APPENDIX L

EXCAVATED ROCK PLACEMENT ASSESSMENT

ANNEXURE G– ERP MODELLING
– CONSTRUCTION AND
ANNEXURE H– ERP MODELLING
– COMMISSIONING

Annexure G ERP Modelling – Construction

REPORT

Snowy 2.0 Excavated Rock Placement

Snowy 2.0: Talbingo Reservoir Modelling – Construction

Client: Snowy Hydro Limited

Reference: PA1804 ERP Modelling Report
Status: 1.0.1/Final
Date: 11 September 2019

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Enhancing Society Together

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Classification

Project related

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Acronym	Definition
ADCP	Acoustic Doppler Current Profiler
AEMO	Australian Energy Market Operator
AHD	Australian Height Datum
ANC	Acid Neutralising Capacity
ARI	Average Recurrence Interval
APET	Areal potential evapotranspiration data
AWM	AW Maritime Pty Ltd
BOM	Bureau of Meteorology
CFD	Computational Fluid Dynamics
CFL	Courant-Friedrichs-Lewy
COLREGs	Convention on the International Regulations for Preventing Collision at Sea 1972
COPC	Contaminants of Potential Concern
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSSI	Critical State Significant Infrastructure
CTD	Conductivity, Temperature, Depth (Pressure)
D&B	Drill and Blast
DoEE	Commonwealth Department of Environment and Energy
DEM	Digital Elevation Model
DFL	Design Flood Level
DGV	Default Guideline Value
DIDO	Drive In Drive Out
DPIE	Department of Planning, Industry and Environment (NSW)
ECVT	(Emergency) Egress, Cable and Ventilation Tunnel
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EP&A	Environmental Planning & Assessment Act 1979
EPBC	Environment Protection and Biodiversity Conservation Act 1999
ERP	Excavated Rock Placement
FG	Future Generation
FIFO	Fly In Fly Out
FM	Flexible Mesh
FSL	Full Supply Level
FU	Functional Unit

Acronym	Definition
GIS	Geographic Information System
HD	Mike 3 Flow ‘Hydrodynamic’ Model
ISQG	Interim Sediment Quality Guidelines
KNP	Kosciuszko National Park
L/S	Liquid to Solid Ratio
LGA	Local Government Area
LOA	Length Overall
m	Metres
MAT	Main Access Tunnel
MOL	Minimum Operating Level
MPA	Maximum Potential Acidity
MT	Mud Transport
MVA	Mega Volt Amp
MW	Megawatt
MWh	Megawatt hours
NAGD	National Assessment Guidelines for Dredging
NEM	National Electricity Market
NIA	Navigation Impact Assessment
NOA	Naturally Occurring Asbestos
NPWS	National Parks and Wildlife Service (NSW)
NSW	New South Wales
NTU	Nephelometric Turbidity Unit
PSD	Particle Size Distribution
QA	Quality Assurance
RHDHV	Royal HaskoningDHV
RMS	NSW Roads and Maritime Service
SEARs	Secretary’s Environmental Assessment Requirements
SEPP	State Environmental Planning Policy
SRD	State and Regional Development
SSI	State Significant Infrastructure
T2	Tumut 2 Power Station
T3	Tumut 3 Power Station
TBM	Tunnel Boring Machine

Acronym	Definition
TN	True North
TSS	Total Suspended Sediments
WED	Wake Enhancement Device
XRF	X-ray Fluorescence

1 Introduction

1.1 The Project

Snowy Hydro Limited (Snowy Hydro) proposes to develop Snowy 2.0, a large-scale pumped hydro-electric storage and generation project which would increase hydro-electric capacity within the existing Snowy Mountains Hydro-electric Scheme (Snowy Scheme). Snowy 2.0 is the largest committed renewable energy project in Australia and is critical to underpinning system security and reliability as Australia transitions to a decarbonised economy. Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground.

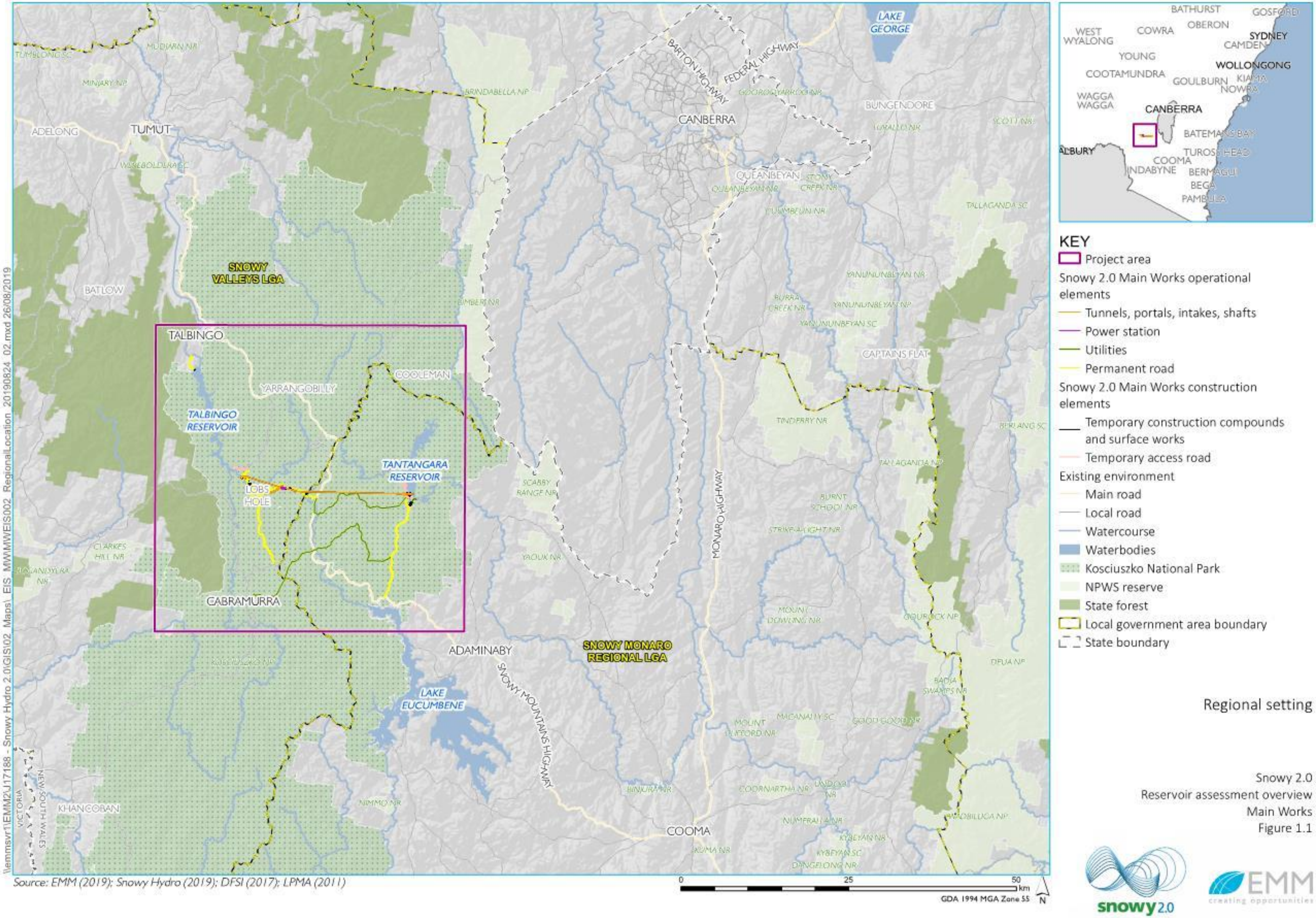
Snowy 2.0 has been declared to be State significant infrastructure (SSI) and critical State significant infrastructure (CSSI) by the former NSW Minister for Planning under Part 5 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) and is defined as CSSI in clause 9 of Schedule 5 of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

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

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

This **Excavated Rock Placement (ERP) Modelling (Construction)** assessment has been prepared to accompany an application and supporting EIS for the **Snowy 2.0 Main Works**. As the title suggests, this stage of the project covers the major construction elements of Snowy 2.0, including permanent infrastructure (such as the underground power station, power waterways, access tunnels, chambers and shafts), temporary construction infrastructure (such as construction adits, construction compounds and accommodation), management and storage of excavated rock material and establishing supporting infrastructure (such as road upgrades and extensions, water and sewage treatment infrastructure, and the provision of construction power). Snowy 2.0 Main Works also includes the operation of Snowy 2.0.

Snowy 2.0 Main Works is shown in **Figure 1-1** and **Figure 1-2**. If approved, the Snowy 2.0 Main Works would commence before completion of Exploratory Works.



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

Regional setting

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 1.1

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

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

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

1.2 Project Location

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

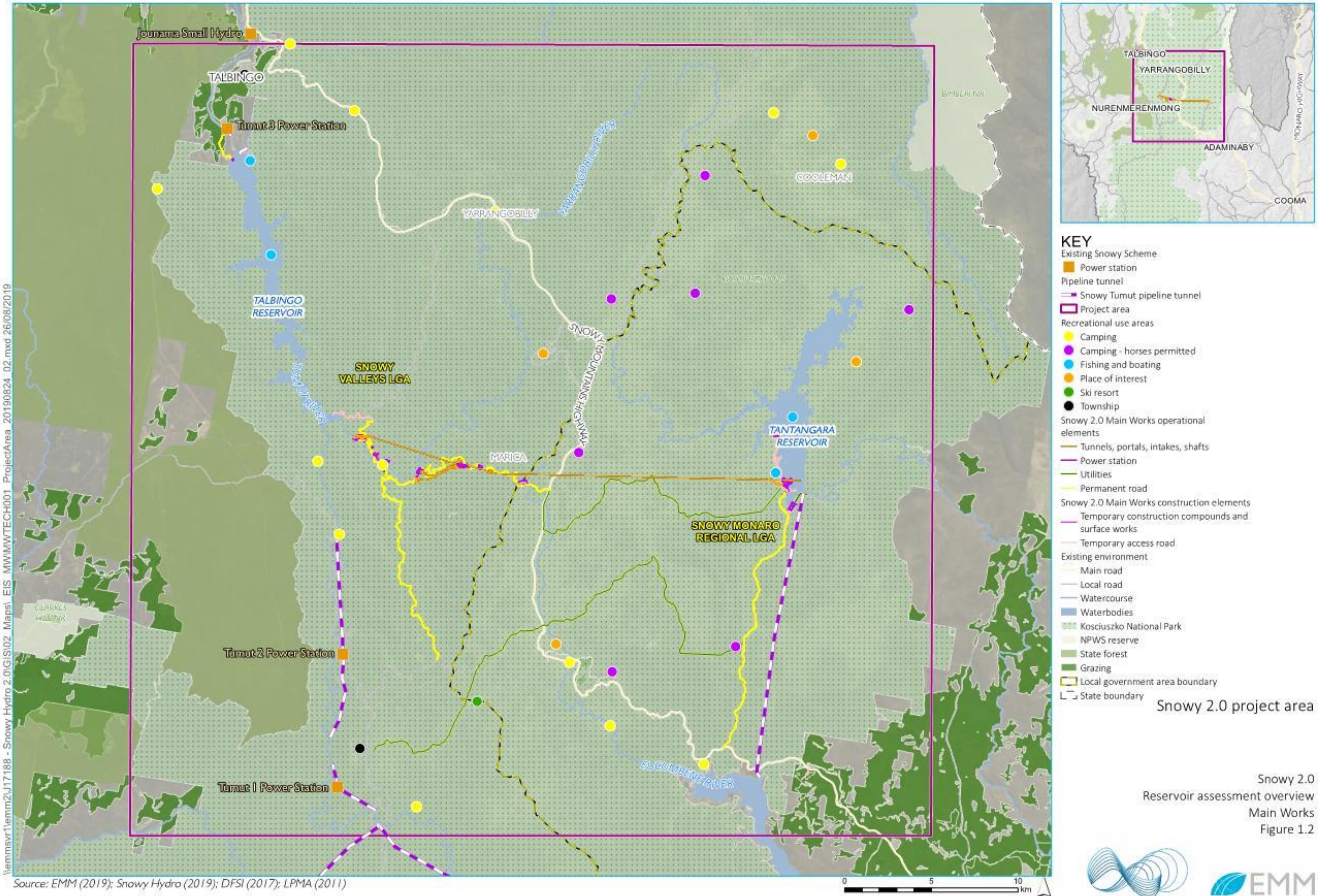
The nearest large towns to Snowy 2.0 Main Works are Cooma and Tumut. Cooma is located about 50 kilometres (km) south east of the project area (or 70 km by road from Providence Portal at the southern edge of the project area), and Tumut is located about 35 km north west of the project areas (or 45 km by road from Tumut 3 (T3) power station at the northern edge of the project area). Other townships near the project area include Talbingo, Cabramurra, Adaminaby and Tumbarumba. Talbingo and Cabramurra were built for the original Snowy Scheme workers and their families, while Adaminaby was relocated in 1957 to make way for the establishment of Lake Eucumbene.

The location of the Snowy 2.0 Main Works with respect to the region is shown in **Figure 1-1**.

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

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

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



Snowy 2.0 project area

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 1.2

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

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

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

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

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

The project is described in more detail in **Section 2**.

1.2.1 Project Area

The project area for Snowy 2.0 Main Works has been identified and includes all the elements of the project, including all construction and operational elements. The project area is shown on **Figure 1-2**. Key features of the project area are:

- the water bodies of Tantangara and Talbingo reservoirs, covering areas of 19.4 square kilometres (km^2) and 21.2 km^2 respectively. The reservoirs provide the water to be utilised in Snowy 2.0

- major watercourses including the Yarrangobilly, Eucumbene and Murrumbidgee rivers and some of their tributaries, and

- KNP, within which the majority of the project area is located. Within the project area, KNP is characterised by two key zones: upper slopes and inverted treelines in the west of the project area (referred to as the ‘ravine’) and associated subalpine treeless flats and valleys in the east of the project area (referred to as the ‘plateau’); and

- farm land southeast of KNP at Rock Forest.

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

1.2.2 ERP Modelling Study Area

The study area for this ERP modelling assessment focuses on Talbingo Reservoir, although hydrodynamic models for Tantangara Reservoir have also been developed.

1.3 Proponent

Snowy Hydro is the proponent for the Snowy 2.0 Main Works. Snowy Hydro is an integrated energy business – generating energy, providing price risk management products for wholesale customers and delivering energy to homes and businesses. Snowy Hydro is the fourth largest energy retailer in the NEM and is Australia's leading provider of peak, renewable energy.

1.4 Purpose of Report

This **Excavated Rock Placement (ERP) Modelling (Construction) Report** supports the EIS for the Snowy 2.0 Main Works. It documents the methodology and results of impact modelling for the **ERP phase** of Snowy 2.0. The report details an assessment of hydrodynamics and suspended sediment transport and deposition, to inform the environmental impact assessment (EIA) of Snowy 2.0.

The objective of this modelling assignment was to develop hydrodynamic and sediment transport models for investigating and assessing key processes (e.g. freshwater flow, thermal stratification and sedimentary processes) in the study reservoirs. The developed models were also used to:

- investigate existing (pre-placement) conditions,
- potential changes to Talbingo Reservoir during the main ERP,
- provide data to assess the potential impact of proposed and alternative ERP activities.

1.4.1 Assessment Guidelines and Requirements

This ERP modelling assessment has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for Snowy 2.0 Main Works, issued on 31 July 2019, as well as relevant government assessment requirements, guidelines and policies, and in consultation with the relevant government agencies. The SEARs must be addressed in the EIS.

Table 1-1 lists the matters relevant to this assessment and where they are addressed in this report.

Table 1-1: Relevant matters raised in SEARs

Requirement	Section Addressed
• an assessment of the impacts of the project on: • the quantity and quality of the region's surface and ground water resources, including Yarrangobilly River, Wallaces Creek, and the Tantangara and Talbingo Reservoirs;	Potential water quality impacts due to the placement of excavated rock material is presented in Section 6 & 7.
• a strategy to manage the emplacement of excavated rock in the Tantangara and Talbingo Reservoirs and to enhance any new landforms created;	Potential water quality impacts due to the placement of excavated rock material is presented in Section 6 & 7. The placement methodology includes use of a silt curtain to minimise Total Suspended Sediments (TSS). An alternative placement methodology in which only Drill & Blast (D&B) material is placed in Talbingo Reservoir is also presented.

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

1.5 Related Projects

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

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

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

1.6 Other relevant reports

This **Excavated Rock Placement (ERP) Modelling (Construction) Report** has been prepared with reference to other technical reports that were prepared as part of the Snowy 2.0 Main Works EIS. The other relevant reports referenced in this **Excavated Rock Placement (ERP) Modelling (Construction)** assessment are listed below.

- Aboriginal cultural heritage assessment (NSW Archaeology 2019) – Appended to the EIS;
- Air quality and greenhouse gas impact assessment (EMM 2019) – Appended to the EIS;
- Aquatic ecology assessment (Cardno 2019) – Appended to the EIS;
- Biodiversity development assessment (EMM 2019) – Appended to the EIS;
- Bushfire risk and hazard assessment (EcoLogical 2019) – Appended to the EIS;
- Cenozoic geodiversity report (Troedson 2019 – Appended to the EIS;
- Contamination assessment (EMM 2019) – Appended to the EIS;
- Economic assessment (Gillespie 2019) – Appended to the EIS;
- Groundwater assessment (EMM 2019) – Appended to the EIS;
- Hazard and risk assessment (Sherpa 2019) – Appended to the EIS;
- Heritage assessment and statement of heritage impact (NSW Archaeology 2019) – Appended to the EIS;
- Navigation assessment (RHDHV 2019) – Appended to the EIS;
- Noise and vibration impact assessment (EMM 2019) – Appended to the EIS;
- Paleozoic geodiversity report (Percival 2019) – Appended to the EIS;
- Recreational users study (TRC 2019) – Appended to the EIS;
- Reservoir assessment overview (RHDHV 2019) – Appended to the EIS;
- Social impact assessment – (Elton Consulting 2019) – Appended to the EIS;
- Soils and land assessment (EMM 2019) – Appended to the EIS;
- Surface water assessment (EMM 2019) – Appended to the EIS;
- Traffic and Transport Assessment Report (SCT 2019) – Appended to the EIS; and
- Water assessment (EMM 2019) – Appended to the EIS.

1.7 Structure of Report

This report assumes the reader has a good knowledge of the Snowy 2.0 and associated civil works, and is structured as follows:

- **Section 2** provides an overview of the existing Snowy Scheme and the proposed Snowy 2.0 works.
- **Section 3** provides information on the development of hydrodynamic and sediment transport models for investigating and assessing key processes (e.g. freshwater flow, thermal stratification and sedimentary processes) in the study reservoirs.
- **Section 4** outlines the model calibration undertaken. It demonstrates the model's ability to reproduce observed features such as reservoir water levels, currents, temperatures and sediment plume behaviour.
- **Section 5** provides details of the model sensitivity testing and external model review undertaken to increase confidence in model prediction of hydrodynamics and likely ERP impacts.
- **Section 6** provides details of the assessment of likely sediment and plume behaviour due to constructions activities associated with the Contractor's proposed ERP design and an alternative placement options.
- **Section 7** provides details of s sensitivity assessment of the influence of a high fines particle size distribution (PSD) assumption on plume behaviour due to ERP activities.
- **Section 8** provides a summary and concluding remarks.

2 Description of the Project

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

2.1 Overview of Snowy 2.0

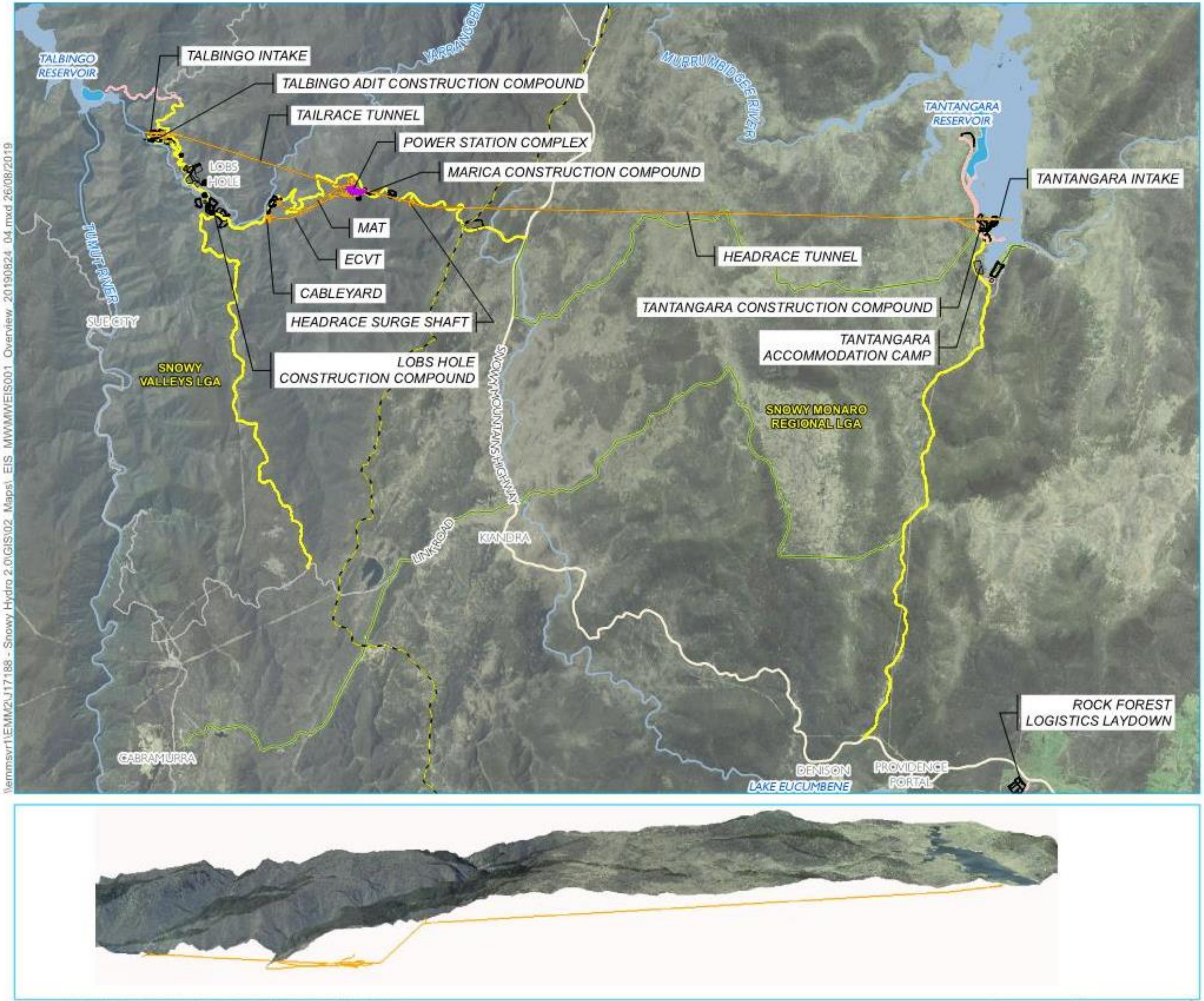
Snowy 2.0 will link the existing Tantangara and Talbingo Reservoirs within the present Snowy Scheme through a series of new underground tunnels and a hydro-electric power station, to be constructed within a cavern. Most of the project's facilities will be underground.

An overview of Snowy 2.0 is shown on **Figure 2-1**, and the key project elements of Snowy 2.0 are summarised in **Table 2-1**.

Table 2-1: Overview of Snowy 2.0 Main Works

Project Element	Summary of the project
Project area	The project area is the broader region within which Snowy 2.0 will be built and operated, and the extent within which direct impacts from the Snowy 2.0 Main Works are anticipated.
Permanent infrastructure	Snowy 2.0 infrastructure to be built and operated for the life of the assets include the: • intake and gate structures and surface buildings at Tantangara and Talbingo reservoirs • power waterway tunnels primarily comprising the headrace tunnel, headrace surge structure, inclined pressure tunnel, pressure pipelines, tailrace surge tank and tailrace tunnel • underground power station complex comprising the machine hall, transformer hall, ventilation shaft and minor connecting tunnels • access tunnels (and tunnel portals) to the underground power station comprising the main access tunnel (MAT) and emergency egress, communication, and ventilation tunnel (ECVT) • establishment of a portal building and helipad at the MAT portal • communication, water and power supply including the continued use of the Lobs Hole substation • cable yard adjacent to the ECVT portal to facilitate the connection of Snowy 2.0 to the NEM • access roads and permanent bridge structures needed for the operation and maintenance of Snowy 2.0 infrastructure • fish control structures on Tantangara Creek and near Tantangara Reservoir wall.
Temporary infrastructure	Temporary infrastructure required during the construction phase of the Snowy 2.0 Main Works area: • construction compounds, laydown, ancillary facilities and helipads • accommodation camps for construction workforce • construction portals and adits to facilitate tunnelling activities • barge launch ramps • water and wastewater management infrastructure (treatment plants and pipelines) • communication and power supply, and

Project Element	Summary of the project
	- temporary access roads.
Disturbance area	The disturbance area is the extent of construction works required to build Snowy 2.0. The maximum disturbance area is about 1 680 hectares (ha), less than 0.25% of the total area of KNP. Parts of the disturbance area will be rehabilitated, and landformed and other parts will be retained permanently for operation (operational footprint).
Operational footprint	The operational footprint is the area required for permanent infrastructure to operate Snowy 2.0. The maximum operational footprint is about 99 ha. This is 0.01% of the total area of KNP.
Tunnelling and excavation method	The primary tunnelling method for the power waterway is by tunnel boring machine (TBM), with portals and adits using drill and blast methods. Excavation for other underground caverns, chambers and shafts will be via combinations of drill and blast, blind sink, and/or raise bore techniques.
Excavated rock management	Excavated rock will be generated as a result of tunnelling activities and earthworks. The material produced through these activities will be stockpiled and either reused by the contractor (or NPWS), placed permanently within Tantangara or Talbingo reservoirs, used in final land forming and rehabilitation of construction pads in Lobs Hole, or transported offsite.
Construction water and wastewater management	Water supply for construction will be from the two existing reservoirs (Talbingo and Tantangara) and reticulated via buried pipelines (along access roads). Raw water will be treated as necessary wherever potable water is required (e.g. at accommodation camps). Water to be discharged (comprising process water, wastewater and stormwater) will be treated before discharge to the two existing reservoirs (Talbingo and Tantangara) as follows: • treated process water will be reused onsite where possible to reduce the amount of discharge to reservoirs, however excess treated water will be discharged to the reservoirs. • collected sewage will be treated at sewage treatment plants to meet the specified discharge limits before discharge and/or disposal, and • stormwater will be captured and reused as much as possible.
Rehabilitation	Rehabilitation of areas disturbed during construction including reshaping to natural appearing landforms or returning to pre-disturbance condition, as agreed with NPWS and determined by the rehabilitation strategy. This includes construction areas at Lobs Hole which comprise surplus cut materials that are required for the construction. Areas to be used by Snowy Hydro in the long-term may be re-shaped and rehabilitated to maintain access and operational capabilities (e.g. intakes and portal entrances).
Construction workforce	The construction workforce for the project is expected to peak at around 2 000 personnel.
Operational life	The operational life of the project is estimated to be 100 years.
Operational workforce	The operational workforce is expected to be 8-16 staff, with fluctuations of additional workforce required during major maintenance activities.
Hours of operation	Construction of Snowy 2.0 will be 24/7 and 365 days per year. Operation of Snowy 2.0 will be 24/7 and 365 days per year.
Capital investment value	Estimated to be $4.6 billion.



KEY

Existing environment
— Main road
— Local road
— Watercourse
▨ Waterbodies
▭ Local government area boundary

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

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

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

Snowy 2.0 project elements

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.1

2.2 Construction of Snowy 2.0

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

Table 2-2 provides an overview of the construction elements, their purpose and location within the project area.

Table 2-2: Snowy 2.0 Construction Elements

Construction Element	Purpose	Location
Construction sites	Due to the remoteness of Snowy 2.0, construction sites are generally needed to: • Provide ancillary facilities such as concrete batching plants, mixing plants and on-site manufacturing; • Store machinery, equipment and materials to be used in construction; • Provide access to underground construction sites; and • Provide onsite accommodation for the construction workforce.	Each construction site needed for Snowy 2.0 is shown on **Figure 2.2** to **Figure 2.6**.
Substations and power connection	One substation is required to provide permanent power to Snowy 2.0, at Lobs Hole. This substation will be built as part of Exploratory Works with a capacity of 80 mega volt amp (MVA). It will continue to be used for Main Works, however requires the establishment of further power supply cables to provide power to the work sites and TBM at Tantangara, as well as Talbingo, in particular to power the TBMs via the MAT, ECVT, Talbingo and Tantangara portals.	The supporting high voltage cable route mostly follows access roads to each of the work sites, using a combination of aerial and buried arrangements.
Communications system	Communications infrastructure will connect infrastructure at Tantangara and Talbingo reservoirs to the existing communications system at the T3 power station (via the submarine communications cable in Talbingo Reservoir established during Exploratory Works) and to Snowy Hydro's existing communications infrastructure at Cabramurra.	The cable will be trenched and buried in conduits within access roads. Crossing of watercourses and other environmentally sensitive areas will be carried out in a manner that minimises environmental impacts where possible, such as bridging or underboring.
Water and waste water servicing	Drinking water will be provided via water treatment plants located at accommodation camps. Water for treatment will be sourced from the nearest reservoir. There are three main wastewater streams that require some form of treatment before discharging to the environment, including:	Utility pipelines generally follow access roads. Water treatment plants (drinking water) will be needed for the accommodation camps and will be located in proximity.

Construction Element	Purpose	Location
	- Tunnel seepage and construction wastewater (process water) - Domestic sewer (wastewater), and - Construction site stormwater (stormwater).	Waste water treatment plants will similarly be located near accommodation camps. Process water treatment plants will be at construction compounds and adits where needed to manage tunnel seepage and water during construction.
Temporary and permanent access roads	Access road works are required to: - provide for the transport of excavated material between the tunnel portals and the excavated rock emplacement areas; - accommodate the transport of oversized loads as required; and - facilitate the safe movement of plant, equipment, materials and construction workers into and out of construction sites. The access road upgrades and establishment requirements are shown on **Figure 2.2** to **Figure 2.6**. These roads will be used throughout construction including use of deliveries to and from site and the external road network. Some additional temporary roads will also be required within the footprint to reach excavation fronts such as various elevations of the intakes excavation or higher benches along the permanent roads.	The access road upgrades and establishment requirements are shown across the project area. Main access and haulage to site will be via Snowy Mountains Highway, Link Road and Lobs Hole Ravine Road (for access to Lobs Hole), and via Snowy Mountains Highway and Tantangara Road (for access to Tantangara Reservoir) (see **Figure 2.1**).
Excavated rock management	Approximately 9 million m^3 (unbulked) of excavated material will be generated by construction and require management. The strategy for management of excavated rock will aim to maximise beneficial reuse of materials for construction activities. Beneficial re-use of excavated material may include use for road base, construction pad establishment, selected fill and tunnel backfill and rock armour as part of site establishment for construction. Excess excavated material that cannot be re-used during construction will be disposed of within Talbingo and Tantangara reservoirs, used in permanent rehabilitation of construction pads to be left in situ in Lobs Hole, or transported for on-land disposal if required.	Placement areas are shown on **Figure 2.2** and **Figure 2.6**. Further details of the proposed and alternative placement of Excavated Rock into Talbingo Reservoir is provided in **Section 2.5**
Barge launch facilities	Barge launch facilities on Talbingo Reservoir will have already been established during Exploratory Works for the placement of the submarine communications cable, and will continued to be used for Main Works for construction	Barge launch sites are shown on **Figure 2.2** and **Figure 2.6**.

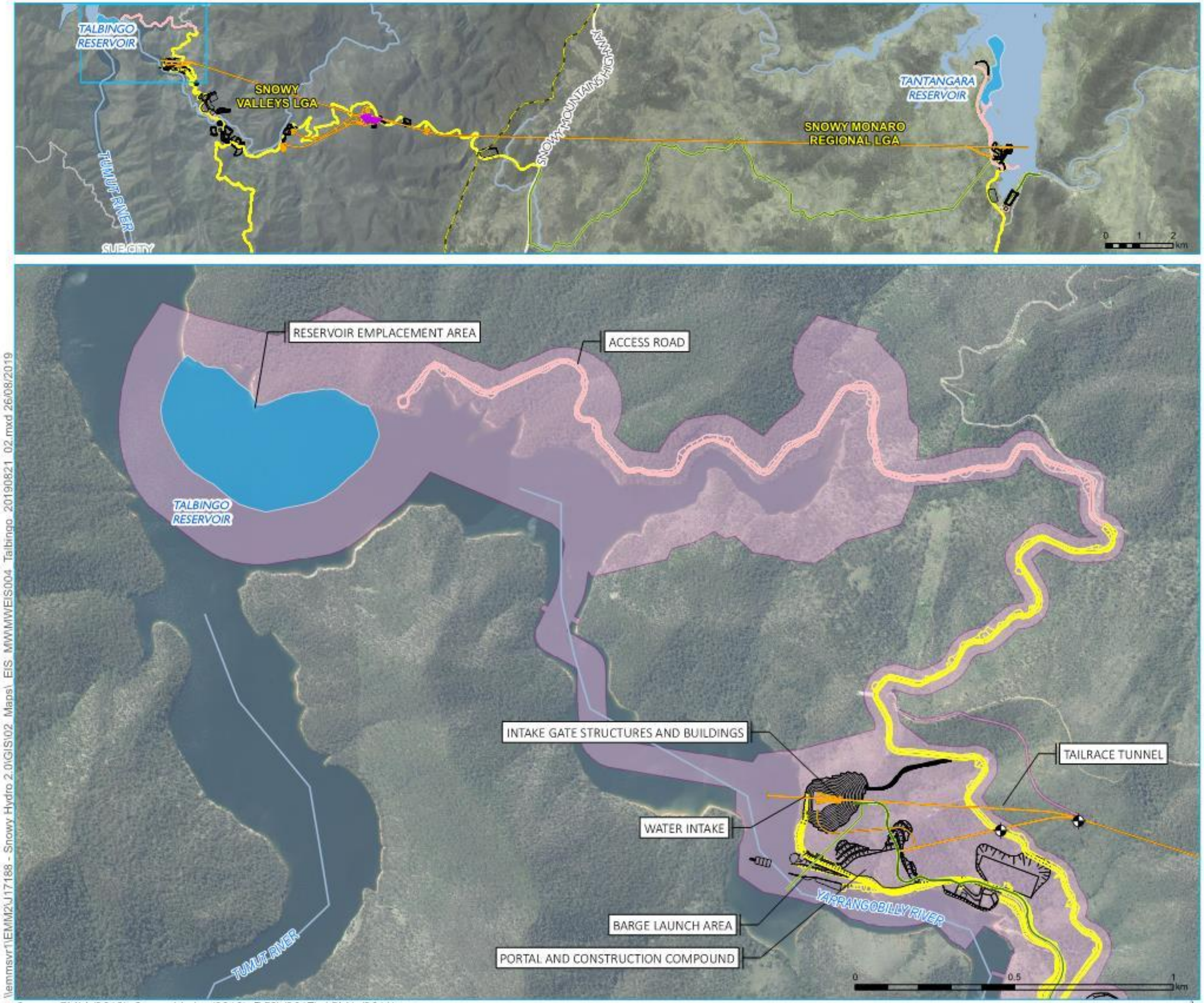
Construction Element	Purpose	Location
	works associated with the Talbingo intake structure. The Main Works will require the establishment of barge launch facilities on Tantangara Reservoir to enable these similar works (removal of the intake plug).	
Construction workforce	The construction workforce will be accommodated entirely on site, typically with a FIFO/DIDO roster. Private vehicles will generally not be permitted and the workforce bused to and from site.	Access to site will be via Snowy Mountains Highway.

The key areas of construction are shown on **Figure 2-2** to **Figure 2-6** and can be described across the following locations:

- **Talbingo Reservoir** – Talbingo Reservoir provides the lower reservoir for the pumped hydro-electric project and will include the tailrace tunnel and water intake structure. The site will also be used for temporary construction compounds and other temporary ancillary activities.
- **Lobs Hole** – this site will be used primarily for construction (including construction of the MAT and ECVT portals and tunnels to the underground power station and the headrace tunnel (and headrace tunnel surge shaft), underground tailrace surge shaft and a temporary accommodation camp).
- **Marica** – the site will be used primarily for construction to excavate the ventilation shaft to the underground power station as well as for the excavation and construction of the headrace surge shaft.
- **Plateau** – the land area between Snowy Mountains Highway and Tantangara Reservoir is referred to as the Plateau. The Plateau will be used to access and construct a utility corridor and construct a fish weir on Tantangara Creek.
- **Tantangara Reservoir** – Tantangara Reservoir will be the upper reservoir for the pumped hydro project and include the headrace tunnel and intake structure. The site will also be used for a temporary construction compound, accommodation camp and other temporary ancillary activities, and
- **Rock Forest** – a site to be used temporarily for logistics and staging during construction. It is located beyond the KNP along the Snowy Mountains Highway about 3 km east of Providence Portal.

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

A key construction element for the project is the excavation and tunnelling for underground infrastructure including the power station, power waterway (headrace and tailrace tunnels) and associated shafts. The primary methods of excavation are shown in **Figure 2-8** with further detail on construction methods provided at Appendix D of the EIS.



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

GDA 1994 MGA Zone 55

KEY

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

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

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

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

Talbingo Reservoir - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.2

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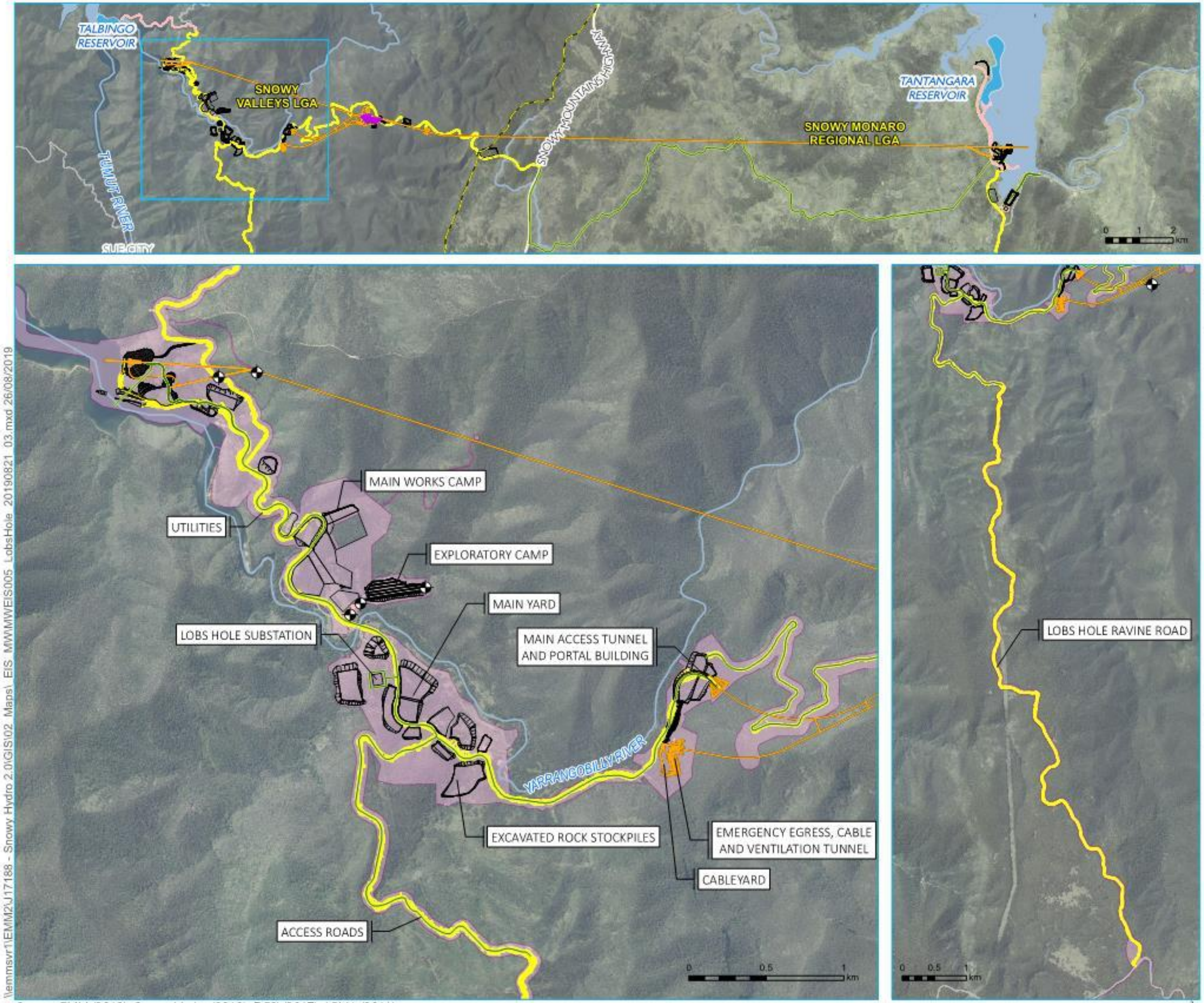

Source: *EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)*

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KEY

Existing environment

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

Snowy 2.0 Main Works operational elements

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

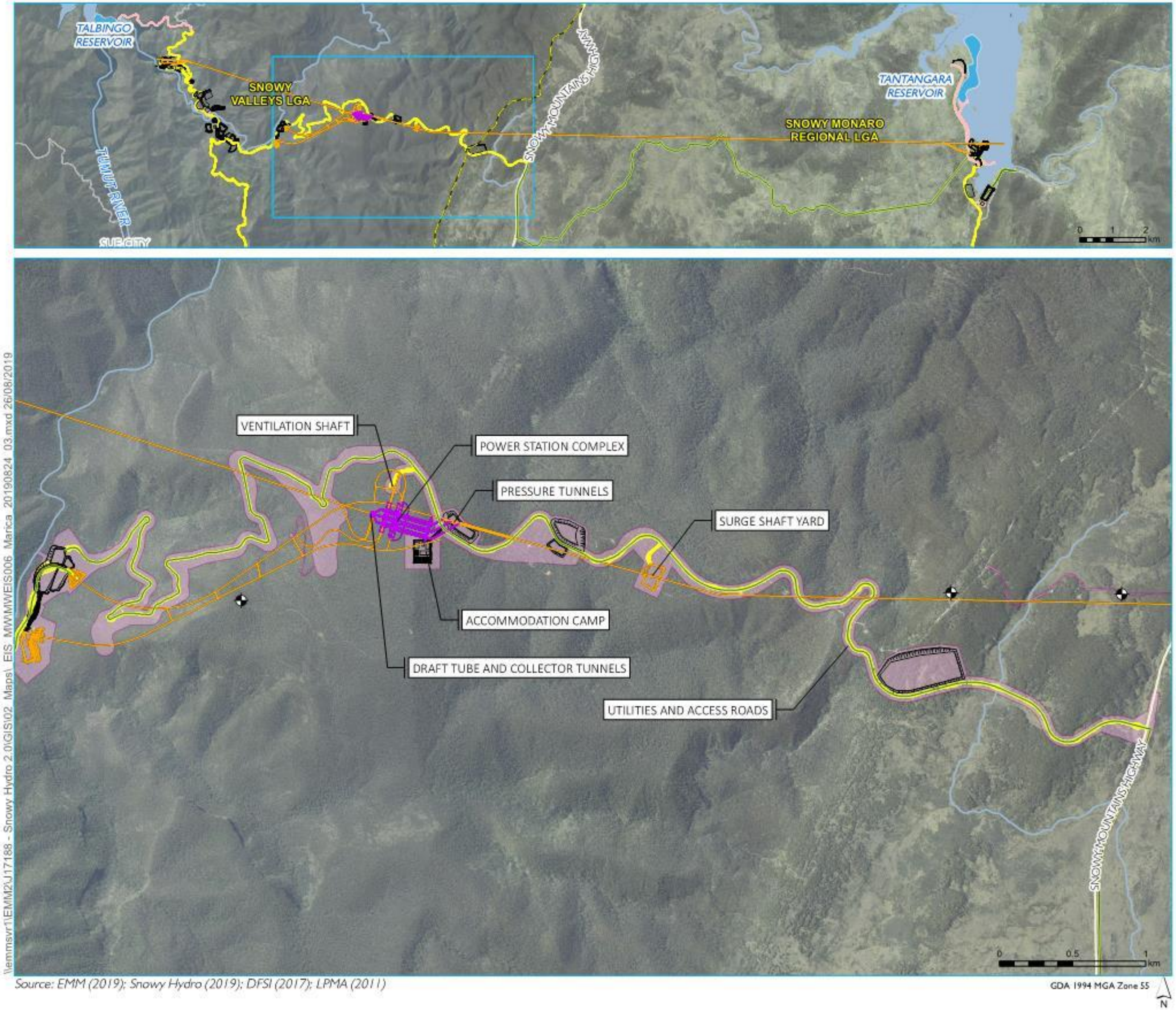
Snowy 2.0 Main Works construction elements

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

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

Lobs Hole - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.3



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

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KEY

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

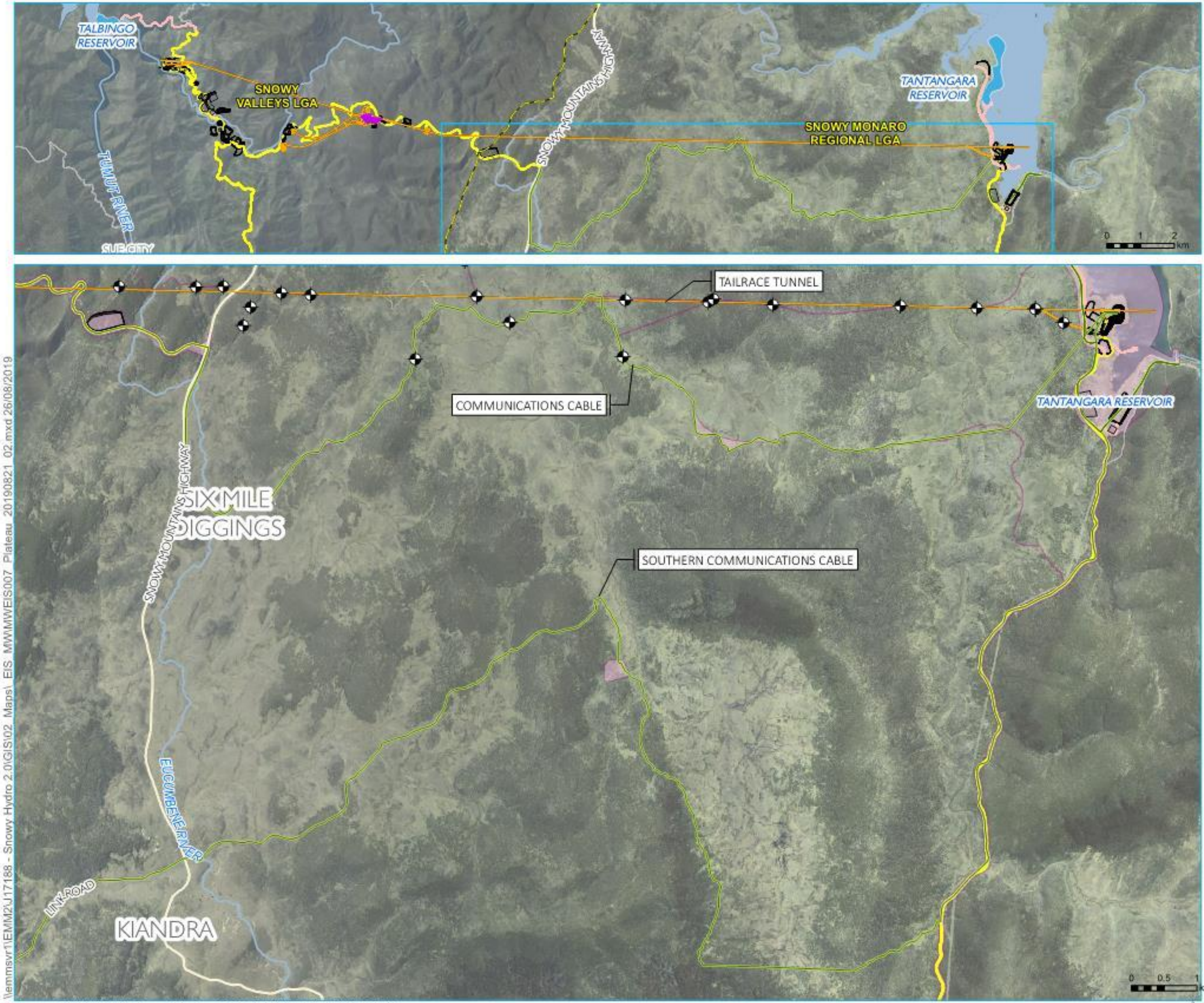
Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

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

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

Marica - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.4



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

GDA 1994 MGA Zone 55

N

KEY

Existing environment

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

Snowy 2.0 Main Works operational elements

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

Snowy 2.0 Main Works construction elements

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

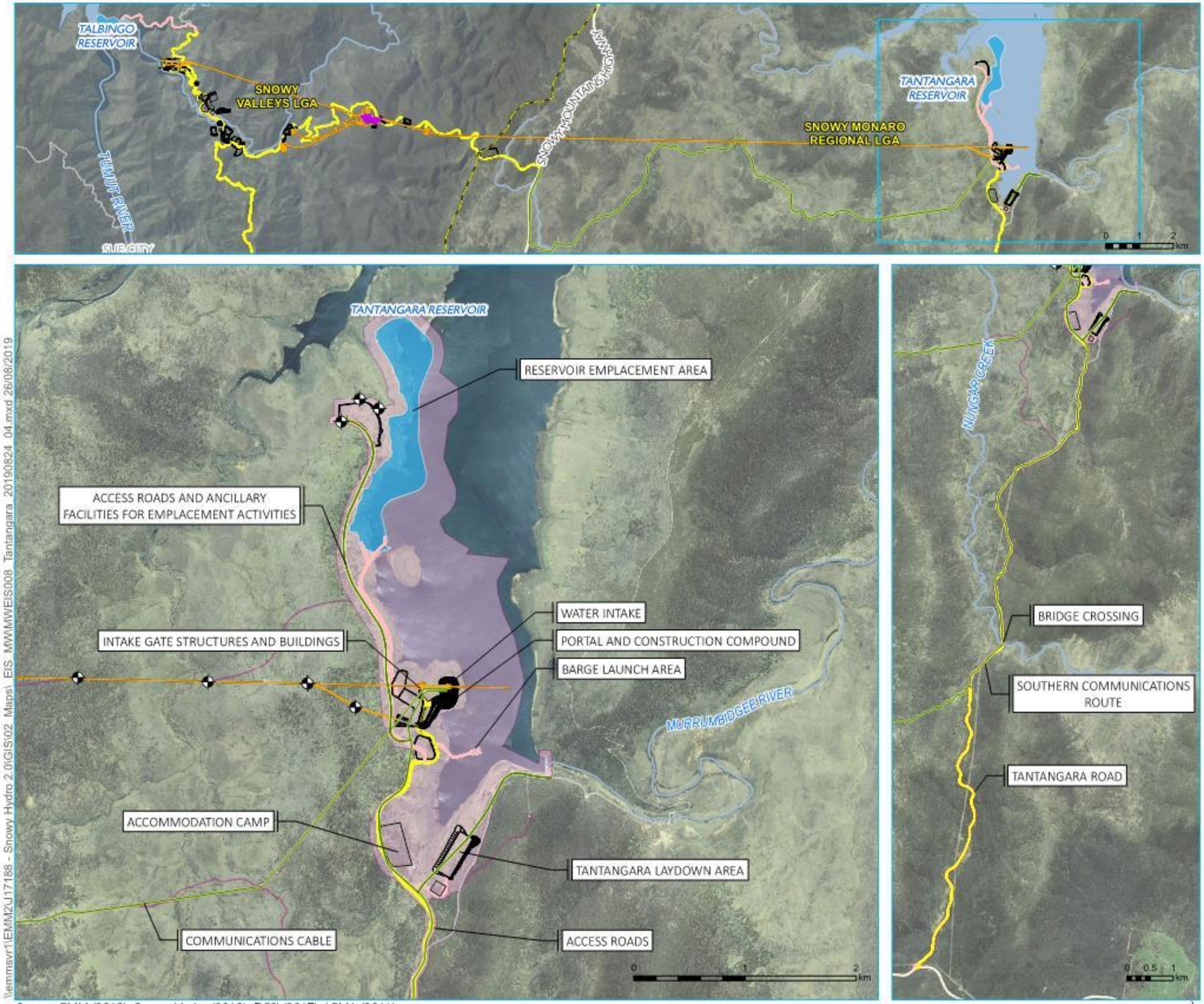
Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during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

Plateau - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.5

snowy2.0

EMM
creating opportunities



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

KEY

Existing environment

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

Snowy 2.0 Main Works operational elements

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

Snowy 2.0 Main Works construction elements

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

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

GDA 1994 MGA Zone 55

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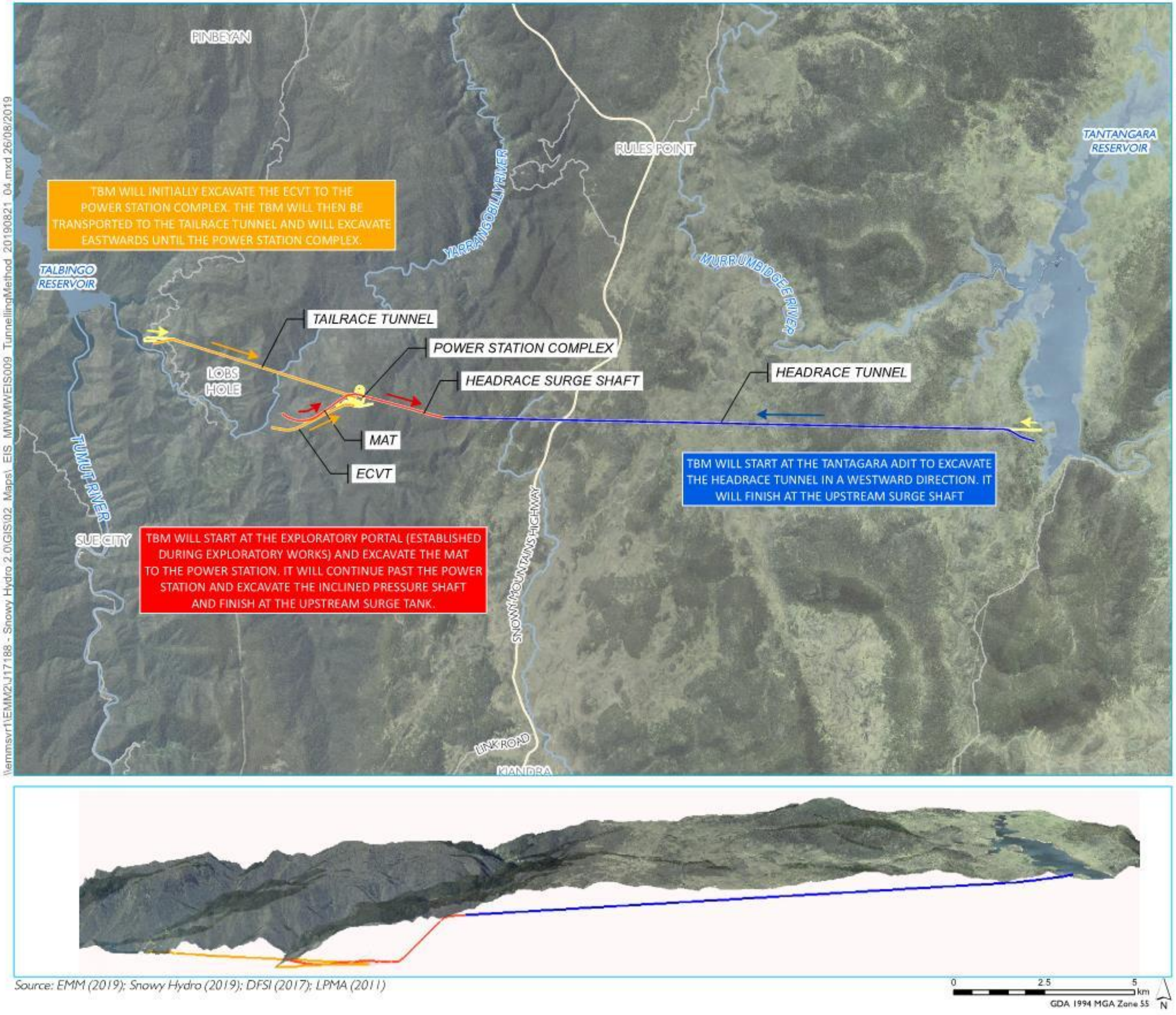
Tantangara Reservoir - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.6

snowy 2.0

EMM creating opportunities



TBM WILL INITIALLY EXCAVATE THE ECVT TO THE POWER STATION COMPLEX. THE TBM WILL THEN BE TRANSPORTED TO THE TAILRACE TUNNEL AND WILL EXCAVATE EASTWARDS UNTIL THE POWER STATION COMPLEX.

TBM WILL START AT THE TANTAGARA ADIT TO EXCAVATE THE HEADRACE TUNNEL IN A WESTWARD DIRECTION. IT WILL FINISH AT THE UPSTREAM SURGE SHAFT

TBM WILL START AT THE EXPLORATORY PORTAL (ESTABLISHED DURING EXPLORATORY WORKS) AND EXCAVATE THE MAT TO THE POWER STATION. IT WILL CONTINUE PAST THE POWER STATION AND EXCAVATE THE INCLINED PRESSURE SHAFT AND FINISH AT THE UPSTREAM SURGE TANK.

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

KEY

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

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

Primary excavation methods – drill and blast and tunnel boring machine

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.8

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWMWEIS009_TunnellingMethod_20190821_04.mxd 26/08/2019

2.3 Operation of Snowy 2.0

2.3.1 Scheme Operation and Reservoir Management

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

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

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

Talbingo Reservoir currently has the following operational functions:

- collects releases from Tumut 2 (T2) power station
- collects releases from the Yarrangobilly and Tumut rivers
- acts as head storage for water pumped up from Jounama Pondage, and
- acts as head storage for generation at the T3 power station.

Due to its historic relationship to both the upstream T2 power station and downstream T3 power station, Talbingo Reservoir has had more operational functions than Tantangara Reservoir in the current Snowy Scheme.

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

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

2.3.2 Permanent Access

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

2.3.3 Maintenance Requirements

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

- maintenance of equipment and systems within the power station complex, intake structures, gates and control buildings

- maintenance of access roads (vegetation clearing, pavement works, snow clearing)
- dewatering of the tailrace and headrace tunnel (estimated at once every 15 to 50 years, or as required); and
- maintenance of electricity infrastructure (cables, cable yard, cable tunnel).

2.3.4 Rehabilitation and Final Land Use

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

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

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

2.4 Summary of Reservoir Characteristics

A summary of the key features of the two reservoirs modelled in this study are provided in **Table 2-3** and **Table 2-4**.

Table 2-3: Features of Talbingo Reservoir

Talbingo Reservoir	
Total capacity	921 GL
Catchment area	1 093 square kilometres
Surface area	1 936 hectares
Maximum water depth	110 metres
Existing Snowy operations	T2 discharges and T3 pumping/generation
Minimum Operating Level	534.323 m AHD
Full Supply Level	543.223 m AHD
Operation range	8.9 metres – levels currently fluctuate over shorter timescales (days and weeks) in Talbingo Reservoir compared to in Tantangara Reservoir.

Table 2-4: Features of Tantangara Reservoir

Tantangara Reservoir	
Total capacity	254 GL
Catchment area	460 square kilometres
Surface area	2 118 hectares
Maximum water depth	35 metres
Existing Snowy operations	Transfer of water to Eucumbene via Providence Portal and releases (generally environmental flows) to Murrumbidgee River via the Tantangara Dam wall.
Minimum Operating Level	1205.823 m AHD
Full Supply Level	1228.823 m AHD
Operating range	23 metres – the reservoir can experience large variations in water level in response to catchment rainfall, evaporation and releases to Lake Eucumbene.

2.5 Details of Proposed and Alternative ERP Methodologies

2.5.1 Background - ERP (Construction) Design

The construction methodology (in terms of placement method, grading of excavated rock fractions and rates of disposal) has evolved during the course of the project and can be defined by a number of stages including:

a) Reference Design
b) Tender Design
c) Ravine Bay Placement
d) Ravine Bay Placement with updated placement rates (i.e. proposed Ravine Bay option)
e) Alternative “Hybrid” Placement (where only D&B material is placed in Talbingo Reservoir)

Details of the proposed placement methodology are provided in **Section 2.5.2**, while details of the alternative placement methodology is presented in **Section 2.5.3**.

The reference design indicated ERP placement would occur in both Talbingo and Tantangara Reservoirs. Subsequently it is proposed that with appropriate water level management in Tantangara Reservoir, all placement would occur in the dry. This means that 3D reservoir modelling of plume behaviour from ERP in Tantangara Reservoir is no longer required (i.e. this report focuses on Talbingo Reservoir only).

2.5.2 Proposed ERP Design

In July 2019, Snowy Hydro were provided with the excavated rock management strategies for Talbingo and Tantangara Reservoirs. The documents are provided in **Attachment G** with key features described below.

Talbingo Reservoir

Placement of excavated rock in Talbingo Reservoir involves pushing excavated rock from the shoreline into the reservoir by conventional earth-moving plant, such as dumping trucks and excavators, and installing a rock armour layer formed by large size excavated rocks (>200 mm).

Placement of excavated rock in Talbingo Reservoir will be carried out in stages when surplus quantity of excavated rock from construction activities becomes available. The proposed construction staging is presented in **Figure 2-9** and **Figure 2-11**, while the final excavated rock footprint in presented in **Figure 2-10**.

A summary of the excavated rock volume versus time required for excavated rock emplacement in Talbingo Reservoir is shown in **Table 2-5** while initial estimate of volume above and below 200 mm is provided in **Table 2-6**. It is considered that excavated rock (>200 mm) used for rock armour can be obtained by using rock grizzly screens during construction.

Details of the assumed sediment particle size distributions and assumptions behind the percentage of placed material that is assumed to be entrained in the water column are presented in **Section 6.3**.

Table 2-5: Excavated rock volume (Bank volume, m^3) for construction staging at Talbingo

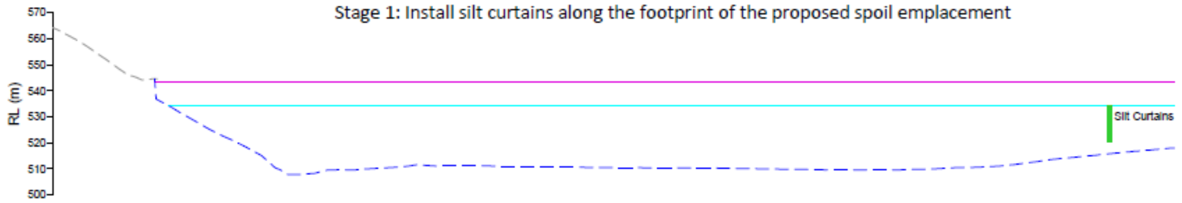
Incremental vol.	0.5 year	1yr	1.5yr	2yrs	Subtotal
TBM	561,129	202,407	377,323	192,512	1,333,370
D&B	332,024	516,565	425,447	253,390	1,527,425
					2, 860, 796

Table 2-6: Volume of excavated rock in different sizes in Talbingo Area (bank volume, m^3)

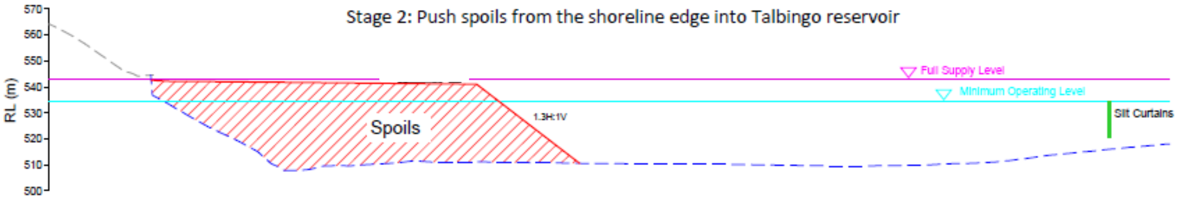
Excavated rock size	D&B		TBM		Total	
	100%		100%		100%	
>200 mm	40%	585,417	0%	0	21%	585,417
0-200 mm	60%	878,126	100%	1,370,668	79%	2,248,794
	Subtotal	1,463,543		1,370,668		2,834,211*

Note*: Data as provided. Data in **Table 2-5** was adopted for ERP Modelling.

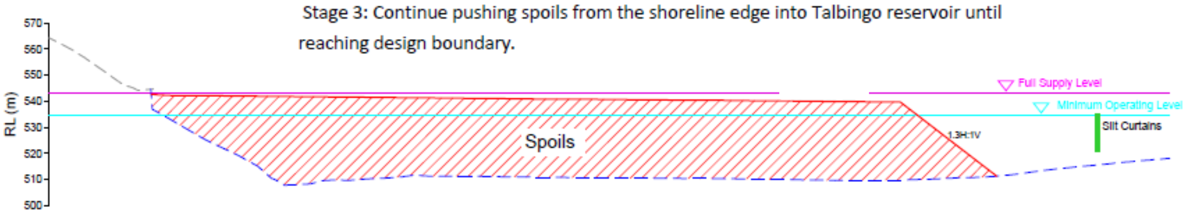
Stage 1: Install silt curtains along the footprint of the proposed spoil emplacement



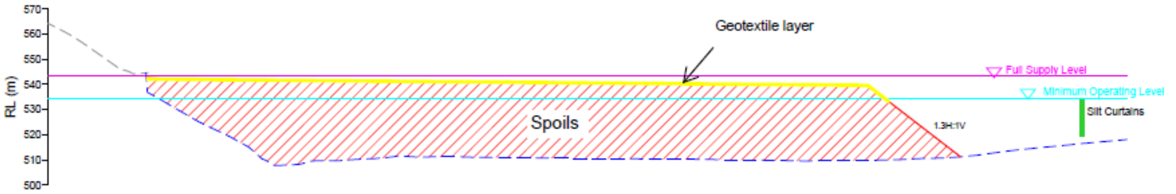
Stage 2: Push spoils from the shoreline edge into Talbingo reservoir



Stage 3: Continue pushing spoils from the shoreline edge into Talbingo reservoir until reaching design boundary.



Stage 4:: Install a geotextile layer on the batter slope of the spoil dump for erosion protection.



Stage 5:Install the rock amour layer (i.e. >200mm spoils) for long term spoil emplacement stability and erosion protection.

Note: this is general construction design and that the final placement level may be above FSL

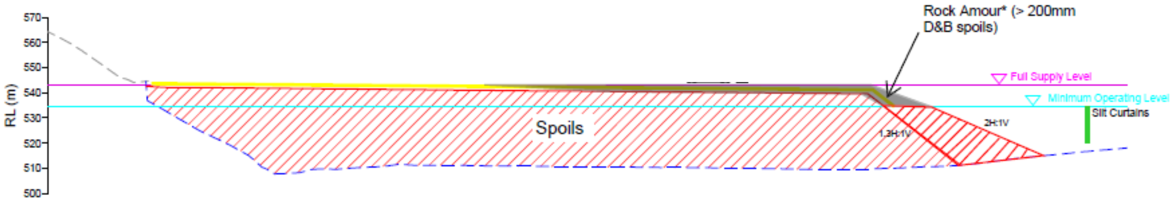


Figure 2-9: Talbingo – ERP Construction Staging

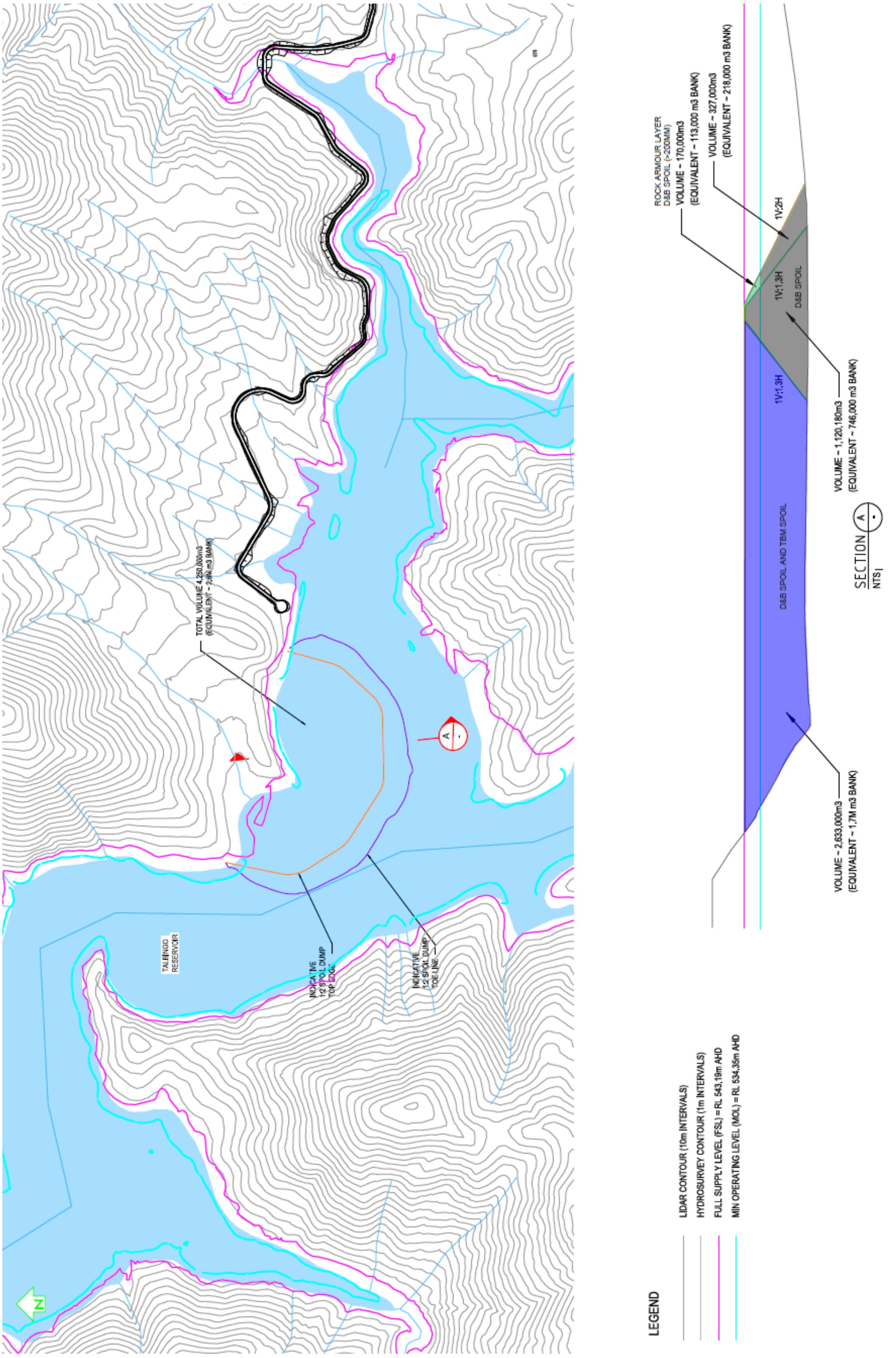
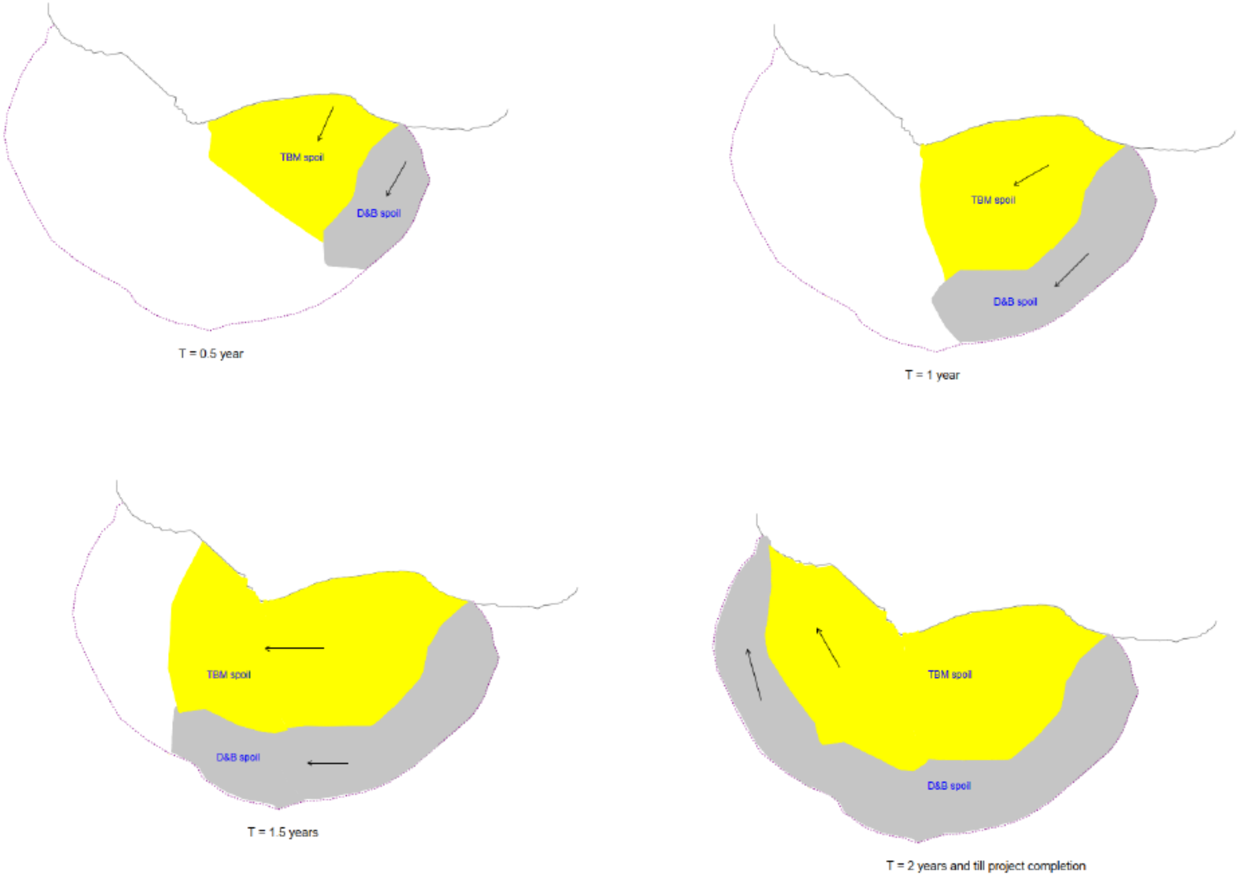


Figure 2-10: Talbingo – Finished excavated rock footprint and section



T = 0.5 year

T = 1 year

T = 1.5 years

T = 2 years and till project completion

Figure 2-11: Indicative development of Talbingo ERP footprints versus time

2.5.3 Alternative Hybrid (D&B Only to Reservoir) Design

A “Hybrid Placement” alternative ERP methodology has also been proposed in which only D&B excavated rock is placed in Talbingo Reservoir, with land placement being used for all TBM material.

In this scenario, it is assumed that 1.4 Million m^3 (bank) of excavated rock would be placed in the reservoir using the “edge push” method that was presented in the above section. The placement time period is assumed to be 27 months at an average placement rate of 1750 m^3/day. The resultant placement footprint would be reduced from that defined in **Section 2.5.2**.

2.5.4 Proposed Mitigation Measures

To reduce the potential environmental impact related to ERP in Talbingo Reservoir, silt curtains will be installed around the footprint of the proposed excavated rock emplacement. Single Class 3, XR5 heavy duty premium Silt Curtains that are considered suitable for medium risk applications with moderate wind and/or water forces, such as rivers and calm harbours, are currently proposed for this project. Final selection of the silt curtain would occur during the detailed design phase. The silt curtains are suspended from floatation on the surface and prevent or restrict water and sediment movement in the top 12m of the water column depending on permeability (refer **Figure 2-12**). The silt curtains have been assumed to be impermeable for purposes of the modelling in this report.

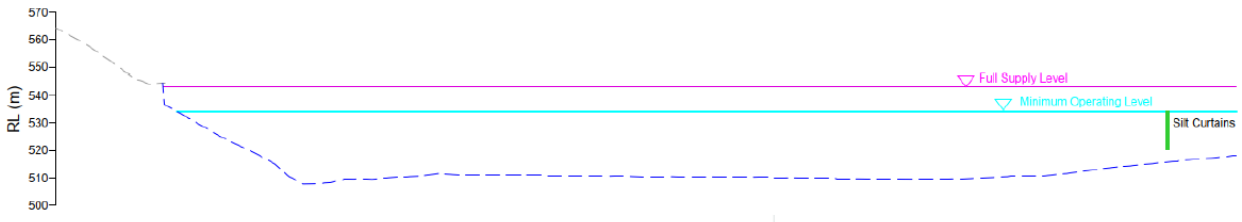


Figure 2-12: Proposed Use of Silt Curtains in Talbingo Reservoir

3 Development of the Reservoir Models

3.1 Scope and Objectives

The primary objectives of the modelling has been to develop hydrodynamic and sediment transport models for the investigation and assessment of key processes (e.g. freshwater flow, thermal stratification and sedimentary processes) in Talbingo Reservoir. The developed models have been used to determine existing (pre-placement) conditions and subsequently to investigate the likely changes to Talbingo Reservoir during the Main Works ERP.

The modelling methodology adopted for this project is summarised in the following sections.

3.2 Model Selection

The MIKE-3-FM model (https://www.mikepoweredbydhi.com/products/mike-3) was selected to satisfy the modelling scope and objectives. MIKE-3-FM is a three-dimensional (3D), flexible mesh, finite volume model code that solves the basic fluid dynamic equation used to describe the movement of the water (currents), the distribution of temperature and salinity, and reservoir water level. It is particularly suited to the study of stratified systems and has been validated with field measurements across a range of sites, including large lakes and stratified reservoirs, estuaries and coastal lagoons and the coastal ocean. Many reports and non-published studies have also tested and applied the model for a range of environmental management investigations.

The system is based on the numerical solution of the 3D incompressible Reynolds averaged Navier-Stokes equations invoking assumptions of Boussinesq and of hydrostatic pressure. The model consists of continuity, momentum, temperature, salinity and density equations, and includes a turbulent closure scheme. Turbulent mixing (turbulence) is modelled using an eddy viscosity concept described separately for vertical and horizontal transport. The free surface is considered using a sigma coordinate transformation approach. Heat exchange through the water's surface is described by standard bulk transfer models found in the literature. The energy transfer across the free surface is separated into non-penetrative components of long-wave radiation, sensible heat transfer, and evaporative heat loss, complemented by penetrative shortwave radiation. Non-penetrative effects are introduced as sources of temperature in the surface-mixed layer, whereas penetrative effects are introduced as source terms in one or more grid layers based on an exponential decay and an extinction coefficient (Beer's law) (DHI, 2017).

MIKE-3 considers other important processes such as:

- wind driven circulation
- circulation due to changes in reservoir level
- density driven circulation
- river and catchment run-off
- transport of heat and salt
- Coriolis effect due to the rotation of the earth, and
- bottom friction.

Further details of model bathymetry, model geometry and boundary condition data adopted for the reservoir model is provided in the following sections.

3.3 Relationship between TSS Concentration and Turbidity

As part of the environmental management of major projects involving the placement of materials into the water column, water quality limits relating to impacts on sensitive receptors are commonly specified in terms of TSS[1]. In accordance with standard industry practice, compliance with these limits is typically assessed through real time turbidity[2] monitoring, as suspended solid concentrations are not as easily and quickly measured in the field.

A TSS-turbidity relationship is, therefore, used to convert water quality limits into turbidity values that can be readily measured in the field during the proposed works and thus used for compliance monitoring and triggers for management actions. The relationship between TSS and turbidity is highly site-specific, being dependant on the physical, optical and geochemical properties of suspended solids. As such, testing is required to establish relationships between these properties for each of the various crushed rock types that would be encountered. These relationships should be supplemented with field data where possible. Laboratory testing undertaken as part of the broader ERP study by RHDHV derived preliminary site-specific relationships between TSS concentration and turbidity (NTU) for different geological formations as presented in **Figure 3-1** below.

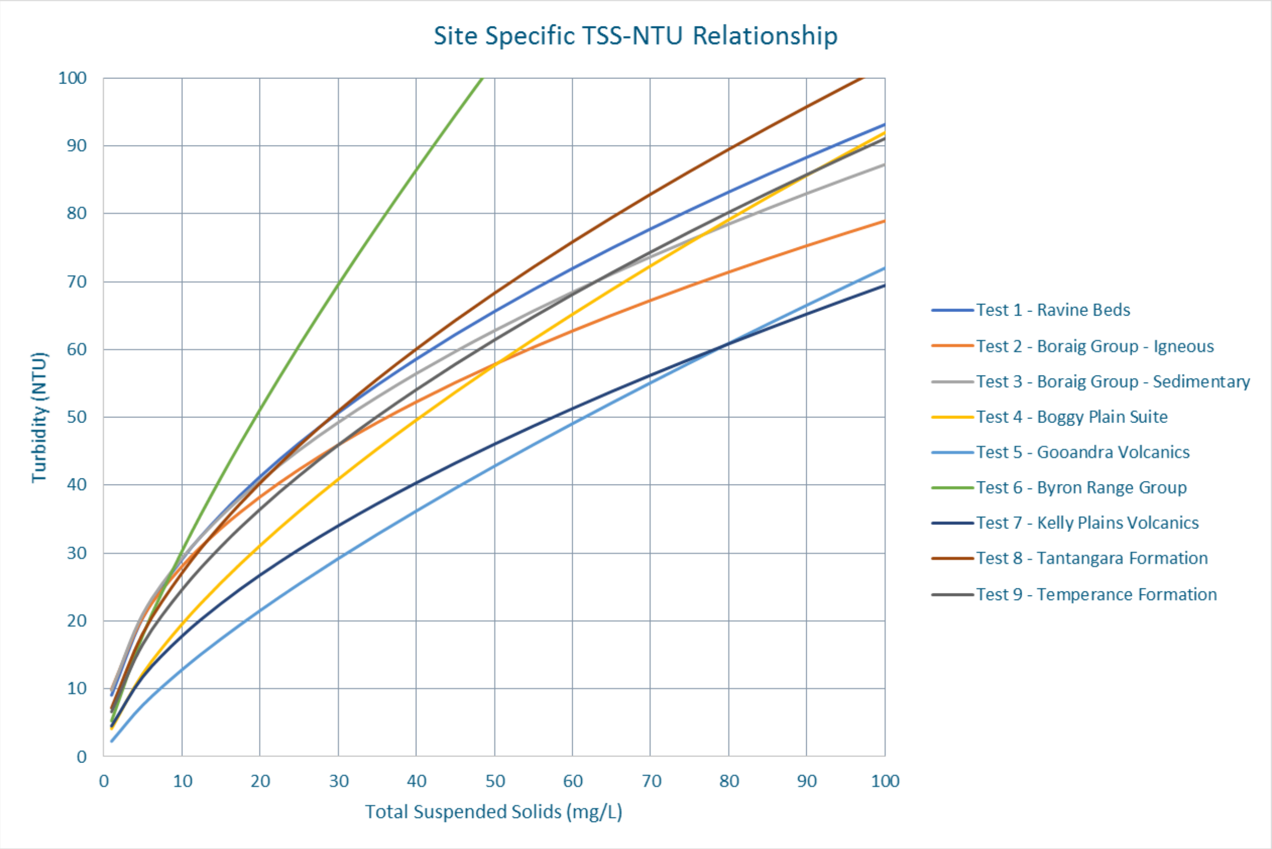


Figure 3-1: Relationship between TSS Concentration and NTU

Notes: above graph is a sub-set of that presented in the ERP – Lab Testing Report delivered by RHDHV to Snowy Hydro, 18 December 2018. 1000 mg/L is equal to 1 kg/m^3 (i.e. 1 g/L)).

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[1] *TSS is a measurement of mass per unit volume, usually specified in mg/L.*

[2] *Turbidity is an optical property of water, measured in nephelometric turbidity units (NTU).*

3.4 Data Used for Model Development

Development of computer models requires a considerable amount of data to adequately represent hydrodynamic, thermal stratification/mixing, wind induced current/wave and sediment transport processes occurring in the reservoir. In general, a model requires the following key datasets to adequately calibrate and/or simulate hydrodynamic, baroclinic and advection-dispersion processes:

- **Bathymetric survey data** – used to describe the topography of a reservoir over the domain of a numerical model system.
- **Water level and current/flow data** – used to calibrate and/or verify model predictions. Water level and inflow and outflow data are most commonly used to ensure the model adequately represents the water balance or hydrodynamics of the waterbody. Existing Snowy Hydro scheme flows including T2 and T3 Power Stations are the largest sources of flow in Talbingo Reservoir.
- **River flow data** – used to define river flow conditions of major freshwater inputs. For Talbingo Reservoir, there are several large river inflows, namely the Tumut River and Yarrangobilly River.
- **Local catchment runoff data** – used to define freshwater inputs to the water body from adjacent catchment areas draining laterally to the water body.
- **Physio-chemical water quality data** – used to define initial conditions (i.e. vertical profiles of water temperature, conductivity, TSS / fine sediment in the reservoirs) and to calibrate and/or verify model predictions.

Additional data specific to the study area has also been required for calibrating and / or simulating other heating, cooling and transport processes. This additional data has included environmental forcing data, which may be used to define meteorological conditions (e.g. rainfall, air temperature, wind speed, solar radiation, and relative humidity) or other model constituents (e.g. salinity, water temperature, turbidity, nutrients) during a calibration or simulation period. Where gauged flow data was not available (e.g. local sub-catchments fringing the reservoirs), a catchment model was used to estimate runoff volumes from the ungauged sub-catchments.

Details of the catchment model developed as part of the ERP modelling study are provided in **Attachment C**. While catchment models are available for the study catchments, modelled runoff was not used to estimate local catchment runoff to the reservoirs, and instead flow at ungauged sites was estimated using area ratio and the gauged flow at Yarrangobilly River.

A summary of the data used for the development (and calibration) of the reservoir model is provided in **Table 3-1**.

Further details regarding the development of the catchment, water balance and reservoir models, including the data used in the preparation of model extents and the important boundary conditions used by the model, is presented and discussed in **Section 3.5** to **Section 3.7**.

Table 3-1: Data Used for Model Development and Calibration

Data Requirement	Used for…	Data Sources
Meteorological data measured at weather stations in the study catchment: • Rainfall • Evaporation • Solar (short wave) radiation • Air temperature • Relative humidity • Wind speed.	creating boundary conditions to surface of model (inputs needed for the heat budget).	Weather Underground https://www.wunderground.com Snowy Hydro. Cardno (2019) field data collection program.
Snowy Hydro operations for Talbingo and Tantangara Reservoirs: • Inflows (flow, water temperature, TSS, conductivity). • Outflows (flow rate only). • Environmental flow releases (flow rate only).	assessing the water balance and defining boundary conditions to the model for baseline (existing) conditions.	Snowy Hydro.
Streamflow data for stations within the study catchments: • Gauging location • Flow gauging's and rating curves • Measured streamflow.	understanding the hydrology, overall water balance of the system – data used to calibrate the rainfall-runoff (catchment) model.	Water Data Online http://www.bom.gov.au/waterdata Snowy Hydro.
Bathymetric data (hydro survey).	reservoir model development (a key model requirement to define the storage properties of the reservoir).	Snowy Hydro.
Ground elevation data (LiDAR or similar) of the study region.	extending bathymetry data to define land-water boundary and other low-lying floodplain areas that surround the reservoirs. terrain analysis and catchment mapping.	ELVIS - Elevation Foundation Spatial Data http://elevation.fsdf.org.au. Snowy Hydro.
Historical reservoir water level and flow data.	calibrating hydrodynamics of the reservoir models.	Snowy Hydro.
Crest levels of dam spillway and outlet configuration (e.g. outlet dimensions, gate configurations).	representing the water balance and configuring the reservoir model geometry and defining boundary conditions to the model for baseline (existing) conditions.	Snowy Hydro.
Water quality data (conductivity, temperature and turbidity).	calibration of water temperature (heat budget) and sediment transport (TSS/turbidity).	Snowy Hydro Cardno field data collection program.

3.5 Hydrodynamics (MIKE-3 Flow (HD) Flexible Mesh (FM) Module)

The MIKE-3 Flow (HD) Flexible Mesh (FM) module simulates the hydrodynamics (HD) (water level variations and currents) in response to a variety of forcing functions. It includes a wide range of hydraulic phenomena in the simulations and it can be used for any 3D free surface flow. The flexible mesh (FM) version, which uses a depth and surface adaptive vertical grid, is particularly suitable in areas with a high-water level range (DHI, 2017).

3.5.1 Model Extents and Geometry

The spatial discretization of the model equations is performed using a cell-centred finite volume method (DHI, 2017). The flexible mesh approach involves the discretisation of the model domain into elements of varying sizes. Hence, the spatial resolution can differ throughout the model domain, allowing the schematisation to concentrate computational effort on specific areas of interest. The MIKE-3 FM model geometry consists of nodes interconnected by a series of non-overlapping triangular elements to form a two-dimensional mesh of the waterway system. In the horizontal plane, an unstructured grid is used, while in the vertical domain a structured mesh is used (DHI, 2017). The principle of meshing for 3D models is shown in **Figure 3-2**.

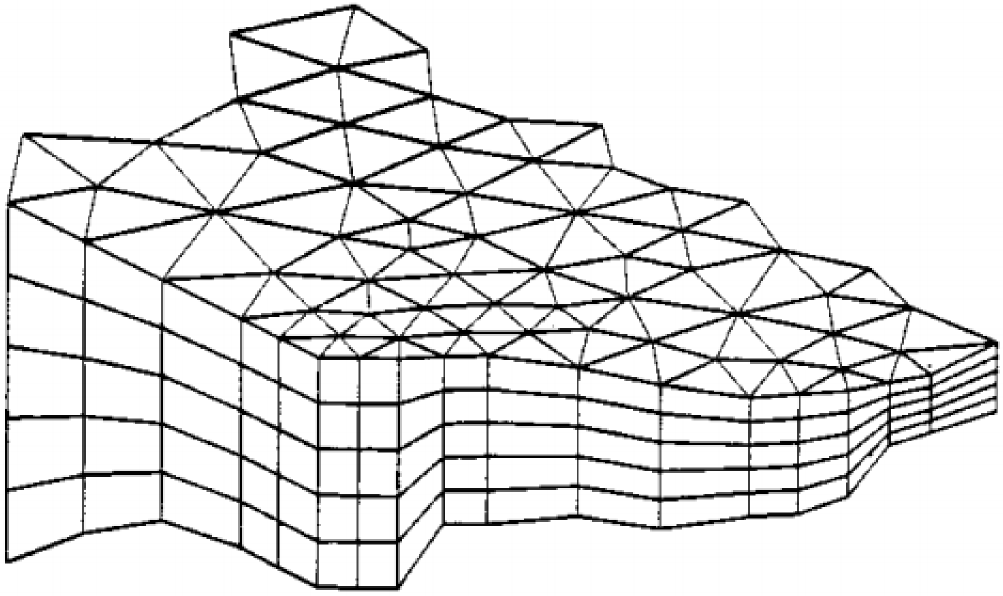

Figure 3-2: Principle of meshing for the three-dimensional case (DHI, 2017).

The horizontal and vertical resolution of the model is defined to resolve the dominant horizontal (surface) and vertical (water column) hydrodynamic and thermodynamic processes (e.g. catchment runoff events and thermal stratification of the water column during warmer months). The primary advantage of using a flexible mesh system is that it provides an accurate representation of the important processes without using a high resolution everywhere, as is required for fixed grid models. The detail contained in the geometry captures adequate system detail to model the important processes while minimising the time it takes to complete a simulation.

The vertical mesh is based on either sigma-coordinates or combined sigma/z-level coordinates. For the hybrid sigma/z-level mesh, sigma coordinates are used from the free surface to a specified depth and z-level coordinates are used below. The different types of vertical mesh are illustrated in **Figure 3-3**.

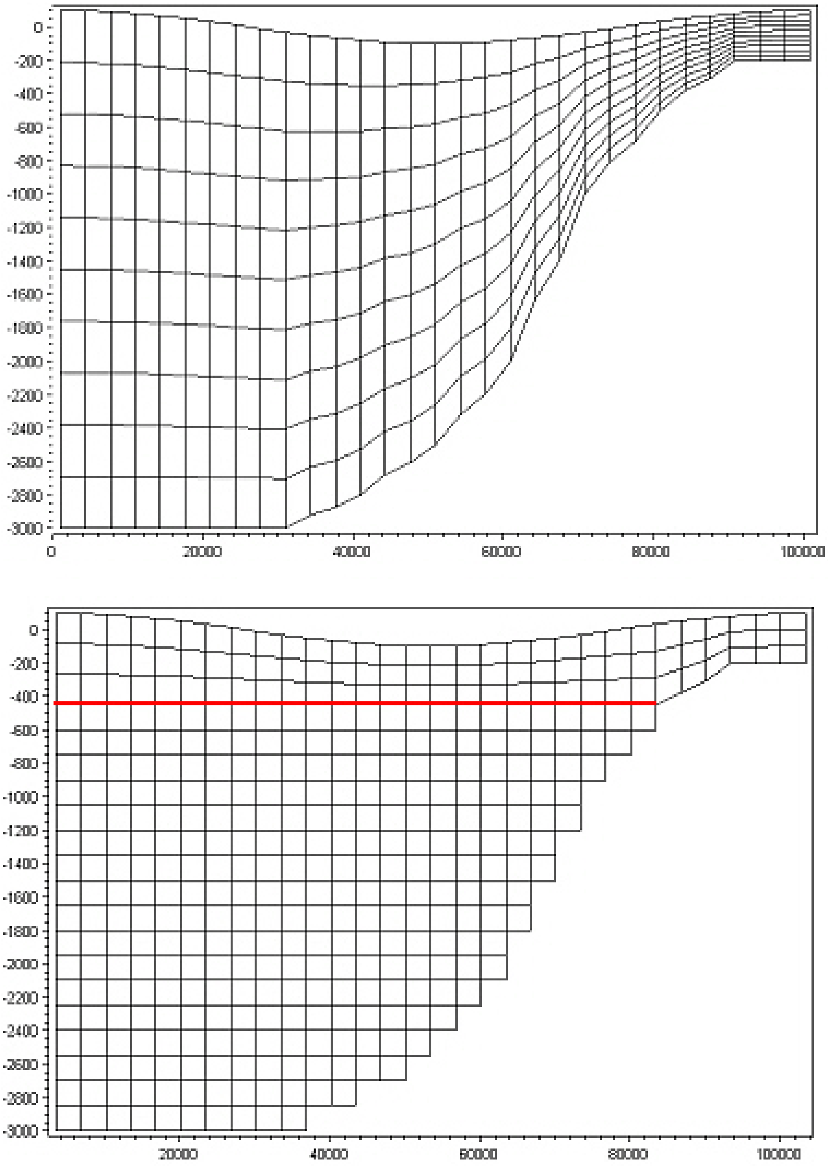

Figure 3-3: Illustrations of the different vertical grids (DHI, 2017).

In the upper plot, a sigma mesh is shown and in the lower plot, a hybrid (combined sigma/z-level) mesh with simple bathymetry adjustment. The red line shows the interface between the z-level domain and the sigma-level domain. In the case of the models developed for Talbingo Reservoir, a hybrid mesh was adopted.

The extent of the models includes the Talbingo Reservoir in its entirety and to the FSL. The horizontal resolution of the model geometry was configured using a typical cell size of 50 metres to capture important bathymetric features including the main waterway channels, deep and shallow areas and other connections present within the study reservoirs. The model geometry includes enough detail to capture the deep-water areas along the submerged drowned valleys (thalweg) of the reservoir whilst also accounting for the storage capacity of the reservoir. The model geometry prepared for Talbingo Reservoir is presented in **Figure 3-4.**

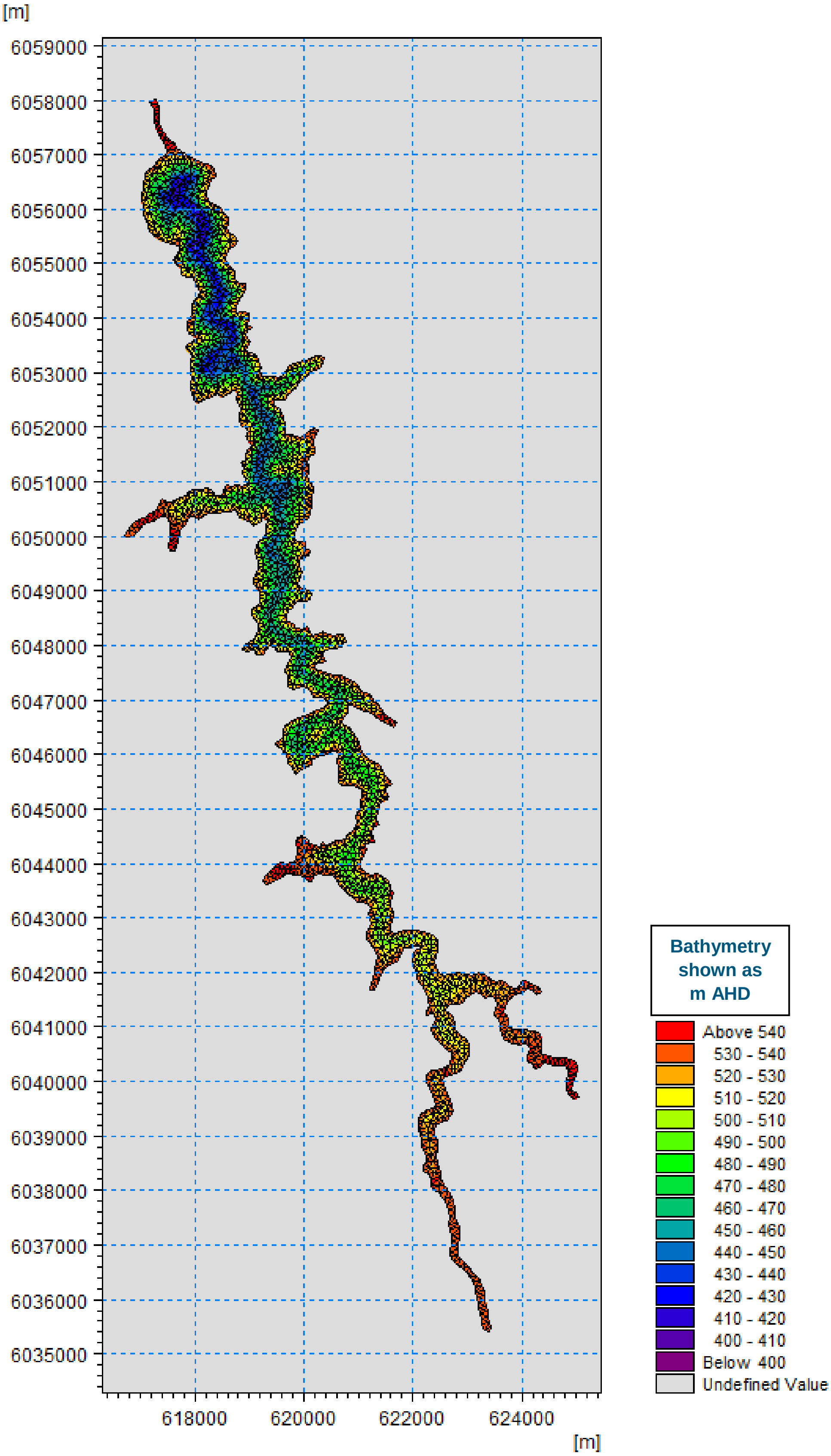

Figure 3-4: Talbingo Reservoir Model Mesh.

The vertical discretisation (dz) of the water column was defined using the hybrid sigma/z-coordinate mesh. The MIKE-3 model of Talbingo Reservoir was specified using a total of 19 layers (i.e. five sigma layers (varying layer thickness) on top of up to fourteen z-coordinate layers (fixed layer thickness of six at 5 m, then eight at 10 m)). For Talbingo Reservoir, the sigma depth was set at 522 m AHD[3] meaning that at all times, there are five sigma layers present above a level of 522 m AHD, even in shallower areas.

The accuracy and stability of the simulation method may be affected by the degree of non-uniformity of the layers. That is, a model grid that has a dz that varies gradually will perform well, while a grid with abrupt changes in dz may be comparably less accurate. The spacing of the vertical layers was therefore selected to provide enough vertical grid resolution to adequately resolve density (baroclinic) processes of thermal stratification. To demonstrate the adequacy of vertical resolution within the MIKE-3 model, the vertical layering is presented in **Figure 3-5**, which shows the relationship between mesh resolution and the reservoir temperature depth profile (note: higher vertical resolution is used where larger changes in water temperature occur around the thermocline). The adopted vertical mesh discretisation is therefore capable of resolving the sharp water temperature gradients present in the reservoirs during a period of heating (thermal stratification).

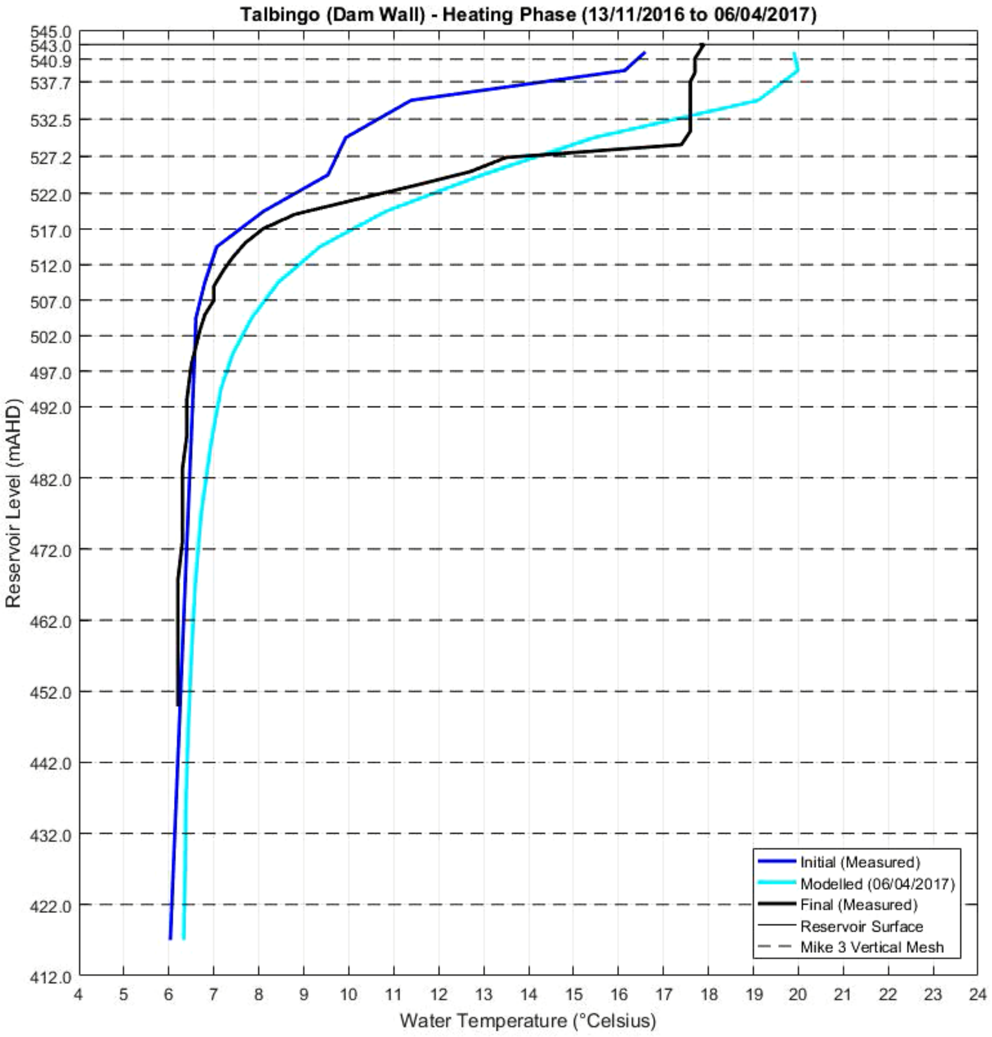

Figure 3-5: Vertical Talbingo Model Grid Spacing and Observed and Modelled Temperature Profiles.

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[3] *Conversion between m AHD and Snowy Mountain Datum (SHD) is given as: SMD = AHD + 1.177 m*

3.5.2 Model Bathymetry

Recent bathymetry data was used for model development and is based on 2017-18 hydrographic survey provided by Snowy Hydro as shown in **Figure 3-6.**

The hydrographic survey data was checked to confirm its applicability for model development and processed in GIS for input into the MIKE-3 model. Minor data gaps in the hydrographic survey for Talbingo Reservoir were manually accounted for by interpolating the edge of the hydrographic survey with surrounding topography based on available ground elevation data.

3.5.3 Model Configuration

The model is a fully 3-dimensional hydrodynamic model developed with additional modules to simulate: water temperature, density, wind and atmospheric pressure, heat exchange, and sediment transport.

The main features and boundary forcing conditions included in the MIKE-3-FM model were:

- flooding and drying
- momentum dispersion
- bottom shear stress
- Coriolis force
- wind shear stress
- barometric pressure gradients
- precipitation/evaporation, and
- sources and sinks.

The influence of the Coriolis force was calculated with latitude of -35.7 degrees south (°S). Salinity was not modelled as all inflows are fresh and there would be no significant density effects from salinity. The horizontal momentum mixing model adopted was the Smagorinsky formulation with a coefficient of 0.2, while a k-epsilon vertical mixing model was used, which while computationally expensive, can provide the most accurate representation of vertical mixing processes in the model. MIKE has an adaptive timestep algorithm which automatically adjusts the model timestep to resolve hydrodynamic and advection dispersion processes based on user specified Courant-Friedrichs-Lewy (CFL) stability criterion. The scalar mixing model adopts the eddy viscosity model which calculates non-isotropic diffusivity using coefficients for horizontal and vertical directions. The influence of vertical stratification on mixing is inherent through the adoption of the k-epsilon mixing model.

MIKE accounts for wetting and drying dynamically based of cell depths of 0.1 m and 0.005 m respectively. The drying value corresponds to a minimum depth below which the cell is dropped from computations (subject to the status of surrounding cells). The wet value corresponds to a minimum depth below which cell momentum is set to zero, to avoid unrealistic velocities at very low depths. Bottom drag or bed roughness is specified as a constant roughness height of 0.05 m, which is standard for many 3D hydrodynamic models.

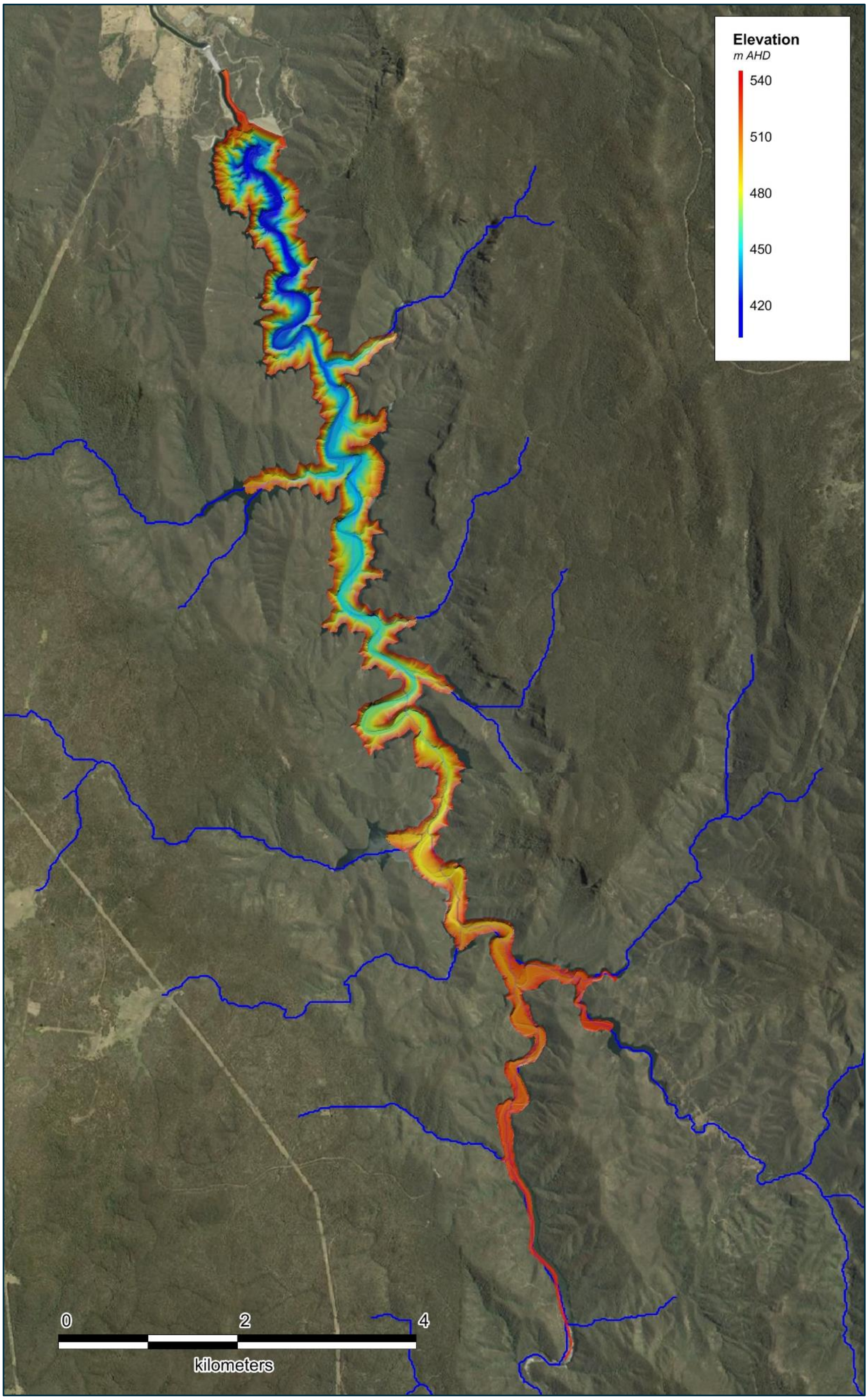

Figure 3-6: Hydrographic Survey Data for Talbingo Reservoir.

Details of the HD model configuration are provided in **Table 3-2** for the Talbingo Reservoir model.

Table 3-2: Summary of MIKE-3 HD Model Configuration

Parameter	Value
Solution Technique	Time integration: High order Space discretization: High order Critical CFL number: 0.8
Enable Flood and Dry	Drying depth: 0.005m Flooding depth: 0.05m Wetting depth: 0.1m
Density	Type: Function of temperature Reference temperature: 10 °C Reference salinity 0.15 PSU
Horizontal Eddy Viscosity	Eddy type: Smagorinsky formulation Format: Constant Value: 0.28 Min eddy viscosity: 1.8e-006 m^2/s Max eddy viscosity: 10000000000 m^2/s
Vertical Eddy Viscosity	Eddy type: K-epsilon formulation Min eddy viscosity: 1.8e-006 m^2/s Max eddy viscosity: 0.4 m^2/s Damping: enabled TKE (Vertical and Horizontal Prandtl): 1 Dissipation of TKE (Vertical and Horizontal Prandtl): 1.3
Bed resistance	Resistance type: Roughness height Format: Constant Constant value: 0.05 m
Coriolis Forcing	Enabled, varying in domain
Wind Forcing	Enabled Format: Varying in time, constant in domain From file: Dfs0_Wind_Talbingo_20161112_to_20170407_v02.dfs0
Wind friction	Friction type: Constant Constant value: 0.001255
Precipitation - Evaporation	**Specified Precipitation** Format: Varying in time, constant in domain From file: Dfs0_Precipitation_Talbingo_20161112_to_20170407.dfs0. **Evaporation**: Dfs0_Evaporation1p0_Talbingo_1990_to_2018.dfs0
Sources (Reservoir Inflow and Outflows)	Source type: Simple source Format: Varying in time From file: *.dfs0 Item: Discharge (m^3/s) T2 inflows, T3 (inflows (pumping) and outflows, catchment inflows)
Initial conditions	**Water Level** Type: Constant Elevation: 542.26 m **Water Temperature** Format: Varying in domain From file: Dfsu_TBG_zF_520mMaxBed_DS_initialWaterTemperature_20161115_v03b_MZ.dfsu Based on observed CTD data

Parameter	Value
Heat Exchange	Include heat exchange: Enabled **Latent Heat** Daltons Constant: 0.5 Wind coefficient.: 0.9 Critical wind speed: 2m/s **Sensible Heat** Transfer coefficient. Heating: 0.0011 Transfer coefficient. Cooling: 0.0011 Critical wind speed: 2m/s **Short Wave Radiation** Format: Varying in time, constant in domain From file: SolarRadiation_INEWSOUT391_20161113_to_20170406.dfs0 Item: Heat Flux **Long Wave Radiation** Formulation: Empirical **Atmospheric Conditions** Air Temperature Format: Varying in time, constant in domain From file: Dfs0_Temperature_Talbingo_20161112_to_20170407_v02.dfs0 Relative Humidity Format: Varying in time, constant in domain From file: Dfs0_Humidity_Talbingo_20161112_to_20170407_v02.dfs0 Clearness coefficient: Format: Constant Constant value: 70%

3.6 Model Boundary Conditions (External Forcing)

Model boundary conditions are used to define point source inflows (e.g. catchment inflows, inflow/outflow from existing Snowy Hydro operations), sediment sources (e.g. ERP) and spatially and temporally varied meteorological forcing applied to the water surface (e.g. wind field, solar radiation, rainfall). Key inflow/outflow locations to Talbingo Reservoir are shown in **Figure 3-10**.

Boundary conditions of the models include:

- **meteorological forcing** data applied to the entire model including rainfall, air temperature, relative humidity, wind speed/direction
- **river flow and water temperature** data for the larger tributary rivers (i.e. Yarrangobilly River and Tumut River)
- **catchment flow and water temperature** data for local sub-catchments draining to the reservoir, and
- **Snowy Hydro flow and water temperature** data for existing (and predicted) Snowy Hydro operations (i.e. T2 Power Station generation (inflow), T3 Power Station pumping (inflow) / generation (outflow)).

Boundary condition data used to define model scenarios is based on actual gauging data wherever possible to ensure that the scenarios are reflective of actual conditions experienced within the study area.

Example time series of model boundary conditions adopted by the Talbingo Reservoir model are provided in **Figure 3-7** to **Figure 3-9**. A complete set of model boundary conditions used by the reservoir model is provided in **Attachment A**.

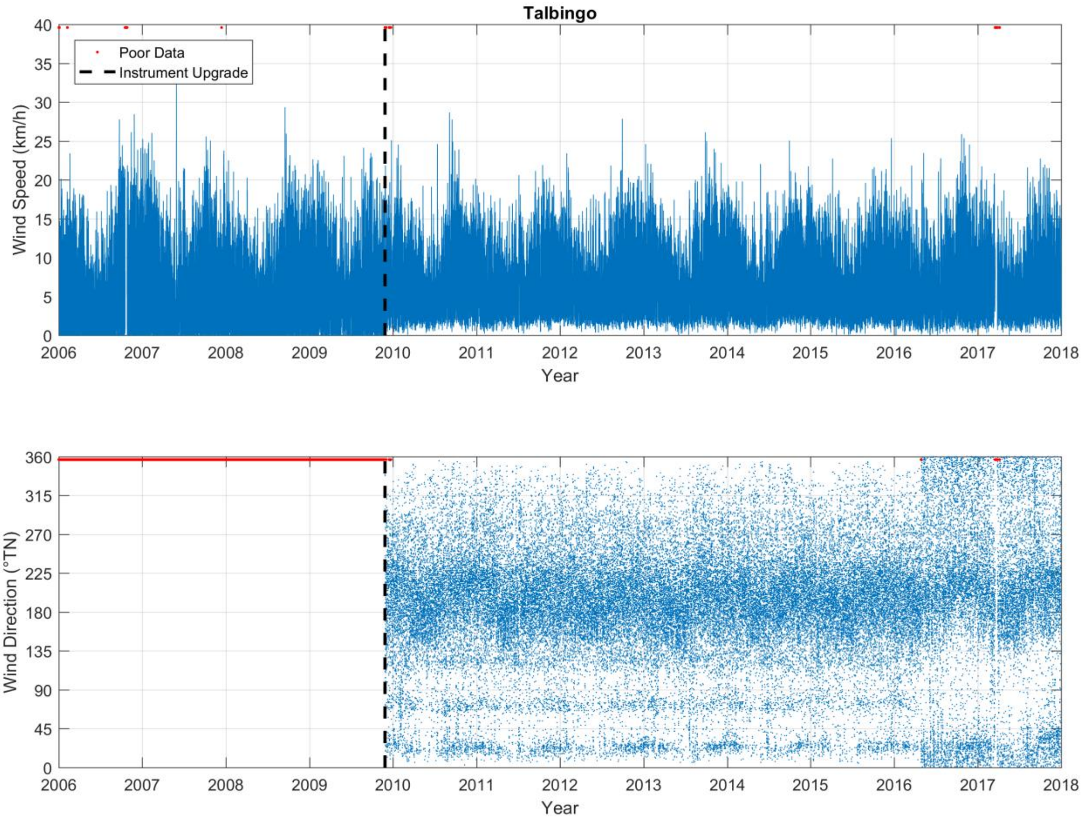

Figure 3-7: Example time series of hourly wind speed and direction at Talbingo Reservoir

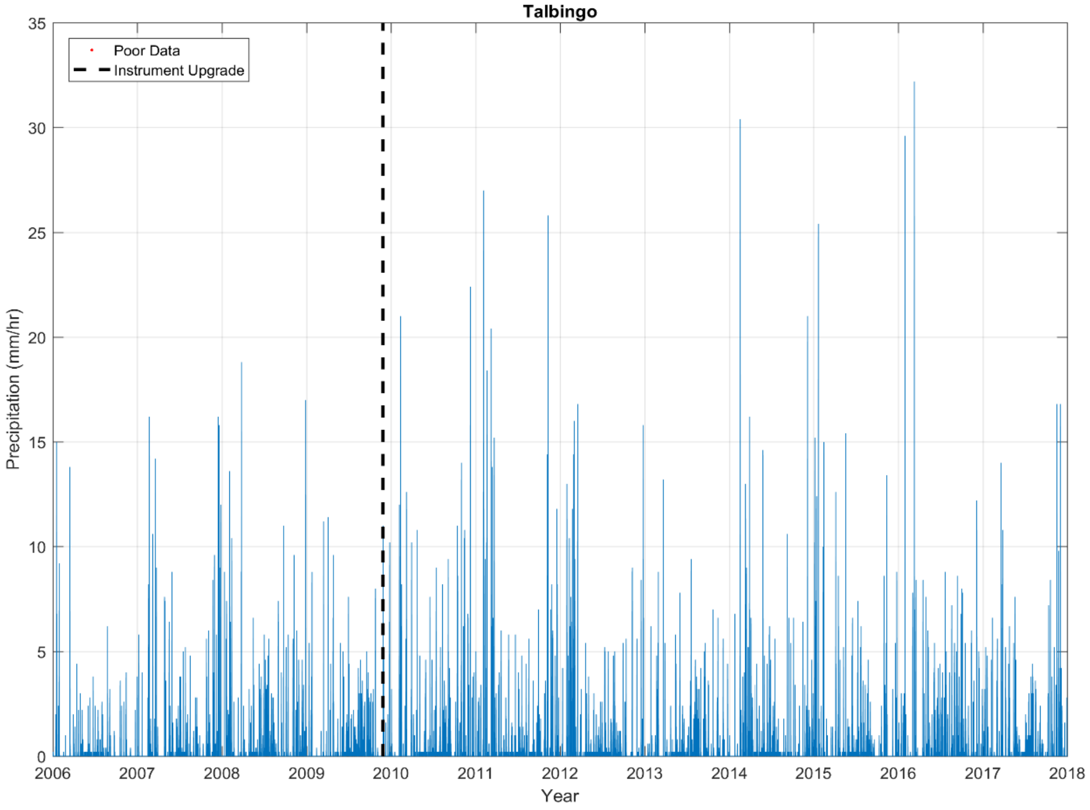

Figure 3-8: Example time series of hourly rainfall at Talbingo Reservoir

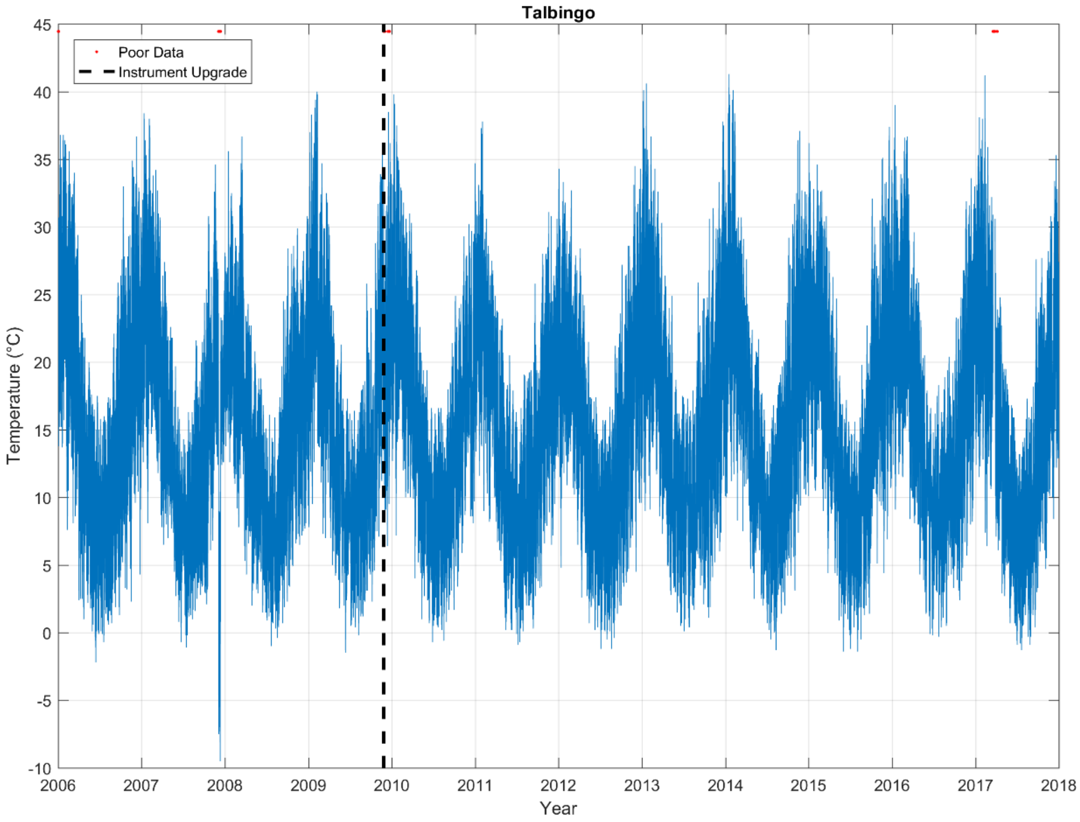

Figure 3-9: Example time series of hourly air temperature at Talbingo Reservoir

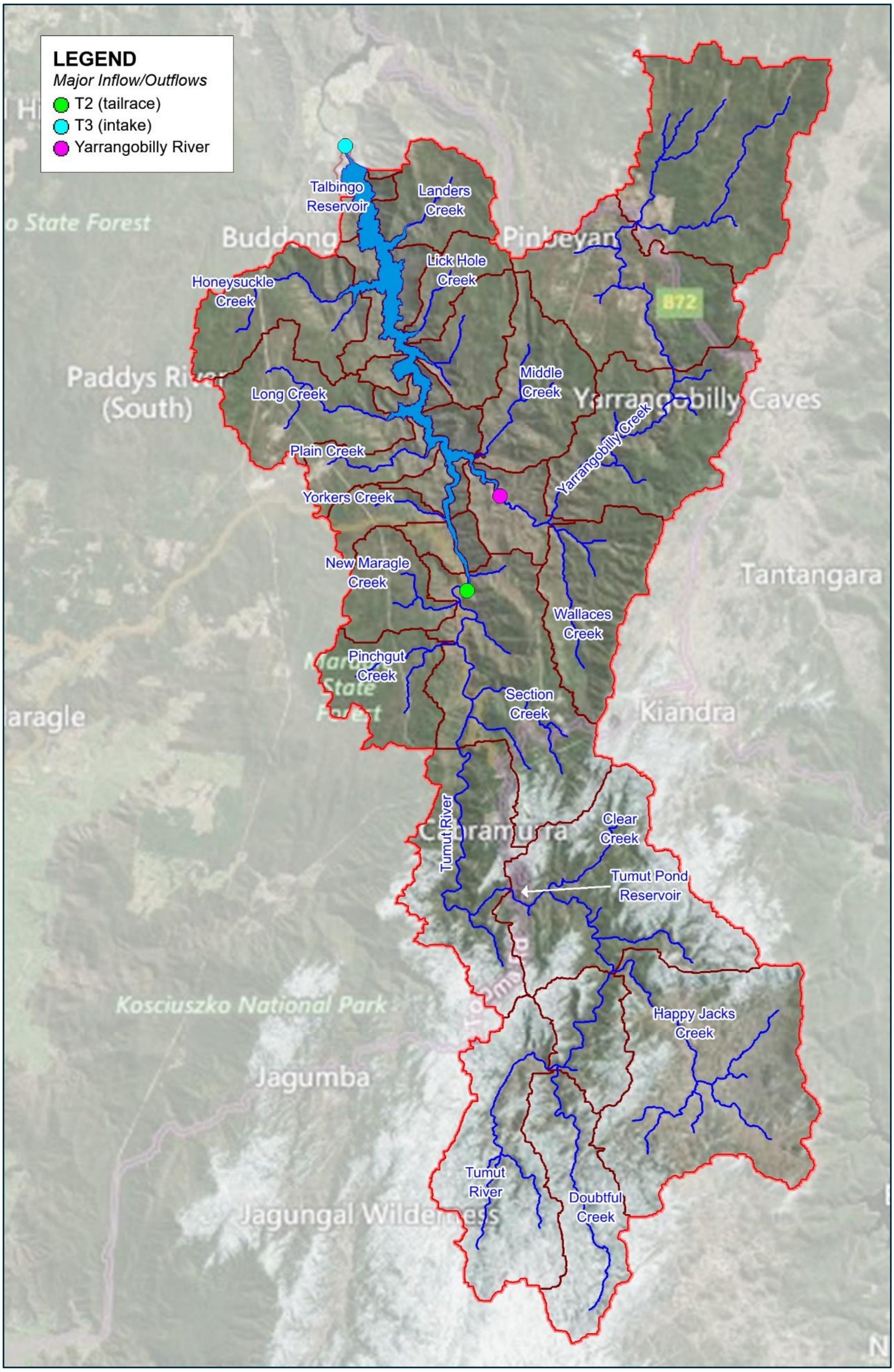

Figure 3-10: Key Inflow and Outflow Locations - Talbingo Reservoir

3.7 Sediment (Mud Transport (MT) Module)

The Sediment (Mud Transport (MT) module is an extension of the HD model (described previously in **Section 3.5**). The MT module is a combined multi-fraction and multilayer model that describes erosion, transport and deposition of mud (cohesive sediments). A dredging module is available allowing dynamic simulation of all stages of the dredging process (DHI, 2017), which includes features and capabilities appropriate for simulating processes needing to be considered for assessment of ERP activities. The MT module was therefore used for simulating sediment transport processes in the study reservoir.

The sediment transport component aims to simulate the typical patterns of sediment transport as governed by the hydrodynamics and applied boundary forcing. The processes and characteristics incorporated into the MT model include:

- sediment transport (plume advection and dispersion, sedimentation/deposition and erosion)
- bed-evolution and slumping of unstable slopes (not used in this study)
- sediment classes and ability to spatially vary sediment properties, and
- threshold velocities for deposition and erosion.

3.7.1 Model Bathymetry

The model bathymetry files used are identical to those used by MIKE-3 FM as presented in **Section 3.5.2**. The bathymetry was altered for some of the scenarios modelled during this study to represent pre- and post-placement conditions.

3.7.2 Model Configuration

Inputs required by the MT model (other than currents generated by HD model which are used to drive sediment transport processes) are the:

- number of sediment fractions to be modelled
- settling velocity for each sediment fraction
- mass flux (kg/s) of fine sediments to be released into the model domain, and
- percentage of the total fine sediment mass represented by each sediment fraction.

Further details of the MT model configuration are provided in **Section 6.3**.

4 Calibration of Model Hydrodynamics and Heat Budget

4.1 Data Availability

4.1.1 Snowy Hydro Limited

The review of background information provided by Snowy Hydro identified the following relevant data sources for model calibration and validation:

- Water level data (refer to **Section 4.3.1**).
- Temperature depth profile data (refer to **Section 4.3.3**).

The above data sources represent the data sets used to compare the modelled results to observed conditions at the study reservoir. Data used to force the model during the calibration period is presented in **Section 3.3** and **Section 3.6**.

Further details of the recent data collection undertaken for the study reservoir including measurement sites, collection methods, and limitations of the data are provided in **Section 4.1.2**.

4.1.2 2018 Field Data Collection Program

Data and Monitoring locations

A range of environmental, hydrographic and limnologic data to assist in the design and assessment of Snowy 2.0 was commissioned for this study. This included measurement of current speed (Acoustic Doppler Current Profiler (ADCP)), water temperature and quality profiles (thermistor string below a moored surface pontoon, conductivity-temperature-depth (CTD) instruments and other water quality sensors). The locations of the data collection points in Talbingo Reservoir are presented in **Figure 4-1.**

The two ADCP's were deployed in Talbingo Reservoir on 19 April 2018 and recovered (1st data download) on 12 July 2018. Characteristics of this data was compared to modelled current speeds for the 2017 "winter" calibration as presented in **Section 4.3.2**. A review of the accuracy and reliability of the ADCP data is presented in **Attachment D**.

The three moored thermistor strings were deployed in Talbingo Reservoir in early June 2018 and the first data download occurred in late-October 2018. Characteristics of this data were compared to modelled current speeds for the 2017 "winter" calibration as presented in **Section 4.3.3**.

Due to available project time frames, a direct comparison to the field data is yet to occur. Validation or re-calibration to these recent high-quality data sets is recommended to further increase confidence in model predictions.

Further details of the 2018 field data collection program methodology are provided by Cardno (2019).

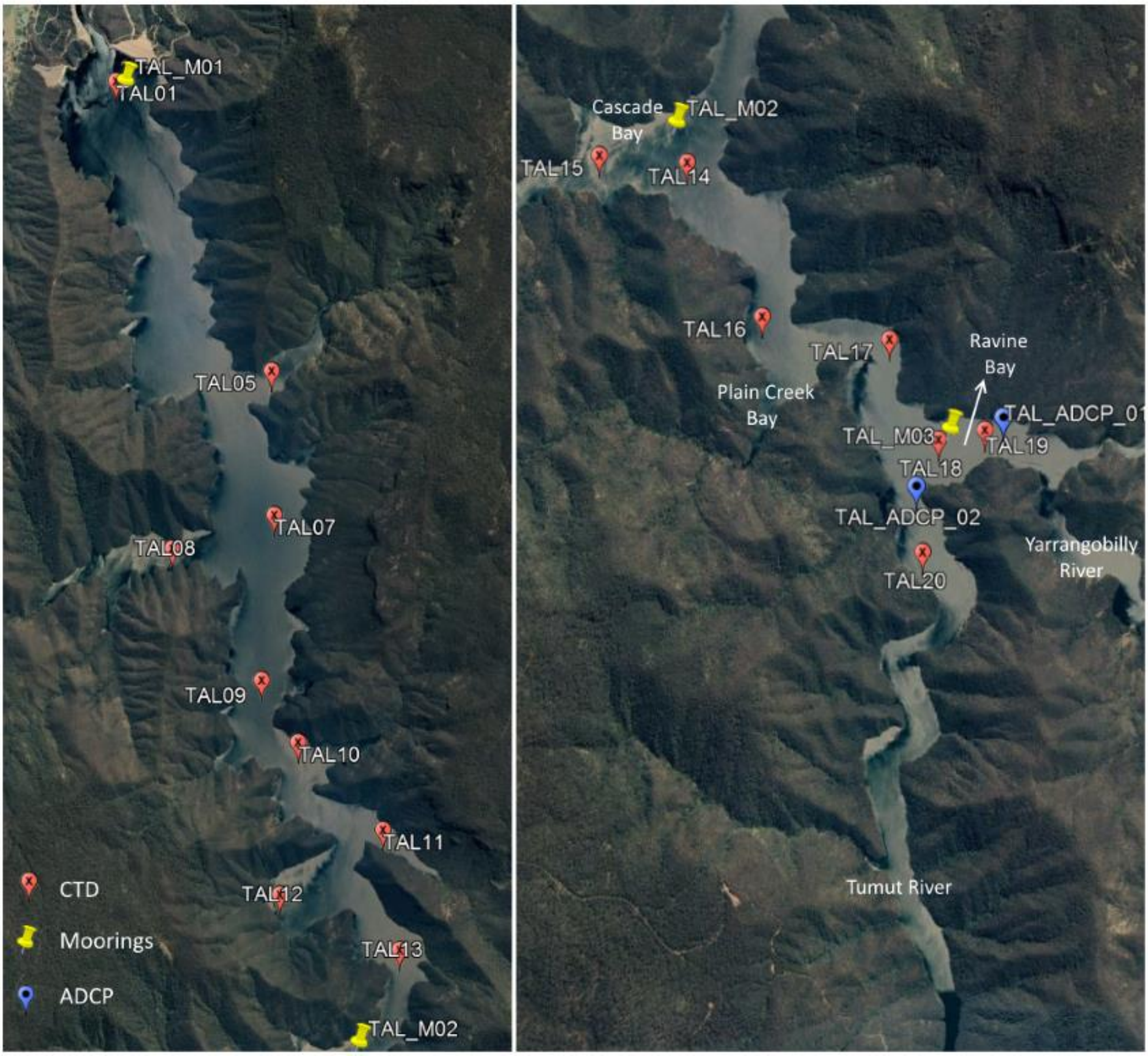

Figure 4-1: Location of 2018 Data Collection Points - Talbingo Reservoir[4].

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[4] *ADCP_02 was moved to Plain Creek Bay in November 2018*

4.2 Calibration Approach

The approach to model calibration was to prepare the model geometry and adjust model parameters and boundary conditions to represent hydrodynamics (i.e. water level and range, current velocity/flow) and water temperature (which influences vertical mixing behaviour) as best as possible using available data.

Using available data, the numerical model was run for a continuous period of:

- Five months (13 November 2016 to 5 April 2017) – a recent summer heating period, and
- Seven months (5 April 2017 to 28 October 2017) – a recent winter cooling period.

Calibration results including water level, current speed and water temperature were extracted from the models and compared to data collected during the monitored period. The results of the calibration of model hydrodynamics and heat budget for Talbingo Reservoir is presented in the following sections.

4.3 Results

4.3.1 Hydrodynamics – Water Levels

The calibration focussed on defining reservoir storage as accurately as possible and the major inflows and outflows to the reservoir. The overall aim of the hydrodynamic calibration was to achieve a good fit to measured water level and current speed data.

The calibrated models were able to adequately represent measured water level conditions during historical periods, as shown in **Figure 4-2.**

The comparison of measured to modelled water levels for Talbingo Reservoir is presented in **Figure 4-2**, and shows data for both the calibration heating (13/11/2016 to 5/4/2017) and cooling (5/4/2017 to 28/10/2017) periods. The time series of modelled water levels closely matches the observed water levels, however, there is an apparent “drift” (or divergence) of the modelled water levels away from the observed. This gradual divergence is most likely due to the T3 and T2 scheme flow data inaccuracies which arise from conversion errors between power generation and pumping data and flow rates. Due to the high magnitude of the scheme flows (in the order of 1,000 m^3/s), even relatively minor errors (e.g. 5-10%) in estimates of flow can result in a significant difference in the volume of water transferred over a period of months and consequently the modelled water levels in the reservoir. However, these differences in water levels are not considered to cause significant issues with the predictions of sediment movement as they have only minimal influence in predicted advective and general mixing behaviours. The impact of the long-term “drift” in model water levels is further reduced by regularly restarting the model with an appropriate measured initial water level, which is the approach adopted for this modelling investigation.

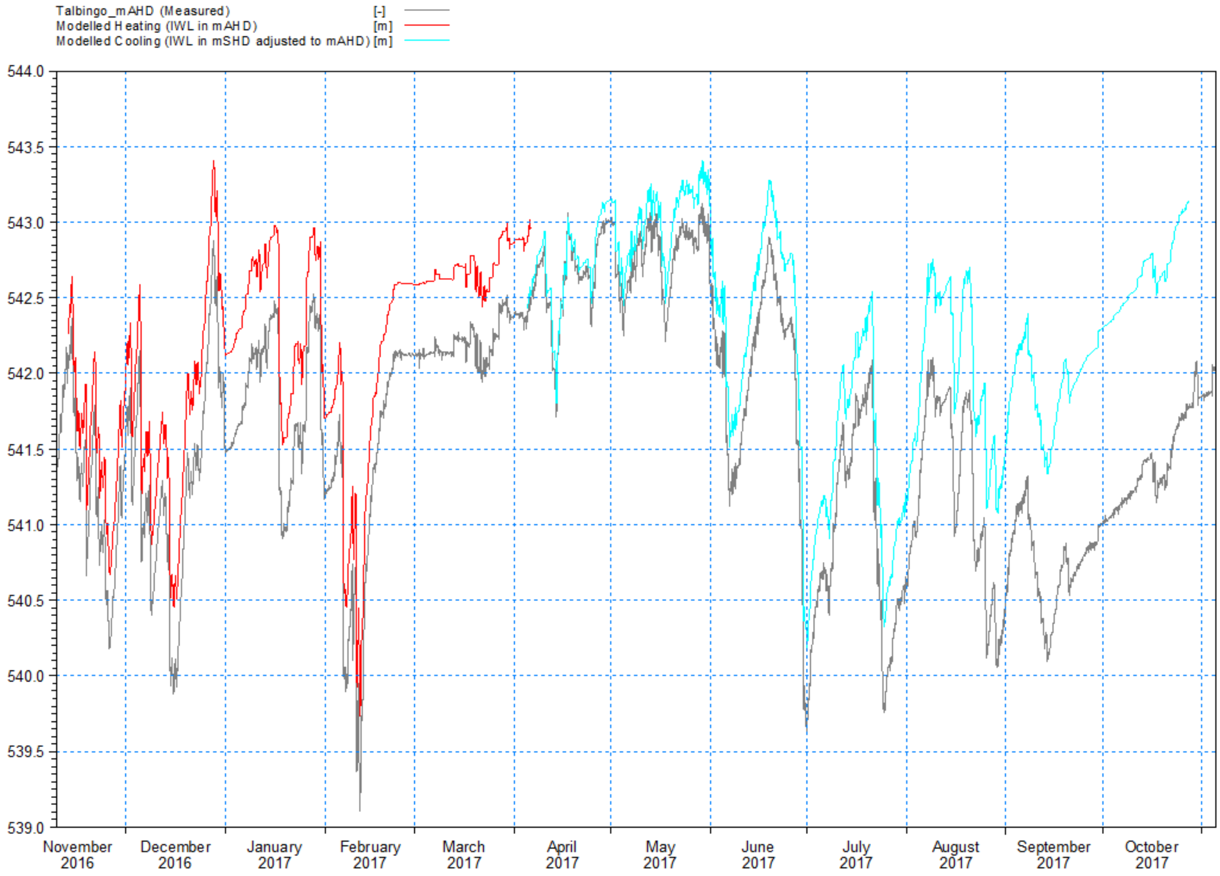

Figure 4-2: Observed and Simulated Water Level (m AHD) at Talbingo Reservoir.

4.3.2 Hydrodynamics – Current Speeds

An indirect comparison (i.e. different time periods and hence boundary forcing to the models) between observed and simulated current speeds for the ADCP monitoring sites at Talbingo Reservoir (TAL1 and TAL2) is presented in **Attachment D**.

The results show that the calibrated model produces current speeds of a similar magnitude to those measured (Cardno, 2019). The ADCP measurements and simulated currents produced by the model are reflective of a low energy depositional environment with current speeds in the order of 1 to 5 cm/s.

4.3.3 Heat Budget – Water Temperature

Vertical differences in water temperature influence the transport and mixing behaviour of a body of water. An important part of the model calibration involved ensuring that the model was able to simulate important features of the reservoir heat budget and the influence of temperature-based density differences.

Checks on the model performance were undertaken to ensure that the model could:

- reproduce observed temperature depth probe (CTD) data at the end of the heating or cooling calibration period, i.e. a comparison between the modelled and observed temperate depth profile at the measurement location. This comparison used the CTD data collected every 6 months by Snowy Hydro in their operational reservoirs, and
- simulate characteristic short term (diurnal) and long-term (seasonal) temperature changes. This was done by comparing data from the winter (cooling) calibration period (2017) to the project

specific data collected (Cardno, 2019) as discussed in **Section 4.1.2** which included thermistor string data for approximately 5 months from 9 June to 22 October 2018.

The locations of the data sources are presented in **Figure 4-3**.

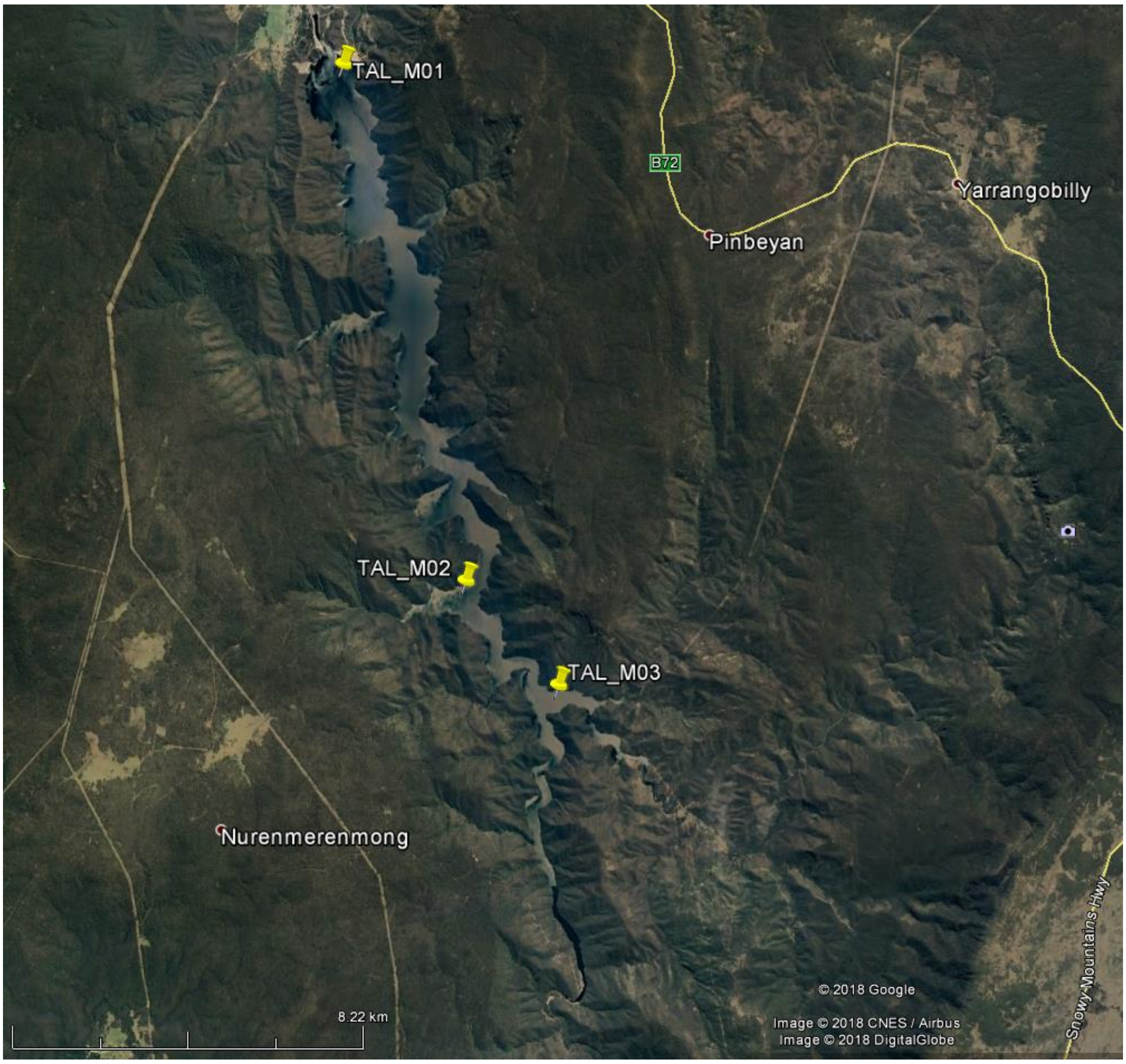

Figure 4-3: Location of Thermistor Mooring Observation Buoys in Talbingo Reservoir

4.3.3.1 Comparison of modelled and observed temperature depth probe CTD data

Prior to the availability of moored thermistor string data (Cardno, 2019) the heat budget calibration was initially limited to comparisons to the bi-annual CTD data.

The comparison of measured (CTD) to modelled temperature depth data for Talbingo Reservoir is presented in **Figure 4-4** (for a location near the Dam wall) and **Figure 4-5** (for a location at Lobs Hole (near TAL_M03)) for the calibration heating period (13/11/2016 to 5/4/2017) and in **Figure 4-6** (for a location near the dam) for the cooling period (5/4/2017 to 28/10/2017).

It is useful to note that the model was initialised using the observed CTD data at the start of the run, so an assessment of model performance can only be made by comparing the observed CTD data to the predicted temperature depth model at the end of the run. The figures show that the model was able to closely replicate the observed temperature depth characteristics and provide suitable density characteristics to appropriately predict transport and mixing behaviour in the reservoir. While there was some discrepancy in the absolute water temperature predicted by the model (in the order of 1-2°C) when compared to observed, the overall trend and gradient of water temperature and, hence, density over the water column is well predicted by the model. This result provides confidence in the model's ability to capture the formation of thermally stratified layers in the reservoir during a period of heating and also the loss of stratification over a period of cooling.

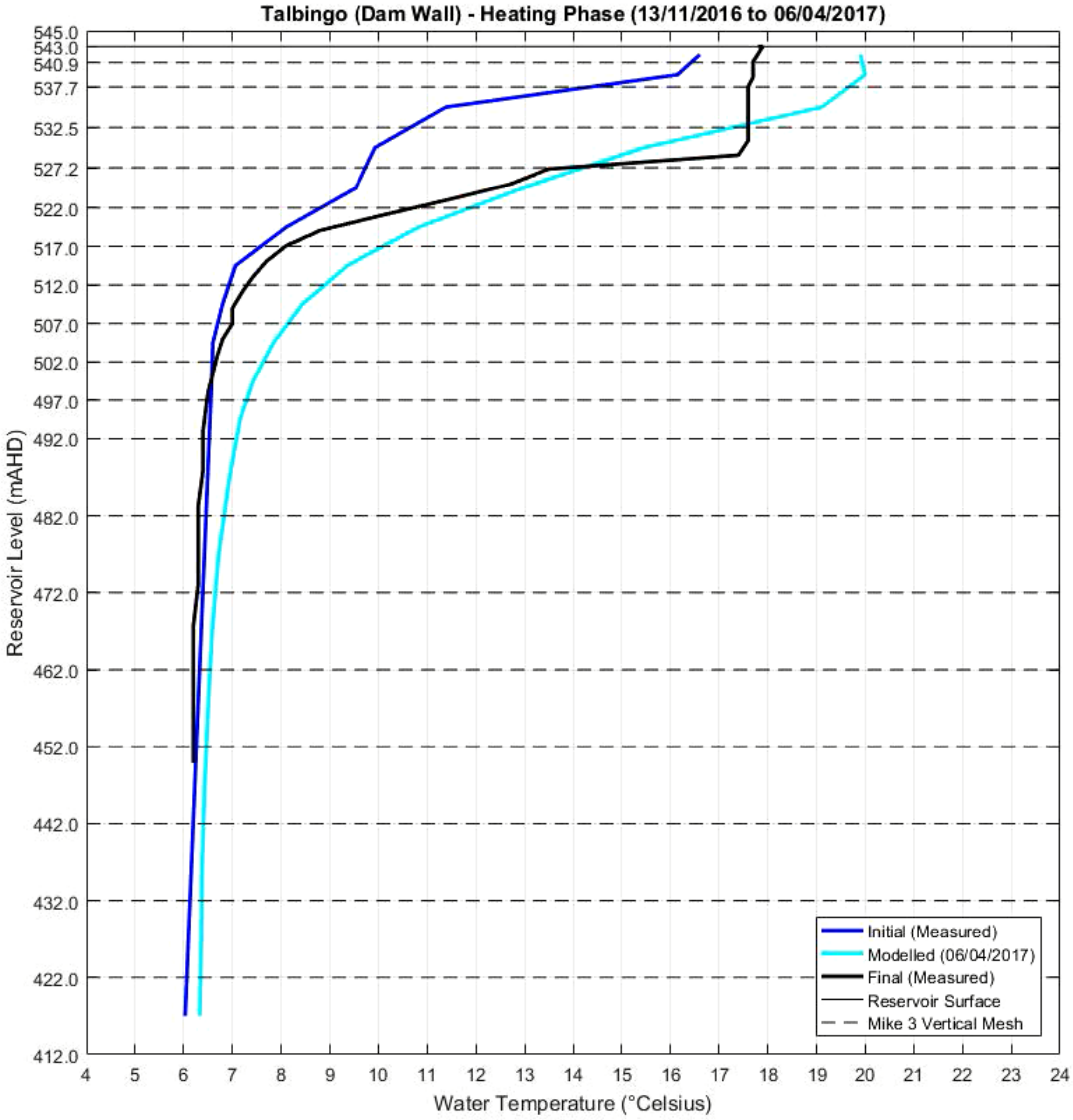

Figure 4-4: Comparison of Modelled (Heating Phase) to Observed Temperature Depth (CTD) Data – Near Dam Wall (Talbingo Reservoir).

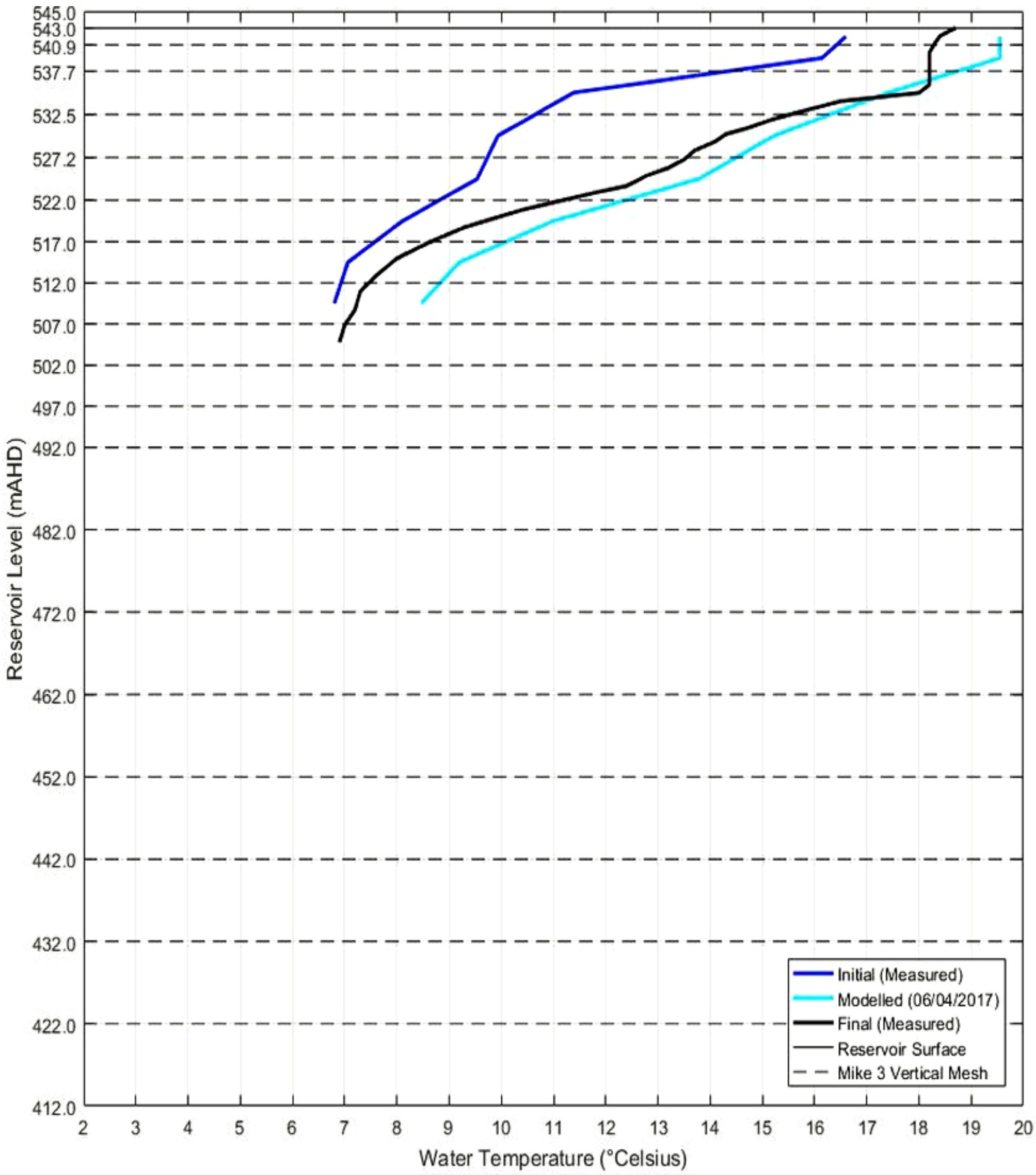

Figure 4-5: Comparison of Modelled (Heating Phase) to Observed Temperature Depth (CTD) Data – Lobs Hole (Talbingo Reservoir).

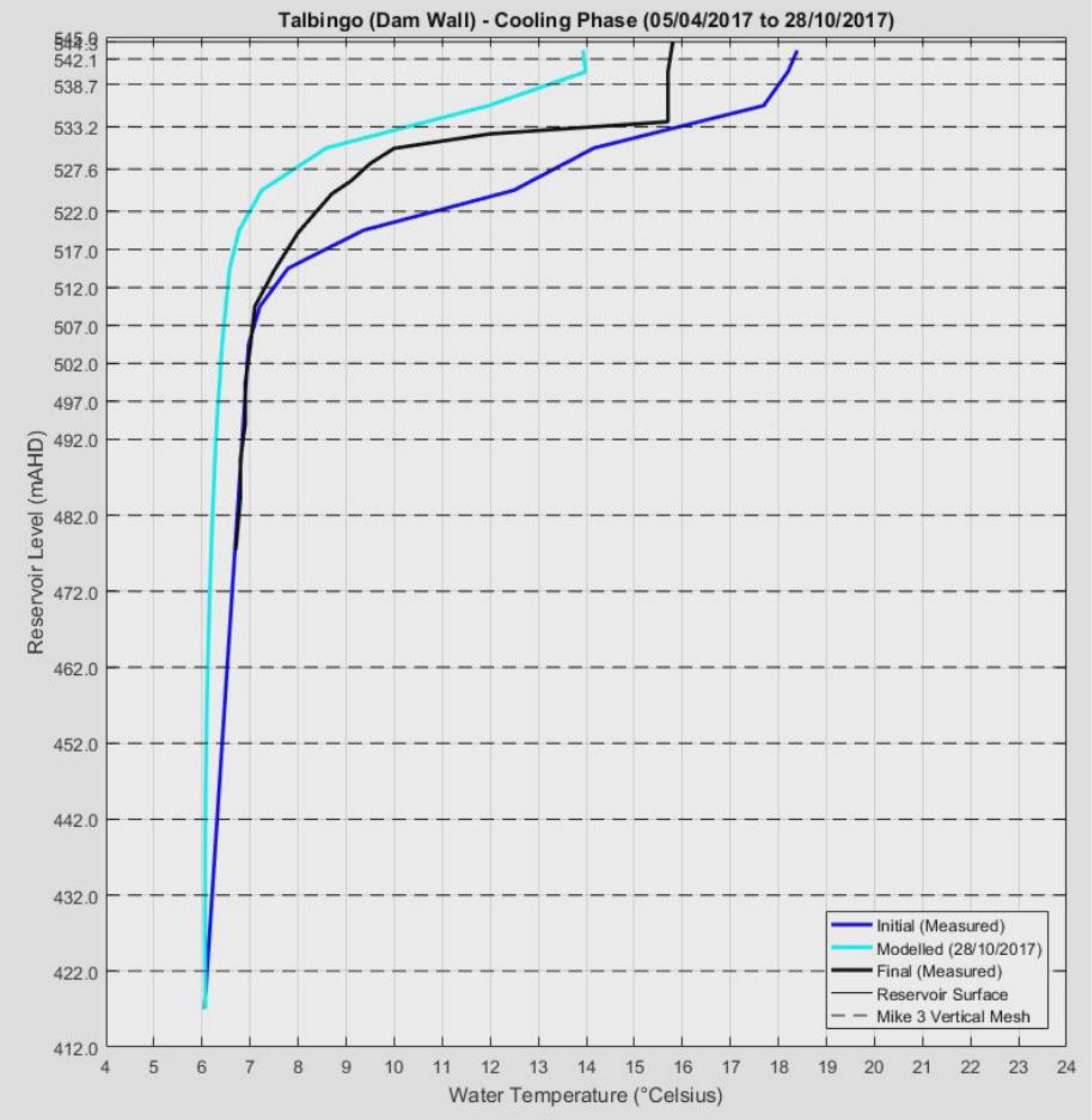

Figure 4-6: Comparison of Modelled (Cooling Phase) to Observed Temperature Depth (CTD) Data – Near Dam Wall (Talbingo Reservoir).

4.3.3.2 Comparison of modelled (2016/7) and observed thermistor string (2018) data

High resolution thermistor string data was collected by Cardno (2019) as part of the Snowy 2.0 Project from June 2018 (refer to **Section 4.1.2**) for three locations in Talbingo Reservoir (M01, M02 and M03). The locations of these data collection mooring sites are presented in **Figure 4-3**. While the collected thermistor string data does not coincide with the calibration period (due to available project timeframe, the model calibration phase occurred in parallel to the data collection period), comparison of the high-quality data to the modelled data allows for a check to be made that the model is able to replicate key characteristics of the observed data.

Talbingo Reservoir

A comparison of time series data of observed (winter 2018) to modelled (winter 2017) temperatures at five discrete water depths is presented in **Figure 4-7** and **Figure 4-8**. A total of five depths were selected from the model to aid interpretation, comparison and characterisation.

Curtain plots (i.e. temperature, depth contour plots) showing all available water temperature data are provided in **Figure 4-9** for observed (winter 2018) and **Figure 4-10** for modelled (winter 2017) temperatures at M01 (near the Dam wall).

A direct comparison of observed (2018 data) to modelled (2017 data) surface temperatures is presented in **Figure 4-11** and shows that the model could reproduce observed water temperature variations throughout a day (diurnal) and between months of the year (seasonal). A direct comparison of observed (2018 data) to modelled (2017 data) near bed water temperature is presented in **Figure 4-12** and shows that the model could reproduce the diurnal and seasonal changes of water temperature typical for Talbingo Reservoir at this (winter) time of the year.

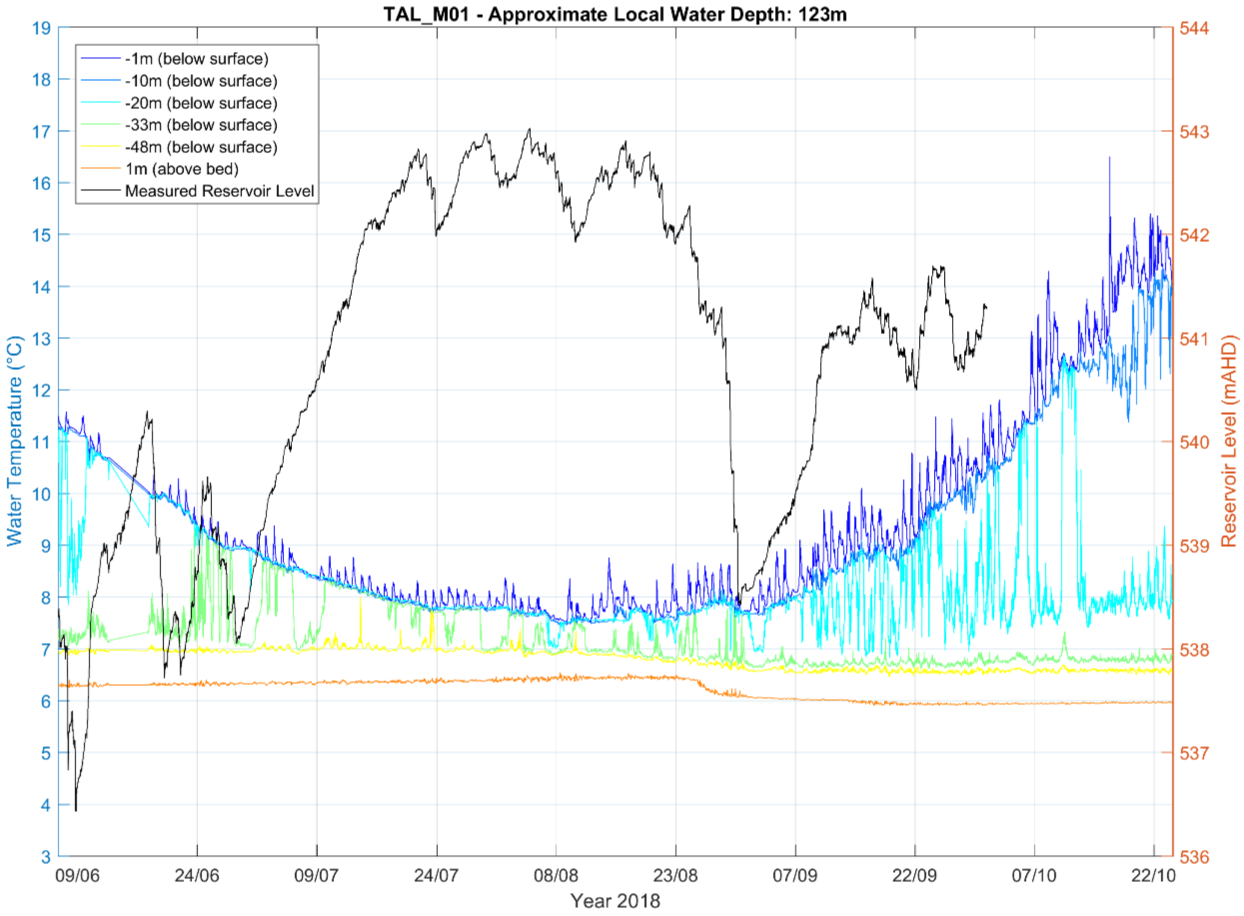

Figure 4-7: Observed Thermistor String Temperature Data (5 Depths) - 2018 Winter Deployment – Near Dam Wall (TAL-M01).

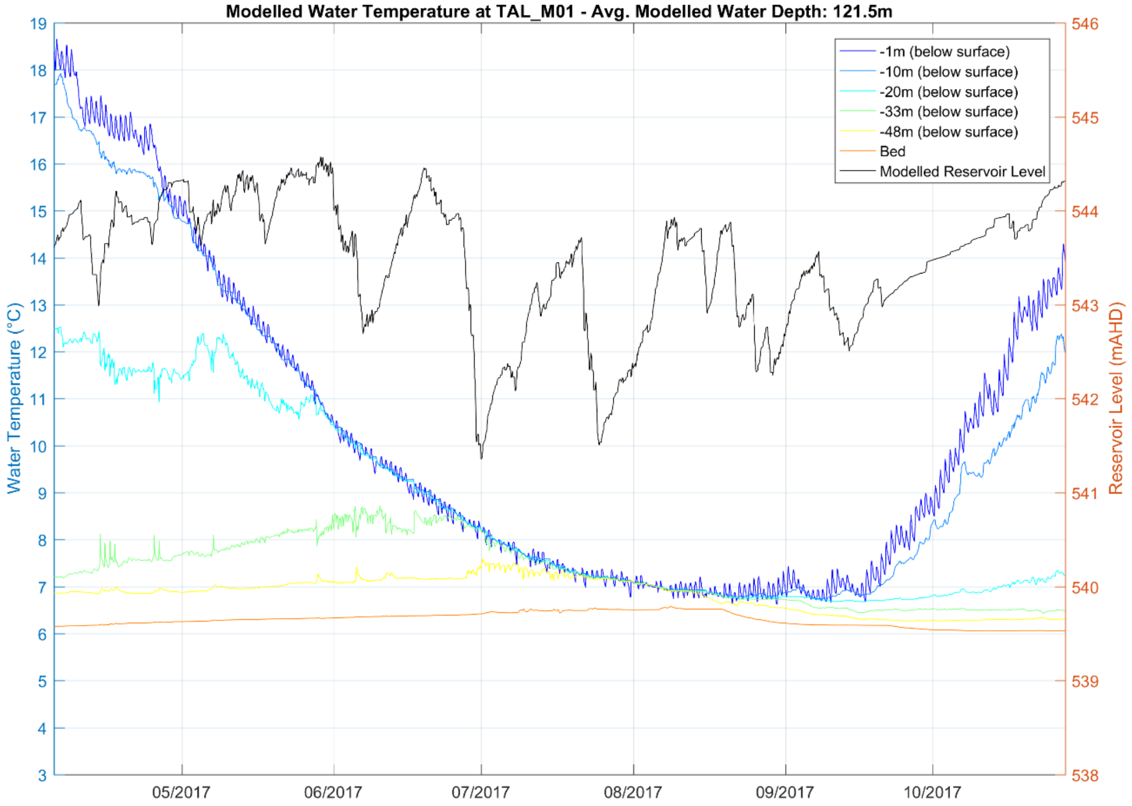

Figure 4-8: Modelled Temperature Data (5 Depths) - 2017 Winter 7 Month Simulation – Near Dam Wall (TAL-M01).

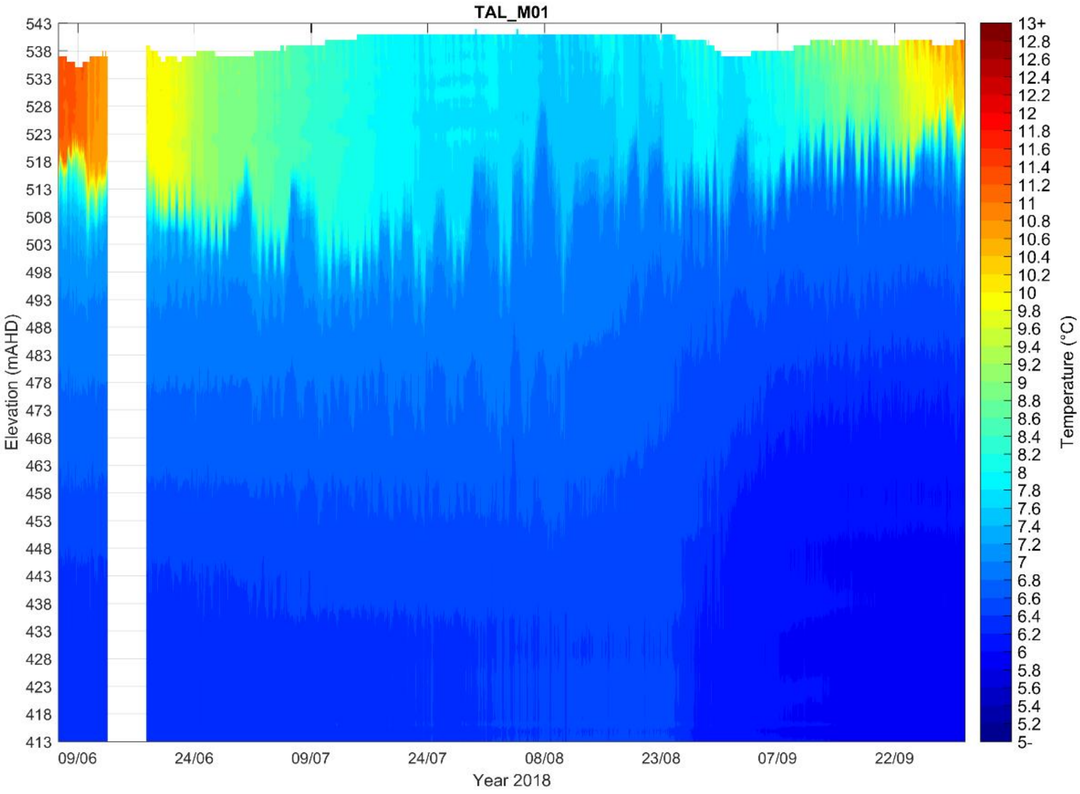

Figure 4-9: Observed Thermistor String Temperature Data (Curtain) - 2018 Winter Deployment – Near Dam Wall (TAL-M01).

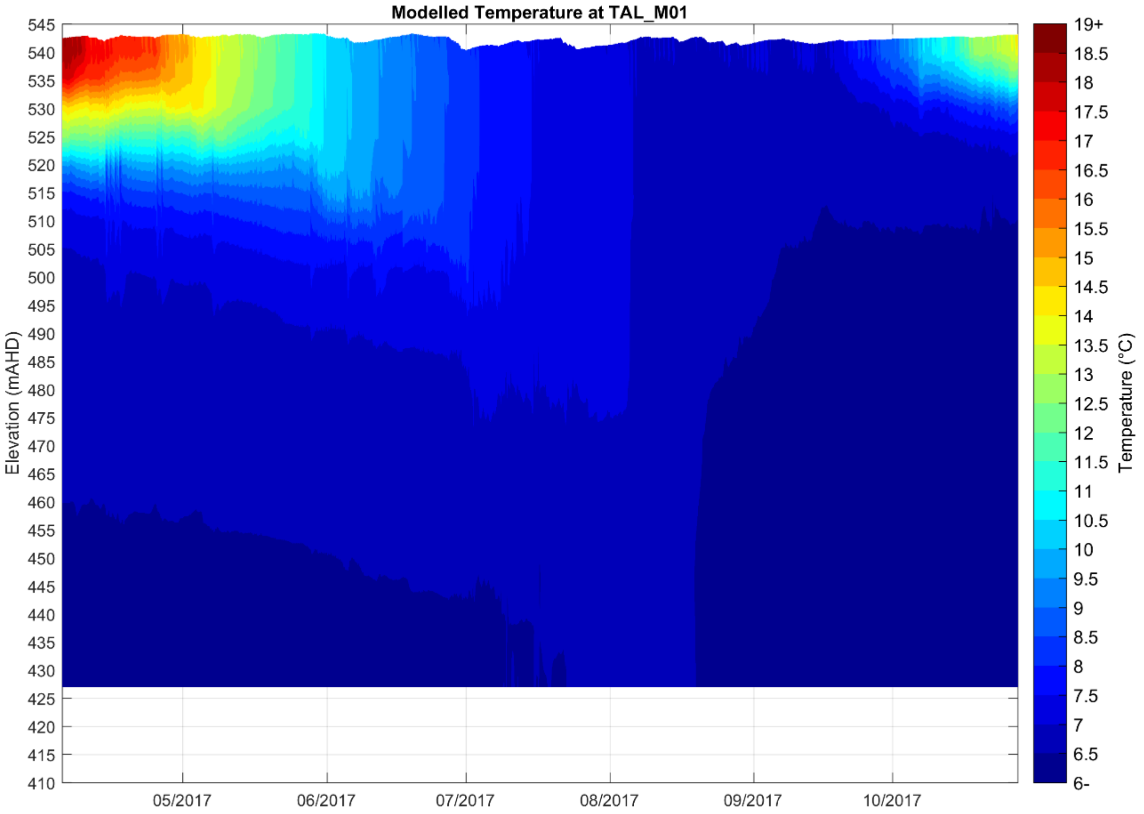

Figure 4-10: Modelled Temperature Data (Curtain) - 2017 Winter 7 Month Simulation – Near Dam Wall (TAL-M01).

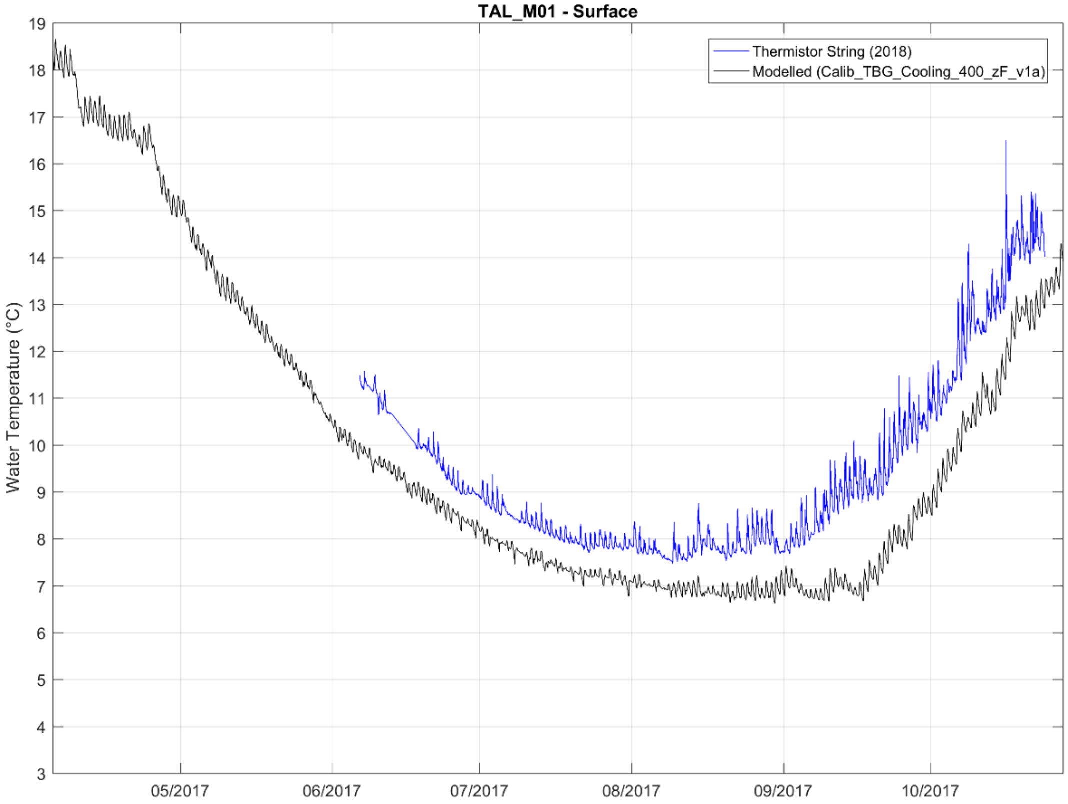

Figure 4-11: Indirect Comparison of Modelled (2017) to Observed (2018) Surface Temperature Data – Near Dam Wall (TAL-M01).

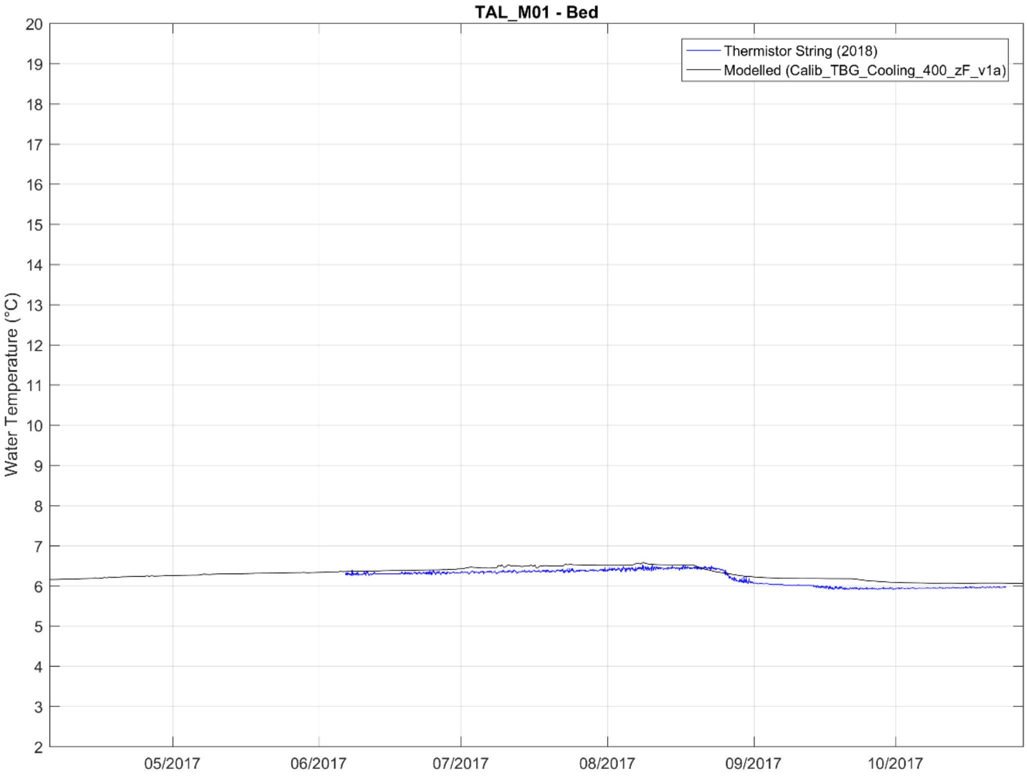

Figure 4-12: Indirect Comparison of Modelled (2017) to Observed (2018) Bed Temperature Data – Near Dam Wall (TAL-M01).

4.4 Verification of Sediment Transport Model (Observed Runoff Event)

A verification of the sediment modelling has been undertaken to increase confidence in the model results. Anecdotal evidence was available for a visible sediment plume observed within the Ravine Bay area for a period of 1 to 2 weeks during September 2018, following a minor fresh event on the Yarrangobilly River.

A review of online stream flow data (www.bom.gov.au/waterdata/) showed that the observed plume was likely related to a daily flow in the order of 900 ML/d (peak discharge of 10.5 m3/s) in the Yarrangobilly River as presented in **Figure 4-13**. A similar event (refer to **Figure 4-14**) was observed in November 2016 which is included in the calibration period. The modelled peak inflow was 11.1 m3/s on 14 November 2016, which is approximately a 1yr-ARI (average recurrence interval) event. Baseflow on the days before and after the peak was approximately 3 to 5 m3/s.

A flow event with suspended sediment (SS) concentration of 25 mg/L[5] was assumed in the model. The background SS concentration was assumed to be 0 mg/L in the model and, therefore, the modelled SS concentration can be considered as “above background”. Outside of the flow event, the SS concentration was assumed to be 0 mg/L.

Figure 4-15 presents the modelled surface plume in the Yarrangobilly Arm of the reservoir for 15 November a day after the inflow event. Vertical slices (along the 4.2 km long profile defined in **Figure 4-15**) showing plume behaviour are presented in **Figure 4-16** to **Figure 4-23** and show the development and dissipation of the low concentration plume (light blue is 1-5 mg/L SS) following the peak flow event. Surface plume plots are presented in **Figure 4-15** (15 Nov), **Figure 4-19** (18 Nov – peak visual plume)

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[5] *To convert from mg/L to kg/m^3, divide by 1000. For example, 1 mg/L = 0.001 kg/m^3*

and **Figure 4-23** (25 Nov – visual plume barely visible). The model predicts no surface SS concentration above 1 mg/L on the 26 Nov, 12 days after the fresh event, and is in general agreement with anecdotal evidence from the September 2018 plume observed at Ravine Bay which was observed for a period of 1 to 2 weeks.

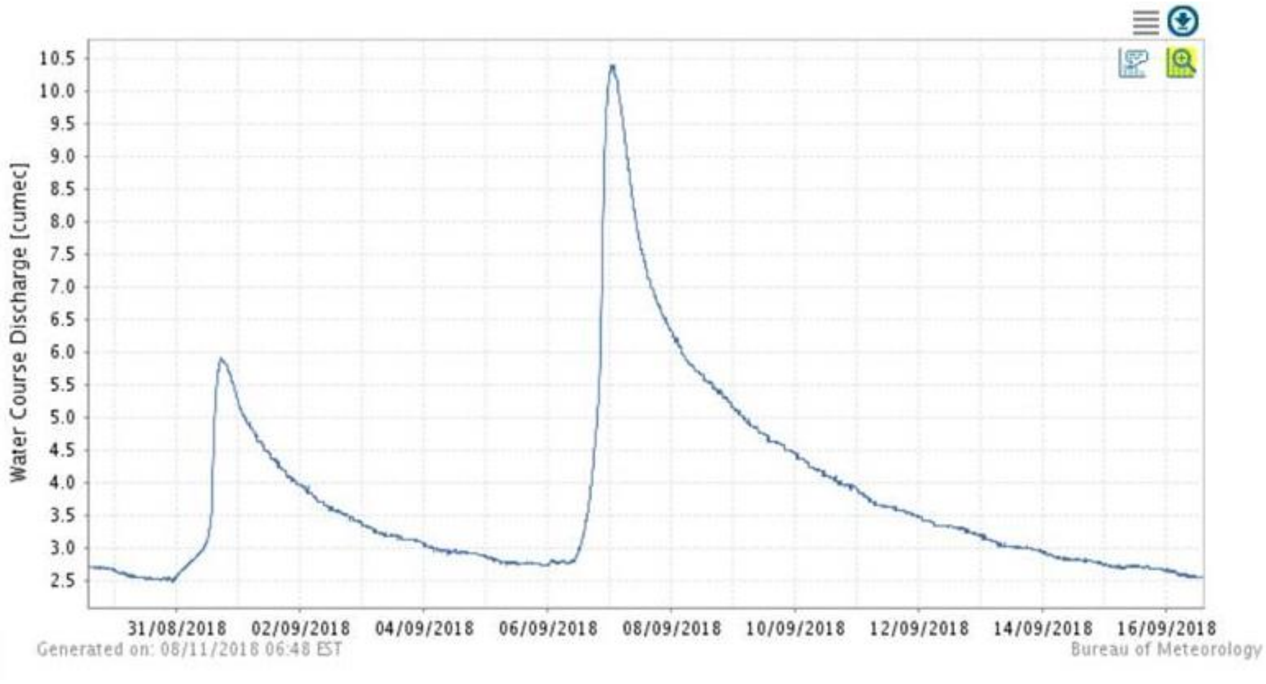

Figure 4-13: Measured September 2018 Flood Hydrograph (Source: BoM Water Data Online).

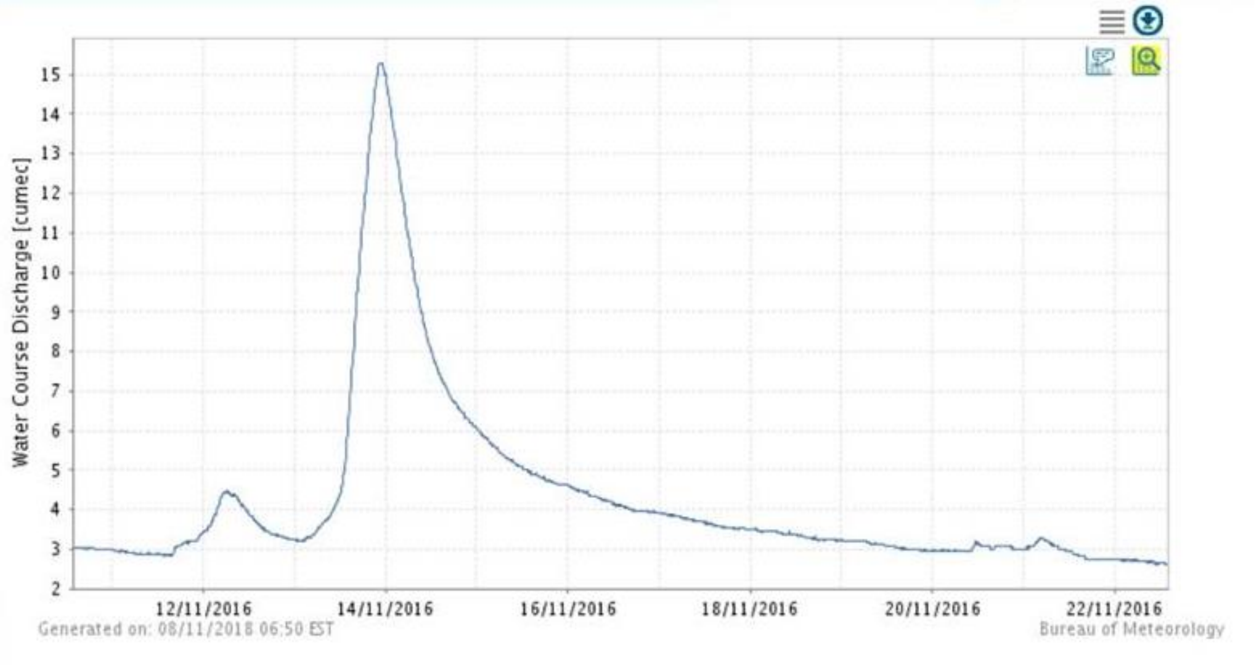

Figure 4-14: Simulated November 2016 Flood Hydrograph (Source: BoM Water Data Online).

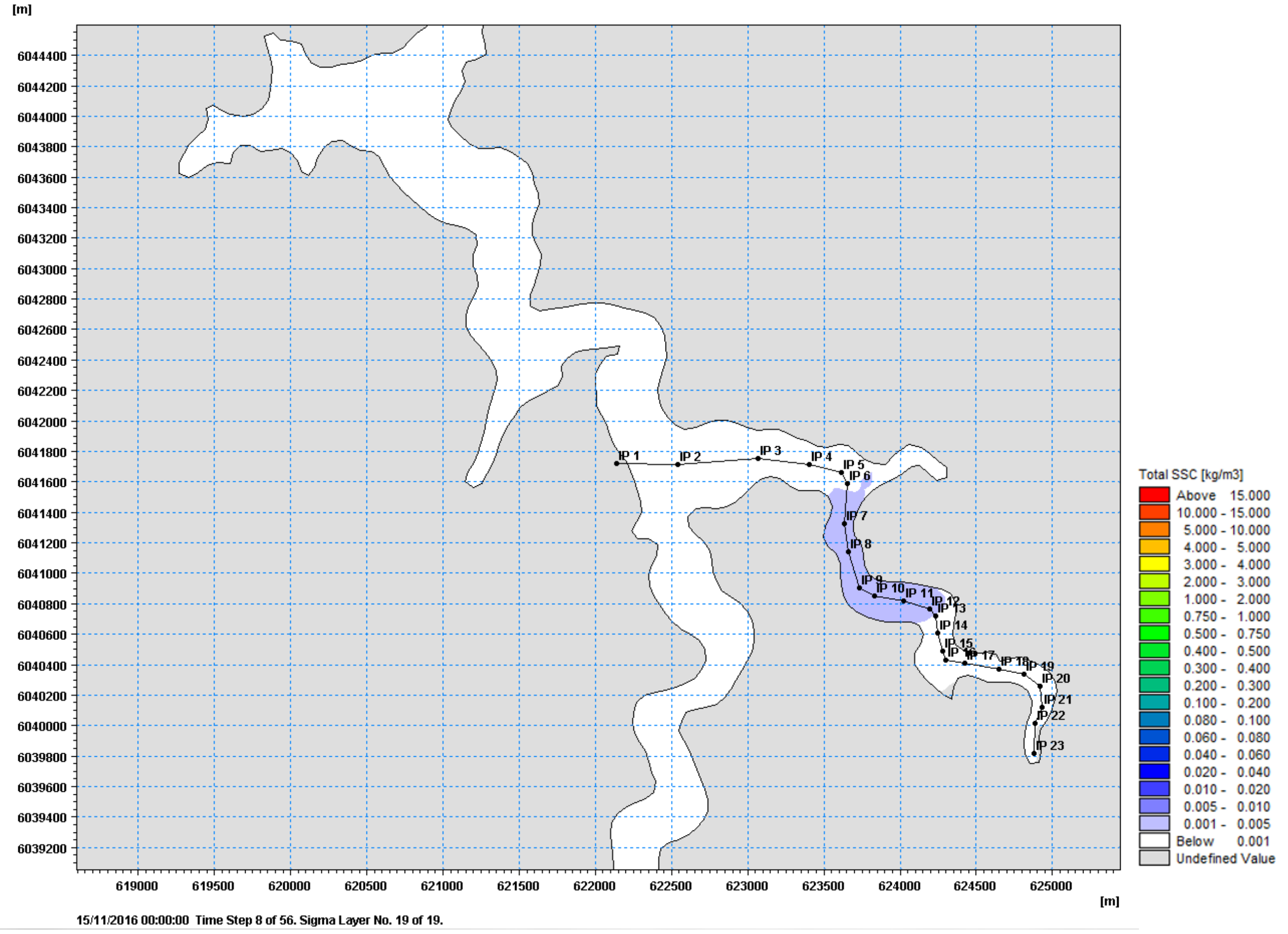

Figure 4-15: Simulated Surface Plume 15th November 2016 0:00.

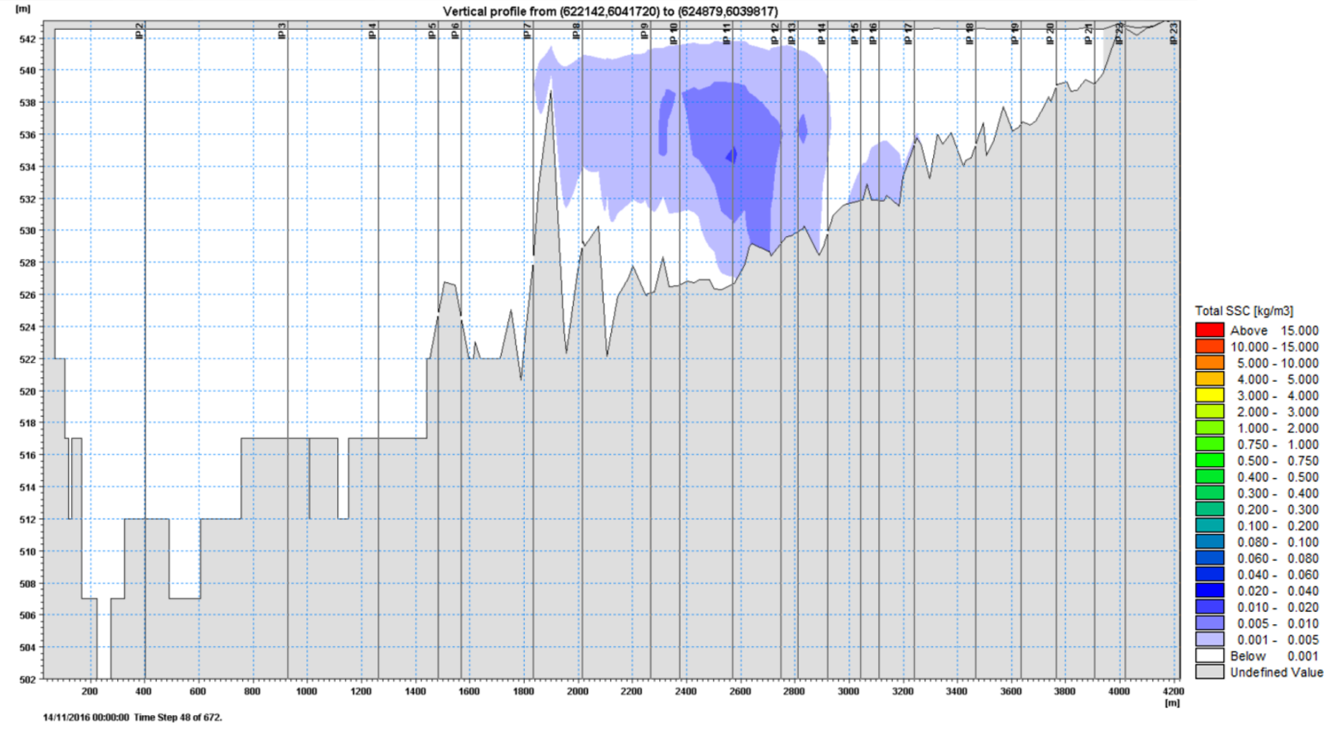

Figure 4-16: Simulated Plume 14th November 2016 0:00 (Vertical Slice).

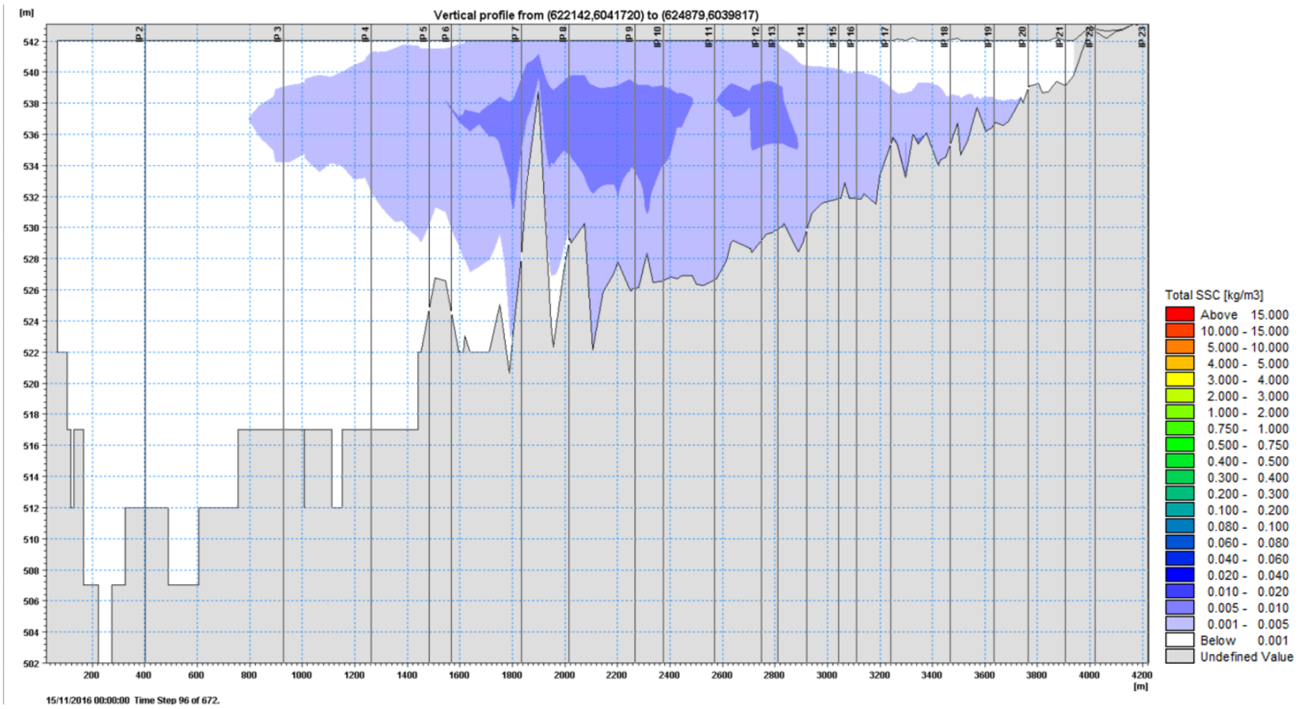

Figure 4-17: Simulated Plume 15th November 2016 0:00 (Vertical Slice).

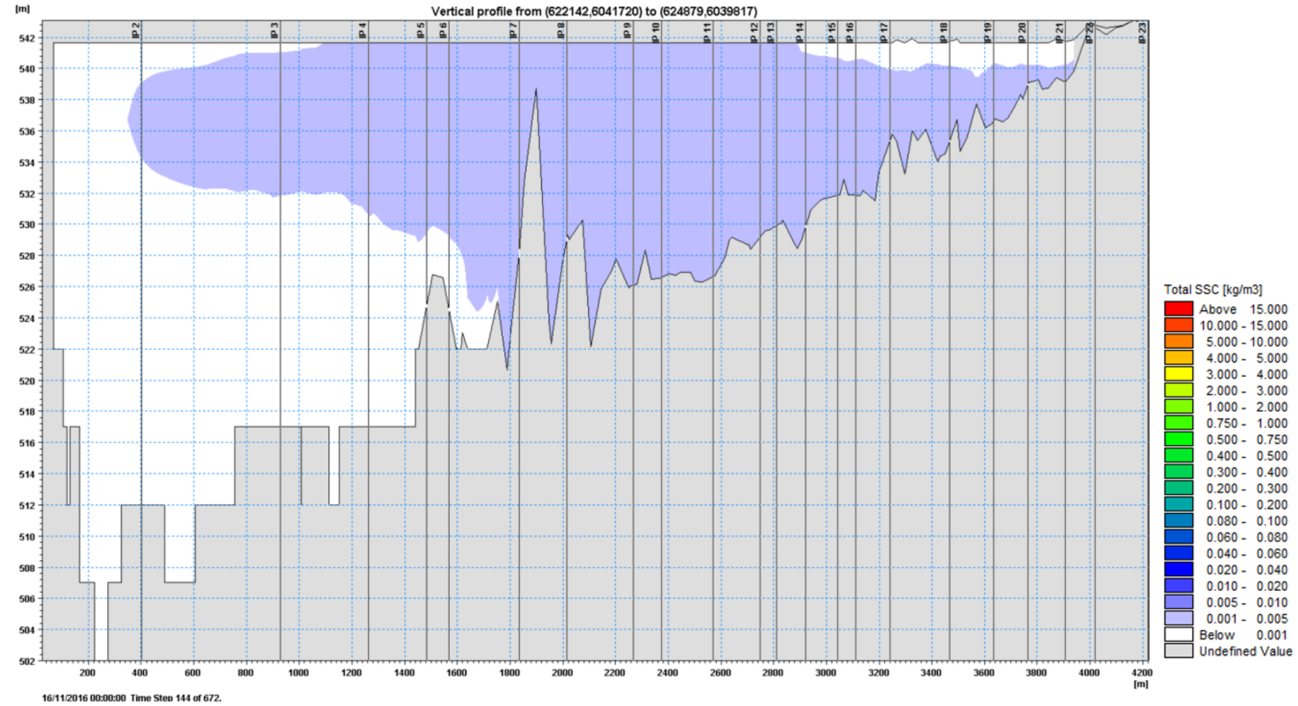

Figure 4-18: Simulated Plume 16th November 2016 0:00 (Vertical Slice).

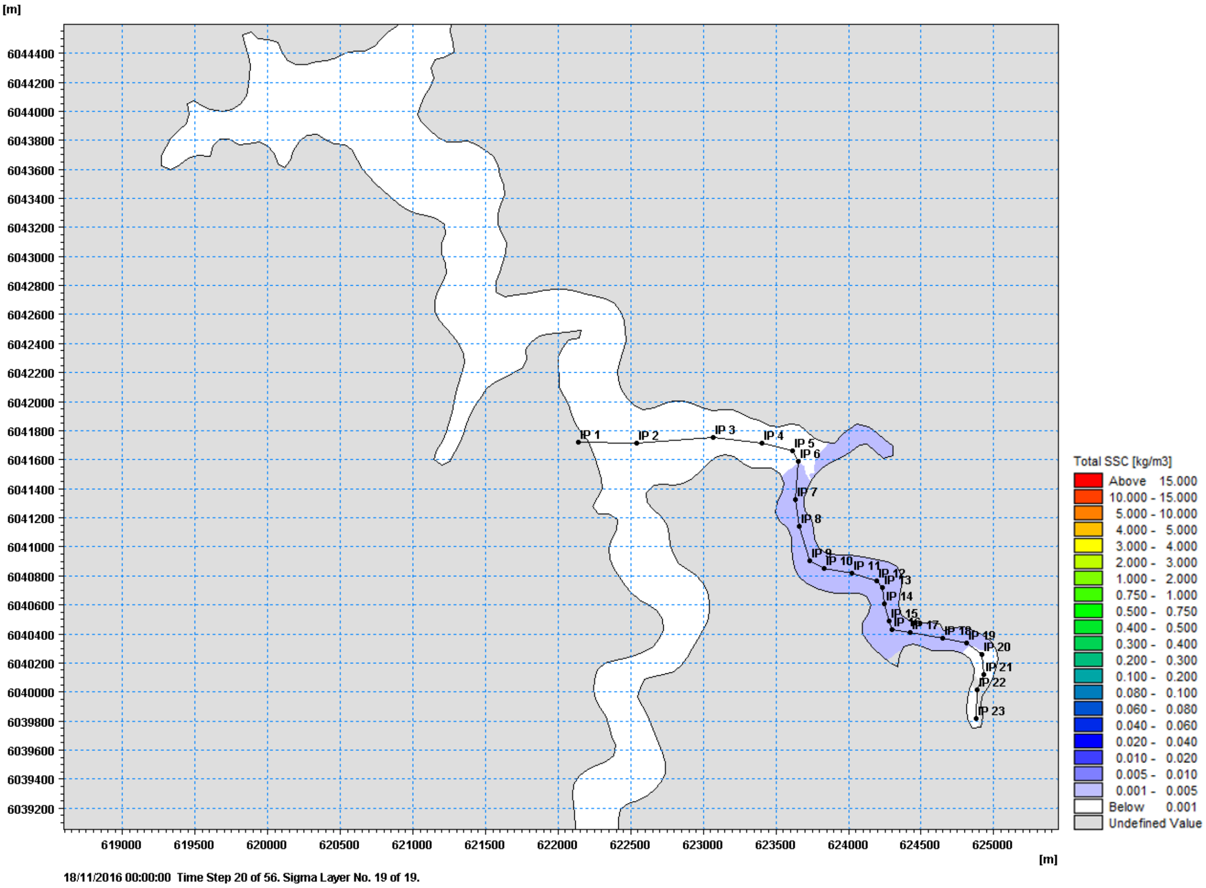

Figure 4-19: Simulated Surface Plume 18th November 2016 0:00.

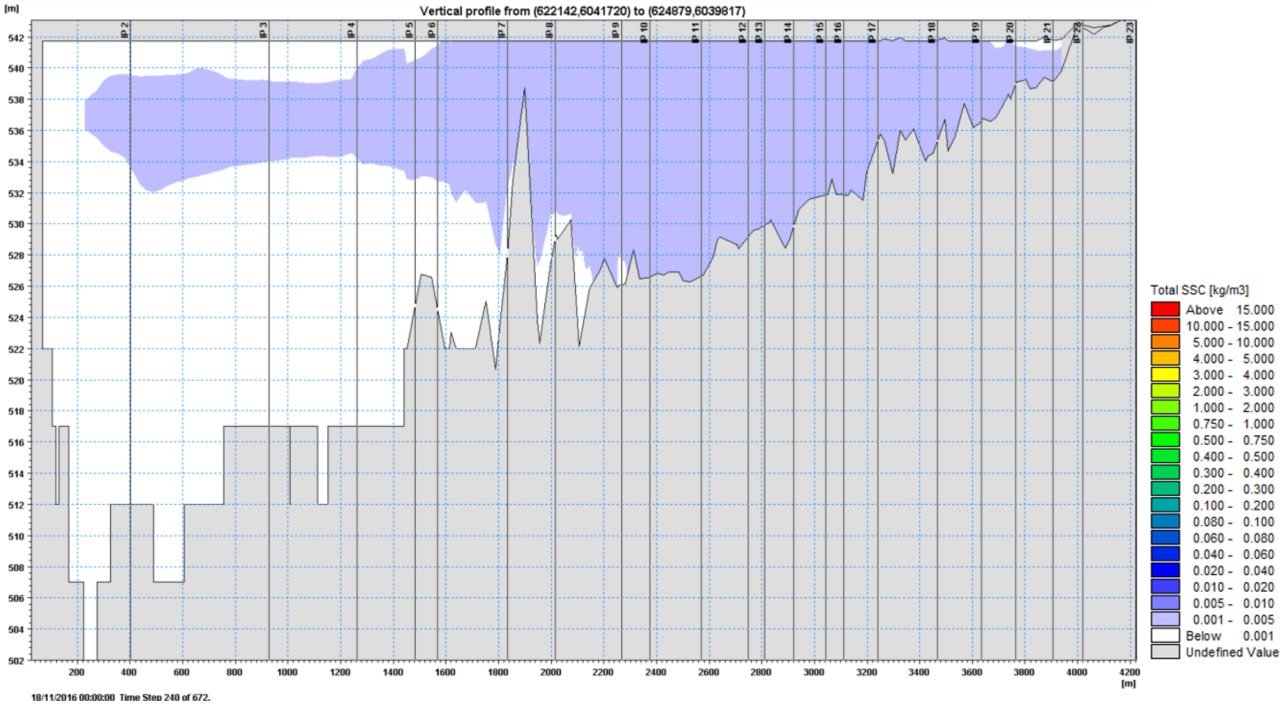

Figure 4-20: Simulated Plume 18th November 2016 0:00 (Vertical Slice).

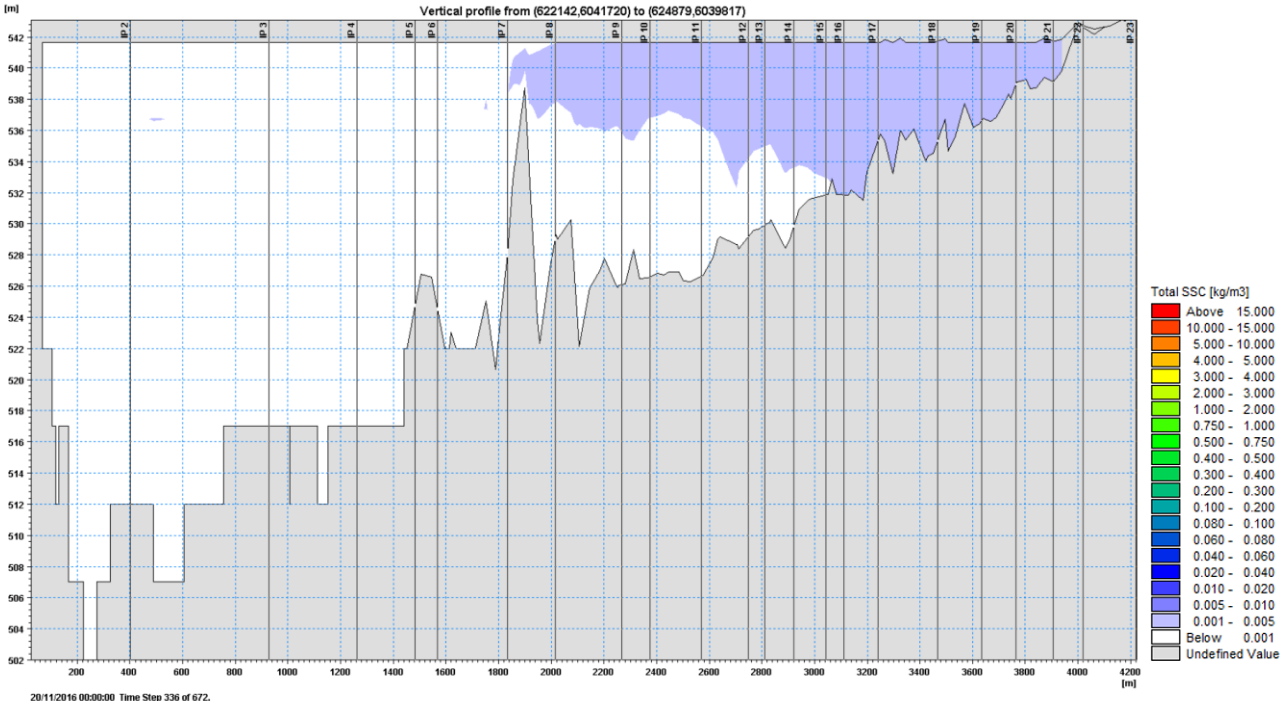

Figure 4-21: Simulated Plume 20th November 2016 0:00 (Vertical Slice).

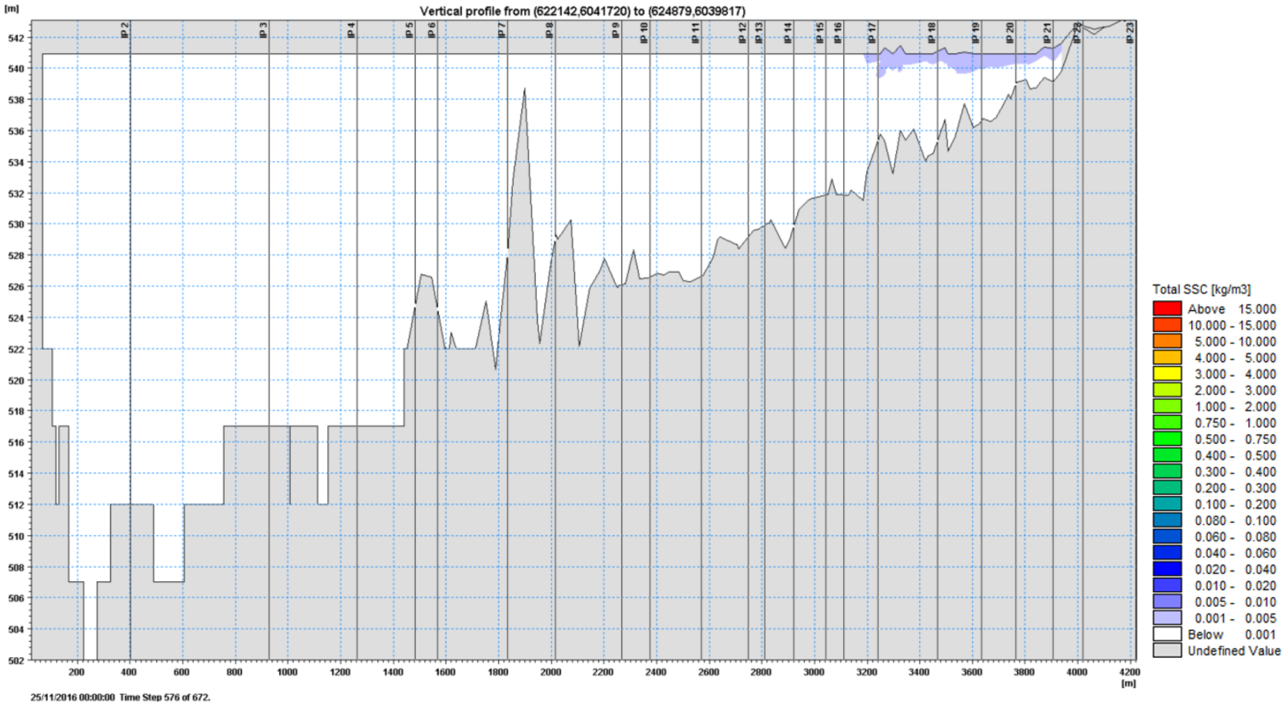

Figure 4-22: Simulated Plume 25h November 2016 0:00 (Vertical Slice).

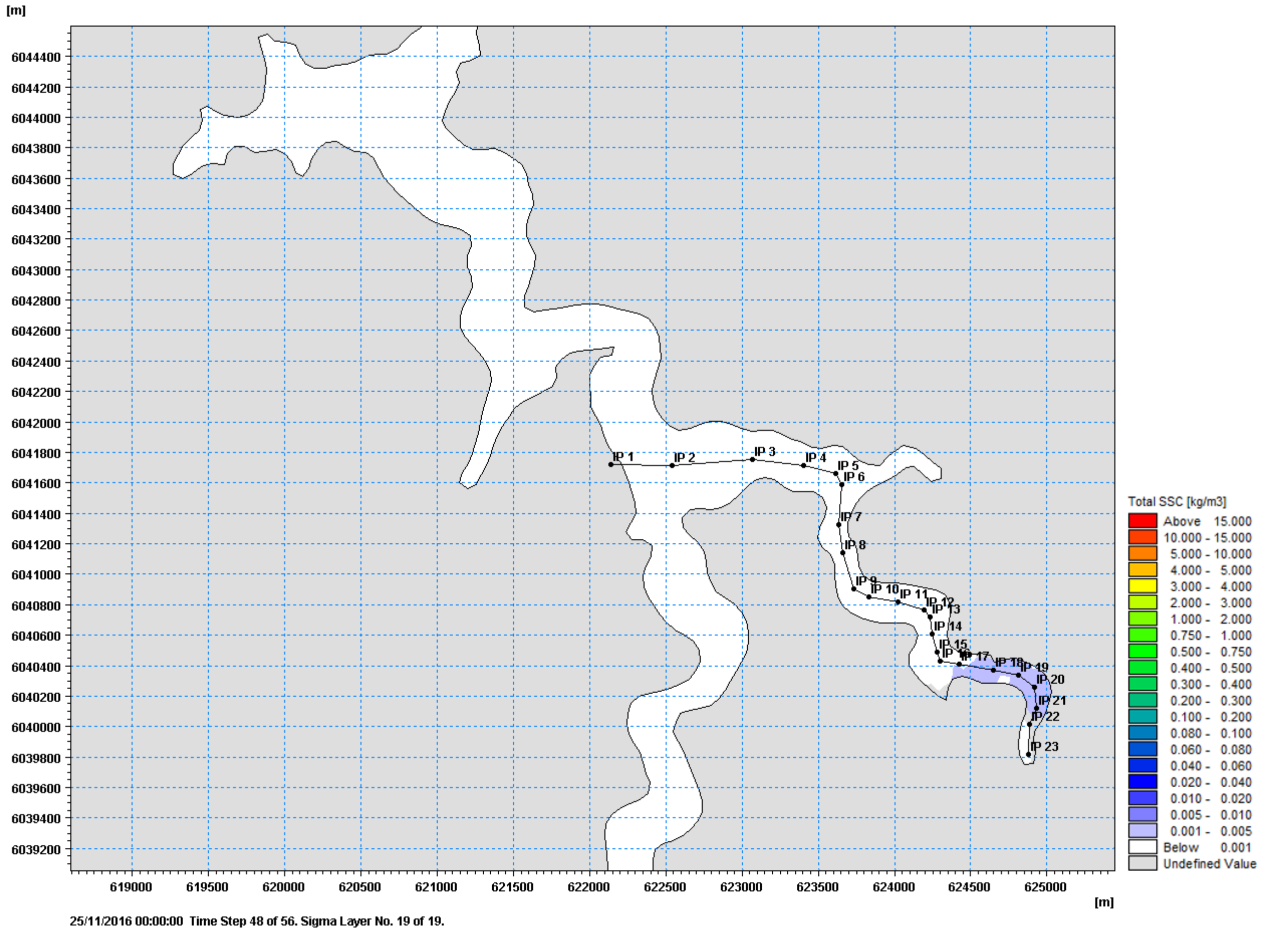

Figure 4-23: Simulated Surface Plume 25^{h} November 2016 0:00.

4.5 Summary and Comments

Overall, the numerical model provides a good prediction of water level and transport/mixing behaviour of the reservoirs. The ability of the model to better predict the observed reservoir water temperatures (which influences the density field and hence hydrodynamics and sediment mixing behaviour) could be improved with measured T2 inflow temperatures, and on-water meteorological data (importantly solar and wind data).

However, the overall calibration indicates that the model is able to suitably represent and predict key hydrodynamic and sediment transport processes and is able to predict the likely movement of sediment plumes within the reservoir.

5 Model Sensitivity Testing and External Model Review

5.1 Sensitivity Testing of the Models

A low level of monitoring data for all major inputs/outputs to the study reservoir complicates the process of calibrating and validating a computer model. Uncertainty surrounding model calibration often arises due to data gaps or errors (e.g. changes to bathymetry over time, indirect measurement of inflows/outflows, temporal and spatial variability of meteorological conditions and gauging errors) associated with data used for a selected calibration period. As such, the sensitivity of the model was assessed using additional model simulations to investigate the effect of changing model parameters and boundary conditions on hydrodynamics and sediment transport conditions.

Groups of model simulations were run for a period of 14 days (and a month for longer term processes) to investigate the sensitivity of:

- **Model parameters**:
    - Advection-dispersion
    - Vertical mixing parameters, and
    - Sediment transport (settling velocity).

- **Model configuration**:
    - Horizontal mesh resolution, and
    - Vertical mesh resolution.

- **Boundary conditions**:
    - Meteorological variables such as solar radiation scale factors
    - Water temperature of T2 inflows, and
    - Influence of scheme flows on mixing (i.e. no T2 or T3 flows).

The results of the sensitivity tests were reviewed during the modelling investigations, and while alternate parameter selection would have a minor influence on the model results, the adopted model parameters and model configuration were found to produce a complete and defensible estimate of hydrodynamics and sediment plume behaviour in Talbingo Reservoir.

Sensitivity testing of the assumptions regarding PSD used in sediment transport / plume modelling is presented in **Section 7**.

5.2 External Model Review

5.2.1 Resource Management Associates

To increase confidence in model predictions and project outcomes, an external model review was undertaken by Dr Ian King[6] (Director of Resource Management Associates Pty Ltd). Dr King is an expert numerical modeller with extensive involvement in limnological, estuarine and coastal 3D hydrodynamic studies. He is the lead author and developer of the RMA2 and RMA10/11 suite of hydrodynamic models which have been used to model a range of complex hydrodynamic environments in Australia and Internationally over the past 30 years.

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[6] *The model review was undertaken using a staged approach with two separate day long meetings used to review the model setup and outputs on 17 October 2018 and 15 November 2018. The results of requested sensitivity tests and answers to specific questions from Dr King were provided by email.*

The review findings by Dr King are presented in **Attachment E**. In general, the review process was used to improve and optimise the model through the project and while no significant issues were found, the review process helped expedite a successful modelling program and increased confidence in model predictions.

5.2.2 AW Maritime

Further external peer review of the hydrodynamic and sediment transport model was undertaken by AW Maritime Pty Ltd (AWM) in May 2019. AWM was engaged by Snowy Hydro to complete an independent, third- party review of the model for the Snowy 2.0 ERP Works. The review process included handover of all MIKE model files and data used in the development of the hydrodynamic and sediment transport models of the Talbingo and Tantangara Reservoirs, and accompanying report detailing the development, calibration and assessment of ERP options.

Following a meeting on 2 May 2019, AWM were requested to document any comments in a register to enable RHDHV to formally respond. A comments register prepared by AWM was used to track external peer review comments and responses. AWM comments were based on a review of the report prepared by RHDHV dated 1 February 2019 and titled “Snowy 2.0 Subaqueous Excavated Rock Placement: Model Development, Calibration and Scenario Model Investigations.” and subsequent modelling scenarios which were captured in PowerPoint presentations, screenshots and images.

The comments register was divided into two sections:

- Review of Hydrodynamic and Sediment Transport Model, and
- Review of the ERP Inputs and Modelling Scenarios.

A copy of the comments register, including all comments raised by AWM and responses provided by RHDHV, is presented in **Attachment F**.

Overall, the review by AWM concluded that:

> “*the modelling work is extensive and overall RHDHV have made the best use of the limited data available to them. Of the data available, all was suitable for implementation into the model and RHDHV provided rational explanations and reasoning for data that required further manipulation.”*
>
> *“It is our opinion that the RHDHV model adequately addresses the hydrodynamics and sediment transport processes of the two reservoirs including the associated hydrological and meteorological forces on the reservoir systems. The model results can be used for comparison purposes and shortlisting disposal scenarios for further investigation.”*

6 Assessment of Proposed and Alternative ERP Options

6.1 Existing (Pre-Placement) Conditions

Modelling of pre-placement conditions undertaken as part of the model development and calibration phase produced results which accurately described the hydrodynamics of Talbingo Reservoir. **The available data suggests that the reservoir typically exhibits very low levels of suspended sediment in the water column. Because the existing levels of suspended sediment are very low, it was considered appropriate to model sediment plume behaviour as being "above background".**

The main potential sources of sediment input under existing conditions are:

- catchment inflows during large rainfall events, and
- potential edge / bank erosion due to wind generated waves.

The only modelling of existing sediment behaviour undertaken was a verification exercise as reported in **Section 4.4**, where the model was tested to reproduce the behaviour of an observed visible sediment plume observed in the Ravine Bay area (in September 2018) following a minor catchment rainfall event on the Yarrangobilly River.

6.2 Overview of Modelled Scenarios

Development and validation of the reservoir model (refer to **Section 3**, **Section 4** and **Section 5**) was undertaken to investigate existing (pre-placement) conditions and then subsequent changes to the reservoir during the construction of Snowy 2.0. Hence, computer modelling was undertaken to:

- understand the physical processes of the existing reservoir environments and to establish a baseline for estimating the magnitude of change caused by ERP activities (refer **Section 4.4** and **6.1**).
- understand the potential change in suspended solids concentration and deposition due to the placement of excavated rock in Talbingo Reservoir. The effects of two methodologies for ERP have been assessed including:
    - Proposed Ravine Bay Placement – Refer **Section 6.3.2** and **6.4**.
    - Alternative Hybrid (D&B Only) Placement - Refer **Section 6.3.3** and **6.5**.
- sensitivity test the adopted PSD used to assess the above impacts (please refer to **Section 7**).

The assessment of the placement of excavated rock is based on a three year simulation of suspended sediment behaviour which includes two years of placement and a year to simulate the return of the reservoir to near background suspended sediment levels. Please note that for the hybrid scenario, placement duration was for 27 months with only 9 months of no placement being simulated. This was still sufficient time for the reservoir to return to near background TSS levels.

6.3 ERP Assumptions and Modelling Setup

6.3.1 Settlement Characteristics of Fine Crushed Rock

Laboratory investigations were undertaken by RHDHV in 2019 to assess the settling performance of the different rock types (geological formations) that would potentially be placed in the reservoir. In total, nine main geological formations are located within the tunnel alignment and, hence, could have been placed in one of the reservoirs. Six (potentially 7) rock types from individual geological zones are proposed to be placed in Talbingo Reservoir including: Boggy Plain Suite, Gooandra Volcanics, Byron Range Group, Boraig Group (Igneous), Boraig Group (Sedimentary), Ravine Beds and potentially Temperance Formation.

The scope of work for the laboratory investigations comprised four detailed tests which were undertaken for each geological formation, including:

1. Column test to establish TSS-turbidity relationship (refer **Section 3.3**)
2. Settlement test to determine the settling behaviour of crushed rock
3. Flocculation trial to assess whether a chemical flocculant would clarify the water, and
4. Critical particle size analysis to determine the maximum particle size remaining in suspension.

It was apparent from the column and settlement tests that once fine crushed rock entered the water column, a portion of the finer particles remained in suspension for an extended period, in the order of several weeks or more. Crushed rock from the Tantangara Formation, Ravine Beds and Boraig Group geological zones generally resulted in extended periods of higher surface turbidity. In comparison, crushed rock from the Gooandra Volcanics geological zone settled out of suspension relatively quickly. Furthermore, crushed rock from the Byron Range Group geological zone behaved differently to the other rock zones (i.e. while the material settled quickly in the settlement tests, elevated surface turbidity was recorded (higher than other tests) for an extended period when the water and crushed rock mixture was agitated for the column test).

Except for Byron Range Group, the TSS-turbidity correlations for the geological zones were similar (refer **Section 3.3**). Turbidity equivalent to a TSS concentration of 50 mg/L varied between 43 NTU (Gooandra Volcanics) and 68 NTU (Tantangara Formation and Ravine Beds). The crushed rock was generally light grey to grey/blue in colour, except for the Byron Range Group, which was red-orange. The darker colour resulted in less light penetration and higher turbidity for an equivalent TSS concentration. Turbidity equivalent to a TSS concentration of 50 mg/L was 102 NTU for the Byron Range Group.

The tests also aimed to determine the maximum particle size in suspension after a given period of time. After 15 minutes, the maximum particle size in suspension was 15 µm to 37 µm reducing to 2.5 µm to 6 µm after 24 hours, except for the Byron Range Group. The PSD was coarser at depth within the columns. Settlement velocities determined from the critical particle size analysis are slower than those predicted by Stokes Law.

Based on the laboratory investigation, it was inferred that:

- placement of crushed rock near the bed of the reservoir reduces turbidity within the water column
- placement at depth within the reservoirs when a thermocline is apparent (i.e. during summer) is less likely to result in vertical mixing and advection of crushed rock towards the surface
- management measures that minimise or control the release of such fine fractions may improve the management of surface turbidity during rock placement activities
- minor disturbances to the water column during field rock placement activities in the reservoirs (e.g. due to fresh water flows, operational flows from the existing Snowy scheme (T2 and T3) wave action and propeller wash) are likely to disrupt the settlement process and/or re-suspend fine particles, and
- the settling velocity of critical particle sizes could be less than settling velocities calculated based on gravitational and drag forces alone (i.e. Stokes Law). This suggests that other processes such as particle charge, which can introduce repulsion between very fine particles (i.e. very fine silt, clays), may prevent small particles from aggregating and settling under the action of gravity. The

possibility of scale effects and the confinement introduced by the settling tube walls need to be considered in interpreting the laboratory data.

6.3.2 Assumptions for Modelling Proposed Ravine Bay Placement Method

Assumptions regarding placement and sediment properties used in ERP modelling for the proposed Ravine Bay Placement, edge push (TBM and D&B) placement design (as detailed in Section 2.5.2) is presented in:

- **Table 6-1** – Summary of ERP Assumptions for Proposed Method
- **Table 6-2** – Summary of placement rate assumptions
- **Table 6-3** – Particle Size Distribution Assumptions
- **Table 6-4** – Fall Velocity Assumptions, and
- **Table 6-5** – Placement Method Assumptions.

The assumptions that were used to create inputs for the MIKE-3 dredge module are shown below. A number of these assumptions (such as the daily placement rate, proportion of fines (i.e. PSD) and the “source term” (i.e. the proportion of the fines, as a percentage, that are entrained in the water column during the placement activity (conversely the proportion of fines that **do not** fall and settle immediately to the bed)) could significantly influence the magnitude of the predicted sediment plume. Sensitivity testing of PSD is presented in Section 7.

Table 6-1: Summary of ERP Assumptions for Proposed Ravine Bay Placement Method

Assumption		Comment
Total Placed (bank) Volume (m^3)	2 860 797	Refer **Table 2-5**.
TBM Placed (bank) Volume (m^3)	1 333 371	46.6 % of Total.
D&B Placed (bank) Volume (m^3)	1 527 426	53.4 % of Total.
TBM Percentage of total excavated volume as Fines (<63 µm) (%)	6.0	
D&B Percentage of total excavated volume as Fines (<63 µm) (%)	2.0	
TBM Percentage of total excavated volume as Clay (<4 µm) (%)	0.7	
D&B Percentage of total excavated volume as Clay (<4 µm) (%)	0.3	
Assumed density of *in-situ* rock (kg/m^3)	2 710	Estimate (typical) based on density of rock material.
Total mass of fines (kg).	299 592 614	Assume dry bulk density of 2710 kg/m^3
Number of Days of Placement.	730	
Typical days per week of placement (days/week).	7	
Placement Rate (bank m^3/day)	4935 to 2423	Varies each 6 months (see below table)
Average Placement Rate (bank m^3/day)	3919	

Table 6-2: Summary of ERP Placement Rate Assumptions for Proposed Ravine Bay Placement Method

Period	TBM volume to be placed (bank m^3)	D&B volume to be placed (bank m^3)	Total volume to be placed (bank m^3)	% TBM material	Number of placement days	Placement rate (bank m^3/day)

0-6 months	561,129	332,024	893,153	62.8	181	4935
6-12 months	202,407	516,565	718,972	28.2	184	3907
12-18 months	377,323	425,447	802,770	47.0	181	4435
18-24 months	192,512	253,390	445,902	43.2	184	2423
Total	**1,333,371**	**1,527,426**	**2,860,797**	**46.6**	**730**	**3919 (Average)**

Table 6-3: Summary of MIKE-3 Sediment Transport Model Configuration – Particle Size Distribution (PSD) Assumptions

Sediment Class	Model ID	Sediment Fraction	Particle Size (µm)	TBM % of Total Fines	D&B % of Total Fines
SILT	SS1	Coarse silt	63-31	22.08%	21.25%
	SS2	Medium silt	31-16	22.08%	21.25%
	SS3	Fine silt	16-8	22.08%	21.25%
	SS4	Very fine silt	8-4	22.08%	21.25%
CLAY	SS5	Clay	<4	11.67%	15.00%

Table 6-4: Summary of MIKE-3 Sediment Transport Model Configuration – Fall Velocity Assumptions

Representative Particle Size (µm)	Model ID	Settling Velocity @ 18 °C – (Stokes Law)	
		m/s	cm/s
47	SS1	0.0018780	0.1877979
24	SS2	0.0004897	0.0489686
12	SS3	0.0001224	0.0122421
6	SS4	0.0000306	0.0030605
2	SS5	0.0000034	0.0003401

Table 6-5: Summary of MIKE-3 Sediment Transport Model Configuration – Placement Method "Source Term" Assumptions

Assumption		Comment
% Silt entrained in water column during placement	45%	Assumed evenly distributed through the water column
% Clay entrained in water column during placement	60%	40% of this is released in the surface layer (top 2m) 60% of this is evenly distributed through the water column
Mass of silt in water column (kg)	117,846,267	Placed mass x PSD x "Source Term"
Mass of clay in water column (kg)	22,627,213	Placed mass x PSD x "Source Term"
Total Mass fines in water column (kg)	140,473,479	

Notes: Source term estimate provided by RHDHV based on experience with ERP activities.

Percentages indicate the proportion of total fines expected to be entrained/released into the water column because of ERP.

6.3.3 Assumptions for Modelling Alternative Hybrid (D&B Only) Placement

Assumptions regarding placement and sediment properties used in ERP modelling for the alternative Hybrid Placement, edge push method (D&B only) placement design (as detailed in **Section 2.5.3**) are presented in **Table 6-6**. PSD and fall velocity assumptions are unchanged (i.e. refer **Table 6-3** and **Table 6-4**). A summary of the adopted "source term" and total mass assumed to be released into the water column is presented in **Table 6-7**. Compared to the proposed method, the alternative introduces only 25% of the total fines to the water column. Because of differences in the PSD assumptions between TBM and D&B material, compared to the proposed method, the alternative method introduces only 30% of the clay mass to the water column.

Table 6-6: Summary of ERP Assumptions for Alternative Hybrid Placement (D&B Only) Method

Assumption		Comment
D&B Placed (bank) Volume (m^3)	1,400,000	
D&B Percentage of total excavated volume as Fines (<63 µm) (%)	2.0	
D&B Percentage of total excavated volume as Clay (<4 µm) (%)	0.3	
Assumed density of *in-situ* rock (kg/m^3)	2,710	Estimate (typical) based on density of rock material.
Total mass of fines (kg).	75,880,000	Assume dry bulk density of 2710 kg/m^3
Number of Days of Placement.	800	Approximately 27 months
Typical days per week of placement (days/week).	7	
Placement Rate (bank m^3/day)	1750	

Table 6-7: Summary of MIKE-3 Sediment Transport Model Configuration – Alternative Hybrid Method "Source Term" Assumptions

Assumption		Comment
% Silt entrained in water column during placement	45%	Assumed evenly distributed through the water column
% Clay entrained in water column during placement	60%	40% of this is released in the surface layer (top 2m) 60% of this is evenly distributed through the water column
Mass of silt in water column (kg)	29,024,100	Placed mass x PSD x "Source Term"
Mass of clay in water column (kg)	6,829,200	Placed mass x PSD x "Source Term"
Total Mass fines in water column (kg)	35,853,300	

Notes: Source term estimate provided by RHDHV based on experience with ERP activities.
Percentages indicate the proportion of total fines expected to be entrained/released into the water column because of ERP.

6.3.4 Details of Modelling Methodology

Using available data previously described, the reservoir model was updated to include a structure to represent the influence of the silt curtain (which for modelling purposes was assumed to be impermeable). The hydrodynamic model was then run for a continuous period of:

- Five months (13 November 2016 to 5 April 2017) – a recent summer heating period, and
- Seven months (5 April 2017 to 13 November 2017) – a recent winter cooling period.

The period is a slight (approximately 2 week) extension of the calibration period which then provides a full 12 months of reservoir hydrodynamics. By repeating the 12 month (13 November 2016 to 13 November 2017) period three times, a 3 year duration of sediment transport simulation was used to assess the impact of proposed ERP. This includes a 2 year period of placement and a 1 year period of recovery. At the end of the 1 year period of recovery, virtually all remaining suspended sediment had either settled to the reservoir bed or had been flushed from Talbingo Reservoir (though the T3 outlet).

Suspended sediment was input to the Mike MT module using a dredger input module using the assumptions defined in:

- Section 6.3.2 for the proposed Ravine Bay method
- Section 6.3.3 for the alternative “Hybrid” (D&B only) Ravine Bay method.

6.4 Predicted Impact of Proposed Ravine Bay ERP in Talbingo Reservoir

A range of model outputs have been generated to assist assessing the predicted sediment plume which would result from the proposed Ravine Bay placement. A summary of the outputs includes:

- **Maps of Maximum TSS Concentration**: these maps show the maximum TSS concentration during the simulation at the surface (see **Section 6.4.1**).
- **TSS Concentration Time Series Plots**: Time series of TSS at the surface, mid-depth and bed for various locations along the reservoir (see **Section 6.4.2**). Please note that the right hand axis on the graph presents the rate (kg/s) of silts and clays that are assumed to be released to the water column (grey chart lines).
- **Sediment Mass Flux Calculations**: which summarise the mass of sediment leaving the reservoir through the T3 outlet near the dam wall (see **Section 6.4.3**).
- **Sediment Deposition Depth Plots**: which present the total thickness of sediment deposited over the simulation period (see **Section 6.4.4**).

6.4.1 Predicted Peak Surface Suspended Sediments Concentration

Predicted peak surface TSS for the three year simulation is presented in **Figure 6-1**. This is the highest TSS concentration that was predicted at any time during the simulation. The results show that peak TSS within the silt curtain surrounding the placement area is above 500 mg/L, while in the main body of the reservoir between Ravine Bay and the dam wall the TSS ranges from 32 to 16 mg/L. Upstream of the placement area along the Tumut and Yarrangobilly arms, there are significantly higher peak concentrations of between 50 and 100 mg/L predicted. This occurs during the summer, when colder T2 and Yarrangobilly inflows produces a cool dense current that flows downstream towards the dam wall. This produces a hydrodynamic response in which a warmer surface current travels upstream, transporting high TSS material that is trapped above the thermocline with it.

The time-series TSS results (presented in **Section 6.4.2**) show that the peak surface TSS typically occurs in the first six months of placement during the summer period (when TSS is trapped above the thermocline).

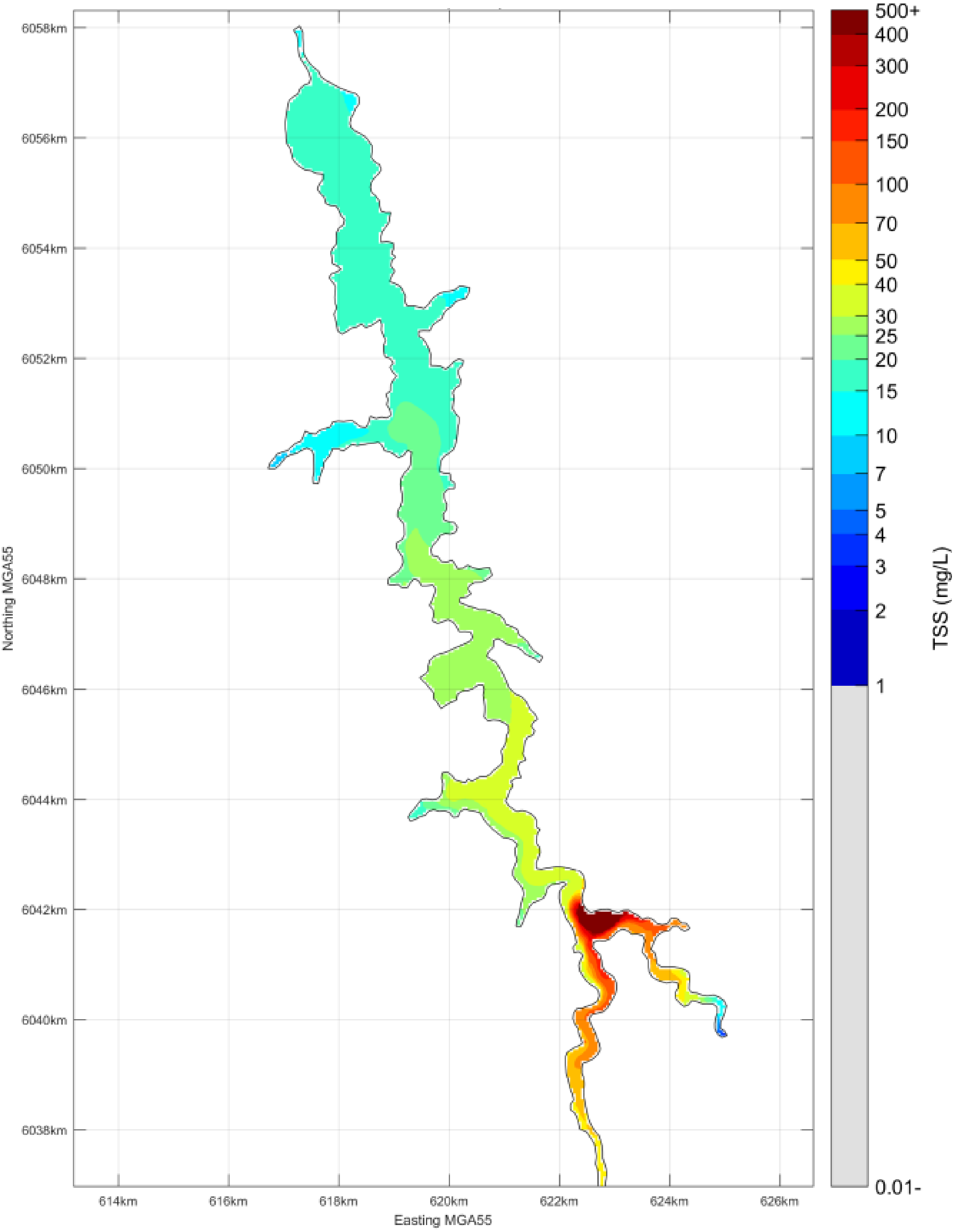

Figure 6-1: Predicted Maximum Surface TSS for Proposed Ravine Bay Method

6.4.2 Predicted Time Series of Suspended Sediments Concentration

Time-series of TSS at the surface, mid-depth and bed for 11 locations along the reservoir (defined in **Figure 6-2**) were extracted from the 3D plume model. Four key time series are presented in **Figure 6-3** to **Figure 6-6** and are summarised in **Table 6-8**. The remaining figures are presented in **Attachment H**.

A number of key observations can be made regarding the TSS time-series data:

- Peak surface concentrations occur during the “heating” months (October to April) as stratification traps the TSS in the surface layer.
- Peak TSS concentrations occur closer to the placement site and reduce with distance away from Ravine Bay towards the dam wall.
- As the reservoir cools during the winter months, thermal destratification occurs and TSS is able to mix downwards through the water column. This is presented in **Figure 6-4** (Lick Hole Creek), where:
  - surface TSS begins to fall in late-April,
  - mid-depth TSS rapidly rises in June, and
  - bed TSS rapidly rises a few months later in August.
- As the reservoir begins to stratify in the spring and summer, mid-depth and bed TSS levels begin to drop while surface TSS rises.
- Peaks occur during the first year of the simulation due to the higher placement rates that occur.
- When placement finishes (after 2 years), TSS levels drop rapidly as much of the Reservoir is flushed by incoming T2 discharge. **Figure A-3** shows that the T2 inflow for the modelled year is ~1000GL, which (assuming full flushing) is able to completely replace the available 921 GL of reservoir volume.
- At location 11 (500m east of the placement area), the TSS levels are much higher and there is greater fluctuation in predicted TSS levels. These fluctuations are due to the influence of advection (water movement), which occurs due to the high frequency water level fluctuations (see **Figure 4-2**). The difference in peak TSS between the first and second year is due to the progression of the placement site moving further to the west over this period.

Table 6-8: Summary of TSS Time-Series Results (Proposed Ravine Bay Placement Method)

Location (Figure No)	Peak Surface TSS (mg/l))
Location 1 (near dam wall) **Figure 6-3**	16
Location 4 (Lick Hole Creek) **Figure 6-4**	26
Location 9 (~1 km North of Placement Area) **Figure 6-5**	32
Location 11 (500m East of Placement Area) **Figure 6-6**	80

A more detailed summary of time-series TSS concentration data including an estimation of the equivalent turbidity values is presented in **Table 6-9**.

Table 6-9: Summary of Predicted Surface TSS Concentrations and Estimated Turbidity (Proposed Ravine Bay Placement Method)

Location	Location description	Estimated TSS concentration (mg/L)				Estimated turbidity (NTU)[3]		
		Annual		**Warming**	**Cooling**	**Annual**	**Warming**	**Cooling**
Talbingo Reservoir background level (2018–2019)		**<1–6 mg/L[1]**				**1-5 NTU[4]**		
Default guideline value		**note 2**				**1-20 NTU[5]**		
11	Yarrangobilly Arm, approximately 500 m of placement area	Median	18	43	9	39	61	28
		Maximum	80	80	70	83	83	78
9	Approximately 1 km north of placement area	Median	7	18	7	24	39	24
		Maximum	31	31	25	52	52	46
4	Adjacent Lick Hole Creek, approximately half-way along the reservoir	Median	8	15	5	26	36	20
		Maximum	26	26	22	47	47	43
1	Adjacent the dam wall	Median	6	10	3	22	29	16
		Maximum	16	16	14	37	37	34

Notes:

1. Discrete water quality samples collected 2018-2019.
2. There is no default ANZECC/ARMCANZ (2000) TSS concentration guideline value.
3. Ravine beds: NTU = 9.0649 x TSS $^{0.506}$
4. Time-series results from mooring in reservoir (2018/2019), 1st-percentile to 99th-percentile
5. Default turbidity guideline value for freshwater lakes and reservoirs in South-Eastern Australia (ANZECC/ARMCANZ 2000)

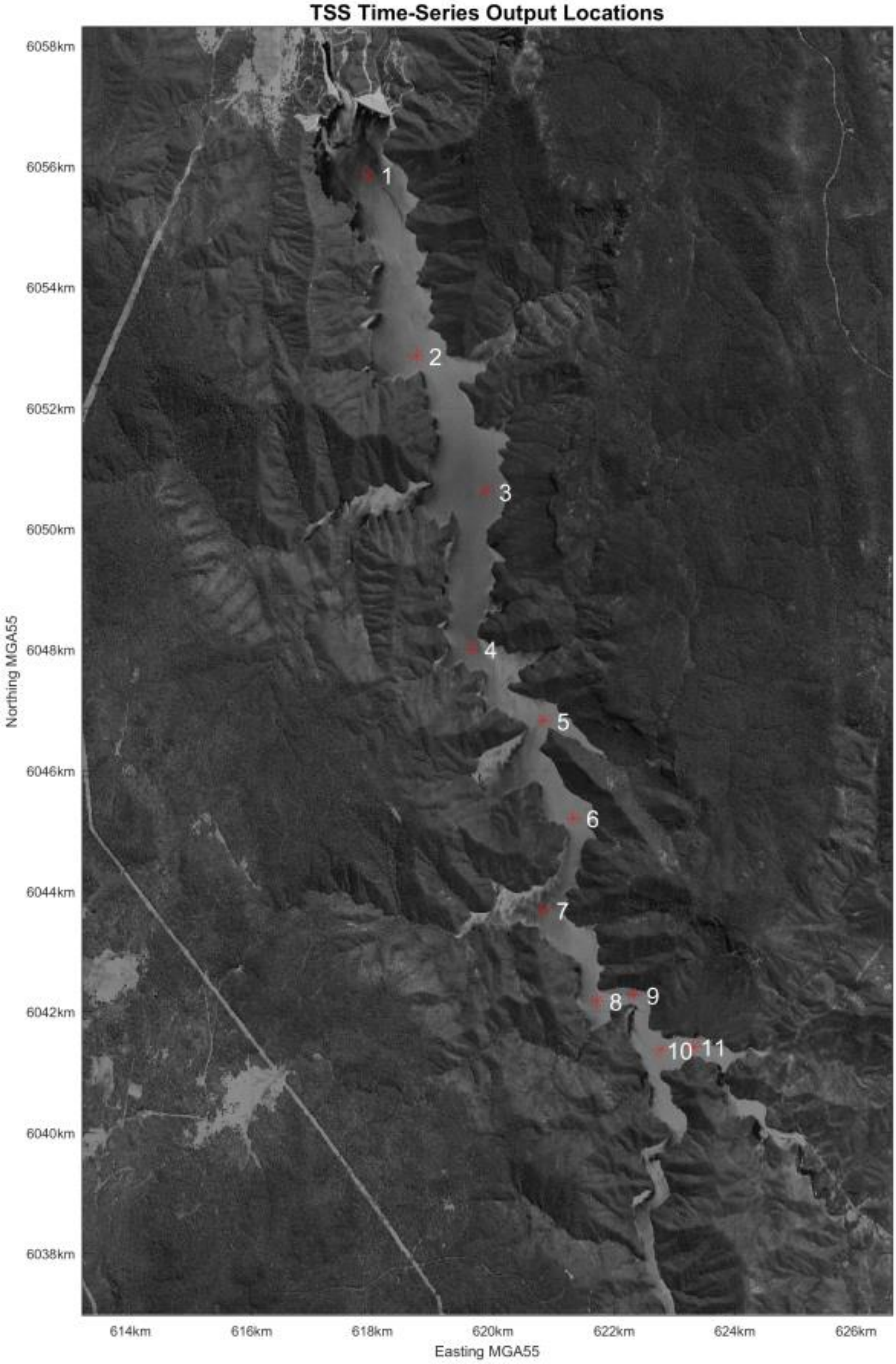

Figure 6-2: Location of Time Series Output Points in Talbingo Reservoir

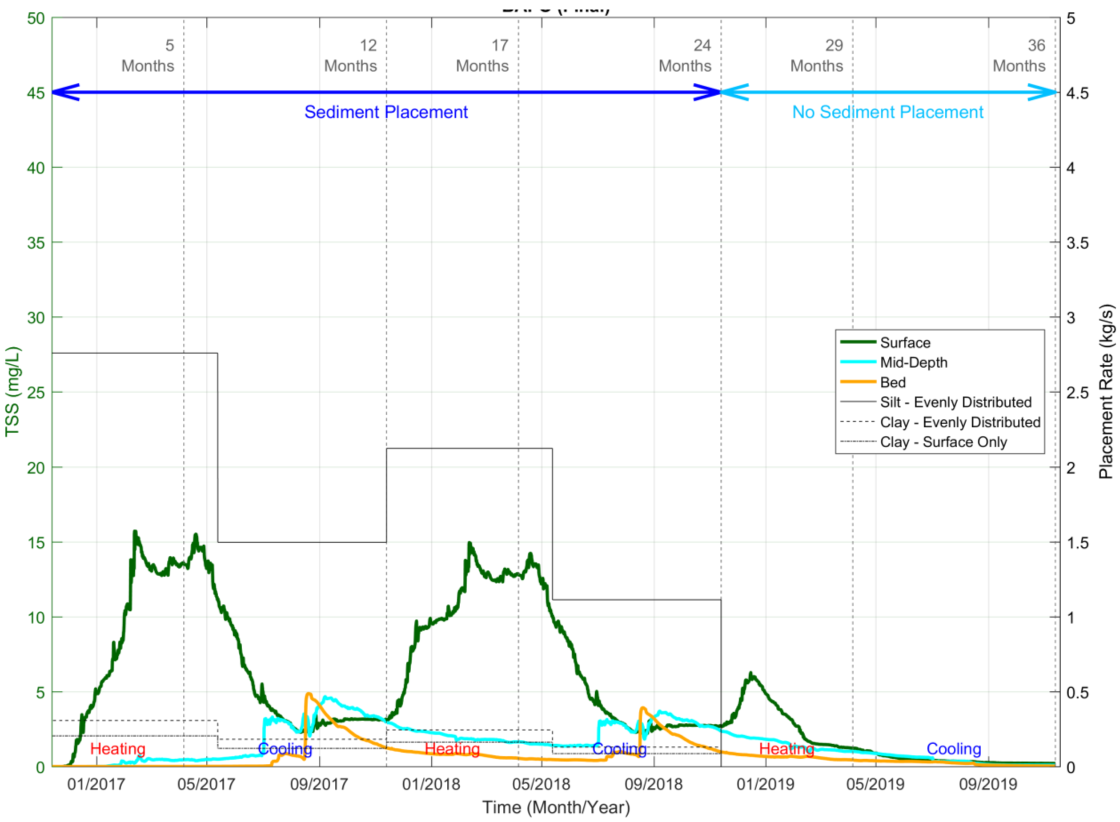

Figure 6-3: Time Series of TSS (Surface, Mid-depth and Bed) Location 1 (near dam wall) for Proposed Method

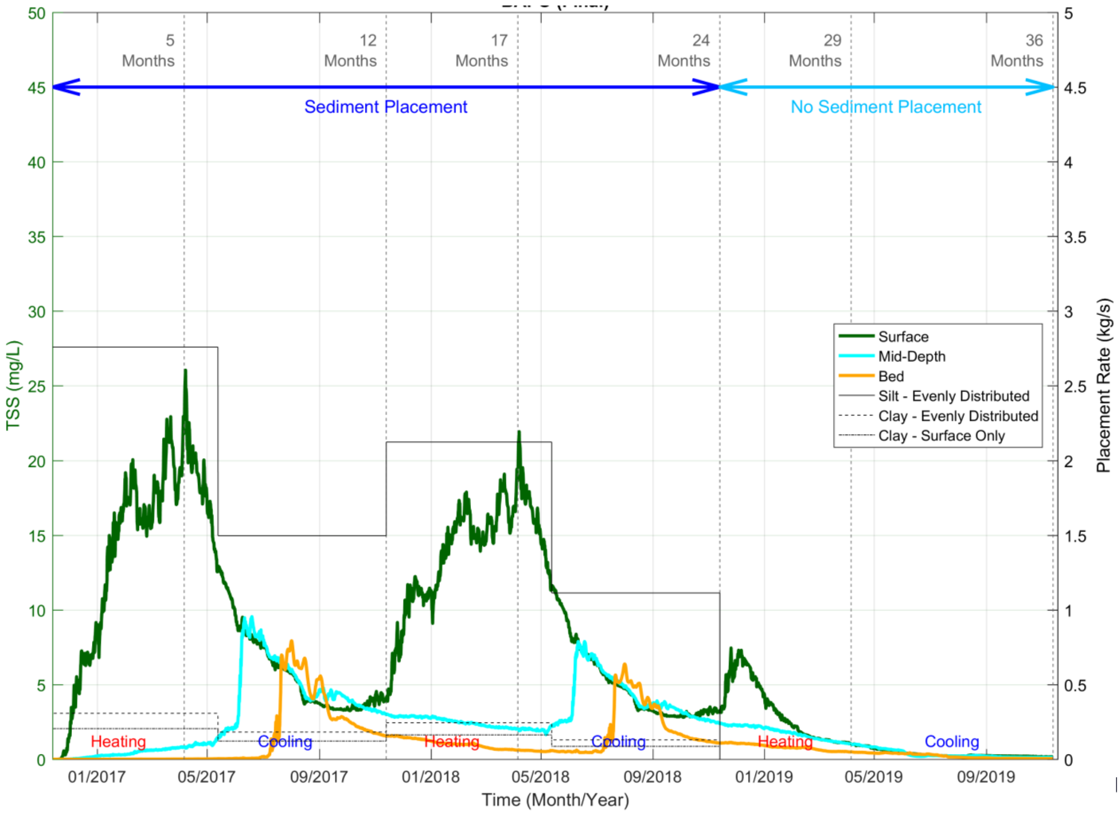

Figure 6-4: Time Series of TSS (Surface, Mid-depth and Bed) Location 4 (Lick Hole Creek) for Proposed Method

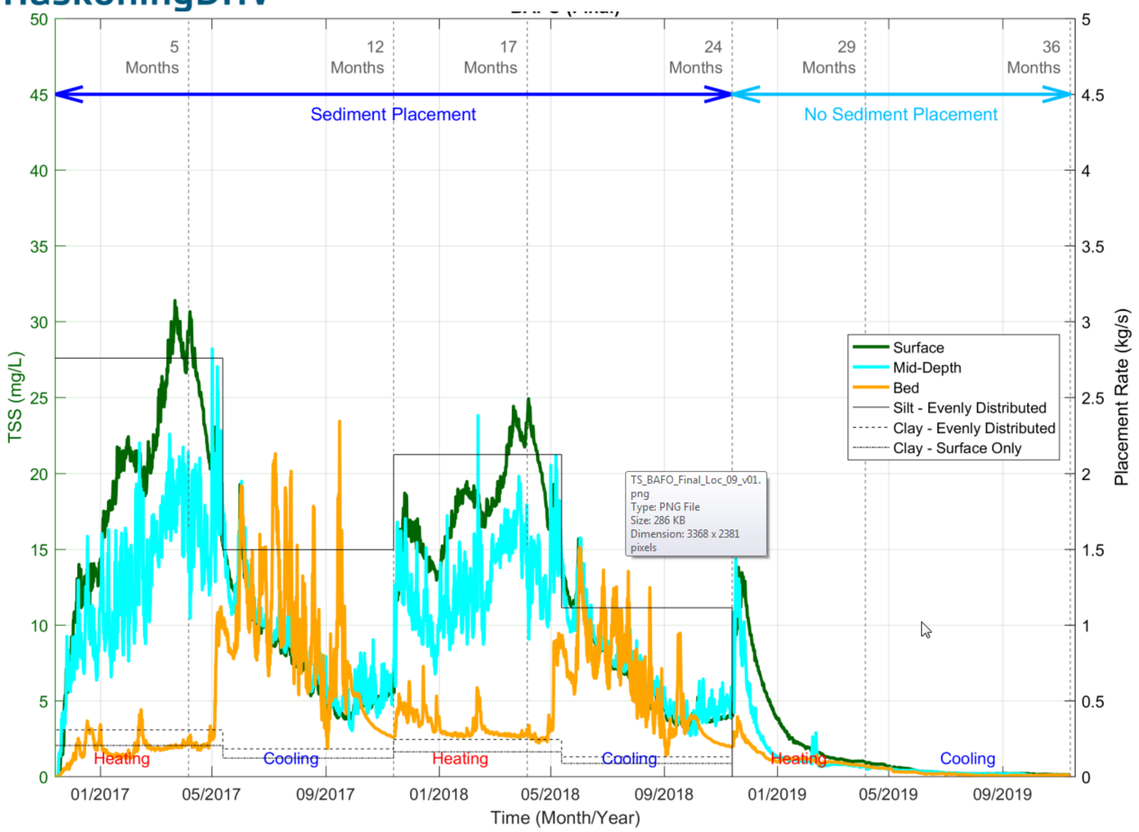

Figure 6-5: Time Series of TSS (Surface, Mid-depth and Bed) Location 9 (~1 km North of Placement Area) for Proposed Method

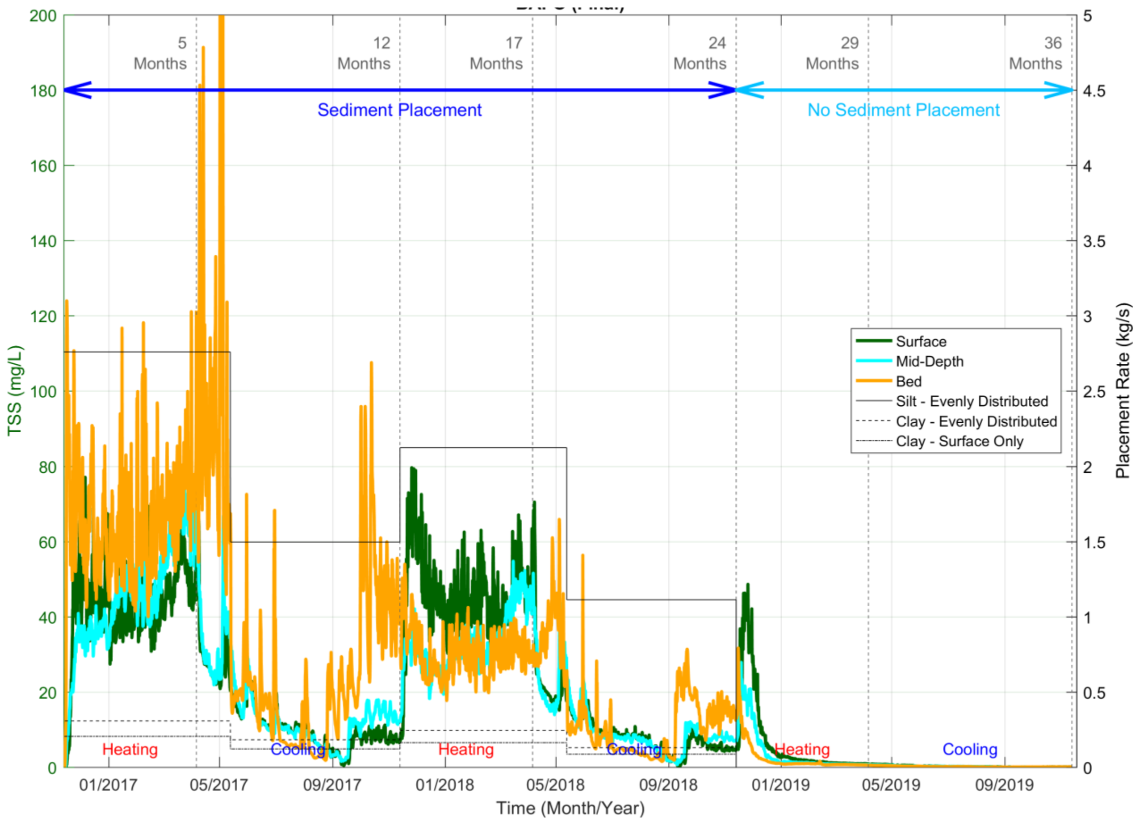

Figure 6-6: Time Series of TSS (Surface, Mid-depth and Bed) Location 11(500m East of Placement Area) for Proposed Method

6.4.3 Predicted Mass of Sediment Transported from Talbingo Reservoir

Table 6-10 presents an analysis on the predicted mass of sediment that is:

- introduced to the water column in Talbingo Reservoir
- transported downstream into Jounama Pondage (via T3 outflows)

The calculation of mass of fines (silts, clay and total) is based on:

- the type (TBM or D&B) and volume of excavated rock that is to be placed in the reservoir;
- the assumed PSD of the material (this defines the fractions of fine material (i.e. % of silt and clays)); and
- the assumed percentage (i.e. "source term") of fines that when placed in the reservoir does not immediately settle on the bed and instead is released into the water column as suspended sediment.

The calculations show that of the proposed 2.86 Million m^3 (bank) of excavated rock material that is to be placed in Talbingo Reservoir using the proposed Ravine Bay placement method, 140,473 tonnes of fine sediment, including 22,627 tonnes of clay, would be released to the water column.

The model is able to calculate the mass of sediment that is predicted to be transported from Talbingo Reservoir through the T3 outflows into Jounama Pondage. The model predicts that at the end of the three year simulation period, 16,021 tonnes of fines will have been discharged through T3. This comprises of 6,018 tonnes of silts and 10,003 tonnes of clay sized sediments. This indicates that 95% of available "source term" silts will settle in Talbingo Reservoir, while only 56% of clay sized sediments will be retained in the reservoir.

The concentration of TSS leaving the reservoir will be similar to that predicted at Location 1 (refer **Figure 6-2**).

Table 6-10: Summary of Modelled TSS Mass Leaving Talbingo Reservoir (Proposed Ravine Bay Placement Method)

Quantity	Mass (Tonnes)	Comment
Mass of silt released to reservoir (tonnes)	117,846[1]	Silts comprise 84% of fines introduced to the water column
Mass of clay released to reservoir (tonnes)	22,627[1]	Clays comprise 16% of fines introduced to the water column
Total Mass fines released to reservoir (tonnes)	140,473[1]	Sum of silt & clay fractions
Mass of silt leaving the reservoir (tonnes)	6,018	5% of silts introduced to the water column leaves the reservoir through T3
Mass of clay leaving the reservoir (tonnes)	10,003	44% of clay introduced to the water column leaves the reservoir through T3
Total Mass fines leaving the reservoir (tonnes)	16,021	11% of fines leave the reservoir

[1] "Source Term" multiplied by PSD assumption multiplied by mass placed (TBM and D&B)

6.4.4 Predicted Sediment Deposition Thickness

Maps of predicted sediment deposition thickness for the proposed Ravine Bay, ERP method are presented in **Figure 6-7** (after 12 months), **Figure 6-8** (after 24 months) and **Figure 6-9** (after 36 months).

The maps show that:

- sedimentation rates are highest closest to the placement location;
- sedimentation rates are higher in shallow parts of the reservoir (i.e. reservoir edges);
- there is only minor additional sedimentation after placement finished at the end of 24 months;
- in the northern half of the reservoir, predicted sedimentation rates, due to the proposed Ravine Bay placement are 1-10mm/year;
- in the southern half of the reservoir, predicted sedimentation rates, due to the proposed Ravine Bay placement are 5-30mm/year; and
- Closer to the placement area sedimentation rates above 100mm/yr are predicted.

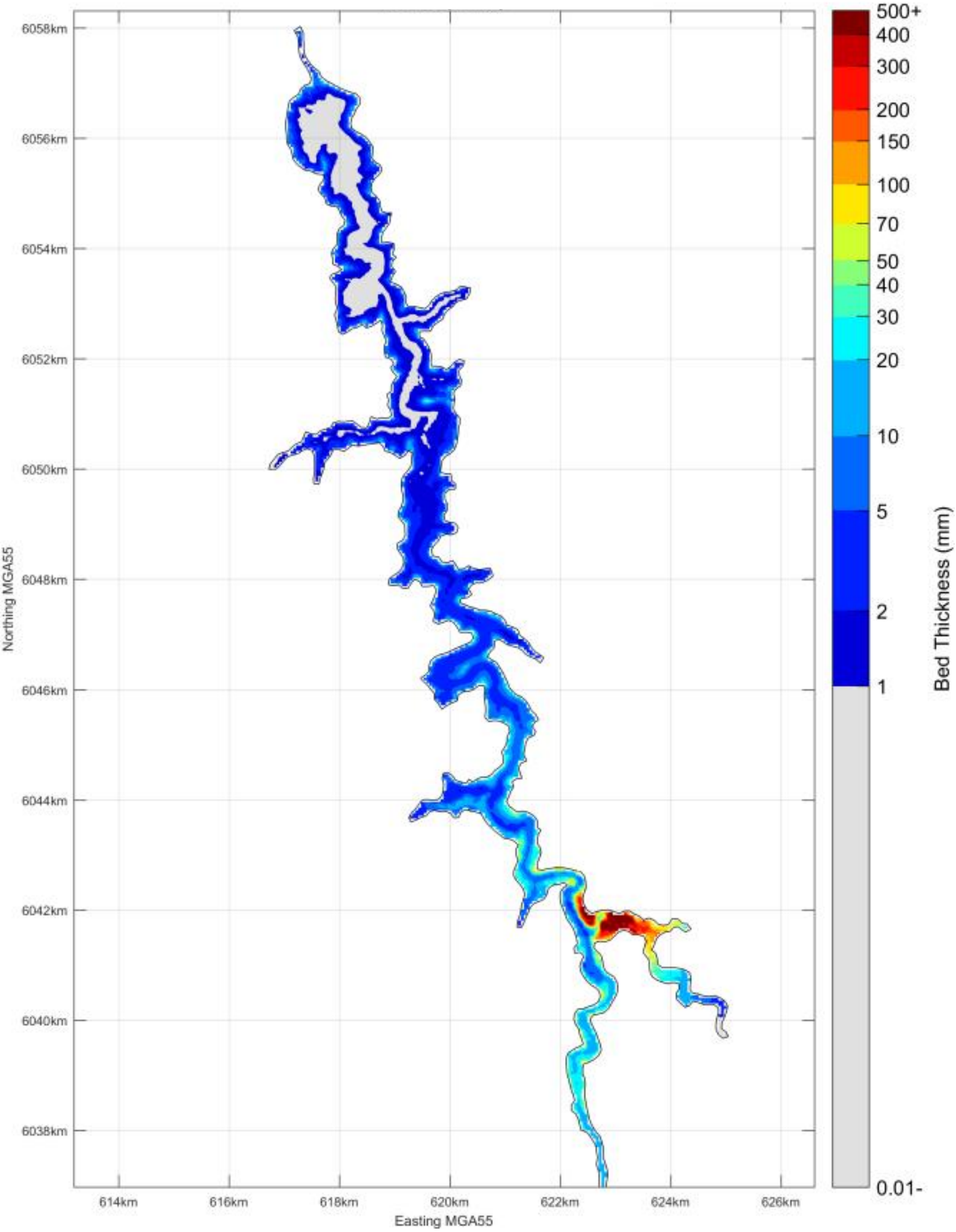

Figure 6-7: Map of Sediment Deposition Thickness (End 12 month simulation) for Proposed Ravine Bay Method

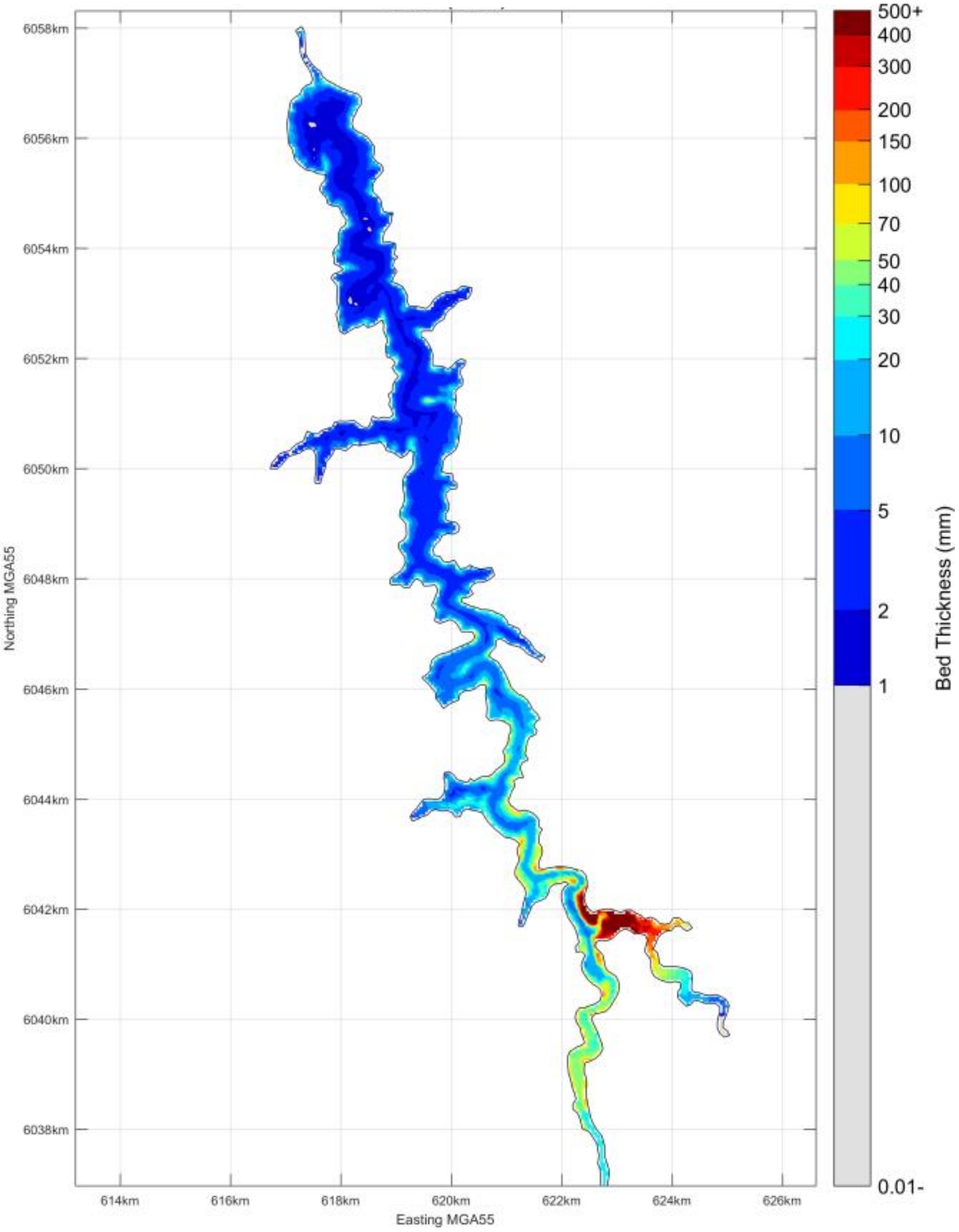

Figure 6-8: Map of Sediment Deposition Thickness (End 24 month simulation) for Proposed Ravine Bay Method

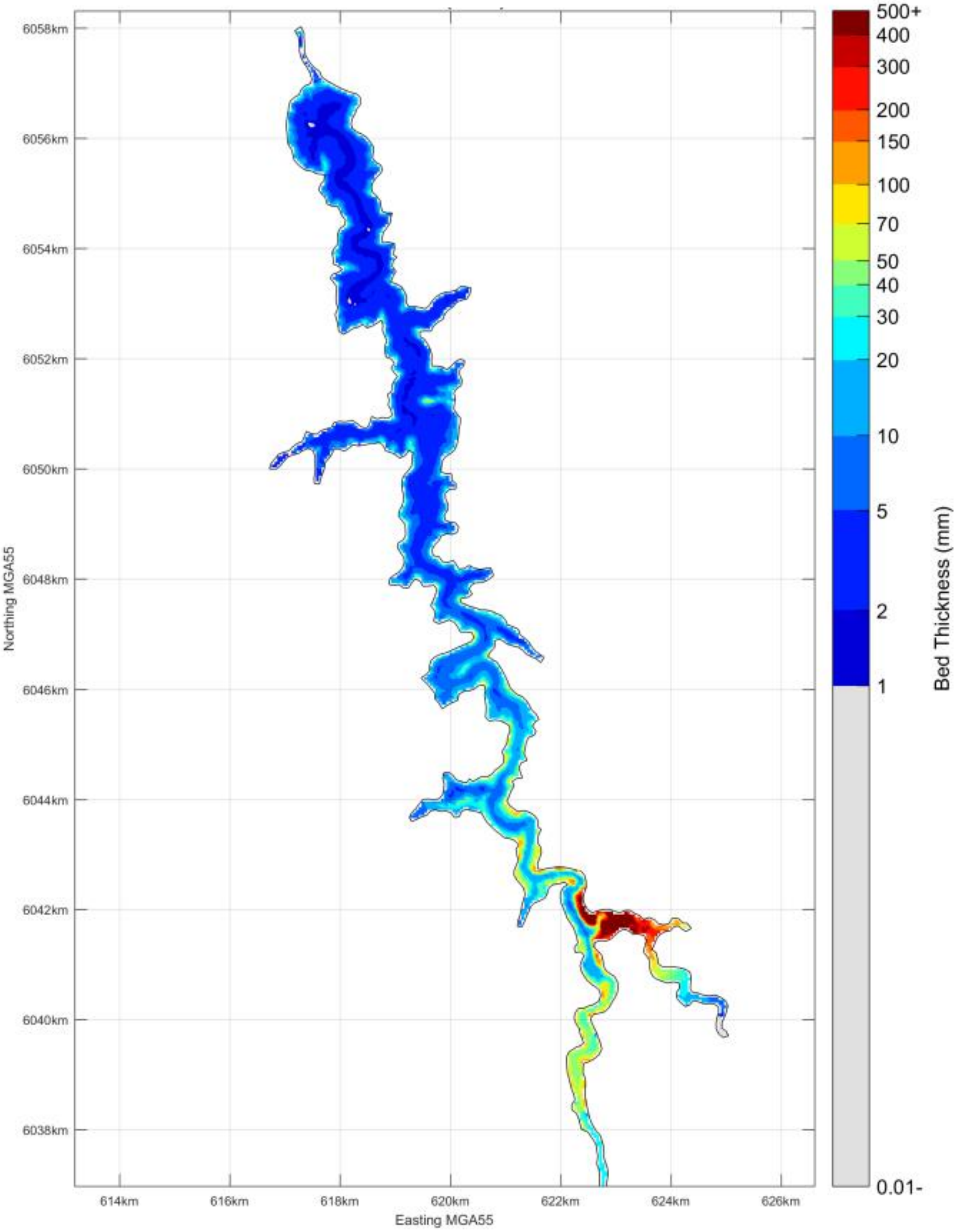

Figure 6-9: Map of Sediment Deposition Thickness (End 36 month simulation) for Proposed Ravine Bay Method

6.5 Predicted Impact of Alternative Hybrid (D&B Only) ERP in Talbingo Reservoir

A range of model outputs have been generated for the alternative Hybrid (D&B Only) ERP method as described in **Sections 2.5.4** and **6.3.3**. A summary of the outputs includes:

- **Maps of Maximum TSS Concentration**: these maps show the maximum TSS concentration during the simulation at the surface (see **Section 6.5.1**).
- **TSS Concentration Time Series Plots**: Time series of TSS at the surface, mid-depth and bed for various locations along the reservoir (see **Section 6.5.2**).
- **Sediment Mass Flux Calculations**: which summarise the mass of sediment leaving the reservoir through the T3 outlet near the dam wall (see **Section 6.5.3**).
- **Sediment Deposition Depth Plot**: which present the total thickness of sediment deposited over the simulation period (see **Section 6.5.4**).

6.5.1 Predicted Peak Surface Suspended Sediments Concentration

Predicted peak surface TSS for the three year simulation is presented in **Figure 6-10**. This is the highest TSS concentration that was predicted at any time during the simulation. The results show that peak TSS within the silt curtain surrounding the placement area is above 400 mg/L, whilst in the main body of the reservoir between Ravine Bay and the dam wall the TSS ranges from 4 to 7 mg/L. Upstream of the placement area along the Tumut and Yarrangobilly arms, there are significantly higher peak concentrations of TSS between 15 and 50 mg/L predicted. This occurs during the summer, when colder T2 and Yarrangobilly inflows produces a cool dense current that flows downstream towards the dam wall. This produces a hydrodynamic response in which a warmer surface current travels upstream, transporting high TSS material that are trapped above the thermocline with the warmer water.

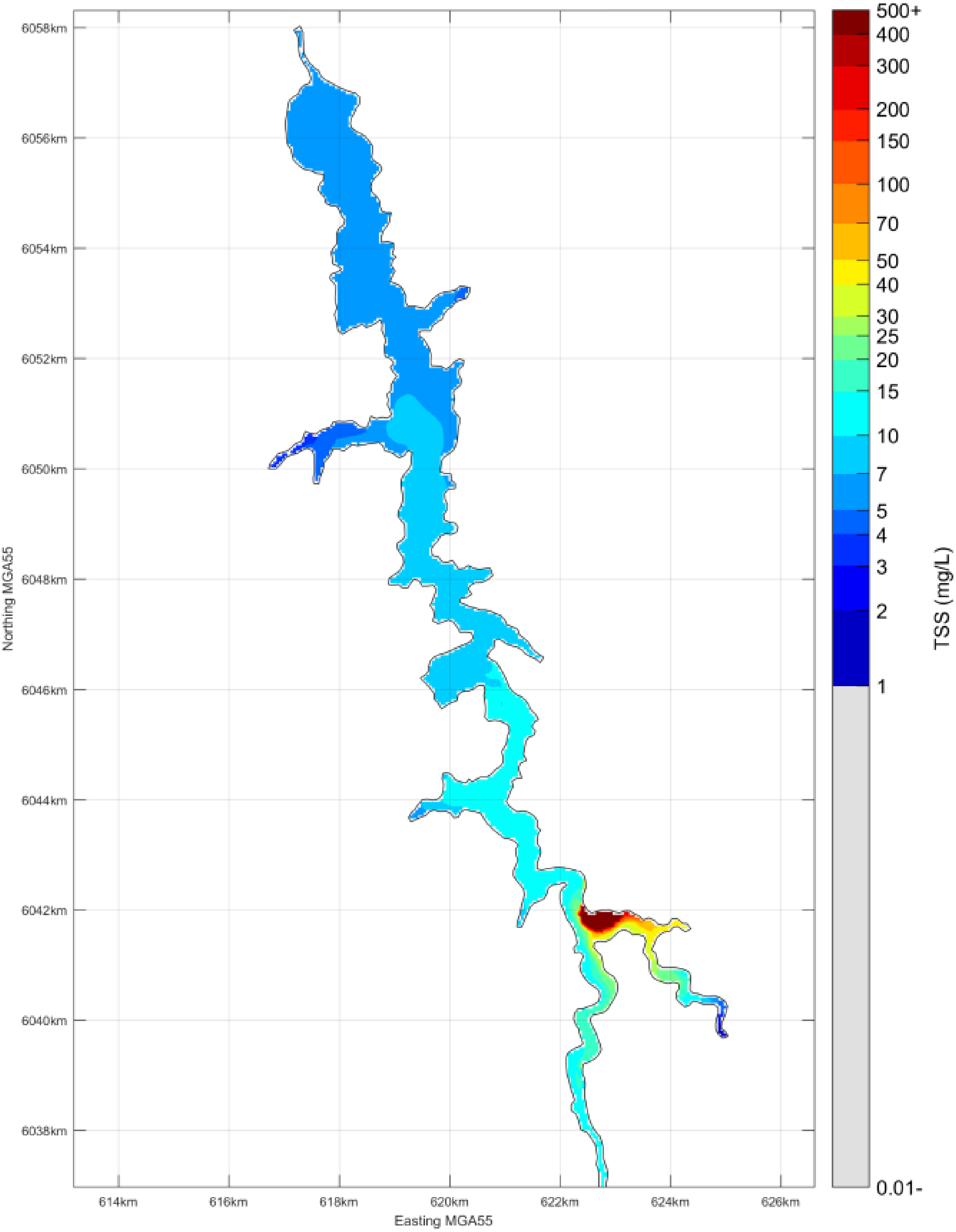

Figure 6-10: Predicted Maximum Surface TSS for Alternative Hybrid (D&B Only) Method

6.5.2 Predicted Time Series of Suspended Sediments Concentration

Time-series of TSS at the surface, mid-depth and bed for 11 locations along the reservoir (defined in **Figure 6-2**) were extracted from the 3D plume model. Four key time series are presented in **Figure 6-11** to **Figure 6-14** and are summarised in **Table 6-11**. The remaining figures are presented in **Attachment H**.

A number of key observations can be made regarding the TSS time-series data:

- In the first year, concentrations are very low as high reservoir flow through is able to prevent TSS concentration from building up in the surface layer.
- In the second year, the surface TSS is higher as TSS accumulates behind the silt curtain during winter. This in then flushed into and through the reservoir during the period of high flows in November and December.
- Peak surface concentrations occur during the “heating” months as stratification traps the TSS in the surface layer.
- Peak TSS concentrations occur closer to the placement site and reduce with distance away from Ravine Bay towards the dam wall.
- As the reservoir cools during the winter months, thermal destratification occurs and TSS is able to mix downwards through the water column. This is presented in **Figure 6-12** (Lick Hole Creek), where:
    - surface TSS begins to fall in late-April,
    - mid-depth TSS rapidly rises in June, and
    - bed TSS rapidly rises a few months later in August.
- As the reservoir begins to stratify in the spring and summer, mid-depth and bed TSS levels begin to drop while surface TSS rises.
- When placement finishes (after 27 months), TSS levels drop rapidly as much of the Reservoir is flushed by incoming T2 discharge. **Figure A-3** shows that the T2 inflow for the modelled year is ~1000GL, which (assuming full flushing) is able to completely replace the available 921 GL of reservoir volume.
- At location 11 (500m east of the placement area), the TSS levels are much higher and there is greater fluctuation in predicted TSS levels. These fluctuations are due to the influence of advection (water movement), which occurs due to high frequency water levels fluctuations (see **Figure 4-2**). The difference in peak TSS between the first and second year is due to the flushing of TSS that has accumulated at the end of the previous year.

Table 6-11: Summary of TSS Time-Series Results (Alternative Hybrid (D&B Only) Placement)

Location (Figure No)	Peak Surface TSS (mg/l)) – Alternative Hybrid	Peak Surface TSS (mg/l)) – Proposed Ravine Bay
Location 1 (near dam wall) **Figure 6-11**	**3-4**	16
Location 4 (Lick Hole Creek) **Figure 6-12**	**4-5**	26
Location 9 (~1 km North of Placement Area) **Figure 6-13**	**7**	32
Location 11 (500m East of Placement Area) **Figure 6-14**	**33**	80

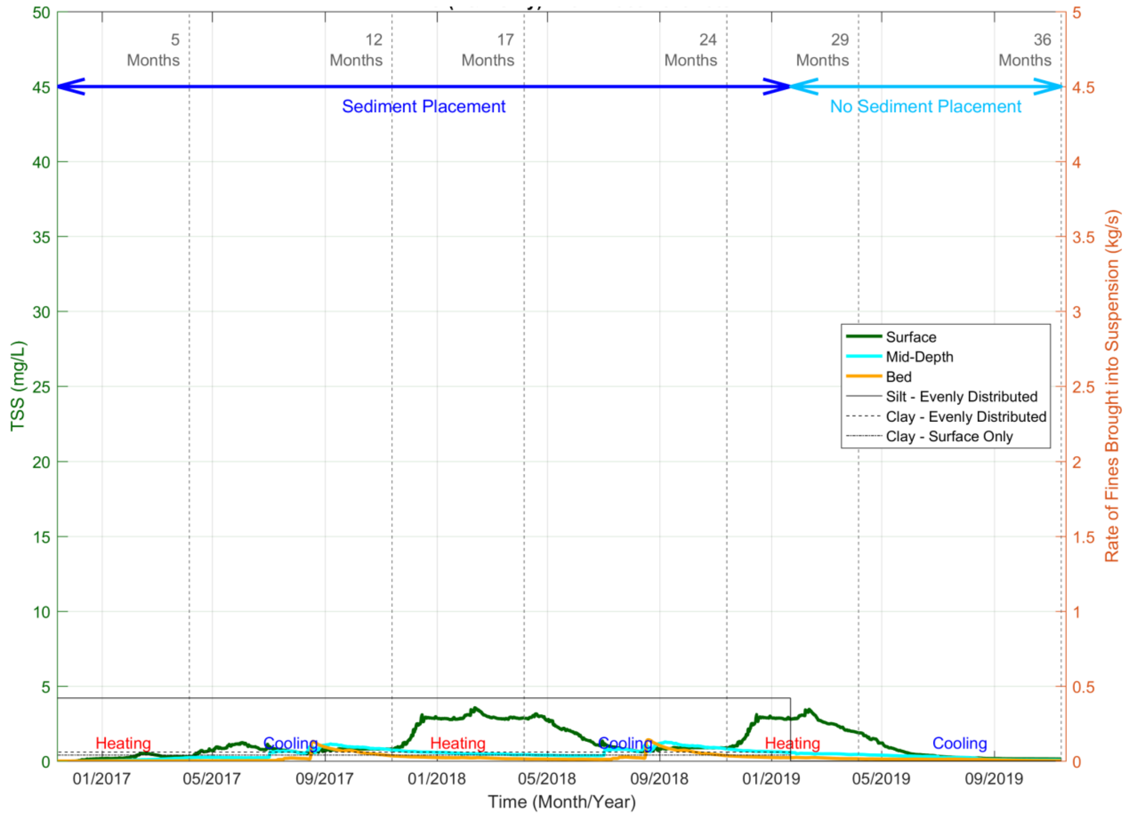

Figure 6-11: Time Series of TSS (Surface, Mid-depth and Bed) Location 1 (near dam wall) for Alternative Hybrid Method

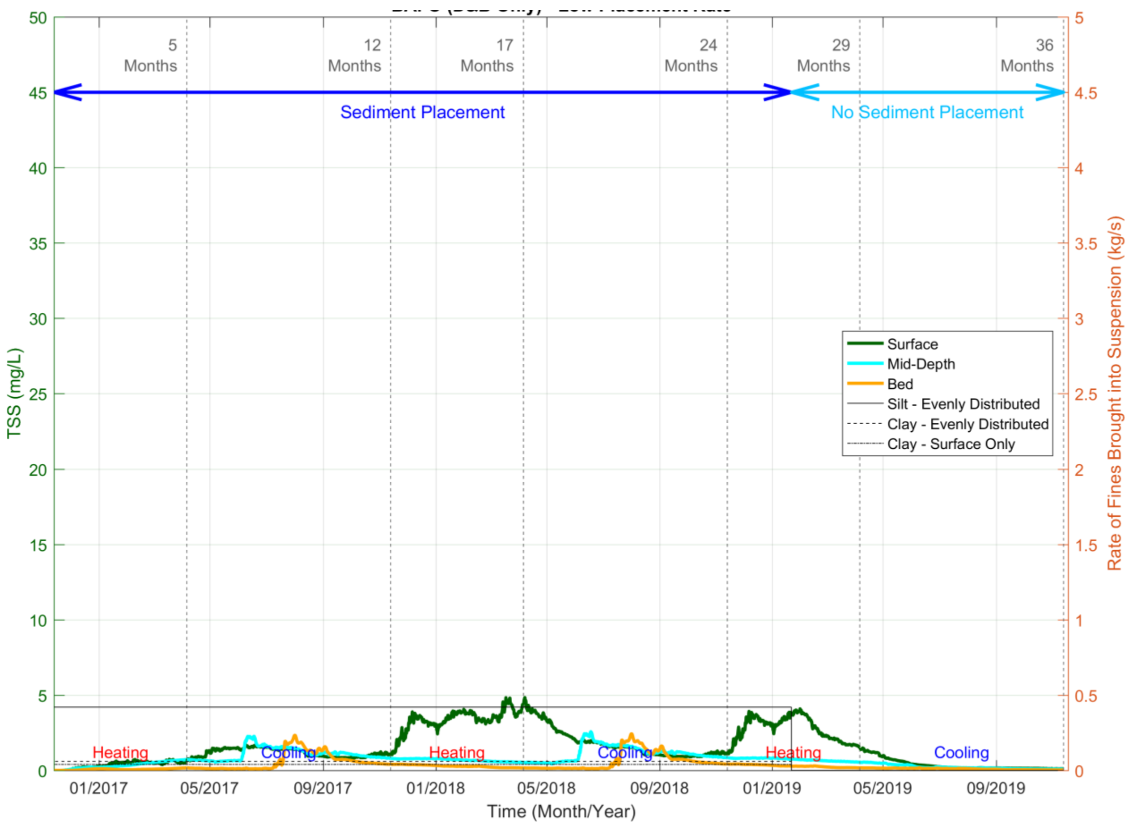

Figure 6-12: Time Series of TSS (Surface, Mid-depth and Bed) Location 4 (Lick Hole Creek) for Alternative Hybrid Method

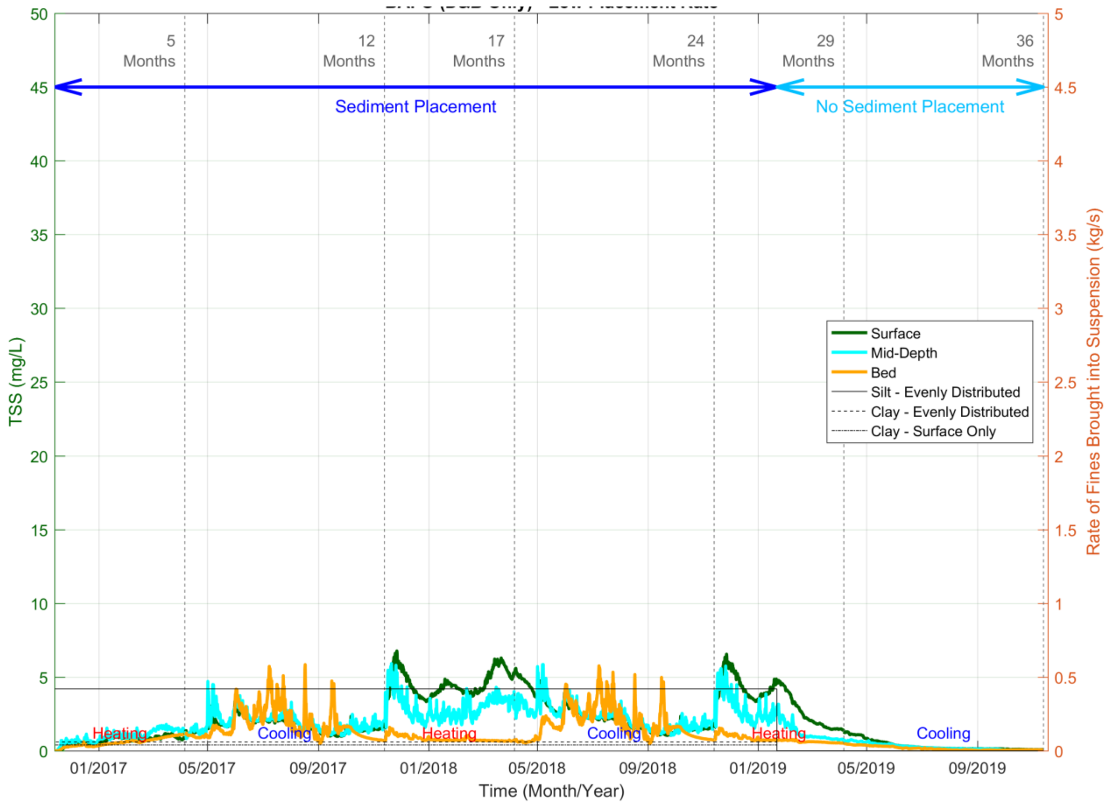

Figure 6-13: Time Series of TSS (Surface, Mid-depth and Bed) Location 9 (~1 km North of Placement Area) for Alternative Hybrid Method

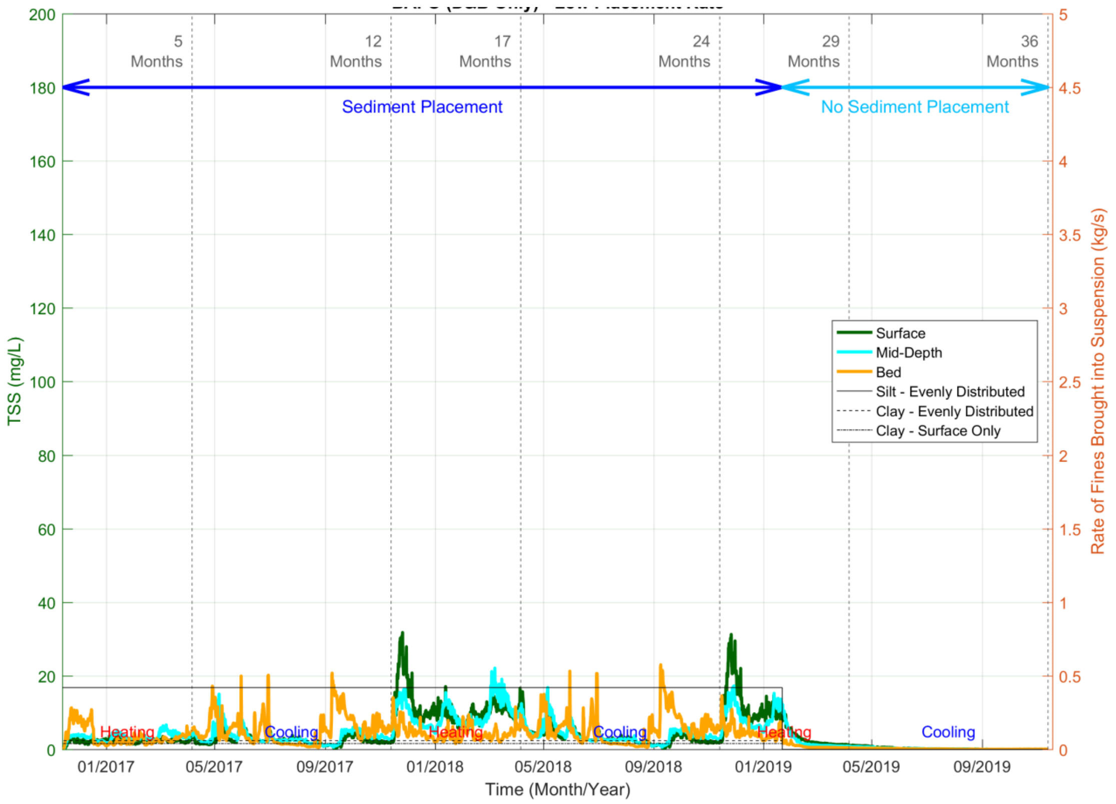

Figure 6-14: Time Series of TSS (Surface, Mid-depth and Bed) Location 11(500m East of Placement Area) for Alternative Hybrid Method

6.5.3 Predicted Mass of Sediment Transported from Talbingo Reservoir

Table 6-12 presents an analysis on the predicted mass of sediment that is:

- introduced to the water column in Talbingo Reservoir
- transported downstream into Jounama Pondage (via T3 outflows)

The calculation of mass of fines (silts, clay and total) is based on:

- the type (D&B only in this instance) and volume of excavated rock that is to be placed in the reservoir;
- the assumed PSD of the material (this defines the fractions of fine material (i.e. % of silt and clays)); and
- the assumed percentage (i.e. "source term") of fines that when placed in the reservoir does not immediately settle on the bed and instead is released into the water column as suspended sediment.

The calculations show that of the proposed 1.4 Million m^3 (bank) of D&B excavated rock material that is to be placed in Talbingo Reservoir using the alternative Hybrid method, 35,835 tonnes of fine sediment, including 6,829 tonnes of clay, would be released to the water column.

The model predicts that at the end of the three year simulation period, 4067 tonnes of fines will have been discharged through T3. This comprises of 1209 tonnes of silts and 2858 tonnes of clay sized sediments. This indicates that 96% of available "source term" silts will settle in Talbingo Reservoir, while only 58% of clay sized sediments will be retained in the reservoir.

The concentration of TSS leaving the reservoir will be similar to that predicted at Location 1 (refer **Figure 6-11**).

Table 6-12: Summary of Modelled TSS Mass Leaving Talbingo Reservoir (Alternative "Hybrid (D&B Only)" Method)

Quantity	Mass (Tonnes)	Comment
Mass of silt released to reservoir (tonnes)	29,024[1]	Silts comprise 81% of fines introduced to the water column
Mass of clay released to reservoir (tonnes)	6,829[1]	Clays comprise 19% of fines introduced to the water column
Total Mass fines released to reservoir (tonnes)	35,835[1]	Sum of silt & clay fractions
Mass of silt leaving the reservoir (tonnes)	1,209	4% of silts introduced to the water column leaves the reservoir through T3
Mass of clay leaving the reservoir (tonnes)	2,858	42% of clay introduced to the water column leaves the reservoir through T3
Total Mass fines leaving the reservoir (tonnes)	4,067	11% of fines leave the reservoir

[1] "Source Term" multiplied by PSD assumption multiplied by mass placed (D&B Only)

6.5.4 Predicted Sediment Deposition Thickness

A map of the predicted sediment deposition thickness for the alternative Hybrid (D&B only) ERP method is presented in **Figure 6-15** (after 36 months).

The maps show that:

- sedimentation rates are highest closest to the placement location;
- sedimentation rates are higher in shallow parts of the reservoir (i.e. reservoir edges);
- in the northern half of the reservoir, predicted sedimentation rates, due to the alternative Hybrid (D&B Only) placement are up to 3 mm/year;
- in the southern half of the reservoir, predicted sedimentation rates, due to the alternative Hybrid (D&B Only) placement are 1-8 mm/year;
- Closer to the placement area sedimentation rates above 20mm/yr are predicted.

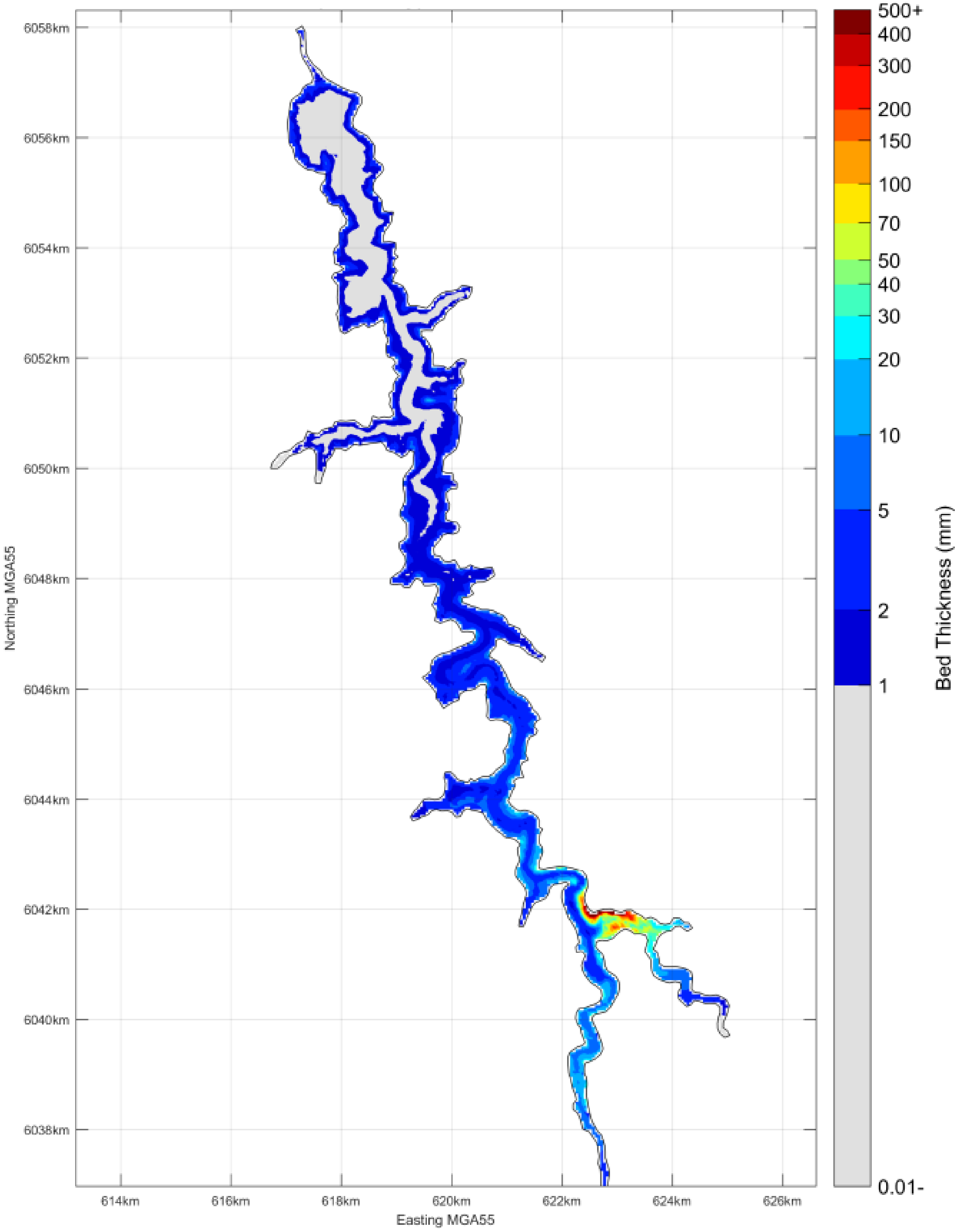

Figure 6-15: Map of Sediment Deposition Thickness (End 36 month simulation) for Alternative Hybrid Method

7 Sensitivity Testing of PSD Assumptions

Predictions of TSS concentrations and sediment deposition thickness are dependent on a number of assumptions regarding the placed material and placement method including:

- Assumed placement rate and volume/mass of excavated rock;
- Assumed PSD of excavated material (i.e. the percentage of fine material and the proportion of fines which is clay sized); and
- Assumed fraction of excavated rock that is entrained into the water column as it is placed and does not immediately settle on the bed of the Reservoir (i.e. “source term”).

The mass (and therefore TSS concentration) of sediment entrained into the Talbingo Reservoir water column is calculated by:

$$mass\ of\ sediment\ in\ water\ column = \text{placement rate x assumed PSD x assumed source term (equation 1)}$$

The assumed PSD adopted for the assessment (presented in Section 6) and the “high fines” adopted in the sensitivity testing analysis is presented in **Table 7-1**. The percentage fines (i.e. material <63 µm) was increased by nominally 50% for both TBM and D&B materials. Due to rounding, the clay fraction increased by 57.1% and 67.1% for TBM and D&B materials. It should be noted that based on equation 1, the 50% increase in percentage of fines in the PSD (i.e. “High Fines”) will increase the mass of sediment entrained in the water column by 50%, which could also be achieved by a similar sensitivity testing of a 50% increase in either placement rate or source term. Therefore, no individual sensitivity testing of placement rate or source term assumption was required.

The sensitivity testing of the assumptions regarding PSD was requested during Agency consultation and is in addition to the sensitivity testing of the hydrodynamic model described in **Section 5**.

Table 7-1: Summary of ERP Assumptions for PSD (Base Case and High Fines for Sensitivity Testing)

Material	Assumed PSD (Base Case)[1]	High Fines (Sensitivity Test)	% Increase
TBM Percentage of total excavated volume as Fines (<63 µm) (%)	6.0	**9.0**	50%
D&B Percentage of total excavated volume as Fines (<63 µm) (%)	2.0	**3.0**	50%
TBM Percentage of total excavated volume as Clay (<4 µm) (%)	0.7	**1.1**	57.1%
D&B Percentage of total excavated volume as Clay (<4 µm) (%)	0.3	**0.5**	66.7%

[1] as presented in **Section 6.3**

7.1.1 Assumptions for Sensitivity Testing of Proposed Ravine Bay Placement

Assumptions regarding placement and sediment properties used in ERP modelling for the sensitivity testing of the proposed Ravine Bay Placement, edge push (TBM and D&B) placement design (as detailed in **Section 2.5.2** and above) is presented in **Section 6.3.2** and **Table 7-1**. A summary of the total mass of silts and clays entering the water column is provided in **Table 7-2** and shows that while total fines have increased by 50%, after application of the “source term”, total silts have increased by 49% and total clay has increased by 60%.

Table 7-2: Summary of MIKE-3 Sediment Transport Model Configuration – Sensitivity Test of Proposed Ravine Bay Placement

Mass	Assumed PSD (Base Case)[1]	High Fines (Sensitivity Test)	% Increase
Mass of silt in water column (kg)	117,846,267	**175,025,029**	49%
Mass of clay in water column (kg)	22,627,213	**36,266,647**	60%
Total mass of fines in water column (kg)	140,473,479	**211,291,676**	50%

[1] as presented in Section 6.3.2

7.1.2 Assumptions for Sensitivity Testing of Alternative Hybrid Placement

Assumptions regarding placement and sediment properties used in ERP modelling for the sensitivity testing of alternative Hybrid (D&B Only) placement design (as detailed in Section 2.5.3 and above) is presented in **Section 6.3.2** and **Table 7-1**. A summary of the total mass of silts and clays entering the water column is provided in **Table 7-3** and shows that while total fines have increased by 50%, after application of the “source term” total silts have increased by 47% and total clay has increased by 67%.

Table 7-3: Summary of MIKE-3 Sediment Transport Model Configuration – Sensitivity Test of Alternative Hybrid (D&B Only)

Mass	Assumed PSD (Base Case)[1]	High Fines (Sensitivity Test)	% Increase
Mass of silt in water column (kg)	29,024,100	**42,682,500**	47%
Mass of clay in water column (kg)	6,829,200	**11,382,000**	67%
Total mass of fines in water column (kg)	35,853,300	**54,064,500**	50%

[1] as presented in Section 6.3.3

7.2 Effect of Proposed Ravine Bay Placement in Talbingo Reservoir (Sensitivity Testing of High Fines PSD)

A range of model outputs have been generated to assist in assessing the effect of the sensitivity testing of a high fines PSD on the predicted sediment plume. A summary of the outputs includes:

- **Maps of Maximum TSS Concentration**: these maps show the maximum TSS concentration during the simulation at the surface (see **Section 7.2.1**).
- **TSS Concentration Time Series Plots**: Time series of TSS at the surface, mid-depth and bed for various locations along the reservoir (see **Section 7.2.2)**.
- **Sediment Mass Flux Calculations**: which summarise the mass of sediment leaving the reservoir through the T3 outlet near the dam wall (see **Section 7.2.3**).
- **Sediment Deposition Depth Plots**: which present the total thickness of sediment deposited over the simulation period (see **Section 7.2.4**).

7.2.1 Predicted Peak Surface Suspended Sediments Concentration

Predicted peak surface TSS for the three year sensitivity test simulation is presented in **Figure 7-1**. This is the highest TSS concentration that was predicted at any time during the simulation. The results show that peak TSS within the silt curtain surrounding the placement area is above 500 mg/L, while in the main body of the reservoir between Ravine Bay and the dam wall TSS ranges from 50 to 25 mg/L. Upstream of the placement area, along the Tumut and Yarrangobilly arms, there are significantly higher peak concentrations between 75 and 150 mg/L. This occurs during the summer, when colder T2 and Yarrangobilly inflows produce a cool dense current that flows downstream towards the dam wall. This produces a hydrodynamic response in which a warmer surface current travels upstream, transporting high TSS material that is trapped above the thermocline with it.

Given that the sensitivity test assumes an increase in the percentage of fines (in the PSD) of approximately 50%, predicted peak concentrations are also approximately 50% higher than when using the best available assumptions of PSD (see results presented in **Section 6.4.1**).

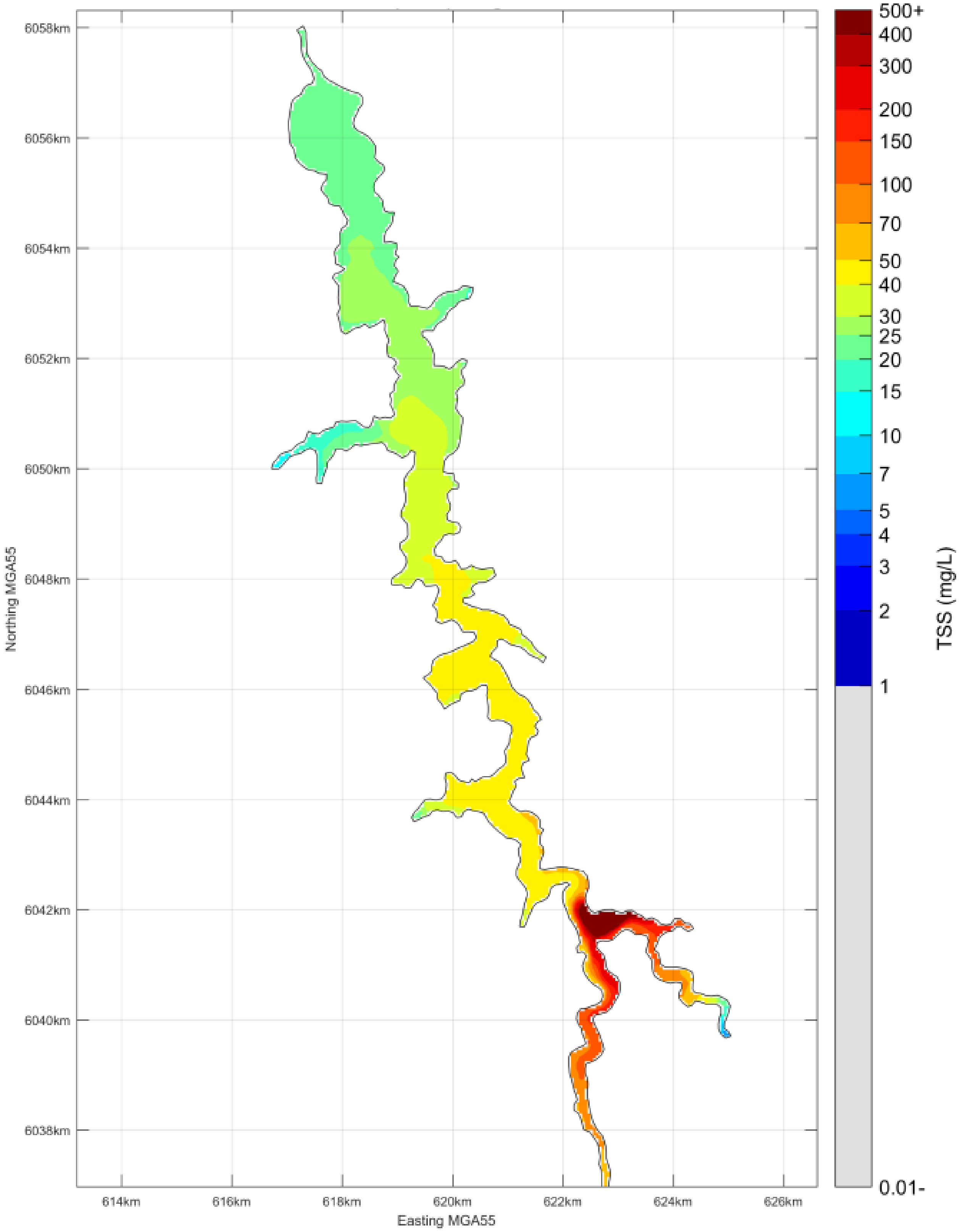

Figure 7-1: Predicted Maximum Surface TSS for Proposed Ravine Bay Placement Method (High Fines PSD Sensitivity Test)

7.2.2 Predicted Time Series of Suspended Sediments Concentration

Time-series of TSS at the surface, mid-depth and bed for 11 locations along the reservoir (defined in **Figure 6-2**) were extracted from the 3D plume model. Four key time series are presented in **Figure 7-2** to **Figure 7-5** and are summarised in **Table 7-4**.

The behaviour of the plume in this sensitivity test (and therefore TSS fluctuations) are the same as described in **Section 6.4.2** (proposed Ravine Bay placement method using best available assumptions) though they are increased by approximately 50%.

Table 7-4: Summary of TSS Time-Series Results Proposed and Proposed Ravine Bay with High Fines PSD

Location (Figure No)	Peak Surface TSS (mg/l)) – Proposed (with High Fines PSD)	Peak Surface TSS (mg/l)) - Proposed
Location 1 (near dam wall) **Figure 7-2**	**24**	16
Location 4 (Lick Hole Creek) **Figure 7-3**	**39**	26
Location 9 (~1 km North of Placement Area) **Figure 7-4**	**48**	32
Location 11 (500m East of Placement Area) **Figure 7-5**	**120**	80

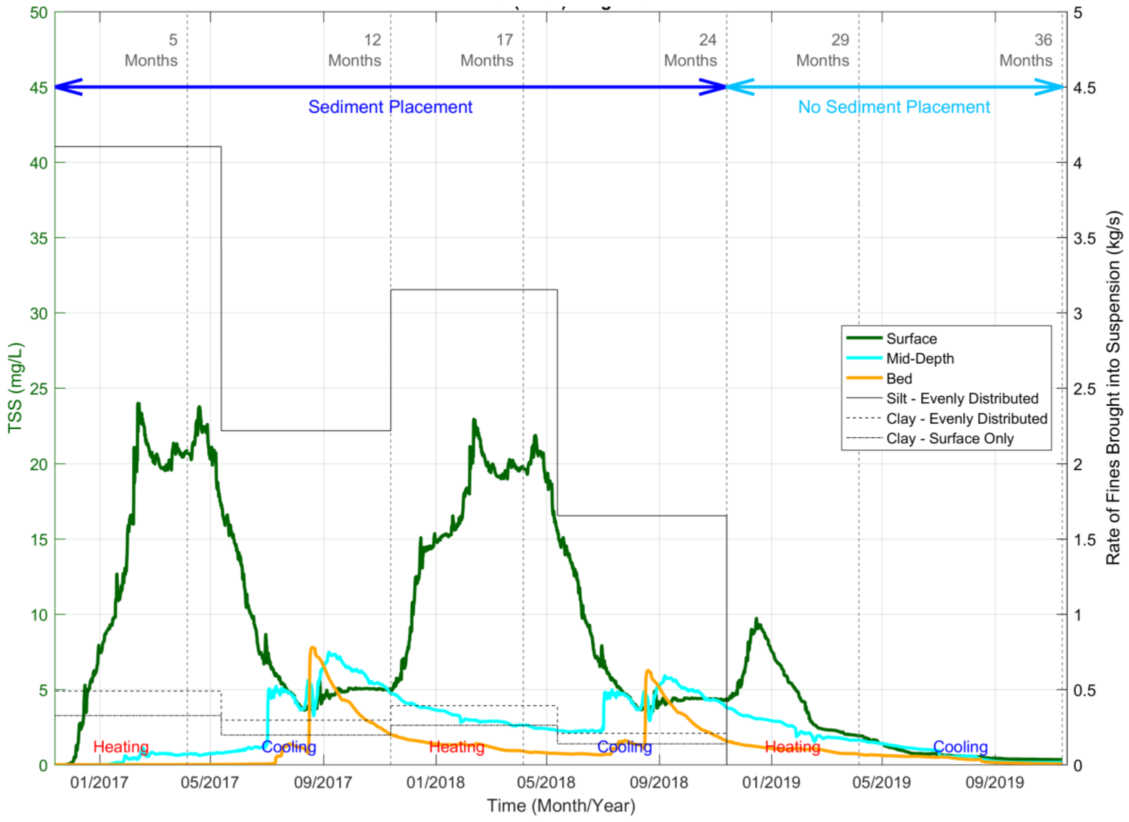

Figure 7-2: Time Series of TSS (Surface, Mid-depth and Bed) Location 1 (near dam wall) for Proposed Method with High Fines PSD

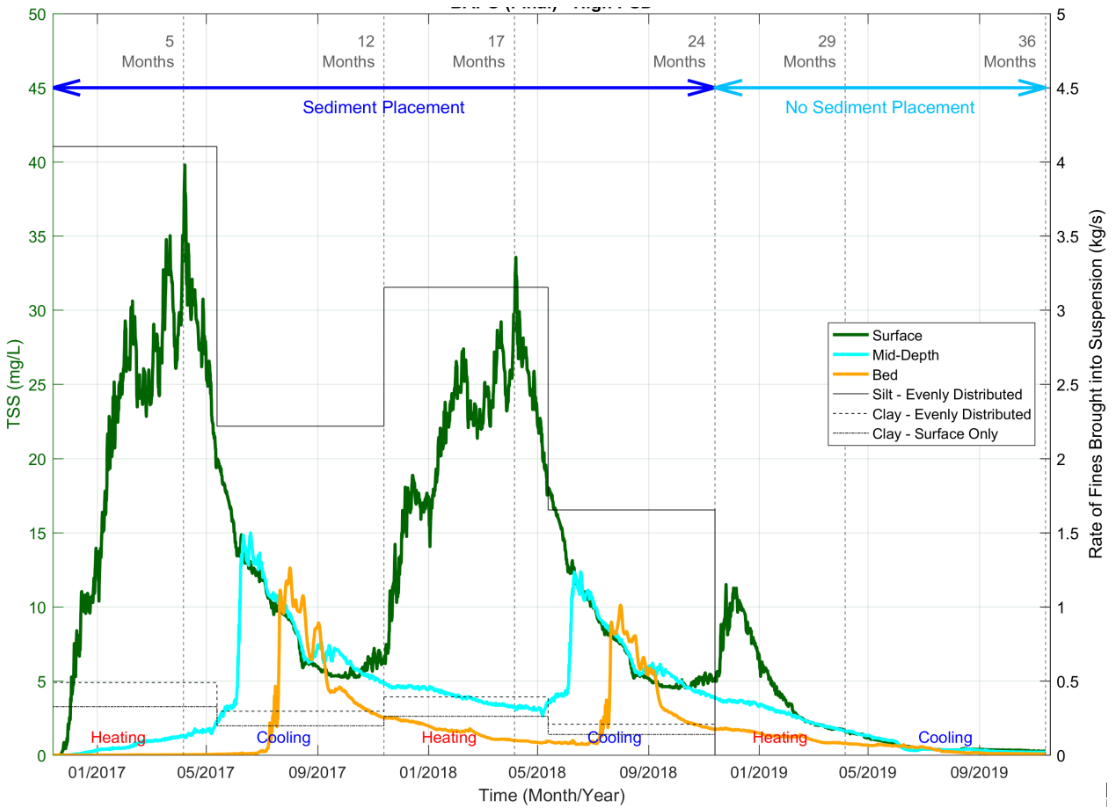

Figure 7-3: Time Series of TSS (Surface, Mid-depth and Bed) Location 4 (Lick Hole Creek) for Proposed Method with High Fines PSD

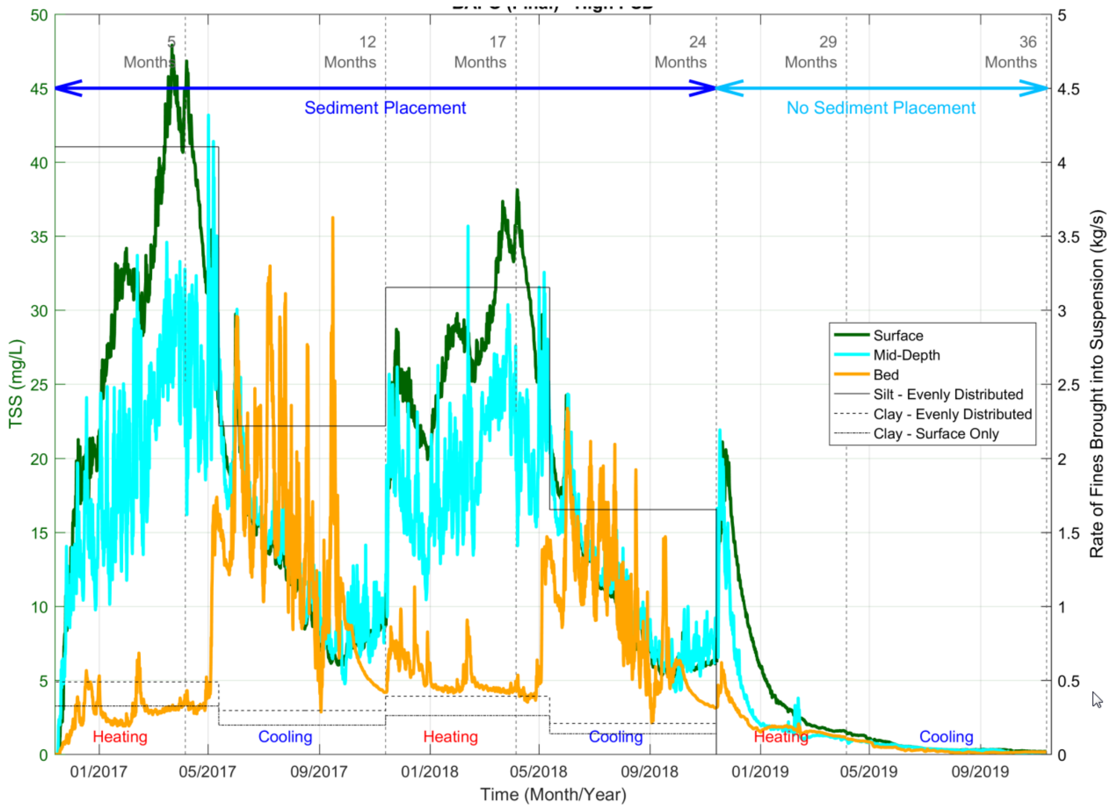

Figure 7-4: Time Series of TSS (Surface, Mid-depth and Bed) Location 9 (~1 km North of Placement Area) for Proposed Method with High Fines PSD

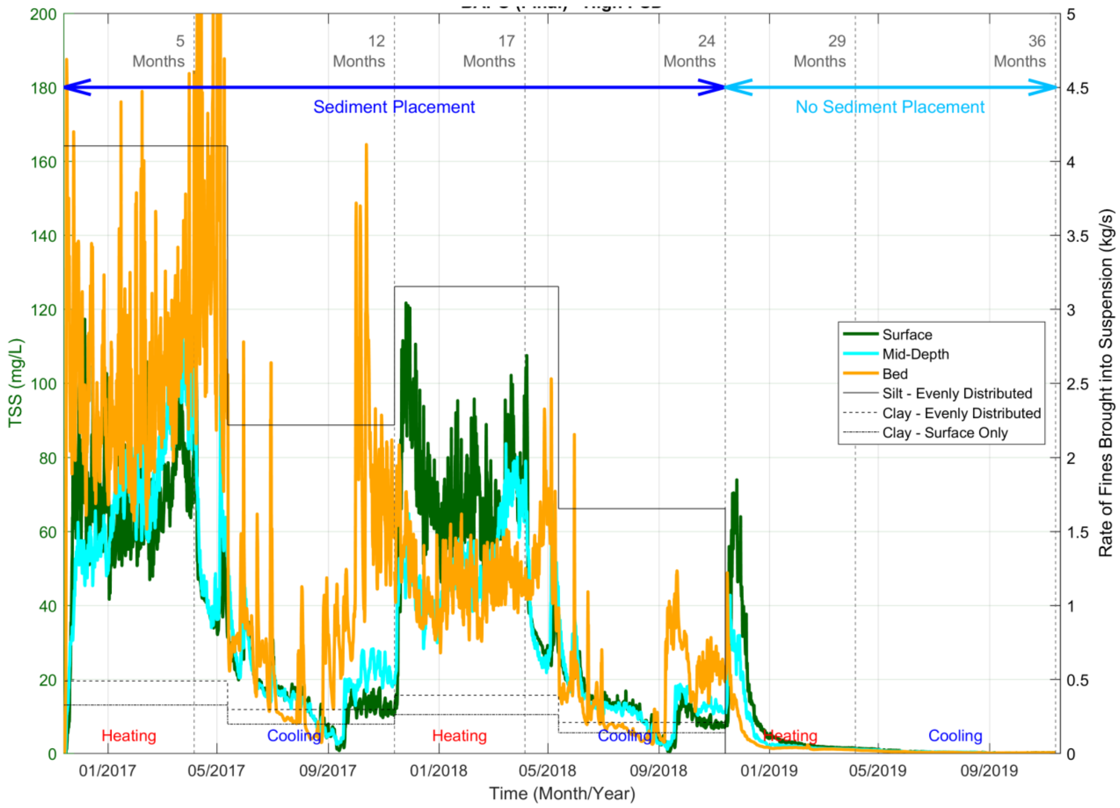

Figure 7-5: Time Series of TSS (Surface, Mid-depth and Bed) Location 11(500m East of Placement Area) for Proposed Method with High Fines PSD

7.2.3 Predicted Mass of Sediment Transported from Talbingo Reservoir

Table 7-5 presents an analysis on the predicted mass of sediment that is transported downstream into the Jounama Pondage (via T3 outflows), whilst the calculated mass introduced to the water column in Talbingo Reservoir is presented in **Table 7-2**.

The calculations show that of the proposed 2.86 Million m^3 (bank) of excavated rock material that is to be placed in Talbingo Reservoir using the proposed Ravine Bay placement method (using the high fines PSD assumption), 211,292 tonnes of fine sediment, including 36,267 tonnes of clay, would be released into the water column.

The model is able to calculate the mass of sediment that is predicted to be transported from Talbingo Reservoir through the T3 outflows into Jounama Pondage. The model predicts that at the end of the three year simulation period, 24,937 tonnes of fines will have been discharged through T3. This comprises of 8,930 tonnes of silts and 16,007 tonnes of clay sized sediments.

The concentration of TSS leaving the reservoir will be similar to that predicted at Location 1 (refer **Figure 7-2**).

Table 7-5: Summary of Modelled TSS Mass Leaving Talbingo Reservoir (Sensitivity Testing of Proposed Ravine Bay Scenario)

Quantity	Mass (Tonnes) – Proposed (with High Fines PSD)	Mass Tonnes - Proposed
Mass of silt leaving the reservoir (tonnes)	**8,930**	6,018
Mass of clay leaving the reservoir (tonnes)	**16,007**	10,003
Total Mass fines leaving the reservoir (tonnes)	**24,937**	16,021

7.2.4 Predicted Sediment Deposition Thickness

A map of the predicted sediment deposition thickness for the proposed high fines PSD, Ravine Bay ERP method is presented in **Figure 7-6** (after 36 months).

The maps show that:

- sedimentation rates are highest closest to the Ravine Bay placement location;
- sedimentation rates are higher in shallow parts of the reservoir (i.e. reservoir edges);
- in the northern half of the reservoir, predicted sedimentation rates, due to the proposed Ravine Bay placement are 2-15mm/year;
- in the southern half of the reservoir, predicted sedimentation rates, due to the proposed Ravine Bay placement are 7-45mm/year; and
- closer to the placement area sedimentation rates above 150mm/yr are predicted.

The deposition rates for the proposed Ravine Bay high fines sensitivity test are typically 50% higher than those predicted for the base case proposed Ravine Bay scenario (refer **Section 6.4.4**).

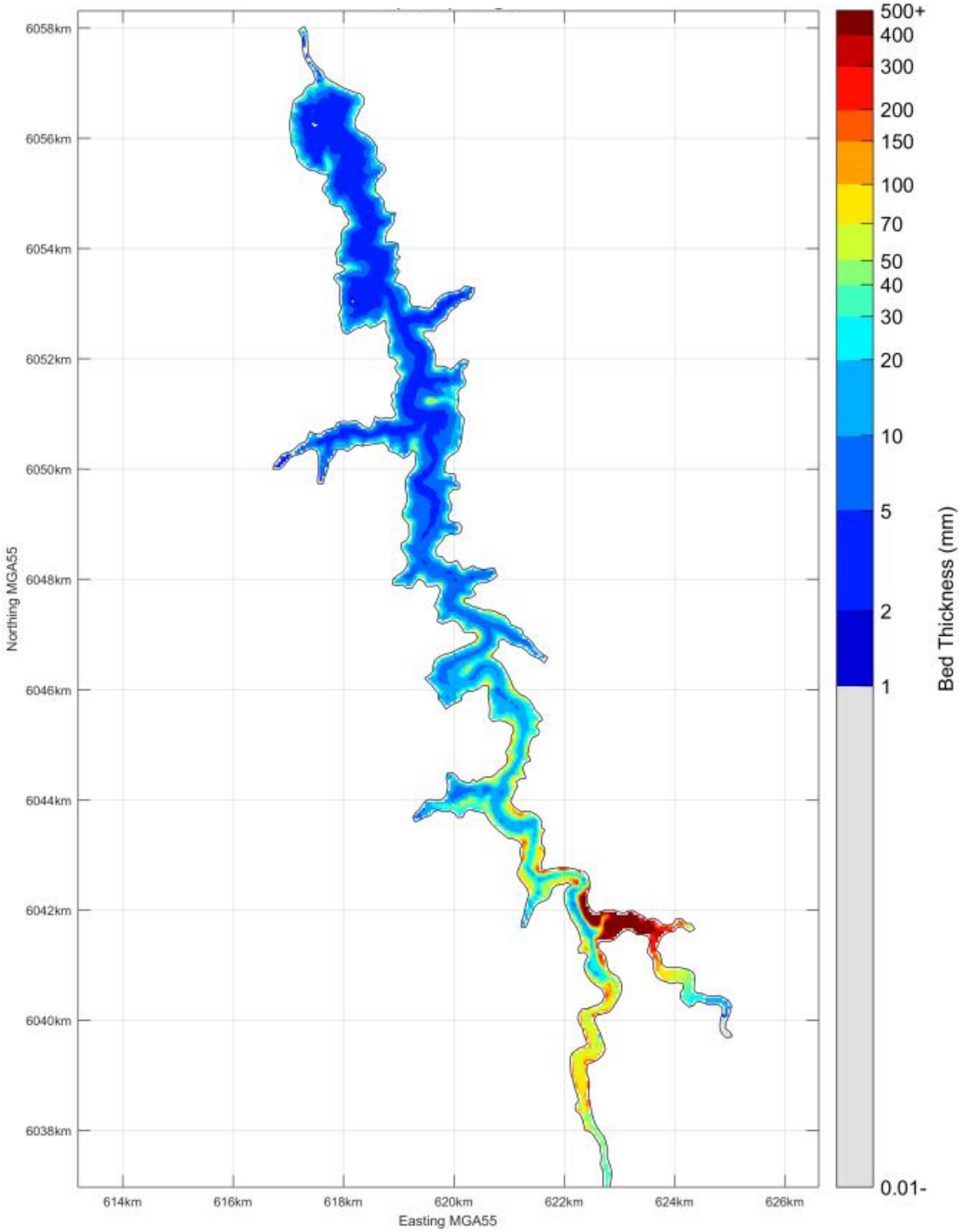

Figure 7-6: Map of Sediment Deposition Thickness (End 36 month simulation) for Proposed Ravine Bay Method with High Fines PSD

7.3 Effect of Alternative Hybrid (D&B Only) ERP in Talbingo Reservoir (Sensitivity Testing of High Fines PSD)

A range of model outputs have been generated to assist in assessing the effect of the sensitivity testing of High Fines PSD on the predicted sediment plume. A summary of the outputs includes:

- **Maps of Maximum TSS Concentration**: these maps show the maximum TSS concentration during the simulation at the surface (see **Section 7.3.1**).
- **TSS Concentration Time Series Plots**: Time series of TSS at the surface, mid-depth and bed for various locations along the reservoir (see **Section 7.3.2)**.
- **Sediment Mass Flux Calculations**: which summarise the mass of sediment leaving the reservoir through the T3 outlet near the dam wall (see **Section 7.3.3**).
- **Sediment Deposition Depth Plots**: which present the total thickness of sediment deposited over the simulation period (see **Section 7.3.4**).

7.3.1 Predicted Peak Surface Suspended Sediments Concentration

Predicted peak surface TSS for the three year sensitivity test simulation is presented in **Figure 7-7**. This is the highest TSS concentration that was predicted at any time during the simulation. The results show that peak TSS within the silt curtain surrounding the placement area is above 500 mg/L, while in the main body of the reservoir between Ravine Bay and the dam wall TSS ranges from 5 to 7 mg/L. Upstream of the placement area, along the Tumut and Yarrangobilly arms, significantly higher peak concentrations of between 20 and 50 mg/L are predicted. This occurs during the summer, when colder T2 and Yarrangobilly inflows produce a cool dense current that flows downstream towards the dam wall. This produces a hydrodynamic response in which a warmer surface current travels upstream, transporting high TSS material that is trapped above the thermocline with it.

Given that the sensitivity test assumes an increase in the percentage of fines (in the PSD) of approximately 50%, predicted peak concentrations are also approximately 50% higher than when using the best available assumptions of PSD (see results presented in **Section 6.4.1**).

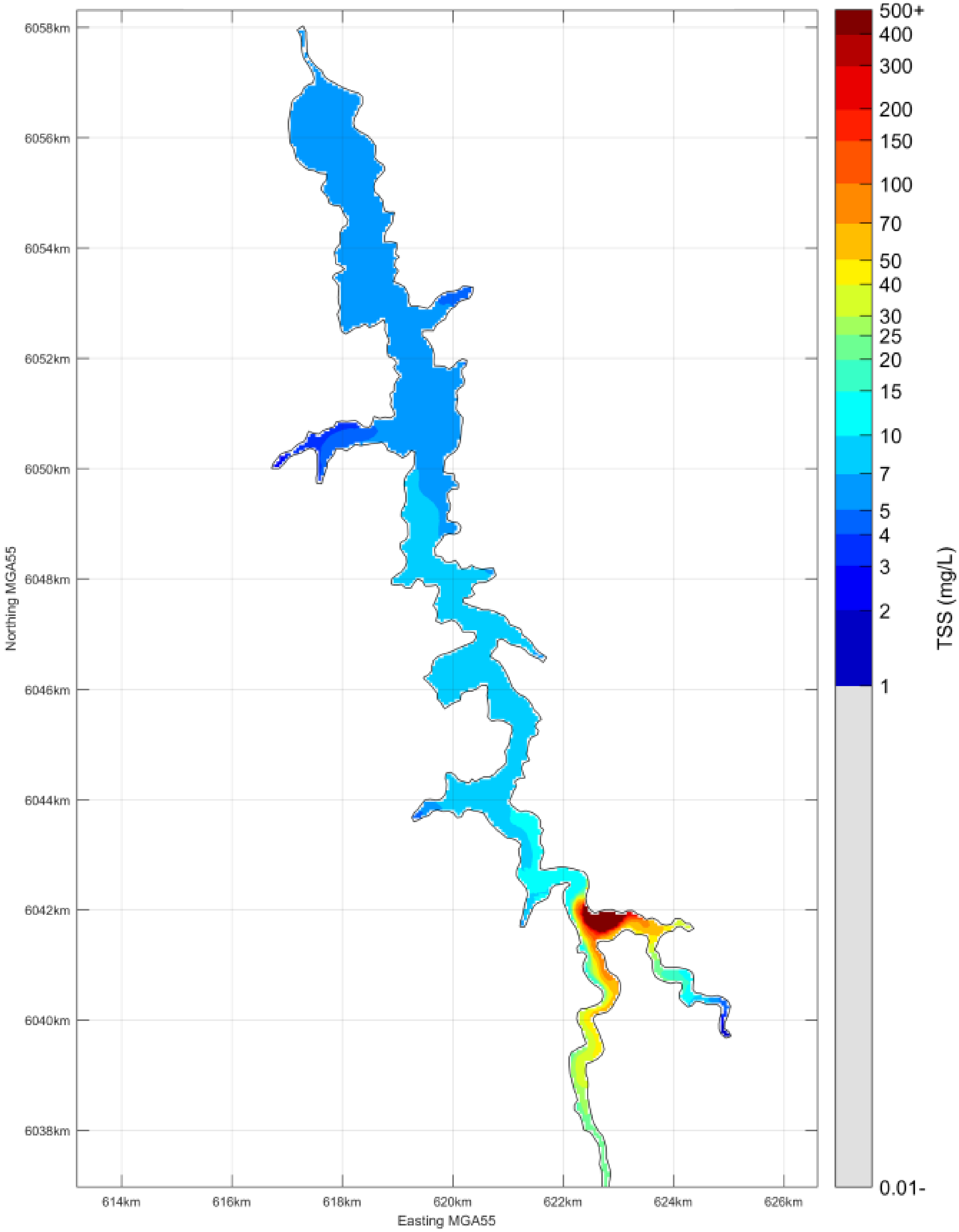

Figure 7-7: Predicted Maximum Surface TSS for Alternative Hybrid (D&B Only) Method (High Fines PSD) Sensitivity Test

7.3.2 Predicted Time Series of Suspended Sediments Concentration

Time-series of TSS at the surface, mid-depth and bed for 11 locations along the reservoir (defined in **Figure 6-2**) were extracted from the 3D plume model. Four key time series are presented in **Figure 7-8** to **Figure 7-11** and are summarised below in **Table 7-4**.

The behaviour of the plume in this sensitivity test (and therefore TSS fluctuations) are the same as described in **Section 6.5.2** (alternative Hybrid (D&B Only) method using best available assumptions) though they are increased by approximately 50%.

Table 7-6: Summary of TSS Time-Series Results Alternative and Alternative with High Fines PSD

Location (Figure No)	Peak Surface TSS (mg/l)) – Alternative Hybrid (with High Fines PSD)	Peak Surface TSS (mg/l)) – Alternative Hybrid
Location 1 (near dam wall) **Figure 7-8**	**5**	3-4
Location 4 (Lick Hole Creek) **Figure 7-9**	**7**	4-5
Location 9 (~1 km North of Placement Area) **Figure 7-10**	**11**	7
Location 11 (500m East of Placement Area) **Figure 7-11**	**50**	33

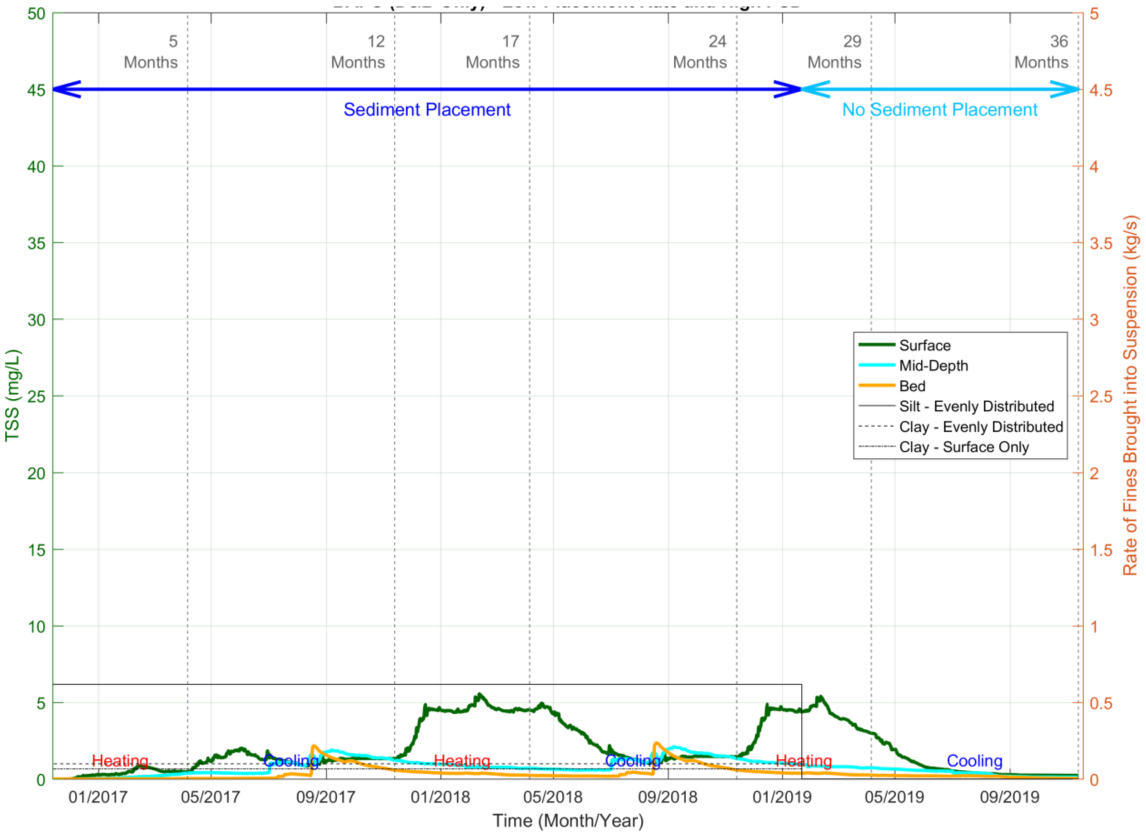

Figure 7-8: Time Series of TSS (Surface, Mid-depth and Bed) Location 1 (near dam wall) for Alternative Hybrid (D&B Only) Method with High Fines PSD

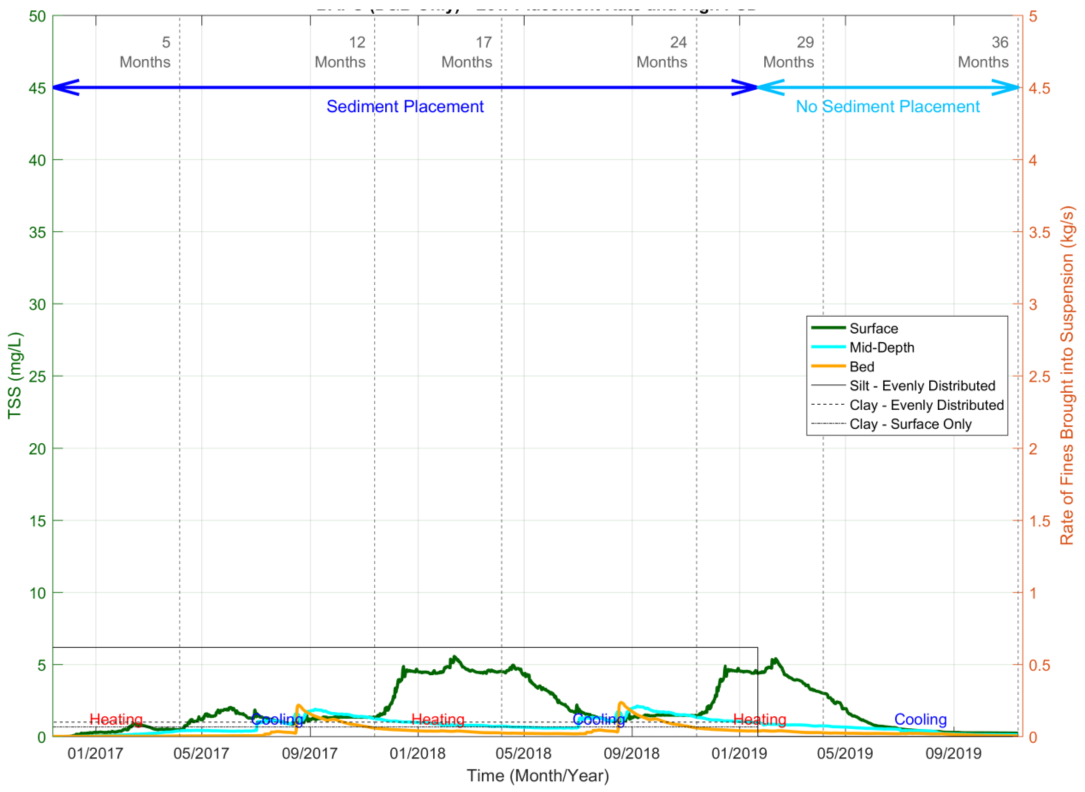

Figure 7-9: Time Series of TSS (Surface, Mid-depth and Bed) Location 4 (Lick Hole Creek) for Alternative Hybrid (D&B Only) Method with High Fines PSD

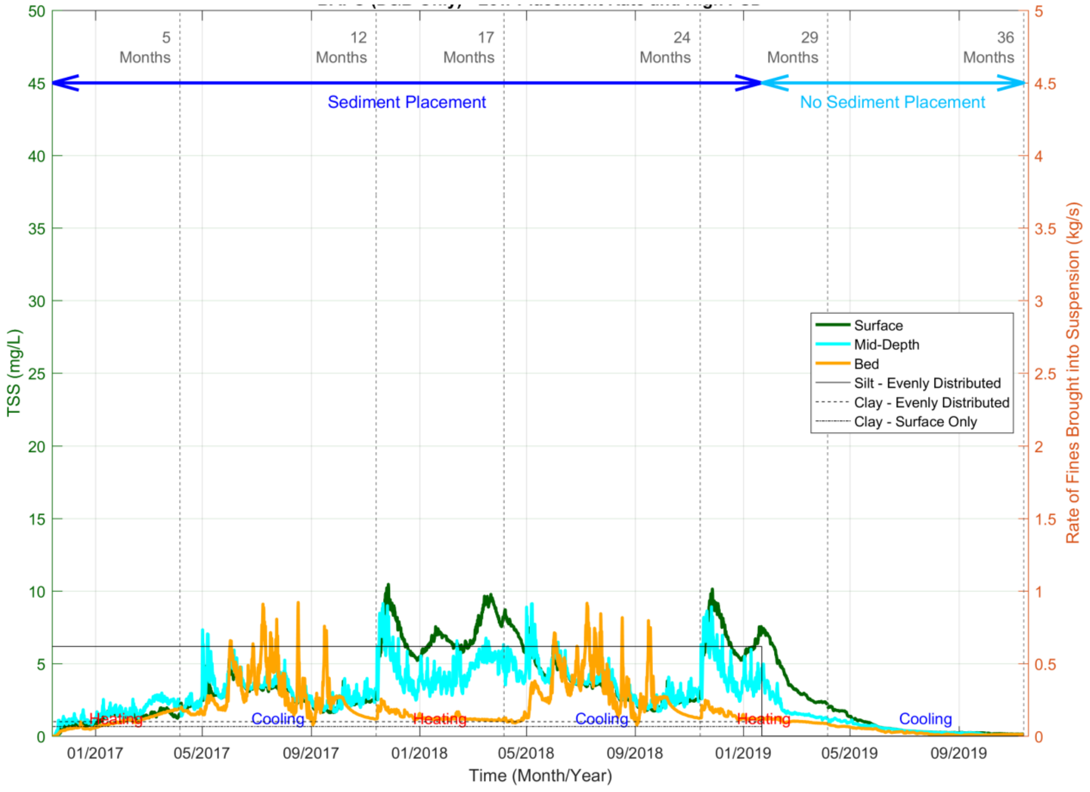

Figure 7-10: Time Series of TSS (Surface, Mid-depth and Bed) Location 9 (~1 km North of Placement Area) for Alternative Hybrid (D&B Only) Method with High Fines PSD

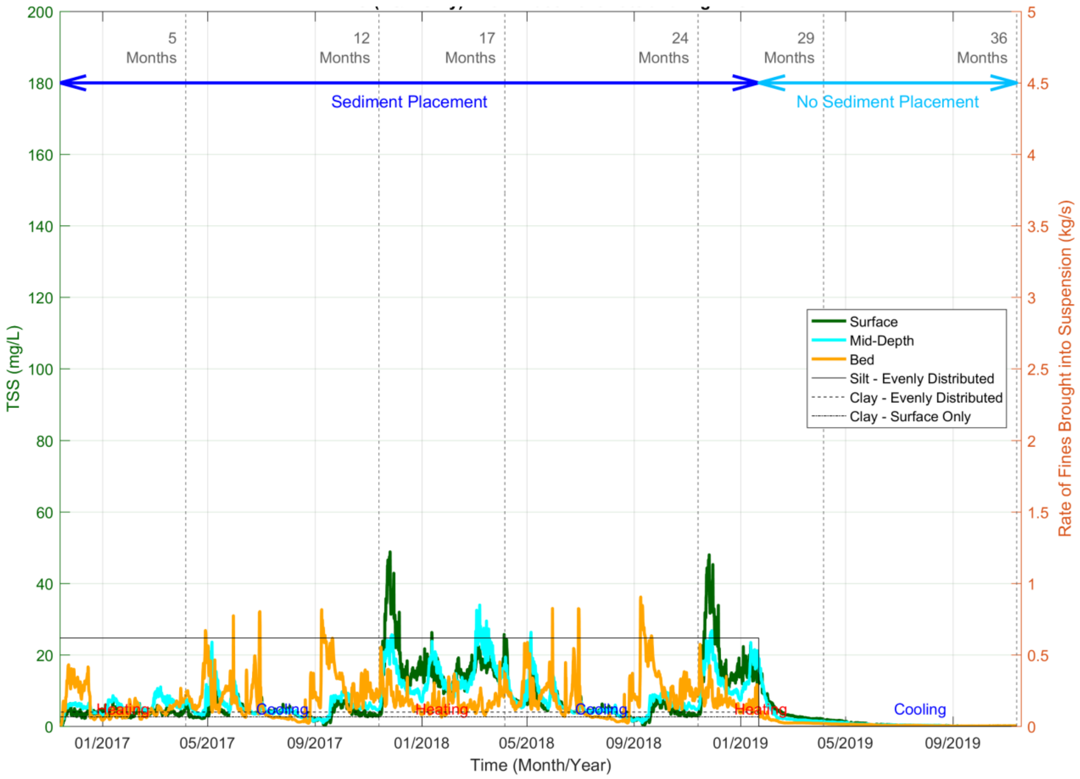

Figure 7-11: Time Series of TSS (Surface, Mid-depth and Bed) Location 11(500m East of Placement Area) for Alternative Hybrid (D&B Only) Method with High Fines PSD

7.3.3 Predicted Mass of Sediment Transported from Talbingo Reservoir

Table 7-7 presents an analysis on the predicted mass of sediment that is transported downstream into Jounama Pondage (via T3 outflows) while the calculated mass introduced to the water column in Talbingo Reservoir is presented in **Table 7-2**.

The calculations show that of the proposed 1.4 Million m^3 (bank) of D&B excavated rock material that is to be placed in Talbingo Reservoir using the proposed alternative Hybrid method, 54,065 tonnes of fine sediment, including 11,382 tonnes of clay, would be released to the water column.

The model is able to calculate the mass of sediment that is predicted to be transported from Talbingo Reservoir through the T3 outflows into Jounama Pondage. The model predicts that at the end of the three year simulation period, 6,539 tonnes of fines will have been discharged through T3. This comprises of 1,778 tonnes of silts and 4,761 tonnes of clay sized sediments.

The concentration of TSS leaving the reservoir will be similar to that predicted at Location 1 (refer **Figure 7-8**).

Table 7-7: Summary of Modelled TSS Mass Leaving Talbingo Reservoir (Sensitivity Testing of Alternative (D&B Only) Scenario)

Quantity	Mass (Tonnes) – Alternative Hybrid (with High Fines PSD)	Mass Tonnes – Alternative Hybrid
Mass of silt leaving the reservoir (tonnes)	**1,778**	1,209
Mass of clay leaving the reservoir (tonnes)	**4,761**	2,858
Total Mass fines leaving the reservoir (tonnes)	**6,539**	4,067

7.3.4 Predicted Sediment Deposition Thickness

A map of the predicted sediment deposition thickness for the alternative Hybrid (D&B Only) High Fines PSD ERP method is presented in **Figure 7-12** (after 36 months).

The maps show that:

- sedimentation rates are highest closest to the placement location;
- sedimentation rates are higher in shallow parts of the reservoir (i.e. reservoir edges);
- in the northern half of the reservoir, predicted sedimentation rates, due to the alternative Hybrid (D&B Only) placement, with High Fines PSD assumption are up to 5 mm/year;
- in the southern half of the reservoir, predicted sedimentation rates, due to the alternative Hybrid (D&B Only) placement, with High Fines PSD assumption are 2-12 mm/year;
- Closer to the placement area sedimentation rates above 30mm/yr are predicted.

The deposition rates for the alternative Hybrid high fines sensitivity test are typically 50% higher than those predicted for the base case alternative Hybrid scenario (refer **Section 6.5.4**).

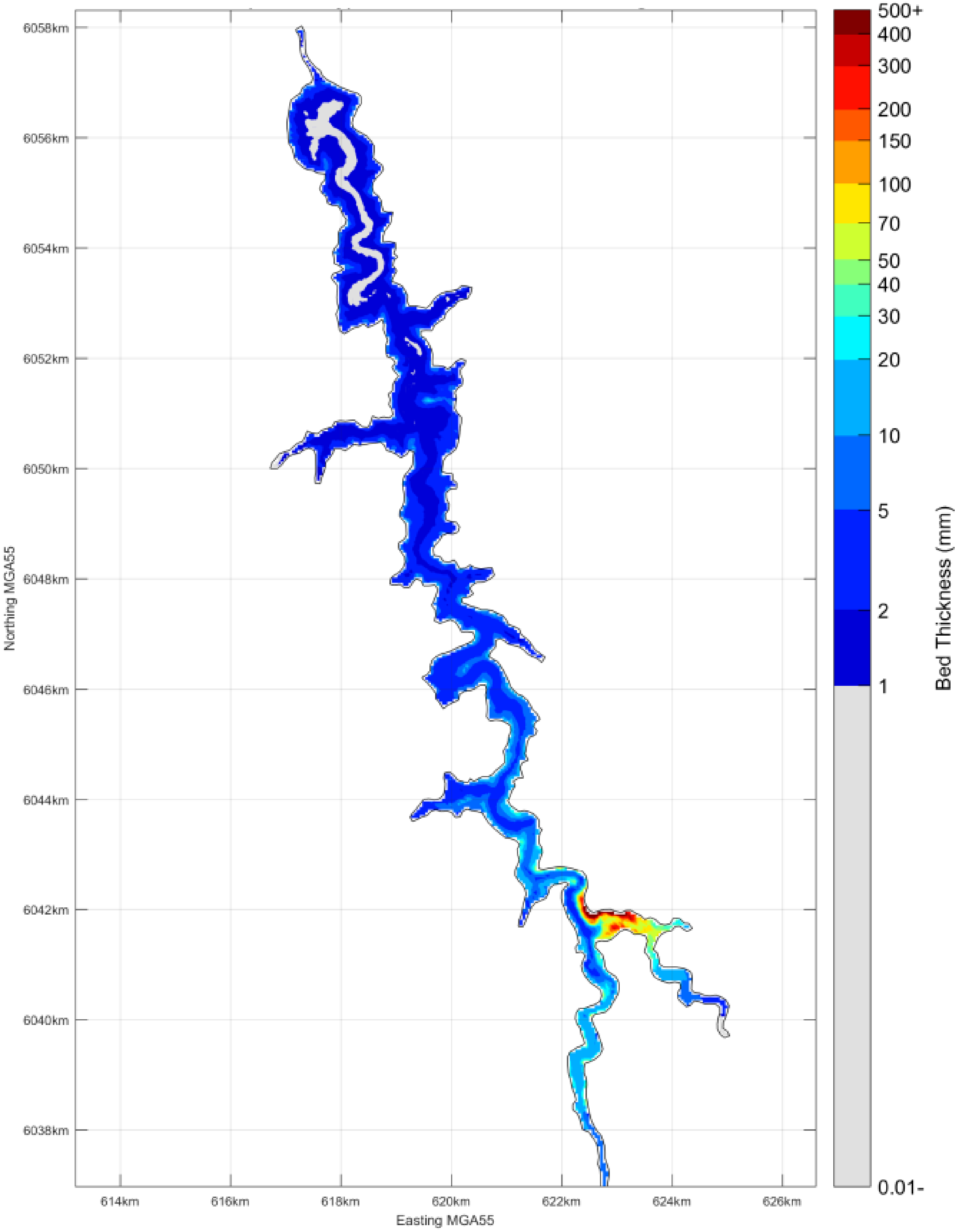

Figure 7-12: Map of Sediment Deposition Thickness (End 36 month simulation) for Alternative Hybrid (D&B Only) Method with High Fines PSD

8 Conclusions

Approximately 2.8 million m^3 (banked) of excavated rock material is to be placed in Talbingo Reservoir. It is estimated that approximately half this material would be from a TBM (tunnel boring machine), with the remaining 1.4 million m^3 (banked) from D&B (drill and blast) excavation. This study uses numerical modelling techniques to provide a prediction of the sediment plume resulting from the proposed methodology to edge push all this material into Ravine Bay from the northern shore over a two year period (Ravine Bay Placement).

An alternative Hybrid option, in which only the 1.4 million m^3 (banked) D&B (drill and blast) excavated rock is placed in the reservoir was also assessed.

Sensitivity testing of the assumed PSD was also undertaken for both the above approaches.

A model of Talbingo Reservoir has been developed to assist with conceptual engineering design and impact assessment of construction activities associated with the proposed Snowy 2.0. The model has been calibrated against observed water levels, water temperatures and current speeds. In some cases, certain model boundary conditions were approximated or based on data measurements for locations beyond the immediate study region (i.e. short wave solar radiation).

The model is also able to simulate the potential sediment plumes associated with the ERP activities. The existing model is suitable for comparative assessments. Incorporation of all of the data collected to date (some of which was not available when the model was calibrated) will allow for further model refinement.

The assessment of the impact of placement of excavated rock is based on a three year simulation of suspended sediment behaviour which includes two years of placement and a year to simulate the return of the reservoir to near background suspended sediment levels.

A range of model outputs have been provided to assess the potential impacts of the ERP in Talbingo Reservoir including:

- **Maps of Maximum TSS Concentration**: these maps show the maximum TSS concentration during the simulation at the surface. These are summarised in **Table 8-1.**
- **TSS Concentration Time Series Plots**: Time series of TSS at the surface, mid-depth and bed for various locations along the reservoir. A summary of the peaks is provided in **Table 8-1,** while a description of the seasonal changes is provided in **Sections 6.4.2** and **6.5.2**.
- **Sediment Mass Flux Calculations**: which summarise the mass of sediment leaving the reservoir through the T3 outlet near the dam wall. These are summarised in **Table 8-2**.
- **Sediment Deposition Depth Plots**: which present the total thickness of sediment deposited over the simulation period. Refer **Figure 6-9, Figure 6-15, Figure 7-6** and **Figure 7-12**. A summary of predicted deposition rates is provided in **Table 8-3.**

Table 8-1: Summary of TSS Time-Series Results

Location	Peak Surface TSS (mg/l))			
	Proposed Ravine Bay	Alternative Hybrid	Proposed Ravine Bay (with High Fines PSD)	Alternative Hybrid (with High Fines PSD)
Location 1 (near dam wall)	**16**	3-4	**24**	5
Location 4 (Lick Hole Creek)	**26**	4-5	**39**	7
Location 9 (~1 km North of Placement Area)	**32**	7	**48**	11
Location 11 (500m East of Placement Area)	**80**	33	**120**	50

Table 8-2: Summary of Modelled TSS Mass Leaving Talbingo Reservoir

Location	Mass (Tonnes)			
	Proposed Ravine Bay	Alternative Hybrid	Proposed Ravine Bay (with High Fines PSD)	Alternative Hybrid (with High Fines PSD)
Mass of silt leaving the reservoir (tonnes)	**6,018**	1,209	**8,930**	1,778
Mass of clay leaving the reservoir (tonnes)	**10,003**	2,858	**16,007**	4,761
Total Mass fines leaving the reservoir (tonnes)	**16,021**	4,067	**24,937**	6,539

Table 8-3: Summary of Modelled Deposition Rates (mm/yr)

Location	Deposition Rates (mm/yr)			
	Proposed Ravine Bay	Alternative Hybrid	Proposed Ravine Bay (with High Fines PSD)	Alternative Hybrid (with High Fines PSD)
Northern Half of Reservoir	**1-10**	<3	**2-15**	4-5
Southern Half of Reservoir	**5-30**	1-8	**7-45**	2-12
Near Ravine Bay	**>100**	>20	**>150**	>30

Because the alternative Hybrid places only half the volume of excavated rock into Talbingo Reservoir, and D&B material has less than half the volume of fines of the TBM and D&B materials combined, TSS concentrations and deposition thickness for the alternative Hybrid are typically only 25% of the proposed option. The sensitivity testing option investigated a scenario where the PSD comprised 50% more fines than the amount of fines assumed in the “base case” scenario. TSS concentrations and deposition thickness for the sensitivity model runs are typically 50% more than that of the “base case” (proposed and alternative) options.

9 References

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

DHI, 2017. MIKE 21 & MIKE 3 Flow Model FM: Hydrodynamic and Transport Module Scientific Documentation.

Attachment A: Model Boundary Conditions

Attachment A provides additional details of model boundary conditions including:

- existing scheme and catchment inflows
- catchment inflow temperature assumptions, and
- solar radiation data assumptions.

Existing Scheme and Catchment Inflows

Timeseries of existing Snowy Scheme inflows and over the calibration period is presented in:

- **Figure A-1** – T2 Talbingo Reservoir Inflows
- **Figure A-2** – T3 Pumping (Talbingo Reservoir Inflows) and Release (Talbingo Reservoir Outflow)
- **Figure A-3** – Cumulative Scheme Inflows, Outflows and Net Change (excluding catchment inflows, rainfall and evaporation). The 1400 GL outflow that occurred over the near 12 month calibration period is approximately 1.5 times the 921 GL storage volume of Talbingo Reservoir.
- **Figure A-4** – Yarrangobilly River (Talbingo) Inflow Timeseries

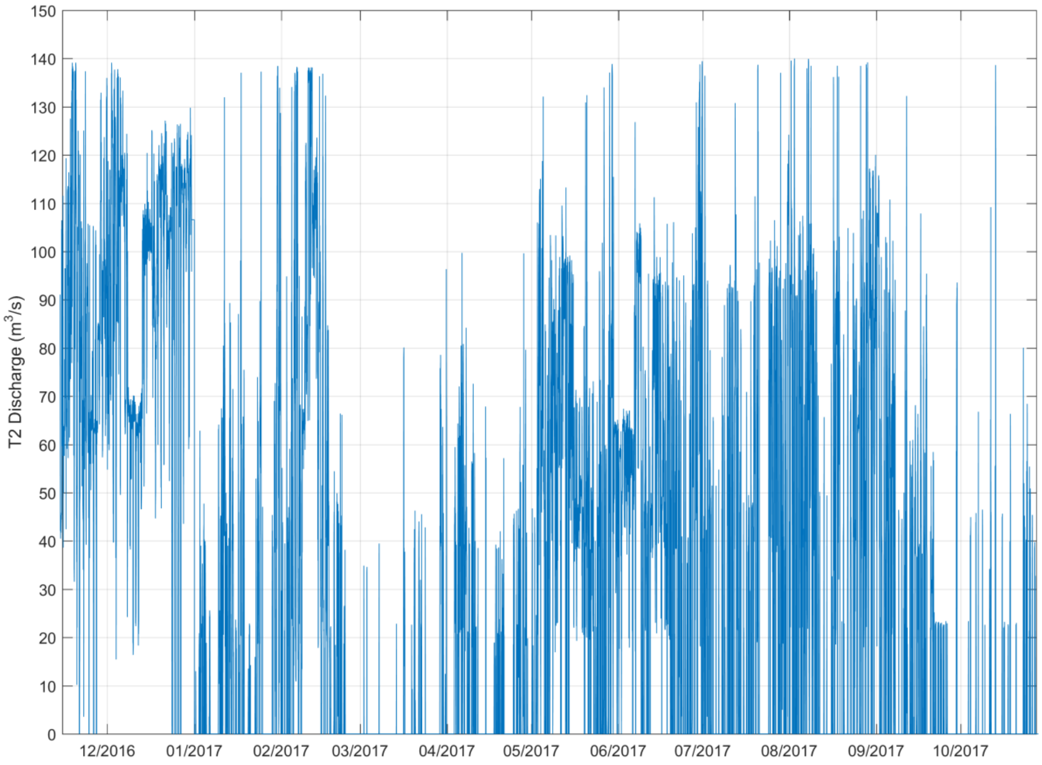

Figure A-1:T2 Inflow Timeseries.

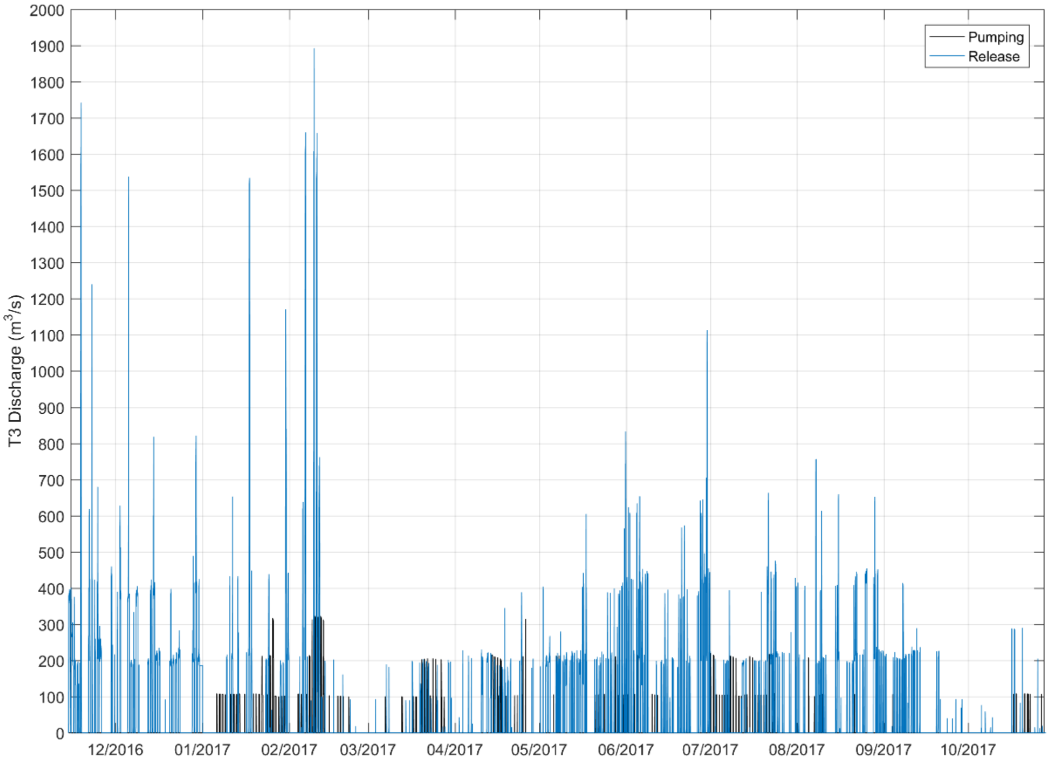

Figure A-2: T3 Pumping and Release (outflow) Timeseries.

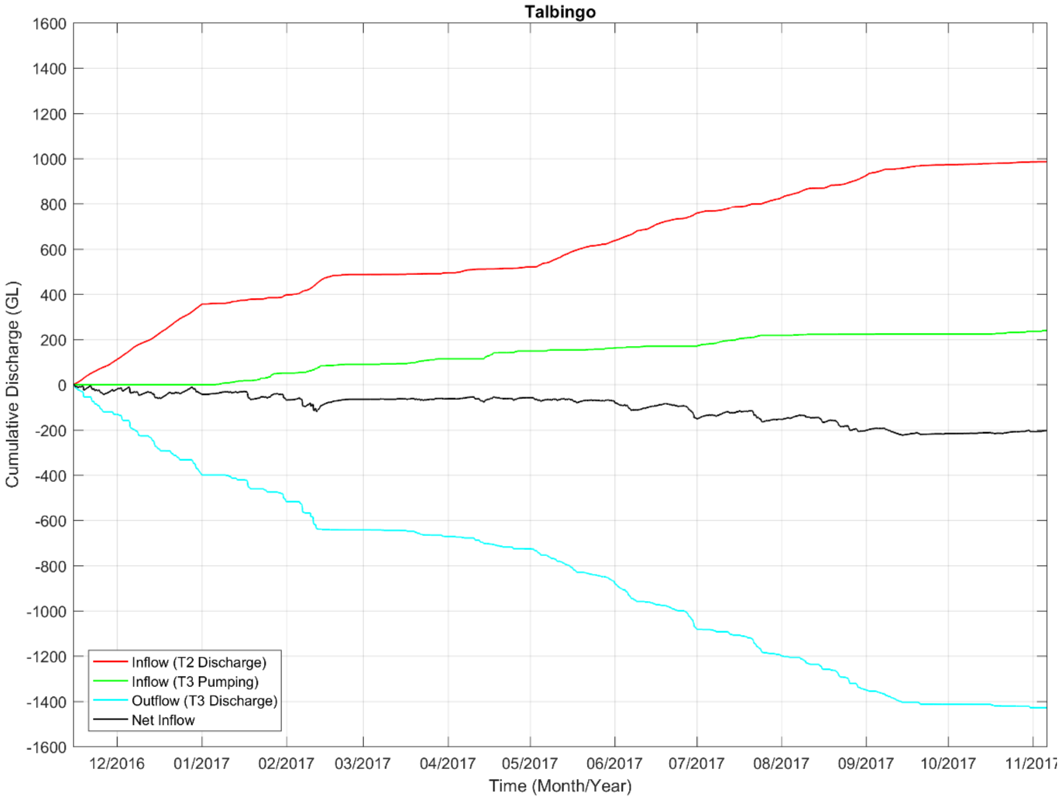

Figure A-3: Cumulative Scheme (T2 & T3) Inflow and Outflow Timeseries.

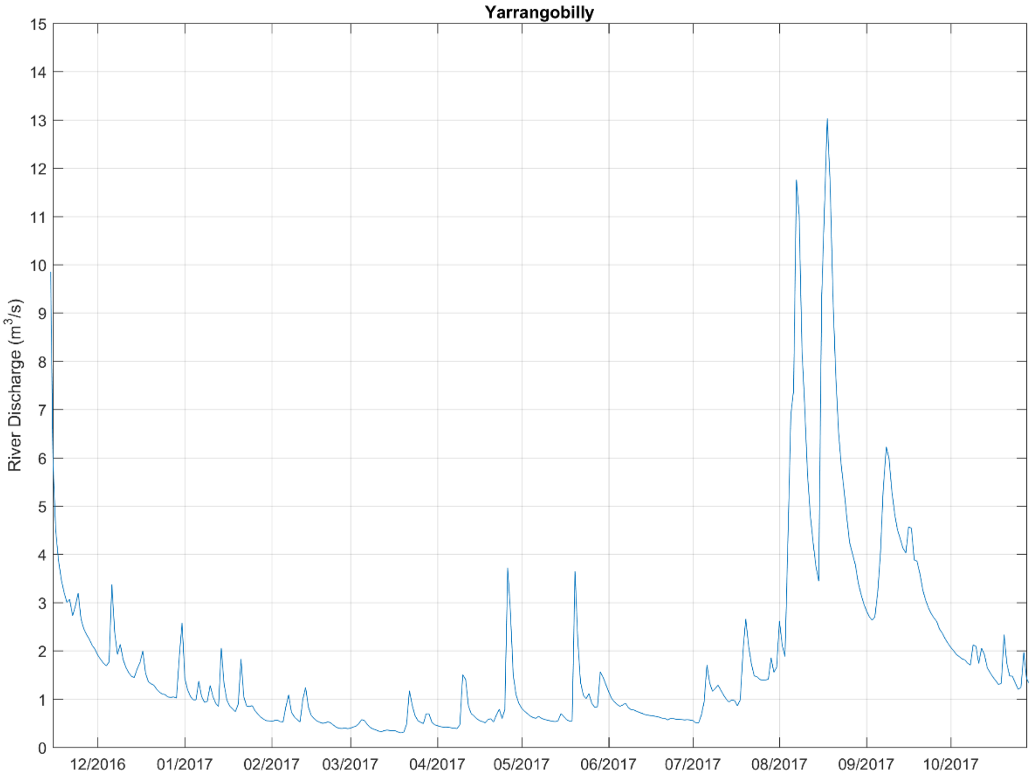

Figure A- 4: Yarrangobilly River (Talbingo) Inflow Timeseries.

Catchment Inflow Temperature Assumptions

In the absence of catchment inflow temperature data for Talbingo and Tantangara for the required modelling periods, *typical* annual catchment inflow temperature time-series were generated based on actual data at Yarrangobilly River at Ravine (Talbingo; 2002-2005).

This was achieved by calculating a fit through the daily mean of available measured data and applying a diurnal variation (refer **Figure A-5**).

While this assumption provides a good match to the characteristics of the observed water temperature data, differences of up to 5 °C occur.

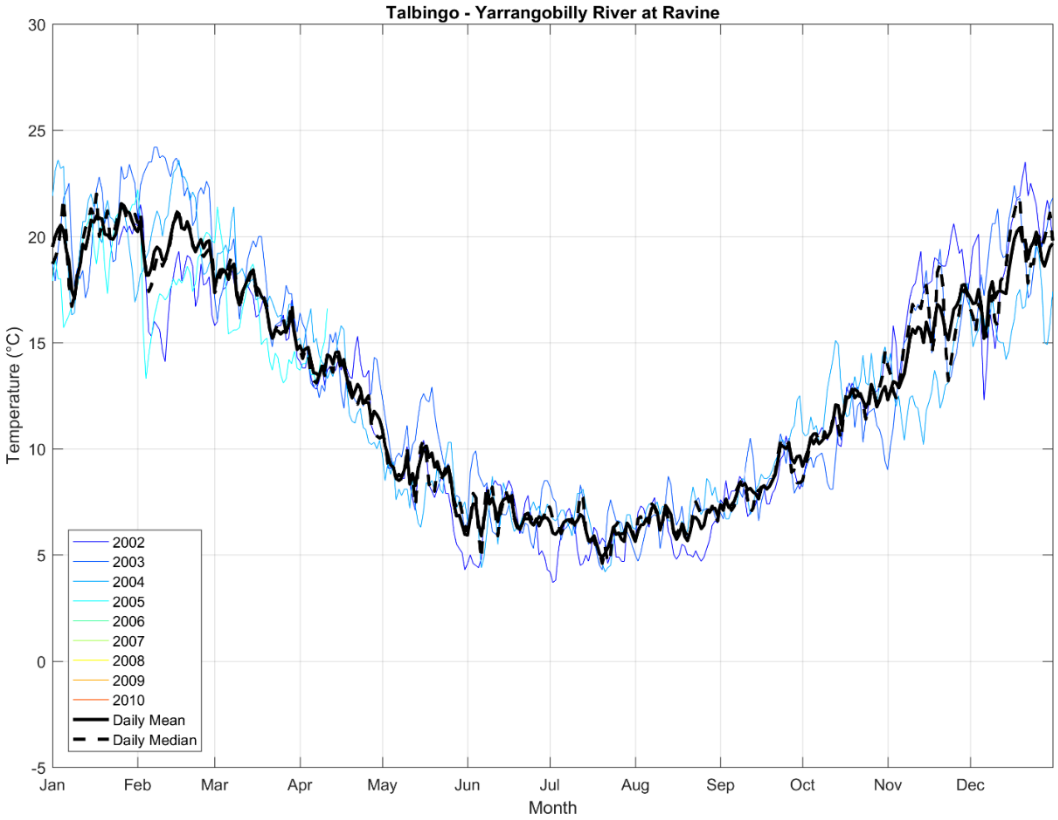

Figure A-5: Measured catchment inflow temperature data – Yarrangobilly River (Talbingo).

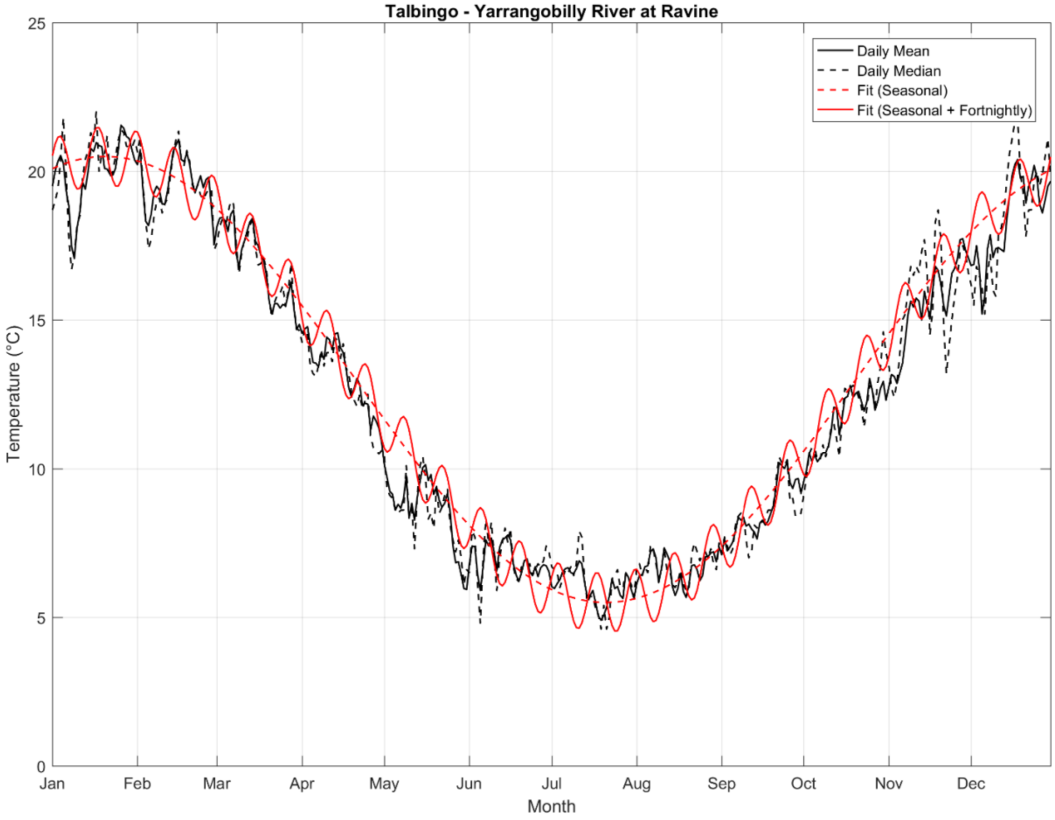

Figure A-6: Typical annual catchment inflow temperature time-series estimate – Talbingo.

Solar Radiation Data Assumptions

In the absence of direct local instrument data at a sufficiently small time-step, solar radiation data was obtained from an alternative source at two locations (**refer Figure A-7)**

- Weather Underground (WU):
    - INEWSOUT1163, and
    - INEWSOUT391.

Figure A-7: Solar radiation data source locations.

Data Analysis

Figure A-8 presents time-series of solar radiation at these two Weather Underground locations. WU is a global community of people connecting data from environmental sensors like weather stations and air quality monitors. This data was subsequently verified against daily solar radiation (remote-sensing) data available via (refer to **Figure A-7**):

- Bureau of Meteorology AWS, and
- SILO (average of three locations).

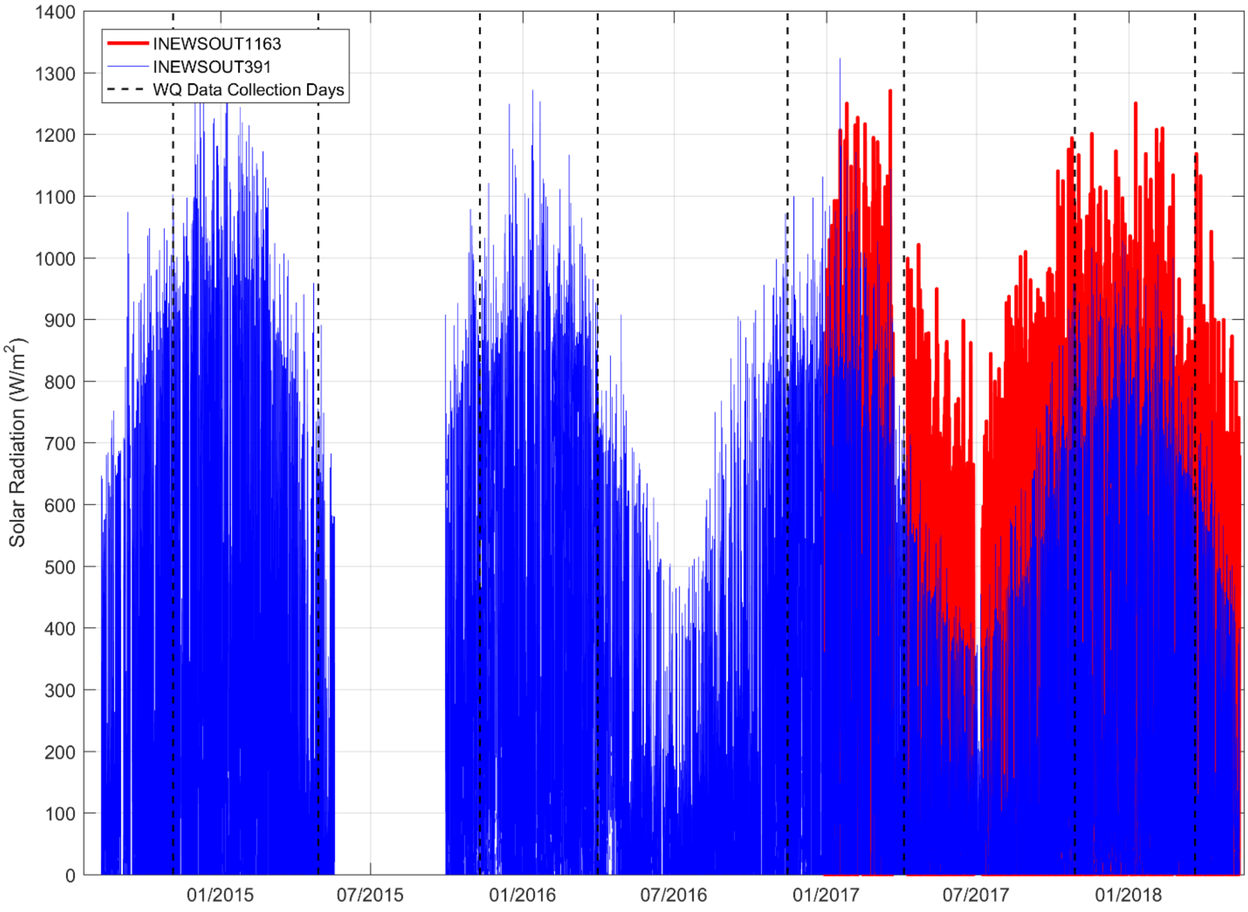

Figure A-8: WU solar radiation time-series.

The BoM daily solar radiation data is based on a computer model using visible images from geostationary meteorological satellites to estimate daily global solar exposures at ground level. SILO estimate total incoming solar energy incident upon the Earth's surface at a given location. The estimate includes contributions from both the direct and diffuse components of solar exposure. It can be calculated from data measured directly by radiometers and indirectly from observational estimates of cloudiness and hours of sunshine duration.

Figure A-9 shows daily solar radiation total in kWh/m^2 comparing BoM and SILO data (Talbingo) and the two WU stations (time-series data was integrated to obtain daily solar radiation values) for a selected a period of nearly six months for which continuous solar radiation data was available at both WU stations. Polynomial fits were generation for easier comparison.

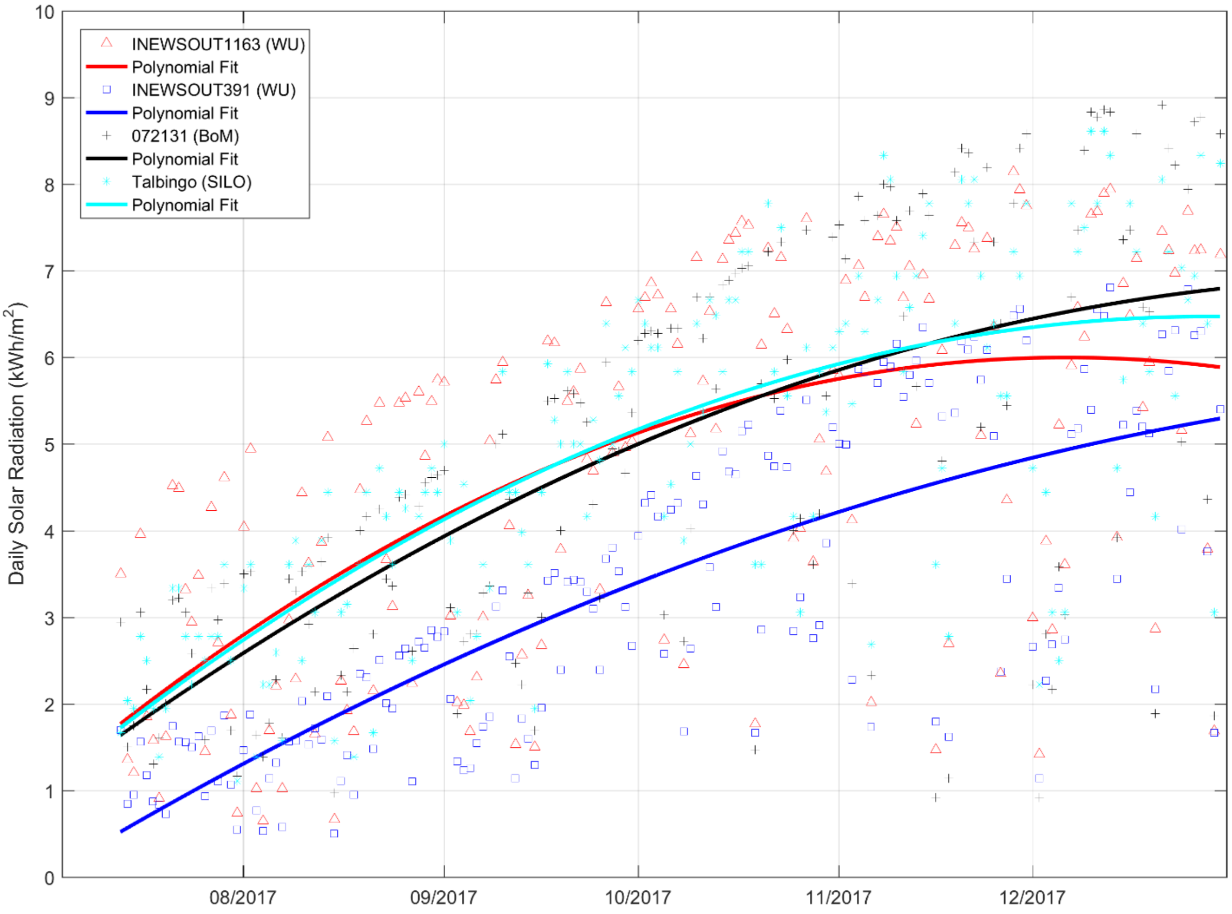

Figure A-9: Daily solar radiation comparing WU with BoM and SILO solar radiation data.

The BoM and SILO data lines up well with WU station INEWSOUT1163. WU station INEWSOUT391 is underestimating solar radiation compared to the BoM, SILO and WU INEWSOUT1163data.

Scale Factor Development

Despite most confidence being placed in the WU station INEWSOUT1163, (since its solar radiation data agreed with BoM and SILO daily solar radiation data), WU station INEWSOUT391 data was selected for modelling purposes, as it spans a longer period. To account for the discrepancy between WU station INEWSOUT391 data and BoM, SILO and WU station INEWSOUT1163 data, a scale factor was developed. Initially a scale factor of 1.5 was applied to the daily solar radiation (refer **Figure A-10**):

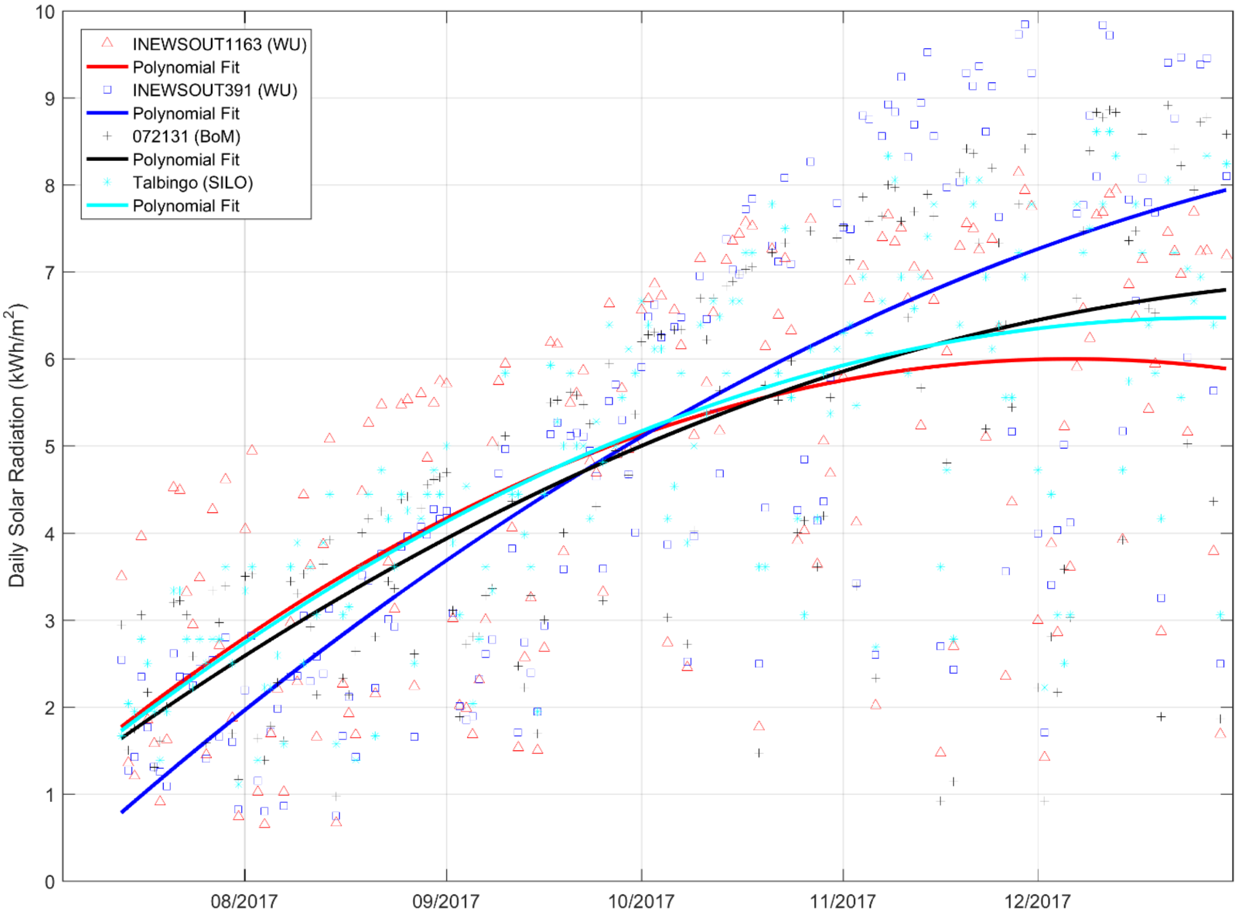

Figure A-10: WU INEWSOUT391 solar radiation multiplied by 1.5

Subsequently, the scale factor was assessed in more detail by taking three sub-sets of the full solar radiation time-series at WU station INEWSOUT391, representative of a ‘winter’, ‘spring’ and ‘summer’ period (refer **Figure A-11, Figure A-12,** and **Figure A-13):**

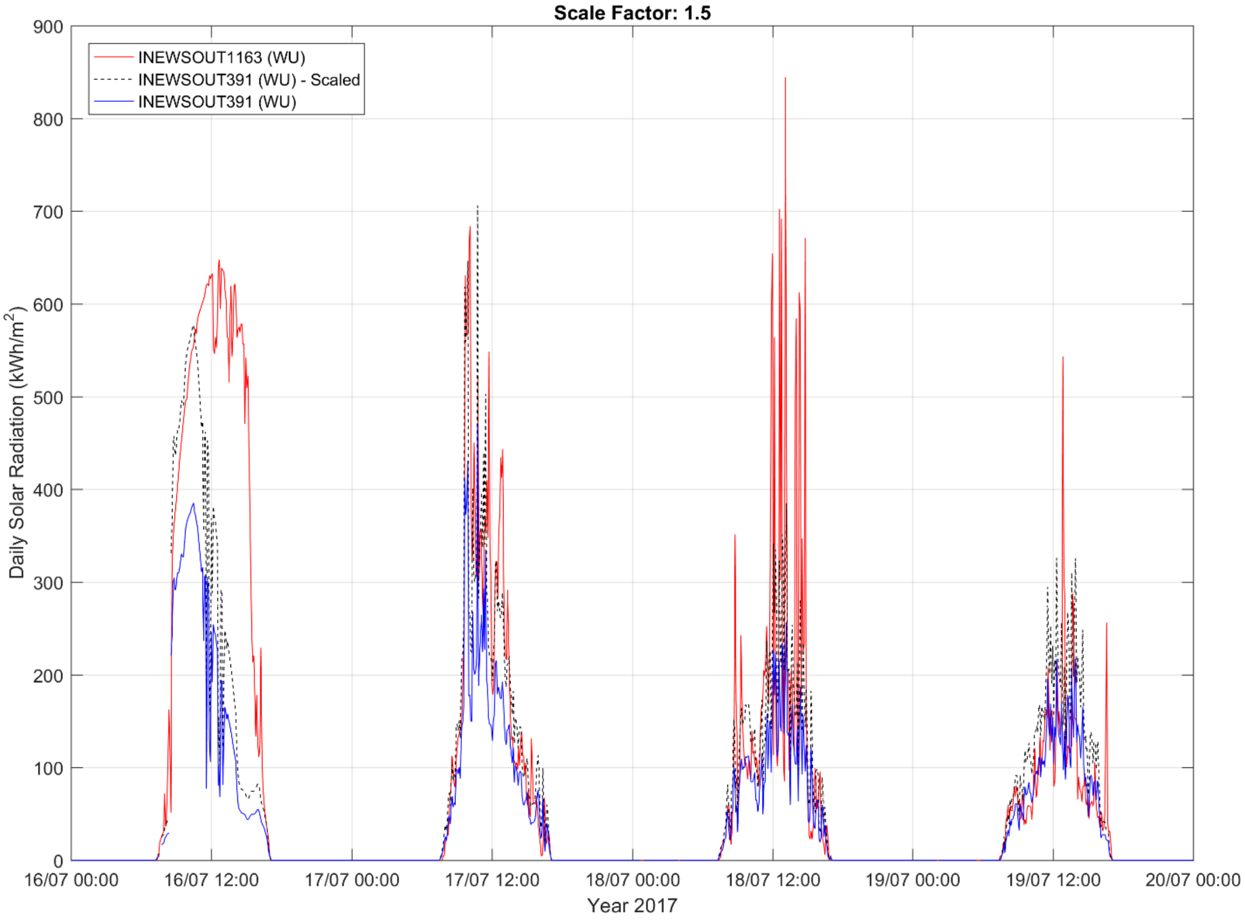

Figure A-11: WU 391 solar radiation multiplied by 1.5 – 'winter.'

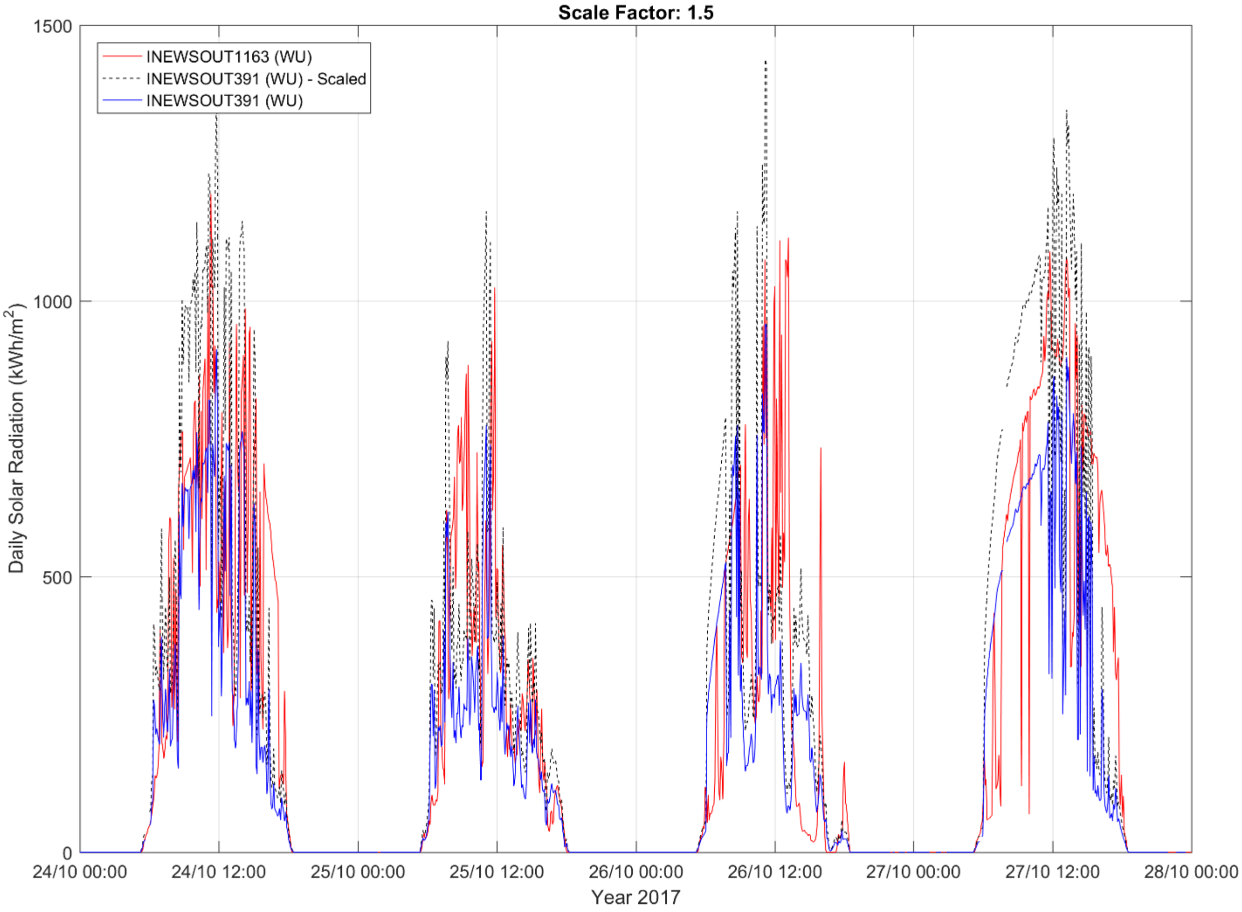

Figure A-12: WU 391 solar radiation multiplied by 1.5 – ‘spring’.

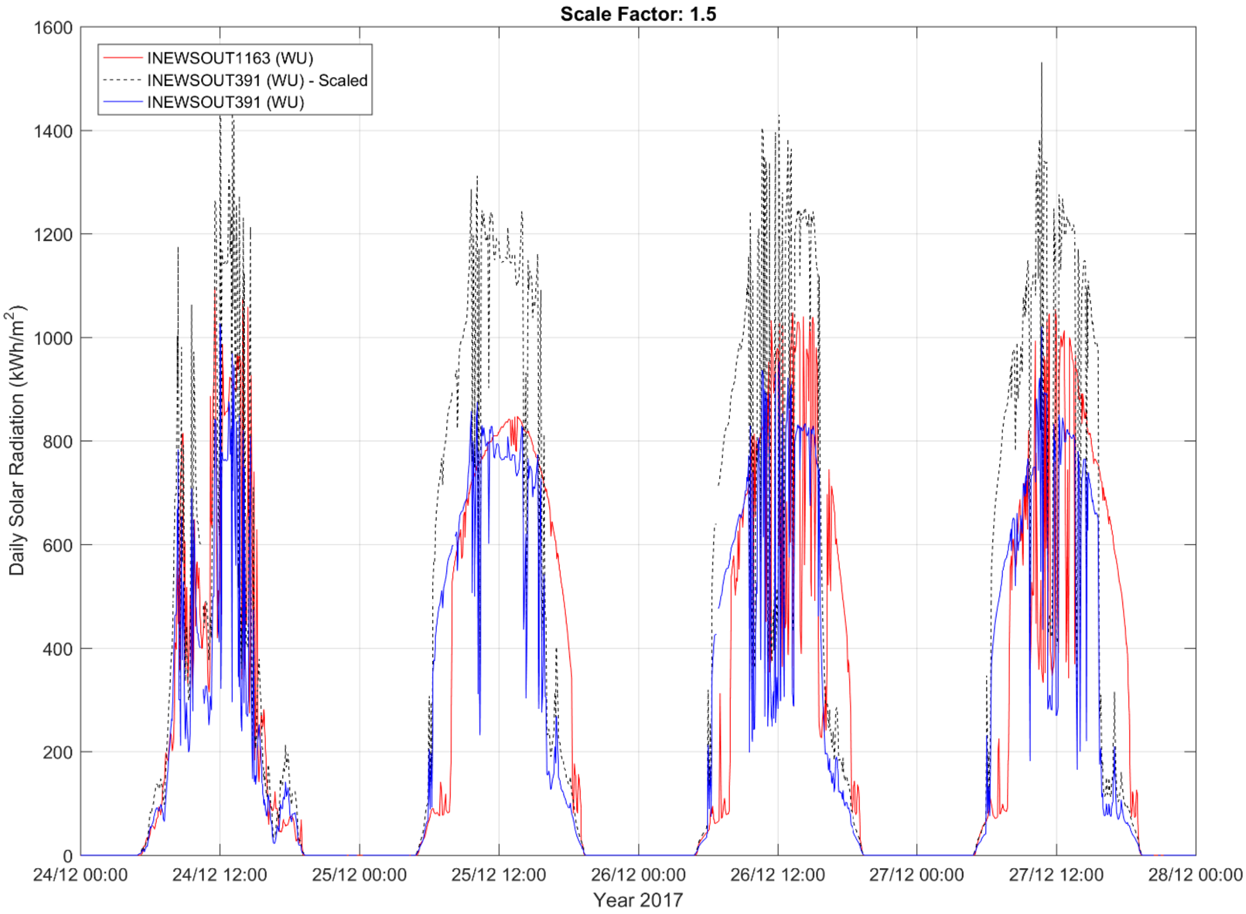

Figure A-13: WU 391 solar radiation multiplied by 1.5 – 'summer'.

As solar radiation with a scale factor of 1.5 resulted in a slight overestimation, it was decided to apply a scale factor of 1.25 to solar radiation data utilised for the Talbingo model (heating and cooling phase). Refer to **Figure A-14** and **Figure A-15** for final solar radiation time-series applied to the model.

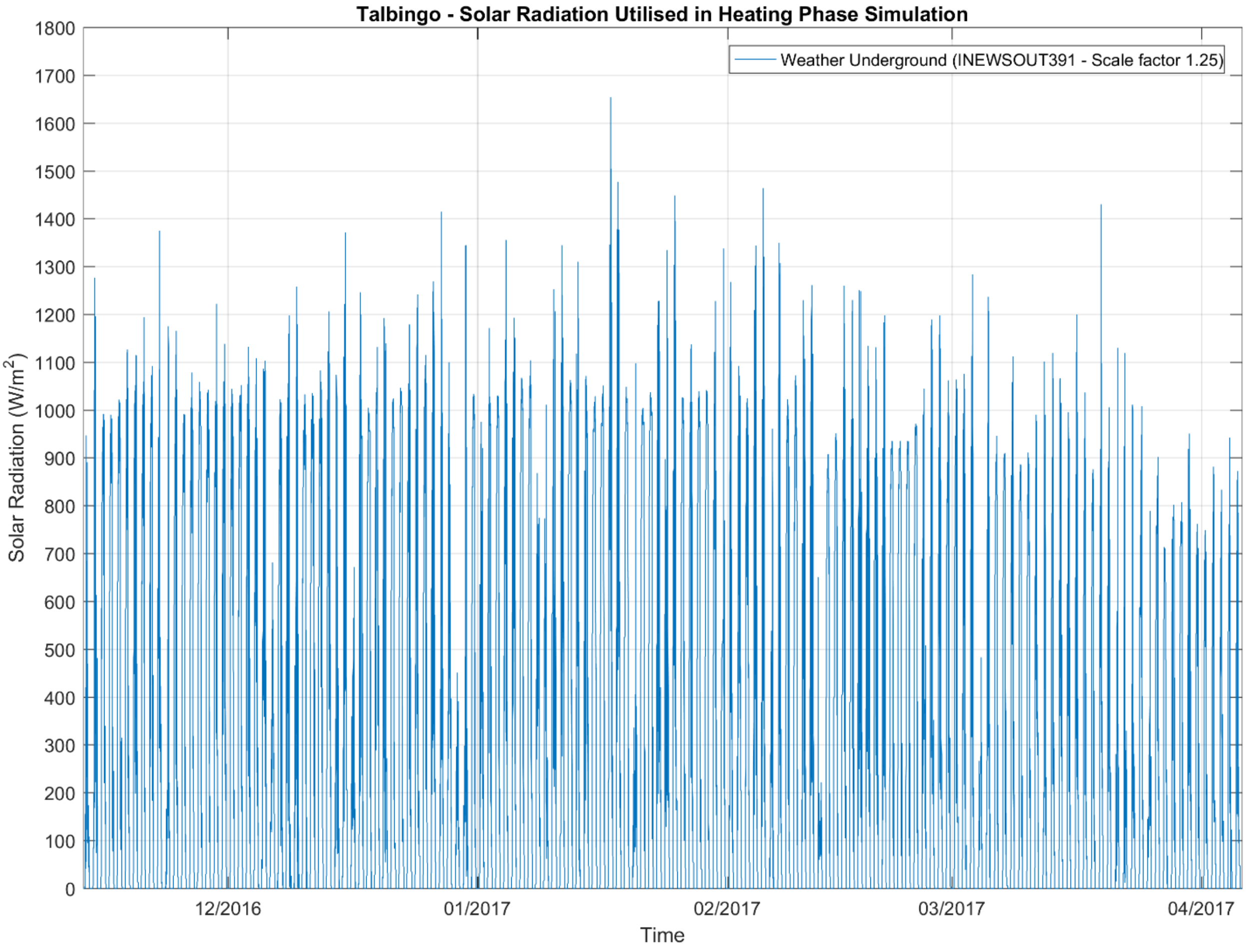

Figure A-14: Solar radiation utilised in Talbingo heating phase simulation.

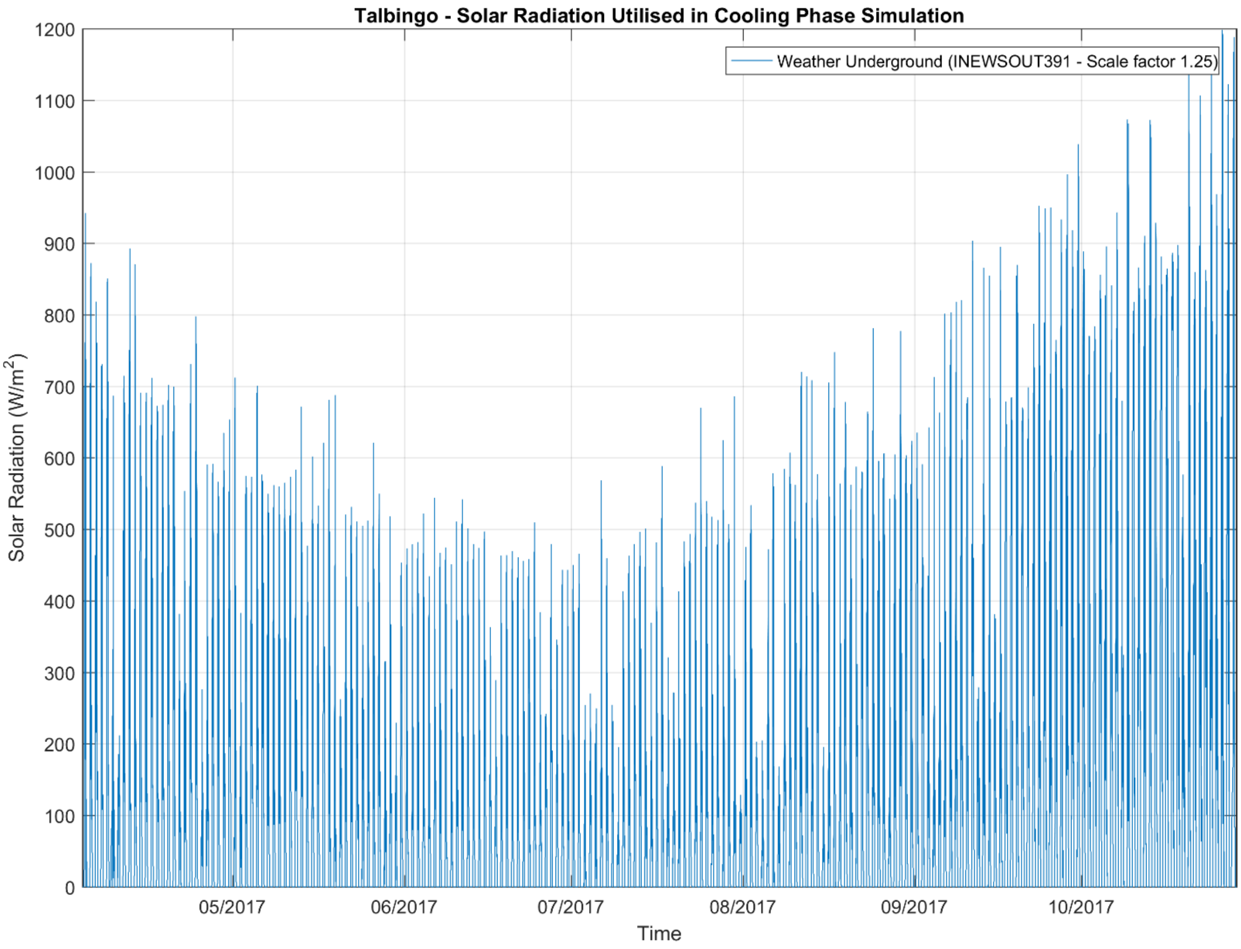

Figure A-15: Solar radiation utilised in Talbingo cooling phase simulation.

Attachment B: Water Balance Modelling

Daily water balance models were prepared for Talbingo Reservoirs using spreadsheet software (MS Excel). The water balance was configured to account for:

- storage conditions, i.e. variations in storage volume, storage level and surface area
- rainfall, evaporation and catchment runoff
- Snowy Hydro operations (inflow and outflows) and environmental flow releases, and
- other gains and losses including seepage.

The water balance calculates the ‘end of day’ volume using **Equation 1:**

$$V_{end} = V_{start} + R_i + P_i - E_i - S_i + H_i \qquad \text{(Equation 1)}$$

Where

V_{end} is the storage volume at the end of the day i

V_{start} is the storage volume at the start of the day / end of the previous day i

R_i is the total runoff volume for the current day i

P_i is the rainfall volume over the surface of the reservoir for the current day i

E_i is the evaporation volume over the surface of the reservoir for the current day i

S_i is the seepage volume from the reservoir for the current day i

H_i is the net volume of water pumped or released from the storage for the current day i

The water balance model allows for the following inputs to be specified assisting with the long-term balance of water:

- Initial storage level
- Conversion factor to apply to Morton’s Shallow Lake Evaporation to estimate Deep Lake Evaporation
- Level of the spillway (maximum storage volume). Volume of water above this level is assumed to spill, and
- Seepage rate.

Data inputs required by the model include:

- daily rainfall and evaporation (obtained from SILO climate database)
- stage-volume and stage-surface area relationships (derived from DEMs of hydrographic survey data and ground elevation data where required), and

- total catchment runoff volume (obtained from a combination of gauged flows and scaled gauged flows for the ungauged areas).

The Stage-Volume-Area curves derived for the Talbingo Reservoir is shown in **Figure B-1.**

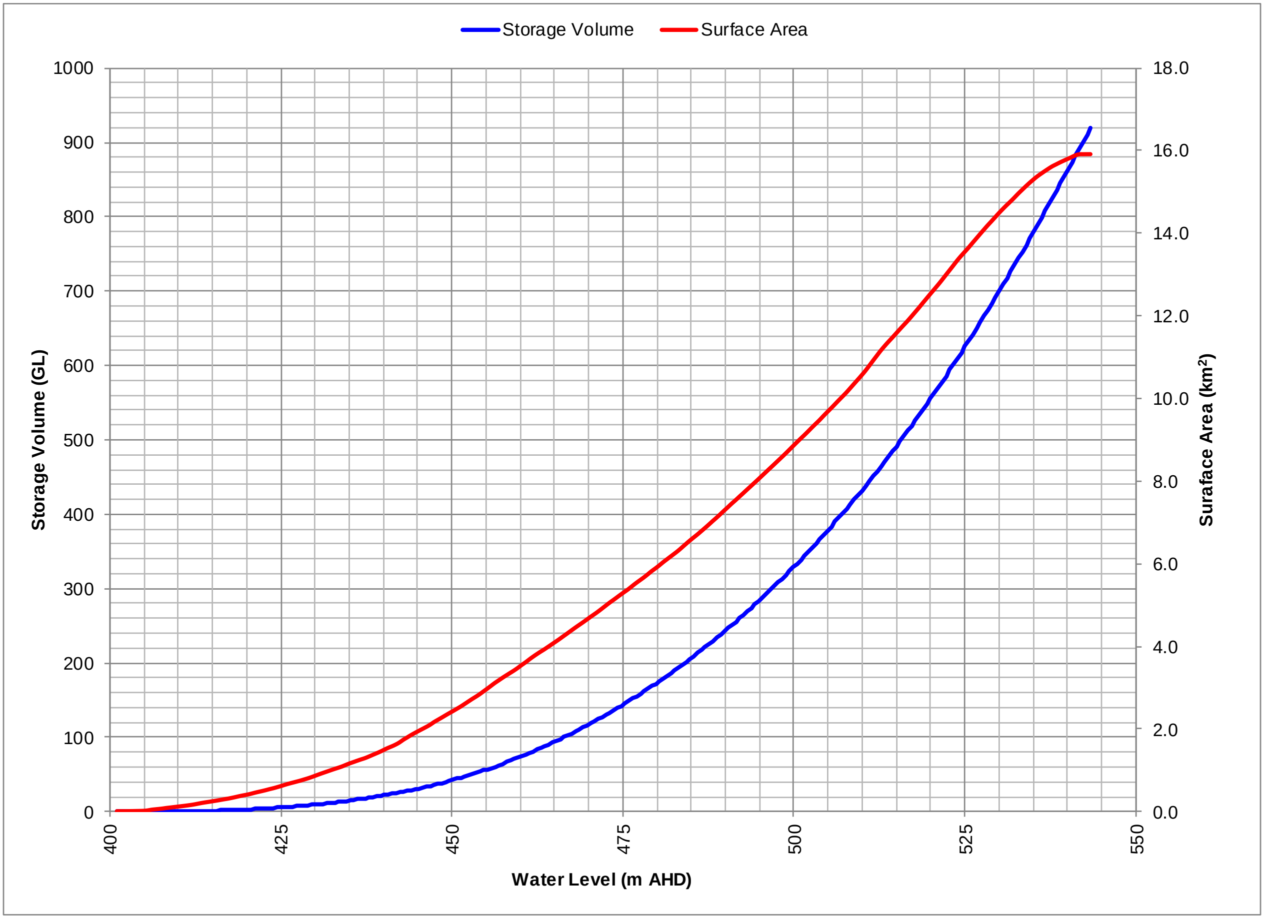

Figure B-1: Stage-Volume-Area Curves for Talbingo Reservoir.

The water balance models were configured to estimate the long-term balance of water for the record of historical water levels (1999 to 2018) available for Talbingo and Tantangara reservoirs.

Modelled and recorded water levels for the period October 2016 to January 2018 at Talbingo Reservoir is shown in **Figure B-2**. The modelled result was obtained using streamflow data for the gauged sub-catchments and scaling of catchment flows (based on area) for the remaining ungauged sub-catchments.

The results show that the balance of surface water in the study reservoir could be simulated by accounting for the major inputs and outputs of the system outlined above. The modelled water level compares well to the recorded water level with respect to the timing and magnitude of drawdown and filling of the storages which occur on a cyclical basis each year.

The water balance modelling highlights that Snowy Hydro operations are a significant source and sink to the water balance for Talbingo Reservoir.

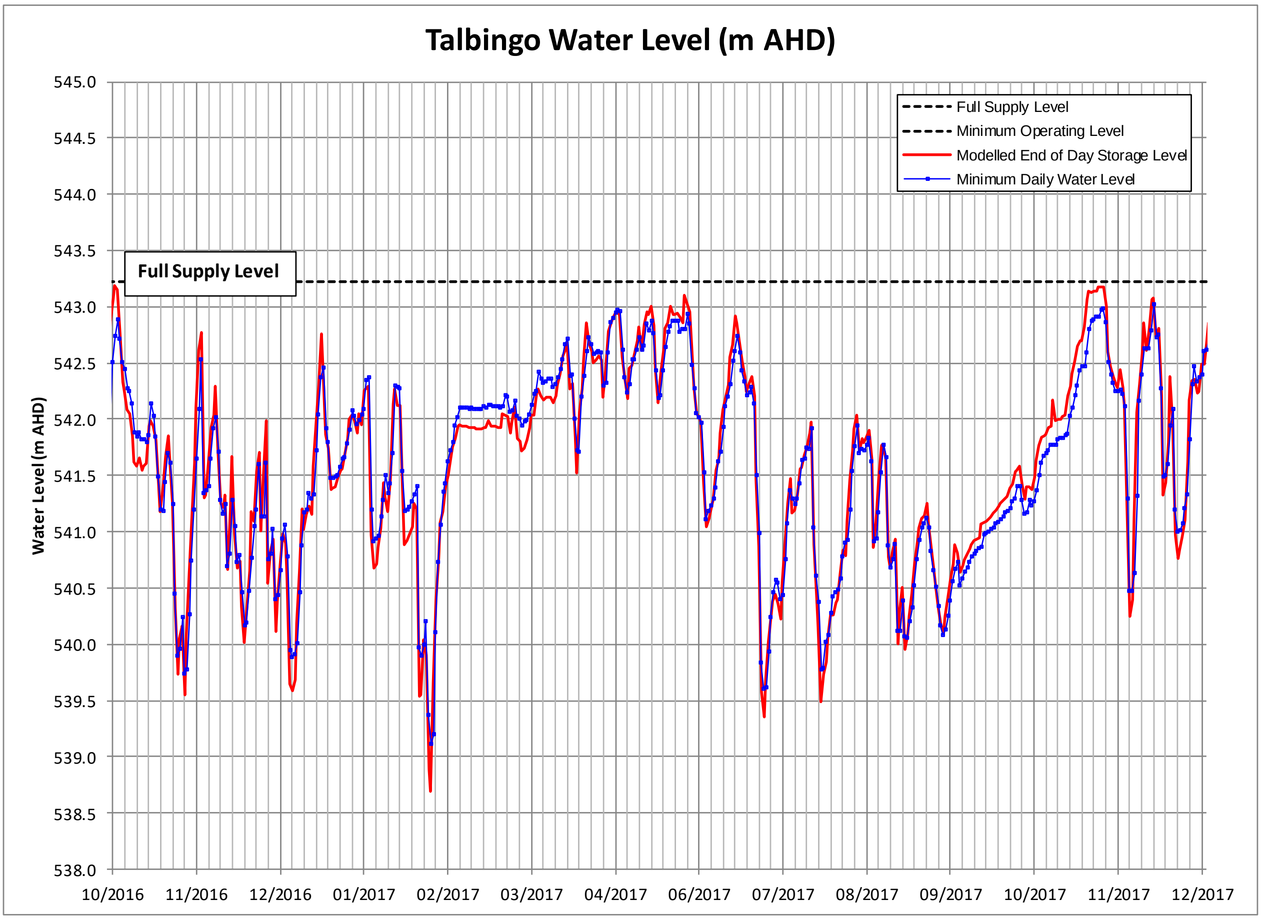

Figure B-2: Water Balance Model Results for Talbingo Reservoir.

Attachment C: Catchment Model Development and Calibration

The Source Modelling Framework

The eWater Source Modelling Framework Version 4.3 (herein referred to as Source) (http://www.ewater.com.au/products/ewater-source/) was used to simulate the daily runoff from the catchments draining to Talbingo Reservoir.

Source is an application that can be used for both catchment and river modelling. Source provides a flexible structure that allows users to select a level of model complexity appropriate to the problem at hand and within any constraints imposed by your available data and knowledge. Users can construct models by selecting and linking component models from a range of available options (Delgado et al., 2013).

Source is designed to:

- support the construction and operation of models that mimic water resource systems, and can be analysed for periods that range from days to many years, and
- allow users to construct and interrogate water and contaminant transport models to assess the impact of future change, on parameters of interest.

Source integrates an array of models, data and knowledge that can be used to simulate how climate and catchment variables (rainfall, evaporation, land use, vegetation) affect runoff, sediment and contaminants. The output can be used to offer clear scenarios and options for making improvements in a catchment (or a particular water management system).

For this assignment, Source was configured as a stand-alone (catchment) model to estimate the volume of surface runoff generated by the study catchments. Time series of surface runoff simulated by the catchment models are used by to define inflows to the reservoir models at discrete locations such as major tributary (creek) systems and the smaller adjacent areas that drain directly into the reservoirs.

Data Collation

Development of the Source models requires the gathering of a range of data sets to assist with establishing locally specific model input parameters including:

- **Aerial photography** – recent aerial imagery was available from Nearmap (https://www.nearmap.com.au)
- **Digital Elevation Model (DEM)** – data sources include the Shuttle Radar Topography Mission (SRTM) Derived Digital Elevation Model datasets and Snowy Hydro LiDAR data which can be used for catchment delineation and terrain processing.
- **Sub-catchments** – using available DEM data, the distribution of sub-catchments to be adopted within the Source models are prepared using GIS and digital terrain processing techniques
- **Land use** – aerial photography is used to define broad categories of land use such as bushland, cleared, developed etc.
- **Catchment imperviousness** – Directly connected proportions to be estimated based on our experience in the local catchments or as determined through model calibration procedures.
- **Climate** – daily rainfall and evapotranspiration data are available from the SILO database (https://legacy.longpaddock.qld.gov.au/silo)

Information contained in the above data sources relevant to the development of the catchment model is further presented and discussed in the sections below.

Catchment Delineation

The Source models include all sub-catchments that drain to the study reservoirs. A DEM with a grid resolution of 25 m by 25 m was used to digitise the catchment area draining to the study reservoirs.

The extent of sub-catchments delineated for the catchment model is shown in **Figure C-1**. For Talbingo Reservoir, a total of 39 sub-catchments were delineated with a combined area of approximately 1 084 km^2.

Functional Units

When creating a catchment model, sub-catchments are divided into areas with a common hydrologic response or behaviour called functional units (FUs), based on various combinations of land use or cover management (e.g. forest, urban, rural), position in landscape (flat, hill slope, and ridge) and/or hazard. FUs are therefore used to reflect the different hydrologic responses in the area of interest (Delgado et al., 2013).

Recent aerial imagery was used to derive a map of FUs for the study area based on land use. FUs were broadly classified according to the amount of impervious surfaces expected within. Two (2) broad categories were identified and adopted in preparing the Source models to account for differing runoff response to rainfall. The categories adopted include:

- **bushland** – Includes areas of uncleared native bushland and some areas of cleared bushland / native vegetation but not disturbed or developed, and
- **cleared** – Includes cleared areas.

The spatial distribution of the above FUs were mapped in a GIS and used as input to the Source models. Areas of each FU within the sub-catchments were automatically assigned by the model software using a gridded input dataset.

Model Extents

The final Source model layout for the Talbingo Catchment is shown in **Figure C-2**.

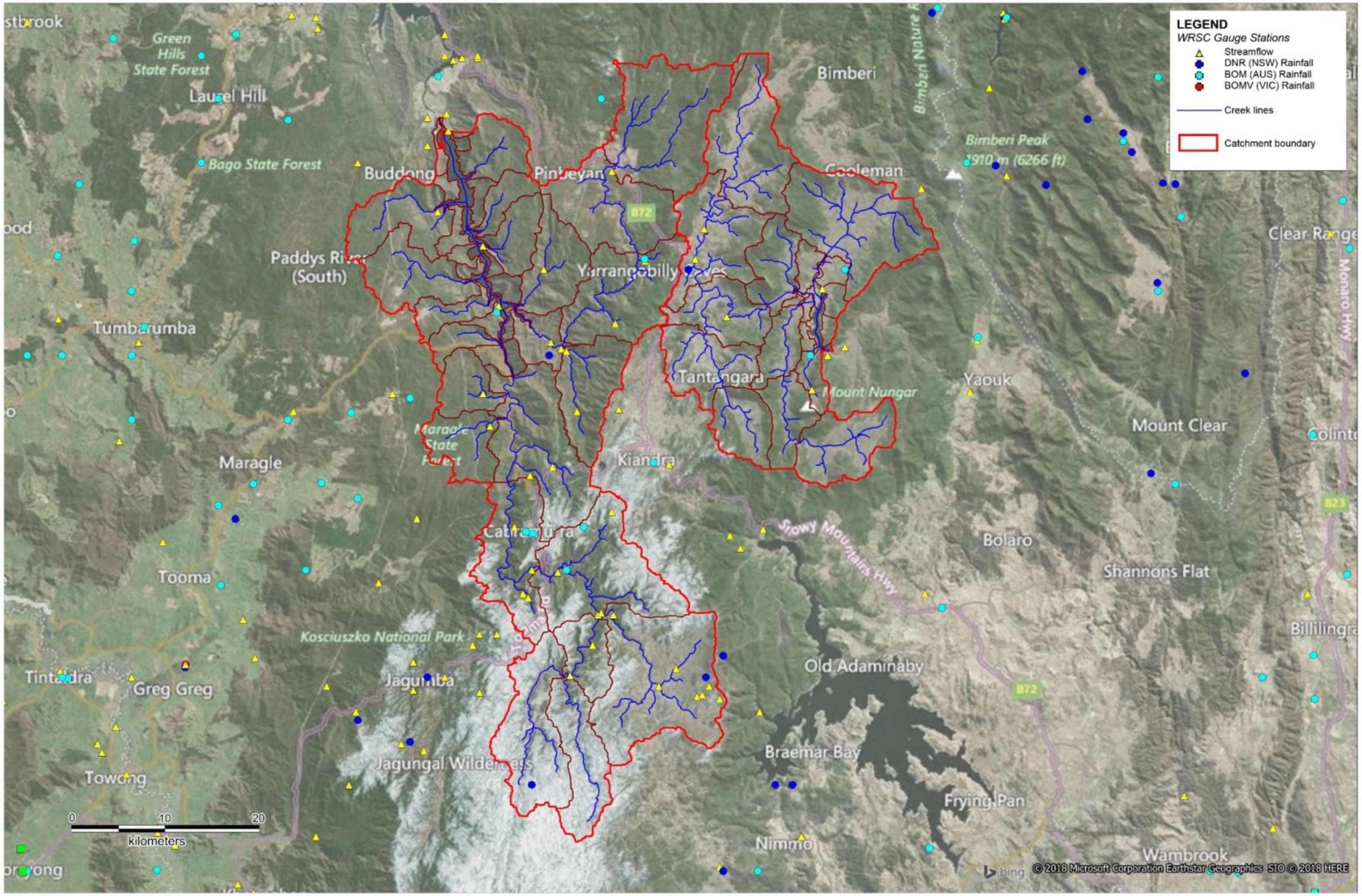

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FIGURE C1 TANTANGARA AND TALBINGO CATCHMENTS

CO-ORDINATE SYSTEM: Datum: GDA94 Projection: MGA Zone 55
CREATED BY: L. KIDD
REVISION A
DATE 10/10/2018
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Enhancing Society Together

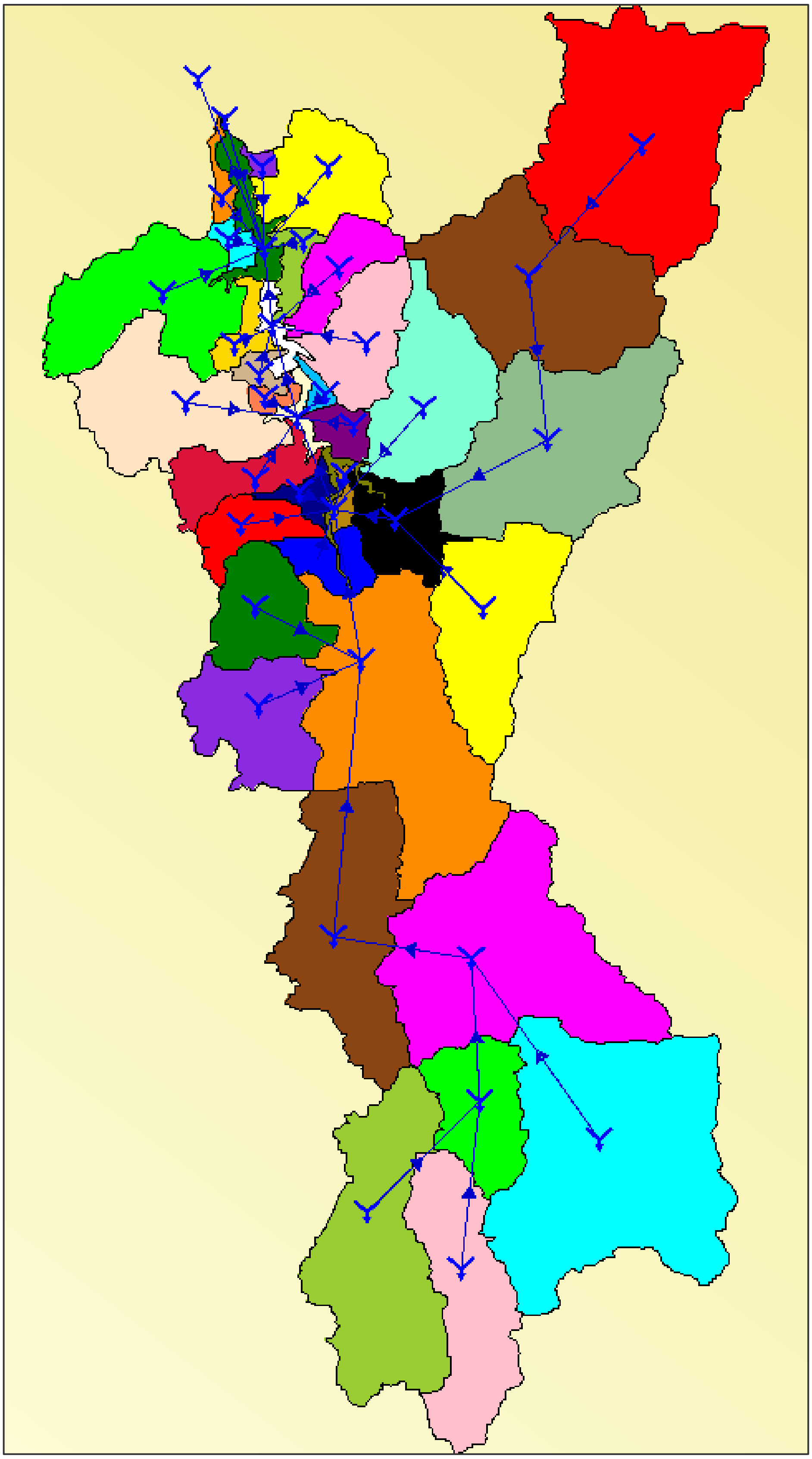

Figure C-2: Source Model Layout – Talbingo Reservoir Catchment.

Rainfall-runoff Model

The SIMHYD rainfall-runoff model was used to model runoff for all surface types defined in the model. SIMHYD is a conceptual rainfall-runoff model, which is itself a simplified version of the daily conceptual rainfall-runoff model, HYDROLOG that was developed in 1972.

The model simplifies the rainfall-runoff processes and requires input of the following variables to perform the hydrological assessment:

- Rainfall data
- Potential evapotranspiration data
- Catchment parameters (area, % impervious and pervious areas), and
- Impervious and pervious area parameters (rainfall threshold, infiltration rates, field capacity, soil storage depths and groundwater parameters).

SIMHYD has been widely used in Australia and was applied for generating runoff for the Murray Darling Basin Sustainable Yields study in 2006-2008 (Delgado et al., 2012), and has been used for numerous other catchments throughout Australia.

SILO Meteorological Data

The SIMHYD rainfall-runoff model estimates daily streamflow from daily rainfall and areal potential evapotranspiration data (APET). SILO is an enhanced climate database containing Australian climate data from 1889 (current to yesterday), in several ready-to-use formats.

Source utilises gridded SILO meteorological data to calculate spatially weighted (catchment average) rainfall and APET time series to each FU within each sub-catchment of the model. Example time series of daily rainfall and APET used by the Source model are shown in **Figure C-3** and **Figure C-4** respectively.

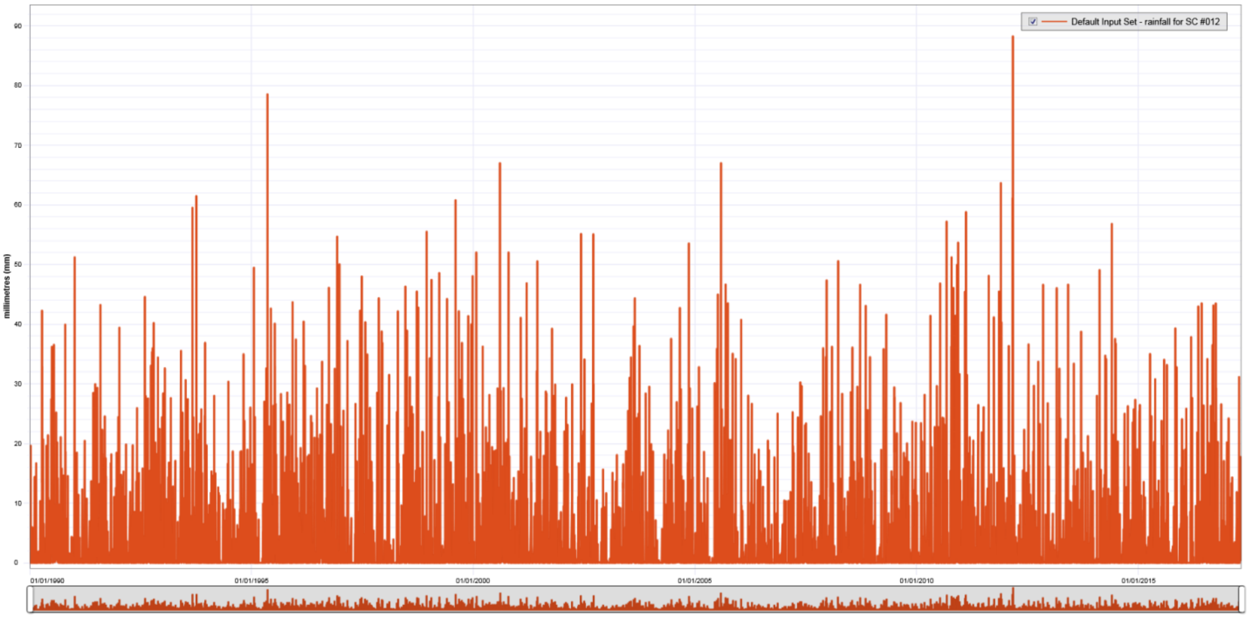

Figure C-3: Example Daily Rainfall Data used by Talbingo Source Catchment Model.

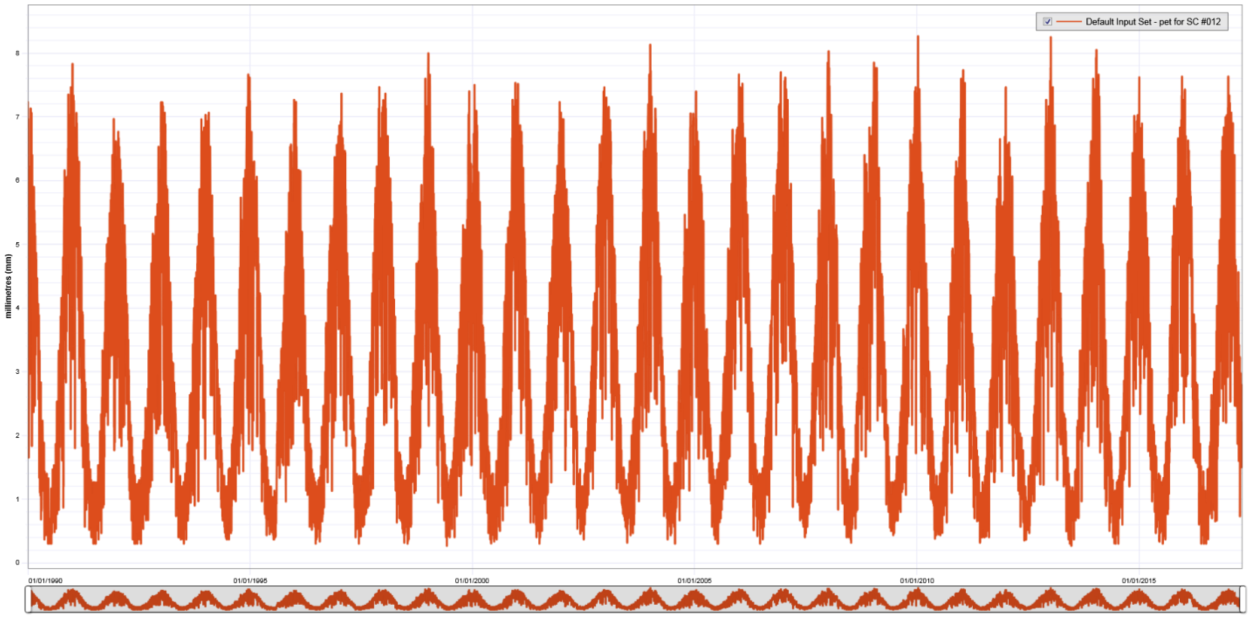

Figure C-4: Example Daily APET Data used by Talbingo Source Catchment Model.

Model Calibration

SIMHYD model parameters are typically derived for calibration of the SIMHYD rainfall-runoff model to stream flow records if available. Streamflow records were available at:

- **Gauge No. 410574** – Yarrangobilly at Ravine.

SIMHYD model parameters were calibrated using stream flow data available for the above stream gauges which are shown in **Figure C-5** below.

Yarrangobilly River sub-catchment is a perennial stream that is part of the Talbingo Reservoir catchment. The catchment is largely undisturbed bushland and was calibrated assuming a single function unit (land use) of bushland.

A summary of the calibrated SIMHYD model parameters is provided in **Table C-1**.

A comparison of the observed and simulated streamflow for Yarrangobilly River at Ravine (Gauge No. 410574) is provided in **Figure C-6**. The result shows a very good model calibration (NSE > 0.8 and R-squared > 0.8) for the gauged sub-catchment.

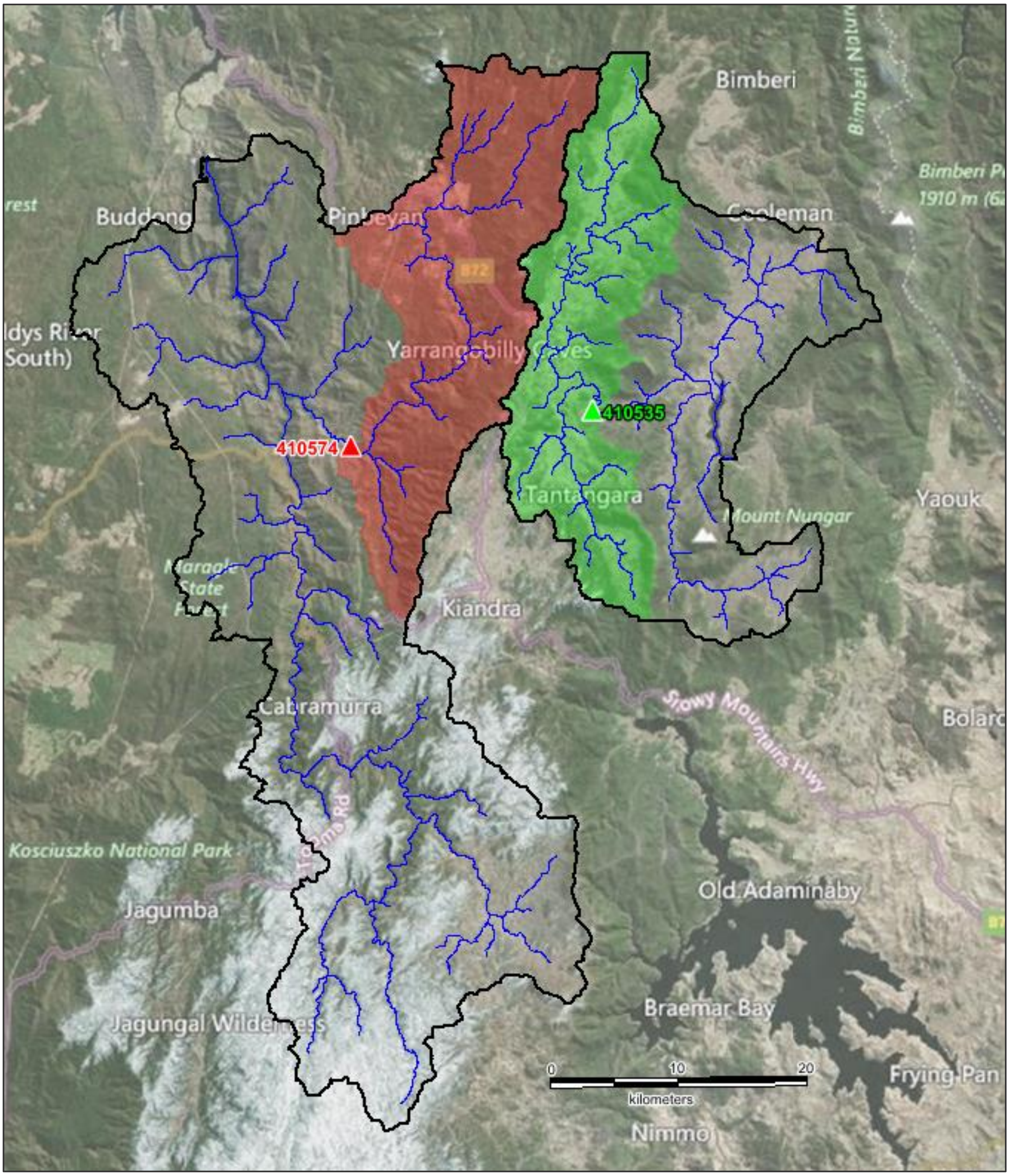

Figure C-5: Location of Yarrangobilly Sub-catchment and Murrumbidgee Sub-catchment and Stream Gauging Sites (Gauge No. 410574 and Gauge No 410535).

Table C-1: Adopted SIMHYD Model Parameters.

Parameter		**Yarrangobilly Sub-catchment**
		Bushland
Impervious Area	Impervious Threshold (mm)	0.0
Pervious Area	Pervious Fraction	1.0
	Soil Moisture Storage Capacity (mm)	312
	Rainfall Interception Store Capacity (mm)	5.0
	Infiltration Coefficient	196
	Infiltration Shape	1.82
	Interflow Coefficient	0.040
	Recharge Coefficient	0.414
	Baseflow Coefficient	0.053

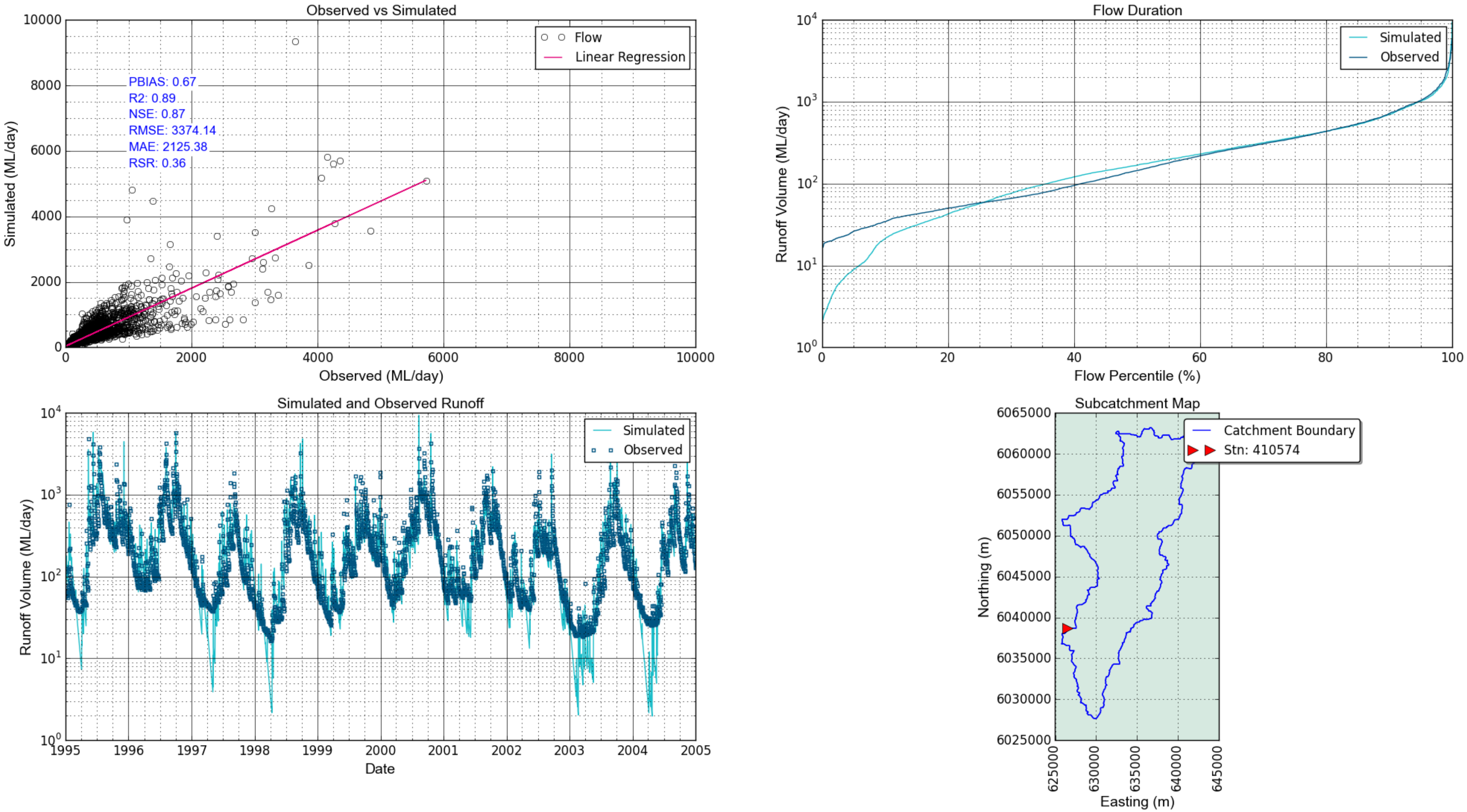

Figure C-6: Results of SIMHYD model calibration (Yarrangobilly at Ravine Gauge No. 410574)

Attachment D: ADCP Data and Modelled Current Speeds

The report chapter was written to assist in the understanding and interpretation of recent ADCP collected by Cardno and to (indirectly) compare it to modelled current speeds (albeit for a different period).

ADCP Data Collection

Introduction

In support of the assessment of impacts associated with the sub-aqueous placement of excavated rock within Talbingo Reservoir, a data collection program was undertaken by Cardno (2019), comprising among other deployment of ADCP (Acoustic Doppler Current Profiler) instruments (Cardno, 2019). Two locations were chosen for Talbingo reservoir:

- **TAL_ADCP_01** (deployed in the Yarrangobilly arm), and
- **TAL_ADCP_02** (deployed in the Tumut arm).

Both locations are near the confluence of the two arms. A locality plan is presented **Figure D-1.**

Figure D-1: ADCP Deployment Locations in Talbingo Reservoir.

Quality Assurance, Accuracy and Limitations

Quality Assurance

The quality assurance (QA) process followed by Cardno can be summarised as follows:

- initial manual review to check data completeness and the instrument's pitch/roll/orientation, particularly for any indication of interference during deployment,
- export of instrument's depth data (both pressure sensor and acoustic surface track for cross checks), with correction of pressure data for barometric pressure,
- export of data with bins flagged 'bad' based on checks of:
    - echo intensity
    - beam correlation, and
    - beam percent 'good'.
- data trim of bins at or above water surface based on processed depth data.

Accuracy

The ADCPs in Talbingo are 600 kHz instruments, configured with 10-minute ensembles consisting of 140 pings – based on the Teledyne RDI planning software the standard deviation of each bin's velocity is 3.4 mm/sec. This standard deviation (sd) is simply based on the estimated single ping accuracy for the bin size, with the relevant averaging applied for the ping count.

Additionally, the instruments calculate an error velocity for each bin. The instrument uses four beams to resolve the 3D velocities. The method used calculates the x-axis horizontal velocity and vertical velocity from one pair of beams, while the second pair of beams is used to calculate the y-axis horizontal velocity and vertical velocity. The reported error velocity is then the difference between the two calculations of vertical velocity. As an example, based on the second deployment dataset from TAL_ADCP02, the error velocity is almost always within the range +/- 9 mm/sec and on average falls within the range +/- 2.8 mm/sec.

Limitations

Initial analysis by RHDHV of the ADCP data identified a discrepancy between measured and modelled peak surface current speeds under comparable Snowy operational conditions (measuring period and simulation period are disjoint). In a discussion with Cardno it was noted that the ADCP surface bin data should be handled with due caution. Potential reasons (among other) are acoustic reflection off the water surface which could lead to noise, and the potential presence of wind wave influences.

Data Analysis

TAL_ADCP_01 (Yarrangobilly Arm)

Figure D-2 and **Figure D-3** present time-series of total current speed and vertical current speed for TAL_ADCP_01 at four selected bins:

- surface (total current speed only)
- sub-surface

- mid-depth, and
- bottom (near bed).

Generally, current speeds are low. Average total current magnitudes measured by the ADCP for the selected bins are in the range 7-17 mm/s, with higher peaks up to 300 mm/s (surface bin). The instrument accuracy is in the order of 3 mm/sec. The majority of the measured current magnitude is in the horizontal components, with the vertical component generally low and in the order of the instrument accuracy.

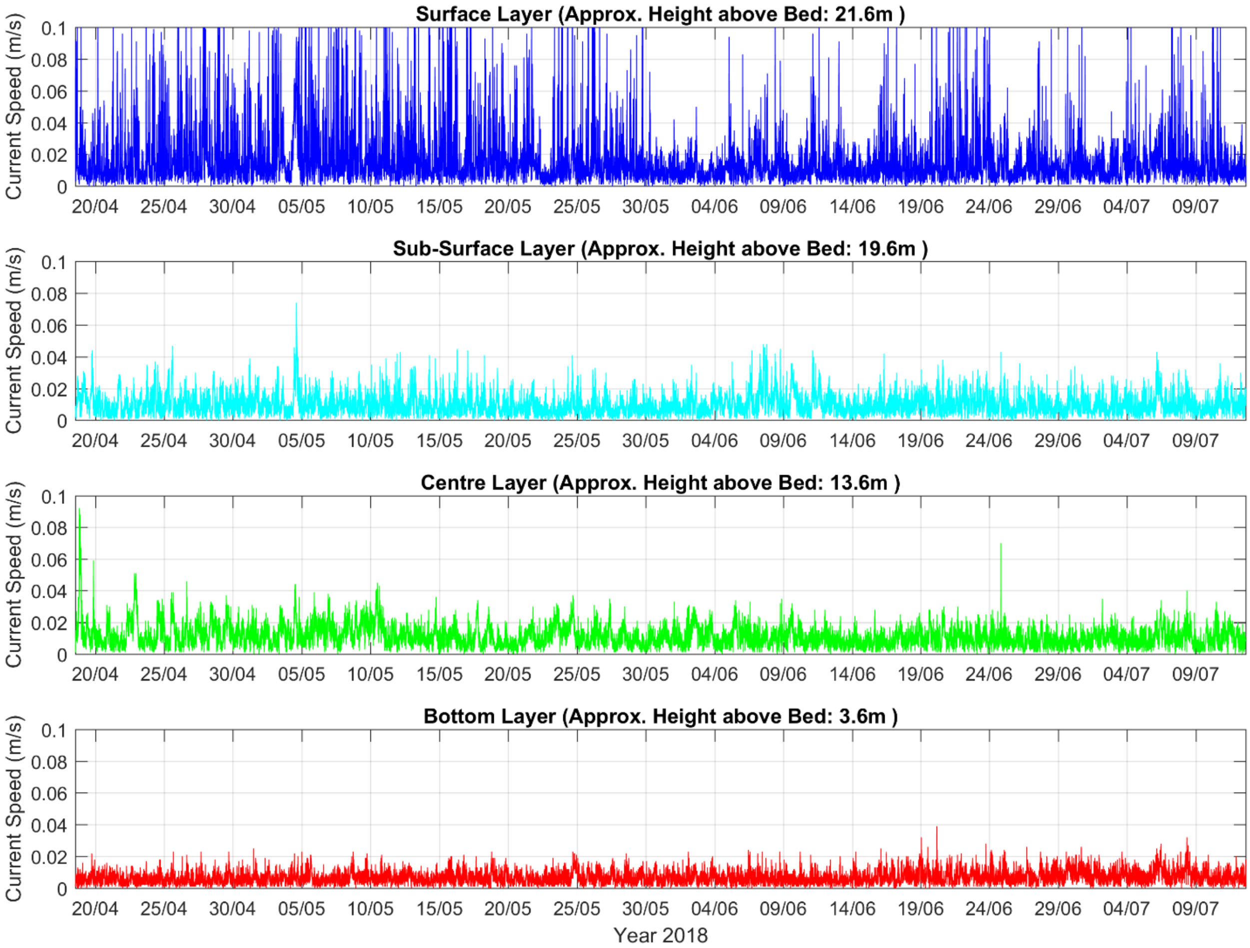

Figure D-2: Total current speed time-series - TAL_ADCP_01 deployment period.

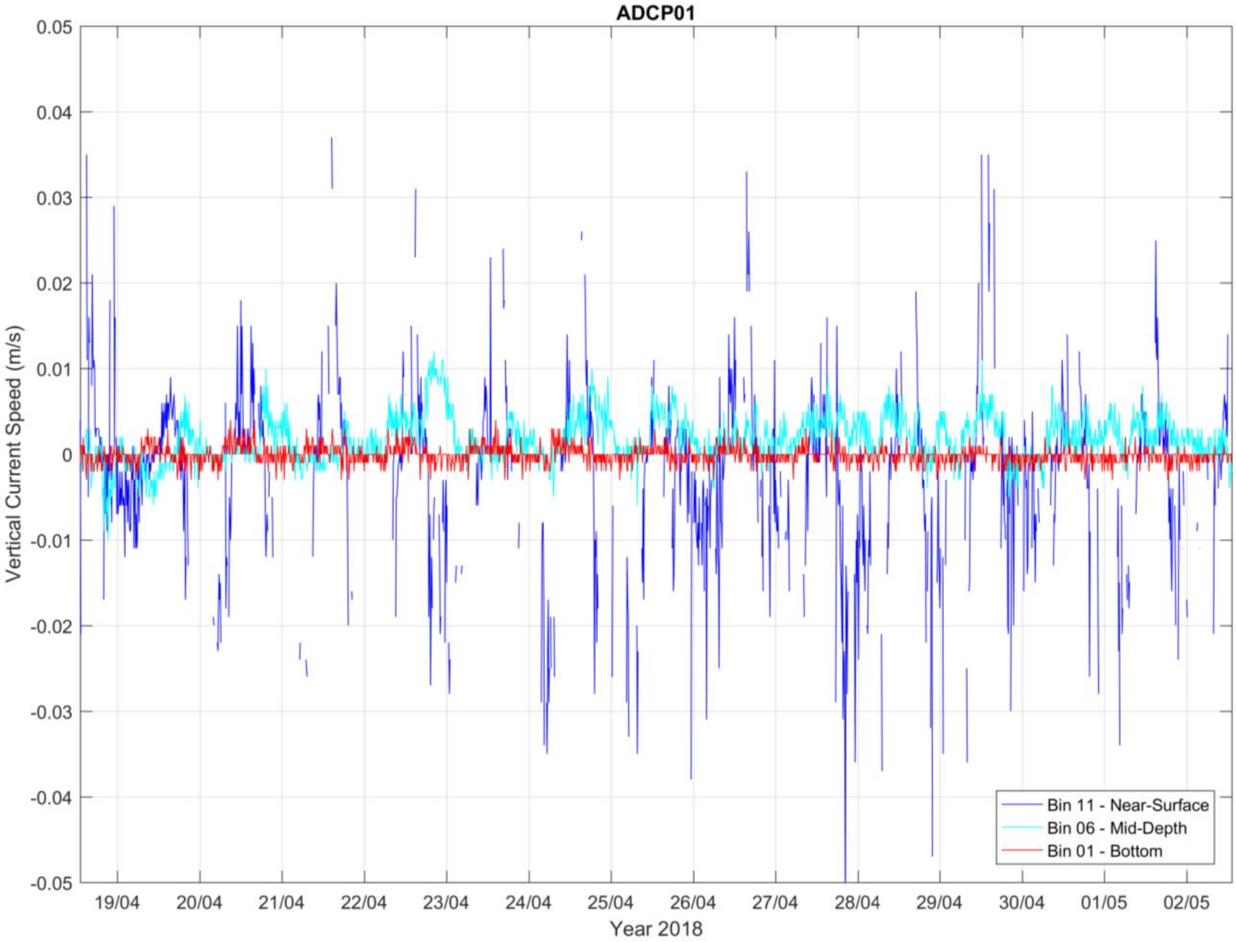

Figure D-3: Vertical current speed time-series - TAL_ADCP_01 deployment period.

TAL_ADCP_02 (Tumut Arm)

Figure D-4 and **Figure D-5** present time-series of total current speed and vertical current speed for TAL_ADCP_02. Similar to TAL_ADCP_01, total current speeds are generally low; 20-34 mm/s, and vertical current speeds are generally low as well and again in the order of the instrument accuracy.

The total bottom (noting that the actual bin nearest to the bed didn’t contain any data and instead data was taken from the next bin up) current speed on average is 20% greater than at mid-depth and sub-surface. This might be due to density currents (T2 release flow).

The surface bin does show some (unusually) high peaks up to 900 mm/s. These peaks potentially are (but not limited to being):

- wind-driven, and/or
- driven by T2 release.

Wind speeds are generally low and on average 1.2 m/s (2006 – 2018) with peaks up to just over 7 m/s. Measured wind data was not available for the ADCP deployment period, however it is unlikely wind is the cause of such high, sustained current speeds.

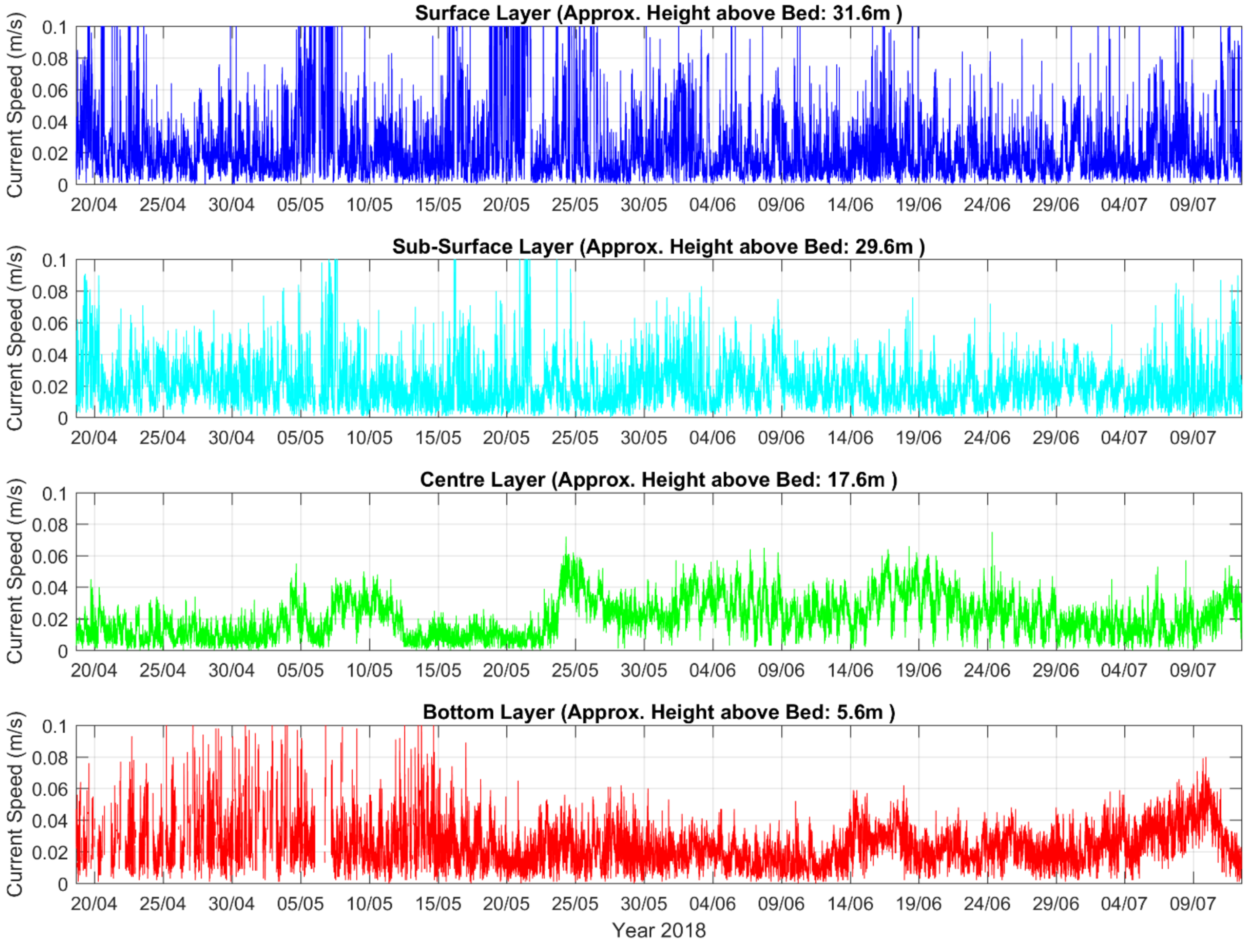

Figure D-4: Total current speed time-series - TAL_ADCP_02 deployment period.

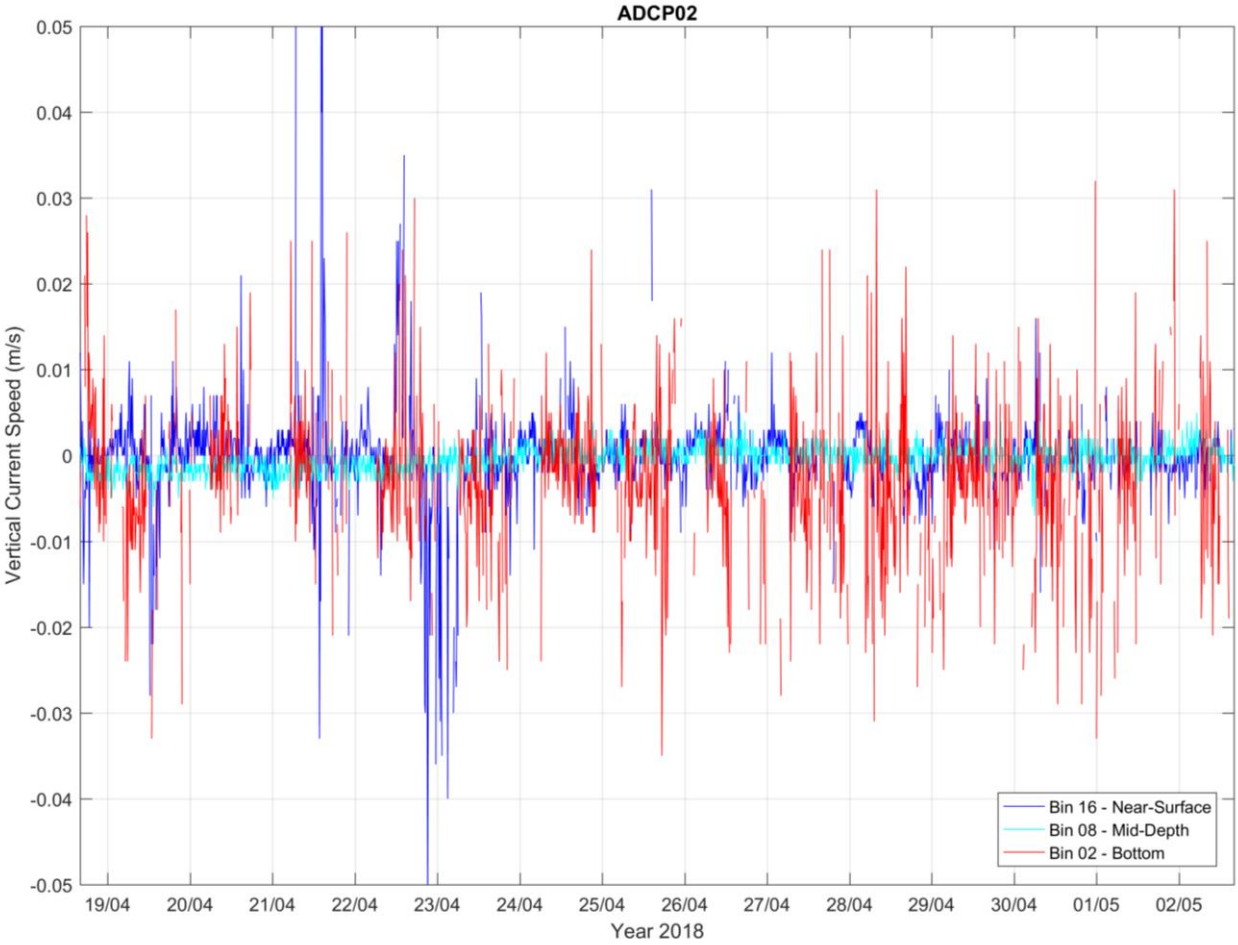

Figure D-5: Vertical current speed time-series - TAL_ADCP_02 deployment period.

T2 release data was available for part of the ADCP deployment period and a visual correlation analysis was performed for this period, presented in **Figure D-6**. It is apparent from the graph that no correlation exists between surface current speed measured at TAL_ADCP02 and T2 release flow data; current speed peaks occurs both during and in absence of T2 release discharge. A time lag between current speed at the ADCP deployment sites and T2 releases would exist. Assuming a current speed of 0.25 m/s, the distance between TAL_ADCP02 and the T2 release point (approximately 7 500 m) would be travelled in approximately eight hours. Applying this shift does not alter the outcome of the correlation analysis.

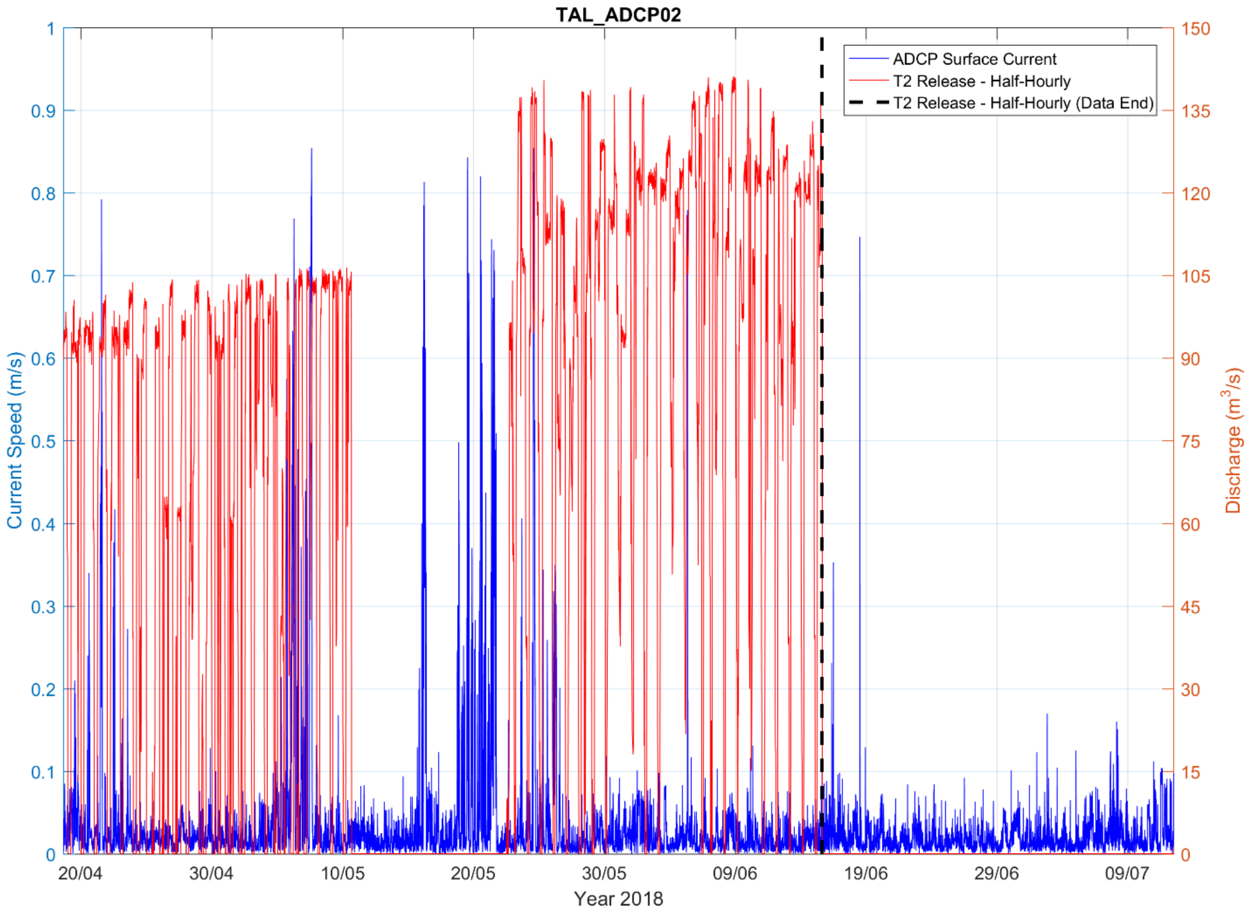

Figure D-6: Correlation analysis of surface current speed and T2 release flow data.

A sub-set of the total current speed time-series is presented in **Figure D-7**, focusing on a period where a number of current speed peaks occur. It shows that during these peaks, surface flow direction is consistently either 115 or 315 degrees True North (°TN). These directions are somewhat similar to the local orientation of the river (refer **Figure D-8**) and hence a natural cause of these peaks cannot be ruled out.

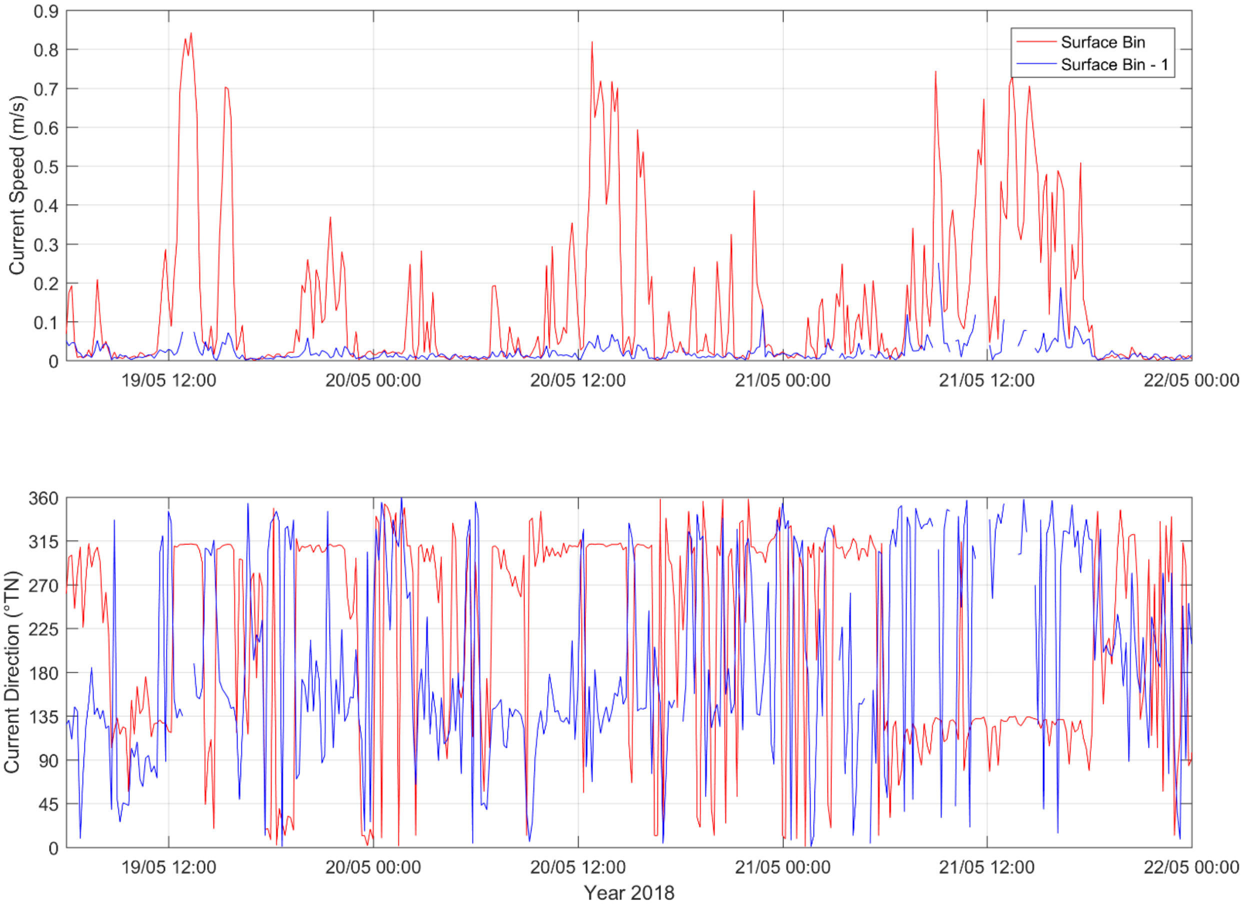

Figure D-7: Total surface current speed and direction for a selected period.

Figure D-8: Flow direction during current peaks (red arrows).

Comparison to Modelled Data

For comparison with measured data, *modelled* current speed time-series near the two ADCP locations in Talbingo reservoir are presented in the following sections. The selected model simulation is that of a cooling period starting in April 2017. This period overlaps the ADCP deployment period in terms of season (not year). Typical boundary conditions such as wind, air temperature, solar radiation, etc. are presumed to be similar for the time of year (autumn). More uncertainty exists around the main driver of hydrodynamics in Talbingo Reservoir, i.e. T2 release discharges. Consequently, measured and modelled currents will mostly be compared qualitatively. It is noted that different plot scales and units have been applied (to not lose resolution), hence care should be taken when comparing figures.

TAL_ADCP_01

Figure D-9 and **Figure D-10** present time-series of total modelled current speed and vertical current speed near the TAL_ADCP_01 deployment location at four selected model bins which best align with the selected ADCP bins.

Generally, modelled total current speeds are low. Average modelled total current magnitudes for the selected bins are in the range 4-10 mm/s, with peaks up to approximately 40 mm/s (surface bin). This places modelled average total current magnitudes at TAL_ADCP_01 in the same order of magnitude as measured total currents, however modelled peaks are an order of magnitude lower.

The majority of the modelled current magnitude is in the horizontal components, with the modelled vertical component virtually non-existent at TAL_ADCP_01.

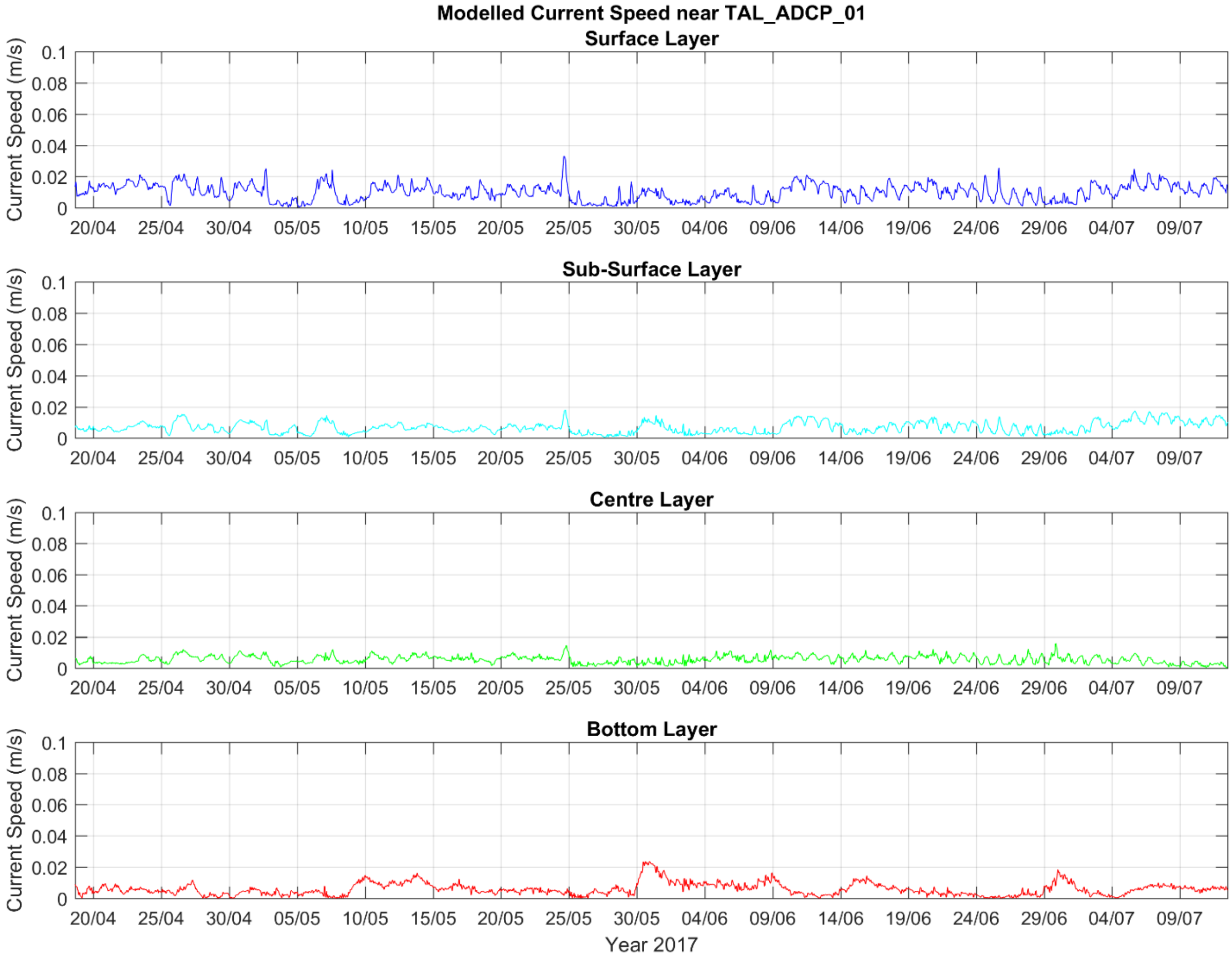

Figure D-9: Total current speed time-series – modelled.

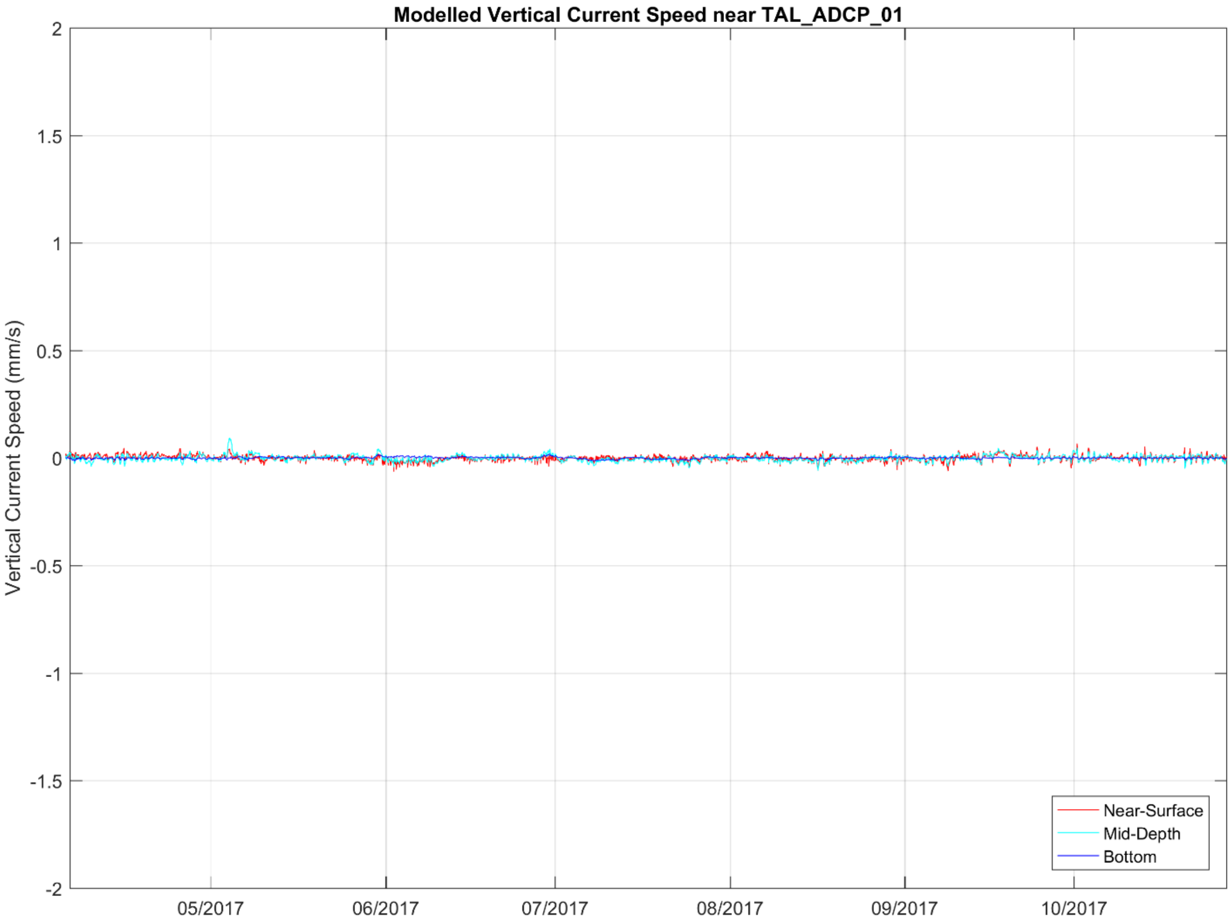

Figure D-10: Vertical current speed time-series – modelled.

TAL_ADCP_02

Figure D-11 and **Figure D-12** present time-series of modelled total current speed and vertical current speed for a location near TAL_ADCP_02. Similar to TAL_ADCP_01, modelled total current speeds are generally low; 11-29 mm/s with peaks up to approximately 90 mm/s (surface bin). This generally places modelled average total current magnitudes at TAL_ADCP_02 in the same order of magnitude as measured total currents (bottom current magnitudes on average are half of average measured current magnitudes), however modelled peaks are one to two orders of magnitude lower.

The majority of the modelled current magnitude occurs in the horizontal component, with the modelled vertical component generally low at TAL_ADCP_02.

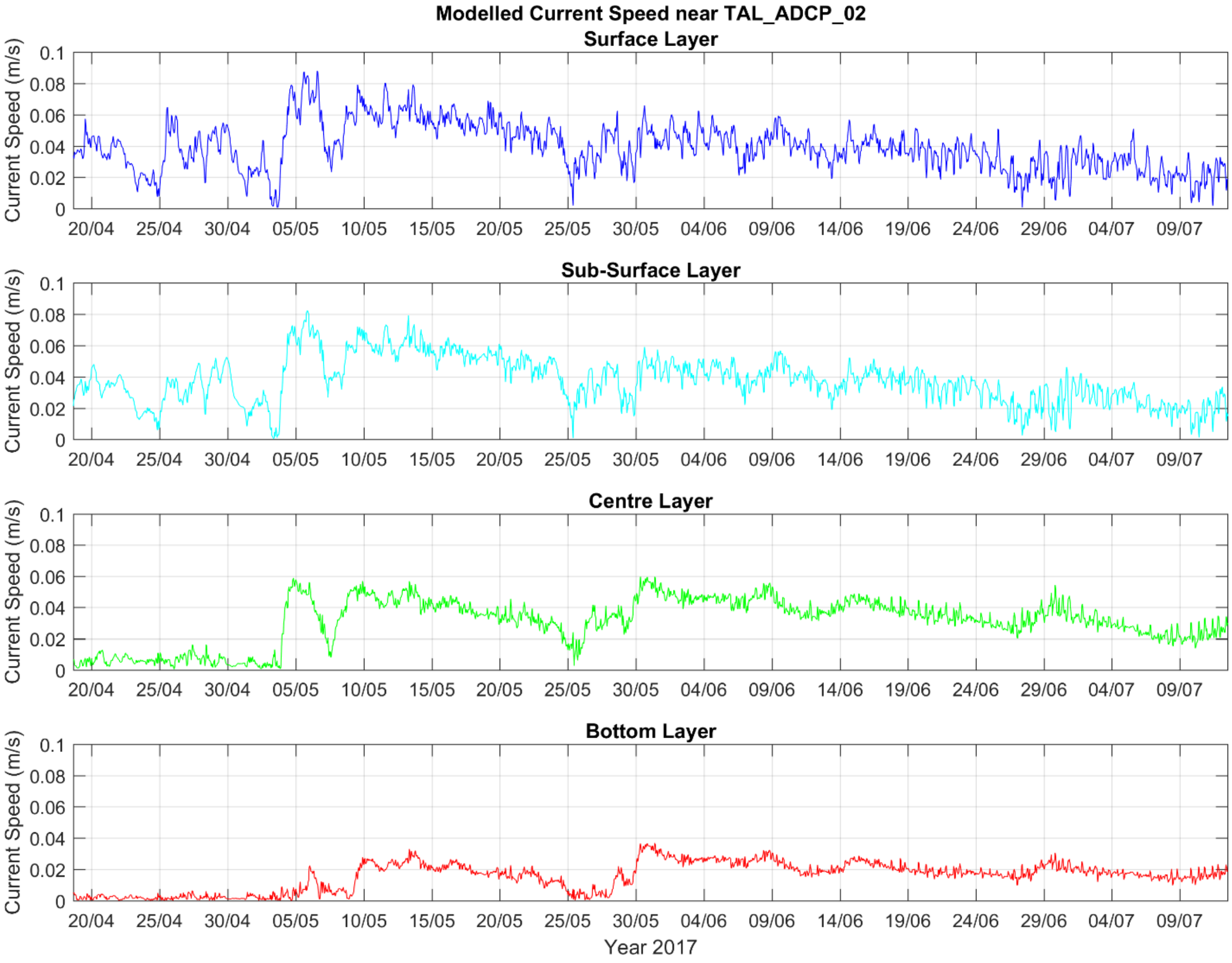

Figure D-11: Total current speed time-series – modelled.

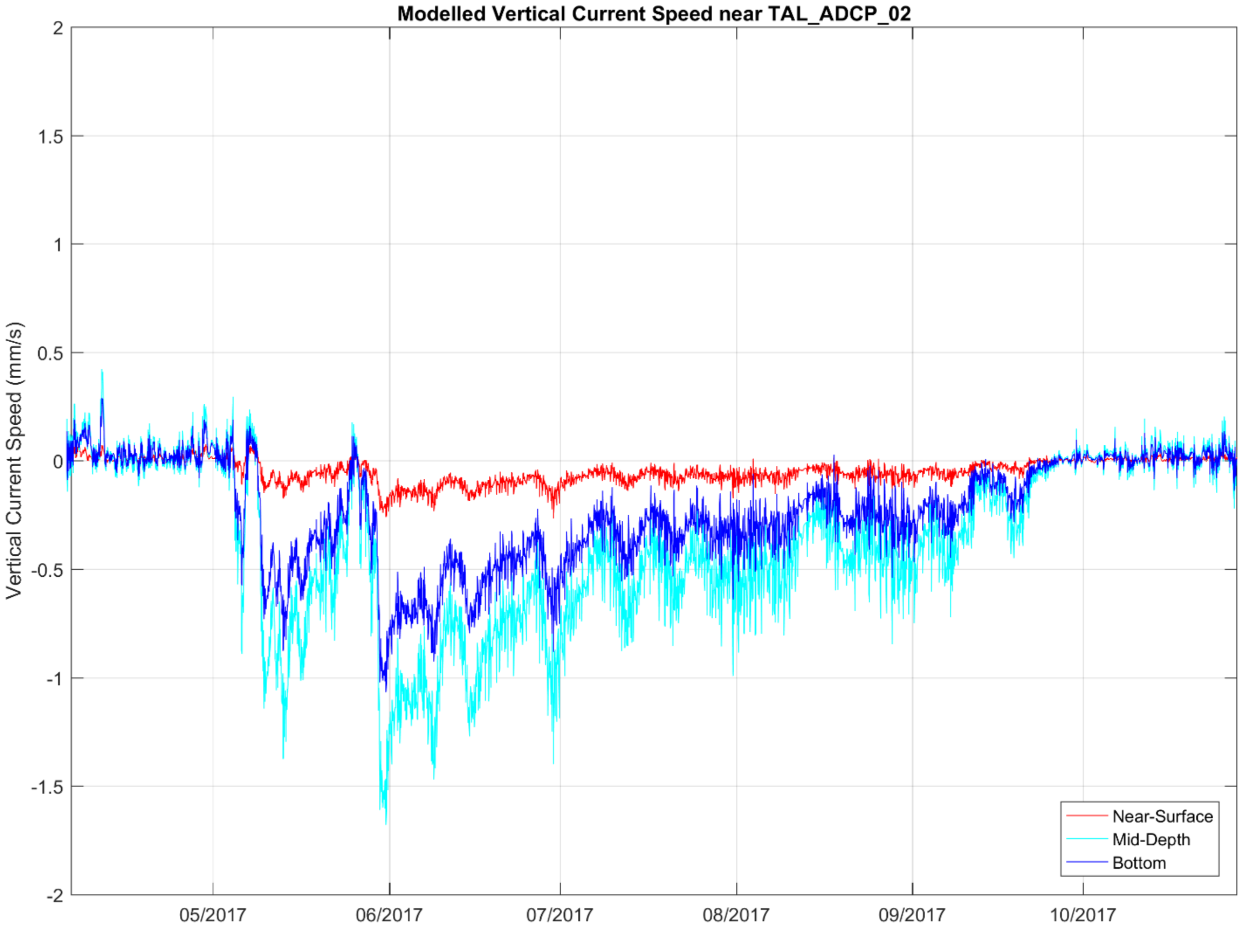

Figure D-12: Vertical current speed time-series – modelled.

References

Cardno, 2019. Snowy 2.0 - Reservoir Monitoring Program Methodology. Prepared for EMM Consulting Pty Ltd.

Delgado, P., Kelley, P., Murray, N., & Satheesh, A. 2013, Source User Guide, eWater Cooperative Research Centre, Canberra, Australia.

Attachment E: External Model Review (RMA Pty Ltd)

REVIEW OF ROYAL HASKONING MODELLING OF TALBINGO AND TANTANGARA RESERVOIRS IN THE SNOWY 2.0 PROJECT

IAN P KING

RESOURCE MODELLING ASSOCIATES

DECEMBER 2018

INTRODUCTION

BACKGROUND

The so-called SNOW 2.0 project requires construction of pipelines that will connect existing reservoirs within the current Snowy scheme. A significant amount of spoil will be generated due to this tunnelling and an option is that this spoil will be disposed of into these reservoirs.

Thus this section of the overall project has been designed to develop and apply a computer model to simulate the impact of this disposal. Two issues are currently being studied.

1. What is the ultimate location on the bed of the added sediment?
2. What is the impact of changed reservoir depths on the new current structure when Snowy 2.0 is operating and what, if any, is resulting new bed location of this added sediment and possibly any existing unconsolidated sediment the bed of the reservoirs.

This process is complex because

1 The reservoir systems are three-dimensional and have variable stratification over an annual cycle.

2 This requires models that are at the limit of present technology. Because of the complexity of the reservoir layout and the detail required, these models can be slow in a computer sense to operate for the long period simulations will most likely be required

3 There is limited data available for full description of:

- the inflows to and outflows from the reservoirs
- the flow and water temperatures regimes within the reservoirs.
- The weather conditions that drive heating and cooling of the reservoirs

4 In their current state the water velocities are generally very low but when Snowy 2.0 is operating new current regimes will operate where currents can be expected to be considerably higher.

REVIEW PROCESS

The purpose of this review is ensure that models developed for these studies are best engineering practice and are capable of addressing the issues that have already been named and would be suitable for any other relevant questions that might arise in the course of the overall project.

The process applied in this review has been interactive to ensure that results of this review could be incorporated directly into the model development and subsequent application for scenario studies. With this in mind the review had two main components:

1. Meetings with project staff where they presented the background, objectives, progress and initial results for this study. These were followed by detailed discussions so that the next steps could lead to an improved model that will best represent the protype system. As a result of these meetings project staff have modified the geometric layout of the model and adjusted some of the model coefficients and options and then carried out testing that demonstrated improved model consistency and performance

2. Review of the draft report “Snowy 2.0 Subaqueous Excavated Rock Placement - Model Development, Calibration and Scenario Model Investigations - ” dated December 20 2018. Note that this report as supplied did not include the results of the sensitivity testing and in the interests of expediency to complete this review they have not been included in my discussion.

REVIEW

In this review, various aspects of the modelling process will be considered and commented on.

MODEL SELECTION

MIKE 3 has been selected for this study. This is a state of the art 3-D finite volume hydrodynamic simulation model with and additional “Mud” component for modelling of sediment transport. It has a considerable track record of use for simulation of reservoir flow regimes. It is used in two stages, first the hydrodynamics and temperature conditions are simulated for the study period. Then, the circulation data developed in this first pass is used to drive the sediment transport component as a passive constituent. It is known that sediment itself can influence circulation but it is reasonably believed that inertial and circulation impacts from the temperature stratification outweigh this influence. The associated sediment transport package from MIKE 3 is then used to model the dispersal of the various sized particles that may be added to the reservoir in a given scenario. Results from hydrodynamic model (currents, water depth and temperature) are used as the transport driver.

MODEL SETUP

Application of this type of simulation requires construction of a geometric layout that represents the reservoir system. In plan view, this is a system of triangles (connected together at vertices or nodes) of variable size that match the surface area of the models and describe the underlying bathymetry. A nominal set of three dimensional elements are then formed by projecting vertically downwards adding nodes at a predetermined input spacing over a vertical line below each node. In MIKE 3 the lower nodes on the vertical line can be considered fixed so that a constant layers are formed. Above an input transition level MIKE 3 has been setup so that the node levels are adjusted (but kept to a constant distribution vertically) so that any variation of the water surface can be matched. These upper elements are often referred to sigma transformation layers

The key aspect of model[1] setup is that the layout of the triangles and vertical layers be of sufficient density to match the expected variation of the principal dependent variables (currents, temperature and sediment concentration). There are no definitive rules that can be generally applied so this decision is subjective and relies on the modellers expertise and experience. If the modellers err in the direction of too much nodal density computer run times can be excessive, if too little, important spatial variations can be missed. In order to resolve this issue, it is important that testing of model layout be undertaken with a view to evaluating the sensitivity of the model results. For this purpose, results from short term simulation (the whole study period is not needed) of this varied network density can then be evaluated.

Another necessary test (particularly for slow moving reservoir simulations) is to ensure that the model layout does not induce non-physical small circulations that are driven by errors in the computation of hydrostatic pressures for adjacent locations when the vertical structure is not entirely consistent. These errors can be detected by setting up initial artificial quasi static situations with purely horizontal stratification in an otherwise quiescent reservoir and then testing for any local circulation.

In this study, the modellers have carried out these tests and demonstrated that the model developed, in particular with respect to the network layout, is applicable to this low velocity environment.

DATA AVAILABILITY

The principal data requirements are

1. Data to describe the outline geometry and bathymetry of the reservoir.
   This is available from maps, surveys and details of the structures that control the water level and is then used as the basis for network construction

2. Data to describe the initial and ongoing conditions in the reservoir
   This requires that, at a series of time points, information is required that describes water levels, and, for all points within the reservoir, currents, water temperature and sediment concentrations. This data is then used to describe initial conditions and also to provide values that can be used for calibration at later times.

3. Data describing natural features that influence the reservoir conditions over time.
   This requires time series for all reservoir inflows from catchments, streams and water transfers (flow rate, temperature and sediment concentration) and outflows. In addition, meteorologic data that describe the atmospheric conditions that influence reservoir temperature and thus to some degree drive reservoir circulation.

4. Data describing man made influences on the reservoir.
   In this case, the location and quantity of spoil that will be introduced. And possibly operation of Snowy 2.0 when completed.

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[1] For the context of this document the word model refers the MIKE 3 FM simulation program and the geometric data input to describe the reservoir that will be simulated. The “model” is then subject to a time series of inputs that describe the events that force all the processes.

ASSESSMENT OF DATA USED

The list above provides an ideal list of data. The reality is that for modelling efforts there is seldom sufficient data. Using the item list above I have the following comments on the data and data used in this project. Referring to the numbers above

1 Generally, this data is adequately available for development of the geometric representation of the reservoirs.

2 Only limited data is available to describe the instantaneous status of the reservoirs, however by selection of a starting time when the reservoir is starting to stratify it is possible to create an initial condition that is realistic and acceptable for modelling purposes. At these times velocity magnitudes can be assumed to be reasonably small and a zero-velocity assumption is an acceptable starting point. It is assumed (quite reasonably) that any errors would quickly dissipate. At present data for calibration is extremely limited with only occasional reservoir profiles. They do at least provide a starting point for model calibration. For the scenarios with Snowy Hydro 2.0 fully active, the model will have to rely on planned operational scenarios and no initial calibration will be possible.

3 This is the most complex issue, it is impossible to accurately record all the necessary data. Runoff and most small streamflow inflows for example cannot be measured. However acceptable estimates are possible using runoff models driven by recorded rainfall. These estimates have been verified with a simple box model (using a correct volume versus elevation representation based on the reservoir geometry and the assumption of a level water surface) that tracks water level against estimated outflows and inflows. These results will be assessed in a later comment. For meteorologic data it has been necessary to resort to the nearest available sites and assume that conditions are similar. There is very little practical alternative but this process is liable to error possibly significant and may account for the issues with the model for Tantangara Reservoir.

4 This data should be readily available however the challenge is to incorporate into the model the expected methods of release of the spoil and the size distribution and in the future, operating policies.

A data collection program has been undertaken and key data such as reservoir temperature (which is influenced by circulation) is being gathered and ADCP measurements have measured water velocities at sites within the reservoirs. However, the magnitude of the measured currents (and in fact the computed) is exceedingly small and the error bar makes any practical statistical comparison between measured and computed velocities extremely difficult.

Graphs presented in the reports for both reservoirs show a consistently accumulating bias in water levels between that for the model and the reported water levels. For Talbingo Reservoir, the error accumulates to approximately 0.5 metres during the 5 month warm up period and approximately 1.0 metres during the seven month winter period. Similar errors are reported for Tantangara Reservoir. In both cases the model overestimates the water level suggesting inflows are over estimated or discharges under estimated. This has limited the models use for very long simulations (a year or longer) and caused the modelers to reset the levels for subsequent simulations in the results that are presented. It is asserted that that this error has negligible impact on the overall flow regime. <u>It would be instructive if a computation was made of the necessary flow adjustment (say discharge increase) for each</u>

reservoir so that this could be compared with the actual discharge rate and thus demonstrate that the impact is small.

HYDRODYNAMIC MODELLING

As discussed earlier the selected simulation model developed appears suitable for modelling of these reservoirs. Thus, to prepare for scenario analysis it is important to assess whether the model (with the data) adequately describes the prototype system.

The conventional process is to isolate a data set (both input and measurements that can be used to compare with the results) from a time series and then carry out calibration without this information. On completion, an independent validation simulation is then executed and comparison then made with the measure data. Typically for reservoirs this would require calibration using data for one year and then validating using a different year. At this point in the project there is not sufficient data available for a process like this. In fact, the calibration cases have had to rely almost all the data that is available

This leaves three possible alternatives:

1. Delay modelling until sufficient data is available.
2. Repeat the simulation with a different three-dimensional model to see if the same input specifications leads to demonstrably similar results.
3. Carry out detailed sensitivity analysis where the input parameters are adjusted and then demonstrate that the overall results/conclusions are not significantly changed.

In this study for the purposes of this report, option 3 has been chosen and the report presents an appendix that details the variations that have been tested.

SEDIMENT TRANSPORT MODELLING

Sediment transport modelling is the ultimate step where scenarios are studied. Although technically separate the model uses the same network layout and the computed currents, temperatures and depths from the hydrodynamic model. The only significant additions to the parameters used for the hydrodynamics are the mass inputs and their locations and the particle size distributions and settling velocities. The settling velocities may be taken from the literature or from laboratory tests of the actual material to be added. The other inputs are dependent on the exact scenario to be studied.

MODEL RESULTS, CALIBRATION and SENSITIVITY

As noted above in this system full calibration is limited by the lack of available data. The result is that the model has only been calibrated on a qualitative basis.

For each reservoir simulations have been executed for two time periods. Processed separately partly because of the desire to better match the water levels through the entire period and partly to ensure that model and measured data agree on the initial conditions. The first step was to simulate circulation from an initial time point in the annual warming cycle (where measured temperature profiles were available) to a point seven months later where data is again available that shows the development of stratification.

A second simulation was undertaken in order to model the destratification that occurs due to late season cooling. Thus this simulation starts at the end point of the first simulation but instead of using the computed temperature distribution from the first execution it uses the measured distribution and adjusted water levels.

There are three dependant variables computed during the modelling of hydrodynamic system that are of interest.

1 Reservoir surface elevation

2 Temperature distribution over the entire system. Variation over depth of temperature (stratification) serves to control velocity distributions over the reservoir depth.

3 Horizontal and vertical velocities over the entire system.

In this modelling surface elevations appear reasonably calibrated (subject to the discussion above).

For Talbingo Reservoir predicted temperatures during the heating simulation show a reasonable agreement with measured values. Although there is some evidence of extra diffusion[2] in the model results near the dam wall where the reservoir is at its deepest, the overall accumulation of heat appears to validate the heat budget computation. Profiles at Lobs Hole are more encouraging with the main issue a lack of surface mixing. The cooling phase profile for the near dam site shows similar results to the heating phase with the same issues (extra mixing in the thermocline and not enough mixing near the surface. It is possible that the model treatment of discharges from the reservoir are influencing these results. It would have been helpful if results for Lobs Hole had been available to complete this assessment.

For Tantangara Reservoir the results are less convincing. The heating period is not represented with a fully mixed reservoir the final result of a “heating simulation”. It has been suggested that this is an issue of timing given the higher elevation of Tantangara Reservoir, the greater uncertainty over the meteorologic data and the variation if the onset of winter from year to year.

There is also a surprising result for the winter period that suggests temperatures for the whole water column down to 1deg C for a one month period. Under these conditions I would have expected reverse stratification to develop and perhaps ice formation for that year. Again, this suggest issues with the meteorologic data.

The most complex problem for calibration of a deep/stratified reservoir system is assessing the accuracy of the computed currents which unfortunately is probably the most important because accurate prediction of transport relies on these velocities and yet they are extremely small when compared to say river or ocean currents. In this application no current data is available for the calibration period. There are however two sources of data that permit an indirect evaluation.

1 Both reservoirs have been instrumented and starting in 2018 ADCP’s are reporting current data for several locations. These can at least offer order of magnitude comparisons.

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[2] This extra diffusion may be due to relatively coarse representation of the section where the thermocline is most defined.

2 Tracking a sediment plume provides an opportunity to evaluate net transport. A sediment plume event occurred in November 2016 due to large inflows from the Yarrangobilly River was simulated using the sediment transport component of MIKE 3. This plume was anecdotally reported to fade from view after about one to two weeks which was at about the same time as the model predicted. Whilst this indicates that the mixing process may be appropriate it does offers limited insight into the velocities involved in these processes.

This has constituted the calibration process. In the absence of usable current data this process is the only feasible approach and is appropriate.

The sediment plume simulation also provided an opportunity to demonstrate that the mud transport model provides results that are consistent with the prototype system.

IMPLICATIONS AND RECOMMENDATIONS

The results so far suggest that the Talbingo Reservoir is close to acceptable calibration and that it will be capable of simulating the typical behaviour of the reservoir. Tantangara Reservoir is less well calibrated and needs further evaluation before it can be considered calibrated.

Several adjustments/extensions are possible at this point that can lead to an improved model performance for the two reservoirs.

1 The geometrical model layout can be reconstructed to add additional elements in the plan view so that the reservoir bathymetry is better fitted and additional layers introduced to allow a better fit to the vertical gradients of diffusion and velocity.

2 An adjustment be made to the flow levels (say the discharges) of both reservoirs so that these flows lead to consistent water levels.

3 Model parameters and options be adjusted/selected in order to adjust the vertical diffusion of heat to better fit the measured temperatures especially near to the surface.

4 For Tantangara Reservoir the meteorologic input be adjusted to improve model performance.[3]

5 The modelling period be extended to cover 2018 as far as possible with some time period set aside for a formal verification process.

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[3] It is my understanding that scale factors have been applied to measured meteorologic data in attempt to obtain an overall heat balance with differing factors in summer and winter. These factors should be systematized.

Attachment F: External Model Review (AW Maritime Pty Ltd)

AW Maritime Pty Ltd
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27th May 2019
our reference: 3427

Dave Evans
Director of Engineering
Snowy 2.0 Project
Snowy Hydro Limited
PO Box 332
Cooma NSW 2630

Dear Dave,

Snowy 2.0 SERP – RHDHV Model Review

AW Maritime Pty Ltd (AWM) has completed our review of the hydrodynamic and mud transport model setup, calibration and initial scenario investigations by Royal Haskoning DHV (RHDHV) for the Snowy 2.0 Subaqueous Excavated Rock Placement (SERP). During the course of our review, RHDHV provided sufficient and satisfactory responses by way of:

- Model Development, Calibration and Scenario Model Investigations Report dated 01-Feb-2019
- Powerpoint modelling updates dated 08-Mar-2019 and 08-Apr-2019
- Discussions during our meeting on 02-May-2019 and teleconference on 16-May-2019
- Responses to our Comments Register Revision 3 dated 24-May-2019
- Sharing of example MIKE-3 model setup files and result files

DHI's MIKE-3 model was used to examine the hydrodynamic processes and associated thermal structure of the Talbingo and Tantangara Reservoirs. The MIKE-3 Hydrodynamic (HD) Module and Mud Transport (MT) Module was utilised, which simulates three-dimensional hydrodynamic circulation and transport of sediments. The HD Module includes a sub-algorithm to invoke Temperature/Salinity (TS) which simulates the thermal and density-driven contribution to the flow dynamics, which is a critical component for both reservoir systems.

The modelling work is extensive and overall RHDHV have made the best use of the limited data available to them. Of the data available, all was suitable for implementation into the model and RHDHV provided rational explanations and reasoning for data that required further manipulation. The model calibration approach was wholly dictated by the scarcity of field data, and we agree with this approach in the absence of data. Model calibration was simulated for two periods: a summer period (Nov-16 to Apr-17) and a winter period (Apr-2017 to Oct-2017). Direct and indirect model comparisons were then made for the water levels, current speeds and water temperature. Direct model comparisons were made to measured daily water levels of each reservoir and to semi-annual CTD measurement at discrete locations in each reservoir. Indirect (relative) comparisons for each season were made to Cardno field data collected in 2018.

RHDHV performed model sensitivity runs in addition to the model calibration. Mixing, mesh and boundary/external forcing variations were tested to evaluate their sensitivity, and RHDHV concluded that the adopted model parameters and assumptions were the most appropriate combinations to calibrate the model. Based on our review of the parameters, they were appropriate for this stage of the project.

RHDHV rationalized the predictive modelling by a variety of scenarios along with recommendations to improve the model confidence/reliability. The hydrodynamic processes are the primary driver for the fate and transport of the suspended fine sediments in the reservoirs. Understanding and rationalizing the flow dynamics is therefore central to assessing suitable locations for spoil disposal which minimize the spreading of suspended sediments. It is our opinion that the RHDHV model adequately addresses the hydrodynamics and sediment transport processes of the two reservoirs including the associated hydrological and meteorological forces on the reservoir systems. The model results can be used for comparison purposes and shortlisting disposal scenarios for further investigation. We consider our review of the model setup and calibration closed with the Comments Register between RHDHV and AWM attached.

As discussed during the teleconference on 16-May-2019, we would recommend the following to conclude RHDHV's model setup:

1. RHDHV perform a validation simulation for 2018 utilizing the recent and more comprehensive field data collected in 2018
2. RHDHV improve the water balance model for the 2018 validation simulation by way of more accurate T2 & T3 flow rates provided by Snowy Hydro Limited (SHL)
3. RHDHV include varying water temperatures for T2 & T3 flows provided by Snowy Hydro Limited (SHL) for the 2018 validation simulation

Please do not hesitate to contact us should you have any further questions/comments.

Yours sincerely,

CBell

Catherine Bell
AW Maritime Pty Ltd

Attachment: 3427.C001 Model Review Comments Register_Rv3

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COMMENTS REGISTER

SUBJECT: Snowy 2.0 – Model Review Rv3

DATE: 24 May 2019

AW Maritime Pty Ltd (AWM) has been engaged by the Snowy 2.0 Project to complete an independent, third-party review of the model for the Snowy 2.0 Subaqueous Excavated Rock Placement (SERP) Works. Following a meeting on 02-May-2019, AWM were requested to document any comments in a register to enable Royal Haskoning DHV (RHDHV) to formally respond.

The comments are based on our review of report prepared by RHDHV dated 1-Feb-2019 and titled "Snowy 2.0 Subaqueous Excavated Rock Placement: Model Development, Calibration and Scenario Model Investigations." and subsequent modelling scenarios which have been captured in PowerPoint presentations, screenshots and images.

The comments register has been divided into two sections:

1. Review of Hydrodynamic and Sediment Transport Model
2. Review of the SERP Inputs and Modelling Scenarios

RHDHV-RH – answers provided by Rohan Hudson

RHDHV-GB – answers provided by Greg Britton

AWM – responses by Chris Goshow, Catherine Bell and Tom Atkins

RHDHV-GB – answers provided by Greg Britton

RHDHV-RH – answers provided by Rohan Hudson

AWM – responses by Chris Goshow, Catherine Bell and Tom Atkins

HYDRODYNAMIC and SEDIMENT TRANSPORT MODEL			
No.	**Comment**	**By**	**Date**
Model mesh			
1.	The report states a maximum cell size of "50m" for the horizontal model mesh (50m²?), which does not appear to match with the Figures in the report. Please clarify.	AWM	08/05/19
	Mesh length scale is typically about 50 metres. A more detailed/precise table of mesh size can be provided, though this will not influence the broader results ….. Report text was updated to provide greater clarity. *The adopted mesh resolution was a compromise between horizontal resolution, vertical resolution and resulting run time. It currently takes approx. 2 weeks to simulate 6 months of hydrodynamics.*	*RHDHV-RH*	*9/5/19*
	We would like to see the final mesh for each reservoir from RH.	*AWM*	*14/5/19*
	The model mesh was provided 17 May for Talbingo Reservoir as part of results review. Please advise if a copy of the model mesh is not	*RHDHV-RH*	*21/5/19*

HYDRODYNAMIC and SEDIMENT TRANSPORT MODEL			
No.	**Comment**	**By**	**Date**
	available.		
	Closed.	*AWM*	*23/05/19*
2.	In areas where the spoil placement was examined, was the model mesh refined to better capture the far-field dispersion specifically in and around the spoil placement location(s)? We do not see any figures to support this point. Please clarify.	AWM	08/05/19
	Due to the required compromise between mesh resolution and model run time, no additional resolution was used. However, the adopted resolution is able to adequately resolve sediment plume behaviour, which generally spread through much of the reservoir.	*RHDHV-RH*	*9/5/19*
	The model mesh is acceptable for the construction scenario because the flows are very low/negligible, and fines are spreading quite substantially. However in the operational scenario, when the flows are larger we would want to see improved mesh. Please comment.	*AWM*	*16/5/19*
	A suitable (potentially higher) mesh resolution will be adopted for commissioning (scour) tests if required. This would include localized increased on mesh resolution where current speed and concentration gradients are greatest.	*RHDHV-RH*	*21/5/19*
	Closed.	*AWM*	*24/05/19*
3.	The choice of vertical discretization can alter the model results and the sensitivity analyses suggested variations in mesh discretization were tested, but no further details were provided. We also note that the top layers in both reservoirs were applied with sigma layer scheme; however, the layer differs dramatically between Talbingo and Tantangara. What is the expected impact on results from this difference in vertical discretisation?	AWM	08/05/19
	No, the layers when specified at average water level (i.e. (FSL-MOL)/2) are very similar, it is just that the water level variation is much greater in Tantangara Reservoir than Talbingo Reservoir. The model appears to behave appropriately so no impact on results is likely.	*RHDHV-RH*	*9/5/19*
	Closed. Tantangara Reservoir does not behave well in terms of stratified representation but because it is proposed to receive spoil in the dry, this is less of an issue.	*AWM*	*15/5/19*
4.	We believe there is a typo in Figure 3-6. It should read Tantangara, not Talbingo. Please confirm.	AWM	08/05/19
	Corrected – thank you – in text description was updated.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*14/5/19*
5.	The hydrographic survey data utilised to generate the model bathymetry is presented as surface data in Figure 3-7 and Figure 3-8. There is no indication of the actual hydrographic survey data points to assess the resolution, detail and validity of the survey data. Please provide details.	AWM	08/05/19
	This data can be provided if required. But the available survey data was appropriate in all key areas.	*RHDHV-RH*	*9/5/19*
	We do not need the raw data but would like RH to provide a description of the resolution, detail and validity of the bathymetry survey data.	*AWM*	*14/5/19*
	RHDHV will provide additional commentary describing the resolution	*RHDHV-*	*21/5/19*

HYDRODYNAMIC and SEDIMENT TRANSPORT MODEL			
No.	**Comment**	**By**	**Date**
	and validity of the bathymetry survey data provided by SHL. This will however not affect the existing (or future) modeling outcomes.	*RH*	
	Closed.	*AWM*	*23/05/19*
6.	The structure and arrangement of the model (horizontal) mesh can also affect the modelling results. Ideally, the mesh should be arranged with polylines to mimic the geomorphic and typology features. For example, given the varying water levels one would expect the mesh to be developed with polylines generally offset of the FSL contour. In doing so, the numerical computations and water depths smoothly transition with changes in the water level. Similarly, typological features (e.g., reference to a portion of the reservoir as flood plains) should be mapped and integrated into the model mesh so that the bed resistance can be adjusted for these varying features. Were these points considered when developing the model mesh? clarify.	AWM	08/05/19
	As above, there was a required compromise between mesh resolution and model run time. Talbingo Reservoir is typically very deep and steep sided, so meshing consideration are less important than in an estuary. The mesh was tested and did not create spurious velocities under no flow boundary conditions. Hence, the above point was considered during model development it was not important for this model.	*RHDHV-RH*	*9/5/19*
	Closed. Based on the geometry of this reservoir, it is unlikely to substantially change results in areas of deep water and/or low flows.	*AWM*	*14/5/19*
7.	Tantangara model mesh (particularly to the northern extents) appears to be short of the entire domain encompassing the FSL. While RHDHV acknowledge that the northern domain was extended, inspection of Google Earth imagery (historic images) indicates the FSL extends further north than shown in the model mesh. Please clarify.	AWM	08/05/19
	The model was extended to cover areas up to FSL. The stage-volume characteristics of the model were adjusted until comparable to the more detailed bathymetry and data provided by SHL.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*15/5/19*
Model setup			
8.	The report could benefit with a plan view model image of each reservoir identifying the primary point sources, sinks and other relevant spatial information in the model setup. Similarly, time series of the various point sources and sinks flow rates and temperatures – similar to the time series provided for the winds, rainfall and air temperature (Figure 3-9 to Figure 3-11) – would be helpful to further understand the model setup. Without such figures, we find it difficult to follow and fully comprehend. Please provide.	AWM	08/05/19
	Other reports (EMM / Cardno) are available that describe the surface water and limnological characteristics of the reservoir. The focus of this report was sediment transport / SERP modelling. Further graphs showing boundary condition data are presented in Appendix A.	*RHDHV-RH*	*9/5/19*
	We did not receive these reports, however as a modelling report an additional figure should be included to show the key influencing locations which are referenced on numerous occasions - Dam Wall, T2 flows, T3 flows and major rivers, etc. We are still not sure where the T2 and T3 flows are located!	*AWM*	*14/5/19*

HYDRODYNAMIC and SEDIMENT TRANSPORT MODEL			
No.	**Comment**	**By**	**Date**
	The model was provided 17 May for Talbingo Reservoir as part of results review. The model files include the location of all inflows/outflows as coordinates projected in MGA Zone 55 GDA 94.	*RHDHV-RH*	*21/5/19*
	Closed. We have reviewed the model files and deduced the locations of inflows, outflows and sub catchment flows. However as a modelling report an additional figure should be included to show the key influencing locations which are the T2 Inflow, T3 Inflow, T3 Outflow, Yarrangobilly Inflow and SC17. The report is difficult to read without this information. We will consider the comment "Closed" in this register for the purposes of finalizing our review.	*AWM*	*23/05/19*
9.	Point sources and sinks were modelled as simple sources. Were standard sources as opposed to point sources considered in the model simulations? What were the vertical positions in the water column for each source? More details would benefit our understanding. Please clarify.	AWM	08/05/19
	Point sources were modelled appropriately and away from the immediate boundary and will have negligible influence on hydrodynamics. None of the sediment plumes are located near the modelled sources.	*RHDHV-RH*	*9/5/19*
	As stated in response 8, we do not know where these sources are relative to the spoil disposal location. Are the T2 and T3 pipeline flows? If so they could be standard sources so the model includes velocities as added term to the momentum equation. The high flows in the operational cases should be implemented as such. Please comment.	*AWM*	*14/5/19*
	The model was provided 17 May for Talbingo Reservoir as part of results review. This details the location of all inflows/outflows. For future operational cases, an appropriate model setup (including inflow type) will be adopted.	*RHDHV-RH*	*21/5/19*
	Closed.	*AWM*	*24/05/19*
10.	Bed roughness was assumed as 0.05m ubiquitously, which is the default value for MIKE3; however, we would argue that this is typical for coastal and estuarine applications and may not be wholly applicable to a mountainous lake system. What is the bed material and is it uniform across the reservoir? At the meeting in Sydney a "coarse silt" habitat was discussed. From our own inspection of images on Google, we have observed images of these reservoirs that contain various cobbles, boulders, and submerged trees in shallow water. One would think similar reservoir bed conditions (i.e., rougher reservoir bed) exist throughout as these are man-made reservoirs. Similarly, RHDHV references flood plains within the model which would likely have a different bed roughness. Manning's number for the conditions noted above are readily available in literature. Please clarify.	AWM	08/05/19
	Typical reservoir velocities are << 5cm/s and the reservoir is typical >10m deep. Hence adopted roughness values will have negligible influence on hydrodynamics, and this was tested as during the model development phase.	*RHDHV-RH*	*9/5/19*
	Due to the deep water in the Talbingo Reservoir, the roughness would have lesser influence on the model. In the shallower Tantangara Reservoir, the bed roughness would have more influence but if the sensitivity of this parameter was tested and there was no difference,	*AWM*	*16/5/19*

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	then the roughness value can be concluded to have a negligible influence. Please confirm this sensitivity test was also completed for Tantangara.		
	Tantangara Reservoir has much lower magnitude current forcing boundaries, so velocities are significantly lower than in Talbingo Reservoir. Even though the reservoir is shallower, the velocities (and hence influence of selected roughness parameter) is also low. Because it is proposed Tantangara Reservoir will receive spoil in the dry, any minor inaccuracy in the velocity field due to a possibly sub-optimal selection of roughness parameterization would not be an issue.	*RHDHV-RH*	*21/5/19*
	Closed.	*AWM*	*24/05/19*
11.	The table does not indicate the formulation and value used for the horizontal and vertical dispersion within Temperature/Salinity Module, only those values used in the Turbulence Module. Where variations tested to simulate the sensitivity of this parameter? Please explain.	AWM	08/05/19
	Horizontal dispersion is based on the Smagorinsky coefficients (from the HD), while vertical dispersion values are based on coefficients from the k-epsilon formula. *While computationally expensive, use of these turbulence models to describe mixing/dispersion provided the most appropriate and accurate mixing parameters for the study.*	*RHDHV-RH*	*9/5/19*
	Closed. Discussed in teleconference on 16/05/19 that sensitivity tests were conducted with a range of values and the default value of 1 was found to provide stable temperature stratification.	*AWM*	*17/5/19*
12.	We note that evaporation was specified as an input parameter to the model rather than computed within the heat exchange formulations of the temperature/salinity (TS) module. Were sensitivity tests run to examine results for computed evaporation and/or scaled variations of specified evaporation in an attempt to improve upon the water balance model? Please explain.	AWM	08/05/19
	Our experience is that computed evaporation is very sensitive to available wind data. Due to the likely variation in wind data over Talbingo Reservoir, use of an input evaporation was considered desirable. The input is based on daily SILO (Qld Govt) data estimates of Morton Shallow Lake Evaporation which we have found to be most appropriate for studies of this nature. It also allowed the same data set that was used in a daily water balance model (refer Appendix B). It should be noted that for Talbingo Reservoir, the evaporation is only a very small portion of the overall water balance which is dominated by T3/T2 flows.	*RHDHV-RH*	*9/5/19*
	Closed based on the concerns with the wind data available.	*AWM*	*15/5/19*
13.	We note that a constant clearness coefficient was applied while the other heat exchange parameters utilised time varying results. We assume this decision was due to a lack of time series of data for the clearness coefficient. Did RHDHV attempt to correlate the clearness coefficient to the short wave radiation as a means to develop a time series for the clearness coefficient? Please explain.	AWM	08/05/19

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No.	**Comment**	**By**	**Date**
	Are you referring to sky clearness / cloudiness? Which can be used to derive solar radiation in the absence of actual measurements of solar radiation? *We used actual measurements of solar radiation which is significantly more accurate than the above method.* *The clearness coefficient was only required to calculate long wave radiation inputs (for which we used an empirical model). Long-wave radiation only has a minor influence on the reservoir heat-budget so the assumed 70% was adopted in the absence of any actual data.*	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*14/5/19*
14.	In Section 2.2 Tantangara Reservoir the maximum water depth is stated as 19m, yet the operating range is stated as 23m. Please clarify.	AWM	08/05/19
	Noted. Fig b-2 (stage-volume) indicates max depth of ~35m is more likely. *This data won't affect the modelling. We have updated the report to address this comment.*	*RHDHV-RH*	*9/5/19*
	Closed. RHDHV suggests the maximum water depth in Tantangara Reservoir is 35m rather than the previously stated 19m.	*AWM*	*14/5/19*
Model Calibration – Water Levels			
15.	Water levels accumulate an error over each simulation period, indicating that the water balance model is in error. For Tantangara, the error represents a considerable portion of the total water depth. RHDHV postulate the cause of the error and further state that the error does not affect the sediment dispersion results. We feel that improvements could be made to refine the water balance model through checks on the various inflows/outflows and evaporation rates. Please comment. A difference plot over time for Figure 4-3 and Figure 4-4 may offer additional insight into the error.	AWM	08/05/19
	The volume differences and hence water level differences are actually a very small component of the overall water balance. Differences are due to inaccuracies in T3 and T2 inflows/outflows data (as provided by SHL). Note: data provided for T2/T3 is an indirect measurement of inflow/outflow based on pump data and may have an error of ±10%. RHDHV would like more accurate data but don't believe it is available.	*RHDHV-RH*	*9/5/19*
	The water balance model for both reservoirs could be improved. Discussed in teleconference 16/5/19 that errors in the hourly T3 and T2 data were causing a divergence of the water balance. When modelling over short timeframes (e.g. two week scenarios) this was not a problem, but over larger timescales (e.g. annual scenarios) there was a noticeable divergence between the observed and simulated water levels. SHL advised they could provide accurate data, so this was to be discussed between RH and SHL after the teleconference. The T2 inflow was nominated as the most important and the biggest influencer.	*AWM*	*17/5/19*
	T3 magnitudes are larger than T2 so more likely to be a source of error. RHDHV will re-check the water balance if/when it receives more accurate data from SHL. However, our current understanding of the	*RHDHV-RH*	*21/5/19*

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	system modelled is that the pumped-hydro throughput versus the volume of water level difference is unlikely to have any influence on the plume results provided to date.		
	Closed, on the premise agreed during teleconference 16/05/19 that 2018 model validation run will include updated/more accurate T2 & T3 flow rates from SHL to resolve the water balance error and also include time series of water temperature for T2 & T3 inflows. *(Note that while T3 flows are greater, then frequency of T3 is substantially less than T2; we would conclude that T2 is the primary "driving" mechanism over the long-term).*	*AWM*	*24/05/19*
Model Calibration – Current Speeds and Wind Waves			
16.	Spatial plan view figures of current speeds across the model domain would be of benefit to understanding the hydrodynamics. Please provide.	AWM	08/05/19
	Current speeds are generally very low <<5cm/s and are often 3D in nature. They are also often transient in nature and vary with stratification / season. Such plots would be largely meaningless. It is better to look at the movement of tracers (i.e. sediment plumes) to get an idea of water movement. *We would be happy to show you the 3D results in our offices.*	*RHDHV-RH*	*9/5/19*
	Discussed in teleconference 16/5/19 that horizontal flows in the reservoir are complex and a screenshot in time would not be representative of the general flow pattern. For AWM to understand the general horizontal flows and the extent of T2 and T3 flows, it was agreed that setup and result files from MIKE would be shared between RH and AWM.	*AWM*	*17/5/19*
	Model input files and results were provided to AWM of 17/5/19.	*RHDHV-RH*	*21/5/19*
	Closed.	*AWM*	*24/05/19*
17.	ADCP were deployed for 3 months in Talbingo Reservoir which showed current speeds in the order of 1 to 5 cm/s which is very low. Were these 3 months reflective of "typical conditions" for the reservoir?	AWM	08/05/19
	The three months would have covered a large amount of T2/T3 inflows/outflows, so would cover a range of hydrodynamic conditions most likely including some typical ones. *It is a deep and wide reservoir which will mostly have very low velocities.*	*RHDHV-RH*	*9/5/19*
	Closed, however there is no figure in the report showing the location of the T2 or T3 flows so this inclusion would benefit the report overall.	*AWM*	*14/5/19*
18.	ADCP were deployed in Talbingo Reservoir, specifically two locations near Ravine Bay. How are these locations directly influenced by the inflow of Yarrangobilly River (specially over the three months of data collection)?	AWM	08/05/19
	River inflows are very small compared to T2/T3 flows. The ADCP may show some velocities due to river inflows but due to the depth and width of the reservoir velocities are characteristically very low.	*RHDHV-RH*	*9/5/19*
	Closed, however, there is no figure in the report showing the location of	*AWM*	*14/5/19*

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	the T2 or T3 flows so this inclusion would benefit the report overall.		
19.	What are the modelled currents in the main body of reservoir? At the meeting it was discussed the entire reservoir was replaced annually so this suggests there is some current in the reservoir. Please confirm.	AWM	08/05/19
	See response to question 16 above.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*14/5/19*
20.	RHDHV question the validity of the measured high current speeds at the surface. A comparison to T2 release was attempted but indicated no correlation. RHDHV suggest that winds are unlikely to be the cause, based on average winds of 1.2m/s over a 12-year measurement period. As a rule of thumb, surface currents can be estimated around 3% of the wind speed, which would equate to a surface current of 0.04m/s for the average wind speed of 1.2m/s. Coupled with potential funnelling of winds from the mountain ranges (microclimate behaviour) could very well contribute to a large portion of the observed surface currents. Please comment	AWM	08/05/19
	High currents were only observed in the surface layer and not the layer immediate below. This indicated instrument error. We could plot current speed against wind speed if you think it is going to be important. In this case, our review and liaison with Cardno suggests instrument error.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*15/5/19*
21.	The report should address wind waves and its contribution or lack thereof to the sediment dispersion results and potential resuspension of sediments, particularly in shallow waters. Please clarify.	AWM	08/05/19
	The reservoir banks are typically very steep. It is unlikely for wind wave suspension to be a significant issue. The aim of the modelling was to investigate sediment disposal options. Larger issues are due to fines which tend to not settle, and so resuspension was less of an issue/concern for this assessment.	*RHDHV-RH*	*9/5/19*
	Closed, however we recommend that wind waves are addressed in the report for completeness.	*AWM*	*15/5/19*
Model Calibration - Temperature			

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No.	**Comment**	**By**	**Date**
22.	RHDHV compared model results of temperature profiles to measured CTD profiles for the available time periods and locations of CTD data. For Talbingo, the model results are generally representative of the thermal structure and stratification of the water column (more so for the heating phase than the cooling phase). For Tantangara, the model results are not very convincing. It would be difficult to pinpoint any one particular issue that could be modified to improve the thermal structure. We would speculate that possible issues could be a result of too much vertical mixing, poor mesh discretization of the vertical water column, constant inflow temperatures rather than varying in time, and/or microclimate behaviour not detected within the meteorological data. RHDHV state that several sensitivity runs were performed to inspect the model performance to variations of several of the issues above, although no further information is provided. Even for Talbingo, the modelled temperatures are 1 – 2degC off from the measured temperature so it would be useful to understand (even narratively speaking) how much the results were off during the sensitivity testing to conclude the model calibration is unlikely to improve further. Please comment.	AWM	08/05/19
	Most issues with Talbingo Reservoir model are due to lack of certainty in available data (e.g. onsite measurements of solar radiation). For Tantangara Reservoir, there is no data for inflow water temperature, which at low reservoir volumes is a key component of the heat budget. Likewise at low levels the ground temperature can significantly influence the heat budget. Because sediment placement in Tantangara Reservoir is proposed to be dry, it is less of an issue than initially thought during the SERP modelling study.	*RHDHV-RH*	*9/5/19*
	Discussed in teleconference 16/5/19 that temperature data for T2 is now available and this information could be used to improve the model.	*AWM*	*17/5/19*
	Available 'T2 temperature' data will be used to improve the proposed (though yet to be commissioned) model calibration based on the 2018 datasets collected by SHL.	*RHDHV-RH*	*21/5/19*
	Closed, on the premise agreed during teleconference 16/05/19 that 2018 model validation run will include updated/more accurate T2 & T3 flow rates from SHL to resolve the water balance error and also include time series of water temperature for T2 & T3 inflows. The latest temperature data from SHL will be used and superseded the previous assumption of a constant 5°C temperature.	*AWM*	*24/05/19*
23.	The thermistor data indicates substantially more variability in the surface temperature data than what the model calculates. This trend is consistent in nearly all the thermistor comparison figures, suggesting that perhaps the daily variations in the model inputs for the meteorological data and/or heat exchange calculations are smoothing out these daily variations. We would speculate that this then may have a compounding effect on the results thermal structure of the upper water column. Please comment.	AWM	08/05/19

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	RHDHV consider the model responds quite well in the surface for water temperature. It is important to remember a direct comparison can't be made as the time periods of model and observed are different. Comparisons of CTD show a good match to modelled and observed thermal structure.	*RHDHV-RH*	*9/5/19*
	Closed. Our comment was an observation in the context of perhaps improving on the thermal structure of the upper water column.	*AWM*	*15/5/19*
Model Calibration - Mud Transport			
24.	Input assumptions to the mud transport simulation are provided (hydrograph, TSS of source, etc); however, there is no indication of the source location within the model domain (horizontal nor vertical). Plan and section views of the setup for the mud transport simulations would be of great benefit. Please provide.	AWM	08/05/19
	Split hopper barge inputs to the surface layer, fall pipe inputs to the bed layer. Looking at the provided maps/figures, the input locations occur within the red polygon shown in Figure 6-5 for example.	*RHDHV-RH*	*9/5/19*
	Closed, however the report would benefit from a set of "setup" figures that show the plan and section views of the setup for the mud transport simulations.	*AWM*	*15/5/19*
25.	What were the horizontal and vertical dispersion factors applied in the mud transport model? Please clarify.	AWM	08/05/19
	Horizontal dispersion is based on the Smagorinsky coefficients (from the HD), while vertical dispersion values are based on coefficients from the k-epsilon formula. *While computationally expensive, use of these turbulence models to describe mixing/dispersion provides the most appropriate/accurate mixing parameters.*	*RHDHV-RH*	*9/5/19*
	Closed. Discussed in teleconference on 16/05/19 that sensitivity tests were conducted with a range of values and the default value of 1 was found to provide stable temperature stratification.	*AWM*	*17/5/19*
26.	Settlement velocities – derived from the geotechnical analysis – are noted as slower than those predicted by Stokes Law; yet, Table 6-3 provides input model assumptions for settling velocities according to Stokes Law. Further to the discussion of hindered settling, please clarify whether any sensitivity runs were completed to test the impact of settling velocities.	AWM	08/05/19
	Observed settling velocities are likely to be affected by laboratory conditions (i.e. hindered settling etc.). Sensitivity runs could be conducted, though given settling velocities are so low and finer fractions are not settling out, it is unlikely to make a significant difference to the study findings.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*15/5/19*
27.	Settlement velocities are provided at 18degC which is fine for summer simulations; however, the winter reservoir temperatures drop to 6degC. Were settling velocities in cool water temperatures tested as input to the winter simulations? Please explain.	AWM	08/05/19

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No.	**Comment**	**By**	**Date**
	This was considered, however, as settling velocities are already extremely low, minor changes will have minimal impact on results. Also, there is likely to be greater uncertainty regarding PSD data, and so more precise settling velocity information would only be beneficial if combined with more accurate PSD data.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*15/5/19*
28.	While the supporting numbers/assumptions to derive a mass loading rate are provided, the report would benefit by stating the calculated mass loading rate implemented in the model. Also, a typical example of a time series of the spill rate would be useful to comprehend the simulation assumptions. Please clarify.	AWM	08/05/19
	All the assumptions/data are clearly laid out. For example, Section 6.6.1.3 shows examples calculations and provides a summary of mass placed over the 206 days simulation period. The total placement rate for a fall pipe is 207 tonnes/day – however this is scaled up by a factor of 7/6.5 to 2229.1 tonnes/day to achieve and average 5000m^3/day placement with 0.5 days/week downtime on a Sunday afternoon. Note: placement rate depends on method due to differences in the source term.	*RHDHV-RH*	*9/5/19*
	Closed. Discussed in teleconference 16/5/19 and confirmed typo of 229 tonnes/day.	*AWM*	*17/5/19*
29.	The report does not mention the sediment dispersion values used. Please clarify.	AWM	08/05/19
	See response provided to Comment 25 above.	*RHDHV-RH*	*9/5/19*
	Closed. Discussed in teleconference on 16/05/19 that sensitivity tests were conducted with a range of values and the default value of 1 was found to provide stable temperature stratification.	*AWM*	*17/5/19*
30.	Have mass budget checks been performed to ensure conservation of mass? From past experience, we have noted evidence that MIKE models can sometimes error in this regard. Please clarify.	AWM	08/05/19
	Yes, mass budgets were checked and found to be correct.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*15/5/19*

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Geology			
31.	Total mass of fines is assumed based on a bulk density of 1,529kg/m3. Is the actual data from the geotechnical findings available rather than assumed density? Please clarify.	AWM	08/05/19
	This assumption is no longer adopted to calculate mass of fines. As discussed at the meeting on 2 May 2019, the mass is calculated directly from the bank volume of rock and a specific gravity of the rock of 2,710kg/m^3. This specific gravity is based on the laboratory testing conducted for Snowy 2.0. Bulking factor and bulk density are relevant for assessing the volume the excavated rock may occupy in the placement locations. Bulking factors in the range of 1.5 to 1.7 have been considered.	*RHDHV-GB*	13/05/19
	Closed.	*AWM*	*14/5/19*
32.	Particle size distributions are provided in Table 6-2. Sediment fractions are split by sediment classification (coarse silt, medium silt, fine silt, very fine silt, clay) – 5 fractions in total. The table states the particle size distribution is dependent on the process to crush the rock rather than the type of rock. Further information on the range of particle sizes based on the various processes to crush rock would be of benefit. Have the most conservative particle size distributions been considered? Please explain.	AWM	08/05/19
	The most conservative particle size distributions have not necessarily been considered to this point. The distributions are based on information supplied by FG JV and agreed with FG JV as likely being representative. Once comparative modelling is concluded and a short list of placement options is determined the intention is to test the sensitivity to adopted particle size grading. Separate particle size gradings have been adopted for TBM and D&B materials reflecting the different excavation processes.	*RHDHV-GB*	13/05/19
	How will the separate particle size gradings for D&B and TBM be reflected in the model? Will there be updated modeling runs that have different transport simulations for the different PSDs based on excavation processes?	*AWM*	*14/5/19*
	The two different excavation methods (D&B, TBM) are expected to produce different particle size distributions (PSDs) as previously advised. PSDs were based on information supplied by FG JV and agreed with FG JV as likely being representative, as noted above. The quantity of D&B excavation versus TBM excavation was supplied by FG JV. The PSDs are applied to the respective excavation quantities to determine the mass in each sediment fraction which is an input to the reservoir model. This is an integrated process, i.e. separate transport simulations were not run for each excavation process, which generally occur simultaneously. *Modelling of the preferred placement option(s) can take into account the latest estimate of the relative quantities of D&B and TBM excavation materials and the sequencing of the placement of these materials, as supplied by FG JV, and also test the sensitivity of PSDs for*	*RHDHV-GB*	*21/5/19*

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	the materials.		
	Closed.	*AWM*	*23/05/19*
33.	Please provide an updated Table 6-4 showing the assumptions for all the new modelled scenarios for Edge Push, Fall Pipe (Deep) and Fall Pipe (5m). The %silt and %clay were provided in the Scenario Summary_v02 however the sediment release height was not provided.	AWM	08/05/19
	RH Response		
	No response from RH provided.	*AWM*	*14/5/19*
	Refer to the attached Table. Note the sediment release location in practice and how this was adopted in the model.	*RHDHV-GB*	*21/5/19*
	Closed.	*AWM*	*23/05/19*
34.	Please confirm how the <63µm for TBM=3% and D&B=1%, and <4µm for TBM=0.4% and D&B=0.2% shown in the 08/04/19 PowerPoint update were determined. Are these the latest assumptions?	AWM	08/05/19
	These values relate to the 'washed' scenario. They correspond to 50% of the unwashed values (rounded up for the clays) based on discussions with FG JV – refer to response to Comment 36. They are the latest assumptions for the washed scenario.	*RHDHV-GB*	13/05/19
	The RH Spoil Placement Update presentation 08/04/2019 Slide 3 stated Updated Assumptions for fines% without reference for them being for the washed scenario. Are the assumptions therefore for the unwashed scenario doubled? Please confirm. *Percentage <63µm for TBM=6% and D&B=2%* *Percentage <4µm for TBM=0.8% and D&B=0.4%*	*AWM*	*14/5/19*
	The above percentages are for the unwashed scenarios. They are double the washed scenario. *All percentages were supplied to SHL in tabular form on 3 May 2019 for supply to AW Maritime.*	*RHDHV-GB*	*21/5/19*
	Closed.	*AWM*	*23/05/19*
35.	We would suspect that the spoil material placed on the reservoir bed will include a wide range of material sizes (although there is no indication of the overall particle/material size distribution). Was the bed roughness modified to account for this change in bed type? Please explain.	AWM	08/05/19
	Typical reservoir velocities are << 5cm/s and the reservoir is typical >10m deep. Hence, adopted roughness values will have negligible influence on hydrodynamics.	*RHDHV-RH*	*9/5/19*
	Closed as the (similar) question 10 is still open.	*AWM*	*16/5/19*
36.	Please provide details on washing and the assumption made regarding the reduction of fines.	AWM	08/05/19

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No.	**Comment**	**By**	**Date**
	Washing has been proposed by FG JV as an option. It would likely involve use of hydrocyclones. It is not possible with washing to completely remove all the fines. FG JV have advised based on discussions with equipment suppliers that approximately 50% of the fines could be removed. Accordingly, the percentages of fines have been halved for the washed scenario (with rounding up for the clays).	*RHDHV-GB*	13/05/19
	Hydrocyclones are used to separate the coarse grains from the fines and perhaps it is realistic that 50% of the fines can be separated. The equipment suppliers are in the best position to advise for this material based on their experience. However what is the project proposal for the disposal of the 50% fines which have been separated? Are they to be placed in Tantangara in the dry and therefore still a potential impact in operation when the water level is raised?	*AWM*	*14/5/19*
	It is understood from information supplied by FG JV that the 50% of fines separated by a washing process would be road transported to Tantangara Reservoir and placed in active storage, in the dry. Should this be the case, RHDHV have advised that the fines would need to be encapsulated within a properly engineered design such that migration of fines was not possible during water level fluctuations and wave action.	*RHDHV-GB*	*21/5/19*
	Closed.	*AWM*	*23/05/19*
37.	In the FGJV Answers to RFI 01/02/2019 document, the contractor suggests the material placed in the dry will be compacted. What methods of compaction are proposed?	AWM	08/05/19
	This is really a matter for FG JV but it would be anticipated that conventional compaction methods would be used such as vibratory rollers.	*RHDHV-GB*	13/05/19
	Closed.	*AWM*	*14/5/19*
38.	In the FGJV Answers to RFI 01/02/2019 document, the contractor acknowledges that the design of the TBM head and driving mode during excavation will influence the PSD. How much discussion has occurred already regarding this to reduce the generation of fines?	AWM	08/05/19
	The importance of reducing the generation of fines during excavation, whenever practicable, has been discussed with the contractor on numerous occasions.	*RHDHV-GB*	13/05/19
	Closed.	*AWM*	*14/5/19*
Silt Curtains			
39.	Some scenarios include 12m silt curtains; however, there is no further explanation as to how these features were implemented in the model. Please clarify.	AWM	08/05/19
	Silt curtains are implemented as impermeable gate structures, which completely block flow in the top 12m of the water column where the curtain is to be placed.	*RHDHV-RH*	*9/5/19*
	We caution against over-representing the effectiveness of silt curtains when it comes to the next stage of modelling the short listed options in more detail and suggest that sensitivity runs be completed. Please	*AWM*	*15/5/19*

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	comment.		
	The current modelling has considered both impermeable silt curtains and no silt curtain so as to 'book-end' the range of possible outcomes for management of fines in suspension. FG JV is yet to fully confirm the actual silt curtain proposed. RHDHV's view is that the silt curtains should be impermeable unless field trials with permeable curtains can be shown to be satisfactory.	*RHDHV-GB*	*21/5/19*
	Closed, silt curtains to be further discussed with FGJV.	*AWM*	*23/05/19*
40.	It would be useful to know the depths of the spoil placement and silt curtains for each scenario in the report. This information would also assist the reader in making sense of the results. Please clarify.	AWM	08/05/19
	This information is available where long-section / vertical slices have been presented. Are there any in particular you would like to see?		
	Closed, however a summary table would improve the report readability.	*AWM*	*15/5/19*
Underwater Bunds			
41.	What is the ambient water depth prior to implementation of the bund in the model? We assume the bathymetry was modified to reflect this feature. Please explain.	AWM	08/05/19
	This depends on which bund you are referring to. *Bunds were implemented by changing the model bathymetry.* *Depths can be determined by looking at the vertical slices i.e. Figure 6-48.*	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*14/5/19*
42.	The figures only provide winter results for the bund at 530mAHD. For completeness, the report should include similar figures for FP and SHB placement with a bund at 530mAHD for the summer time. Please clarify.	AWM	08/05/19
	Sediment fluxes for the different scenarios are summarised in Table 6-9. They are a better way of quantifying the effectiveness of the bund.	*RHDHV-RH*	*9/5/19*
	Closed, however the RH response does not answer the question! But because this modelling is superseded by more relevant and recent scenarios it is of minimal consequence.	*AWM*	*14/5/19*
43.	The report then mentions results for the bund elevation of 515mAHD; yet there are no figures for this case. Please explain.	AWM	08/05/19
	As above - Sediment fluxes for the different scenarios are summarised in Table 6-9. They are a better way of quantifying the effectiveness of the bund.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*15/5/19*
44.	The report should also note the effectiveness of the underwater bund is likely a maximum when the bund is constructed and placement begins (i.e., greatest elevation differential), and that its effectiveness will diminish as the spoil crest level increases to the crest level of the bund. Please clarify.	AWM	08/05/19

SERP INPUTS and MODELLING SCENARIOS			
No.	**Comment**	**By**	**Date**
	Yes this is correct. This was an initial investigation into the effectiveness of underwater bunds. A more complete investigation will be undertaken once there is greater certainty in the final proposed placement method(s).	*RHDHV-RH*	*9/5/19*
	Closed, on the basis that the report should explicitly state our comment.	*AWM*	*15/5/19*
45.	The latest assumptions have a 10m bund height above bed. What is the proposed height of spoil placement by the contractor? Is it expected to exceed the bund?	AWM	08/05/19
	A subaqueous bund 10m high above the reservoir bed has been proposed by FG JV in one scenario in Ravine Bay. The height of spoil placement by the contractor would be well above the crest of the bund, reaching up to FSL. *In the 'Gregs' scenario, a bund would be constructed across the mouth of Plain Creek Bay. In this case, the bund would be progressively raised in conjunction with the placement activity behind, to control migration of fines.*	*RHDHV-GB*	13/05/19
	This requires further discussion as a group on FGJV construction methodologies / modelling scenarios.	*AWM*	*14/5/19*
	Further discussion may occur and is likely to be productive, but this is a matter for SHL. RHDHV's current understanding is that FG JV do not propose underwater bunds and do not propose use of Plain Creek Bay.	*RHDHV-GB*	*21/5/19*
	Closed, underwater bunds to be further discussed with FGJV.	*AWM*	*23/05/19*
Spoil Placement			
46.	The daily placement rate was assigned a value of 5,000m3/day in the report. Has there been a detailed consideration of plant and equipment to confirm that the FP and SHB methods can both be executed at a rate of 5,000m3/day? At first impression we would expect the FP method to be slower than the SHB. Please explain.	AWM	08/05/19
	The 5,000m3/day placement rate has now been superseded by the placement rate of 6,500m3/day for 4 months and 3,500m3/day for 19 months, as advised by FG JV. *RHDHV undertook studies to confirm that the FP and SHB methods could achieve placement rates up to a peak of 10,200m^3/day, as noted in the Draft Engineering Options Report (RHDHV, 12 December 2018).* *FG JV currently do not propose use of FP or SHB as a primary placement method.* *In the 'Gregs' scenario, use of the FP method is proposed, but only for a minor proportion of the total excavated material (the finer fraction), hence only a minor proportion of the production rate. This rate could be readily achieved.*	*RHDHV-GB*	13/05/19
	A time series of actual rates should be implemented by methodology, etc into the model as applicable when the final testing is done. Please confirm.	*AWM*	*15/5/19*
	*Naturally, the time series of the actual proposed placement rates, placement locations, placement methods, and excavation methods (PSD), **would be** modelled when such information is finalised.*	*RHDHV-GB*	*21/5/19*

SERP INPUTS and MODELLING SCENARIOS

No.	**Comment**	**By**	**Date**
	Closed.	*AWM*	*23/05/19*
47.	How was the non-stationary SHB placement simulated in the mud transport model? Please explain.	AWM	08/05/19
	Non-stationary SHB was modelled using a higher source term than a stationary SHB. The location in the model was the same as the stationary SHB scenario. The exact placement in the placement area is likely to be less important than the mass placed and hydrodynamic movement / exchange from the bays.	*RHDHV-RH*	*9/5/19*
	Closed. Discussed in teleconference on 16/5/19 that SHB on the run was modelled with a greater disposal of fines.	*AWM*	*17/5/19*
48.	Table 6-4 provides additional spoil placement options, which indicates the percentage of silts released during spoil disposal differs from the percentage of clays released for the FP and SHB Stationary Methods. Please explain.	AWM	08/05/19
	Firstly, the value in Table 6-4 in the report dated 1 February 2019 for the percentage silts released in the SHB Stationary Method is in error. This should have been 66.7%, not 75%, and thus the same as for the percentage of clays released. This value is corrected in the final modelling report. *The adopted percentage of silts released does still differ to the percentage of clays released in the case of the FP method (25% versus 33%). This is based on the experience of the RHDHV team having regard to the different characteristics of the silts and clays.* *If AWM wish to supply the release percentages they would normally adopt for a FP method these can be discussed. Please supply.*	*RHDHV-GB*	13/05/19
	Can RH explain why there are differences based on their experiences?	*AWM*	*15/5/19*
	Differences in the source terms adopted for silts and clays, for certain placement methods, are based on actual observations of sediment behaviour during dredging and reclamation projects by the RHDHV team, principally Frans Hoogerwerf. Inevitably, some judgement is required. *We have previously requested that if AWM have alternative source terms, then please supply and discuss. Such information has not been received to date.*	*RHDHV-GB*	*21/5/19*
	Closed.	*AWM*	*23/05/19*
49.	The 08/04/19 PowerPoint presentation shows assumed banked placement rates of 6500m3/day for 4 months and 3500m3/day for 19 months for Talbingo. This seems in contradiction to the Contractor proposed rates in the Answer to RDI 01/02/2019. Please explain.	AWM	08/05/19
	The placement rates of 6,500m3/day for 4 months and 3,500m^3/day for 19 months for Talbingo are the latest values provided by the contractor. They represent an update, they are not a contraction.	*RHDHV-GB*	13/05/19
	The contradiction appears with the contractor's proposed rates in the Answer to RFI 01/02/2019 on page 5 for Talbingo. The graph indicates 9500m3/day for 4 months and 3500m3/day for 19 months. Please explain.	*AWM*	*14/5/19*

SERP INPUTS and MODELLING SCENARIOS			
No.	**Comment**	**By**	**Date**
	RHDHV pointed out to SHL that information within the FG JV RFI 01/02/2019 was inconsistent including the rates of placement, duration of placement, and total quantity to be placed. We were subsequently advised to adopt 6,500m^3/day for 4 months and 3,500m^3/day for 19 months. These are the latest placement rates confirmed by FG JV.	*RHDHV-GB*	*21/5/19*
	Closed.	*AWM*	*23/05/19*
Model Scenarios			
50.	The report uses the terminology "worst-case" which we would argue is inappropriate use of the word. We believe a more appropriate wording would be "conservative case." Without further evidence of a range of permutations and/or statistical basis, there is no way to state these results as worst-case. Please clarify	AWM	08/05/19
	The use of conservative can be miss-interpreted, hence we have used "worst-case". Each time we used it we have qualified it's use *i.e. Preliminary "worst case" (i.e. with no silt curtains or bunding) long-term simulations indicate ……*	*RHDHV-RH*	*9/5/19*
	Closed, however we would still use conservative and its qualified use.	*AWM*	*15/5/19*
51.	The report would benefit from more detail in terms of the implementation of the disposal scenarios within the dredge module of the MT model. For example, how and where are the spill locations presented in the model domain for each scenario? Please explain.	AWM	08/05/19
	Spill locations are shown on maps and vertical slices as the areas of highest concentration. SHB is placed in the surface layer, fall-pipe on/near the bed layer.	*RHDHV-RH*	*9/5/19*
	Closed, however a summary table would improve the report readability.	*AWM*	*15/5/19*
52.	Similarly, the scenario modelling involves modifications to the bathymetry to reflect the various stages of construction and post-construction scenario; however, there are no figures of the modified bathymetries utilised for each scenario. For example, four proposed placement locations were undertaken in the placement evaluation; however, there are no figures to illustrate these locations within the model domain. Please clarify.	AWM	08/05/19
	The maps (Figures 6-1 to 6-9) show location of the silt curtains which corresponds to the placement areas.	*RHDHV-RH*	*9/5/19*
	Closed. A figure showing the three considered placement locations (Ravine, Cascade and Plain Creek) would add to the report readability as it is not stated anywhere and only inferred once the modelling has been completed based on high concentration levels.	*AWM*	*14/5/19*
53.	We assume for each location that end of construction would be the more conservative result represented with a shallow built-up reservoir bed that would spread the fines further horizontally, but understand from the meeting of 02/05/19 that only the existing bathymetry has been modelled for comparison purposes, is this correct? Has the sensitivity of model results to bathymetry changes been considered?	AWM	08/05/19

SERP INPUTS and MODELLING SCENARIOS			
No.	**Comment**	**By**	**Date**
	This is correct, the model was undertaken as an initial screening only. Once a placement method is confirmed, more detailed modelling will be undertaken to better quantify the likely impact.	*RHDHV-RH*	*9/5/19*
	Closed. As discussed in teleconference 16/5/19 future modelling will continue beyond the submission of the Main Works EIS and after the completion of trials. We recommend that a method statement is prepared for future modelling works.	*AWM*	*17/5/19*
54.	The report contains seasonal simulation periods but this isn't wholly representative of long-term placement, particularly given that the sediment plumes are still present at the end of the simulation periods. For example, discussion of Figures 6-18 to 6-21 state that the plume is only present on the surface until late October; however, the simulation terminates in late October so there is no way to assess how much longer the plume resides on the surface and at what concentration. We understand from the meeting of 02/05/19 that this may have since been addressed. Please clarify and confirm.	AWM	08/05/19
	Correct, initial modelling was for discrete heating or cooling phases. Subsequent modelling has included 2 years of "looped" modelling. This means that the initial condition for subsequent runs is based on the last step of the previous simulation, allowing a full two year periods of placement to be simulated using only a year of available hydrodynamics.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*14/5/19*
Modelling Results			
55.	Figure 6-5 and Figure 6-6 results appear in contradiction to the trend and behaviour in Figures 6-1 to 6-4. Please explain.	AWM	08/05/19
	They show higher concentration at the surface for SHB. Not sure how this is considered different to the other figures which show a similar behaviour.	*RHDHV-RH*	*9/5/19*
	Figure 6-5 and Figure 6-6 show a southerly direction for the movement of fines which is different from the other figures which indicate a northerly movement. Please explain the differences and why this is occurring.	*AWM*	*14/5/19*
	See response to Q56 (below) – i.e. 3D hydrodynamics are complex. Model input and results provided to AWM of 17/5/19. Suggest reviewing results using a range of vertical and horizontal slices to better understand the complex 3D behavior.	*RHDHV-RH*	*21/5/19*
	Closed.	*AWM*	*24/05/19*
56.	What is causing the upstream movement of fines? The report notes this behaviour but does not offer any further explanation. In the summer time, the report notes that nearly 17% of fines are moving upstream. Without any hydrodynamic figures, it's difficult to rationalize. Is this just from diffusion alone? Please explain.	AWM	08/05/19

SERP INPUTS and MODELLING SCENARIOS			
No.	**Comment**	**By**	**Date**
	3D hydrodynamics due to stratification can cause the surface and deeper layers to move in different directions. It is due to advection more than diffusion. A lot of maps would be required to show the behaviour but with the full 3D results available, the behaviour and reasons for it are more easily understood. *Figure 6-24 to Figure 6-29 show that the plume moves upstream (away from dam wall) below the thermocline, and then moves back downstream as the plume is moved into shallow area and in mixed above the thermocline when it is then transported downstream (towards the dam wall) above the thermocline.)*	*RHDHV-RH*	*9/5/19*
	Same as comment 55. Further explanation of plume behaviour needed.	*AWM*	*14/5/19*
	3D hydrodynamics are complex, and particular so where a pumped-hydro scheme is operational. *Model input and results provided to AWM of 17/5/19. Suggest reviewing results using a range of vertical and horizontal slices to better understand the complex 3D behavior.*	*RHDHV-RH*	*21/5/19*
	Closed	*AWM*	*24/05/19*
57.	Why does the long-section in Figure 6-24 not include the placement location? Figure 6-11 the long section includes the placement location.	AWM	08/05/19
	Figure 6-24 was provided to show behaviour along the main alignment of the reservoir.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*14/5/19*
58.	What is causing the discontinuity in Figure 6-24 and Figure 6-26? Please explain.	AWM	08/05/19
	3D behaviour – these figures are presenting a vertical slice, and so movement may be outside the slice.	*RHDHV-RH*	*9/5/19*
	The figures show areas without fines yet further from the placement location there are fines showing. This discontinuity (areas of white) appears odd for the model. More explanation is needed.	*AWM*	*14/5/19*
	3D hydrodynamics are complex. *Model input and results provided to AWM of 17/5/19. Suggest reviewing results using a range of vertical and horizontal slices to better understand the complex 3D behavior.*	*RHDHV-RH*	*21/5/19*
	Closed.	*AWM*	*24/05/19*
59.	We believe Figures 6-34 to 6-42 (excluding Figure 6-35) are missing "FP" and should read "Cascade Bay FP Placement" as in Figure 6-35. Please clarify.	AWM	08/05/19
	Correct – report has been updated – in figure captions were correct. Also no long-term SHB simulations were undertaken.	*RHDHV-RH*	*9/5/19*
	Closed	*AWM*	*14/5/19*
60.	We note a scale change from Figure 6-41 to Figure 6-42, but assume the depth to maximum TSS at the placement location is the same, or relatively close to similar, for both figures. Please clarify.	AWM	08/05/19

SERP INPUTS and MODELLING SCENARIOS			
No.	**Comment**	**By**	**Date**
	Correct – placement location was the same. Change in scale provided to allow clearer interpretation of data.	*RHDHV-RH*	*9/5/19*
	Closed	*AWM*	*14/5/19*
61.	Sediment dispersion results for this scenario are only presented for Talbingo. What about similar results for Tantangara? Please explain.	AWM	08/05/19
	Initial plume modelling for Tantangara Reservoir is presented in Section 6.5.2. No long-term simulations were undertaken for Tantangara reservoir as dry placement is currently proposed.	*RHDHV-RH*	*9/5/19*
	Closed	*AWM*	*14/5/19*
Post-Placement Bed Stability			
62.	The Snowy 2.0 operational flow scenario is represented by 2036, noted as a “busy” year. If the projected operational flows are known, then we would expect a stronger statistical basis for the year in consideration (perhaps 90 percentile flow), rather than qualitatively labelling it a “busy” year. How does 360m3/s peak flow compare to the overall operational flows from Snowy 2.0? Please explain.	AWM	08/05/19
	We are only modelling a high flow to test for placement stability. It is likely that these high flows (i.e. order 360m^3/s) would be produced during commissioning tests. We are only modelling a 2-day periods so the year is less important.	*RHDHV-RH*	*9/5/19*
	If the modelled flows are considered high flow, then what are typical flows during operation? What is the extend of the high flows in the model domain. Some of the model assumptions are rationalized because there are low flows, yet here we talk of high flows. Please clarify.	*AWM*	*14/5/19*
	This section investigates the likely resuspension of placed sediment. This will occur during periods of high flow. Typical or low flow periods were considered but not investigated because the design will need to be stable under the highest possible flows. High flow conditions were/are therefore of most relevance to the sediment transport investigations undertaken by RHDHV to date.	*RHDHV-RH*	*21/5/19*
	Closed	*AWM*	*24/05/19*
63.	The report notes current speeds reaching 0.4m/s in Talbingo and 0.6m/s in Tantangara, which is different to the negligible flows presently previously. Please clarify.	AWM	08/05/19
	These are flows from future Snowy 2.0 operation at MOL. Hence much higher velocities than existing flows.	*RHDHV-RH*	*9/5/19*
	Closed	*AWM*	*14/5/19*
64.	The report would benefit from a plan view image (without all the extra labels) that clearly illustrates the location of the subsequent time series plots. For example, where is the specific location for the time series for the currents and bed shear stress results for Yarrangobilly Arm? Please explain.	AWM	08/05/19

SERP INPUTS and MODELLING SCENARIOS			
No.	**Comment**	**By**	**Date**
	We believe the figures are clear. Middle Bay is the Yarrangobilly Arm location. The specific locations are shown on the figures.	*RHDHV-RH*	*9/5/19*
	Closed. However, for report readability if Middle Bay is also Yarrangobilly Arm then just state one of the locations to be consistent.	*AWM*	*15/5/19*
65.	The bed shear stress threshold levels are higher at Middle Bay (Figure 6-56) than Ravine Bay (Figure 6-58) and Cascade Bay (Figure 6-60) for the same materials. Please clarify.	AWM	08/05/19
	No, the threshold levels are the same. However, in Figure 6-58 there is an additional threshold value for very coarse sand. The other figures do not show this value.	*RHDHV-RH*	*9/5/19*
	Closed.	*AWM*	*14/5/19*

Attachment G: Proposed Excavated Rock Strategy for Talbingo Reservoir

Talbingo Consolidated & Current Spoil Strategy for EIS:

- Description of rock placement / construction methods

  Placement of spoils in Talbingo involves pushing spoils from shorelines into the Talbingo reservoir by conventional earth-moving plant, such as dumping trucks and excavators, and installing a rock armor layer formed by large size spoils (>200mm) on spoil emplacement slope batter by barges.

- Description of how the works be staged

  Placement of spoils in Talbingo will be carried out in stages when surplus quantity of spoils from construction activities becomes available. The proposed construction staging can be illustrated in attached Figure 1.

  The footprints of spoil emplacement versus time are determined from the quantity of spoil available for placement during construction. The summary of the spoil volume versus time in determining the footprints of the spoil emplacement is shown in the following table.

Spoil vol. (Bank volume, m^3) for construction staging at Talbingo					
Incremental vol.	0.5 year	1yr	1.5yr	2yrs	subtotal
TBM spoils	561,129	202,407	377,323	192,512	1,333,370
D&B spoils	332,024	516,565	425,447	253,390	1,527,425
					2,860,796

(Table can be seen in file: 20190524_Spoil Quantities based on Contract Programme_for construction staging.xls)

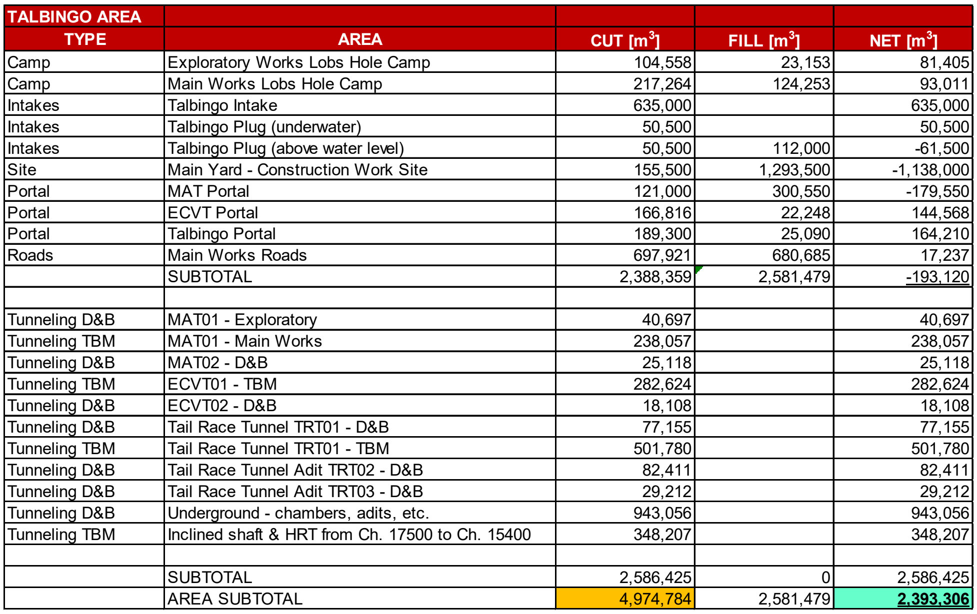
The indicative development of spoil dump footprints versus time is shown in attached Figure 2.

Upon the completion of spoil disposal, the footprint and typical section of the spoil dump are shown in attached Figure 3.

- A breakdown of the material to be placed in the emplacements

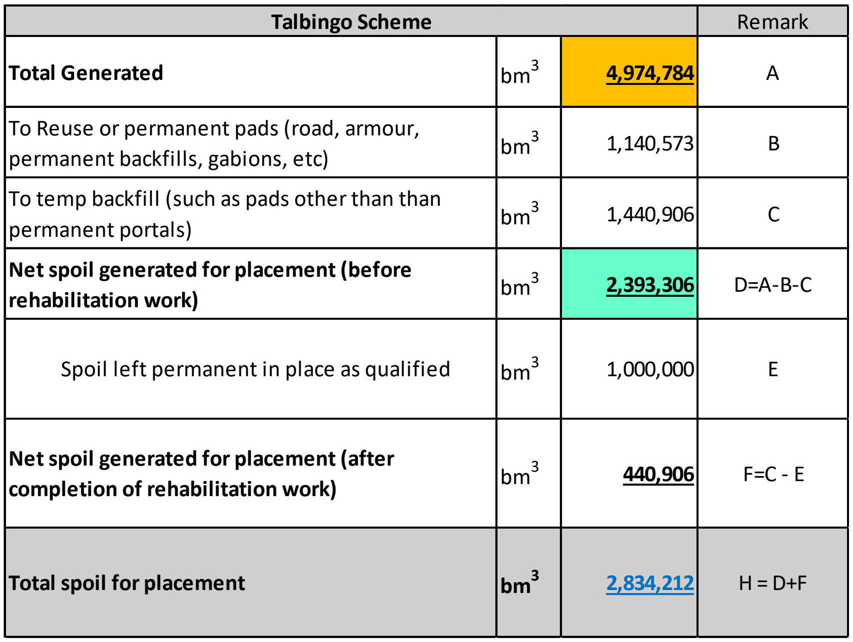
The source and total volume of spoils to be placed in Talbingo reservoir are presented in the tables (a) and (b) below. A total volume (bank volume) of 4,974,784 m^3 spoils will be generated near Talbingo reservoir from construction activities, among which a volume of 2,586,425 m^3 of spoils will be reused for construction of marine infrastructure, temporary and permanent portals, pads, and access roads, and a net volume of 2,393,306 m^3 of spoils will be placed in Talbingo reservoir before rehabilitation work.

Upon the completion of the major construction activities, a total volume of 440,906 m^3spoil placed in ground will be removed and placed into Talbingo reservoir. The volume of 2,140,573 m^3 spoil will remain permanently in ground, which include 1,000,000m^3 qualified quantity of spoils and 1,140,573 m^3 as part of permanent structures, such as roads, permanent pads, and rock armor for rehabilitation work.



TALBINGO AREA				
TYPE	**AREA**	**CUT [m^3]**	**FILL [m^3]**	**NET [m^3]**
Camp	Exploratory Works Lobs Hole Camp	104,558	23,153	81,405
Camp	Main Works Lobs Hole Camp	217,264	124,253	93,011
Intakes	Talbingo Intake	635,000		635,000
Intakes	Talbingo Plug (underwater)	50,500		50,500
Intakes	Talbingo Plug (above water level)	50,500	112,000	-61,500
Site	Main Yard - Construction Work Site	155,500	1,293,500	-1,138,000
Portal	MAT Portal	121,000	300,550	-179,550
Portal	ECVT Portal	166,816	22,248	144,568
Portal	Talbingo Portal	189,300	25,090	164,210
Roads	Main Works Roads	697,921	680,685	17,237
	SUBTOTAL	2,388,359	2,581,479	-193,120
Tunneling D&B	MAT01 - Exploratory	40,697		40,697
Tunneling TBM	MAT01 - Main Works	238,057		238,057
Tunneling D&B	MAT02 - D&B	25,118		25,118
Tunneling TBM	ECVT01 - TBM	282,624		282,624
Tunneling D&B	ECVT02 - D&B	18,108		18,108
Tunneling D&B	Tail Race Tunnel TRT01 - D&B	77,155		77,155
Tunneling TBM	Tail Race Tunnel TRT01 - TBM	501,780		501,780
Tunneling D&B	Tail Race Tunnel Adit TRT02 - D&B	82,411		82,411
Tunneling D&B	Tail Race Tunnel Adit TRT03 - D&B	29,212		29,212
Tunneling D&B	Underground - chambers, adits, etc.	943,056		943,056
Tunneling TBM	Inclined shaft & HRT from Ch. 17500 to Ch. 15400	348,207		348,207
	SUBTOTAL	2,586,425	0	2,586,425
	AREA SUBTOTAL	4,974,784	2,581,479	**2,393,306**

(a) Source of spoils



Talbingo Scheme			Remark
Total Generated	bm^3	**4,974,784**	A
To Reuse or permanent pads (road, armour, permanent backfills, gabions, etc)	bm^3	1,140,573	B
To temp backfill (such as pads other than than permanent portals)	bm^3	1,440,906	C
Net spoil generated for placement (before rehabilitation work)	bm^3	**2,393,306**	D=A-B-C
Spoil left permanent in place as qualified	bm^3	1,000,000	E
Net spoil generated for placement (after completion of rehabilitation work)	bm^3	**440,906**	F=C - E
Total spoil for placement	**bm^3**	**2,834,212**	H = D+F

(b) Spoil volume breakdown

(Table can be found in file: 20190314_Calcolo volumi review_for presentation.xls)

In summary, as shown in Table (c) after leaving a volume of 2,140,573 m^3 spoil in ground forming permanent structures, a volume of 2,834,212m3 of spoils will be placed in Talbingo reservoir.

Talbingo Scheme		
Total spoil generated	bm^3	4,974,784
Spoil left in place as permanent structures after project completion (such as rock armours, gabions, roads, capping for rehabilitation, etc.)	bm^3	(2,140,573)
Spoil to place in Talbingo reservoir	**bm^3**	**2,834,212**

(c). Summary of spoil volume breakdown

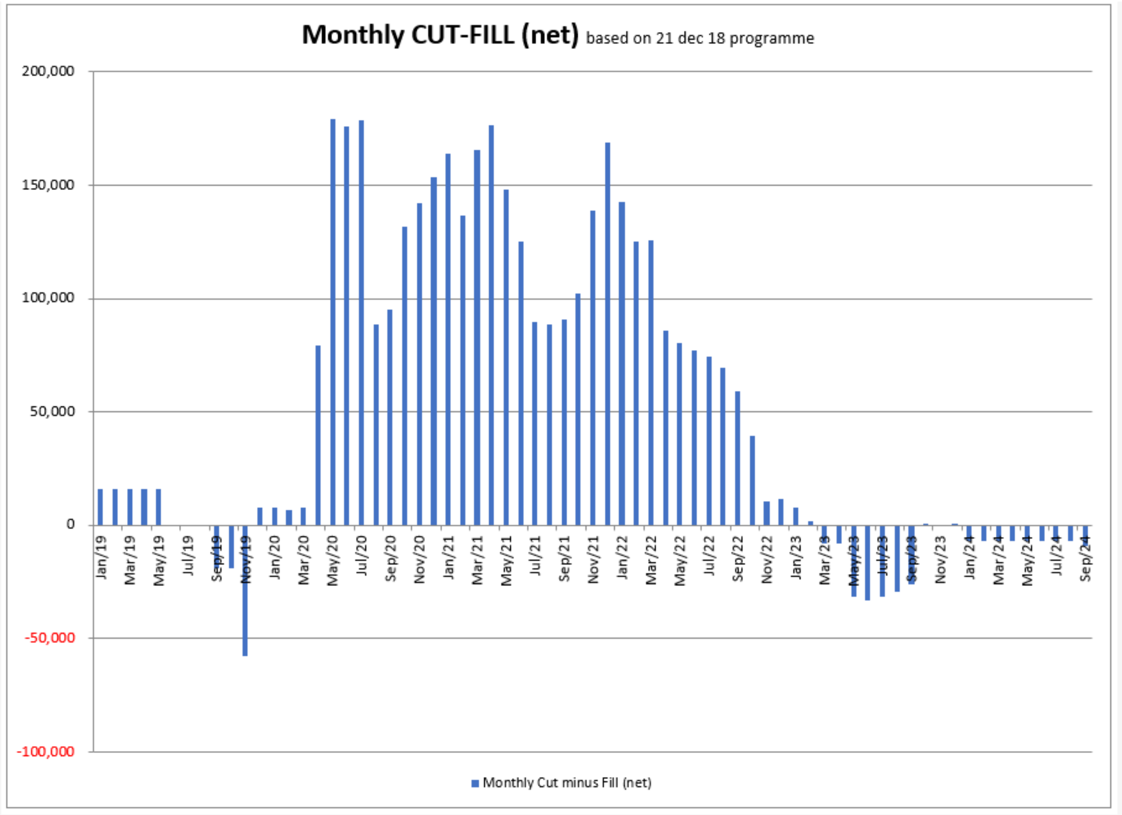
At this stage of the project, little information is available on the properties of spoil that will be generated from construction. Based on the current construction planning and published results from other projects that employed similar construction methods in rocks, a set of particle size distribution (PSD) of spoil has been proposed in assisting the assessment of spoil management for the EIS study. The breakdown volume of spoil to be placed in Talbingo reservoir is shown in the table below. It is considered that spoil (> 200mm) used for rock armour can be obtained by using rock grizzly screens during construction.

Volume of spoils in different sizes in Talbingo Area (bank volume, m^3)						
Spoil size	**D&B**		**TBM**		**Total**	
	100%		**100%**		**100%**	
> 200 mm	40%	585,417	0%	0	21%	585,417
0 -200 mm	60%	878,126	100%	1,370,668	79%	2,248,794
	Subtotal	**1,463,543**		**1,370,668**		**2,834,211**

(Table can be found in file: Spoil Distribution SC_for presentation.xls)

- Indicative construction schedule

  In terms of spoil generation please consider the following chart representing net quantity per month, considered as Delta between total cut and total fill along Talbingo scheme.



- Design measures to minimize impacts

(1) Optimisation of spoil emplacement slope batter

Slope stability assessment has been carried out to determine optimal spoil emplacement slope batter for spoil placement. A commercially available computer software, Geostudio 2016, was adopted in the analyses with the following assumptions:

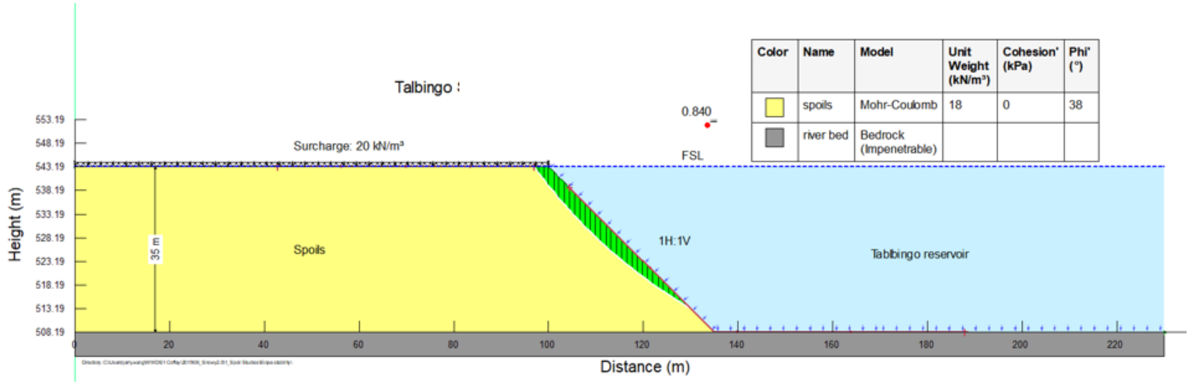
- Spoil properties
    - Unit weight (γ) = 18 kN/m3
    - Cohesion (c) = 0 kPa
    - Friction angle = 38^0
- Talbingo river bed is impenetrable, i.e., slip surfaces will not pass through the river bed.
- Reservoir water impact is not considered.
- Design surface of 20 kPa is considered.
- Minimum factor of safety (FOS) for short term slope stability during construction = 1.0.
- Minimum FOS for long term slope stability = 1.5.
- Highest water level = RL 543.19 m AHD (Full supply level)
- Lowest water level = RL 534. 35 m AHD (Minimum operating level)

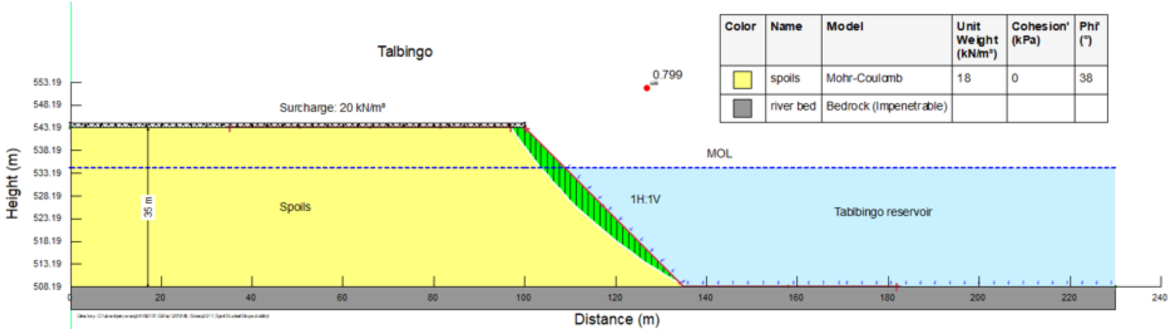
Table below summarises the slope stability assessment results. It indicates that a temporary spoil emplacement with a minimum slope batter of 1.3H:1V will likely be formed by pushing spoil into Talbingo reservoir. To achieve the long term stability for a permanent spoil emplacement, a minimum slope batter of 2H:1V will be required.

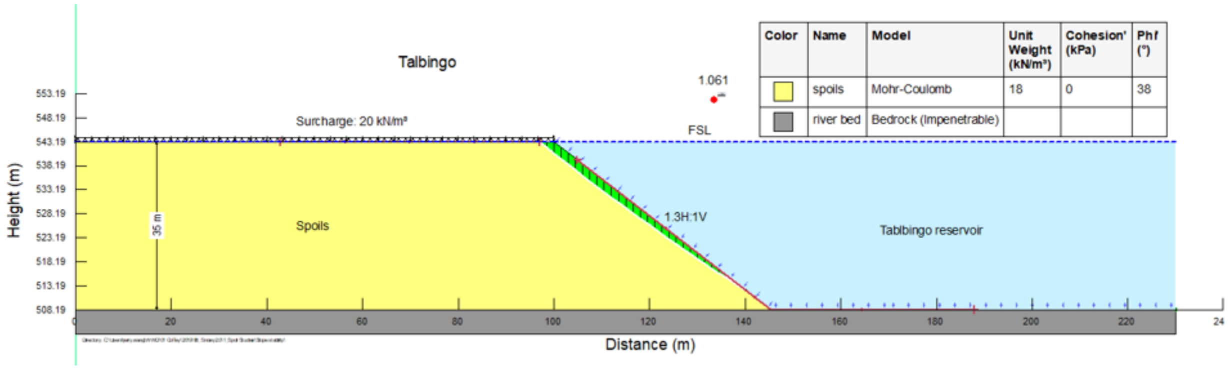
Min. FOS for spoil dumps at Talbingo			
slope batter	Tablbingo water level		Remark
	FSL	MOL	
1H:1V	0.84	0.8	-
1.3H:1V	**1.06**	**1.01**	**FOS>1, temporary slope batter during construction, after free dumping**
2H:1V	**1.589**	**1.487**	**FOS>1.5, permanent slope batter after completion**

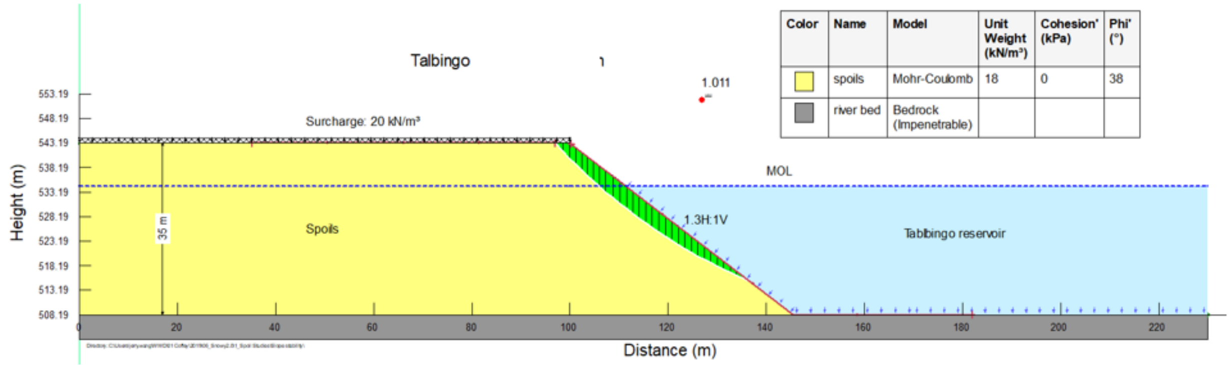
(Table can be found in file: summary of slope stability results.xls)

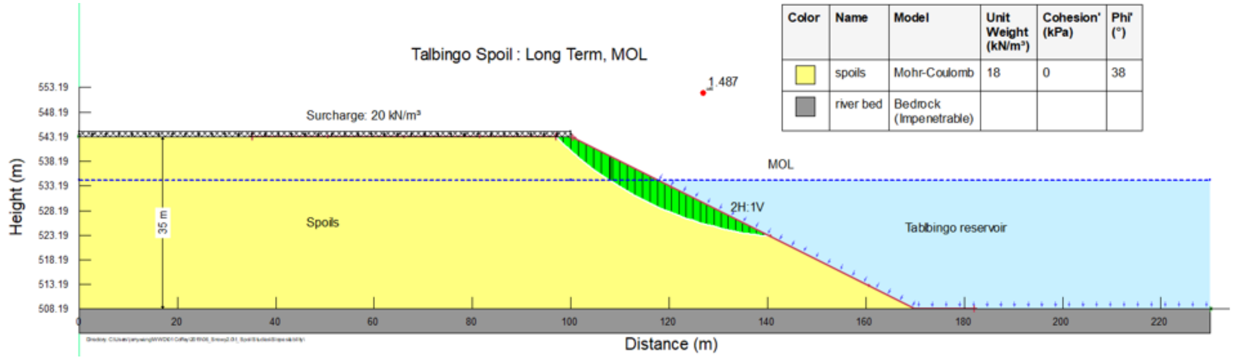
The outputs of the slope stability assessments are shown below.

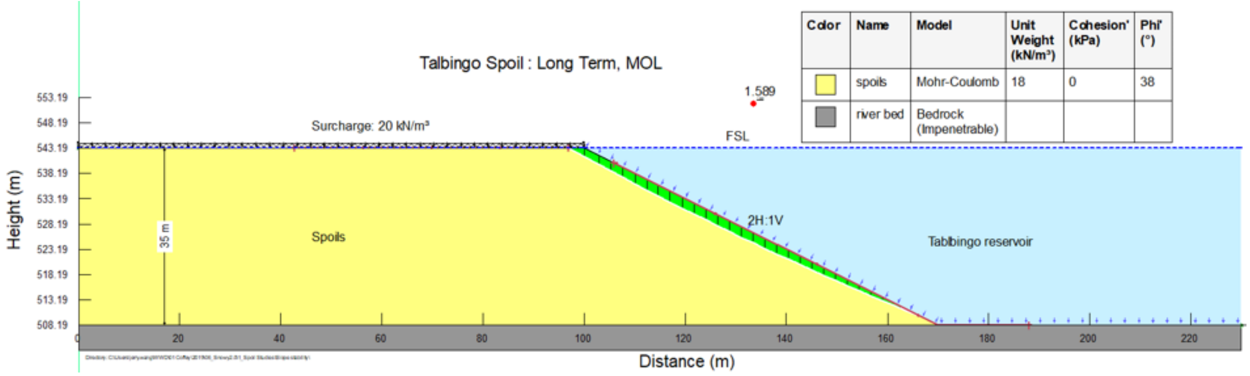












(2) Installation of geotextile for fine contents protection

To reduce the potential of fine content loss related to the fluctuation of Talbingo water levels during operation, a geotextile layer of BIDIM A40 or equivalent is suggested to be installed on the spoil emplacement slope surfaces.

(3) Installation of rock armor for slope surface protection

A nominal 1m thick rock armor layer above MOL will be installed for the protection of spoil emplacement slope surface. The rock armor consists of spoil greater than 200mm, which is to be obtained by screening D&B spoils with rock grizzly screens on site. The rock armour so defined will be installed along the shore exposed from MOL to FSL. The area below MOL is considered as rock armour but will be composed of mixed D&B material since it's required for long term stability of the slopes purposes only. As per refined calculations, non considered in Bafo, to get a Safety Factor FS=1.5 the slope has to be 2H:1V.

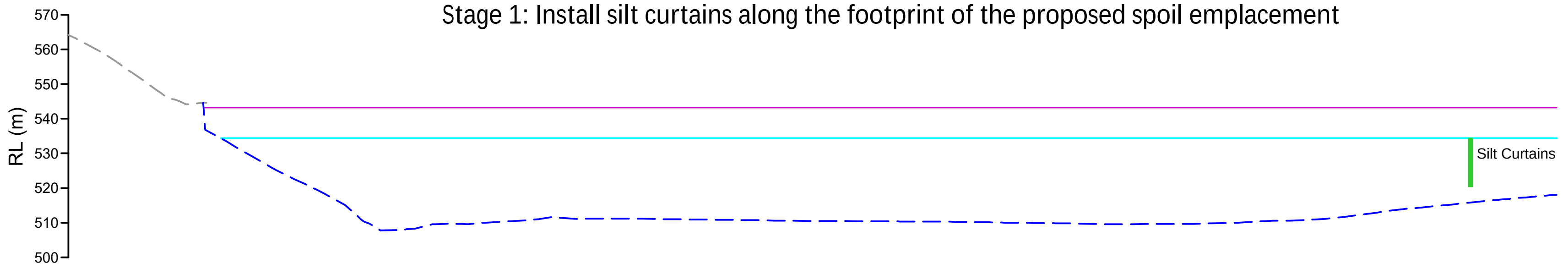
- Interim management measures during the construction;
  NIL
- Final management measures that will be left in place (e.g. armouring? Confirm where?depth?)

As discussed previously, a nominal 1m thick rock armor above MOL will be installed for the protection of spoil emplacement slope surface. The rock armor consists of spoil greater than 200mm, which is to be obtained by screening D&B spoils with rock grizzly screens on site.

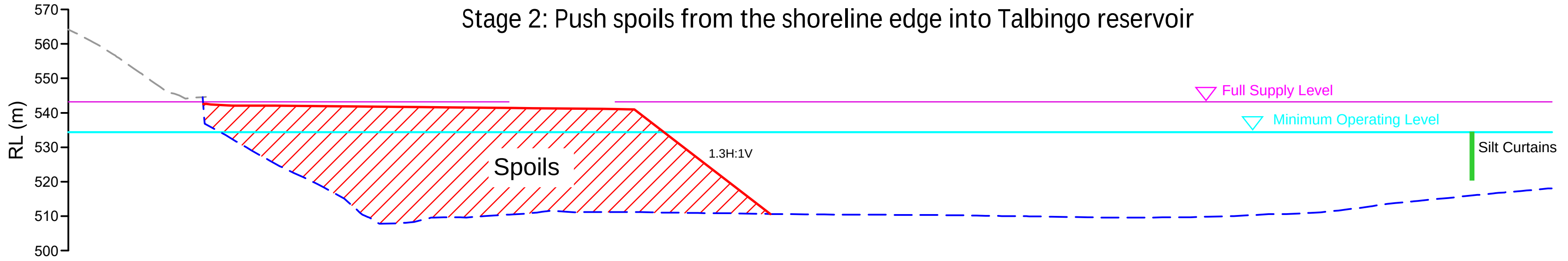
- Any other active/passive measures (e.g. silt curtains)

To reduce the potential environment impact related to spoil placement in Talbingo reservoir, silt curtains will be installed around the footprint of the proposed spoil emplacement. Single Class 3, XR5 heavy duty premium Silt Curtains are suitable for medium risk applications with moderate wind and/or water forces such as rivers and calm harbors, and therefore are proposed for the project.

Stage 1: Install silt curtains along the footprint of the proposed spoil emplacement



Stage 2: Push spoils from the shoreline edge into Talbingo reservoir



Stage 3: Continue pushing spoils from the shoreline edge into Talbingo reservoir until reaching design boundary.

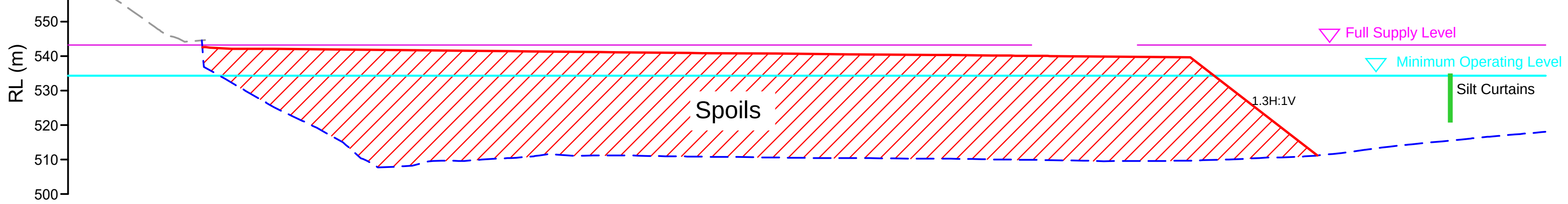
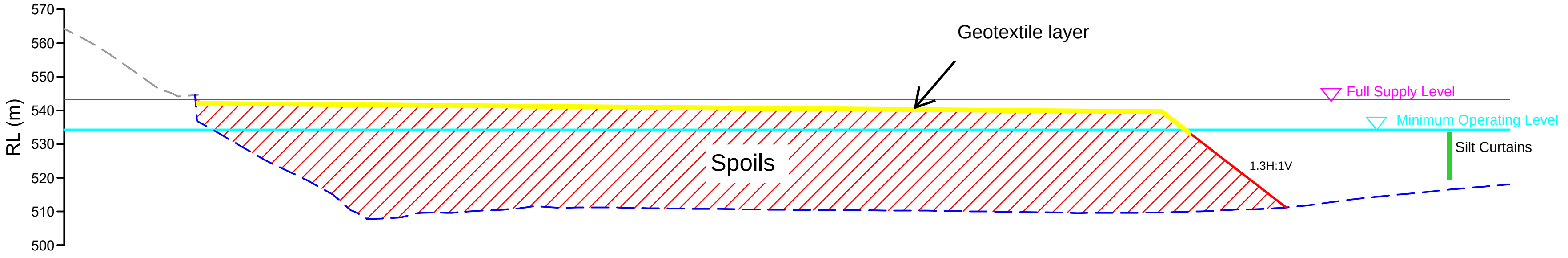


Figure 1 : Talbingo - construction staging

Stage 4:: Install a geotextile layer on the batter slope of the spoil dump for erosion protection.



Stage 5:Install the rock amour layer (i.e. >200mm spoils) for long term spoil emplacement stability and erosion protection.
Barges will be adopted for the installation of the rock amour and spoil forming 2H:1V batter under MOL.

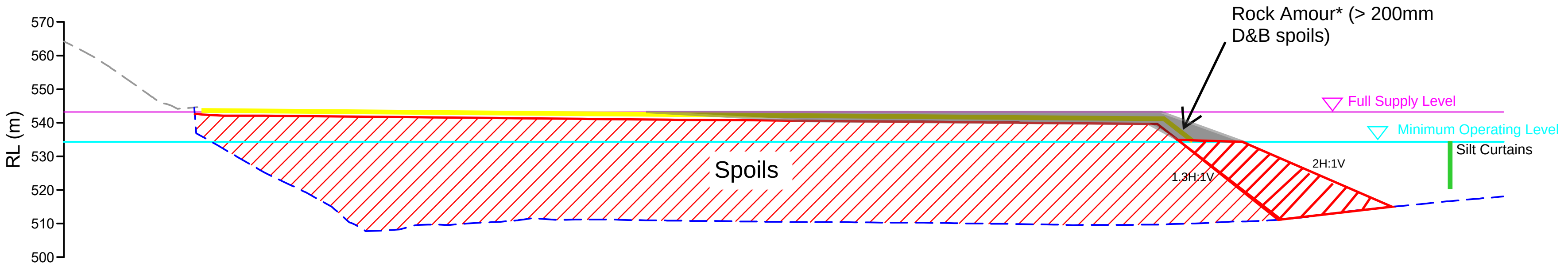
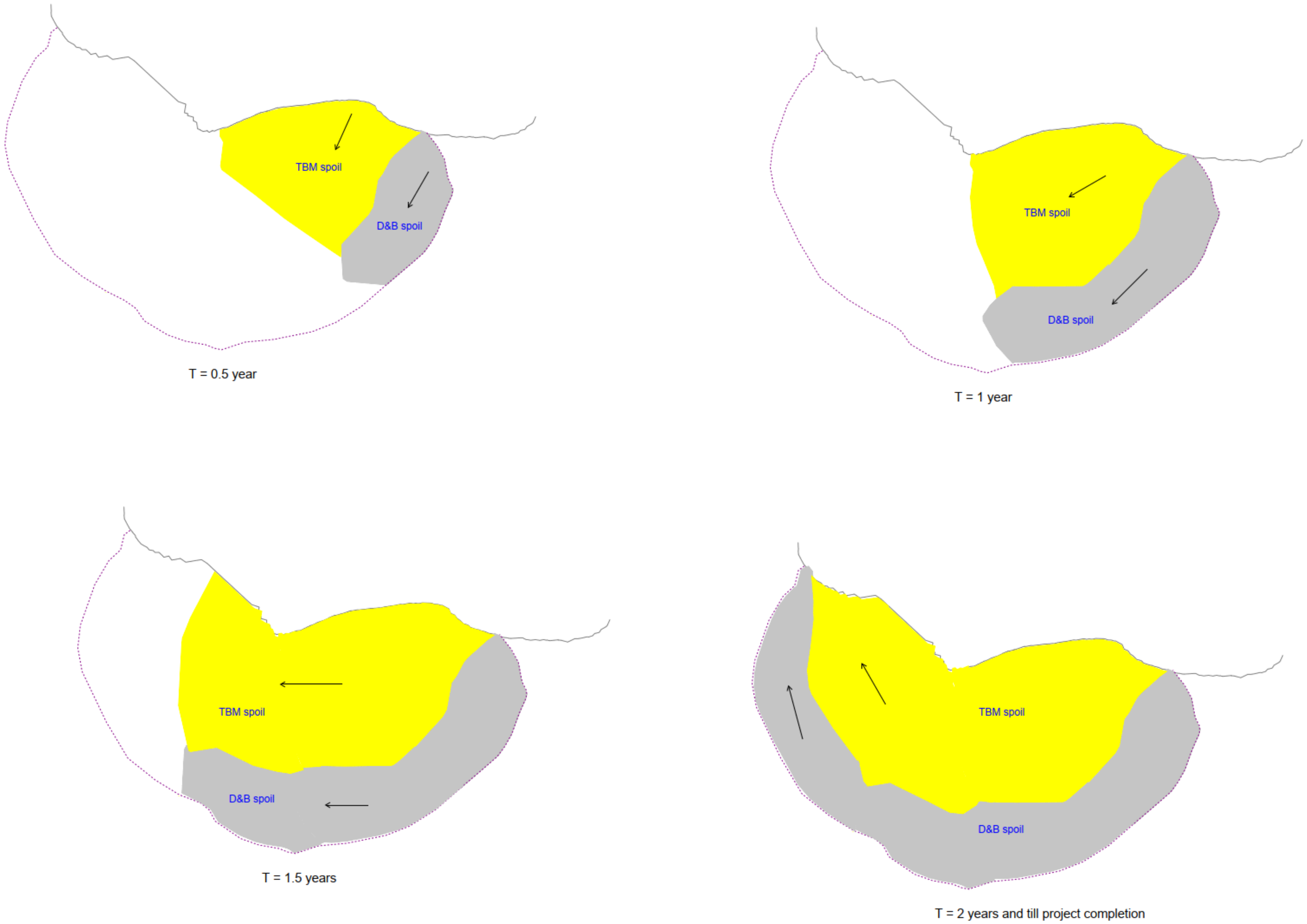


Figure 1 : Talbingo - construction staging
(continued)



T = 0.5 year

T = 1 year

T = 1.5 years

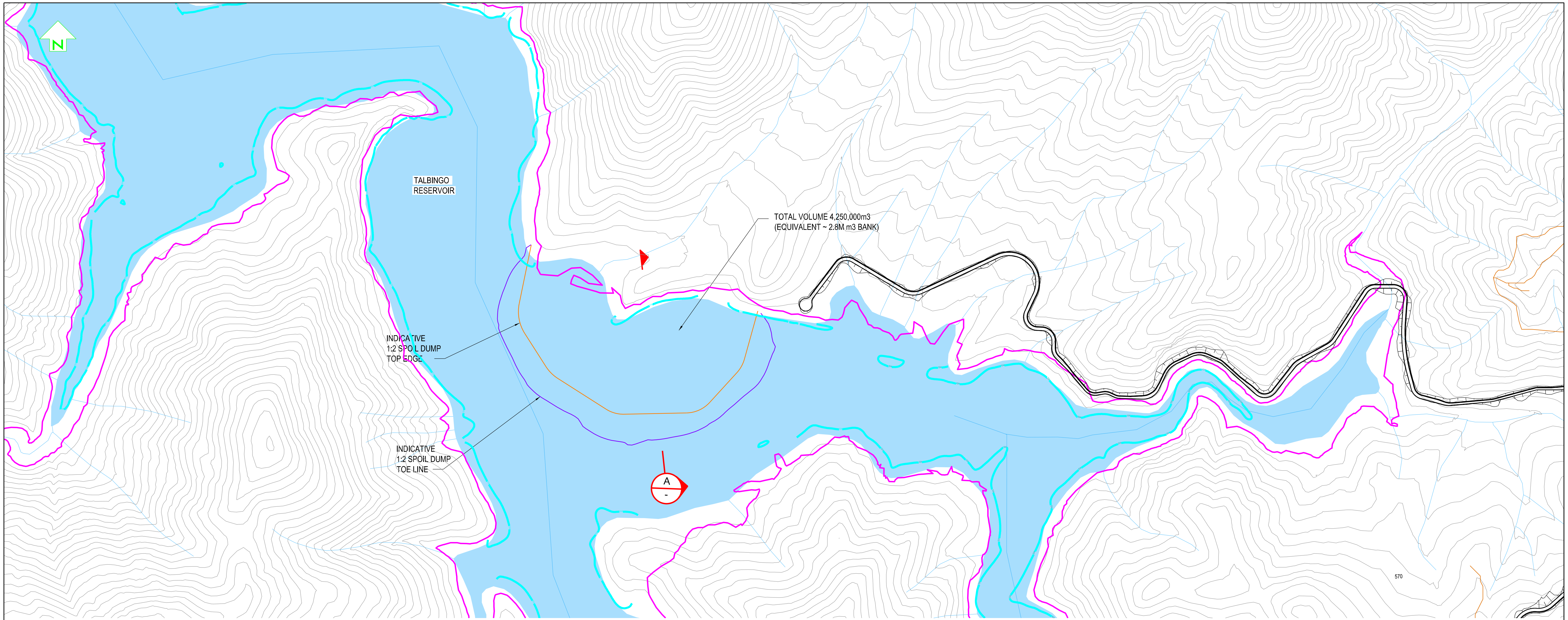
T = 2 years and till project completion

Spoil vol. (Bank volume, m^3) for construction staging at Talbingo

Incremental vol.	0.5 year	1yr	1.5yr	2yrs	subtotal
TBM spoils	561,129	202,407	377,323	192,512	1,333,370
D&B spoils	332,024	516,565	425,447	253,390	1,527,425
					2,860,796

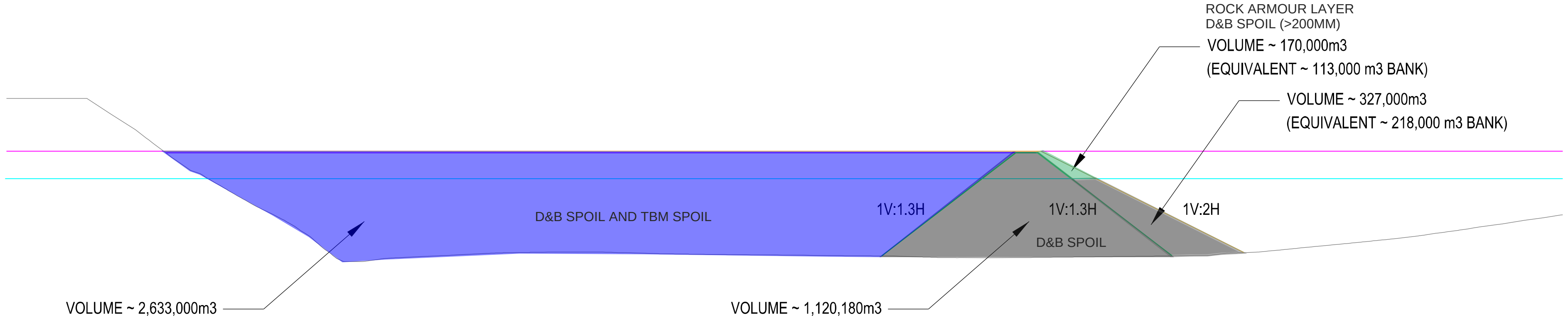
Figure 2:

Indicative development of Talbingo spoil emplacement footprints versus time



LEGEND

LIDAR CONTOUR (10m INTERVALS)
HYDROSURVEY CONTOUR (1m INTERVALS)
FULL SUPPLY LEVEL (FSL) = RL 543.19m AHD
MIN OPERATING LEVEL (MOL) = RL 534.35m AHD



SECTION A -
NTS

Figure 3: Talbingo
Finished spoil footprint and section

Attachment H: Additional Time Series of Suspended Sediment Concentration Plots

This attachment contains modelled TSS concentration at 7 locations (as defined in **Figure 6-2**, Section 6.4.2). Figures for locations 1, 4, 9 and 11 are included in the main body of this report.

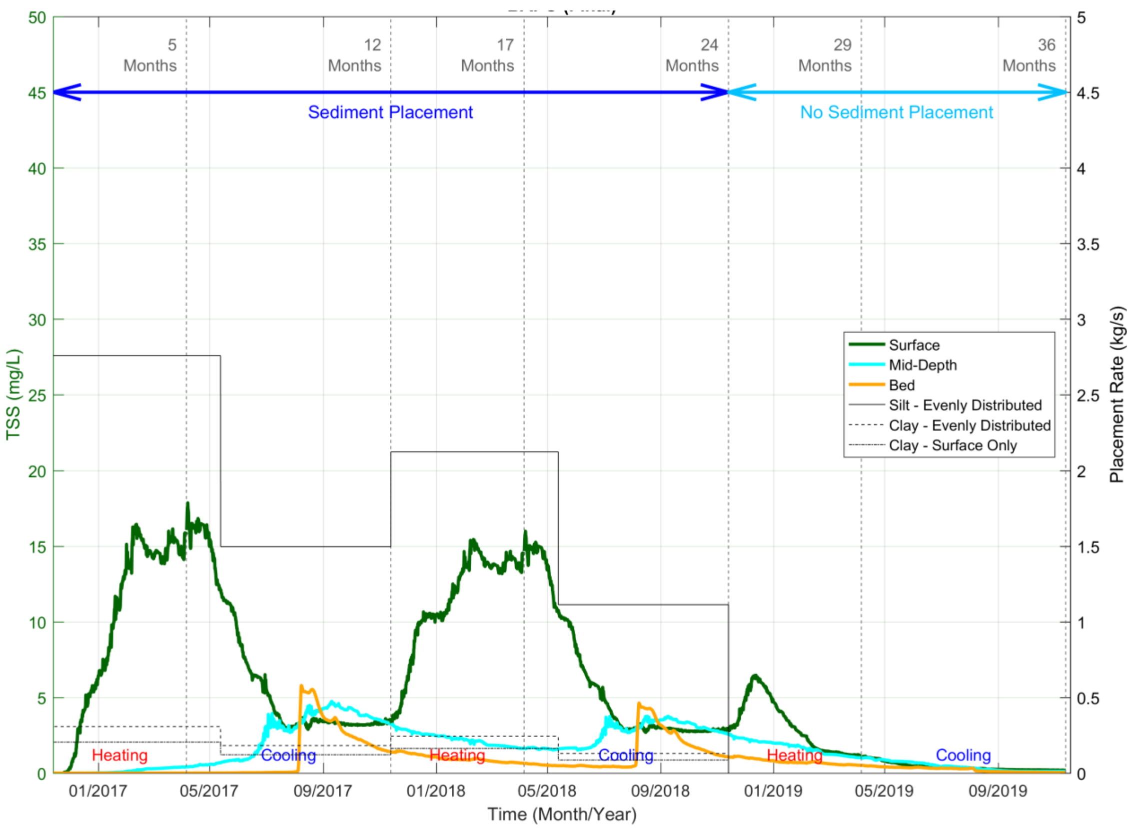


Figure H-1: Location 2 - Proposed Ravine Bay Placement Method

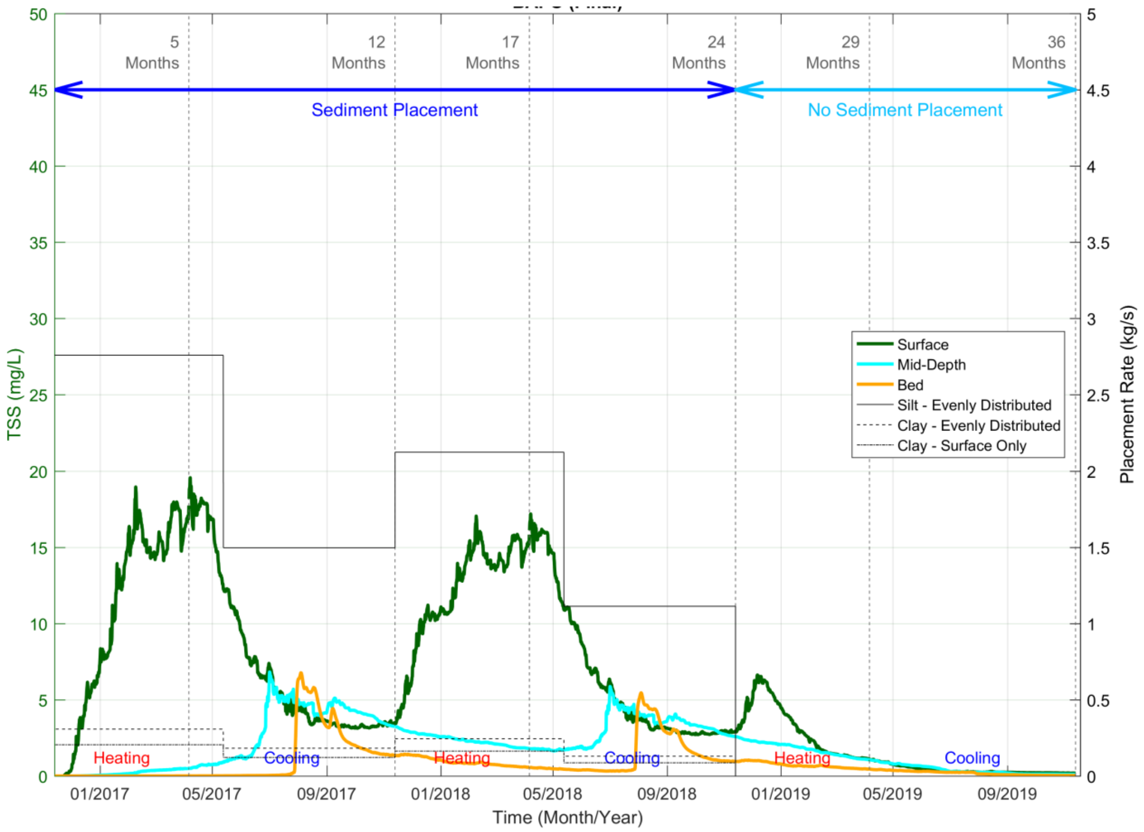


Figure H-2: Location 3 - Proposed Ravine Bay Placement Method

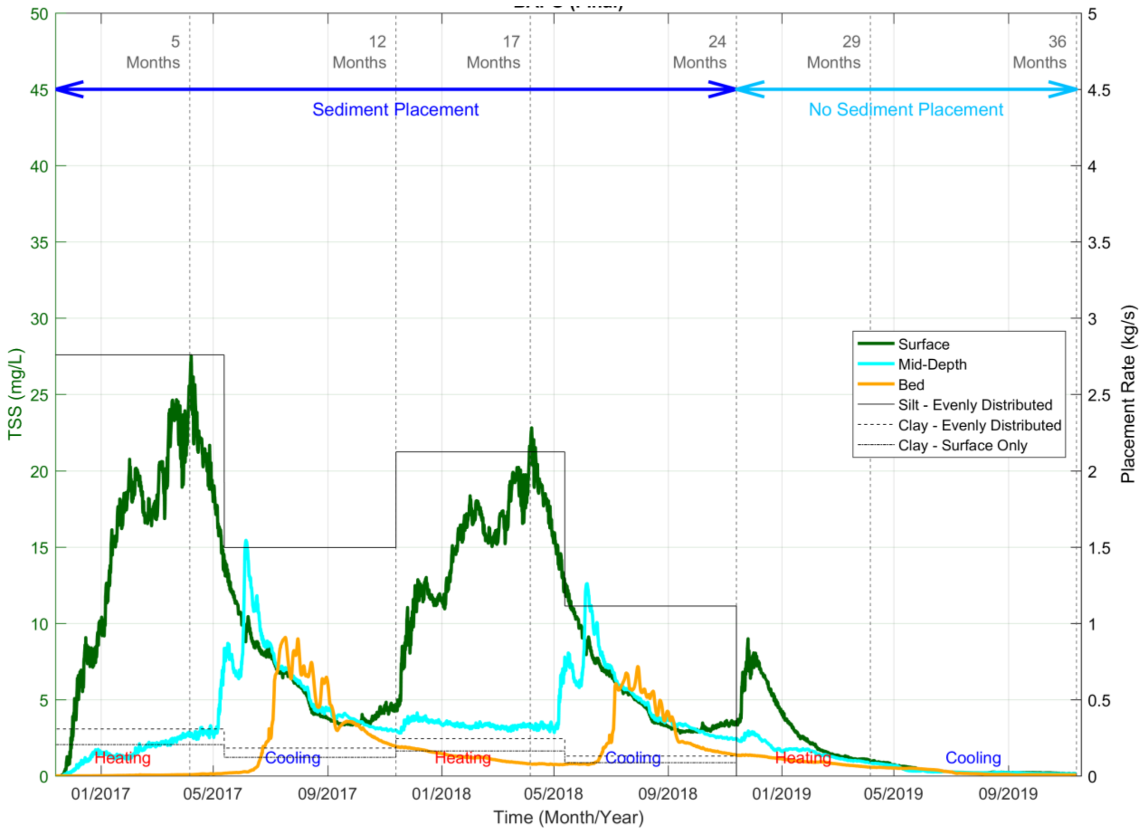


Figure H-3: Location 5 - Proposed Ravine Bay Placement Method

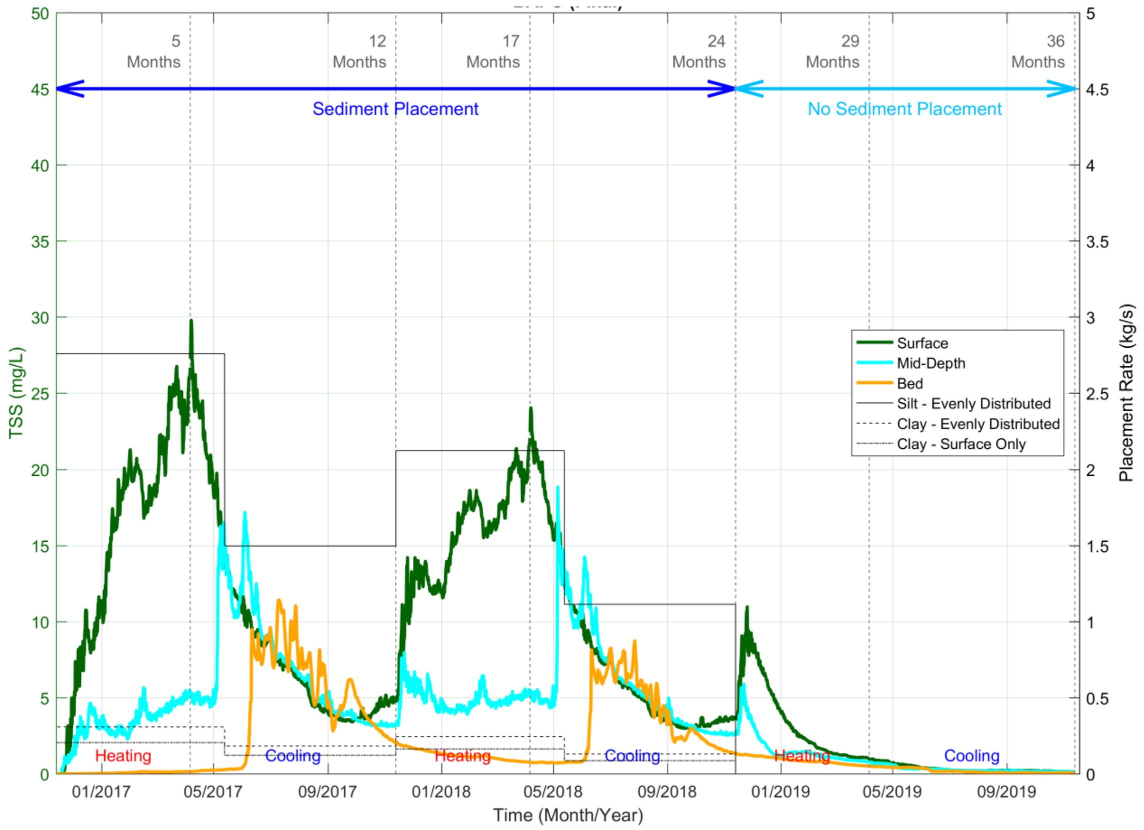


Figure H-4: Location 6 - Proposed Ravine Bay Placement Method

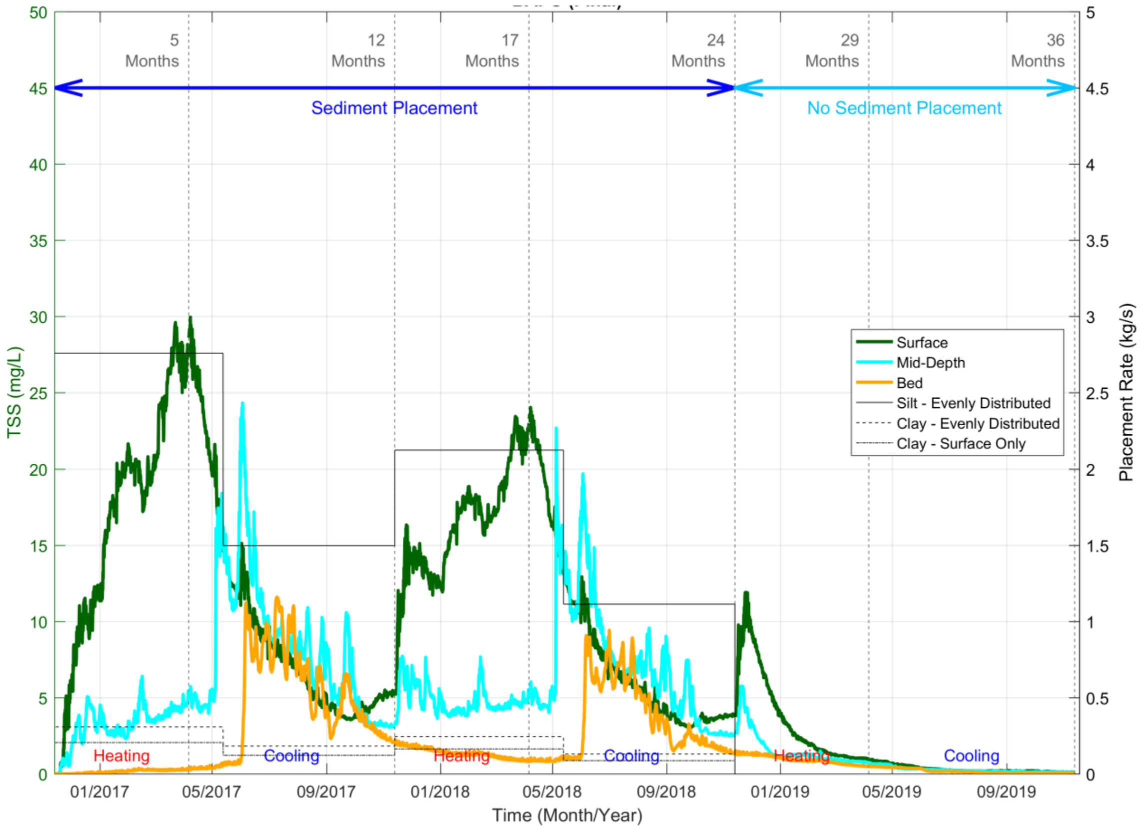


Figure H-5: Location 7 - Proposed Ravine Bay Placement Method

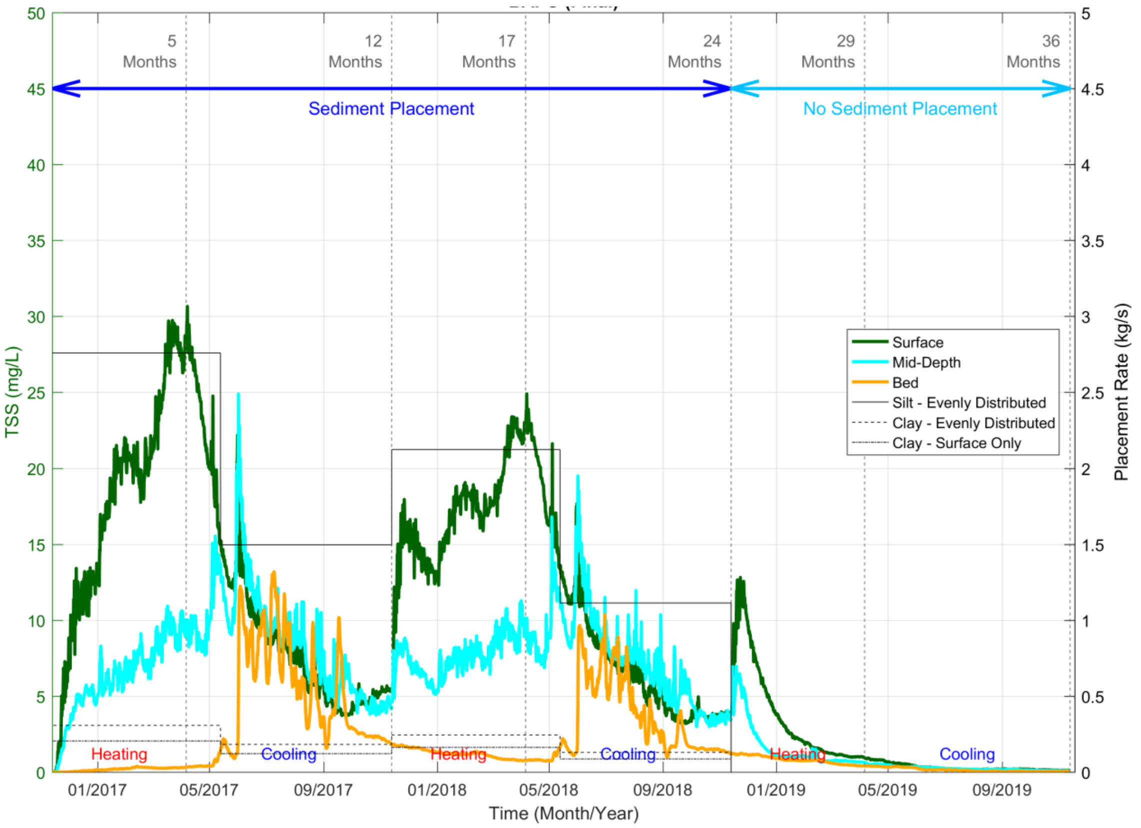


Figure H-6: Location 8 - Proposed Ravine Bay Placement Method

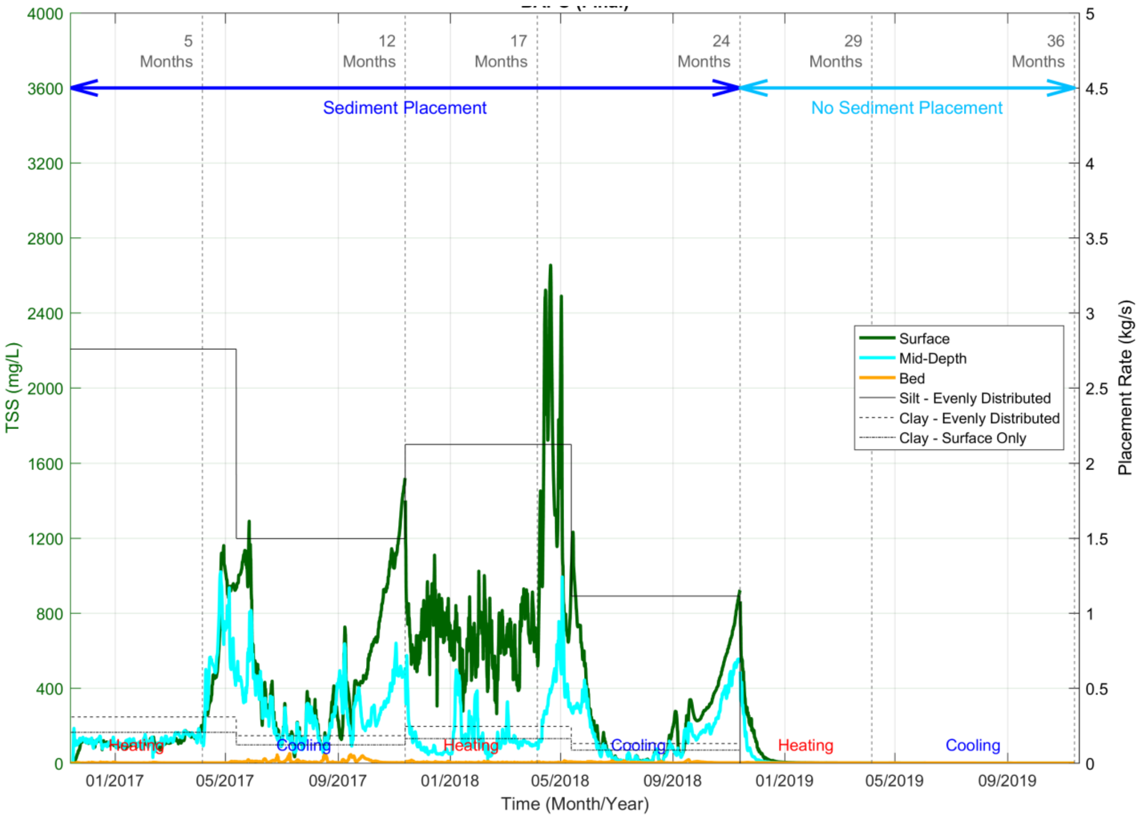


Figure H-7: Location 10 - Proposed Ravine Bay Placement Method

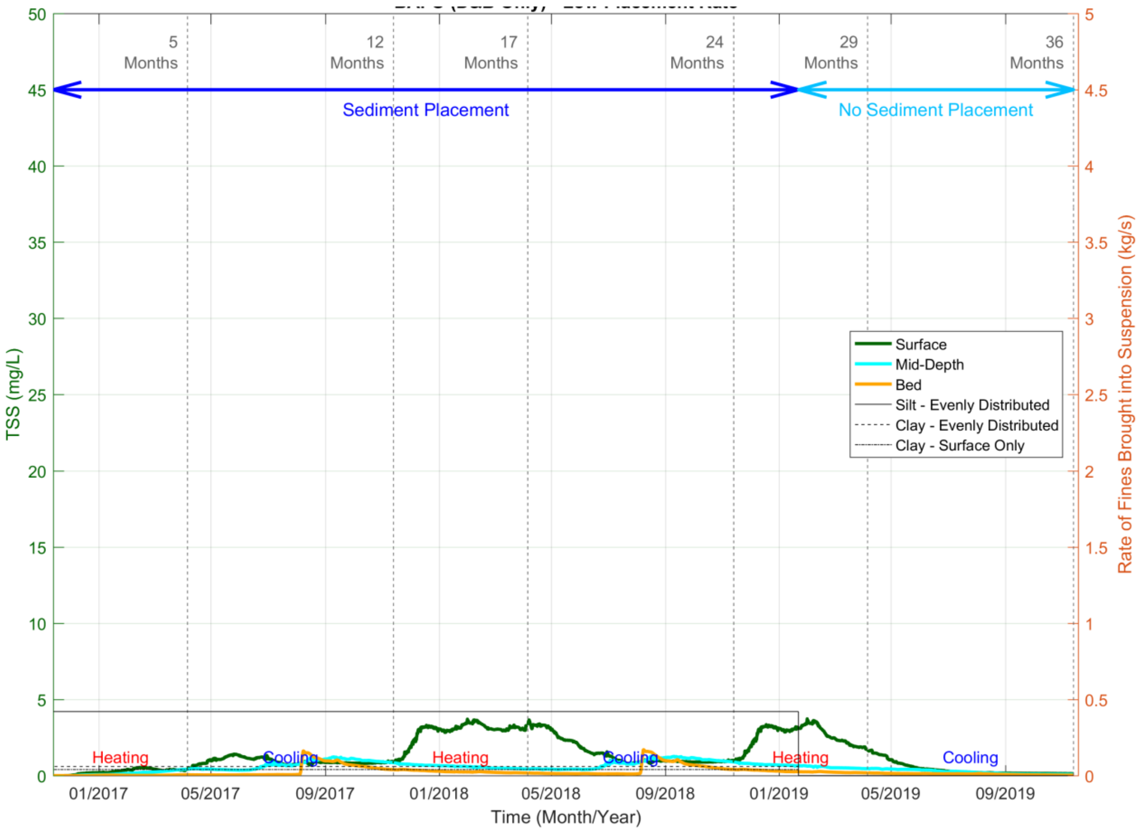


Figure H-8: Location 2 – Alternative Hybrid Placement Method

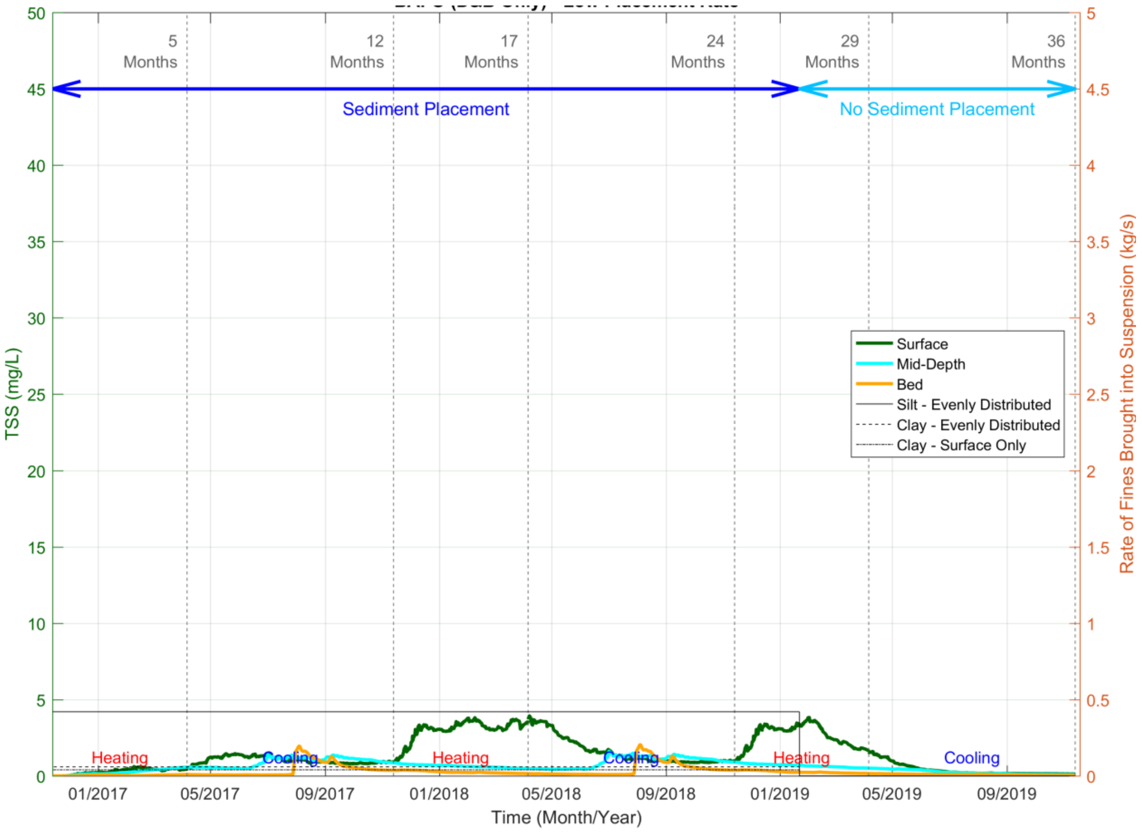


Figure H-9: Location 3 - Alternative Hybrid Placement Method

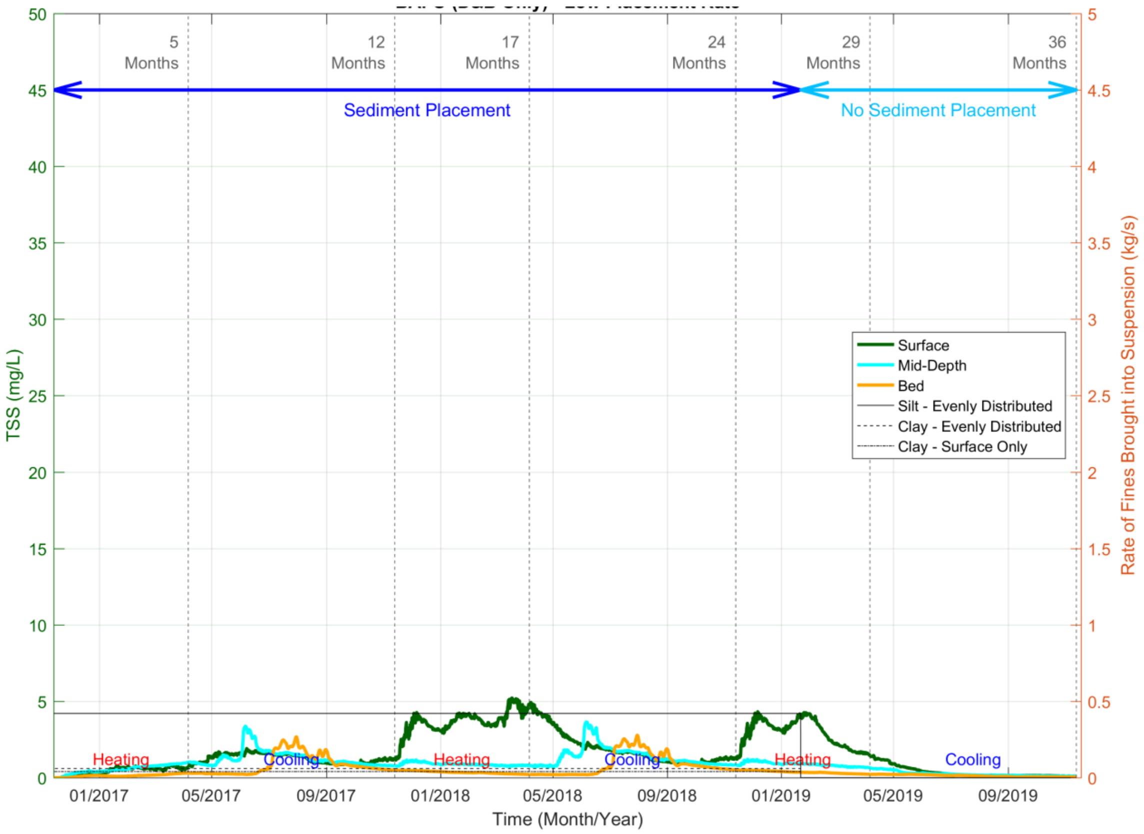


Figure H-10: Location 5 - Alternative Hybrid Placement Method

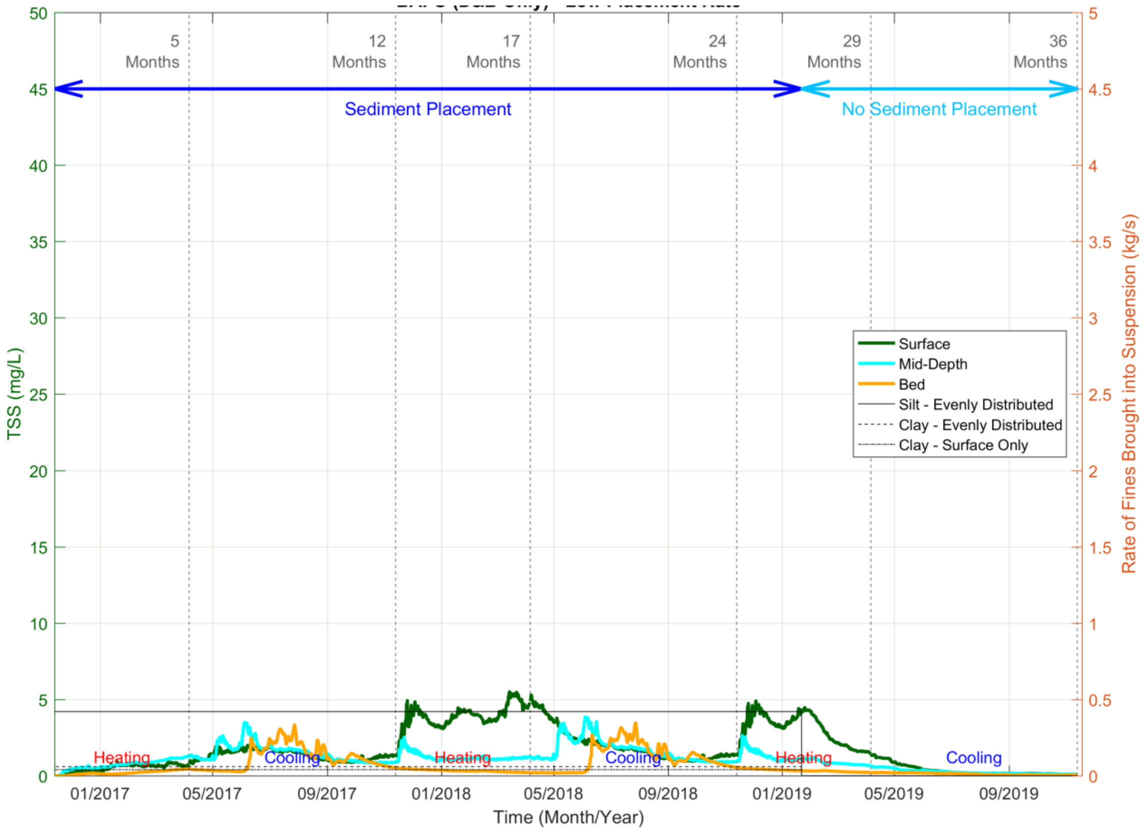


Figure H-11: Location 6 - Alternative Hybrid Placement Method

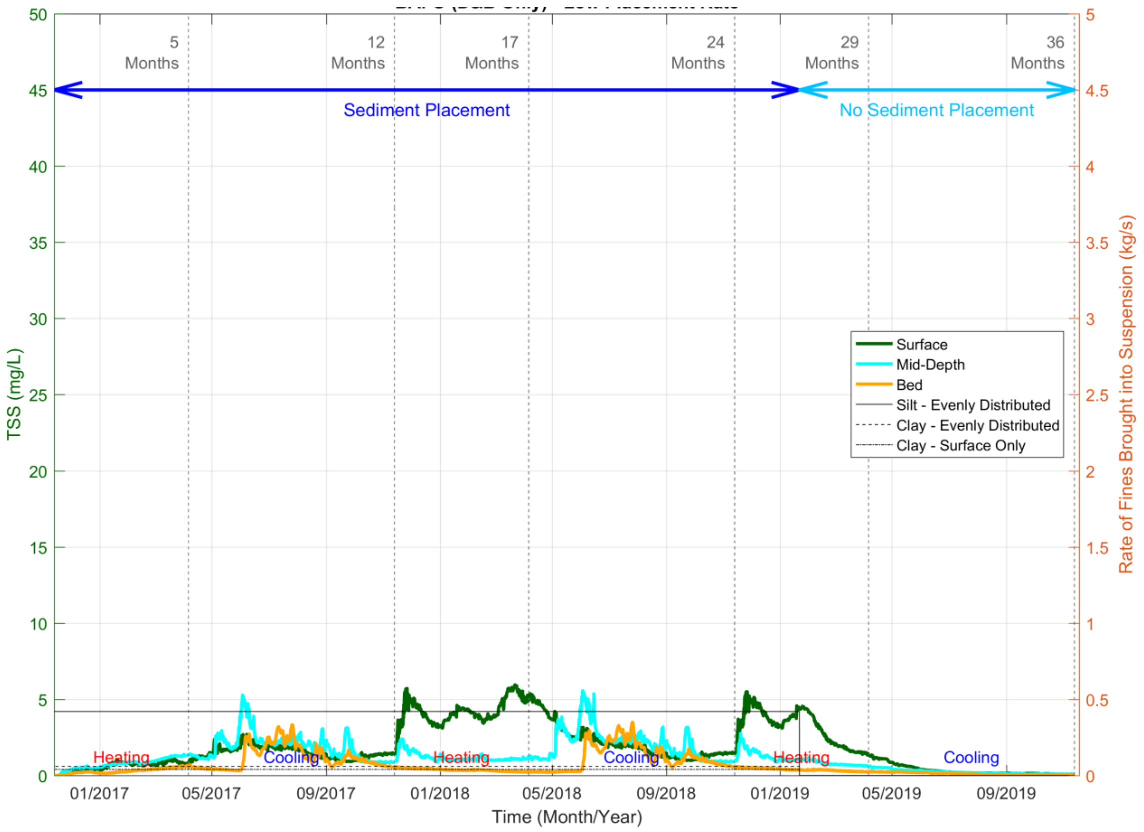


Figure H-12: Location 7 - Alternative Hybrid Placement Method

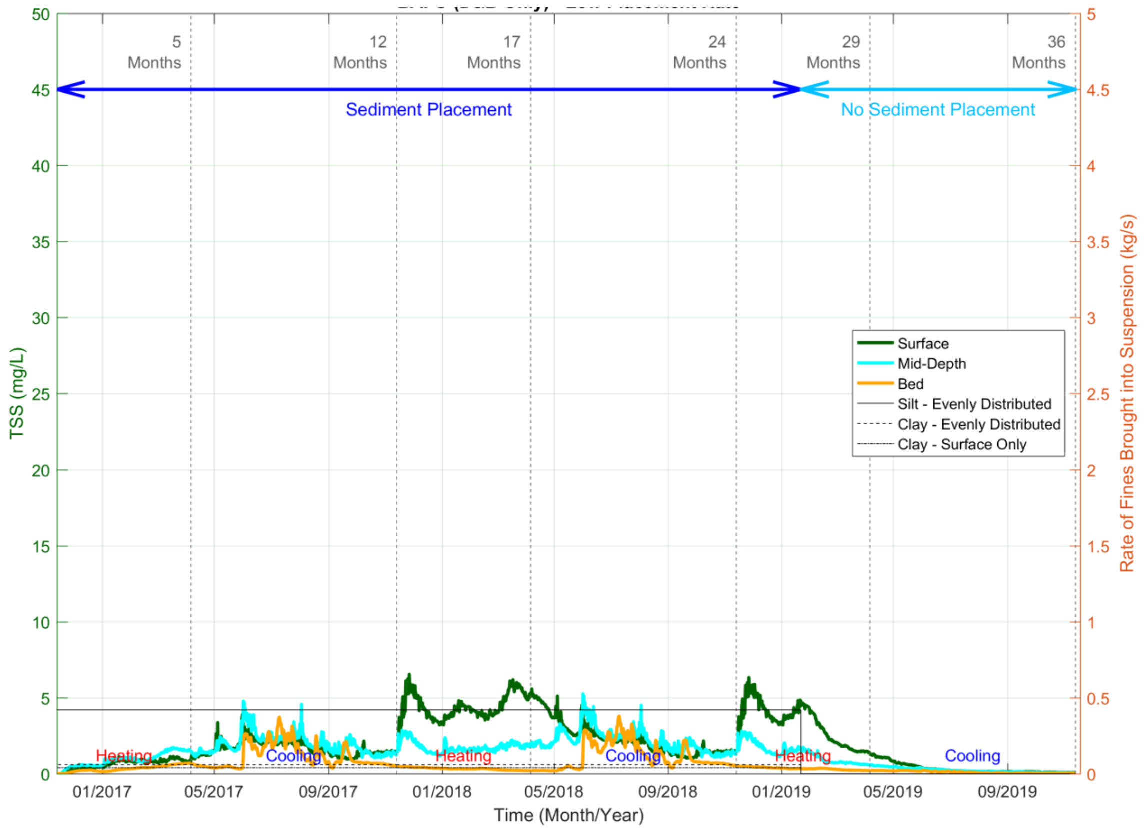


Figure H-13: Location 8 - Alternative Hybrid Placement Method

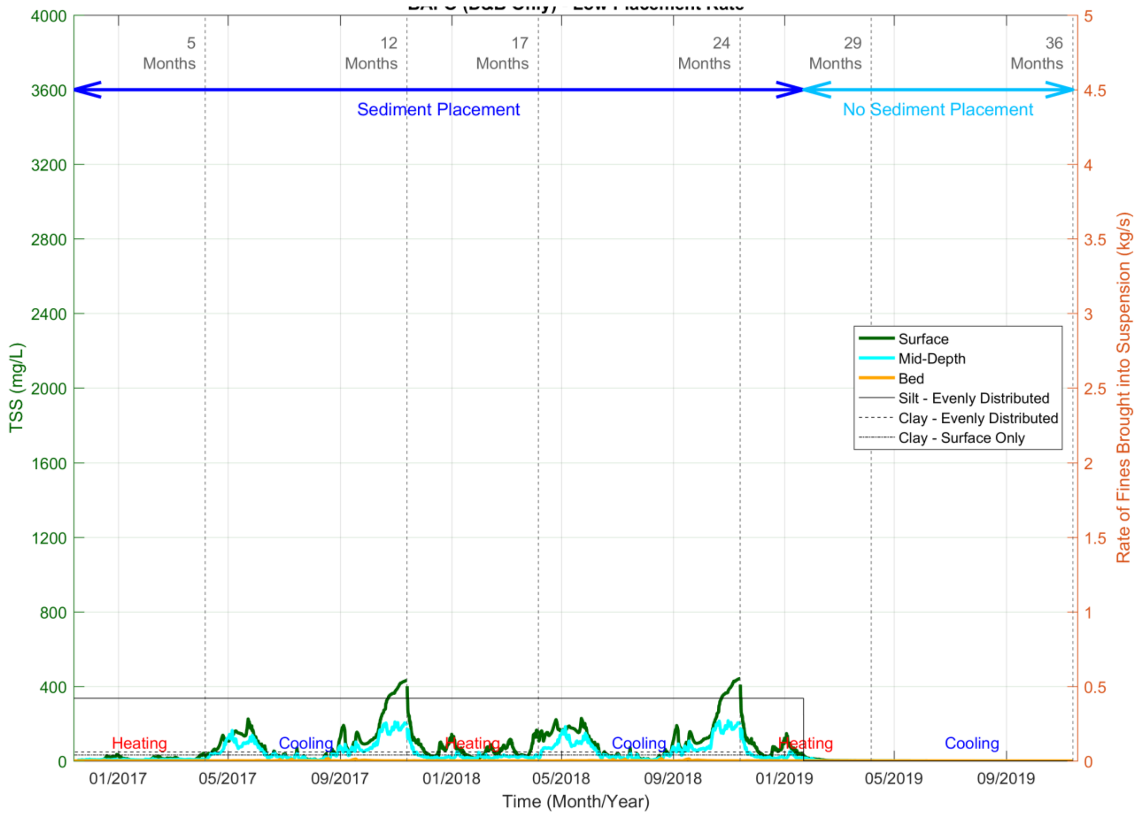


Figure H-14: Location 10 - Alternative Hybrid Placement Method

Annexure H ERP Modelling – Commissioning

REPORT

Snowy 2.0 Excavated Rock Placement

Snowy 2.0: Reservoir Modelling – Commissioning Phase Operation

Client:	Snowy Hydro Limited
Reference:	PA1804 Modelling Commissioning
Status:	Final/P02.01
Date:	11 September 2019

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Document title: Snowy 2.0 Excavated Rock Placement

Document short title: Reservoir Modelling - Commissioning
Reference: PA1804 Modelling Commissioning
Status: P02.01/Final
Date: 11 September 2019
Project name: Snowy 2.0
Project number: PA1804
Author(s): Luke Kidd

Drafted by: Luke Kidd

Checked by: Martin Budd

Date / initials: 11.09.2019 M.B

Approved by: Greg Britton

Date / initials: 11.09.2019 G.B

Classification
Project related

Disclaimer

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Acronym	Definition
ADCP	Acoustic Doppler Current Profiler
AEMO	Australian Energy Market Operator
AHD	Australian Height Datum
ANC	Acid Neutralising Capacity
ARI	Average Recurrence Interval
AWM	AW Maritime Pty Ltd
CFD	Computational Fluid Dynamics
CFL	Courant-Friedrichs-Lewy
COLREGs	Convention on the International Regulations for Preventing Collision at Sea 1972
COPC	Contaminants of Potential Concern
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSSI	Critical State Significant Infrastructure
CTD	Conductivity, Temperature, Depth (Pressure)
D&B	Drill and Blast
DoEE	Commonwealth Department of Environment and Energy
DFL	Design Flood Level
DGV	Default Guideline Value
DIDO	Drive In Drive Out
DPIE	Department of Planning, Industry and Environment (NSW)
ECVT	(Emergency) Egress, Cable and Ventilation Tunnel
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EP&A	Environmental Planning & Assessment Act 1979
EPBC	Environment Protection and Biodiversity Conservation Act 1999
ERP	Excavated Rock Placement
FG	Future Generation
FIFO	Fly In Fly Out
FM	Flexible Mesh
FSL	Full Supply Level
GIS	Geographic Information System
HD	Mike 3 Flow ‘Hydrodynamic’ Model
ISQG	Interim Sediment Quality Guidelines

Acronym	Definition
KNP	Kosciuszko National Park
L/S	Liquid to Solid Ratio
LGA	Local Government Area
LOA	Length Overall
m	Metres
MAT	Main Access Tunnel
MOL	Minimum Operating Level
MPA	Maximum Potential Acidity
MT	Mud Transport
MVA	Mega Volt Amp
MW	Megawatt
MWh	Megawatt hours
NAGD	National Assessment Guidelines for Dredging
NEM	National Electricity Market
NIA	Navigation Impact Assessment
NOA	Naturally Occurring Asbestos
NPWS	National Parks and Wildlife Service (NSW)
NSW	New South Wales
NTU	Nephelometric Turbidity Unit
PSD	Particle Size Distribution
RHDHV	Royal HaskoningDHV
RMS	NSW Roads and Maritime Service
SEARs	Secretary’s Environmental Assessment Requirements
SEPP	State Environmental Planning Policy
SRD	State and Regional Development
SSI	State Significant Infrastructure
T2	Tumut 2 power station
T3	Tumut 3 power station
TBM	Tunnel Boring Machine
TSS	Total Suspended Sediments
WED	Wake Enhancement Device
XRF	X-ray Fluorescence

1 Introduction

1.1 The project

Snowy Hydro Limited (Snowy Hydro) proposes to develop Snowy 2.0, a large-scale pumped hydro-electric storage and generation project which would increase hydro-electric capacity within the existing Snowy Mountains Hydro-electric Scheme (Snowy Scheme). Snowy 2.0 is the largest committed renewable energy project in Australia and is critical to underpinning system security and reliability as Australia transitions to a decarbonised economy. Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground.

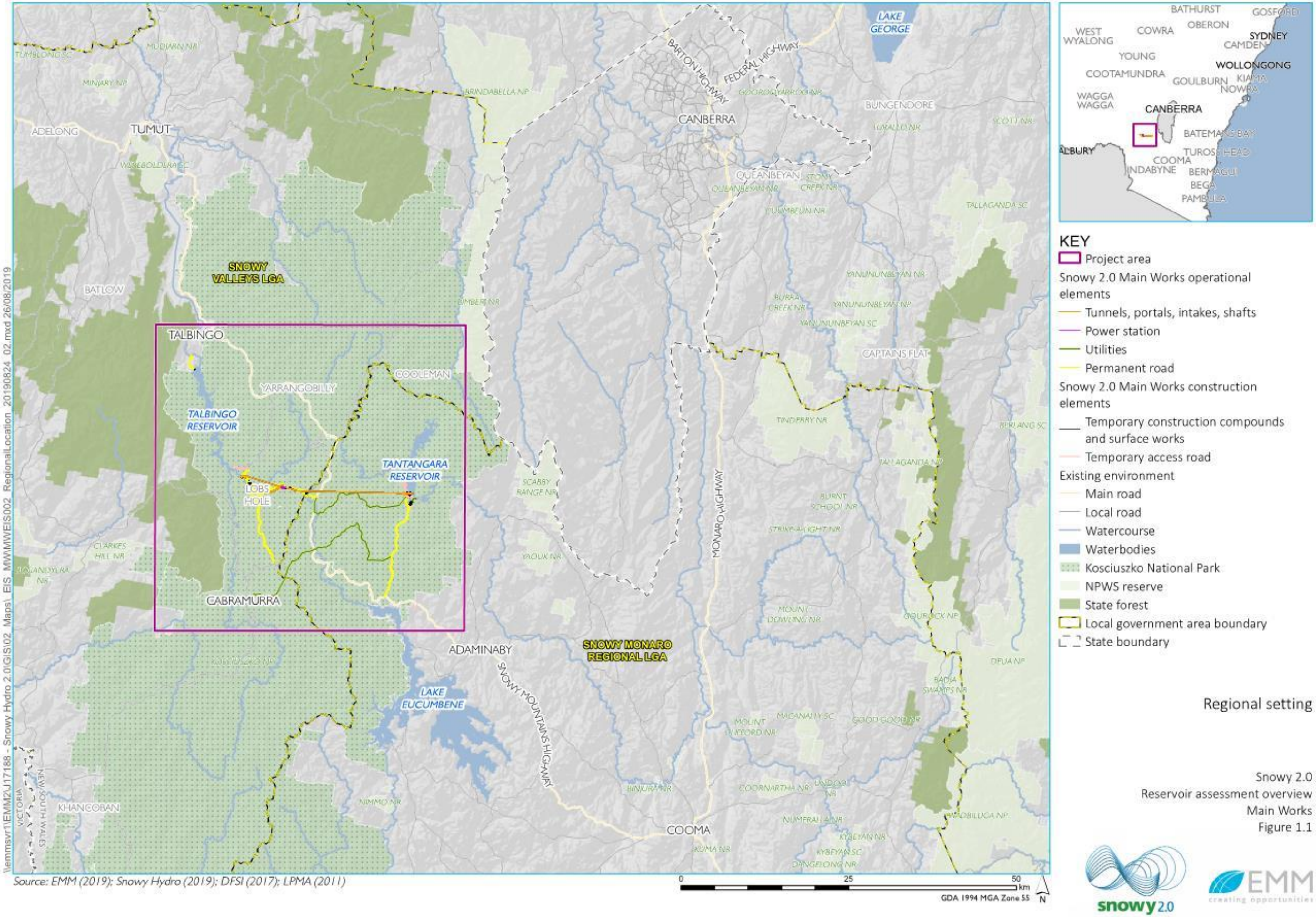
Snowy 2.0 has been declared to be State significant infrastructure (SSI) and critical State significant infrastructure (CSSI) by the former NSW Minister for Planning under Part 5 of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) and is defined as CSSI in clause 9 of Schedule 5 of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

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

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

This **commissioning phase operation modelling assessment** has been prepared to accompany an application and supporting EIS for the **Snowy 2.0 Main Works**. As the title suggests, this stage of the project covers the commissioning phase of Snowy 2.0 which is to be undertaken over a period of approximately two years following construction of Snowy 2.0. The commissioning operations phase will include pumping and generation tests to demonstrate to the Australian Energy Market Operator (AEMO) that Snowy 2.0 is ready to be connected to the grid.

Snowy 2.0 Main Works is shown in **Figure 1-1**. If approved, the Snowy 2.0 Main Works would commence before completion of Exploratory Works.



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

Regional setting

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 1.1

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

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

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

1.2 Project location

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

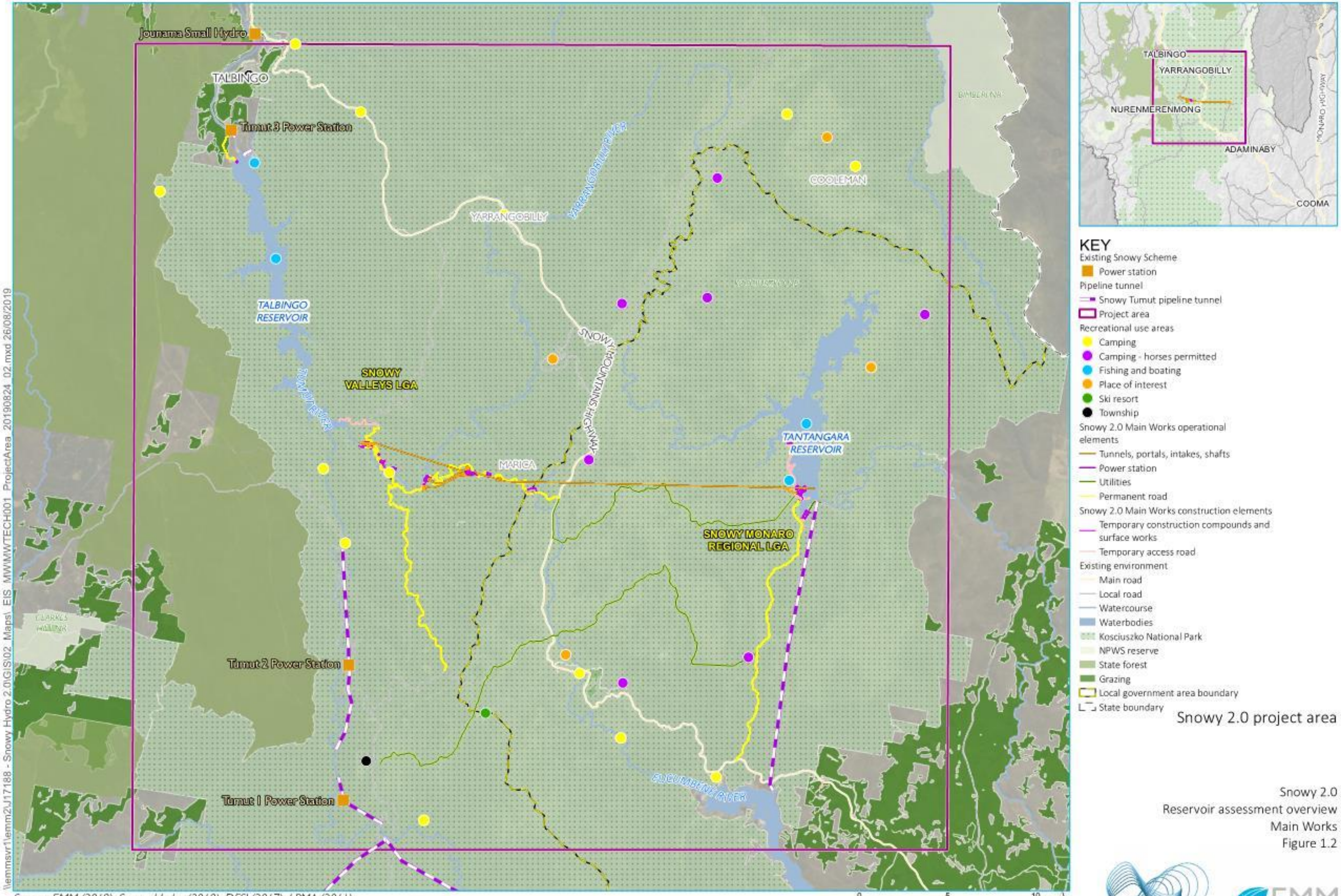
The nearest large towns to Snowy 2.0 Main Works are Cooma and Tumut. Cooma is located about 50 kilometres (km) south east of the project area (or 70 km by road from Providence Portal at the southern edge of the project area), and Tumut is located about 35 km north west of the project areas (or 45 km by road from Tumut 3 (T3) power station at the northern edge of the project area). Other townships near the project area include Talbingo, Cabramurra, Adaminaby and Tumbarumba. Talbingo and Cabramurra were built for the original Snowy Scheme workers and their families, while Adaminaby was relocated in 1957 to make way for the establishment of Lake Eucumbene.

The location of the Snowy 2.0 Main Works with respect to the region is shown in **Figure 1-2**.

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

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

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



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

Snowy 2.0 project area

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 1.2

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

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

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

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

The project is described in more detail in **Section 2**.

1.2.1 Project area

The project area for Snowy 2.0 Main Works has been identified and includes all the elements of the project, including all construction and operational elements. The project area is shown on **Figure 1-2**. Key features of the project area are:

- the water bodies of Tantangara and Talbingo reservoirs, covering areas of 19.4 square kilometres (km^2) and 21.2 km^2 respectively. The reservoirs provide the water to be utilised in Snowy 2.0

- major watercourses including the Yarrangobilly, Eucumbene and Murrumbidgee rivers and some of their tributaries

- KNP, within which the majority of the project area is located. Within the project area, KNP is characterised by two key zones: upper slopes and inverted treelines in the west of the project area (referred to as the 'ravine') and associated subalpine treeless flats and valleys in the east of the project area (referred to as the 'plateau'), and

- farm land southeast of KNP at Rock Forest.

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

1.2.2 Commissioning modelling study area

The study area for the commissioning modelling assessment includes the Talbingo and Tantangara Reservoirs. Specifically, the modelling assessment is focussed on the following study areas:

- Snowy 2.0 intake structure on the Yarrangobilly Arm of Talbingo Reservoir

- Ravine Bay placement area at Talbingo Reservoir
- Snowy 2.0 intake structure on the western shoreline of Tantangara Reservoir, and
- Tantangara dry (above Minimum Operating Level (MOL)) placement area.

1.3 Proponent

Snowy Hydro is the proponent for the Snowy 2.0 Main Works. Snowy Hydro is an integrated energy business – generating energy, providing price risk management products for wholesale customers and delivering energy to homes and businesses. Snowy Hydro is the fourth largest energy retailer in the NEM and is Australia's leading provider of peak, renewable energy.

1.4 Purpose of report

This **Reservoir Modelling – Commissioning Phase Operations Report** supports the EIS for the Snowy 2.0 Main Works. This report details:

- the results of the modelling and shows the effects of commissioning flows[1] (generation/pumping) on currents (speed of water) and sediment transport potential (bed shear stress), in proximity to the Ravine Bay placement area and the intake-outlet structures, and
- the potential for disturbance of sediment within Talbingo Reservoir and Tantangara Reservoir during commissioning of Snowy 2.0 and the potential management solutions to address sediment disturbance.

There are two families of sediments to consider; fine excavated rock (sediment) that has settled away from the placement area during the construction phase, and existing (*in situ*) sediments within the reservoir. The outer face of the emplacement areas may also be considered to be sediment, albeit of a large particle size. The primary areas of interest in the reservoirs are around the intake structures, where velocities will be greatest.

The specific objectives of this assessment are to:

- identify the relevant sediment locations, properties and quantities in Talbingo Reservoir and Tantangara Reservoir
- identify flow scenarios for Snowy 2.0 commissioning to assess the potential for bed sediment disturbance[2]
- undertake hydrodynamic modelling of commissioning flow scenarios to assess the potential for disturbance of sediments, and
- undertake a conceptual desktop study to identify engineering solutions to mitigate issues and risks due to sediment disturbance without impacting on the operation or maintenance of facilities.

The report has been prepared on the basis that the reader has a good knowledge of Talbingo Reservoir and Tantangara Reservoir and the Snowy 2.0 project.

1.4.1 Assessment guidelines and requirements

This modelling assessment has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for Snowy 2.0 Main Works, issued on 31 July 2019, as well as

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[1] *To occur over a period of approximately 2 years following construction of Snowy 2.0*

[2] *In the current study, flow scenarios were restricted to a constant flow associated with power generation (flow from Tantangara Reservoir to Talbingo Reservoir),and a constant flow associated with pumping (flow from Talbingo Reservoir to Tantangara Reservoir) each over a period of several days.*

relevant government assessment requirements, guidelines and policies, and in consultation with the relevant government agencies. The SEARs must be addressed in the EIS.

Table 1-1 lists the matters relevant to this assessment and where they are addressed in this report.

Table 1-1: Relevant matters raised in SEARs

Requirement	Section Addressed
A description of the likely changes to the hydrological regime of the existing water storages of the Snowy Hydro Scheme up to the authorised full supply level, and any associated biodiversity impacts.	Impacts on the hydrological regime, specifically changes to current speeds and resultant sediment transport potential, with consideration of the commissioning of Snowy 2.0 is presented in **Section 3**.
An assessment of the impacts of the project on: • the quantity and quality of the region's surface and ground water resources, including Yarrangobilly River, Wallaces Creek, and the Tantangara and Talbingo Reservoirs, and • a strategy to manage the emplacement of excavated rock in the Tantangara and Talbingo Reservoir and enhance any new landforms created.	Assessment of potential disturbance of sediments presented in **Section 5** and identification of solutions to mitigate issues and risks due to sediment disturbance presented in **Section 6**.

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

1.5 Related projects

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

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

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

2 Description of the project

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

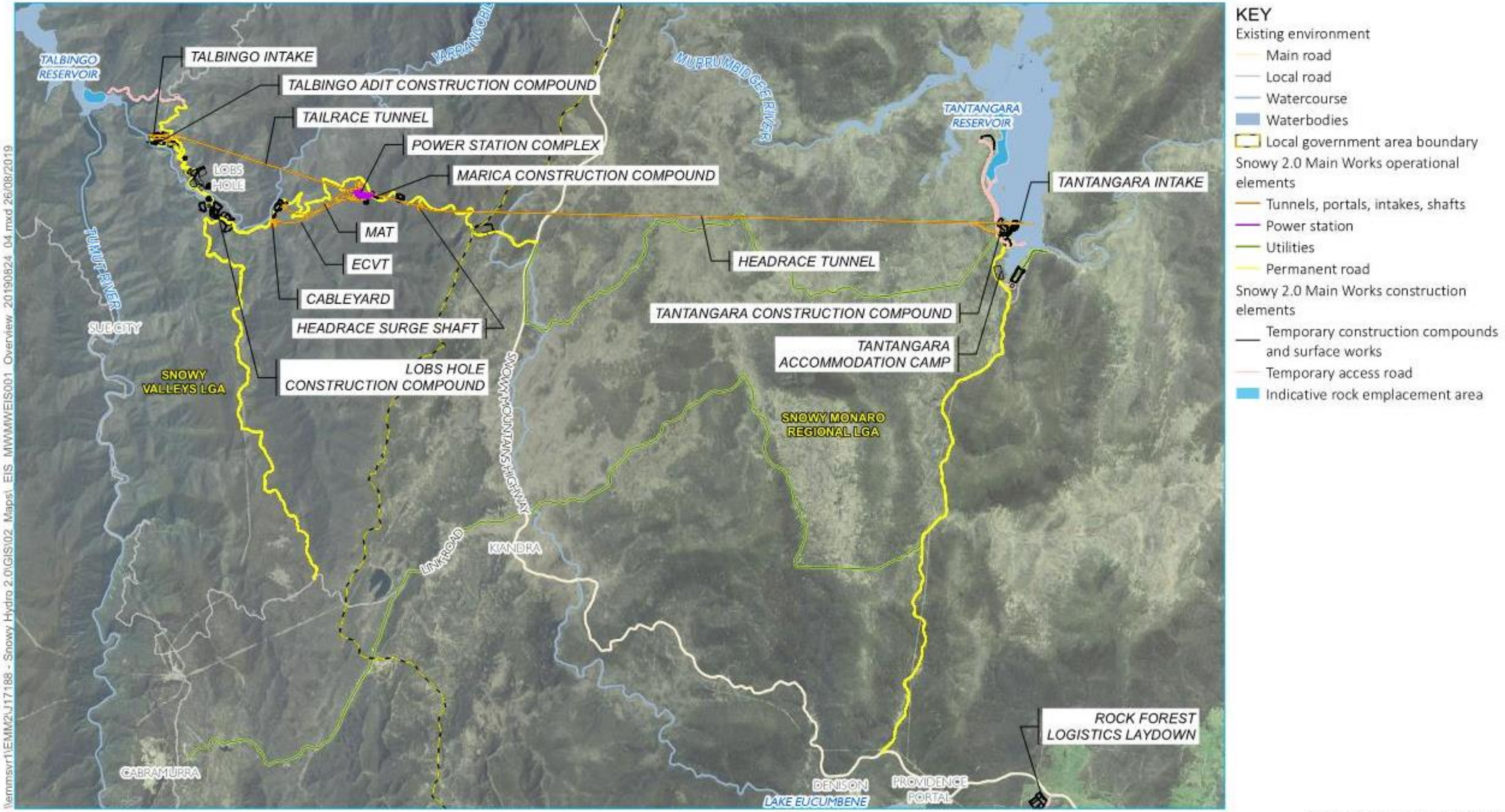
2.1 Overview of Snowy 2.0

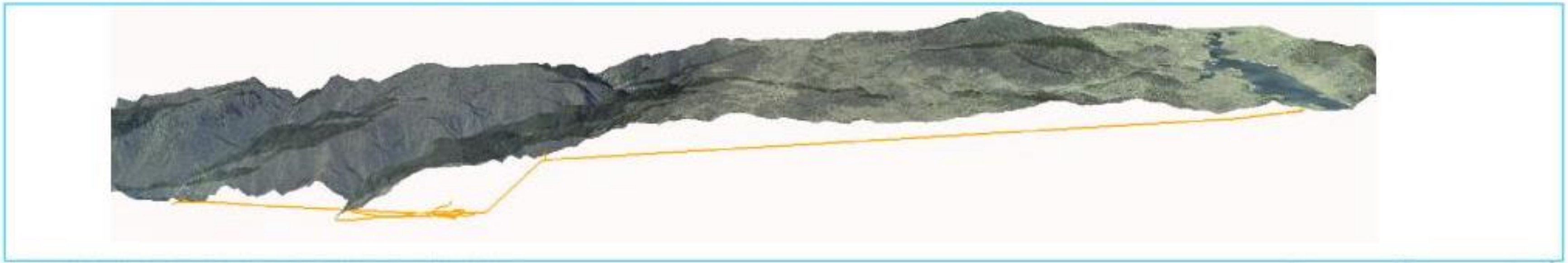
Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground.
An overview of Snowy 2.0 is shown on **Figure 2-1**, and the key project elements of Snowy 2.0 are summarised in **Table 2-1**.

Table 2-1: Overview of Snowy 2.0 Main Works

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

Project Element	Summary of the project
Disturbance area	The disturbance area is the extent of construction works required to build Snowy 2.0. The maximum disturbance area is about 1 680 hectares (ha), less than 0.25% of the total area of KNP. Parts of the disturbance area will be rehabilitated, and landformed and other parts will be retained permanently for operation (operational footprint).
Operational footprint	The operational footprint is the area required for permanent infrastructure to operate Snowy 2.0. The maximum operational footprint is about 99 ha. This is 0.01% of the total area of KNP.
Tunnelling and excavation method	The primary tunnelling method for the power waterway is by tunnel boring machine (TBM), with portals and adits using drill and blast methods. Excavation for other underground caverns, chambers and shafts will be via combinations of drill and blast, blind sink, and/or raise bore techniques.
Excavated rock management	Excavated rock will be generated as a result of tunnelling activities and earthworks. The material produced through these activities will be stockpiled and either reused by the contractor (or NPWS), placed permanently within Tantangara or Talbingo reservoirs, used in final land forming and rehabilitation of construction pads in Lobs Hole, or transported offsite.
Construction water and wastewater management	Water supply for construction will be from the two existing reservoirs (Talbingo and Tantangara) and reticulated via buried pipelines (along access roads). Raw water will be treated as necessary wherever potable water is required (e.g. at accommodation camps). Water to be discharged (comprising process water, wastewater and stormwater) will be treated before discharge to the two existing reservoirs (Talbingo and Tantangara) as follows: • treated process water will be reused onsite where possible to reduce the amount of discharge to reservoirs, however excess treated water will be discharged to the reservoirs. • collected sewage will be treated at sewage treatment plants to meet the specified discharge limits before discharge and/or disposal, and • stormwater will be captured and reused as much as possible.
Rehabilitation	Rehabilitation of areas disturbed during construction including reshaping to natural appearing landforms or returning to pre-disturbance condition, as agreed with NPWS and determined by the rehabilitation strategy. This includes construction areas at Lobs Hole which comprise surplus cut materials that are required for the construction. Areas to be used by Snowy Hydro in the long-term may be re-shaped and rehabilitated to maintain access and operational capabilities (e.g. intakes and portal entrances).
Construction workforce	The construction workforce for the project is expected to peak at around 2 000 personnel.
Operational life	The operational life of the project is estimated to be 100 years.
Operational workforce	The operational workforce is expected to be 8-16 staff, with fluctuations of additional workforce required during major maintenance activities.
Hours of operation	Construction of Snowy 2.0 will be 24/7 and 365 days per year. Operation of Snowy 2.0 will be 24/7 and 365 days per year.
Capital investment value	Estimated to be $4.6 billion.





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

Snowy 2.0 project elements

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.1

2.2 Construction of Snowy 2.0

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

Table 2-2: Snowy 2.0 construction elements

Construction Element	Purpose	Location
Construction sites	Due to the remoteness of Snowy 2.0, construction sites are generally needed to: • Provide ancillary facilities such as concrete batching plants, mixing plants and on-site manufacturing • Store machinery, equipment and materials to be used in construction • Provide access to underground construction sites, and • Provide onsite accommodation for the construction workforce.	Each construction site needed for Snowy 2.0 is shown on **Figure 2-2** to **Figure 2-6**.
Substations and power connection	One substation is required to provide permanent power to Snowy 2.0, at Lobs Hole. This substation will be built as part of Exploratory Works with a capacity of 80 mega volt amp (MVA). It will continue to be used for Main Works, however requires the establishment of further power supply cables to provide power to the work sites and TBM at Tantangara, as well as Talbingo, in particular to power the TBMs via the MAT, ECVT, Talbingo and Tantangara portals.	The supporting high voltage cable route mostly follows access roads to each of the work sites, using a combination of aerial and buried arrangements.
Communications system	Communications infrastructure will connect infrastructure at Tantangara and Talbingo reservoirs to the existing communications system at the T3 power station (via the submarine communications cable in Talbingo Reservoir established during Exploratory Works) and to Snowy Hydro's existing communications infrastructure at Cabramurra.	The cable will be trenched and buried in conduits within access roads. Crossing of watercourses and other environmentally sensitive areas will be carried out in a manner that minimises environmental impacts where possible, such as bridging or underboring.
Water and waste water servicing	Drinking water will be provided via water treatment plants located at accommodation camps. Water for treatment will be sourced from the nearest reservoir. There are three main wastewater streams that require some form of treatment before discharging to the environment, including: • Tunnel seepage and construction wastewater (process water)	Utility pipelines generally follow access roads. Water treatment plants (drinking water) will be needed for the accommodation camps and will be located in proximity. Waste water treatment plants will similarly be located near accommodation camps.

Construction Element	Purpose	Location
	- Domestic sewer (wastewater), and - Construction site stormwater (stormwater).	Process water treatment plants will be at construction compounds and adits where needed to manage tunnel seepage and water during construction.
Temporary and permanent access roads	Access road works are required to: - provide for the transport of excavated material between the tunnel portals and the excavated rock emplacement areas - accommodate the transport of oversized loads as required, and - facilitate the safe movement of plant, equipment, materials and construction workers into and out of construction sites. The access road upgrades and establishment requirements are shown on **Figure 2-2** to **Figure 2-6**. These roads will be used throughout construction including use of deliveries to and from site and the external road network. Some additional temporary roads will also be required within the footprint to reach excavation fronts such as various elevations of the intakes excavation or higher benches along the permanent roads.	The access road upgrades and establishment requirements are shown across the project area. Main access and haulage to site will be via Snowy Mountains Highway, Link Road and Lobs Hole Ravine Road (for access to Lobs Hole), and via Snowy Mountains Highway and Tantangara Road (for access to Tantangara Reservoir) (see **Figure 2-1**).
Excavated rock management	Approximately 9 million m^3 (unbulked) of excavated material will be generated by construction and require management. The strategy for management of excavated rock will aim to maximise beneficial reuse of materials for construction activities. Beneficial re-use of excavated material may include use for road base, construction pad establishment, selected fill and tunnel backfill and rock armour as part of site establishment for construction. Excess excavated material that cannot be re-used during construction will be disposed of within Talbingo and Tantangara reservoirs, used in permanent rehabilitation of construction pads to be left in situ in Lobs Hole, or transported for on-land disposal if required.	Placement areas are shown on **Figure 2-2** and **Figure 2-6**.
Barge launch facilities	Barge launch facilities on Talbingo Reservoir will have already been established during Exploratory Works for the placement of the submarine communications cable, and will continued to be used for Main Works for construction works associated with the Talbingo intake structure. The Main Works will require the establishment of	Barge launch sites are shown on **Figure 2-2** and **Figure 2-6**.

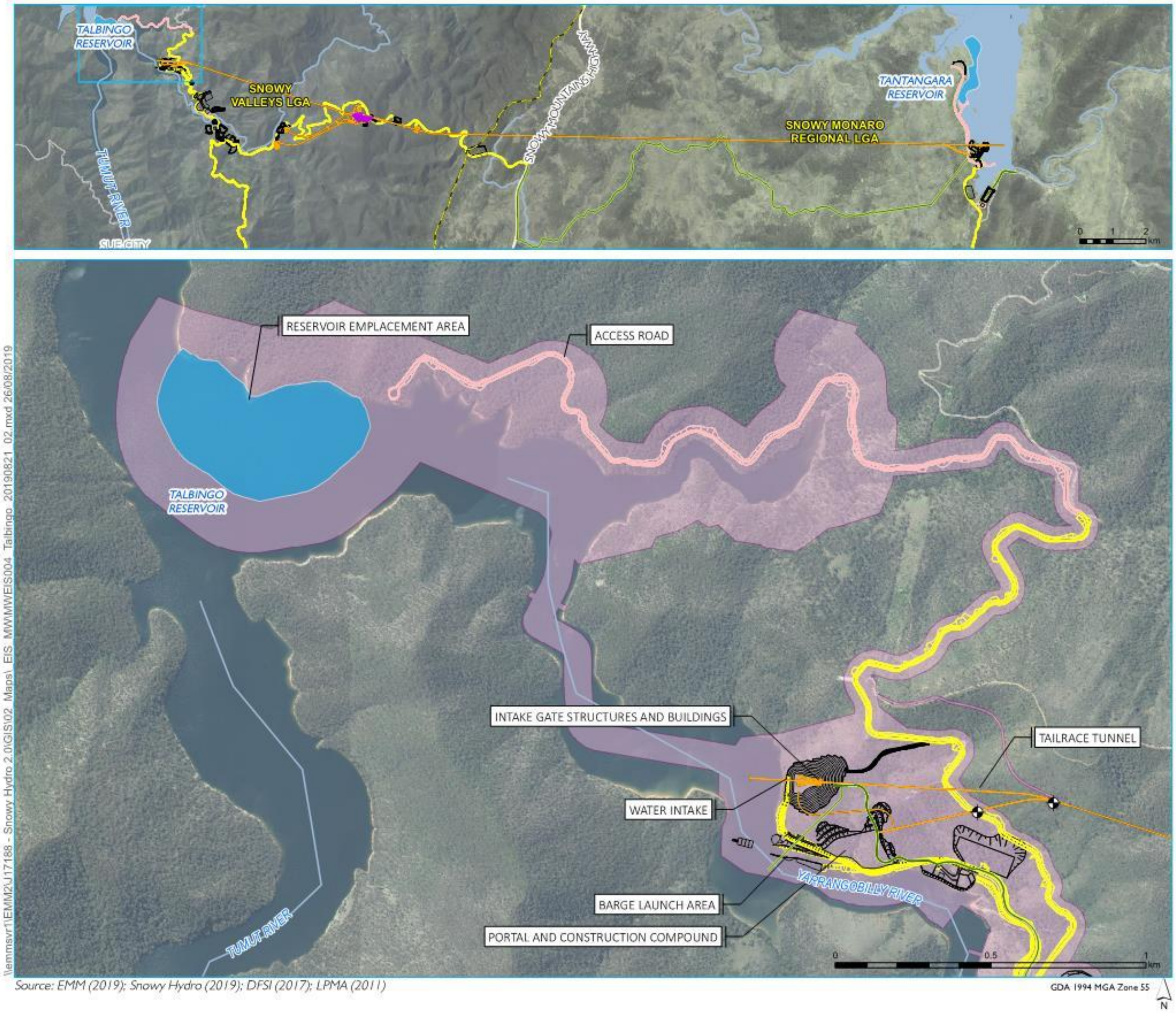
Construction Element	Purpose	Location
	barge launch facilities on Tantangara Reservoir to enable these similar works (removal of the intake plug).	
Construction workforce	The construction workforce will be accommodated entirely on site, typically with a FIFO/DIDO roster. Private vehicles will generally not be permitted and the workforce bused to and from site.	Access to site will be via Snowy Mountains Highway.

The key areas of construction are shown on **Figure 2-2** to **Figure 2-6** and can be described across the following locations:

- **Talbingo Reservoi**r – Talbingo Reservoir provides the lower reservoir for the pumped hydro-electric project and will include the tailrace tunnel and water intake structure. The site will also be used for temporary construction compounds and other temporary ancillary activities.
- **Lobs Hole** – this site will be used primarily for construction (including construction of the MAT and ECVT portals and tunnels to the underground power station and the headrace tunnel (and headrace tunnel surge shaft), underground tailrace surge shaft and a temporary accommodation camp).
- **Marica** – the site will be used primarily for construction to excavate the ventilation shaft to the underground power station as well as for the excavation and construction of the headrace surge shaft.
- **Plateau** – the land area between Snowy Mountains Highway and Tantangara Reservoir is referred to as the Plateau. The Plateau will be used to access and construct a utility corridor and construct a fish weir on Tantangara Creek.
- **Tantangara Reservoir** – Tantangara Reservoir will be the upper reservoir for the pumped hydro project and include the headrace tunnel and intake structure. The site will also be used for a temporary construction compound, accommodation camp and other temporary ancillary activities.
- **Rock Forest** – a site to be used temporarily for logistics and staging during construction. It is located beyond the KNP along the Snowy Mountains Highway about 3 km east of Providence Portal.

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

A key construction element for the project is the excavation and tunnelling for underground infrastructure including the power station, power waterway (headrace and tailrace tunnels) and associated shafts. The primary methods of excavation are shown in **Figure 2-8** with further detail on construction methods provided at Appendix D of the EIS.



KEY

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

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

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

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

Talbingo Reservoir - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.2

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

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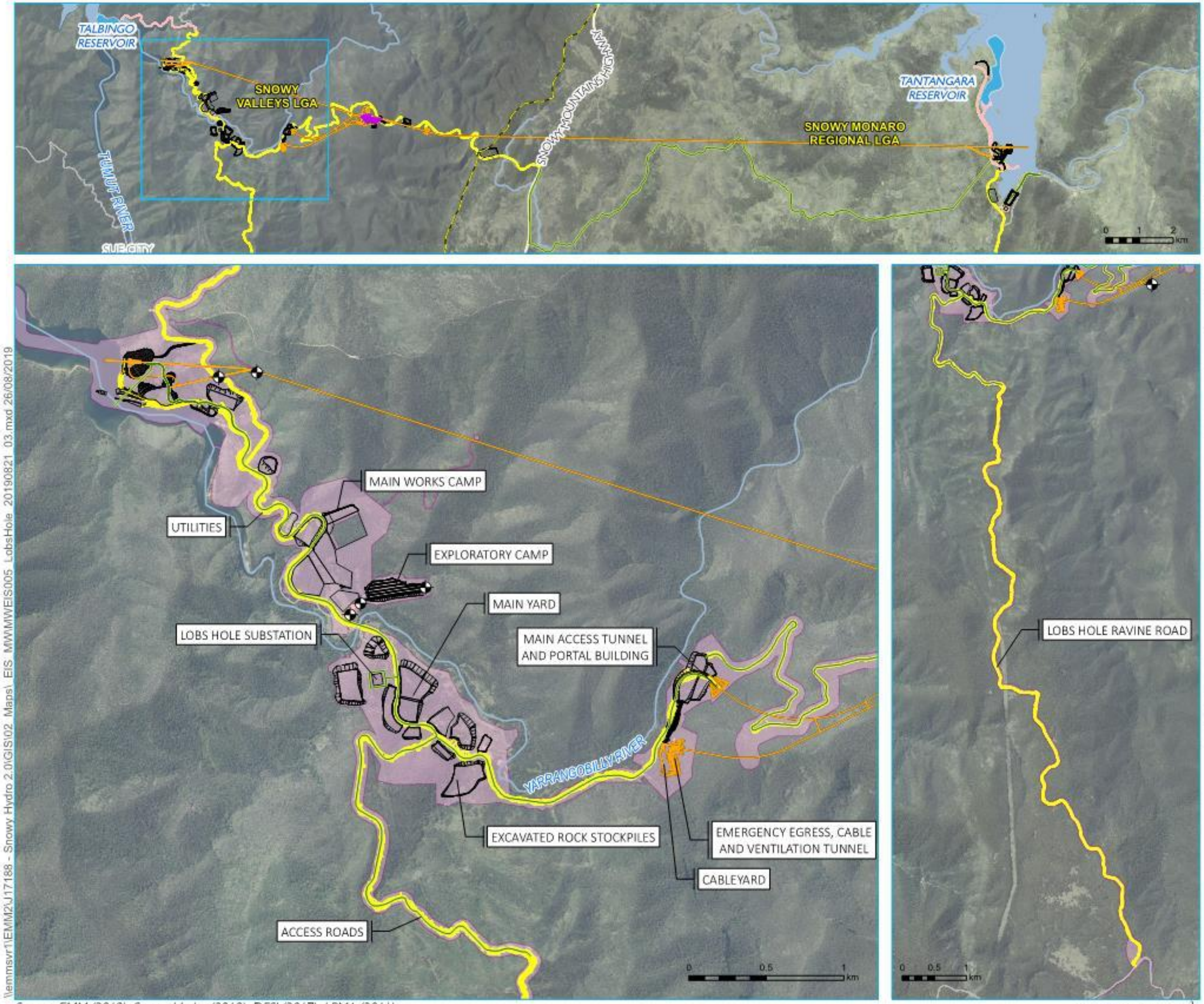

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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

Existing environment

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

Snowy 2.0 Main Works operational elements

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

Snowy 2.0 Main Works construction elements

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

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

Lobs Hole - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.3

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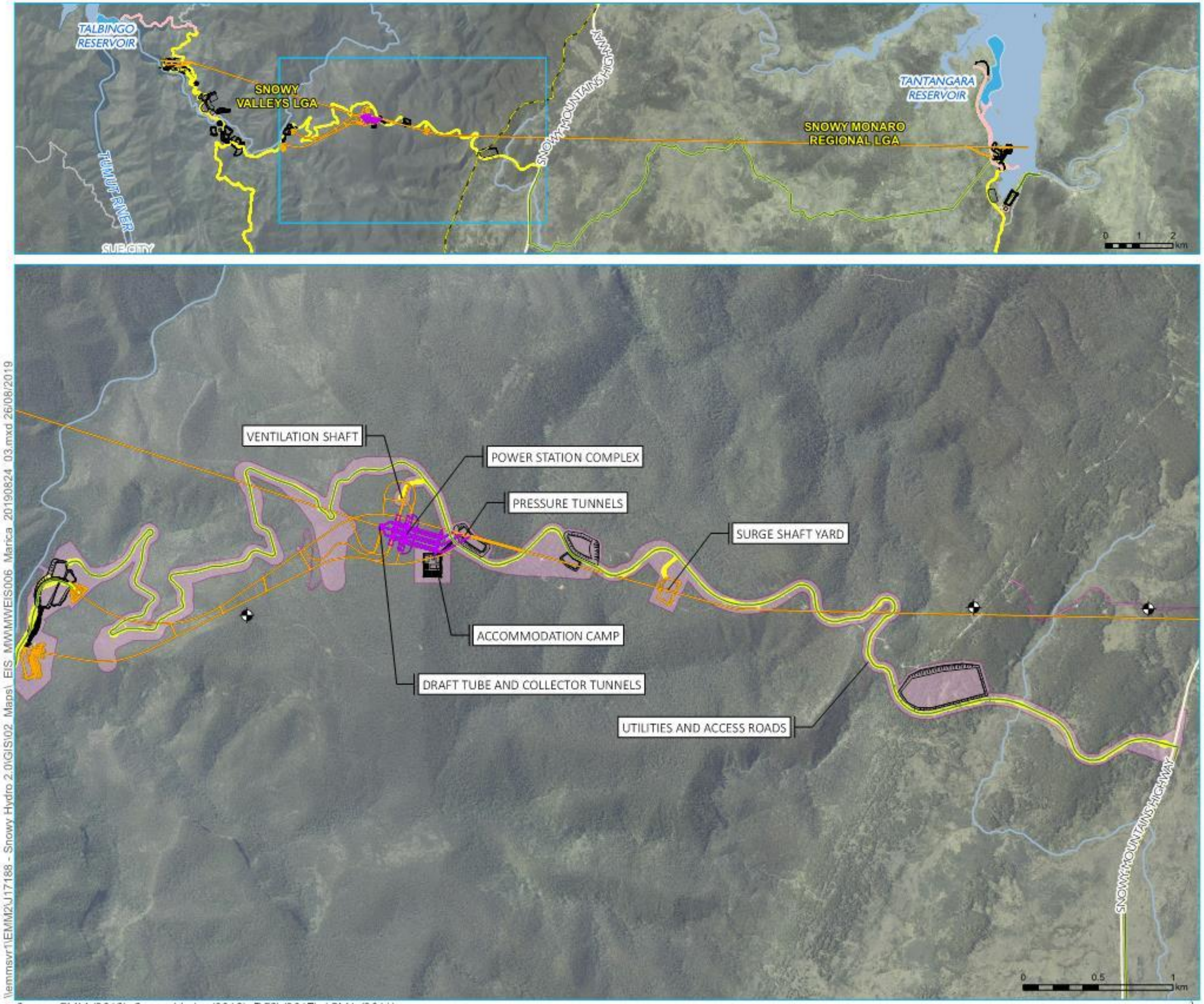
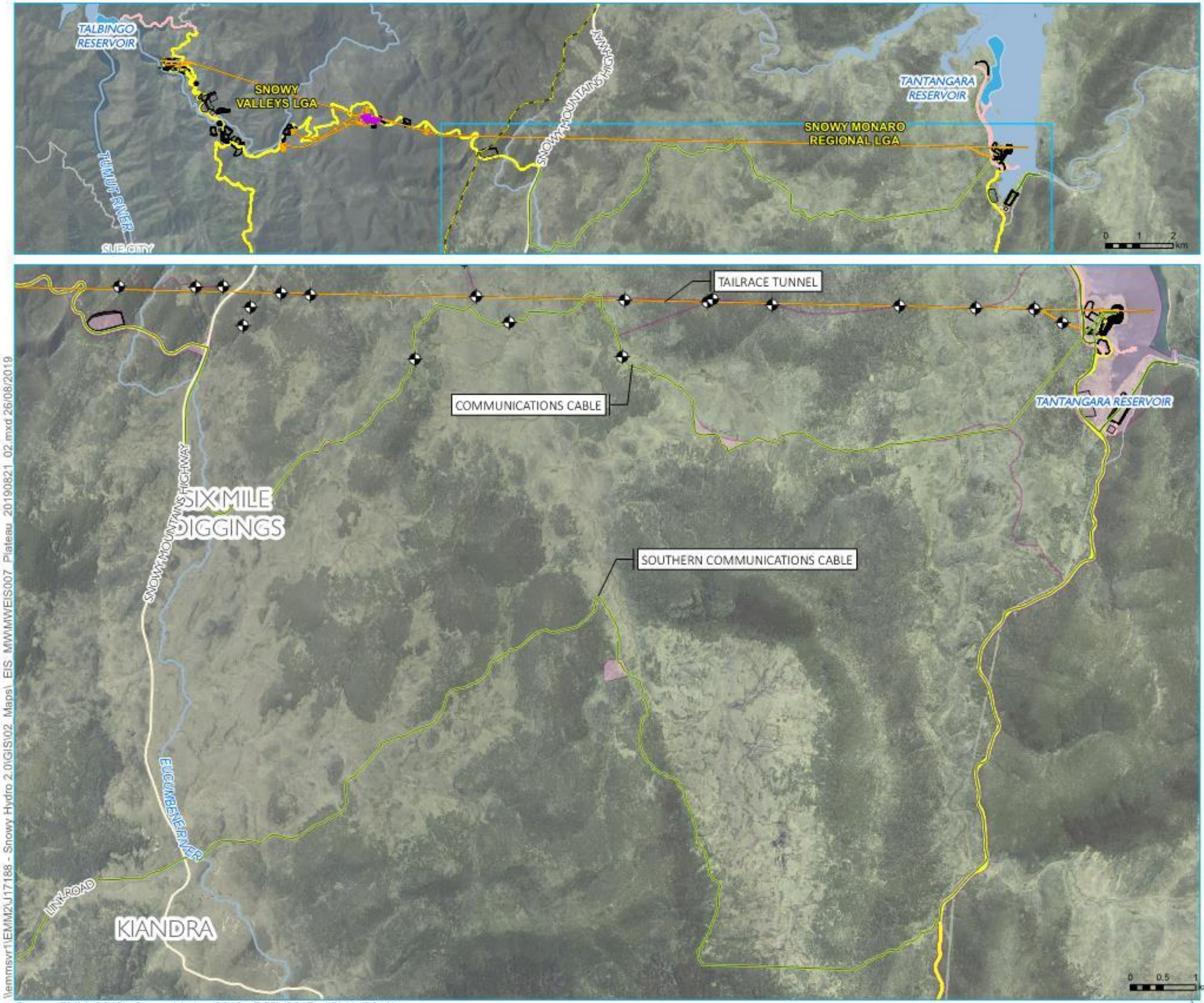


Note: the disturbance area is the extent of construction works required to build Snowy 2.0. It has been identified to allow an assessment of impacts for the EIS, and represents a defined maximum extent where construction works will be carried out. The area will be minimised as much as possible during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

Marica - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.4

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



KEY

Existing environment

- — Main road
- — Local road
- — Watercourse
- ▨ Waterbodies
- ☐ Local government area boundary

Snowy 2.0 Main Works operational elements

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

Snowy 2.0 Main Works construction elements

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

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

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

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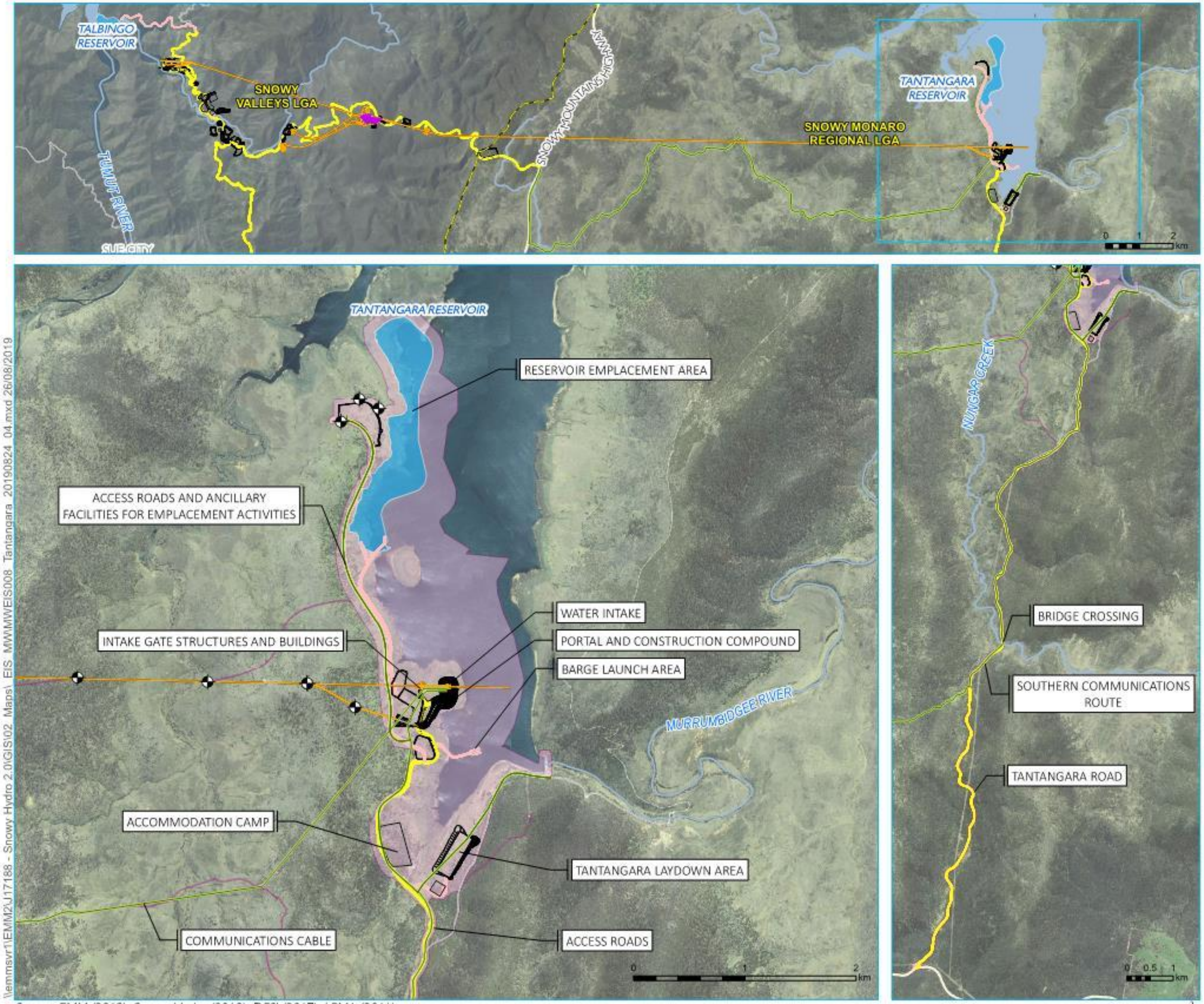
Plateau - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.5

snowy 2.0

EMM
creating opportunities



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

GDA 1994 MGA Zone 55

KEY

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

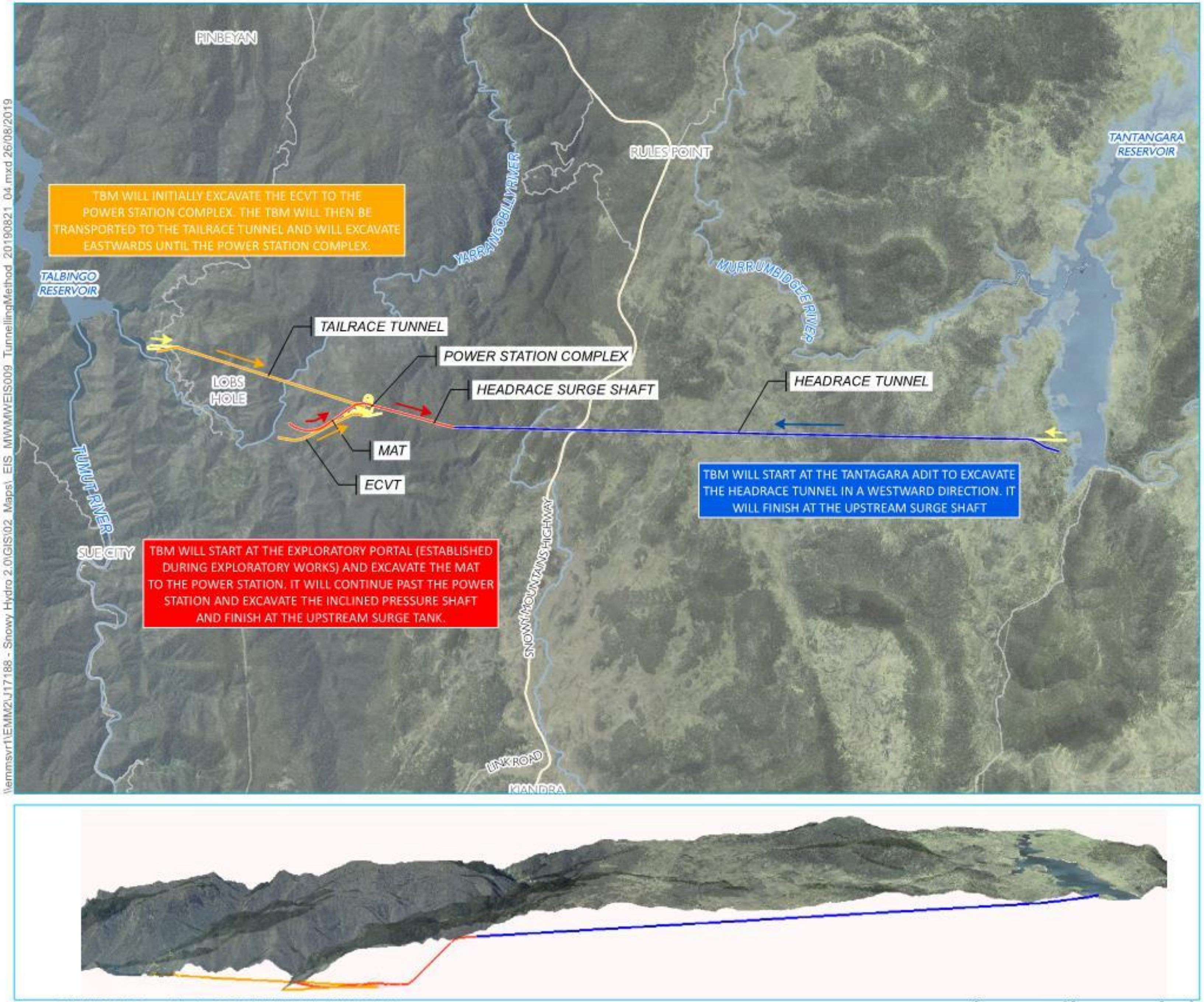
Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

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

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

Tantangara Reservoir - project elements, purpose and description

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.6



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

KEY

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

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

Primary excavation methods – drill and blast and tunnel boring machine

Snowy 2.0
Reservoir assessment overview
Main Works
Figure 2.8

snowy 2.0

EMM
creating opportunities

2.3 Operation of Snowy 2.0

2.3.1 Scheme operation and reservoir management

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

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

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

Talbingo Reservoir currently has the following operational functions:

- Collects releases from Tumut 2 (T2) power station
- Collects releases from the Yarrangobilly and Tumut rivers
- Acts as head storage for water pumped up from Jounama Pondage, and
- Acts as head storage for generation at the T3 power station.

Due to its historic relationship to both the upstream the T2 power station and downstream T3 power station, Talbingo Reservoir has had more operational functions than Tantangara Reservoir in the current Snowy Scheme.

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

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

2.3.2 Permanent access

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

2.3.3 Maintenance requirements

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

- maintenance of equipment and systems within the power station complex, intake structures, gates and control buildings

- maintenance of access roads (vegetation clearing, pavement works, snow clearing)
- dewatering of the tailrace and headrace tunnel (estimated at once every 15 to 50 years, or as required), and
- maintenance of electricity infrastructure (cables, cable yard, cable tunnel).

2.3.4 Rehabilitation and final land use

A Rehabilitation Strategy has been prepared for Snowy 2.0 Main Works and appended to the EIS. It is proposed that all areas not retained for permanent infrastructure will be revegetated and rehabilitated. At Lobs Hole, final landform design and planning has been undertaken to identify opportunities for the reuse of excavated material in rehabilitation to provide landforms which complement the surrounding topography in the KNP.

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

2.4 Proposed and alternative placement methods

Proposed and alternative placement methods were identified for Snowy 2.0, which need to be considered as part of the commissioning operation modelling. Construction of the following excavated rock placement options in Talbingo Reservoir were assessed in RHDHV (2019a):

i) Ravine Bay Placement design, and
ii) alternative Hybrid Placement design.

All excavated rock placement at Tantangara Reservoir will occur in the dry. Further details of placement methods relevant to the commissioning modelling are summarised below.

2.4.1 Talbingo Reservoir

Ravine Bay Placement

Placement of excavated rock in Talbingo Reservoir involves pushing excavated rock from shorelines into the reservoir by conventional earth-moving plant, such as dump trucks and excavators, and installing a rock armour layer formed by large size spoils (>200 mm) on emplacement slope batter. Placement of excavated rock in Talbingo Reservoir will be carried out in stages when a surplus quantity of excavated rock from construction activities becomes available.

The footprint of excavated rock emplacement versus time are determined from the quantity of excavated rock available for placement during construction. The total (bank) volume of excavated rock to be placed in Talbingo Reservoir for the Ravine Bay Placement design is approximately 2.8 Mm^3 (bank). The proposed finished excavated rock footprint and cross section are shown on **Figure 2-9**.

Alternative Hybrid (D&B Only to Reservoir) Placement

An alternative “Hybrid” excavated rock placement methodology has also been assessed in which only drill and blast (D&B) excavated rock is placed in Talbingo Reservoir with land placement being used for all tunnel boring machine (TBM) material. In this scenario is assumed that 1.4 Mm^3 (bank) of excavated D&B rock would be placed in the reservoir using the Ravine Bay Placement method that was presented in the section above. The placement period is assumed to be 27 months, at an average placement rate of 1 750 m^3/day. The resultant Ravine Bay placement footprint would be less than that defined in **Section 2.4.1**.

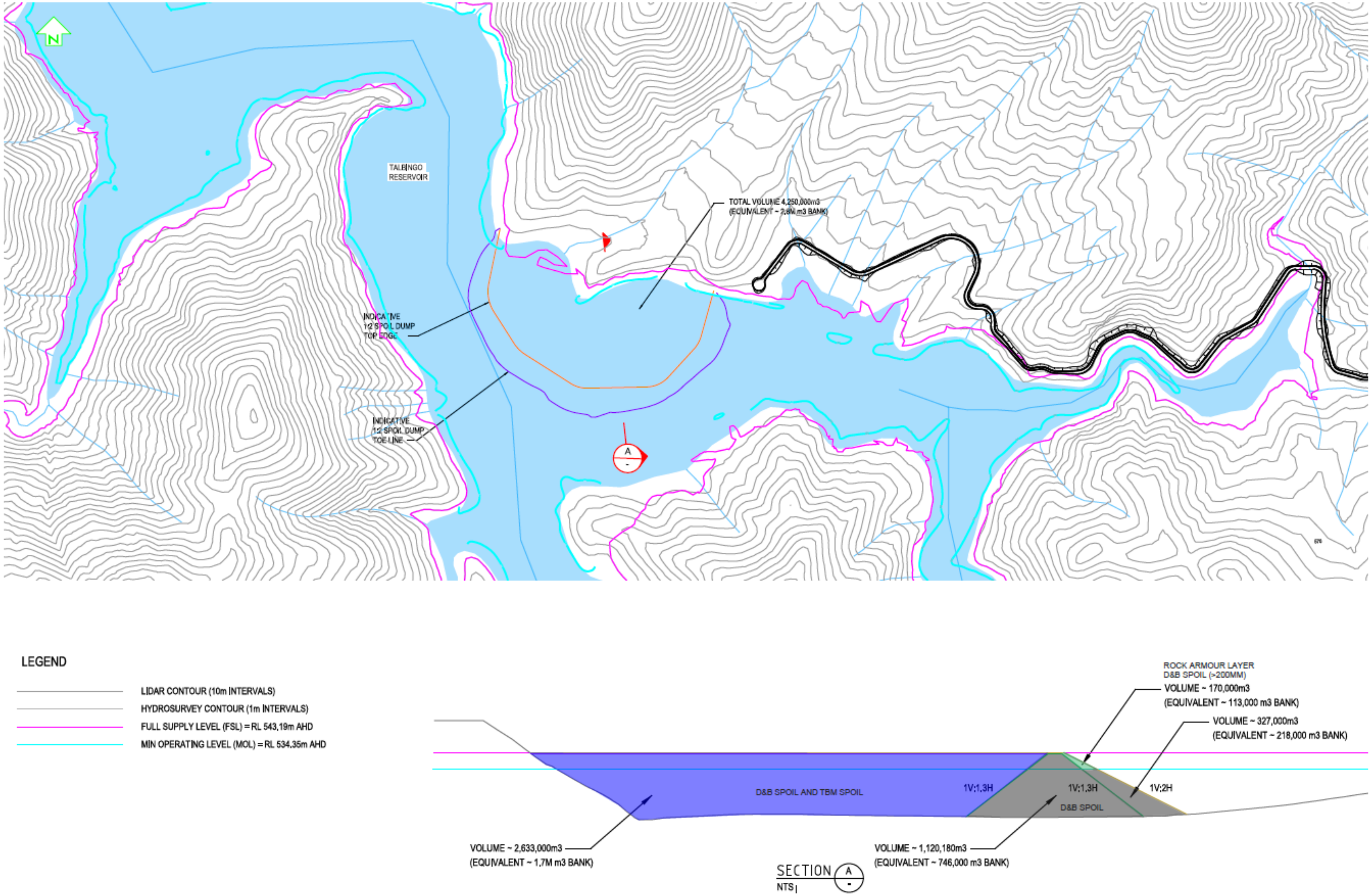

Figure 2-9: Talbingo–excavated rock footprint and section for Ravine Bay Placement method

2.4.2 Tantangara Reservoir

Dry Placement Above MOL

Placement of excavated rock in Tantangara Reservoir would involve staged placement in active storage areas of the reservoir by conventional earth-moving plant, such as dump trucks and excavators. Placement of excavated rock in Tantangara will be carried out in stages from the boundary of FSL towards the active storage areas of the reservoir. To minimize the disturbed areas and unprotected excavated rock emplacement slope surface, staged containment cells will be constructed. The final level for the placed material will be above FSL to ensure that permanent rehabilitation can occur.

In summary, the total volume of approximately 2.6 Mm^3 (bank) of material will be placed in the Tantangara Reservoir emplacement. The final excavated rock emplacement footprint (shaded blue) is shown in **Figure 2-10**.

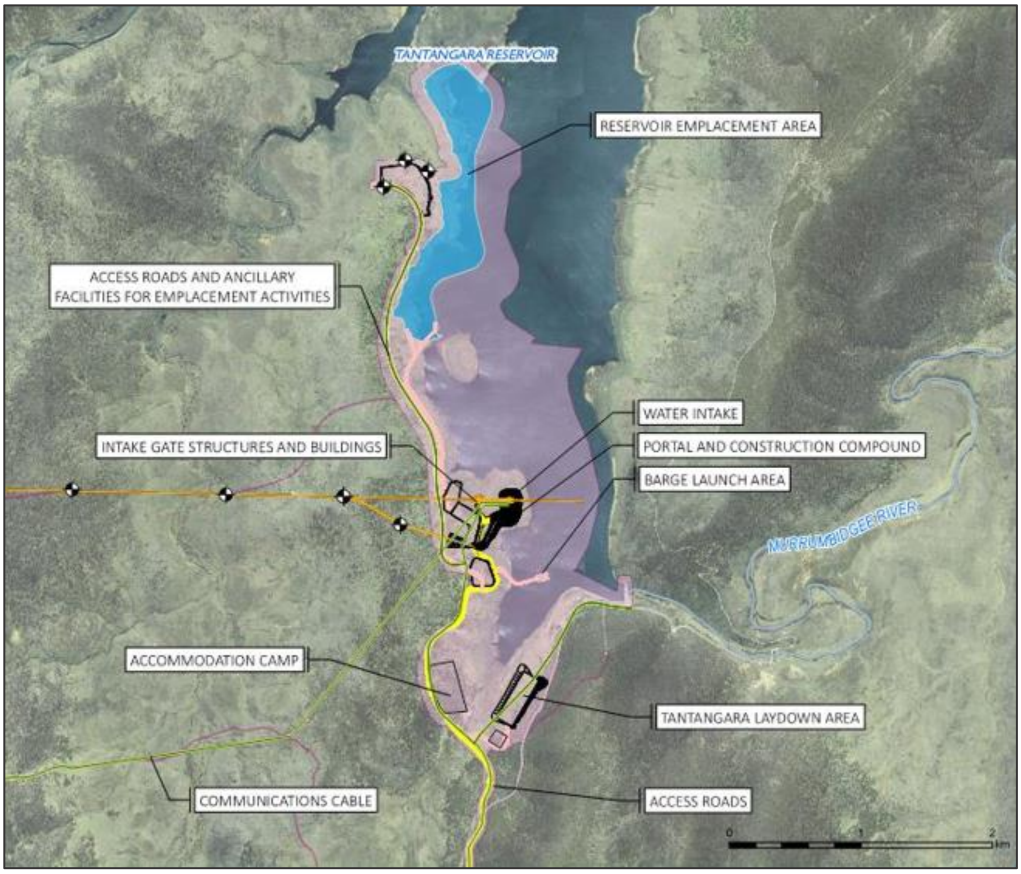

Figure 2-10: Tantangara Reservoir – excavated rock emplacement footprint

2.5 Snowy 2.0 intake-outlet structures

Intake-outlet structures are required for Snowy 2.0 to enable water to be transferred between Talbingo and Tantangara reservoirs. The intake-outlet structures are where water is either pumped from (intake) or discharged into (outlet) the reservoirs. Depending on the mode of operation (pumping or generation) and the end of the pumped hydro system (Talbingo or Tantangara reservoir), the structure may behave as either an intake (to draw flow into) or an outlet (to discharge from) the pumped hydro system.

3 Sediment locations, properties and quantities

3.1 Existing reservoir sediments

3.1.1 General

A sediment sampling and testing exercise was carried out by RHDHV in Talbingo Reservoir and Tantangara Reservoir to assess the physical properties of the existing sediments and the thickness of sediment layers. Sediments were collected using coring techniques (piston corer, gravity driven piston corer, and medium weight vibrocorer). A separate report has been prepared for that sampling and testing exercise, RHDHV (2019) *Sediment Sampling Investigation Operational Scenario Assessment, Talbingo and Tantangara Reservoirs* (**Annexure A** of the Water Assessment Report (**EIS Appendix J**)).

In Tantangara Reservoir, relevant information on sediments is also available from a borehole (BH 1114) drilled in the footprint of the inlet channel.

3.1.2 Talbingo Reservoir

The sediment core locations in Talbingo Reservoir are shown in Drawing S2-RHD-TAL-SKE-1400 Rev A (refer **Attachment A**). A total of four sediment strata, of different origin, were identified:

- **lacustrine (reservoir) deposits** – unconsolidated surface material deposited in standing water such as a reservoir
- **topsoil** – formed prior to reservoir construction, typically exhibiting some organic accumulation and darker and more fertile than underlying layers
- **alluvial deposits** – formed by flowing water, prior to reservoir construction, and
- **residual soil** – *in situ* weathering of parent rock to form a soil profile that has experienced minimal lateral movement.

Bedrock was also encountered at numerous locations including TAL03, TAL03a, TAL04, TAL08 and TAL20.

The recorded thicknesses of the four recovered sediment strata, as measured in the cores, are listed in **Table 3-1**. Generally speaking, the overall depth of sediments was relatively shallow and did not exceed about 0.8 m. The available borehole data in the vicinity of the study area also suggests the overall sediment thickness is relatively shallow.

Table 3-1: Thickness of sediment strata at Talbingo Reservoir

Core ID	Thickness of Strata (m)				Shallow Bedrock	Core Loss (m)	Depth of Core Penetration (m)
	Lacustrine Deposit	Topsoil	Alluvial Deposit	Residual Soil			
TAL01	0.18		0.44				0.62
TAL02	0.24		0.08				0.32
TAL03					Yes	<0.10*	<0.10*
TAL03a					Yes	<0.20*	<0.20*
TAL04					Yes	<0.05*	<0.05*
TAL05	0.15			0.17		0.32	0.64
TAL06	0.25					Unknown	Unknown
TAL07		0.05		0.06		0.04	15
TAL08					Yes	Unknown	Unknown
TAL08a	0.01	0.09		0.02		0.12	0.24
TAL09		0.03		0.31			0.34
TAL10	0.30					Unknown	Unknown
TAL11	0.23		0.54				0.77
TAL13	0.04	0.07		0.56			0.67
TAL14	0.20					Unknown	Unknown
TAL15	0.17		0.65				0.82
TAL17				0.05			0.05
TAL20					Yes	~0.05*	~0.05*
TAL25				0.10			0.10
TAL26				0.05		0.30	0.35
TAL27		0.18				0.12	0.30

*estimated based on site observations of vessel's depth sounder, visual observations of surrounding geology and 'feel' of the coring equipment on the bottom of the reservoir.

A total of seven samples of lacustrine deposits, one sample of topsoil, four samples of alluvial deposits and five samples of residual soil were submitted for determination of particle size distribution (PSD). The average of the PSD is shown in **Figure 3-1**. The percentage of fines (silt plus clay) was around 90% for the lacustrine deposits (clay 40%) and around 40-50% for the other sediment types (clay 15-20%).

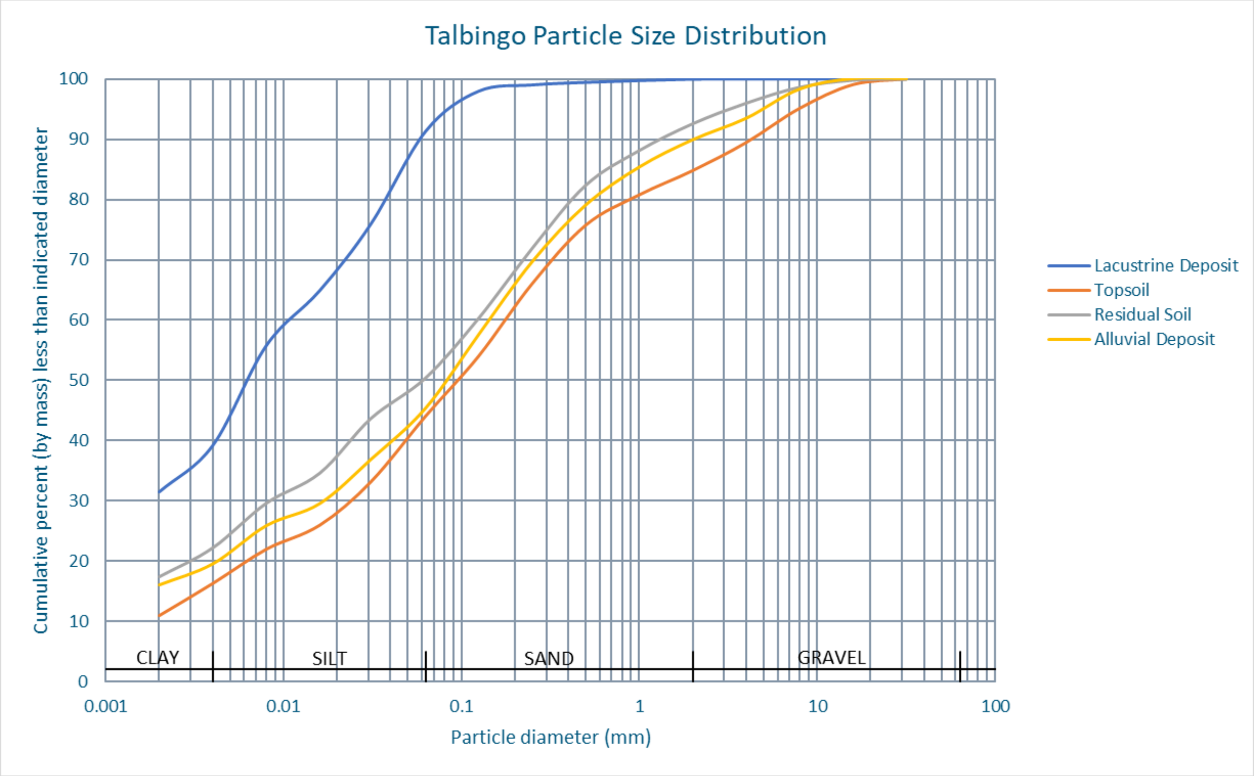

Figure 3-1: Average PSD for the sediment strata recovered at Talbingo Reservoir

3.1.3 Tantangara Reservoir

The core locations in Tantangara Reservoir are shown in Drawing S2-RHD-TAN-SKE-1400 Rev A (refer **Attachment A**). Similar to Talbingo Reservoir, a total of four sediment strata, of different origin, were identified:

- lacustrine (reservoir) deposits
- topsoil
- alluvial deposits, and
- residual soil.

The recorded thicknesses of the four recorded sediment strata, as measured in the cores, are listed in **Table 3-2**. The available borehole data (refer below) and observations of soil profiles in eroded embankments suggest that the thickness of the overall sediment/soil profile (particularly residual soil) is generally greater at Tantangara Reservoir compared to Talbingo Reservoir. The coring is expected to have refused on the residual soils and in places on gravels.

Table 3-2: Thickness of sediment strata at Tantangara Reservoir

Core ID	**Thickness of Strata (m)**				**Shallow Bedrock**	**Core Loss (m)**	**Depth of Core Penetration (m)**
	Lacustrine Deposit	Topsoil	Alluvial Deposit	Residual Soil			
TANT01	0.18	0.34					0.52
TANT01a	0.15	0.55					0.70
TANT01b	0.06	0.24					0.30
TANT02		0.30		0.25			0.55
TANT02a							
TANT03		0.30		0.10			0.40
TANT04					Yes	0.05*	
TANT05	0.10	0.42					0.52
TANT06	0.06	0.44					0.50
TANT07					Yes	0.05–0.10*	
TANT08	0.02		0.26	0.12			0.40
TANT09					Yes	<0.05*	
TANT10	0.08	0.47				0.30	0.85
TANT10a	0.05	0.85					0.90
TANT11d	0.06	0.39					0.45
TANT11s	0.02	0.33				0.10	0.45
TANT11sa	0.04	0.32		0.04			0.40
TANT13	0.13		0.73				0.86
TANT15	0.18	0.37					0.55
TANT16	0.06	0.39					0.45
TANT30					Yes	<0.05*	
TANT31	0.03	0.47					0.50

**estimated based on site observations of vessel's depth sounder, visual observations of surrounding geology and 'feel' of the coring equipment on the bottom of the reservoir.*

A total of seven samples of lacustrine deposits, 15 samples of topsoil, two samples of alluvial deposits and three samples of residual soil were submitted for determination of PSD. The average PSD are shown in **Figure 3-2**. The percentage fines (silt plus clay) was around 90% for the lacustrine deposits (clay 50%) and around 50-70% for the other sediment types (clay 10-30%).

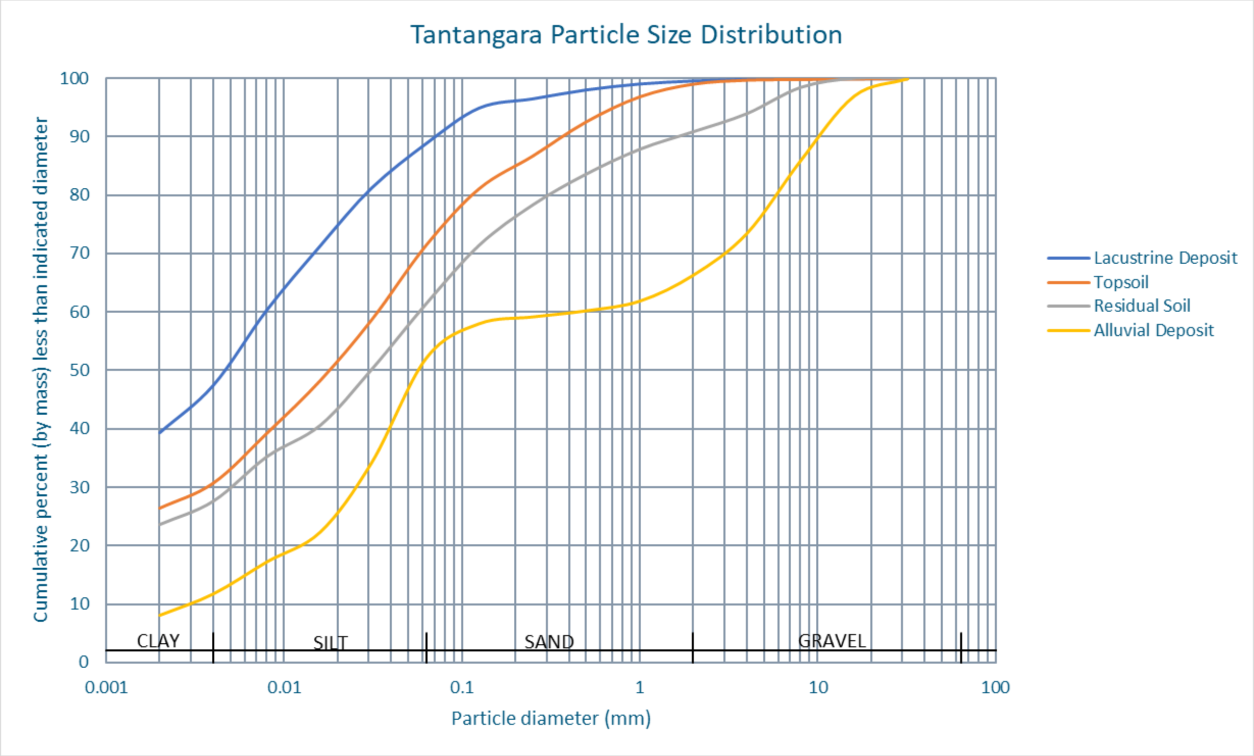

Figure 3-2: Average PSD for the sediment strata recovered at Tantangara Reservoir

Borehole BH 1114 was drilled in the footprint of the Tantangara inlet channel, as shown in Drawing S2-RHD-TAN-SKE-1400 Rev A (refer **Attachment A**). This borehole indicated a depth of 5.7 m of sediment/soil materials overlying weathered rock of thickness approximately 2 m, overlying bedrock. The surface sediment was a very soft dark grey clayey silt with a trace of organics and is likely to have comprised a combination of lacustrine deposits and topsoil. The soil profile with depth included interbedded firm to stiff clays and very soft to soft clays.

The borelog from BH 1114 is included in **Attachment B**.

3.2 Fine excavated rock

A proportion of the fines (silt plus clay) fraction of excavated rock placed subaqueously in Talbingo Reservoir during the construction phase migrates away from the placement area, settles out, and may be potentially disturbed (remobilised) during Snowy 2.0 commissioning and/or operations[3].

The results of hydrodynamic and sediment transport modelling carried out for the construction phase at Talbingo Reservoir for the two placement options presented in the EIS (Ravine Bay Placement and Hybrid Placement) includes the locations where these fine materials settle out and the thickness of the deposits. **Figure 3-3** and **Figure 3-4** show the results for Ravine Bay Placement and Hybrid Placement options respectively[4].

Figure 3-3 shows that a proportion of the fines settle out in Ravine Bay and Middle Bay outside the footprint of the Ravine Bay placement area at a thickness greater than 700 mm.

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[3] *Note that subaqueous placement of excavated rock at Tantangara Reservoir is not proposed.*

[4] *Ravine Bay Placement involves placement of rock excavated by both drill and blast (D&B) and tunnel boring machine (TBM) methods. Hybrid Placement involves placement of D&B material only and thus a reduced total amount of fines.*

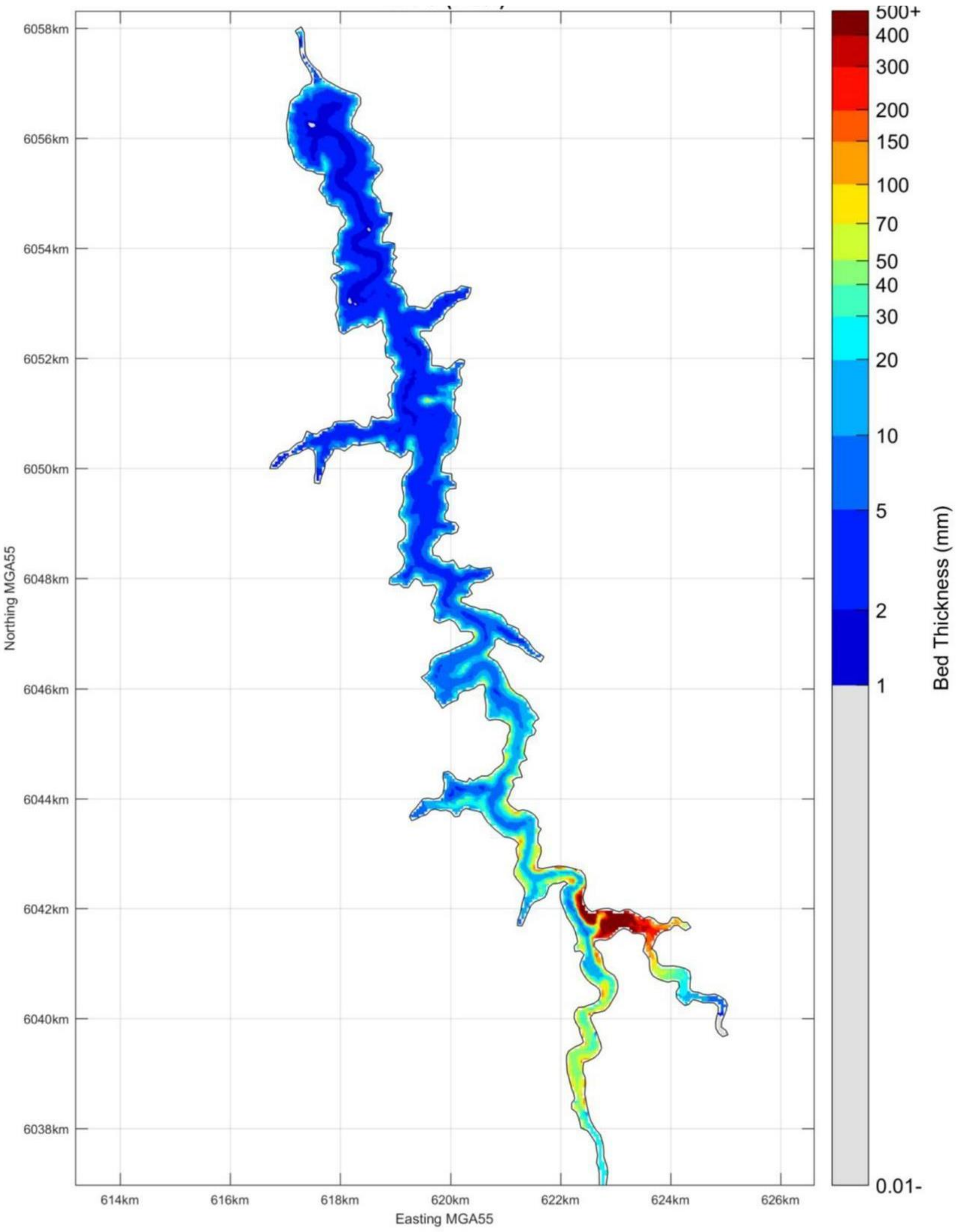

Figure 3-3: Deposition of fines for Ravine Bay Placement

Figure 3-4 shows that for Hybrid Placement, a proportion of the fines also settle out in Ravine Bay and Middle Bay outside the footprint of the Ravine Bay placement area, but less than for the Ravine Bay Placement option, due to the lesser total amount of fines introduced to the reservoir. The maximum thickness of the deposit is in the order of 200 mm.

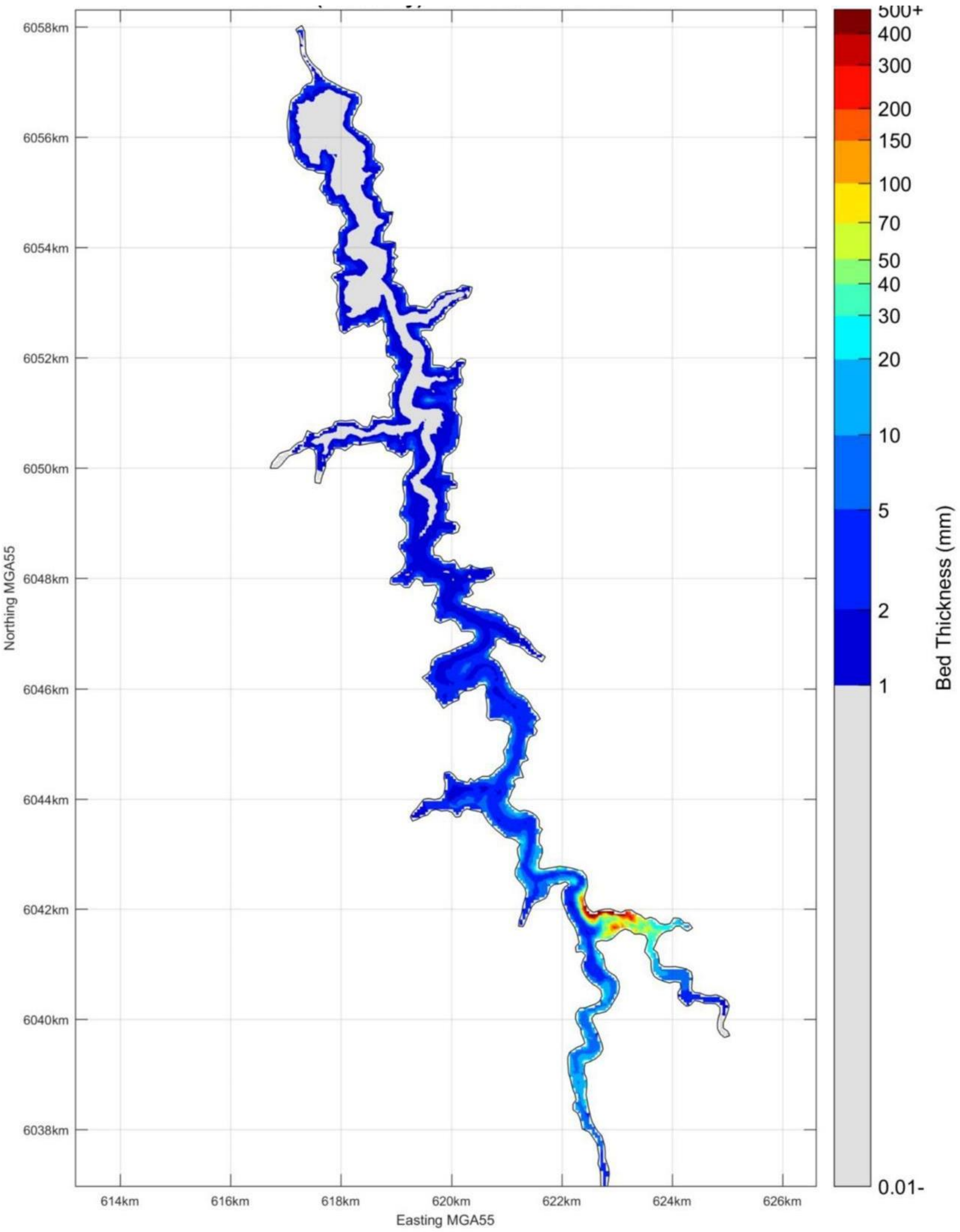

Figure 3-4: Deposition of fine for Hybrid Placement

4 Modelling of Snowy 2.0 commissioning flows

4.1 Overview

Hydrodynamic and sediment transport models were developed for investigating and assessing key processes (e.g. freshwater flow, thermal stratification and sedimentary processes) in the reservoirs. The models were used to investigate existing (pre-placement) conditions and changes to the reservoirs during the Main Works Excavated Rock Placement (ERP) (RHDHV, 2019a), and the influence of Snowy 2.0 commissioning flows on reservoir hydrodynamics, shear stress near the bed and the likelihood of bed sediments being transported (this report).

This phase of the commissioning modelling is expected to represent a potential worst-case for the re-suspension of existing bed sediments, i.e. higher sediment transport rates and morphodynamical changes in the reservoir are expected to occur immediately once Snowy 2.0 is operational and the reservoir bathymetry (post-construction) begins to adjust to new flow conditions created by the new intake-outlet structures.

Commissioning of the turbines is to be undertaken over a period of approximately two years following construction of Snowy 2.0. Snowy 2.0 commissioning will be carried out independently of T2 and T3 flows.

4.2 Available information

The following information was available to inform the modelling assessment of Snowy 2.0 commissioning phase operation:

- Commissioning information including the type, schedule and water flows for commissioning tests provided by Snowy Hydro
- General arrangement details of intake-outlet structures
- Location(s), shape and final design profile of the placement areas, and
- Design drawings of the intake-outlet works.

This information was used to configure model scenarios to assess commissioning flow conditions for Snowy 2.0 as defined above.

4.3 Commissioning flows

National Electricity Rules (NER) compliance testing will be undertaken by Snowy Hydro to demonstrate to the Australian Energy Market Operator (AEMO) that each pump/turbine unit is ready to be connected to the grid. The six Snowy 2.0 pumps/turbines will be commissioned sequentially over 2 years. The water flow from the intake-outlet structures during this time will vary significantly over the commissioning period.

Therefore, this assessment focuses on short-term (days and weeks) simulations for a range of flows that may arise during commissioning tests (during both pumping and generation modes of operation).

A summary of Snowy 2.0 commissioning tests and flows was provided by Snowy Hydro including the following details:

- category of commissioning tasks
- commissioning task
- expected timeframe for completion of each task, and

- peak flow rate/number of pumps or turbines to be operated.

Available commissioning flow information is provided in **Attachment C**. Commissioning flow information was reviewed and short-term scenarios defined for the assessment of hydrodynamics and bed shear stress, which are used to inform this assessment and the potential impact of commissioning flows on navigation (RHDHV, 2019b).

Due to the complexity and number of tests identified for Snowy 2.0 commissioning, not all commissioning tests could (or need) to be modelled. Instead, the scenarios investigated were primarily focussed on those commissioning tasks with the longest duration and greatest flow rate (pumping/generation) as these operational conditions would result in the greatest impact on hydrodynamic and sediment transportation potential in the reservoirs under low operating water levels (e.g. near MOL).

A summary of generation and pumping flow rates as a function of the number of units (turbines/pumps) operating is shown in **Table 4-1**. The flow rate information presented below was provided by Snowy Hydro for the purposes of this assessment and used to define inflow/outflow boundary conditions to the reservoir models for the scenarios investigated (refer to **Section 4.4.4**).

Table 4-1: Snowy 2.0 generation and pumping flow rates

Mode	Number of Units Operating	Flow rate (m^3/s)
Generation (Turbines operating with discharges to Talbingo Reservoir)	1	62
	2	124
	3	186
	4	248
	5	310
	6	**372**
Pumping (Pumps operating with discharges to Tantangara Reservoir)	1	45
	2	90
	3	135
	4	180
	5	225
	6	**270**

Other scenarios (not reported here) were considered to investigate if smaller flow rates could potentially mobilise reservoir sediments (natural and material placed during construction) and transport them away from the intake-outlet structures.

4.4 Modelling approach

4.4.1 Overview

An assessment of the Snowy 2.0 commissioning was undertaken by modelling hydrodynamics and sediment transport separately. The magnitude of bed shear stress is a function of water surface slope, channel geometry and flow. The moment where the directive forces (shear forces) overcome restrictive forces (inertia, friction) is known as the moment of incipient motion and is the threshold of sediment particle entrainment. The shear stress at this threshold is known as the critical shear stress.

The modelling approach included the simulation of hydrodynamic conditions (flow, current speed and water level) for representative commissioning phase scenarios. Modelling results were used to assess the tendency for bed erosion to occur and to determine where in the reservoirs it is most likely. A semi-quantitative assessment links model outputs to the current understanding of sediment characteristics and their behaviour (based on literature and engineering judgement), the construction techniques to be adopted, and the general operation of the reservoirs and Snowy scheme as a whole. The model results were also used to inform the Navigation Impact Assessment (RHDHV, 2019b).

4.4.2 Model extents and geometry

The model extents previously adopted for the assessment of suspended sediment transport and deposition due to Snowy 2.0 construction (RHDHV, 2019a) were used for the commissioning modelling. Small changes were made to the geometry of the reservoir models to increase the spatial resolution and definition of bed levels near the proposed placement areas and the intake-outlet structures.

4.4.3 Model bathymetry

Model bathymetry was updated to reflect the underwater profile in the Talbingo and Tantangara reservoirs following construction of Snowy 2.0. The modelled bathymetry of Talbingo Reservoir was updated to reflect the final placement profile for the Ravine Bay emplacement area. For completeness, the bathymetry of Tantangara Reservoir was adjusted to reflect placement of material above MOL even though the proposed placement will not materially affect the storage volume or hydrodynamics of the reservoir.

Table 4-2 details the placement designs included in the modelling assessment.

Table 4-2: Placement designs modelled for Snowy 2.0 commissioning scenarios

Reservoir	Placement Design	Alias
Talbingo	Proposed Ravine Bay Placement	Ravine
	Alternative hybrid (D&B material only to reservoir)	Hybrid
Tantangara	Dry placement above MOL	

4.4.4 Scenarios investigated

Information provided by Snowy Hydro related to commissioning tests for Snowy 2.0 was reviewed and used to define commissioning scenarios. Commissioning scenarios identified for the hydrodynamic and bed shear stress assessment are summarised in **Table 4-3**.

Table 4-3: Hydrodynamics and bed shear stress commissioning scenarios

Commissioning Scenario	Snowy 2.0 Flow Condition	Flowrate (m^3/s)	Initial Reservoir Water Level	
			Talbingo	Tantangara
G1	NER compliance test for turbines (six units operating for 5 days) – discharge to Talbingo Reservoir.	372	MOL – 534.3 m AHD	
G2	NER compliance test for turbines (six units operating for 5 days) – outflow from Tantangara Reservoir.	372		between MOL and FSL – 1217m AHD
P1	NER compliance test for pumps (six units operating for 5 days) – discharge to Tantangara Reservoir.	270		between MOL and FSL – 1217m AHD
P2	NER compliance test for pumps (six units operating for 5 days – outflow from Talbingo Reservoir.	270	MOL plus 0.5m 534.8 m AHD	

Sub-scenarios were defined for Talbingo Reservoir to simulate the combined impact of commissioning flows and two options for placement design. For Tantangara Reservoir, sub-scenarios were not necessary as only a single placement design is proposed. Thermally stratified conditions within the reservoirs were also considered for each flow condition scenario but modelled results did not differ greatly from those obtained for an unstratified reservoir.

4.4.5 Reporting locations

Reporting locations used for the assessment are presented in **Table 4-4** and shown in **Figure 4-1** (Talbingo Reservoir) and **Figure 4-2** (Tantangara Reservoir). The location of intake-outlet structures, and the extent of the placement areas at Talbingo Reservoir are also shown for reference.

Table 4-4: Reporting locations

Reservoir	Reporting ID	Name	GDA94 / MGA Zone 55	
			Easting (m)	Northing (m)
Talbingo	TBG1	Talbingo Intake-Outlet	624 101	6 040 839
	TBG2	Talbingo ERP Area	622 935	6 041 832
	TBG3	Tumut River	622 836	6 040 566
	TBG4	Long Creek	620 792	6 044 025
	TBG5	Lick Hole Creek	619 518	6 048 337
	TBG6	Landers Creek	619 015	6 052 733
	TBG7	Dam Wall	617 620	6 056 945
Tantangara	TTG1	Tantangara Intake-Outlet	649 632	6 038 195
	TTG2	Dam Wall	650 176	6 037 441
	TTG3	Middle	649 787	6 040 587
	TTG4	Murrumbidgee River	648 964	6 042 043
	TTG5	Mosquito Creek	650 160	6 043 811

4.4.6 Limitations and assumptions

Model limitations and caveats for the commissioning modelling assessment are summarised as follows:

- **Model resolution** – the reservoir model is suitable for simulating hydrodynamics (water level, velocity, sediment transport) at the reservoir scale (i.e. the change in water levels, currents and total suspended solids across the entire reservoir or one of the large tributaries such as Yarrangobilly Creek). The model resolution near the Snowy 2.0 intake-outlet structures was modelled at a spatial resolution in the order of 50 m^2 (triangular cells with sides of approximately 10 metres). Complex turbulent flow patterns close to the intake-outlet structure cannot be completely resolved by the reservoir models. Nevertheless, the level of detail provided by the reservoirs models is adequate to provide an estimate of hydrodynamic conditions and sediment transport potential for areas near (in the order of hundreds of metres) to the intake-outlet structures.

- **Bed Shear Stress** – also called critical tractive stress was estimated from available literature based on known PSD of bed sediment and emplaced excavated rock. However, the critical shear stress for fine grained material is known to be somewhat variable and dependant on cohesion, particle shape, degree of compaction or consolidation, bed slope and shape. As such, a range of stresses for a given PSD were considered during the assessment.

- **Near-field processes** such as the distribution of high flows, turbulence and current velocities occurring close to the intake-outlet structure cannot be resolved by the reservoir model. A Computational Fluid Dynamics (CFD) model of the intake-outlet structure(s) would be required to model these complex and highly localised impacts on hydrodynamics. It is understood CFD modelling is within the scope of work of the Contractor, and as such near-field processes are not considered in this assessment.

- **Representation of the proposed design** – Snowy 2.0 commissioning operation was included in the reservoir models as accurately as possible. The modelled inflow was represented as a ‘simple’ source at a location (easting, northing) as close as possible to the proposed intake-outlet structure sites based on the design drawings provided by Snowy Hydro. The vertical model layer that is closest to the depth of the intake-outlet structure was used to introduce the discharge. The initial reservoir water level(s) adopted for the model scenarios are consistent with commissioning test conditions including the flow rate and duration of releases. The volume of water to be pumped/discharged and the corresponding storage volume change that would result were checked to ensure the reservoir water levels did not exceed the physical (spillway) or operational (FSL) limits of the reservoirs.

- **Commissioning of Snowy 2.0** – the modelling assessment was focussed on ‘short-term’ impacts during commissioning of the Snowy 2.0 pumps/turbines rather than long-term changes to hydrodynamics and sediment transport that could arise as a result of the Talbingo and Tantangara Reservoirs being linked by the new pumped hydro system.

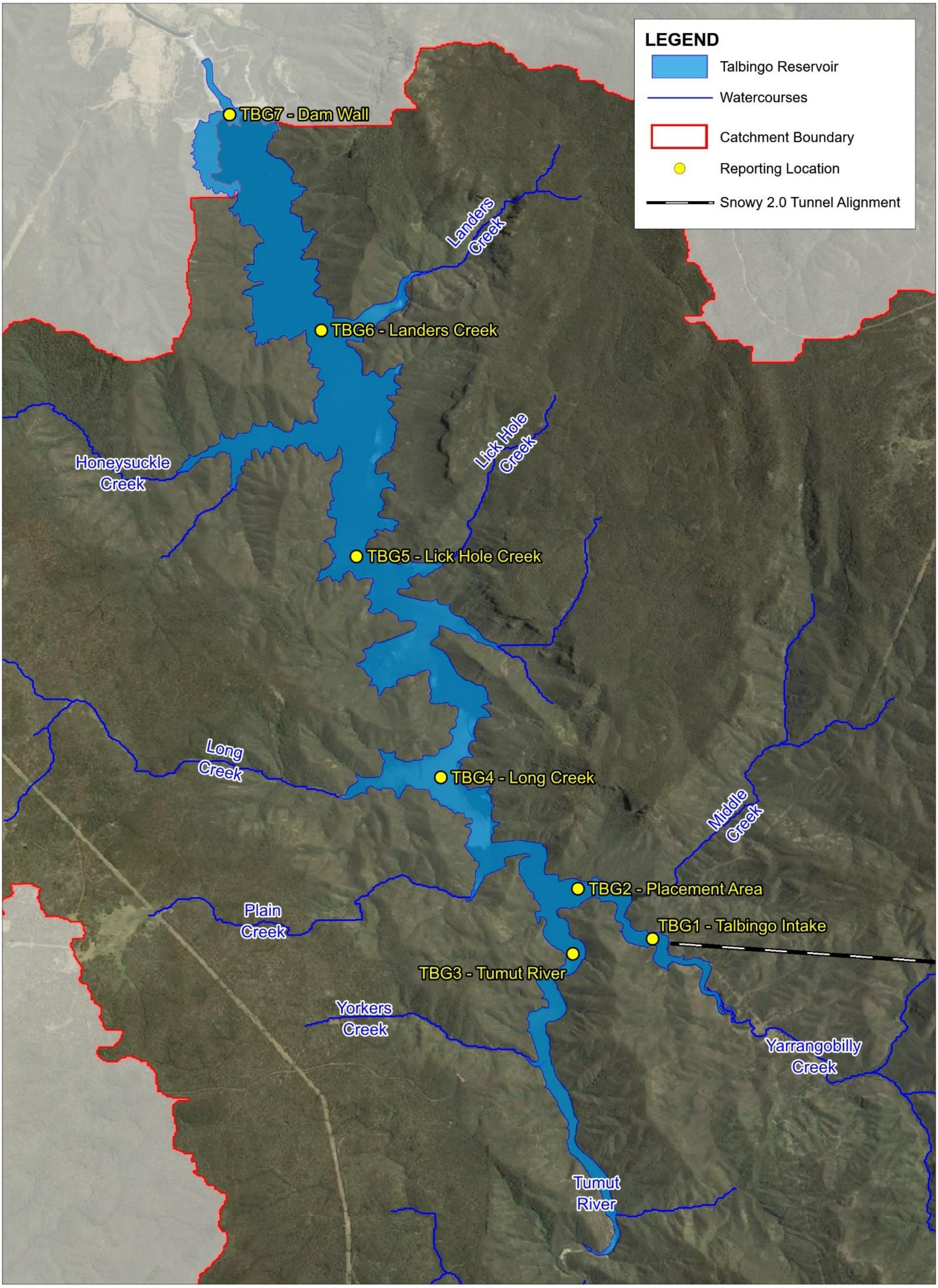

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FIGURE 4-1 **Reporting Locations (Talbingo Reservoir)**

NORTH

0 0.75 1.5km
Approx. Scale

SCALE 1:80,000

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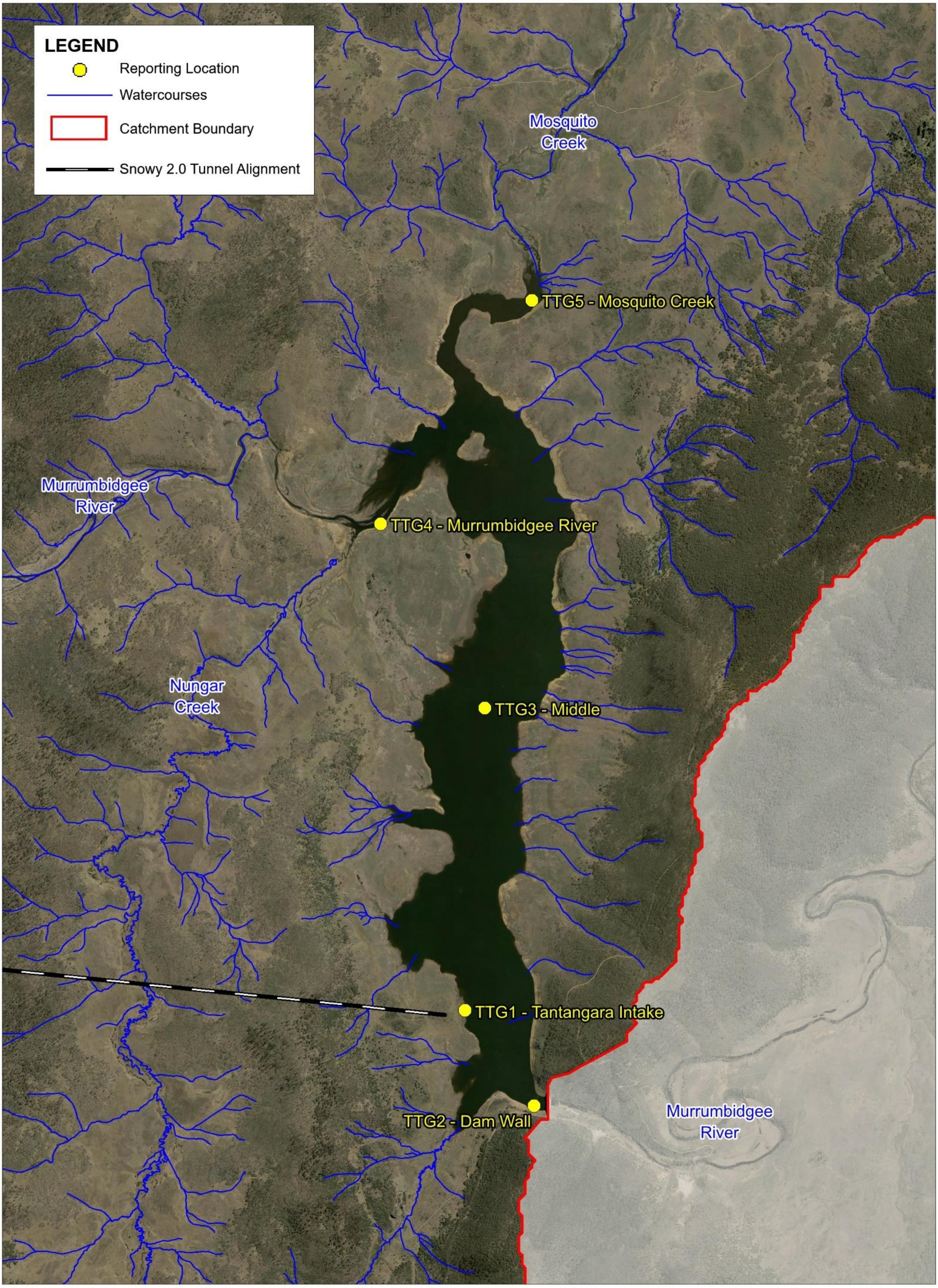

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FIGURE 4-2 Reporting Locations (Tantangara Reservoir)

NORTH

0 375 750m
Approx. Scale

SCALE 1:40,000

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4.5 Model results

Modelled current speed and bed shear stress are presented below for the Talbingo and Tantangara reservoirs for the following areas:

- along the Yarrangobilly Arm downstream of Talbingo intake structure
- near the Ravine Bay (Talbingo Reservoir) placement area, and
- near the Tantangara intake approach channel.

Modelled results presented below include spatial plots of peak (bed) current speeds and bed shear stress. For Talbingo Reservoir, model results are provided for the proposed and alternative placement designs. A single set of model results is presented for Tantangara Reservoir which assumes dry placement above MOL.

The results are based on a water level near MOL, which corresponds to the highest current speed and bed shear stress (being the shallowest water depth)[5].

4.5.1 Talbingo Reservoir

Plots of peak current (near bed) speed for generation (G1) and pumping (P2) scenarios with the inclusion of the Ravine Bay Placement and Hybrid Placement designs are presented in **Figure 4-3** to **Figure 4-6**.

Similarly, plots of peak bed shear stress for the G1 and P2 scenarios with the Ravine Bay Placement and Hybrid Placement designs are presented in **Figure 4-7** to **Figure 4-10**.

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[5] *Modelling during generation commences with a water level at MOL. Modelling during pumping commences with a water level 0.5m above MOL.*

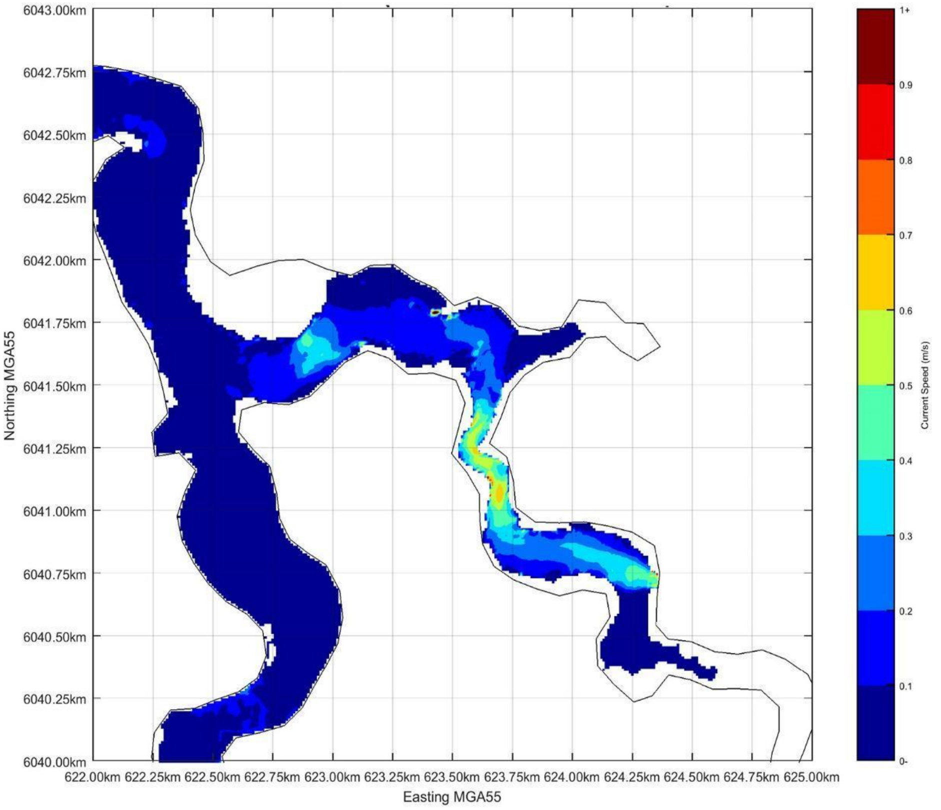


Figure 4-3: Talbingo Reservoir Ravine Bay Placement – Scenario G1 peak current (bed) speed

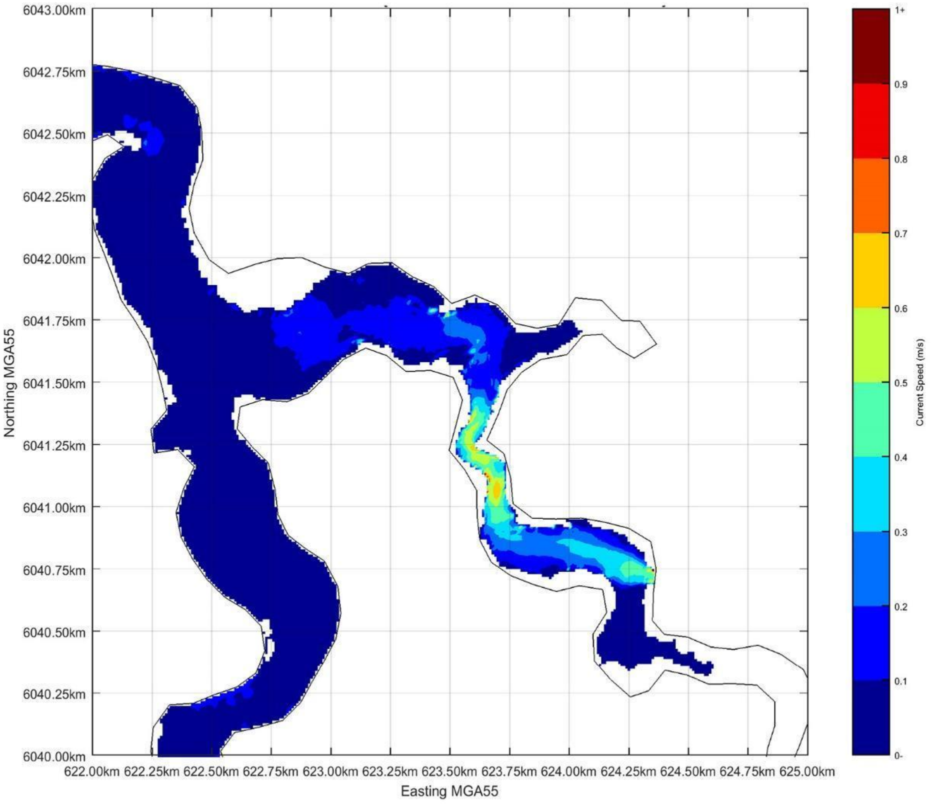


Figure 4-4: Talbingo Reservoir Hybrid Placement – Scenario G1 peak current (bed) speed

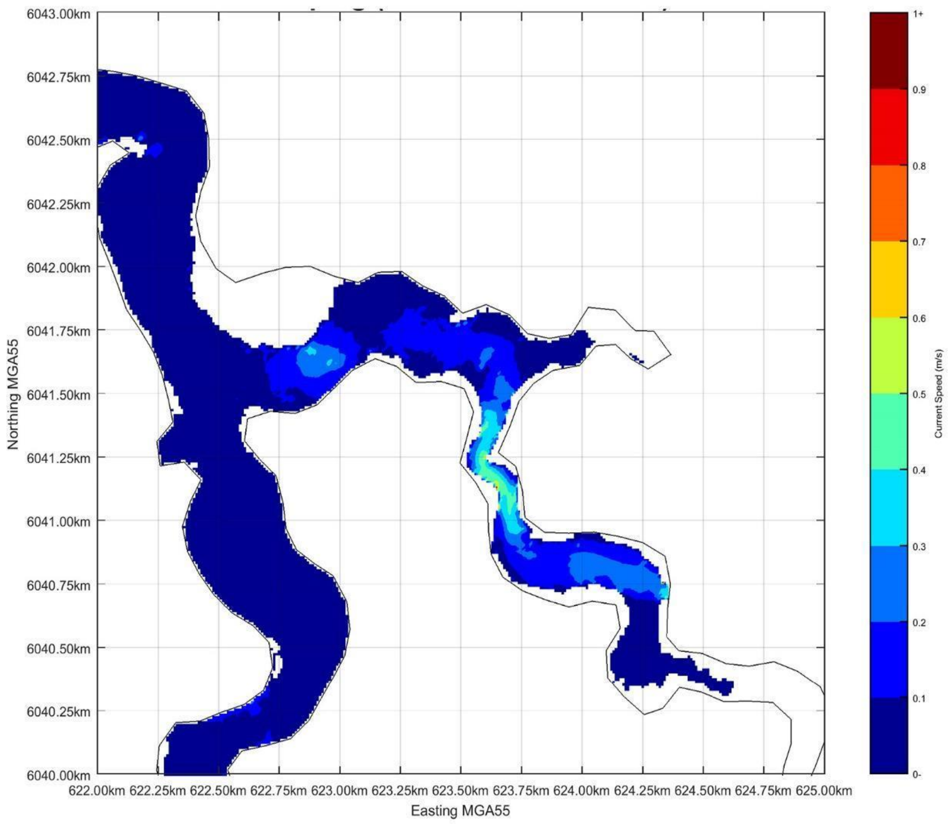


Figure 4-5: Talbingo Reservoir Ravine Bay Placement – Scenario P2 peak current (bed) speed

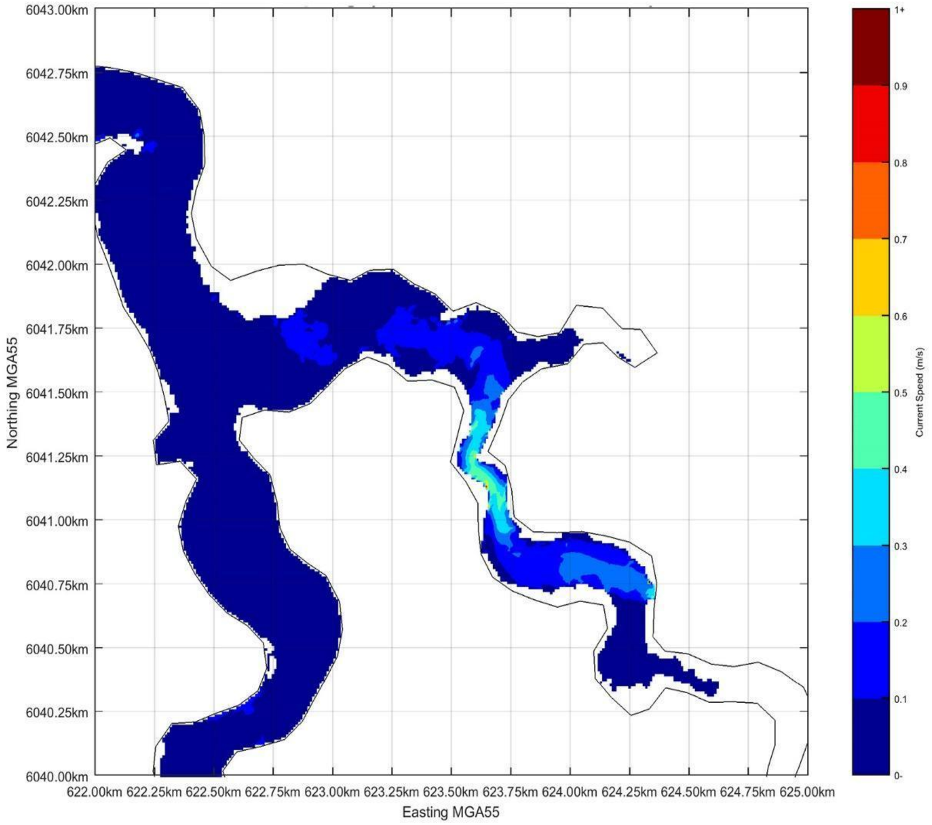


Figure 4-6: Talbingo Reservoir Hybrid Placement – Scenario P2 peak current (bed) speed

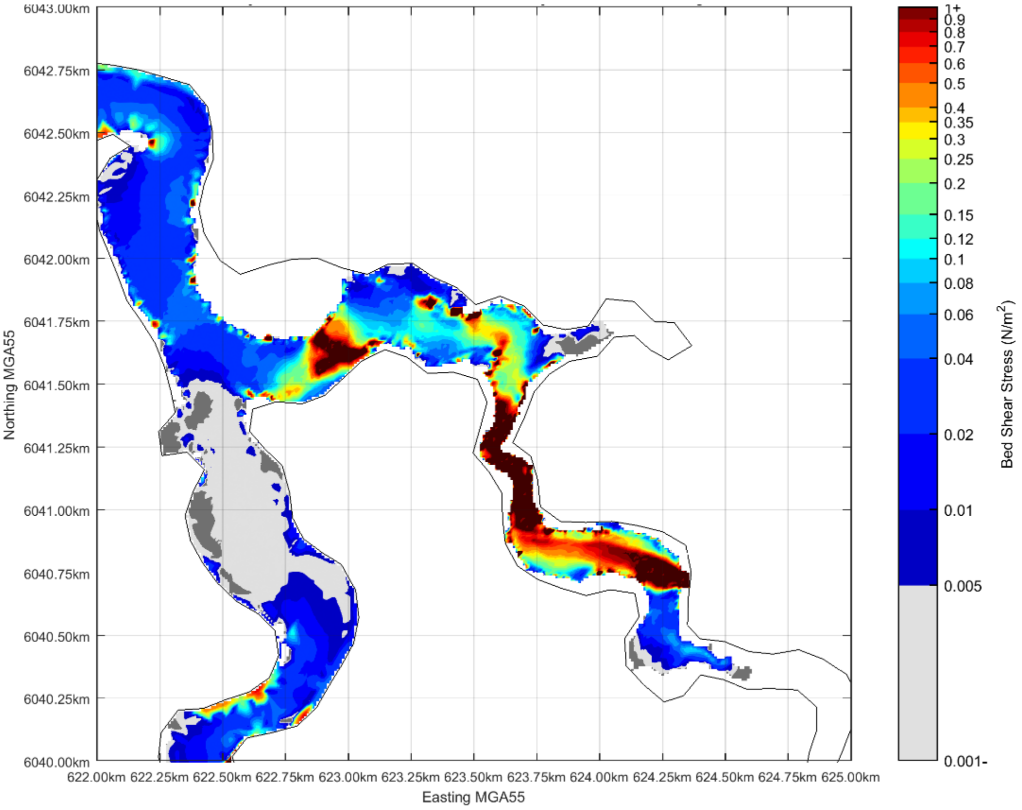


Figure 4-7: Talbingo Reservoir Ravine Bay Placement – Scenario G1 peak bed shear stress

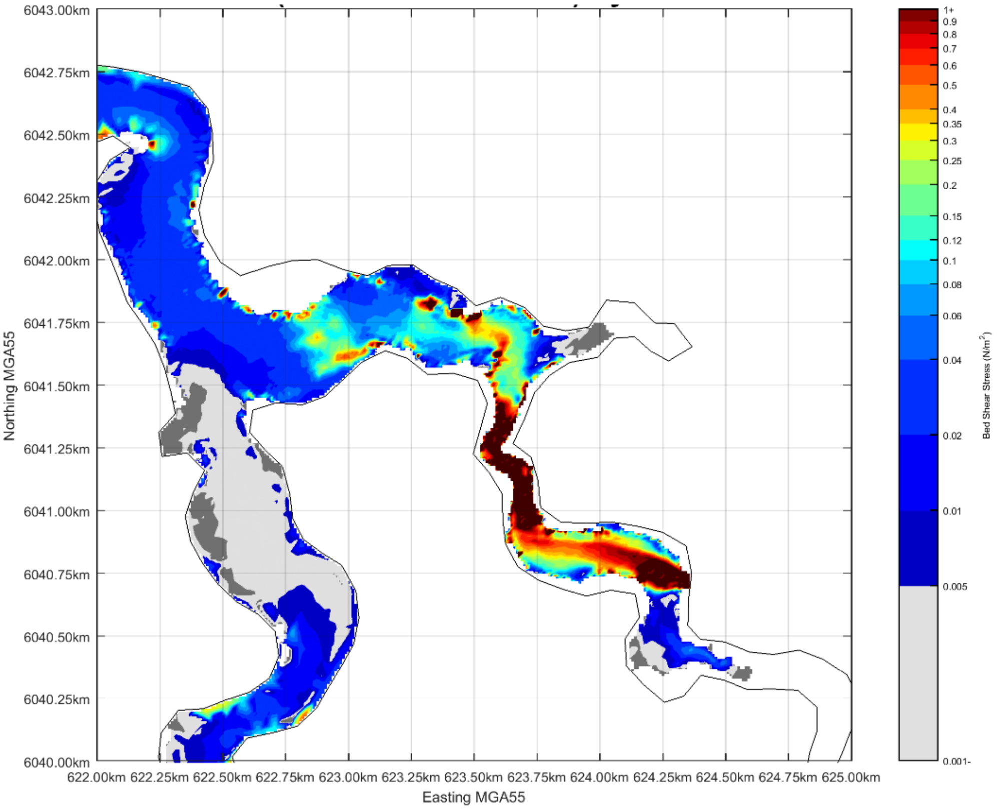


Figure 4-8: Talbingo Reservoir Hybrid Placement – Scenario G1 peak bed shear stress

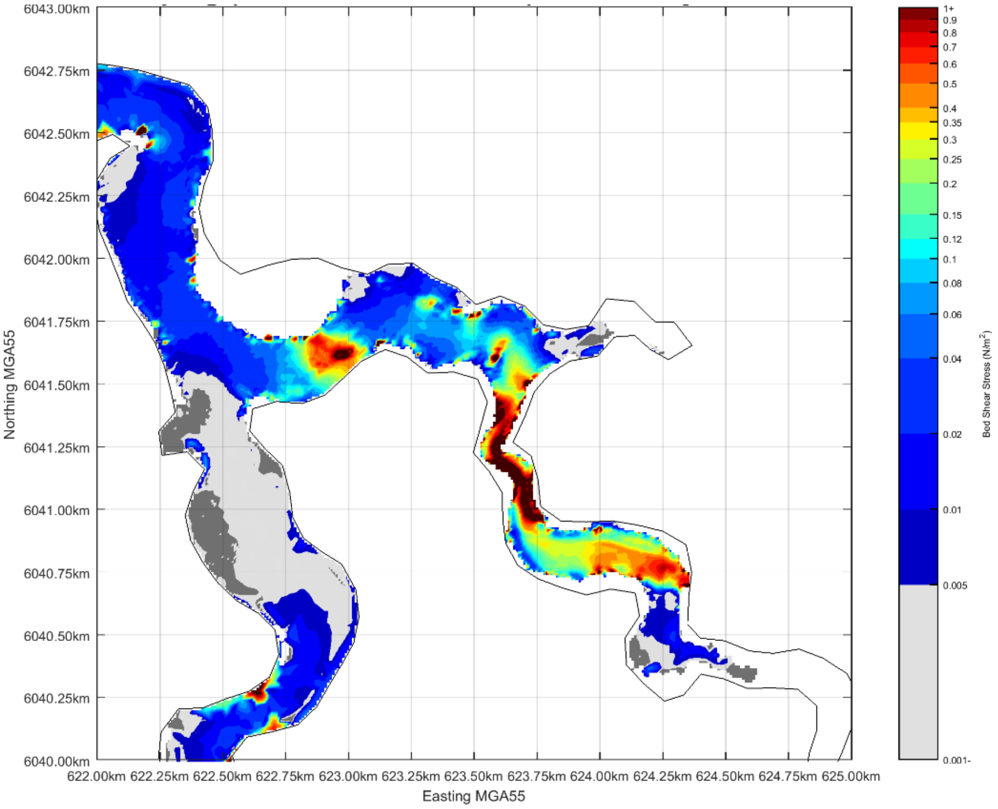


Figure 4-9: Talbingo Reservoir Ravine Bay Placement – Scenario P2 peak bed shear stress

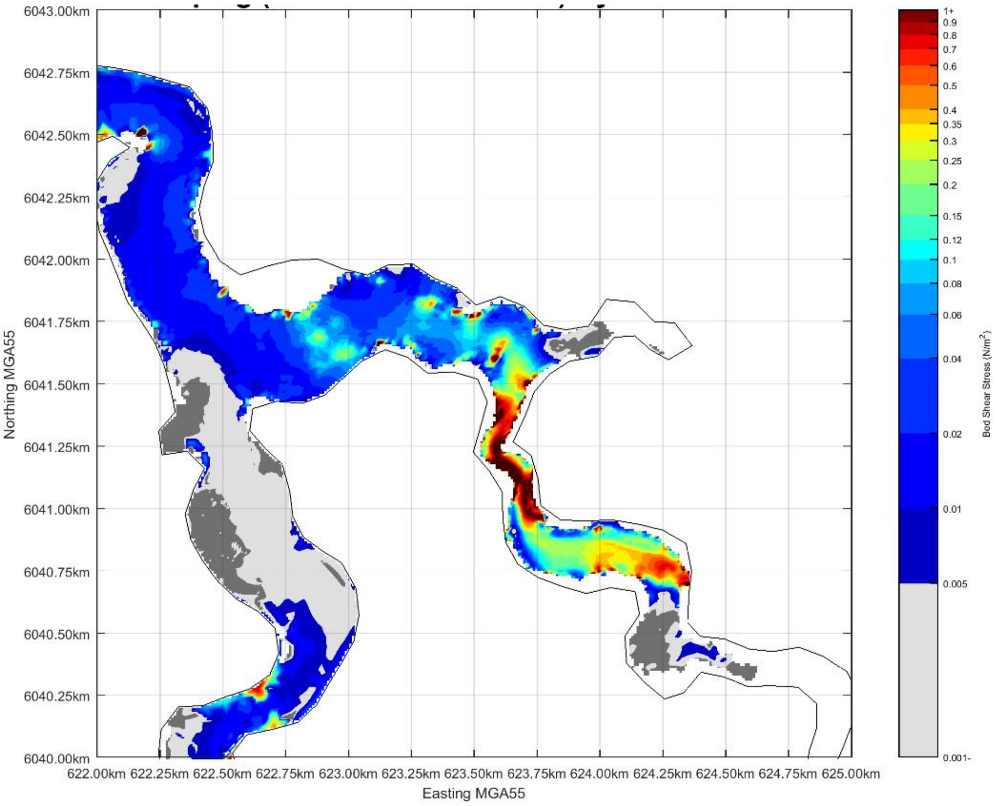


Figure 4-10: Talbingo Reservoir Hybrid Placement – Scenario P2 peak bed shear stress

Based on the above results, a number of general observations can be made:

- currents and bed shear stresses are higher during generation than during pumping, within the inlet channel
- during generation (G1 scenario – discharge to Talbingo Reservoir), peak near bed current speeds in the order of 0.5 to 0.7 m/s are predicted along the Yarrangobilly Arm extending downstream as far as the Ravine Bay placement area. During pumping (P2 scenario – outflow from Talbingo Reservoir), peak currents of up to 0.5 m/s between the placement area and the Snowy 2.0 intake structure are predicted
- the relatively narrow 'throat' section between Middle Bay and Ravine Bay is an area of higher currents and higher bed shear stress
- the magnitude of the currents and bed shear stress in the throat section are similar for the two placement options
- the currents and bed shear stress adjacent to the placement area (between the placement area and the opposite southern shoreline), are higher for the Ravine Bay Placement option than the Hybrid Placement option due to the greater constriction of the flow created in the former case. This flow constriction is due to the reduced waterway area/conveyance for the Ravine Bay Placement option compared to the smaller footprint of the Hybrid Placement design, and
- there is a particular 'hot spot' of higher currents and bed shear stress adjacent to the south-eastern edge of the placement area for both placement options.

4.5.2 Tantangara Reservoir

Plots of peak current (near bed) speed for generation (G2) and pumping (P1) are presented in **Figure 4-11** and **Figure 4-12**.

Similarly, plots of peak bed shear stress for the G2 and P1 scenarios are presented in **Figure 4-13** and **Figure 4-14**.

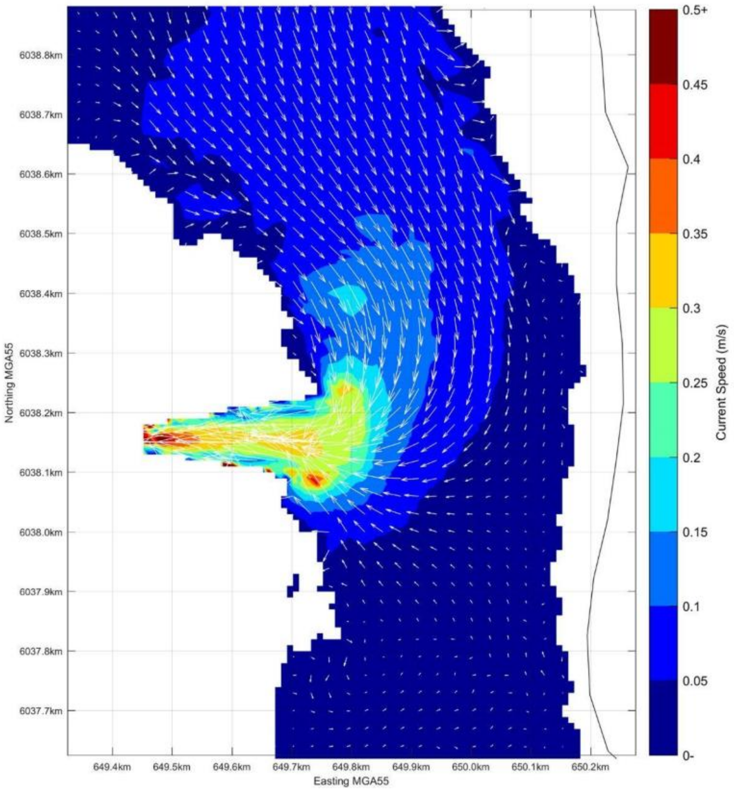


Figure 4-11: Tantangara Reservoir – Scenario G2 peak current (bed) speed

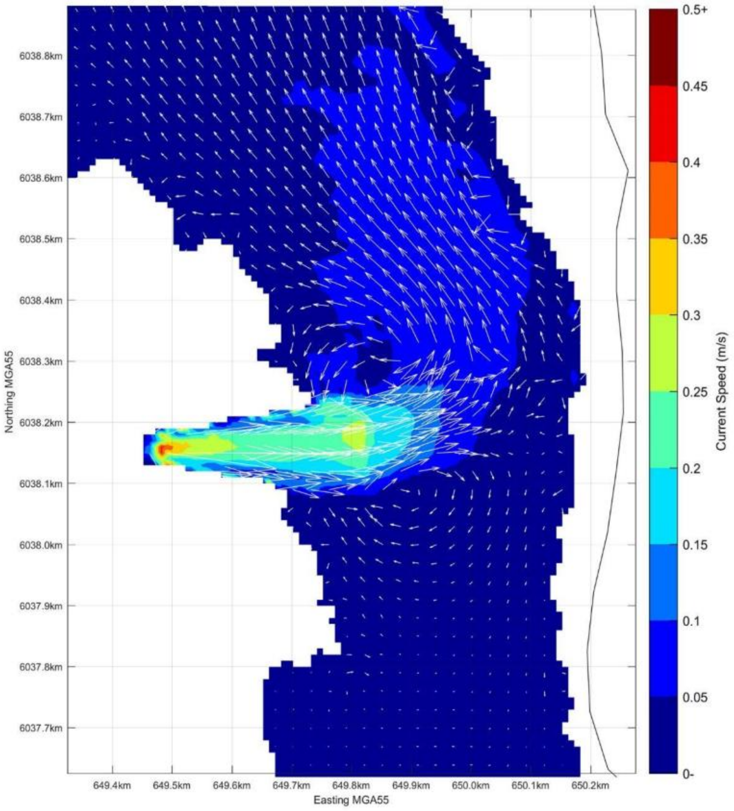


Figure 4-12: Tantangara Reservoir – Scenario P1 peak current (bed) speed

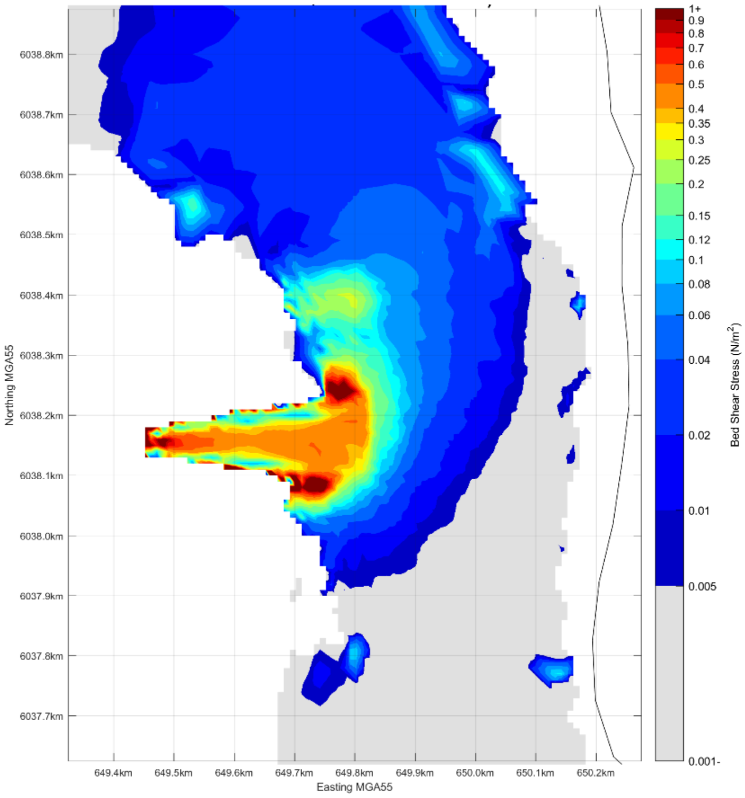


Figure 4-13: Tantangara Reservoir – Scenario G2 peak bed shear stress

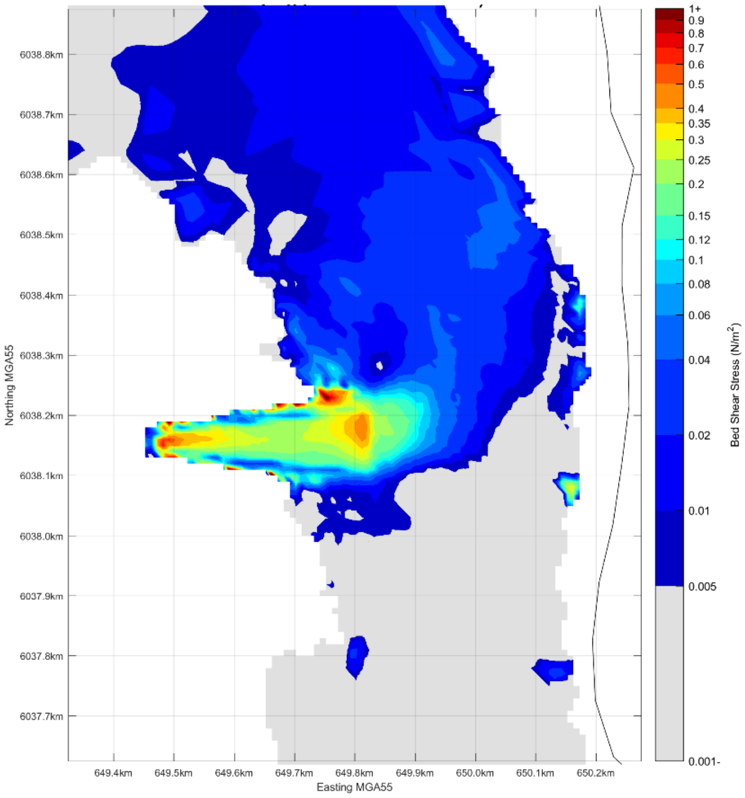


Figure 4-14: Tantangara Reservoir – Scenario P1 peak bed shear stress

Based on the above results, a number of general observations can be made:

- currents and bed shear stresses are higher during generation than during pumping, within the inlet channel
- during generation water is drawn mainly from the northern section of the reservoir
- during pumping, the exit jet is directed along the axis of the inlet channel towards the opposite shore of the reservoir before turning northwards
- the proposed placement area, situated between MOL and FSL, is located well to the north of the intake structure and does not interact with generation and pumping flows to any material extent
- during generation (G2 scenario – outflow from Tantangara Reservoir), peak near bed current speeds in the order of 0.4 to 0.8 m/s are predicted along the intake approach channel. During pumping (P1 scenario – discharge to Tantangara Reservoir), peak currents along the intake approach channel of between 0.2 m/s and 0.4 m/s are predicted
- within the main body of the reservoir, current speeds are much lower than the intake channel, with peak current speeds of less than 0.1 m/s predicted. For other locations (e.g. near the dam wall and areas more than 500 metres from the main intake channel), modelled current speeds are less than 0.05 m/s
- during generation (outflow from Tantangara Reservoir), bed shear stress of between 0.4 and 0.7 N/m^2 is predicted along the intake approach channel. During pumping (discharge to Tantangara Reservoir), bed shear stress of between 0.2 and 0.4 N/m^2 is predicted. Localised areas near the intake channel are subject to higher bed shear stress conditions in the range of 0.5 to 1 N/m^2 during pumping and generation modes of operation. This indicates high sediment transport potential along the intake approach channel, and
- beyond the intake approach channel, bed shear stress is less due to lower peak current speeds and greater water depth conditions in the main body of the reservoir.

5 Assessment of potential disturbance of sediments

5.1 General

Section 4 sets out the modelling approach adopted to inform the assessment of the potential disturbance of sediments during the operational (commissioning) flows. Essentially this involved estimation of the bed shear stress for a range of flow conditions that could be expected (refer **Table 4-3**). The bed shear stress could then be compared to the critical bed shear stress for mobility, for the range of possible sediments on the bed of the reservoirs described in **Section 3,** namely:

- fine excavated rock (sediment) that has settled away from the placement area during the construction phase, and
- existing (*in situ*) sediments.

The potential for disturbance is discussed separately for Talbingo Reservoir and Tantangara Reservoir in the following sections.

The adopted range of critical shear stress values for different sediments are summarised in **Table 5-1** in Newtons per square metre (N/m^2). It is noted that critical shear stress values are not provided for clay as these values can vary widely depending on factors such as the degree of cohesion. For the clayey textured lacustrine deposits and the settled clays from excavated rock placement, the degree of cohesion would be extremely low and a critical shear stress value corresponding to very fine silt could be considered.

Table 5-1: Adopted critical shear stress values for different sediment classes

Sediment Class	Critical shear stress (N/m^2)
Coarse sand	0.27 – 0.47
Medium sand	0.19 – 0.27
Fine sand	0.15 – 0.19
Very fine sand	0.11 – 0.15
Coarse silt	0.08 – 0.11
Medium silt	0.06 – 0.08
Fine silt	0.04 – 0.06
Very fine silt	0.02 – 0.04

Source: US Geological Survey, Scientific Investigations Report 2008-5093

5.2 Talbingo Reservoir

5.2.1 Disturbance of fine excavated rock (settled material)

As noted earlier, a proportion of the fine material (silt and clay) contained in the excavated rock placed subaqueously in Talbingo Reservoir during the construction phase migrates away from the immediate placement area and settles in Ravine Bay and Middle Bay, as shown in **Figure 3-3** (Ravine Bay Placement) and **Figure 3-4** (Hybrid Placement). These sediments would have a ‘fluffy’ consistency with little or no shear strength.

The bed shear stresses shown in **Section 4.5.1**, when compared to the critical shear stress values in **Table 5-1**, indicate that the fine settled material would be expected to be remobilised during both generation and pumping phases, for both the Ravine Bay Placement and Hybrid Placement options for a period of time post-construction. Remobilisation during generation operations means the fine sediments would be transported downstream. Remobilisation during pumping operations means the fine sediments would be transported upstream into the intake and through to Tantangara Reservoir.

The period of time over which the critical shear stress could be exceeded in an area where fine sediments would have settled during construction, for generation and pumping operations, and for the two placement options, Ravine Bay Placement and Hybrid Placement has been assessed.

The location selected for illustration of the time series of bed shear stress is near the south-eastern edge of the placement area in Ravine Bay where fines would have settled and where currents and bed shear stress values are highest (the ‘hot spot’ referred to earlier).

As a guide, **Figure 5-1** shows the variation in bed shear stress over a 24 hour period during generation, commencing at MOL, for Ravine Bay Placement (solid line) and for Hybrid Placement (dashed line). The following is evident:

- there is a gradual reduction in bed shear stress over the 24 hour period as the water level rises
- bed shear stresses are higher for Ravine Bay Placement than for Hybrid Placement, due to the greater constriction of the flow in the former case, as noted earlier
- the critical shear stress for the settled sediments would be exceeded over the complete 24 hour modelled period, and longer, for the Ravine Bay Placement option. Accordingly, remobilisation of settled sediments is expected to continue over this period while some bed sediment remains.

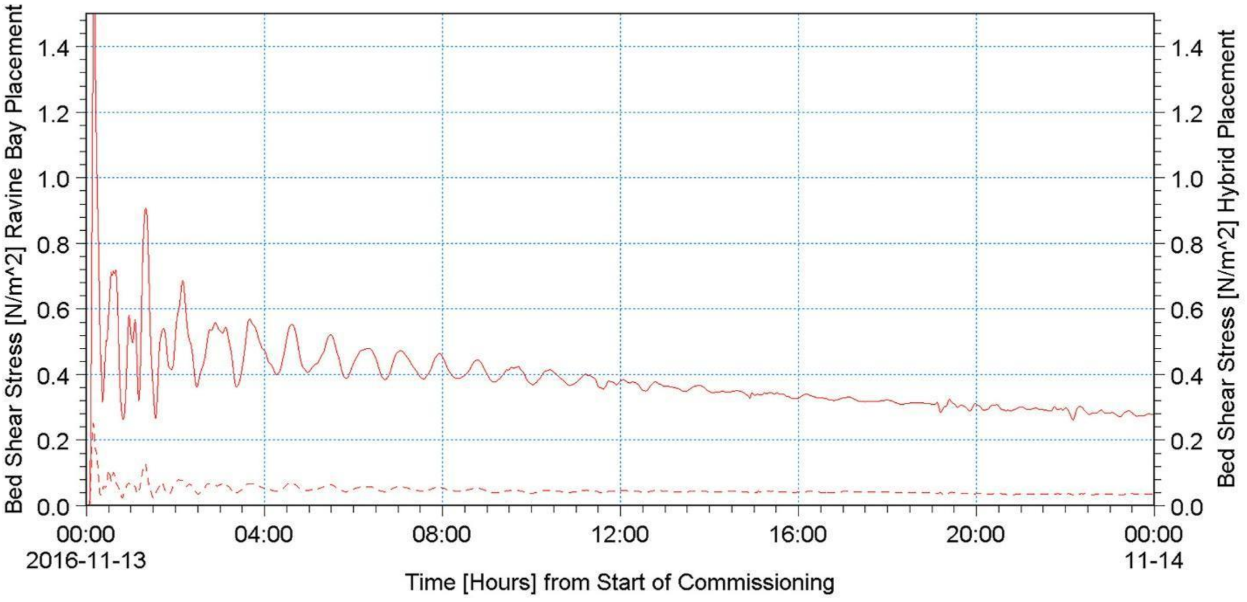


Figure 5-1: Variation in bed shear stress over time (generation SE edge of placement area)

Time series plots of bed shear stress during pumping (not shown here) also show that remobilisation of sediments during pumping would be expected to extend over hours while bed sediment remain available for re-suspension.

5.2.2 Disturbance of existing reservoir sediments

As noted earlier, the existing sediments on the reservoir bed comprise four strata; lacustrine deposits, topsoil, alluvial deposits and residual soil. All of the sediments contain considerable amounts of fines (silt and clay). With the exception of the residual soils which can be firm to stiff, the sediments would have negligible shear strength and would be potentially readily erodible.

The shear stresses shown in **Section 4.5.1**, when compared to the critical shear stress values in **Table 5-1**, indicate that the lacustrine deposits and the majority of the topsoil and alluvial materials within Middle Bay downstream of the intake works and over large areas of Ravine Bay would be expected to be eroded during both generation and pumping phases for both the Ravine Bay Placement and Hybrid Placement options. No conclusion can be drawn regarding the disturbance of residual soils but erosion of these materials over a similar spatial extent cannot be ruled out.

In terms of the period of time over which the critical shear stress could be exceeded for existing reservoir sediments, **Figure 5-2** shows the variation in bed shear stress over a 24 hour period during generation, commencing at MOL, for two locations in the throat area between Middle Bay and Ravine Bay, for Ravine Bay Placement (solid lines) and for Hybrid Placement (dashed lines).

The trends are similar to those described above for the location near the south-eastern edge of the placement area in Ravine Bay, except that bed shear stresses are higher. Disturbance of existing reservoir sediments would be expected to occur over the complete 24 hour period, and longer, for the Ravine Bay Placement option and for the Hybrid Placement option, while sediments remain.

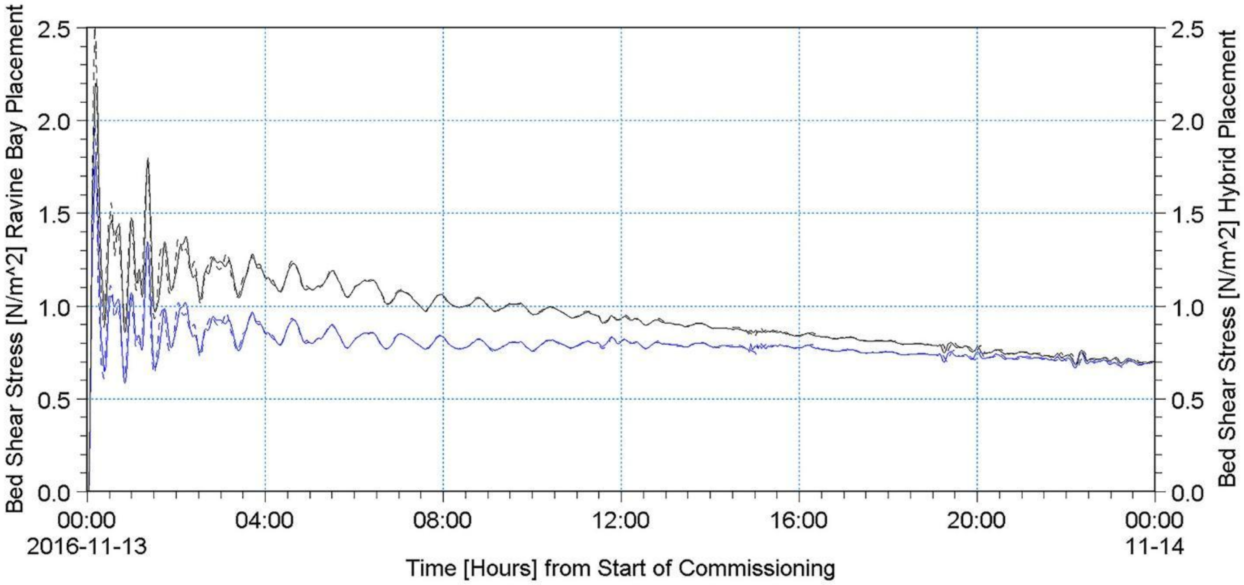


Figure 5-2: Variation in bed shear stress over time (generation 2 locations)

Time series plots of bed shear stress during pumping (not shown here) also show that disturbance of existing sediments would be expected to extend over hours while sediments remain.

5.2.3 Disturbance at edge of placement area

The modelling can also be used to assess whether the excavated rock materials placed along the edge of the placement area in Ravine Bay could be subject to disturbance during generation or pumping. As noted earlier, the highest bed shear stresses occur at a ‘hot spot’ at the south-eastern edge of the placement area and are highest during generation. These bed shear stresses are in the range 1.5-2.0 N/m^2.

Based on **Table 5-1**, the placed material along the edge of the placement area would not be subject to disturbance providing it was medium size gravel, in the order of 8-16 mm nominal diameter. It is proposed to armour the edge of the placement area with 200 mm size material, which would be more than adequate to prevent disturbance.

5.3 Tantangara Reservoir

5.3.1 Disturbance of existing sediments

The shear stresses presented in **Section 4.5.2**, when compared to the critical shear stress values in **Table 5-1**, indicate that the lacustrine deposits, topsoil and alluvial materials, plus the very soft to soft clays at depth (as indicated in borehole BH 1114), located within the intake channel and areas directly offshore and adjacent (mostly to the north), would be expected to be eroded during generation and pumping. No conclusion can be drawn regarding the disturbance of residual soils but erosion of these materials over a similar spatial extent cannot be ruled out.

5.3.2 Disturbance at edge of placement area

As noted earlier, the proposed placement area is situated between MOL and FSL and located well to the north of the intake structure, and does not interact with generation and pumping flows to any material extent.

As such, potential disturbance to the edges of the placement area by generation and pumping flows is negligible and therefore not an issue. Instead, armouring requirements for edges of the placement area would be governed by other factors such as wind generated waves, boat wash, and surface water flows.

6 Solutions to mitigate issues and risks due to sediment disturbance

6.1 Summary of potential sediment disturbance

It is evident from the discussion in **Section 5** that:

- in **Talbingo Reservoir**, both fine settled material from the construction phase and existing reservoir sediments located within Middle Bay downstream of the intake works and over large areas of Ravine Bay, would be expected to be disturbed by generation and pumping flows for a period of time post-construction until a long term equilibrium is established, and
- in **Tantangara Reservoir**, existing reservoir sediments located within the intake channel and areas directly offshore and adjacent (mostly to the north) would be expected to be disturbed by generation and pumping flows for a period of time post-construction until a long term equilibrium is established.

For both reservoirs, there is a greater potential for disturbance during generating than during pumping, due to the higher flows involved in the former mode of operation.

In Talbingo Reservoir, the potential for disturbance in Ravine Bay is greater for the Ravine Bay Placement option compared to the Hybrid Placement option, due to the greater constriction of flow created by the former. The potential disturbance in the ‘throat’ area between Middle Bay and Ravine Bay is similar for both placement options.

Disturbance of sediments would be expected to continue over hours during generation and pumping while bed sediments remain in the area affected by elevated bed shear stresses.

6.2 Commitments

Snowy Hydro has established a number of commitments which are relevant to the matter of sediment disturbance, as listed below:

- minimise turbulence and the creation of surface waves which have the potential to present a hazard to members of the public as a result of sudden commencement of flow through the intake structure
- prevent scour of the approach channel and surrounding areas of the reservoir
- prevent the formation of vortices
- minimise the potential for debris being moved toward the intake (which may then require removal), and
- minimise the amount of sediment being mobilised and drawn into the waterway or dispersed into the reservoir.

In addition to the above, the following studies are to be undertaken to inform construction design:

- sediment mobilisation analysis in order to understand the extent of underwater excavation required as well as the type and extent of surface treatments required, and
- analysis of the structure outlet velocity profiles in both pump and generation mode using CFD to optimise head and eliminate scour and erosion issues.

6.3 Identification of solutions

A number of potential solutions can be identified to mitigate issues and risks due to sediment disturbance. A ‘do nothing’ approach would not appear to be acceptable as it would not satisfy the current criteria established by Snowy Hydro. It is also assumed that a reduction in the generating and pumping flows, to reduce currents and bed shear stress, is not possible.

The potential solutions are considered to be as follows, possibly in combination:

- modification of the works, e.g. inlet works and placement areas
- removal of sediments from the potential disturbance zones, and
- armouring of the sediments in the potential disturbance zones.

At the time of assessment, acceptable solutions were under consideration by Snowy Hydro.

7 Conclusion

Commissioning scenarios with operation of Snowy 2.0 pumps/turbines were assessed for Talbingo and Tantangara Reservoirs. Reservoir models were updated to represent the proposed placement design profiles and the incorporation of commissioning flows at the Snowy 2.0 intake structure locations. The modelling indicates that with commissioning of Snowy 2.0, bed current speeds and shear stress in both reservoirs would remobilise unconsolidated fine sediments near the intake-outlet structures for a period of time post-construction until a balanced equilibrium is established.

In Talbingo Reservoir, both fine settled material from the construction phase and existing reservoir sediments located within Middle Bay downstream of the intake works and over large areas of Ravine Bay, would be expected to be disturbed by generation and pumping flows during commissioning of Snowy 2.0.

In Tantangara Reservoir, existing reservoir sediments located within the intake approach channel and areas directly offshore and adjacent would be expected to be disturbed by generation and pumping flows. Within the main body of the reservoir, the potential for re-suspension of bed sediments is substantially less than that estimated along the intake approach channel.

Overall, localised morphological adjustment near both intake-outlet structures is expected to occur as fine sediments (especially those present at locations of shallow water depth) are re-distributed to establish a new sediment transport equilibrium with the new operational flow regime in the reservoirs.

8 References

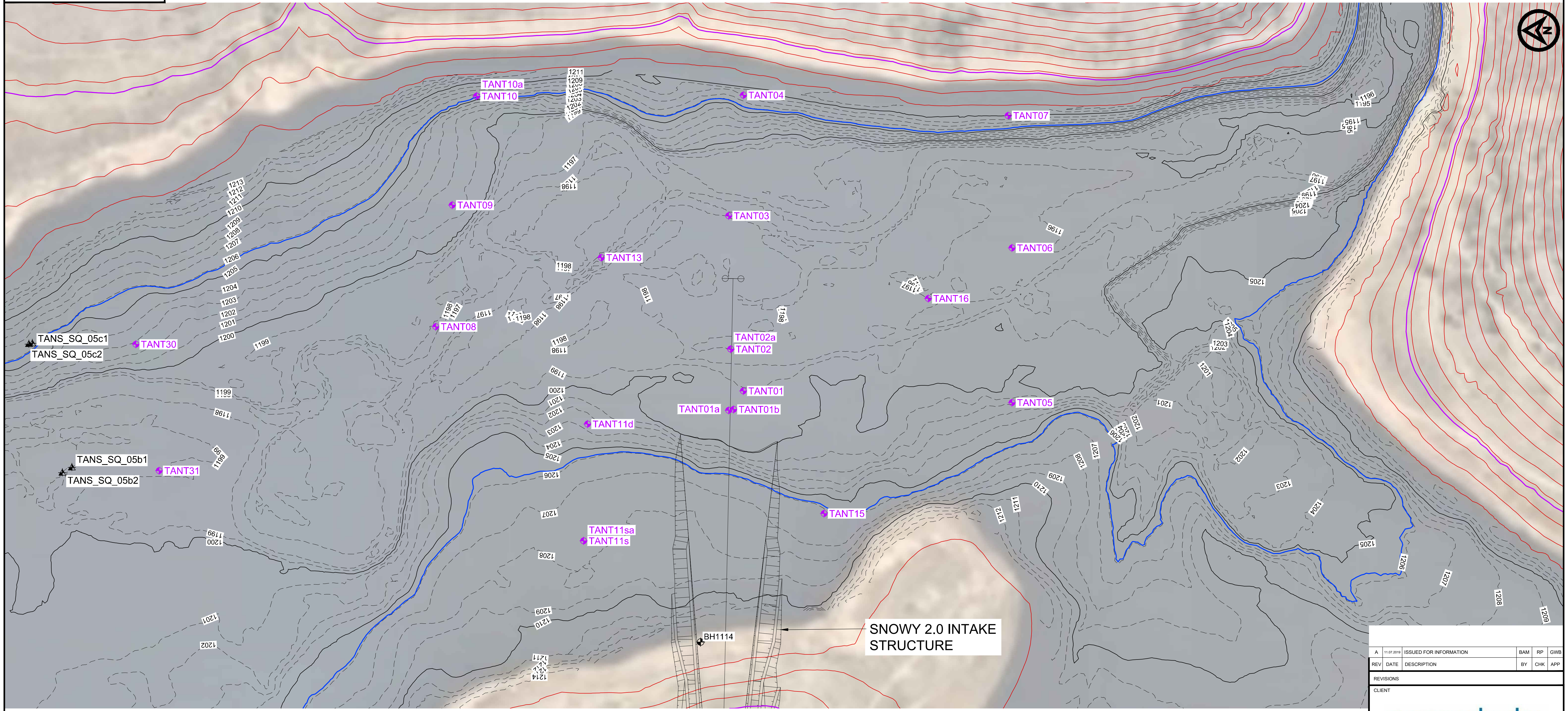
RHDHV, 2019a. Snowy 2.0 Excavated Rock Placement, Talbingo Reservoir Modelling – Construction, prepared for Snowy Hydro, September 2019.

RHDHV, 2019b Navigation Impact Assessment for Talbingo and Tantangara Reservoirs, prepared for Snowy Hydro, September 2019.

Attachment A: Drawings (Core Location)

DRAWING No.
S2-RHD-TAN-SKE-1400

DO NOT SCALE



AS-BUILT CORE COORDINATES TABLE

ID	EASTING	NORTHING
TANT01	649864	6038136
TANT01a	649844	6038151
TANT01b	649845	6038146
TANT02	649907	6038149
TANT02a	649907	6038149
TANT03	650044	6038151
TANT04	650168	6038136
TANT05	649852	6037860
TANT06	650011	6037860
TANT07	650147	6037864
TANT08	649930	6038452
TANT09	650055	6038435
TANT10	650167	6038410
TANT10a	650167	6038410
TANT11d	649830	6038296
TANT11s	649710	6038300
TANT11sa	649710	6038300
TANT13	650001	6038282

AS-BUILT CORE COORDINATES TABLE

ID	EASTING	NORTHING
TANT15	649738	6038053
TANT16	649959	6037946
TANT30	649912	6038760
TANT31	649782	6038736

NOTES

1. BATHYMETRIC SURVEY DATED 26/02/2018. LEVELS TO AHD.
2. ALL LEVELS AND DIMENSIONS ARE SUBJECT TO DESIGN DEVELOPMENT.

LEGEND

– – –	LIDAR CONTOURS
– – –	BATHYMETRIC CONTOURS
———	FULL SUPPLY LEVEL (FSL) = RL 1228.69mAHD
———	MIN. OPERATING LEVEL (MOL) = RL 1205.88mAHD

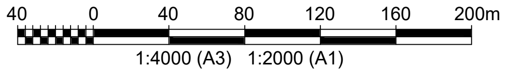
SEDIMENT SAMPLE LOCATIONS:

BH1114	BOREHOLE LOCATION (SMEC, 2018)
TANS_SQ_05c1	GRAB SAMPLE (CARDNO, 2018)
TANT01	AS-BUILT CORE LOCATION (RHDHV, 2019)

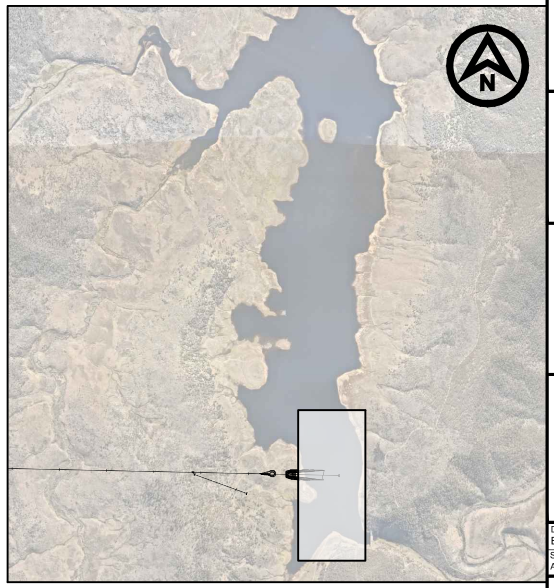
S2 FOR INFORMATION

NOT FOR CONSTRUCTION

AUSTRALIAN HEIGHT DATUM



1:4000 (A3) 1:2000 (A1)



KEY PLAN

REV	DATE	DESCRIPTION	BY	CHK	APP
A	11.07.2019	ISSUED FOR INFORMATION	BAM	RP	GWB

REVISIONS

CLIENT

snowyhydro
renewable energy

PROJECT

SNOWY 2.0
SEDIMENT SAMPLING
INVESTIGATION

TITLE

TANTANGARA RESERVOIR
CORE LOCATION

Royal HaskoningDHV
Enhancing Society Together

Level 14, 56 Berry Street
North Sydney NSW 2060
Australia
Tel +61 2 88545000
Fax +61 2 99290960
Email: project.admin.australia@rhdhv.com
Website: www.royalhaskoningdhv.com

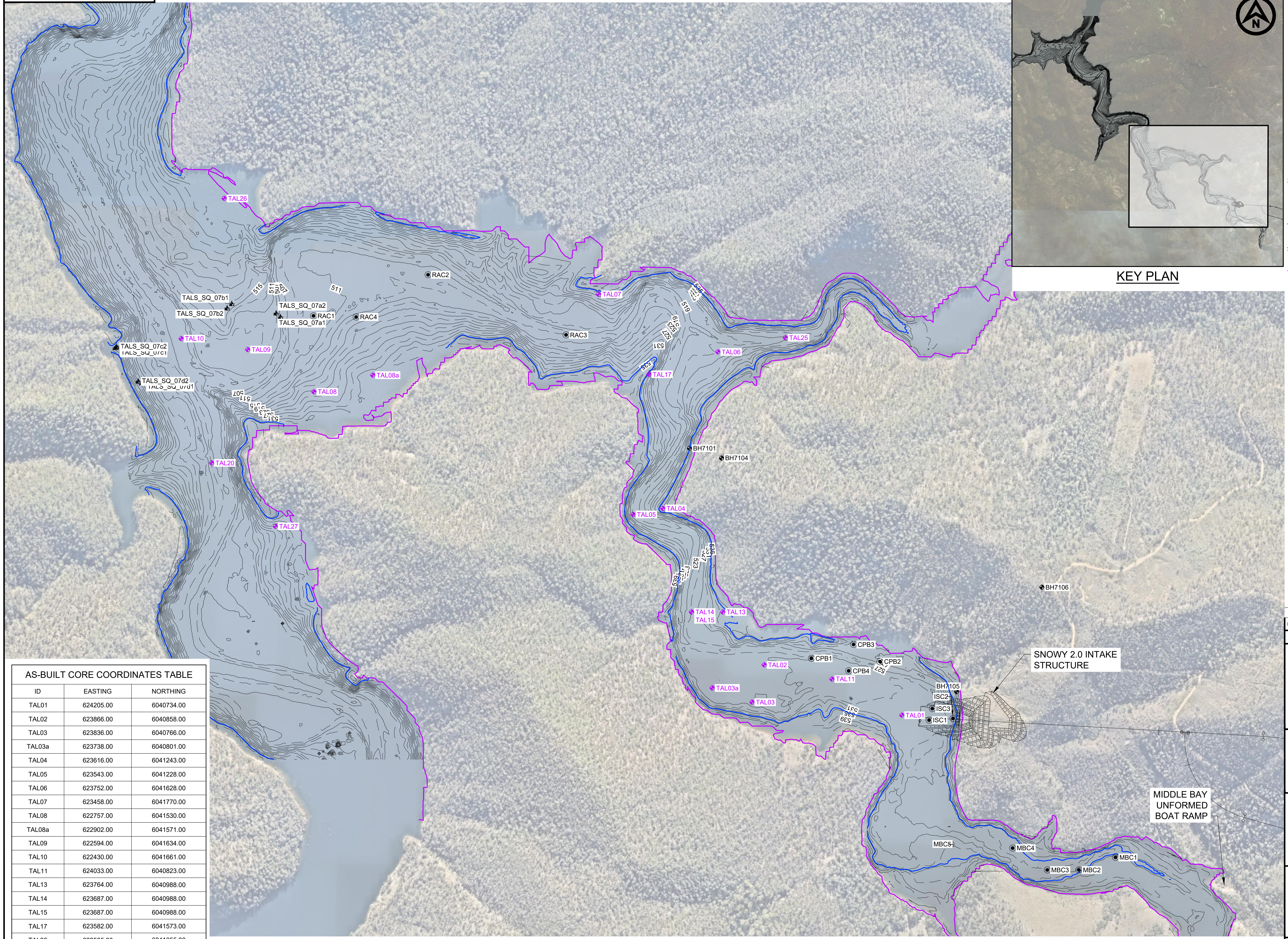
DRAWN	COORD. SYSTEM	DATUM	DATE
BAM	MGA ZONE 55	AHD	11.07.2019

SCALE AT A1 AS SHOWN
REF. S2-RHD-TAN-MOD-1400-GEOTECH

DRAWING No. S2-RHD-TAN-SKE-1400
REVISION A

DRAWING No.
S2-RHD-TAL-SKE-1400

DO NOT SCALE



NOTES

1. BATHYMETRIC SURVEY DATED 26/02/2018, ADDITIONAL PLACEMENT AREA SURVEY PROVIDED AUGUST 2018. LEVELS TO AHD.

LEGEND

— — —	LIDAR CONTOUR
— — —	BATHYMETRIC CONTOUR
——	FULL SUPPLY LEVEL (FSL) = RL 543.19mAHD
——	MIN. OPERATING LEVEL (MOL) = RL 534.35mAHD

SEDIMENT SAMPLE LOCATIONS:

● RAC1	VIBROCORE LOCATION (RHDHV, 2018)
● BH7101	BOREHOLE LOCATION (SMEC/GHD, 2019)
▲ TALS_SQ_07a1	GRAB SAMPLE (CARDNO, 2018)
● TAL01	AS-BUILT CORE (RHDHV, 2019)

AS-BUILT CORE COORDINATES TABLE

ID	EASTING	NORTHING
TAL01	624205.00	6040734.00
TAL02	623866.00	6040858.00
TAL03	623836.00	6040766.00
TAL03a	623738.00	6040801.00
TAL04	623616.00	6041243.00
TAL05	623543.00	6041228.00
TAL06	623752.00	6041628.00
TAL07	623458.00	6041770.00
TAL08	622757.00	6041530.00
TAL08a	622902.00	6041571.00
TAL09	622594.00	6041634.00
TAL10	622430.00	6041661.00
TAL11	624033.00	6040823.00
TAL13	623764.00	6040988.00
TAL14	623687.00	6040988.00
TAL15	623687.00	6040988.00
TAL17	623582.00	6041573.00
TAL20	622505.00	6041355.00
TAL25	623918.00	6041663.00
TAL26	622536.00	6042006.00
TAL27	622662.00	6041199.00

S2 FOR INFORMATION

NOT FOR CONSTRUCTION

AUSTRALIAN HEIGHT DATUM

80 0 80 160 240 320 400m
1:9000 (A3) 1:4500 (A1)

A	11.07.2019	ISSUED FOR INFORMATION	BAM	RP	GWB
REV	DATE	DESCRIPTION	BY	CHK	APP

REVISIONS

CLIENT

snowy hydro
renewable energy

PROJECT

SNOWY 2.0
SEDIMENT SAMPLING
INVESTIGATION

TITLE

TALBINGO RESERVOIR
CORE LOCATION

Royal HaskoningDHV
Enhancing Society Together
Level 14, 56 Berry Street
North Sydney NSW 2060
Australia
Tel +61 2 88545000
Fax +61 2 99290960
Email: project.admin.australia@rhdhv.com
Website: www.royalhaskoningdhv.com

DRAWN	COORD. SYSTEM	DATUM	DATE
BAM	MGA ZONE 55	AHD	11.07.2019

SCALE AT A1 AS SHOWN
REF. S2-RHD-TAL-MOD-1400-GEOTECH

DRAWING No. S2-RHD-TAL-SKE-1400
REVISION A

I:\PA1804\TECHNICAL_DATA\~PA1804 - SNOWY HYDRO DAMS\E02 WORKING DRAWINGS\S2-RHD-TAL-MOD-1400-GEOTECH

Attachment B: Borelog from BG 1114

NON-CORE DRILL HOLE - ENGINEERING LOG

HOLE NO : BH1114
PROJECT NUMBER : 30012060
SHEET : 1 OF 5
FINAL DEPTH : 30.28 m

CLIENT : Snowy Hydro Limited
LOCATION : Tantangara Reservoir
PROJECT : Snowy 2.0 Feasibility Study

POSITION : E: 649605.9, N: 6038179.9 (MGA94 Zone 55) SURFACE ELEVATION : 1218.10 (AHD) INCLINATION° / ORIENTATION° : 90° / N/A

RIG TYPE : Hanjin DB 8D MOUNTING : Track CONTRACTOR : Mulligan Geotechnical HOLE DIA :

DATE STARTED : 14/09/2017 DATE COMPLETED : 16/09/2017 LOGGED BY : KS CHECKED BY : AJB

DRILLING

PROGRESS: DRILLING & CASING: NW 0.0–2.4 m; WB / HW 0.0–5.6 m (arrows to 7.90 m)
DRILLING FLUID: 10% LOSS 0.0–4.0 m; 10% LOSS 4.0–7.90 m
PENETRATION: VE F VH

SAMPLES & FIELD TESTS
SPT 2,2,2 N=4 0.45m
0.60m SPT 4,4,7 N=11 1.05m
SPT 2,2,2 N=4 1.50m
SPT RW/1000mm
2.50m SPT RW/850mm
3.35m SPT 0,1,2 N=3 3.80m
SPT 2,3,5 N=8 4.25m
4.40m SPT 0,0,4 N=4 4.85m
SPT 1,2,3 N=5 5.30m
SPT 0,2,6 N=8 5.75m
SPT 2,6,8 N=14 6.20m
SPT 11,14,22 N=36 6.65m
6.95m SPT 14,16,30 N=46 7.40m
SPT 14,31 N=R 7.71m

ELEVATION: 1218.0, 1217.0, 1216.0, 1215.0, 1214.0, 1213.0, 1212.0, 1211.0, 1210.0, 1209.0
DEPTH (m): 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0

MATERIAL

DEPTH TO	CLASSIFICATION SYMBOL	MATERIAL DESCRIPTION SOIL NAME : plasticity or particle characteristic, colour, secondary and minor components ROCK NAME : grain size, colour, texture and fabric, features, inclusion and minor components	MOISTURE CONDITION	CONSISTENCY RELATIVE DENSITY	STRUCTURE & Other Observations
0.40m	ML	**Clayey SILT**: low plasticity, dark grey, trace organics, some fine grained, sub-rounded sand, organic odour	W	VS	**ALLUVIUM**
1.00m	CH	**Gravelly Sandy CLAY**: high plasticity, red-brown, fine to coarse grained sand, fine grained (<5mm), sub-angular to angular gravel		S St	
1.50m	CH	**Sandy CLAY**: high plasticity, red-brown, fine to coarse grained sand, some fine grained (<2mm), sub-angular gravel		F	
2.80m	SC	**Clayey SAND**: medium to coarse grained, red-brown, high plasticity clay, trace fine grained (<2mm), sub-angular gravel 2.3m: medium grained, angular to sub-angular gravel (<5mm) in diameter	M (>LL)	VL	
4.10m	CH	**CLAY**: high plasticity, red-brown, trace fine to medium grained (<3mm), angular to sub-angular gravel, some fine to medium grained sand	M (=cLL)	VS S F to St	
4.40m	CH	**Sandy CLAY**: high plasticity, dark red-brown, fine to coarse grained, angular to sub-angular sand, some fine grained (<2mm), angular to sub-angular gravel			
5.70m	CH	**CLAY**: high plasticity, red-brown, trace fine grained (<3mm) sand 5.45m: becoming yellow-brown		VS F	
6.05m	SC	**Clayey SAND**: fine grained, yellow-brown, high plasticity clay	M (=PL)	St	**WEATHERED ROCK**
7.90m	SC	**Gravelly Clayey SAND**: fine to coarse grained, yellow-brown, red/brown, high plasticity clay, <15mm, rounded to angular gravel		D	
		Continued as Cored Drill Hole			

METHOD

HA	Hand auger
AS	Auger screwing
ADV	Auger drilling with V bit
ADT	Auger drilling with TC bit
WB	Wash-bore drilling
RR	Rock Roller
NQ	NQ core barrel (42mm diameter)
NMLC	NMLC core barrel (52mm diameter)
HQ	HQ Core Barrel (62mm diameter)

SUPPORT / CASING

C	Casing	Hw	114.3mm
M	Mud	NW	88.9mm
W	Water	PVC	150mm

PENETRATION

VE E F H VH

No Resistance

Very Hard / Refusal

WATER

▼	dd/mm/yy Level on Date shown
▽	Drilling water level
▶	water inflow
◀	water outflow

SAMPLES & FIELD TESTS

B	Bulk Disturbed Sample
D	Disturbed Sample
U	Undisturbed Sample
ES	Environmental Sample
W	Water Sample
PP	Hand Penetrometer (kPa)
SPT	Standard Penetration Test
N	Result of SPT (*=sample taken)
R	Hammer Bouncing / Refusal
U50	Undisturbed Sample (50mm dia)
U75	Undisturbed Sample (75mm dia)
VS	Vane Shear; peak/remouded(kPa)
PT	Push Tube
MC	Moisture Content

CLASSIFICATION SYMBOLS & SOIL DESCRIPTION
Based on Unified Classification System

MOISTURE

D	Dry
M	Moist
W	Wet
PL	Plastic limit
LL	Liquid limit

CONSISTENCY/ RELATIVE DENSITY

VS	- Very Soft
S	- Soft
F	- Firm
St	- Stiff
VSt	- Very Stiff
H	- Hard
Fb	- Friable
VL	- Very Loose
L	- Loose
MD	- Medium Dense
D	- Dense
VD	- Very Dense

See Explanatory Notes for details of abbreviations & basis of descriptions.

SMEC AUSTRALIA

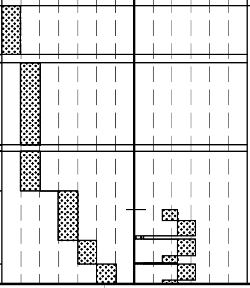
CORED DRILL HOLE - ENGINEERING LOG

HOLE NO : BH1114
PROJECT NUMBER : 30012060
SHEET : 2 OF 5
FINAL DEPTH : 30.28 m

CLIENT : Snowy Hydro Limited
LOCATION : Tantangara Reservoir
PROJECT : Snowy 2.0 Feasibility Study

POSITION : E: 649605.9, N: 6038179.9 (MGA94 Zone 55)   SURFACE ELEVATION : 1218.10 (AHD)   INCLINATION° / ORIENTATION° : 90° / N/A
RIG TYPE : Hanjin DB 8D   MOUNTING : Track   CONTRACTOR : Mulligan Geotechnical   HOLE DIA :
DATE STARTED : 14/09/2017   DATE COMPLETED : 16/09/2017   LOGGED BY : KS   CHECKED BY : AJB
CASING DIAMETER : HW/NW   BARREL (Length) :   BIT :   BIT CONDITION :

DRILLING							MATERIAL				FRACTURES		
PROGRESS: DRILLING & CASING	DRILLING FLUID	TCR% RQD% DRILL DEPTH	GROUND WATER LEVELS	SAMPLES & FIELD TESTS	ELEVATION	DEPTH (m)	GRAPHIC LOG	MATERIAL DESCRIPTION ROCK NAME : grain size, colour, texture and fabric, features, inclusion and minor components	Weathering / Alteration	ESTIMATED STRENGTH Is(50) ● - Axial O - Diametral EL -0.03 VL -0.1 L -0.3 M -1 H -3 VH -10 EH	DEFECT SPACING (mm) 20 60 200 600 2000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
					1218.0	0.0							
					1217.0	1.0							
					1216.0	2.0							
					1215.0	3.0							
					1214.0	4.0							
					1213.0	5.0							
					1212.0	6.0							
					1211.0	7.0							
					1210.0		7.90m	START CORING AT 7.90m					
HMLC	5% LOSS	0% LOSS 0% RQD 8.27			12	8.0	8.27m	**DACITE**: coarse grained, orange brown, extremely weathered, <70mm, sand matrix, clast supported rounded to sub-angular, various components sandstone	XW				
							8.33m	CORE LOSS 0.06m (8.27-8.33)					
		11% LOSS 0% RQD 8.95						**DACITE**: coarse grained, orange brown, distinctly bedded at 10°, trace fine grained gravel 8.37m - 8.42m: band of rounded to sub-rounded gravels (<50mm in diameter) 8.61m - 8.68m: band of rounded to sub-rounded gravels (<50mm in diameter)	HW				
					1209.0	9.0	8.95m 9.00m	CORE LOSS 0.05m (8.95-9.00)					
		3% LOSS 53% RQD						9.67m: becoming grey green	XW MW SW				9.44 Jt, 35°, FLD, Pl, Sm, 13 mm 9.52 Jt, 35°, CT, Pl, Sm, 10 mm 9.64 Jt, 35°, CT, Pl, Sm, 3 mm 9.65 Jt, 35°, Fe SN, Ir, Ro 9.66 Jt, 35°, Fe SN, Ir, Ro 9.79 Jt, 10°, Fe SN, Ir, Ro
						10.0							



DRILLING

AD/T	Auger Drilling with TC Bit
AD/V	Auger Drilling with V Bit
AS	Auger Screwing
DB	Washbore with Drag Bit
DT	Diatube
HMLC	HMLC Core Barrel
HQ3	HQ3 Core Barrel
NMLC	NMLC Core Barrel
NQ3	NQ3 Core Barrel
PQ3	PQ3 Core Barrel
R	Rock Roller
HA	Hand Auger

WATER

▽	dd/mm/yy Water Level on Date shown
▽	Drilling water level
▶	water inflow
◀	water outflow

WEATHERING

FR	Fresh
SW	Slightly Weathered
MW	Moderately Weathered
HW	Highly Weathered
XW	Extremely Weathered

STRENGTH

EH	Extremely High
VH	Very High
H	High
M	Medium
L	Low
VL	Very Low
EL	Extremely Low

ROUGHNESS

POL	Polished
SL	Slickensided
S	Smooth
RF	Rough
VR	Very Rough

DEFECT TYPE

BP	Bedding Plane
CL	Cleavage
CS	Crushed Seam
CZ	Crushed Zone
FC	Fracture
FL	Foliation
IS	Infilled Seam
JT	Joint
SM	Seam
SS	Shear Seam
SZ	Shear Zone
VN	Vein
VO	Void
FA	Fault
DB	Drilling Break
HB	Handling Break

COATING

CN	Clean
CT	Coating (>= 1.0mm)
FILLED	Filled
SN	Stained
VR	Veneer (< 1.0mm)

PLANARITY

CU	Curved
DIS	Discontinuous
IR	Irregular
PR	Planar
ST	Stepped
UN	Undulose

INFILL

CA	Calcite
CLAY	Clay
FE	Iron Oxide
FE CLAY	Iron Oxide Clay
KT	Chlorite
MS	Secondary Mineral
MU	Unidentified Mineral
QZ	Quartz
X	Carbonaceous

See Explanatory Notes for details of abbreviations & basis of descriptions.

CORED DRILL HOLE - ENGINEERING LOG

HOLE NO : BH1114
PROJECT NUMBER : 30012060
SHEET : 3 OF 5
FINAL DEPTH : 30.28 m

CLIENT : Snowy Hydro Limited
LOCATION : Tantangara Reservoir
PROJECT : Snowy 2.0 Feasibility Study

POSITION : E: 649605.9, N: 6038179.9 (MGA94 Zone 55)
SURFACE ELEVATION : 1218.10 (AHD)
INCLINATION° / ORIENTATION° : 90° / N/A

RIG TYPE : Hanjin DB 8D
MOUNTING : Track
CONTRACTOR : Mulligan Geotechnical
HOLE DIA :

DATE STARTED : 14/09/2017
DATE COMPLETED : 16/09/2017
LOGGED BY : KS
CHECKED BY : AJB

CASING DIAMETER : HW/NW
BARREL (Length) :
BIT :
BIT CONDITION :

DRILLING

PROGRESS: DRILLING & CASING: HMLC (to 10.55); HQ3

DRILLING FLUID: 5% LOSS; 5% LOSS; 5% LOSS

TCR% RQD% DRILL DEPTH:
- 3% LOSS, 53% RQD
- 10.55
- 0% LOSS, 95% RQD
- 13.40
- 0% LOSS, 100% RQD
- 16.40
- 0% LOSS, 100% RQD
- 19.40
- 0% LOSS, 93% RQD

GROUND WATER LEVELS:

SAMPLES & FIELD TESTS:
- a=4.07 d=1.61
- a=3.46 d=3.24
- a=2.06 d=2.69
- a=1.81 d=4.72
- a=1.82 d=4.64
- a=3.8 d=2.69
- a=5.5 d=3.07
- a=6.19 d=4.37
- a=7.43 d=3.5
- a=7.45 d=5.8
- a=3.95 d=2.63
- a=5.73 d=3.01
- a=3.67 d=4.19
- a=6.87 d=5.53

ELEVATION	DEPTH (m)
1208.0	10.0
1207.0	11.0
1206.0	12.0
1205.0	13.0
1204.0	14.0
1203.0	15.0
1202.0	16.0
1201.0	17.0
1200.0	18.0
1199.0	19.0
	20.0

MATERIAL

MATERIAL DESCRIPTION
ROCK NAME : grain size, colour, texture and fabric, features, inclusion and minor components

DACITE: coarse grained, brown to orange brown, porphyritic, numerous bedded defects at 0-90°, iron staining, irregular *(continued)*
From 10m: numerous thin quartz vein ~1mm at 0-90°, healed joints planar
10.56m: phenocryst ~15mm diameter, irregular, quartz

10.80m

DACITE: coarse grained, grey blue, porphyritic, with white, grey, green and black mottling/minerals, <10mm, numerous irregular quartz vein ~1mm at 0-90°

11.8m: phenocryst of green mineral <20mm (every 0.15m), irregular shape, angular

12.4m to 12.65m: sub-vertical quartz vein,~3mm thick, stepped

From 13m: zoning apparent in green phenocrysts

14.22m: quartz lamination on healed joint, 50°, planar, 30mm

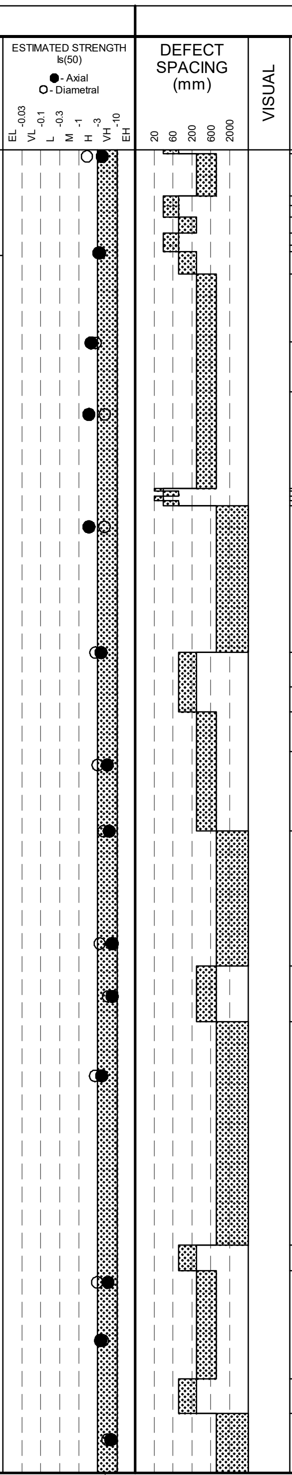
15.45m: quartz lamination on healed joint, 65°, 10-15mm thick, green alteration

15.74m: quartz lamination on healed joint, 55°, 5-25mm thick

18.19m: quartz infill of healed fractures, 55°, planar, ~3-5mm wide

19.21m: quartz vein, closed sub-horizontal 3-5mm thick
19.26m to 19.47m: quartz vein, closed sub-horizontal 3-7mm thick, 75-80°

Weathering / Alteration: SW (to 10.80m); FR



FRACTURES

ADDITIONAL DATA
(joints, partings, seams, zones, etc)
Description, orientation, infilling or coating, shape, roughness, thickness, other

- 9.84 Jt, 10 - 45°, Fe SN, Ir, Ro
- 9.85 Jt, 55°, Fe SN, Ir, Ro, Cl
- 9.97 Jt, 55°, Fe SN, Ir, Ro
- 10.03 Jt, 0 - 30°, Fe SN, Ir, Ro
- 10.35 Jt, 65°, 2-5m, closed Qz infill
- 10.42 Jt, 65°, 2-5m, closed Qz infill
- 10.51 Jt, 65°, 2-5m, closed Qz infill
- 10.63 Jt, 65°, 2-5m, closed Qz infill
- 10.72 Jt, 20°, Fe SN, Ir, Ro
- 10.77 Jt, 15°, Fe SN, Pl, Ro
- 10.94 Jt, 25°, CN, Ir, Ro
- 11.45 Jt, 30°, CN, Ir, Ro
- 11.83 Jt, 0°, CN, Ir, Ro
- 12.56 Jt, 30°, Qz VNR, Pl, Sm
- 12.58 Jt, 45°, Qz VNR, Pl, Ro
- 12.62 FC, 90°, CN, Ir, Ro
- 12.65 Jt, 45°, Qz VNR, Pl, Ro
- 12.69 Jt, 50°, CN, Pl, infilled healed joint
- 13.80 Jt, 35°, CN, Un, Ro
- 14.06 Jt, 10 - 15°, MU VNR, Ir, Ro
- 14.25 Jt, 5°, CN, Ir, Ro
- 14.55 Jt, 40°, CN, Un, Ro
- 15.15 Jt, 25°, CN, Ir, Ro
- 16.17 Jt, 45°, Qz VNR, Pl, Ro
- 16.59 Jt, 45°, Qz VNR, Pl, Ro
- 18.28 Jt, 65°, Qz VNR, Pl, Ro
- 18.47 Jt, 30°, CN, St, Ro
- 19.29 Jt, 70°, Qz FILLED, Pl, Ro
- 19.55 Jt, 35°, Qz VNR, Pl/Un, Ro

DRILLING

AD/T	Auger Drilling with TC Bit
AD/V	Auger Drilling with V Bit
AS	Auger Screwing
DB	Washbore with Drag Bit
DT	Diatube
HMLC	HMLC Core Barrel
HQ3	HQ3 Core Barrel
NMLC	NMLC Core Barrel
NQ3	NQ3 Core Barrel
PQ3	PQ3 Core Barrel
R	Rock Roller
HA	Hand Auger

WATER

▽	dd/mm/yy Water Level on Date shown
▽	Drilling water level
▶	water inflow
◀	water outflow

WEATHERING

FR	Fresh
SW	Slightly Weathered
MW	Moderately Weathered
HW	Highly Weathered
XW	Extremely Weathered

STRENGTH

EH	Extremely High
VH	Very High
H	High
M	Medium
L	Low
VL	Very Low
EL	Extremely Low

ROUGHNESS

POL	Polished
SL	Slickensided
S	Smooth
RF	Rough
VR	Very Rough

DEFECT TYPE

BP	Bedding Plane
CL	Cleavage
CS	Crushed Seam
CZ	Crushed Zone
FC	Fracture
FL	Foliation
IS	Infilled Seam
JT	Joint
SM	Seam
SS	Shear Seam
SZ	Shear Zone
VN	Vein
VO	Void
FA	Fault
DB	Drilling Break
HB	Handling Break

COATING

CN	Clean
CT	Coating (>= 1.0mm)
FILLED	Filled
SN	Stained
VR	Veneer (< 1.0mm)

PLANARITY

CU	Curved
DIS	Discontinuous
IR	Irregular
PR	Planar
ST	Stepped
UN	Undulose

INFILL

CA	Calcite
CLAY	Clay
FE	Iron Oxide
FE CLAY	Iron Oxide Clay
KT	Chlorite
MS	Secondary Mineral
MU	Unidentified Mineral
QZ	Quartz
X	Carbonaceous

See Explanatory Notes for details of abbreviations & basis of descriptions.

SMEC AUSTRALIA

CORED DRILL HOLE - ENGINEERING LOG

HOLE NO : BH1114
PROJECT NUMBER : 30012060
SHEET : 4 OF 5
FINAL DEPTH : 30.28 m

CLIENT : Snowy Hydro Limited
LOCATION : Tantangara Reservoir
PROJECT : Snowy 2.0 Feasibility Study

POSITION : E: 649605.9, N: 6038179.9 (MGA94 Zone 55) SURFACE ELEVATION : 1218.10 (AHD) INCLINATION° / ORIENTATION° : 90° / N/A

RIG TYPE : Hanjin DB 8D MOUNTING : Track CONTRACTOR : Mulligan Geotechnical HOLE DIA :

DATE STARTED : 14/09/2017 DATE COMPLETED : 16/09/2017 LOGGED BY : KS CHECKED BY : AJB

CASING DIAMETER : HW/NW BARREL (Length) : BIT : BIT CONDITION :

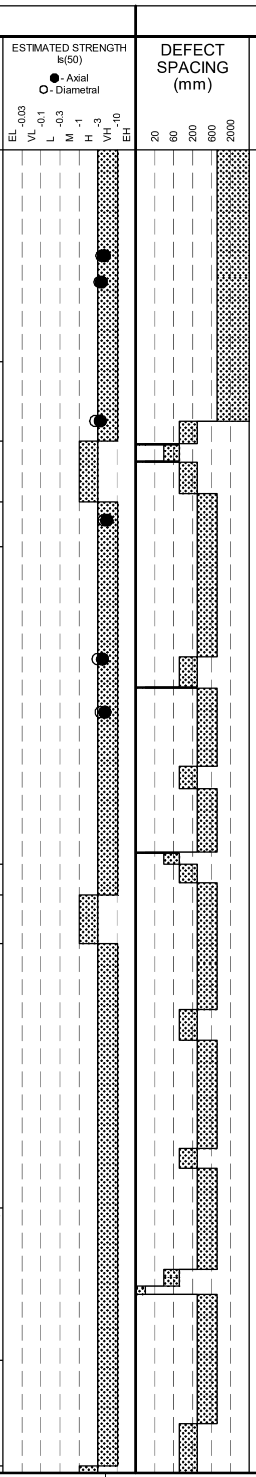
DRILLING

PROGRESS: DRILLING & CASING	DRILLING FLUID	TCR% RQD% DRILL DEPTH	GROUND WATER LEVELS	SAMPLES & FIELD TESTS	ELEVATION	DEPTH (m)
HQ3	5% LOSS (20.0–24.0)	0% LOSS 93% RQD				20.0
				a=4.49 d=3.84 a=3.77 d=3.41	1197.0	21.0
				a=3.53 d=2.63	1196.0	22.0
		22.36 1% LOSS 96% RQD		a=5.21 d=4.37	1195.0	23.0
				a=4.03 d=3.03 a=4.68 d=3.61	1194.0	24.0
	5% LOSS (24.0–30.0)	25.35 0% LOSS 100% RQD			1193.0	25.0
					1192.0	26.0
					1191.0	27.0
		28.35 0% LOSS 86% RQD			1190.0	28.0
					1189.0	29.0
						30.0

MATERIAL

MATERIAL DESCRIPTION
ROCK NAME : grain size, colour, texture and fabric, features, inclusion and minor components

Depth (m)	MATERIAL DESCRIPTION	Weathering / Alteration
20.0	**DACITE**: coarse grained, grey blue, porphyritic, with white, grey, green and black mottling/minerals, <10mm, numerous irregular quartz vein ~1mm at 0-90° *(continued)*	FR
	From 21.6m: becoming grey-green, slightly altered	SW
	From 22.2m: becoming pale green, highly altered	HW
	From 22.66m: becoming grey-green, slightly altered	SW
	From 23m: dark grey-blue	FR
	23.77m to 24m: healed shear zone, fluid movement apparent 24m: phenocryst typically <7-8mm, isolated phenocryst <10mm	
		SW
	25.6m to 25.79m: numerous vesicles irregular, <40mm, long by brown wide crystal infilled, 5-15mm defects some along quartz veins	HW
	From 25.63m: becoming pale green 25.68m: vesicle 15mm×10mm×5mm deep 25.74m: vesicle 20mm×5mm×15mm deep From 26m: becoming grey-green 26.38m: quartz vein, closed ~25°, ~3mm thick, green chlorite alteration 5-10mm either side 26.55m: quartz vein, closed ~30°, ~3mm thick, green chlorite alteration 10-15mm either side	SW
	28m: moderately altered, pale green	MW
	From 28.64m: becoming pale blue 28.82m: vesicle in quartz vein, 20mm×5mm×5mm deep	
	From 29.15m: becoming green	SW
	29.68m: phenocryst of dark yellow mineral	



FRACTURES

VISUAL

ADDITIONAL DATA
(joints, partings, seams, zones, etc)
Description, orientation, infilling or coating, shape, roughness, thickness, other

- 20.96 Jt, 30°, Qz VNR, Pl/Un, Ro
- 22.05 Jt, 45°, Qz VNR, Pl, Ro
- 22.22 SZ, 30°, Qz VNR, Ir, Ro, 5 mm, gravel
- 22.23 Jt, 30°, Qz VNR, Pl/Ir, Ro
- 22.27 Jt, 65°, Cl VNR, Pl, Sm
- 22.35 Jt, 30°, Cl VNR, Pl/St, Sm
- 22.36 Jt, 65°, Cl VNR, Pl, Sm
- 22.60 Jt, 20 - 35°, Cl VNR, Ir, Ro
- 23.15 Jt, 80°, Pl, healed
- 23.83 Jt, 30°, CN, Pl/St
- 24.06 Jt, 10°, CN, Pl, Ro
- 24.07 Jt, 50°, CN, Pl/St, Ro
- 24.66 Jt, 85 - 90°, Qz VNR, Un
- 24.83 Jt, 30°, Qz VNR, Pl, Ro
- 25.31 Jt, 60°, Qz VNR, Pl, Ro
- 25.32 Jt, 30°, Qz VNR, Pl, Ro
- 25.40 Jt, 0°, Qz VNR, Pl/St, Ro
- 25.54 Jt, 0 - 20°, Qz VNR, Ir
- 26.15 Jt, 35°, Qz VNR, Pl/Un, Ro
- 26.50 Jt, 30°, QZ/Fe VNR/SN, Un/Ir
- 26.73 Jt, 30°, QZ/Fe VNR/SN, Un/Ir
- 27.16 Jt, Qz VNR, St/Ir, Ro
- 27.55 Jt, CN, Ir, Ro
- 27.70 Jt, Qz VNR, Pl, closed~4mm
- 28.46 Jt, 30°, CN, Pl/Ir, Ro
- 28.52 Jt, 5°, Cl VNR, Un
- 28.59 Jt, 10°, Cl VNR, Un
- 28.60 FZ
- 28.65 Jt, 10°, Cl VNR, Pl
- 29.63 Jt, 20 - 85°, Qz VNR, Ir/St, Ro
- 29.89 Jt, 50°, Cl VNR, Ir/St, Ro

DRILLING

AD/T	Auger Drilling with TC Bit
AD/V	Auger Drilling with V Bit
AS	Auger Screwing
DB	Washbore with Drag Bit
DT	Diatube
HMLC	HMLC Core Barrel
HQ3	HQ3 Core Barrel
NMLC	NMLC Core Barrel
NQ3	NQ3 Core Barrel
PQ3	PQ3 Core Barrel
R	Rock Roller
HA	Hand Auger

WATER

⊻	dd/mm/yy Water Level on Date shown
⊻	Drilling water level
▶	water inflow
◀	water outflow

WEATHERING

FR	Fresh
SW	Slightly Weathered
MW	Moderately Weathered
HW	Highly Weathered
XW	Extremely Weathered

STRENGTH

EH	Extremely High
VH	Very High
H	High
M	Medium
L	Low
VL	Very Low
EL	Extremely Low

ROUGHNESS

POL	Polished
SL	Slickensided
S	Smooth
RF	Rough
VR	Very Rough

DEFECT TYPE

BP	Bedding Plane
CL	Cleavage
CS	Crushed Seam
CZ	Crushed Zone
FC	Fracture
FL	Foliation
IS	Infilled Seam
JT	Joint
SM	Seam
SS	Shear Seam
SZ	Shear Zone
VN	Vein
VO	Void
FA	Fault
DB	Drilling Break
HB	Handling Break

COATING

CN	Clean
CT	Coating (>= 1.0mm)
FILLED	Filled
SN	Stained
VR	Veneer (< 1.0mm)

PLANARITY

CU	Curved
DIS	Discontinuous
IR	Irregular
PR	Planar
ST	Stepped
UN	Undulose

INFILL

CA	Calcite
CLAY	Clay
FE	Iron Oxide
FE CLAY	Iron Oxide Clay
KT	Chlorite
MS	Secondary Mineral
MU	Unidentified Mineral
QZ	Quartz
X	Carbonaceous

See Explanatory Notes for details of abbreviations & basis of descriptions.

SMEC AUSTRALIA

CORED DRILL HOLE - ENGINEERING LOG

HOLE NO : BH1114
PROJECT NUMBER : 30012060
SHEET : 5 OF 5
FINAL DEPTH : 30.28 m

CLIENT : Snowy Hydro Limited
LOCATION : Tantangara Reservoir
PROJECT : Snowy 2.0 Feasibility Study

POSITION : E: 649605.9, N: 6038179.9 (MGA94 Zone 55) SURFACE ELEVATION : 1218.10 (AHD) INCLINATION° / ORIENTATION° : 90° / N/A

RIG TYPE : Hanjin DB 8D MOUNTING : Track CONTRACTOR : Mulligan Geotechnical HOLE DIA :

DATE STARTED : 14/09/2017 DATE COMPLETED : 16/09/2017 LOGGED BY : KS CHECKED BY : AJB

CASING DIAMETER : HW/NW BARREL (Length) : BIT : BIT CONDITION :

DRILLING							MATERIAL					FRACTURES		
PROGRESS														
DRILLING & CASING	DRILLING FLUID	TCR% RQD% DRILL DEPTH	GROUND WATER LEVELS	SAMPLES & FIELD TESTS	ELEVATION	DEPTH (m)	GRAPHIC LOG		MATERIAL DESCRIPTION ROCK NAME : grain size, colour, texture and fabric, features, inclusion and minor components	Weathering / Alteration	ESTIMATED STRENGTH Is(50) ● - Axial O - Diametral EL -0.03 VL -0.1 L -0.3 M -1 H -3 VH -10 EH	DEFECT SPACING (mm) 20 60 200 600 2000	VISUAL	ADDITIONAL DATA (joints, partings, seams, zones, etc) Description, orientation, infilling or coating, shape, roughness, thickness, other
HQ3	↓	30.28			1188.0	30.0	+ · +	30.28m	29.9m to 30.05m: dense congregation of thin quartz vein, <1mm, 0-89°, irregular From 29.95m: becoming pale green 30.24m: vesicles in quartz vein, <10mmx2mm Hole Terminated at 30.28 m	HW				30.05 Jt, 30°, Qz VNR, Pl/St, Ro 30.13 Jt, 20°, Qz VNR, Pl/St, Ro
					1187.0	31.0								
					1186.0	32.0								
					1185.0	33.0								
					1184.0	34.0								
					1183.0	35.0								
					1182.0	36.0								
					1181.0	37.0								
					1180.0	38.0								
					1179.0	39.0								
						40.0								

DRILLING

AD/T	Auger Drilling with TC Bit
AD/V	Auger Drilling with V Bit
AS	Auger Screwing
DB	Washbore with Drag Bit
DT	Diatube
HMLC	HMLC Core Barrel
HQ3	HQ3 Core Barrel
NMLC	NMLC Core Barrel
NQ3	NQ3 Core Barrel
PQ3	PQ3 Core Barrel
R	Rock Roller
HA	Hand Auger

WATER

▽	dd/mm/yy Water Level on Date shown
▽	Drilling water level
▶	water inflow
◀	water outflow

WEATHERING

FR	Fresh
SW	Slightly Weathered
MW	Moderately Weathered
HW	Highly Weathered
XW	Extremely Weathered

STRENGTH

EH	Extremely High
VH	Very High
H	High
M	Medium
L	Low
VL	Very Low
EL	Extremely Low

ROUGHNESS

POL	Polished
SL	Slickensided
S	Smooth
RF	Rough
VR	Very Rough

DEFECT TYPE

BP	Bedding Plane
CL	Cleavage
CS	Crushed Seam
CZ	Crushed Zone
FC	Fracture
FL	Foliation
IS	Infilled Seam
JT	Joint
SM	Seam
SS	Shear Seam
SZ	Shear Zone
VN	Vein
VO	Void
FA	Fault
DB	Drilling Break
HB	Handling Break

COATING

CN	Clean
CT	Coating (>= 1.0mm)
FILLED	Filled
SN	Stained
VR	Veneer (< 1.0mm)

PLANARITY

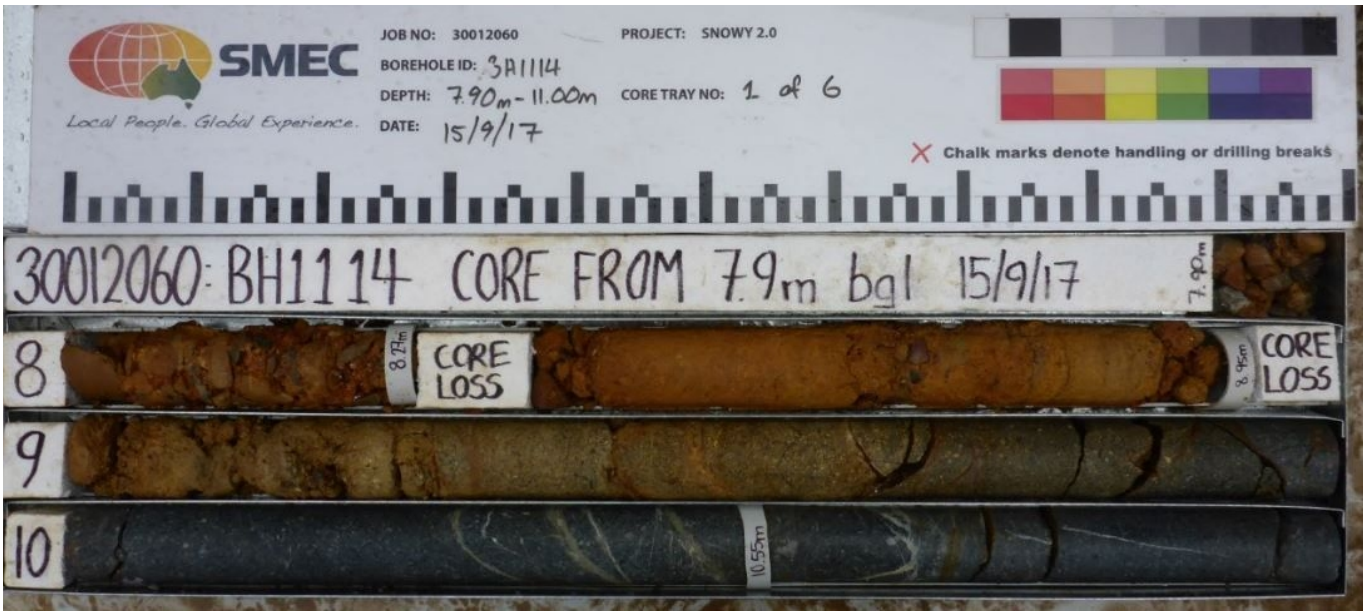
CU	Curved
DIS	Discontinuous
IR	Irregular
PR	Planar
ST	Stepped
UN	Undulose

INFILL

CA	Calcite
CLAY	Clay
FE	Iron Oxide
FE CLAY	Iron Oxide Clay
KT	Chlorite
MS	Secondary Mineral
MU	Unidentified Mineral
QZ	Quartz
X	Carbonaceous

See Explanatory Notes for details of abbreviations & basis of descriptions.

SMEC AUSTRALIA



PointID : BH1114 - 7.90 - 11.00 m - 7.90 - 11.00 m

PointID : BH1114 - 11.00 - 15.00 m - 11.00 - 15.00 m

SMEC	TITLE Snowy Hydro Limited SMEC Snowy Mountains, NSW Snowy 2.0 Feasibility Study Core Photo - BH1114	DRAWN TT	DATE 20/10/2017	
		CHECKED	DATE 20/10/2017	
		SCALE Not To Scale		A4
		PROJECT No 30012060	FIGURE No 1/3	

JOB NO: 30012060
PROJECT: SNOWY 2.0
BOREHOLE ID: BH1114
DEPTH: 15.00m-19.00 m
CORE TRAY NO: 3 of 6
DATE: 15/9/17

PointID : BH1114 - 15.00 - 19.00 m - 15.00 - 19.00 m

JOB NO: 30012060
PROJECT: SNOWY 2.0
BOREHOLE ID: BH1114
DEPTH: 19.0 - 23.0 m
CORE TRAY NO: 4 of 6
DATE: 16/9/17

PointID : BH1114 - 19.00 - 23.00 m - 19.00 - 23.00 m

SMEC	TITLE Snowy Hydro Limited SMEC Snowy Mountains, NSW Snowy 2.0 Feasibility Study Core Photo - BH1114	DRAWN TT	DATE 20/10/2017
		CHECKED	DATE 20/10/2017
		SCALE Not To Scale	A4
		PROJECT No 30012060	FIGURE No 2/3

PointID : BH1114 - 23.00 - 27.00 m - 23.00 - 27.00 m

PointID : BH1114 - 27.00 - 30.28 m - 27.00 - 30.28 m

SMEC	TITLE Snowy Hydro Limited SMEC Snowy Mountains, NSW Snowy 2.0 Feasibility Study Core Photo - BH1114	DRAWN TT	DATE 20/10/2017
		CHECKED	DATE 20/10/2017
		SCALE Not To Scale	A4
		PROJECT No 30012060	FIGURE No 3/3

GrfcTbl DG PHOTO CORE PHOTO 2 PER PAGE SNOWY HYDRO 2.0 MASTER.GPJ | Lib: SMEC 1.04.3 2016-08-08 Prj: SMEC 1.04.0 2016-07-22

Attachment C: Summary of Commissioning Flow Information

Category	Task	Duration (days)	Start	End	Peak Flow (m3/s)	Remarks
Tunnel Filling	Tantangara Rock Plug Removal	400	06-Oct-23	08-Nov-24		Extracted from FG Programme Rev 1
	Talbingo Rock Plug Removal	411	05-Aug-23	18-Sep-24		
	HRT Filling	29	30-Dec-24	27-Jan-25	1.50	Assumed tunnel fill is over 10 days as 29 days is too long
	TRT Filling	28	26-Dec-24	22-Jan-25	0.75	Assumed tunnel fill is over 7 days as 28 days is too long
U06 Wet Commissioning	Total	60	06-Feb-25	06-Apr-25		Extracted from FG Programme Rev 1
	Bearing run, tests @ SNL	3			6.2	Unit not connected to grid so very low water consumption
	Overspeed tests	1			6.2	Unit not connected to grid so very low water consumption
	NER compliance tests - turbine	5			62	Unit will be tested at various setpoints testing the adequecy of the unit performance before proceeding to next setpoint. Proves satisfactory performance to AEMO to allow unit grid connection. Flow will vary from min load to full load for both pump and turbine modes. This is highly dependent on commissioning engineer skill + VH compliance to NER.
	NER compliance tests - pump	5			-45	
	Synchronization	1			62	Will be tested at varying loads up to full load (62m3/s)
	Load rejection tests (turbine mode)	3			62	Will be completed at varying loads up to full load (62m3/s)
	Parametrization, load up/down	3			62	Will be completed at varying loads up to full load (62m3/s)
	Heat Run	1			62	Will be completed at full load (62m3/s)
	Mode change test	4			62	Will be completed for both pump and turbine directions at varying loads up to full load (62m3/s for turbine, 45m3/s for pump)
	Pumping tests	5			-45	Will be completed at varying loads up to full load (45m3/s)
	Turbine Performance tests	5			62	Will be completed at varying loads up to full load (62m3/s)
	Pump Performance tests	5			-45	Will be completed at varying loads up to full load (45m3/s)
U06 Trial Run	Total	60	12-Apr-25	10-Jun-25	62	Market available so varying loads (62m3/s)
U05 Wet Commissioning	Total	90	12-Apr-25	10-Jul-25		
	Bearing run, tests @ SNL	3			68.2	All units will go through the same tests. Peak flow provided, as the previous unit is now commercially available and could be operating during the tests of the subsequent units.
	Overspeed tests	1			68.2	
	NER compliance tests - turbine	5			124	
	NER compliance tests - pump	5			-90	
	Synchronization	1			124	
	Load rejection tests (turbine mode)	3			124	
	Parametrization, load up/down	3			124	
	Heat Run	1			124	
	Mode change test	4			124	
	Pumping tests	5			-90	
	Turbine Performance tests	5			124	
	Pump Performance tests	5			-90	
U05 Trial Run	Total	60	16-Jul-25	13-Sep-25	124	Two units commercially available with peak capacity up to 1
U04 Wet Commissioning	Total	45	16-Jul-25	29-Aug-25		
	Bearing run, tests @ SNL	3			130.2	
	Overspeed tests	1			130.2	
	NER compliance tests - turbine	5			186	
	NER compliance tests - pump	5			-135	
	Synchronization	1			186	
	Load rejection tests (turbine mode)	3			186	
	Parametrization, load up/down	3			186	
	Heat Run	1			186	
	Mode change test	4			186	
	Pumping tests	5			-135	
	Turbine Performance tests	5			186	
	Pump Performance tests	5			-135	
U04 Trial Run	Total	60	02-Sep-25	31-Oct-25	186	Three units commercially available.
U03 Wet Commissioning	Total	60	25-Sep-25	23-Nov-25		
	Bearing run, tests @ SNL	3			192.2	
	Overspeed tests	1			192.2	
	NER compliance tests - turbine	5			248	
	NER compliance tests - pump	5			-180	
	Synchronization	1			248	
	Load rejection tests (turbine mode)	3			248	
	Parametrization, load up/down	3			248	
	Heat Run	1			248	
	Mode change test	4			248	
	Pumping tests	5			-180	
	Turbine Performance tests	5			248	
	Pump Performance tests	5			-180	
U03 Trial Run	Total	60	27-Nov-25	25-Jan-26	248	Four units commercially available.
U02 Wet Commissioning	Total	45	27-Nov-25	10-Jan-26		
	Bearing run, tests @ SNL	3			254.2	
	Overspeed tests	1			254.2	
	NER compliance tests - turbine	5			310	
	NER compliance tests - pump	5			-225	
	Synchronization	1			310	
	Load rejection tests (turbine mode)	3			310	
	Parametrization, load up/down	3			310	
	Heat Run	1			310	
	Mode change test	4			310	
	Pumping tests	5			-225	
	Turbine Performance tests	5			310	
	Pump Performance tests	5			-225	
U02 Trial Run	Total	60	14-Jan-26	14-Mar-26	310	Five units commercially available.
U01 Wet Commissioning	Total	60	14-Jan-26	14-Mar-26		
	Bearing run, tests @ SNL	3			316.2	
	Overspeed tests	1			316.2	
	NER compliance tests - turbine	5			372	
	NER compliance tests - pump	5			-270	
	Synchronization	1			372	
	Load rejection tests (turbine mode)	3			372	
	Parametrization, load up/down	3			372	
	Heat Run	1			372	
	Mode change test	4			372	
	Pumping tests	5			-270	
	Turbine Performance tests	5			372	
	Pump Performance tests	5			-270	
U01 Trial Run	Total	60	18-Mar-26	16-May-26	372	All six units commercially available.
Station Load Rejection Tests		4	14-Mar-26		372	Conduct load rejection tests at gradual power setpoints to check validity of simulations and calibrate model to establish peak conditions under worst cases. Run unit/s up to power setpoint, wait until conditions stabilise (up to 1 hour) and then trip unit. Repeat for each setpoint potentially up to 2000MW in both turbine and pump (370/270m3/s)