone is the predominant form of interflow.
- Baseflow – refers to water discharged from the shallow groundwater system. The rate of baseflow varies in line with groundwater levels in the shallow groundwater system. During wet weather conditions, baseflow forms only a small portion of streamflow but is the predominant source of streamflow during dry conditions.

Key hydrologic processes are presented in Figure 7.4.

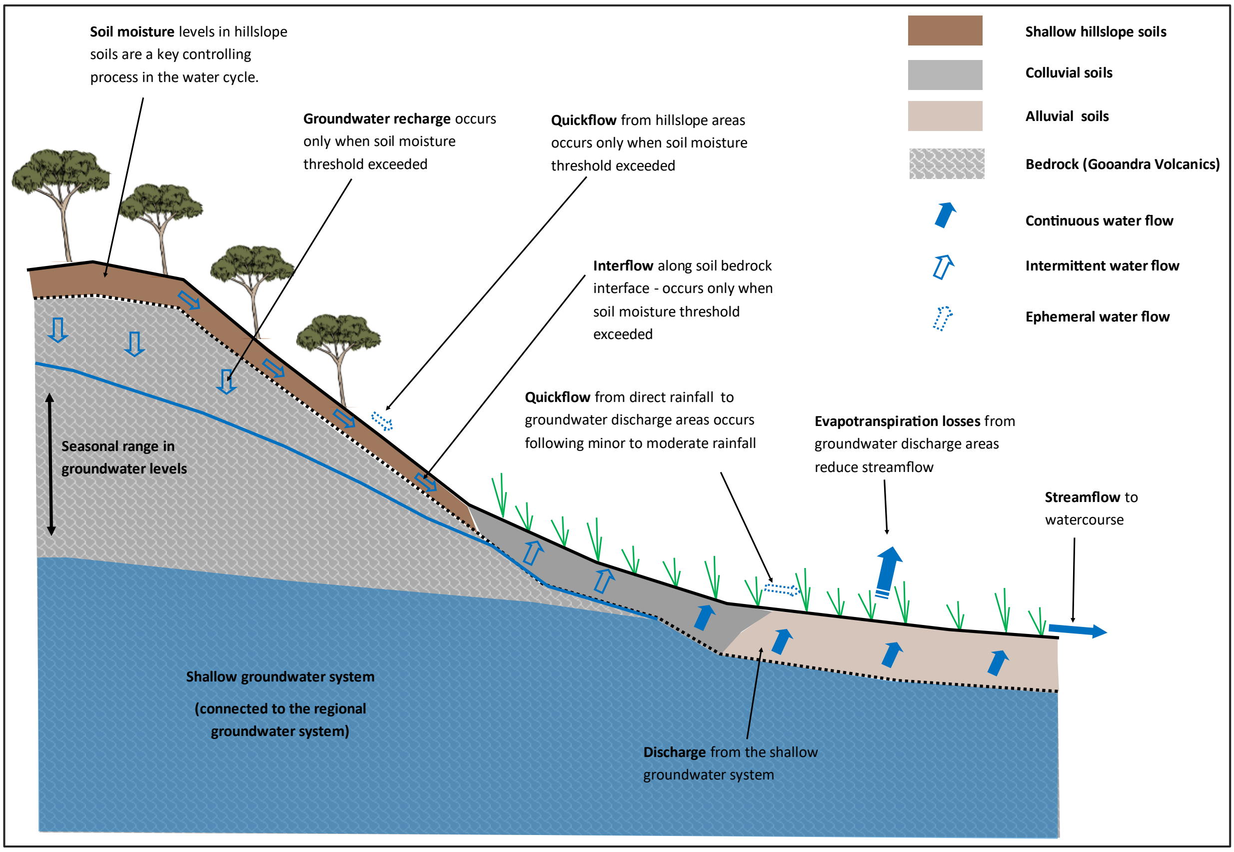


Figure 7.4 Hydrologic processes – simplified concept

ii Regional streamflow

Streamflow in the Murrumbidgee and Eucumbene rivers has been recorded at Snowy Hydro operated gauges located upstream of Tantangara Reservoir and Lake Eucumbene respectively.

Streamflow statistics and trends from each gauge are summarised in the following table and figures:

- Table 7.2 presents annualised streamflow statistics that have been calculated from gauge records.
- Figure 7.5 and Figure 7.6 plot monthly streamflow statistics that have been calculated from gauge records. The gauged monthly flows over the EIS monitoring period (2018 to May 2019) are provided for context.

Table 7.2 Annual streamflow statistics – plateau

	Murrumbidgee River (410535)		Eucumbene River (222522)	
	Annual runoff	**Runoff coefficient[1]**	**Annual runoff**	**Runoff coefficient[2]**
Gauge record[3]	1978 - 2019		1978 - 2019	
Minimum	20 GL/year	15% of rainfall	26 GL/year	23% of rainfall
10^{th} percentile	88 GL/year	38% of rainfall	102 GL/year	41% of rainfall
50^{th} percentile	126 GL/year	49% of rainfall	137 GL/year	56% of rainfall
Average	144 GL/year	50% of rainfall	148 GL/year	57% of rainfall
90^{th} percentile	210 GL/year	63% of rainfall	214 GL/year	75% of rainfall
Maximum	236 GL/year	76% of rainfall	232 GL/year	90% of rainfall

Notes: 1. The runoff coefficient has been calculated using rainfall from the Yarrangobilly Caves (72141) rainfall record, adjusted to reflect median rainfall contours in each catchment.

2. The runoff coefficient has been calculated using rainfall from the Cabramurra (72161) rainfall record, adjusted to reflect median rainfall contours in each catchment.

3. Record period based on the record available in electronic format. Earlier data may be available in non-electronic format.

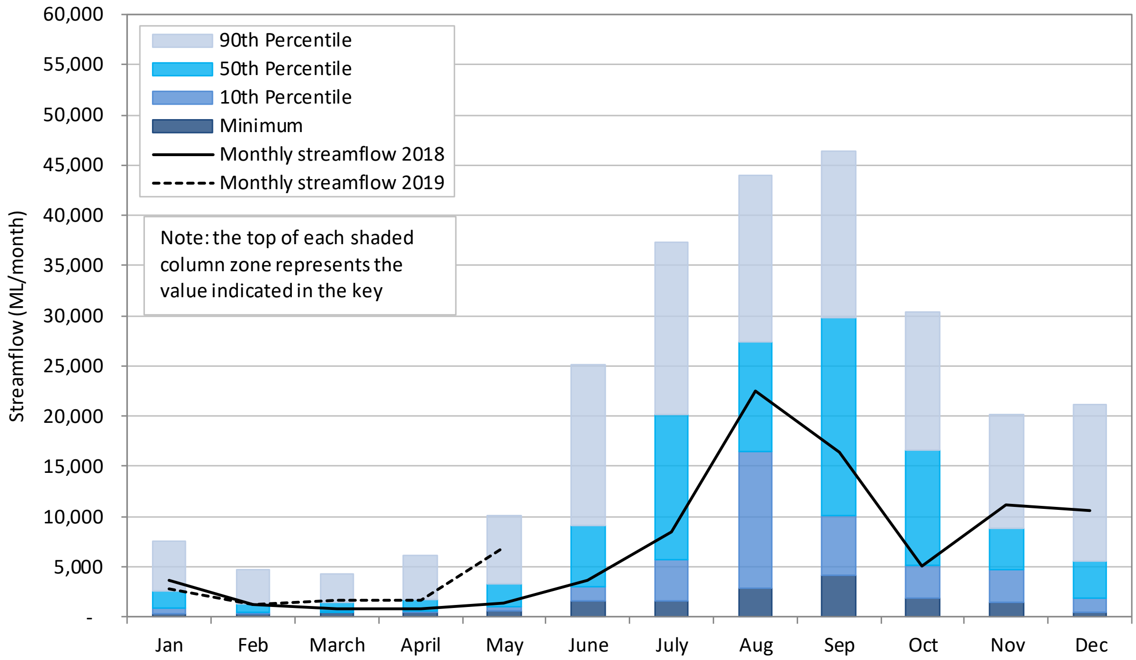


Figure 7.5 Monthly streamflow statistics (Murrumbidgee River – 410535)

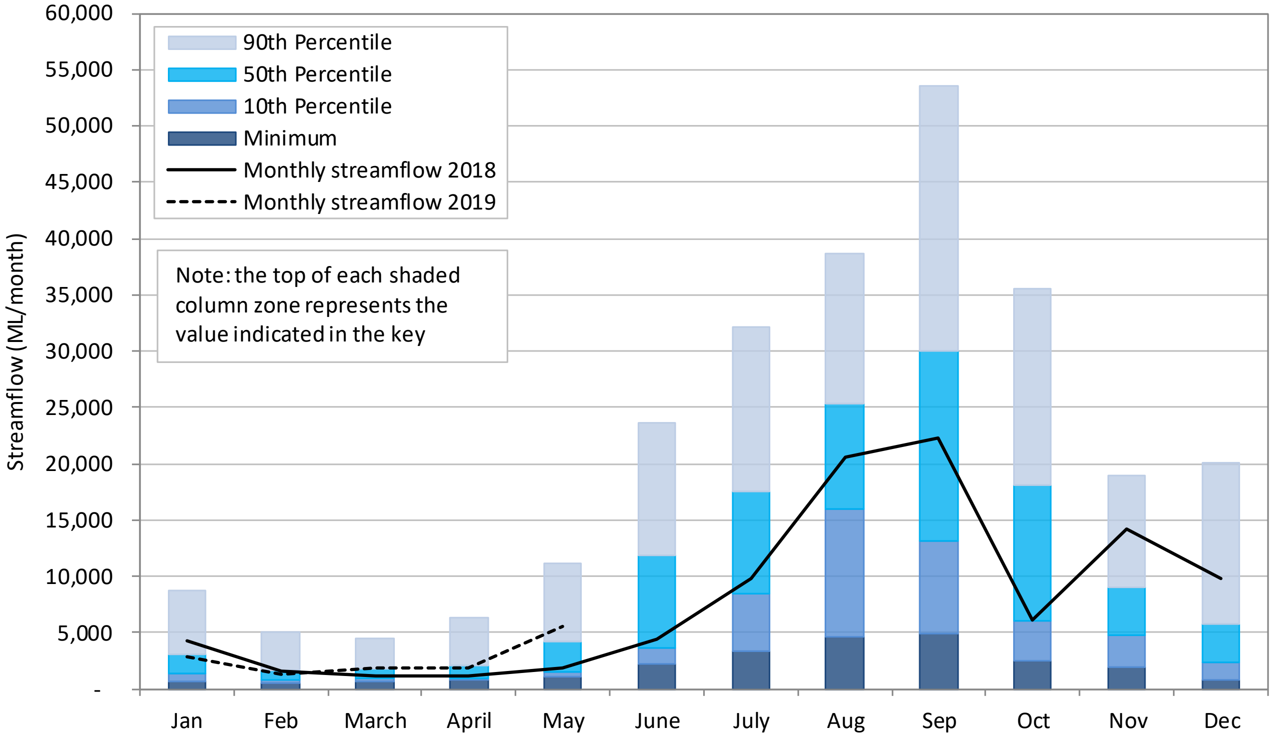


Figure 7.6 Monthly streamflow statistics (Eucumbene River – 222522)

With reference to the data presented above, regional streamflow regimes are described as follows:

- The average runoff coefficient for the Murrumbidgee River catchment is estimated to be 50% of rainfall but ranges between 15% of rainfall in drought years to 76% of rainfall in wet years. The average runoff coefficient for the Eucumbene River catchment is higher at 57% of rainfall but ranges between 23% of rainfall in drought years to 90% of rainfall in wet years.

- In both catchments, the majority of runoff occurs in late winter and early spring. Streamflow progressively recedes over summer and generally remains low until the winter months. This is a typical regime for rivers in the Australian Alps.

- Winter and spring runoff volumes were abnormally low in 1982 and 2006, following abnormally dry winter months. The lowest monthly flow on record for both the Murrumbidgee and Eucumbene river catchments occurred in February 1983 following an abnormally dry winter and spring in 1982. This data indicates that permanent streamflow is maintained in watercourses by groundwater discharge during drought conditions.

- The 90th percentile streamflow in summer and early autumn months is not substantially higher than the 10th and 50th percentile flows. This indicates that significant streamflow in summer or early autumn will only occur as a result of flood-producing rainfall.

iii Groundwater recharge regimes

Overall, groundwater recharge shows a positive correlation to soil moisture conditions and will only occur when soil moisture thresholds are exceeded. Recharge events are therefore only expected to occur:

- during winter and early spring due to persistent rainfall, low evapotranspiration rates and snow melt influences; and

- during late spring, summer and autumn following significant rainfall events.

iv Baseflow regimes

Perennial streamflow is maintained in most watercourses due to discharge from the shallow groundwater system. This groundwater discharge is referred to as baseflow. Understanding baseflow regimes is an important aspect of the water assessment, as the shallow groundwater system is vertically connected to the underlying regional groundwater system in the Gooandra Volcanics geological unit (located between Eucumbene River and Tantangara Creek).

On a regional scale, baseflow rates are interpreted to broadly be a function of:

- Groundwater levels – discharge from the shallow groundwater system is a function of groundwater levels, with higher discharge occurring when levels are high, and lower discharges occurring when levels are close to the surface level of the discharge location.

- Evapotranspiration losses – as most groundwater is discharged at low rates into vegetated areas, evapotranspiration losses occur near the discharge location. Material losses are only expected in summer and autumn. As a result, during summer and autumn, groundwater discharge to the surface environment is higher than streamflow in receiving watercourses.

These two principles were applied to manually separate baseflow from the gauged streamflow in the Murrumbidgee River. This approach is demonstrated in Figure 7.7 and Figure 7.8. Figure 7.7 plots the gauged streamflow against the groundwater levels within nearby monitoring bore TMB04. Baseflow was assumed to form 100% of streamflow during known dry periods. These assumed rates of baseflow were applied to other periods that had similar groundwater levels, but higher streamflow. It is noted that this analysis compares groundwater levels from a single bore to streamflow from a regional gauge. While this is a clear limitation, similar periods of recharge and recession occurred at nearly all groundwater hydrographs in hillslope bores in the plateau.

Material evapotranspiration losses are interpreted to occur near groundwater discharge locations, which often comprise broad areas of riparian vegetation. This is evident in Figure 7.8 which compares the interpreted baseflow to the gauged streamflow in the Murrumbidgee River. In 2018, the lowest groundwater levels occurred in mid-June (see Figure 7.7), which would correlate with the lowest discharge rates from the shallow groundwater system occurring at this time. As evident in Figure 7.8, the interpreted baseflow and the gauged streamflow were well below mid-June 2018 levels during late summer and autumn, indicating the magnitude of evapotranspiration losses that occur near groundwater discharge locations.

The term Baseflow Index (BFI) is used to describe the portion of streamflow that originates from baseflow. The following BFIs were calculated for 2018 using the manual baseflow separation method described above:

- baseflow before evapotranspiration losses – 0.50 or 50% of streamflow; and

- baseflow after evapotranspiration losses – 0.43 or 43% of streamflow.

The 2018 annual gauged streamflow in the Murrumbidgee River was 86 GL, which is less than the 10th percentile annual streamflow presented in Table 7.2 (88 GL/year). As such, it is expected that BFIs would be materially lower in higher streamflow years as runoff from quickflow and interflow processes would be proportionally greater.

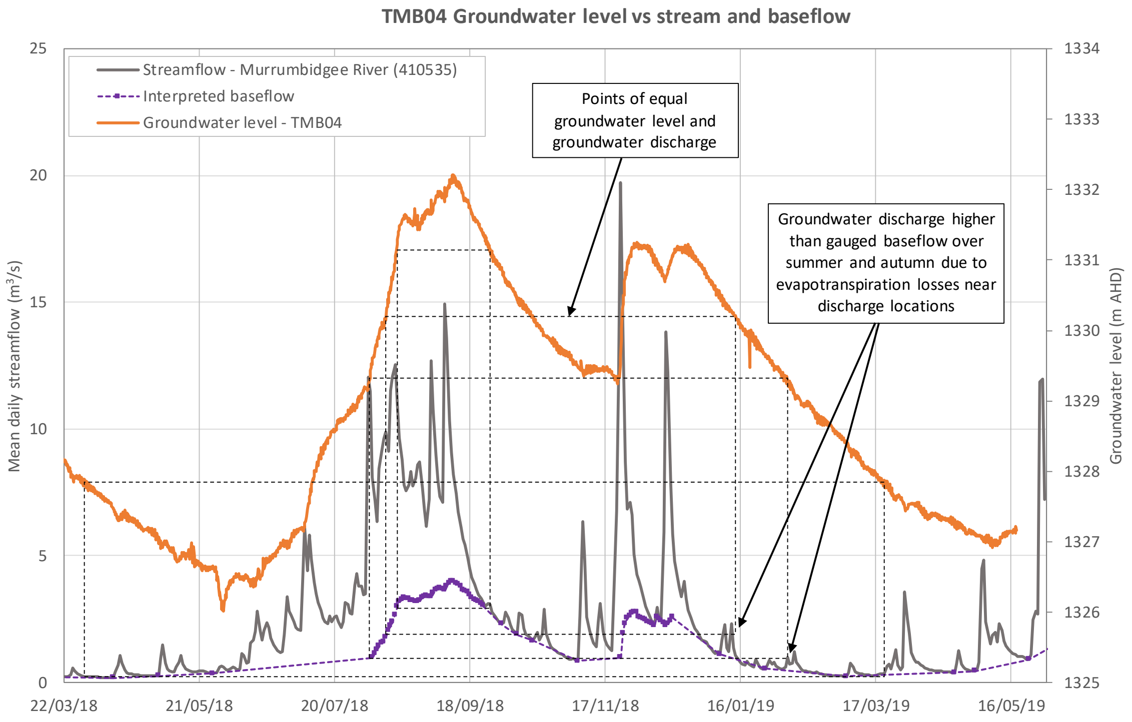


Figure 7.7 Manual baseflow separation

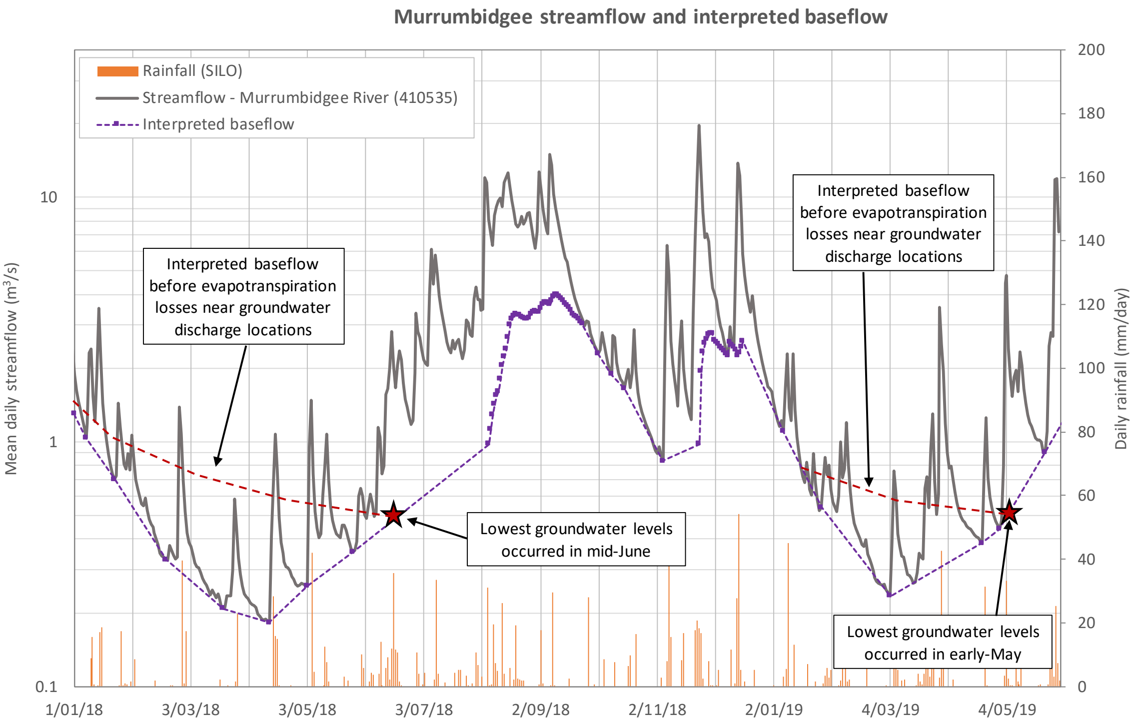


Figure 7.8 Evapotranspiration losses near groundwater discharge locations

7.2.3 Water quality characterisation

Water quality characteristics for the plateau watercourses are described as follows:

- The Murrumbidgee and Eucumbene rivers, Tantangara, Gooandra, Nungar and Kellys Plain creeks have similar water quality during dry weather conditions, key characteristics include:
    - pH that generally ranges between 6.2 and 8.5, with occasional lower and upper bound exceedances;
    - carbonate and salinity vary seasonally, with higher levels occurring in summer/autumn; and
    - low concentrations of suspended solids and low turbidity.
- The water quality of minor watercourses in the vicinity of the proposed surface works near Tantangara Reservoir is generally poorer than larger watercourses, with elevated suspended sediment, nutrients and some metals (aluminium and iron).
- The water quality during wet weather conditions is poorly understood. It is expected that concentrations of suspended sediment and some metals may be higher than dry weather concentrations. Wet weather sampling is proposed prior to commencement of works.

Box and whisker plots for key water quality parameters discussed above are provided in Figure 7.9. The box (the rectangle) represents the data range (for all streamflow categories) for the middle 50% of values (the data between the first and third quartiles). The horizontal line in the middle of the box represents the median value. The whiskers represent the minimum and maximum values, excluding outliers.

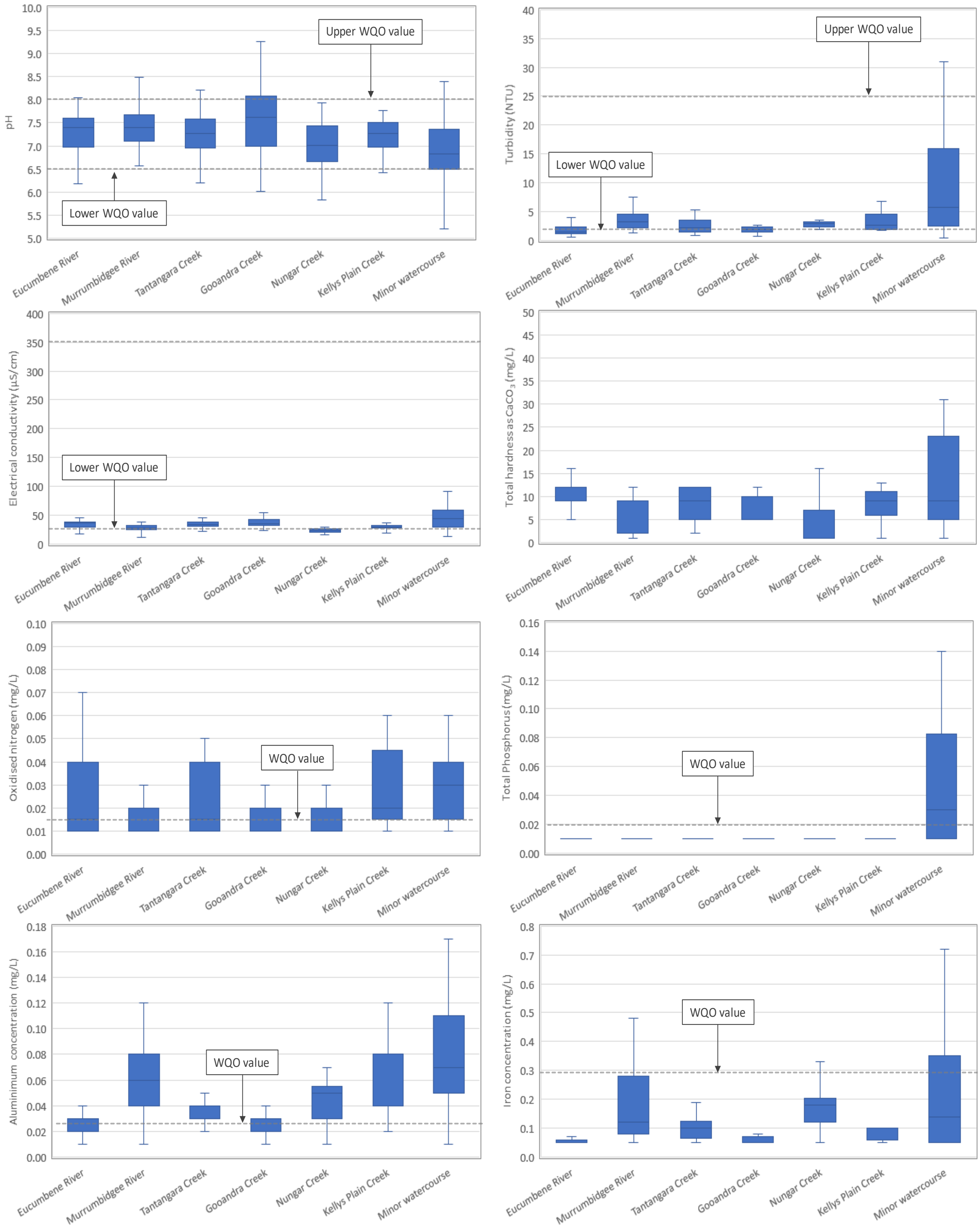


Figure 7.9 Plateau surface water quality summary – Box and Whisker plots

7.3 Ravine

7.3.1 Physical setting

The Yarrangobilly River catchment and major watercourses in the ravine are shown in Figure 7.10.

The stream order, catchment area and flow regime of key watercourses that are discussed further in this section are described in Table 7.3.

Table 7.3 Watercourse characteristics – ravine

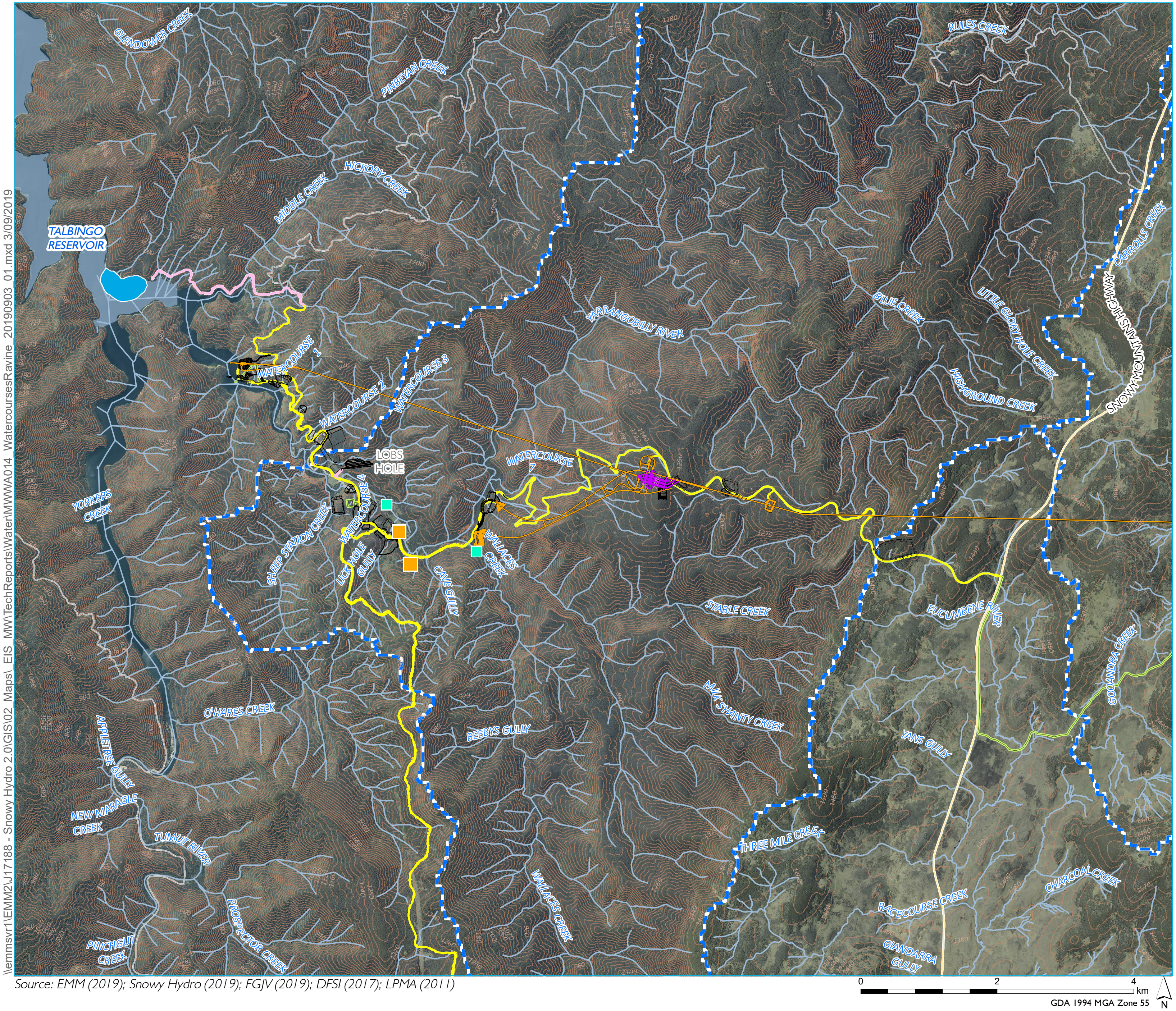
Name	Stream order[1]	Catchment area	Flow regime[2]
Yarrangobilly River	7th order watercourse	280 km^2	Perennial
Tumut River	6th order watercourse	510 km^2	Perennial
Wallaces Creek	6th order watercourse	44 km^2	Perennial
Stable Creek	5th order watercourse	19.5 km^2	Perennial
Cave Gully	3rd order watercourse	1.4 km^2	Intermittent
Lick Hole Gully	3rd order watercourse	1.5 km^2	Intermittent
Sheep Station Creek	3rd order watercourse	3.9 km^2	Intermittent
Highground Creek	4th order watercourse	9.7 km^2	Perennial
Watercourse 1	3rd order watercourse	0.5 km^2	Intermittent
Watercourse 2	3rd order watercourse	1.2 km^2	Intermittent
Watercourse 3	3rd order watercourse	2.3 km^2	Intermittent
Watercourse 4	2nd order watercourse	0.3 km^2	Ephemeral
Watercourse 5	2nd order watercourse	0.6 km^2	Intermittent
Watercourse 6	2nd order watercourse	0.4 km^2	Ephemeral
Watercourse 7	3rd order watercourse	2.2 km^2	Intermittent

Notes: 1. Stream order has been established using the Strahler system of ordering watercourses using information provided on a 1:25,000 topographic map.
2. The flow regimes of ungauged watercourses have been estimated based on-site observations and catchment characteristics.

i Watercourse characterisation

a Lobs Hole

A geomorphic characterisation assessment of the Lobs Hole area in the ravine was undertaken by Flow and Loam Environmental (2019). The full geomorphic characterisation report is provided in Attachment A of the water characterisation report Annexure A).



\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MW\TechReports\Water\MWWA014_WatercoursesRavine_20190903_01.mxd 3/09/2019

Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

KEY

- Weather station
- Streamflow gauge
- Key watercourse
- 20m contour
- Catchment area

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 construction elements

- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement area

Existing environment

- Main road
- Local road
- Waterbodies

Watercourses - ravine

Snowy 2.0
Water assessment
Main Works
Figure 7.10

snowy 2.0

EMM creating opportunities

The following points summarise the geomorphic characterisation:

- the Yarrangobilly River is characterised as a partly confined, platform-controlled river that has low sinuosity and frequent pool and riffle sequences. The river flows through a steep sided valley that has a flat valley floor, which is interpreted to comprise coarse cobbles and boulders (remnant of a paleochannel) that have been covered with a thin veneer of finer sediments;

- only larger watercourses such as Wallaces and Sheep Station creeks have had sufficient flow to have incised a channel through the valley floor; and

- most runoff from these watercourses is interpreted to infiltrate into the valley floor and flow into the Yarrangobilly River as subsurface flow.

b Marica

Proposed works at Marica are located on a ridgeline between the headwaters of the Stable Creek and Highground Creek catchments, within the eastern portion of the Yarrangobilly River catchment. Watercourses in this area are characterised as steep headwater streams with ephemeral flow regimes. The upper portion of these streams typically have no defined channel. Down catchment, discontinuous channels commence in well-defined channel zones and become continuous with increasing catchment area.

7.3.2 Hydrology

This section summarises the hydrology of the ravine, further detail is provided in Section 7.3.2 of the water characterisation report (Annexure A).

i Hydrologic processes

The hydrologic regime of watercourses in the ravine is strongly influenced by seasonal changes in climate.

It is expected that most streamflow in the Yarrangobilly River originates from the higher elevation headwater catchments. Hydrologic processes in the lower portions of the catchment are expected to be less complex, with quickflow and baseflow being the predominant processes. Most third order and larger watercourses generally exhibit intermittent flow regimes, with baseflow typically commencing in early winter and ceasing mid-summer. Smaller watercourses generally have ephemeral flow regimes.

Streamflow regimes are described further in the following sections.

ii Regional streamflow

Streamflow in the ravine has been recorded at Snowy Hydro operated gauges located in Yarrangobilly River (at Lobs Hole), Wallaces Creek and Brownleys Back Creek.

Streamflow statistics and trends from each gauge are summarised in the following table and figure:

- Table 7.4 presents annualised streamflow statistics that have been calculated by EMM from the gauge records.

- Figure 7.11 plots monthly streamflow statistics that have been calculated from the Yarrangobilly River gauge record. The gauged monthly flows over the data collection period (2018 to May 2019) are provided for context.

Table 7.4 Annual streamflow statistics – ravine

	Yarrangobilly River (410574)		Wallaces Creek (410507)		Brownleys Back Creek (600577)	
	Annual runoff	Runoff coefficient[1]	Annual runoff	Runoff coefficient[1]	Annual runoff	Runoff coefficient[1]
Record[2]	1985 – 2019		1982 - 1999		1984 - 2019	
Minimum	15 GL/year	10% of rainfall	8 GL/year	20% of rainfall	3 GL/year	14% of rainfall
10^{th} percentile	58 GL/year	21% of rainfall	9 GL/year	22% of rainfall	8 GL/year	20% of rainfall
50^{th} percentile	99 GL/year	31% of rainfall	20 GL/year	41% of rainfall	17 GL/year	34% of rainfall
Average	115 GL/year	32% of rainfall	19 GL/year	37% of rainfall	20 GL/year	36% of rainfall
90^{th} percentile	184 GL/year	47% of rainfall	28 GL/year	48% of rainfall	31 GL/year	54% of rainfall
Maximum	235 GL/year	53% of rainfall	32 GL/year	59% of rainfall	38 GL/year	62% of rainfall

Notes: 1. The runoff coefficient has been calculated using rainfall from the Yarrangobilly Caves (72141) rainfall record, adjusted to reflect mean rainfall contours.
2. Record period based on the record available in electronic format. Earlier data may be available in non-electronic format.

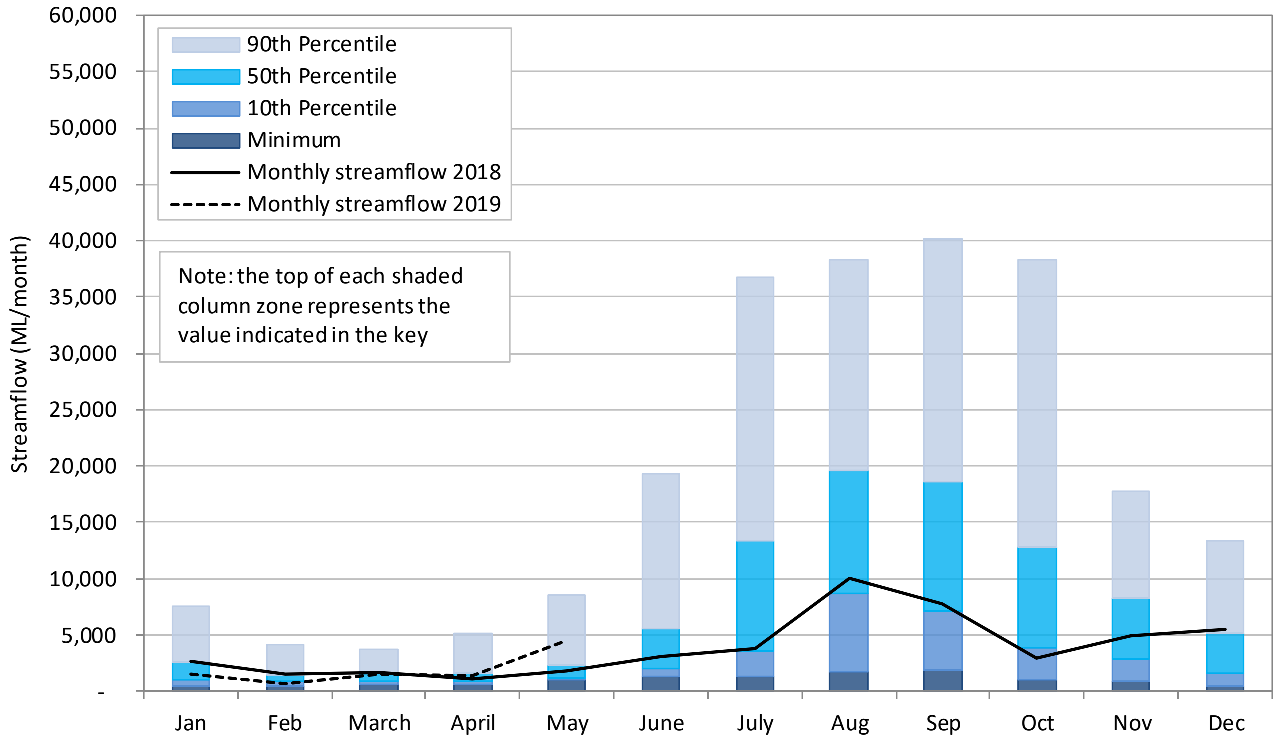


Figure 7.11 Monthly streamflow statistics (Yarrangobilly River – 410574)

With reference to the data presented above, regional streamflow regimes are described as follows:

- The average runoff coefficient for the Yarrangobilly River catchment is estimated to be 32% of rainfall but ranges between 10% of rainfall in dry years to 53% of rainfall in wet years.
- The majority of runoff occurs in late winter and early spring. Streamflow progressively recedes over summer and generally remains low until the winter months. This is a typical regime for rivers in the Australian Alps.

- Winter and spring runoff volumes were abnormally low in 1982 and 2006, following abnormally dry winter months. The lowest monthly flow on record for both the Yarrangobilly River and Wallaces Creek occurred in February 1983 following an abnormally dry winter and spring/summer in 1982. This data indicates that permanent baseflow is maintained in the river by groundwater discharges during drought conditions.

- The Yarrangobilly River and Wallaces Creek have a similar flow regime. The total gauged flows over the 1983 to 1998 period were equivalent to 15% of the total gauged flows in the Yarrangobilly River, which is similar to the relative catchment area ratios.

- A comparison of the Yarrangobilly River and Brownleys Back Creek indicates that streamflow in Brownleys Back Creek is proportionally higher than the Yarrangobilly River. The total gauged flows over the 1985 to 2019 period were equivalent to 18% of the total gauged flows in the Yarrangobilly River, which is 20% greater than the relative catchment area ratios (15%).

iii Localised streamflow

There are several smaller watercourses near the Lobs Hole and Marica compounds. Most third order and larger watercourses in the ravine exhibit intermittent flow regimes, with baseflow typically commencing in early winter and ceasing mid-summer. Smaller watercourses generally have ephemeral flow regimes.

7.3.3 Water quality characterisation

Water quality characteristics for the ravine watercourses are described as follows:

- Yarrangobilly River and Wallaces Creek have similar water quality during dry weather conditions. Key characteristics include:

  - pH ranges between 6.2 to 8.5, with occasional lower and upper bound exceedances;

  - low concentrations of suspended solids and low turbidity; and

  - carbonate and salinity vary seasonally, with higher levels occurring in summer/autumn.

- The water quality during dry weather conditions in minor watercourses in Lobs Hole is generally poorer than larger watercourses, with elevated suspended sediment, nutrients and some metals (aluminium and copper).

- The understanding of water quality during wet weather conditions is informed by data from monitoring undertaken in March and May 2019 following moderate rainfall. Receiving water quality during wet weather conditions is generally poorer relative to baseflow conditions with higher turbidity, lower pH, higher nutrients and potential for non-trivial concentrations of some metals such as aluminium and copper.

- Runoff samples were collected from existing disturbed areas in Lobs Hole such as access tracks and remnant copper mining areas in May and March 2019. Disturbed area runoff is characterised as being mildly acidic, having very high suspended sediment and turbidity levels, high total nitrogen and total phosphorous, and very high aluminium and copper concentrations. During wet weather conditions (when runoff is occurring to local watercourses in Lobs Hole), the water quality in the Yarrangobilly River is expected to be degraded as it passes through Lobs Hole.

Box and whisker plots for key water quality parameters discussed above are provided in Figure 7.12. The box (the rectangle) represents the data range (for all streamflow categories) for the middle 50% of values (the data between the first and third quartiles). The horizontal line in the middle of the box represents the median value. The whiskers represent the minimum and maximum values, excluding outliers.

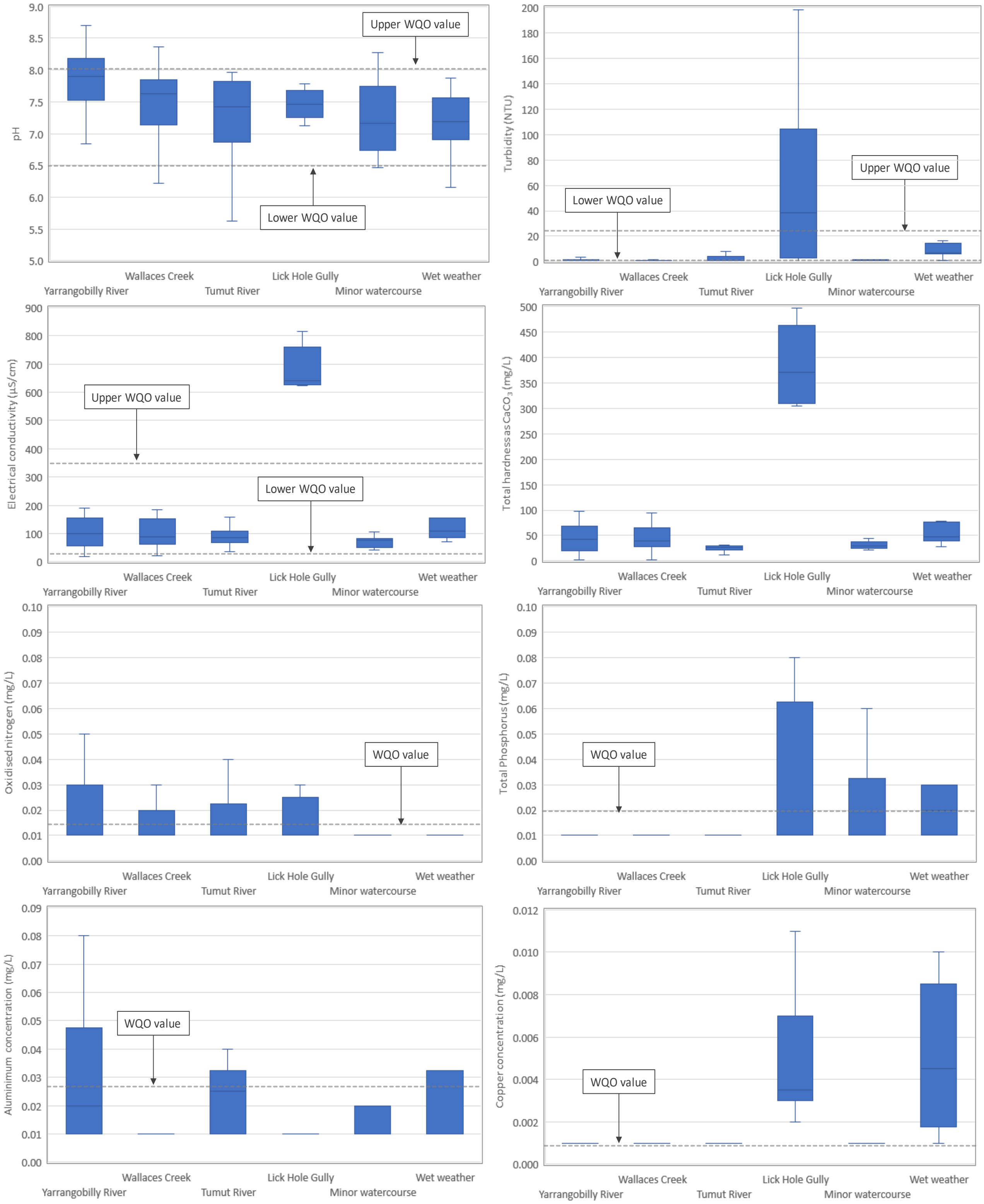


Figure 7.12 Ravine surface water quality summary – Box and Whisker plots

8 Conceptual water model

8.1 Plateau

8.1.1 Overview

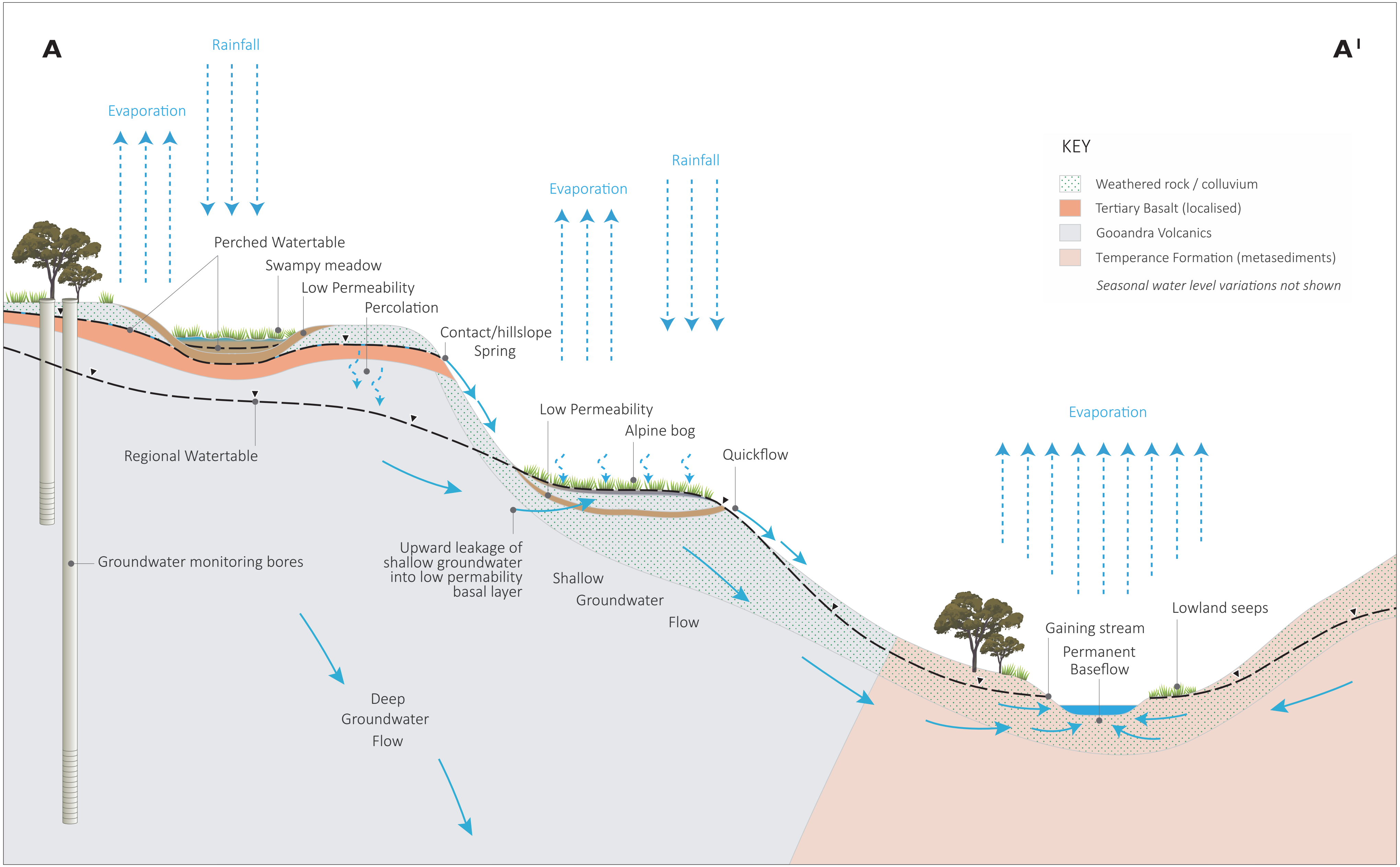
The hydrogeological units of the plateau area have been simplified as follows:

- **Alluvium, colluvium and weathered rock:**
  - groundwater in shallow alluvium along creeks and rivers is recharged during moderate to high rainfall, flooding events and snow melt. The alluvium provides bank storage during high flow events;
  - groundwater in shallow colluvium is recharged during rainfall events and a shallow watertable is maintained due to high soil moisture and basal recharge from the shallow fractured rock groundwater system;
  - groundwater in thin basalt caps in higher topographies is recharged during moderate to high rainfall events and snow melt; and
  - in higher topographies, perched groundwater is likely to occur in weathered rock and potentially some colluvium and basalt cap areas.
- **Shallow fractured rock:**
  - shallow fractured rocks have low to moderate permeability in the plateau. Groundwater in these rocks is recharged by moderate to high rainfall and snow melt (occurring when soil moisture conditions are exceeded).
- **Deep fractured rock:**
  - the deeper fractured rocks are recharged by infiltration of rainfall migrating from shallow groundwater systems. Permeability is generally lowest in the central section of the plateau and higher in the east and western areas of the plateau. There is downward flow of groundwater from shallow aquifers in recharge areas and upward flow to shallow aquifers in discharge areas.

Being a fractured rock groundwater system, there will always be local variability and uncertainties in groundwater flow, vertical connectivity and baseflow contributions to bogs and fens, and watercourses. A graphical depiction of the conceptual hydrogeological understanding for the plateau area is shown in Figure 8.1. Watertables oscillate between wet winter/spring recharge periods and dry summer periods when there is negligible recharge. Some residual uncertainty surrounds the occurrence of mid-slope alpine bogs and whether they are regionally groundwater dependent or recharged by local perched systems or are a combination of both. The understanding of the types of groundwater expressions in the landscape has been simplified as follows:

- **Type 1 –** Contact/hillslope springs: springs displaying visible flow from perched or regional groundwater, typically on hillslopes. These are generally found in the upstream sections of more defined tributaries and occasionally in low lying areas.

- **Type 2 –** Lowland seeps: visible seeps from regional groundwater into sediment storage (ie floodplains). These were typically found in low-lying areas adjacent to large watercourses and tributaries and contribute to the baseflows of permanent streams.
- **Type 3 –** Alpine bogs: boggy, wet ground, typically associated with colluvium and depressions in the landscape. The most common groundwater discharge feature across the plateau and generally occur in the upstream section of smaller tributaries. These are associated with both perched and regional groundwater systems, and most contribute to the baseflows of permanent watercourses.



Groundwater occurrence and flow – simplified concept

Snowy 2.0

Water assessment

Figure 8.1

8.1.2 Groundwater recharge, discharge and flow

i Recharge

Groundwater recharge is predominantly from infiltration of rainfall and snow melt. Recharge is higher when the soil and weathered rock is saturated which generally occurs during winter and spring or following significant rainfall events.

ii Discharge

Groundwater discharge processes for the plateau are:

- drainage to surface water (baseflow to watercourses);
- evaporation from the watertable where it is shallow, ie seeps, springs and escarpments;
- transpiration from overlying GDEs (such as some alpine bogs and fens) and vegetation intercepting shallow groundwater systems; and
- regional groundwater throughflow toward Tantangara Reservoir in the east.

iii Flow

Groundwater flow processes for the plateau are:

- groundwater flow within the colluvium/alluvium (when saturated) is via primary porosity, and within the shallow and deeper fractured rock occurs via secondary porosity (ie fractures, joints and bedding planes);
- regional groundwater flow direction is to the east, influenced by stratigraphy, dip of the strata, faulting, fractures and topography;
- downward gradients are mostly observed between shallow and deeper groundwater systems in recharge areas, and upward gradients in discharge areas; and
- steeper vertical gradients occur where creeks/rivers are incised, and escarpments occur.

8.1.3 Surface and groundwater interaction

Surface and groundwater interactions on the plateau are:

- major creeks/rivers, such as Eucumbene River, Gooandra Creek and Tantangara Creek, are permanent and gaining watercourses with the regional groundwater system providing baseflow;
- minor streams and/or gullies, such as those feeding into major creeks/rivers, are both ephemeral and permanent. Where ephemeral, they are disconnected from perched and regional groundwater, and where permanent they are connected to perched or regional groundwater systems;
- bogs and fens (and GDEs) are predominantly sustained by rainfall /snowmelt and their relationship to the different groundwater systems is variable:
    - swampy meadows in elevated areas are usually perched and disconnected from regional groundwater. The perched watertable varies with seasonal rainfall and evapotranspiration trends;

- alpine bogs and fens in mid-slope areas are perched in upper catchment areas where the regional watertable is deep and there is no permanent flow in adjacent creeks and gullies. They are likely to be sustained by seasonal rainfall and interflow;

- alpine bogs and fens in mid-slope area are connected at their base to shallow groundwater in lower catchment areas where the regional watertable is shallow and there is permanent flow in adjacent creeks and rivers. These ecosystems (especially the peat horizons) are likely to be predominantly sustained by seasonal rainfall and interflow but there is also a shallow groundwater discharge component; and

- lowland seeps supporting riparian bogs and fens and vegetation are connected to shallow and sometimes deep groundwater in catchment areas where the regional watertable is shallow and there is baseflow in adjacent creeks and rivers.

8.1.4 Plateau groundwater dependent ecosystems

i Terrestrial

Groundwater dependent PCTs on the plateau have been identified as being entirely/obligate or facultative-opportunistic type GDEs, and intercept shallow and/or regional groundwater systems (refer to biodiversity development assessment report for further discussion). Other PCTs are non-dependent on groundwater.

Where there is a reduction in depth to groundwater, or variability in climate, this may be reflected as a proportional change in ecosystem prevalence for facultative-opportunistic PCTs, but the ecosystem remains resilient in the absence of groundwater (Serov et al 2012).

ii Subterranean

Existing stygofauna are assumed to be like those encountered in other fractured rock systems in NSW. Stygofauna are likely to be more common in bogs and fens, hyporheic zones and shallow fractured rock groundwater systems due to the greater availability of dissolved oxygen and nutrients (refer to Appendix M.1 of the EIS).

8.2 Ravine

8.2.1 Overview

Conceptually, the boundary between the ravine and plateau is separated by the LPF, which acts as a groundwater divide between the two areas. Much of the processes described in Section 8.1 also apply to formations in the ravine. Regardless, the ravine has been simplified into the following groundwater systems:

- alluvium, colluvium and weathered rock:

- groundwater in shallow alluvium along creeks and rivers (Yarrangobilly River) is recharged during moderate to high rainfall and corresponding flooding events. The alluvium provides bank storage during high streamflow events; and

- groundwater in shallow colluvium is recharged during most rainfall events. Colluvium is likely fast draining given the topography of the ravine.

- Shallow fractured rock:

- shallow fractured rocks have low to moderate permeability. Groundwater in these rocks are recharged by moderate to high rainfall (occurring when soil moisture conditions are exceeded).

- Deep fractured rock:
  - the deeper fractured rocks have the lowest permeability and are recharged by rainfall infiltrating from shallow groundwater systems.

8.2.2 Groundwater recharge, discharge and flow

i Recharge

The ravine groundwater system is largely recharged by rainfall and associated flooding, the Yarrangobilly River (and storages) and the lateral movement of groundwater from locally higher elevations such as the plateau and elevated Ravine Bed outcrops.

ii Discharge

Groundwater discharge processes for the ravine are:

- drainage to the Yarrangobilly River and its tributaries;
- transpiration from overlying vegetation intercepting shallow groundwater systems;
- seepage/springs and evaporation along escarpments; and
- regional groundwater throughflow toward Talbingo Reservoir.

iii Flow

Groundwater flow processes in the ravine are:

- the LPF is a regional high point and considered a flow boundary rather than a conduit, with regional groundwater flow from the LPF moving east to the plateau, and west to the ravine;
- the bulk of groundwater movement and permeability in the shallow and deep groundwater systems is determined by secondary porosity. Permeability in the alluvium and colluvium is via primary porosity; and
- localised groundwater flow direction is largely controlled by stratigraphy, dip of the strata, faulting, fractures and topography.

8.2.3 Surface and groundwater interaction

The Yarrangobilly River is considered a gaining system, receiving groundwater discharge as baseflow along its length. Tributaries flowing to the Yarrangobilly River are likely to be both ephemeral and permanent as they intercept perched and shallow groundwater along their lengths.

8.2.4 Ravine groundwater dependant ecosystems

i Terrestrial

Groundwater dependent PCTs on the plateau have been identified as being facultative-proportional or facultative-opportunistic type GDEs, and intercept shallow and/or regional groundwater systems. Other PCTs are non-dependent on groundwater (refer to biodiversity development assessment report for further discussion).

Where there is a reduction in depth to groundwater, or variability in climate, this may be reflected as a proportional change in ecosystem prevalence for facultative-proportional and facultative-opportunistic PCTs, but the ecosystem remains resilient in the absence of groundwater (Serov et al 2012).

ii Subterranean

Subterranean stygofauna have not been identified in the ravine area (refer to Appendix M.1 of the EIS). However, if stygofauna are present, they are likely to be more common in hyporheic zones and shallow fractured rock groundwater systems due to the greater availability of dissolved oxygen and nutrients.

Part B

Impact assessment

9 Assessment approach

9.1 Overview

The assessment of project-related impacts to water resources and water users considers the requirements of the *WMA 2000*, the relevant WSPs and the AIP. In addition, the licensing requirements of the project have also been assessed against the *WMA 2000,* relevant WSPs and the AIP.

Direct effects arising from mining, quarry and excavation projects can be defined under four categories:

- altered surface water or groundwater quantity (streamflow, surface water availability, flooding regime, groundwater levels, pressures and fluxes);
- altered surface water or groundwater quality (concentration of salts and other important water quality constituents);
- altered surface water – groundwater interaction; and
- physical disruption of aquifers (excavation for underground works below the water table).

9.2 Direct and indirect effects

Table 9.1 presents a description of the water affecting activities related to the project, the processes / potential impact associated with the activity and a summary of the criteria used for the impact assessment. Further description of the water affecting activities related to the project is provided in Section 2.

Groundwater receptors in the region that may be affected by the project include:

- ecosystems that potentially rely on groundwater (terrestrial vegetation, aquatic ecosystems and subterranean ecosystems); and
- watercourses, drainage lines, creeks, springs and swamps that receive baseflow.

Surface water receptors in the region that may be affected by the project include:

- surface water users; and
- watercourse and reservoir environments.

Table 9.1 Water affecting activities and assessment criteria

Direct effect	Water affecting activity	Potential effect	Assessment criteria
Quantity	Excavation	Watertable drawdown, aquifer depressurisation, changed groundwater flow paths	AIP [1]
	Stockpiling	Altered recharge Hydraulic loading of aquifer	AIP [1]
	Built infrastructure (roads, buildings, plant, bridges, culverts)	Altered flooding regime, watercourse diversion, erosion of banks	NSW Floodplain development manual NSW Floodplain risk management guide
	Operation of the project	Watertable drawdown, aquifer depressurisation, changed groundwater flow paths Reservoir storage changes	AIP [1]
	Dewatering for maintenance purposes	Water management, discharge management and erosion risk	Baseline streamflow regimes
	Groundwater supply – abstraction	Watertable drawdown, aquifer depressurisation	AIP [1]
	Surface water supply – extraction	Changes to streamflow and reservoir flow and storage	River flow objectives
	Wastewater ponds and storage	Perched watertable, seepage	AIP [1] WQOs, comparison to baseline
Quality	Excavation – drill and blast	Changes to groundwater quality through introduced chemicals used in blasting and / or mixing of groundwater from different aquifers as a result on enhanced connectivity developed by blasting	AIP [1] WQOs, comparison to baseline
	Stockpiling	Acid mine drainage Leachate of solutes	AIP [1] WQOs, comparison to baseline

Table 9.1 Water affecting activities and assessment criteria

Direct effect	Water affecting activity	Potential effect	Assessment criteria
	Wastewater ponds and storage	Leaching of solutes Overflow to watercourses	WQOs, comparison to baseline
	Built infrastructure (roads, buildings, plant)	Solutes in runoff	
	Hazardous goods storage (containment failure)	Solutes in runoff Short-term release of contaminants	
	Construction and operational process water management (including stormwater discharge)	Changes to watercourse / reservoir water quality	
	Water treatment to meet discharge requirements	Leaching of waste product	
Surface water – groundwater interaction	Excavation	Altered baseflow to watercourses	River flow objectives AIP [1]
Aquifer disruption	Excavation	Removal of part or whole of aquifer, changed groundwater flow paths	AIP [1]

Notes: 1. See Section 16 for the AIP assessment framework

Indirect effects of water affecting activities are those that arise in response to direct effects (Moran et al 2010) and typically relate to the potential for impact on sensitive receptors. The assessment of potential receptor exposure to adverse changes in the surface water and/or groundwater regime (quantity, quality, groundwater and surface water interactions and physical disruption of aquifers) requires the following:

- knowledge of the location of sensitive receptors within the landscape, particularly in relation to the location and area of influence of water affecting activities;
- an understanding of the receptor reliance on water (eg depth to watertable, groundwater flux to baseflow fed streams, water quality to meet beneficial purposes);
- an understanding of the capacity for receptors to adapt to altered surface water and /or groundwater regimes (resilience and resistance); and
- an understanding of the spatial and temporal scale of direct effects at the location of sensitive receptors.

EVs have been identified for the project area and provide a basis for assessing receptors that may be sensitive to altered water resource condition (Table 9.2). Table 9.3 presents a summary of direct effects against relevant EVs and possible scale of effect.

Table 9.2 Environmental values and identified receptors

Environmental value that may be impacted	Potentially sensitive receptor
Aquatic ecosystems	Baseflow fed watercourses
Terrestrial ecosystems	Facultative-opportunistic and entirely dependent PCTs
Subterranean ecosystems	Stygofauna in plateau area
Groundwater (bore) supply	None identified
Surface water user	None identified
Cultural / spiritual	Recreational use of reservoirs

Table 9.3 Link between direct effects and environmental values

Direct effect	Environmental value that may be impacted	Potential effect
Quantity	Aquatic ecosystems	Altered baseflow within the zone of potential drawdown impact
	Terrestrial ecosystems	Possible effect where the depth to watertable is reduced within the potential zone of drawdown impact
	Subterranean ecosystems	Possible effect where the watertable elevation is reduced, reducing habitat
	Groundwater (bore) supply	No effect expected (no users)
	Surface water user	No effect expected (no users)
	Cultural / spiritual	Negligible effect expected
Quality	Aquatic ecosystems	Potential water quality impact from discharge of process water (including stormwater discharge)
	Terrestrial ecosystems	Potential effect where groundwater quality is altered due to seepage from waste rock emplacement areas, affecting quality of water accessed by vegetation
	Subterranean ecosystems	Potential effect where the water quality is affected, reducing habitat
	Groundwater (bore) supply	No effect expected (no users)
	Surface water user	No effect expected (no users)
	Cultural / spiritual	Negligible effect expected

9.3 Cumulative effects

Cumulative water-related effects have been assessed for the project within the following context:

- existing pre-project cumulative: drawdown; baseflow reduction; and surface water quality of existing works (ie Exploratory Works);
- cumulative drawdown: baseflow reduction; and surface water quality of the project and of existing works (ie Exploratory Works); and
- the influence of: drawdown; baseflow reduction and surface water quality of the project, and due to other existing works.

Given the location of the project, the already approved Exploratory Works activities is the only activity contributing to changes to water resources in the vicinity of Snowy 2.0 Main Works.

10 Groundwater flow assessment

10.1 Overview

This section provides a summary of the groundwater impact assessment conducted using a numerical groundwater flow model which was loosely coupled to the surface water model. This section discusses potential impacts associated with the project from a groundwater level and flow perspective only. Further detail regarding the groundwater flow model work completed is provided in Annexure B (Water model report).

10.2 Numerical groundwater flow model

A regional numerical groundwater flow model, referred to as SH4.0, was developed for the Snowy 2.0 Main Works water assessment (see Annexure B). The SH4.0 model is based on the SH1.0 model, developed for the Exploratory Works groundwater assessment (EMM 2018), but is informed by datasets that have expanded, both spatially and temporally, since the Exploratory Works modelling, enabling greater conceptual understanding of the groundwater system and its interaction with surface environments. Key expanded datasets include groundwater and surface water monitoring, hydraulic and geophysical testing. Modelling was expanded to include all infrastructure planned for Snowy 2.0 Main Works. Some structural alterations to the model were required.

SH4.0 was prepared in accordance with the *Australian groundwater modelling guidelines* (AGMG, Barnett et al 2012), and in accordance with the requirements of the Aquifer Interference Policy (DPI Water, 2012). The model was developed using the Graphical User Interface (GUI) Groundwater Vistas 7 and operated in MODFLOW USG. The model and associated predictions meet 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 modelling relate to the groundwater level dataset, which is largely two-dimensional, and duration of monitoring available to inform the conceptualisation and calibration. Additionally, geological and hydrogeological mapping and testing is largely two-dimensional, along the project alignment. SH4.0 uses outputs from the surface water catchment model (refer Section 11) to inform rainfall-derived recharge as well as to provide soft history matching/validation targets for baseflow.

SH4.0 was peer reviewed by Hugh Middlemis of HydroGeoLogic Pty Ltd. The peer reviewer deemed that the model objectives were satisfied, the model calibration was satisfactory, the model predictions conformed to best practice and that the model is fit for purpose. The peer review report is included in Attachment A of Annexure B.

10.2.1 Model objectives

The modelling objectives were to quantify potential regional-scale impacts on the groundwater system resulting from construction and operation of Snowy 2.0. Specifically, the outcomes required predictions of:

- watertable drawdown;
- groundwater inflows to excavations; and
- changes to the groundwater water balance.

The model domain encompasses all underground excavations of the Snowy 2.0 project, Yarrangobilly Caves, all major rivers and creeks as well as all project-related groundwater monitoring sites. Hydrogeological units have been assigned to the model for each of the geological units mapped by drilling and geophysical surveys along the project alignment. Model design, extent, spatial discretisation, boundary conditions and calibration are described in Annexure B. The SH4.0 model domain is presented in Figure 10.1.

10.3 Scenario modelling

To meet the model objectives, in regard to both the delivering the project and minimising environmental impacts, one predictive scenario was modelled, representing:

- the pre-construction groundwater system;
- construction of the project, with model boundary conditions added in accordance with the project tunnel design and schedule, considering wet, dry and average climate sequences;
- a 20-year operation period; and
- post-construction steady state groundwater conditions.

Climate change was not explicitly simulated. Tests utilising wet and dry climate sequences indicated that groundwater inflow rates to the project are insensitive to climate.

10.3.1 Construction and operation scenario

Groundwater will enter the underground excavations during construction. This has the potential to cause drawdown of the watertable near ground surface. Mitigation of groundwater inflow will include at a minimum the following engineering controls:

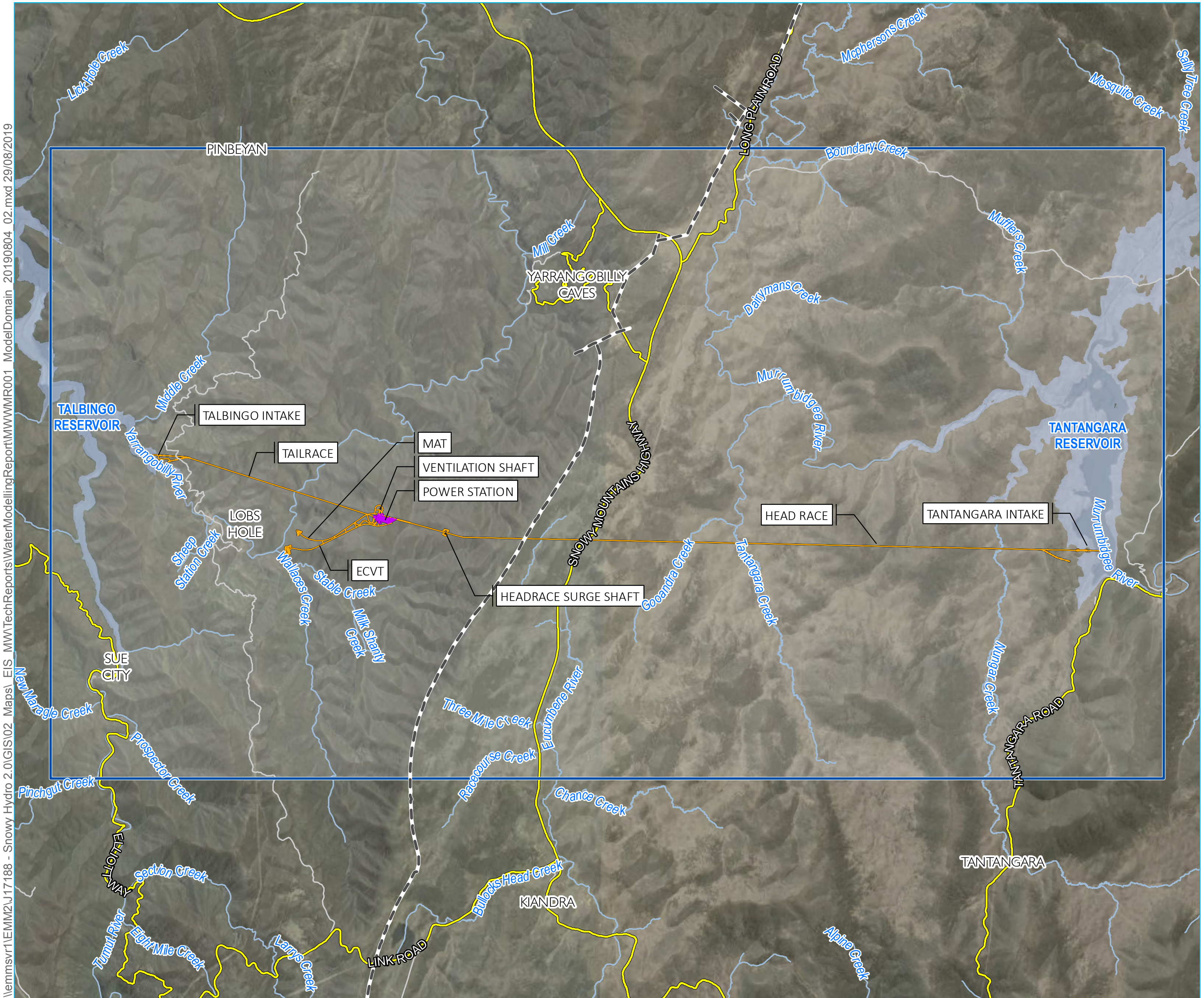
- excavation sequencing;
- pre-grouting;
- post-grouting; and
- segmental lining.

The proposed engineering controls establish competent ground conditions and allow works to be completed safely. In doing so, the controls also mitigate impacts to water resources. The exact locations and extent of inflow mitigation strategies are not yet known and, hence, the SH4.0 model adopted a conservative approach of simulating all excavations as non-mitigated/controlled. As such, model predictions are expected to be worst case.

i Excavation sequencing

Excavation sequencing is the process of managing the order that the excavation occurs to ensure critical sections (sections that are expected to have the greatest inflow or instability) remain open for the least amount of time possible. Early identification of critical sections of highly permeable or vertically connected formations (such as the Gooandra Volcanics) has been undertaken as part of pre-construction baseline groundwater and geotechnical investigations.

Understanding the critical nature of sensitive locations has been factored into the proposed construction program. This includes ensuring that these critical locations are constructed as late as possible in the program to ensure the excavation remains open for the shortest period of time.



\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MW\TechReports\WaterModellingReport\MWWMR001_ModelDomain_20190804_02.mxd 29/08/2019

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

- Long Plain Fault
- Model domain

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station

Existing environment

- Main road
- Local road
- Perennial watercourse
- Scheme storage

SH4.0 model domain and major features

Snowy 2.0
Water assessment
Main Works
Figure 10.1

snowy 2.0

EMM creating opportunities

10.3.2 Predictive uncertainty analysis

The AGMG states that groundwater model "results presented to decision-makers should include estimates of uncertainty" (Barnett et al. 2012). The approach adopted for SH4.0 was to select, consistent with the current hydrogeological conceptualisation, the aquifer property values that would create the greatest inflows and environmental impacts (drawdown and reduction in baseflow). These were combined to create the "minimum and maximum plausible impact" realisation based on values for aquifer properties and river bed conductance.

A total of 29 uncertainty analysis runs (including the base case) have been assessed to provide estimates of uncertainty associated with the base case predictions. Further information regarding the uncertainty analysis is provided in Annexure B.

10.4 Predicted watertable drawdown

The groundwater model is considered to be conservative and the results presented from the model itself do not consider the planned mitigation and management measures that will occur during construction. Base case predictions are therefore need to be considered with this in mind. Base case predicted drawdown of the regional watertable following one, two, three, four and five years of construction is presented in Figure 10.2 through Figure 10.6. The model outputs represent climate transient stresses and the evolving construction and operational schedule of Snowy 2.0 Main Works. As mentioned in Section 10.3.1, drawdown impacts represent a non-mitigated/uncontrolled excavation and are therefore considered to represent a worst case scenario.

The reasons that the model results are considered conservative are:

- the geological formations of the Gooandra Volcanics, and the Kellys Plain Volcanics have hydraulic conductivity values that are two orders of magnitude higher than for the rest of the deeper hydrostratigraphic units. These higher values align to pumping test results from pumping bores that intercepted fractures, and although parts of these units will behave in this manner other parts are expected to be less permeable; and

- excavations were modelled as unlined with no groundwater controls, although Snowy Hydro has a number of options for controlling groundwater inflows to excavations and any associated drawdown impacts at near surface environments

The following is a summary and discussion of the predicted watertable drawdown during construction and operations.

<u>Construction</u>

- After one year of construction, almost no drawdown of the regional watertable is predicted, with the exception of minor (<0.5 m) drawdown above the proposed power station cavern (see Figure 10.2).

- Within two years of construction, significant (>2 m) watertable drawdown is predicted between Tantangara Reservoir and Nungar Creek; associated with the construction of the headrace tunnel. The model simulates the geological unit (Kellys Plain Volcanics) intercepted by the project at this location to have a much higher permeability (consistent with values estimated from field assessments) when compared with the majority of the model domain (see Figure 10.3).

- After three and four years of construction the drawdown footprint associated with the Kellys Plain Volcanics expands and increases in magnitude immediately above the headrace tunnel to over 50 m. Small pockets of minor drawdown are predicted above other parts of the project and a significant region of drawdown is predicted to be growing above the headrace tunnel in the Gooandra Volcanics region (see Figure 10.4 and Figure 10.5).

- After five years of construction the Kellys Plain Volcanics drawdown is predicted to further expand and the drawdown in the Gooandra Volcanics is predicted to reach magnitudes of greater than 20 m (see Figure 10.6).

Operations

- Figure 10.7 and Figure 10.8 present predicted base case drawdown after one year and 20 years of operation.
- The predicted drawdown footprint to the east of the project and within the Kellys Plain Volcanics reduces from one to 20 years of operation.
- Drawdown in the Gooandra Volcanics area continues to expand and increase in magnitude to over 50 m by the end of the 20-year operational period. Patchy, localised drawdown in the less permeable Ravine Beds is predicted to increase.
- Predicted steady state operational drawdown (Figure 10.9) is reduced across the plateau area when compared with 20 years of operation (Figure 10.8). This indicates that a long-term (decades) period required to fill the power waterway with water is predicted to result in re-equilibration of the groundwater system.
- Whilst drawdown of the watertable is predicted to exceed 50 m across a 1 km section in the Kellys Plain Volcanics and for a large section around 5 km long in the Gooandra Volcanics, the predicted 0.5 m drawdown contour remains several kilometres south from the Yarrangobilly Caves.

10.4.1 Potential impacts on terrestrial vegetation

Groundwater dependent PCTs identified in the plateau are predicted to experience varying degrees of impact depending on the contribution of groundwater in sustaining the PCTs. PCT GDEs sustained by rainfall or perched groundwater will not be affected by drawdown within the shallow groundwater system. In areas where a regional groundwater contribution is suspected and the GDEs are located within the predicted drawdown area, then PCT GDEs may be impacted due to a reduction in groundwater contribution.

The following summarises impacts to the identified groundwater dependent terrestrial vegetation:

- PCT 303: predicted impacts to 23.69 ha of the PCT, which represents 6% of the 370 ha of the PCT mapped in the project area. These GDEs are at low risk of predicted impacts;
- PCT 679: predicted impacts of less than 3 ha of the community and predicted to experience less than 5 m BGL of drawdown. These GDEs are at low risk of predicted impacts;
- PCT 637: predicted impacts to 17.51 ha of the PCT, which represents approximately 25% of the 70.11 ha of the PCT mapped in the project area. Furthermore, impacted PCT represents 0.2% of the mapped extent in the Snowy Mountains and 0.15% of the 11,100 ha mapped nationally. While there is a high risk of impact to some portion of the community, the overall risk to the community and listed community is considered low; and
- PCT 1225: predicted impacts to 10.37 ha of the PCT, which represents 6% of the 163 ha of the PCT mapped in the project area. These GDEs are at low risk of predicted impacts.

Groundwater dependent PCTs identified in the ravine are predicted to experience minimal to no drawdown given their location with respect to Snowy 2.0 construction or operation, and their ability to access alternate sources of water such as precipitation, streamflow and interflow due to their non-dependent relationships with groundwater.

10.4.2 Potential impacts on subterranean fauna

The predicted drawdown will reduce the extent of habitat available to stygofauna. Drawdown of less than 20 m is considered unlikely to affect many stygofauna species given the ability of these species to relocate within the saturated zone as groundwater level decline; eg drawdown of 5 m would be unlikely to have any significant effect.

Stygofauna communities are considered by Serov et al (2012) to be at high risk. However, only a small area (383 ha) of habitat is predicted to be affected by drawdown, and the species diversity of the local area has not been demonstrated to be high. Therefore, it is anticipated that impacts to stygofauna communities will be low. It is again noted that the drawdown predictions are worst case based on conservative hydraulic conductivity values in the model and un unmitigated tunnel construction methods. Snowy proposes to undertake mitigation and management during construction.

10.4.3 Potential impacts on aquatic fauna

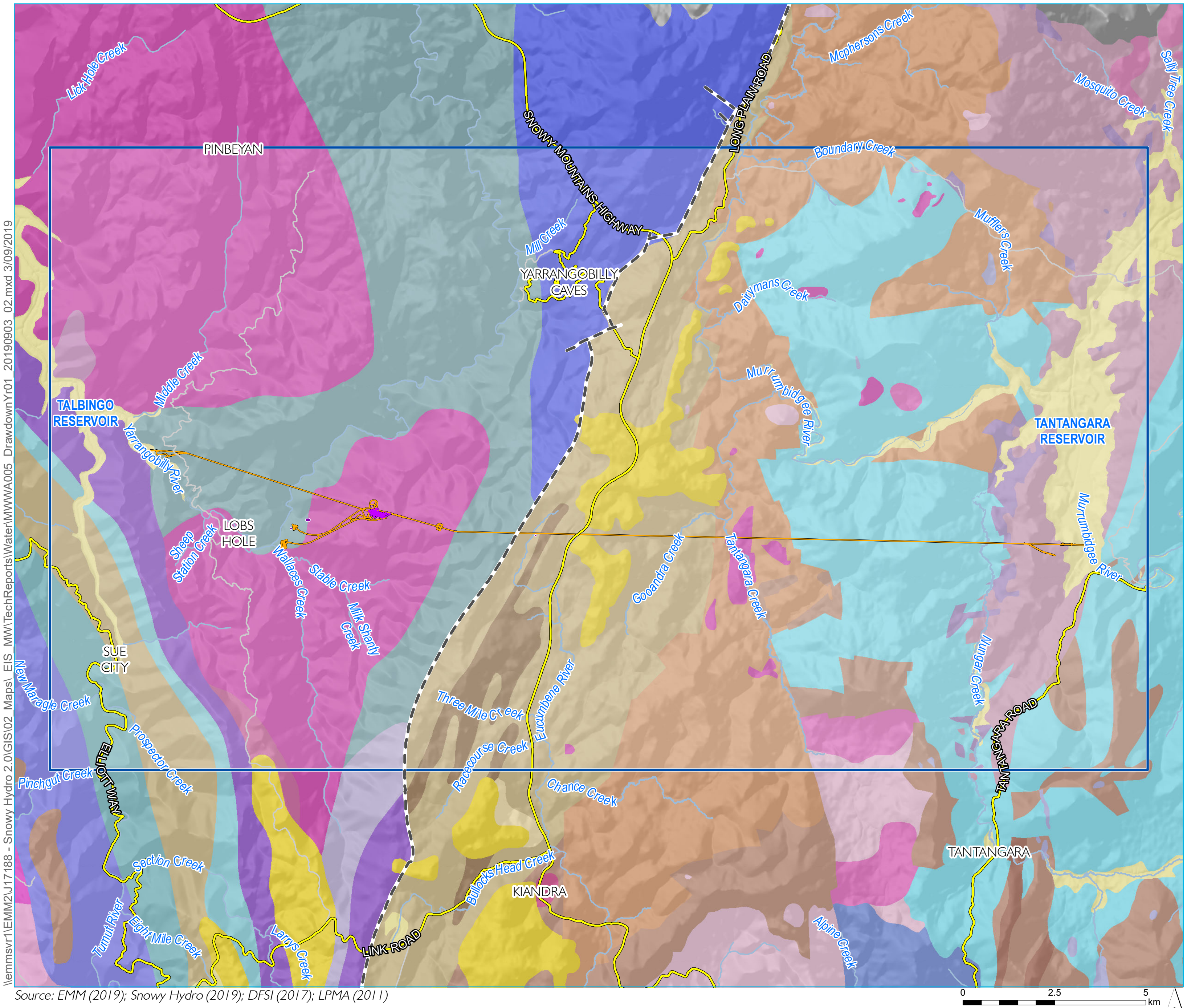
The inflow of water during tunnelling will depressurise aquifers, reduce water tables and baseflow in watercourses above and adjacent to the tunnel alignment. Depending on the amount of drawdown, there could be drying of stream reaches and loss of aquatic habitat in local waterbodies. Despite the conservative modelling approach of simulating unmitigated (no grout) tunnelling, the model predictions of localised increases in the number of no flow days is not expected to result in noticeable changes in flow in the main channels of either Tantangara Creek or the upper Murrumbidgee River. The increase in the number of no flow days predicted in Gooandra Creek and its tributaries could result in an overall reduction in the availability of aquatic habitat in these watercourses. Reduction in the habitat availability during low flows and no flow periods could result in reduced populations of aquatic biota and potential local mortality if any reaches dry out. Predicted reductions in the availability of aquatic habitat would be expected to be most noticeable during late summer during periods of lower rainfall.

Although reductions in flow in Gooandra Creek could result in impacts to local biota, such impacts would be largely localised to this catchment, and are not expected to extend to the wider Tantangara Creek and upper Murrumbidgee River catchments. In comparison with the entire length of watercourses in each catchment, only small sections could experience reduced flow as a result of groundwater drawdown. At the scale of the upper Murrumbidgee River catchment, impacts to aquatic habitat and biota that would occur in Gooandra Creek and in other tributaries due to localised drawdown would be relatively minor.

A reduction in longitudinal connectivity could impact the ability of aquatic fauna to move between different sections of watercourses in search of food, refuge or for reproduction (such as riffle sections or aquatic plants). Such impacts would be restricted to sections of Gooandra Creek and other tributaries and would be relatively minor in the context of the wider upper Murrumbidgee River catchment. Similarly, the extent of associated impacts to aquatic habitat and biota in the Eucumbene River (and its associated tributaries) would be relatively minor in the context of the Lake Eucumbene catchment.

There could be some reduction in the availability of aquatic habitat and reductions in habitat connectivity in approximately 6 km of Yarrangobilly River and 4 km of Stable Creek and in other tributaries of the Yarrangobilly River catchment. However, these changes affect a relatively minor component of the entire Yarrangobilly River catchment. Such affects would be restricted to upstream reaches, and no reduction in flow is predicted for downstream at the Yarrangobilly and Wallaces gauges.

Given the abundance of key fish habitat in each of the catchments, associated impacts to fish and crayfish is likely be relatively minor. Given the abundance of habitat throughout the Yarrangobilly River catchment, and the localised potential effects on flow availability due to drawdown, any impacts to Murray crayfish do not represent a risk to the population of this species.



KEY

Modelled drawdown (m)
- 0.5
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse

Geology (1:250,000)

Cainozoic

Devonian
- Boggy Plain Adamellite
- Coolamine Igneous Complex
- Crack Hardy Point Monzodiorite
- Free Dampier Adamellite
- Hell Hole Creek Adamellite
- Kellys Plain Volcanics
- Lobs Hole Adamellite
- Mountain Creek Volcanics
- Pennyweight Adamellite
- Undifferentiated

Ordovician
- Gooandra Volcanics
- Shaw Hill Gabbro
- Temperance Formation

Ordovician (cont.)
- Warbisco Shale
- Undifferentiated

Quaternary

Silurian
- Gang Gang Adamellite
- Goobarragandra Volcanics
- Green Hills Granodiorite
- Jackalass Slate
- Kings Cross Formation
- Peppercorn Formation
- Ravine Beds/Yarrangobilly Limestone
- Rough Creek Tonalite
- Tantangara Formation
- Tumut Ponds Sepentinite
- Undifferentiated

Tertiary

Predicted base case drawdown after 1 year of construction, September 2020

Snowy 2.0
Water assessment
Main Works
Figure 10.2

snowy 2.0

EMM creating opportunities

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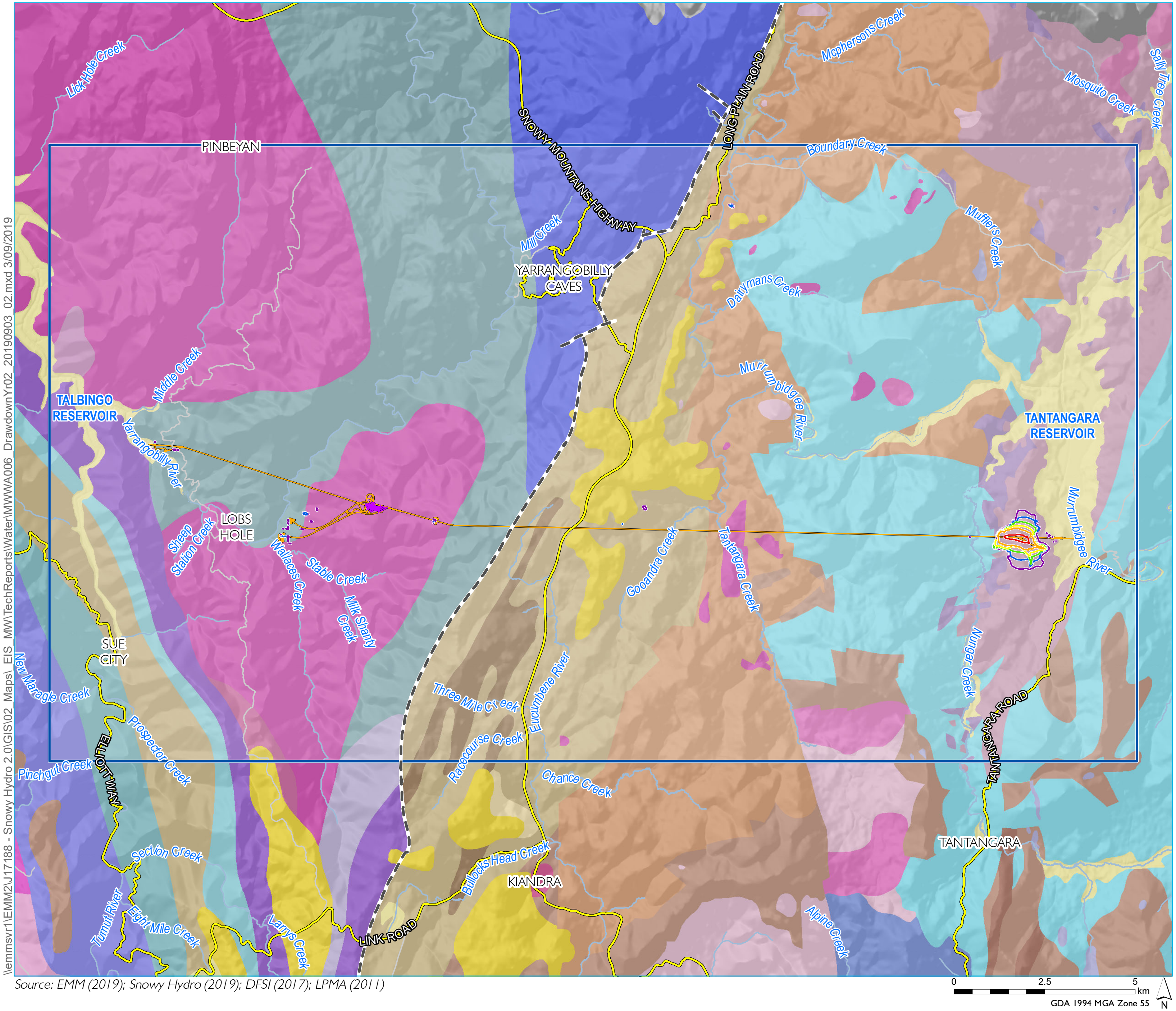

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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse

Geology (1:250,000)

Cainozoic

Devonian
- Boggy Plain Adamellite
- Coolamine Igneous Complex
- Crack Hardy Point Monzodiorite
- Free Dampier Adamellite
- Hell Hole Creek Adamellite
- Kellys Plain Volcanics
- Lobs Hole Adamellite
- Mountain Creek Volcanics
- Pennyweight Adamellite
- Undifferentiated

Ordovician
- Gooandra Volcanics
- Shaw Hill Gabbro
- Temperance Formation

Ordovician (cont.)
- Warbisco Shale
- Undifferentiated

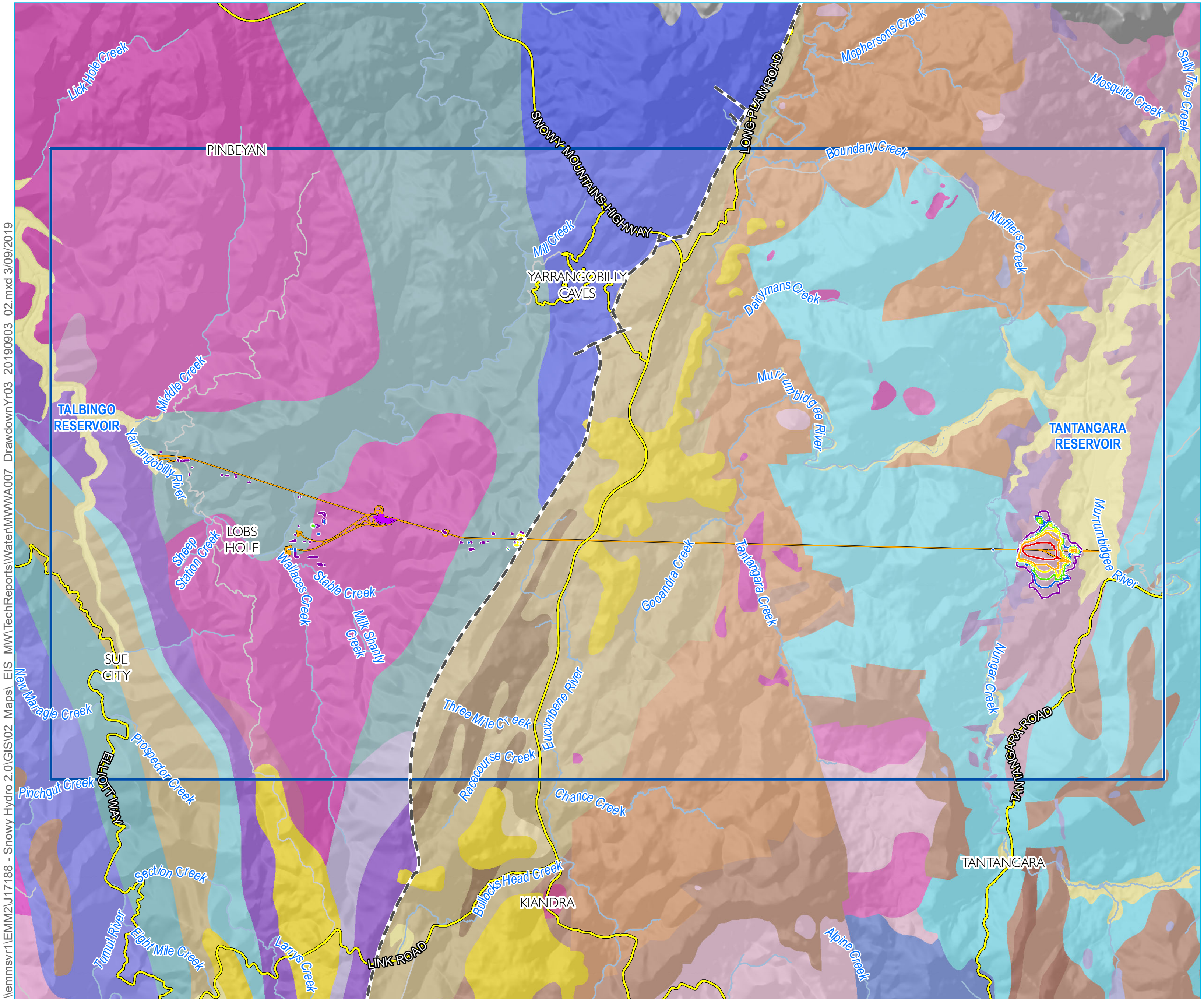
Quaternary

Silurian
- Gang Gang Adamellite
- Goobarragandra Volcanics
- Green Hills Granodiorite
- Jackalass Slate
- Kings Cross Formation
- Peppercorn Formation
- Ravine Beds/Yarrangobilly Limestone
- Rough Creek Tonalite
- Tantangara Formation
- Tumut Ponds Sepentinite
- Undifferentiated

Tertiary

Predicted base case drawdown after 2 years of construction, September 2021

Snowy 2.0
Water assessment
Main Works
Figure 10.3



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse

Geology (1:250,000)

Cainozoic

Devonian
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- Coolamine Igneous Complex
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- Free Dampier Adamellite
- Hell Hole Creek Adamellite
- Kellys Plain Volcanics
- Lobs Hole Adamellite
- Mountain Creek Volcanics
- Pennyweight Adamellite
- Undifferentiated

Ordovician
- Gooandra Volcanics
- Shaw Hill Gabbro
- Temperance Formation

Ordovician (cont.)
- Warbisco Shale
- Undifferentiated

Quaternary

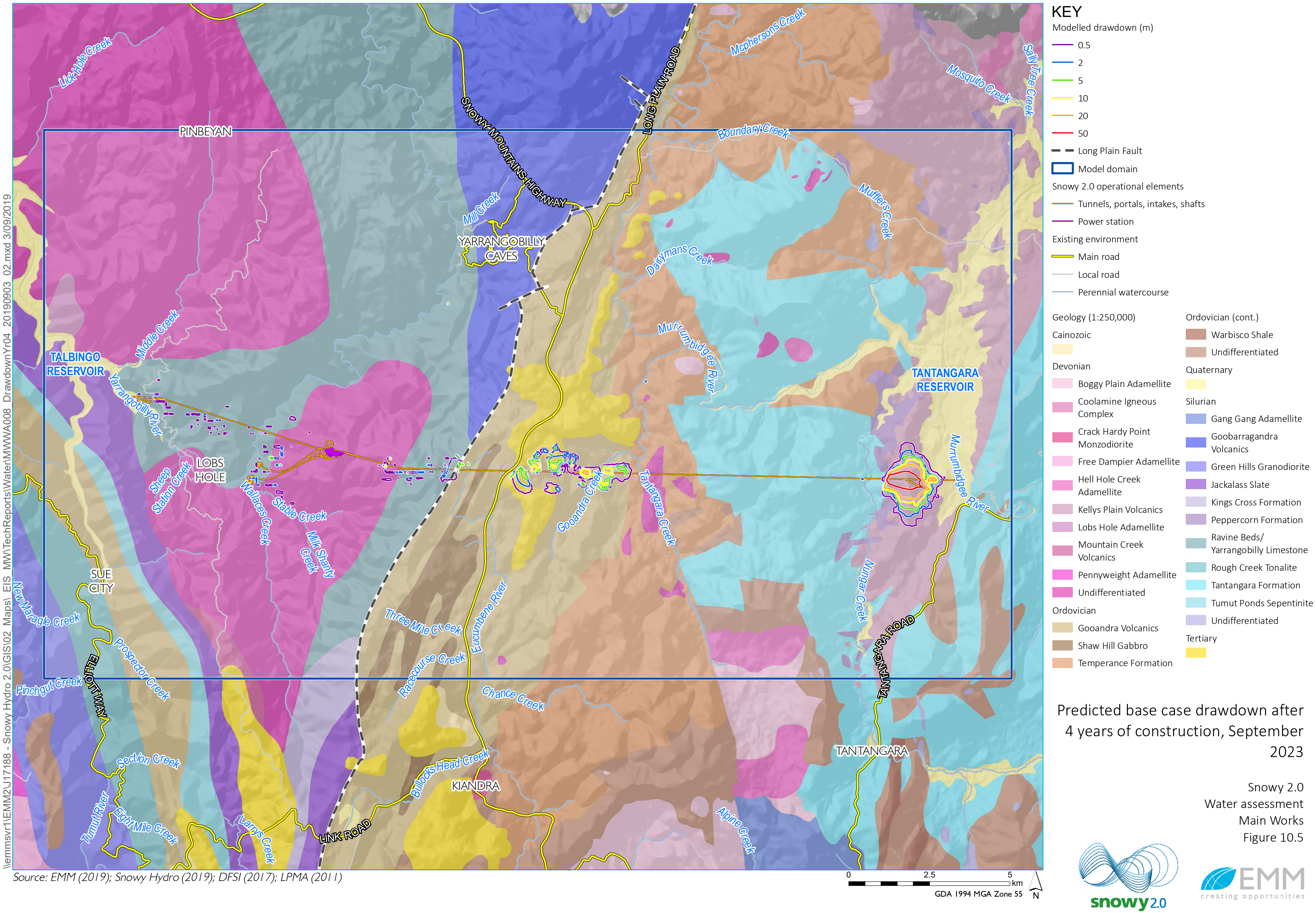
Silurian
- Gang Gang Adamellite
- Goobarragandra Volcanics
- Green Hills Granodiorite
- Jackalass Slate
- Kings Cross Formation
- Peppercorn Formation
- Ravine Beds/ Yarrangobilly Limestone
- Rough Creek Tonalite
- Tantangara Formation
- Tumut Ponds Sepentinite
- Undifferentiated

Tertiary

Predicted base case drawdown after 3 years of construction, September 2022

Snowy 2.0
Water assessment
Main Works
Figure 10.4

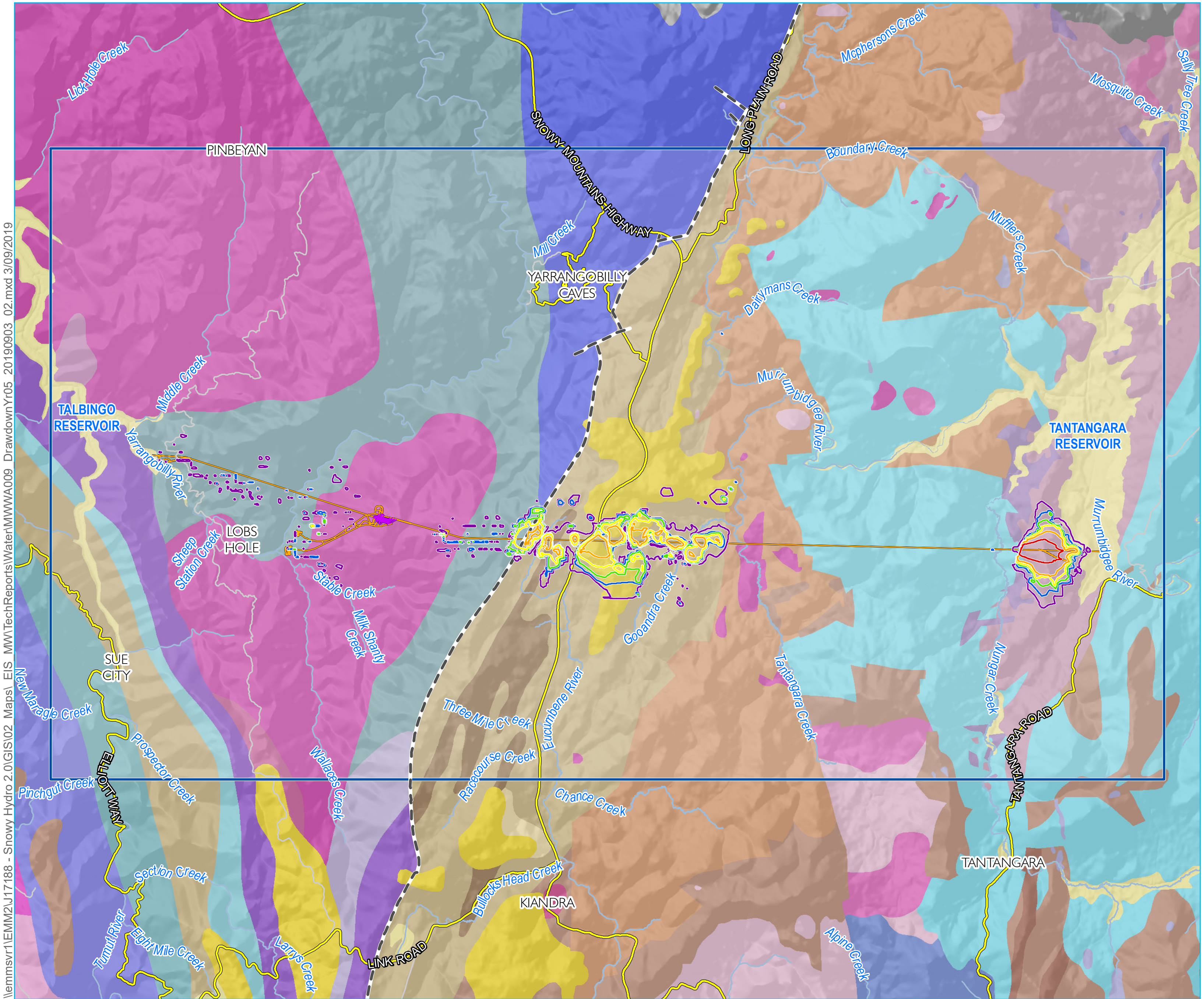
snowy 2.0
EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

Predicted base case drawdown after 4 years of construction, September 2023

Snowy 2.0
Water assessment
Main Works
Figure 10.5



KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse

Geology (1:250,000)

Cainozoic

Devonian
- Boggy Plain Adamellite
- Coolamine Igneous Complex
- Crack Hardy Point Monzodiorite
- Free Dampier Adamellite
- Hell Hole Creek Adamellite
- Kellys Plain Volcanics
- Lobs Hole Adamellite
- Mountain Creek Volcanics
- Pennyweight Adamellite
- Undifferentiated

Ordovician
- Gooandra Volcanics
- Shaw Hill Gabbro
- Temperance Formation

Ordovician (cont.)
- Warbisco Shale
- Undifferentiated

Quaternary

Silurian
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- Green Hills Granodiorite
- Jackalass Slate
- Kings Cross Formation
- Peppercorn Formation
- Ravine Beds/ Yarrangobilly Limestone
- Rough Creek Tonalite
- Tantangara Formation
- Tumut Ponds Sepentinite
- Undifferentiated

Tertiary

Predicted base case drawdown after 5 years of construction, September 2024

Snowy 2.0
Water assessment
Main Works
Figure 10.6

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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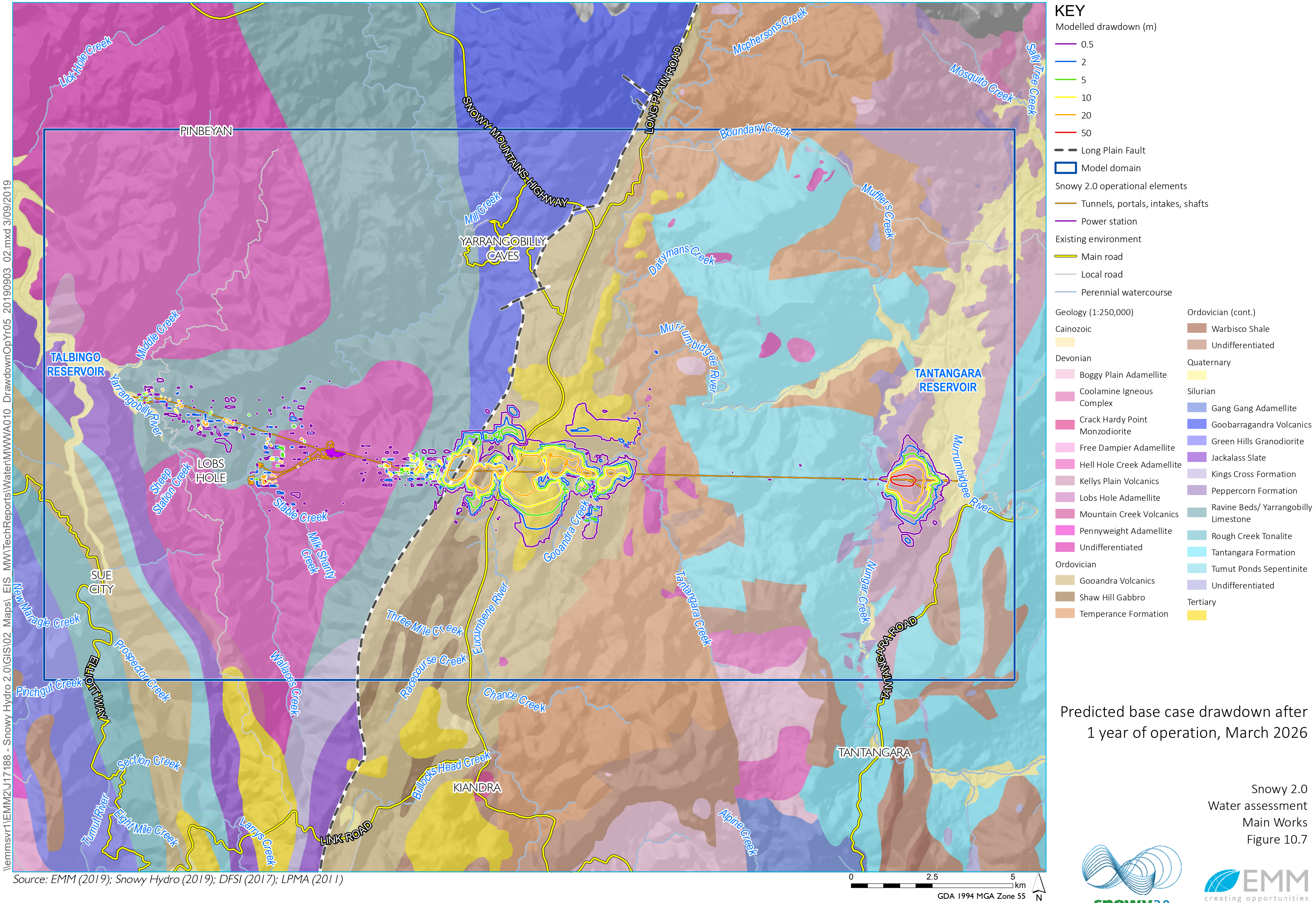
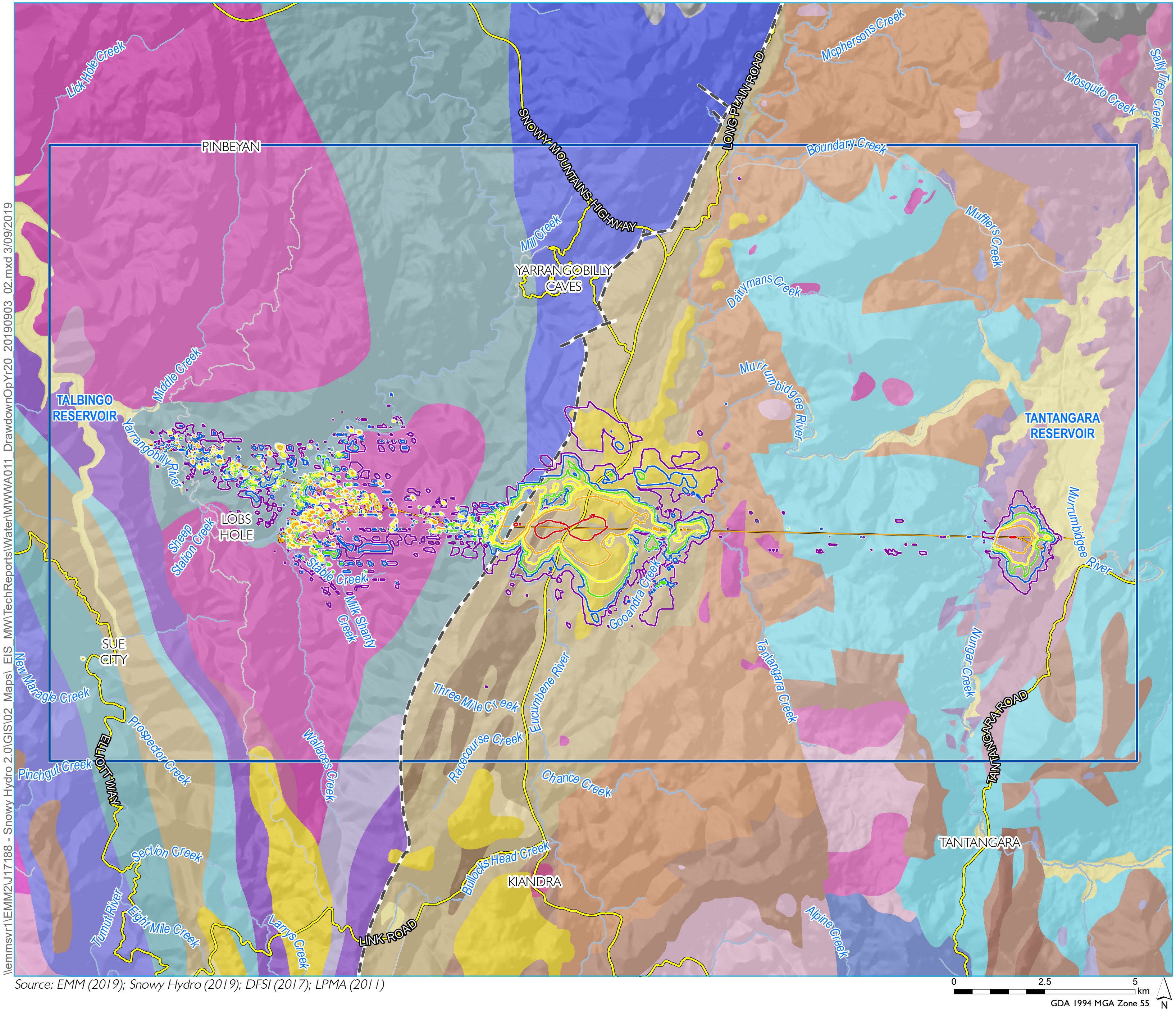


Predicted base case drawdown after 1 year of operation, March 2026

Snowy 2.0
Water assessment
Main Works
Figure 10.7

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50

- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse

Geology (1:250,000)

Cainozoic

Devonian
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- Coolamine Igneous Complex
- Crack Hardy Point Monzodiorite
- Free Dampier Adamellite
- Hell Hole Creek Adamellite
- Kellys Plain Volcanics
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- Mountain Creek Volcanics
- Pennyweight Adamellite
- Undifferentiated

Ordovician
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- Temperance Formation

Ordovician (cont.)
- Warbisco Shale
- Undifferentiated

Quaternary

Silurian
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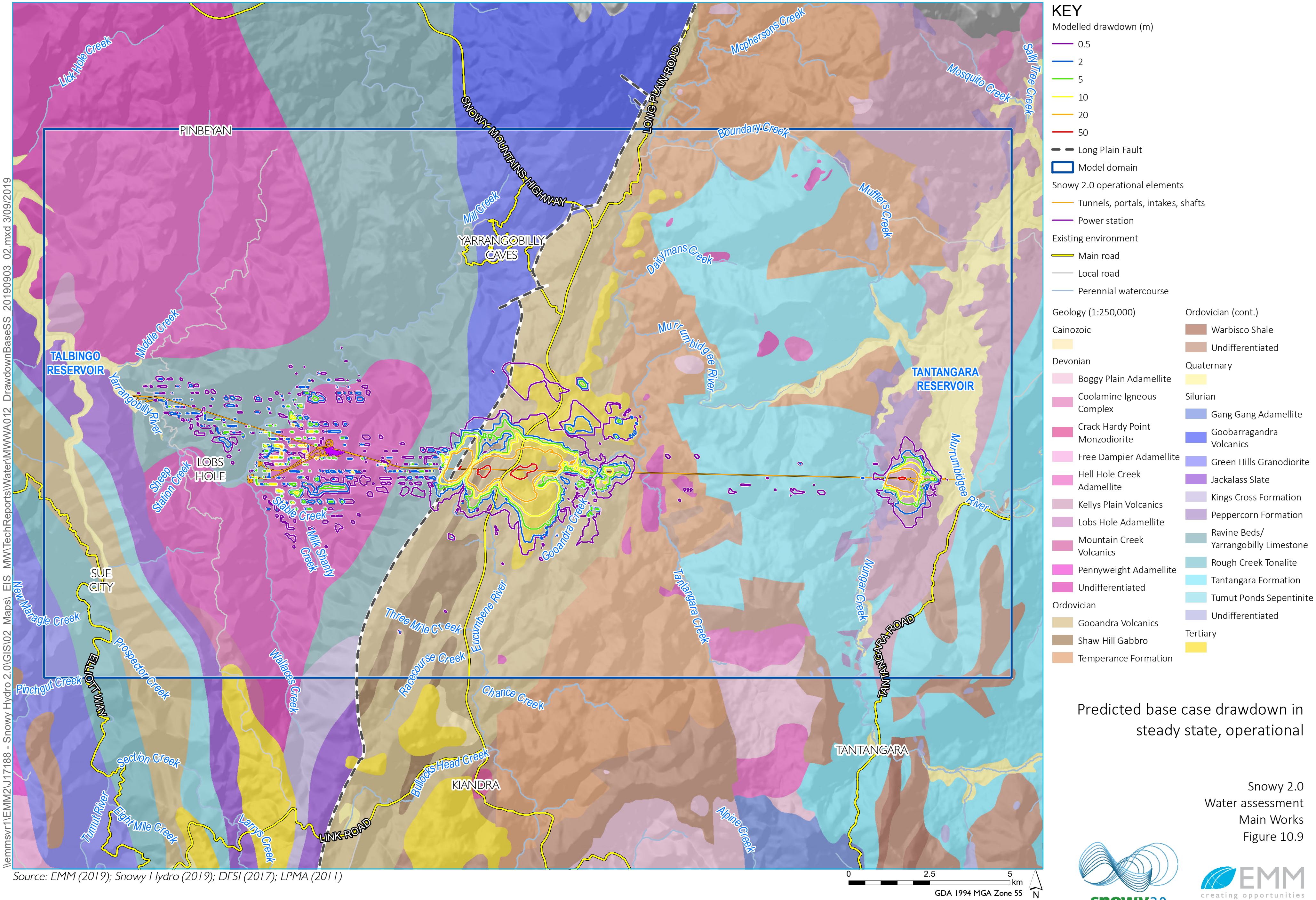
- Green Hills Granodiorite
- Jackalass Slate
- Kings Cross Formation
- Peppercorn Formation
- Ravine Beds/ Yarrangobilly Limestone
- Rough Creek Tonalite
- Tantangara Formation
- Tumut Ponds Sepentinite
- Undifferentiated

Tertiary

Predicted base case drawdown after 20 years of operation, March 2045

Snowy 2.0
Water assessment
Main Works
Figure 10.8



Predicted base case drawdown in steady state, operational

Snowy 2.0
Water assessment
Main Works
Figure 10.9

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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10.5 Baseflow

All permanent creeks and rivers in the project area are assessed as receiving groundwater baseflow (ie gaining streams) throughout the year (ie both in summer and winter). The numerical model results indicate that due to drawdown in the water table in the more permeable rock units, the volume of groundwater contributing to baseflows reduces as the project enters the operational phase. The groundwater model predicted that each creek would continue to receive baseflow discharges; and that the model predicts that no creek reaches or sub-catchments are predicted to change from 'gaining' to 'losing'.

The groundwater model and water balance report indicate that on a reach scale the creeks are always gaining even during peak drawdown. The two streams sections that experience the greatest groundwater drawdown are the upper reaches of the Eucumbene River and Gooandra Creek and they were considered in detail. For Gooandra Creek the model predicts that groundwater levels always remain above the creek. For a very short section of the Eucumbene River (immediately overlying the head race tunnel alignment) the model predicts the groundwater table does becomes disconnected from the surface water features and the stream becomes a 'potentially losing' stream for a very short length (a few hundred metres), and then it is fully gaining again downstream.

Overall the catchments and streams remain gaining, and it is expected that impacts will be limited to baseflow reductions, and the quickflow component of streamflow (surface runoff in response to rainfall).

The area that is of most significance to drawdown is related to the geology, and in particular the Gooandra and Kellys Plains Volcanics, which have been modelled as having a high vertical connectivity. The conductivity values adopted for these units are approximately two orders of magnitude higher than for the rest of the deeper hydrostratigraphic units. The elevated conductivity values in these units is consistent with pumping test results conducted at two locations across these units.

The modelling is conservative and based on available data, and results are therefore considered 'worse case' for two main reasons:

- modelling does not consider actual design, management or mitigating activities. In reality, during construction, the discrete fractures that yield excess water will be grouted and will reduce the actual overall tunnel inflow volume (potentially significantly); and

- hydraulic parameters within the numerical model for the Gooandra Volcanics and the Kellys Plain Volcanics are conservative and assume significant connection to the water table based on pumping test data. However, in reality the entire unit will not behave like this, with some parts expected to be much less permeable.

The model predictions of tunnel inflow, drawdown extent, and baseflow reductions are likely to be over estimated when compared to the actual results during tunnel construction and operation.

The reduced groundwater baseflows are a localised effect of the project, and only occur in some of the permanent streams that directly overlie the headrace tunnel and are within the predicted water table drawdown areas. Streamflow impacts are predicted to be largest at sites immediately downstream of the impacted headwater sub-catchments in Gooandra Creek and the Eucumbene River particularly when dry climatic conditions prevail during summer and autumn, and when baseflows dominate the total streamflow. The streamflow impacts due to reduced baseflow lessen in the river reaches downstream of these sites, because streams continue to receive flow from unaffected catchment areas. The baseflow contribution to streams occurs locally and laterally along the stream bank. The groundwater baseflow contributions to streamflow immediately upstream and downstream of the identified drawdown area will remain unchanged. Figure 10.10, which loosely represents the Gooandra Creek and indicates how it continues to be a gaining stream even during peak drawdown periods.

Table 10.1 presents the predicted annual average change in baseflow and the percentage change in the context of total annual average baseflow for a number of scenarios, including:

- Steady state (ie long-term) with constant climate influence;
- Construction – Year 1, with seasonal climate influence;
- Construction – Year 5, with seasonal climate influence;
- Operations – Year 10, with seasonal climate influence; and
- Combined downstream effects during the peak impact year.

The model predicts reduced groundwater baseflow contribution to creeks and rivers occurs in the catchments upstream of Tantangara Reservoir, Lake Eucumbene, and Talbingo Reservoir. Although inflows to the excavations are predicted to peak in the final year of construction (see Section 10.5), impacts to baseflow are predicted to develop more slowly, with peak impacts occurring several decades after the completion of construction. The total steady state reduction in baseflow is approximately equivalent to the tunnel inflow volume (inflows to the tunnel are directly offset by reduction in baseflow, with a time lag as the impact propagates to the surface).

The surface water features in the ravine area, specifically the Upper Tumut Water Source (Middle Creek, Yarrangobilly River, Wallaces Creek and Stable Creek) display minor to negligible effects arising from the construction and operation of the project in the context of total water availability within the larger catchment.

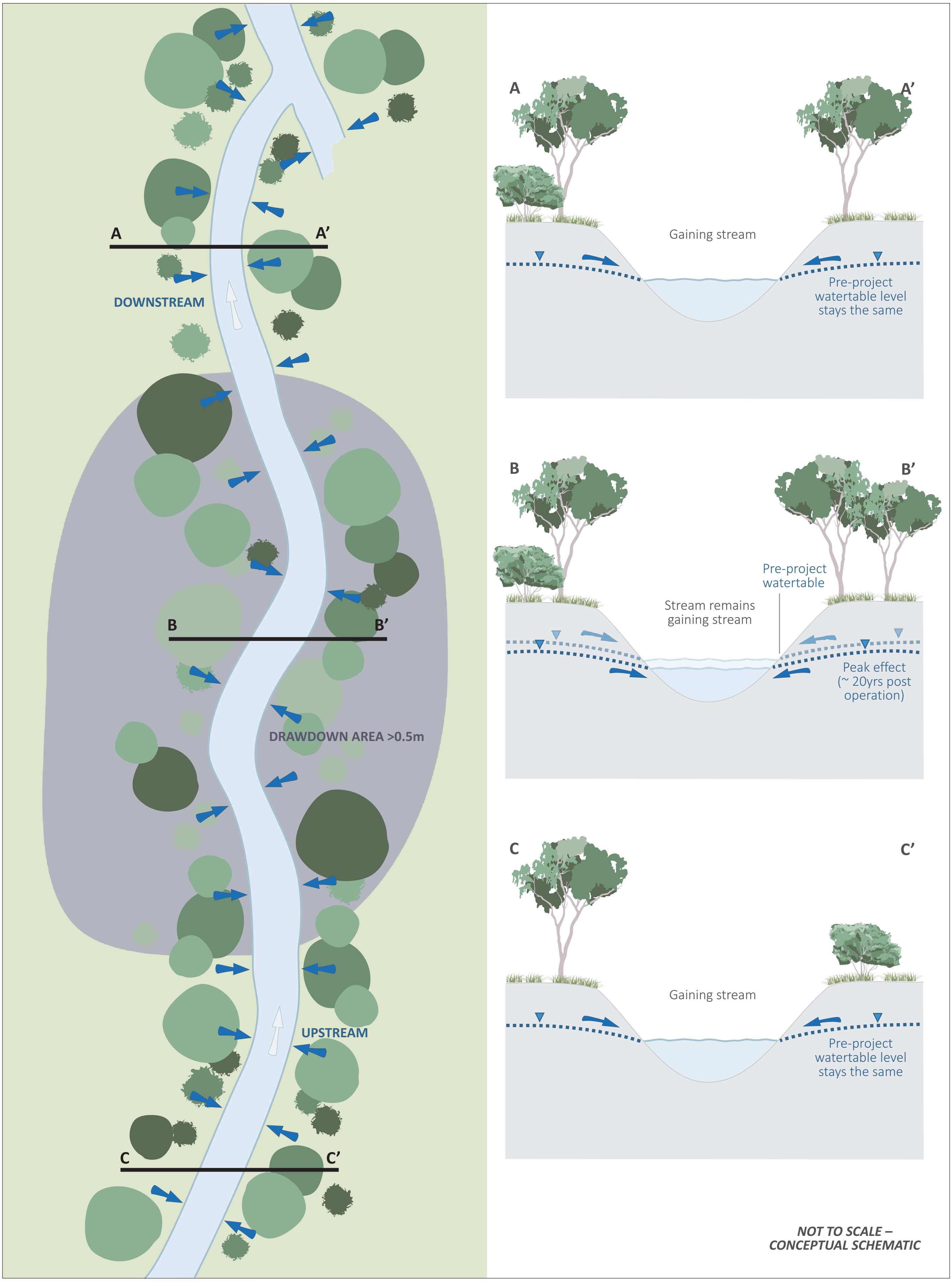
Reduced groundwater baseflows to the Lake Eucumbene water source, specifically Eucumbene Creek is predicted to increase as the construction schedule progresses, with an estimated 3.7% (186 ML) predicted reduction in baseflow occurring in Year 5, toward the conclusion of construction. Baseflow continues to be impacted through operation of Snowy 2.0 as the system reaches a new equilibrium, with modelled peak reductions in baseflow estimated to be approximately 12.5% (840 ML/yr) long-term.

The Tantangara water source includes Gooandra Creek, Tantangara Creek and Nungar Creek. Reduced groundwater available for baseflow to Tantangara Creek and Nungar Creek throughout construction and operation of the scheme are predicted to be minimal to negligible.

Reduced groundwater available for baseflow to the Gooandra Creek are expected within the area of mapped groundwater drawdown (see Section 10.4). Reduced groundwater for baseflow in Year 5 of construction are predicted to result in a 20% (536 ML) change from pre-construction conditions as measured within the impacted zone. The percentage impact drops off significantly as the river moves downstream due to ongoing and unchanged baseflow contributions outside of the immediate drawdown zone and due to contributions from other, non-affected creeks and river tributaries. Operational and long-term steady state baseflow losses are predicted to be 972 ML/yr, and although this equates to approximately 30% change in the drawdown zone area, the percentage change decreases rapidly downstream and on the Murrumbidgee River upstream of Tantangara Reservoir the change is approximately 0.7% of the streamflow at that location.

Baseflow losses to Camerons Creek, within the Murrumbidgee Zone 1 water source is not expected due to the construction and operation of the Rock Forest facility, as the numerical groundwater model (see Annexure B) does not predict groundwater drawdown due to power waterway excavation will reach or approach this area.

Downstream of the predicted drawdown area, the percentage impact to streamflow rapidly declines. As demonstrated in Table 10.1, the percentage impact of the reduced groundwater available for baseflow in the three most effected Rivers at downstream monitoring locations (ie near reservoirs) is 0.7% for the Murrumbidgee River, 0.3% for Yarrangobilly River and 0.6% for the Eucumbene River.



snowy 2.0 EMM creating opportunities

Changes to baseflow in effected watercourses

Snowy 2.0

Water Assessment

Figure 10.10

Table 10.1 Predicted change in groundwater available for baseflow

Water source/ catchment	Steady state with constant climate		Construction – Year 1 with seasonal climate variation		Construction – Year 5 with seasonal climate variation		Operations – Year 10 with seasonal climatic variation		Downstream change	
	Change (ML/yr)	Change (%)	Change (ML/yr)	Change (%)	Change (ML/yr)	Change (%)	Change (ML/yr)	Change (%)	Change (ML/yr)	Change (%)
Lachlan Fold Belt (MBD) Groundwater Source/Upper Tumut water source									On the Yarrangobilly River near Talbingo	
Yarrangobilly River	310	-2.9%	-2	0.0%	18	-0.2%	166	-1.6%	375	0.3%
Wallaces Creek	7	-0.5%	0	0.0%	-1	0.1%	0	0.0%		
Stable Creek	56	-2.8%	0	0.0%	5	-0.3%	25	-1.2%		
Middle Creek	2	-0.1%	0	0.0%	-5	0.2%	-7	0.2%		
Lachlan Fold Belt Coast Groundwater Source Lake Eucumbene water source									On the Eucumbene River near Eucumbene Reservoir	
Eucumbene River	840	-12.5%	-3	0.1%	186	-3.7%	629	-12.7%	840	0.6%
Lachlan Fold Belt (MBD) Groundwater Source/Tantangara water source										
Tantangara Creek	152	-1.5%	-5	0.1%	67	-0.9%	97	-1.2%	On the Murrumbidgee River near Tantangara	
Gooandra Creek	972	-28.8%	-1	0.0%	536	-20.2%	787	-30.0%	1,180	0.7%
Nungar Creek	56	-0.9%	-3	0.1%	31	-0.7%	34	-0.7%		

10.6 Groundwater inflows

Figure 10.11 presents predicted inflow to the Snowy 2.0 Main Works features. The figure shows predicted annual groundwater inflow to both the 'power waterway' component of the project and 'other' ancillary components; including adits, shafts etc. Predicted groundwater inflow to the project has been provided for both construction and operation up to 2045, representing the conclusion of the operational 20-year simulation. A steady state (ie long-term, after the system has re-equilibrated) simulation has also been provided for context.

As expected, groundwater inflows are greatest during construction, particularly once the majority of the power waterway and ancillary features have been excavated. The reduction in overall groundwater inflow as the project transitions into operation is a function of stability controls (see Section 10.3.1) and the groundwater system reaching a new equilibrium.

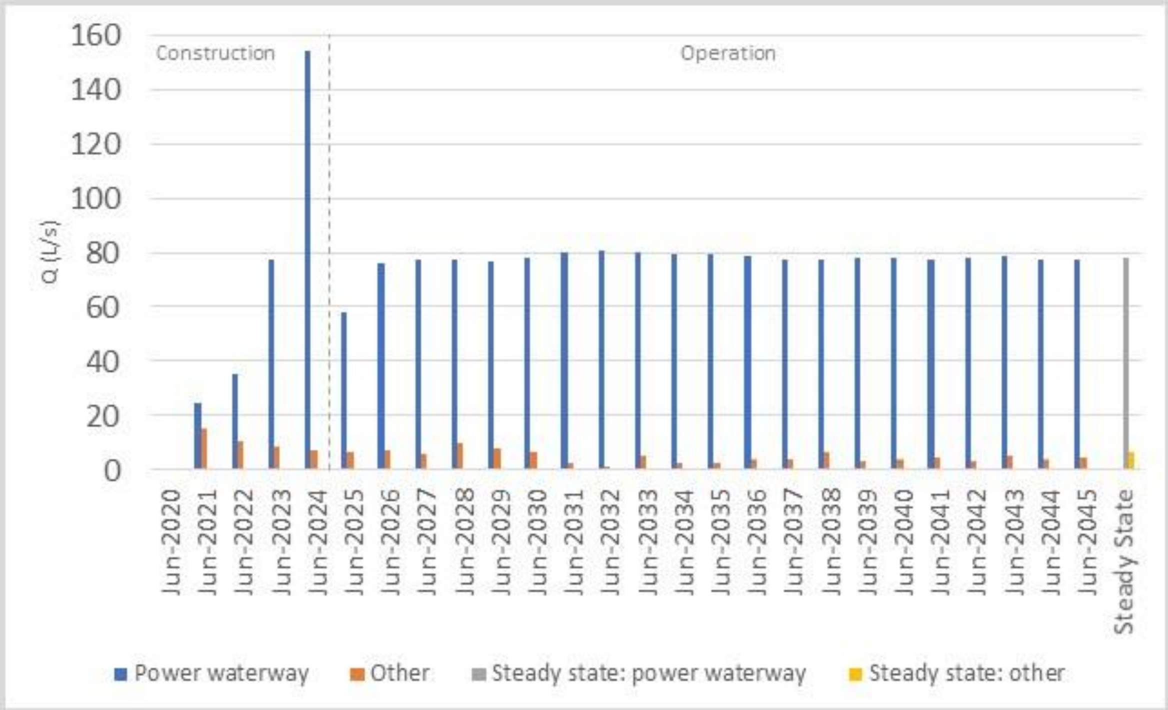


Figure 10.11 Predicted Snowy 2.0 Main Works groundwater inflows

Table 10.2 presents predicted annualised project inflows, commencing with the first year of construction and included one and 20 years of operation. A steady state annual inflow has also been presented by way of demonstrating predicted total annual average long-term groundwater inflow to the project, once commissioned.

Table 10.2 Predicted annual groundwater inflow/outflow to the project

Prediction	Inflow (ML/yr)	Outflow (ML/yr)
Construction: Year 1 groundwater inflow (ML)	3	0
Construction: Year 2 groundwater inflow (ML)	474	0
Construction: Year 3 groundwater inflow (ML)	1,343	0
Construction: Year 4 groundwater inflow (ML)	1,981	0
Construction: Year 5 groundwater inflow (ML)	4,476	0
Operation: Year 1 groundwater inflow (ML)	2,568	116
Operation: Year 20 groundwater inflow (ML)	2,682	61
Operation: Steady state groundwater inflow (ML)	2,745	61

10.7 Cumulative impacts

The project is located in the KNP, and the main other aquifer interference activity in the area is existing tunnels and the approved but yet to be constructed Exploratory Works. Existing tunnels are likely having localised effects, which are unlikely to intercept with Snowy 2.0 Main Work predicted water table drawdown effects.

The updated SH4.0 groundwater model supersedes the model (SH1.0) developed as part of the Exploratory Works EIS (EMM 2018a) and factors the construction and operation of the Exploratory Tunnel into the Snowy 2.0 Main

Works project. As such, the information presented in this section considered cumulative impacts to groundwater resources, including impacts to baseflow, groundwater levels and water take.

10.8 Predicted impacts on groundwater users

The predicted effects on sensitive receptors, as identified in Section 5.4, 6 and 7, are described below. In summary:

- high priority ecosystems that rely on groundwater (ie GDEs listed in a WSP):
  - there are no predicted impacts to GDEs (ie the Yarrangobilly Caves) as a result of the project.
- ecosystems that potentially rely on groundwater:
  - the potential impact on groundwater dependent PCTs is expected to be low; and
  - the potential impact on stygofauna communities is expected to be low;
- watercourses such as rivers, creeks and drainage lines that receive baseflow:
  - baseflow reduction is expected to occur in most rivers and creeks lying directing over the project, however only the Gooandra Creek and upper reaches of the Eucumbene River area expected to have significantly altered streamflow as a result of the project. These stretches of creeks may have periods of no flow during dry climatic periods, however the impact is not predicted to continue further downstream, as flows from catchment areas unaffected by the project alleviate the predicted impacts;
- there are no registered groundwater extraction users, within 20 km of the project area. As such, there are **no impacts predicted** to occur on landholder bores; and
- there is the potential for groundwater quality to be impacted by AMD, however this will be managed through appropriate management of waste, including PAF material (refer Section 13 for further discussion).

11 Surface water flow assessment

11.1 Overview

This section summarises various work completed and reported in the supporting Annexures and Attachments to the water assessment, including:

- Modelling report (Annexure B) – surface water catchment scale rainfall runoff model which assessed the potential reduction in streamflow as a result of the project;
- Flood risk assessment (Annexure C and Flood study) – flooding assessment;
- Water management report (Annexure D) - proposed water management system, including management measures; characterises all discharge in terms of location, volume and frequency; describe works on waterfront land; and provide estimates of water take to supply construction activities. This includes the water balance model provided in Attachment C of Annexure D.

11.2 Catchment water balance and runoff model

The surface water catchment model extent covered the Murrumbidgee River upstream of the Tantangara Reservoir, the Yarrangobilly River upstream of the Talbingo Reservoir, the Eucumbene River within the groundwater model domain extent, Nungar Creek and Middle Creek (see Figure 11.1). This extent included the area where groundwater drawdown was predicted to reach the surface.

The model has been calibrated using approximately 40 years of daily streamflow data at gauge stations 410535 and 410574 located on the Murrumbidgee and Yarrangobilly rivers. Model validation was undertaken using streamflow data collected at several locations across the plateau, via manual and automated gauging.

The surface water model was peer reviewed by Hugh Middlemis of HydroGeoLogic Pty Ltd. The peer reviewer deemed that:

- the catchment model has been prepared in a manner consistent with best practice surface water modelling guidelines; and
- the coupled models are fit for the purpose of assessing catchment water balance impacts, and to inform management strategies and licensing.

The peer review report is included in Attachment A of Annexure B.

11.2.1 Model objectives

The catchment water balance and rainfall-runoff model has been undertaken for two purposes:

- to develop a catchment scale daily water balance consistent with measured streamflow data and the hydrological concept of the area; and
- to develop a framework in which project impacts to surface water flows can be assessed.

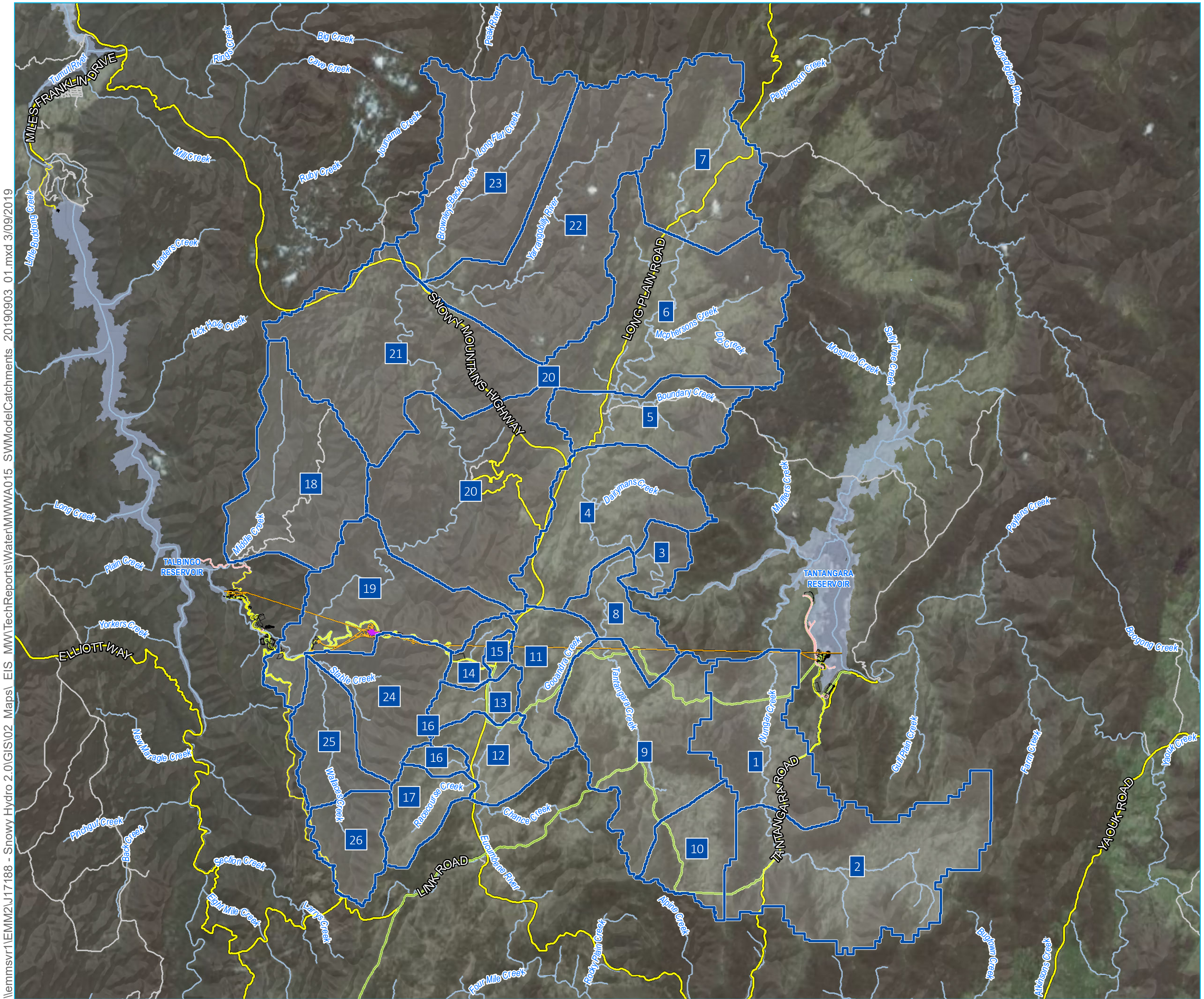
The model was set up such that changes to baseflow due to the project (an output from the groundwater model), or discharges of excess water, can be modelled and compared to unaffected runoff. Details regarding model design, calibration and sensitivity analysis are provided in Annexure B.

11.2.2 Scenario modelling

Consistent with the groundwater model, one scenario was modelled, representing the following project phases:

- the pre-construction surface water system;
- construction of the project considering wet, dry and average climate sequences; and
- operation of the project (ie post-construction steady state groundwater conditions).

Climate change was not explicitly modelled. Sensitivity analysis indicated that runoff statistics are sensitive to changes in rainfall, but that the change to runoff statistics due to project impacts is relatively insensitive to changes in rainfall or evapotranspiration.



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

Catchments

Snowy 2.0 Main Works operational elements

- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements

- Temporary construction compounds and surface works
- Temporary access road

Existing environment

- Main road
- Local road
- Perennial watercourse
- Scheme storage

Surface water model sub-catchments

Snowy 2.0
Water assessment
Main Works
Figure 11.1

snowy 2.0

EMM creating opportunities

11.3 Predicted change in streamflow

The groundwater model predicted that impacts to permanent creeks and river baseflow would develop over time, with the largest impacts seen after construction is complete, and showed that groundwater drawdown at the surface will be very localised and mainly occur in the vicinity of Gooandra Creek and the Eucumbene River headwaters. Baseflow reductions were applied in the surface water model to sub-catchments within this region; Gooandra Creek and the Eucumbene River north of the Snowy Highway (see Figure 11.1).

All stream reaches continue to receive groundwater baseflow even during peak drawdown. The reduction in baseflow discharges to surface water features resulted in streamflow reductions as illustrated in Figure 11.2.

11.3.1 Construction phase

Assuming no schedule delays, the groundwater model predicts during construction:

- baseflow in Gooandra Creek may decline by up to 20%, beginning in year 4 of construction; and
- baseflow in the upper reaches of the Eucumbene River may decline by up to 5%, beginning in year 5 of construction.

Baseflow reduction in Gooandra Creek during the construction period is predicted to cause no discernible changes to streamflow through winter months. However, during March – April in the final two years of excavation, baseflow reduction may result in cease to flow conditions within the Gooandra Creek catchment under dry climatic conditions. Within the Eucumbene River, baseflow reduction during the construction period is not expected to cause discernible changes to streamflow.

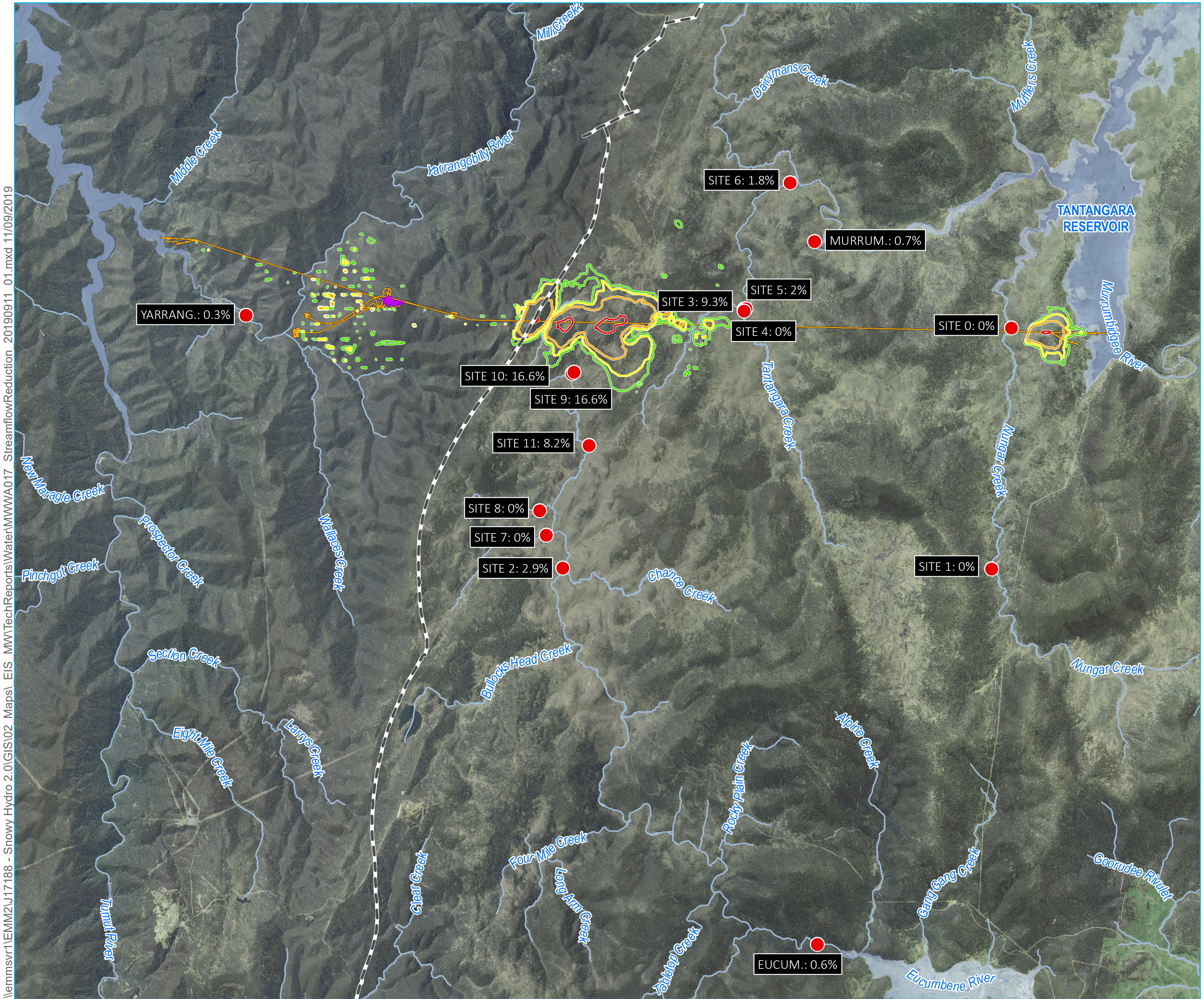
Modelling results indicate a lag between maximum tunnel inflow and maximum baseflow impacts occurring; with peak impacts expected to occur following completion of the construction phase (ie during the operating phase of the project).

11.3.2 Operational phase

The groundwater model predicts long-term baseflow reductions of 29% in Gooandra Creek and 12.5% in the upper reaches of the Eucumbene River. Permanent reductions in baseflow resulting from the tunnel excavation and operation of the project are predicted to have a noticeable impact on the streamflow regime at these sites and in the river reaches immediately downstream of them.

The groundwater model predicts that each creek would continue to receive baseflow discharge (in upstream and downstream areas beyond the extent of drawdown), and therefore remain gaining systems.

Predicted streamflow impacts are largest at sites immediately downstream of the impacted headwater sub-catchments in Gooandra Creek and the Eucumbene River; particularly when dry climatic conditions prevail and during summer and autumn, when baseflows contribute the majority of total streamflow. The streamflow impacts due to reduced baseflow lessen in the river reaches further downstream, as they receive flow from unaffected catchment areas.



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

- Reporting points

Modelled drawdown (m)

- 5
- 10
- 20
- 50
- Long Plain Fault

Snowy 2.0 Main Works operational elements

- Tunnels, portals, intakes, shafts
- Power station
- Perennial watercourse
- Scheme storage

Long term total streamflow reduction

Snowy 2.0
Water assessment
Main Works
Figure 11.2

River flow objectives are used by the NSW Government in the management of environmental flows and set out aspects of flow considered to be critical for the protection or restoration of river health, ecology and biodiversity (DECCW 2006). To demonstrate the predicted changes to the streamflow regime, the following flow categories have been used, as defined within the NSW river flow objectives:

- very low flows: flows below the level naturally exceeded on 95% of all days with flow;
- low flows: flows below the level naturally exceeded on 80% of all days with flow; and
- high flows: flows that are greater than the level naturally exceeded on 30% of all days with flow.

In addition to the flow categories listed above, a "no flow" category has also been assessed such that zero flow is assumed to occur for modelled flows less than 0.1 ML/day. Flows falling between low flows and high flows have been termed "medium flows" in this assessment.

Using these flow categories, the percentage of modelled days within each flow category under existing conditions (pre-construction phase) and under the operating phase of the project (presented as a change in percentage of modelled days within each flow category) are given in Table 11.1 for impacted sites in Gooandra Creek and Table 11.2 for impacted sites in Eucumbene River. Predicted streamflow changes of more than 5% are highlighted in red.

The surface water model predicts that, during the operating phase, Gooandra Creek is likely to change from a perennial streamflow regime to ephemeral (days with 'no flow' increase from 0% to 9% at Site 3, upstream of the confluence with Tantangara Creek). Days with no flows and very low flows are predicted to increase, particularly in summer and autumn and the number of days with low, medium and high flows are predicted to decrease correspondingly. The model predicts that flows from the unaffected Tantangara Creek catchment area would alleviate impacts in the river reaches downstream of Gooandra Creek.

During the operating phase, the streamflow regime in the headwaters of the Eucumbene River is predicted to change from perennial to ephemeral (days with 'no flow' increase from 0% to approximately 20-25% at Site 10 and Site 9 (see Figure 2.30 in Annexure B)). This impact does not continue further downstream along the Eucumbene River, as flows from catchment areas unaffected by the project alleviate the predicted impact. Days with no flows and very low flows increase significantly in the upper reaches of the Eucumbene River (Site 10 and Site 9), particularly in summer and autumn. Low, medium and high flows decrease correspondingly.

Table 11.1 Predicted streamflow changes during operation at Gooandra Creek

	Flow category	Percentage number of days under existing conditions (pre-construction) [1]	Change in percentage number of days during operations [2]
Total	No flow	0%	+9%
	Very low flows	5%	+4%
	Low flows	15%	-4%
	Medium flows	50%	-7%
	High flows	30%	-3%
Summer	No flow	0%	+13%
	Very low flows	8%	+6%
	Low flows	25%	-1%
	Medium flows	58%	-17%
	High flows	8%	-1%

Table 11.1 Predicted streamflow changes during operation at Gooandra Creek

	Flow category	Percentage number of days under existing conditions (pre-construction) [1]	Change in percentage number of days during operations [2]
Autumn	No flow	0%	+21%
	Very low flows	11%	+6%
	Low flows	29%	-18%
	Medium flows	45%	-8%
	High flows	15%	-1%

Notes: 1. Percentage of modelled days within each flow category.
2. Change in percentage of modelled days within each flow category when compared to existing conditions.

Table 11.2 Predicted streamflow changes during operation in the upper reaches of Eucumbene River

Season	Flow category	Eucumbene River upper reaches (Site 9)		Eucumbene River further downstream (Site 11)	
		Percentage number of days under existing conditions (pre-construction) [1]	Change in percentage number of days during operations [2]	Percentage number of days under existing conditions (pre-construction) [1]	Change in percentage number of days during operations [2]
Total	No flow	1%	+21%	0%	
	Very low flows	5%	-1%	5%	+8%
	Low flows	15%	-6%	15%	
	Medium flows	49%	-9%	50%	-6%
	High flows	30%	-5%	30%	-2%
Summer	No flow	4%	+35%	0%	
	Very low flows	7%	+2%	8%	+13%
	Low flows	26%	-10%	26%	+3%
	Medium flows	56%	-25%	58%	-15%
	High flows	8%	-2%	9%	-1%
Autumn	No flow	2%	+38%	0%	
	Very low flows	11%	-7%	10%	+17%
	Low flows	27%	-19%	28%	-9%
	Medium flows	45%	-10%	46%	-7%
	High flows	15%	-2%	15%	-1%

Notes: 1. Percentage of modelled days within each flow category.
2. Change in percentage of modelled days within each flow category when compared to existing conditions.

11.4 Water management

11.4.1 Overview

Snowy 2.0 project activities will take place through a number of broad but overlapping phases, being pre-construction works, construction works (including progressive rehabilitation) and testing and commissioning of permanent infrastructure (see Figure 11.3). Interfaces between the project activities and the water cycle (ie both groundwater and surface water) will change overtime as each of the project activities begins or is completed through the construction and operation project phases.

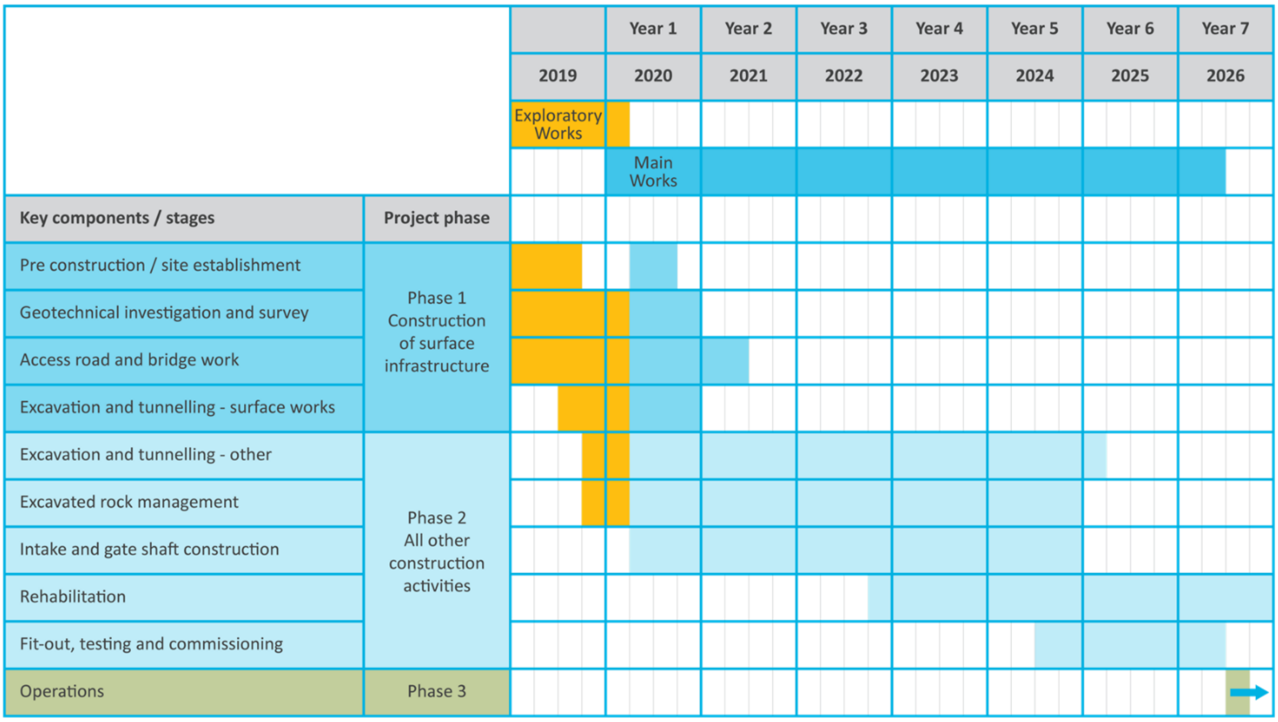


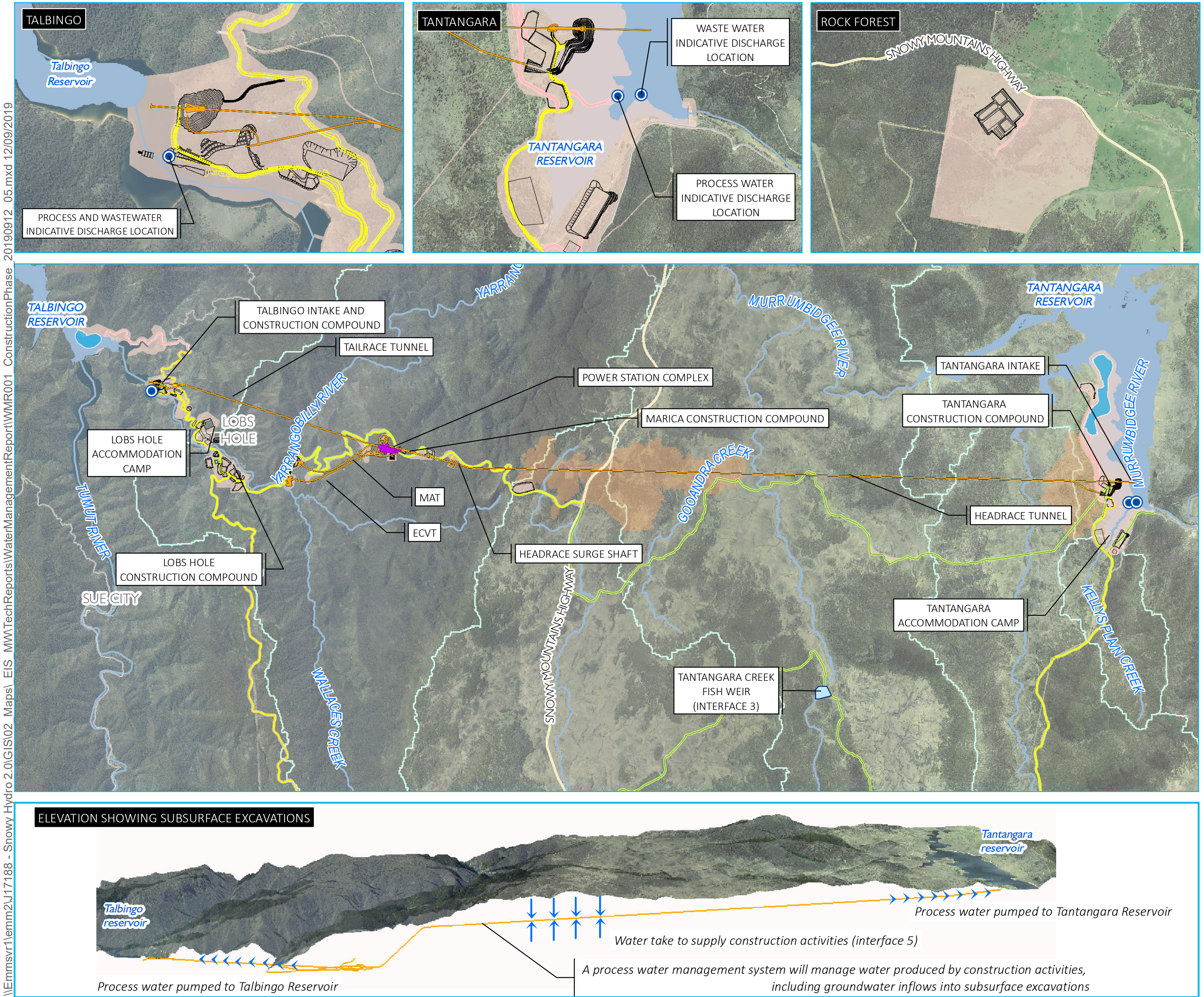
Figure 11.3 Snowy 2.0 Main Works – construction staging for key project components/phases

i Construction phase

Table 11.3 describes the key water cycle interfaces during the construction phase of the project. Information on the interface locations and mechanisms is also provided. Figure 11.4 shows the location of interfaces relative to the conceptual project layout.

Table 11.3 Water cycle interfaces – construction phase

Interface	Mechanisms	Locations
1 – Impacts to groundwater and connected surface water systems due to subsurface excavations	• Impacts to the shallow groundwater system due to groundwater inflows into subsurface excavations	• Some areas in the plateau
2 – Stormwater discharges	• Stormwater discharges from areas disturbed by construction of surface works (ie construction phase 1) • Stormwater discharges from surface infrastructure that will support broader construction activities (ie construction phase 2)	• All watercourses downstream of disturbance areas • Talbingo and Tantangara reservoirs
3 – Instream works and disturbance of waterfront land	• Watercourse diversions • Fish weir • Watercourse crossings (ie bridges and culverts) • Works within 40 m of a watercourse	• Some watercourses that are in proximity to the disturbance boundary
4 – Excavated rock placement	• Runoff and seepage from spoil placements into Talbingo and Tantangara reservoirs	• Talbingo and Tantangara reservoirs
5 – Water take to supply construction activities	• Potable water supply • Water supply to construction activities	• Talbingo and Tantangara reservoirs • Groundwater resources
6 – Controlled discharges to reservoirs	• Discharges of treated wastewater (ie sewage) • Discharges of treated process or tunnel affected water	• Talbingo and Tantangara reservoirs



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 55
N

KEY

Water cycle interfaces

- Approximate groundwater drawdown extent (interface 1)
- Project disturbance area (including interfaces 2 & 3)
- Excavated rock emplacement (interface 4)
- Reservoir discharge locations (interface 6)

Existing environment

- Main road
- Local road
- Watercourse
- Regional catchment divide
- Reservoir

Snowy 2.0 Main Works operational elements

- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Snowy 2.0 Main Works construction elements

- Temporary construction compounds and surface works
- Temporary access road

Water cycle interfaces (construction)

1 - Impacts to groundwater and connected surface water systems due to subsurface excavations
2 - Stormwater discharges
3 - Instream works and disturbance of waterfront land
4 - Excavated rock emplacement
5 - Water take to supply construction activities
6 - Controlled discharges to reservoirs

Water cycle interfaces - construction phase

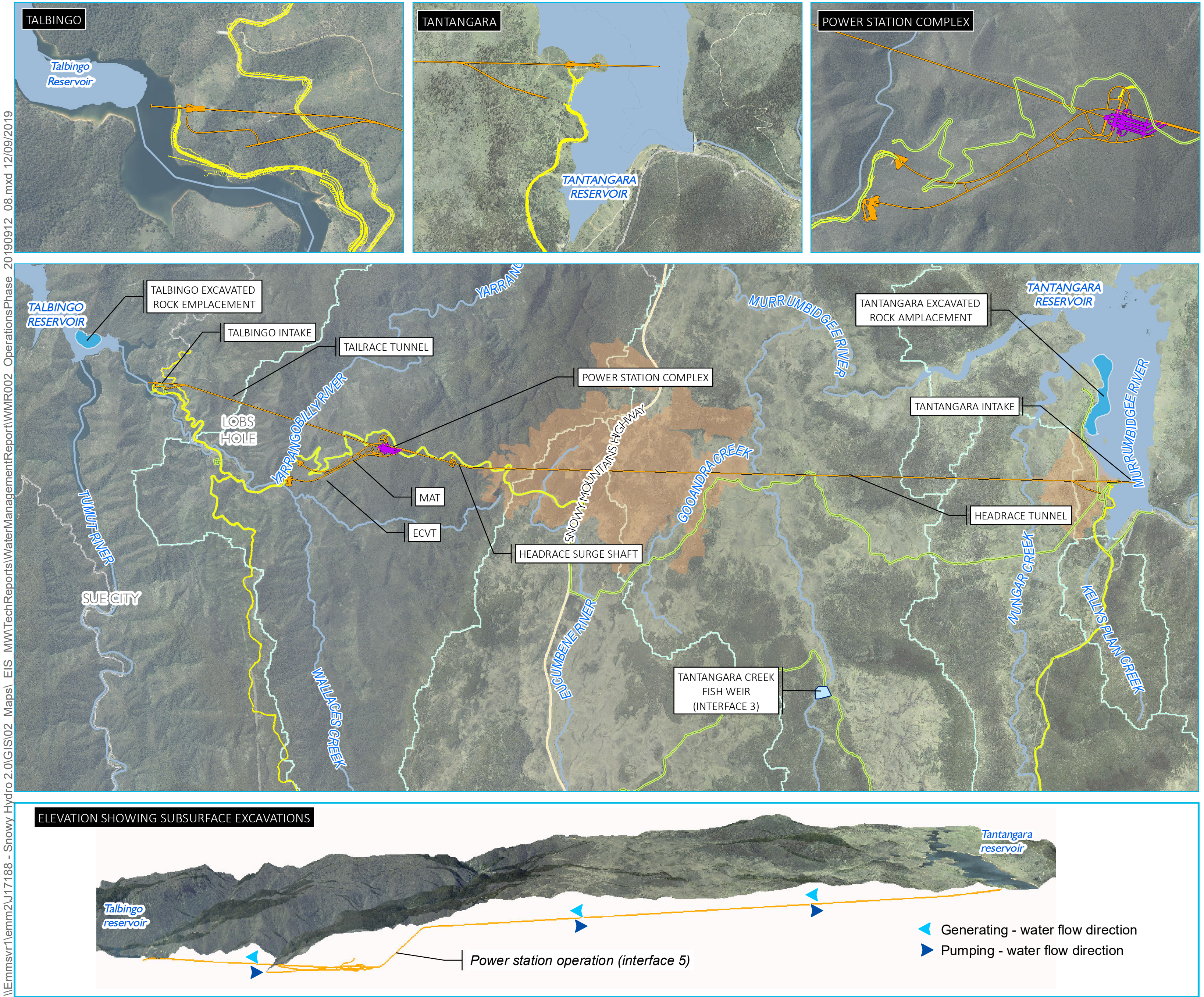
Snowy 2.0
Water assessment
Main Works
Figure 11.4

ii Operational phase

Table 11.4 describes the key water cycle interfaces during the operational phase of the project. Information on the interface locations and mechanisms is also provided. Figure 11.5 shows the location of interfaces relative to the conceptual layout of permanent infrastructure.

Table 11.4 Water cycle interfaces – operational phase

Interface	Mechanisms	Locations
1 – Groundwater inflow to to subsurface excavations	• Drawdown in the water table due to groundwater inflows into subsurface excavations • Reduced groundwater available for baseflow to surface water streams in areas of water table drawdown	• Some localised areas in the plateau
2 – Stormwater discharges	• Stormwater discharges from permanent infrastructure (ie access roads and tunnel portals)	• All watercourses downstream of permanent infrastructure • Talbingo and Tantangara reservoirs
3 – Instream works and disturbance of waterfront land	• Permanent watercourse diversions • Fish weir • Permanent watercourse crossings (ie bridges and culverts) • Permanent works within 40 m of a watercourse	• Some watercourses that are in proximity to the disturbance boundary
4 – Excavated rock placement	• Runoff and seepage from spoil placements into Talbingo and Tantangara reservoirs	• Talbingo and Tantangara reservoirs
5 – Power station operation	• Water exchange between Talbingo and Tantangara reservoirs	• Talbingo and Tantangara reservoirs



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KEY

Water cycle interfaces

- Approximate groundwater drawdown extent (interface 1)
- Excavated rock emplacement (interface 4)

Existing environment

- Main road
- Local road
- Watercourse
- Regional catchment divide
- Reservoir

Snowy 2.0 Main Works operational elements (interface 2)

- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

Water cycle interfaces (operation)

1 - Impacts to groundwater and connected surface water systems due to subsurface excavations
2 - Stormwater discharges
3 - Instream works and disturbance of waterfront land
4 - Excavated rock emplacement
5 - Power station operation

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

Water cycle interfaces - operations phase

Snowy 2.0
Water assessment
Main Works
Figure 11.5

Impacts to groundwater and connected surface water systems due to project construction activities (including excavation) is discussed in Section 10, 11.2 and 11.3. Management of all other activities requiring water management or affecting the water cycle are discussed in this section and have been grouped into water management categories (see Table 11.5). Proposed management measures and discharge characteristics for each of the water management categories described in Table 11.5 are discussed in further detail in Annexure D and summarised in the following sections:

- Section 11.4.2 summarises the approaches proposed for managing stormwater runoff;
- Section 11.4.3 summarises the approaches proposed for managing process water;
- Section 11.4.4 summarises the approaches proposed for managing potable water; and
- Section 11.4.5 summarises the approaches proposed for managing wastewater.

Section 11.4.6 summarises the approaches proposed for managing water which may be dewatered from the tailrace tunnel during maintenance activities

Table 11.5 Water management categories

Category ID	Category name	Description
WM 1 – Construction phase – Construction of surface infrastructure		
WM 1.1	Clean water management	Runoff from clean water catchments that traverse surface construction disturbance areas.
WM 1.2	Minor works	Runoff from areas disturbed by the construction of roads, service trenches and minor works typically disturbing only a small portion of catchment areas for less than 3 months.
WM 1.3	Major works	Runoff from areas disturbed by the construction of tunnel portals, construction pads, accommodation camps and other major surface works typically requiring large scale clearing/earthworks for 3 to 6 months.
WM 1.4	Water supply	Water supply for construction activities.
WM 2 - Construction phase – All other construction activities		
WM 2.1	Temporary watercourse diversions	Temporary clean water diversions around temporary surface infrastructure.
WM 2.2	Accommodation camps	Runoff from accommodation camp facilities once operational. Accommodation camps will comprise road and carparks and other hardstand areas, buildings and landscaped areas.
WM 2.3	Construction pads	Runoff from construction pads and tunnel portals during their use to support broader construction activities, eg activities such as equipment assembly, material handling, concrete batching, fuel storage and refuelling and workshops.
WM 2.4	Access roads	Runoff from access roads
WM 2.5	Large temporary stockpiles	Runoff from stockpiles of material produced by earthworks (ie road cuttings).
WM 2.6	Stockpiles – spoil placement areas	Runoff from spoil stockpiles produced by underground excavations.
WM 2.7	Large surface excavations	Water pumped from the sumps of large surface excavations such as the headrace and tailrace intakes

Table 11.5 Water management categories

Category ID	Category name	Description
WM 1 – Construction phase – Construction of surface infrastructure		
WM 2.8	Process water	Water produced by and used by construction activities.
WM 2.9	Potable water	Potable water supply system.
WM 2.10	Wastewater	Wastewater produced by accommodation camps and other facilities
WM 3 – Operational phase		
WM 3.1	Watercourse diversions	Permanent watercourse diversions
WM 3.2	Permanent surface infrastructure	Runoff from permanent surface infrastructure such as tunnel portals and substations.
WM 3.3	Permanent access roads	Runoff from permanent access roads
WM 3.4	Tailrace tunnel dewatering	Water pumped from the tailrace tunnel to enable maintenance access.

11.4.2 Stormwater management

Activities within the following disturbance categories will potentially affect stormwater management:

- During construction of surface infrastructure:
  - WM 1.2, WM 1.3
- During construction of all other infrastructure:
  - WM 2.1, WM 2.2, WM 2.3, WM 2.4, WM 2.5, WM 2.6, WM 2.7
- During operation:
  - WM 3.1, WM 3.2, WM 3.3

Potential effects associated with the management of stormwater are described below. Many of these potential effects apply to only a sub-set of the activities described in this section.

- potential for clean water runoff to enter disturbance areas resulting in an increase to the volume of water that requires management and reduced effectiveness of management measures;
- potential for impacts on adjoining watercourses if diversion works increase the effective catchment area to an adjoining watercourse;
- potential for erosion at the upstream and downstream interfaces with undisturbed watercourses;
- stormwater flooding issues and/or erosion of modified landforms due to inadequate drainage system design; and
- changes to runoff regimes due to the introduction of impervious surfaces.

The management measures proposed for each disturbance category are detailed in Annexure D, and are summarised below:

- diversion of unaffected runoff around construction areas where practical;
- utilising source control procedures to minimise soil erosion rates;
- staging of works and progressive rehabilitation to minimise the area disturbed at any given time;
- preparing an Erosion and Sediment Control Plan (ESCP) for each construction area; and
- bunding of excavations to exclude runoff ingress.

The general approach to stormwater management within the project site will be to:

- divert clean water around disturbance areas; and
- treat and release water from disturbed areas.

Rainfall runoff will be harvested by the project at the accommodation camps through the use of rainwater tanks, and from excavation sumps when water quality testing indicates that the water is not suitable for discharge. These instances represent a small portion of the total rainfall runoff that will occur over the project site.

11.4.3 Process water

The process water system (WM 2.8) will supply water to, and manage water produced by construction activities. Key water uses (or system demands) include water used for subsurface construction (primarily TBM cooling and dust suppression), concrete production and access road dust suppression. Key inflows into the system include water pumped from subsurface and large surface excavations.

The process water system will comprise separate systems at the Tantangara and Talbingo construction compounds. These systems are referred to as the Tantangara and Talbingo process water systems and will operate independently (ie they will not be connected). Each system will:

- be isolated from the stormwater management system;
- discharge to a reservoir when net inflows into the system exceed net usage; and
- be topped up from the water supply system when net usage exceeds net inflows.

The net process water usage from each system will be approximately the sum of water used for concrete production and access road dust suppression as water from other processes will be recycled (refer Annexure D Attachment C).

The peak process water top-up requirement in the Tantangara system (0.2 ML/day) is expected to occur during the project commissioning phase, when groundwater intercepted by the excavation is expected to be unavailable to use as process water (see Figure 11.6). The peak discharge from the Tantangara system is expected to occur in the final year of construction, with a discharge rate of approximately 12.4 ML/day.

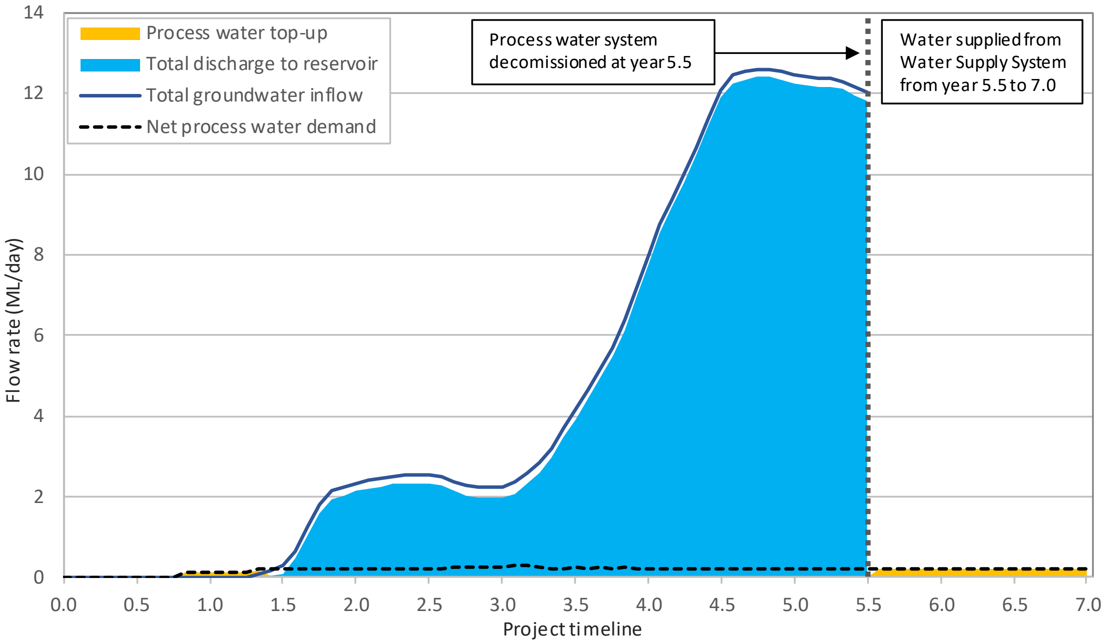


Figure 11.6 Tantangara process water system water balance

During the establishment of surface infrastructure, the Talbingo processes water system will require top-up, with a peak rate of approximately 0.8 ML/day (Figure 11.7). From approximately 1.5 years into construction until the start of commissioning, groundwater flows into excavations will be sufficient to supply the process water demands, with peak discharges estimated to be in the order of 1 ML/day. During commissioning it is expected that groundwater intercepted by the excavation will be unavailable to use as process water, and approximately 0.7 ML/day top-up will be required.

Process water top-up will most likely be sourced from regional groundwater sources, but may also source water from Tantangara and/or Talbingo reservoirs. Extraction from watercourses will be avoided. The most suitable extraction locations and water sources will be established at detailed design.

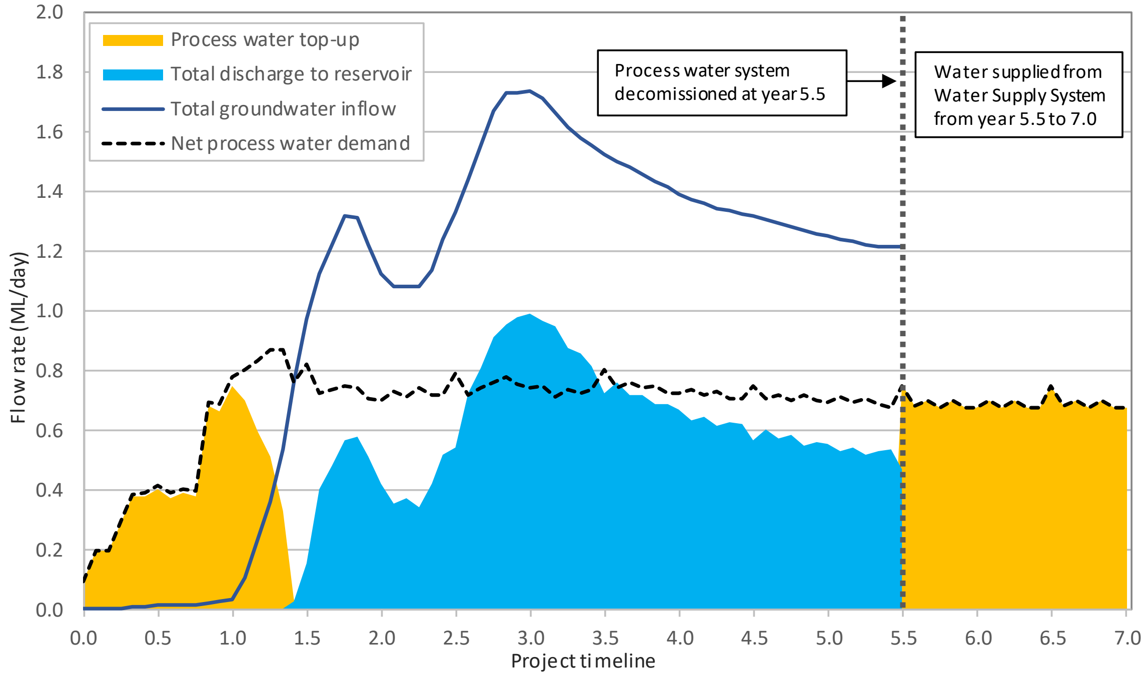


Figure 11.7 Talbingo process water system water balance

11.4.4 Potable water

During construction, potable water will be supplied to all accommodation camps and construction facilities that will have amenities. Water will be sourced from regional groundwater sources but may also source water from Tantangara or Talbingo reservoirs. The water will then be treated to a potable standard. Extraction from watercourses will be avoided. The most suitable extraction locations and water sources will be established at detailed design.

Potable water usage will vary over the construction phase of the project, consistent with the size of the construction workforce, and is expected to peak at 7 ML/day.

Small amounts of potable water will be required to supply drinking water and amenities at the power station during the operation phase of the project. Supply arrangements will be established at detailed design.

11.4.5 Wastewater management

During construction, wastewater will be produced at all construction camps and facilities that have amenities. No trade waste will be discharged to the wastewater system.

11.4.6 Tailrace tunnel maintenance dewatering

During operation, the tailrace tunnel will occasionally need to be dewatered to enable maintenance access. To achieve this, approximately 520 ML of water will be pumped from the tunnel at a rate of approximately 170 ML/day (2 m^3/sec) over a period of approximately 3 days. The water will be discharged into a drainage system that will convey the water to the Yarrangobilly River. The drainage system will be designed and constructed to have non-erosive hydraulic capacity and be structurally sound for the discharge rate and duration.

No impacts to the Yarrangobilly River are expected as:

- the discharge rate is well within the natural flow regime of the river; and
- the water contained in the tailrace to be discharged will have originated from either Tantangara or Talbingo reservoirs, which have similar water quality to the Yarrangobilly River.

11.4.7 Works on waterfront land

The Water Management Act 2000 defines waterfront land as the bed of any river, lake or estuary and any land within 40 m of a riverbank, lake shore or estuary mean high water mark. Instream works refer to modifications or enhancements to a watercourse. Table 11.6 describes proposed instream works and other works on waterfront land. Proposed management approaches are also described.

Table 11.6 Works on waterfront land

Type	Description	Management approach
Instream works		
Fish weir	A fish weir is proposed in the upper reaches of Tantangara Creek to protect the Tantangara Galaxias from the threat of potential migration of the larger Climbing Galaxia (Aquatic ecology impact assessment – Appendix M.2 to the EIS).	The fish weir will be designed to achieve its purpose of restricting fish passage from downstream watercourses to the upper reaches of Tantangara Creek. The weir design will also seek to minimise scour and erosion of adjoining banks and the downstream watercourse reach.
Watercourse diversions	Any watercourse that traverses the project disturbance area may be temporarily or permanently diverted.	1. The WMR describes the approach for temporary watercourse diversions 2. The WMR describes the approach for permanent watercourse diversions
Culverts and bridges	Culvert and bridge crossings of watercourses are proposed at numerous locations within the project disturbance area.	All culverts and bridges will be designed by a suitably qualified professional in accordance with the relevant Austroads Guidelines.
Service crossings	Service crossings of watercourses are proposed at numerous locations within the project disturbance area.	All service crossings will be designed by a suitably qualified professional in accordance with best practice methods.
Other works		
Works within 40 m of the top of bank of a watercourse or reservoir	Disturbance may occur on any land within the project disturbance area that is within 40 m of a watercourse or reservoir.	3. Stormwater will be managed in accordance with the relevant water management category. 4. Temporary works will be rehabilitated in accordance with the rehabilitation strategy (EIS Appendix F).

11.5 Flood risk assessment

A flood risk assessment (included as an attachment in Annexure C) was undertaken utilising methods published in Australian Rainfall and Runoff (Ball et al 2019) in accordance with methods outlined in the NSW Floodplain Development Manual (DIPNR 2005) and Australian Disaster Resilience Handbook 7 (AIDR 2017). The flood risk assessment (FRA) considered flooding characteristics and potential flood impacts for reservoirs and major watercourses for the following key project areas:

- Ravine – including Talbingo Reservoir and Yarrangobilly River at Lobs Hole;
- Plateau – including Tantangara Reservoir and Kellys Plain Creek; and
- Rock Forest.

The key flood impact mechanisms that were considered in these key project areas are associated with:

- locating temporary and/or permanent surface infrastructure on flood prone land (ie land susceptible to flooding by the Probable Maximum Flood (PMF)), including instream works and works on the adjacent floodplain;
- placement of excavated material in Talbingo and Tantangara reservoirs, which may reduce the volume of reservoir storage available during flood events; and
- operation of permanent infrastructure for power generation and pumped storage, which may also reduce the volume of reservoir storage available during flood events.

Flood modelling, including a range of hydrologic and hydraulic analysis methods, was used to inform an understanding of baseline flooding characteristics for the key project areas.

A summary of the flood impacts for key project areas is provided in Table 11.7.

Table 11.7 Summary of flood impacts for key project areas

Project area	Location	Construction phase	Operation phase
Ravine	Talbingo Reservoir	• No significant change to flooding characteristics for Talbingo Reservoir is anticipated as the volume of excavated material to be placed in the reservoir is very small in comparison to the existing storage.	• As for construction phase impacts, no significant change to reservoir flooding characteristics due to the placement of excavated material is anticipated. • Proposed Snowy 2.0 scheme operation is also not expected to result in significant change to flooding characteristics.
	Lobs Hole	• Whilst the spatial extent and magnitude of impacts is extensive throughout Lobs Hole, in particular for floods of 1% AEP and above, these impacts are not anticipated to impact on existing infrastructure or other areas of significance, and the design of temporary works can accommodate the changed flooding characteristics.	• Flooding impacts in Lobs Hole are anticipated to be reduced during the operational phase, relative to the construction phase, as a result of rehabilitation works and associated permanent landform changes.
Plateau	Tantangara Reservoir	• No significant change to flooding characteristics for Tantangara Reservoir is anticipated as the volume of excavated material to be placed in the reservoir is small in comparison to the existing storage.	• As for construction phase impacts, no significant change to reservoir flooding characteristics due to the placement of excavated material is anticipated. • Proposed Snowy 2.0 scheme operation is also not expected to result in significant change to flooding characteristics.

Table 11.7 Summary of flood impacts for key project areas

Project area	Location	Construction phase	Operation phase
	Kellys Plain Creek	• Temporary surface infrastructure in the vicinity of Kellys Plain Creek largely avoids flood prone land and therefore will not significantly impact on existing flooding characteristics. Minor increases to peak flood levels are expected to occur from the proposed upgraded road crossing of this watercourse, however these impacts will be localised are not anticipated to impact on infrastructure or other areas of significance.	• As described for construction phase impacts, permanent infrastructure will not significantly impact on existing flooding characteristics.
Rock Forest	N/A	• Temporary surface infrastructure associated with the proposed logistic yard at Rock Forest largely avoids flood prone land and therefore will not impact on existing flooding characteristics.	• There will be no permanent flooding impacts at Rock Forest as this site will not be used for operational purposes.

The potential for adverse flood impacts in other project areas during both construction and operational phases is considered minor and manageable with the implementation of proposed stormwater management measures, including measures for clean water management, watercourse diversions and stormwater runoff.

Public safety risks arising due to flooding and related impacts are minimal during construction as access to key project areas including flood prone land will be restricted.

New permanent recreational sites that are proposed to be established at Lobs Hole and Tantangara accommodation camps as part of rehabilitation lie above the level of the PMF. The proposed use of these sites is therefore considered broadly compatible with flooding conditions. Flood risk and emergency response will be considered during future development of a masterplan to support proposed final land use domains including recreational sites

11.6 Predicted impacts on surface water users

The following is a summary of the predicted potential impacts on surface water users (including the environment):

- the greatest potential change to the surface water flow regime is predicted to be a reduction in baseflow contribution to total flows in the Gooandra Creek and upper reaches of the Eucumbene River. These affected watercourses represent a small area of the project area and the impact does not continue further downstream, as flows from catchment areas unaffected by the project alleviate the predicted impacts;
- increases in flood water levels are expected to be limited to locations in the immediate vicinity of the project works. No increase in flood risk to private property was identified. No change to total flood runoff will occur. Tantangara and Talbingo reservoirs will receive the same volumes of flood water that they would in the absence of the project; and
- changes to terrestrial and aquatic communities could occur as a result of decreased baseflow along some stream segments but are expected to be localised and relatively minor in the context of the catchment areas.

12 Water quality assessment

12.1 Overview of water affecting activities

As discussed in Section 9, water affecting activities associated with the project have the potential to affect groundwater and / or surface water quality changes as a result of:

- runoff from construction areas laden with coarse sediment resulting in sedimentation in receiving waters;
- discharge of runoff laden with fine and/or dispersive material that will not readily settle under gravity in receiving waters;
- increased concentrations and loads of suspended solids and nutrients in runoff from impervious surfaces;
- unplanned discharge of untreated process water, water or chemicals used for firefighting purposes or a major leak or spill;
- seepage from stockpile emplacement of potentially acid forming material (ie waste rock) in the Tantangara Adit. The potential for leachate in the form of acid mine drainage is considered;
- excavated rock emplacement at the reservoirs;
- mixing water between Tantangara and Talbingo reservoirs as a result of two-way direct transfers between the reservoirs;
- seepage from wastewater storages to the watertable or spill from storages to watercourses, introducing water with varying water quality;
- stormwater discharges; and
- tunnel excavation via blasting introducing nutrients (ammonium nitrate) to groundwater.

12.2 Water quality objectives and environmental values

The *NSW Water Quality and River Flow Objectives* (DECCW 2006) provides Water Quality Objectives (WQOs) that are consistent with ANZECC/ARMCANZ (2000) water quality guidelines for the protection of the aquatic environment. The WQOs are "primarily aimed at maintaining and improving water quality, for the purposes of supporting aquatic ecosystems, recreation and where applicable water supply and the production of aquatic foods suitable for consumption and aquaculture activities" (DECCW 2006).

Water Quality Objectives are provided for catchments throughout NSW (DECCW 2006). Waterbodies potentially impacted by Snowy 2.0 Main Works are within the 'Murrumbidgee River and Lake George catchment'. Tantangara and Talbingo reservoirs and watercourses within the plateau and ravine are classified as 'streams affected by the Snowy Scheme'. Watercourses within Rock Forest are classified as 'uncontrolled streams'.

12.2.1 Trigger values

The trigger values applicable to each water quality objective are provided in *NSW Water Quality and River Flow Objectives* (DECCW 2006). The trigger values vary depending on the environmental value, with the trigger values for the protection of aquatic ecosystems generally being the lowest.

The default trigger values for aquatic ecosystem protection have been applied to the water assessment. The default trigger values do not make allowance for site-specific factors that may influence water quality. The default trigger values may be superseded by site-specific trigger values (SSTVs) during construction phase monitoring if sufficient data is available.

12.2.2 Aquatic ecosystem protection

The ANZECC/ARMCANZ (2000) guidelines present default trigger values for the protection of 99%, 95%, 90%, and 80% of aquatic species. The guidelines also present default trigger values for the protection of slightly–moderately disturbed ecosystems that are based on the default trigger values for the protection of 95% of species, but which use the lower default trigger values for the protection of 99% of species for chemicals for which possible bioaccumulation and secondary poisoning effects should be considered.

12.2.3 Summary of water quality objectives

Water Quality Objectives (WQOs) for watercourses and reservoirs are based on the *NSW Water Quality and River Flow Objectives* (DECCW 2006) and are presented in Table 12.1. WQOs are assigned based on the type of waterbody and existing ecosystem condition.

There is currently insufficient data to prepare SSTVs for all monitoring locations, streamflow conditions and operating regimes (in the case of reservoirs). Hence, the default values presented in able 12.1 have been applied to characterise and assess water quality. These values are referred to as WQO values throughout the water assessment. SSTVs can be prepared during construction phase monitoring if sufficient data is available.

Table 12.1 Summary of water quality objective values

Waterbody type	Project area	Ecosystem condition	Ecosystem condition justification	Proposed WQO approach	Default WQO values
Watercourses	Plateau	High conservation	• Watercourses are located within KNP. • A number of watercourses provide relatively undisturbed aquatic and riparian habitat – non-native species of fish (brown trout and rainbow trout) are abundant, but there are climbing galaxias, Murray crayfish and other native species in the river.	• Physical and chemical stressors – no change to natural variability	• Default trigger values for upland rivers in South Eastern Australia[1]
	Ravine			• Toxicant trigger values for the protection of 99% of aquatic species	• Toxicant trigger values for the protection of 99% of freshwater aquatic species[3]
	Rock Forest	slightly–moderately disturbed	• The area adjacent to, and downstream of Main Works has been predominantly cleared for grazing. • Instream farm dams located upstream of Rock Forest have modified flow regimes within the primary watercourses.	• Physical and chemical stressors – some change to natural variability acceptable	• Default trigger values for upland rivers in South Eastern Australia[1]
				• Toxicant trigger values for slightly to moderately disturbed ecosystems	• Toxicant trigger values for slightly to moderately disturbed ecosystems[3]
Reservoirs	Tantangara Reservoir	slightly–moderately disturbed	• The reservoirs are artificial water bodies created by flooding natural river valleys in the 1960s to 1970s. • Water levels in the reservoirs are not natural, being controlled for electricity generation as part of the Snowy Scheme. • The reservoirs support low biodiversity, consistent with their relatively recent construction and its largely homogeneous bed habitat.	• Physical and chemical stressors – some change to natural variability acceptable	• Default trigger values for freshwater lakes and reservoirs in South Eastern Australia[2]
	Talbingo Reservoir			• Toxicant trigger values for slightly to moderately disturbed ecosystems	• Toxicant trigger values for slightly to moderately disturbed ecosystems[3]

12.3 Reservoir water quality

The key mechanisms with the potential to impact reservoir water quality are:

- release of suspended solids during construction of the Ravine Bay excavated rock emplacement in Talbingo Reservoir and changes to the reservoir water quality due to interactions between the water and suspended sediment (excavated rock particles) during construction;
- runoff from the parts of the excavated rock emplacements that are above water during intense rainfall resulting in erosion and sedimentation during construction and operations;
- wave erosion of the emplacement outer surfaces during construction and operations;
- water infiltration into the excavated rock emplacements from: upslope runoff (Tantangara Reservoir only), rainfall, and water movement into submerged parts of the emplacements leading to seepage from the emplacement or directly into reservoir water during construction and operations;
- underwater removal of the intake rock plug and channel excavation resulting in the formation of turbid plumes in the reservoir;
- bed sediment disturbance during commissioning (and potentially operations);
- mixing of water between the reservoirs changing the water quality in both reservoirs during commissioning and operations; and
- stormwater discharges and controlled discharges of treated wastewater and process water.

These are described below.

12.3.1 Release of suspended solids during construction of the Ravine Bay excavated rock emplacement

The Ravine Bay excavated rock emplacement will expand from the shore as excavated rock is pushed over the advancing face into the reservoir. The excavated rock will travel down the submerged slope of the emplacement until it reaches the bottom or comes to rest on the slope. As the material travels down the slope, fine sediments will be released into the water column. These suspended sediments will form a turbid plume that will then disperse. As the turbid water moves away from the area where it was generated, the turbidity in the reservoir surface water will be reduced by a silt curtain surrounding the emplacement area. The silt curtain will not extend to the bed of the reservoir, so currents will carry some of the suspended sediment beyond the silt into the body of the reservoir.

Work conducted by RHDHV examined (*Excavated Rock Placement Assessment Summary*, Appendix L):

- the settling characteristics of excavated rock particles in reservoir water (*Subaqueous Excavated Rock Placement, Settlement Characteristics of Fine Crushed Rock - Laboratory Assessment Factual Report,* Appendix L);
- modelling of (*Excavated Rock Placement, Talbingo Reservoir Modelling – Construction,* Appendix L):
  - the dispersion of turbid plumes in the reservoir over time;
  - sediment deposition in the reservoir; and
  - the mass of sediment that is predicted to be discharged through the T3 Power Station.

While work conducted by CSIRO examined:

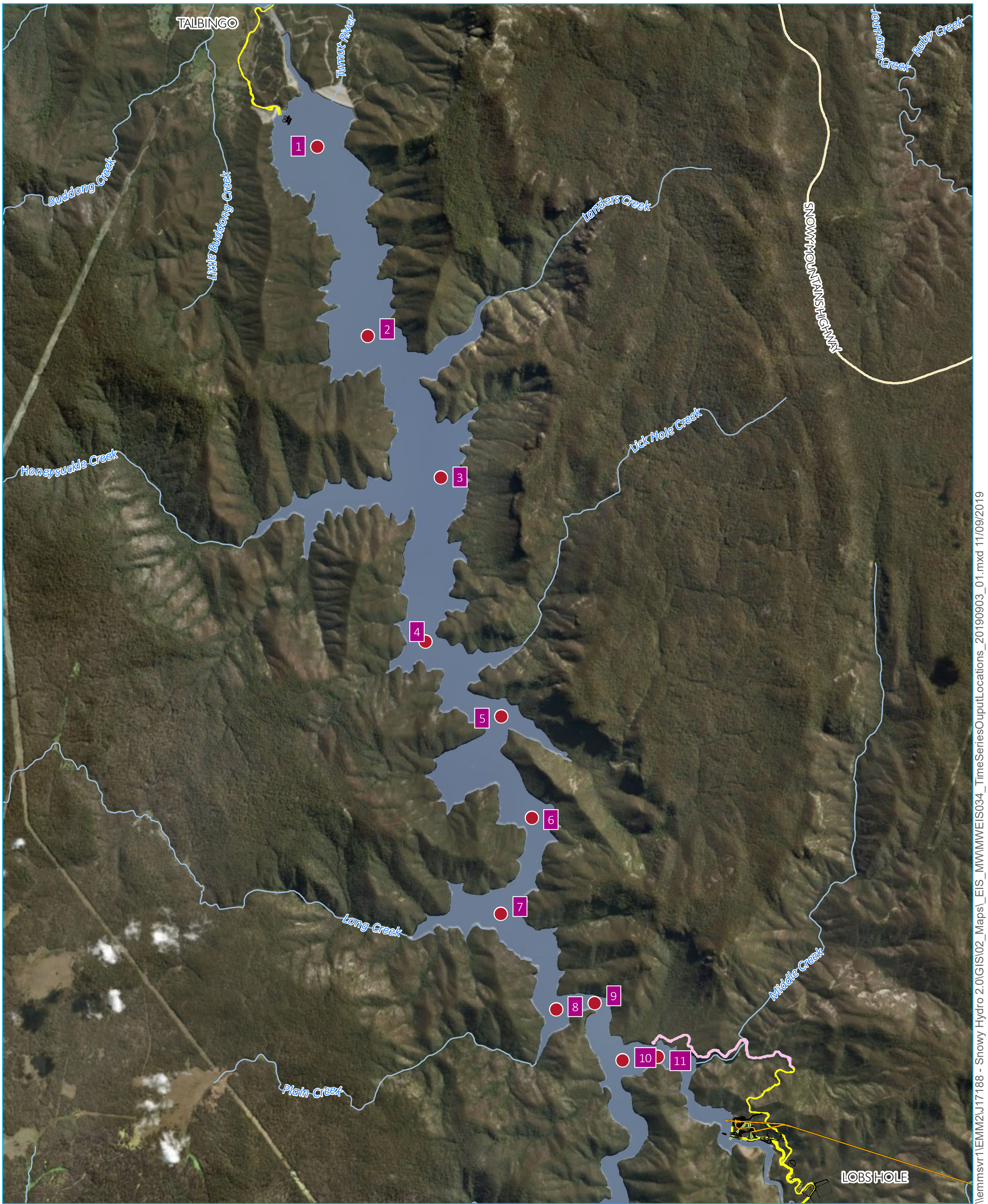
- the chemical composition and geochemistry of the rock to be excavated (*P1 - Comprehensive Geochemistry Examination Report*, Appendix L, and *P2 - Environmental Risk Categorisation of Rock Materials Report*, Appendix L);
- water quality changes caused by mixing fine particles of excavated rock with reservoir water (*P4 - Environmental Characterisations of Excavated Rock Interactions with and Potential Impacts on Reservoir Waters and Sediments,* Appendix L); and
- the potential ecotoxicity of mixtures of excavated rock and reservoir water, and excavated rock and reservoir sediment (*P5 - Ecotoxicology Assessment of Excavated Rock Leachates in Water and Excavated Rock-Sediment Mixtures Report*, Appendix L).

The methods used in the program and the key results are summarised by RHDHV in *Excavated Rock Placement Assessment Summary* (Appendix L) and below.

The RHDHV/CSIRO program found that the key stressors of potential concern (SOPC) and contaminants of potential concern (COPC) were (Appendix L): TSS/turbidity; pH; electrical conductivity; and aluminium. These are discussed below.

i TSS/turbidity

The Ravine Bay emplacement will take about 2 years to construct. The maximum predicted TSS concentrations across the reservoir were modelled over the placement period and the following year (ie for 3 years in total). Time series plots showing the maximum predicted TSS concentrations in the surface water, at mid-depth and at the bottom of the water column were prepared for 11 representative locations (Figure 12.1). These time series plots are provided below for locations either side of the placement area (Locations 11 and 9, Figure 12.2 and Figure 12.3 respectively), approximately half-way along the reservoir adjacent to Lick Hole Creek (Location 4, Figure 12.4) and at the dam wall (Location 1, Figure 12.5). Locations are presented from south to north (ie from Location 11 to Location 1) with increasing distance from the placement area as the placement area is in the southern part of the reservoir.



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011); RHDHV (2019)

KEY

Time series output location

Snowy 2.0 Main Works operational elements

Tunnels, portals, intakes, shafts

Utilities

Permanent road

Snowy 2.0 Main Works construction elements

Temporary construction compounds and surface works

Temporary access road

Existing environment

Main road

Perennial watercourse

Scheme storage

Time series output locations

Snowy 2.0
Water assessment
Main Works
Figure 12.1

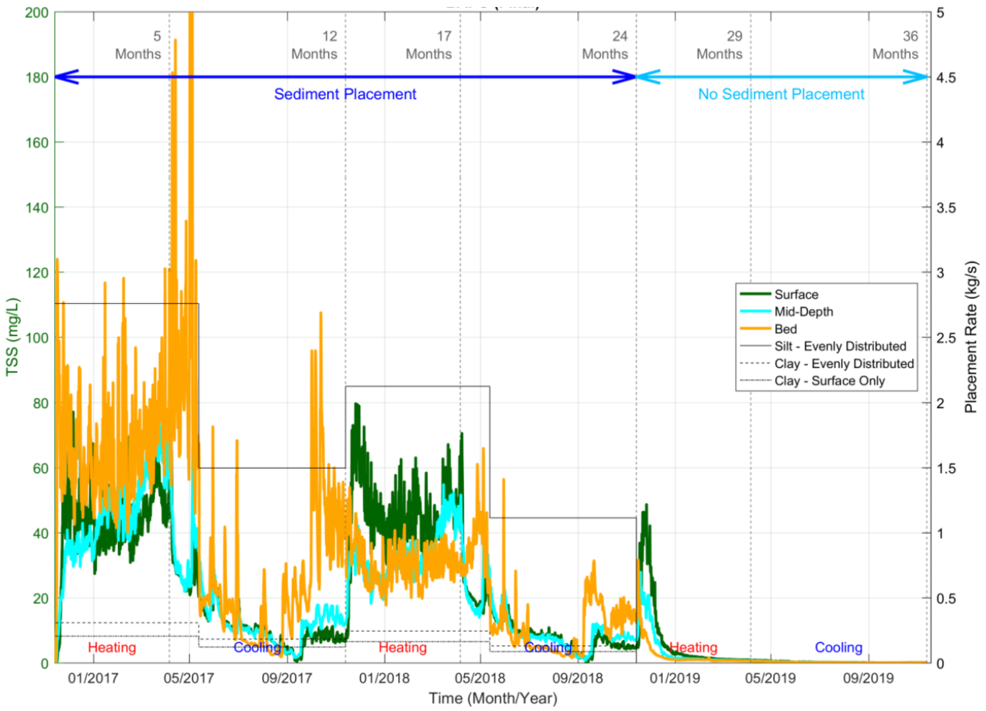


Figure 12.2 Time series of TSS concentrations – Location 11 (approximately 500 m east of the placement area)

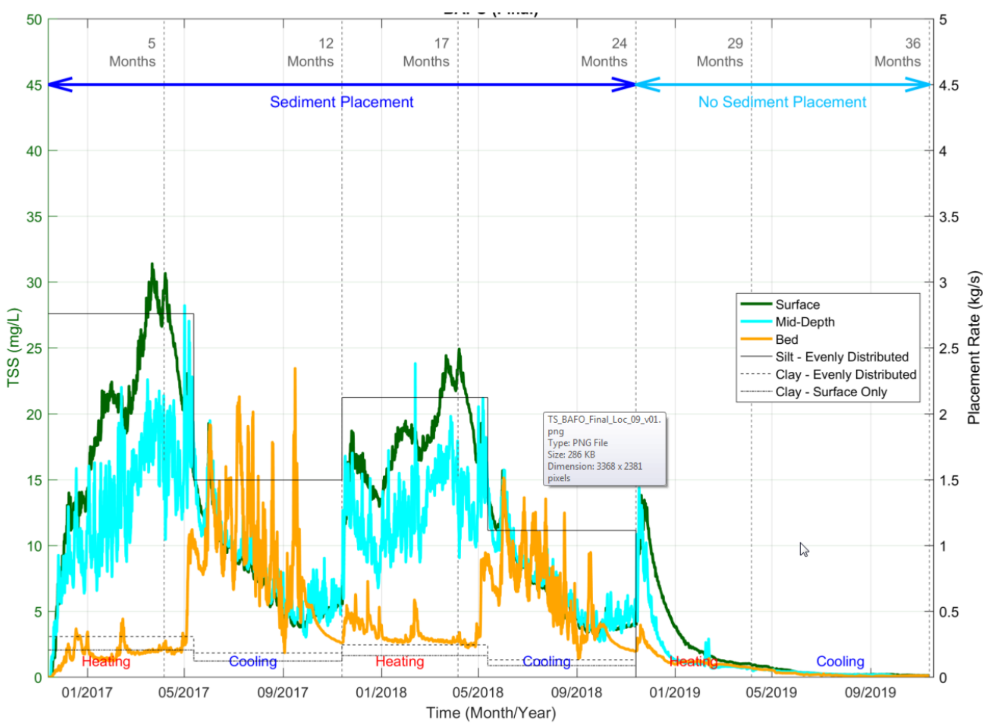


Figure 12.3 Time series of TSS concentrations – Location 9 (approximately 1 km north of placement area)

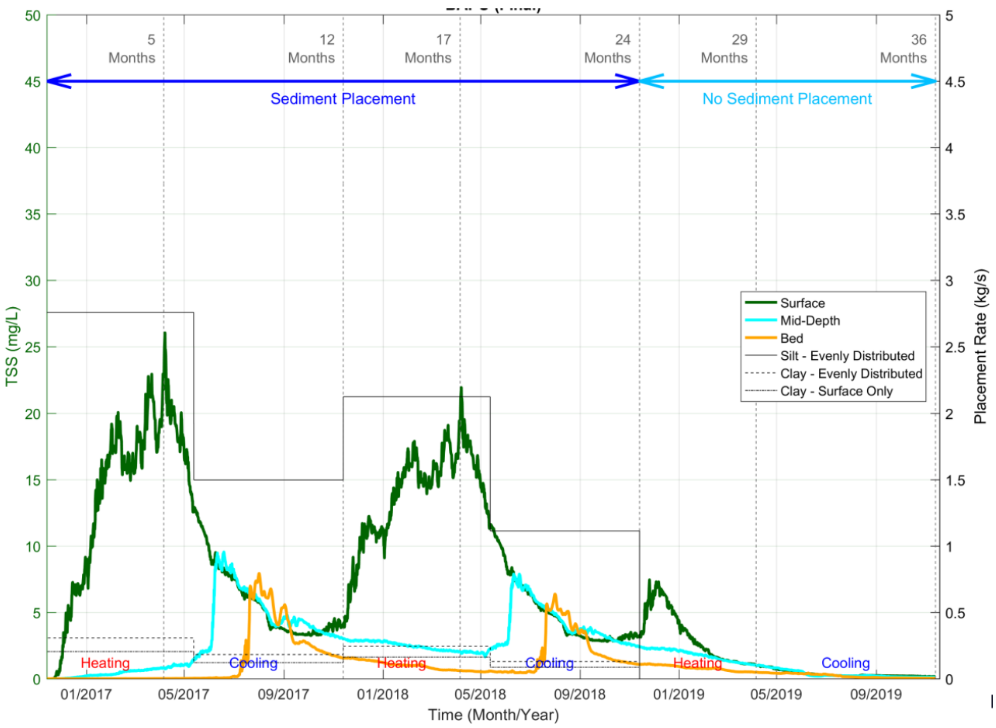


Figure 12.4 Time series of TSS concentrations – Location 4 (adjacent Lick Hole Creek, approximately half-way along the reservoir)

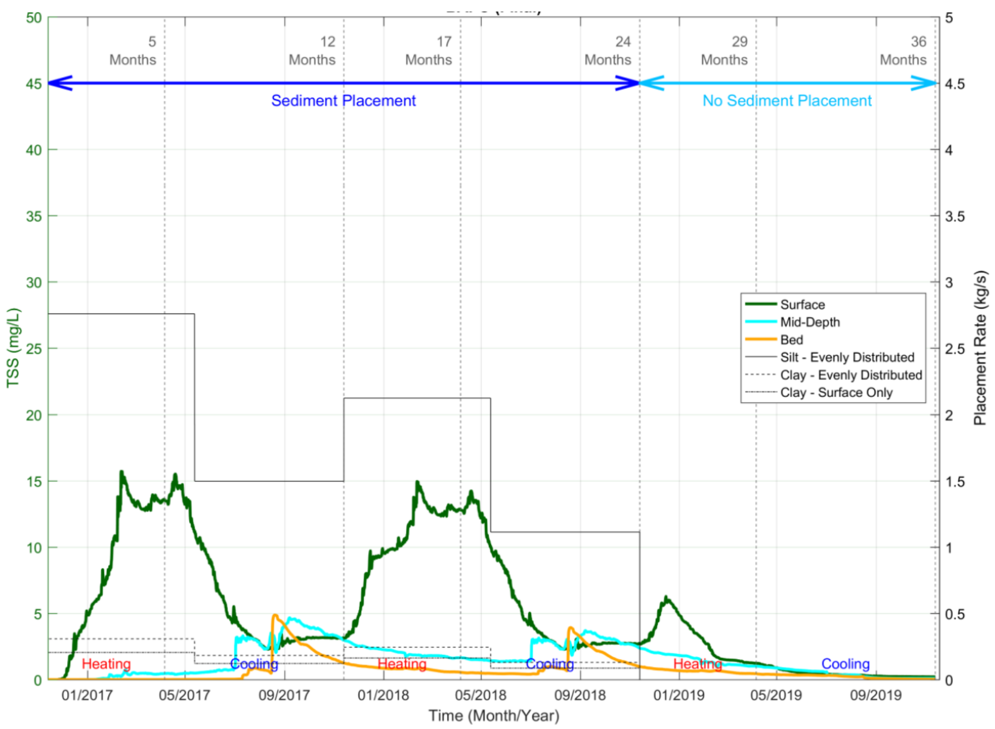


Figure 12.5 Time series of TSS concentrations – Location 1 (adjacent the dam wall)

The maximum TSS concentration within the silt curtains surrounding the placement area is predicted to be high, up to 2,700 mg/L. The maximum TSS concentrations at the surface at locations 1, 4, 9 and 11 are compared to baseline TSS concentrations, baseline turbidity and ANZECC/ARMCANZ (2000) default guideline values in Table 12.2.

Table 12.2 Predicted maximum TSS concentrations and sediment deposition rates at selected representative locations

Location	Location description	Maximum predicted TSS concentration (mg/L)	Estimated maximum turbidity (NTU)[3]
Talbingo Reservoir background level (2018–2019)		<1–6 mg/L[1]	1–5 NTU[4]
Default guideline value		-[2]	1–20 NTU[5]
11	Yarrangobilly Arm, approximately 500 m of placement area	80	96
9	Approximately 1 km north of placement area	32	38
4	Adjacent Lick Hole Creek, approximately half-way along the reservoir	25	30
1	Adjacent the dam wall	16	19

Notes: 1. Discrete water quality samples collected 2018¬2019.
2. There is no default ANZECC/ARMCANZ (2000) TSS concentration guideline value.
3. Based on turbidity ≈ 1.2 x TSS concentration (Appendix L).
4. Time-series results from mooring in reservoir (2018¬2019), 1st-percentile to 99th-percentile.
5. Default turbidity guideline value for freshwater lakes and reservoirs in South-Eastern Australia (ANZECC/ARMCANZ 2000).

The predicted maximum TSS concentrations in surface waters are predicted to exceed baseline concentrations throughout the reservoir at times. This will occur primarily in summer (see Figure 12.2 to Figure 12.5), when the reservoir water column is stratified, trapping suspended solids in the upper layers of the water column. Surface turbidity will return to close to background levels within approximately 8 months of the completion of the Ravine Bay emplacement.

The estimated maximum turbidity will exceed the default guideline values at times throughout the reservoir with the exception of at Location 1, adjacent to the dam wall, where the turbidity is estimated to remain below the upper limit of the default guideline value (20 NTU).

ii Sediment deposition

The vast majority of excavated rock discharged in the placement area will travel down the slope of the emplacement and deposit within the emplacement footprint. However, some of the suspended sediment dispersed in the reservoir will settle to the bed of the reservoir. Current sediment deposition rates have been estimated based on the examination of sediment cores collected from the reservoir (*Water Characterisation Report*, Annexure A). Current annual sediment deposition rates in parts of the Yarrangobilly Arm have been estimated to be 5–15 mm/year, while it is estimated that very little sediment deposition (<1 mm/year) currently occurs in the rest of the reservoir.

During construction, it is predicted that sediment deposition rates will be:

- highest (above 150 mm/year) closest to the placement location;
- 7–45 mm/year in the southern half of the reservoir;

- 2–15 mm/year in the northern half of the reservoir; and
- higher in shallow parts of the reservoir (ie reservoir edges) than in the deeper parts.

iii Sediment discharged from the reservoir

The predicted TSS concentration at Location 1 (see Figure 12.2) is representative of the TSS concentration that will be discharged from the reservoir via the T3 Power Station (ie water with a TSS concentration of up to 16 mg/L will be discharged at times during the 2 year construction period). It is predicted that a total of 16,021 tonnes of suspended sediment will be discharged from the reservoir in total.

iv pH, electrical conductivity and aluminium

Testwork conducted by CSIRO examined (Appendix L) examined the potential changes to pH, electrical conductivity and aluminium water quality due to suspended excavated rock particles. The findings are summarised below.

Mixing excavated rock particles in reservoir water at high concentrations (3,300 mg/L), increased the pH such that baseline pH (pH 6.3–8.2) and the default guideline values (pH 6.5–8.0) would be exceeded. However, this TSS concentration is greater than the estimated maximum TSS (2,700 mg/L) in the placement area. At lower TSS concentrations (100 mg/L), the measured pH was 7.9–8.0 after 24 hours, ie within the range in the reservoir and within the default guideline values.

Mixing excavated rock particles in reservoir water at high TSS concentrations (3,300 mg/L), increased the electrical conductivity such that baseline conductivity (11–44 µS/cm based on discrete water samples) and the default guideline values (20–30 µS/cm) would be exceeded. At lower TSS concentrations (100 mg/L), the measured conductivity was 55–74 µS/cm after 24 hours. Therefore, the conductivity in the reservoir is predicted to exceed the baseline conductivity and default guideline values until dilution and sediment deposition decreases the TSS concentrations significantly below 100 mg/L.

Mixing excavated rock particles in reservoir water is predicted to result in aluminium concentrations that exceed baseline and default guideline values close to the emplacement area. Higher aluminium concentrations were measured in water at 21 °C compared to in water at 6 °C. Further analysis of aluminium concentrations by CSIRO (Appendix L) found that the default trigger value for slightly to moderately disturbed ecosystems (55 µg/L) may not be met immediately outside of the silt curtain around the placement area but is estimated to be met 500 m from the silt curtain. Therefore, a mixing zone 500 m from the silt curtain would be required to meet the default guideline value for aluminium.

12.3.2 Runoff from the parts of the excavated rock emplacements that are above water during intense rainfall

i Ravine Bay excavated rock emplacement

The upper section of the Ravine Bay excavated rock emplacement will be above water during construction. The surface of the emplacement will be traversed by earthmoving equipment and there will be mechanism to control runoff into the reservoir. However, the sediment carried from the unsubmerged parts of the emplacement into to the reservoir during intense rainfall is expected to me minimal compared to the volume of sediment actively pushed into the reservoir during emplacement construction. Any fugitive sediment entering the reservoir in runoff will be contained within the silt curtain surrounding the placement area.

The emplacement will be armoured with rocks >200 mm diameter during the final stages of construction. This will minimise sediment transport from unsubmerged parts of the emplacement to the reservoir during intense rainfall.

Over time, the emplacement will behave similarly to the existing parts of the reservoir shore that are covered by rocks (eg around the Talbingo boat ramp).

ii Tantangara Reservoir excavated rock emplacement

As far as possible, the water level in Tantangara Reservoir will be maintained so that it is below the toe of the excavated rock emplacement during its construction. The emplacement to be constructed using 'dry' earthmoving methods so there will be no direct sediment input to the reservoir during construction.

Native vegetation will be maintained in the area immediately upslope of the emplacement area. The construction of temporary diversion drains upslope of the emplacement to divert clean water around the emplacement and into the reservoir will prevent sediment from the emplacement entering this clean water.

The outer face of the final emplacement will have a series of benches (nominally 3 m wide) with interspersed batters (nominally 5 m high and with a nominal 1:8 (vertical: horizontal) slope) to minimise runoff velocities and potential erosion. Silt fences will be installed downslope of the emplacement, and surrounding disturbed areas, to capture fugitive sediment. Other downslope sediment control measures may include capture drains, temporary sedimentation basins, and a temporary flood protection levee. If sediment laden water is discharged to Tantangara Reservoir, a silt curtain will be installed in the reservoir around the discharge area (or areas).

The specifications and locations of these measures will be determined as part of detailed design. They will be designed such that water quality criteria agreed with the regulators, with the application of a mixing zone if required.

The emplacement will be armoured with rocks >200 mm diameter during the final stages of construction of each cell. This will minimise sediment transport from unsubmerged parts of the emplacement to the reservoir during intense rainfall. Over time, the emplacement the amount of any fugitive sediment released will decrease.

12.3.3 Wave erosion of the emplacement outer surfaces

The rock armouring of the emplacements will also minimise the potential for wave erosion of the emplacement outer surfaces when and where they form part of the reservoir shoreline.

12.3.4 Water infiltration into the excavated rock emplacements

The potential for acid mine drainage from emplacements and proposed further assessments are discussed in Appendix N.1.

12.3.5 Intake structure - rock plug removal and channel excavation

i Talbingo Reservoir

The rock plug will be removed from the front of the Talbingo Reservoir intake structure and a 1:16 (vertical:horizontal) channel excavated from the intake into the reservoir. The channel will be approximately 150 m long. With the reservoir water level at FSL, the water depth at the end of the channel will be approximately 28 m (19 m at MOL). An estimated 95,000 bank m^3 of material will be removed from the plug and the channel.

Due to the large volume of rock to be excavated and discarded, various excavation options are being considered including:

- drill and blast – using dry methods as far as possible when the reservoir level is low and then using underwater blasting; and

- removal of material by dredging machine or barge-mounted excavator.

The excavated material will be transported to the Ravine Bay emplacement area for placement. The transport mechanism and method for placement of the dredged material to the emplacement area will be determined as part of detailed design. All of these activities have the potential to generate turbidity plumes. Silt curtains will be installed around the underwater blast zone and area of underwater material removal to minimise the dispersion of turbidity.

The impacts of rock plug removal and channel excavation in Talbingo Reservoir will be dependent on the methods used and the duration of these activities. The specifications and locations of the proposed environmental measures will be determined as part of detailed design. They will be designed such that water quality criteria for Talbingo Reservoir agreed with the regulators, with the application of a mixing zone if required. However, given that the volume of material to be removed will be small (2-3%) compared to the volume of excavated material placed in the Ravine Bay, with the implementation of appropriate management measures, the impacts of rock plug removal and channel excavation on water quality are expected to be small in comparison.

ii Tantangara Reservoir

The rock plug will be removed from the front of the Tantangara Reservoir intake structure and a 1:16 (vertical:horizontal) channel excavated from the intake into the reservoir. The channel will be approximately 350 m long and, with the reservoir water level at MOL, the water depth at the end of the channel will be approximately 21 m. An estimated 140,000 m^3 of material will be removed from the plug and the channel.

As for the Talbingo Reservoir, various excavation options are being considered including drill and blast, and removal of material by dredging machine or barge-mounted excavator. The excavated material will be transported to the shore for placement in the Tantangara Reservoir emplacement area. Silt curtains will be used as for rock plug removal and channel excavation in Talbingo Reservoir.

The impacts of rock plug removal and channel excavation in Tantangara Reservoir will be dependent on the methods used and the duration of these activities. The specifications and locations of the proposed environmental measures will be determined as part of detailed design. They will be designed such that water quality criteria for Tantangara Reservoir agreed with the regulators, with the application of a mixing zone if required.

12.3.6 Bed sediment disturbance during commissioning

Commissioning, and later operation, of the six Snowy 2.0 turbines/pumps will generate currents in the Yarrangobilly Arm of Talbingo Reservoir. The maximum water discharge into the Yarrangobilly Arm during commissioning will be up to 372 m^3/s, when six turbines are operated for 5 days as part of the NER compliance test. Lower flows (up to 270 m^3/s) will be experienced towards the intake during pumping.

Similarly, flows will be generated around the Tantangara Reservoir intake. The maximum water discharge from the reservoir during commissioning will be 372 m^3 and there will be lower flows into the reservoir (up to 270 m^3/s) into the reservoir during pumping.

The physical properties of the sediments are generally homogenous throughout both reservoirs, primarily comprising silts (mainly coarse silts) and clay. As described above construction of the Ravine Bay emplacement will also result in the deposition of additional sediment on the bed of Talbingo Reservoir.

In Talbingo Reservoir, both the fine settled material from the construction phase and the existing reservoir sediments in Middle Bay, downstream of the intake works, and over large areas of Ravine Bay, would be expected to be disturbed by generation and pumping flows. The >200 mm rock armouring placed on the upper slope of the Ravine Bay emplacement will not be disturbed by these flows and, if the drill and blast material on the lower part of the slope is >8 mm, it is also predicted not to be disturbed.

In Tantangara Reservoir, the existing reservoir sediments located within the intake channel and areas directly offshore and adjacent (mostly to the north) would be expected to be disturbed by generation and pumping flows. The Tantangara Reservoir excavated rock emplacement will be well to the north of the intake structure and will not be intersected by generation and pumping flows to any material extent.

Potential measures to minimise the disturbance of bed sediments include: redesigning the intake structures and channels; dredging sediments from the potential disturbance zones and placing them in another part of the reservoir; and/or armouring the sediments in the potential disturbance zones. These options are currently being assessed.

12.3.7 Mixing of water between the reservoirs during commissioning and operations

The construction and commissioning impacts described above will cease at the end of these phases or gradually decrease over time. Over the long-term (years to decades), the primary impact on water quality in the reservoirs will be changes due to the mixing of the water between the reservoirs. These changes may not be deleterious but will result in a new dynamic equilibrium being established in both reservoirs but most likely with a larger change in the water quality of Tantangara Reservoir as it does not currently receive water from Talbingo Reservoir and its total volume is smaller than Talbingo Reservoir so transferred water will make up a larger portion of the total volume. While it is desirable to accurately predict what these changes will be, only broad conclusions can be drawn as the water quality in each of the reservoirs will depend on the transfer regime and the transfer regime will vary widely depending on SHL operational decisions and planning within the highly competitive national electricity market.

The change from one-way transfers of water from Tantangara Reservoir to Talbingo Reservoir (via Lake Eucumbene, Tumut Pond and T2 Dam) to two-way direct transfers between the reservoirs has the potential to change the water quality in both reservoirs due to water mixing. Any changes to the water quality (for example, changes to water temperature or nutrient concentrations) will be dependent on the water quality in each reservoir and the transfer regime.

Following the completion of the commissioning and any associated changes to water quality, the water quality of the transferred water and of the water into which it flows (Talbingo Reservoir when Snowy 2.0 is generating electricity and Tantangara Reservoir when it is pumping) will depend on factors that will vary widely including:

- the level of the reservoir – particularly for Tantangara Reservoir which has an operating range of approximately 23 m;
- the origin of the water in the reservoir (lateral location and depth) – longer pumping and generation periods will draw water from further away from the intake structure and discharge it further into the receiving reservoir;
- the season – which has a strong influence on the surface water temperature in Talbingo Reservoir and the whole of the water column in Tantangara Reservoir;
- natural water inflows from the reservoir’s catchment;
- meteorology – particularly wind, that may alter the currents in the reservoirs; and
- climate – including long-term temperature and rainfall trends.

The transfer regime will vary will depend on SHL operational decisions and planning within the highly competitive national electricity market including:

- short-term operational decisions (minutes to hours) whether to pump, generate or idle Snowy 2.0 based on short-term power prices that fluctuate very widely based on a wide range of factors outside of SHL's control;

- medium-term operational planning (days to months) of the overall Snowy Scheme – there will continue to be a range of interacting, and at times competing, considerations when determining where to send and store water such as water requirements for Tumut 2 Power Station (generation); Tumut 3 Power Station (generation or pumping); and Tantangara (environmental releases and diversions to Lake Eucumbene) based on meteorological, climatic and market forecasts; and

- long-term planning (years to decades) as the energy market changes (potentially dramatically) – SHL require operational flexibility to respond to these changes.

All of these many factors will continuously vary such that it is not possible to predict the transfer of water between the reservoirs or the resulting change in water quality in the reservoirs during the operation of Snowy 2.0. Further, there are such a large range of independent factors that the scenarios that combine various states for each factor are effectively limitless.

However, some general predictions may be made regarding changes to water quality:

- water levels have varied widely in Tantangara Reservoir on a monthly and annual basis between MOL and FSL and this will continue;

- water levels in Talbingo Reservoir have varied between MOL and FSL on a daily and weekly basis and this will continue;

- as the Tantangara Reservoir active storage is approximately 93.9% of the gross storage (ie the maximum volume of water that may be transferred between the reservoirs), the potential for water temperature change is higher in Tantangara Reservoir than in Talbingo Reservoir where active storage is approximately 17.3% of the gross storage but that these changes cannot be predicted in the absence of an accurately forecast of water transfers;

- based on 2018–2019 water quality monitoring in the reservoirs:

  - the pH was similar in both reservoirs – mixing of the reservoir waters as a result of the operation of Snowy 2.0 is expected to have a minimal impact on pH which will generally remain within the default guideline values for freshwater lakes and reservoirs in South-Eastern Australia;

  - the electrical conductivity is low in both reservoirs, generally within or below the default guideline value range, but is approximately 30% lower in Tantangara Reservoir – mixing of the reservoir waters is expected to increase the electrical conductivity in Tantangara Reservoir and correspondingly (but to a much lesser degree) decrease the electrical conductivity in Talbingo Reservoir but the electrical conductivity will generally remain within the default guideline value range in both reservoirs;

  - the turbidity is low in both reservoirs, at the lower end of the default guideline value range, but is marginally higher in Tantangara Reservoir than in Talbingo Reservoir – mixing of the reservoir waters is expected to have a minimal impact on the turbidity in the reservoirs will generally remain within the guideline value range in both reservoirs;

  - the dissolved oxygen concentration (measured as percent saturation) is higher in Talbingo Reservoir than in Tantangara Reservoir but is generally within the default guideline value range – mixing of the reservoir waters is expected to have a minimal direct impact on the dissolved oxygen concentrations in both reservoirs, but the changes to water temperature may impact dissolved oxygen concentrations;

 - the nutrient concentrations (total nitrogen, oxidised nitrogen, ammonia and total phosphorus) were generally low in both reservoirs (some exceeded the default guideline values for freshwater lakes and reservoirs in South-Eastern Australia) – mixing of the reservoir waters is expected to have a minimal impact on nutrient concentrations in the reservoirs; and

 - metal concentrations were low in both reservoirs, but measured aluminium concentrations were higher in Talbingo Reservoir and copper concentrations were higher in Tantangara Reservoir based on sampling to date – the representativity of these results needs to be confirmed through further monitoring.

In summary, the greatest change to the water quality in the reservoirs is likely to be changes in water temperature, particularly in Tantangara Reservoir. However, water temperature changes (including the change in water temperature with depth) cannot be accurately predicted due to the wide range of independent factors that will determine the transfer of water between the reservoirs and environmental factors such as the weather. These changes to water temperature may change the aquatic ecology of the reservoir. Water temperature will be monitored through the water column in both reservoirs as has occurred historically.

12.4 Stormwater discharges and controlled discharges of treated wastewater and process water

The following water management system discharges have potential to change reservoir water quality:

- stormwater discharges into watercourses that flow into reservoirs; and
- controlled discharges of treated wastewater and process water directly to reservoirs.

Table 12.3 provides estimates of the change in median ambient salinity levels (as indicated by electrical conductivity) and total nitrogen and phosphorus concentrations in Tantangara Reservoir and the Yarrangobilly River arm of Talbingo Reservoir. It is noted that:

- The change in salinity levels and nutrient concentrations is likely to be less due to:
  - decay and assimilation (nutrients only); and
  - mixing between the Yarrangobilly River arm and the greater Talbingo Reservoir (not relevant to Tantangara Reservoir).
- Higher concentration increases may occur near treated wastewater and process water discharge locations. However, the spatial extent of higher concentrations (also referred to as a mixing zone) is expected to be within tens of metres of discharge locations.
- Additional changes to reservoir water quality may occur due to spoil management activities.

Table 12.3 Summary of potential changes to ambient reservoir water quality

	Units	Summer/autumn (drought)[1]	summer/autumn (typical)	winter/spring (typical)
Tantangara Reservoir				
Construction phase 1 – Applies to the initial 15 months of the 6 year construction program				
Salinity (as indicated by EC)	µS/cm	27 to 27	27 to 27	22 to 22
Total nitrogen	mg/L	0.20 to 0.27	0.20 to 0.22	0.12 to 0.12
Total Phosphorus	mg/L	0.03 to 0.05	0.03 to 0.04	0.01 to 0.01
Construction phase 2 – Applies for the majority of the 6 year construction program				
Salinity (as indicated by EC)	µS/cm	27 to 33	27 to 28	22 to 23
Total nitrogen	mg/L	0.20 to 0.24	0.20 to 0.21	0.12 to 0.12
Total Phosphorus	mg/L	0.03 to 0.04	0.03 to 0.03	0.01 to 0.01
Operational phase – Applies for perpetuity following construction				
Salinity (as indicated by EC)	µS/cm	27 to 27	27 to 27	22 to 22
Total nitrogen	mg/L	0.20 to 0.21	0.20 to 0.20	0.12 to 0.12
Total Phosphorus	mg/L	0.03 to 0.03	0.03 to 0.03	0.01 to 0.01
Yarrangobilly River arm of Talbingo Reservoir				
Construction phase 1 – Applies to the initial 15 months of the 6 year construction program				
Salinity (as indicated by EC)	µS/cm	22 to 22	22 to 22	14 to 14
Total nitrogen	mg/L	0.20 to 0.22	0.20 to 0.21	0.11 to 0.11
Total Phosphorus	mg/L	0.03 to 0.04	0.03 to 0.03	0.01 to 0.01
Construction phase 2 – Applies for the majority of the 6 year construction program				
Salinity (as indicated by EC)	µS/cm	22 to 40	22 to 27	14 to 15
Total nitrogen	mg/L	0.20 to 0.29	0.20 to 0.23	0.11 to 0.11
Total Phosphorus	mg/L	0.03 to 0.04	0.03 to 0.03	0.01 to 0.01
Operational phase– Applies for perpetuity following construction				
Salinity (as indicated by EC)	µS/cm	22 to 22	22 to 22	14 to 14
Total nitrogen	mg/L	0.20 to 0.20	0.20 to 0.20	0.11 to 0.11
Total Phosphorus	mg/L	0.03 to 0.03	0.03 to 0.03	0.01 to 0.01

Notes: The predicted values for total nitrogen and total phosphorus make no allowance for decay and assimilation and are therefore conservative.
Ambient values refer to typical or median values
1. Calculations based on reservoir inflows and calculated stormwater discharges for the 2006/2007 summer/autumn period.

In conclusion, the combination of stormwater discharges and controlled discharges of treated wastewater and process water during the construction phase of the project have potential to increase the ambient salinity levels and nutrients concentrations in reservoirs. The magnitude of change is expected to be greater:

- in summer/autumn due to lower seasonal streamflow into reservoirs; and
- during drought conditions due to lower streamflow into reservoirs.

No material changes to reservoir water quality are expected during the operational phase of the project.

No material changes to the greater Talbingo Reservoir are expected due to mixing with the significant year-round discharge from Tumut 2 power station that enters Talbingo Reservoir via the Tumut River.

12.5 Surface water quality

It is proposed to discharge all treated process and wastewater directly to reservoirs. Hence, stormwater discharges are the only discharge mechanism that can impact watercourses. The potential for stormwater discharges to change receiving water streamflow regimes and water quality will vary based on discharge characteristics and the location, area and duration of disturbance.

The potential for changes is proportionally greater:

- during the initial 15 months of the project when the greatest area of disturbance and poorest water quality will occur due to surface construction activities;
- in watercourses that have small catchment areas relative to the disturbance within the catchment; and
- in summer and autumn during moderate rainfall conditions when discharges from the stormwater system may occur but there is insufficient rainfall to generate runoff from the broader catchment.

The potential for changes is proportionally lower:

- following the initial 15 months of the project when disturbance due to construction of surface infrastructure is complete;
- in watercourses that have large catchment areas relative to disturbance within the catchment;
- in winter and spring when streamflow is seasonally high; and
- in summer and autumn during significant rainfall events that result in high streamflow.

Potential changes to water quality in the Yarrangobilly River, the upper Eucumbene River and Kellys Plain Creek have been assessed using a conceptual stormwater discharge model. Table 12.4 provides a summary of the estimated disturbance durations and profiles and potential magnitude of changes to receiving water quality. Potential changes to water quality are described using the following categories that represent varying magnitudes of change relative to the relevant WQO value:

- no change;
- 0 to 10% increase;
- 10 to 50% increase;
- 50 to 100% increase; and
- greater than 100% increase.

Table 12.4 Summary of potential changes to water quality due to discharges

	Construction phase		Operational phase
	Phase 1 (Construction of surface infrastructure)	**Phase 2** (All other construction activities)	
Disturbance duration	For the Initial 15 months of the 6 year construction program	For the majority of the 6 year construction program	For perpetuity following construction
Disturbance footprint[1]	533 ha	148 ha	55 ha
Percentage of time no change to receiving water quality is expected			
Yarrangobilly River[2]	85%	85%	85%
Upper Eucumbene River	73%	80%	85%
Kellys Plain Creek[3]	83%	76%	81%
Percentage of time concentrations of suspended solids, nutrients or metals in receiving waters may increase by between 0 to 10% of WQO values[4]			
Yarrangobilly River[2]	2%	12%	13%
Upper Eucumbene River	6%	8%	7%
Kellys Plain Creek[3]	0%	8%	7%
Percentage of time concentrations of suspended solids, nutrients or metals in receiving waters may increase by between 10 to 50% of WQO values[4]			
Yarrangobilly River[2]	7%	3%	2%
Upper Eucumbene River	6%	8%	7%
Kellys Plain Creek[3]	0%	8%	7%
Percentage of time concentrations of suspended solids, nutrients or metals in receiving waters may increase by between 50 to 100% of WQO values[4]			
Yarrangobilly River[2]	3%	0%	0%
Upper Eucumbene River	5%	2%	1%
Kellys Plain Creek[3]	1%	3%	3%
Percentage of time concentrations of suspended solids, nutrients or metals in receiving waters may increase by more than 100% of WQO values[4]			
Yarrangobilly River[2]	3%	0%	0%
Upper Eucumbene River	10%	1%	0%
Kellys Plain Creek[3]	17%	5%	3%

Notes: 1. Refers the estimated actual disturbance footprint for each project phase.
2. Results for Yarrangobilly River include discharge from disturbance areas adjacent to the Yarrangobilly River arm of Talbingo Reservoir.
3. Results for Kellys Plain Creek include discharge from disturbance areas to the north of Kellys Plain Creek that also drain into the southern portion of Tantangara Reservoir.
4. WQO values refer to the Water Quality Objective values established in Section 12.2.

No changes to the streamflow regimes in key receiving waters are expected during the construction and operational phase of the project.

12.6 Wastewater

All wastewater will be reticulated or trucked to a wastewater treatment plant. It is expected that wastewater treatment plants will include biological and chemical treatment, filtration, disinfection and either enhanced tertiary treatment or reverse osmosis. The most suitable treatment processes and plant configurations will be established at detailed design.

Treated wastewater will be discharged to Tantangara and Talbingo reservoirs via diffuser arrangements. Discharge rates are expected to be similar to potable water usage rates.

Small amounts of wastewater will be produced by amenities at the power station during the operation phase of the project. All wastewater produced will be trucked to a licensed wastewater treatment plant.

12.7 Groundwater quality

12.7.1 Material stockpiling

Surface excavation works, including road upgrades and construction areas, as well as tunnel boring will intersect areas with confirmed Potential Acid Forming (PAF) rocks. Along the tunnel alignment it was determined that PAF materials were highly variable due to the tendency of pyrite to occur in veins and seams. The host rock has Acid Neutralizing Capacity (ANC) which can be utilised to manage leachate impacts of PAF excavated rock but may be less available for the management of tunnel seepage. PAF material is widely distributed across the project area and has been confirmed within the:

- Tantangara Formation (one sample was PAF-LC);
- Temperance Formation (one sample was PAF-LC);
- Gooandra Volcanics (multiple samples); and
- Ravine Beds (multiple samples).

The potential Acid Mine Drainage (AMD) impacts via the generation of acidic leachate from the improper temporary or permanent storage of excavated PAF rock poses a risk to localised and wider (regional scale) groundwater environment.

SMEC 2019b concluded that the relative rates of acidity (ie PAF) versus alkalinity (ie ANC) generation in geological formations at the site are uncertain and require further investigation, and that for many of the formations there remains insufficient information on the compositional variation.

It is proposed that all PAF and NOA material be placed in the Tantangara Adit. Given oxidation of PAF material is likely to result in the generation of acid leachate, which has the potential to interact with groundwater, there will be a need to mitigate impacts through the implementation of adequate management controls (see Annexure D).

12.7.2 Material transport

The transportation of existing PAF material, expected to be deposited in the Eastern Stockpile at Lobs Hole as part of Exploratory Works, has the potential to generate AMD unless adequately treated, stored and managed.

The impacts associated with incorrect transportation, disposal and stockpile management of PAF material are consistent with those mentioned in Section 12.7.1.

12.7.3 Storage and transportation of chemicals and fuels

There is the potential for the project construction works to cause contamination to the groundwater resource. This predominately encompasses either spills of hazardous materials/chemicals and/or the generation of solid or liquid waste. Examples of this include spills of hydrocarbons while refuelling or lubricants used by machinery, and generation of solid construction waste or liquid waste during tunnelling. All scenarios have the potential to impact human and environmental health depending on the type of contaminant if not managed accordingly.

13 Impact summary and risk assessment

13.1 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 and surface water impacts arising from these impacts discussed in Section 10, 11, and 12.

A risk assessment matrix has been used to quantify the level of environmental risk based on the following (see Table 13.1):

- 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 13.2 and Table 13.3, respectively.

Table 13.1 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 13.2 Classification of likelihood for construction activities

Level	Categorisation of likelihood	Description
A	almost certain	is expected to occur during Snowy 2.0 Main Works
B	likely	will probably occur during Snowy 2.0 Main Works
C	moderate	might occur at some time during Snowy 2.0 Main Works
D	unlikely	could occur at some time during Snowy 2.0 Main Works
E	rare	only occur in exceptional circumstances

Table 13.3 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 Snowy 2.0 Main 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 13.1:

- 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.

13.2 Risk evaluation

The risks of potential impacts caused by Snowy 2.0 Main Works activities, assuming no controls are in place are summarised in Table 13.4. 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 15.1.

Table 13.4 Assessment of unmitigated potential impacts

Potential impact mechanism	Potential impact	Risk analysis (likelihood and consequence)			
		Low	Medium	Significant	High
Changes to groundwater **quantity** (flow/levels)	Localised drawdown - construction			3B	
	Localised drawdown - operation			3B	
	Regional drawdown - construction		2B		
	Regional drawdown - operation		2B		
Changes to surface water **quantity**	Localised streamflow impacts - construction		2C		
	Localised streamflow impacts - operation			3B	
	Regional streamflow impacts - construction	1D			
	Regional streamflow impacts - operation		1B		
Changes to surface water **quality**	Stormwater			3C	
	Process and wastewater			3C	

Table 13.4 Assessment of unmitigated potential impacts

Potential impact mechanism	Potential impact	Risk analysis (likelihood and consequence)			
		Low	Medium	Significant	High
	Water quality in reservoirs			3C	
Flooding	Localised flooding		2C		

Notes: Extreme risks were not identified for the project and as such are not presented in this table.

Part C

Licensing, mitigation and management

14 Water licences

14.1 NSW water legislation and policies for licensing water

Snowy Hydro is required to licence water that is either taken or intercepted in accordance with the WMA 2000 and the AIP. This includes water taken for use as well as water intercepted and managed as a result of project activities. Snowy Hydro is required to holds WALs in each affected water source to account all water extracted and intercepted.

In accordance with the AIP, the project is required to licence both the direct and indirect take from adjacent and overlying water sources. The volume of water to be licensed for the project is defined as:

- groundwater inflow to the project that is physically handled by the water management system;
- groundwater inflow to the project that is evaporated and thereby lost from the system;
- reduced baseflow to overlying water sources; and
- increases in induced leakage from overlying water sources.

The results of the groundwater modelling have been used to estimate the required groundwater licence entitlements for the project, based on the predicted total groundwater inflow rates to the project and baseflow changes in permanent stream flows in the vicinity of the subsurface infrastructure (primarily the headrace tunnel).

The WALs and associated shares need to be held for the water year in which the impact occurs. All shares and WALs do not need to be held prior to the project approval, as some effects do not occur for years after construction and operation commences. However, a valid pathway needs to be demonstrated to prove the shares can be obtained. Snowy Hydro has proposed valid pathways for obtaining the required licence shares over time, allowing them to hold the required entitlements for each year of the project lifespan.

14.2 Volumetric tunnel inflow predictions

14.2.1 Tunnel inflow

The volumetric inflow to the tunnel from the construction of the project will occur directly from the LFB MDB Fracture Rock groundwater source and the LFB South Coast groundwater source. The groundwater inflow comprises groundwater inflow to excavations and constructed subsurface features and reduced groundwater available for baseflow to streams. The predicted inflow rates directly into the tunnel are summarised below:

- the predicted excavation inflow rate (and take) during construction in year one is **3 ML/year**;
- the peak predicted excavation inflow rate to (and take) occurs during construction in year five and is **4,476ML/year**;
- the excavation inflow rate decreases following year five of construction and then reduces further as the project construction concludes and it enters an operation phase;
- once operation commences, the tunnel become a throughflow system – with all water remaining within water sources (ie the physical take of water ceases once operation commences);

- following 20 years of operation the tunnel inflow is 2,658 ML/year. Of which 61 ML/yr is throughflow back into the LFB MDB Fractured Rock groundwater source, and 2,5 ML/year flows via the tunnel into the Upper Tumut water source and into Talbingo Reservoir; and
- the steady state (ie long-term) inflow rate is 2,683 ML/yr, of which 61 ML/yr is throughflow back into the LFB MDB Fractured Rock groundwater source, and 2,622 ML/year flows into the Upper Tumut water source and into Talbingo Reservoir.

14.2.2 Water sources for tunnel inflow

The groundwater model predicts effects on overlying surface water features as a result of tunnel inflow. The predicted reductions to baseflow are restricted to areas immediately adjacent to the tunnel alignment and result in reduced baseflow in localised areas to a number of rivers and creeks within the project area (see Section 10.4).

The reductions to baseflow are considered over time and the source of this water has also been considered in accordance with AIP. The AIP requires the peak baseflow reductions to be considered for licensing purposes form each source of the water. The peak tunnel inflow occurs in year five of construction, this volume comes initially from storage within the surrounding groundwater system. Time lags in the depressurisation of the overlying groundwater systems mean that the peak reductions to groundwater available for baseflow does not occur until year 20 of tunnel operation.

Reductions in groundwater available for baseflow to watercourses was considered from the ultimate source perspective, as per a legal interpretation of the AIP, and in accordance with how the AIP has been implemented for other EIS assessments. Reductions in streamflow (from a licence perspective) are either:

- reduced groundwater available for baseflow contributions (ie less gaining stream – but ultimately still a gaining stream) – this is licensed as groundwater; and/or
- induced losses from the surface water system to the underlying groundwater system (ie induced leakage from the surface water source) – this is licensed as surface water.

The source of the water has been determined in the groundwater modelling to be all as a result of reduced baseflow in all cases. Therefore, it will all be licensed as groundwater from within the LFB MDB Fractured Rock groundwater source and the LFB South Coast water source.

The peak reduction in baseflow as a result of the project within the LFB MDB Fractured Rock groundwater source is 1,350 ML which occurs in year 19 of operation (not shown in Table 14.1.) The peak reduction in baseflow as a result of the project within the LFB South Coast groundwater source is 778 ML which occurs in year 19 of operation (not shown in Table 14.1). The maximum predicted baseflow reduction at each surface water source is presented and grouped into their respective water sources below.

i LFB MBD Fractured Rock groundwater source

- Baseflow to the Yarrangobilly River to reduce by a peak of up to 310 ML/yr in year 20 of operation;
- baseflow to collectively the Wallaces Creek, Stable Creek and Middles Creek to reduce by a peak of up to 696 ML/yr in year 5 of operation;
- baseflow to Tantangara Creek to reduce by a peak of up to 792 ML/yr in year 4 of operation;
- baseflow to Gooandra Creek to reduce by a peak of up to 972 ML/yr in year 20 of operation; and
- baseflow to Nungar Creek to reduce by a peak of up to 56 ML/yr in year 20 of operation.

ii LFB South Coast groundwater source

- Baseflow to Eucumbene River to reduce by a peak of up to 840 ML/yr in year 20 of operation.

No licenses are needed from the overlying surface water sources of the Upper Tumut Water Source, Eucumbene River Water Source or the Murrumbidgee 1 Unregulated Water Source for tunnel inflow or reduced groundwater for baseflow.

14.2.3 Potable and process water requirements

The volumetric requirements for process water (dust suppression, machinery cooling requirements etc), and for potable supply have been considered (see Section 11). During construction (except year 1), the process water requirements can be sourced from the tunnel inflows. Once the tunnel construction is finished, then water inflows to the tunnel are no longer available for process water and therefore additional water supply (top up process water) is required for the project.

During tunnel construction, water entering the tunnel will be captured and enter the water management system, with some of it being used as a project water supply with water being then released into either Talbingo Reservoir (Upper Tumut Water Source), or Tantangara Reservoir (Murrumbidgee Zone 1 Water Source)

Potable supply is required during construction and this volume is required from fresh supply and not from recycled tunnel water inflows.

The source of process top up and potable supply could be either surface water (via Talbingo and Tantangara Reservoirs), or from bores. The impact associated with take from both surface water and groundwater has been considered. However, until the amendments are made to the Regulated and Unregulated Murrumbidgee River WSPs to allow trading across water source boundaries, the licences proposed to be obtained for this water to be supplied is from the LFB MDB Fractured Rock groundwater source and this is reflected in the final licence requirements for the project (see Table 14.1).

14.2.4 Total project licence requirements

The total project licence requirements is presented on a yearly time-step in Table 12.1 and Figures 12.1 and 12.2.

Table 14.1 Required licences and licence components

Date year ending	Year	LFB MDB Fractured Rock groundwater source				LFB South Coast groundwater source			
		Flow to excavations (ML)[1]	Tunnel inflow (indirect) (ML) Reduced baseflow	Potable and process water (ML)	Total LFB MDB (ML)	Tunnel inflow (ML)	Tunnel inflow (indirect) (ML) Reduced baseflow	Potable and process water (ML)	Total LFB South Coast (ML)
1/06/2019	Early works			1	**1**				
1/06/2020	C1	3		119	**122**				
1/06/2021	C2	474		241	**715**				
1/06/2022	C3	1,343		90	**1,433**				
1/06/2023	C4	1,981	71	94	**2,075**				
1/06/2024	C5	3,529	326	85	**3,684**	947	31		**947**
1/06/2025	0	3,199	726	158	**3,729**	1,000	227		**1,000**
1/06/2026	1	1,906	906	345	**3,206**	684	358		**684**
1/06/2027	2	1,984	1,012	190	**3,438**	676	445		**676**
1/06/2028	3	2,060	1,113		**3,518**	687	554		**687**
1/06/2029	4	2,036	1,005		**3,700**	671	544		**671**
1/06/2030	5	2,010	1,078		**3,571**	663	573		**663**
1/06/2035	10	1,992	1,157		**3,148**	651	659		**1,310**
1/06/2040	15	1,986	1,223		**3,210**	649	695		**1,344**
1/06/2044	20	2,005	1,226		**3,229**	652	719		**1,372**
	Steady State	*1,801*	*1,555*		***3,388***	*882*	*840*		***1,722***
	Maximum				**3,729**				**1,722**

Notes: 1. ML = megalitres

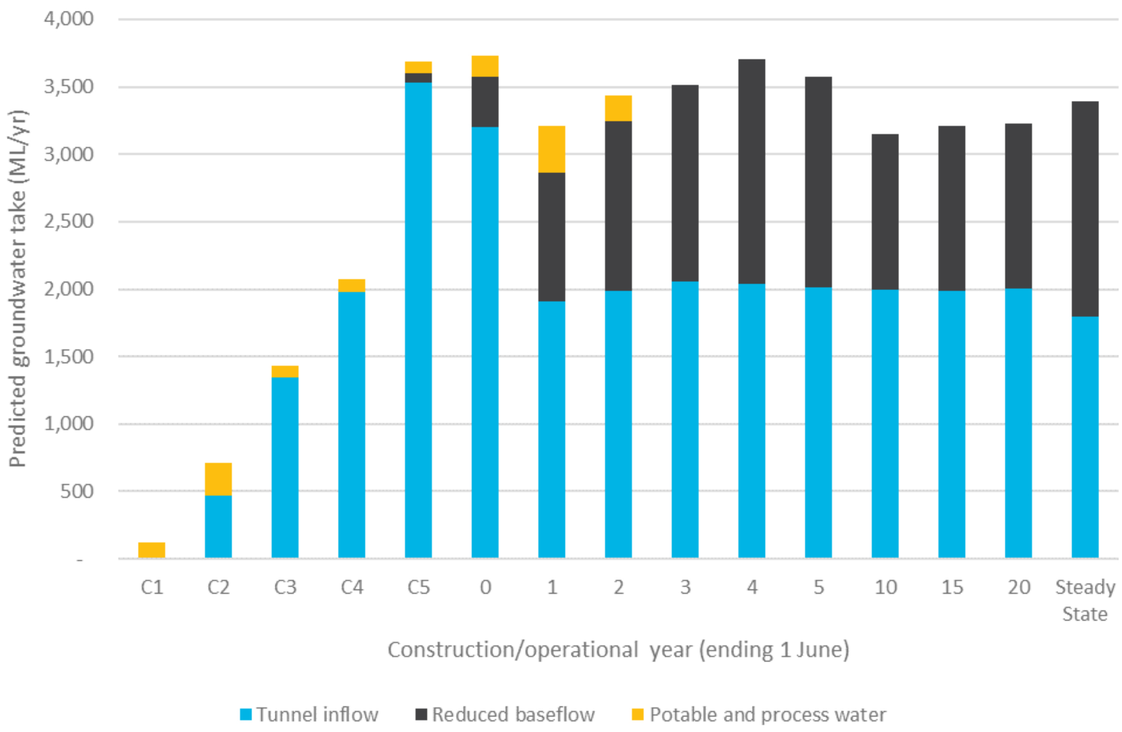


Figure 14.1 LFB MDB Groundwater Source yearly licence requirements

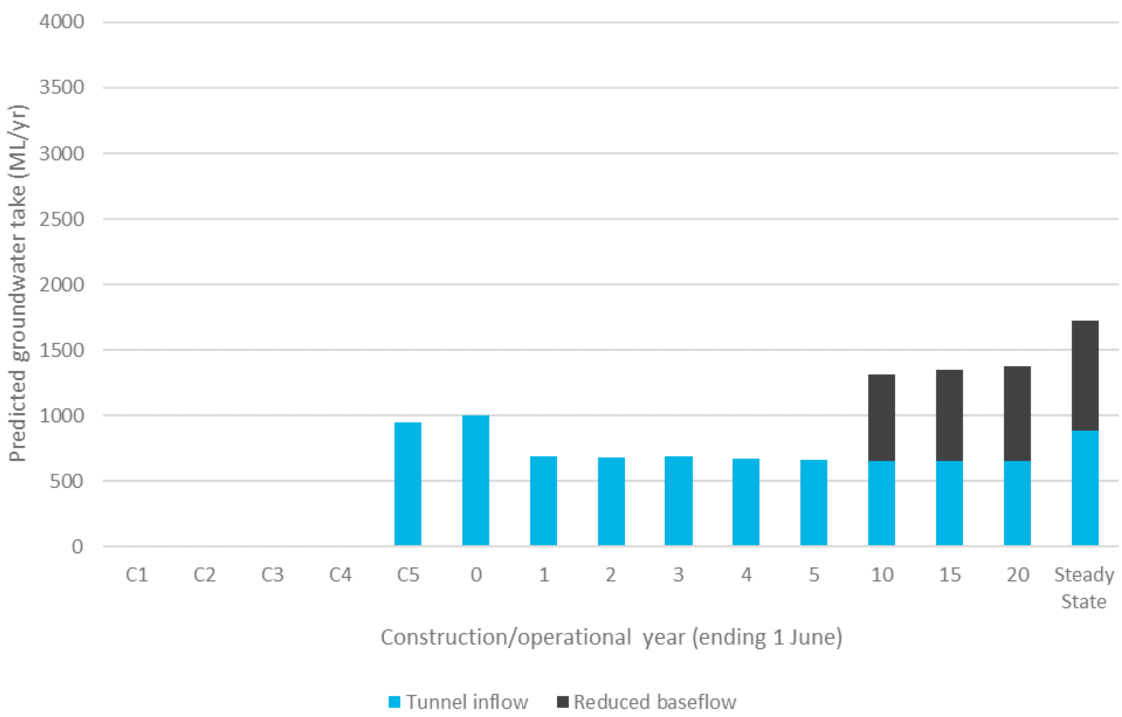


Figure 14.2 LFB South Coast Groundwater Source yearly licence requirements

14.3 Licence summary

Once operation of the scheme commences, the tunnel acts as a throughflow system, with groundwater inflow from the LFB both entering the tunnel and water in the tunnel also flowing back into the LFB groundwater sources. The steady state flow back into the LFB (South Coastal and MDB combined) is 61 ML/yr.

It is also noted that groundwater inflow to the tunnel re-enters Talbingo Reservoir (Upper Tumut Water Source) and will be available and provide additional water into the downstream Regulated Murrumbidgee River Water Source. This water would have eventually always made its way into the Murrumbidgee River system and once operational, the presence of the tunnel will effectively increase the rate at which water can flow from the LFB groundwater source into the Murrumbidgee River (unregulated and regulated) river systems in this portion of the Murrumbidgee catchment. This will manifest as an increased reliability of water in the downstream system. The net benefit of the project from a water supply perspective is the ongoing contribution of the LFB MDB groundwater source into the regulated Murrumbidgee River at an increased annual rate.

It is noted that currently the groundwater licences required are not all yet held by Snowy Hydro, and are dependent on the NSW Government release of the controlled allocations which will be announced on 8 October 2019.

It is not anticipated that additional surface water licences are required for the project. However, should they be required, the impacts have been assessed and they can be purchased on the open market following amendments to the WSP as per the *DRAFT WSP for the Murrumbidgee Unregulated River Water Sources 2012 (amended 2019).*

Table 14.2 provides a summary of the strategy for obtaining the required water licences for the project.

The groundwater model will be reviewed and recalibrated (if necessary) in year 2 of construction. Revisions to the model predictions will be used to confirm the licensing requirements in subsequent years. This approach aligns with the approved groundwater monitoring and modelling plan for the project commitment to periodically calibrate the groundwater model (see Section 13).

Table 14.2 Summary strategy for obtaining required water licences

Water Source	Peak volume for licensing	Year of peak	Current licences held	Remaining licence to acquire	Available water for trade from existing licences	Available water that can be purchased from the NSW Government via controlled allocation	Strategy for licensing
LFB MDB Groundwater Source	3,729 ML[1]	First year of operation	354 ML (PAP 1346924)	3,375 ML	67,257 ML	729,960 ML	Snowy will apply for 3,375 shares in the upcoming controlled allocation order scheduled for 8th October 2019 Peak in first year of operation, then drops back to 3,388 for long term steady state operation. The strategy will be to acquire then hold sufficient licences for the project construction and operational lifetime.
LFB South Coast Groundwater Source	1,722ML	Steady state operation	0 ML	1,722ML	1,210.5 ML	16,051 ML	Snowy will likely apply for shares in the upcoming controlled allocation order scheduled for 8th October 2019 Peak occurs once steady state operation occurs. The strategy will be to hold sufficient licences to account for the peak take in year 20 of operation

Notes: 1. ML = megalitres

15 Management/mitigation measures and residual impacts

15.1 Environmental management measures

Water management for the project combines site surface water management, management of groundwater inflow and the transportation and temporary/permanent emplacement of waste rock and chemicals. 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 objectives of environmental management measures, as they relate to water resources, are to minimise and/or mitigate the potential for environmental impacts arising from project activities. The water management report (see Annexure D) provides a comprehensive list of proposed management measures which are designed to mitigate predicted impacts and address assessment objectives.

As an example, Snowy Hydro are proposed to implement a construction method which will include pre-grouting, segmental lining and post-grouting. Whilst this construction methodology hasn't been modelled in SH4.0, the proposed management controls are likely to restrict groundwater inflows during construction and operation of the project, which will likely result in reduced impacts to water resources. The residual risk levels, which are presented in Section 15.1.2, reflect the outcomes of management and mitigation measures.

A brief approach to environmental management to water resources has been listed below. As suggested earlier, readers are encouraged to review comprehensive commitments in Annexure D if required.

15.1.1 Water management

A comprehensive overview of the proposed water management system has been presented in the water management report (Annexure D).

The principles of the water management system are to:

- segregate different water sources and different water qualities (ie raw water from the groundwater inflows, sediment-laden water);
- the stormwater management approach will vary based on the type of disturbance, construction activities and environmental factors such as topography as outlined in Annexure D;
- capture, contain, treat and discharge process water and wastewater to receiving water environments;
- a water supply system will be established to supply water for potable water use and construction activities;
- extraction from watercourses is not proposed;
- reuse of intercepted groundwater to minimise construction water demands from groundwater supply bores or via reservoir extraction;
- capture and segregate runoff from the following locations:
  - 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 WMP, which will include the capture and reuse / treatment of sediment laden water in sediment dams;
- reuse and recycle water in tunnelling operations;
- project commitment to pre-grouting, post-grouting and segmental lining as defined in project specifications;
- 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 the WMP (ie DPIE, NSW EPA).

15.1.2 Residual risk levels and environmental management measures

Specific management measures to address the requirements relating to water and the potential impacts identified in Table 13.4 have been broadly outlined in Table 15.1. In addition, the residual risk associated with each potential impact has been recalculated.

As seen in Table 15.1 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 blue book design of the water management system).

Table 15.1 Assessment of residual impacts

Higher level potential impact mechanism	Potential impact	Control measure	Risk analysis (likelihood and consequence)			
			Low	Medium	Significant	High
Changes to groundwater **quantity** (flow/levels)	Localised drawdown - construction	Pre-grout/post-grout areas of groundwater inflow to prevent further ingress Segmental lining all tunnels		3D		
	Localised drawdown - operation			3D		
	Regional drawdown - construction	Groundwater level monitoring as early warning mechanism	2D			
	Regional drawdown - operation		2D			

Table 15.1 Assessment of residual impacts

Higher level potential impact mechanism	Potential impact	Control measure	Risk analysis (likelihood and consequence)			
			Low	Medium	Significant	High
Changes to surface water **quantity**	Localised streamflow impacts - construction	Pre-grout/post-grout areas of groundwater inflow to prevent further ingress	2D			
	Localised streamflow impacts - operation	Segmental lining all tunnels		3D		
	Regional streamflow impacts - construction	Surface water monitoring as early warning mechanism	1C			
	Regional streamflow impacts - operation		1E			
Changes to surface water **quality**	Stormwater discharge	Refer Annexure D		3D		
	Process and wastewater	Refer Annexure D	3E			
	Water quality in reservoirs	Refer Annexure D and RHDHV (2019b) Reservoir overview assessment			3C	
Flooding	Localised flooding	Refer Annexure D		2D		

Following the implementation of control and mitigation management measures the residual risk of the potential impacts have reduced for all impact mechanisms.

Table 15.2 lists potential risks to the project from potential deviations from the model predictions and identified impacts. Proposed management measures are also provided.

Table 15.2 Potential risks to the project and management measures from potential deviations

Potential impact deviation	Management measure
Groundwater drawdown (levels and extent) is significantly larger than predicted	Groundwater monitoring to provide early indication of potential change in predicted impacts. Reconciliation of groundwater model predictions against groundwater monitoring data. For eg, increased drawdown, verified by groundwater monitoring, can be mitigated with further grouting treatments.
Groundwater inflow rates to the tunnel are higher than predicted, affecting water management system, project licensing (compliance)	Metering and monitoring will be in place to record the volume of water removed from the tunnel. Notify regulators. Standby pumps to increase volume removed from the underground for safe operation. Review of groundwater model.
Impacts on baseflow are greater than predicted	Monitoring during operations to provide indication of impact. Triggers and trigger action response plans (TARP), detailing potential mitigation measures, to be assigned within WMP. Notify regulators.

Table 15.2 Potential risks to the project and management measures from potential deviations

Potential impact deviation	Management measure
Changes to surface water quality are significantly worse than predicted	Routine monitoring of stormwater discharge, process and wastewater and reservoirs. Triggers and trigger action response plans (TARP), detailing potential mitigation measures, to be assigned within WMP. Notify regulators.
Changes to reservoir water quality are significantly worse than predicted	Establish a mixing zone 500 m from the silt curtain to reduce aluminium concentrations. Undertake investigations to minimise the disturbance of bed sediments due to water flows during commissioning. Water quality monitoring (including pH, temperature, turbidity, dissolved oxygen, nutrient and metal concentrations) to be detailed in the WMP.
Flooding impacts are worse than predicted	Further consideration of flooding conditions and impacts, including flood modelling where necessary. Flood emergency response plans will be developed for both construction and operation phases.

15.2 Water management strategy and plans

15.2.1 Management Plan

A WMP will be developed for the project to support construction activities. 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 DPIE, EPA, WaterNSW and key local stakeholders, 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.

15.2.2 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 DPIE (formally 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.

Baseline data will continue to be collected from this network throughout the life of the Snowy 2.0 Main 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:

- shallow groundwater monitoring of selected bogs and fens within the drawdown 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 project; and
- monitoring quality and metering the volume of water releases to Talbingo and Tantangara 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 project. 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 DPIE and WaterNSW.

15.2.3 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 completed as required.

16 AIP assessment framework

This chapter reproduces the DPIE AIP assessment framework with commentary to assist the DPIE with the assessment.

Table 16.1 Does the activity require detailed assessment under the AIP?

Consideration		Response
1	Is the activity defined as an aquifer interference activity?	Yes
2	Is the activity a defined minimal impact aquifer interference activity according to Section 3.3 of the AIP?	Yes

16.1 Accounting for, or preventing the take of water

Table 16.2 Accounting for, or preventing the take of water, has the proponent:

AIP requirement		Proponent response
1	Described the water source(s) the activity will take water from?	Yes, this information is provided in Section 6, 7 and 8, Part A of the Water Assessment.
2	Predicted the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Yes, this information is provided in Section 10 and 11, Part B of the Water Assessment.
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	No, this does not apply to the project.
4	Made these predictions in accordance with Section 3.2.3 of the AIP?	Yes, this information is provided in Section 10 and 11, Part B and Section 14, Part C of the Water Assessment.
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	Yes, this information is provided in Section 10 and 11, Part B and Section 14, Part C of the Water Assessment.
6	Described how any licence exemptions might apply?	Yes, this has been described in Section 4, Part A of the Water Assessment.
7	Described the characteristics of the water requirements?	Yes, this has been described in Part C of the Water Assessment and Annexure D (Water Management Report).
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	Yes, this has been provided in Section 4, Part A and Section 14, Part C of the Water Assessment by water source.
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	Yes, this has been provided in Section 4, Part A of the Water Assessment.
10	Determined how it will obtain the required water?	Yes, the approach to obtain the required water has been outlined in Section 4, Part A and Section 14, Part C of the Water Assessment.

Table 16.2 Accounting for, or preventing the take of water, has the proponent:

AIP requirement		Proponent response
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	Yes, this has been considered in Section 10 and 11, Part B and Section 14, Part C of the Water Assessment.
12	Considered actions required both during and post-closure to minimize the risk of inflows to a mine void as a result of flooding?	Not applicable.
13	Developed a strategy to account for any water taken beyond the life of the operation of the project?	Not applicable.
Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? If **YES**, items 14-16 must be addressed.		Yes.
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Yes, impacts have been discussed in Section 10, Part B. Risk has been quantified in Section 13, Part B of the Water Assessment.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	Yes, uncertainty analysis has been documented in Annexure B of the Water Assessment.
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the project, and how these requirements will be accounted for?	Yes, commitment is made in Section 15, Part C for model verification following ongoing collection of water monitoring data during construction and operation of the project.

Table 16.3 Determining water predictions in accordance with Section 3.2.3 (complete one row only – consider both during and following completion of activity)

AIP requirement		Proponent response
1	For the Gateway process, is the estimate based on a simple modelling platform, using suitable baseline data, that is, fit-for-purpose?	Yes. Details of the modelling platform is provided in Annexure B, Water Assessment. A description of available baseline data used for model calibration has been described briefly in Part A and in detail in Annexure A of the Water Assessment.
2	For State Significant Development or mining or coal seam gas production, is the estimate based on a complex modelling platform that is: •Calibrated against suitable baseline data, and in the case of a reliable water source, over at least two years? •Consistent with the Australian Modelling Guidelines? •Independently reviewed, robust and reliable, and deemed fit-for-purpose?	The project is Critical State Significant Infrastructure. Numerical modelling has been calibrated to a reliable baseline data record, described in detail in Annexure A, Water Assessment The model (SH4.0) has been developed in accordance with the requirements of the Australian Groundwater Modelling Guidelines (Barnett et al 2012). SH4.0 has been peer reviewed by Hugh Middlemis of HydroGeoLogic (Attachment A, Annexure B) and deemed fit-for-purpose.

Table 16.3 Determining water predictions in accordance with Section 3.2.3 (complete one row only – consider both during and following completion of activity)

	AIP requirement	Proponent response
3	In all other processes, estimate based on a desk-top analysis that is: •Developed using the available baseline data that has been collected at an appropriate frequency and scale; and •Fit-for-purpose?	The duration and frequency of monitoring are adequate for the assessment. Details of which have been provided in Annexure A, Water Assessment.

Table 16.4 Other requirements to be reported on under Section 3.2.3 of the AIP Has the proponent provided details on:

	AIP requirement	Proponent response
1	Establishment of baseline groundwater conditions?	Yes – see Section 5, Part A and Annexure A of the Water Assessment.
2	A strategy for complying with any water access rules?	Yes – see Section 4, Part A and Section 14, Part C of the Water Assessment.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	Not applicable – see above.
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	Not applicable – see above.
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	Yes – see Section 10, 11 and 12, Part B of the Water Assessment.
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	Yes – see Section 12, Part B of the Water Assessment.
7	Potential to cause or enhance hydraulic connection between aquifers?	Yes – see Section 13, Part B of the Water Assessment.
8	Potential for river bank instability, or high wall instability or failure to occur?	Not applicable.
9	Details of the method for disposing of extracted activities (for coal seam gas activities)?	Not applicable.

16.2 Addressing the minimal impact considerations

Two sources are impacted: the LFB MDB Fractured Rock and LDB South Coast groundwater sources. Both water sources are defined as ‘less productive’ groundwater systems in the fractured rock sub-grouping.

Table 16.5 Minimal impact considerations

Aquifer	Fractured rock
Category	**Less productive**
Level 1 Minimal Impact Consideration	**Assessment**
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: •high priority groundwater dependent ecosystem or •high priority culturally significant site listed in the schedule of the relevant water sharing plan. OR A maximum of a 2-metre water table decline cumulatively at any water supply work.	Predicted impacts have been presented in Part B of the Water Assessment.
Water pressure A cumulative pressure head decline of not more than a 2-metre decline, at any water supply work.	No water supply works predicted to be impacted by the project.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Not anticipated due to project construction or operational activities.

16.3 Proposed remedial actions where impacts are greater than predicted

Table 16.6 Proposed remedial actions where impacts are greater than predicted, has the proponent:

AIP requirement		Proponent response
1	Considered types, scale, and likelihood of unforeseen impacts *during operation*?	Impacts to water resources during project operations have been detailed in Part B of the Water Assessment.
2	Considered types, scale, and likelihood of unforeseen impacts *post closure*?	Not applicable.
3	Proposed mitigation, prevention or avoidance strategies for each of these potential impacts?	Management, mitigation strategies have been recommended to address predicted impacts to water resources. These have been described in Section 15, Part C of the Water Assessment.
4	Proposed remedial actions should the risk minimization strategies fail?	Yes, see Section 15, Part C of the Water Assessment.
5	Considered what further mitigation, prevention, avoidance or remedial actions might be required?	Yes, see Section 15, Part C of the Water Assessment.
6	Considered what conditions might be appropriate?	Yes, see Section 15, Part C of the Water Assessment.

16.4 Other considerations

Table 16.7 Other considerations, has the proponent:

AIP requirement		Proponent response
1	Addressed how it will measure and monitor volumetric take? (page 4 of the AIP)	Yes – see Section 14, Part C of the Water Assessment.
2	Outlined a reporting framework for volumetric take? (page 4 of the AIP)	Yes – see Section 14, Part C of the Water Assessment.

17 Conclusions

The water assessment forms part of the EIS for Snowy 2.0 Main Works. This assessment has been informed by the reference design for the project. The following aspects of the project have been addressed in this assessment:

- Assessment of environmental and human users dependent on groundwater, including:
  - terrestrial GDEs;
  - subterranean GDEs;
  - aquatic GDEs; and
  - landholder water supplies.
- Management of groundwater during construction and operation of Snowy 2.0 Main Works, including:
  - consideration for excavation sequencing, pre-grouting, post-grouting and segmental lining influence on groundwater inflow and environmental impacts; and
  - changes to water quality due to construction.
- Assessment of the project against the assessment requirements of the AIP, including:
  - consideration for the minimal impact criteria, as it relates to groundwater pressures, levels and quality;
  - consideration for impacts to *High Priority* (as defined by relevant WSPs) listed GDEs; and
  - consideration for Level 1 and 2 impacts.
- Flood risk management associated with the Snowy 2.0 Main Works that are proposed on flood prone land.
- Water management during construction of access roads, the accommodation camp, portal construction pad and other infrastructure.
- Water management during operation including:
  - stormwater runoff from the access roads, accommodation camp and portal construction pad;
  - water produced by and used by the construction activities; and
  - wastewater (ie sewage).
- Water management for rock and soil emplacement areas.

Numerical modelling predicted localised watertable drawdown directly underlying the Snowy 2.0 Main Works headrace tunnel alignment in areas where faulted and steeply dipping geological material exists (Gooandra and Kellys Plain Volcanics). The geology in these areas results in accentuated hydraulic vertical connection between the deeper regional groundwater system and the shallower groundwater system.

Predicted watertable drawdown will result in very localised areas of less groundwater available for baseflow contributions and potential effects on potential terrestrial and aquatic GDEs in the headrace tunnel area. Outside of the localised drawdown area (ie immediately downstream), there is insignificant change predicted.

Groundwater flow into the tunnel is via fractures. The groundwater model assumes significant connection between the tunnel and the watertable (ie modelled the long plains fault as a conduit) in the Gooandra and Kellys Plain Volcanics. However, it is expected that although parts of this unit may behave like this, the entire unit may not, and other sections of this geology will be much less permeable. These units adopted conservative hydraulic parameters were adopted in the groundwater model for these units.

The model cannot simulate individual fractures because the locations and conductivity of individual fractures are not known until the tunnel intersects them. Because the exact locations and extent of inflow mitigation strategies are not yet known the groundwater modelling adopted a conservative approach of simulating all excavations as non-mitigated/controlled. Attempts to 'constrain' the model to simulate unknown geological occurrences or design elements are not in line with the AGMG and have therefore not been undertaken.

The modelling results are therefore conservative for two reasons:

- modelling does not consider actual design, management or mitigating activities. In reality during construction the discrete fractures that yield excess water will be grouted and will reduce the actual overall tunnel inflow volume (potentially significantly); and
- hydraulic parameters within the numerical model for the Gooandra Volcanics and the Kellys Plain Volcanics are conservative and assume significant connection to the water table based on pumping test data. However, in reality the entire unit may not behave like this, with some parts expected to be much less permeable.

Therefore, the model predictions of tunnel inflow, baseflow reduction and water table drawdown are likely to be over estimating project impacts.

There are no identified High Priority GDEs within the project area. Yarrangobilly Caves is the only High Priority GDE listed within the WSP for the LFB MDB Fractured Rock groundwater source within the groundwater model domain. The Yarrangobilly Caves are approximately 5 km north of the nearest infrastructure feature. Modelling predicts no impacts on the Yarrangobilly Caves with a maximum lateral drawdown extent of 2 km predicted (ie 3 km south of the Yarrangobilly Caves).

The volumetric inflow to the tunnel from the construction and operation of the project will occur directly from the LFB MDB Fractured Rock groundwater source and the LFB South Coast groundwater source. The peak predicted groundwater take during construction occurs in year five and is 4,476 ML/year and 2,684 ML/year (inclusive of outflow) following 20 years of operation in modelled steady state.

It is noted that the numerical model is conservative and predicts that impacts are very localised. Regionally, there is little change. Also, with the inclusion of design mitigation options and a potential refinement of the hydraulic parameters adopted for the Gooandra and Kellys Plain Volcanics the inflow volumes required for licensing may be reduced and these localised impacts will also be reduced.

The peak reduction in baseflow as a result of the project within the LFB MDB Fractured Rock groundwater source occurs in year 19 of operation and is 1,350 ML. The peak reduction in baseflow as a result of the project within the LFB South Coast groundwater source occurs in year 20 of operation and is 840 ML. Baseflow reduction occurs across both the ravine and plateau, impacting most creeks and rivers directly overlying the project. The effected watercourse reach will be limited to the extent of the peak predicted watertable drawdown extent (ie less than 3 km in most areas across the plateau and less than 100 m in most areas across the ravine).

The predicted drawdown results are localised and the reduced groundwater available for baseflow occurs only for those watercourses that directly overlie the tunnel alignment. Gooandra Creek and upper reaches of the Eucumbene River are the only surface water features expected to have measurable, but locally altered streamflow as a result of the project. These stretches of creeks may have extended periods of no flow during dry climatic periods, however the impact is not predicted to extend downstream, as local lateral flows from catchment areas remain unaffected by the project and are significant contributors to streamflow and therefore alleviate the predicted impacts.

It is noted that the predicted drawdown and baseflow reduction estimates is based on the numerical groundwater model, which is conservative in its selection of hydraulic parameters for key geological units and although proposed in the tunnel design, the model does not simulate mitigation or management options (ie grouting))

Increases in flood water levels are expected to be limited to locations in the immediate vicinity of the project works. No increase in flood risk to private property was identified. No change to total flood runoff will occur. Tantangara and Talbingo reservoirs will receive the same volumes of flood water that they would in the absence of the project

Both groundwater sources impacted by the project have sufficient entitlement available to licence peak predicted take. Snowy Hydro have identified a pathway to secure the full licence share from each water source via controlled allocation in late 2019. 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.

Water supply during initial stages of construction will likely be accessed from groundwater supply bores. Groundwater supply bores will access water from LFB MDB Fractured Rock groundwater source and as such, the licensed peak predicted take will cover initial water supply demands.

Management controls have been proposed to mitigated environmental impacts to water resources. These are briefly discussed in this water assessment and in more detail in Annexure D.

An overarching and adaptive WMP will be prepared for Snowy 2.0 Main Works in consultation with NSW Government agencies.

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Units

Unit	Description
$	Australian dollar
%	percent
°C	degrees Celsius
µm	micrometre
µS/cm	microsiemens per centimetre
ha	hectare
kg/yr	kilograms per year
L/s	litres per second
km	kilometre
km^2	square kilometres
m	metres
m/day	metres per day
m/year	metres per year
m^3/day	cubic metres per day
mAHD	metres Australian Height Datum
mbgl	metres below ground level
mbtoc	metres below top of casing
meq/L	milliequivalents per litre
mg/L	milligrams per litre
ML	megalitres
ML/day	megalitres per day
ML/yr	megalitres per year
mm/day	millimetres per day
mm/hr	millimetres per hour
Mt	million tonnes
Mtpa	million tonnes per annum
pH	pH, unit of acidity and alkalinity

Abbreviations

Abbreviation	Description
ADWG	Australian Drinking Water Guidelines
AHD	Australian height datum
AIP	Aquifer Interference Policy 2012
ALS	Australian Laboratory Services
ANZECC and ARMCANZ	Australian and New Zealand guidelines for fresh and marine water quality
AR	Agency recommendation
ARI	Average recurrence interval
AWBM	Australian Water Balance Model
BOD	Biochemical oxygen demand
BoM	Bureau of Meteorology
BTEX	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
DEC	Department of Environment and Conservation
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
DPI	Department of Primary Industries
DSITAI	Department of Science, Information Technology, Innovation and the Arts QLD
DTIRIS	Department of Trade and Investment, Regional Infrastructure and Services NSW
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
EV	Environmental value

Abbreviation	Description
GDE	Groundwater dependent ecosystem
GMMP	Groundwater monitoring and modelling plan
IBRA	Interim Biogeographic Regionalisation for Australia
K	Hydraulic conductivity
Kh	Horizontal hydraulic conductivity
KNP	Kosciuszko National Park
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
NorBE	Neutral or beneficial effect
NOW	NSW Office of Water, now DPIE Water
NSW	New South Wales
NUDLC	National Uniform Drillers Licensing Committee
NWC	National Water Commission
NWQMS	National Water Quality Management Strategy
OEH	Office of Environment and Heritage
PRM	Probabilistic rational method
OWMP	Operation water management plan
PAH	Polycyclic aromatic hydrocarbons
PMF	Predicted maximum flood
PMP	Probable maximum precipitation
POEO Act	*Protection of the Environment Operations Act 1997*
QA/QC	Quality assurance/quality control
RC	Riparian corridors
REF	Review of Environmental Factors
SD	Standard deviation
SEARs	Secretary’s environmental assessment requirements
SEPP	State Environmental Planning Policy
SST	Sandstone
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
TRH	Total recoverable hydrocarbons

Abbreviation	Description
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
WSP	Water sharing plan
WTP	Water treatment plant

Glossary

Term	Definition
Abstraction	The removal of water from a water store.
Allocation	The specific volume of water allocated to water access entitlements in a given water year or allocated as specified within a water resource plan.
Alluvium	Loose, unconsolidated (not cemented together into a solid rock), soil or sediments (including clay, silt, sand, gravel, cobbles and boulders), eroded, deposited and reshaped by water in some form in a non-marine setting.
Announced allocation	A number, expressed as a percentage, which is used to determine the maximum volume of water that may be accessed from a water source in a water year.
Antecedent soil moisture	Water present in the soil profile prior to a rainfall event.
Aquifer	A geological formation or group of formations; able to receive, store and transmit significant quantities of water. Means a geological structure or formation, or an artificial landfill, that is permeated with water or is capable of being permeated with water (NSW Water Management Act 2000 definition).
Aquifer, confined	An aquifer overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer. Typically, groundwater in a confined aquifer is under pressure significantly greater than atmospheric pressure.
Aquifer, fractured rock	An aquifer that occurs in sedimentary, igneous and metamorphosed rocks which have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding planes, fractures and faults.
Aquifer interference activity	Means an activity involving any of the following: (a) the penetration of an aquifer, (b) the interference with water in an aquifer, (c) the obstruction of the flow of water in an aquifer, (d) the taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations, (e) the disposal of water taken from an aquifer as referred to in paragraph (d). (NSW Water Management Act 2000 definition).
Aquifer, unconfined	An aquifer in which there is no confining bed between the zone of saturation and the surface. The watertable is the upper boundary of an unconfined aquifer and is at atmospheric pressure.
Aquitard	A geological formation that may contain groundwater but is not capable of transmitting significant quantities of it under normal hydraulic gradients. May function as a confining bed.
Available water determination	The water made available from time to time to water access licence holders in NSW. Expressed as ML/unit share (but still publicised to users as percentage allocations).
Bank storage	Bank storage generally refers to water held in weathered rock and sediments along the bank of a stream during and immediately after a flood event. It is released back into the stream as a flood event recedes.
Baseflow	The component of streamflow supplied by groundwater discharge. Baseflow is characterised by an exponential decay curve following the cessation of surface runoff.
Baseflow separation	The process of dividing a hydrograph into baseflow and quickflow (or surface flow) components.
Bathymetry	The topography or the shape of the land below the water surface.

Bed conductance	As a property of a physical unit, conductance is equal to the hydraulic conductivity in the direction of flow (usually considered to be vertical distance) divided by the thickness of the unit. Conductance is the inverse of Hydraulic resistance. As a parameter applied in a numerical model to represent the bed of surface water body, Bed conductance is the product of Conductance (see above) and the length and width of a reach of river or of a cell or element beneath a surface water body. Bed conductance as a model parameter cannot be measured directly. It is a surrogate for the combination of hydraulic conductivities and geometries that occur in the near field of the water body. A number of analytical solutions give guidance for this kind of conductance, but values are generally either assumed or chosen during model calibration.
Bogs and fens	Collective term for endangered ecological communities (EECs) listed under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and NSW Biodiversity Conservation Act 2016 (BC Act).
Bore	A hole drilled in the ground, a well or any other excavation used to access groundwater. May be used for observation of groundwater (including water level, pressure or quality).
Calibration	Process of adjusting the values of model parameters within physically defensible ranges until the model performance adequately matches observed historical data from one or more locations represented by the model (ie a match is obtained that is robust and fit for purpose).
Catchment	The land area draining to a point of interest, such as a water storage or monitoring site on a watercourse.
Colluvium	Unconsolidated sediments that have been deposited at the base of hillslopes or depressions in the landscape by either runoff, sheet wash, slow continuous downslope creep, or a variable combination of these processes.
Conceptual model	Documentation or schematic of the conceptual understanding of groundwater recharge and discharge processes, flow within a groundwater system, and the interaction of groundwater with surface water and GDEs.
Consumptive use	Use of water for private benefit consumptive purposes including irrigation, industry, urban and stock and domestic use.
Dead storage	In a water storage, the volume of water stored below the level of the lowest outlet (the minimum supply level). This water cannot be accessed under normal operating conditions.
Dewatering	Removal of water from an aquifer as part of the construction phase of a development or part of ongoing activities to maintain access, serviceability and/or safe operating conditions. (NSW AIP).
Drawdown	The lowering of water levels in a surface water or groundwater storage resulting from the loss or take of water from the storage.
Eco-hydrogeological zone	A region where similar processes determine the interaction between groundwater and ecosystems, due to similar ecology, geology, climate, and groundwater/surface water connections.
Ecological water requirement	Description of the water regimes needed to sustain the ecological values of water-dependent ecosystems at a low level of risk.
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.
Electrical conductivity (EC)	Electrical conductivity (EC) measures dissolved salt in water. The standard EC unit is microSiemens per centimetre (µS/cm) at 25 °C.
Elevated wetland	A terrestrial ecosystem that occurs high in the KNP landscape with little or no catchment area. They are maintained by rainfall, snowmelt and perched groundwater and are not considered bogs or fens.
Environmental flow	The streamflow required to maintain appropriate environmental conditions in a waterway or water body.
Ephemeral	Something which only lasts for a short time. Typically used to describe rivers, lakes and wetlands that are intermittently dry.

Evaporation	A process that occurs at a liquid surface, resulting in a change of state from liquid to vapour. In relation to water resource assessment and water accounting, evaporation refers to the movement of water from the land surface (predominantly liquid) to the atmosphere (water vapour). The liquid water at the land surface that may be available for evaporation includes surface water, soil water, shallow groundwater, water within vegetation, and water on vegetation and paved surfaces.
Evapotranspiration	The combined loss of water from a given area during a specified period of time by evaporation from the soil or water surface and by transpiration from plants.
Extraction	Synonymous with abstraction in the case where water is removed from a groundwater store.
Floodplain	Flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding.
Full supply level	The normal maximum operating water level of a surface water storage when not affected by floods. This water level corresponds to 100% capacity.
Gaining stream	A stream where groundwater discharge contributes to streamflow.
Groundwater	Water contained within rocks and sediments below the ground surface in the saturated zone, including perched systems above the regional watertable.
Groundwater access entitlement	Water access entitlement granted on the groundwater resource. In NSW, equivalent to an aquifer access licence.
Groundwater allocation	Volume of water resulting from an allocation announcement made on a groundwater access entitlement.
Groundwater, artesian	Groundwater that is under pressure when tapped by a bore and rises above the level at which it is first encountered. It may or may not flow out at ground level.
Groundwater Dependent Ecosystem (GDE)	Natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis, so as to maintain their communities of plants and animals, ecosystem processes and ecosystem services.
Groundwater, deep	Groundwater below the regional watertable in the fractured rock groundwater system that has a long circulation flowpath and discharges to regional features (generally low in the landscape) such as incised gorges and permanent creeks and rivers.
Groundwater discharge	The process by which groundwater is released into the environment usually either via baseflow or evapotranspiration.
Groundwater flow	Water that flows in aquifers and aquitards.
Groundwater level	The level of groundwater in an aquifer, typically measured in a groundwater bore. In the case of an unconfined aquifer, the groundwater level is equal to the watertable level.
Groundwater, perched	A region in the unsaturated zone where the soil or rock may be locally saturated because it overlies a low-permeability unit. In the KNP, perched groundwater is very shallow groundwater above the regional watertable that is derived from rainfall and is retained in the elevated wetlands and some mid-slope bogs/fens, and potentially some basalt caps.
Groundwater, regional	A collective term for shallow and deep groundwater.
Groundwater recharge	The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the watertable and/or by surface water infiltrating to the watertable from a stream. Other forms of recharge include flooding and irrigation, and artificial recharge can also occur through various means, including bore injection.
Groundwater, shallow	Groundwater below the regional watertable in the weathered fractured rock groundwater system that has a short circulation flowpath and discharges to local features (generally in upper and mid catchment landscape areas) such as springs and permanent creeks.
Groundwater system	Multiple aquifers that are overlying or adjacent but not necessarily connected, and are hydrogeologically similar regarding geological province, hydraulic characteristics and water quality. A system may consist of groundwater in one or more geological formations.

Hydraulic conductivity	A property of soil or rock, which describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation. Saturated hydraulic conductivity describes water movement through saturated media.
Hydraulic gradient	Calculated as the difference between two hydraulic head measurements divided by the distance between the two measurements. Hydraulic gradient is used in the calculation of water flow.
Hydraulic resistance (vertical)	The resistance against flow experienced by water moving vertically through or between hydrostratigraphic units. It is mostly used in the description of vertical flow between aquifers, through aquitards. Hydraulic resistance increases with aquitard thickness and decreases with aquitard hydraulic conductivity. The inverse of hydraulic resistance is the hydraulic conductance.
Hydrogeologic unit	One or more geologic units which have similar hydrogeological characteristics and behaviour.
Hydrograph	A graph showing the surface level, discharge, velocity, or some other feature of water, with respect to time.
Hydrostratigraphic unit	The subsurface is divided into hydrostratigraphic units that have similar properties from the point of view of storage and transmission of groundwater. Units that store significant amounts of water and transmit this water relatively easily are called aquifers. Units that offer a high resistance to flow are called aquitards, or confining layers. See also Hydrogeologic unit.
Incidental water	Water that is taken by an aquifer interference activity that is incidental to the activity; including water that is encountered within and extracted from mine workings, tunnels, basements or other aquifer interference structures that must be dewatered to maintain access, serviceability and/or safe operating conditions. (NSW AIP).
Infiltration	The process by which water on the ground surface enters the soil profile.
Interflow	Water that infiltrates the soil surface and then moves laterally through the upper soil horizons toward stream channels, either as unsaturated flow, or more usually, as shallow perched saturated flow above the regional watertable.
Karst	Terrain characterised by sinkholes, caves and springs, developed most commonly in carbonate rocks, where significant dissolution of the rock has occurred due to flowing water.
Losing stream	A stream from which water is lost to the surrounding and underlying substrate via infiltration through the streambed and banks.
Mid-slope bog/fen	A terrestrial ecosystem that occurs on mid-slopes in the KNP landscape and in gullies and occasionally adjacent to an ephemeral stream.
Monitoring site	A place where observations of the environment are made; typically a physical location where sensors are used to measure the properties of one or more features of the environment (eg depth of a river, water level in a bore, surface or groundwater quality).
Nested bore	A bore with more than one pipe or a group of nearby bores, open at different levels in aquifers/aquitards, used to evaluate the vertical variation in groundwater pressure head or chemistry.
Non-consumptive use	Non-consumptive use is when there is no diversion from or diminishment of resource, for example water used to generate hydroelectricity. Held and planned environmental water is a non-consumptive water use.
Observed river height (or ‘stage’)	The depth of water at a river height measuring gauge located along the river. In most cases a zero reading is the lowest water-level that is reached during dry conditions.
Overland flow	Surface runoff, which is caused when either, the ground surface is impervious, the underlying soil is saturated and cannot accommodate any more water, or because the intensity of rainfall is greater than the soil’s capacity to infiltrate it.
Parameter	A measurable characteristic of a physical entity (feature); for example, the temperature of water in a river.
Peak river height	The highest river height observed during a flood event at the specified site on the river.

Permeability	The measure of the ability of a rock, soil or sediment to transmit a fluid. The magnitude of the permeability depends largely on the porosity and the connectedness of pores spaces. Synonymous with hydraulic conductivity when water is the fluid involved.
pH	Value that represents the acidity or alkalinity of an aqueous solution. It is defined as the negative logarithm of the hydrogen ion concentration of the solution.
Piezometer	A non-pumping bore, generally of small diameter, that is used to measure the elevation of the watertable or potentiometric surface.
Potentiometric surface	A surface representing the hydraulic head of groundwater; represented by the watertable altitude in an unconfined aquifer or by the altitude to which water will rise in a properly constructed bore in a confined aquifer.
Precipitation	All forms in which water falls on the land surface and open water bodies as rain, sleet, snow, hail, or drizzle.
Quickflow	The component of streamflow that has travelled through the catchment as interflow or across the surface as overland flow or is released from bank storage during the recession from a flood peak.
Regulated river	River on which a licensed entitlement regime exists with centralised allocation, and from which orders may be placed for upstream release of a licensed allocation. A necessary, but not sufficient condition for a river to be regulated is that it is located downstream of a surface water storage.
Riparian	An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation.
Riparian bog/fen	A terrestrial ecosystem that occurs low in the KNP landscape and adjacent to a permanent stream.
Saturated zone	The soil and geological layers below the land surface where all spaces between soil/sediment/rock particles are filled with water. It encompasses all the soil and geological layers below the watertable.
Soil moisture	The water content in the unsaturated zone of a soil profile.
Seepage	The infiltration of water from streams, irrigation channels, water storages, farm dams, natural surface water features and septic tanks into the groundwater system. It is a form of surface water–groundwater interaction and groundwater recharge. The term can also apply to low volumes of groundwater discharge.
Sensitivity	The degree to which numerical model outputs are affected by changes in selected input parameters.
Specific yield	The storage property for an unconfined aquifer that defines the quantity of water that can be drained from an aquifer under the influence of gravity or extracted by pumping.
Standing water level	Depth to groundwater below a datum point or reference point, usually from the top of casing or natural surface.
Storage	A pond, lake or basin, whether natural or artificial, for the storage, regulation and control of water.
Storage level	The elevation of the water surface in a water storage at a particular time and date, measured relative to a specified datum, typically the Australian Height Datum (AHD).
Storativity	The volume of water a confined aquifer will release when the water-level is lowered due to pumping or natural discharge. Upon the lowering of potentiometric water levels in such aquifers, they remain fully saturated so that no dewatering occurs (ie the potentiometric surface remains above the top of the confined aquifer formation). The water released is volumetrically equivalent to the volumetric expansion of the water and contraction of the pore space.
Stratification	The formation of layers in a water body that show differences in temperature, turbidity, pH, nutrients, salinity, dissolved oxygen or light penetration at various depths.
Stream	A watercourse and its tributaries. A stream can be permanent or ephemeral.
Streamflow	The flow of water in streams, rivers and other channels.
Stygofauna	Aquatic animals found in groundwater; sometimes used as a synonym of stygobite.
Surface runoff	Water from precipitation or other sources that flows over the land surface.

Surface water	Water that flows over or is stored on the surface of the earth that includes: (a) water in a watercourse, lake or wetland and (b) any water flowing over or lying on land: (i) after having precipitated naturally or (ii) after having risen to the surface naturally from underground.
Take	Take water from a water resource means to remove water from, or to reduce the flow of water in or into, the water resource including by any of the following means: (a) pumping or siphoning water from the water resource; (b) stopping, impeding or diverting the flow of water in or into the water resource; (c) releasing water from the water resource if the water resource is a wetland or lake; (d) permitting water to flow from the water resource if the water resource is a well or watercourse; and includes storing water as part of, or in a way that is ancillary to, any of the processes or activities referred to in paragraphs (a) to (d). (Commonwealth Water Act 2007 definition).
Total dissolved solids (TDS)	The sum of all particulate material dissolved in water. Usually expressed in terms of milligrams per litre (mg/L).
Total suspended solids (TSS)	In relation to a water sample, the measure of the particles mixed in the water sample.
Transmissivity	The rate at which water moves through a unit width of aquifer or aquitard under a unit hydraulic gradient. It is the product of aquifer thickness and hydraulic conductivity.
Turbidity	Means the measure of the light scattering properties of water and is an indicator of the presence of suspended solids.
Uncertainty	A state of lack of confidence to exactly describe the current or future condition of a system when limited knowledge of that system is available. Uncertainty is often categorised into two main types (AGMG; Barnett et al. 2012): • deficiency in our knowledge of the natural world (including the effects of error in measurements) • failure to capture the complexity of the natural world (or what we know about it) in a model. Formal definition from AS/NZS ISO 310000:2009: Uncertainty is the state, even partial, of deficiency of information related to the understanding or knowledge of an event, its consequence, or its likelihood.
Unregulated river	A river where there is no entitlement system at all or where there is an entitlement system that does not allow orders to be placed for upstream release of a licensed allocation.
Unsaturated zone	The soil between the land surface and the regional watertable in which the pore space contains both air and water.
Validation	Where observations and model simulations are compared using data that were not part of the model calibration.
Verification	Verification involves comparing the predictions of the calibrated model to a set of measurements that were not used to calibrate the model, in order to confirm that the model is suitable for use as a predictive tool.
Water access entitlement	A perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plan. In NSW, equivalent to a water access licence (ie an access licence referred to in section 56 of the Water Management Act 2000).
Water balance	The flow of water into and out of, and changes in the storage volume of, a surface water system, groundwater system, catchment or specified area over a defined period of time.
Water quality	The physical, chemical and biological characteristics of water. Water-quality compliance is usually assessed by comparing these characteristics with a set of reference standards. Common standards used are those for drinking water, safety of human contact and the health of ecosystems.
Water resource	All natural water (surface water or groundwater) and alternative water sources, such as recycled or desalinated water, that has not yet been abstracted or used.

Water sharing plan	A legislated plan that establishes rules for managing and sharing water between ecological processes and environmental needs of the respective water source (river/aquifer). It manages water access licences, water allocation and trading, water extraction, operation of dams, management of water flows, and use and rights of different water users.
Water source	In NSW, water source means the whole or any part of: (a) one or more rivers, lakes or estuaries, or (b) one or more places where water occurs on or below the surface of the ground (including overland flow water flowing over or lying there for the time being), and includes the coastal waters of the State. (NSW Water Management Act 2000 definition).
Watertable	The top of an unconfined aquifer which can be either perched or regional. It is at atmospheric pressure and, in a regional context, indicates the level below which soil and rock are saturated with water.
Water year	A continuous twelve-month period starting from a specified month for water accounting purposes. In NSW this is 1 July to 30 June each year.
Wetland	An area of land whose soil is saturated with moisture either permanently or intermittently. Wetlands are typically highly productive ecosystems. They include areas of marsh, fen, parkland and open water. Open water can be natural or artificial; permanent or temporary; static or flowing; and fresh, brackish or salty.