Annexure A

Water characterisation report

Water characterisation report

Annexure A to water assessment

Prepared for Snowy Hydro Limited
September 2019

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Water characterisation report

Annexure A to water assessment

Report Number

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Client

Snowy Hydro Limited

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Prepared by **Approved by**

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12 September 2019	12 September 2019	12 September 2019	12 September 2019	12 September 2019

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1 Introduction

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 hydro-electric power station. The major construction elements of Snowy 2.0 include permanent infrastructure, temporary construction infrastructure, management and storage of excavated rock and establishing supporting infrastructure. Snowy 2.0 Main Works also includes the operation of Snowy 2.0.

To assess impacts from the project, an Environmental Impact Statement (EIS) has been prepared (EMM 2019). Chapter 2 of the Snowy 2.0 Main Works EIS describes the construction and operation of the project in detail. The regional location of the Snowy 2.0 project area is shown in Figure 1.1.

In order to assess potential groundwater and surface water related issues from the construction and operation of Snowy 2.0, a water assessment (Appendix J to the EIS) has been prepared as an appendix to the Snowy 2.0 Main Works EIS.

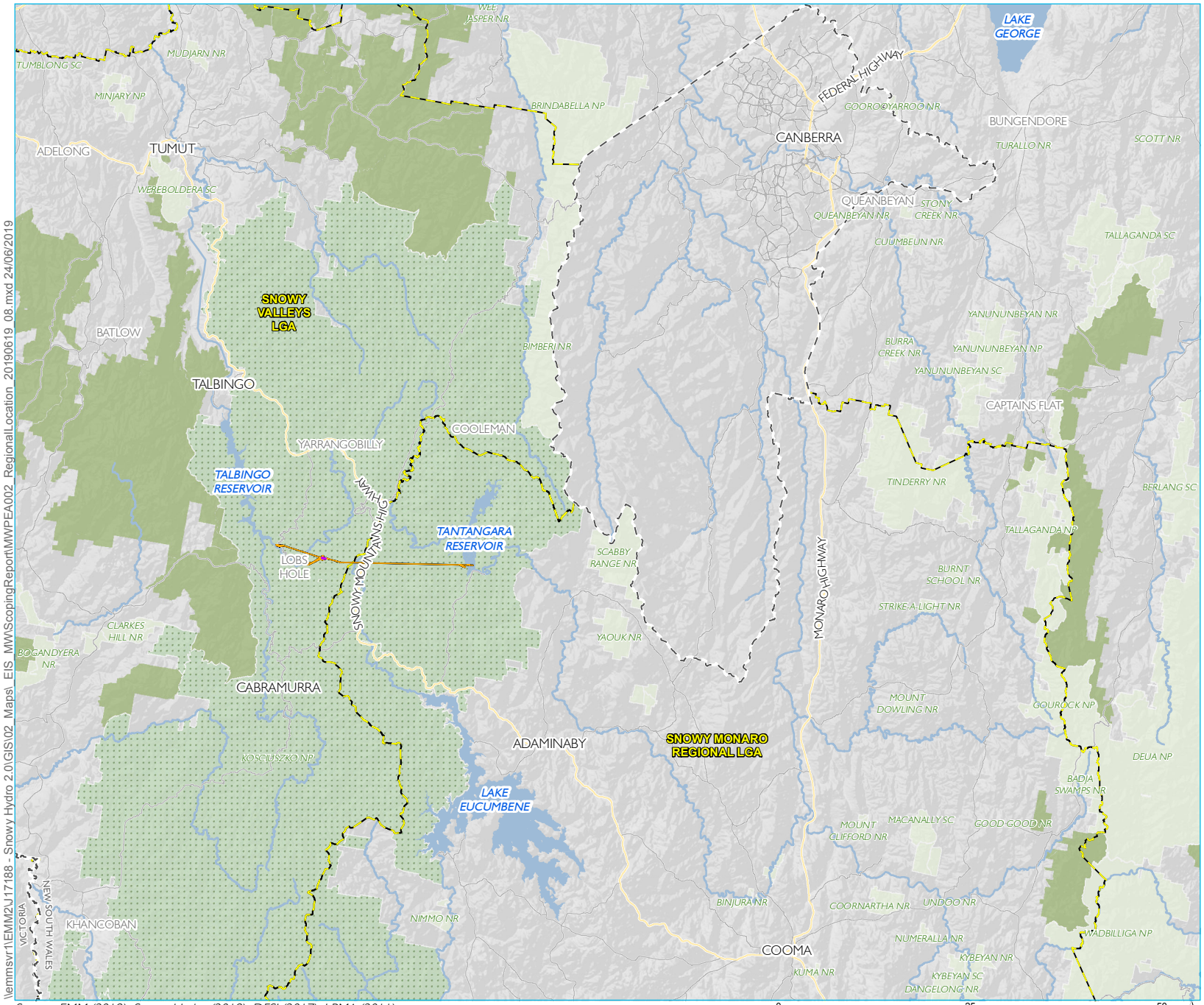
The water assessment has a number of supporting technical reports which are termed annexures. Each annexure has further supporting technical reports which are termed attachments.

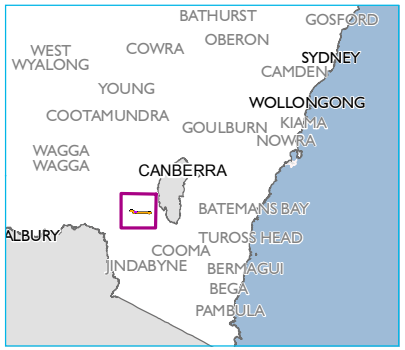
This water characterisation report (WCR) is an annexure to the water assessment. The document structure of the technical reports and assessments which support the overall water assessment are shown in Figure 1.2.

1.1 Purpose of this report

The key objectives of the WCR are to:

- describe the available data, monitoring programs and field surveys that inform the water assessment.
- describe the existing surface water and groundwater environment and establish baseline conditions within the project area and surrounds.
- describe the conceptual model of the water cycle within the project area, including the interaction between surface water and groundwater.





KEY

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station

Existing environment

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

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

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Regional location of Snowy 2.0 project area

Snowy 2.0
Water Characterisation Report
Main Works
Figure 1.1

snowy 2.0

EMM creating opportunities

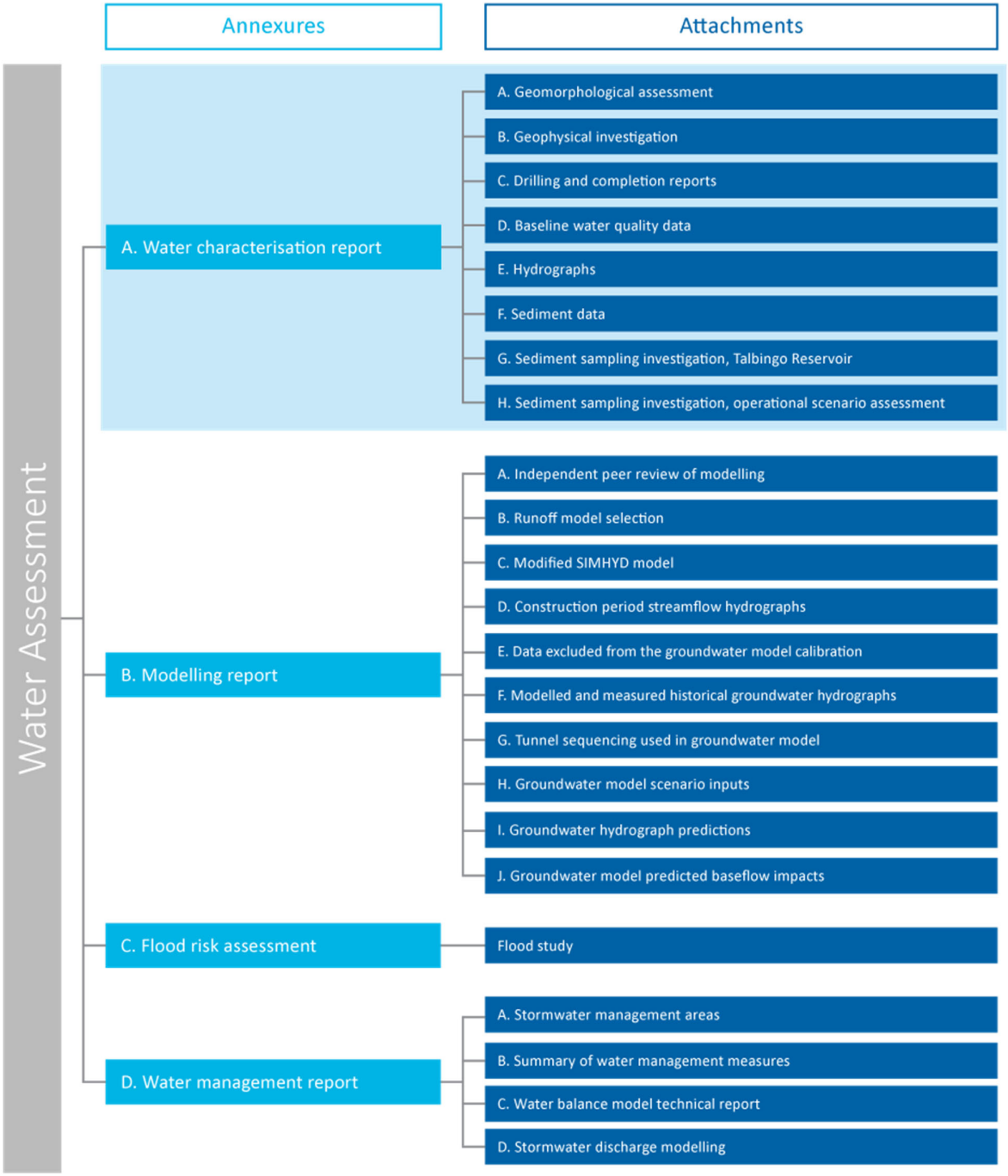


Figure 1.2 Water assessment and WCR structure

2 Available data

2.1 Overview

This section provides an overview of data and field surveys that inform the water assessment. Data collection methods are described in Chapter 3. All data is presented and discussed in Chapters 4 to 10.

2.2 Data

A summary of all data referenced in this report is provided in Table 2.1.

Table 2.1 Summary of available data

Data type	Record period	Data source	Relevant section of this report
Rainfall			
Daily rainfall data at Talbingo (72131)	1997–2019	Snowy Hydro	Section 4.2
Daily rainfall data at Yarrangobilly Caves (72141)	1906–1919 1978–2019	BoM[1]	Section 4.2
Daily rainfall data at Cabramurra SMHEA AWS (72161)	1996–2019	BoM[1]	Section 4.2
Daily rainfall data at Adaminaby (Yaouk) (71040)	1969–1972 1987–2019	BoM[1]	Section 4.2
Daily rainfall data at Adaminaby Alpine Tourist Park (71000)	1886–2019	BoM[1]	Section 4.2
Daily rainfall at Ravine (Lobs Hole)	1992-2019	Snowy Hydro	Section 4.2
Daily rainfall data at Tantangara Reservoir (00185)	1991–2019	Snowy Hydro	Section 4.2
Interpolated daily rainfall timeseries	various	SILO[3]	Section 4.2
Temperature			
Monthly and annual temperature statistics at Cabramurra SMHEA AWS (72161)	1996–2018	BoM[1]	Section 4.3
Hourly dry bulb temperature record at Tantangara Reservoir	1993–2018	Snowy Hydro	Section 4.3
Hourly dry bulb temperature record at Talbingo	2006–2017	Snowy Hydro	Section 4.3
Evaporation/evapotranspiration			
Average monthly and annual evaporation depths	1975–2005[2]	BoM[1]	Section 4.4
Average monthly and annual evapotranspiration depths	1961–1990[2]	BoM[1]	Section 4.4
Daily Morton's areal potential evapotranspiration depths	1970–2019	SILO[3]	Section 4.4
Stream gauge			
Eucumbene River at Providence 2 (222522)	1978[4]–2019	Snowy Hydro	Section 7.2.2
Murrumbidgee River above Tantangara Reservoir (410535)	1978[4]–2019	Snowy Hydro	Section 7.2.2
Yarrangobilly River at Ravine (410574)	1972[4]–2019	Snowy Hydro	Section 7.3.2
Wallaces Creek (410507)	1982–1999	Snowy Hydro	Section 7.3.2

Table 2.1 Summary of available data

Data type	Record period	Data source	Relevant section of this report
Brownleys Back Creek (600577)	1984–2019	Snowy Hydro	Section 7.3.2
Streamflow			
In situ streamflow measurements	2018–2019	EMM	Section 7.2.2
Reservoir			
Tantangara Reservoir water level	1999[4]–2019	Snowy Hydro	Section 8.1
Talbingo Reservoir water level	1999[4]–2019	Snowy Hydro	Section 8.2
Goodradigbee River Aqueduct flows	2002[4]–2019	Snowy Hydro	Section 8.1
Tantangara Reservoir dam release	1999[4]–2019	Snowy Hydro	Section 8.1
Providence Portal – Murrumbidgee to Eucumbene tunnel transfers	1983[4]–2018	Snowy Hydro	Section 8.1
Power station flow rates			
Tumut 2 discharge	1994[4]–2019	Snowy Hydro	Section 8.2
Tumut 3 discharge	1994[4]–2019	Snowy Hydro	Section 8.2
Tumut 3 pumping	1994[4]–2019	Snowy Hydro	Section 8.2
Groundwater			
Six hourly groundwater level data at various sites across the plateau and ravine	2018–2019	EMM	Chapter 9
Six hourly groundwater level data at various sites across the plateau and ravine	2018–2019	SMEC[5]/GHD[6]	Chapter 9
Slug test data for plateau and ravine groundwater bores	2018–2019	EMM	Chapter 9
Pump testing at plateau and ravine production bores	2018–2019	EMM	Chapter 9
Drill stem test data for plateau and ravine groundwater bores	2018–2019	SMEC[5]/GHD[6]	Chapter 9
Packer test data for plateau and ravine groundwater bores	2018–2019	SMEC[5]/GHD[6]	Chapter 9
Water quality			
Monthly surface water quality data from plateau	2018–2019	EMM	Section 7.2.3
Monthly surface water quality data from ravine	2018–2019	EMM	Section 7.3.3
Monthly surface water quality data from Rock Forest	2018–2019	EMM	Section 7.4
Tantangara Reservoir water quality data	2018–2019	Cardno	Section 8.1.3
Talbingo Reservoir water quality data	2018–2019	Cardno	Section 8.2.3
Monthly groundwater quality data from plateau	2018–2019	EMM	Section 9.2.3
Monthly groundwater quality data from ravine	2018–2019	EMM	Section 9.3.3
Wet weather water quality data from Lobs Hole, including receiving waters and runoff from disturbed areas	Mar 2019 and May 2019	EMM	Section 7.2.3
In-stream water quality data for Murrumbidgee and Yarrangobilly rivers	Sep 2018 to May 2019	Cardno	Section 7.2.3 Section 7.3.3

Table 2.1 Summary of available data

Data type	Record period	Data source	Relevant section of this report
Sediment quality			
Sediment quality data at Tantangara Reservoir	Mar 2018 to Mar 2019	Cardno, RHDHV[7]	Section 8.1.4
Sediment quality data at Talbingo Reservoir	Mar 2018 to Mar 2019	Cardno, RHDHV[7]	Section 8.2.4
Spatial			
LiDAR	26–28 Oct 2018	Photomapping Services	Chapter 7
Aerial imagery	26–28 Oct 2018	Photomapping Services	Chapter 7
Field survey			
Geomorphology survey – sediment spear data at 102 locations across the plateau and ravine	Nov 2018–Jan 2019	Flow and Loam Environmental	Chapter 7 Attachment A
Geomorphology survey – spatial extent of sediment storage areas adjacent to key watercourses across the plateau and ravine	Nov 2018–Jan 2019	Flow and Loam Environmental	Chapter 7 Attachment A
Geomorphology survey – 267 individual geomorphology field observations	Nov 2018–Jan 2019	Flow and Loam Environmental	Chapter 7 Attachment A
Groundwater spring survey – spatial extent and classification of 227 groundwater discharge locations	Feb and Apr 2019	EMM	Section 7.2.1
Geophysical investigation – gravity and magnetics (geophysical) survey data	Nov–Dec 2018	SMEC[5]	Section 5.2 Attachment B

Notes:
1. Bureau of Meteorology (BoM).
2. Average values based on at least 10 years of records within the specified record period.
3. Scientific Information for Land Owners (SILO).
4. Record period based on the record available in electronic format. Earlier data may be available in non-electronic format.
5. SMEC Pty Limited (SMEC).
6. GHD Pty Limited (GHD).
7. Royal Haskoning DHV (RHDHV).

3 Data collection program

3.1 Overview

Data collection to inform the water assessment commenced in June 2017 and is ongoing. Data collected up to the end of May 2019 is documented in this report in most cases. The data collection program includes surface water and groundwater monitoring and several field surveys. This section describes data collection methods and the temporal and spatial scale of collected data. It is noted that third-party data such as stream gauge data provided by Snowy Hydro is not described in detail but may be included for reference where appropriate. All collected data plus relevant third-party data is presented and discussed in Chapters 4 to 10.

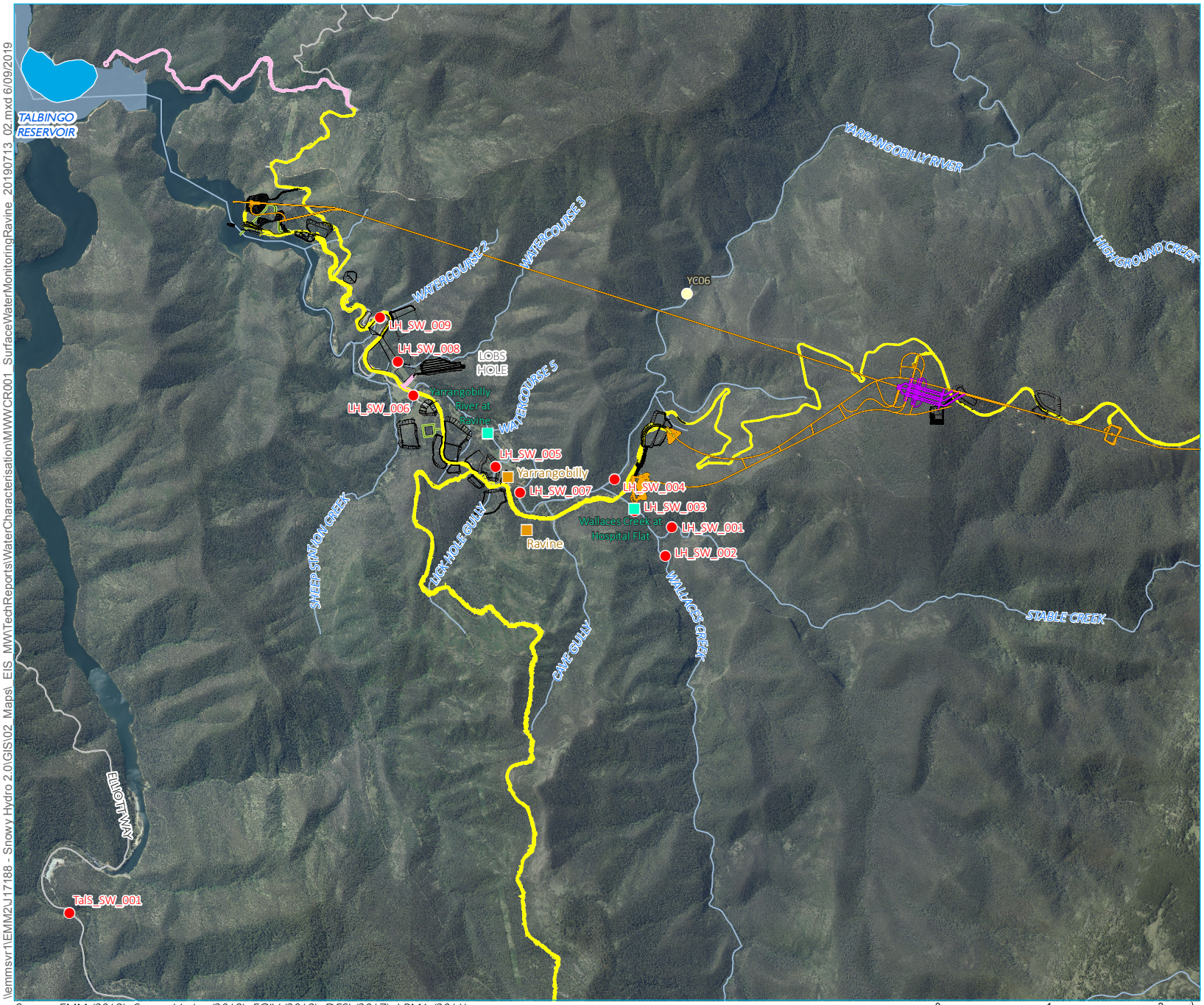
3.2 Surface water monitoring

3.2.1 Monitoring network

The following surface water monitoring was undertaken as part of the data collection program:

- surface water quality monitoring from watercourses in the ravine and plateau as well as Talbingo and Tantangara reservoirs; and
- in situ measurements of streamflow within some plateau watercourses.

Monitoring locations in the ravine and plateau are shown in Figure 3.1. The location of regional stream gauges and weather stations are also provided for context. A figure showing reservoir monitoring locations is provided in Section 3.2.3. The following sections provide detailed information on the monitoring methods, locations and frequencies.



KEY

- Streamflow gauge
- Surface water monitoring location
- Weather station
- Yarrangobilly Caves 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

- Local road
- Watercourse
- Waterbodies

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

0 1 2 km

GDA 1994 MGA Zone 55

N

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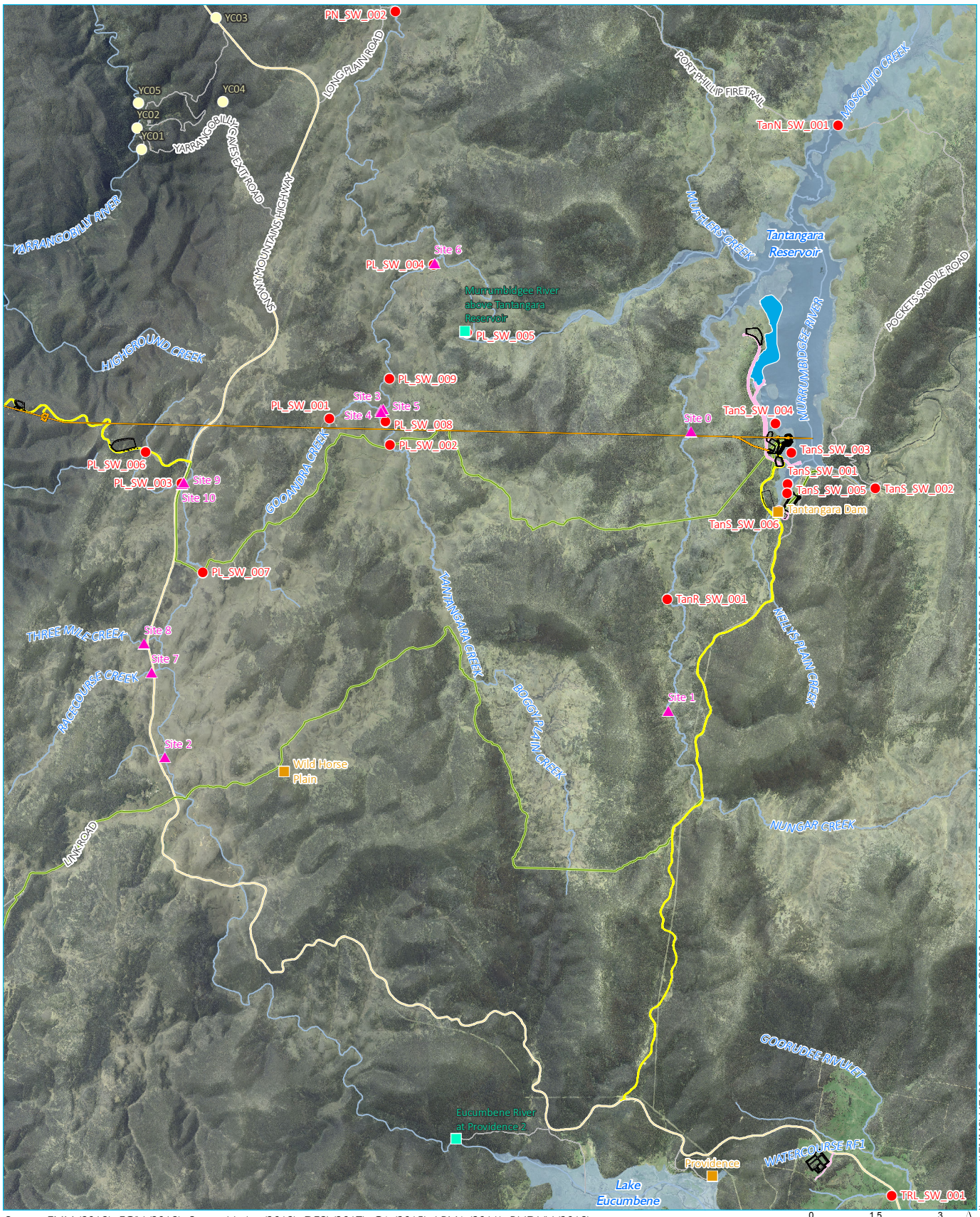
Surface water monitoring locations - ravine

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.1a

snowy 2.0

EMM creating opportunities



Source: EMM (2019); FGJV (2019); Snowy Hydro (2019); DFSI (2017); GA (2015); LPMA (2011); RHDHV (2019)

0 1.5 3 km

GDA 1994 MGA Zone 55

N

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KEY

- In situ streamflow location
- Weather station
- Streamflow gauge
- Surface water monitoring location
- Yarrangobilly Caves monitoring location

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 or track
- Watercourse
- Waterbodies

Surface water monitoring locations - plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.1b

snowy 2.0

EMM creating opportunities

3.2.2 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 2.1). In situ measurements of streamflow were undertaken within some plateau watercourses on a monthly basis from October 2018, using a handheld propeller flow meter. 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.

A summary of available streamflow data for the plateau is provided in Table 3.1.

Table 3.1 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[1]
Murrumbidgee River above Tantangara Reservoir (410535)	Murrumbidgee River	Murrumbidgee River downstream of Tantangara Creek confluence	Continuous[1]
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

Notes: 1. Measurements taken at 10-minute intervals.

ii Ravine

Streamflow data is available from three Snowy Hydro operated stream gauges in the Yarrangobilly River catchment. Gauge locations near the project area are indicated in Figure 3.1. Record periods are provided in Table 2.1.

3.2.3 Water quality monitoring

i Watercourses

A baseline surface water quality monitoring program commenced in February 2018 and is ongoing. Monitoring locations for the ravine and plateau are indicated in Figure 3.1. Further information, including the location and number of samples collected, is provided Table 3.2.

Table 3.2 Surface water quality baseline monitoring locations

ID	Location	Number of samples[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 samples 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
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

Table 3.2 Surface water quality baseline monitoring locations

ID	Location	Number of samples[1]
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 undertaken at a monthly frequency, predominantly during dry conditions. However, monitoring during wet weather conditions was undertaken in Lobs Hole in March and early May 2019. The monitoring timeline at each location is shown in Figure 3.2. Wet weather samples and monitoring locations that were dry at the time of sampling are also identified.

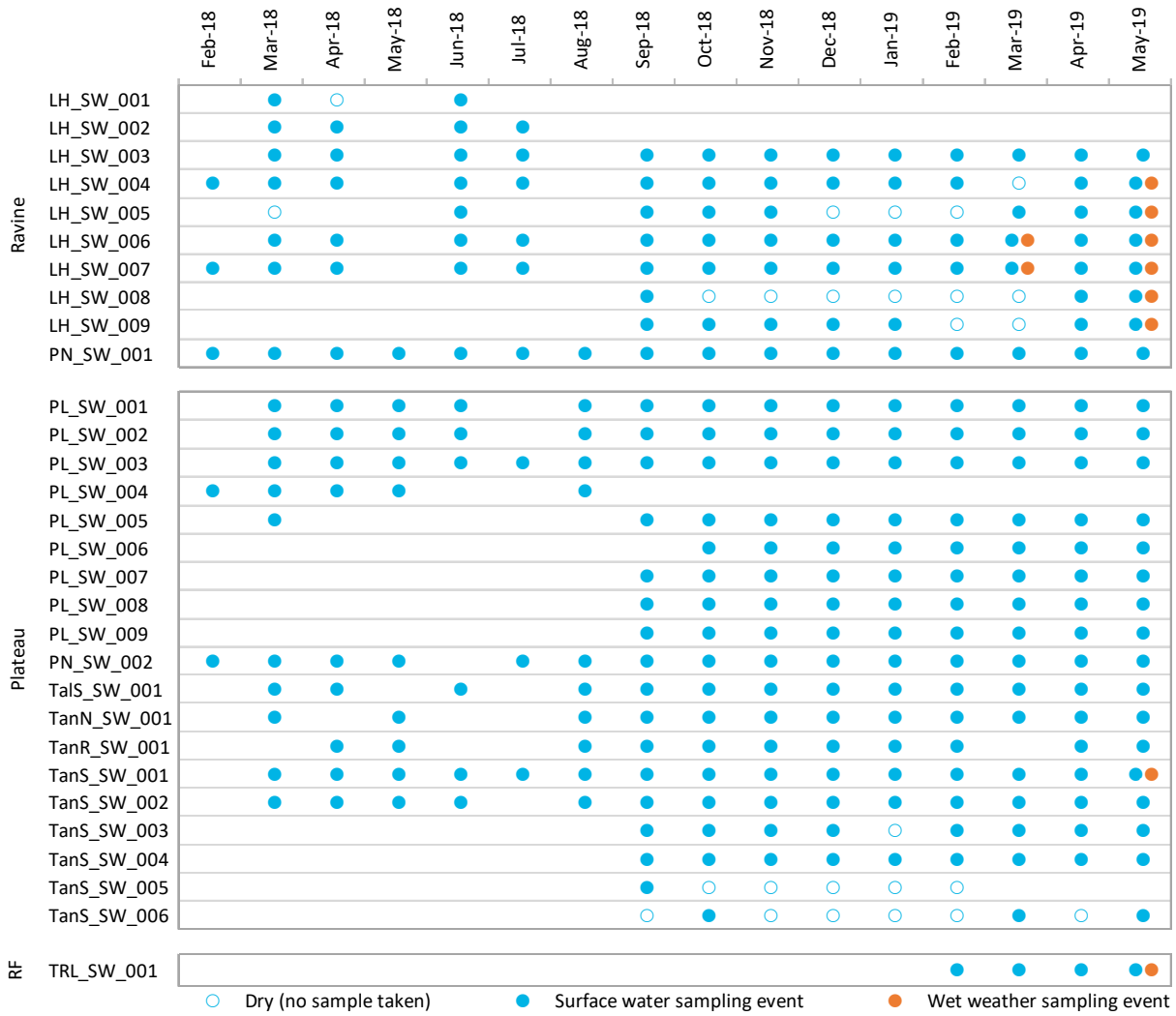


Figure 3.2 Watercourse water quality sampling events

Table 3.3 describes the analytes and analysis methods applied to the surface water monitoring program.

Table 3.3 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 3.3 Analysis methods and parameters

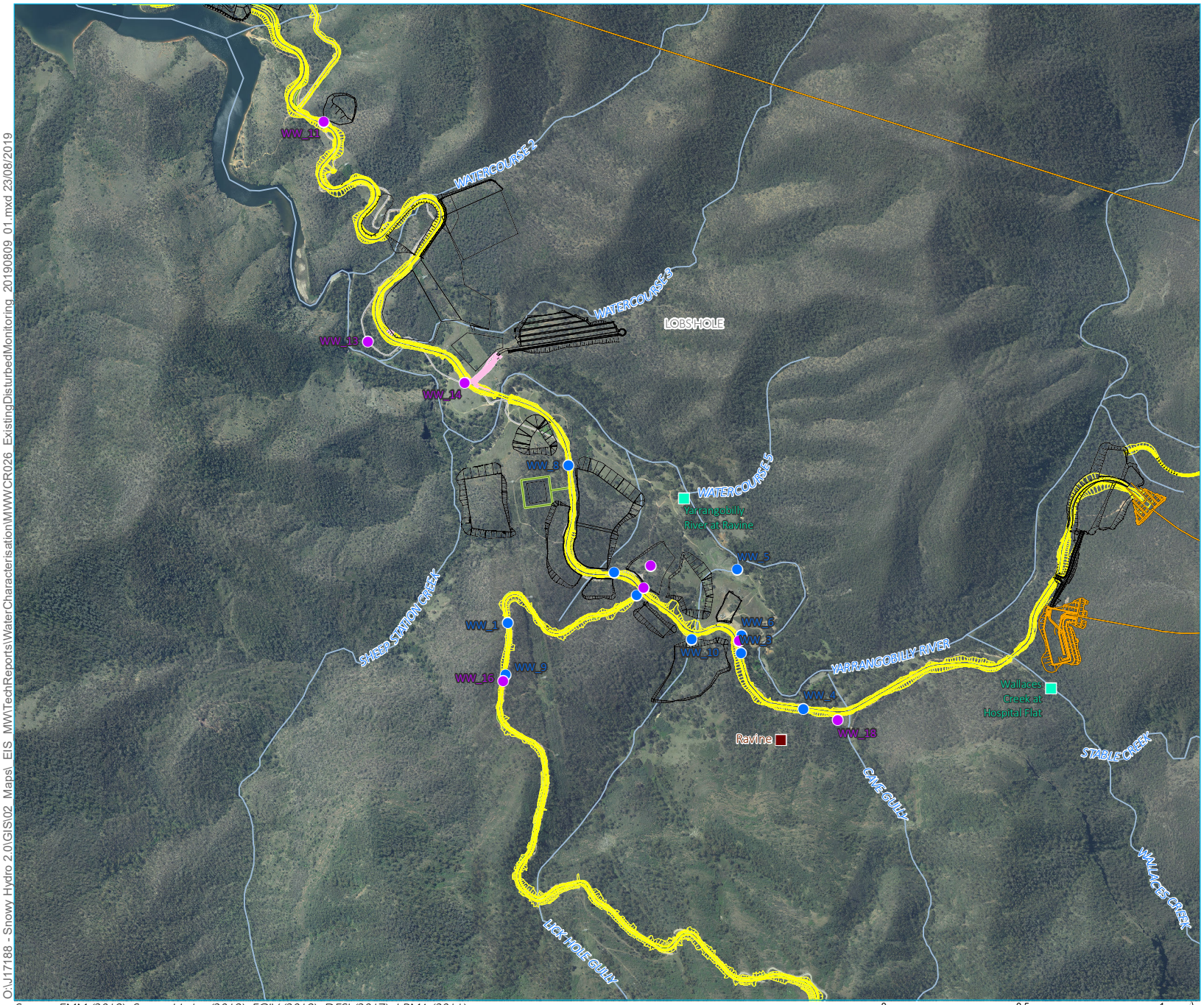
Category	Monitoring analytes	Analysis method
Inorganics	cyanide	
Metals (field filtered)	Al, As, Ag, B, Ba, Be, Cd, Cr (total), Co, Cu, Fe, Hg, Mn, Ni, Pb, Se, V and Zn	

ii Disturbed area runoff monitoring

Runoff samples were collected from existing access tracks and areas disturbed by historic construction and mining activities. These areas are referred to as existing disturbed areas as they were constructed/disturbed prior to activities associated with the project. The objective of this monitoring was to understand the water quality profile of runoff from existing disturbed areas and its influence on receiving water quality. This data has also been applied to estimate discharge characteristics from areas that will be disturbed by the construction of surface infrastructure (water management report, Annexure D to the water assessment).

Disturbed area runoff samples were collected in Lobs Hole during the March (10 locations) and May (8 locations) 2019 wet weather monitoring events. Monitoring locations are shown in Figure 3.3. Samples were typically collected from roadside drainage or areas where minor concentrated flows occur. Typical disturbed area monitoring locations are shown in Photograph 3.1. The analytes and analysis methods described in Table 3.3 were applied to all existing disturbed area runoff monitoring.

Photograph 3.1 Typical existing disturbed area monitoring locations



KEY

- Streamflow gauge
- Weather station

Disturbed area and runoff monitoring location

- March 2019
- May 2019

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

Existing environment

- Local road
- Watercourse

Existing disturbed area monitoring locations

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.3

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

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snowy 2.0

EMM creating opportunities

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iii Reservoir monitoring

a Overview

A baseline reservoir monitoring program was undertaken by Cardno (2019a). This section describes the water quality and sediment monitoring programs. Reservoir monitoring also included time-series physicochemical data (including temperature, conductivity and turbidity) from water quality instruments installed and moored by Cardno, as documented in Talbingo and Tantangara Reservoirs Physical Limnology Report (Appendix K to the EIS).

b Water quality

The reservoir water monitoring program comprised comprehensive monitoring at Talbingo and Tantangara reservoirs in March and October 2018 and monthly water monitoring at select locations from November 2018. Monitoring locations are shown in Figure 3.4 and described in Table 3.4. For the March and October 2018 monitoring rounds, samples were collected from the surface, mid-depth and near the bottom of the reservoir at each location. All sampling undertaken from November 2018 was restricted to near surface sampling. The analytes and analysis methods described in Table 3.3 were applied to reservoir sampling.

Table 3.4 Surface water monitoring locations – reservoirs

ID	Location	Number of sampling events[1]	Record period
	Talbingo Reservoir		
TAL01	Northern end of reservoir, adjacent to the dam wall	2	Mar and Oct 2018
TAL09	Middle portion of the reservoir	2	Mar and Oct 2018
TAL13	Middle portion of the reservoir	1	Oct 2018
TAL14	Middle portion of the reservoir, adjacent to Long Creek inlet	1	Oct 2018
TAL15	Long Creek inlet	7	Mar 2018 to Feb 2019
TAL15B	Long Creek inlet (same location as TAL15)	1	Mar 2018
TAL18	Confluence of Tumut and Yarrangobilly rivers	6	Oct 2018 to Feb 2019
TAL19	Southern end of reservoir, Tumut River inlet	2	Mar and Oct 2018
TAL20	Southern end of reservoir, Yarrangobilly River inlet	2	Mar and Oct 2018
TAL21	Plain Creek inlet	5	Nov 2018 to Feb 2019
TAL22	Yarrangobilly River arm of the reservoir, near Lobs Hole	5	Nov 2018 to Feb 2019
	Tantangara Reservoir		
TAN01	Southern end of reservoir, adjacent dam wall	2	Mar and Oct 2018
TAN04	Middle portion of the reservoir	2	Mar and Oct 2018
TAN06	Middle portion of the reservoir	2	Mar and Oct 2018
TAN08	Northern end of reservoir, Murrumbidgee River inlet	2	Mar and Oct 2018
TAN09	Northern end of reservoir, Mosquito Creek inlet	2	Mar and Oct 2018
TAN_M01	Southern end of reservoir	5	Nov 2018 to Feb 2019
TAN_M02	Middle portion of the reservoir	5	Nov 2018 to Feb 2019
TAN11	Middle portion of the reservoir	5	Nov 2018 to Feb 2019

Table 3.4 Surface water monitoring locations – reservoirs

ID	Location	Number of sampling events[1]	Record period
TAN_ADCP_01	Middle portion of the reservoir	5	Nov 2018 to Feb 2019

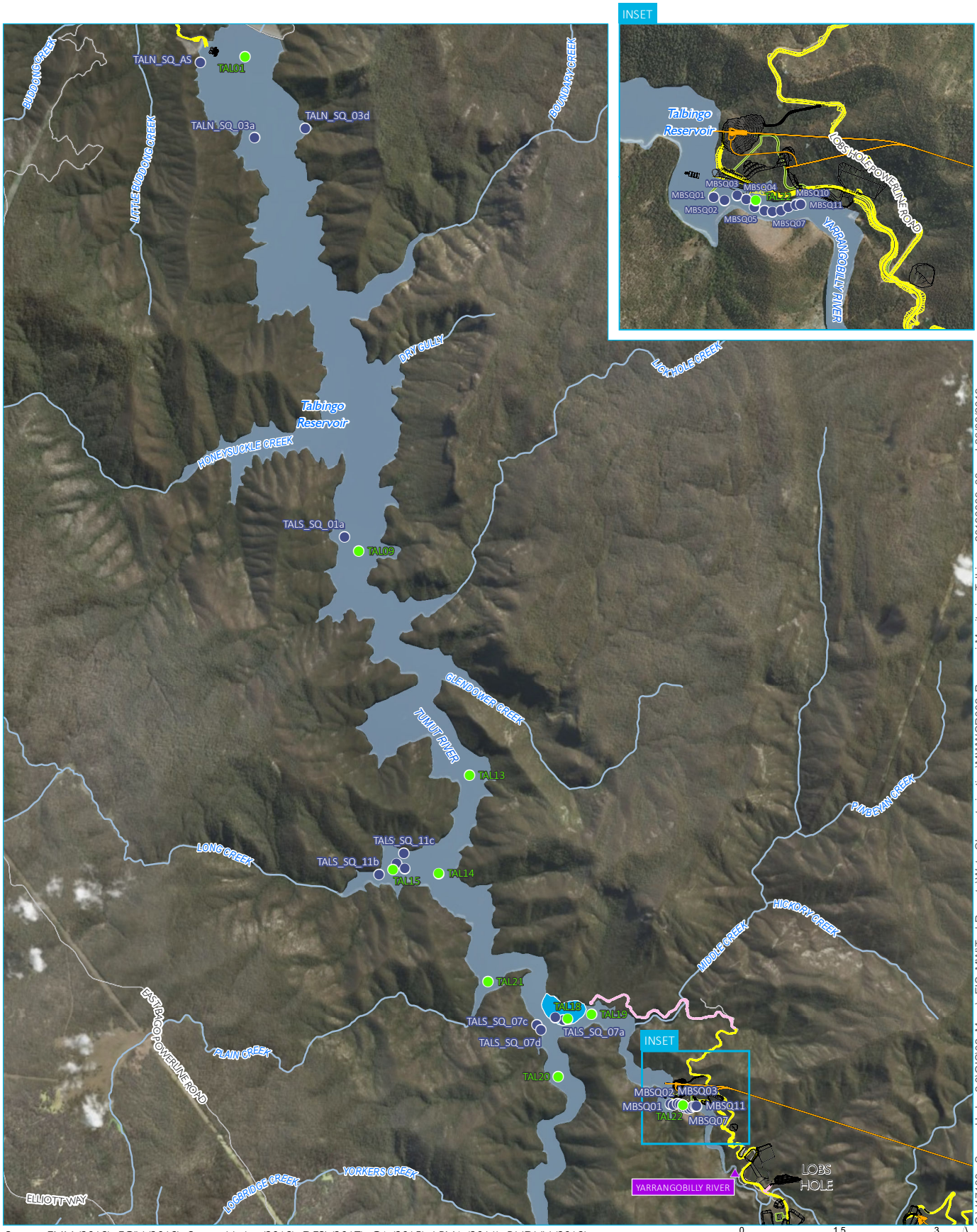
Notes: 1. Samples were collected from the surface, mid-depth and near the bottom of the reservoir at each location for the March and October 2018 monitoring rounds. All sampling undertaken from November 2018 was restricted to near surface sampling.

Cardno also installed in-stream water quality instruments in the Yarrangobilly and Murrumbidgee rivers. The instruments were installed immediately upstream of reservoir inflow locations and were configured to measure water quality at 10 to 15 minute intervals. Instrument locations are shown in Figure 3.4 and described in Table 3.5.

Table 3.5 In-stream instrumentation

ID	Location	Analytes measured	Record period
Yarrangobilly River[1]	Yarrangobilly River, upstream of the Talbingo Reservoir inlet	Turbidity, chlorophyll, temperature, depth and electrical conductivity	Sep 2018 to May 2019
Murrumbidgee River[2]	Murrumbidgee River, upstream of the Tantangara Reservoir inlet	Temperature, depth and electrical conductivity	Sep 2018 to May 2019

Notes: 1. The Yarrangobilly River in-stream instrument was relocated from within the upper arm of Talbingo Reservoir to within the Yarrangobilly River (location indicated in Figure 3.4) in December 2018. In December 2018, the instrument suite was also expanded to include temperature, depth and conductivity.
2. A Murrumbidgee River in-stream instrument was initially installed 15 May 2018 but was subsequently inundated by the reservoir water level and are therefore not considered to represent in-stream conditions (Cardno 2019a).



Source: EMM (2019); FGJV (2019); Snowy Hydro (2019); DFSI (2017); GA (2015); LPMA (2011); RHDHV (2019)

KEY

- Reservoir monitoring location
- Sediment sampling location
- In-stream monitoring intstrument

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 or track
- Watercourse
- Waterbodies

Reservior monitoring locations
- Talbingo Reservoir

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.4a

snowy 2.0

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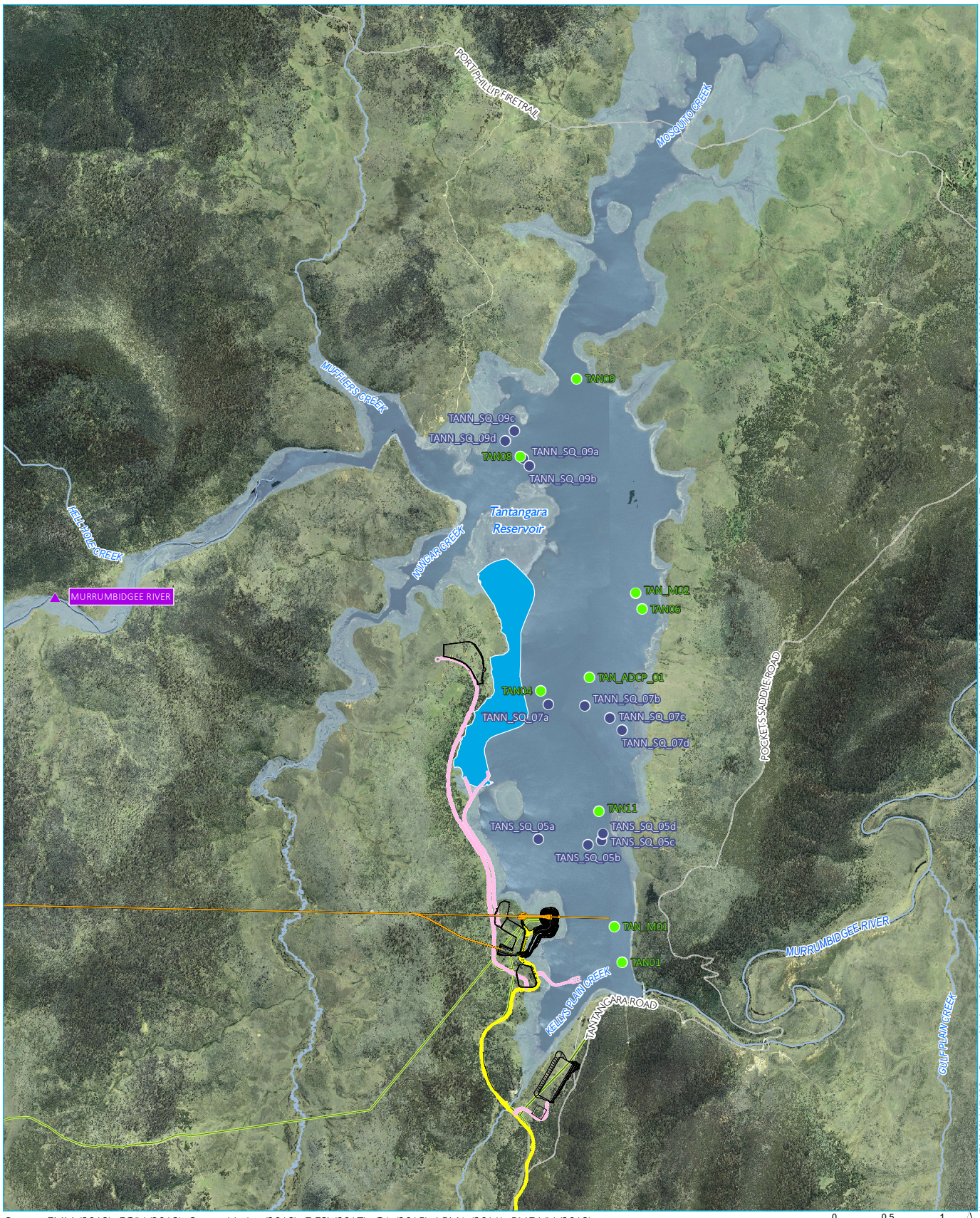

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Source: EMM (2019); FGJV (2019); Snowy Hydro (2019); DFSI (2017); GA (2015); LPMA (2011); RHDHV (2019)

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KEY

- Reservoir monitoring
- Sediment sampling
- In-stream monitoring

Snowy 2.0 operational

- Tunnels, portals, intakes,
- Permanent

Snowy 2.0 construction

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

Existing

- Local road or

Reservior monitoring locations
- Tantangara Reservior

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.4b

snowy 2.0

EMM creating opportunities

c Sediment characteristics

The reservoir sediment characteristics program comprised bulk sediment sampling and sediment coring at Talbingo and Tantangara reservoirs between March 2018 and March 2019. Sediment sampling events were undertaken by Cardno and RHDHV and are described in Table 3.6. Cardno sediment sampling locations are shown in Figure 3.4 and sediment quality data is provided in Attachment F. Further details on the RHDHV sediment sampling program are provided in Attachment G and Attachment H.

Table 3.6 Sediment sampling locations – reservoirs

Reservoir location	No. of sample locations	Sample type	Date	Source
Talbingo Reservoir				
Northern, middle and southern portion of reservoir (see Figure 3.4)	12	Bulk sediment sample	March 2018	Cardno
Ravine Bay, Plain Creek Bay and Cascade Bay	9	Bulk sediment sample	July 2018	RHDHV
Within the Yarrangobilly River arm of reservoir (see Figure 3.4)	11	Bulk sediment sample	May 2018	Cardno
Middle Bay, Ravine Bay, Plain Creek Bay and Cascade Bay	18	Sediment core	August 2018	RHDHV
Middle Bay and Ravine Bay	19	Sediment core	March 2019	RHDHV
Tantangara Reservoir				
Northern, middle and southern portion of reservoir (see Figure 3.4)	12	Bulk sediment sample	March 2018	Cardno
Middle portion of reservoir	3	Bulk sediment sample	July 2018	RHDHV
Approximately 600 m from intake location	16	Sediment core	March 2019	RHDHV

3.3 Groundwater monitoring

3.3.1 Monitoring network

EMM, Snowy Hydro, GHD, and SMEC have designed and implemented a groundwater monitoring network to investigate hydrogeological and geotechnical conditions in the project area. 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)

GHD and SMEC geotechnical boreholes were completed above the alignment with many of these boreholes converted to monitoring bores and vibrating wire piezometers (VWP). Hydrogeological monitoring and test bores, installed by EMM and Snowy Hydro, where also installed above the alignment to better understand vertical connectivity and hydraulic gradients between the shallow and deep groundwater systems. Monitoring bores located off the alignment were installed to further understand the regional groundwater system. All monitoring bores and piezometers have been interpreted and used to inform baseline EIS monitoring and the groundwater numerical model (modelling report, Annexure B to the water assessment).

The groundwater monitoring network includes conventional groundwater monitoring bores, VWPs, drive point piezometers/shallow auger holes, and a stilling well located in a cave pool. Monitoring sites were selected to provide spatial coverage, investigate the major hydrogeological environments, and monitor potentially sensitive features. Specifically, the groundwater monitoring network was designed to:

- identify and characterise water bearing units in the project area, with 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 conditions in the project area;
- 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).

3.3.2 Monitoring bores

The groundwater monitoring network consists of:

- Forty-eight groundwater monitoring bores at 39 locations (see Table 3.7). At some locations multiple monitoring bores (nested bores) are installed at different depths to target different horizons within the fractured groundwater systems. Water 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 pumping bores used to test indicative groundwater yields and quality at the proposed tunnel depth (see Table 3.7). Nested monitoring bores and VWPs accompany test pumping bores and were used to estimate horizontal and vertical hydraulic conductivities of tested geological formations. Following testing, test pumping bores have been used as additional monitoring bores to collect groundwater levels and quality.
- Two production bores that were installed in Lobs Hole to provide water supply options for Exploratory Works construction (see Table 3.7).
- Four shallow drive point piezometers and 12 swamp monitoring bores (see Table 3.7). 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 3.8). These sensors monitor groundwater pressures within the very deep (up to 993.9 m below ground level (BGL)) sections of the fractured rock groundwater system, generally just above the invert of the proposed subsurface engineered structures (ie tunnels, power station cavern, etc). The VWP sensors monitor hydrostatic pressure and can be converted to groundwater levels.

Monitoring bore locations are shown in Figure 3.5. Drilling and completion reports, providing a summary of drilling methodology, bore construction details, and equipment installation information, are included in Attachment C.

Table 3.7 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
	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	Siltstone/sandstone
	RSMB2	570	30.0	27.0–30.0	Siltstone/sandstone
	RSMB3	593	30.0	27.0–30.0	Siltstone/sandstone
	TMB01B	582	72.0	63.0–69.0	Siltstone

Table 3.7 Summary of groundwater monitoring bores

Target formation	Bore ID	Ground level (m AHD)[1]	Total depth (m BGL)	Screen interval (m BGL)	Target lithology
	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
	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 bores					
Boggy Plain Suite	PB03	1336	215.0	200.0–215.0	Granite
Gooandra Volcanics	PB04	1341	200.0	185.0–200.0	Chloritic schist
	TMB03C	1478	250.0	237.0–249.0	Chloritic schist
Kellys Plain Volcanics	PB01	1231	60.0	30.0–60.0	Dacite
Ravine Beds East	PB09	1330	300.0	200.0–300.0	Siltstone
Ravine Beds West	PB05	614	100.0	50.0–100.0	Siltstone
Tantangara Formation	PB06	1436	318.0	298.0–318.0	Sandstone
Temperance Formation	PB10	1382	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

Table 3.7 Summary of groundwater monitoring bores

Target formation	Bore ID	Ground level (m AHD)[1]	Total depth (m BGL)	Screen interval (m BGL)	Target lithology
	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
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.

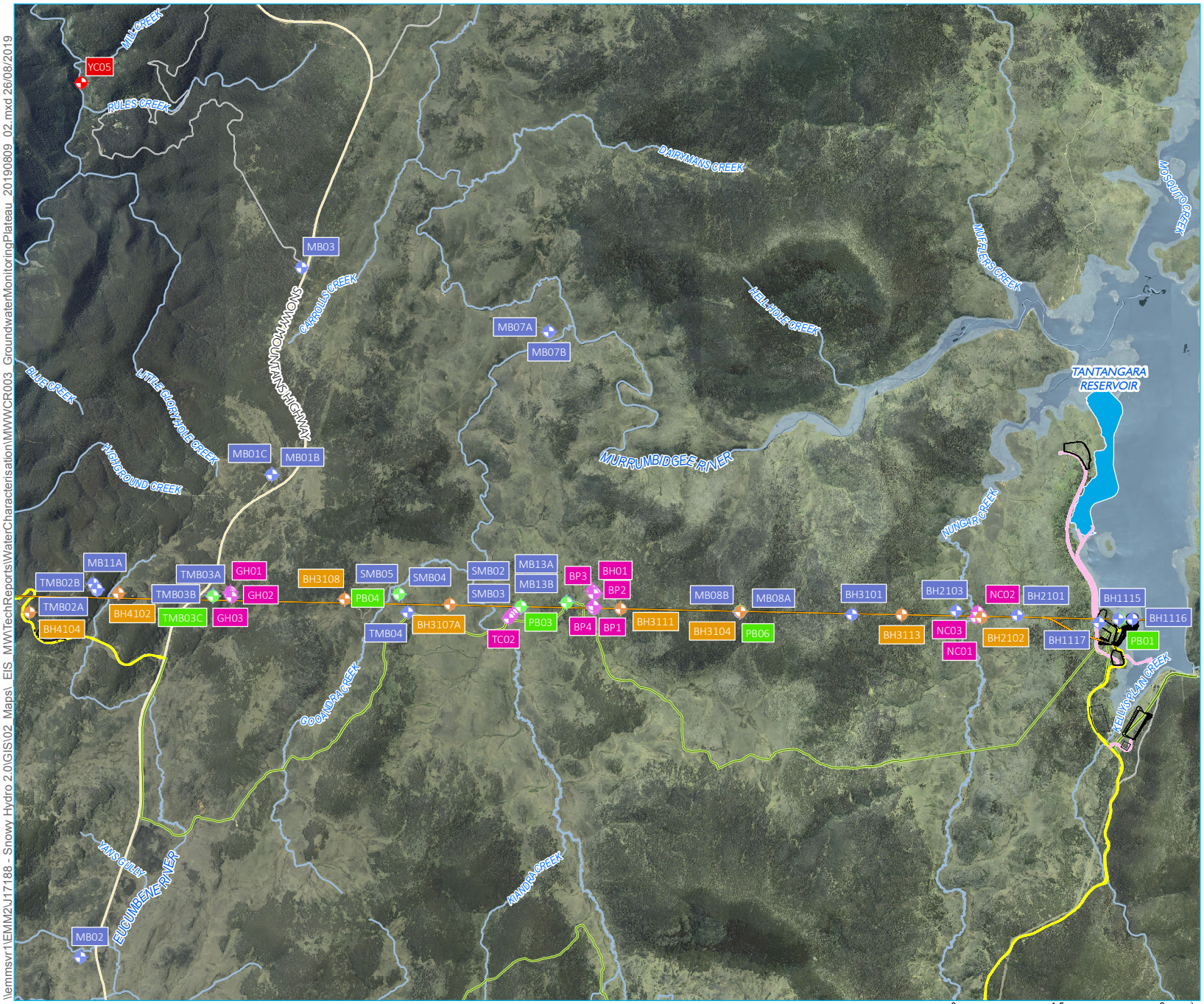
Table 3.8 Summary of Vibrating Wire Piezometers (VWPs)

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	1,369	90	998.8	998.0	620.0, 342.0, 250.0	Schist
	BH3111	1,502	90	406.4	406.4	354.6, 252.5, 120.5	Metasiltstone, Metasandstone
	BH4101	1,479	69	1176.1	1100.2	883.9, 729.6, 542.5	Metarhyolite
	BH4102	1,460	62	605.1	534.3	455.6, 374.3, 246.3	Gneiss, Phyllite
	BH4103	1,471	75	401.9	388.2	335.6, 232.2, 139.5	Metatuff, Tuff, Gneiss
Ravine Beds East	BH4104	1,484	77	941.0	916.9	628.4, 506.6	Siltstone
	BH5101A	1,390	81	1036.6	1023.8	248.0	Siltstone
	BH5102	1,329	87	951.5	950.2	818.8, 619.1, 419.4	Siltstone with Interbedded Mudstone/Sandstone
	BH5103	1,272	90	882.0	882.0	765.0, 562.0, 352.0	Tuff, Conglomerate, Interbedded Conglomerate and Sandstone
	BH5104A	1,187	82	856.3	848.0	673.3, 475.3, 376.3	Sandstone, Siltstone
	BH5107	1,162	90	774.4	774.4	737.5, 554.5, 381.4	Interbedded Siltstone and Sandstone
	BH5108	1,141	90	764.0	764.0	666.0, 431.0, 380.3	Siltstone
	BH5110	1,196	64	856.3	769.6	687.5, 435.4, 267.3	Sandstone, Conglomerate, Interbedded Siltstone and Sandstone
	BH5111	1,351	90	271.9	271.9	232.4, 180.7, 116.5	Interbedded Siltstone and Sandstone, Siltstone
	BH5114	1,287	61	601.9	526.4	491.9, 359.0, 208.5	Siltstone
	BH5115	1,330	90	789.0	789.0	292.0, 192.0	Siltstone
	BH8106	1,096	90	673.0	673.0	669.0, 431.0	Sandstone/Interbedded Siltstone and Sandstone
Ravine Beds West	BH6103	601	61	251.5	220.0	218.7, 131.2	Interbedded Siltstone and Sandstone
Tantangara Formation	BH2102	1,246	69	155.2	144.8	107.2, 41.8	Interbedded Metasiltstone and Metasandstone
	BH3104	1,436	90	339.0	339.0	287.0, 174.0, 72.9	Sandstone, Siltstone

Table 3.8 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
	BH3113	1,334	90	233.9	233.9	184.8, 94.9	Interbedded Metasandstone and Metasiltstone
Temperance Formation/Boggy Plain Suite	BH3106	1,335	79	256.8	252.1	194.3, 150.1	Pyroxenite, Diorite
Temperance Formation/Gooandra Volcanics	BH3107A	1,325	79	241.4	237.0	200.2, 133.5	Interbedded Siltstone and Sandstone

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



KEY

- Cave monitoring

Groundwater monitoring network

- Monitoring piezometer
- 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
- State boundary

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

0 1.5 3 km

GDA 1994 MGA Zone 55

N

Groundwater monitoring locations - plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.5b

snowy 2.0

EMM creating opportunities

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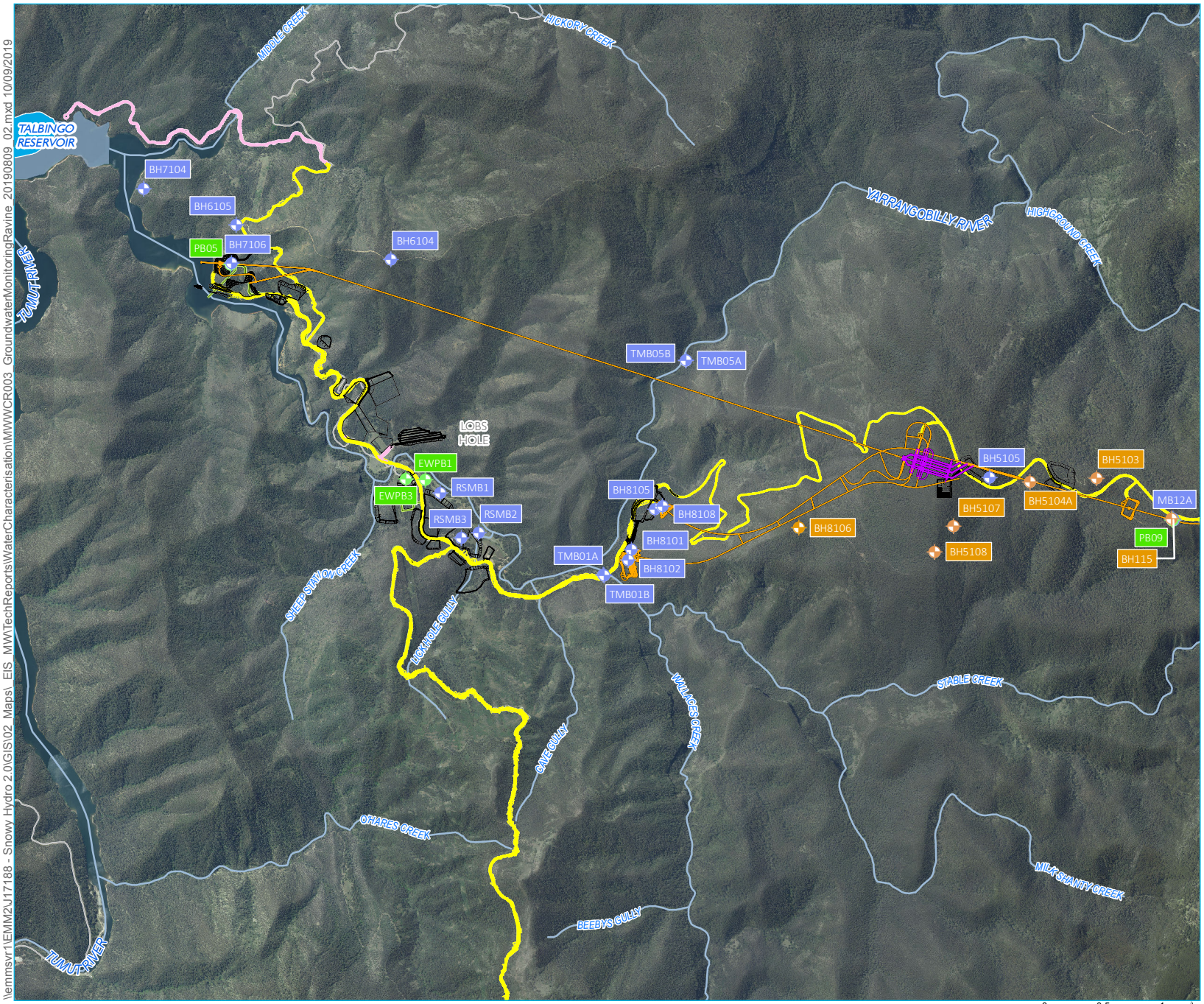

KEY

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

Groundwater monitoring locations - ravine

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.5a

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

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3.3.3 Hydraulic testing

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

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

The locations of hydraulic tests are shown in Figure 3.6. A summary of the methodology for each hydraulic test completed is provided below and further summarised in Table 3.9. The results of hydraulic testing are presented in Attachment C.

i Pumping tests

Pumping tests 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 are a direct and reliable method to obtain estimates of aquifer hydraulic properties, including storativity, transmissivity, and horizontal and vertical hydraulic conductivity. Pumping tests can also provide information on 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 tests. Groundwater level observations from the test and monitoring bores have been assessed using computer based 'AQTESOLVE' and 'MLU' algorithms for confined groundwater systems.

A total of 7 pump tests in 7 boreholes were completed as part of the Snowy 2.0 groundwater monitoring program.

ii Rising and falling head tests (slug tests)

Slug testing was completed in conventional groundwater monitoring bores and is used to estimate the bulk hydraulic conductivity, or rate of groundwater flow, in the immediate vicinity of the screened interval.

Slug testing involves installing an automated water level datalogger in the monitoring bore and lowering a slug (solid bailer) to instantly displace water in the bore. When the water level increases (falling head test) or decreases (rising head test) as a result of lowering or removing the slug from the bore, the change in water level is captured by the datalogger and the aquifer response used to calculate horizontal hydraulic conductivity.

A total of 78 slug test in 27 boreholes were completed as part of the Snowy 2.0 groundwater monitoring program.

iii Packer tests

Packer testing (also known as Lugeon testing) is an in situ method of testing the average hydraulic conductivity of a rock mass. 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 tests were completed following geotechnical drilling. Boreholes were flushed to remove drill fines to improve overall hydraulic results.

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 one litre of water per metre of the test interval under a constant pressure.

Packer testing is essentially a controlled falling head test. The accuracy of the test is limited by the act of forcing (injecting) water through the test section which can cause dilation and blocking of fractures as well as leakage between the packers and formation. In many boreholes, packer testing showed low or no flow during testing due to the very low permeabilities of the test formations.

A total of 49 packer tests in 9 boreholes were completed as part of the Snowy 2.0 groundwater monitoring program.

iv Drill stem tests

Drill stem tests provide an estimate of horizontal hydraulic conductivity across an isolated section of an aquifer (test section) within a borehole. The test section is isolated using pneumatic or hydraulic inflatable packers fitted to the drill stem that encase a wireline tool which is fitted with a series of valves that control the release of fluid and air. The drill stem is lowered into the borehole and is set at the test depth, followed by the packer and wireline tool. DST tests were completed following geotechnical drilling. Boreholes were flushed to remove drill fines to improve overall hydraulic results.

Compressed air is introduced to push down the water level in the drill stem creating a displacement. When the desired, or maximum, displacement is achieved, the compressed air is released and the water level in the drill stem allowed to return to equilibrium. The aquifer response to the test is measured using an automated logger and the data is used to estimate the horizontal hydraulic conductivity of the test section.

DST's are essentially large-scale rising head tests, causing a greater displacement and stressing the test section/aquifer more readily than a slug or packer test. Towards the end of the geotechnical drilling program, DST testing was preferred over packer testing because the method was better suited to the low permeabilities observed in many of the formations being tested.

A total of 25 DST's in 12 boreholes were completed as part of the Snowy 2.0 groundwater monitoring program.

Table 3.9 Summary of hydraulic test analysis by formation

Geological unit	Test method	No. of tests	Bore ID	Approximate test depth range[1] (m BGL)
Bullocks Hill Bog	Slug test	2	BH01, BH03	0.4–0.9
Gooandra Hill Bog	Slug test	12	GH01, GH02, GH03	0.6–1.0
Tantangara Creek Bog	Slug test	3	TC01, TC02, TC03	0.8–1.1
Boggy Plain Suite	Pumping test	1	PB03 (SMB02, SMB03)[2]	49.0–215.0
Boraig Group	Slug test	4	TMB01A	14.0
	DST	1	BH5105C[3]	675.0
Gooandra Volcanics	Slug test (shallow)	3	TMB02A	14.0
	Slug test (deep)	20	TMB02B, MB01C, MB02, MB03, TMB04	51.0–197.0
	Pumping test	2	PB04 (SMB04, SMB05) [2] TMB03C (TMB03A, TMB03B)[2]	32.5–249.0

Table 3.9 Summary of hydraulic test analysis by formation

Geological unit	Test method	No. of tests	Bore ID	Approximate test depth range[1] (m BGL)
	DST	5	BH3110, BH3111, BH4106	209.0–402.0
Kellys Plain Volcanics	Pumping test	1	PB01 (BH1115, BH1116)[2]	51.0–89.5
	Packer test	9	BH1115, BH2101	23.0–181.0
Ravine Beds West	Slug test (shallow)	4	TMB05A	18.0
	Slug test (deep)	2	TMB01B, TMB05B	69.0–74.0
	Pumping test	1	PB05 (BH7106) [2]	100.0–154.0
Ravine Beds East	DST	16	BH4105[3], BH5107, BH5110, BH5111, BH5113C[3], BH5114, BH5115	169.0–794.0
	Pumping test	1	PB09 (MB12A, MB12B)[2]	36.0–300.0
Tantangara Formation	Slug test (shallow)	10	MB08A	29.0
	Slug test (deep)	2	PB06, MB08B	297.0–318.0
	Packer test	23	BH2102, BH2103, BH3101, BH3104	105.0–339.0
	DST	2	BH3113	184.0-231.7
Temperance Formation	Slug test (shallow)	5	MB04A, MB07A	13.0–29.0
	Slug test (deep)	6	MB04B, MB07B, MB13B	57.0–189.0
	Pumping test	1	PB10 (MB13A, MB13B, BH3102) [2]	60.0–230.0
	Packer test	17	BH3102, BH3106, BH3107A	194.0–290.0
Tertiary basalt	Slug test	5	MB01B	6.8

Notes: 1. Bottom of screened/open section.
2. Boreholes shown in brackets used as observation bores during pumping tests.
3. Backfilled geotechnical bore hole.

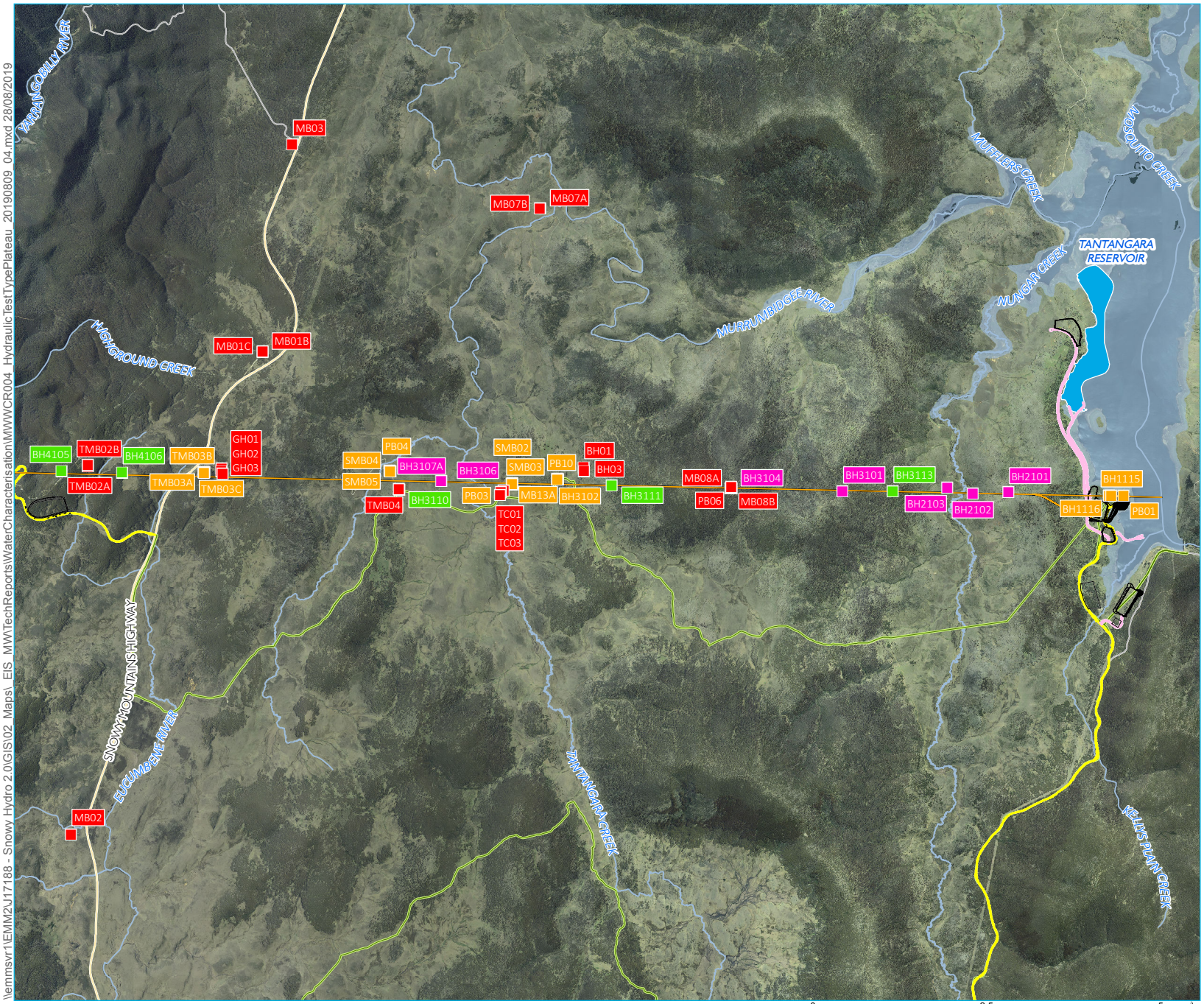
3.3.4 Groundwater level monitoring

Project specific groundwater level monitoring commenced in September 2017, following the installation 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 3.7 and Table 3.8).

Groundwater level is monitored via automated dataloggers (installed in monitoring bores) and VWP pressure sensors. Groundwater level dataloggers in monitoring bores are programmed to record both temperature and total pressure (both atmospheric pressure and hydrostatic pressure) at six-hourly intervals. VWP sensors record hydrostatic pressures at six-hourly intervals.

Total pressures recorded by monitoring bore dataloggers are compensated for atmospheric pressure changes using barometric loggers installed at PB01, TMB03C, TMB01A and YC05. The barometric loggers provide sufficient spatial coverage at representative elevations to capture barometric fluctuations across the project area. All dataloggers and VWP sensors are downloaded monthly and groundwater levels are verified with manual water 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 3.7. A summary of groundwater level monitoring for VWPs and drive point/narrow piezometers is provided in Figure 3.8.



KEY

Hydraulic test type
- DST
- Packer test
- Pump test
- Slug test

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
- State boundary

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

Summary of hydraulic tests - plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.6b

snowy 2.0

EMM creating opportunities

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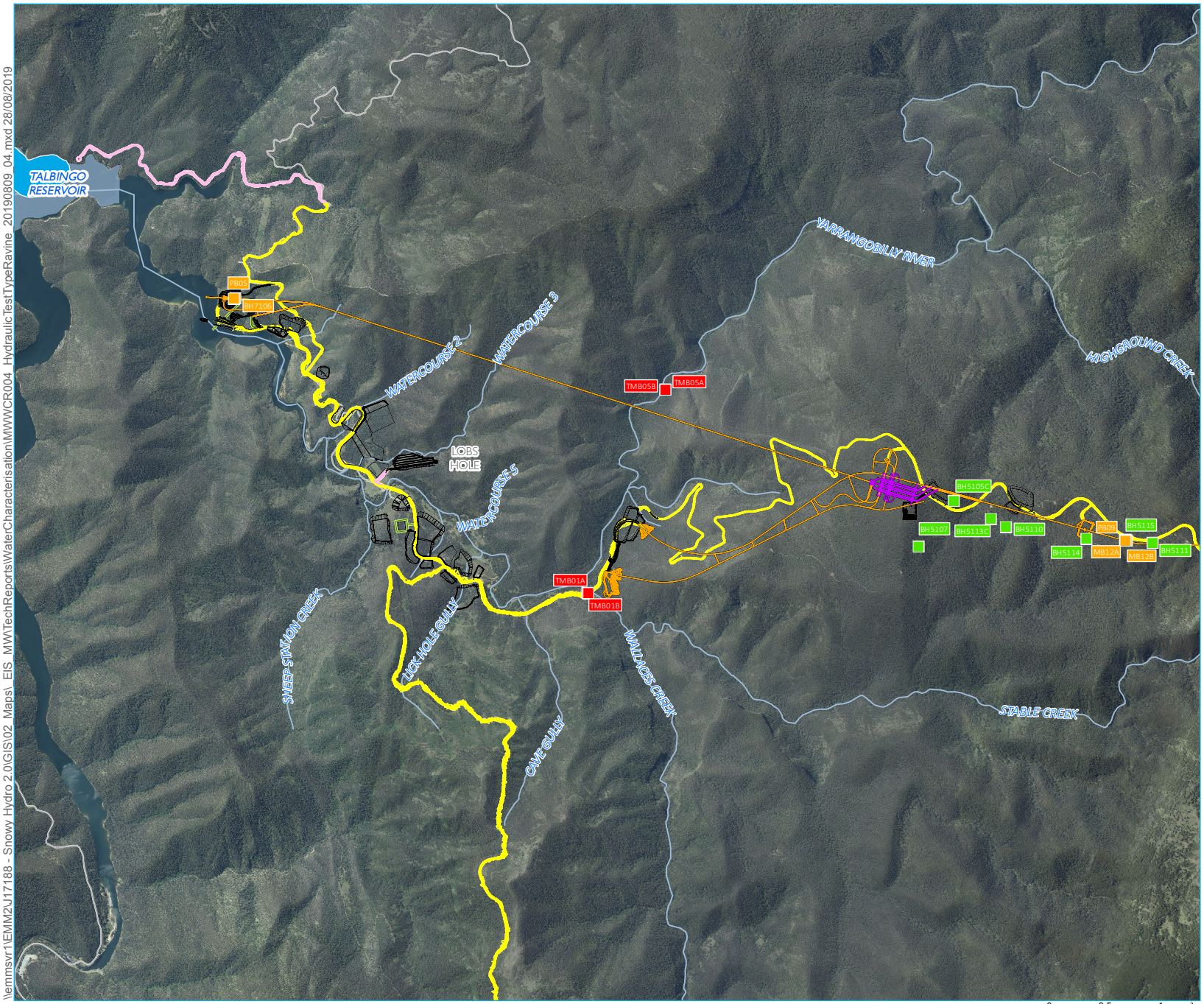

KEY

Hydraulic test type
- DST
- Pump test
- Slug test

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
- 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

Summary of hydraulic tests - ravine

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.6a

snowy 2.0

EMM creating opportunities

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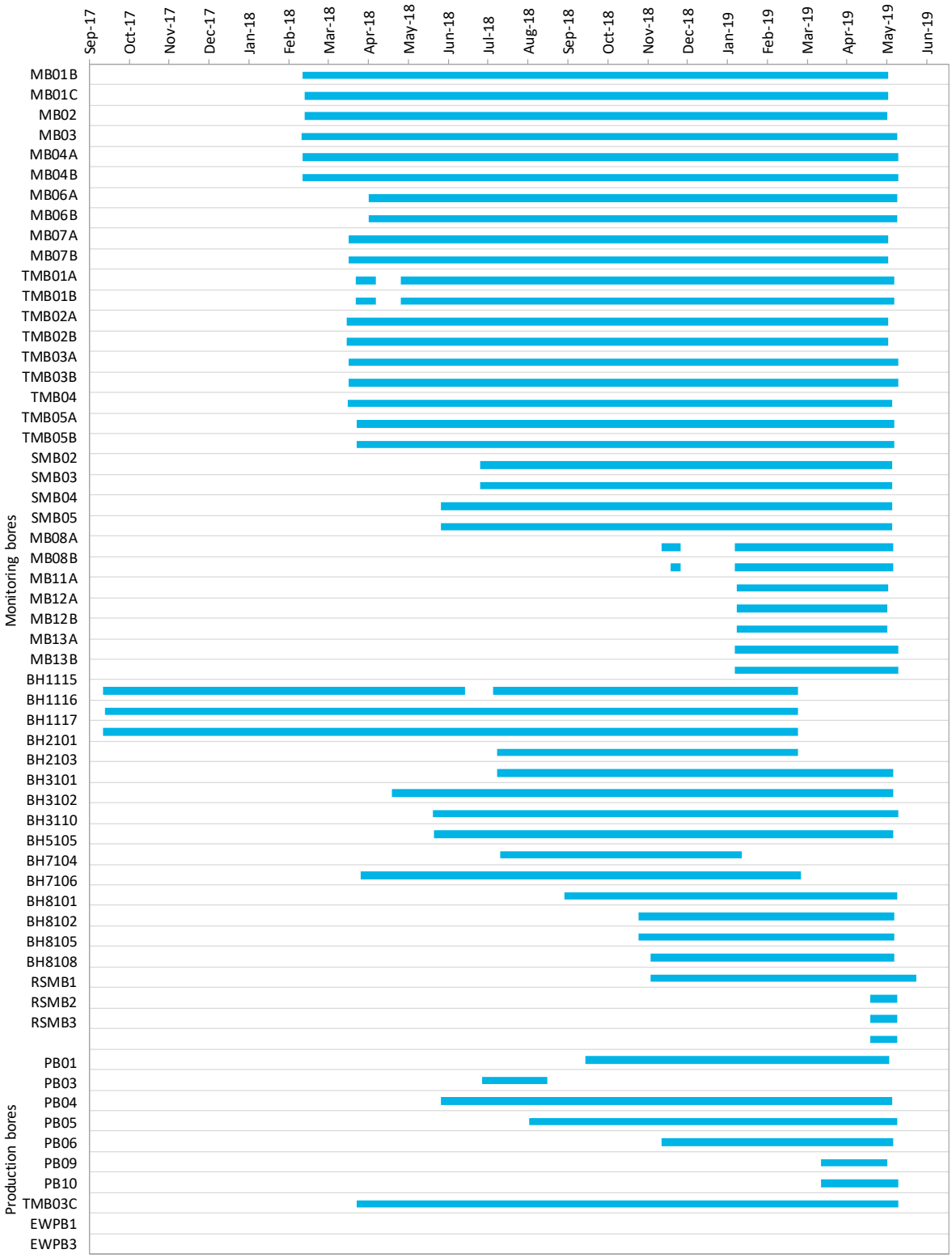


Figure 3.7 Conventional monitoring bores – groundwater monitoring overview

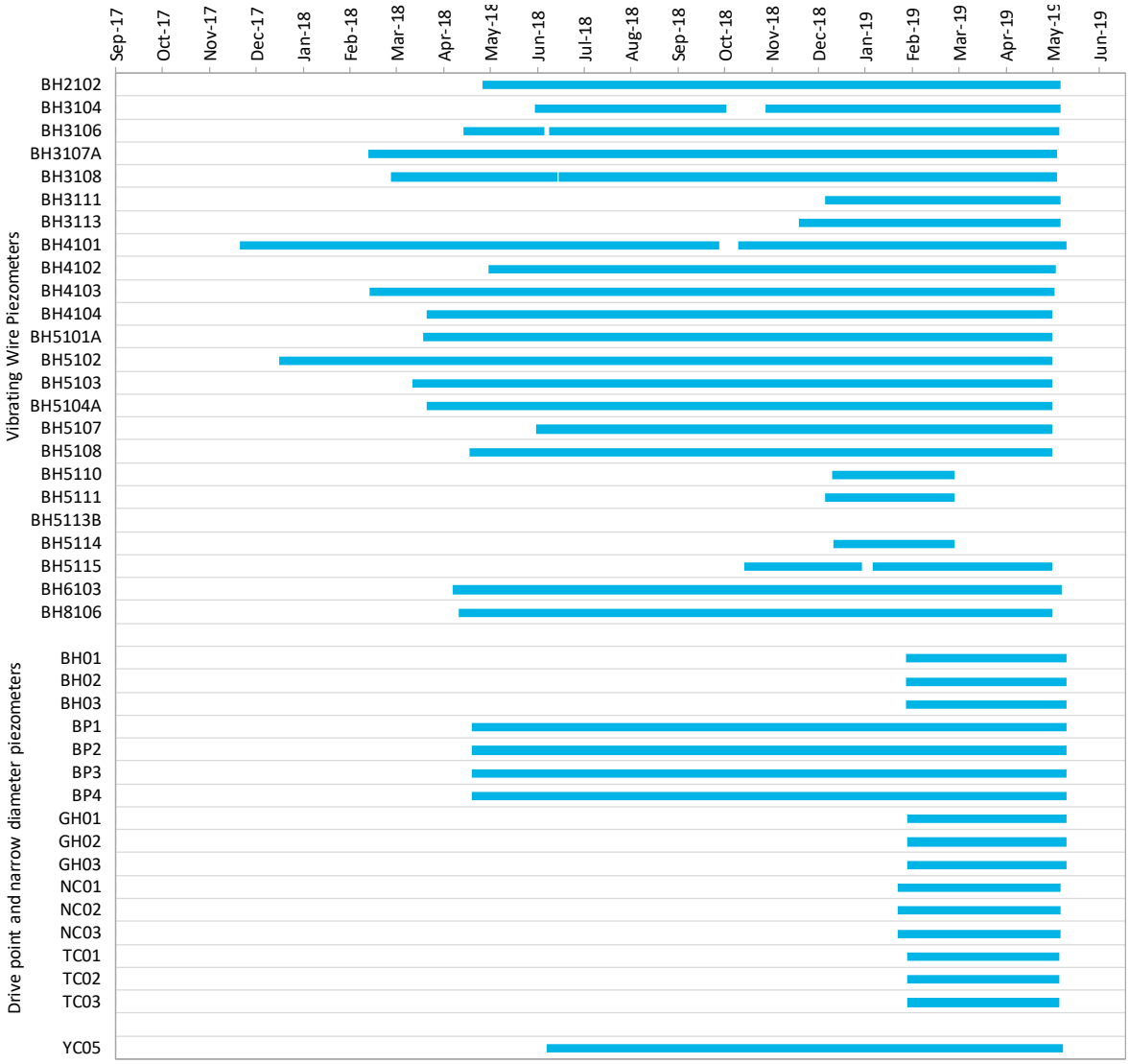


Figure 3.8 **Vibrating Wire Piezometers – groundwater monitoring overview**

3.3.5 Groundwater quality monitoring

A baseline groundwater quality monitoring program commenced in February 2018 following the installation of MB01 and has been progressively expanded as new bores have been installed.

Groundwater sampling is undertaken at a monthly frequency (access dependent) in conjunction with surface water sampling (see Section 3.2.3) 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 used to collect groundwater samples via low-flow sampling methods. Stabilisation of physico-chemical parameters (pH, temperature, electrical conductivity, dissolved oxygen, total dissolved solids and redox potential) and groundwater levels monitored during low-flow sampling indicates when groundwater samples representative of the target formation can be collected. This method is efficient and greatly reduces purging volumes and installed pumps can sample to depths of 300 m BGL.

Water quality samples for laboratory analysis are collected in laboratory provided sample bottles. All samples requiring dissolved metal analysis are filtered through a 0.45 µm membrane filter prior to collection. Samples are then stored on ice and sent to the laboratory under appropriate chain-of-custody protocols.

The analytes and analysis methods that were applied to the groundwater monitoring program are described in Table 3.10. A record of monitoring events is shown in Figure 3.9.

Table 3.10 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	Ca, Cl, Mg, Na, K, SO_{4-}	
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	

	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19
Monitoring bores																
BH8101												●				
BH8102												●				
MB01B	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
MB01C		●	●		●	●	●	●	●	●	●	●	●	●	●	●
MB02	●	●	●		●		●	●	●	●	●	●	●	●	●	●
MB03	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
MB04A	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●
MB04B	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●
MB06A			●		●	●	●	●	●	●	●	●	●	●	●	●
MB06B			●		●	●	●	●	●	●	●	●	●	●	●	●
MB07A		●	●				●	●	●	●	●	●	●	●	●	●
MB07B		●	●				●	●	●	●	●	●	●	●	●	●
MB08A														●	●	
MB08B										●		●	●	●	●	●
MB11A												●	●	●	●	●
MB12A												●	●	●	●	●
MB12B												●	●	●	●	●
MB13A										●		●	●	●	●	●
MB13B										●		●	●	●	●	●
SMB02							●	●	●	●	●	●				
SMB03							●	●	●	●	●	●				
SMB04							●	●	●	●	●	●				
SMB05							●	●	●	●	●	●				
TMB01A			●		●			●	●	●	●	●	●	●	●	●
TMB01B			●		●			●	●	●	●	●	●	●	●	●
TMB02A		●	●	●	●		●	●	●	●	●	●	●	●	●	●
TMB02B		●	●	●	●		●	●	●	●	●	●	●	●	●	●
TMB03A	●	●	●		●		●	●	●	●	●	●	●	●	●	●
TMB03B	●	●	●		●		●	●	●	●	●	●	●	●	●	●
TMB04		●	●	●	●		●	●		●	●	●	●	●	●	●
TMB05A		●				●			●	●				●	●	●
TMB05B		●				●			●	●				●	●	●
Production bores																
PB01						●		●	●	●	●	●				
PB03																
PB04							●	●	●	●	●	●				
PB05								●	●	●	●	●				
PB06																●
PB09												●		●	●	●
PB10														●	●	●
TMB03C							●	●	●	●	●	●	●	●	●	●
EWPB1														●		
EWPB3															●	

● Groundwater sampling event

Figure 3.9 Groundwater quality sampling events

3.4 Yarrangobilly Caves

3.4.1 Monitoring network

Water level monitoring at Yarrangobilly Caves (see Figure 3.8) commenced in June 2018. Water level data is measured from within a cave pool at Ravine Cave (YC05) via a stilling well which has been equipped with an automated logger. The purpose of the installation is to capture baseline cave pool fluctuations in response to recharge and "flushing" events. The logger is programmed to measure hydrostatic pressure at 15-minute intervals. The Yarrangobilly Caves water level monitoring location is shown in Figure 3.5.

Water quality monitoring at Yarrangobilly Caves commenced in July 2018 from the following locations:

- two springs discharging downstream of the cave system, adjacent to the Yarrangobilly River (YC01 and YC02);
- two minor watercourses upstream of the cave system (YC03 and YC04);
- a cave pool, within Ravine Cave (YC05); and
- a site on Yarrangobilly River downstream of the cave system (YC06).

The water quality monitoring suite for the Yarrangobilly Caves monitoring sites is consistent with the analytes listed in Table 3.10. The record of water quality monitoring at Yarrangobilly Caves is shown in Figure 3.10. Yarrangobilly Caves water quality monitoring locations are shown in Figure 3.1.

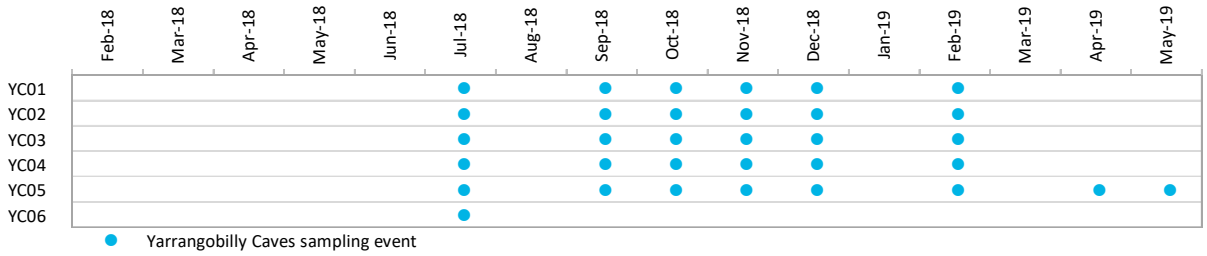


Figure 3.10 Yarrangobilly Caves water quality sampling events

3.5 Field investigations

The following field investigations were completed between June 2018 and May 2019:

- a geomorphic characterisation assessment;
- a groundwater spring survey focused on the plateau; and
- a geophysical investigation.

Each field survey is described further below.

3.5.1 Geomorphology survey

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 – 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.

Assessment areas are indicated in Figure 3.11.

The assessment was undertaken using a modified 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 Chapter 7. The technical report prepared by Flow and Loam Environmental (2019) is provided in Attachment A.

3.5.2 Groundwater spring survey

Groundwater spring surveys were undertaken by EMM in February and April 2019. The objective of the surveys was to locate and characterise the extent of groundwater expression at the surface during summer and autumn conditions, when groundwater discharge is the predominant source of streamflow. The surveys were undertaken during dry conditions within the predicted approximate groundwater drawdown extent. The survey area is indicated in Figure 3.11.

Observed groundwater surface expressions were characterised into one of the following three types:

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

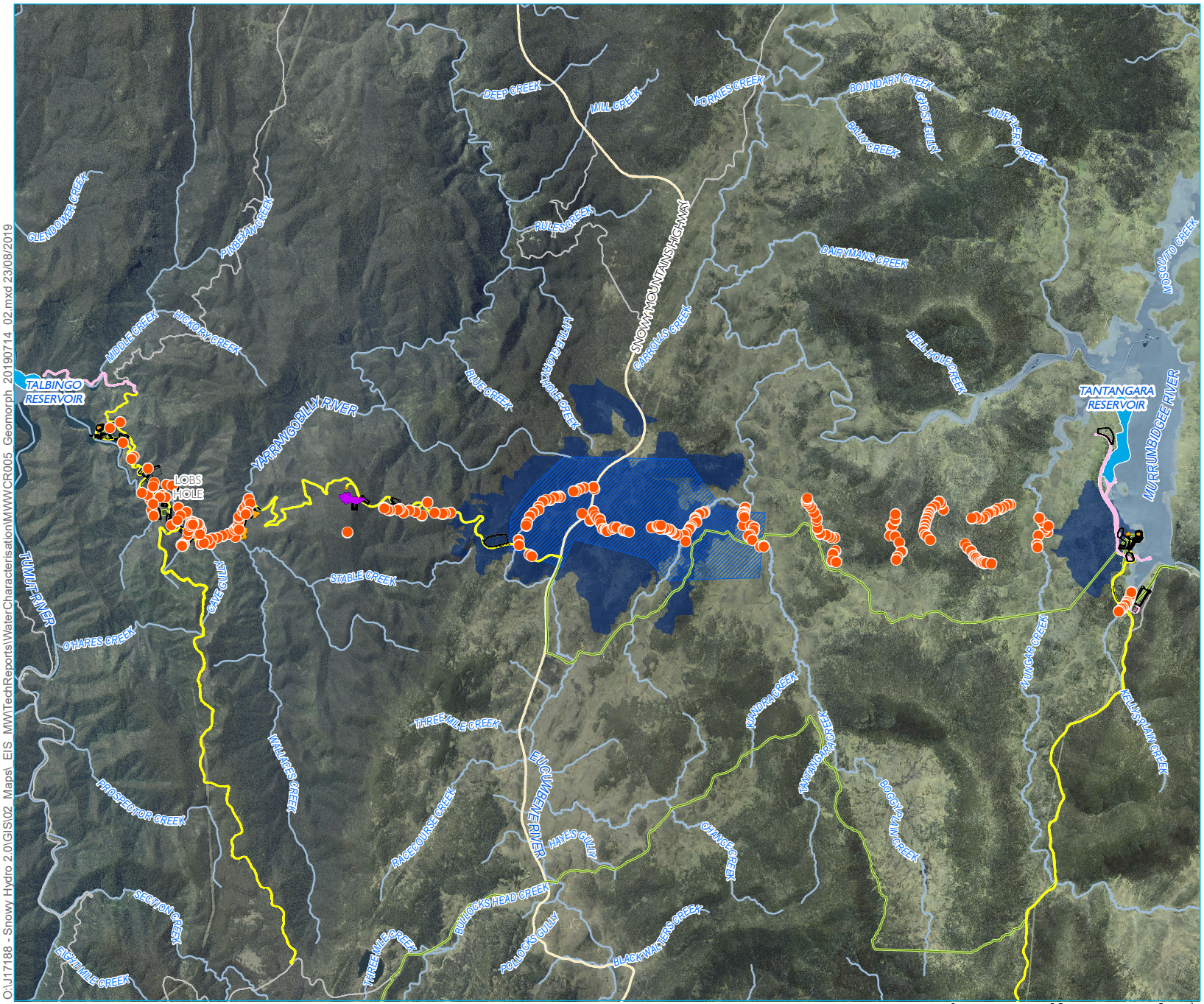
The results of the groundwater spring survey are described in Section 7.2.1.

3.5.3 Geophysical survey

A gravity and magnetics (geophysical) survey was undertaken by SMEC (2019). The purpose of the investigation was to identify and broadly characterise subsurface geologic structure intercepted by the proposed project alignment, specifically across the plateau.

The survey relied on a combination of publicly available regional data, provided by Geoscience Australia, and site-specific survey information. The survey was completed using a geophysical technique that measures differences in gravitational acceleration due to density variations in subsurface rocks at different locations. The observed gravity anomaly (if present) can then be interpreted to characterise structural deformation (ie faulting) and intrusive conditions.

The outcomes of the geophysical investigation are summarised in Section 5.2.2. The technical report prepared by SMEC (2019) is provided in Attachment B.



KEY

- Geomorphology field assessment location
- Groundwater spring survey area
- Approximate groundwater drawdown extent

Snowy 2.0 operational elements

- 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
- State boundary

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

Geomorphic and groundwater spring survey locations

Snowy 2.0
Water Characterisation Report
Main Works
Figure 3.11

snowy 2.0

EMM creating opportunities

O:\J17188 - Snowy Hydro 2.0\GIS\02 Maps\ EIS MW\TechReports\WaterCharacterisation\MWWCR005 Geomorph 20190714 02.mxd 23/08/2019

4 Climate – physical setting

4.1 Overview

The climate of the Australian Alps is heavily influenced by three features of the general circulatory system affecting South Eastern Australia (Brown and Millner 1988):

- the latitudinal position of the westerly airstream that encircles the southern hemisphere;
- the influence of depressions lying off the east coast of NSW; and
- the occasional intrusion of moist tropical air masses from northern Australia.

In general, in winter and spring there is a predominance of westerly weather that results in regular precipitation on the western slopes. Precipitation depths increase in the alpine areas due to orographic effects. From late autumn to early spring, precipitation at higher elevations predominantly occurs as snow. Snow cover usually begins to form in the highest areas in late autumn. By the middle of June, areas above 1,500 m AHD are usually covered. Snow cover usually peaks in August and begins to melt in late winter through to early spring (Brown and Millner 1988).

Summer and autumn are generally drier with the weakening of the westerly circulation. However, there are occasional intrusions of moist air which results in thunderstorm activity that tends to favour the eastern slopes. Summer rainfall is generally of higher intensity and of shorter duration than winter rainfall (Brown and Millner 1988).

The following sections provide further information on climate characteristics across the project area.

4.2 Rainfall

4.2.1 Available data

i Rainfall gauge data

This section describes rainfall characteristics for the project area using available information from regional BoM and Snowy Hydro rainfall gauges, and rainfall maps that are also produced by BoM. Rainfall characteristics are relevant to understanding streamflow and groundwater recharge regimes. It is noted that some rainfall will occur as snowfall and should correctly be referred to as precipitation. However, the term rainfall has been used to maintain consistency with other sections of the EIS.

The following rainfall gauges are in the vicinity the project area and provide the best available information within the catchment:

- Talbingo (72131) – within the township of Talbingo, approximately 3.5 km to the north of the Tumut 3 Power Station and 26 km to the north-west of Lobs Hole.
- Cabramurra SMHEA AWS (72161) – approximately 8 km to the south-west of the head waters of Wallaces Creek, which is a major tributary to the Yarrangobilly River catchment. The gauge is 17 km and 19 km to the south of Lobs Hole and Marica respectively.
- Yarrangobilly Caves (72141) – located centrally in the Yarrangobilly River catchment, approximately 6.5 km to the north of Marica.

- Adaminaby Alpine Tourist Park (71000) – located within the township of Adaminaby, 10 km west of Rock Forest and 25 km to the south-east of Tantangara Reservoir.
- Adaminaby (Yaouk) (71040) – located 23 km north of the township of Adaminaby, 14 km east of Tantangara Reservoir.
- Ravine (Snowy Hydro operated) – located within Lobs Hole, approximately 3 km south-east of Talbingo Reservoir.
- Tantangara Reservoir (00185, Snowy Hydro operated) – located 1.5 km to the south-west of Tantangara Reservoir dam wall and near the proposed Tantangara Adit.

The location of each of the above rainfall gauges relative to the project area is shown in Figure 4.1. Median annual rainfall depth contours sourced from BoM's online climate maps are also shown. Key information and statistical data for the seven rainfall gauges is presented in Table 4.1.

Table 4.1 Rainfall statistics

Rainfall[1] statistic	Units	Talbingo[2] (72131)	Cabramurra SMHEA AWS[2] (72161)	Yarrangobilly Caves[2] (72141)	Adaminaby Alpine Tourist Park[2] (71000)	Adaminaby (Yaouk)[2] (71040)	Ravine (Lobs Hole)[3]	Tantangara Reservoir[3] (00185)
Rainfall record		1997-ongong	1996-ongoing	1906-1919 1978-ongoing	1886-ongoing	1969-1972 1987-ongoing	1992-ongoing	1991-ongoing
Elevation	m AHD	395	1,482	980	1,015	1,140	580	1,237
Average rainfall	mm/year	952	1,179	1,164	689	897	920	1,009
Lowest rainfall	mm/year	361	567	552	302	550	382	579
5th percentile rainfall	mm/year	663	896	820	427	600	616	788
10th percentile rainfall	mm/year	771	1,001	907	506	716	720	807
Median rainfall	mm/year	946	1,204	1,158	689	874	878	997
90th percentile rainfall	mm/year	1,220	1,385	1,507	868	1,181	1,245	1,255
95th percentile rainfall	mm/year	1,313	1,414	1,534	953	1,215	1,298	1,322
Highest rainfall	mm/year	1,343	1,634	1,902	1,152	1,219	1,315	1,383

Notes: 1. Some precipitation will occur as snow fall but has been referred to as rainfall to maintain consistency with other sections in the EIS.
2. Data sourced from BoM website (climate data online).
3. Data provided by Snowy Hydro.

The median annual rainfall depth contours shown in Figure 4.1 indicate that median rainfall within ravine ranges from 920 mm/year at Lobs Hole to 1,400 mm/year in the head water catchments. The spatial variation in median rainfall generally reflects the variation in topography within the catchment. The median annual rainfall depth contours are consistent with median values from the Talbingo, Ravine, Cabramurra SMHEA AWS and Yarrangobilly Caves rainfall gauges. This information indicates that:

- Streamflow in the Yarrangobilly River is likely to be primarily influenced by runoff from the headwater catchments that receive higher rainfall, rather than runoff from lower portions of the catchment around Lobs Hole.

- The median annual rainfall at Ravine is similar to median annual rainfall at Talbingo, indicating that rainfall characteristics at Lobs Hole and Talbingo are likely to be similar. Due to proximity, the Ravine rainfall gauge record is the most reliable representation of rainfall characteristics at Lobs Hole.

- The median annual rainfall at Marica is similar to median rainfall at Yarrangobilly Caves, indicating that rainfall characteristics at Marica and Yarrangobilly Caves are also likely to be similar. Accordingly, Yarrangobilly Caves rainfall gauge (72141) record is the most reliable representation of rainfall characteristics at Marica.

Figure 4.1 shows there is less spatial variation in median annual rainfall across the plateau. Median rainfall ranges from 1,150 mm/year at Tantangara Reservoir to 1,350 mm/year at localised topographical high points. The median annual rainfall depth contours are consistent with median values from the Cabramurra SMHEA AWS and Yarrangobilly Caves rainfall gauges but are higher than the median values from the Tantangara Reservoir rainfall gauge.

Due to proximity, the Tantangara Reservoir gauge (00185) record is the most reliable representation of rainfall characteristics at the Tantangara Adit. Rainfall characteristics across the plateau are likely to be similar to those at Cabramurra SMHEA AWS and Yarrangobilly Caves. However, significant spatial variation may occur for any given event.

Adaminaby Alpine Tourist Park is considered to be the most reliable representation of rainfall records at Rock Forest due to length of record and proximity to the site.

ii SILO climate database

SILO (Scientific Information for Land Owners) is a database of Australian climate data (Queensland Government 2019). Rainfall data is available in the following formats:

- Patched point data: SILO provides a daily time series of data at a point location consisting of station records which have been supplemented by interpolated estimates when observed data is missing (SILO website). Patched datasets have been used to fill in periods of missing data from rainfall gauge records.

- Data drill: a daily time series of data at a point location consisting entirely of interpolated estimates. The data is taken from gridded datasets and is available at any grid point over the land area of Australia (SILO website). Daily time series extracted from data drill have been used for some modelling purposes.

Data extracted from SILO has been reviewed for consistency with regional rainfall gauges prior to use.

KEY

- Rainfall gauges
- Median annual rainfall contour (mm)
- Catchment

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
- State boundary

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

Rainfall across the project area

Snowy 2.0
Water Characterisation Report
Main Works
Figure 4.1

snowy 2.0

EMM creating opportunities

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4.2.2 Seasonal trends

The 10th, 50th and 90th percentile monthly rainfall depths have been calculated by BoM from the Talbingo (72131) and Yarrangobilly Caves (72142) gauge records and are presented in Figure 4.2 and Figure 4.3 respectively. This information indicates that the highest and most consistent rainfall occurs in winter to early spring. Rainfall in summer is more variable with significant differences between the 10th and 90th percentile monthly rainfall depths.

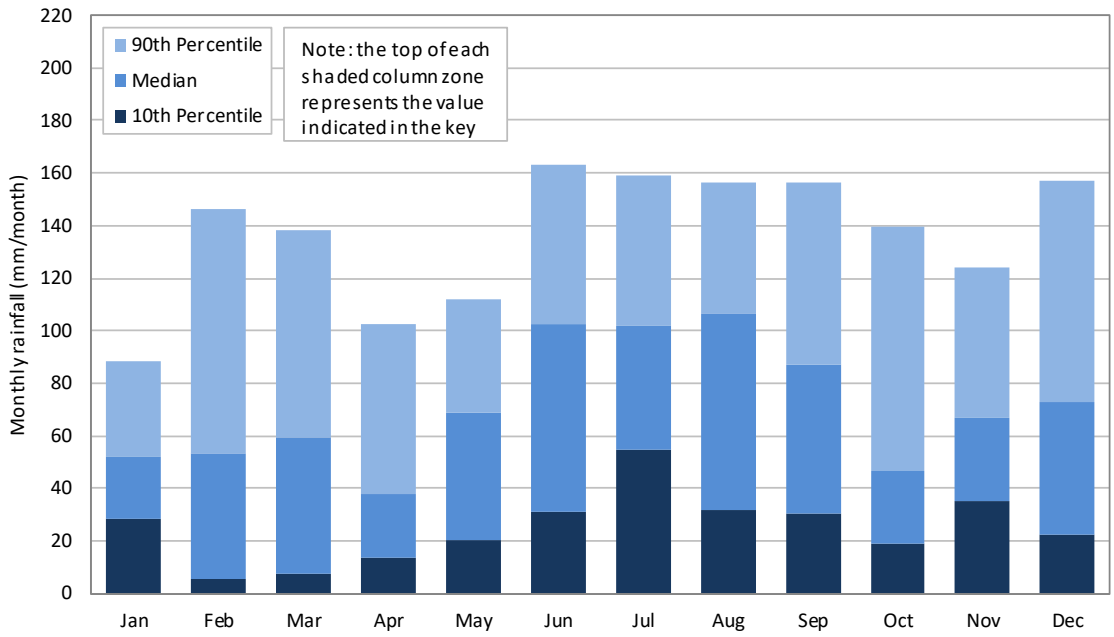


Figure 4.2 Monthly rainfall variability at Talbingo (BoM: 72131) rainfall gauge

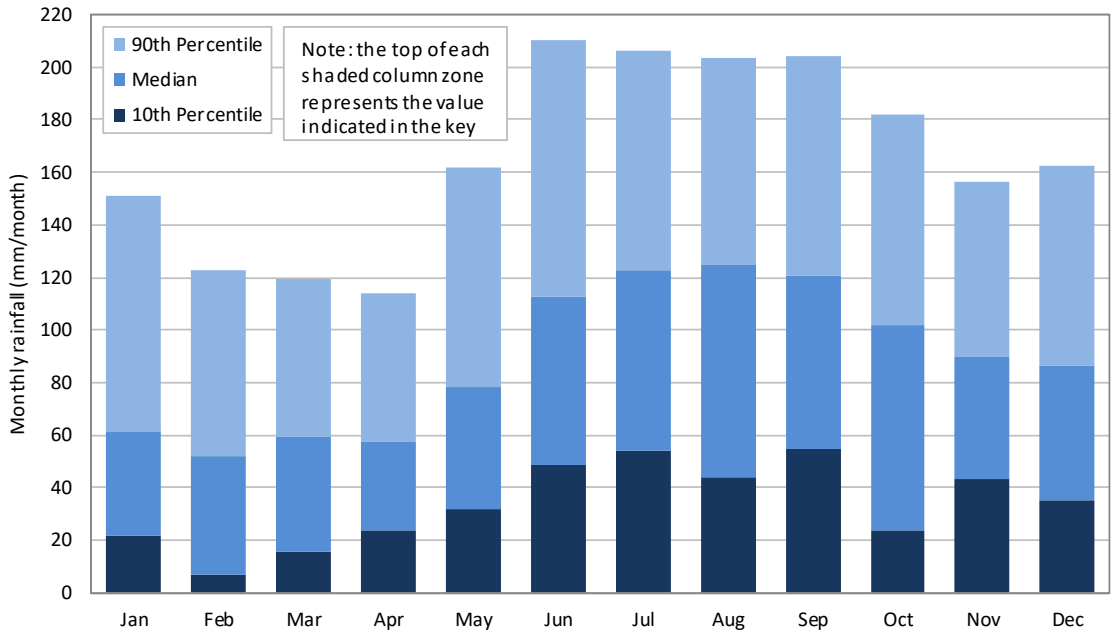


Figure 4.3 Monthly rainfall variability at Yarrangobilly Caves (BoM: 72141) rainfall gauge

4.2.3 Recent rainfall

Monthly rainfall totals recorded at Ravine, Yarrangobilly Caves and Adaminaby Alpine Tourist Park from 1999 to present are shown in Figure 4.4, Figure 4.5 and Figure 4.6 respectively.

The deviation of monthly 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. The magnitude and extent of wet and dry periods can be inferred by the shape and value of the deviation curve. A positive deviation relates to wetter than average conditions while a negative deviation relates to a drier than average conditions. These deficits and excess in rainfall can also correspond to long-term groundwater level and streamflow trends.

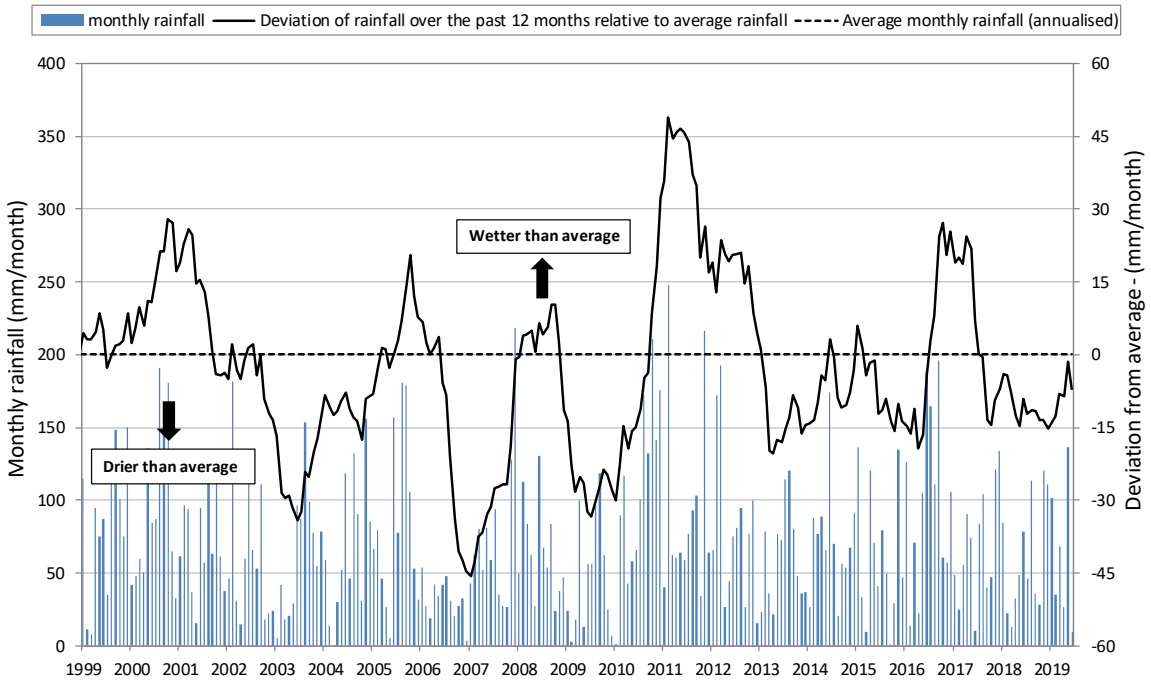


Figure 4.4 Ravine rainfall over the 1999 to 2019 period

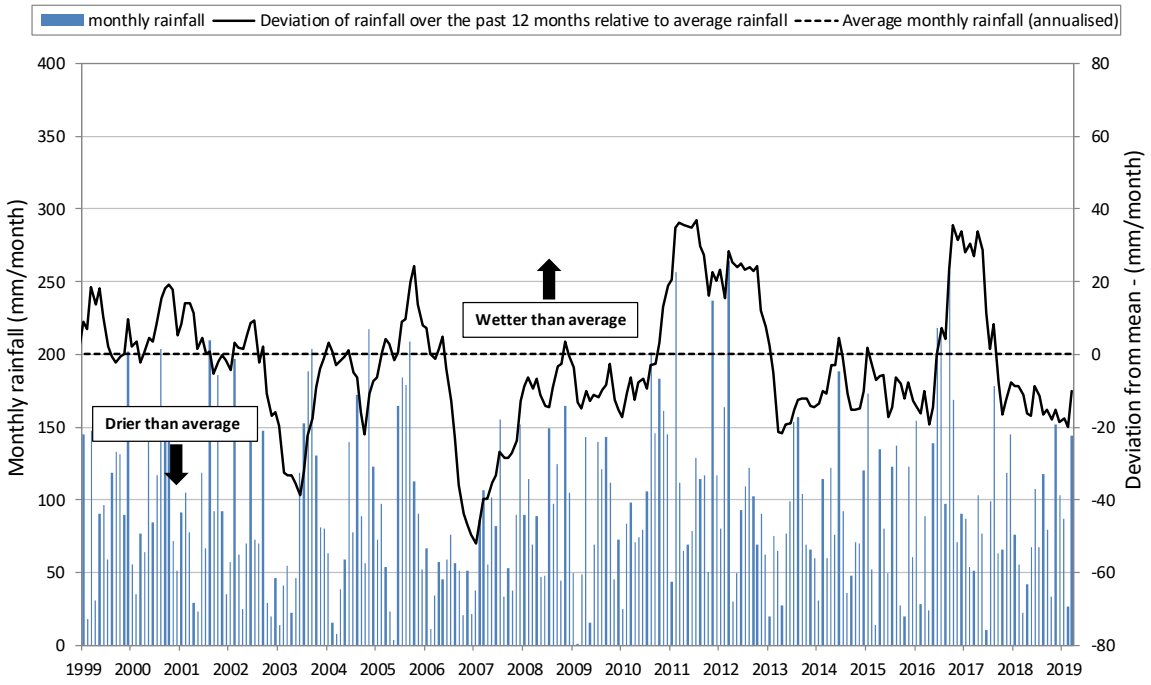


Figure 4.5 Yarrangobilly Caves rainfall over the 1999 to 2019 period

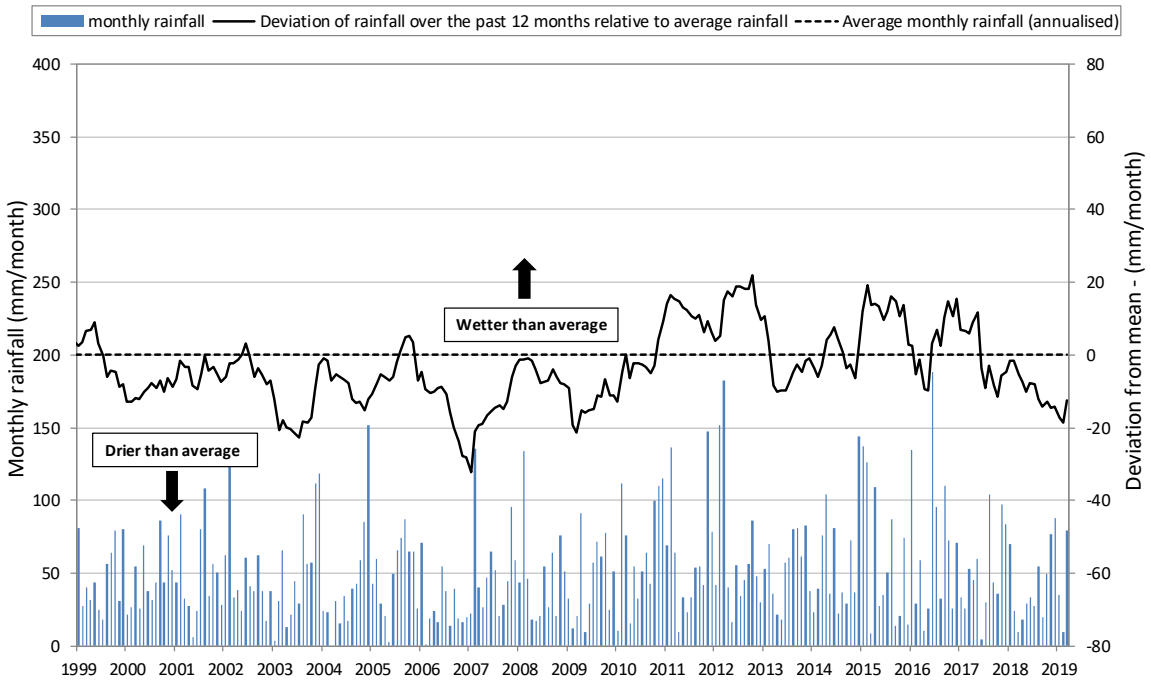


Figure 4.6 Adaminaby Alpine Tourist Park rainfall over the 1999 to 2019 period

The rainfall trends in Figure 4.4, Figure 4.5 and Figure 4.6 indicate that:

- Below average rainfall occurred during the mid-2002 to late 2003, mid-2004 to early 2005, mid-2006 to late 2010, 2013 to mid-2016, and mid-2017 to mid-2019 periods. The most significant negative deviation from average conditions occurred during the mid-2006 to 2010 period. Abnormally low streamflows occurred during this period (see Chapter 7).

- Above average rainfall occurred during the 1999 to mid-2002, mid-2005 to mid-2006, late 2010 to 2013, and mid-2016 to mid-2017 periods.

- Comparable trends were experienced at the three gauges.

Data collected for this EIS during 2018 and early 2019 was collected during drier than average conditions.

4.2.4 Design rainfall

Design rainfall information is used to inform an understanding of flooding potential and to calculate aspects of stormwater and flood risk management systems. The following design rainfall information has been established for Lobs Hole, Tantangara Reservoir, Marica, and Rock Forest:

- Design rainfall depths for a range of Annual Exceedance Probability (AEP) events of varying duration. This information was sourced from the Australian Rainfall and Runoff 2016 data portal (Babister, Trim, Testoni & Retallick 2016).

- Rainfall depths for 2, 5, 10 and 20-day rainfall events. This information was calculated from the rainfall record at the most representative rainfall gauge (see Section 4.2.1) at each location.

The following sections present design rainfall information for Lobs Hole, Tantangara Reservoir, Marica, and Rock Forest.

i Lobs Hole

Design rainfall depths for a range of AEP events at Lobs Hole are provided in Table 4.2. Rainfall depths for 2, 5, 10 and 20-day rainfall events calculated from the Snowy Hydro Ravine rainfall gauge record are provided in Table 4.3.

Table 4.2 Design rainfall depths from Australian Rainfall and Runoff 2016 – Lobs Hole

Rainfall duration	Annual Exceedance Probability – rainfall depth (mm)						
	63.2%	50%	20%	10%	5%	2%	1%
15 min	10	11	14	17	20	24	27
30 min	13	14	19	22	26	31	35
1 hour	17	18	24	28	32	38	43
2 hour	21	24	30	35	40	47	52
3 hour	25	27	35	40	46	53	59
6 hour	32	36	46	52	59	69	76
12 hour	42	46	60	69	78	91	101
24 hour	54	59	77	89	101	118	131
48 hour	65	73	95	109	123	144	160

Table 4.2 Design rainfall depths from Australian Rainfall and Runoff 2016 – Lobs Hole

Rainfall duration	Annual Exceedance Probability – rainfall depth (mm)						
	63.2%	50%	20%	10%	5%	2%	1%
72 hour	72	80	104	120	134	156	173

Notes: Data sourced from Australian Rainfall and Runoff Data Portal.

Table 4.3 Design rainfall depths for frequent events – Lobs Hole

Event probability	Rainfall duration			
	2 day	5 day	10 day	20 day
80th percentile event	7.5 mm	22.6 mm	42.9 mm	79.4 mm
85th percentile event	11.0 mm	28.1 mm	50.2 mm	89.4 mm
90th percentile event	16.0 mm	35.6 mm	60.5 mm	100.6 mm
95th percentile event	26.4 mm	49.0 mm	77.0 mm	123.7 mm

Notes: Rainfall depths have been calculated from the Ravine gauge record.

ii Tantangara Reservoir

Design rainfall depths for a range of AEP events at Tantangara Reservoir are provided in Table 4.4. Rainfall depths for 2, 5, 10 and 20 day rainfall events calculated from the Snowy Hydro Tantangara Reservoir (00185) rainfall gauge record are provided in Table 4.5.

Table 4.4 Design rainfall depths from Australian Rainfall and Runoff 2016 – Tantangara Reservoir

	Annual Exceedance Probability – rainfall depth (mm)						
Rainfall duration	63.2%	50%	20%	10%	5%	2%	1%
15 min	9	10	14	17	19	24	27
30 min	12	13	18	22	25	30	35
1 hour	16	17	23	27	32	37	42
2 hour	21	23	30	35	40	46	51
3 hour	25	27	36	41	47	54	59
6 hour	35	38	49	56	64	74	81
12 hour	48	53	69	80	90	106	117
24 hour	65	72	95	111	127	150	169
48 hour	83	93	124	146	167	200	227
72 hour	93	104	140	165	189	227	257

Notes: Data sourced from Australian Rainfall and Runoff Data Portal.

Table 4.5 Design rainfall depths for frequent events – Tantangara Reservoir

	Rainfall duration			
	2 day	5 day	10 day	20 day
80th percentile event	9.2 mm	25.4 mm	45.9 mm	83.5 mm
85th percentile event	12.8 mm	30.5 mm	53.5 mm	94.2 mm
90th percentile event	18.1 mm	37.0 mm	63.1 mm	107.5 mm
95th percentile event	27.8 mm	51.0 mm	78.8 mm	128.5 mm

Notes: Rainfall depths have been calculated from the Snowy Hydro operated Tantangara Reservoir (00185) gauge record.

iii Marica

Design rainfall depths for a range of AEP events at Marica are provided in Table 4.6. Rainfall depths for 2, 5, 10 and 20 day rainfall events calculated from the Yarrangobilly Caves (72141) rainfall gauge record are provided in Table 4.7.

Table 4.6 Design rainfall depths from Australian Rainfall and Runoff 2016 – Marica

	Annual Exceedance Probability – rainfall depth (mm)						
Rainfall duration	63.2%	50%	20%	10%	5%	2%	1%
15 min	9	10	14	16	19	23	26
30 min	12	14	18	22	25	30	34
1 hour	16	18	23	27	31	37	41
2 hour	21	23	30	35	39	46	51
3 hour	25	28	35	41	46	53	59
6 hour	35	38	48	55	62	72	80
12 hour	47	52	67	77	87	101	112
24 hour	63	70	91	105	119	141	157
48 hour	80	89	117	136	154	183	206
72 hour	89	100	132	153	173	205	231

Notes: Data sourced from Australian Rainfall and Runoff Data Portal.

Table 4.7 Design rainfall depths for frequent events – Marica

	Rainfall duration			
	2 day	5 day	10 day	20 day
80th percentile event	10.2 mm	28.8 mm	52.7 mm	97.2 mm
85th percentile event	14.8 mm	35.2 mm	61.2 mm	109.2 mm
90th percentile event	21.1 mm	43.4 mm	72.6 mm	123.0 mm

Table 4.7 Design rainfall depths for frequent events – Marica

	Rainfall duration			
	2 day	5 day	10 day	20 day
95th percentile event	32.0 mm	56.9 mm	88.8 mm	145.6 mm

Notes: Rainfall depths have been calculated from the Yarrangobilly Caves (72141) gauge record.

iv Rock Forest

Design rainfall depths for a range of AEP events at Rock Forest are presented in Table 4.8. Rainfall depths for 2, 5, 10 and 20 day rainfall events calculated from the Adaminaby Alpine Tourist Park (71000) rainfall gauge record are presented in Table 4.9.

Table 4.8 Design rainfall depths from Australian Rainfall and Runoff 2016 – Rock Forest

	Annual Exceedance Probability – rainfall depth (mm)						
Rainfall duration	63.2%	50%	20%	10%	5%	2%	1%
15 min	9	10	13	16	19	23	26
30 min	11	13	18	21	24	29	33
1 hour	15	17	22	26	30	36	40
2 hour	19	21	28	33	37	43	48
3 hour	23	25	33	38	43	50	55
6 hour	31	34	44	50	57	66	73
12 hour	42	46	60	69	78	91	102
24 hour	55	61	81	94	107	127	142
48 hour	69	78	104	122	139	166	187
72 hour	77	87	116	137	157	186	210

Notes: Data sourced from Australian Rainfall and Runoff Data Portal.

Table 4.9 Design rainfall depths for frequent events – Rock Forest

	Rainfall duration			
	2 day	5 day	10 day	20 day
80th percentile event	5.2 mm	15.7 mm	30.2 mm	57.2 mm
85th percentile event	7.8 mm	20.0 mm	35.5 mm	64.9 mm
90th percentile event	11.9 mm	25.7 mm	43.9 mm	75.6 mm
95th percentile event	19.6 mm	36.1 mm	58.1 mm	95.6 mm

Notes: Rainfall depths have been calculated from the from the Adaminaby Alpine Tourist Park (71000) gauge record.

4.3 Temperature

Key statistics for three temperature gauges in the vicinity of the project area are provided in Table 4.10.

Table 4.10 Temperature statistics

Temperature statistic	Cabramurra SMHEA AWS (72161)[1]	Tantangara Reservoir[2]	Talbingo[2]	Month[3]
Elevation (m AHD)	1,482	1,237	395	-
Mean annual maximum (°C)	12.6	14.7	21.3	-
Highest mean monthly maximum (°C)	21.5	23.1	30.8	January
Lowest mean monthly maximum (°C)	3.8	6.6	12.3	July
Mean annual minimum (°C)	5.1	1.0	9.1	-
Highest mean monthly minimum (°C)	11.5	6.9	16.0	January
Lowest mean monthly minimum (°C)	-0.9	-3.6	3.3	July

Notes: 1. Data sourced from BoM website (climate data online).
2. Data provided by Snowy Hydro.
3. Month in which mean monthly maximum/minimum occurs.

The data in Table 4.10 shows temperatures vary seasonally and with elevation. The mean monthly maximum and mean monthly minimum temperatures for the Cabramurra SMHEA AWS, Tantangara Reservoir and Talbingo temperature gauges are presented in Figure 4.7 and Figure 4.8 respectively.

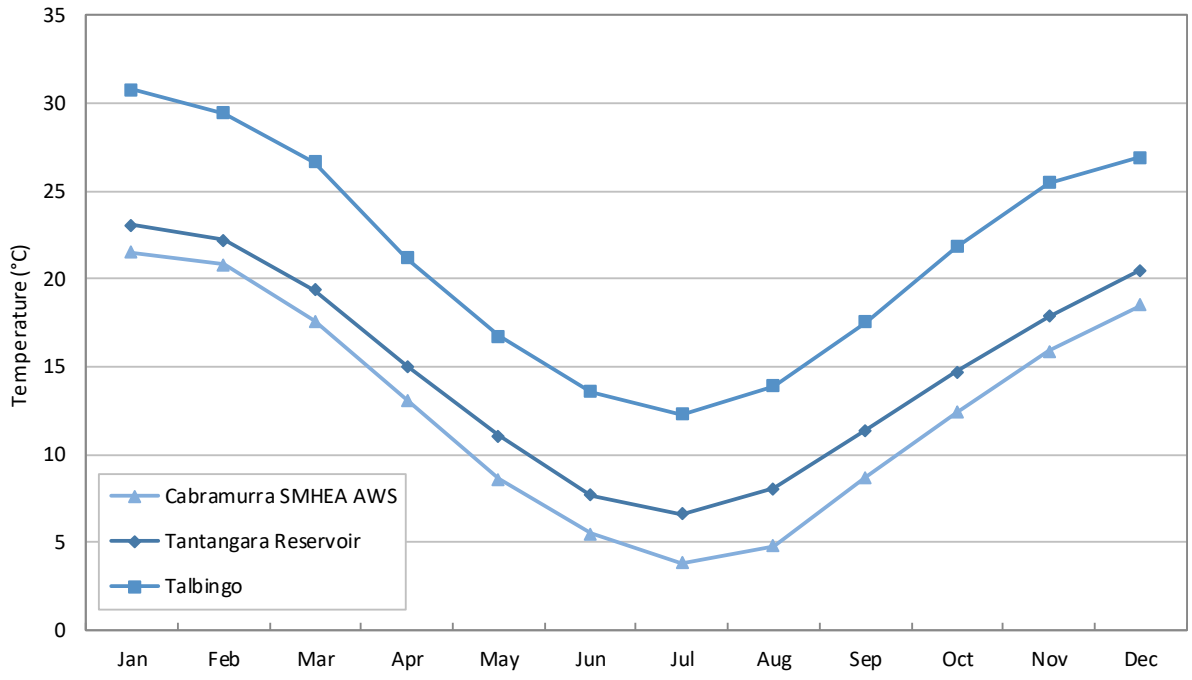


Figure 4.7 Variability in mean monthly maximum temperature

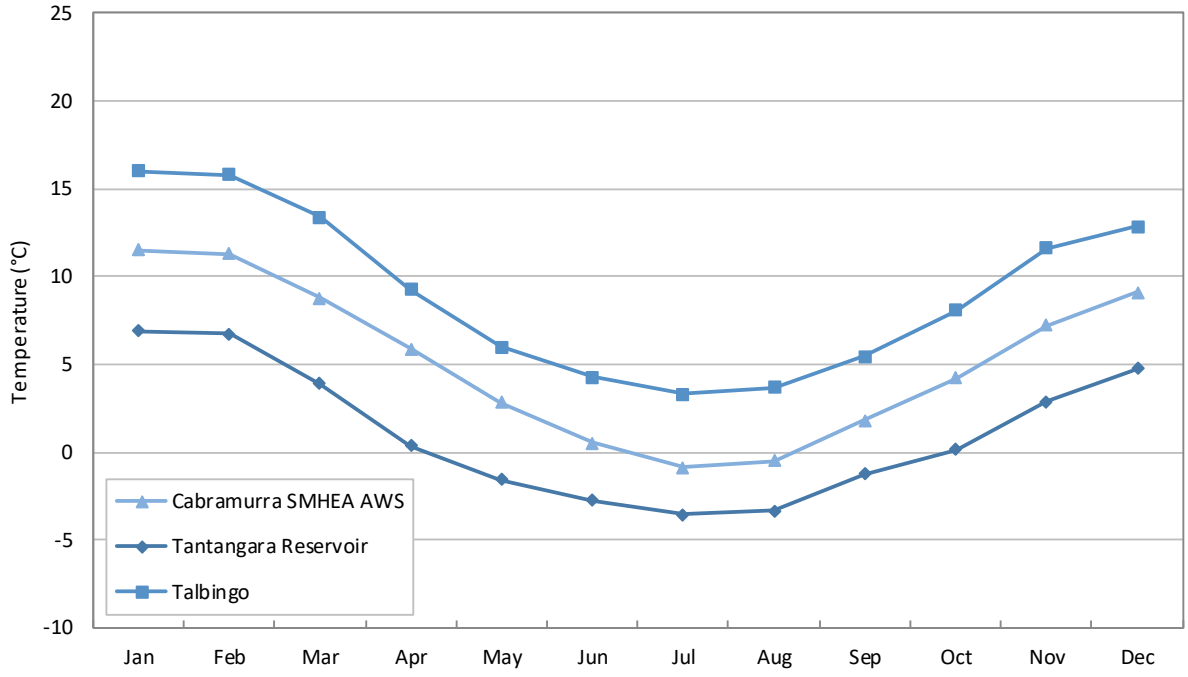


Figure 4.8 Variability in mean monthly minimum temperature

4.4 Evaporation

Mean annual pan evaporation in the Australian Alps ranges from approximately 1,400 mm/year at an elevation of 400 m AHD to approximately 1,000 mm/year at an elevation of 1,300 m AHD (Brown and Millner 1988). Regional monthly mean evaporation and potential evapotranspiration data sourced from evaporation records at Eucumbene (Brown and Millner 1988) and climate maps that are available from BoM's website is presented in Table 4.11.

Monthly mean potential evapotranspiration has also been calculated from daily SILO drill data (see Section 4.2.1) using Morton's areal potential evapotranspiration. This dataset has been developed for the purpose of estimating evapotranspiration from vegetated landscapes for hydrologic modelling and is also included in Table 4.11.

The data presented in Table 4.11 is representative of evaporation characteristics across the project site in areas that receive full sun. Areas that are partially shaded (such as a road cut into steep topography) would be expected to have lower evaporation rates.

Table 4.11 Evaporation and evapotranspiration data

		Mean Class A pan evaporation		Mean areal potential evapotranspiration	Morton's areal potential evapotranspiration
Month	**Units**	**Eucumbene Dam[1]**	**BoM[2]**	**BoM[2]**	**SILO[3]**
January	mm/month	205	206	155	208
February	mm/month	158	169	118	167
March	mm/month	133	139	101	140
April	mm/month	87	76	69	85
May	mm/month	45	42	46	50
June	mm/month	30	27	38	30
July	mm/month	31	29	41	35
August	mm/month	45	46	54	55
September	mm/month	77	70	72	88
October	mm/month	117	110	115	133
November	mm/month	148	148	140	160
December	mm/month	192	191	139	197
Annual	**mm/year**	**1,268**	**1,256**	**1,088**	**1,335**

Notes: 1. Data source (Brown and Millner 1988).
2. Data source: Climate Atlas maps (BoM website).
3. Data source: SILO data drill (SILO website).

4.5 Climate change

Climate change projections for NSW are available from several sources. The following sources provide the most recent and relevant projections and provide reliable information about expected changes to the climate near the project area:

- NSW and ACT Regional Climate Modelling (NARCliM) project (OEH n.d.) and climate change "snapshot" for the Murray Murrumbidgee region, which includes the Snowy Mountains (OEH 2014);
- CSIRO and BoM national climate projections (CSIRO & BoM 2015) and climate projections for the Murray Basin, which includes the project area (Timbal et al 2015); and
- South Eastern Australian Climate Initiative (SEACI) (Post et al 2012).

4.5.1 Temperature

Climate change projections for temperature are robust and there is very high agreement between different climate models. In general, temperatures are expected to increase throughout NSW in all seasons, with increasing warm extremes and decreasing cold extremes.

NARCliM climate projections are available at a 10 km grid scale. For the project area, mean annual temperature is projected to increase by approximately 0.7°C in the near future (2020 to 2039) and approximately 2.1°C in the far future (2060 to 2079). Increases are projected to be higher in summer and lower in winter. NARCLiM projections are relative to a baseline period 1990 to 2009.

By 2090, CSIRO and BoM climate projections indicate mean warming across the Murray Basin of 2.7-4.5°C under a high emissions scenario (Timbal et al 2015). These projections are relative to a baseline period 1986 to 2005.

NARCLiM projections indicate the following changes in other temperature metrics due to climate change:

- the number of cold nights (minimum temperature less than 2°C) is expected to decrease;
- the number of hot days (maximum temperature greater than 35°C) is expected to increase; and
- the intensity, frequency and duration of warm spells is expected to increase.

Projected changes in temperature extremes are sensitive to local climatological factors such as site location and elevation. For example, the number of hot days is projected to increase by +12.9 days per year near the ravine, and by +0.4 at the higher elevation areas of the plateau.

4.5.2 Precipitation

There is greater uncertainty around climate projections for precipitation and lower agreement between climate models. Uncertainty is likely due to the range of rainfall drivers and competing influences on rainfall change as well as their relationship to topographical features (eg the Great Dividing Range and Eastern Seaboard) (CSIRO and Bureau of Meteorology 2015). However, in general, cool season rainfall (winter/spring) is projected to decrease in the project area, and rainfall in the warm season is projected to remain unchanged. For the near future, natural variability is projected to dominate any projected changes.

NARCLiM modelling indicates a decrease in average annual rainfall in the Snowy Mountains area by up to 9% in the far future (2060 to 2079) driven by decreases in winter and spring rainfall; average spring rainfall is projected to decrease by 10-20% (OEH 2014).

CSIRO and BoM modelling indicate the following additional projected changes to precipitation (OEH n.d.):

- Increased extreme rainfall events. As temperatures increase, the moisture-holding capacity of the atmosphere will also increase, enhancing the potential for extreme rainfall.
- Decreased snowfall, increased snowmelt and thus reduced snow cover as temperatures increase. This will be most evident at lower elevations. Late in the century (2090), reduction in snowfall could be up to 80% under a high emissions scenario at high elevations.

4.5.3 Streamflow

In general, it is expected that average runoff in the Murray Basin (as defined by Timbal et al 2015), including in the Snowy Mountains, will reduce in a warming climate due to reduced precipitation, increased evapotranspiration and decreased soil moisture (Timbal et al 2015).

SEACI has produced projected changes in rainfall and runoff for catchments in the Murray-Darling Basin region, including the Snowy Mountains Scheme. Table 4.12 gives projected changes in rainfall specifically for the Snowy Mountains Scheme for 1°C (approximately 2030) and 2°C (approximately 2070) warming (Post et al 2012).

There is large uncertainty associated with runoff projections under climate change, reflected in the range of results presented in Table 4.12. This is because many unknown factors could impact future runoff, such as projected future rainfall, rainfall intensity, seasonality, and changes in vegetation characteristics and land use.

Table 4.12 Projected changes in rainfall and runoff for the Snowy Mountains Scheme

	1°C global warming			2°C global warming		
	Dry extreme	Median	Wet extreme	Dry extreme	Median	Wet extreme
Change in rainfall	-8%	-3%	+3%	-16%	-6%	+5%
Change in runoff	-17%	-7%	+2%	-32%	-13%	+5%

Source: SEACI (Post et al 2012)

5 Geology – physical setting

5.1 Regional setting

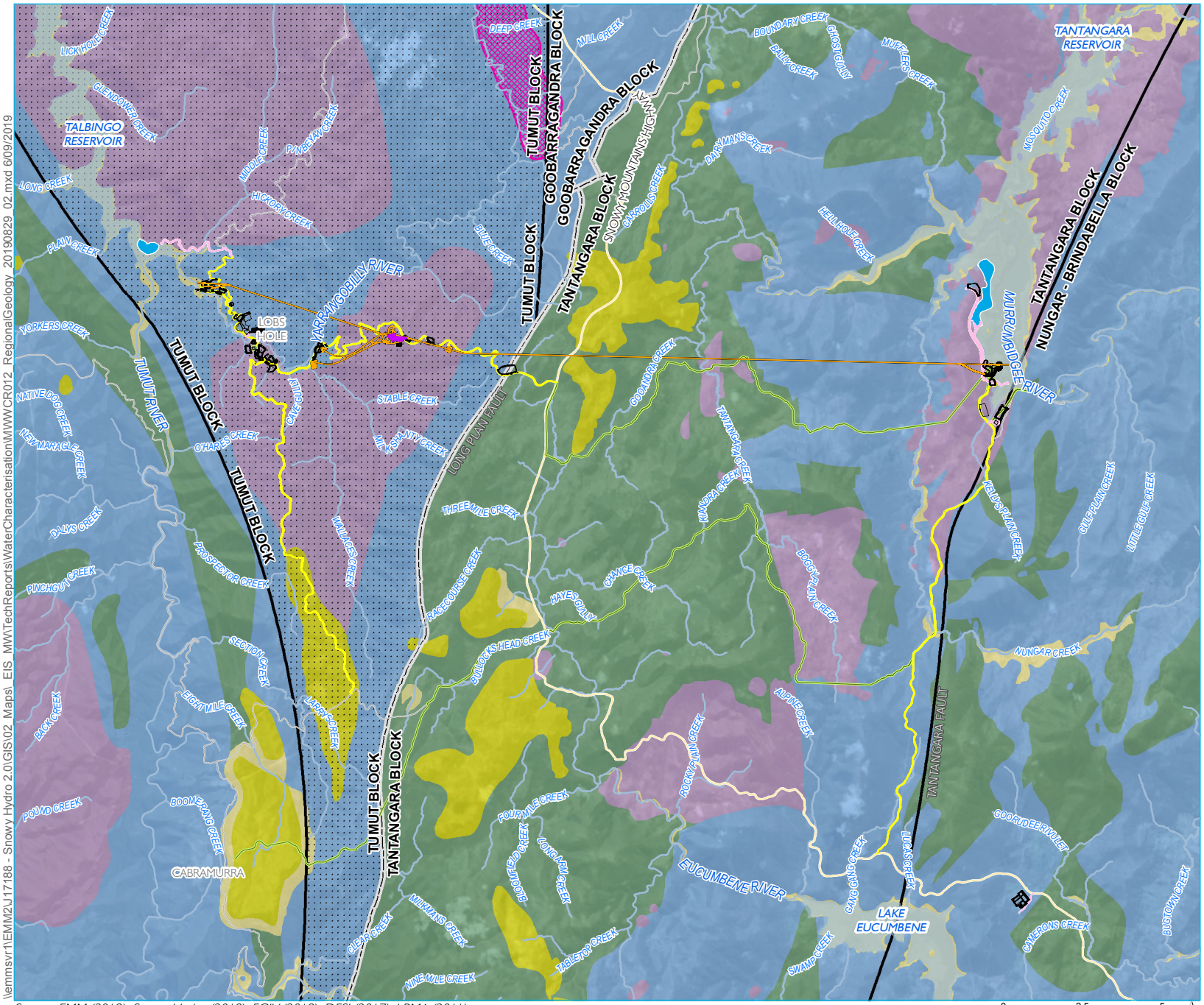
The project area is located within the south-eastern portion of the Lachlan Fold Belt (LFB) of NSW (Stuart-Smith 1991). The LFB comprises a suite of Ordovician to Devonian sedimentary, igneous and metamorphic rocks that have developed during multiple orogenic periods. These orogenic periods are associated 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 emplacement 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 5.1). These two structural blocks form distinct geological terrains; the dominantly Silurian Tumut Block in the west (the incised ravine), 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 5.1).

A conceptual block diagram showing geology and terrains within the Snowy 2.0 project area is shown in Figure 5.2.



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

KEY

Geology (250k) by period

- Quaternary
- Tertiary
- Devonian
- Silurian
- Ordovician
- Long Plain Fault (interpreted)
- Geological domain boundary
- Yarrangobilly Caves complex
- Ravine Incised Area

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

Regional geology and Snowy 2.0 geological terrains

Snowy 2.0
Water Characterisation Report
Main Works
Figure 5.1

snowy 2.0

EMM creating opportunities

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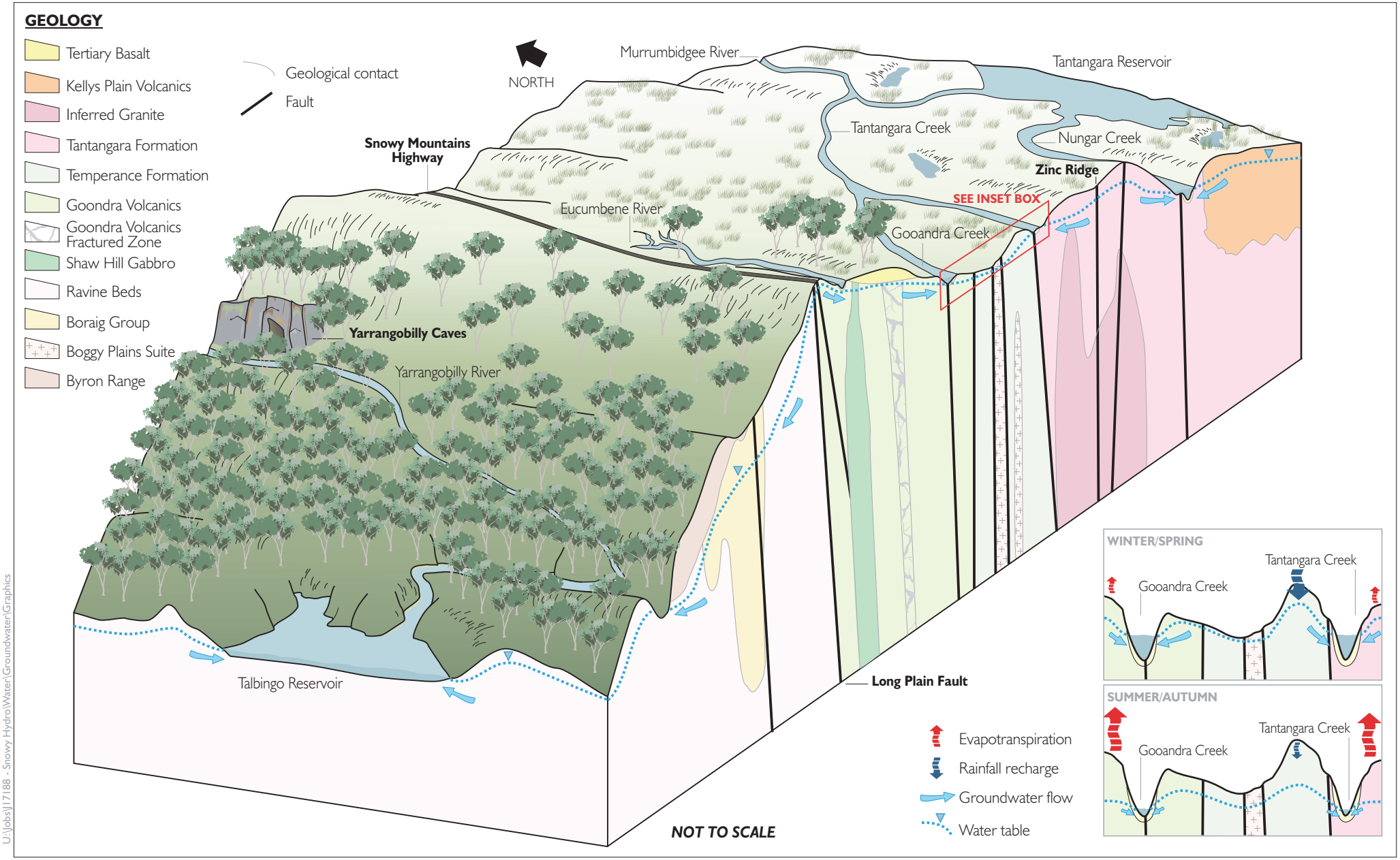

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Snowy 2.0 conceptual geological block diagram

Snowy 2.0
Water Characterisation Report
Figure 5.2

5.2 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 5.1). This area has been significantly deformed through faulting, intrusion and volcanism.

The geological units within the plateau 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.

A summary of the stratigraphy and structural geologic controls across the plateau are summarised below. The relevant geological features in the context of the plateau are shown in Figure 5.3.

5.2.1 Stratigraphy

The stratigraphic succession relevant to the plateau is provided in Table 5.1.

Table 5.1 Tunnel works stratigraphy – plateau

Age	Group	Formation	Symbol	Rock type and occurrence
Tertiary		Tertiary basalt	Tb	Alkali olivine basalt deposited during uplift periods. Occurs as capping on some low hills on the plateau.
Devonian		Kellys Plain Volcanics	Dkv	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	Dkg2, Dkg5, Dkg7	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.
Silurian	Cooleman Plains	Peppercorn formation	Spp	Basal conglomerate, overlain by sandstone, siltstone and cleaved shale, with minor limestone lenses. Shallow marine shelf deposit. Occurs north of the headrace tunnel alignment.
	Yalmy	Tantangara Formation	Syn	Sedimentary turbidite sequence; sandstone, siltstone and shale; quartzite. Deep marine, siliciclastic deposits. Occurs in the eastern section of the plateau, adjacent to Tantangara Reservoir.
Ordovician	Kiandra	Temperance Formation	Oitb, Oitc, Oitd, Oiti	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	Og5	Gabbro, diorite, metabasic intrusive rock and pyroxenite. Shallow crustal-continental deposits. Occurs in the western section of the plateau, adjacent to the LPF.

Notes: 1. See Figure 5.3 – source Geosciences Australia.

5.2.2 Geological structure

There are five main faults/fault zones considered to be significant in the project area:

- Long Plain Fault – forms the western boundary of the Tantangara Block and the plateau. The fault trends in a north-northeast direction over a distance of more than 200 km, from the Upper Murray River to west of the Brindabella Ranges near Canberra. Near the project area, the LPF dips eastwards at 50–60 degrees (SMEC 2019).

- Kiandra Fault – initially understood to be located at the contact between the Temperance Formation and Gooandra Volcanics, the fault is now interpreted to follow a distinct lineament along Gooandra Creek, striking north-east and dipping steeply west (SMEC 2019).

- Boggy Plain Fault – split into two fault traces, the northern fault dips east and trends north-west for approximately 15 km while the southern fault dips west and trends north-west for approximately 22 km (SMEC 2019).

- Jindabyne Thrust – dips west and is over 10 km in length. Understood to be linked to other fault systems further to the south of the project area (SMEC 2019).

- Tantangara Fault – forms the eastern boundary of the Tantangara Block, to the east of Tantangara Reservoir. This fault dips east, and trends north-northeast over a distance of more than 30 km (SMEC 2019).

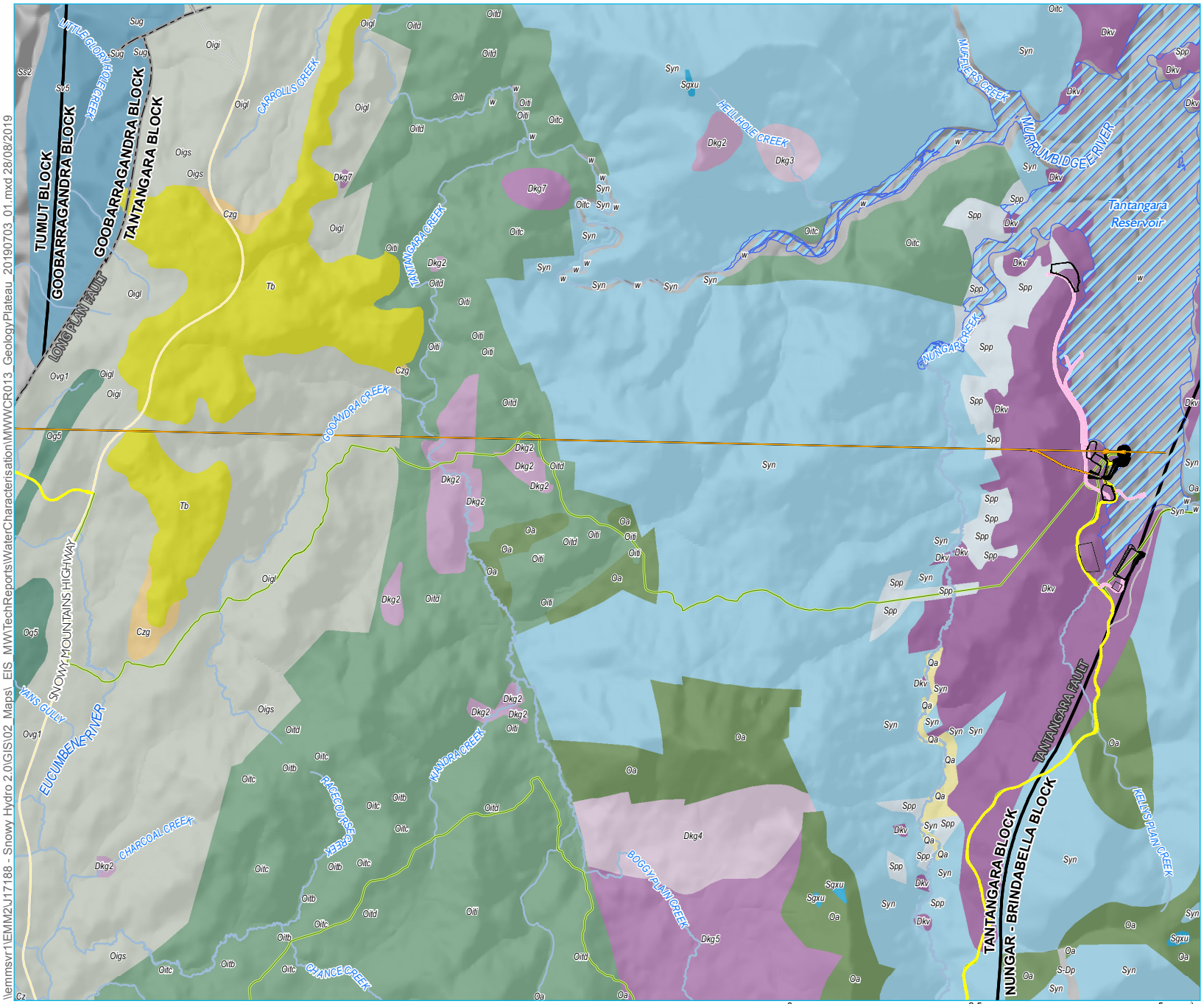
A gravity and magnetics survey was undertaken by SMEC (2019) to assist in characterising the structural geology along the headrace tunnel. The main findings of the SMEC (2019) report are summarised below:

- Basement rock underlying the Tantangara Formation and Kellys Plain Volcanics is shallower than first thought and is expected to be granitic in composition.

- There are likely to be igneous intrusions (ie plutons) within the Kellys Plain Volcanics that are likely to be intersected by the headrace tunnel.

- A gravity low detected within the Gooandra Volcanics is interpreted to be a zone of increased fracturing within the rock which is approximately 500 m wide.

The full SMEC (2019) report is provided in Attachment B.



KEY

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

Existing environment
- Main road
- Local road
- Watercourse
- Scheme storage
- Long Plain Fault (interpreted)
- Geological domain boundary

Quaternary
- *Qa* - Alluvium (undifferentiated)

Tertiary
- *Tb* - Basalt (undifferentiated)

Cainozoic
- *Czg* - Unknown (undifferentiated)

Devonian
- *Dkg3, Dkg4* - unknown (Hell Hole Creek Adamellite)
- *Dkg2*- Boggy Plain Suite (undifferentiated)
- *Dkg5, Dkg7* - Boggy Plain Suite (Boggy Plain Adamellite)
- *Dkv* - Unknown (Kellys Plain

Silurian
- *Spp* - Coolemon Plains Group (Peppercorn Formation)
- *Syn* - Yalmy Group (Tantangara
- *Sgxu* - Unknown (undifferentiated)
- *Sug, Sv5* - Young Suite (Goobarragandra Volcanics)

Ordovican
- *Oigi, Oigl, Oigs, Ovg1* - unknown - Gooandra Volcanics
- *Oitb, Oitc, Oitd, Oiti* - Kiandra Group (Temperance Formation)
- *Oa* - Adaminaby Group (undifferentiated)
- *Og5* - Unknown (Shaw Hill Gabbro)

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

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GDA 1994 MGA Zone 55

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Local geology - plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 5.3

snowy 2.0

EMM creating opportunities

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5.3 Ravine

The ravine is located within a geologic domain referred to as the Tumut Block which extends west of the LPF (see Figure 5.4) 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 Yarrangobilly Caves are also located within the ravine, approximately 4 km north of the Snowy 2.0 Main Works tailrace tunnel alignment. The cave complex lies within the Yarrangobilly Limestone, a geologic unit that is stratigraphically interpreted to sit at the basal extent of the Ravine Beds. The Yarrangobilly Caves are formed within the outcrop of the Yarrangobilly Limestone which is postulated to sit below the Ravine Beds in a synclinal structure. No interpretation of the basal limestone has been undertaken with depth.

The major watercourses, including the Yarrangobilly River, Wallaces Creek and Stable Creek are supported and flanked by extensive colluvium. The unit is composed of subordinate river gravels and boulders transported as till and more recently during high flow events associated with the Yarrangobilly River.

5.3.1 Stratigraphy

The stratigraphic succession relevant to the ravine is provided in Table 5.2.

Table 5.2 Tunnel works stratigraphy – ravine

Age	Group	Formation	Symbol[1]	Rock type and occurrence
Tertiary		Tertiary basalt	Tbm	Alkali olivine basalt deposited during uplift periods. Occurs as capping on some hills within the ravine to the south of the tunnel alignment.
Devonian		Byron Range Group	Dls1	Quartzite, siltstone, sandstone, shale, conglomerate and nodular limestone. Occurs in the central area of the ravine.
		Boraig Group	Dlv2	Rhyolite, rhyodacite, tuff, lapilli tuff, feldspathic sandstone, granophyre deposited in shield building volcanic complexes. Terrestrial – extrusive volcanic deposits.
Silurian		Ravine Beds	Ss2	Shale, slate siltstone and conglomerate. Shallow marine – shelf deposits. Occurs extensively throughout the ravine.

Notes: 1. See Figure 5.4 – source Geosciences Australia.

5.3.2 Geological structure

The LPF is the only significant fault structure relevant to the ravine. The fault zone forms the eastern boundary of the ravine and is interpreted to be approximately 250–300 m wide at the surface (SMEC 2019).

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

The Silurian Ravine Beds are reported to have undergone moderate folding and some faulting, particularly along Yarrangobilly River.

KEY

Snowy 2.0 operational elements

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

Snowy 2.0 contruction elements

- Temporary construction compounds and surface works
- Temporary access road
- Scheme storage
- Main road
- Local road or track
- Watercourse
- Long Plain Fault (interpreted)
- Geological domain boundary

Quaternary

- *Qa* -

Tertiary

- *Tbm* - Basalt

Cainozoic

- *Cz* - Unknown (undifferentiated)

Devonian

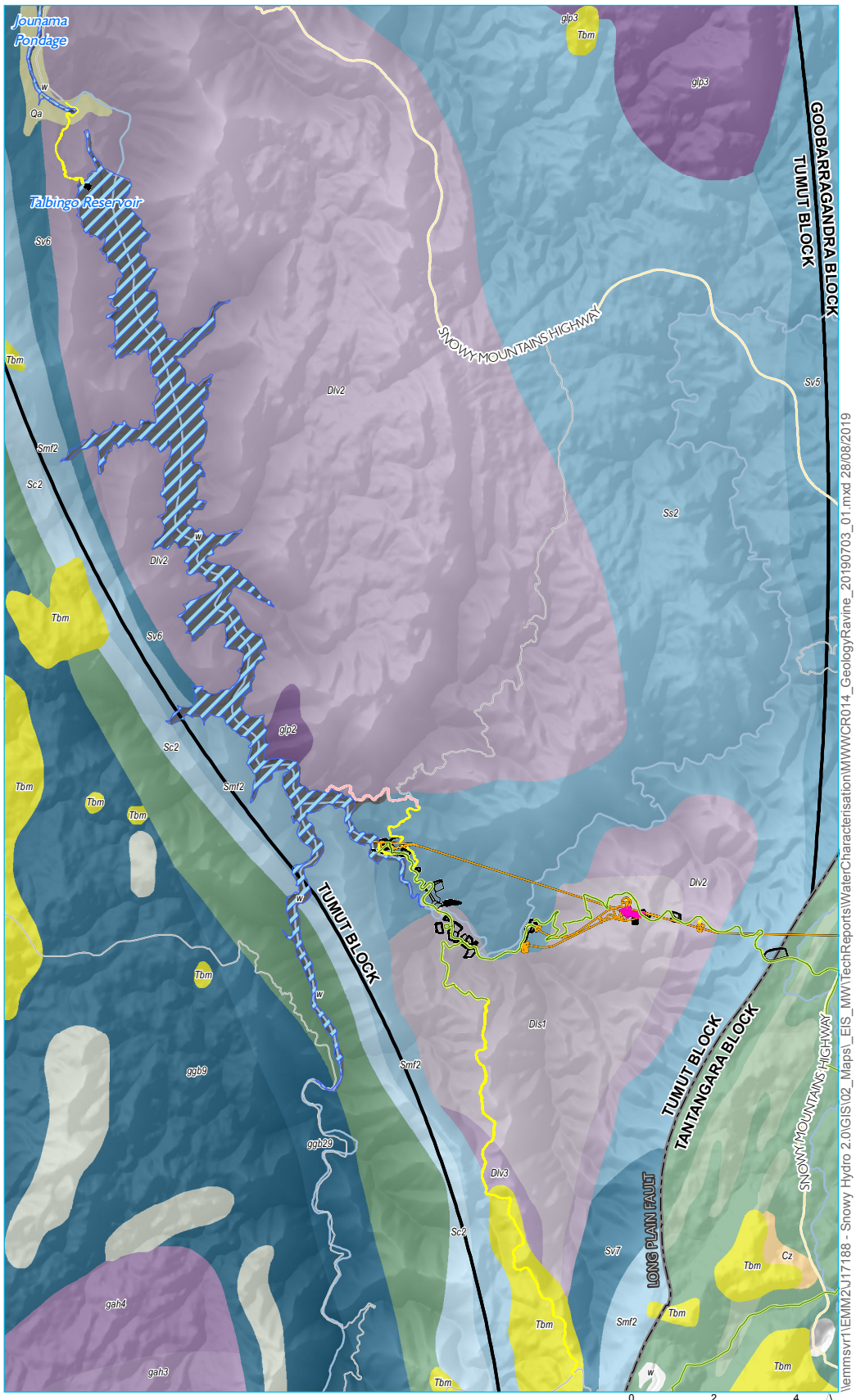
- *Dls1* - Byron Range Group (undifferentiated)
- *Dlv2* - Boraig Group (unnamed)
- *Dlv3* - Black Range Group (Mountain Creek Volcanics)
- *gah3* - Free Damper Suite (Free Dampier Adamellite)
- *gah4* - Free Damper Suite (Pennyweight Adamellite)
- *glp2* - Tumut Granites (Lobs Hole Adamellite)
- *glp3*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

Silurian

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

Ordovician

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



Source: EMM (2019); FGJV (2019); Snowy Hydro (2019); DFSI (2017); GA (2015); LPMA (2011)

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Local geology - ravine

Snowy 2.0
Water Characterisation Report
Main Works
Figure 5.4

snowy 2.0

EMM creating opportunities

5.4 Rock Forest

Rock Forest is situated approximately 15 km south of the southern extent of the plateau region within the Tantangara Block, the same geologic domain as the plateau.

The area, which is largely characterised by the steeply dipping metasediments of the Ordovician Bolton Beds and Kiandra Beds, has been significantly intruded by Devonian undifferentiated granites.

Limited surficial (ie alluvium) deposits are present across Rock Forest.

5.4.1 Stratigraphy

The stratigraphic succession relevant to Rock Forest is provided in Table 5.3.

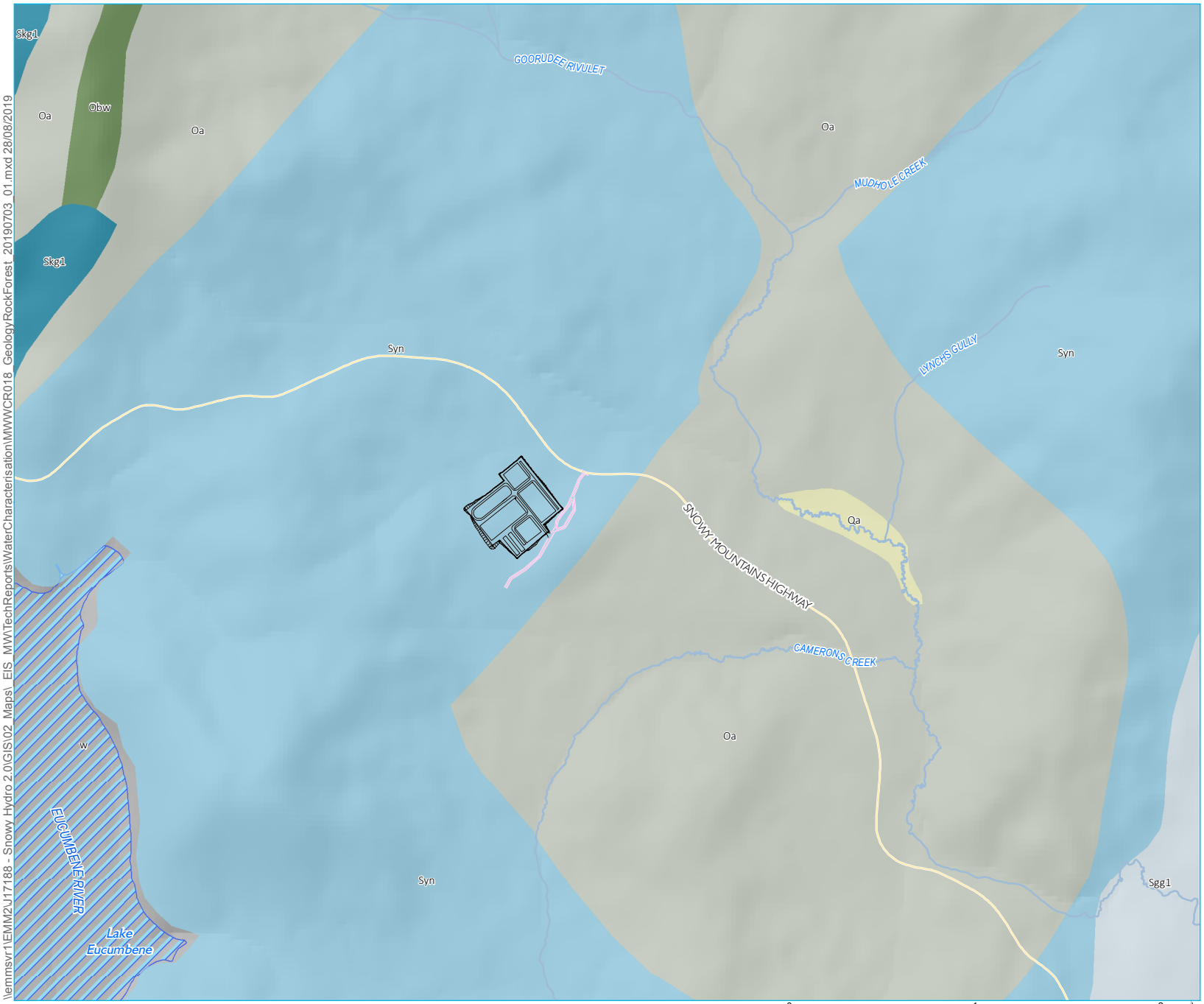
Table 5.3 Stratigraphy – Rock Forest

Age	Group	Formation	Symbol[1]	Rock type
Silurian	Yalmy	Tantangara Formation	Syn	Basal conglomerate, sandstone, shale, chert, minor limestone lenses. Occurs throughout Rock Forest area and surrounds.
Ordovician	Adaminaby	Undifferentiated	Oa	Turbiditic sequence of sandstone, mudstone, shale, carbonaceous shale greywacke, chert, quartzite, phyllite, slate. Occurs throughout Rock Forest area and surrounds.

Notes: 1. See Figure 5.5 – source Geosciences Australia.

5.4.2 Geological structure

Rock Forest sits within the heavily faulted Tantangara Block (see Section 5.2.2).



KEY

Snowy 2.0 construction elements

- Temporary construction compounds and surface works
- Temporary access road

Existing environment

- Main road
- Watercourse
- Scheme storage

Quaternary

- *Qa* - Alluvium (undifferentiated)

Silurian

- *Sgg1*- Jindabyne Suite (Bugtown
- *Syn* - Yalmy Group (Tantangara
- *Skg1* - Bullenbalong Suite (Lucas Creek Granite)

Ordovician

- *Oa* - Adaminaby Group (undifferentiated)
- *Obw* - Bendoc Group (Warbisco Shale)

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

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Local geology - Rock Forest

Snowy 2.0
Water Characterisation Report
Main Works
Figure 5.5

snowy 2.0

EMM creating opportunities

6 Soils – physical setting

6.1 Regional setting

The soils of the project area reflect the extreme climatic gradient across the ravine and plateau, and complex geology (see Chapter 5) on which the soils have formed. Climatic conditions have a more dominant role in soil formation across the alpine and subalpine areas of the plateau compared to the low-lying areas of the ravine. The range of geologies present has led to a wide variety of soils forming across the project area including Kandosols, Tenosols, Rudosols, Dermosols, Chromosols, Vertosols, Ferrosols, and Organosols.

The following sections provide an overview of soil characteristics of the plateau, ravine and Rock Forest. Refer to the soils and land assessment (Appendix N.2 to the EIS) for further details.

6.2 Plateau

Climate in these alpine and subalpine areas has a dominant role in soil formation leading to the development of one soil group, the Alpine Humus Soil, across all parent geological materials (eg volcanic, sediment and metamorphic) (NPWS 2004). Kandosols are the most common soil type from the site data, forming on a range of geologies. Rudosols/Tenosols are the second most common soil type and are most likely to be Alpine Humus Soils with high organic or peaty layers in the profile. Dermosols (on a range of geologies) and Chromosols (on granites and sediments) were also relatively common. Other soil types include Ferrosols (on basic igneous geologies), Hydrosols, and Organosols (in drainage depressions or alluvial areas).

The plateau soils are likely to have high organic matter content and are generally moderately to strongly acidic likely reflecting a highly leached environment. Soils are not likely to be sodic or magnesic. Topsoil erodibility is likely to be low to moderate depending on the organic matter content. The subsoils are generally non-dispersible ranging from loams to clays. Some subsoils are likely to have relatively low coherence particularly for lighter textures (ie loams) or coarser sandy soils.

The erosion hazard of the soils in this area is moderate to very high with the affects of cold climate, shallow soils, highly organic soils and steep slopes increasing the erosion hazard of the soils.

Alpine and subalpine soils with very high organic layers such as the Alpine Humus Soils (most commonly Tenosols) and bog and fen peats (usually Organosols) are fragile soils that are difficult to return to their natural state once disturbed. They are fragile due in part to the restricted growing season of the alpine and subalpine regions, but also due to the very fragile nature of some systems, particularly alpine snowpatch vegetation and the Alpine Sphagnum Bogs and Associated Fens ecological community (Ashton and Williams 1989).

6.3 Ravine

Soils in the ravine have developed on two main types of geology, fine grained acid volcanics and limestone sediments. Both geologies formed similar soils due to the strong influence of topographic factors in the soil development. These soils are generally sandy or silty clay loams that are neutral to strongly acid depending on the parent material. Depending on depth, the soils are generally either Kandosols or Rudosols/Tenosols. Occasionally the lithology of these sediments may result in different soils (eg Dermosols or Ferrosols in limestone or more clay rich layers).

There are relatively minor areas of clayey alluvium of Dermosols and Vertosols associated with the Yarrangobilly River. There are also deeper Kandosol and Ferrosol soils on more gently sloping basic and intermediate volcanics towards the top of Ravine Road.

The topsoils generally have moderate to low erodibility with moderate to high organic matter contents. The subsoils are loams to light clays and have a moderate erodibility and range from non-dispersible to showing some dispersion following remoulding. The majority of the soils have only weak structure, low coherence, and moderate to very high class of erosion hazard due to the steep long slopes and shallow soils of the ravine.

The soils analysed from the Exploratory Works soil survey (EMM 2018b) did not contain any samples that were sodic or magnesic. The NSW Office of Environment and Heritage site data noted one dispersive soil (Sodosol - Yarrangobilly survey site 81), 2.3 km to the north-west of the footprint on rhyolite in a drainage depression. There are seven other sites in the same geology which are Tenosols or Kandosols. Based on the landforms of the project footprint with this geology, Sodosols may potentially occur, but are unlikely.

6.4 Rock Forest

Rock Forest is located on the lower to mid-slopes of gently undulating to undulating rises of sandstone. The soils are likely to be Kandosols and Dermosols that have moderately deep gradational profiles of clay loam over light clays.

The topsoils generally have moderate to low erodibility with possible highly organic layers. The subsoils have a moderate erodibility. The Kandosols have massive to weak structure throughout and are likely to have low coherence. The Dermosols do not have low coherence in the subsoil and are likely to be slightly less erodible due to their better structure. The soils are moderately to strongly acidic likely to reflect a highly leached environment. Soils are not likely to be sodic or magnesic.

The erosion hazard is moderate to high due to the climatic conditions of the area (snow and limited growing season), the possible highly organic topsoils, low coherence of Kandosols, and the gently undulating to undulating slopes.

7 Watercourses

7.1 Overview

Most of the project area is located between Talbingo and Tantangara reservoirs, within the headwater catchments of the Eucumbene (Snowy River catchment), Yarrangobilly (Tumut River/Murrumbidgee River catchment) and Murrumbidgee (Murrumbidgee Catchment) rivers. 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.

This section describes the physical setting, hydrologic processes, streamflow regimes and water quality characteristics of watercourses in the project area. Watercourses in the plateau and ravine are fundamentally different and are therefore described separately in Sections 7.2 and 7.3 respectively. Section 7.4 describes watercourses near Rock Forest, which is outside of KNP. Talbingo and Tantangara reservoirs are described separately in Chapter 8.

7.2 Plateau

7.2.1 Physical setting

i Overview

The plateau is located within the upper reaches of the Murrumbidgee and Eucumbene River catchments, wholly within KNP. Vegetation is characterised by a range of subalpine grasslands and woodlands, tall montane dry sclerophyll forests and alpine bogs and fens. Elevations range from 1,200 m AHD at Tantangara Reservoir to more than 1,500 m AHD at localised high points. Both the Murrumbidgee and Eucumbene rivers flow into reservoirs that form part of the snowy scheme. There are no flow diversions upstream of the reservoirs (in the vicinity of the project area).

The Murrumbidgee and Eucumbene River catchments and major watercourses are shown in Figure 7.1. The locations of stream and rainfall gauges and proposed works are also included for reference. Table 7.1 describes the stream order, catchment area and flow regime of key watercourses that are discussed further in this section. It is noted that Nungar and Kellys Plain creeks are described as tributaries of the Murrumbidgee River, but flow directly into Tantangara Reservoir.

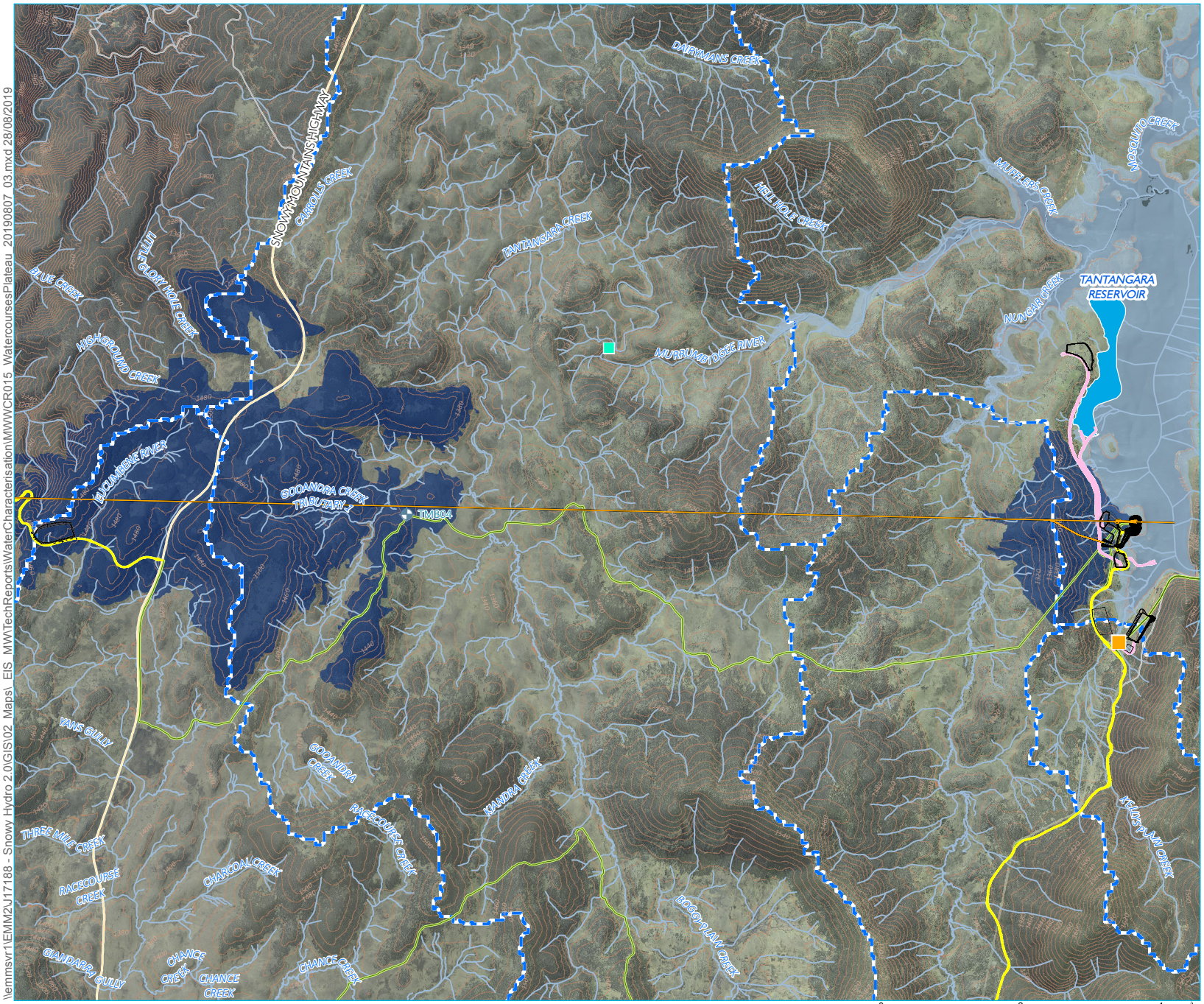
The following sections describe:

- the characteristics of watercourses in potential impact areas; and
- the spatial extent of groundwater discharges in the western section of the plateau, where impacts to the shallow groundwater system are predicted.

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			
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.



KEY

- Weather station
- Monitoring piezometer
- Streamflow gauge
- Key watercourse
- 20m contour
- Catchment area
- Approximate groundwater drawdown extent

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
- Waterbodies

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

Watercourses - plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 7.1

snowy 2.0

EMM creating opportunities

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ii Watercourse characterisation

a Overview

A geomorphic characterisation assessment was undertaken by Flow and Loam Environmental (2019) using a modified River Styles framework (Brierley and Fryirs 2005).

The plateau assessment area included key watercourses above the proposed headrace tunnel alignment as well as Kellys Plain Creek and is indicated in Figure 3.11. The geomorphic characterisation assessment prepared by Flow and Loam Environmental (2019) (see Attachment A) provides a 'reach by reach' description of geomorphic characteristics of surveyed watercourses, referencing the River Styles framework.

The following sections describe watercourse characteristics in the western section of the plateau (between Eucumbene River and Tantangara Creek) and Kellys Plain Creek and include an overview of key geomorphic characteristics, a description of interactions with surface and groundwater systems and a description of any anthropogenic changes that are relevant to the water assessment. The characteristics of Nungar Creek and smaller watercourses between Nungar and Tantangara creeks are not described in this report as no material groundwater impacts are expected in these areas (modelling report, Annexure B to the water assessment).

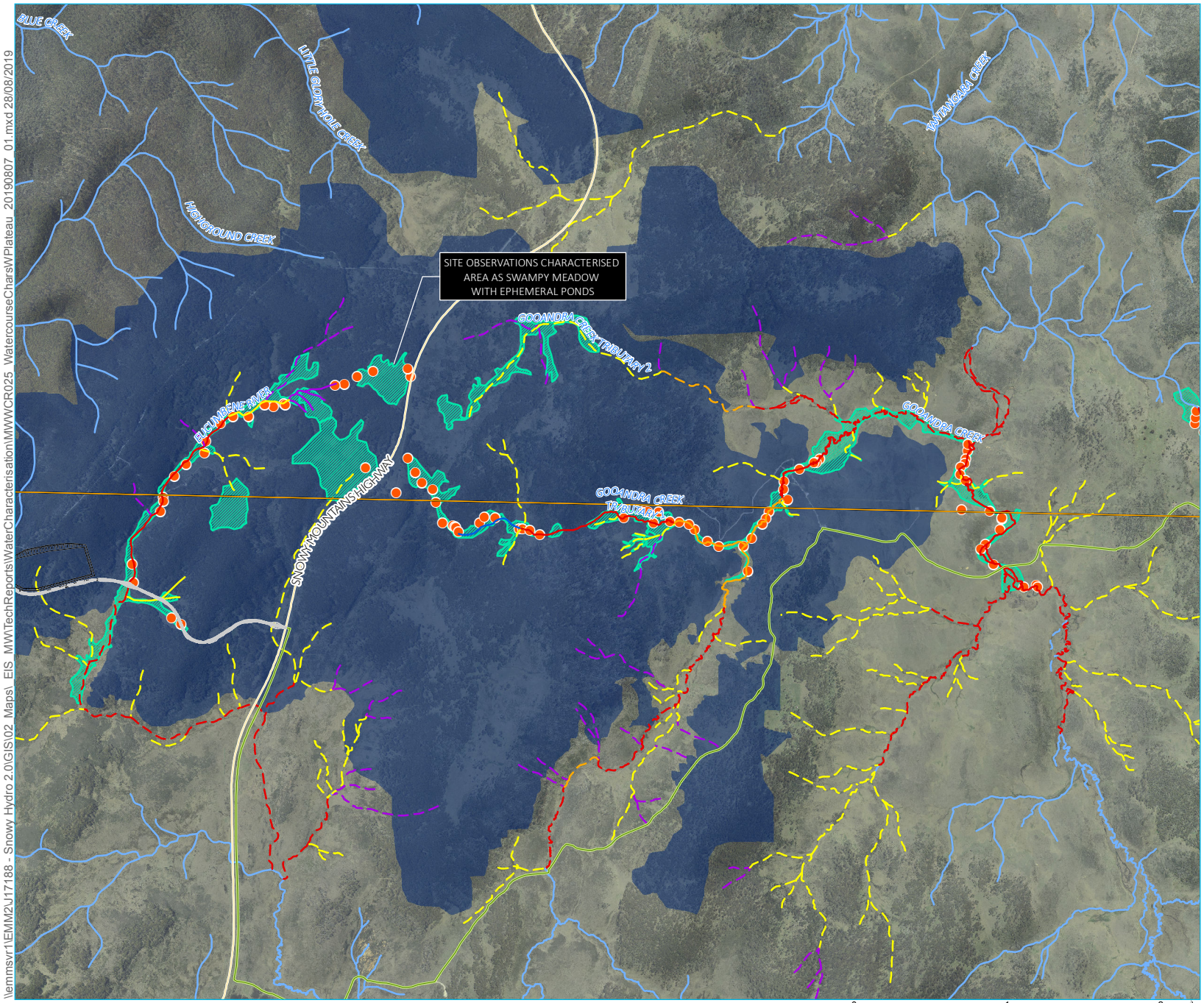
b Western plateau watercourses

The Gooandra Volcanics geological unit is located between Eucumbene River and Tantangara Creek (see Chapter 5). Impacts to the shallow groundwater system within this unit are predicted above and to the north and south of the headrace tunnel alignment (modelling report, Annexure B to the water assessment). Geomorphic surveys were undertaken along key watercourse reaches within this area. The following key categories of headwater (primarily 1st to 3rd order watercourses) and trunk (refers to the watercourses listed in Table 7.1) streams were identified:

- Headwater streams, including:
  - swampy meadow;
  - steep headwater streams; and
  - unconfined valley setting, discontinuous channel.
- Trunk streams, including:
  - confined valley setting; and
  - partly and unconfined valley setting.

The following sections describe each of the above categories, including a description of the interpreted subsurface profiles and interactions with the surface water and groundwater regimes. Figure 7.2 shows:

- geomorphic assessment locations;
- the spatial extent of each of the above categories in the western section of the plateau; and
- the interpreted spatial extent of sediment storage.



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

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

0 1 2 km

GDA 1994 MGA Zone 55

N

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Watercourse characteristics - western plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 7.2

snowy 2.0

EMM creating opportunities

Headwater streams

Swampy meadow

Swampy meadow morphology was found to be common in many headwater settings in the study area (Flow and Loam Environmental 2019). At this position in the landscape there is no continuous channel and no mechanism for fluvial transport or sorting of sediments. Soil profiles are interpreted as silty organic rich sediments overlying saprolite and bedrock. The hydraulic connectivity of the soil profile varies and is dependent upon the volume of clay in each horizon. The surficial sediments of the swampy meadow are silty and organic rich and are interpreted to have a higher hydraulic connectivity than lower profile sediments with higher clay content.

Ephemeral ponds occur in some locations. These ponds are interpreted to capture surface water runoff, which slowly drains or evaporates. The ponds were observed to be dry in early summer 2019 and are therefore not interpreted to receive any groundwater. Photograph 7.1 shows swampy meadow units in the headwaters of the Eucumbene River. The image on the left was taken in late November 2018 after wet weather. The image on the right was taken mid-January 2019 during hot and dry conditions.

Photograph 7.1 Swampy meadow unit in the headwaters of the Eucumbene River catchment.

Steep headwater streams

These watercourses are in the upper catchment and are often steep and short in length. In most locations the groundwater discharge from the adjoining shallow groundwater system occurs in the middle to lower portions of the reach length. Not all steep headwater streams were surveyed as part of the geomorphic assessment.

Laterally unconfined valley setting with a discontinuous channel

These watercourses are typically characterised as broad treeless depressions extending upslope from larger watercourses. Channels are poorly defined, laterally unconfined and discontinuous. Soils are generally shallower than swampy meadow units. Further information on this watercourse category is provided in Attachment A.

Trunk streams

Confined valley setting

These watercourses are in confined valley settings and are often incised into the underlying geology that effectively exerts bedrock control on lateral migration and vertical incision. Discontinuous floodplains occur in some locations. The watercourses are interpreted to be 'gaining streams' with groundwater inflows occurring along the reach length and from small and large tributaries.

Watercourses in confined valley settings predominantly occur in Gooandra Creek (upstream of Gooandra Creek Tributary 1) and Gooandra Creek Tributary 1 and 2. Photograph 7.2 shows two sections of Gooandra Creek. The image on the left is a confined valley setting with a discontinuous floodplain and the image on the right shows a bedrock control. A typical profile of a confined watercourse displaying surface and groundwater interactions is shown in Figure 7.3.

Photograph 7.2 Examples of confined units on Gooandra Creek

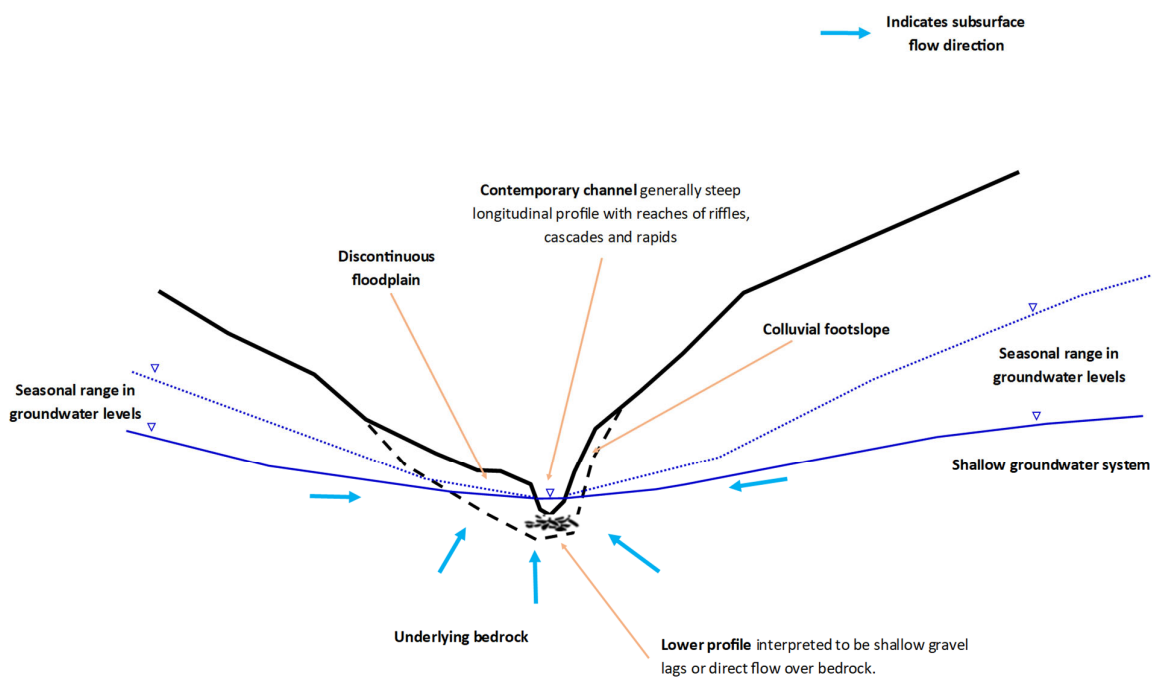


Figure 7.3 Typical profile of a watercourse in a confined valley setting showing surface and groundwater interaction (background image sourced from Flow and Loam Environmental 2019)

Unconfined and partly confined valley setting

These watercourses are in unconfined or partly confined valley settings and are characterised by a meandering channel through a floodplain. In some locations, floodplains have distal backswamps, often at the valley margin in abandoned channels. These backswamps were observed to be generally perched relative to channel water levels and are known to provide habitat to the alpine tree frog and other fauna (biodiversity development assessment report, Appendix M.1 to the EIS). The floodplain fill sediments typically comprise silty and sandy clay loams, with organic matter decreasing down the profile. Channel beds are generally armoured with gravel and cobbles which control vertical incision. Upper profile sediments are interpreted to have higher hydraulic conductivity than sediments in the lower profile which are interpreted to comprise gravel lags with interstitial spaces filled with silty clay. Water conductance within the lower profile is interpreted to be very slow.

The watercourses are interpreted to be 'gaining streams' with groundwater inflows occurring along the reach length and from small and large tributaries. Backswamps on the valley margin are interpreted to receive surface water runoff and groundwater inflows from adjoining hillslope areas. Some backswamps were observed by EMM to dry over summer indicating an ephemeral regime.

Watercourses in unconfined and partly confined valley settings predominantly occur in Gooandra Creek (downstream of Gooandra Creek Tributary 1), Eucumbene River and Tantangara Creek. The following figures and photographs describe these settings further:

- Photograph 7.3 shows two images of the upper reach of the Eucumbene River. The image on the left (looking downstream) was taken in November 2018 after wet weather when streamflow was near bank full. The image on the right (looking upstream) was taken in January 2019, during dry conditions.

- Figure 7.4 shows Tantangara Creek upstream of the Gooandra Creek confluence. The photograph on the top was taken looking north from higher ground in November 2018, following wet weather conditions. Distal backswamps are evident on the valley margin. The aerial image on the bottom was taken in May 2017, approximately 2 weeks after moderate rainfall. The image shows that some backswamps are dry (marked as point 1), while others retain water (marked as point 2).

- Figure 7.5 shows a typical profile of an unconfined or partly confined valley setting showing interpreted surface and groundwater interactions.

Photograph 7.3 Eucumbene River during wet and dry conditions

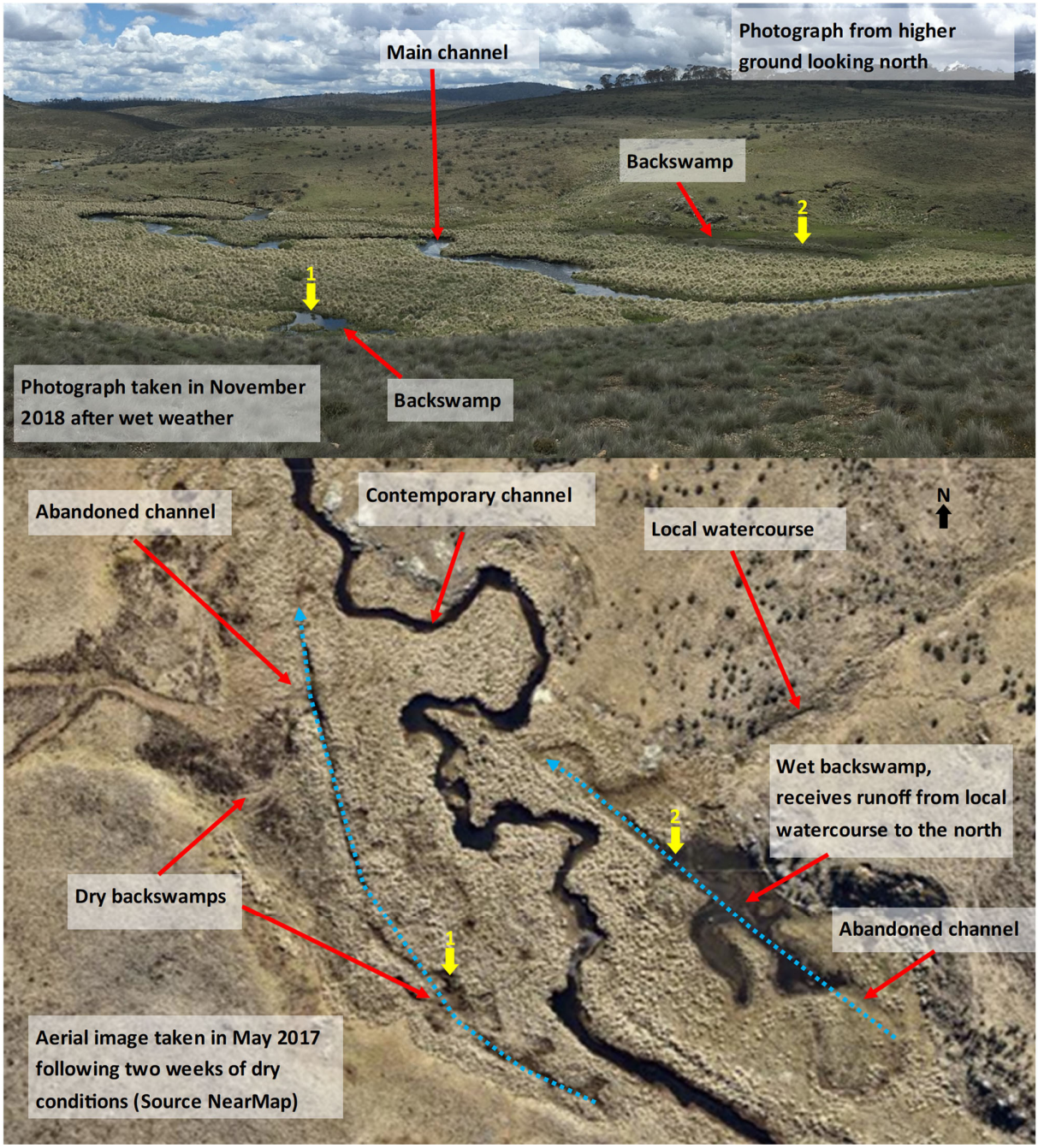


Figure 7.4 Example of a partly confined valley setting with backswamps

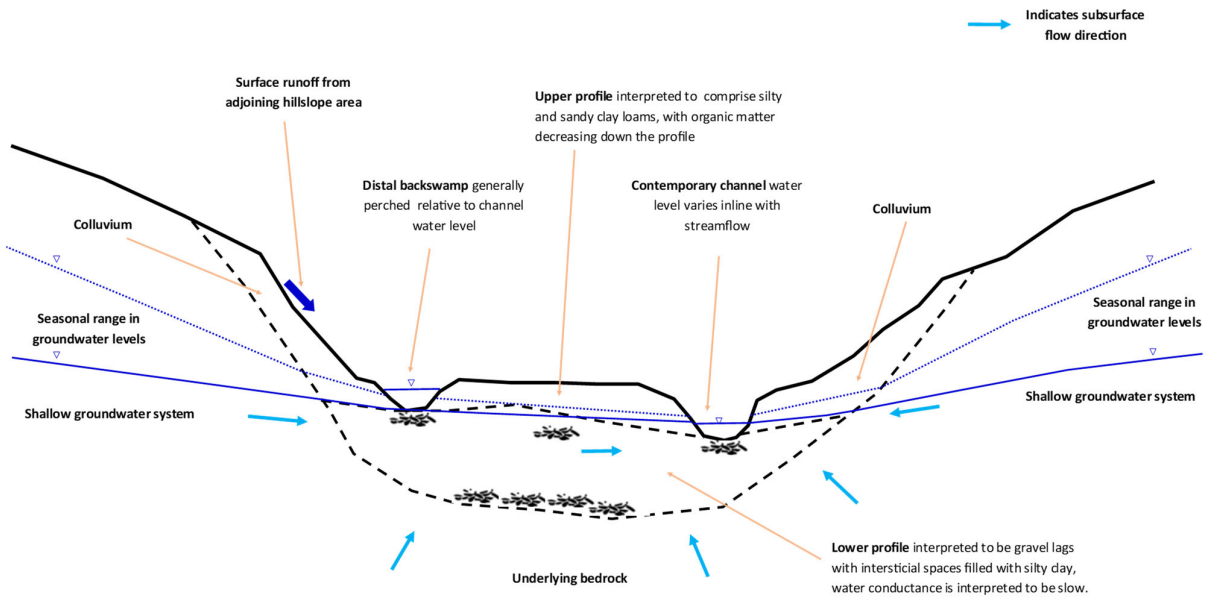


Figure 7.5 Typical profile of an unconfined watercourse showing surface and groundwater interaction (background image sourced from Flow and Loam Environmental 2019)

c Kellys Plain Creek

Kellys Plain Creek is a tributary of the Murrumbidgee River that flows into the southern portion of Tantangara Reservoir. Surface works are proposed in the lower portion of the creek's catchment, in proximity to the creek's channel and floodplain. A remnant hard rock quarry is located to the west of the creek, immediately upstream of the Tantangara Reservoir extent (at full supply level (FSL)). The quarry was a source of hard rock for the construction of the Tantangara Reservoir dam wall and other civil works. The remnant quarry access road and lower levels of the quarry have recently been rehabilitated. Kellys Plain Creek abuts the rehabilitated lower bench, where large angular cobbles and boulders have been placed to stabilise the channel.

A geomorphic survey was undertaken along the lower reach of Kellys Plain Creek by Flow and Loam Environmental (2019). The survey identified an active knickpoint downstream of the quarry. Downstream of the knickpoint the channel has incised into the floodplain. A detailed description of the geomorphology characteristics of the lower portion of Kellys Plain Creek is provided in Attachment A.

Figure 7.6 shows the lower portion of Kellys Plain Creek. The image on the bottom is an aerial image taken in May 2017 and shows the location of the remnant quarry and other disturbance relative to the creek channel. The photographs on the top show the creek reach that is adjacent to rehabilitation works and the abovementioned knickpoint.

It is noted that flood characteristics in Kellys Plain Creek are described separately in the flood risk assessment (Annexure C to the water assessment).

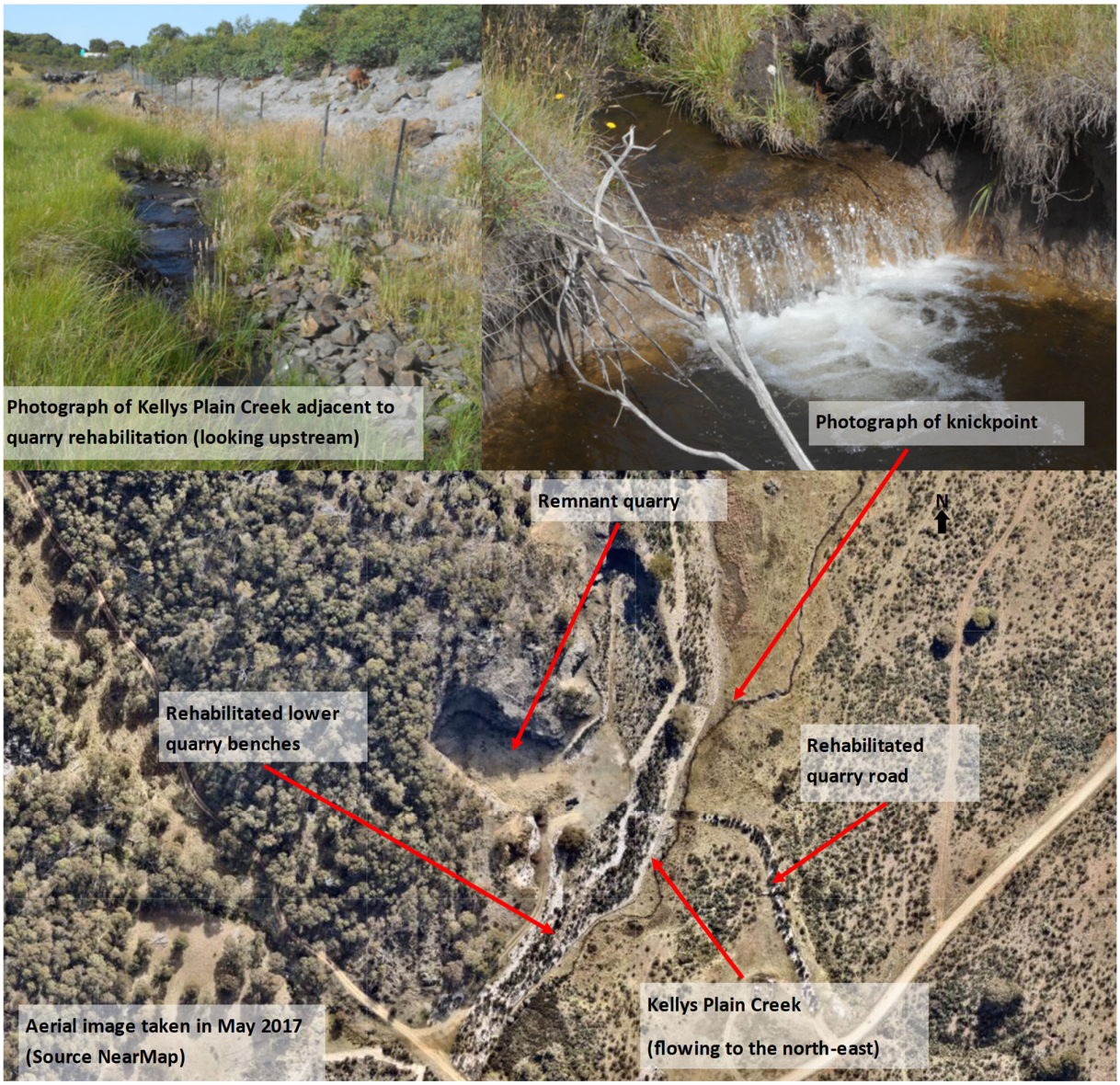


Figure 7.6 Kellys Plain Creek characteristics

iii Groundwater discharge characteristics

Groundwater spring surveys were undertaken by EMM in February and April 2019 (see Section 3.5.2). Observed groundwater surface expressions were characterised into one of the following three types:

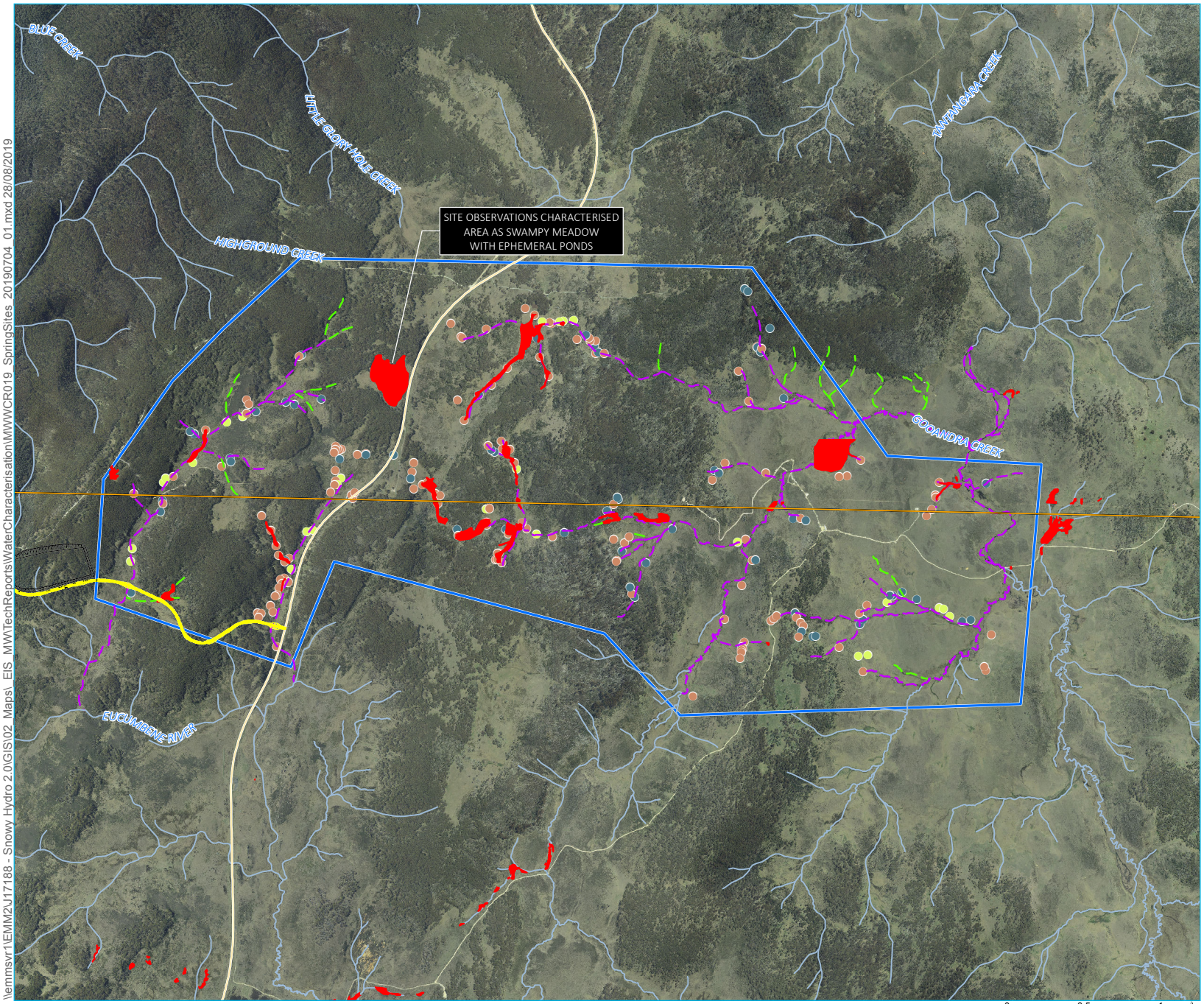
- Type 1 – Contact/hillslope springs: springs displaying visible flow, typically on hillslopes;
- Type 2 – Lowland seeps: visible seeps into sediment storage (ie floodplains); and
- Type 3 – Alpine bogs: boggy, wet ground, typically in depressions in the landscape.

Examples of Type 1, 2 and 3 are shown in Photograph 7.4 to Photograph 7.6 respectively. The surveyed locations of each of the above types is shown Figure 7.7. Figure 7.7 also indicates watercourses that are downstream of known groundwater discharge locations and are interpreted to have a perennial flow regime. These field observations demonstrate that discharges from the shallow groundwater system occur throughout the landscape, often in discrete contact springs or in depressions in the landscape. The rate of discharge at each location is expected to vary due to a range of factors including local geology and topography.

Photograph 7.4 Type 1 – Contact/hillslope springs: springs displaying visible flow, typically on hillslopes

Photograph 7.5 Type 2 – Lowland seeps: visible seeps into sediment storage (ie floodplains)

Photograph 7.6 Type 3 – Alpine bogs: boggy, wet ground, typically in depressions in the landscape



KEY

Groundwater spring type

- Type 1 contact/hillslope spring
- Type 2 lowland seeps
- Type 3 alpine bogs
- Groundwater spring survey area
- PCT 637 - Alpine and sub-alpine peatlands, damp herbfields and fens, South Eastern Highlands Bioregion and Australian Alps Bioregion

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Permanent road

Snowy 2.0 construction elements

- Temporary construction compounds and surface works

Existing environment

- Main road
- Watercourse

Interpreted flow regime

- Perennial
- Ephemeral

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

0 0.5 1 km

GDA 1994 MGA Zone 55

N

Groundwater spring survey

Snowy 2.0
Water Characterisation Report
Main Works
Figure 7.7

snowy 2.0

EMM creating opportunities

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7.2.2 Hydrology

i Hydrologic processes

The hydrologic regime is strongly influenced by seasonal changes to climate. As discussed in Section 4.2, median rainfall across plateau ranges from 1,150 to 1,350 mm/year with higher rainfall occurring in the western portion. Summer rainfall is generally characterised by short duration high intensity events that can have significant spatial variation. During summer and autumn months, evapotranspiration is generally higher than rainfall which results in low soil moisture levels.

In winter months, precipitation is generally of lower intensity, but is more persistent, with some precipitation occurring as snow. Snow cover is generally not maintained consistently over the winter months. The majority of annual groundwater recharge and streamflow occurs in winter and early spring due to the high soil moisture levels and snowmelt influences.

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. In some areas, quickflow is captured in ephemeral swamp features (see Section 7.2.1), which retain or attenuate a portion of the runoff volume. Quickflow from the broader catchment is only expected to occur once soil moisture thresholds are exceeded. However, some quickflow from areas that are wet from groundwater seeps (less than 5% of the catchment area) is expected following minor to moderate rainfall.

- Interflow – refers to the lateral movement of water through the unsaturated zone or shallow perched saturated zone that returns to surface and flows toward stream channels. In the plateau, it is expected that subsurface flow along the soil-bedrock contact zone is the predominant form of interflow. However, lateral flow from discrete shallow perched aquifers may also contribute some interflow. Interflow will generally only occur for several days following rainfall. However, sustained periods of interflow can occur over winter months when soil moisture levels are elevated due to persistent rainfall, low evapotranspiration rates and snowmelt influences.

- 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 predominate source of streamflow during dry conditions. Interactions between surface water and shallow groundwater systems are discussed in detail as impacts to the shallow groundwater system are expected in some areas.

Key hydrologic processes are described diagrammatically in Figure 7.8. The following sections conceptually describe streamflow, groundwater recharge and baseflow regimes.

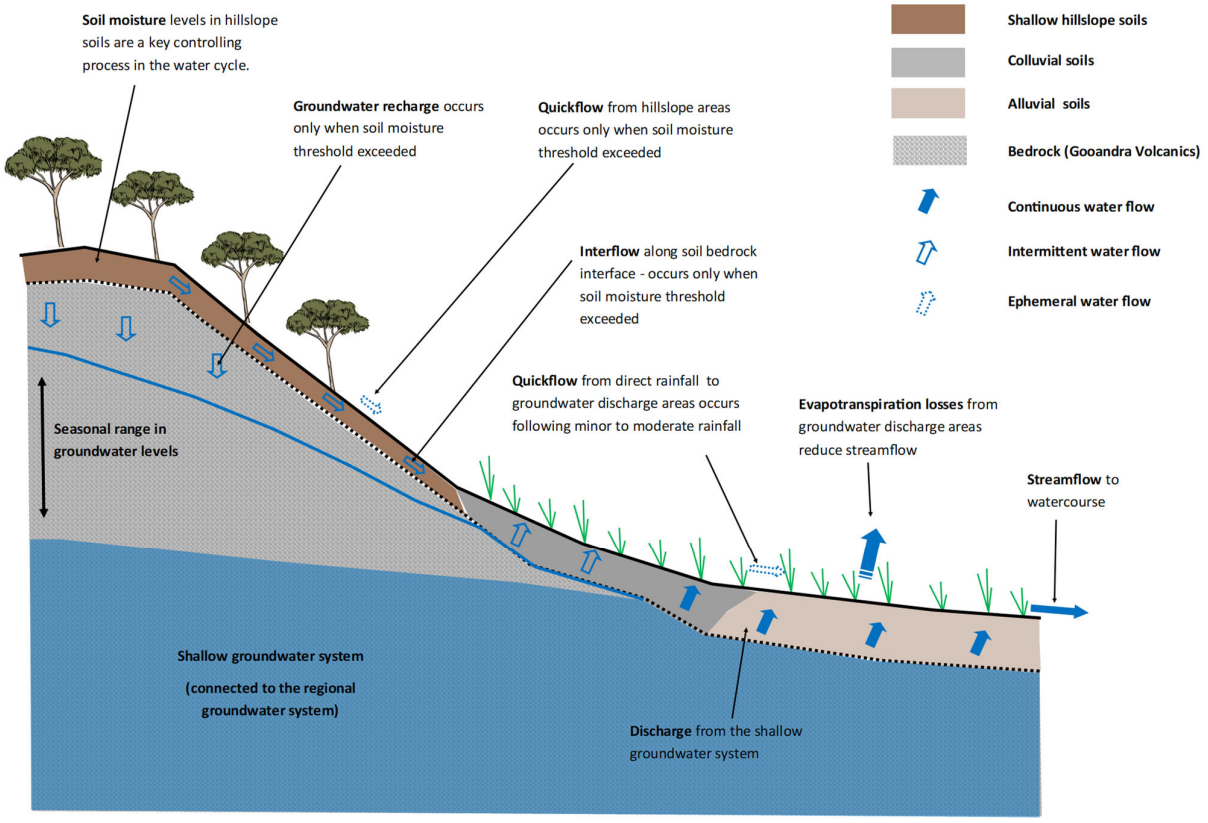


Figure 7.8 Hydrologic processes – simplified concept

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. Digital records from both gauges are available from 1978. Further details on the gauge records are provided in Table 2.1.

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 7.9 and Figure 7.11 plot monthly streamflow statistics that have been calculated from gauge records. The gauged monthly flows over the EIS data collection period (2018 to May 2019) are provided for context.
- Figure 7.10 and Figure 7.12 present the monthly streamflow recorded over the 2000 to 2019 period. The monthly streamflow is compared to median monthly flows 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
10th percentile	88 GL/year	38% of rainfall	102 GL/year	41% of rainfall
50th 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
90th 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.

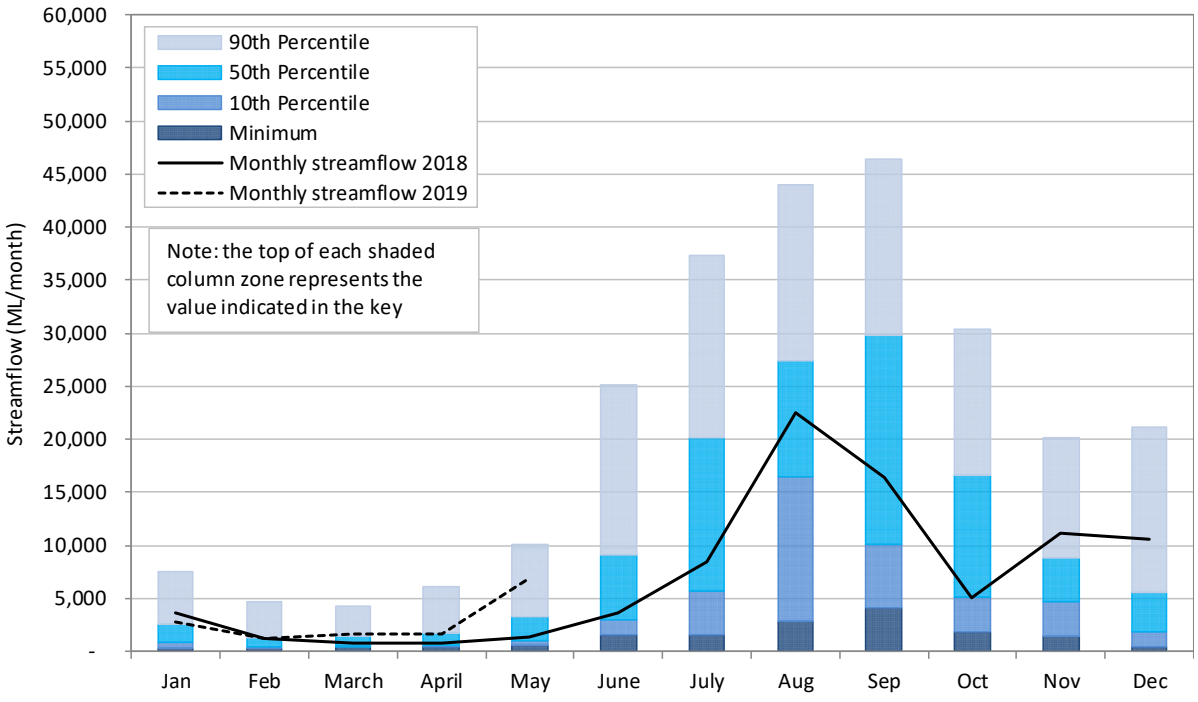


Figure 7.9 Monthly streamflow statistics (Murrumbidgee River – 410535)

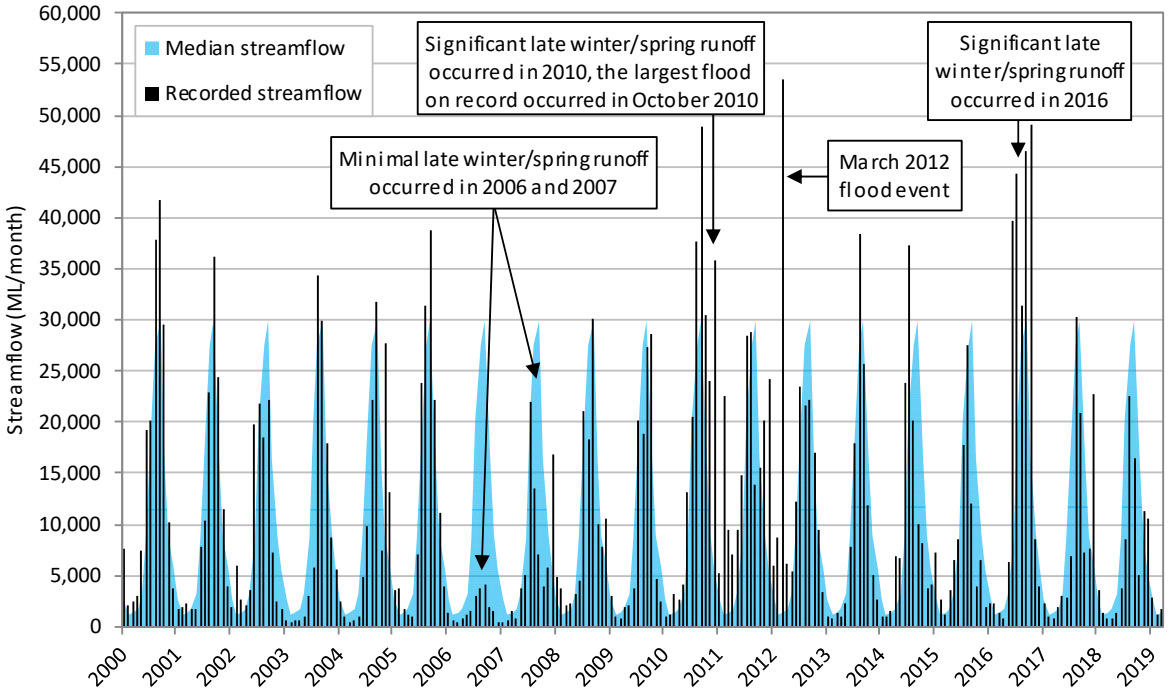


Figure 7.10 Recent streamflow (Murrumbidgee River – 410535)

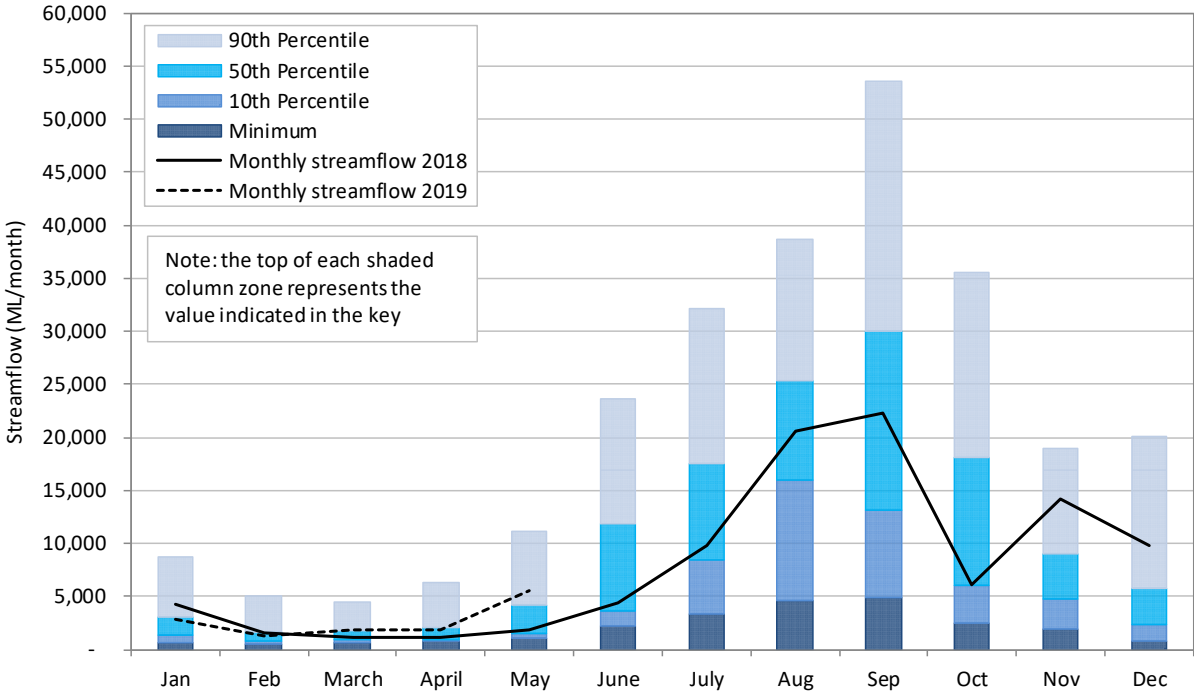


Figure 7.11 Monthly streamflow statistics (Eucumbene River – 222522)

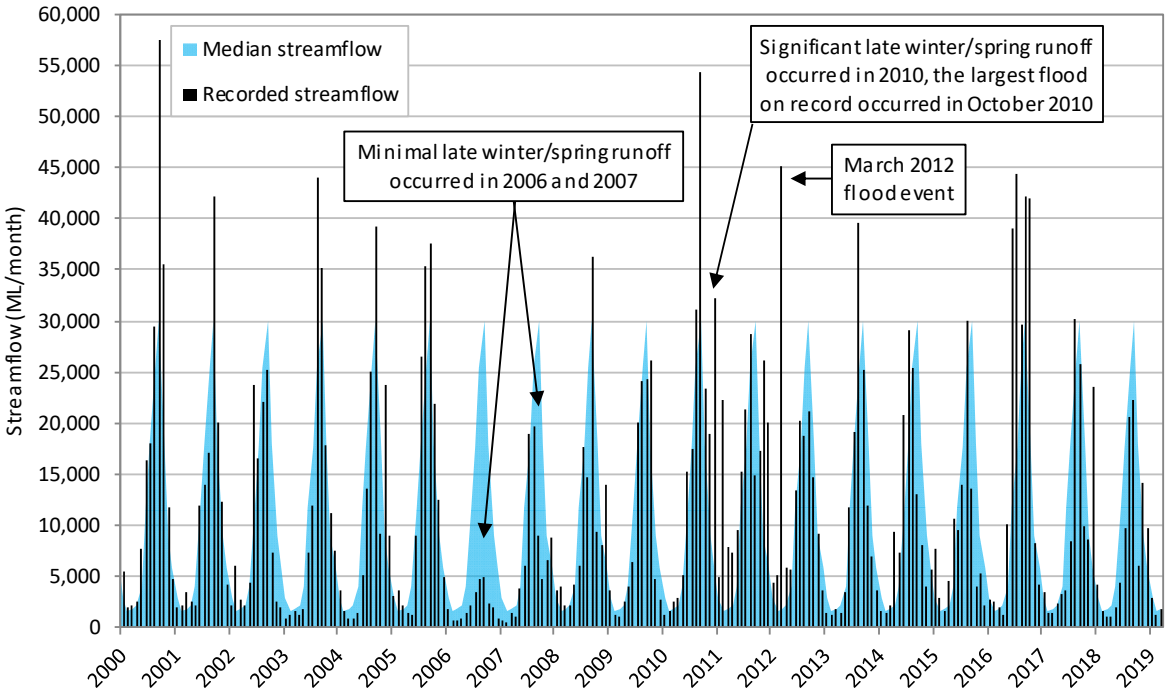


Figure 7.12 Recent streamflow (Eucumbene River – 222522)

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. It is noted that the Eucumbene River receives runoff from higher elevation areas around Mt Selwyn. This is likely to be a contributing factor to the higher runoff coefficients.

- 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 (not shown in Figure 7.10 and Figure 7.12) and 2006, following abnormally dry winter months. The lowest monthly flow on record for both the Murrumbidgee (282 ML/month) and Eucumbene (492 ML/month) 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 Localised streamflow

In situ measurements of streamflow were undertaken within some watercourses using a handheld propeller flow meter (see Section 3.2.2). Measurements were undertaken as part of the surface and groundwater monitoring campaigns and were often collected over several days, during changing streamflow conditions. Hence, the data collected is inconclusive in terms of identifying if streamflow regimes in smaller watercourses are proportionally different from the regional gauged flows. The reliability of the measurements has also not been verified.

iv Groundwater recharge regimes

Groundwater recharge and the subsequent release of groundwater to baseflow is an important aspect of the water cycle. Groundwater recharge regimes can be inferred from analysis of groundwater level data from monitoring bores installed in the plateau. Further information on monitoring bore locations and methods is provided in Section 3.3. Groundwater hydrographs from most bores show clear periods of recharge and recession. Figure 7.13 shows the recorded groundwater hydrograph at monitoring bore TMB04, which is located between Tantangara Creek and Gooandra Creek (see Figure 7.1) on a hillslope location. Hydrographs from other bores are provided in Attachment E.

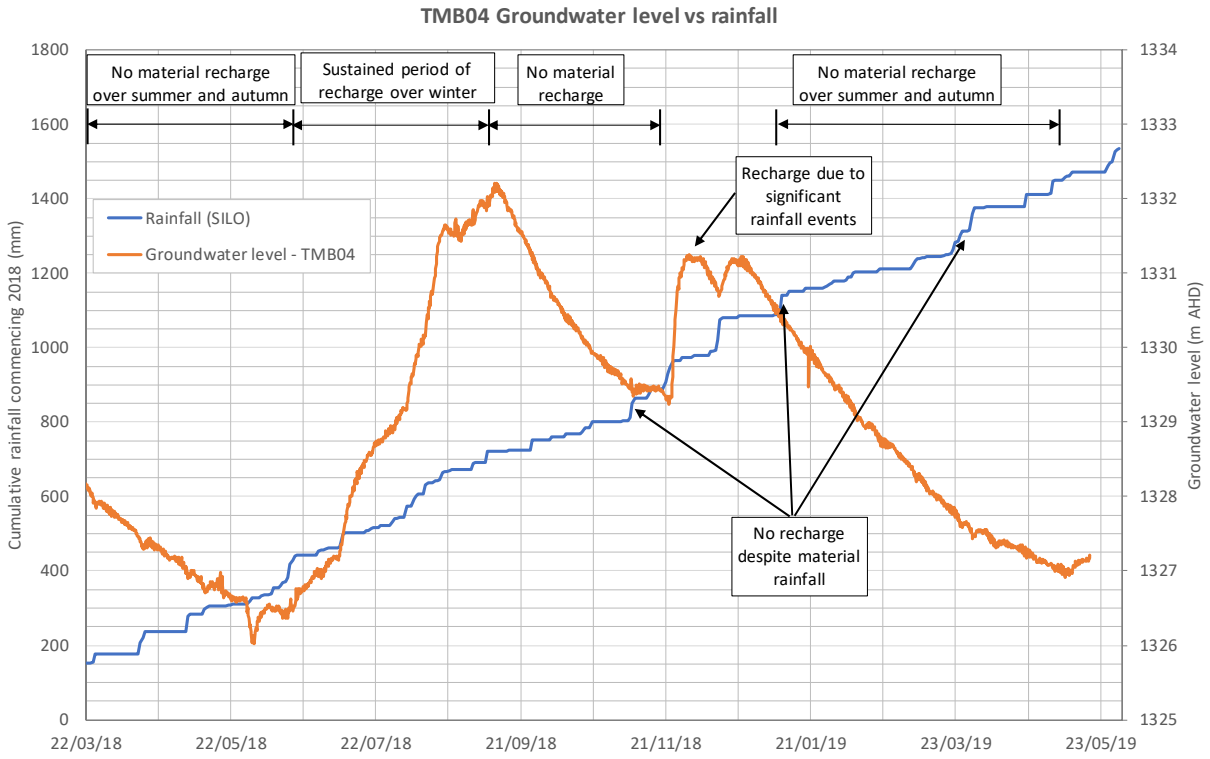


Figure 7.13 Typical groundwater response to rainfall

The following trends are evident in Figure 7.13:

- no material recharge occurred over summer and autumn despite above average rainfall occurring in some months (for example 170 mm of rainfall was recorded at Cabramurra in March 2019);
- a sustained period of recharge occurred over winter and early spring 2018; and

- three significant (greater than 50 mm) rainfall events of similar magnitude occurred in late spring 2018. No material recharge occurred from the first event, but material recharge occurred from the second and third events.

The data indicates that groundwater recharge is correlated 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 snowmelt influences; and

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

v Baseflow regimes

Perennial streamflow is maintained in most watercourses due to discharges from the shallow groundwater system. These discharges are 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). Hence, impacts to the regional groundwater system can result in changes to baseflow regimes.

Section 7.2.1 established that discharges from the shallow groundwater system occur throughout the landscape, often in discrete contact springs or in depressions in the landscape. The rate of discharge at each location is expected to vary due to a range of factors including local geology and topography. On a regional scale, baseflow rates are interpreted to broadly be a function of:

- Groundwater levels – discharges from the shallow groundwater system are interpreted to be a function of groundwater levels, with higher discharges occurring when levels are high, and lower discharges occurring when levels are close to the surface level of the discharge location (as noted in Figure 7.8). The same rate of discharge should occur at any point in the seasonal cycle when the groundwater level is the same.

- 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 7.14 and Figure 7.15. Figure 7.14 plots the gauged streamflow against the TMB04 groundwater level hydrograph. 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. Hydrographs from all bores are provided in Attachment E. Other baseflow separation methods are also documented in the modelling report (Annexure B to the water assessment).

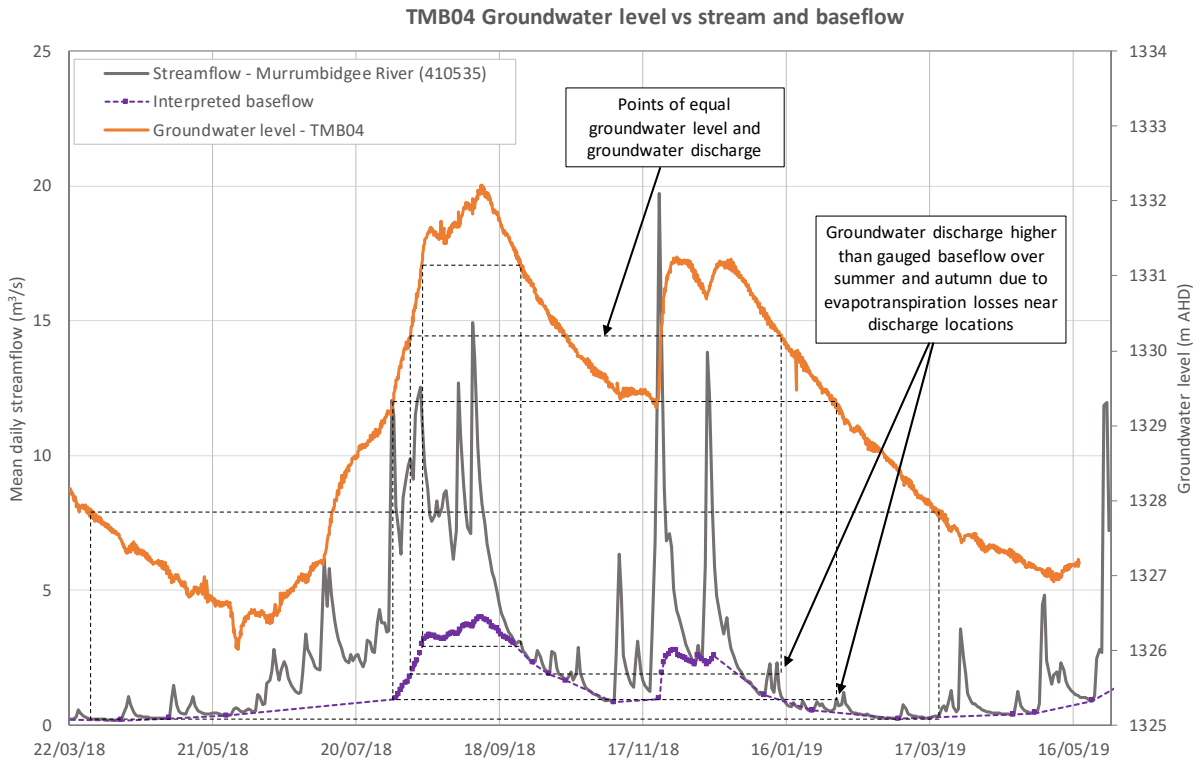


Figure 7.14 Manual baseflow separation

As noted above, material evapotranspiration losses are interpreted to occur near groundwater discharge locations, which often comprise broad areas of riparian vegetation (see Section 7.2.1). This is evident in Figure 7.15 which compares the interpreted baseflow to the gauged streamflow in the Murrumbidgee River. From Figure 7.14 and other representative groundwater hydrographs (see Attachment E), in 2018 the lowest groundwater levels occurred in mid-June. Hence, it is expected that the lowest discharge rates from the shallow groundwater system also occurred at this time. As evident in Figure 7.15, 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 interpreted groundwater discharge rate (ie before evapotranspiration losses) over summer and autumn is indicated in Figure 7.15.

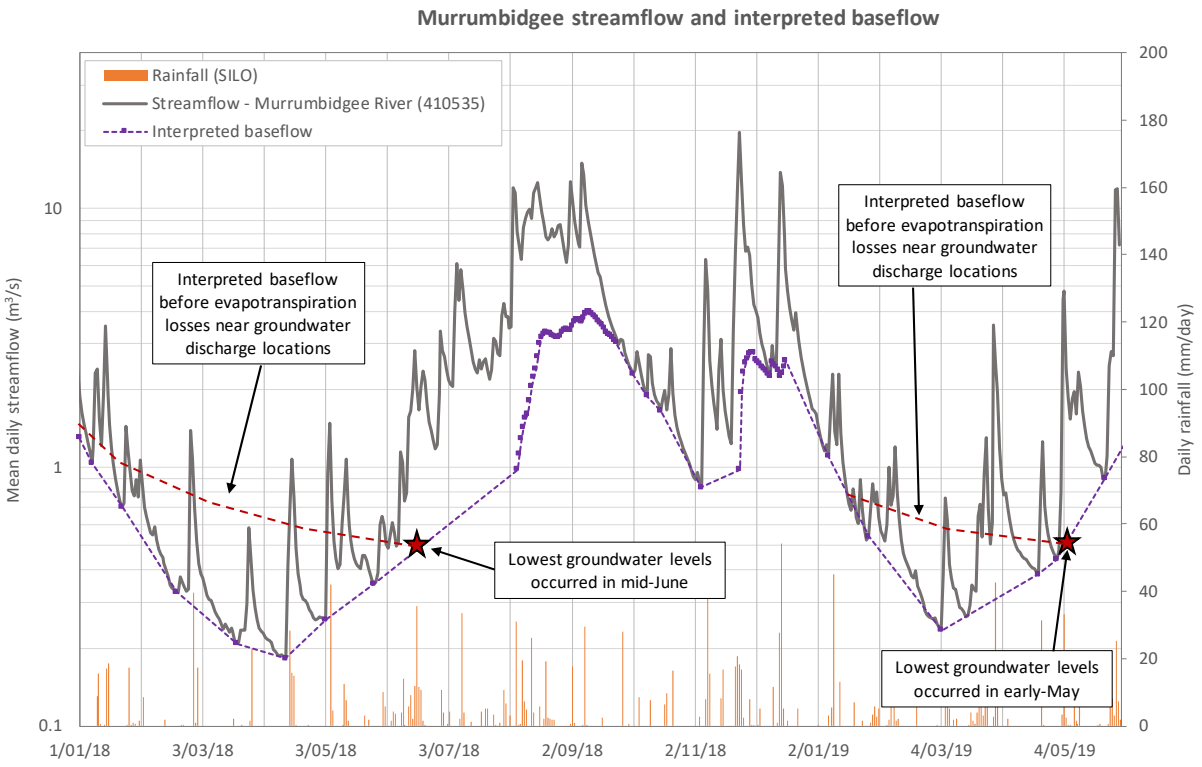


Figure 7.15 Evapotranspiration losses near groundwater discharge locations

The term Baseflow Index (BFI) is used to describe the portion of streamflow that originates from baseflow. The following BFIs were calculated for the 2018 calendar 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.

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

7.2.3 Water quality characterisation

i Monitoring program

Baseline monitoring was undertaken between February 2018 and May 2019 in the Murrumbidgee and Eucumbene rivers, Tantangara, Gooandra, Nungar and Kellys Plain creeks and minor watercourses in vicinity to proposed surface works. Generally, monitoring was undertaken at a monthly frequency, predominantly during dry conditions. Monitoring locations, timelines and methods are described in Section 3.2.3.

ii Water quality objective values

Water Quality Objectives (WQOs) for watercourses based on the *NSW Water Quality and River Flow Objectives* (DECCW 2006) are established in the water assessment (Appendix J to the EIS). Watercourses in the plateau are categorised as high conservation systems, the following WQOs apply:

- physical and chemical stressors – no change to natural variability; and
- toxicant trigger values for the protection of 99% of aquatic species.

There is currently insufficient data to prepare site-specific trigger values (SSTVs) for all monitoring locations and streamflow conditions. Hence, the following default values have been applied to characterise water 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).

These values are referred to as WQO values. SSTVs can be prepared during construction phase monitoring if sufficient data is available.

iii Streamflow categories

A review of baseline water quality data has identified:

- seasonal trends in water quality during dry weather conditions; and
- water quality during wet weather conditions is materially different to the water quality during dry weather conditions.

All baseline data has been assigned to one of the following categories:

- **Summer and autumn dry weather conditions** – Streamflow over summer/autumn is proportionally an order of magnitude lower than winter/spring (see Figure 7.9). During dry weather conditions, summer/autumn streamflow is predominantly groundwater fed (ie baseflow). The water quality of summer/autumn streamflow reflects the groundwater origins of the water and generally exhibits higher salinity and carbonate levels than winter/spring streamflow. Minor watercourses with intermittent flow regimes will typically be dry from mid-summer to the end of autumn.
- **Winter and spring dry weather conditions** – Dry weather streamflow during winter/spring is interpreted to be a combination of interflow and groundwater inflows (see Figure 7.8). The water quality generally exhibits lower salinity and carbonate levels than summer/autumn streamflow. Minor watercourses with intermittent flow regimes will typically maintain a constant flow over winter and spring.
- **Wet weather conditions** – Water quality during wet weather conditions is poorly understood, with minimal data collected from watercourses in the plateau.

Summer/autumn dry weather conditions refer to periods when the median monthly electrical conductivity (a measure of salinity) is greater than 30 µS/cm in the Murrumbidgee River. During the baseline monitoring period, summer/autumn dry weather conditions were assessed to occur from January to April, and winter/spring conditions were assessed to occur from May to December. This range may vary from year to year, with summer/autumn conditions potentially occurring earlier following a dry spring or later if dry conditions occur in early winter. For winters that experience drought conditions (ie 2006), summer/autumn conditions may occur throughout winter/spring. Winter/spring conditions could also occur in summer/autumn for short periods of time following significant wet weather.

Seasonal trends in electrical conductivity in the Murrumbidgee River (upstream of Tantangara Reservoir) are shown in Figure 7.16.

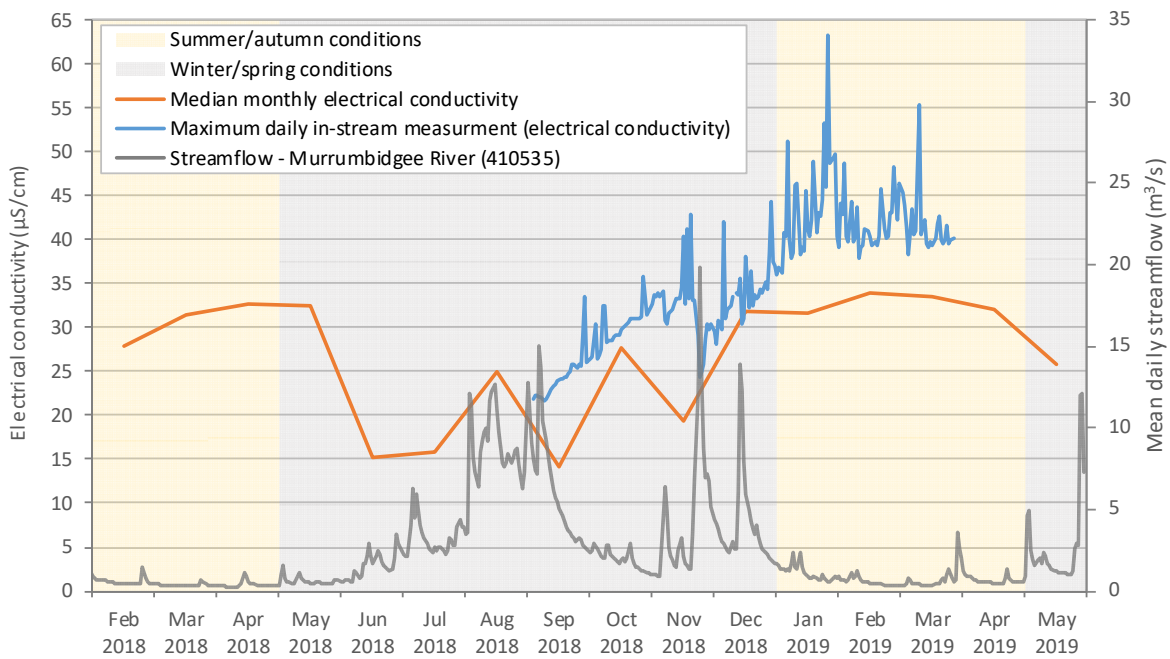


Figure 7.16 Murrumbidgee River – seasonal variation in electrical conductivity

iv Baseline data

A detailed summary of all plateau baseline water quality data is provided in Table D.7 to Table D.13 (see Attachment D). Data is presented separately for the Murrumbidgee and Eucumbene rivers, Tantangara, Gooandra, Nungar and Kellys Plain creeks and minor watercourses in vicinity to proposed surface works (see Figure 7.1 for watercourse locations). In each table, the water quality data is divided into the three streamflow categories described above. For each category, the number of samples collected and number of exceedances of default WQO values is provided along with provisional water quality ranges. The provisional water quality ranges have been calculated as follows:

- where more than ten samples are available, the 10th, 50th and 90th percentile values are provided; and
- where less than ten samples are available, the minimum, 50th percentile and maximum values are provided.

v Water quality characteristics

Water quality characteristics 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 (see Figure 7.16);
    - low concentrations of suspended solids and low turbidity;
    - oxidised nitrogen concentrations exceed WQO values frequently in summer/autumn and occasionally in winter/spring;
    - total and reactive phosphorus concentrations are generally below WQO values; and
    - aluminium concentrations exceed the WQO value on a frequent basis. Copper, iron and zinc concentrations exceed WQO values on an occasional basis.
- The water quality of minor watercourses in the vicinity of the proposed surface works near Tantangara Reservoir (see Table D.7) 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 the key water quality parameters discussed above are provided in Figure 7.17. 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.

Table D.1 in Attachment D provides a summary of WQO departures.

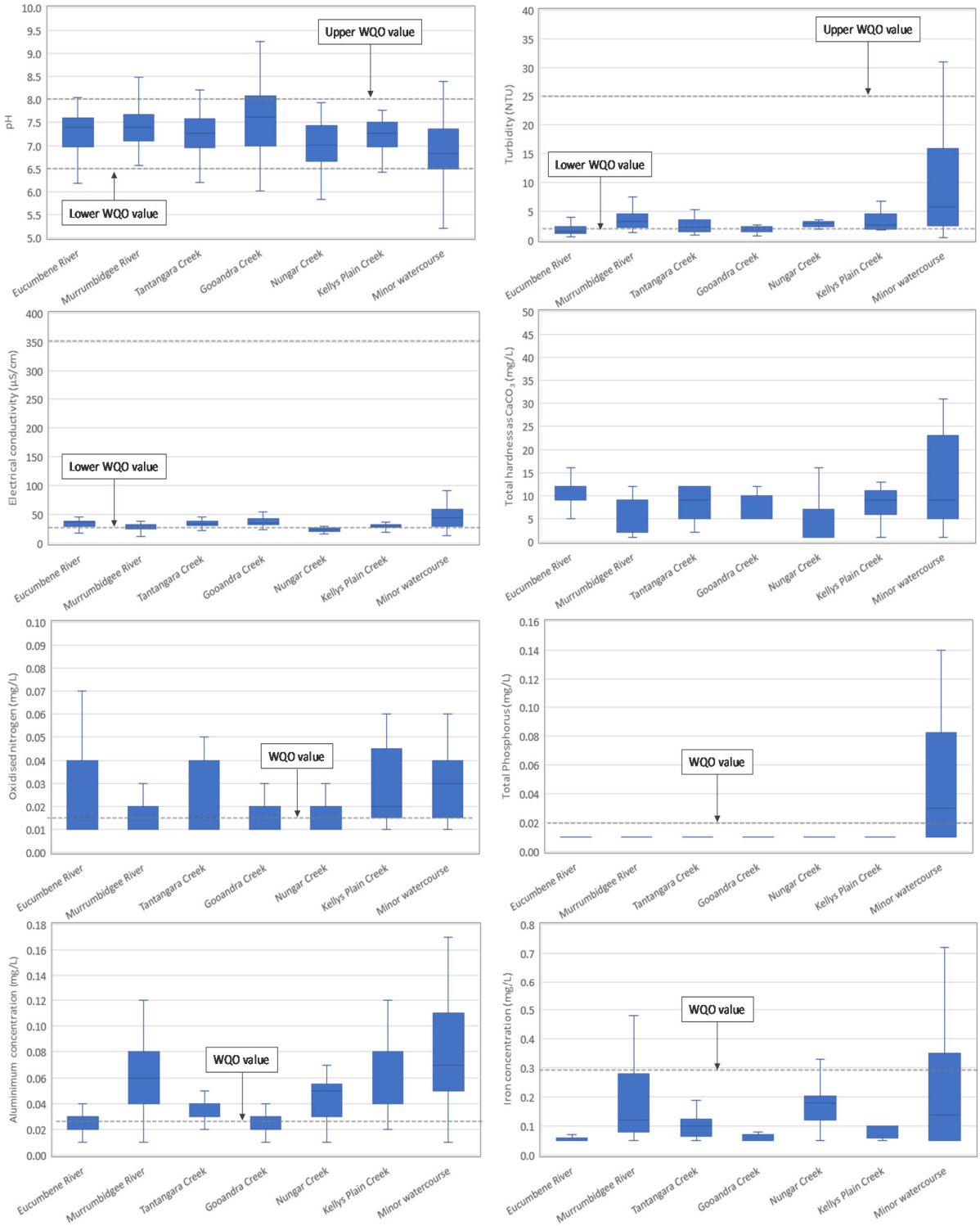


Figure 7.17 Plateau water quality summary

7.3 Ravine

The ravine is located between Talbingo Reservoir (to the west) and the Long Plain Fault to the (to the east). Surface infrastructure is proposed in Lobs Hole and Marica. Marica is located on a ridgeline between the headwaters of the Stable Creek and Highground Creek catchments, within the eastern portion of the Yarrangobilly River catchment. This section describes the physical setting, hydrologic processes, streamflow regimes and water quality characteristics of the Yarrangobilly River and other watercourses that in the vicinity of the proposed works.

7.3.1 Physical Setting

i Overview

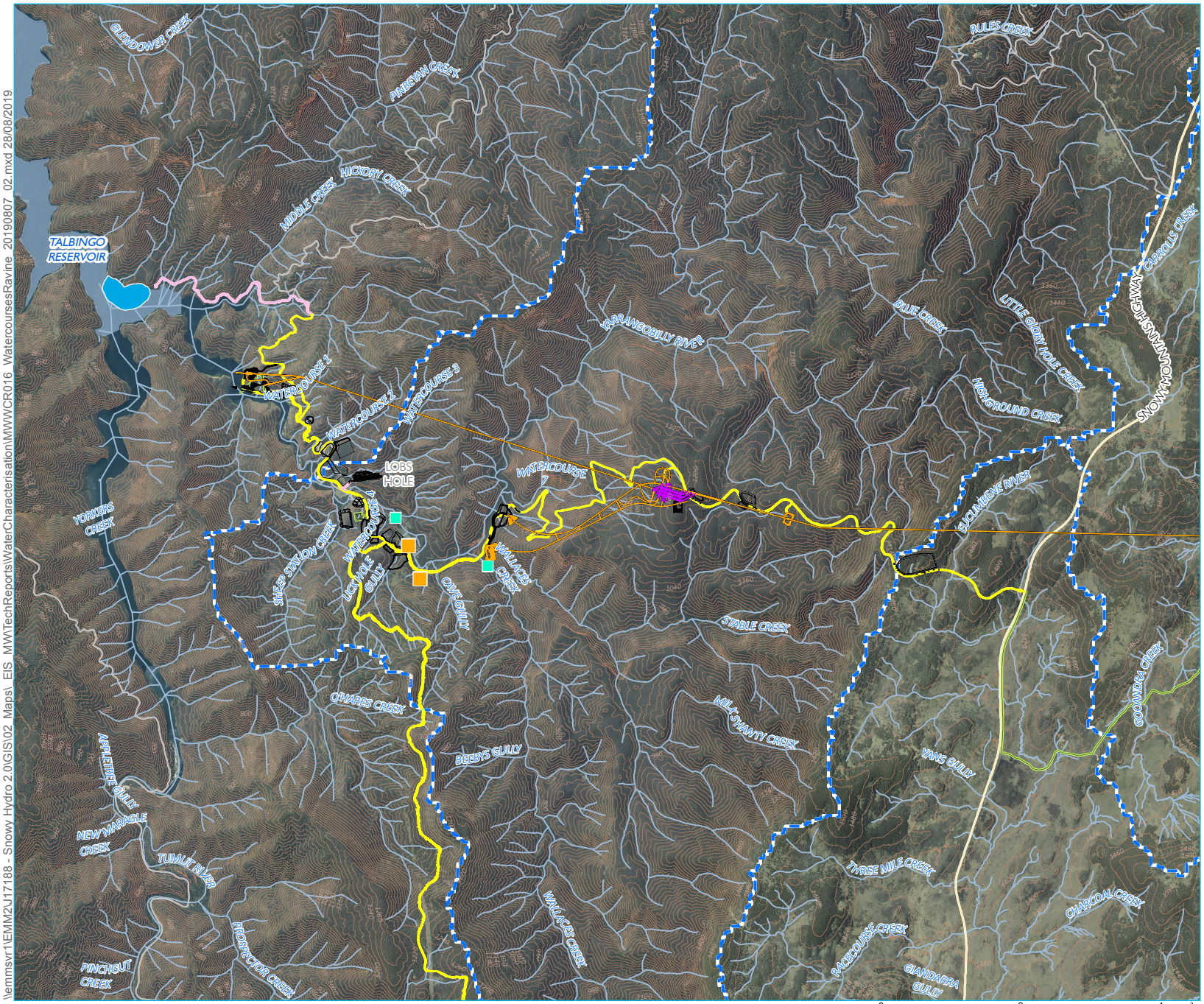
The Yarrangobilly River is a major regional watercourse that flows into Talbingo Reservoir, downstream of Lobs Hole. The river's catchment has an area of 271 km^2 that is wholly with KNP. Vegetation within the catchment includes subalpine grasslands and woodlands and montane dry sclerophyll forests. Elevations range from 550 m AHD at Lobs Hole to more than 1,400 m AHD in the head water catchments.

The Yarrangobilly River catchment and major watercourses in the ravine are shown in Figure 7.18. The locations of stream and rain gauges and proposed works are also included for reference. Table 7.3 describes the stream order, catchment area and flow regime of key watercourses that are discussed further in this section.

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.



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

0 2 4 km

GDA 1994 MGA Zone 55

N

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

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Watercourses - ravine

Snowy 2.0
Water Characterisation Report
Main Works
Figure 7.18

snowy 2.0

EMM creating opportunities

ii Watercourse characterisation

a Lobs Hole

A geomorphic characterisation assessment (see Attachment A) was undertaken by Flow and Loam Environmental (2019), using a modified River Styles framework (Brierley and Fryirs 2005). The assessment characterised the Yarrangobilly River 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 paleo channel) 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. Sediment fans have formed where smaller watercourses such as Lick Hole Gully enter the valley floor. Most runoff from these watercourses is interpreted to infiltrate into the valley floor and flow into the Yarrangobilly River as subsurface flow. Some areas of valley floor are densely vegetated with native and exotic species, while other areas are characterised by open grasslands.

Former mine workings including shafts and spoil piles are located adjacent to the Yarrangobilly River channel and immediate areas. These works are remnant from copper mines that operated intermittently from the late 1800s to early 1900s. Seeps from flooded underground workings are known to discharge directly into the river and are known to have acid mine drainage characteristics (very low pH and high dissolved metal concentrations). The rate of discharge is poorly understood.

Other major watercourses in Lobs Hole are noted in Table 7.3. Photograph 7.7 to Photograph 7.10 show typical reaches of the Yarrangobilly River and its tributaries in Lobs Hole.

Figure 7.19 shows the following information:

- the alignment and names of watercourses in Lobs Hole;
- key geomorphic features such as the extent of sediment storage areas and sediment fans that have been interpreted by Flow and Loam Environmental (2019); and
- the location of mine workings and spoil piles.

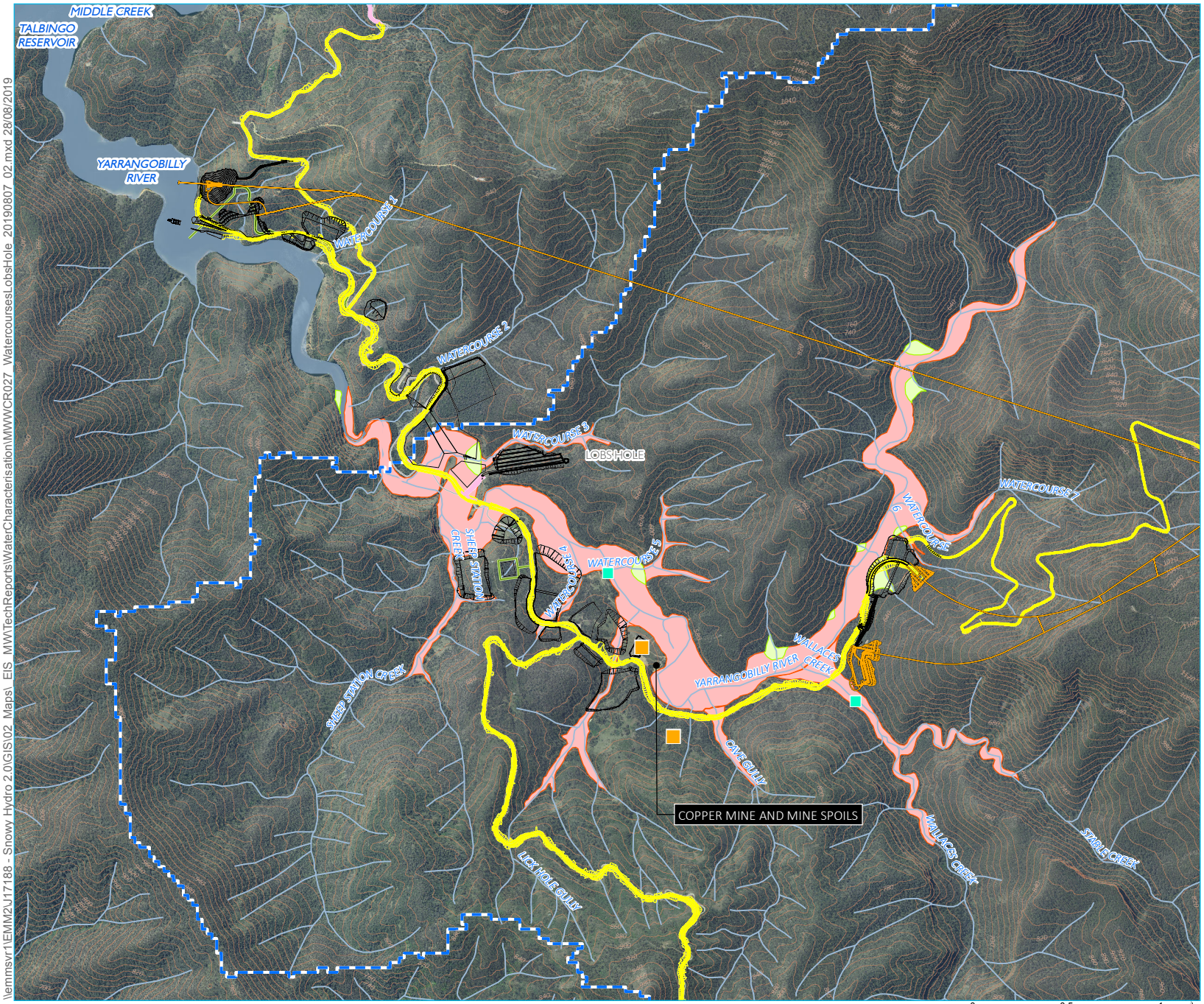
It is noted that flood characteristics in Lobs Hole are described separately in the flood risk assessment (Annexure C to the water assessment).

Photograph 7.7 **Yarrangobilly River at Lobs Hole, looking north from higher ground. Lick Hole Gully is evident in the left of the image.**

Photograph 7.8 **The Yarrangobilly River at Lobs Hole (looking upstream to the east). Mine workings are evident to the right of the river channel.**

Photograph 7.9 **Shows a typical reach of the Yarrangobilly River at Lobs Hole (looking downstream to the west)**

Photograph 7.10 **Wallaces Creek (looking upstream)**



KEY

- Weather station
- Streamflow gauge
- Catchment area
- Sediment fan
- Interpreted sediment storage

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

Existing environment

- Local road
- 20m contour
- Watercourse
- Waterbodies

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

0 0.5 1 km

GDA 1994 MGA Zone 55

N

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Watercourses - Lobs Hole

Snowy 2.0
Water Characterisation Report
Main Works
Figure 7.19

snowy 2.0

EMM creating opportunities

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 (see Photograph 7.11). Down catchment, discontinuous channels commence in well-defined channel zones and become continuous with increasing catchment area. A description of the geomorphology characteristics of headwater streams in proximity to proposed works is provided in Attachment A.

Photograph 7.11 Example headwater stream at Marica

7.3.2 Hydrology

i Hydrologic processes

The hydrologic regime of watercourses in the ravine is strongly influenced by seasonal changes to climate. As discussed in Section 4.2, median rainfall within the Yarrangobilly River catchment ranges from 920 mm/year at Lobs Hole to 1,400 mm/year in the headwater catchments. The spatial variation in median rainfall generally reflects the variation in topography within the catchment.

It is expected that most streamflow in the Yarrangobilly River originates from the higher elevation headwater catchments, which have similar hydrologic processes to those in plateau (see Section 7.2.2). Hydrologic processes in the lower portions of the catchment are expected to be less complex, with quickflow and baseflow being the predominant processes. Most 3rd 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. Gauge locations are indicated in Figure 7.18.

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

- Table 7.4 presents annualised streamflow statistics that have been calculated by EMM from the gauge records.
- Figure 7.20 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.
- Figure 7.21 presents the monthly Yarrangobilly River streamflow over the 2000 to 2019 period. The monthly streamflow is compared to median monthly flows 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
10th percentile	58 GL/year	21% of rainfall	9 GL/year	22% of rainfall	8 GL/year	20% of rainfall
50th 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
90th 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.

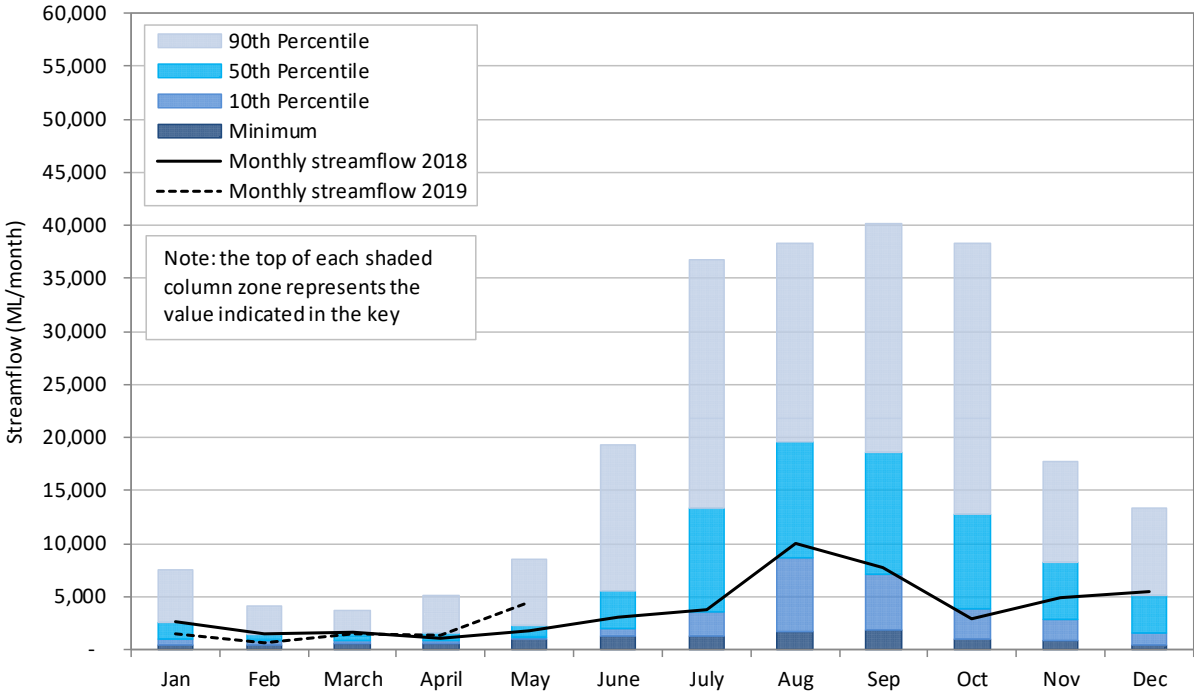


Figure 7.20 Monthly streamflow statistics (Yarrangobilly River – 410574)

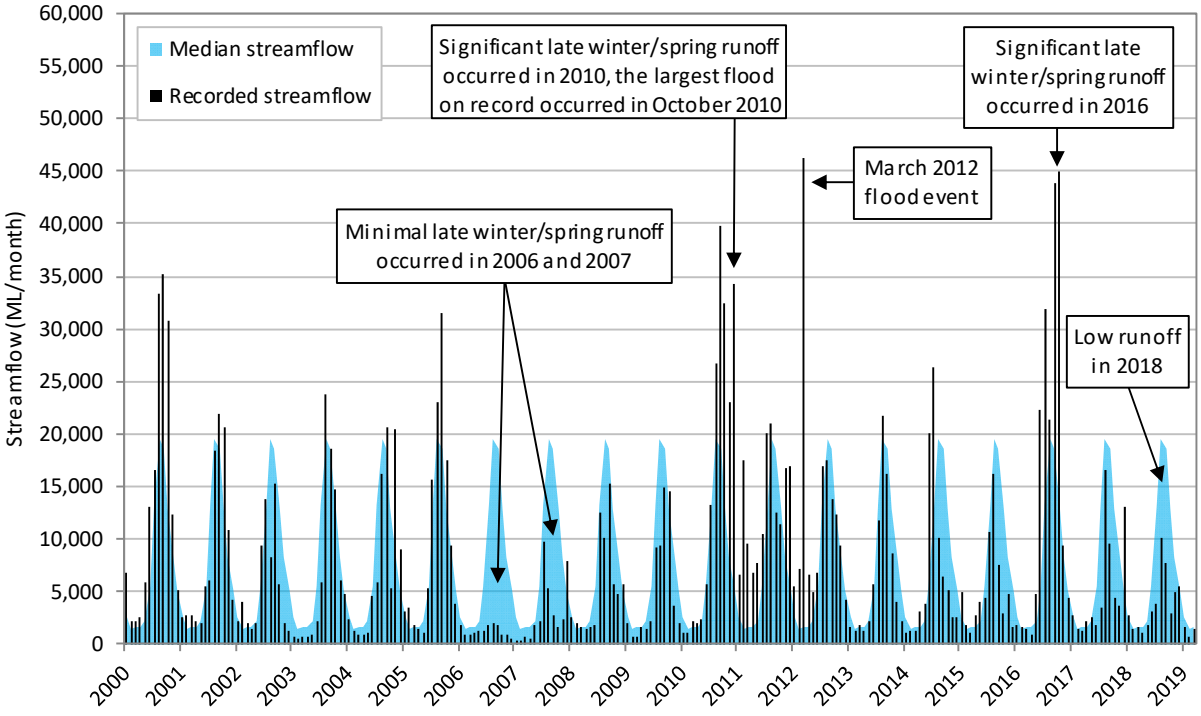


Figure 7.21 Recent streamflow (Yarrangobilly River – 410574)

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 (not shown in Figure 7.21) and 2006, following abnormally dry winter months. The lowest monthly flow on record for both the Yarrangobilly River (385 ML/month) and Wallaces Creek (14 ML/month) 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 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.

- A comparison of the Yarrangobilly River and Wallaces Creek coinciding streamflow record (1983–1998) indicates that both watercourses 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 coinciding streamflow record (1985–2019) 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 construction compounds. Most 3rd 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. Stream order, catchment area and flow regime of 2nd order and larger watercourses that are located near proposed surface works are described in Table 7.3.

7.3.3 Water quality characterisation

i Monitoring program

Baseline monitoring was undertaken between February 2018 and May 2019 in Yarrangobilly River, Wallaces Creek and minor watercourses in the vicinity of proposed surface works. Generally, monitoring was undertaken at a monthly frequency predominantly during dry weather conditions. However, wet weather monitoring was undertaken in March and May 2019. Monitoring locations, timelines and methods are described in Section 3.2.3.

ii Water quality objective values

Watercourses in the ravine are categorised as high conservation systems (see water assessment, Appendix J to the EIS). Hence, the WQOs and characterisation approach is the same as applied to watercourses in plateau (see Section 7.2.3).

iii Seasonal streamflow categories

A review of baseline water quality data has identified:

- seasonal trends in water quality during dry weather conditions; and
- water quality during wet weather conditions is materially different to the water quality during dry weather conditions.

All baseline data has been assigned to one of the following categories:

- **Summer and autumn dry weather conditions** – Streamflow over summer/autumn is proportionally an order of magnitude lower than winter/spring (see Figure 7.20). During dry weather conditions, summer/autumn streamflow is predominantly groundwater fed (ie baseflow). The water quality of summer/autumn streamflow reflects the groundwater origins of the water and generally exhibits higher salinity and carbonate levels than winter baseflow. Minor watercourses with intermittent flow regimes will typically be dry from mid-summer to the end of autumn.
- **Winter and spring dry weather conditions** – Dry weather streamflow during winter/spring is interpreted to be a combination of interflow and groundwater inflows (see Figure 7.8). The water quality generally exhibits lower salinity and carbonate levels than summer/autumn streamflow. Minor watercourses with intermittent flow regimes will typically maintain a constant streamflow over winter/spring.
- **Wet weather conditions** – Water quality during wet weather conditions is poorly understood, with data from only two sampling rounds available since the commencement of sampling in 2018.

Summer/autumn dry weather conditions refer to periods when the median monthly electrical conductivity (a measure of salinity) is greater than 100 µS/cm in the Yarrangobilly River. During the baseline monitoring period, summer/autumn conditions were assessed to occur from January to April, and winter/spring conditions were assessed to occur from May to December. This range may vary from year to year, with summer/autumn conditions potentially occurring earlier flowing a dry spring or later if dry conditions occur in early winter. For winters that experience drought conditions (ie 2006), summer/autumn conditions may occur throughout winter/spring. Winter/spring conditions could also occur in summer/autumn months for short periods of time following significant wet weather.

Seasonal trends in electrical conductivity in the Yarrangobilly River over the baseline monitoring period are shown in Figure 7.22.

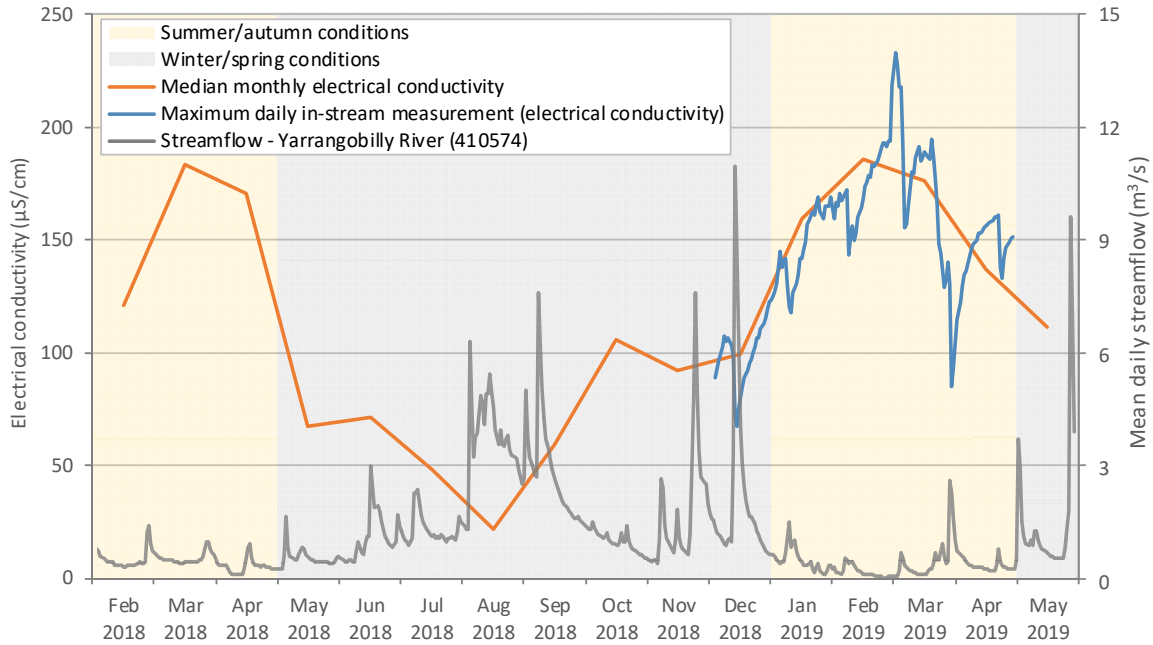


Figure 7.22 Yarrangobilly River – seasonal variation in electrical conductivity

iv Baseline data

A detailed summary of all ravine baseline water quality data is provided in Table D.14 to Table D.18 (see Attachment D). Data is presented separately for the Yarrangobilly River, Wallaces Creek, Lick Hole Gully and minor watercourses (ie Watercourse 2 and 3) – see Figure 7.18 for watercourse locations. In each table, the water quality data is divided into the three streamflow categories described above. For each category, the number of samples collected and number of exceedances of default WQO values is provided along with provisional water quality ranges. The provisional water quality ranges have been calculated as follows:

- where more than ten samples are available, the 10th, 50th and 90th percentile values are provided; and
- where less than ten samples are available, the minimum, 50th percentile and maximum values are provided.

The results from disturbed area runoff samples (see Section 3.2.3) are also provided in Table D.19 and Table D.20 (see Attachment D).

v Water quality characteristics

Water quality characteristics 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;
  - carbonate and salinity vary seasonally, with higher levels occurring in summer/autumn (see Figure 7.22);

- oxidised nitrogen concentrations exceed WQO values frequently in summer/autumn and occasionally in winter/spring;
- total and reactive phosphorus concentrations are generally below WQO values; and
- aluminium concentrations in the Yarrangobilly River exceed WQO values frequently in winter/spring and occasionally in summer/autumn. Copper concentrations in Wallaces Creek exceed WQO values occasionally.

- The water quality during dry weather conditions in minor watercourses in Lobs Hole (see Table 7.3) is generally poorer than larger watercourses, with elevated suspended sediment, nutrients and some metals (aluminium and copper).
- The water quality in Lick Hole Gully generally has higher concentrations of electrical conductivity, total hardness and some dissolved metals compared to the other ravine water courses as it is predominantly groundwater fed, and is often dry during summer/autumn conditions (see Figure 3.2).
- 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 dry weather 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 (see Section 3.2.3). 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 the key water quality parameters discussed above are provided in Figure 7.17. 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.

Table D.2 (see Attachment D) provides a summary of WQO departures.

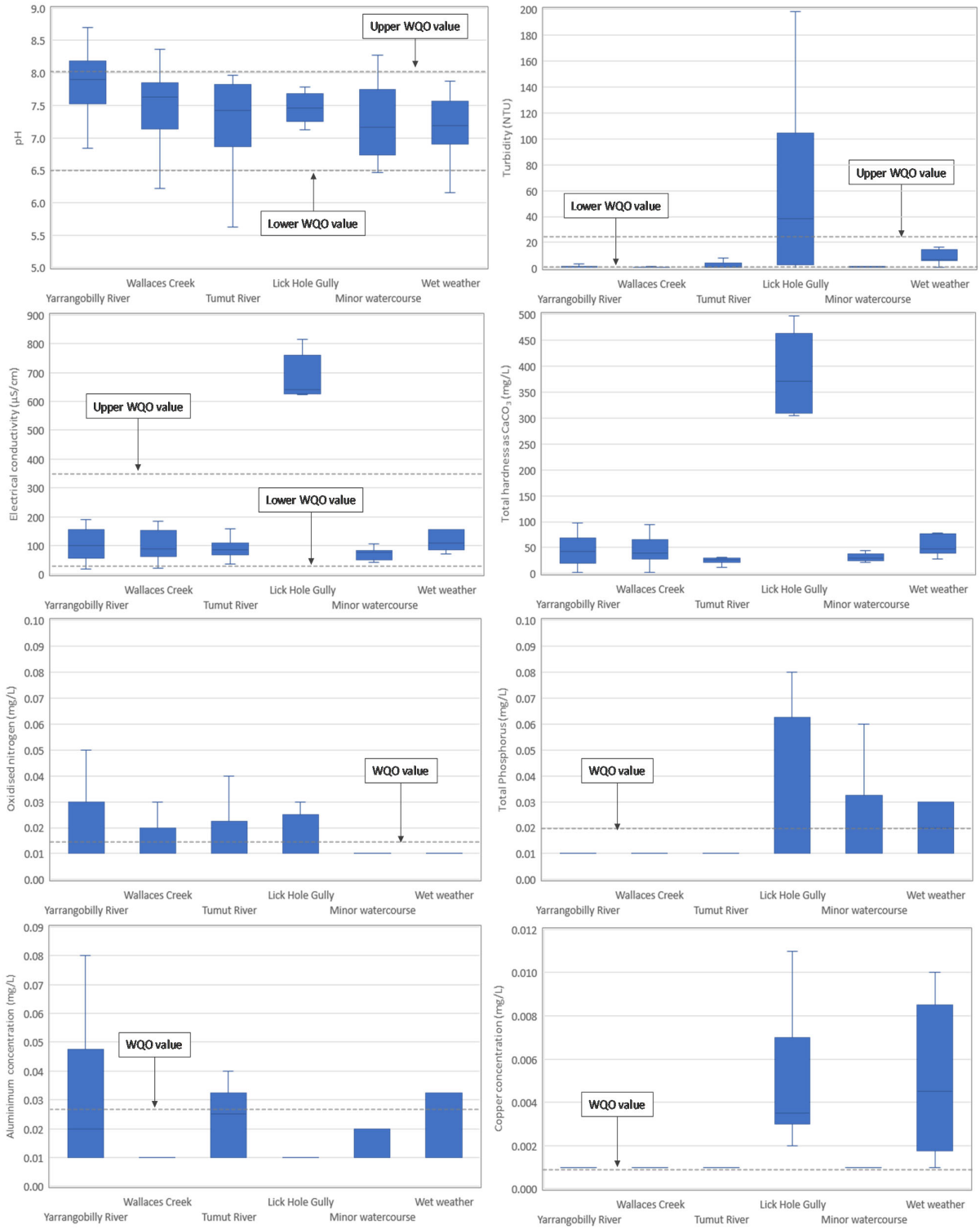


Figure 7.23 Ravine water quality summary

7.4 Rock Forest

Rock Forest is in the headwaters of the Goorudee Rivulet catchment, outside of KNP. The property is characterised by rolling topography that has been predominantly cleared for grazing. The following watercourses traverse the property:

- Camerons Creek is a 4th order watercourse that drains in an easterly direction through the southern portion of the site. The creek has a catchment area of 12.2 km^2. Site observations indicate that the creek ceased to flow over the summer of 2019, indicating an intermittent flow regime. The channel and riparian zone have been cleared and the channel is incised. A typical reach of Camerons Creek is shown in Photograph 7.12.

- An unnamed 3rd order watercourse (referred to as Watercourse RF1) drains in an easterly direction through the northern portion of the property. The creek has a catchment area of 1.9 km^2. Site observations indicate that the creek has an ephemeral flow regime. The channel and riparian zone have been cleared and the channel is incised.

Both Camerons Creek and Watercourse RF1 drain under the Snowy Mountains Highway before joining the Goorudee Rivulet, which flows in easterly direction for approximately 16 km (downstream of Rock Forest), before joining the Murrumbidgee River near the township of Adaminaby. Watercourses in the vicinity of Rock Forest are shown in Figure 7.24.

Five water quality samples were collected from Camerons Creek between February and May 2019. Some samples were collected from a standing pool due to a lack of streamflow. Table D.21 in Attachment D provides a summary of all data. The water quality is characterised as having near neutral pH, low salinity and moderate turbidity. Ammonia, oxidised and total nitrogen, total phosphorus, aluminium and iron exceeded WQO values in at least 4 of out 5 samples. Copper exceeded the WQO value in 2 out of 5 samples.

Photograph 7.12 Camerons Creek looking downstream towards Snowy Mountain Highway

KEY

- Surface water monitoring location
- Watercourse
- 20 m contour

Snowy 2.0 construction elements

- Temporary construction compounds and surface works

Existing environment

- Main road
- Local road
- Waterbodies

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

0 0.5 1 km

GDA 1994 MGA Zone 55

N

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MW\TechReports\WaterCharacterisation\MWWCR017_WatercoursesRockForest_20190701_01.mxd 28/08/2019

Watercourses - Rock Forest

Snowy 2.0
Water Characterisation Report
Main Works
Figure 7.24

snowy 2.0

EMM creating opportunities

8 Reservoirs

8.1 Tantangara

8.1.1 Overview

Tantangara Reservoir is an existing reservoir that forms part of the Snowy Scheme and construction of the dam was finalised in 1960. The reservoir is approximately 14 km long and has a surface area of approximately 21.2 km^2 (at FSL). The reservoir captures runoff from the head waters of the Murrumbidgee River and flows diverted from Goodradigbee River via the Goodradigbee aqueduct. Water is transferred to Lake Eucumbene via the Murrumbidgee to Eucumbene tunnel. Water from Lake Eucumbene is transferred to both the Tumut and Murry schemes. Tantangara Reservoir also provides environmental releases to the Murrumbidgee River.

A summary of key operating levels, storage volumes and tunnel discharge capacities are provided in Table 8.1.

Table 8.1 Tantangara Reservoir information

Characteristic	Value
Full supply level (FSL)	1,228.7 m AHD
Minimum operating level (MOL)	1,205.8 m AHD
Operating range (FSL-MOL)	22.9 m
Spillway crest	1,228.7 m AHD
Active storage (within operating range)	240 GL
Gross storage	254 GL
Murrumbidgee – Eucumbene tunnel peak discharge	22 m^3/s
Murrumbidgee – environmental release	Montane releases with daily, monthly and annual targets. Annual targets can range from 0 to 40 GL/year, with a long-term average of 20 GL/year.

Source: Snowy Hydro

8.1.2 Operating regime

Tantangara Reservoir is operated to divert runoff from the headwaters of the Murrumbidgee River to Lake Eucumbene, whilst meeting environmental release obligations to the Murrumbidgee River. In most years, most inflows occur during winter and spring. Generally, inflows are allowed to accumulate and transfers to Lake Eucumbene are made in early summer. This results in low storage levels over summer and autumn months.

Figure 8.1 shows the reservoir water levels between 2009 and 2019. It is noted that due to the reservoir's bathymetry, water levels change more rapidly at lower storage levels compared to higher levels.

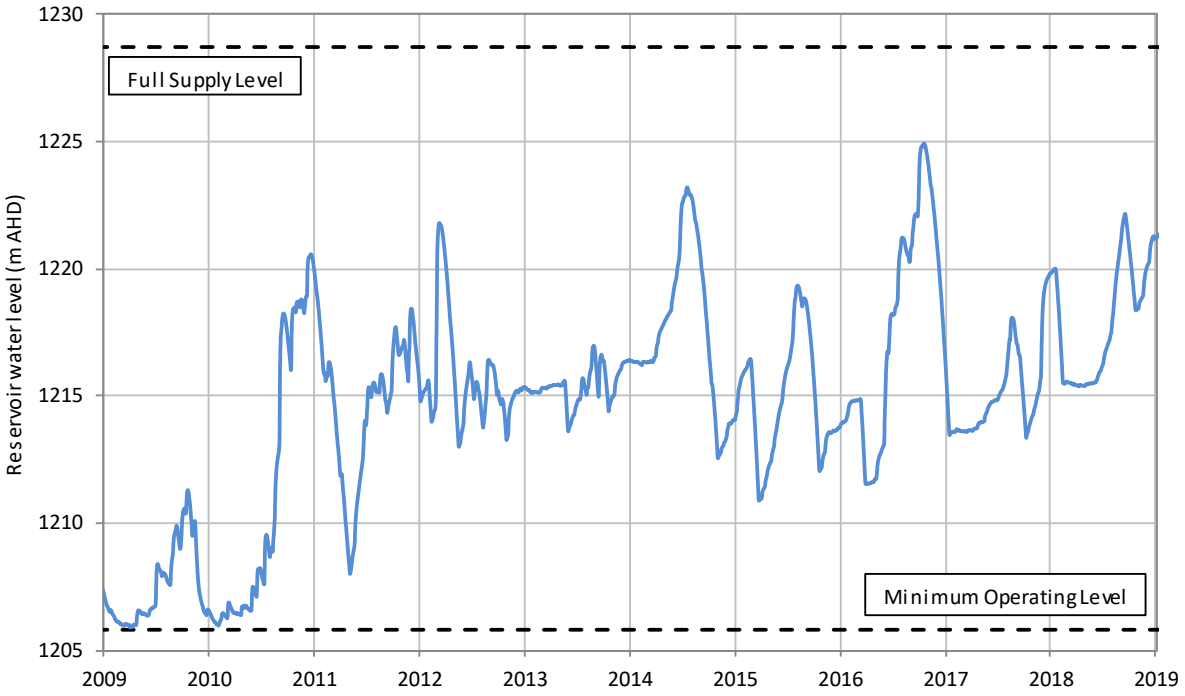


Figure 8.1 Tantangara Reservoir water level regime

Snowy Hydro provided estimates of daily environmental releases from Tantangara Reservoir and transfers from the reservoir to Lake Eucumbene. Annual average values have been calculated over the 2003 to 2018 period. These values are presented in Table 8.2 along with the gauged Murrumbidgee River above Tantangara Reservoir and Goodradigbee River Aqueduct flows over the period.

Table 8.2 Tantangara Reservoir inflow and discharge statistics

	Average annual flow volume[1] (GL/year)	Percentage of inflows/outflows
Inflows		
– Murrumbidgee River	131[3]	58%
– Goodradigbee River Aqueduct	5	2%
– Other (ungagged catchments less evaporation losses)[2]	89	39%
Total inflows	224	-
Outflows		
– Tantangara Dam releases to lower Murrumbidgee River	18	8%
– Tantangara to Eucumbene	207	92%
Total outflows	224	-

Source: Calculated values from data provided by Snowy Hydro.

Notes: 1. Calculated over the 2003 to 2019 period.
2. Value calculated as the difference between inflows and outflows.
3. The average annual flow from the Murrumbidgee River is different to the value provided in Table 7.2. This is due to the values being calculated from different periods.

8.1.3 Water quality characterisation

i Monitoring program

Baseline monitoring was undertaken over the March 2018 to February 2019 period. The program comprised sampling from nine locations within the reservoir. See Section 3.2.3 for further information.

ii Water quality objective values

Water Quality Objectives for reservoirs based on the *NSW Water Quality and River Flow Objectives* (DECCW 2006) are established in the water assessment (Appendix J to the EIS). Reservoirs are categorised as slightly to moderately disturbed systems, the following WQOs apply:

- physical and chemical stressors – some change to natural variability acceptable; and
- toxicant trigger values for slightly to moderately disturbed ecosystems.

There is currently insufficient data to prepare SSTVs for all monitoring locations and operating conditions. Hence, the following default values have been applied to characterise water quality:

- physical and chemical stressors – default trigger values for freshwater lakes and reservoirs in South Eastern Australia that are reported in ANZECC/ARMCANZ (2000); and
- toxicant trigger values for slightly to moderately disturbed ecosystems that are provided in ANZECC/ARMCANZ (2000).

These values are referred to as WQO values. SSTVs can be prepared during construction phase monitoring if sufficient data is available.

iii Water quality categories

As described in Section 8.1, Tantangara Reservoir captures runoff from the headwaters of the Murrumbidgee River and diverted flows from Goodradigbee River. Water is transferred to Lake Eucumbene via the Murrumbidgee to Eucumbene tunnel. The reservoir is generally kept at low levels during summer and autumn, when inflows are low. As a result, the water quality is expected to be more sensitive to seasonal changes in streamflow, water quality and operating regimes than Talbingo Reservoir, which receives year-round inflows from the Upper Tumut scheme. All reservoir baseline data has been assigned to the following categories:

- summer and autumn dry weather conditions;
- winter and spring dry weather conditions; and
- wet weather conditions.

The same categories were also applied to characterise water quality in watercourses (see Chapter 7).

iv Baseline data

A detailed summary of all baseline water quality data is provided in Table D.23 (see Attachment D). Water quality data is divided into the three streamflow categories described above. For each category, the number of samples collected and number of exceedances of default WQO values is provided along with provisional water quality ranges. The provisional water quality ranges have been calculated as follows:

- where more than ten samples are available, the 10th, 50th and 90th percentile values are provided; and
- where less than ten samples are available, the minimum, 50th percentile and maximum values are provided.

v Water quality characteristics

Water quality characteristics are described as follows:

- pH ranges between 6.6 and 8.0, with one lower and upper bound exceedance occurring.
- Low levels of suspended solids and low turbidity.
- Carbonate and salinity vary seasonally, with higher levels occurring in summer/autumn.
- Oxidised nitrogen and ammonia occasionally exceeded WQO values in summer/autumn.
- Total phosphorus frequently exceeded WQO values in summer/autumn and winter/spring while reactive phosphorus occasionally exceeded WQO values.
- All dissolved metal concentrations were below WQO values except for:
  - aluminium concentrations exceeded WQO values on a frequent basis;
  - copper, iron and zinc exceeded WQO values on a frequent basis during summer/autumn; and
  - chromium (total), cobalt and lead exceeded WQO values on an occasional basis during summer/autumn.

  It is noted that all of the copper exceedances and the zinc exceedances occurred during March 2018 sampling, where 100% of samples exceeded the WQO values. Different analysis methods (consistent with the methods applied more broadly to EIS sampling) were applied to subsequent sampling (post-March 2018).
- Reservoir water quality during and following wet weather conditions is poorly understood. There is potential for elevated turbidity, nutrients and some metals to occur near watercourse inflow locations for several weeks following a substantial runoff event.

Table D.6 in Attachment D provides a summary of WQO departures.

8.1.4 Sediment characterisation

The physical and chemical characteristics of reservoir sediments have been determined as a part of a range of programs as described in Section 3.2.3iiic.

Bulk sediment samples were collected in March 2018 from 12 locations across Tantangara Reservoir (Cardno 2019a). The physical and geochemical properties of the sediments are generally homogenous throughout Tantangara Reservoir, primarily comprising silts (mainly coarse silts) and clay. All metal concentrations were below sediment quality guidelines values and all organic compounds concentrations were below the analytical detection limits. Sediment quality results for the March 2018 sampling are provided in Attachment F.

Bulk sediment samples were supplied to CSIRO for analysis as part of the *Environmental Categorisation of Excavated Rock Interactions with and Potential Impacts on Reservoir Waters and Sediments* (CSIRO 2019) program. This included the analysis of nutrients, major ions and metals in sediment pore waters; and particle size distribution, nutrients, major ions and metals (total and dilute acid digestible) in the bulk sediment. Some total metal concentrations were above sediment quality guideline values but were not considered to be bioavailable as dilute acid digestible metal concentrations were all below sediment quality guideline values.

Sediment cores were collected from Tantangara Reservoir (around 600 m from the intake location) in March 2019 (RHDHV 2019). Selected horizons were analysed for particle size distribution. Each core was logged, and the depth of deposited sediment was used to estimate the sedimentation rate at each location. In Tantangara Reservoir, the sedimentation rate is in the range of 0–3 mm/year in the area where cores were collected.

Biological parameters in reservoir sediments, such as benthic infauna assemblages, are reported in the aquatic ecology impact assessment (Appendix M.2 to the EIS). Sediment sampling investigations are further described in Attachment G and Attachment H.

8.2 Talbingo

8.2.1 Overview

Talbingo Reservoir is an existing reservoir on the Tumut River that forms part of the Snowy Scheme. Construction of Talbingo Reservoir was completed in 1971. The reservoir is approximately 25 km long and has a surface area of approximately 19.4 km^2 (at spillway crest). Water is released from the reservoir through the Tumut 3 power station into Jounama Pondage, which releases water into Blowering Reservoir. Blowering Reservoir is operated by Water NSW and releases water into the Tumut River to supply a variety of consumptive users but primarily large irrigation schemes such as that run by Murrumbidgee Irrigation. The Tumut 3 power station also pumps water from Jounama Pondage back into Talbingo Reservoir.

A summary of key operating levels, storage volumes and Tumut 3 power station discharge and pump capacities are provided in Table 8.3.

Table 8.3 Talbingo Reservoir information

Characteristic	Value
Full supply level (FSL)	543.2 m AHD
Minimum operating level (MOL)	534.4 m AHD
Operating range (FSL-MOL)	8.8 m
Spillway crest	544.7 m AHD
Active storage (within operating range)	239 GL
Gross storage	921 GL
Tumut 3 discharge (maximum)	1,133 m^3/s
Tumut 3 pump back rate (maximum)	300 m^3/s

Source: Snowy Hydro

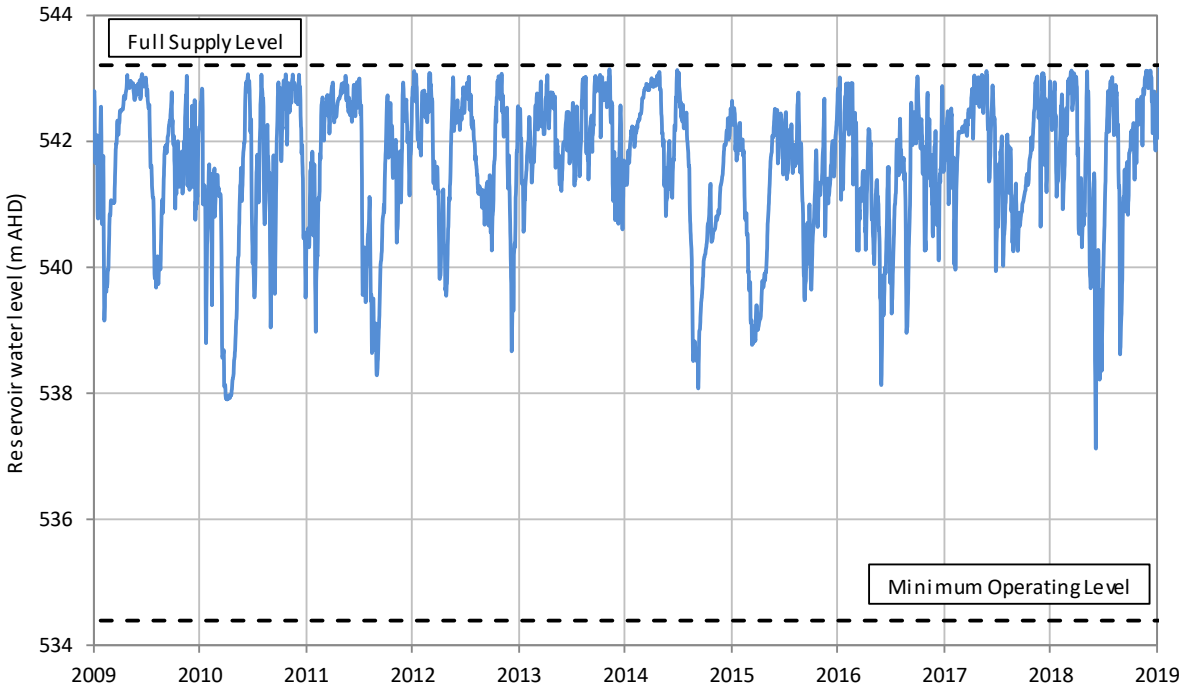
8.2.2 Operating regime

Talbingo Reservoir is operated as head water pondage for generation of hydro-power from the Tumut 3 power station and head storage for the operation of the Tumut 3 pumped storage project. As noted in Table 8.3, the water level is maintained within an 8.8 m operating range, between the FSL and MOL, but generally ranges between 538.0 m AHD and FSL (see Figure 8.2).

The reservoir receives inflows from:

- the Tumut River (primarily from discharges from Tumut 2 power station);
- the Yarrangobilly River;
- pumping from Jounama Pondage; and
- smaller tributaries and direct rainfall.

Water levels can change rapidly due to discharge of water through Tumut 3 power station, inflows due to rainfall, or discharge from Tumut 2 power station. The reservoir water level between 2009 and 2019 is shown in Figure 8.2.



Source: Snowy Hydro

Figure 8.2 Talbingo Reservoir water level regime

Snowy Hydro provided estimates of daily discharge from Tumut 2 and Tumut 3 power stations and Tumut 3 pump-back volumes. Annual average values have been calculated over the 1994 to 2019 period. These values are presented in Table 8.4 along with the gauged Yarrangobilly River streamflow over the period. Estimates of inflows expressed as a percentage of the net discharge from the reservoir are also presented in Table 8.4.

Table 8.4 Talbingo Reservoir inflow and discharge statistics

	Average annual flow volume[1] (GL/year)	Percentage of net discharge through Tumut 3[1, 2]
Inflows		
– Yarrangobilly River	98[4]	8%
– Tumut 2 discharge	1,053	86%
– Tumut 3 pumping	387	-
– Other (ungauged catchments less evaporation losses)[3]	77	6%
Total inflows	1,616	-
Outflows		
– Tumut 3 discharge	1,616	-
Net discharge[2]	1,229	

Source: Calculated values from data provided by Snowy Hydro.
Notes: 1. Calculated over the 1994 to 2019 period.
2. Net discharge refers to Tumut 3 discharge less Tumut 3 pumping.
3. Value calculated as the difference between inflows and outflows.
4. The average annual flow from the Yarrangobilly River is different to the value provided in Table 7.4. This is due to the values being calculated from different periods.

The average residence time or turnover time of water in the reservoir can be calculated as a function of the gross storage volume (921 GL) divided by the average net discharge volume of 1,229 GL/year. This calculation indicates that water on average will remain in the reservoir for nine months before discharge.

8.2.3 Water quality characterisation

i Monitoring program

Baseline monitoring was undertaken over the March 2018 to February 2019 period. The program comprised sampling from ten locations within the reservoir. See Section 3.2.3 for further information.

ii Water quality objective values

Talbingo Reservoir is categorised as a slightly to moderately disturbed system (see water assessment, Appendix J to the EIS). Hence, the WQOs and characterisation approach is the same as applied to Tantangara Reservoir (see Section 8.1.3).

iii Water quality categories

As described in Section 8.2.2, the gross volume of the reservoir is equivalent to 75% of the average annual flow through the reservoir and significant inflows are maintained during the summer months due to diversions from the greater Snowy Scheme. As a result, the water quality is expected to be less sensitive to seasonal changes in streamflow/water quality regimes than watercourses such as the Yarrangobilly River. Notwithstanding, to maintain a consistent approach to characterising surface water quality, all reservoir baseline data has been assigned to the following categories:

- summer and autumn dry weather conditions;

- winter and spring dry weather conditions; and
- wet weather conditions.

The same categories were also applied to characterise water quality in watercourses (see Chapter 7).

iv Baseline data

A detailed summary of all baseline water quality data is provided in Table D.22 (see Attachment D). Water quality data is divided into the three categories described above. For each category, the number of samples collected and number of exceedances of default WQO values is provided along with provisional water quality ranges. The provisional water quality ranges have been calculated as follows:

- where more than ten samples are available, the 10th, 50th and 90th percentile values are provided; and
- where less than ten samples are available, the minimum, 50th percentile and maximum values are provided.

v Water quality characteristics

Water quality characteristics are described as follows:

- pH ranges between 6.3 and 8.2, with occasional lower and upper bound exceedances.
- Low concentrations of suspended solids and low turbidity.
- Carbonate and salinity vary seasonally, with higher levels occurring in summer/autumn, correlating with the higher salinity of streamflow over summer and autumn months (see Chapter 7).
- Oxidised nitrogen concentrations exceeded WQO values frequently in winter/spring and occasionally in summer/autumn. This is the opposite trend to the Yarrangobilly River, were exceedances are more likely to occur in summer/autumn (see Section 7.3.3).
- Ammonia concentrations frequently exceed WQO values during winter/spring, corelating with the elevated oxidised nitrogen.
- Total phosphorus concentrations exceed WQO values in all summer/autumn samples and in approximately 25% of winter/spring samples.
- All dissolved metal concentrations were below WQO values except for:
    - copper and zinc concentrations exceeded WQO values frequently in summer/autumn and occasionally in winter/spring; and
    - chromium (total) and lead concentrations occasionally exceeded WQO values in summer/autumn.

  It is noted that all but one of the copper and zinc exceedances occurred during March 2018 sampling, where 80% of samples exceeded the WQO values. Different analysis methods (consistent with the methods applied more broadly to EIS sampling) were applied to subsequent sampling (post-March 2018).
- Reservoir water quality during and following wet weather conditions is poorly understood. There is potential for elevated turbidity, nutrients and some metals to occur near watercourse inflow locations for several weeks following a substantial runoff event.

Table D.5 in Attachment D provides a summary of WQO departures.

8.2.4 Sediment characterisation

The physical and chemical characteristics of reservoir sediments have been determined as a part of a range of programs as described in Section 3.2.3iiic.

Bulk sediment samples were collected in March 2018 from 12 locations across Talbingo Reservoir (Cardno 2019a). The physical and geochemical properties of the sediments are generally homogenous throughout Talbingo Reservoir, primarily comprising silts (mainly coarse silts) and clay. Some metal concentrations (primarily nickel and copper) were detected above relevant sediment quality guideline values, in particular in Middle Bay. These are not considered to be bioavailable (ie absorbed by organisms) based on the concentrations measured after a dilute acid extraction. Organic compound concentrations were generally below the analytical detection limits, although elevated total recoverable hydrocarbon concentrations were found at some sites in the north of the reservoir close to the spillway and in Ravine Bay. Sediment quality results for the March 2018 sampling are provided in Attachment F.

Bulk sediment samples supplied to CSIRO for analysis as part of the *Environmental Categorisation of Excavated Rock Interactions with and Potential Impacts on Reservoir Waters and Sediments* (CSIRO 2019) program. This included the analysis of nutrients, major ions and metals in sediment pore waters; and particle size distribution, nutrients, major ions and metals (total and dilute acid digestible) in the bulk sediment. Some total metal concentrations were above sediment quality guideline values but were not considered to be bioavailable as dilute acid digestible metal concentrations were all below sediment quality guideline values.

Bulk sediment samples collected from the Yarrangobilly Arm of Talbingo Reservoir (RHDHV 2018a) were analysed for particle size distribution, nutrients, organic carbon, total metals and organic compounds in selected samples. The results were compared to the screening levels provided in the *National Assessment Guidelines for Dredging* (DEWHA 2009). Further testing (dilute acid extraction and elutriate tests) were conducted based on the first round of results. These tests found that up to a 1:25 dilution (reservoir water:sediment) may be required to meet all guideline values following the placement of dredged sediment at a spoil ground on the bed the reservoir but that this level of dilution would be quickly achieved during placement.

Sediment cores were collected from Middle Bay, Ravine Bay, Plain Creek Bay and Cascade Bay in August 2018 (RHDHV 2018b) and Middle Bay and Ravine Bay in March 2019 (RHDHV 2019). Selected horizons were analysed for particle size distribution. Each core was logged, and the depth of deposited sediment was used to estimate the sedimentation rate at each location. In Talbingo Reservoir, the sedimentation rate is in the range of 5–15 mm/year in the Yarrangobilly Arm and negligible in other parts of the reservoir.

Biological parameters in reservoir sediments, such as benthic infauna assemblages, are reported in the aquatic ecology impact assessment (Appendix M.2 to the EIS). Sediment sampling investigations are further described in Attachment G and Attachment H.

8.3 Comparison of reservoir water quality

Snowy 2.0 operations will transfer water between Talbingo Reservoir and Tantangara Reservoir. The water quality in the two reservoirs (see Section 8.1.3 and Section 8.2.3) is compared using box and whisker plots in Figure 8.3 (physico-chemical parameters), Figure 8.4 (nutrients) and Figure 8.5 (selected metals). The box (the rectangle) represents the data range (for all water quality 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. The figures also provide WQO values for Talbingo and Tantangara reservoirs as described in Section 8.1.3ii.

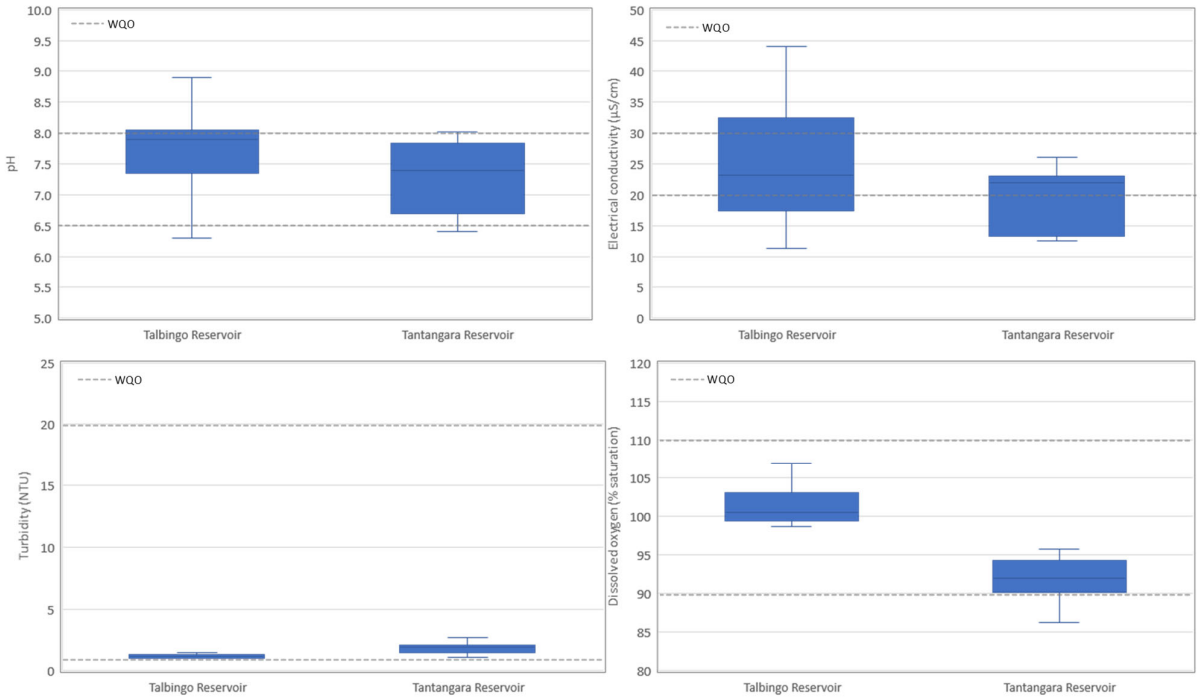


Figure 8.3 Water quality in Talbingo and Tantangara reservoirs – pH, electrical conductivity, turbidity and dissolved oxygen

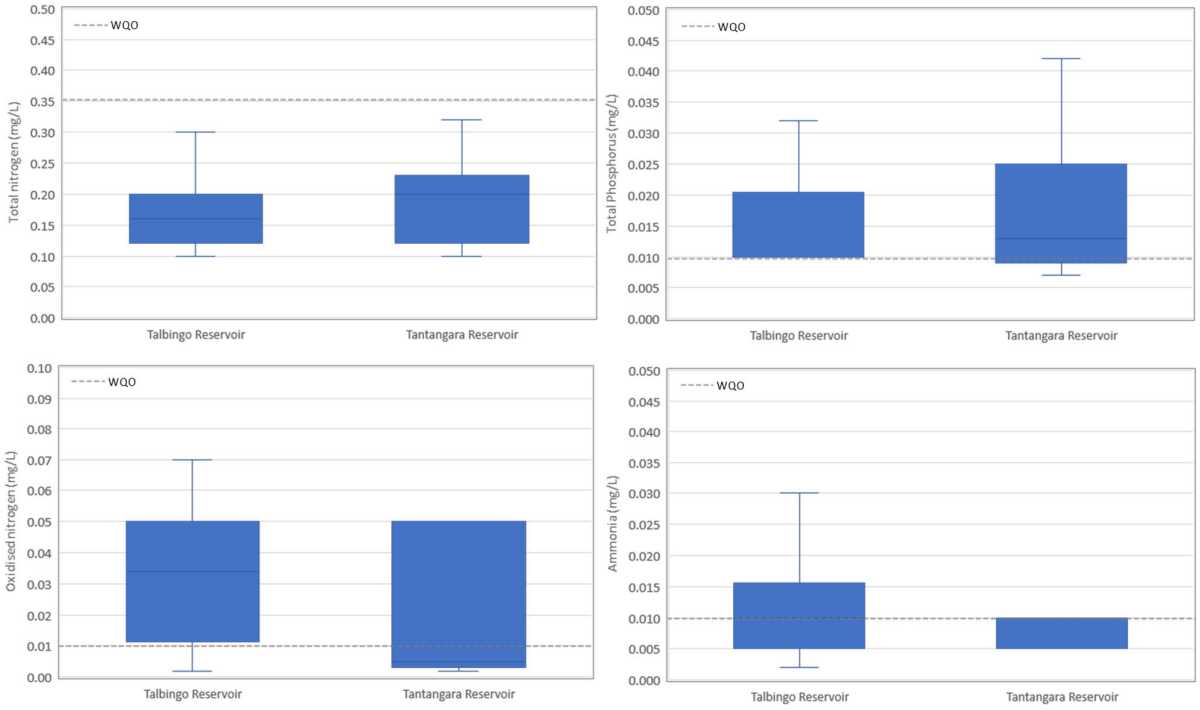


Figure 8.4 Water quality in Talbingo and Tantangara reservoirs – nutrients

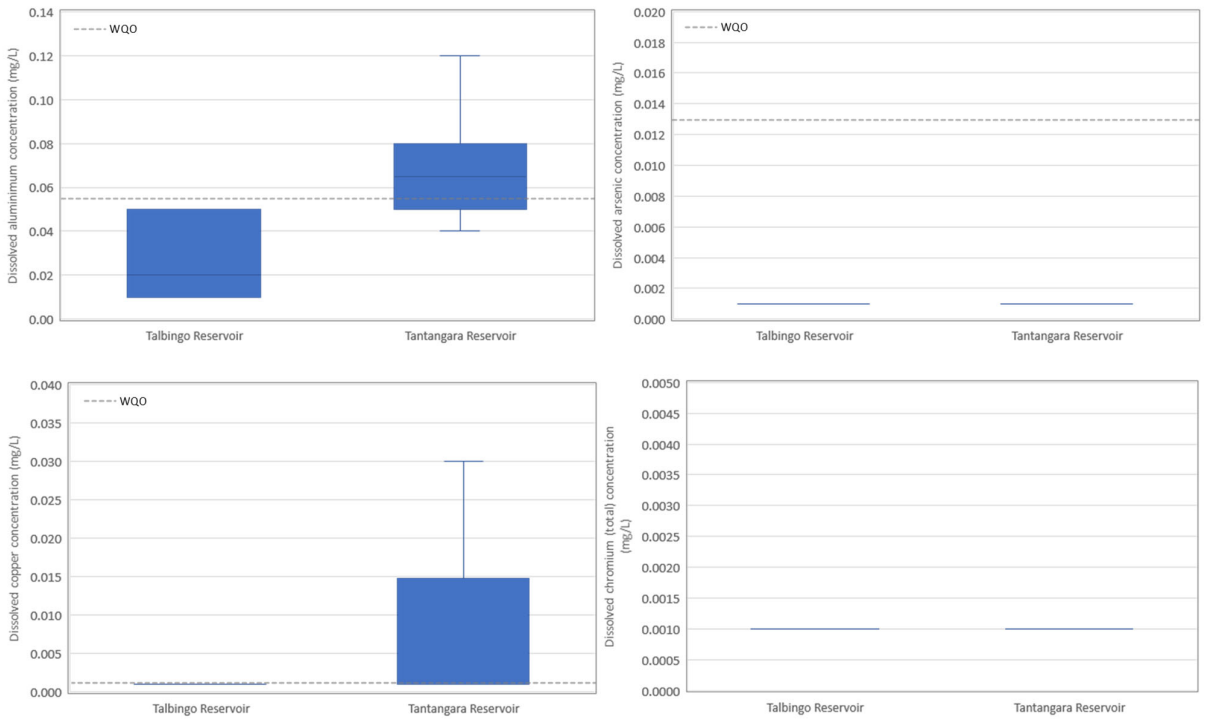


Figure 8.5 Water quality in Talbingo and Tantangara reservoirs – selected metals

Aluminium, arsenic and chromium were identified by CSIRO (2019) as being potential contaminant of concern during subaqueous excavated rock placement, based on the concentrations of these metals exceeding default toxicant trigger values when excavated rock is mixed with reservoir water at high concentrations. Comparison of the water quality between the reservoirs indicates:

- pH is similar in both reservoirs and generally within the WQO range;
- electrical conductivity is higher in Talbingo Reservoir than in Tantangara Reservoir but is generally within or below the WQO range;
- turbidity is low in both reservoirs, but is higher in Tantangara Reservoir than in Talbingo Reservoir, and is at the lower end of the WQO 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 WQO range;
- the total nitrogen concentration is similar in both reservoirs and below the WQO value;
- the total phosphorus concentration is similar in both reservoirs and generally above the WQO value;
- the oxidised nitrogen concentration is similar in both reservoirs and generally above the WQO value;
- the total ammonia concentration is similar in both reservoirs and ranges around the WQO value;
- the dissolved aluminium concentration is higher in Tantangara Reservoir than in Talbingo Reservoir and is below the WQO value in Talbingo Reservoir but higher that the WQO value in Tantangara Reservoir;

- dissolved arsenic concentrations are very low in both reservoirs and well below WQO values;
- dissolved copper concentrations are low in Talbingo Reservoir and below the WQO value;

  It is noted that several copper samples exceeded WQO values at Talbingo Reservoir during March 2018 sampling, where 80% of the samples exceeded the WQO values. As copper concentrations have been below the WQO in all but one other sample, the March 2019 exceedances fall into the outlier category and have therefore not been shown in Figure 8.5. Different analysis methods (consistent with the methods applied more broadly to EIS sampling) were applied to subsequent sampling (post-March 2018).

- dissolved copper concentrations are higher in Tantangara Reservoir and above the WQO value, all but one of the higher copper concentrations were recorded during the March 2018 sampling so may be the result of sampling contamination; and

  It is noted that all of the copper exceedances and the zinc exceedances occurred during March 2018 sampling, where 100% of samples exceeded the WQO values. Different analysis methods (consistent with the methods applied more broadly to EIS sampling) were applied to subsequent sampling (post-March 2018).

- dissolved chromium concentrations are below the analytical detection limit (0.001 mg/L) in both reservoirs.

9 Hydrogeology

9.1 Overview

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.

This section describes groundwater flow regimes, 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 in Sections 9.2 and 9.3 respectively. As only surface works are proposed at Rock Forest, the hydrogeological setting of this area has not been described below.

An overall appreciation of the recharge, discharge and flow patterns, and corresponding shallow and deep water levels along the tunnel alignment is provided in Figure 9.1.

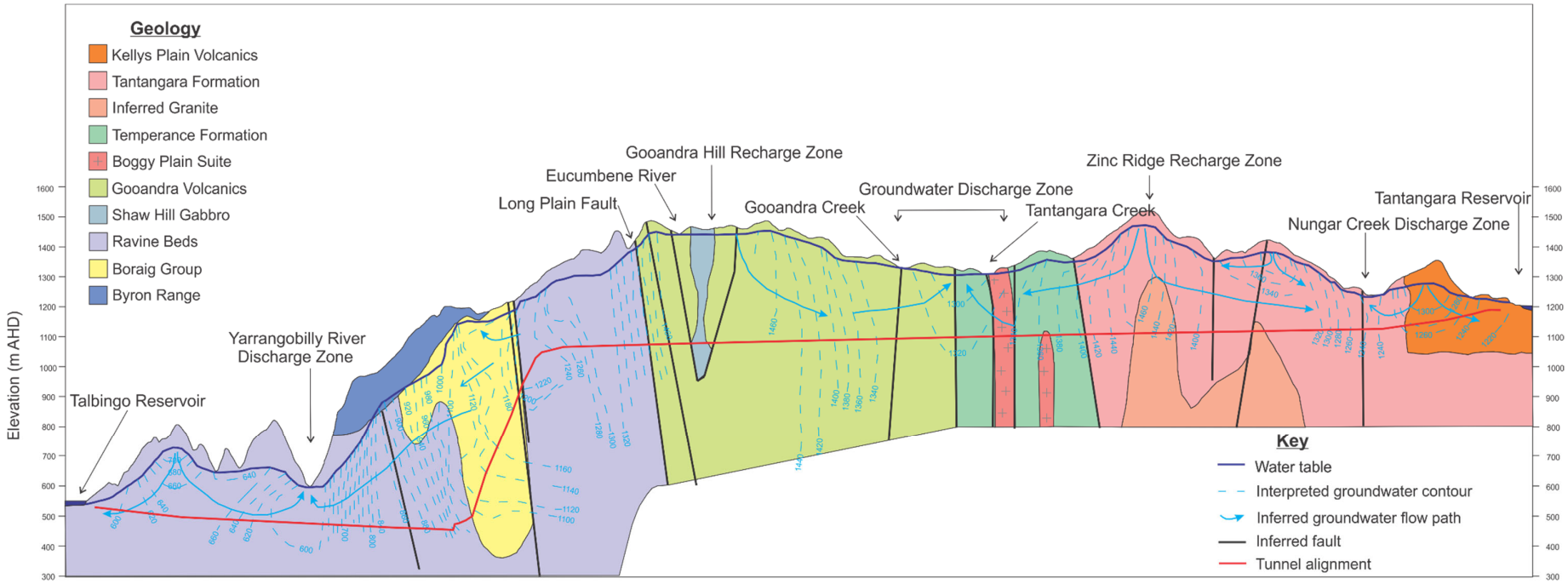


Figure 9.1 Interpreted groundwater recharge, discharge and flow patterns along tunnel alignment

9.2 Plateau

9.2.1 Groundwater levels and flow

Plateau groundwater levels are monitored in the Tertiary basalt, Gooandra Volcanics, Tantangara Formation, Temperance Formation, Boraig Group, Kellys Plain Volcanics, Boggy Plain Suite and within several bog and fen areas. The groundwater level monitoring locations for the plateau are summarised in Table 3.7 and Table 3.8 and groundwater level hydrographs are provided in Attachment E.

i Spatial analysis

a Gooandra Volcanics

Groundwater levels within the Gooandra Volcanics are influenced by the relief that occurs across the plateau and generally mirror the topography.

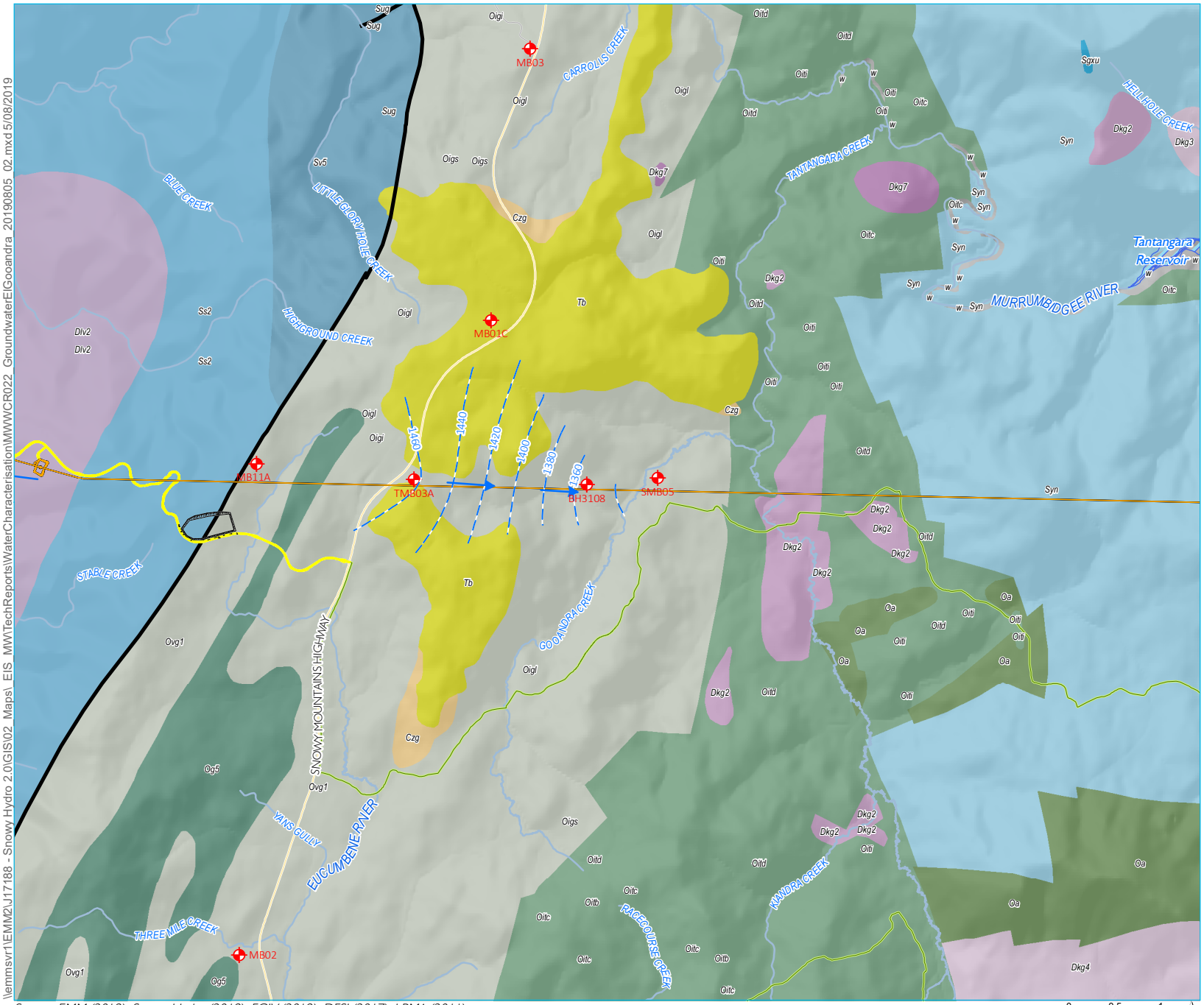
Along the proposed headrace tunnel alignment, groundwater levels as measured in monitoring bores vary from approximately 1,470 m AHD in the topographically elevated terrain near the LPF in the west, to approximately 1,325 m AHD in the topographically lower elevated terrain near monitoring bore SMB05 in the east.

Overall, groundwater levels along the proposed tunnel alignment indicate that groundwater within the Gooandra Volcanics flows west to east from the LPF (see Figure 9.2). The average hydraulic gradient across the Gooandra Volcanics is approximately 0.03.

b Tantangara Formation

Groundwater levels in monitoring bores and VWPs within the Tantangara Formation vary in elevation from approximately 1,245 m AHD to 1,415 m AHD.

Along the proposed headrace tunnel alignment, groundwater elevations are highest in the topographically elevated areas. Groundwater flow is from topographic highs towards the topographic lows to the west and east (see Figure 9.3). The hydraulic gradient along the proposed headrace tunnel alignment within the Tantangara Formation is approximately 0.06.



KEY

- Groundwater elevation
- Groundwater flow direction
- Groundwater monitoring bore

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
- Local road
- Watercourse
- Scheme storage
- Long Plain Fault (interpreted)

Tertiary

- *Tb* - Basalt (undifferentiated)

Cainozoic

- *Czg* - Unknown (undifferentiated)

Devonian

- *Dlv2* - Boraig Group (unnamed)
- *Dkg3, Dkg4* - unknown (Hell Hole Creek Adamellite)
- *Dkg2*- Boggy Plain Suite (undifferentiated)
- *Dkg5, Dkg7* - Boggy Plain Suite (Boggy Plain Adamellite)

Silurian

- *Ss2* - Bredbo Group (Ravine Beds/Yarrangobilly Limestone)
- *Syn* - Yalmy Group (Tantangara
- *Sgxu* - Unknown (undifferentiated)
- *Sug, Sv5* - Young Suite (Goobarragandra Volcanics)

Ordovican

- *Oigi, Oigl, Oigs, Ovg1* - unknown - Gooandra Volcanics
- *Oitb, Oitc, Oitd, Oiti* - Kiandra Group (Temperance Formation)
- *Oa* - Adaminaby Group (undifferentiated)
- *Og5* - Unknown (Shaw Hill Gabbro)

Inferred groundwater elevation and flow direction – Gooandra Volcanics

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

0 0.5 1 km

GDA 1994 MGA Zone 55

N

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.2

snowy 2.0

EMM creating opportunities

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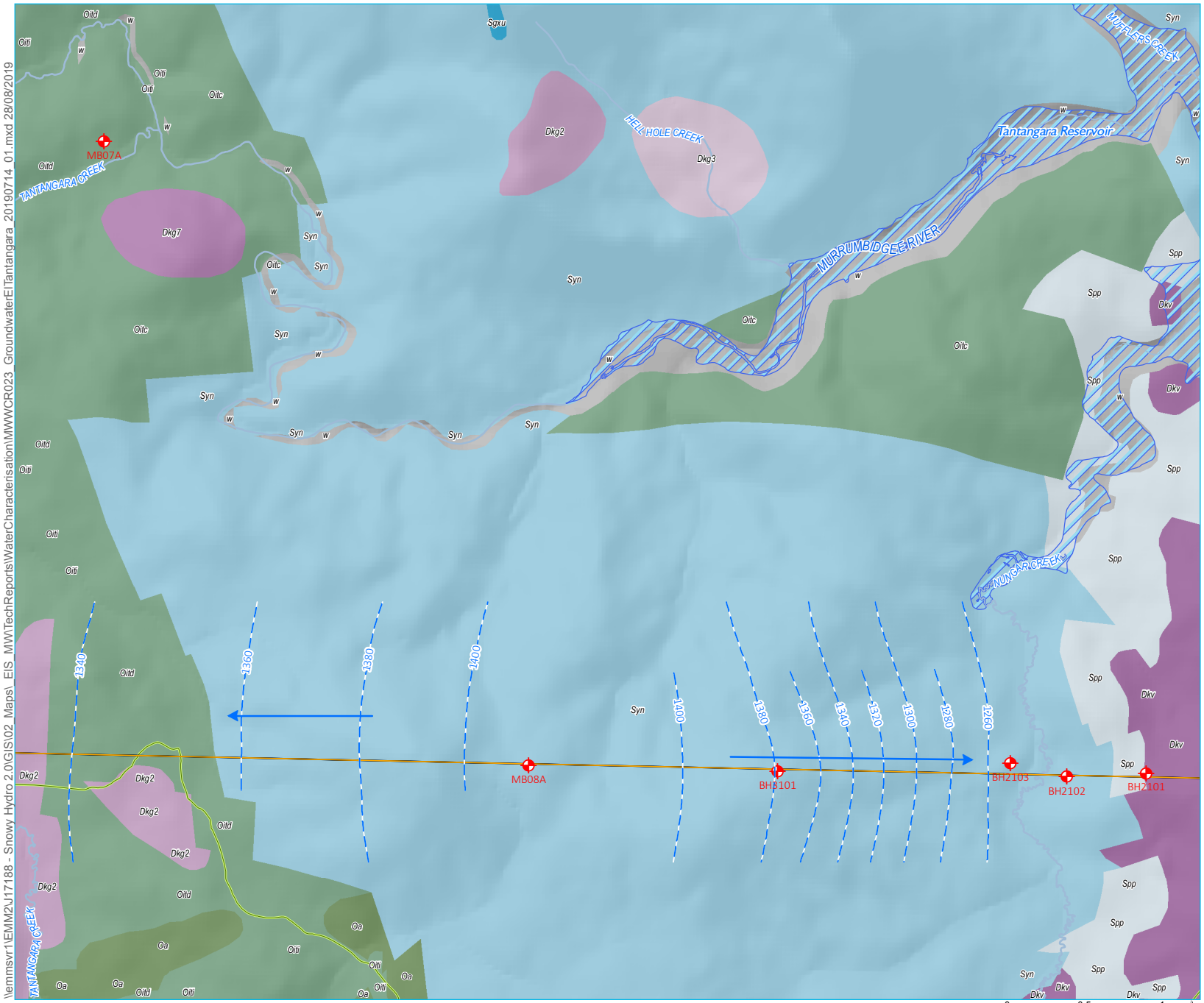


Source: EMM (2019); Snowy Hydro (2019); FGJV (2019); DFSI (2017); LPMA (2011)

0 0.5 1 km

GDA 1994 MGA Zone 55

N

KEY

- Groundwater elevation
- Groundwater flow direction
- Groundwater monitoring bore

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Utilities
- Watercourse
- Scheme storage

Devonian

- *Dkg3, Dkg4* - unknown (Hell Hole Creek Adamellite)
- *Dkg2*- Boggy Plain Suite (undifferentiated)
- *Dkg5, Dkg7* - Boggy Plain Suite (Boggy Plain Adamellite)
- *Dkv* - Unknown (Kellys Plain

Silurian

- *Spp* - Coolemon Plains Group (Peppercorn Formation)
- *Syn* - Yalmy Group (Tantangara
- *Sgxu* - Unknown (undifferentiated)

Ordovican

- *Oitb, Oitc, Oitd, Oiti* - Kiandra Group (Temperance Formation)
- *Oa* - Adaminaby Group (undifferentiated)

Inferred groundwater elevation and flow direction – Tantangara Formation

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.3

snowy 2.0

EMM creating opportunities

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MW\TechReports\WaterCharacterisation\MWWCR023_GroundwaterElTantangara_20190714_01.mxd 28/08/2019

c Temperance Formation

Groundwater levels in monitoring bores and VWPs within the Temperance Formation vary in elevation from approximately 1,325 m AHD to 1,375 m AHD and generally follow the topography.

Along the proposed headrace tunnel alignment, groundwater flow is towards the west.

d Kellys Plain Volcanics

Groundwater levels in monitoring bores screened across Kellys Plain Volcanics vary in elevation from approximately 1,220 m AHD to 1,238 m AHD.

The spatial distribution of monitoring bores within the Kellys Plain Volcanics does not allow for the interpretation of groundwater flow directions and hydraulic gradients.

e Boggy Plain Suite

Groundwater levels in monitoring bores screened across sediments of the Boggy Plain Suite vary in elevation from approximately 1,170 m AHD to 1,200 m AHD.

The spatial distribution of monitoring bores within the Boggy Plain Suite does not allow for the interpretation of groundwater flow directions and hydraulic gradients.

f Tertiary basalt

Groundwater levels in monitoring bore MB01B, screened across Tertiary basalt, vary in elevation from approximately 1,460 m AHD to 1,464 m AHD.

The basalt is very localised in extent. Groundwater flow is expected to be vertical to recharge the underlying fractured rock and horizontal to discharge at the edge of individual outcrops.

ii Temporal trends

Temporal trends within all geological units monitored within the plateau are summarised as follows:

- Groundwater levels within monitoring bores and VWPs have generally shown fluctuations of less than 10 m during the full monitoring record at each location.
- There are no obvious regional or consistent seasonal trends in groundwater levels during the period of monitoring ie some monitoring bores show an upwards trend, some show a downwards trend and others are relatively stable.
- 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.

iii Vertical hydraulic gradients

Nested monitoring bores and VWPs allow for the assessment of the vertical movement of groundwater. Groundwater leakage can be summarised as follows:

- The direction of vertical leakage within the Gooandra Volcanics is variable and potentially complex depending on whether an area is predominantly a recharge or discharge location. Nested monitoring bores TMB3A/TMB3B/TMB3C and VWP BH3108 indicate that groundwater leakage is downwards (suggesting a recharge location), with groundwater in the upper horizons of the unit migrating to deeper horizons. In contrast, nested monitoring bores PB04/SMB04/SMB05 indicate that groundwater leakage is upwards (suggesting a discharge location), with groundwater in the deeper horizons of the unit migrating to shallower horizons. VWPs (BH3111 and BH4103) indicate that vertical gradients change with depth in the formation.

- The direction of vertical leakage within the Tantangara Formation is variable and potentially complex. Nested monitoring bores MB08A/MB08B and VWP BH3104 indicate that groundwater leakage is downwards (suggesting a recharge location), with groundwater in the upper horizons of the unit migrating to deeper horizons. In contrast, VWP BH2102 indicates that groundwater leakage is upwards (suggesting a discharge location), with groundwater in the deeper horizons of the unit migrating to shallower horizons.

- The direction of vertical leakage within the Temperance Formation is variable and potentially complex. Nested monitoring bores MB07A/MB07B and VWP BH3106 indicate that groundwater leakage is downwards (suggesting a recharge location) whilst VWP BH3107A indicates that groundwater leakage is upwards at that location (suggesting a discharge location). Nested monitoring bores MB04A/MB04B have similar water levels and trends which suggests that the top 100 m of the Temperance Formation is hydraulically connected at that location.

Nested monitoring locations MB01B/MB01C allow for the assessment of vertical movement between the Tertiary basalt (MB01B) and underlying Gooandra Volcanics (MB01C). Water levels within the Tertiary basalt are higher than the Gooandra Volcanics indicating a localised perched aquifer and/or potentially a downwards hydraulic gradient.

9.2.2 Groundwater system hydraulic properties

As discussed in section 3.3.3, a range of hydraulic tests were completed to provide site-specific information on the hydraulic properties of the plateau groundwater system. Hydraulic properties have been estimated for most of the geological formations intercepted by the tunnel alignment. The results of hydraulic testing have been used to assess the potential project related impacts during construction and operation (modelling report, Annexure B to the water assessment).

An interpretation of hydraulic testing results is provided below, with detailed reports included in Attachment C. Results from all hydraulic testing completed are summarised in Table 9.1, Figure 9.4 and Figure 9.5.

Table 9.1 Summary of hydraulic properties – plateau

Geological unit	Test method	No. of tests	Bore ID	Approximate test depth range[1] (m BGL)	Estimated horizontal hydraulic conductivity (m/day)			Storativity	Estimated vertical hydraulic conductivity (m/day)
					Minimum	Maximum	Average		
Bullocks Hill Bog	Slug test	2	BH01, BH03	0.4 to 0.9	1.0×10^{-1}	1.3×10^{-1}	1.1×10^{-1}	NA	NA
Gooandra Hill Bog	Slug test	12	GH01, GH02, GH03	0.6 to 1.0	4.1×10^{-1}	1.2	0.8	NA	NA
Tantangara Creek Bog	Slug test	3	TC01, TC02, TC03	0.8 to 1.1	1.3×10^{-2}	3.5×10^{-2}	2.1×10^{-2}	NA	NA

Table 9.1 Summary of hydraulic properties – plateau

Geological unit	Test method	No. of tests	Bore ID	Approximate test depth range[1] (m BGL)	Estimated horizontal hydraulic conductivity (m/day)			Storativity	Estimated vertical hydraulic conductivity (m/day)
					Minimum	Maximum	Average		
Boggy Plain Suite	Pumping test[2]	1	PB03, (SMB02, SMB03)[3]	40.0 to 215.0	5.9×10^{-9}	9.1×10^{-8}	8.9×10^{-8}	NA	NA
Gooandra Volcanics	Slug test (shallow)	3	TMB02A	14.0	0.11	0.12	0.11	NA	NA
	Slug test (deep)	20	TMB02B, MB01C, MB02, MB03, TMB04	51.0 to 197.0	4.0×10^{-2}	42	6.9	NA	NA
	Pumping test[2]	2	PB04 (SMB04, SMB05)[3] TMB03C (TMB03A, TMB03B)[3]	32.5 to 249.0	7.8×10^{-4}	3.2×10^{-2}	1.3×10^{-2}	1.4×10^{-6} to 3.9×10^{-4}	2.0×10^{-2} to 2.0×10^{-1}
	DST[5]	5	BH3110 BH3111, BH4106	208.0 to 404.0	2.7×10^{-3}	4.7×10^{-2}	2.2×10^{-2}	NA	NA
Kellys Plain Volcanics	Pumping test[2]	1	PB01, BH1115, BH1116	51.0 to 89.5	4.6×10^{-3}	1.3×10^{-2}	8.0×10^{-3}	1.9×10^{-7} to 2.6×10^{-5}	0.01
	Packer test	9	BH1115, BH2101	23.0 to 181.0	3.4×10^{-5}	7.9×10^{-1}	1.2×10^{-1}	NA	NA
Tantangara Formation	Slug test (shallow)	10	MB08A	29.0	4.7×10^{-1}	1.2	0.8	NA	NA
	Slug test (deep)	2	PB06, MB08B	297.0 to 318.0	4.1×10^{-6}	6.2×10^{-4}	2.0×10^{-4}	NA	NA
	Packer test	23	BH2102, BH2103, BH3101, BH3104	105.0 to 339.0	1.6×10^{-5}	2.6×10^{-2}	3.4×10^{-3}	NA	NA
	DST	2	BH3113	184.0 to 231.0	5.9×10^{-3}	1.0×10^{-2}	7.9×10^{-3}	NA	NA
Temperance Formation	Slug test (shallow)	5	MB04A, MB07A	13.0 to 29.0	4.0×10^{-3}	72.4	27.5	NA	NA
	Slug test (deep)	6	MB04B, MB07B, MB13B	57.0 to 189.0	2.7×10^{-3}	4×10^{-1}	2×10^{-1}	NA	NA
	Pumping test[2]	1	PB10 (MB13A, MB13B, BH3102)[3]	60.0 to 230.0	6.4×10^{-6}	8.0×10^{-6}	7.2×10^{-6}	5.0×10^{-5} to 1.1×10^{-6}	NA

Table 9.1 Summary of hydraulic properties – plateau

Geological unit	Test method	No. of tests	Bore ID	Approximate test depth range[1] (m BGL)	Estimated horizontal hydraulic conductivity (m/day)			Storativity	Estimated vertical hydraulic conductivity (m/day)
					Minimum	Maximum	Average		
	Packer test	17	BH3102, BH3106, BH3107A	194.0 to 290.0	4.2×10^{-5}	5.3×10^{-3}	2.3×10^{-3}	NA	NA
Tertiary basalt	Slug test	5	MB01B	6.8	8.7	14.7	11.4	NA	NA

Notes: 1. Bottom of screened/open section.
2. Minimum, maximum and average derived from differing methods of analysing pumping test results.
3. Boreholes shown in brackets used as observation bores during pumping tests.

Results of the hydraulic testing can be summarised as follows:

- Slug testing, packer/DST and pumping test results in the Gooandra Volcanics generally yielded higher horizontal hydraulic conductivity (Kh) values when compared to the other geological units (See Figure 9.4).
- Slug testing of shallow monitoring bores generally yielded higher Kh values than the underlying less fractured geological units.
- Pumping tests in the Gooandra Volcanics demonstrated hydraulic connection between shallow and deep observation bores with vertical hydraulic conductivity (Kv) estimated to range between 2.0×10^{-2} m/day to 2.0×10^{-1} m/day (see Table 9.1). Average estimated Kh in the Gooandra Volcanics ranged between 1.3×10^{2} m/day to 6.9 m/day.
- The pumping test in the Kellys Plain Volcanics (near Tantangara Reservoir) showed hydraulic connection within this geological unit, with the Kv estimated at around 1×10^{-2} m/day (See Table 9.1). Average estimated Kh within the Kellys Plain Volcanics ranged between 8.0×10^{-3} m/day to 0.12 m/day.
- Pumping tests completed in the Boggy Plain Suite and Temperance Formation demonstrated no vertical connection between the shallow and deep groundwater observation bores. Average estimated Kh for these formations ranged between 8.9×10^{-8} m/day to 7.2×10^{-6} m/day (See Table 9.1).
- Pumping tests were not completed in the Tantangara Formation because the bore yield was too low. Average estimated Kh within the Tantangara Formation ranged between 2.0×10^{-4} m/day and 0.8 m/day.
- Figure 9.5 shows that Kh values are generally lower with increasing depth in all geological units.

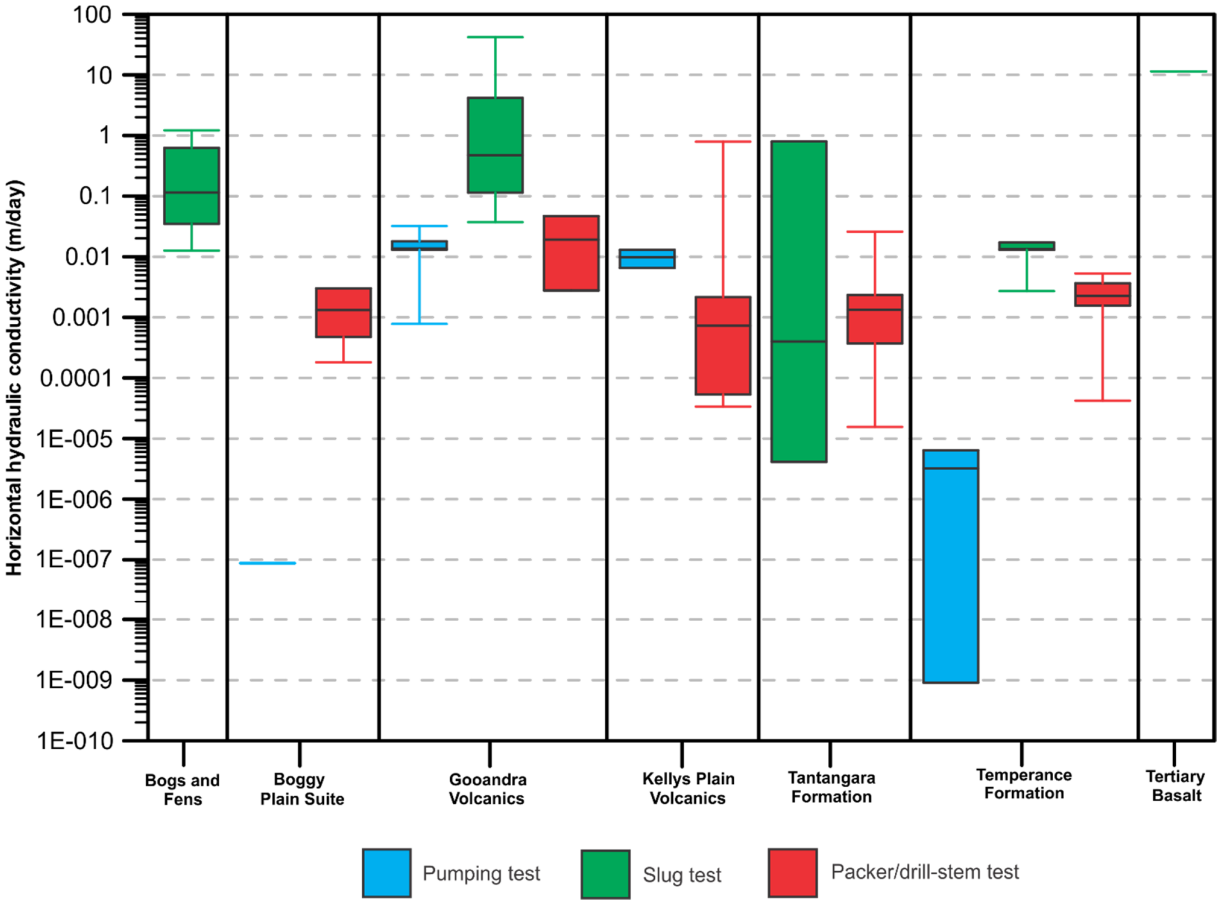


Figure 9.4 **Box and whisker plot – plateau estimated horizontal hydraulic conductivity (Kh)**

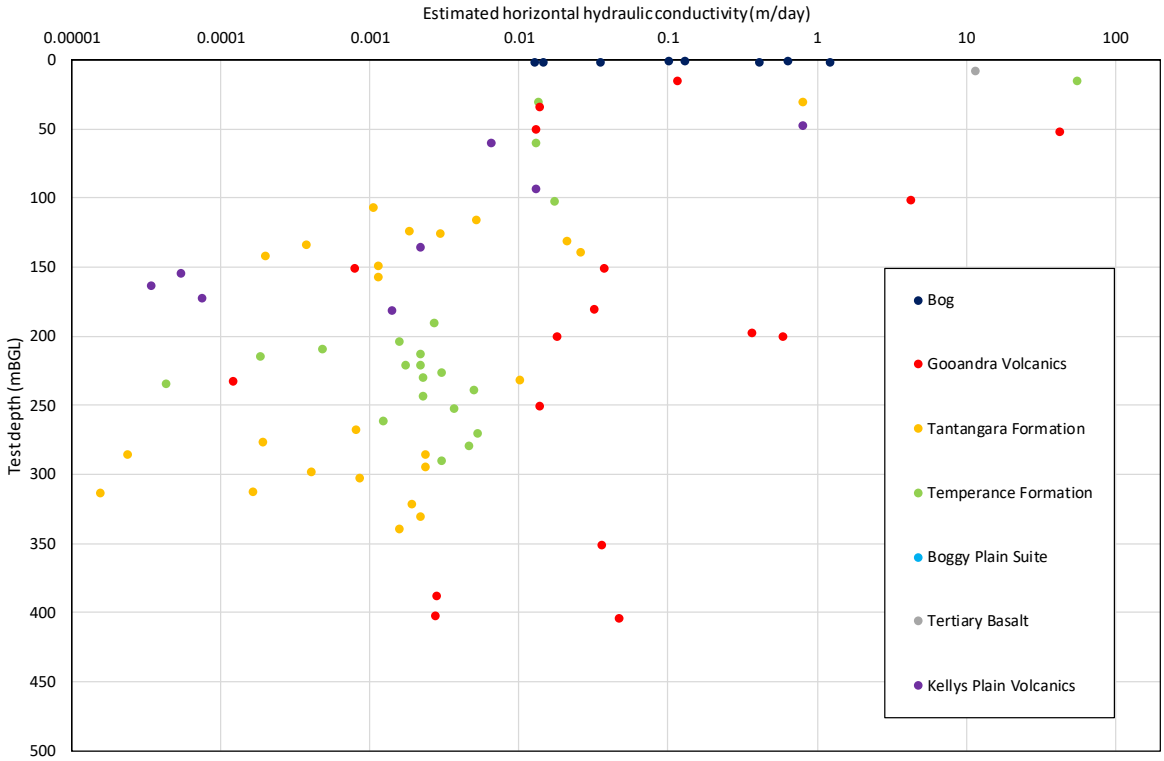


Figure 9.5 Summary of plateau estimated horizontal hydraulic conductivity (Kh) against depth

9.2.3 Aquifer chemistry

This section describes the baseline aquifer chemistry and groundwater quality characteristics of the plateau. The characterisation, statistical and graphical interpretation of the data has been undertaken using the following:

- Stiff diagrams, which are a useful method to compare groundwater composition and assess groundwater recharge sources (Stiff 1951). The cation-anion pairs that were used for this assessment are presented in Figure 9.6 below. A single Stiff plot was created for each monitoring point representing average concentrations over the period of monitoring.

- Piper diagrams (Piper 1944) showing relative concentrations of major ions in milliequivalents per litre (meq/L).

- Box and whisker plots of major ion chemistry. The whiskers of the plots represent the minimum and maximum values and the box represents the 75th percentile and 25th percentile of the data.

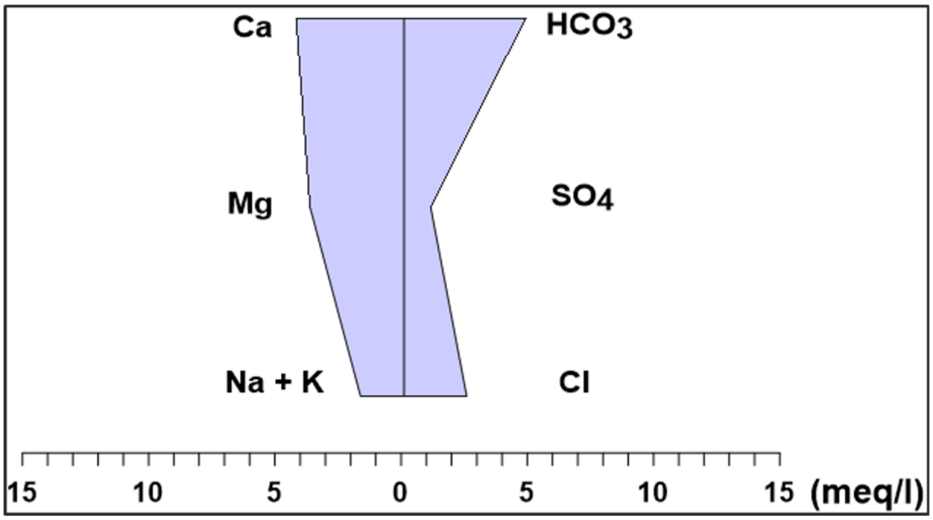


Figure 9.6 Cation-anion pairs used in this assessment for Stiff diagrams

The actual water quality data is presented in:

- Stiff diagrams of major ion concentrations in meq/L showing spatial trends within the plateau (see Figure 9.9) and spatial trends along the proposed tunnel alignment (see Figure 9.10).

- Piper diagrams of the major ion chemistry of all the plateau aquifers (see Figure 9.7).

- Box and whisker plots of major ion chemistry (see Figure 9.8).

- Pie charts showing relative distribution of major ion concentrations in meq/L across the plateau (see Figure 9.11) and spatial trends along the proposed tunnel alignment (see Figure 9.12). The pie charts represent the average concentrations over the period of monitoring for each monitoring bore.

- Trends in electrical conductivity for each of the hydrogeological units over time (see Figure 9.13 to Figure 9.18).

- Summary tables for each aquifer including minimum, maximum and median values and exceedances of WQOs (see Attachment D).

It is noted that concentrations measured below the laboratory limits of reporting (LOR) have been presented as values representing half of the LOR for the purposes of the assessment.

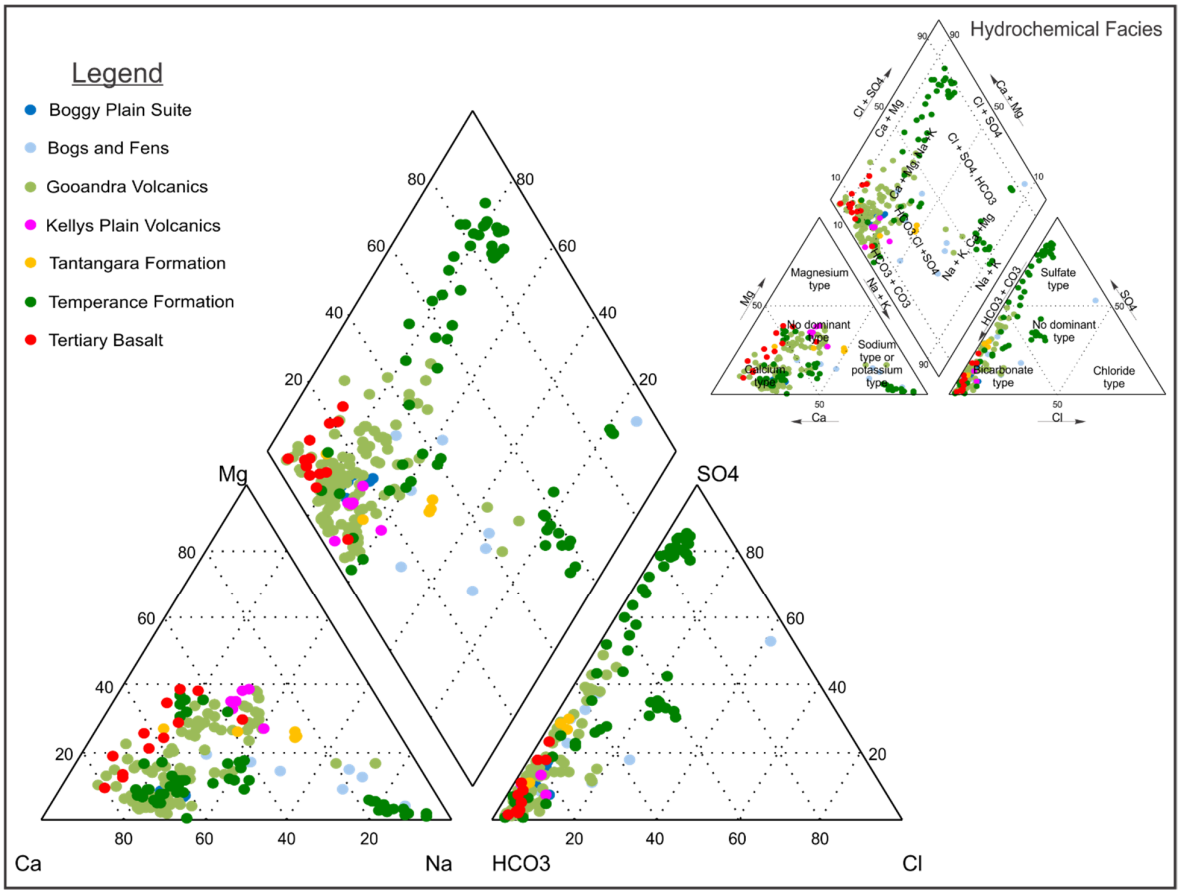


Figure 9.7 Groundwater piper diagram – plateau aquifers

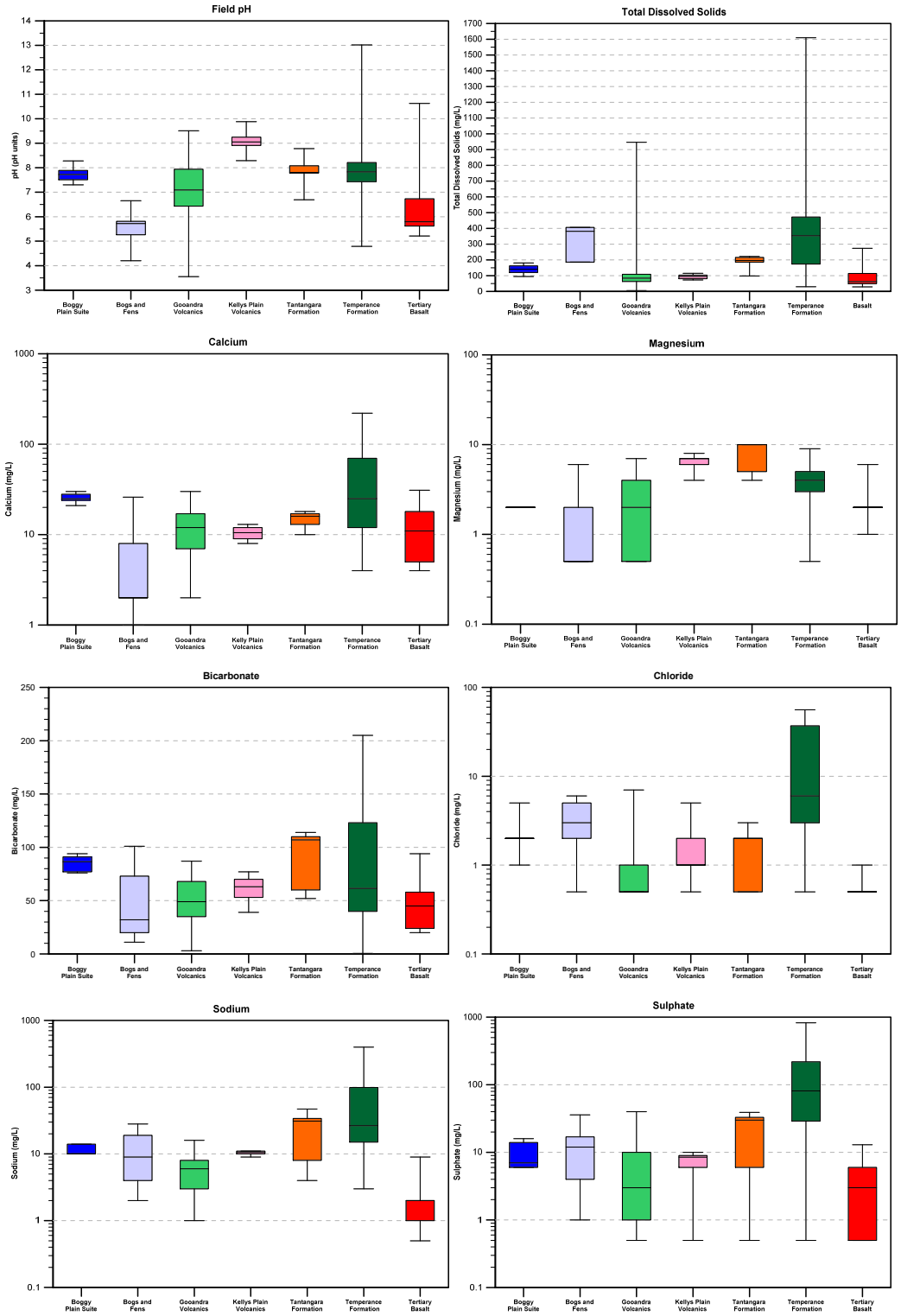
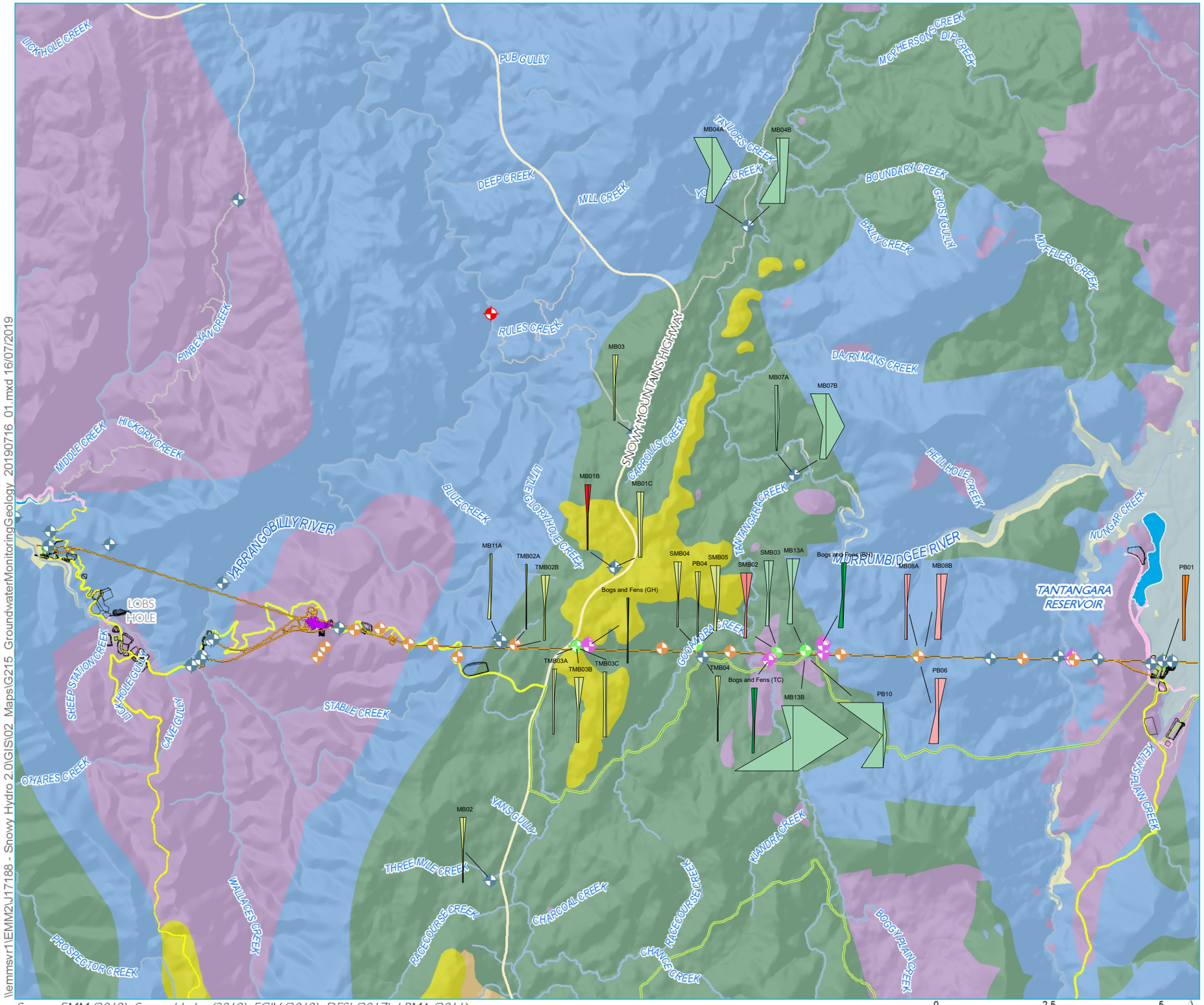


Figure 9.8 Box and whisker plots – plateau



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

0 2.5 5 km

GDA 1994 MGA Zone 55

N

KEY

Groundwater monitoring network
- Monitoring piezometer
- Production bore
- Swamp piezometer
- VWP
- Cave monitoring

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

Geology (250k) by period
- Cainozoic
- Quaternary
- Tertiary
- Devonian
- Silurian
- Ordovician

Stiff plot groups
- Boggy Plain Suite
- Bogs and Fens
- Gooandra Volcanics
- Kellys Plain Volcanics
- Tantangara Formation
- Temperance Formation
- Tertiary Basalt

Spatial distribution of Stiff plot patterns- plateau aquifers

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.9

snowy 2.0

EMM creating opportunities

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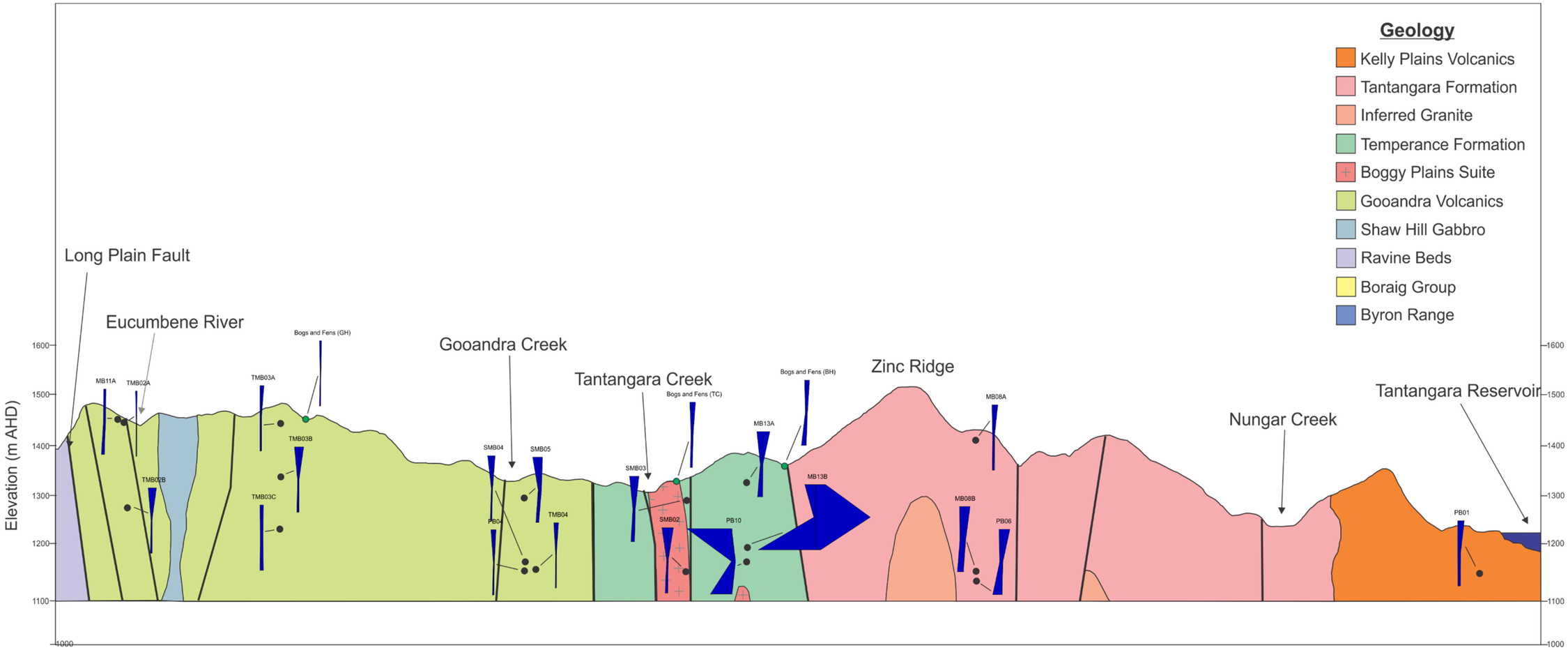
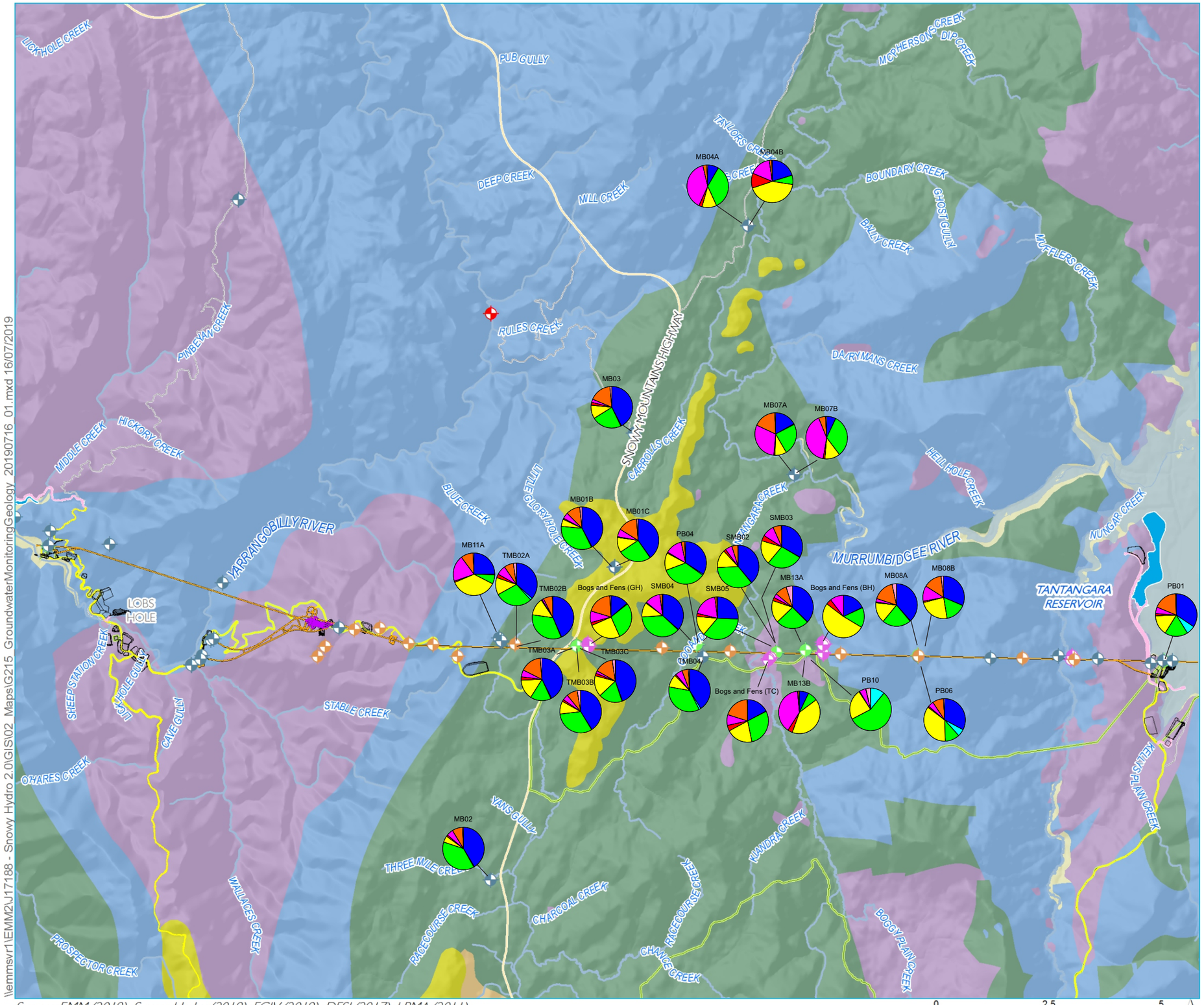


Figure 9.10 Spatial distribution of Stiff plot patterns along proposed tunnel alignment – plateau aquifers



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

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KEY

Groundwater monitoring network
- Monitoring piezometer
- Production bore
- Swamp piezometer
- VWP
- Cave monitoring

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
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Geology (250k) by period
- Cainozoic
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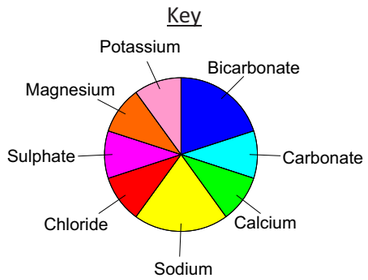


Pie charts of major ion abundance (meq/L) plateau aquifers

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.11

snowy 2.0

EMM creating opportunities

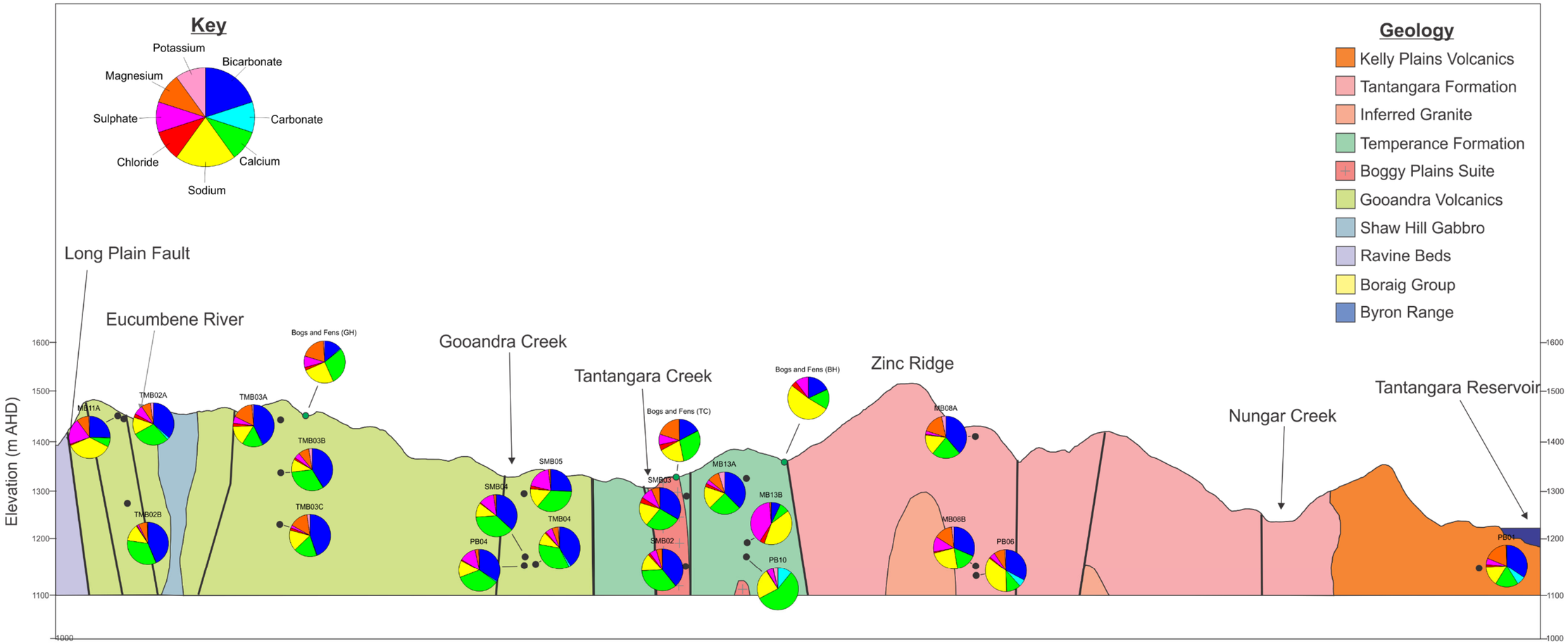


Figure 9.12 Pie charts along proposed tunnel alignment – plateau aquifers

i Water quality objective values

Environmental Values (EVs) and 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 streams within the project area, the primary environmental value 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).

SSTVs can be prepared during the construction phase monitoring if sufficient data is available.

The water chemistry and water quality characterisation for each aquifer monitored, based on interpretation of the above data, is presented in the following sections.

ii Boggy Plain Suite

The piper diagram in Figure 9.7 shows that groundwater in the Boggy Plain Suite exhibits a narrow range in chemical composition which clusters towards the left of the diamond (uppermost) plot. It is noted this clustering may somewhat be related to the smaller sample size for this aquifer (ie only one monitoring bore (SMB02) is screened across the Boggy Plain Suite). The dominant cation is calcium and the dominant anion is bicarbonate. In terms of water type, samples collected from the Boggy Plain Suite can be classified as calcium-bicarbonate ($Ca\text{-}HCO_3$) type water.

The box and whisker plots (see Figure 9.8) show that the groundwater within the Boggy Plain Suite is characterised by:

- pH between 7.3 and 8.3, with a median of 7.7;
- total dissolved solids concentrations ranging between 95 mg/L and 181 mg/L;
- calcium, magnesium, potassium, sodium, chloride and sulphate concentrations less than 30 mg/L;
- bicarbonate concentrations ranging from 76 mg/L to 94 mg/L; and
- nitrate concentrations which are generally less than 0.4 mg/L.

Metal concentrations (see Attachment D) within the Boggy Plain Suite are characterised by:

- minor concentrations of aluminium, barium, chromium, copper, iron, manganese, nickel and zinc which are generally above the laboratory LOR; and
- negligible concentrations of arsenic, beryllium, boron, cadmium, cobalt, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (see Figure 9.9 and Figure 9.10) and pie charts (see Figure 9.11 and Figure 9.12) are summarised in the following points:

- the Stiff pattern and chemical composition of SMB02 is very similar to nearby monitoring bore SMB03 which is screened across the Temperance Formation. Both SMB02 and SMB03 are located within the vicinity of a fault and have similar groundwater levels. The chemical similarities between SMB02 and SMB03, together with the similarities in groundwater levels, indicates that the Temperance Formation and Boggy Plain Suite may be hydraulically connected at this location and that the nearby fault may be acting as a conduit for groundwater flow.

Trends in electrical conductivity for the Boggy Plain Suite are shown in Figure 9.13. Figure 9.13 shows that electrical conductivity has varied by less than 100 µS/cm in SMB02 during the monitoring period.

WQOs were exceeded (see Attachment D) in at least one sample within the Boggy Plain Suite for the following:

- dissolved oxygen, ammonia, oxidised nitrogen, total nitrogen, total phosphorus, aluminium, chromium, copper and zinc.

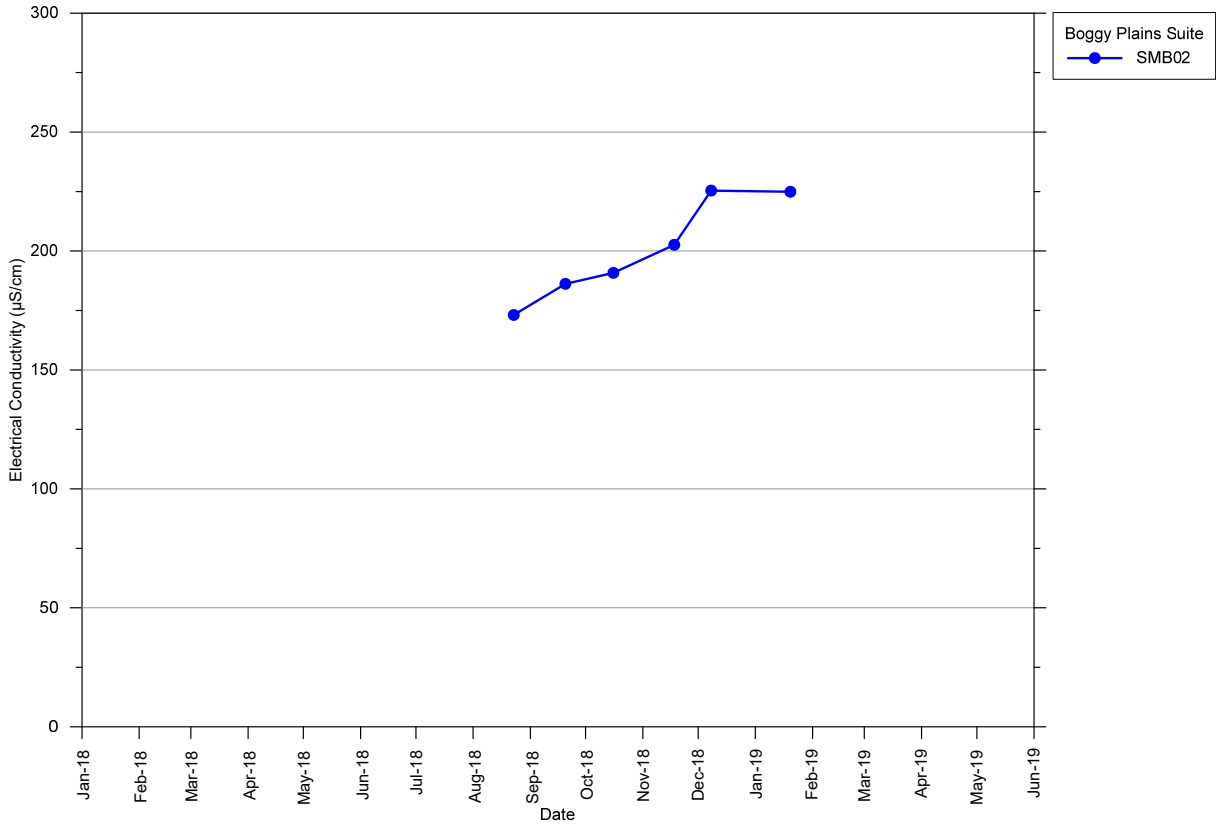


Figure 9.13 Electrical conductivity – Boggy Plain Suite

iii Gooandra Volcanics

The Piper diagram in Figure 9.7 shows that groundwater in the Gooandra Volcanics is typically clustered towards the left of the diamond (ie uppermost) plot. The dominant cation varies from calcium to sodium; the dominant anion is typically bicarbonate. In terms of water type, most samples collected from the Gooandra Volcanics can be classified as either calcium-bicarbonate ($Ca\text{-}HCO_3$), sodium-bicarbonate ($Na\text{-}HCO_3$) or mixed-type water.

The box and whisker plots (see Figure 9.8) show that groundwater within the Gooandra Volcanics is characterised by:

- pH between 3.5 and 9.5, with a median of 7.1 (ie neutral);
- total dissolved solids concentrations ranging between 14 mg/L and 179 mg/L, with a median of 83 mg/L;
- calcium, magnesium, potassium, sodium and sulphate concentrations less than 40 mg/L;
- bicarbonate concentrations ranging between 3 mg/L and 87 mg/L, with a median of 49 mg/L; and
- nitrate concentrations typically less than 0.04 mg/L but as high as 10 mg/L.

Metal concentrations (see Attachment D) within the Gooandra Volcanics are characterised by:

- minor concentrations of aluminium, arsenic, barium, copper, iron, manganese, nickel and zinc which are generally above the laboratory LOR; and
- negligible concentrations of beryllium, boron, cadmium, chromium, cobalt, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (see Figure 9.9 and Figure 9.10) and pie charts (see Figure 9.11 and Figure 9.12) are summarised in the following points:

- all monitoring bores screened across Gooandra Volcanics have narrow Stiff patterns which suggests that the groundwater is rainfall derived, has low residence times and/or has undergone limited interaction with the rock material;
- no obvious trends are evident in the chemical composition of the Gooandra Volcanics both spatially and with depth; and
- similarities between Stiff patterns and the chemical composition of monitoring bores within the Gooandra Volcanics suggests that shallow and deep groundwater is strongly connected, possibly a result of the high degree of fracturing which is present within this geological unit.

Trends in electrical conductivity during the monitoring period for Gooandra Volcanics monitoring bores are shown in Figure 9.14. Figure 9.14 shows that electrical conductivity has varied by less than 200 µS/cm in the Gooandra Volcanics during the monitoring period.

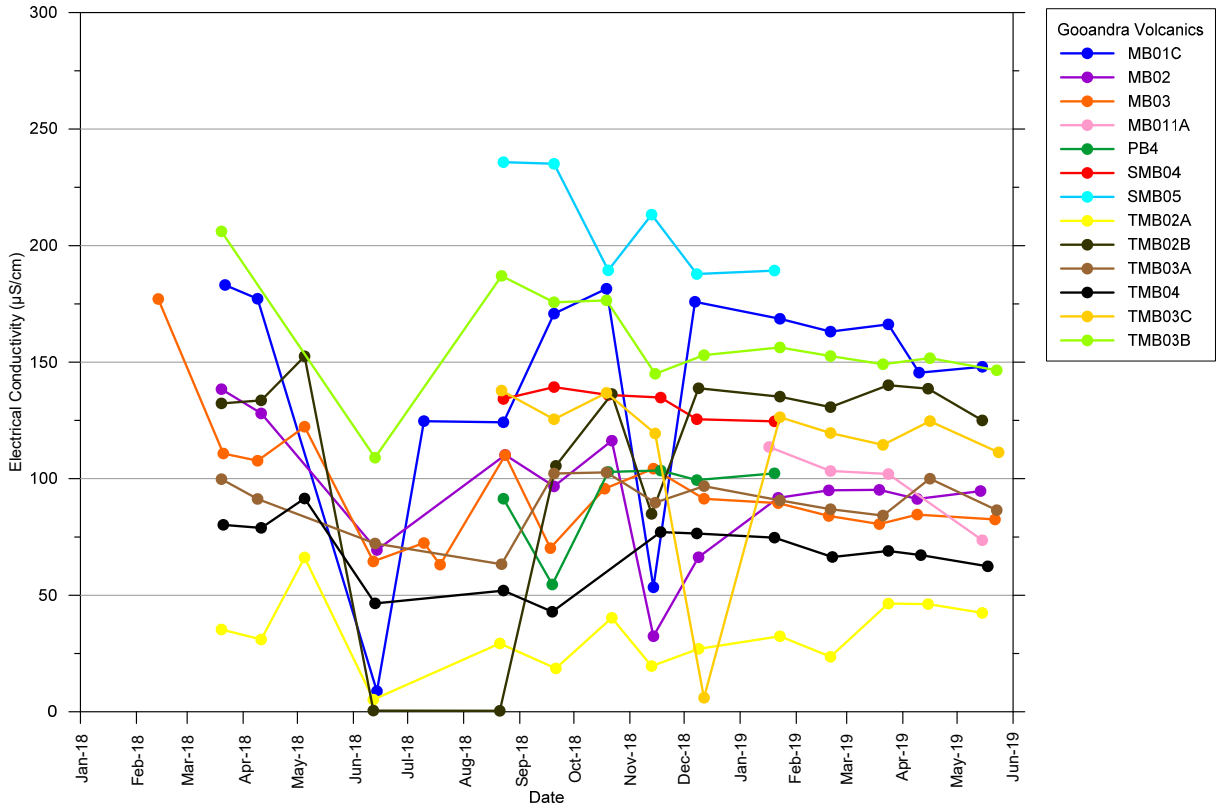


Figure 9.14 Electrical conductivity – Gooandra Volcanics

WQOs were exceeded (see Attachment D) in at least one sample within the Gooandra Volcanics for the following:

- dissolved oxygen, ammonia, oxidised nitrogen, total nitrogen, reactive phosphorus, total phosphorus, arsenic, copper, iron and zinc.

iv Kellys Plain Volcanics

The Piper diagram in Figure 9.7 shows that groundwater in the Kellys Plain Volcanics exhibits a narrow range in chemical composition which clusters towards the left of the diamond (uppermost) plot. It is noted this clustering may somewhat be related to the smaller sample size for this aquifer ie only one monitoring bore (PB01) is screened across the Kellys Plain Volcanics. There is no dominant cation and the dominant anion is bicarbonate. In terms of water type, samples collected from the Kellys Plain Volcanics can be classified as mixed-type water (Ca-Mg-Na HCO_3).

The box and whisker plots (see Figure 9.8) show that the groundwater within the Kellys Plain Volcanics is characterised by:

- pH between 8.3 and 9.9, with a median of 9.1 (ie moderately alkaline);
- total dissolved solids concentrations ranging between 73 mg/L and 115 mg/L;
- calcium, magnesium, potassium, sodium, chloride and sulphate concentrations less than 13 mg/L;

- bicarbonate concentrations ranging from 39 mg/L to 77 mg/L; and
- low nitrate concentrations generally less than 0.04 mg/L.

Metal concentrations (see Attachment D) within the Kellys Plain Volcanics are characterised by:

- minor concentrations of barium, copper, iron and manganese which are generally above the laboratory LOR; and
- negligible concentrations of aluminium, arsenic, beryllium, boron, cadmium, chromium, cobalt, lead, mercury, nickel, selenium, silver, vanadium and zinc (typically less than the laboratory LOR).

Monitoring bore PB01 has a narrow Stiff pattern (see Figure 9.9 and Figure 9.10) which suggests that the groundwater at this location is rainfall derived, has a short residence times and/or has undergone limited interaction with the rock material.

Trends in electrical conductivity for the Kellys Plain Volcanics are shown in Figure 9.15. Overall, Figure 9.15 shows that electrical conductivity has varied by less than 70 µS/cm in PB01 during the monitoring period.

WQOs were exceeded (see Attachment D) in at least one sample within the Kellys Plain Volcanics for the following:

- dissolved oxygen, ammonia, oxidised nitrogen, total nitrogen and copper.

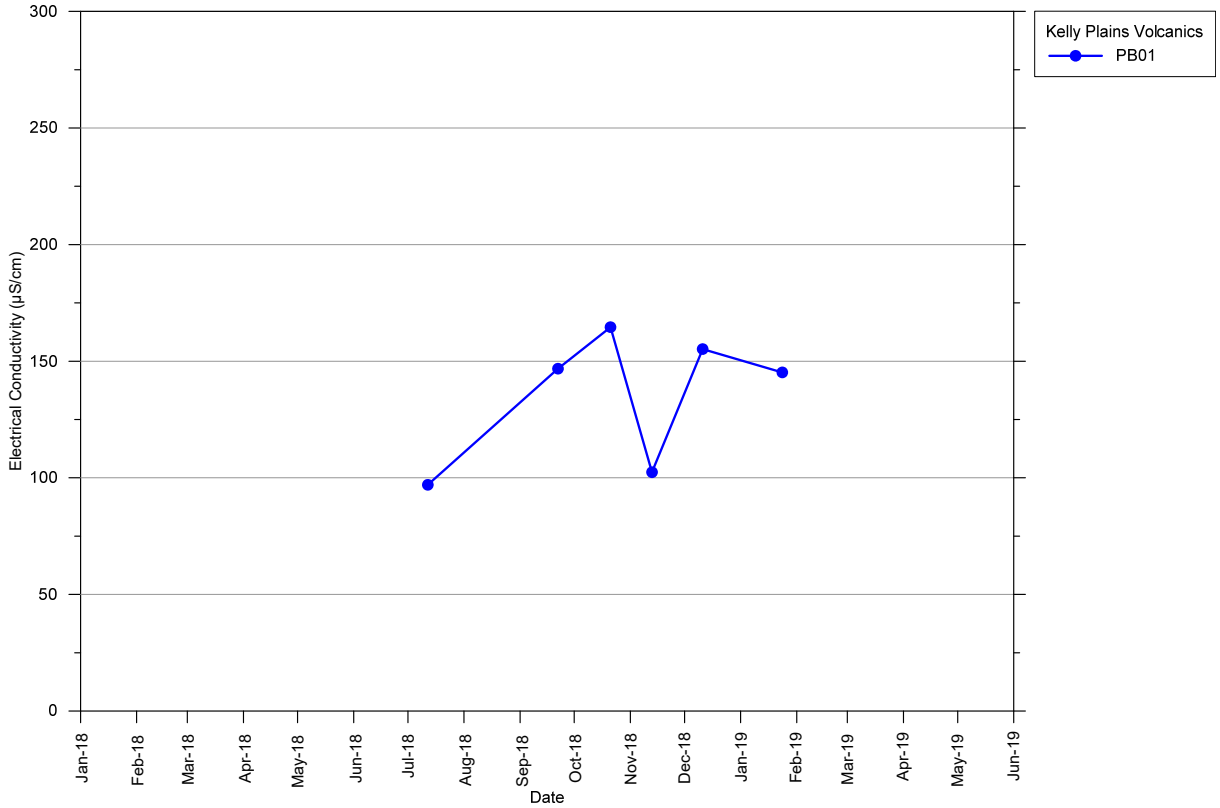


Figure 9.15 Electrical conductivity – Kellys Plain Volcanics

v Tantangara Formation

The Piper diagram in Figure 9.7 shows that groundwater in the Tantangara Formation exhibits a narrow range in chemical composition which clusters towards the middle to left of the diamond (uppermost) plot. The dominant cation is calcium; the dominant anion is bicarbonate. In terms of water type, samples collected from the Tantangara Formation can be classified as a calcium-bicarbonate ($Ca\text{-}HCO_3$).

The box and whisker plots (see Figure 9.8) show that the groundwater within the Tantangara Formation is characterised by:

- pH between 4.8 and 9.3, with a median of 7.8;
- total dissolved solids concentrations ranging between 30 mg/L and 222 mg/L;
- chloride, magnesium and potassium concentrations less than 10 mg/L;
- calcium concentrations ranging between 4 mg/L and 78 mg/L, bicarbonate concentrations ranging between 12 mg/L and 114 mg/L, and sulphate concentrations ranging from less than 1 mg/L to 228 mg/L; and
- low nitrate concentrations which are generally less than 0.02 mg/L.

Metal concentrations (see Attachment D) within the Tantangara Formation are characterised by:

- minor concentrations of aluminium, arsenic, barium, copper, iron, nickel, manganese and zinc which are generally above the laboratory LOR; and
- negligible concentrations of beryllium, boron, cadmium, chromium, cobalt, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (see Figure 9.9 and Figure 9.10) and pie charts (see Figure 9.11 and Figure 9.12) are summarised in the following points:

- monitoring bores MB08A has a narrower Stiff pattern than deeper monitoring bores MB08B and PB06 which suggests that the deeper groundwater at this location has longer residence times/or has greater interaction with the rock material when compared to shallower groundwater; and
- the deeper monitoring bores (MB08B and PB06) have higher proportions of sodium and lower proportions of calcium when compared to the shallow monitoring bore (MB08A).

Trends in electrical conductivity for the Tantangara Formation are shown in Figure 9.16. Figure 9.16 shows that electrical conductivity has varied by less than 200 µS/cm in the Tantangara Formation during the monitoring period.

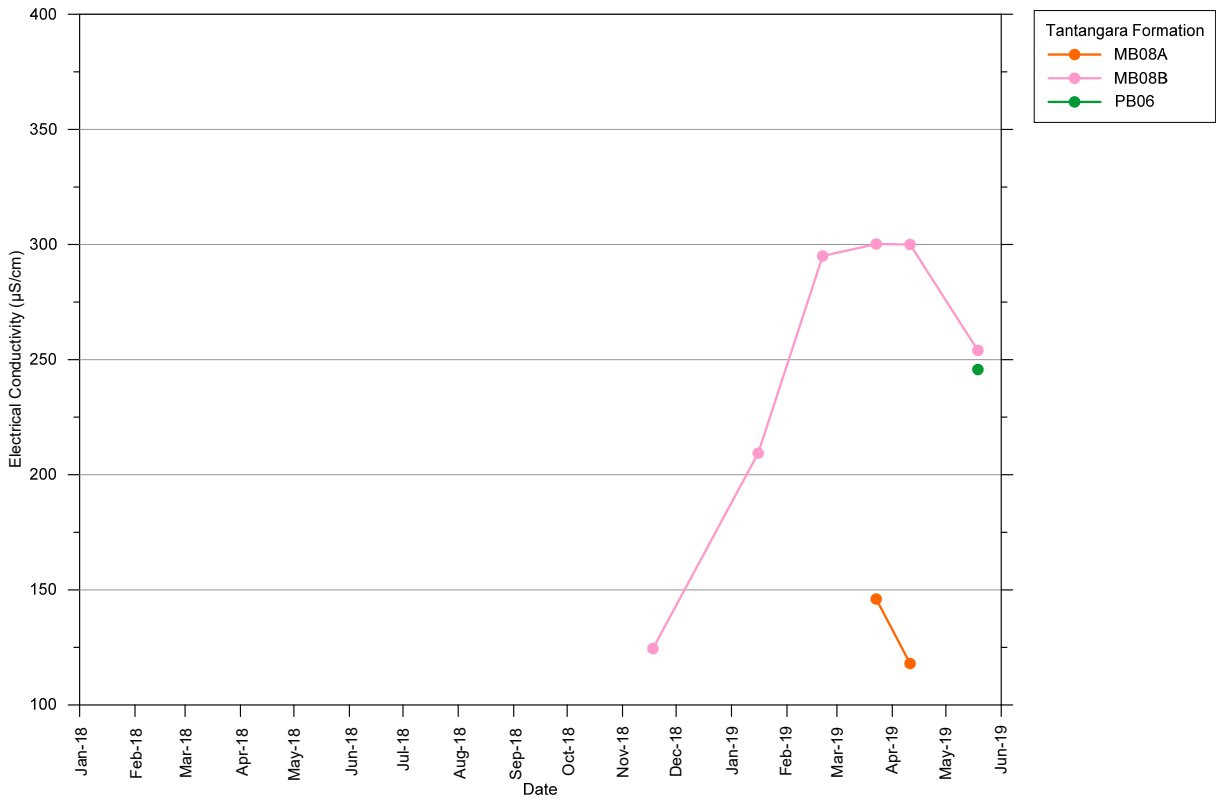


Figure 9.16 Electrical conductivity – Tantangara Formation

WQOs were exceeded (see Attachment D) in at least one sample within the Tantangara Formation for the following:

- dissolved oxygen, ammonia, oxidised nitrogen, total nitrogen, reactive phosphorus, total phosphorus, aluminium, arsenic, chromium, copper, iron, lead and zinc.

vi Temperance Formation

The Piper diagram in Figure 9.7 shows that groundwater in the Temperance Formation samples exhibit a broad range in chemical composition. The dominant cation ranges from calcium to sodium; the dominant anion ranges from bicarbonate to sulphate. In terms of water type, most samples collected from the Temperance Formation can be classified as either calcium-bicarbonate (Ca-HCO_3), calcium-sulphate (Na-SO4) or mixed-type water.

The box and whisker plots (see Figure 9.8) show that groundwater within the Temperance Formation is characterised by:

- pH between 6.4 and 13.0, with a median of 7.8;
- total dissolved solids concentrations ranging between 52 mg/L and 1,610 mg/L, with a median of 420 mg/L;
- magnesium, potassium and chloride concentrations less than 56 mg/L;
- bicarbonate concentrations ranging between 1 mg/L and 205 mg/L, calcium concentrations between 5 mg/L and 220 mg/L, sodium concentrations from 3 mg/L to 398 mg/L, and sulphate concentrations from 1 mg/L to 826 mg/L; and

- nitrate concentrations typically less than 0.2 mg/L but as high as 11 mg/L.

Metal concentrations (see Attachment D) within the Temperance Formation are characterised by:

- minor concentrations of aluminium, arsenic, barium, copper, iron, manganese, nickel and zinc which are generally above the laboratory LOR; and

- negligible concentrations of beryllium, boron, cadmium, chromium, cobalt, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (See Figure 9.9 and Figure 9.10) and pie charts (See Figure 9.11 and Figure 9.12) are summarised in the following points:

- monitoring bores 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;

- deeper monitoring bores along the proposed tunnel alignment have noticeably broader Stiff patterns which suggests that deeper groundwater within the Temperance Formation has longer residence times and/or has undergone greater interaction with the rock material when compared to the shallower bores.

Trends in electrical conductivity during the monitoring period for the Temperance Formation monitoring bores are shown in Figure 9.17 and can be summarised as follows:

- electrical conductivity has generally varied by less than 400 µS/cm during the monitoring period, with the exception of monitoring bore MB04A which has shown variations of up to 800 µS/cm;

- the initial electrical conductivity value for MB13B is significantly lower than subsequent values and may be affected by incompletely flushed drilling fluids; and

- monitoring bores PB10 and MB04A show a general increasing trend during the monitoring period.

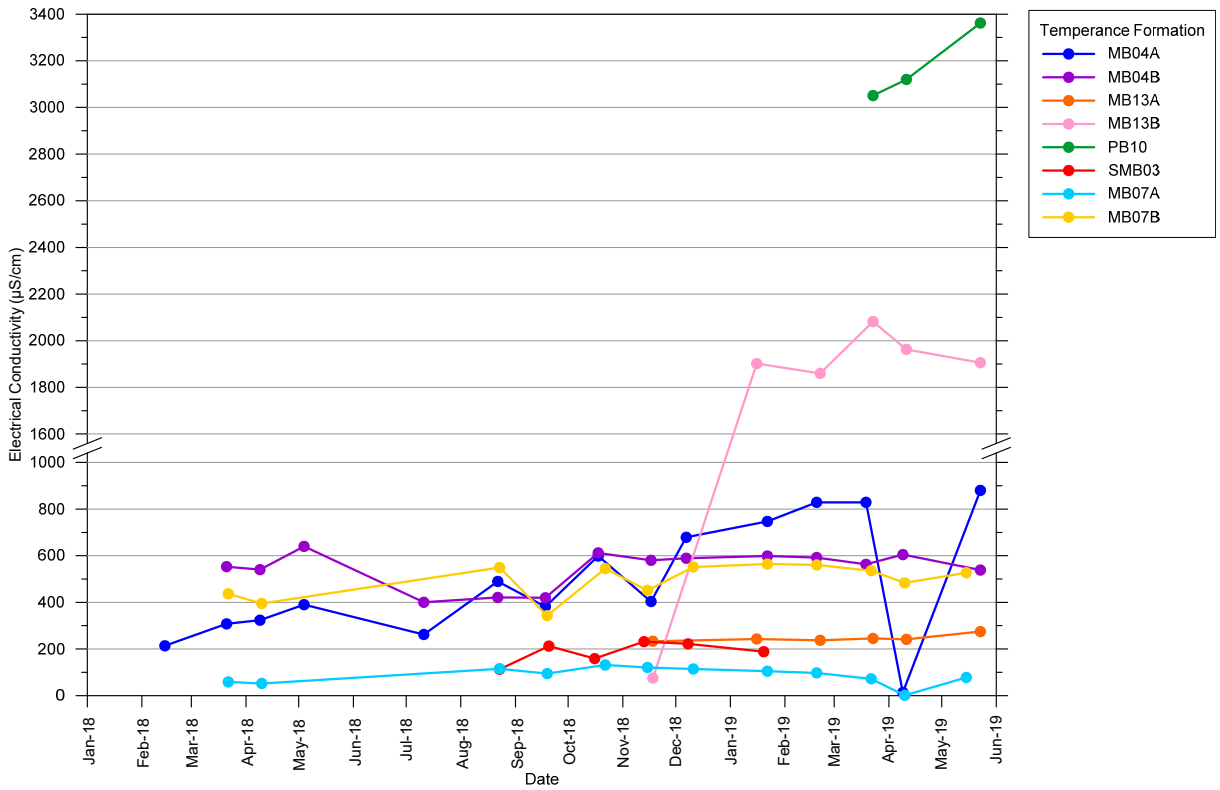


Figure 9.17 Electrical conductivity – Temperance Formation

WQOs were exceeded (see Attachment D) in at least one sample within the Temperance Formation for the following:

- dissolved oxygen, electrical conductivity, ammonia, oxidised nitrogen, total nitrogen, reactive phosphorus, total phosphorus, aluminium, arsenic, copper, iron and zinc.

vii Tertiary basalt

The Piper diagram in Figure 9.7 shows that groundwater in the Tertiary basalt exhibits a narrow range in chemical composition which clusters towards the leftmost corner of the diamond (uppermost) plot. It is noted this clustering may somewhat be related to the smaller sample size for this aquifer ie only one monitoring bore (MB01B) is screened across the Tertiary basalt. The dominant cation is calcium, the dominant anion is bicarbonate. In terms of water type, samples collected from the Tertiary basalt can be classified as calcium-bicarbonate (Ca-HCO_3) type water.

The box and whisker plots (see Figure 9.8) show that the groundwater within the Tertiary basalt is characterised by:

- pH between 5.2 and 10.6, with a median of 5.8 (ie slightly acidic);
- total dissolved solids concentrations ranging between 29 mg/L and 274 mg/L;
- calcium, magnesium, potassium, sodium, chloride and sulphate concentrations less than 31 mg/L;
- bicarbonate concentrations ranging from 20 mg/L to 94 mg/L; and

- nitrate concentrations which are generally less than 0.06 mg/L.

Metal concentrations (see Attachment D) within the Tertiary basalt are characterised by:

- minor concentrations of aluminium, barium, copper, manganese, nickel and zinc which are generally above the laboratory LOR; and

- negligible concentrations of arsenic, beryllium, boron, cadmium, chromium, cobalt, iron, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Monitoring bore MB01B has a narrow Stiff pattern (see Figure 9.9 and Figure 9.10) which suggests that groundwater within the Tertiary basalt at this location is derived from rainfall, has short residence times, and has underground limited interaction with the rock material.

Trends in electrical conductivity for the Tertiary basalt are shown in Figure 9.18. Figure 9.18 shows that electrical conductivity has varied by less than 250 µS/cm in MB01B during the monitoring period.

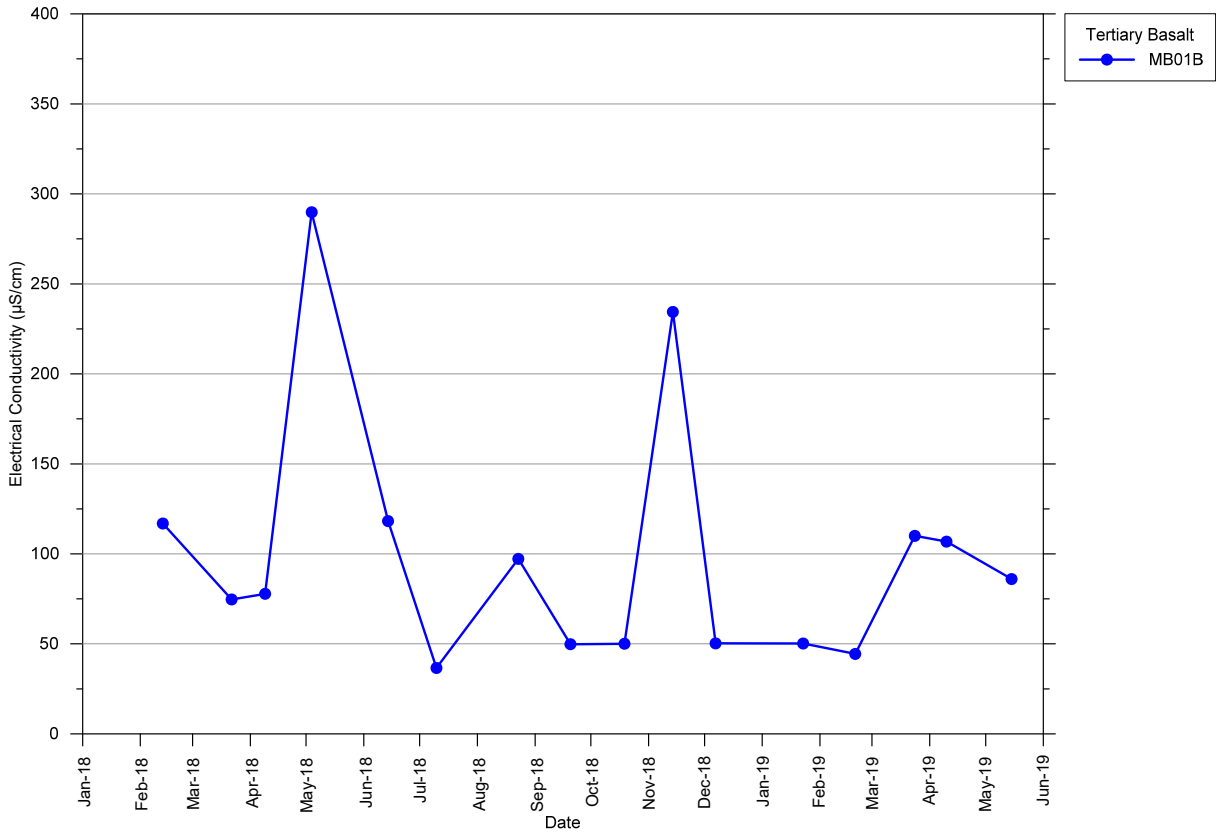


Figure 9.18 Electrical conductivity – Tertiary basalt

WQOs were exceeded (see Attachment D) in at least one sample within the Tertiary basalt for the following:

- dissolved oxygen, ammonia, oxidised nitrogen, total nitrogen, reactive phosphorus, total phosphorus, aluminium, arsenic, boron, chromium, copper and zinc.

viii Bogs and fens

The Piper diagram in Figure 9.7 shows that the deeper groundwater at the base of bogs and fens exhibit a broad range in chemical composition which is reflected in the wide spread of results in the diamond (uppermost) plot. There was no monitoring of the water quality in the near surface peat layer. The dominant cations include calcium at some sites and sodium and other sites; the dominant anion is bicarbonate and with one outlier result for sulphate. In terms of water type, samples collected from the bogs and fens can generally be classified as either calcium-bicarbonate ($Ca\text{-}HCO_3$) or sodium-bicarbonate ($Na\text{-}HCO_3$).

The box and whisker plots (see Figure 9.8) show that the groundwater within the bogs and fens is characterised by:

- pH between 4.2 and 6.7, with a median of 5.7 (ie slightly acidic);
- total dissolved solids concentrations ranging between 186 mg/L and 406 mg/L;
- calcium, chloride, sodium, magnesium, potassium and sulphate concentrations less than 36 mg/L;
- bicarbonate concentrations ranging between 11 mg/L and 101 mg/L, with a median of 32 mg/L; and
- nitrate concentrations which are generally less than 0.2 mg/L but as high as 4 mg/L.

Metal concentrations (see Attachment D) within the bogs and fens are characterised by:

- minor concentrations of aluminium, barium, chromium, cobalt, copper, iron, nickel, manganese and zinc which are generally above the laboratory LOR; and
- negligible concentrations of arsenic, beryllium, boron, cadmium, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (see Figure 9.9 and Figure 9.10) and pie charts (see Figure 9.11 and Figure 9.12) are summarised in the following points:

- some of the groundwater at the base of the bogs and fens is influenced by shallow groundwater discharging from the fractured bedrock;
- shallow monitoring bores within the bogs and fens have narrow Stiff patterns suggesting rainfall recharge, short groundwater residence times and limited interaction with rock material; and
- shallow groundwater associated with bogs and fens near Zinc Ridge (BH series of holes) have noticeably higher sodium and lower calcium and magnesium concentrations than the other monitored bog and fen locations.

As the results for bogs and fens are limited to a single monitoring event, sources of water within the bogs and fens, and trends are unable to be fully assessed.

WQOs were exceeded (see Attachment D) in at least one sample within the bogs and fens for the following:

- dissolved oxygen, pH, ammonia, oxidised nitrogen, total nitrogen, reactive phosphorus, total phosphorus, aluminium, boron, chromium, cobalt, copper, iron, vanadium and zinc.

9.2.4 Surface and groundwater interaction

As described in Section 7.2 and 7.3, the expression of groundwater at surface is an important contributor to alpine bogs, GDEs and associated tributaries. During warmer months of summer and autumn, the portion of water in perennial streams and creeks is dominated by groundwater baseflow and groundwater seeps/springs provide reliable sources of water to support ecological communities. Understanding the interaction between surface water and groundwater is important to accurately assess the potential impacts on these interactions during construction and operation and the effects it may have on sensitive ecological features and local hydrological processes.

i Surface expression of groundwater

As described in section 7.2.1, spring surveys were completed following prolonged dry periods in late summer (February) and early autumn (April) 2019. The surveys were completed following prolonged dry conditions above the proposed headrace tunnel alignment between the Eucumbene River and Tantangara Creek. The surface expression of groundwater was categorised into three types as described below:

- Type 1 – Contact/hillslope springs: springs displaying visible flow, typically on hillslopes. These were generally found in the upstream sections of more defined tributaries and occasionally in low lying areas.
- Type 2 – Lowland seeps: visible seeps into sediment storage (ie floodplains). These were typically found in low-lying areas adjacent to large watercourses and tributaries.
- Type 3 – Alpine bogs: boggy, wet ground, typically in depressions in the landscape. The most common discharge type across the survey area and generally occurred in the upstream section of smaller tributaries.

ii Potential groundwater dependent ecosystems

a Terrestrial

As identified in biodiversity development assessment report (Appendix M.1 to the EIS), five plant community types (PCTs) have an been identified as potential 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 or having facultative-opportunistic dependencies on groundwater (Appendix M.1 to the EIS):

- 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.

- 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.

The assessment compared the un-impacted plateau watertable, from the groundwater model (Annexure B to the water assessment), with the mapped extent (as part of the biodiversity report assessment report (Appendix M.1 to the EIS)) of PCTs. Only PCTs within the model domain have been assessed. Figure 9.19 show the spatial occurrence of GDE PCTs. Table 9.2 demonstrates PCT occurrence with groundwater.

Table 9.2 Occurrence of entirely/obligate and facultative-opportunistic potential GDEs on the plateau

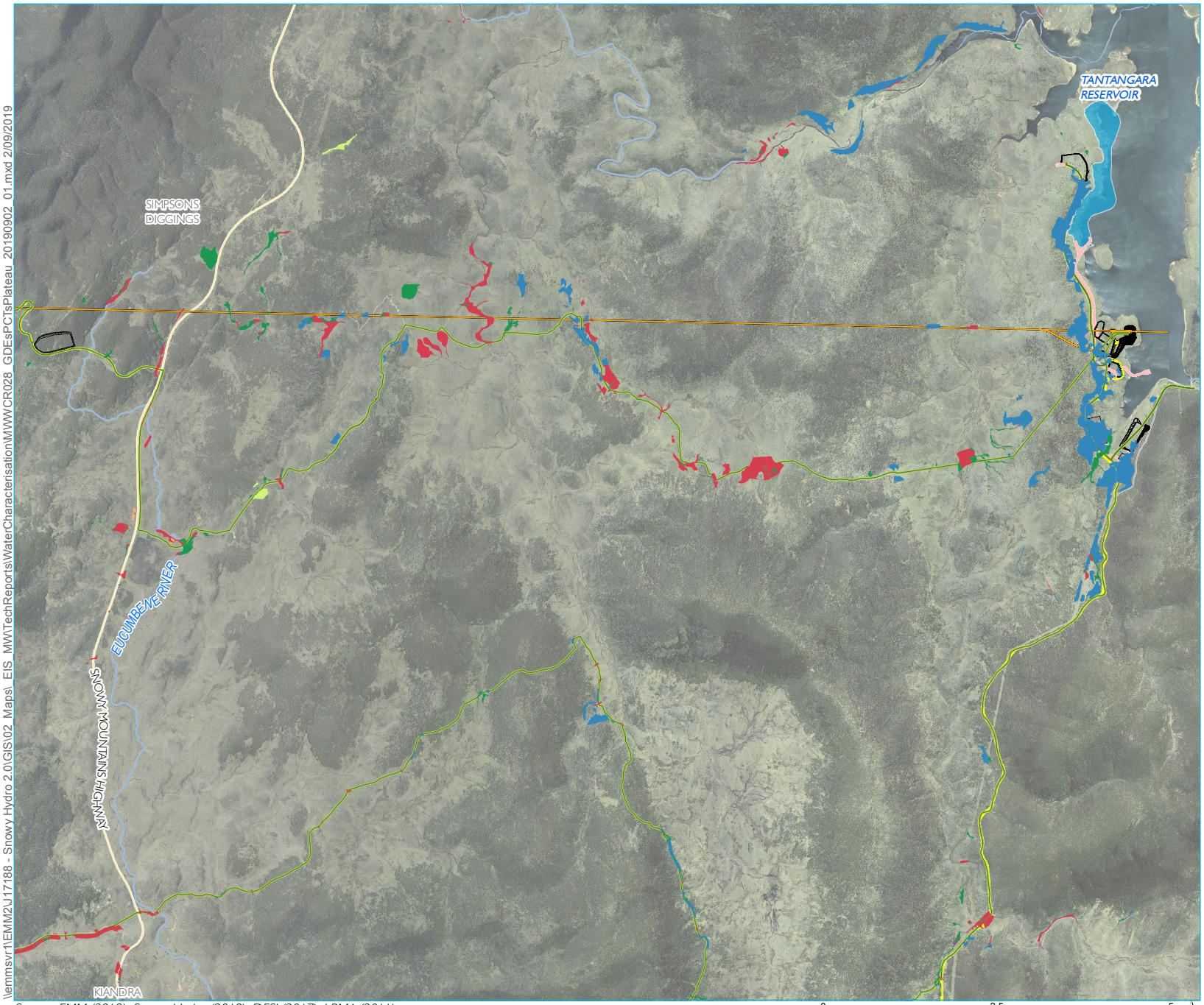
PCT name	Community occurrence within modelled groundwater levels			Entirely/obligate potential GDEs occurring in areas where groundwater is ≤ 2 m BGL	Entirely/obligate potential GDEs occurring in areas where groundwater is ≤ 5 m BGL	Potential GDE type
	0–0.5 m BGL	0.5–2 m BGL	2–5 m BGL			
PCT 303	32%	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
PCT1225	50%	46%	4%	96%	100%	Entirely/obligate

b Subterranean stygofauna

A total of five specimens, likely to be obligate stygofauna representatives, were identified in one (TMB02A) of the 11 fractured rock sites sampled, and two (GH01 and GH02) of the five alpine bog and fen sites sampled (Appendix M.1 to the EIS). Species observed in TMB02A were unique to fractured rock aquifers of the Gooandra Volcanics, while species observed in GH01 and GH02 were unique to the alpine bogs and fens.

Additional stygobiotic species were observed in some of the other sampled monitoring bores. However, it was considered difficult to determine their affinity with groundwater due to the wide variety of habitats in which they occurred (Appendix M.1 to the EIS).

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.



KEY

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

Snowy 2.0 contruction elements
- Temporary construction compounds and surface works
- Temporary access road
- Indicative rock emplacement

Existing environment
- Main
- Local
- Watercourse

Plant community
- PCT 303
- PCT 637
- PCT 679
- PCT 765
- PCT 1225

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

0 2.5 5 km

GDA 1994 MGA Zone 55

N

Entirely/obligate and facultative-opportunistic GDEs - plateau

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.19

snowy 2.0

EMM creating opportunities

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iii Shallow groundwater system and bog water levels

Water levels in swamp piezometers, installed in February 2019, were compared with adjacent groundwater monitoring bores in the fractured rock (see Figure 9.20). The following points summarise observations when comparing hydrographs (see Figure 9.21 and Figure 9.22) in swamp piezometers and nearby monitoring bores:

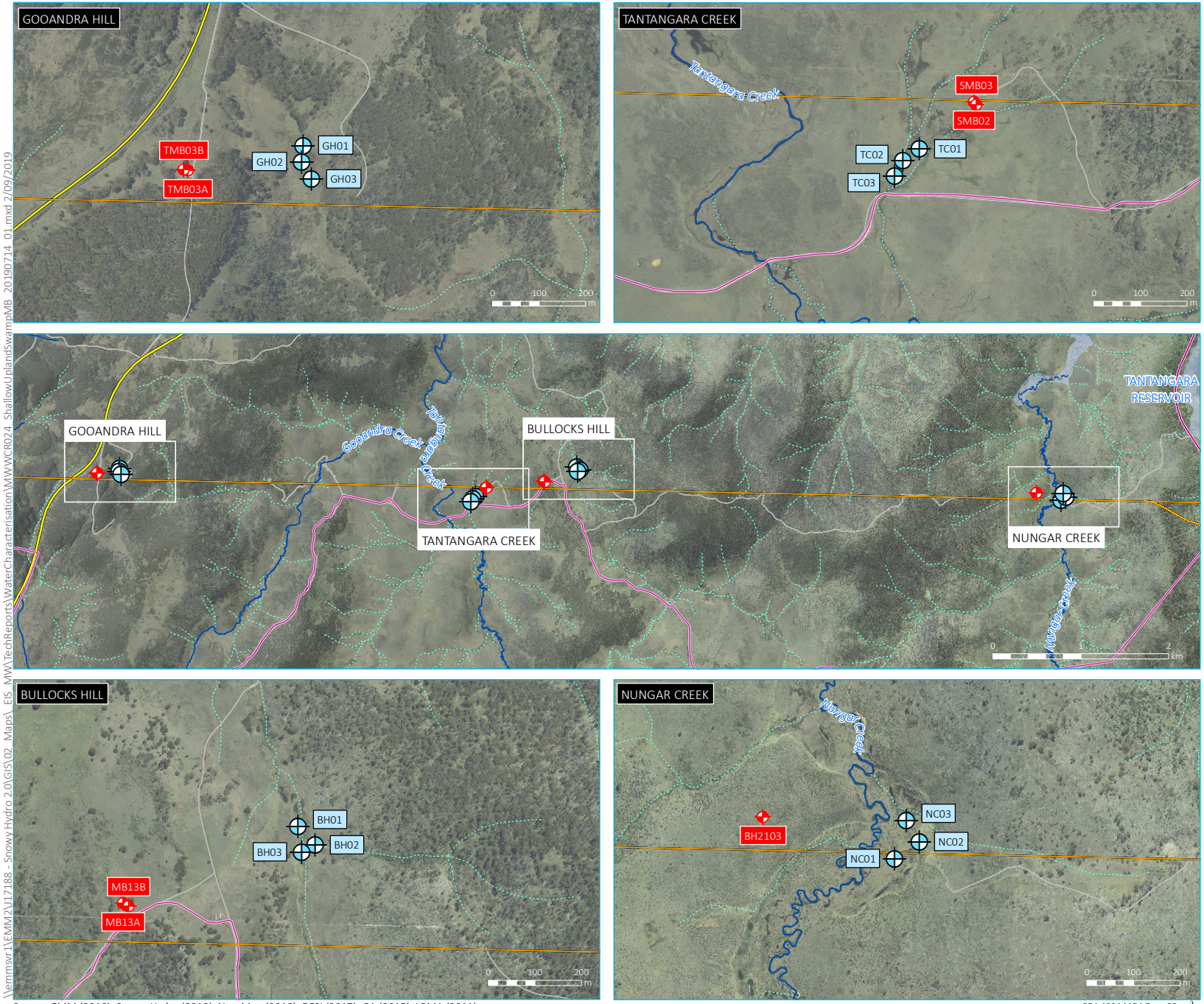
- Gooandra Hill (GH series) swamp piezometers and nearby TMB03A/B monitoring bores: Approximately 250 m from TMB03A/B, GH series water levels averaged approximately 8 m lower than groundwater levels in TMB03A/B. All hydrographs responded to rainfall recharge events.

- Tantangara Creek (TC series) swamp piezometers and nearby SMB02 and SMB03 monitoring bores: Approximately 150 m from SMB02 and SMB03, TC series water levels averaged approximately 10 m lower than groundwater levels in SMB02 and SMB03. There was a small response to rainfall in the swamp piezometers, possible because the available storage was full, and the shallow groundwater system could not accommodate any more recharge. There was a slightly larger response to rainfall recharge in the nearby monitoring bores.

- Bullocks Hill (BH series) swamp piezometers and nearby MB13A/B monitoring bores: Approximately 400 m from MB13A/B, BH series water levels averaged approximately 23 m lower than groundwater levels in MB13A/B. There was a small response to rainfall in the swamp piezometers, possible because the available storage was full, and the shallow groundwater system couldn't accommodate any more recharge. There was no obvious response to rainfall recharge in the nearby monitoring bores.

- Nungar Creek (NC series) swamp piezometers and nearby and BH2103 monitoring bores: Approximately 300 m from BH2103, NC series water levels averaged approximately 9 m lower than groundwater levels in BH2103. There was a moderate response to rainfall in the swamp piezometers. There was no obvious response to rainfall recharge in the nearby monitoring bores.

The differences in piezometric head between nearby monitoring bores in the fractured rock and swamp piezometers in the colluvium implies a local upward hydraulic gradient in the fractured rock aquifer, which is consistent with topography and rainfall recharge. The hydrographs also suggest likely upward leakage of the shallow groundwater from the fractured rock aquifers into the base of the observed bogs. The upward hydraulic gradient and upward leakage indicate that these bogs and fens are reliant on the regional groundwater system, receiving groundwater contributions from adjacent seeps and springs (as described above) in addition to rainfall and runoff. The peat layer at the top of these bogs and fens is likely to be totally dependent on rainfall and runoff.



KEY

- Upland swamp monitoring bore
- Swamp monitoring bore

Existing environment

- Main road
- Named watercourse
- Drainage line

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Utilities
- Scheme storage

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

GDA 1994 MGA Zone 55

Swamp piezometers and nearby monitoring bores

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.20

snowy 2.0

EMM creating opportunities

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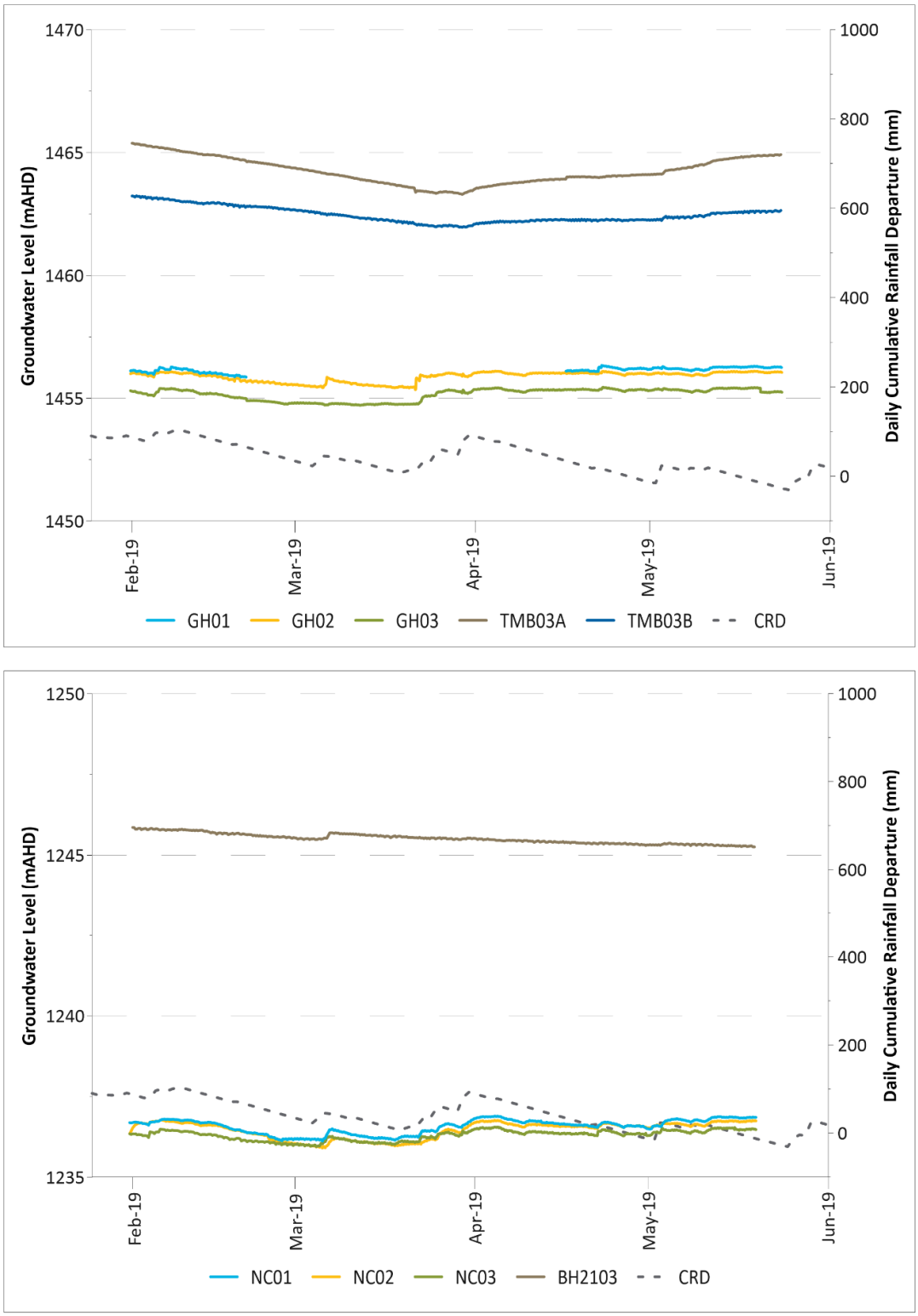


Figure 9.21 **Gooandra Hill and Nungar Creek swamp piezometers hydrographs vs nearby monitoring bore hydrographs**

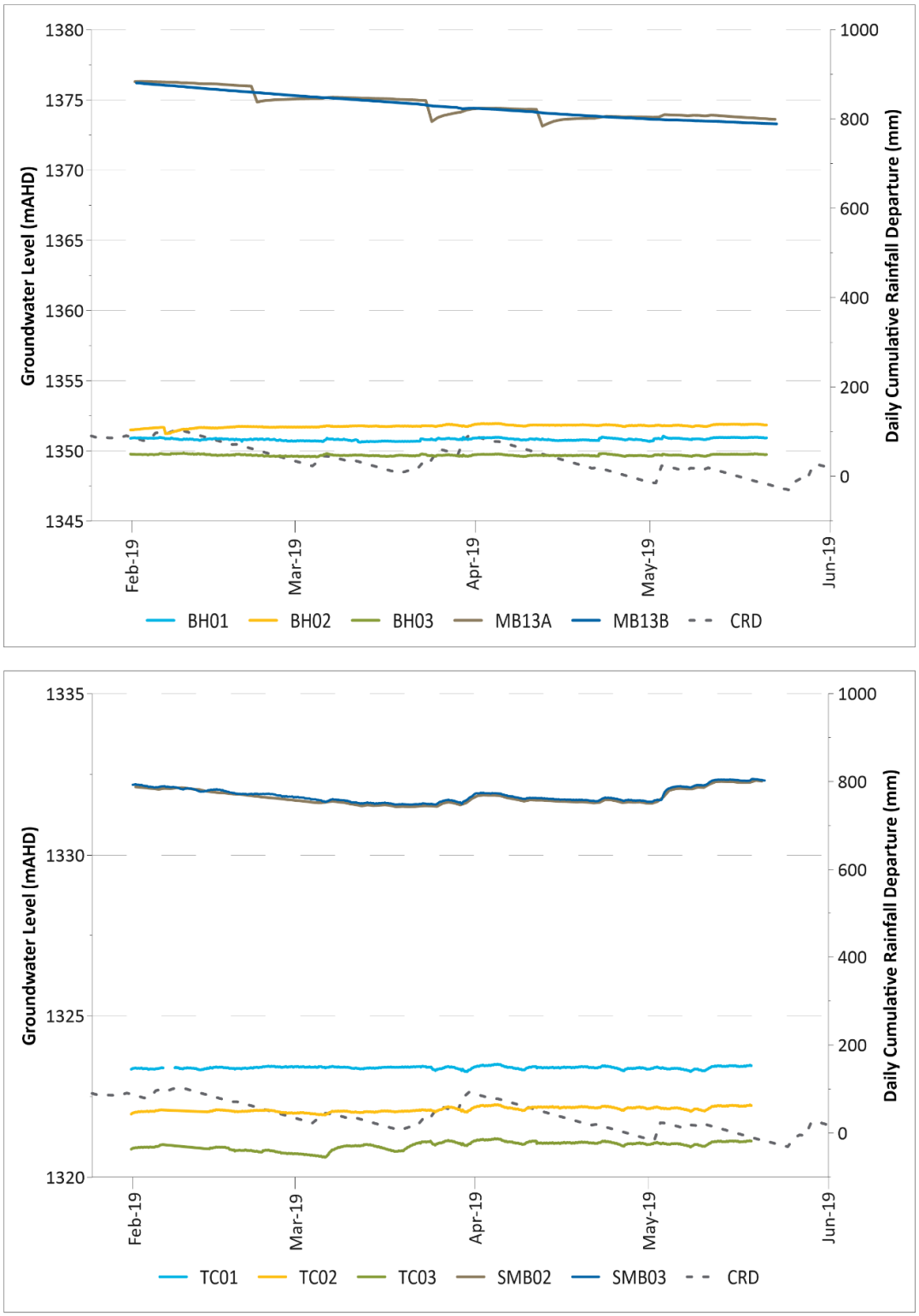


Figure 9.22 **Bullocks Hill and Tantangara Creek swamp piezometer hydrographs vs nearby monitoring bore hydrographs**

9.3 Ravine

9.3.1 Groundwater levels and flow

Ravine groundwater levels are monitored in the Ravine Beds and Boraig Group. The groundwater level monitoring locations for the ravine are shown in Table 3.7 and Table 3.8 and groundwater level hydrographs are provided in Attachment E.

i Spatial analysis

Groundwater levels within the ravine are influenced by the steep relief that exists across the area. Groundwater levels generally follow the topography. Groundwater levels measured in monitoring bores within the Ravine Beds vary from approximately 1,325 m AHD in the topographically elevated terrain adjacent to the LPF towards the east, to approximately 570 m AHD in the topographically lower terrain near Lobs Hole. Overall, groundwater levels indicate that groundwater flow within the Ravine Beds is towards the west from the direction of the LPF in the eastern region of the ravine, and towards the south in the western region of the ravine adjacent to Talbingo Reservoir (see Figure 9.23). The hydraulic gradient from east to west within the Ravine Beds is approximately 0.08.

Groundwater levels within the Boraig Group, show a similar spatial trend to those within the Ravine Beds with measured groundwater levels varying from approximately 1,164 m AHD in the eastern most monitoring bore (BH5105) to approximately 540 m AHD towards the west near Talbingo Reservoir. The hydraulic gradient within the Boraig Group from east to west is approximately 0.08 ie the same as the Ravine Beds.

ii Temporal trends

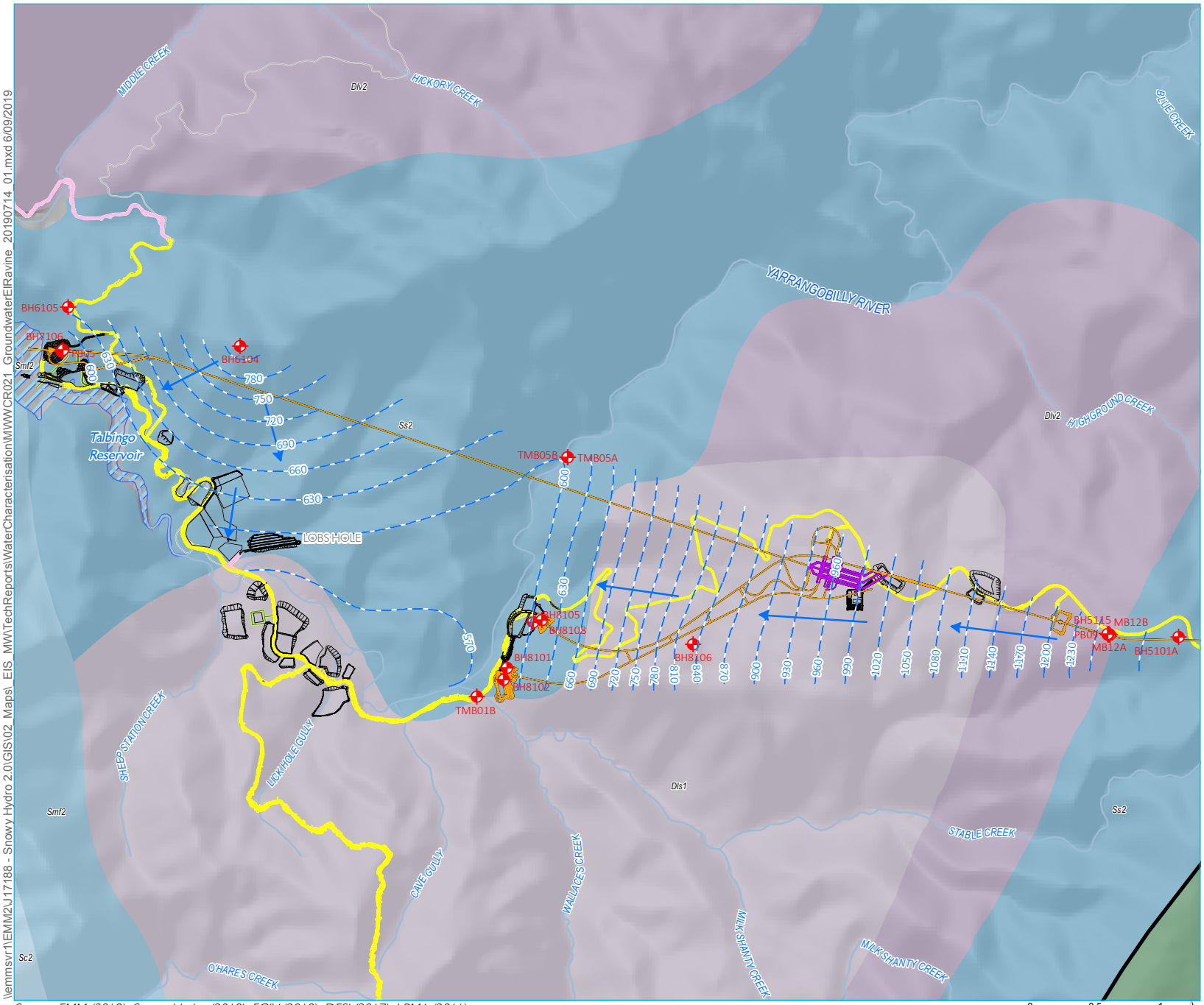
Temporal trends within the Ravine Beds and Boraig Group can be summarised as follows:

- Groundwater levels within monitoring bores have generally shown fluctuations of less than 5 m during the full monitoring period. The exceptions are monitoring bores PB05 and BH6105, which have shown fluctuations of up to 15 m. Water levels in PB05 and BH6105 show an initial slow increase which is likely to be due to slow recharge following drilling of those bores.

- Groundwater pressures within VWPs have generally shown fluctuations of less than 10 m during the full monitoring record for each VWP.

- There are no obvious regional trends in groundwater levels within the Ravine Beds or Boraig Group during the period of monitoring. Some monitoring bores show an upwards trend, some show a downwards trend and others are relatively stable.

- Groundwater levels typically do not show an obvious response to rainfall events or flow events within the Yarrangobilly River.



KEY

- Groundwater elevation
- Groundwater flow direction
- Groundwater monitoring bore

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

Existing environment

- Local road
- Watercourse
- Scheme storage
- Long Plain Fault (interpreted)

Devonian

- *Dls1* - Byron Range Group
- *Dlv2* - Boraig Group (unnamed)

Silurian

- *Sc2* - Unknown (Tumut Ponds
- *Smf2* - Unknown (Jackalass Slate)
- *Ss2* - Bredbo Group (Ravine Beds/Yarrangobilly Limestone)

Ordovician

- *Ovg1* - Unknown (Gooandra

Inferred groundwater elevation and flow direction – Ravine Beds

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.23

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

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iii Vertical hydraulic gradients

Nested monitoring bores and VWPs allow for the assessment of the vertical movement of groundwater. Groundwater leakage can be summarised as follows:

- Water levels within nested monitoring bores (MB12A/MB12B/PB9, TMB05A/TMB05B and PB05/BH7106) suggest that groundwater leakage within the Ravine Beds is downwards within the top 150 m of the unit, with groundwater in the upper horizons of the unit recharging to deeper horizons. This is evidenced by lower groundwater levels within the deeper monitoring bores when compared to the shallower monitoring bores at nested monitoring sites.

- Water levels within VWPs (BH4104, BH5102, BH5103, BH5104, BH5107, BH5108, BH5110, BH5111, BH5114, BH5115, BH6103 and BH8106) suggest that groundwater leakage within the Ravine Beds is also downwards at depths greater than 150 m within the unit. This is evidenced by higher groundwater pressures in the shallower VWP sensors at each VWP location.

- Nested monitoring bores within the Boraig Group (MB06A/MB06B) have similar water levels and trends which suggests that the top 70 m of the Boraig Group sediments have strong hydraulic connection.

Nested monitoring location TMB01A/TMB01B allows for the assessment of vertical movement between the Boraig Group (TMB01A) and underlying Ravine Beds (TMB01B). Water levels within the Boraig Group are higher than the Ravine Beds indicating that groundwater leakage is downwards from the Boraig Group into the Ravine Beds. Water levels within TMB01A and TMB01B show very similar trends which suggests that there is some degree of hydraulic connection between the Boraig Group and Ravine Beds at this location.

9.3.2 Groundwater system hydraulic properties

As discussed in section 3.3.3, a range of hydraulic tests were completed to provide site-specific information on the hydraulic properties of the ravine groundwater system. Hydraulic properties have been estimated for most of the formations intercepted by the proposed project and the results of hydraulic testing have been used to assess the potential project related impacts arising through construction and operation (modelling report, Annexure B to the water assessment).

An interpretation of hydraulic testing results is provided below, with detailed reports included in Attachment C. Results from all hydraulic testing completed are summarised in Table 9.3, Figure 9.24 and Figure 9.25.

Table 9.3 Summary of hydraulic properties – ravine

Geological unit	Test method	No. of tests	Bore ID	Approximate test depth range[1] (m BGL)	Estimated horizontal hydraulic conductivity (m/day)			Storativity	Estimated vertical hydraulic conductivity (m/day)
					Minimum	Maximum	Average		
Boraig Group	Slug test	4	TMB01A	14	3.1	3.6	3.3	NA	NA
	DST	1	BH5105C[4]	675	-	2.0×10^{-5}	-	NA	NA
Ravine Beds West	Slug test (shallow)	4	TMB05A	18	3.0×10^{-2}	1.7×10^{-1}	1.3×10^{-1}	NA	NA
	Slug test (deep)	2	TMB01B, TMB05B	69 to 74	3.4×10^{-4}	6.0×10^{-3}	3.2×10^{-3}	NA	NA
	Pumping test[2]	1	PB05 (BH7106)[3]	100 to 154	3.3×10^{-4}	3.7×10^{-3}	1.6×10^{-3}	2.5×10^{-12} to 6.3×10^{-5}	7.9×10^{-5} to 1.3×10^{-4}
Ravine Beds East	DST	16	BH4105[4], BH5107, BH5110, BH5111, BH5113C[4], BH5114, BH5115	169 to 794	6.5×10^{-6}	5.3×10^{-2}	3.9×10^{-3}	NA	NA
	Pumping test[2]	1	PB09 (MB12A, MB12B)[3]	36 to 300	1.4×10^{-7}	7.0×10^{-4}	3.3×10^{-4}	8.0×10^{-8} to 1.7×10^{-2}	NA

Notes:
1. Bottom of screened/open section.
2. Minimum, maximum and average derived from differing methods of analysing test pumping results.
3. Boreholes shown in brackets used as observation bores during pumping tests.
4. Backfilled geotechnical borehole.

Results of the hydraulic testing can be summarised as follows:

- The pumping test in the Ravine Beds West (near Talbingo Reservoir tailrace tunnel) showed a low to moderate degree of vertical hydraulic connection within this geological unit, with Kv estimated to range between 7.9×10^{-5} m/day and 1.3×10^{-4} m/day. Average estimated Kh in the Ravine Beds West ranged between 3.2×10^{-3} m/day to 1.3×10^{-1} m/day.

- The pumping test in the Ravine Beds East demonstrated that there was no vertical connection between the shallow and deep observation bores at that location. Average estimated Kh in the Ravine Beds East ranged between 3.3×10^{-4} m/day to 3.9×10^{-3} m/day.

- Slug tests completed at TMB01A in the Boraig Group indicate a higher Kh of up to 3.6 m/day (see Figure 9.24). TMB01A is likely hydraulically connected to Wallace Creek therefore demonstrating high Kh at shallow depth (see Figure 9.25).

- Figure 9.25 shows that Kh values are generally lower with increasing depth in all of the geological units.

- Results from hydraulic testing in Ravine Beds East and Ravine Beds West are consistent with conceptual understanding of the area with generally low Kh throughout the formations and low to moderate Kv which is likely associated with Talbingo Reservoir.

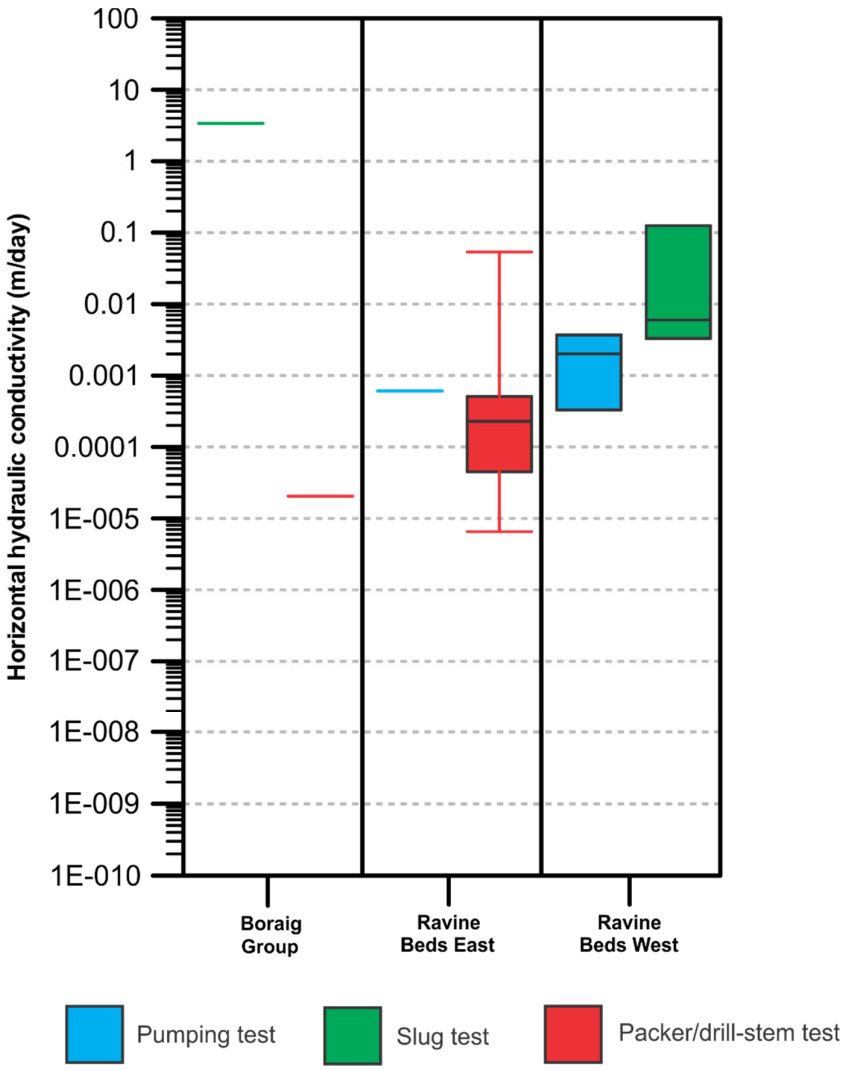


Figure 9.24 **Box and whisker plot – horizontal hydraulic conductivity (Kh) for pump tests, slug tests, packer/drill-stem tests**

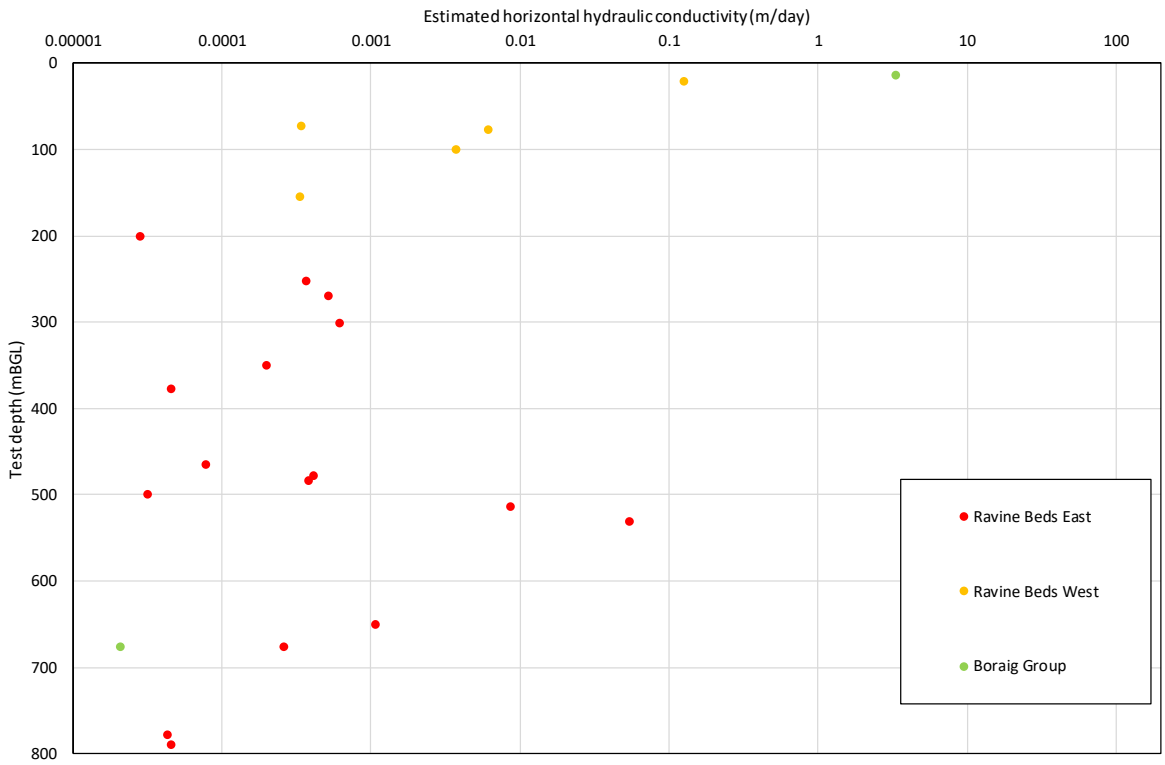


Figure 9.25 Summary of Ravine estimated horizontal hydraulic conductivity (Kh) against depth

9.3.3 Aquifer chemistry

This section describes the baseline aquifer chemistry and groundwater quality characteristics of the ravine. To assist with the characterisation, statistical and graphical interpretation of the data has been undertaken using the following:

- Stiff diagrams. A single Stiff plot was created for each monitoring point representing average concentrations over the period of monitoring.
- Piper diagrams showing relative concentrations of major ions in milliequivalents per litre (meq/L).
- Box and whisker plots of major ion chemistry. The whiskers of the plots represent the minimum and maximum values and the box represents the 75th percentile and 25th percentile of the data.

The actual water quality data is presented in:

- Stiff diagrams of major ion concentrations in meq/L showing spatial trends within the ravine (see Figure 9.28) and spatial trends along the proposed tunnel alignment (see Figure 9.29).
- Piper diagrams of the major ion chemistry (see Figure 9.26).
- Box and whisker plots of major ion chemistry (see Figure 9.27).

- Pie charts showing relative distribution of major ion concentrations in meq/L showing spatial trends within the broader ravine area (see Figure 9.30) and spatial trends along the proposed tunnel alignment (see Figure 9.31). Note, the pie charts represent the average concentrations over the period of monitoring for each monitoring bore.

- Trends in electrical conductivity for each of the hydrogeological units over time (see Figure 9.32 to Figure 9.34).

- Summary tables for each aquifer including minimum, maximum and median values and exceedances of water quality objectives (see Attachment D).

It is noted that concentrations measured below the laboratory LOR have been presented as values representing half of the LOR for the purposes of the assessment.

i Water quality objective values

As per Section 9.2.3i, 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).

SSTVs can be prepared during construction phase monitoring if sufficient data is available.

The water chemistry and water quality characterisation for each aquifer monitored, based on interpretation of the above data, is presented in the following sections.

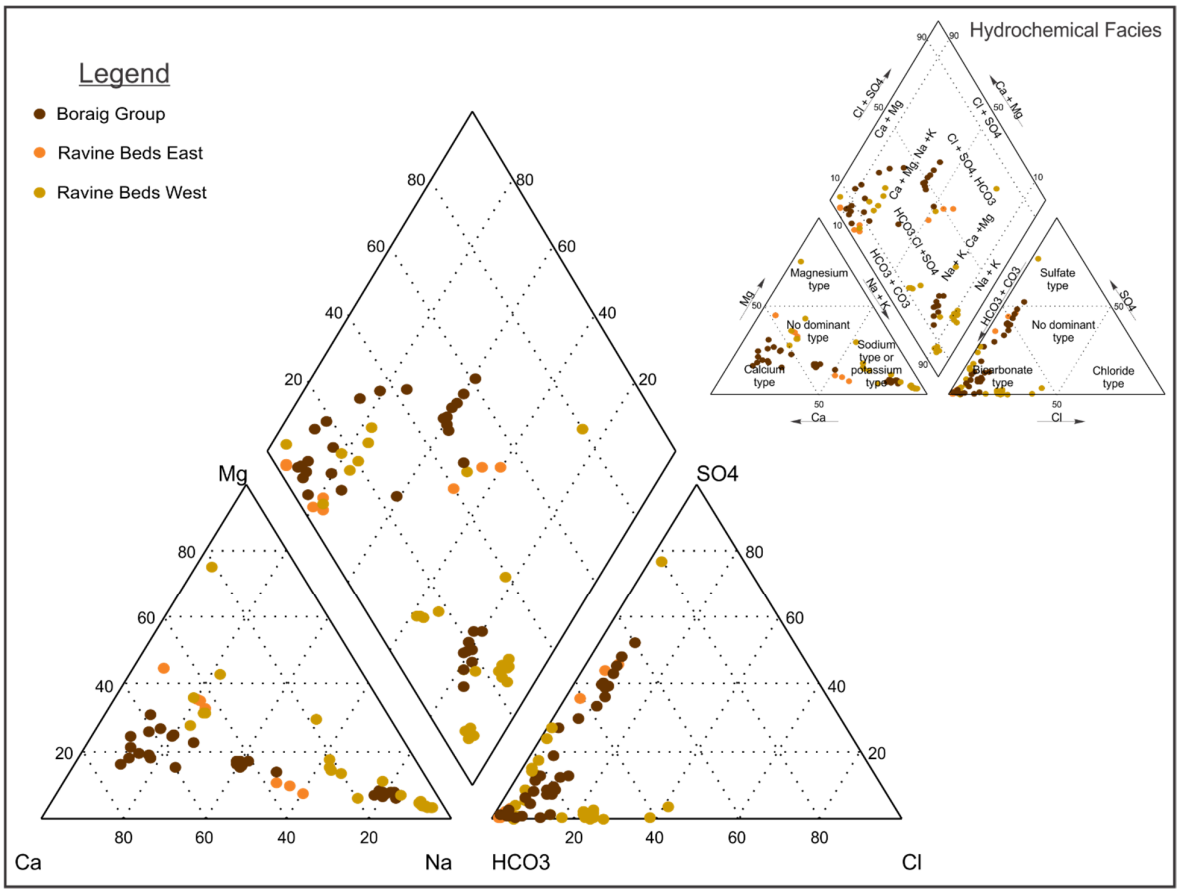


Figure 9.26 Groundwater piper diagram – ravine aquifers

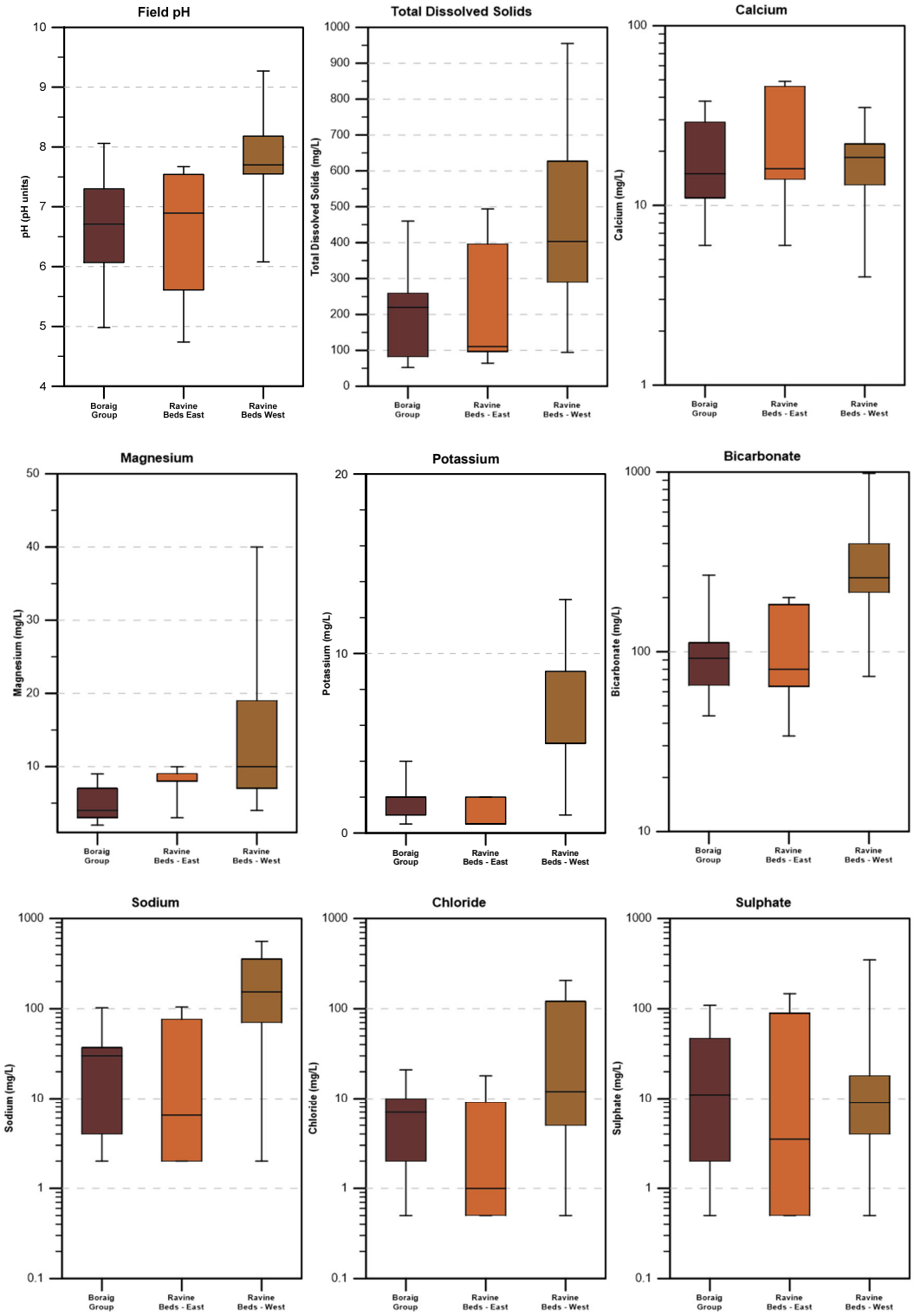
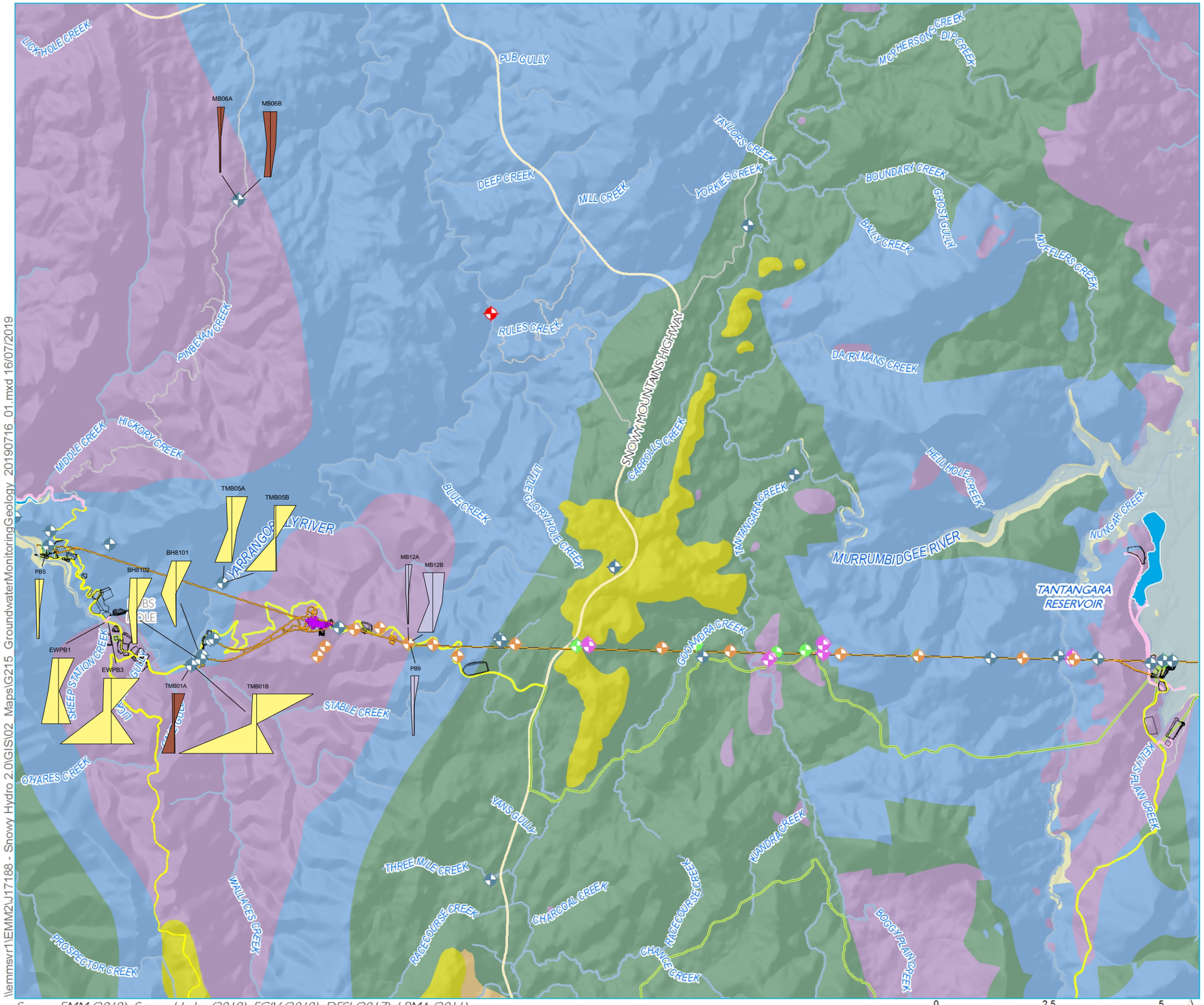


Figure 9.27 Box and whisker plots – ravine



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

0 2.5 5 km

GDA 1994 MGA Zone 55

N

KEY

Groundwater monitoring network
- Monitoring piezometer
- Production bore
- Swamp piezometer
- VWP
- Cave monitoring

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

Geology (250k) by period
- Cainozoic
- Quaternary
- Tertiary
- Devonian
- Silurian
- Ordovician

Stiff plot groups
- Boraig Group
- Ravine Beds East
- Ravine Beds West

Spatial distribution of Stiff plot patterns - ravine aquifers

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.28

snowy 2.0

EMM creating opportunities

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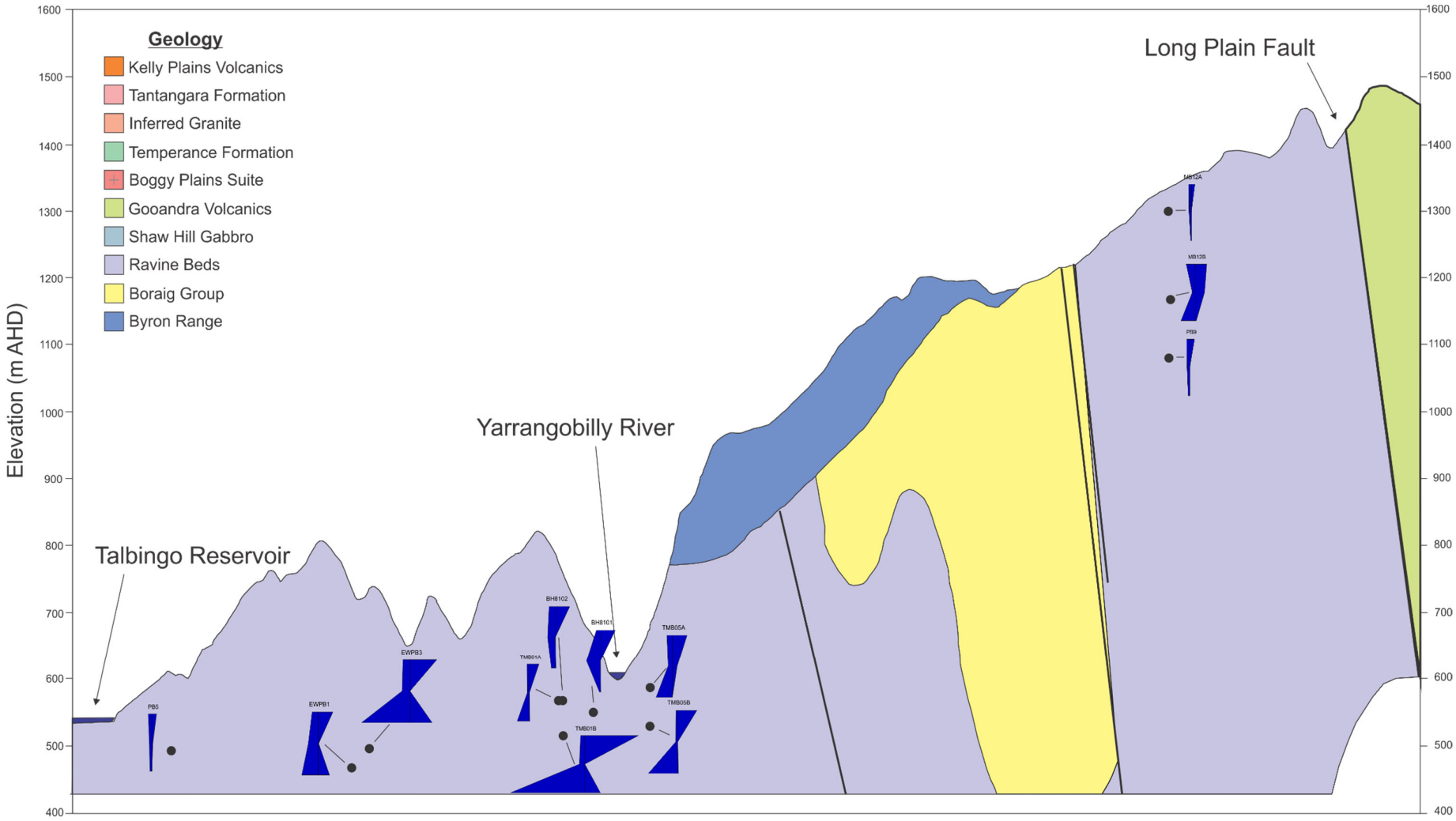
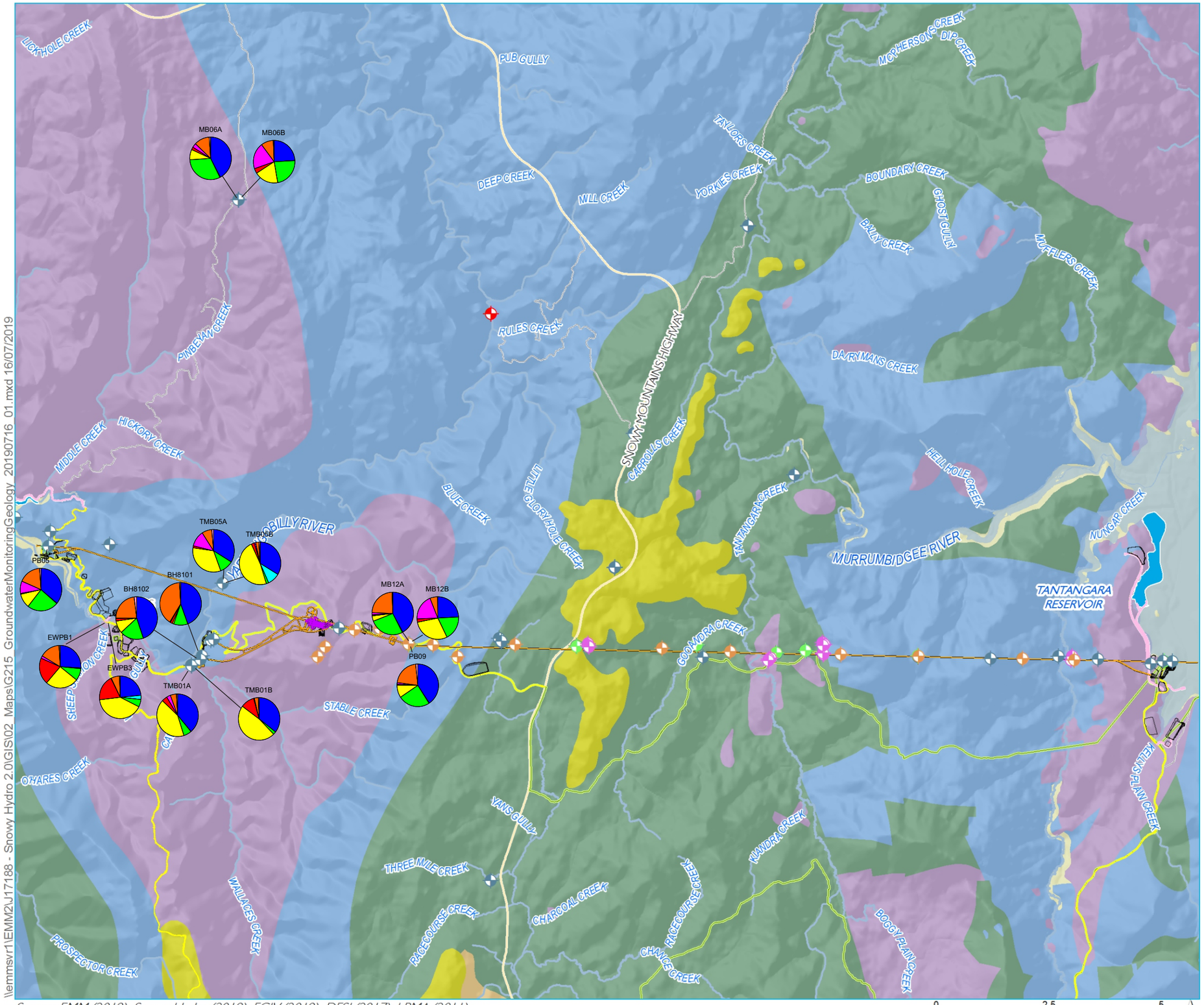


Figure 9.29 **Spatial distribution of Stiff plot patterns along proposed tunnel alignment – ravine aquifers**



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

0 2.5 5 km

GDA 1994 MGA Zone 55

N

KEY

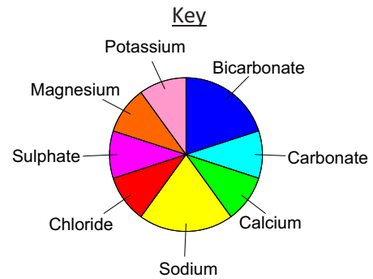
Groundwater monitoring network
- Monitoring piezometer
- Production bore
- Swamp piezometer
- VWP
- Cave monitoring

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

Geology (250k) by period
- Cainozoic
- Quaternary
- Tertiary
- Devonian
- Silurian
- Ordovician



Pie charts of major ion abundance (meq/L) ravine aquifers

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.30

snowy 2.0

EMM creating opportunities

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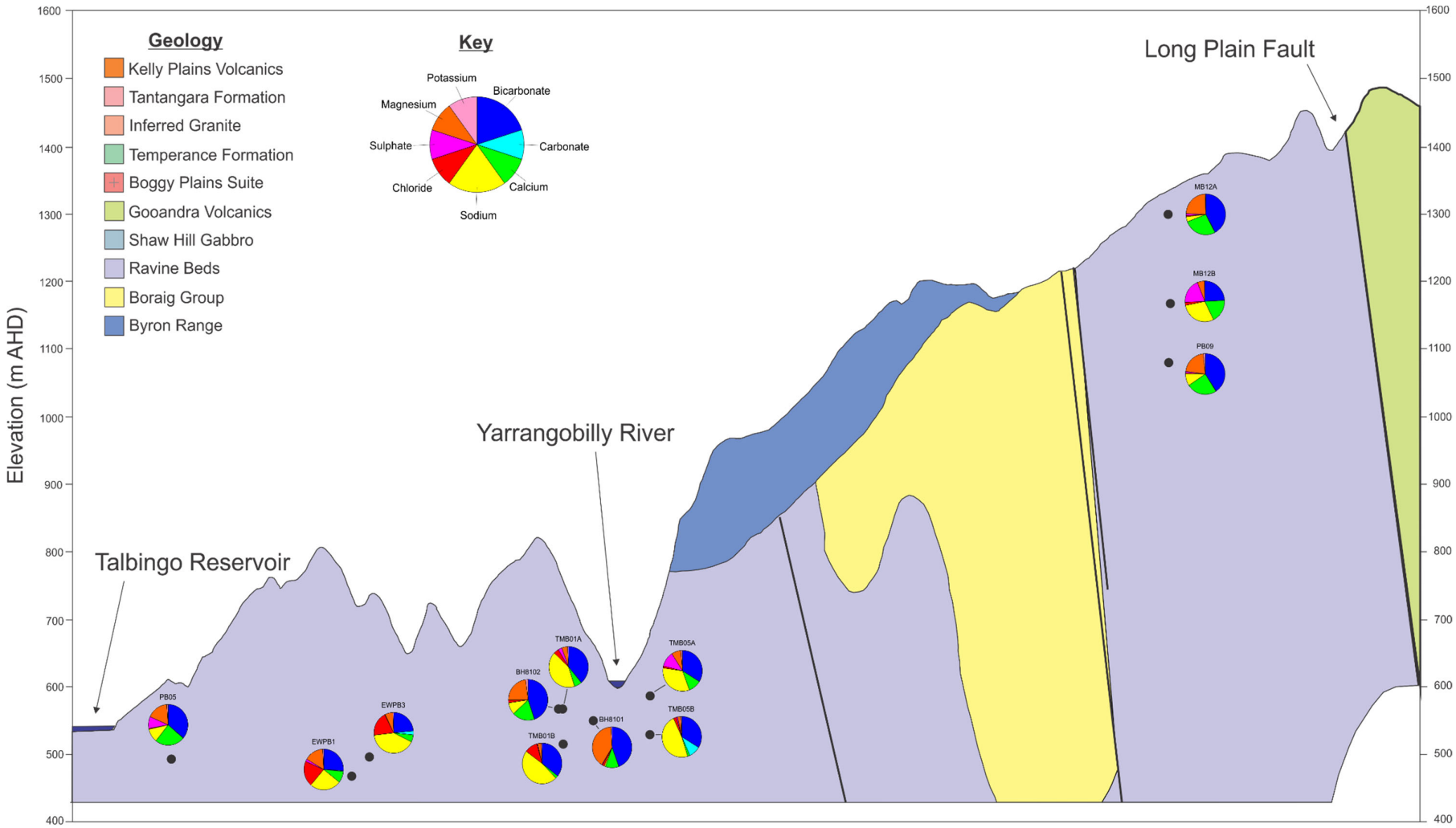


Figure 9.31 Pie charts along proposed tunnel alignment – ravine aquifers

ii Boraig Group

The Piper diagram in Figure 9.26 shows that groundwater in the Boraig Group samples exhibits a broad range in chemical composition. The dominant cations range from calcium to sodium; the dominant anion is bicarbonate. In terms of water type, most samples collected from the Boraig Group can be classified as either calcium-bicarbonate ($Ca\text{-}HCO_3$) or sodium-bicarbonate ($Na\text{-}HCO_3$) type water.

The box and whisker plots (see Figure 9.27) show that groundwater within the Boraig Group is characterised by:

- pH between 5.0 and 8.1, with a median of 6.7 (ie near neutral pH);
- total dissolved solids concentrations ranging between 52 mg/L and 460 mg/L;
- calcium, magnesium, potassium and chloride concentrations less than 40 mg/L;
- a range of sodium and sulphate concentrations from approximately 1 mg/L to 109 mg/L; and
- a broader range of bicarbonate concentrations from 44 mg/L to 267 mg/L, with a median of 92 mg/L.

Metal concentrations (see Attachment D) within the Boraig Group are characterised by:

- minor concentrations of aluminium, arsenic, barium, boron, chromium, copper, iron, manganese, nickel and zinc which are generally above the laboratory LOR; and
- negligible concentrations of beryllium, cadmium, chromium, cobalt, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (see Figure 9.28 and Figure 9.29) and pie charts (see Figure 9.30 and Figure 9.31) are summarised in the following points:

- monitoring bore MB06A has a narrower Stiff pattern than the other two monitoring bores screened across the Boraig Group (MB06B and TMB01A) which suggests that the groundwater at this location has shorter residence times and/or has undergone less interaction with the rock material; and
- groundwater within the Boraig Group in the vicinity of the proposed tunnel alignment (TMB01A) contains noticeably higher proportions of sodium and lower proportions of calcium when compared to the two monitoring bores located further to the north (MB06A and MB06B).

Trends in electrical conductivity for Boraig Group monitoring bores are shown in Figure 9.32. Figure 9.32 shows that electrical conductivity has typically varied by less than 400 µS/cm for all monitoring bores during the monitoring period.

WQOs were exceeded (see Attachment D) in at least one sample within the Boraig Group for the following:

- dissolved oxygen, electrical conductivity, ammonia, oxidised nitrogen, total phosphorus, arsenic, boron, chromium, copper, iron, nickel and zinc.

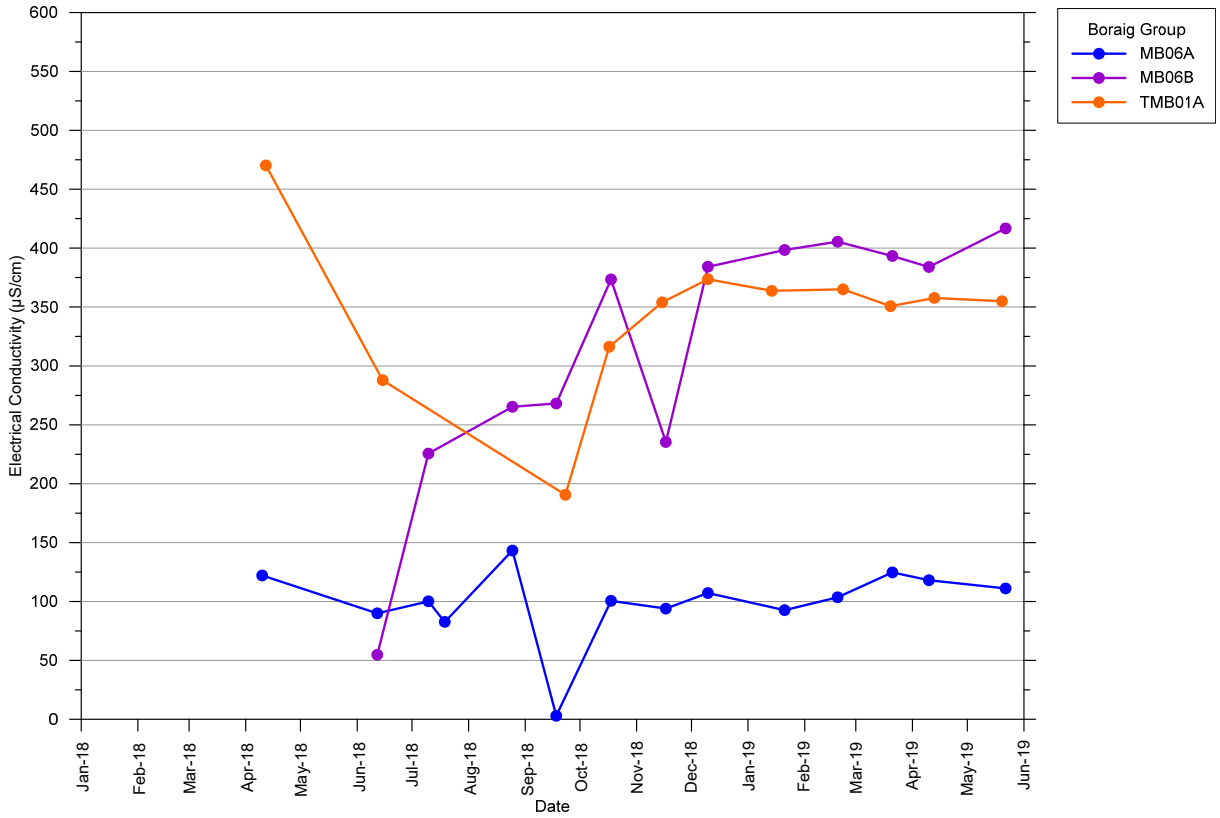


Figure 9.32 Electrical conductivity – Boraig Group

iii Ravine Beds East

The Piper diagram in Figure 9.26 shows that groundwater in the Ravine Beds East samples are clustered towards the middle and left regions of the diamond (ie uppermost) plot. The dominant cation within the Ravine Beds East water samples is sodium. The dominant anion is bicarbonate. In terms of water type, most samples collected from the Ravine Beds East can be classified as sodium-bicarbonate ($Na\text{-}HCO_3$) type water.

The box and whisker plots (see Figure 9.27) show that groundwater within the Ravine Beds East is characterised by:

- pH between 4.7 and 7.7, with a median of 6.9 (ie neutral pH);
- total dissolved solids concentrations ranging between 64 mg/L and 494 mg/L;
- calcium, magnesium, potassium and chloride concentrations less than 50 mg/L; and
- a broader range of sodium and sulphate concentrations from approximately 1 mg/L to 147 mg/L; and bicarbonate concentrations from 34 mg/L to 200 mg/L, with a median of 80 mg/L.

Metal concentrations (see Attachment D) within the Ravine Beds East are characterised by:

- minor concentrations of arsenic, barium, cobalt, copper, iron, manganese, nickel and zinc which are generally above the laboratory LOR; and

- negligible concentrations of aluminium, beryllium, boron, cadmium, chromium, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (see Figure 9.28 and Figure 9.29) and pie charts (see Figure 9.30 and Figure 9.31) are summarised in the following points:

- Monitoring bores MB12A and PB9 have narrower Stiff patterns and are more similar in chemical composition than monitoring bore MB12B which is screened at an intermediate depth between MB12A and PB9. This suggests that there is heterogeneity within the Ravine Beds East with depth.

- Monitoring bore MB12B has noticeably higher proportions of sodium and sulphate, and noticeably lower proportions of magnesium, when compared to MB12A and PB09. This observation, together with the broader Stiff pattern in MB12B, suggests that groundwater at this location has longer residence times and/or has undergone greater interaction with the rock material when compared to MB12A and PB09.

Trends in electrical conductivity for Ravine Beds East monitoring bores are shown in Figure 9.33. Figure 9.33 shows that electrical conductivity has varied by approximately 100 µS/cm in MB12A and PB09, and 400 µS/cm in MB12B during the monitoring period.

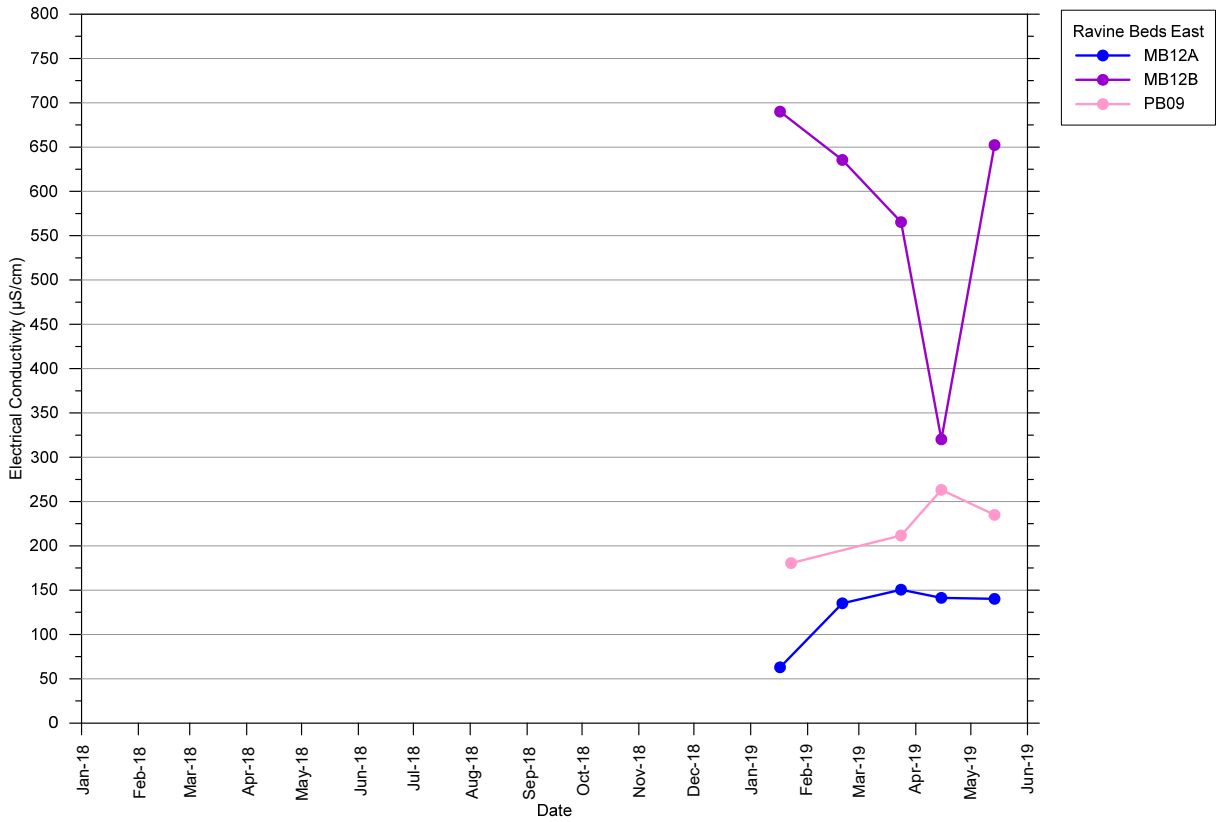


Figure 9.33 Electrical conductivity – Ravine Beds East

WQOs were exceeded (see Attachment D) in at least one sample within the Ravine Beds East for the following:

- dissolved oxygen, electrical conductivity, ammonia, oxidised nitrogen, total nitrogen, total phosphorus, arsenic, cobalt, copper, iron, nickel and zinc.

iv Ravine Beds West

The Piper diagram in Figure 9.26 shows that groundwater in the Ravine Beds West samples exhibits a broad range in chemical composition. The dominant cations range from magnesium to sodium; the dominant anion is bicarbonate. In terms of water type, most samples collected from the Ravine Beds West can be classified as either sodium-bicarbonate ($Na\text{-}HCO_3$) or mixed-type water.

The box and whisker plots (see Figure 9.27) show that groundwater within the Ravine Beds West is characterised by:

- pH between 6.1 and 9.3, with a median of 7.7;
- total dissolved solids concentrations ranging between 94 mg/L and 1,540 mg/L;
- calcium, magnesium and potassium concentrations less than 40 mg/L; and
- a broader range in the concentrations of bicarbonate (73 mg/L to 1,170 mg/L), sodium (2 mg/L to 559 mg/L), chloride (4 mg/L to 206 mg/) and sulphate (1 mg/L to 348 mg/).

Metal concentrations (see Attachment D) within the Ravine Beds East are characterised by:

- minor concentrations of aluminium, arsenic, barium, boron, cobalt, copper, iron, manganese, nickel and zinc which are generally above the laboratory LOR; and
- negligible concentrations of beryllium, cadmium, chromium, lead, mercury, selenium, silver and vanadium (typically less than the laboratory LOR).

Key findings from the Stiff diagrams (see Figure 9.28 and Figure 9.29) and pie charts (see Figure 9.30 and Figure 9.31) are summarised in the following points:

- monitoring bores 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;
- deeper monitoring bores along the proposed tunnel alignment have noticeably higher proportions of chloride and broader Stiff patterns which suggests that deeper groundwater within the Ravine Beds West has longer residence times and/or has undergone greater interaction with the rock material when compared to the shallower bores.

Trends in electrical conductivity during the monitoring period for Ravine Beds West monitoring bores are shown in Figure 9.34 and can be summarised as follows:

- electrical conductivity has varied by less than 200 µS/cm in monitoring bores PB05 and TMB05B;
- the initial electrical conductivity value for TMB05A is significantly higher than subsequent values and may be affected by incompletely flushed drilling fluids; and
- TMB01A shows an increasing trend during the monitoring period from approximately 1,000 mg/L to approximately 2,400 mg/L.

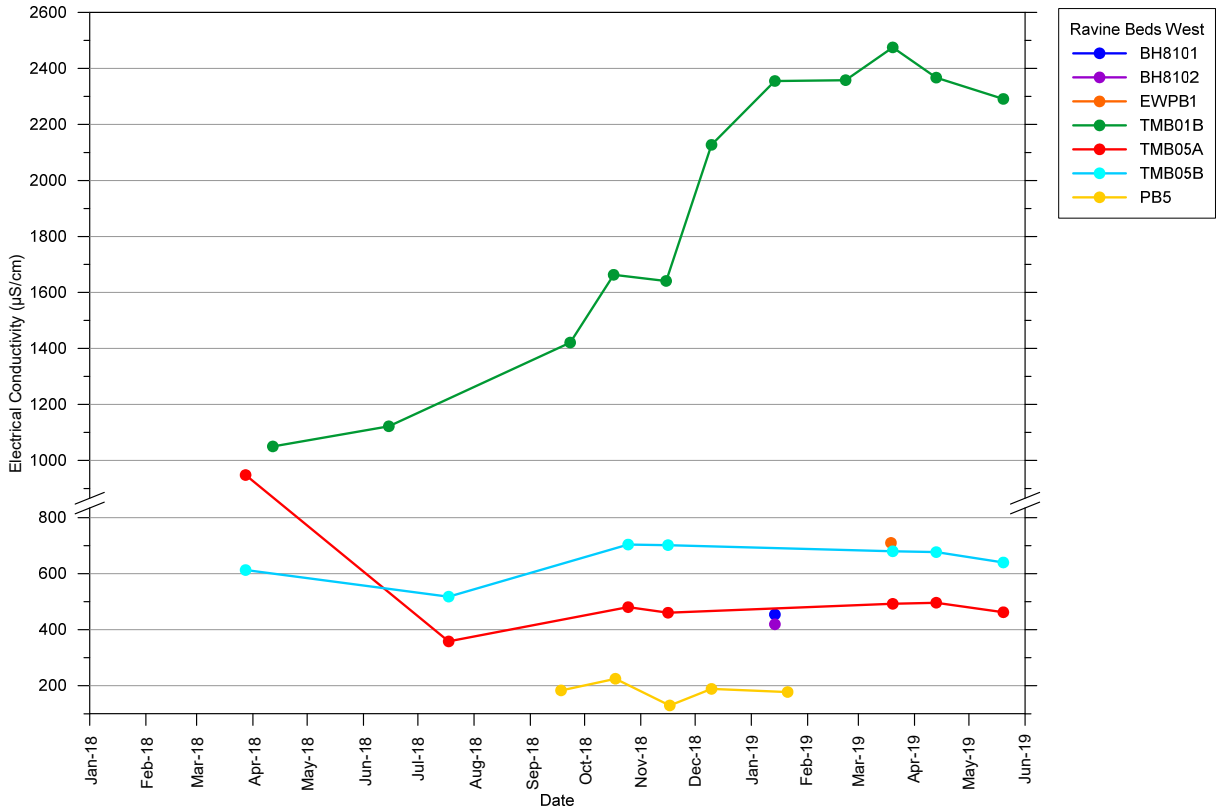


Figure 9.34 Electrical conductivity – Ravine Beds West

WQOs were exceeded (see Attachment D) in at least one sample within the Ravine Beds West for the following:

- dissolved oxygen, electrical conductivity, ammonia, oxidised nitrogen, total nitrogen, reactive phosphorus, total phosphorus, fluoride, aluminium, arsenic, boron, chromium, cobalt, copper and zinc.

9.3.4 Surface and groundwater interaction

i Yarrangobilly Caves monitoring

The Yarrangobilly Caves system is monitored by stilling well YC05 (see Section 3.4). The water level trend at YC05 is stable and shows a strong correlation with rainfall. Using logger data from November 2018 to May 2019, gauged pool water depth ranged from 0.17 m to 0.55 m and averaged 0.25 m (see Figure 9.35).

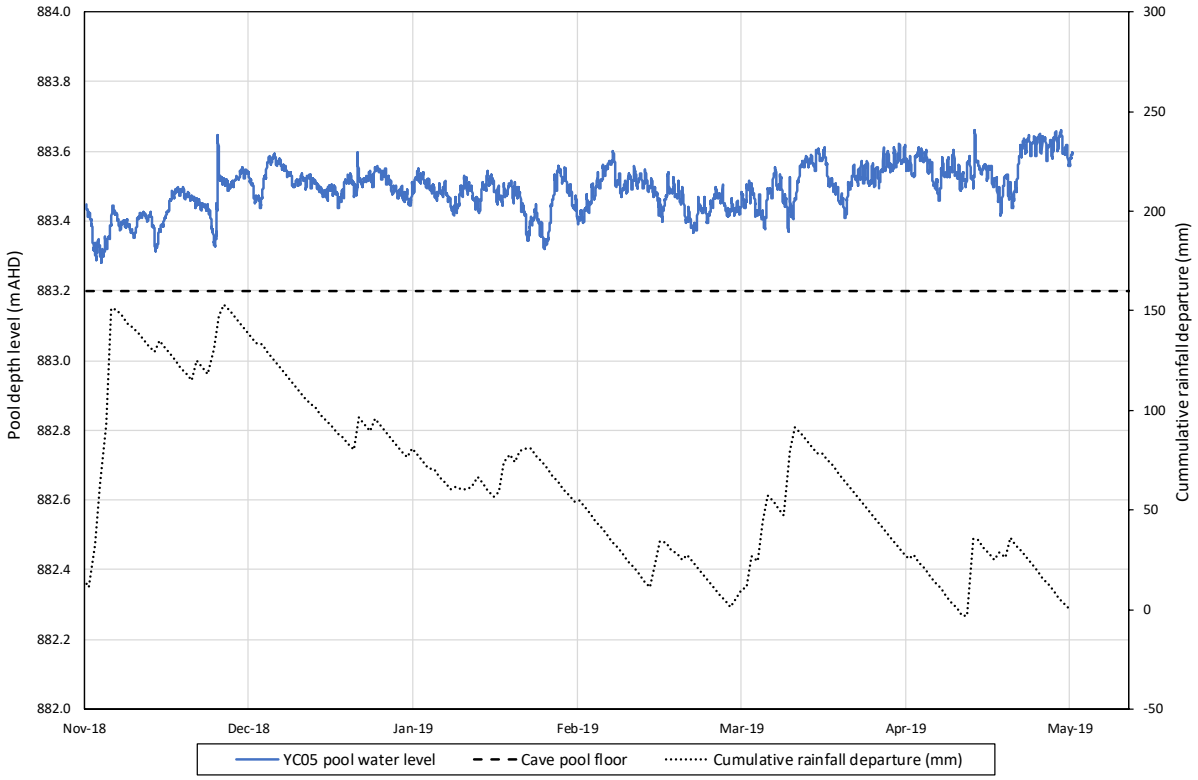


Figure 9.35 YC05 pool depth water level

ii Potential groundwater dependent ecosystems

a Terrestrial

As identified in biodiversity development assessment report (Appendix M.1 to the EIS), four PCTs have an been identified as potential 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. Appendix M.1 to the EIS

These PCTs were assessed as having facultative-proportional or facultative-opportunistic dependencies on groundwater (Appendix M.1 to the EIS):

- 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.
- 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

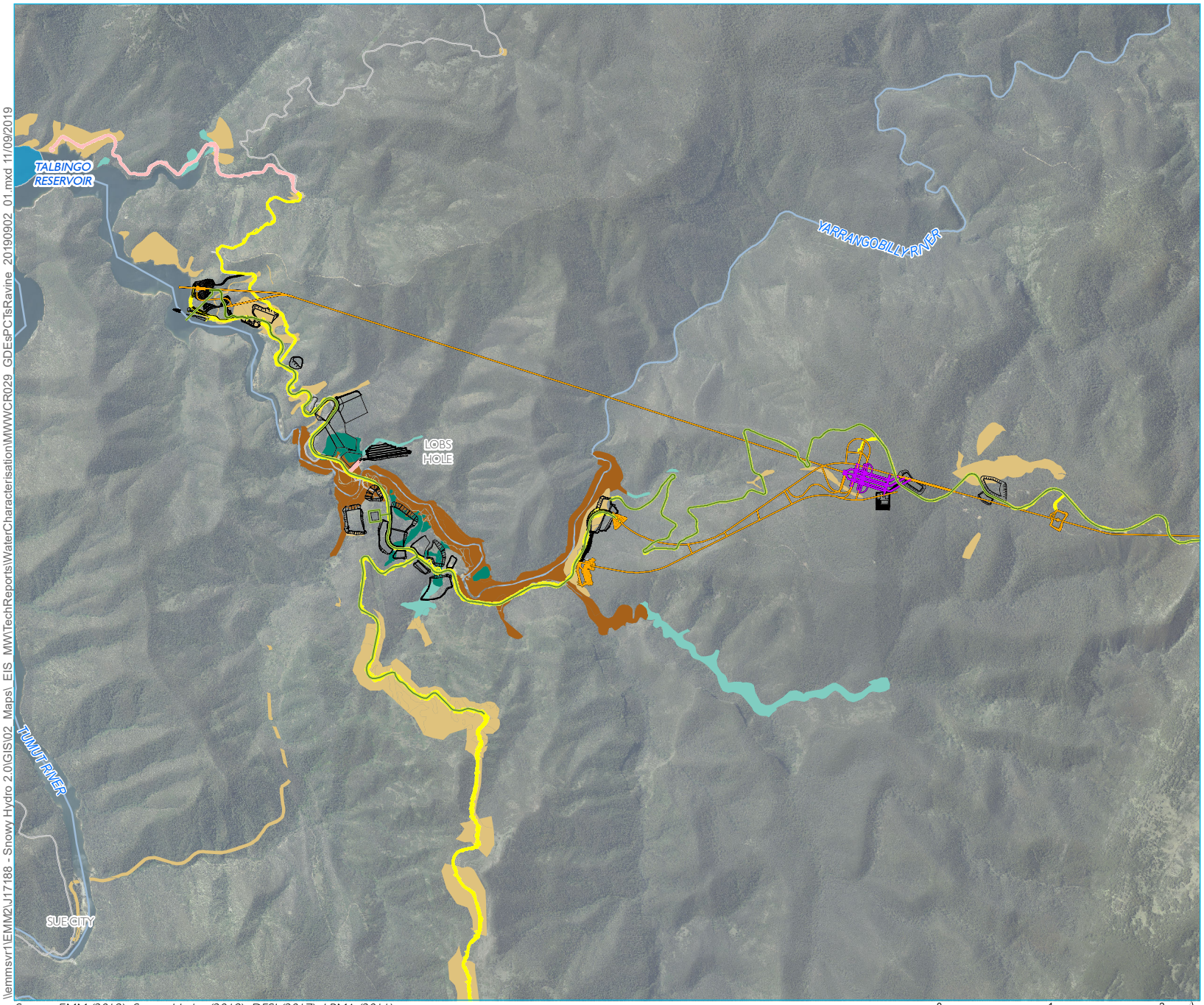
Figure 9.36 shows the spatial occurrence of GDE PCTs. Table 9.4 demonstrates PCT occurrence with groundwater.

Table 9.4 Occurrence of facultative-proportional/opportunistic potential GDEs in the ravine

PCT name	Community occurrence within modelled groundwater levels			Entirely/obligate potential GDEs occurring in areas where groundwater is ≤ 2 m BGL	Entirely/obligate potential GDEs occurring in areas where groundwater is ≤ 5 m BGL	Potential GDE type
	0–0.5 m BGL	0.5–2 m BGL	2-5 m BGL			
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

b Subterranean stygofauna

No stygofauna were observed in sampled monitoring bores. However, existing stygofauna are likely similar those encountered in other fractured rock systems in NSW (Appendix M.1 to the EIS).



KEY

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

Plant community type
- PCT 285
- PCT 299
- PCT 300
- PCT 302

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

0 1 2 km

GDA 1994 MGA Zone 55

N

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Entirely/obligate and facultative-opportunistic GDEs - ravine

Snowy 2.0
Water Characterisation Report
Main Works
Figure 9.36

snowy 2.0

EMM creating opportunities

10 Conceptual model

10.1 Plateau

10.1.1 Overview

The plateau can be simplified into the following hydrogeological units:

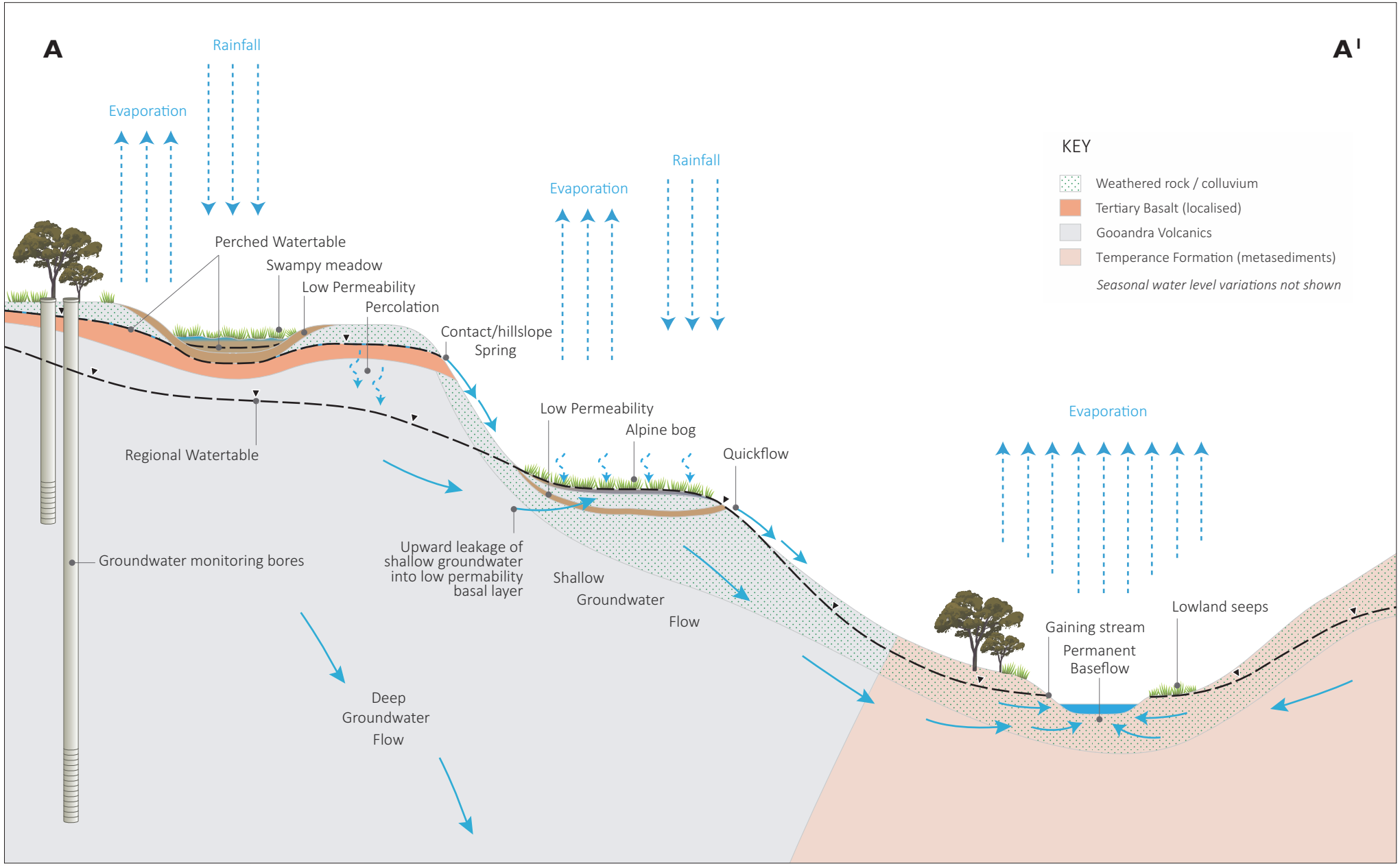
- **Alluvium, colluvium and weathered rock:**
  - Groundwater in shallow alluvium along creeks and rivers is recharged during moderate to high rainfall, flooding events and snowmelt. The alluvium provides bank storage during high flow events.
  - Groundwater in shallow colluvium is recharged during rainfall 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 snowmelt.
  - 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 snowmelt (occurring when soil moisture thresholds are exceeded).
- **Deep fractured rock:**
  - The deeper fractured rocks are recharged by rainfall migrating from shallow groundwater systems. Permeability is lowest in the central section of the plateau and higher in the east and western sections 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 (locally and regionally), vertical connectivity and baseflow contributions to bogs and fens, and streams. A graphical depiction of the conceptual groundwater flow model for the plateau is shown in Figure 10.1. 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 can be 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 streams.



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EMM creating opportunities

Groundwater occurrence and flow – simplified concept

Snowy 2.0

Water Characterisation Report

Figure 10.1

10.1.2 Groundwater recharge, discharge and flow

i Recharge

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

ii Discharge

Groundwater discharge processes for the plateau are:

- drainage to surface water (baseflow to tributaries);
- evaporation from the watertable where it is shallow, ie seeps, springs and escarpments;
- evapotranspiration 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 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.

10.1.3 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 streams with the regional groundwater system providing most 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 potential GDEs) are predominantly sustained by rainfall and their relationship to the different groundwater systems is variable:
    - Swampy meadows in elevated areas are usually perched and disconnected from regional groundwater. Their perched watertables vary in accordance with seasonal rainfall and evapotranspiration trends.

- Upper catchment alpine bogs and fens in mid-slope areas are perched 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.

- Lower catchment alpine bogs and fens in mid-slope areas are connected at their base to shallow groundwater 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 component.

- 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.

10.1.4 Plateau groundwater dependent ecosystems

i Surface

As described in section 9.2.4ii, groundwater dependent PCTs on the plateau have been identified as being entirely/obligate or facultative-opportunistic GDEs, and intercept shallow and/or regional groundwater systems. Other PCTs in the plateau are non-dependent on groundwater.

ii Subsurface

Existing stygofauna are assumed to be similar to 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.

10.2 Ravine

10.2.1 Overview

Conceptually, the boundary between the Ravine Beds and plateau is separated by the LPF. Much of the processes described in Section 10.1 also apply to formations in the ravine. Regardless, the ravine can be 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 flow events.

  - 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 thresholds are exceeded).

- **Deep fractured rock:**
  - The deeper fractured rocks have the lowest permeability and are recharged by rainfall migrating from shallow groundwater systems. There is downward flow of groundwater from shallow aquifers.

10.2.2 Groundwater recharge, discharge and flow

i Recharge

The ravine groundwater system is largely recharged by rainfall/flooding, the Yarrangobilly River (and storages), and the lateral movement of groundwater from 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;
- evapotranspiration 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 (fracture) porosity. Permeability in the alluvium and colluvium is via primary (matrix) porosity.
- Localised groundwater flow and direction is largely controlled by stratigraphy, dip of the strata, faulting, fractures and topography.

10.2.3 Surface and groundwater interaction

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

10.2.4 Ravine groundwater dependant ecosystems

i Surface

As discussed in section 9.3.4ii, groundwater dependent PCTs in the ravine have been identified as being facultative-proportional or facultative-opportunistic type GDEs, and intercept shallow and/or regional groundwater systems. Other PCTs in the ravine are non-dependent on groundwater.

ii Subsurface

Subterranean stygofauna have not been identified in the ravine. 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.

References

ANZECC & ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australian and New Zealand.

Ashton, D & Williams, R 1989, Dynamics of the sub-alpine vegetation in the Victorian region, In *Fenner Conference -The Scientific Significance of the Australian Alps*, Australian Alps National Parks Liaison Committee, Canberra.

AS/NZS 5667.11:1998. Australian Standard for Water Quality Sampling. Water Quality – Sampling Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples.

Babister, M, Trim, A, Testoni, I & Retallick M 2016, *The Australian Rainfall & Runoff Datahub,* 37th Hydrology and Water Resources Symposium Queenstown NZ.

Brierley, G & Fryirs, K 2005, *Geomorphology and River Management: Applications of the River Styles Framework*, Blackwell Publications, Oxford, UK.

Brown, J & Millner, F 1988, Aspects of the meteorology and hydrology of the Australian Alps. In *The Scientific Significance of the Australian Alps*, eds Good R, Australian Academy of Science, Canberra.

BoM 2016, *Maps of average conditions*, Bureau of Meteorology, retrieved 14 January 2019 from http://www.bom.gov.au/climate/averages/maps.shtml

Cardno 2019a, *Snowy 2.0 - Reservoir Monitoring Program Methodology*, Report prepared by Cardno (NSW/ACT) Pty Ltd for EMM Consulting Pty Limited.

- Appendix K to the EIS, *Talbingo and Tantangara Reservoirs Physical Limnology Report*.
- Appendix M.2 to the EIS, *Aquatic Ecology Impact Assessment*.

CSIRO & BoM, 2015, *Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report*, CSIRO and Bureau of Meteorology, retrieved 21 August 2019 from https://www.climatechangeinaustralia.gov.au/media/ccia/2.1.6/cms_page_media/168/CCIA_2015_NRM_TechnicalReport_WEB.pdf

CSIRO 2019, *Snowy 2.0 Assignment P4: Environmental Categorisation of Excavated Rock Interactions with and Potential Impacts on Reservoir Waters and Sediments*, report prepared by Commonwealth Scientific and Industrial Research Organisation for Haskoning Australia on behalf of Snowy Hydro Limited.

DECCW 2006, *NSW Water Quality and River Flow Objectives,* Department of Environment, Climate Change and Water, viewed March 2019, https://www.environment.nsw.gov.au/ieo/index.htm.

DEWHA 2009, *National Assessment Guidelines for Dredging*, Department of the Environment, Water, Heritage and the Arts.

Domenico, PA and Schwartz, FW 1990, *Physical and Chemical Hydrogeology 2nd edition*, John Wiley & Sons, Chichester.

EMM 2018a, *Environmental Impact Statement: Exploratory Works for Snowy 2.0*, prepared for Snowy Hydro Limited by EMM Consulting Pty Limited.

- 2018b*, Soils and land assessment: Exploratory Works for Snowy 2.0.*

EMM 2019, *Environmental Impact Statement: Main Works for Snowy 2.0*, prepared for Snowy Hydro Limited by EMM Consulting Pty Limited.

- Appendix J to the EIS, *Water Assessment*.
- Appendix N.2 to the EIS, *Soils and Land Assessment*.
- Appendix M.1 to the EIS, *Biodiversity Development Assessment Report*.

Flow and Loam Environmental, 2019, *A Geomorphic Assessment and Characterisation of Channel Zones and Floodplains within the Snowy 2.0 Project Area*, prepared for EMM Consulting Pty Ltd by Flow and Loam Environmental.

Geosciences Australia, *1:250 000 Geological maps*, https://resourcesandgeoscience.nsw.gov.au/miners-and-explorers/geoscience-information/products-and-data/maps/geological-maps/1-250-000.

Jacobs 2017, *Geological/geotechnical Assessment of Existing Tunnels Report and Interpretation for New Underground Structures,* prepared for Snowy Hydro Limited by Jacobs Group (Australia) Pty Limited.

NPWS 2004, *Independent Scientific Committee: an assessment of the values of Kosciuszko National Park* , Fyshwick ACT, NSW National Parks and Wildlife Services.

NSW DPI Water 2012, *NSW Aquifer Interference Policy, NSW Government Policy for the licensing and assessment* of aquifer interference activities, NSW Department of Primary Industries Office of Water.

NSW DPI Water 2014, *Groundwater Monitoring and Modelling Plan – Information for prospective mining and petroleum exploration activities,* NSW Department of Primary Industries Office of Water.

NUDLC 2012, *Minimum Construction Requirements for Water Bores in Australia*, Third edition, Australian Government National Water Commission, Uniform Drillers Licensing Committee.

OEH (n.d.), *About NARCliM*, NSW Office of Environment and Heritage, retrieved 21 August 2019 from https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM

OEH 2014, *Murray Murrumbidgee – Climate change snapshot*, NSW Office of Environment and Heritage, retrieved 21 August 2019 from https://climatechange.environment.nsw.gov.au/-/media/NARCLim/Files/Regional-Downloads/Climate-Change-Snapshots/MMsnapshot.pdf

Piper, A M 1944, A graphic procedure in the geochemical interpretation of water analyses. *Transactions, American Geophysical Union*, Vol 25. Pages 914-923.

Post, DA, Chiew, FHS, Teng, J, Wang, B & Marvanek, S 2012, *Projected changes in climate and runoff for south-eastern Australia under 1 °C and 2 °C of global warming,* A SEACI Phase 2 special report, CSIRO, retrieved 21 August 2019 from http://www.seaci.org/publications/documents/SEACI2Reports/SEACI2_Projections_Report.pdf

Pritchard, J & Lamontagne, S 2019, *Yarrangobilly Thermal Springs: Hydrochemistry Investigation*, CSIRO, Australia.

Queensland Government 2019, *SILO: Australian climate data from 1889 to yesterday*, Queensland Government, retrieved from https://www.longpaddock.qld.gov.au/silo/

RHDHV 2018a, *Snowy 2.0 Exploratory Works, Dredging and Dredging Impact Assessment*, report prepared by Royal Haskoning DHV for Snowy Hydro Limited.

- 2018b, *Sediment Sampling Investigation, Talbingo Reservoir*. [Attachment G].

RHDHV 2019, *Sediment Sampling Investigation Operational Scenario Assessment, Talbingo and Tantangara Reservoirs*, report prepared by Royal Haskoning DHV for Snowy Hydro Limited. [Attachment H].

Serov P, Kuginis L, Williams J.P., May 2012, *Risk assessment guidelines for groundwater dependent ecosystems*, *Volume 1 – The conceptual framework*, NSW Department of Primary Industries, Office of Water, Sydney

SMEC 2019, *Gravity and Magnetics Factual and Interpretive Report – Geophysical Factual and Interpretive Report: Issue A*, prepared for Snowy Hydro Limited by SMEC Australia Pty Ltd.

Stuart-Smith, P G 1991 *The Deformational History of a possible Terrane Boundary within the Lachlan Fold Belt,* NSW: The Gilmore Fault Zone.

Stiff, H A 1951. The interpretation of chemical water analyses by means of patterns. *Journal of Petroleum Technology*, Vol 3. Pages 15-17.

Timbal et al, 2015*, Murray Basin Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports*, CSIRO and Bureau of Meteorology, retrieved 21 August 2019 from https://www.climatechangeinaustralia.gov.au/media/ccia/2.1.6/cms_page_media/172/14-00140_MURRAY%20BASIN_NRM%20Report_DRAFT.pdf

Wahl, K and Wahl, T 1995, 'Determining the flow of Comal Springs at New Braunfels, Texas', *Proceedings of Texas Water* 95, August 16–17, 1995, American Society of Civil Engineers, San Antonio, Texas, pp. 77–86.

Wyborn, D, Owen, M & Wyborn, L, 1990, Kosciusko National Park (1:250,000 scale map).

Glossary

Term	Definition
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.
Alpine bog	Boggy, wet ground, typically associated with colluvium and depressions in the landscape.
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, 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.
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.
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).
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.
Contact/hillside springs	Springs displaying visible flow from perched or regional groundwater, typically on hillslopes.
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).

Term	Definition
Drawdown	The lowering of water levels in a surface water or groundwater storage resulting from the loss or take of water from the storage.
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.
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.
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, 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 flow path 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.

Term	Definition
Groundwater, shallow	Groundwater below the regional watertable in the weathered fractured rock groundwater system that has a short circulation flow path 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.
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.
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.
Knickpoint	Part of a watercourse where there is a sharp change in channel grade.
Losing stream	A stream from which water is lost to the surrounding and underlying substrate via infiltration through the streambed and banks.
Lowland seeps	Visible seeps from regional groundwater into sediment storage (ie floodplains).
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.
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.
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.

Term	Definition
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.
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.
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.
Spot-flow gauging (in situ streamflow measurement)	Involves the measurement of the discharge of a watercourse, at a given location, at a point in time.
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.
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.
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.
Unsaturated zone	The soil between the land surface and the regional watertable in which the pore space contains both air and water.
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.

Term	Definition
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 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.
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.

Abbreviations

Abbreviation	Description
AEP	Australian Capital Territory
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ANSTO	Australia's Nuclear Science and Technology Organisation
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AQTESOLVE	Aquifer Test SolverTM
BFI	Baseflow index
BGL	Below ground level
BoM	Bureau of Meteorology
cm	Centimetre
CDFM	Cumulative deviation from the mean
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DECCW	Department of Environment, Climate Change and Water
DO	Dissolved oxygen
DST	Drill stem test
EC	Electrical conductivity
EVs	Environmental values
EIS	Environmental Impact Statement
FSL	Full supply level
GDE	Groundwater dependent ecosystem
GL	Gigalitre
Kh	Horizontal hydraulic conductivity
km	Kilometres
KNP	Kosciuszko National Park
Kv	Vertical hydraulic conductivity
LFB	Lachlan Fold Belt
LGA	Local Government Area
LOR	Limit of reporting
LPF	Long Plain Fault
m	Metres
µS	Micro siemens

Abbreviation	Description
meq	Milliequivalents
mg	Milligram
mm	Millimetre
ML	Megalitre
MLU	Multi-Layer Unsteady stateTM
MOL	Minimum operating level
NARCliM	NSW and ACT Regional Climate Modelling
NSW	New South Wales
PCT	Plant community type
Redox	Oxidation reduction
REF	Review of Environmental Factors
s	Second
SEACI	South Eastern Australian Climate Initiative
SILO	Scientific Information for Land Owners
SSTV	Site-specific trigger value
VWP	Vibrating wire piezometer
WQO	Water quality objective