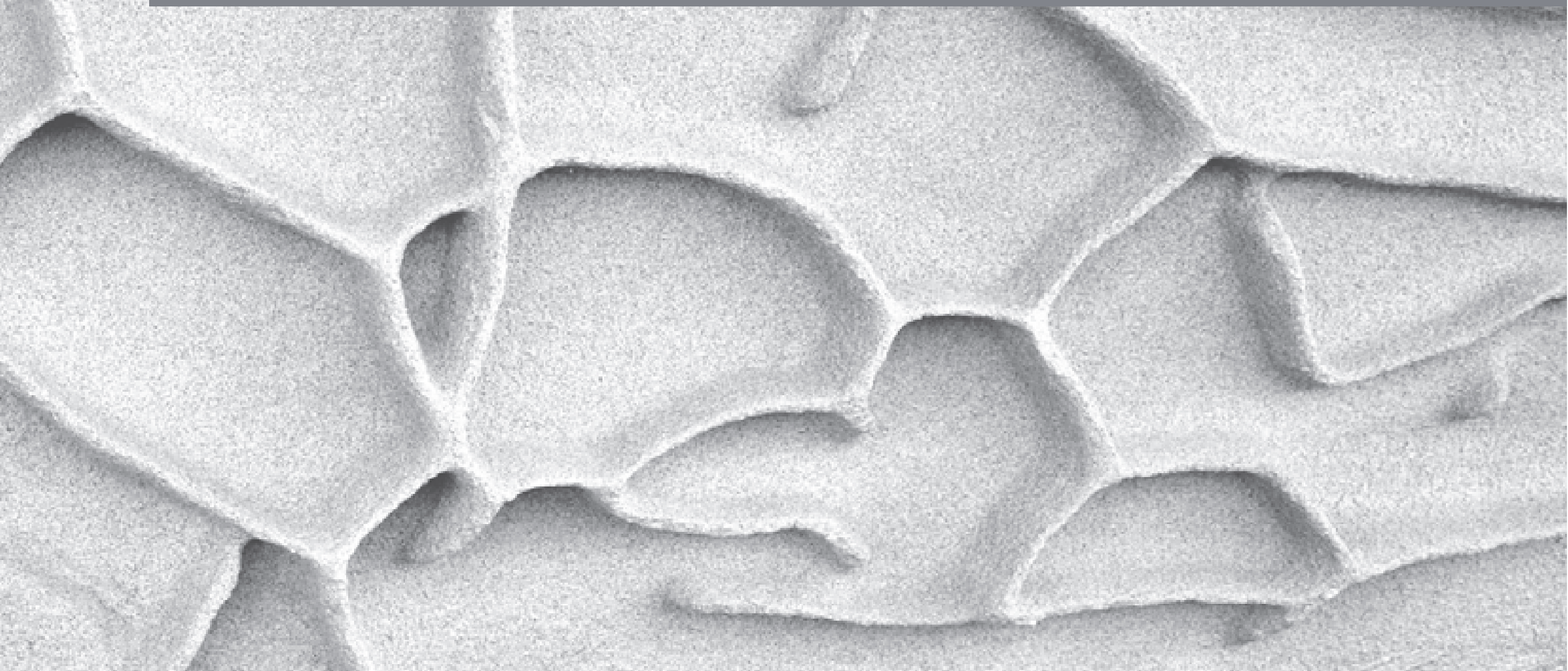
Annexure C

Flood risk assessment



Flood risk assessment

Annexure C to water assessment

Prepared for Snowy Hydro Limited
September 2019

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Flood risk assessment

Annexure C to water assessment

Report Number

J17188 RP84

Client

Snowy Hydro Limited

Date

13 September 2019

Version

v1 Final

Prepared by	**Approved by**
Nick Bartho	**Liz Webb**
Associate Water Resources Engineer	Director
13 September 2019	13 September 2019

Executive Summary

ES1 Introduction

Snowy Hydro Limited (Snowy Hydro) proposes to develop Snowy 2.0, a large-scale pumped hydro-electric storage and generation project which would increase hydro-electric capacity within the existing Snowy Mountains Hydro-electric Scheme (Snowy Scheme). Snowy 2.0 is the largest committed renewable energy project in Australia and is critical to underpinning system security and reliability as Australia transitions to a decarbonised economy.

Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground. The major construction elements of Snowy 2.0 include permanent infrastructure, temporary construction infrastructure, management and storage of extracted rock material and establishing supporting infrastructure. Snowy 2.0 Main Works also includes the operation of Snowy 2.0.

ES2 Report purpose

In order to assess potential groundwater and surface water related issues from the construction and operation of Snowy 2.0, a water assessment (Appendix J) has been prepared as an appendix to the Snowy 2.0 Main Works EIS. The water assessment has several supporting technical reports which are termed annexures. This flood risk assessment (FRA) is annexure C to the water assessment.

The purpose of this report is to:

- describe proposed works that will be undertaken on or in close proximity to flood prone land, and identify potential flood impact mechanisms;
- establish baseline flooding characteristics for key project areas;
- describe potential flood impacts and residual risks, including public safety risks; and
- identify additional mitigation and flood risk management controls that are recommended.

The FRA has been prepared to address the Secretary's Environmental Assessment Requirements for the project which identified the following related to flooding:

- assessment of potential flooding impacts; and
- assessment of public safety risks, including flooding risks.

ES3 Assessment scope and methodology

The focus of this FRA considers flooding characteristics and potential flood impacts for reservoirs and major watercourses for the following key project areas:

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

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

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

Flood modelling, including a range of hydrologic and hydraulic analysis methods, was used to inform an understanding of baseline flooding characteristics for the key project areas. This work was undertaken by GRC Hydro (2019) and is documented in a flood study for Snowy 2.0 Main Works that is provided in Attachment B of this report. Assessment of potential flood impacts for Lobs Hole during construction of Snowy 2.0 Main Works was also informed by flood modelling, and is documented in GRC Hydro (2019).

This FRA presents and interprets the key findings of GRC Hydro (2019), and describes potential flood impacts outside of Lobs Hole where appropriate on the basis of additional qualitative assessment and through reference to proposed water management measures that form part of the project design. Water management measures are described in detail in the water management report (WMR) which is annexure D to the water assessment.

ES4 Baseline flooding characteristics

Baseline flooding characteristics are described for several key project areas, including Talbingo Reservoir and the Yarrangobilly River at Lobs Hole (within the ravine), Tantangara Reservoir and Kellys Plain Creek (on the plateau) and Rock Forest.

Relevant flood mapping is presented in GRC Hydro (2019) in Attachment B.

ES5 Flood impacts and residual risks

ES5.1 Flood impacts

Table ES1 provides a summary of flood impacts for key project areas.

Table ES1 Summary of flood impacts for key project areas

Project area	Location	Construction phase	Operational phase
Ravine	Talbingo Reservoir	• No significant change to flooding characteristics for Talbingo Reservoir is anticipated during construction. • The volume of excavated material to be placed in the reservoir is very small in comparison to the existing storage.	• No significant change to reservoir flooding characteristics during operation due to the placement of excavated material during construction is anticipated. • Proposed Snowy 2.0 scheme operation is not expected to result in significant change to flooding characteristics.

Table ES1 Summary of flood impacts for key project areas

Project area	Location	Construction phase	Operational phase
	Lobs Hole	• The spatial extent and magnitude of impacts throughout Lobs Hole varies by flood frequency. Details of flood impacts, including flood mapping, are contained herein and show predicted construction phase flood impacts. In summary: – For floods up to the 5% annual exceedance probability (AEP), impacts along the Yarrangobilly River are negligible and otherwise are minor and localised. – For the 1% AEP flood, impacts remain minor and localised but start to affect short reaches of the Yarrangobilly River. – For floods larger than 1% AEP, the spatial extent and magnitude of impacts is more widespread throughout Lobs Hole and affect greater length of the Yarrangobilly River. • Predicted changes in flooding characteristics are not anticipated to impact on existing infrastructure or other areas of significance. • The detailed design of temporary and permanent works will need to consider and accommodate the changed flooding characteristics.	• Flooding impacts in Lobs Hole are anticipated to be similar though reduced in both extent and magnitude during the operational phase, relative to the construction phase. • The reduction in extent and magnitude during operation is the result of rehabilitation works and associated permanent landform changes.
Plateau	Tantangara Reservoir	• No significant change to flooding characteristics for Tantangara Reservoir is anticipated. • The volume of excavated material to be placed in the reservoir is small in comparison to the existing storage.	• No significant change to reservoir flooding characteristics due to the placement of excavated material is anticipated during operation. • Proposed Snowy 2.0 scheme operation is not expected to result in significant change to flooding characteristics.
	Kellys Plain Creek	• Temporary surface infrastructure in the vicinity of Kellys Plain Creek largely avoids flood prone land and therefore will not significantly impact on existing flooding characteristics. • Minor increases to peak flood levels are expected to occur from the proposed upgraded road crossing of this watercourse, however these impacts will be localised are not anticipated to impact on existing infrastructure or other areas of significance.	• As described for construction phase impacts, permanent infrastructure will not significantly impact on existing flooding characteristics.
Rock Forest	N/A	• Temporary surface infrastructure associated with the proposed logistic yard at Rock Forest largely avoids flood prone land and therefore will not impact on existing flooding characteristics.	• There will be no permanent flooding impacts at Rock Forest as this site will not be used for operational purposes.

The potential for adverse flood impacts in other project areas during both construction and operational phases is considered minor and manageable with the implementation of proposed stormwater management measures, including measures for clean water management, watercourse diversions and stormwater runoff. These measures are described in the WMR (annexure D to the water assessment).

ES5.2 Residual risks

Management of residual flood risks to the construction workforce is an important consideration, in particular to ensure that effective evacuation and refuge is possible in the event of a major flood occurring. A flood emergency response plan will be prepared as part of the broader Snowy 2.0 Main Works emergency response plans. Several sites, including the accommodation camp, will be established predominantly above PMF levels and so could function as effective flood refuges.

A similar flood emergency response plan will be required to support Snowy 2.0 operations, including to address flood risk to the operational workforce.

ES5.3 Public safety

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

New permanent recreational sites that are proposed to be established at Lobs Hole and Tantangara accommodation camps as part of rehabilitation lie above the level of the PMF. The proposed use of these sites is therefore considered broadly compatible with flooding conditions. Flood risk and emergency response will be considered during future detailed design of proposed final landform changes and associated rehabilitation activities.

ES6 Proposed mitigation measures

Table ES2 provides a summary of proposed additional mitigation measures.

Table ES2 Summary of proposed mitigation

Impact/risk	Measure(s)	Timing	Responsibility
Flooding conditions and impacts	Further consideration of flooding conditions and impacts, including flood modelling where necessary, will be undertaken to support future detailed design of both temporary and permanent works.	Construction Operation	Contractor Snowy Hydro
Residual flood risk	Flood emergency response plans will be developed for both construction and operational phases	Construction Operation	Contractor Snowy Hydro

Table of Contents

Attachments

Tables

Figures

1 Introduction

Snowy Hydro Limited (Snowy Hydro) proposes to develop Snowy 2.0, a large-scale pumped hydro-electric storage and generation project which would increase hydro-electric capacity within the existing Snowy Mountains Hydro-electric Scheme (Snowy Scheme). Snowy 2.0 is the largest committed renewable energy project in Australia and is critical to underpinning system security and reliability as Australia transitions to a decarbonised economy.

Snowy 2.0 will link the existing Tantangara and Talbingo reservoirs within the Snowy Scheme through a series of underground tunnels and a new hydro-electric power station will be built underground. The major construction elements of Snowy 2.0 include permanent infrastructure, temporary construction infrastructure, management and storage of extracted rock material and establishing supporting infrastructure. Snowy 2.0 Main Works also includes the operation of Snowy 2.0.

To assess impacts from the project, an Environmental Impact Statement (EIS) has been prepared (EMM 2019). Chapter 2 of the Snowy 2.0 Main Works EIS describes the construction and operation of the project in detail. The regional location of the Snowy 2.0 project area is shown in Figure 1.1 and the Main Works project area is shown in Figure 1.2.

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

The water assessment has a number of supporting technical reports which are termed annexures. Each annexure has further supporting technical reports which are termed attachments. This flood risk assessment (FRA) is an annexure to the water assessment. The document structure of the technical reports and assessments which support the overall water assessment are shown in Figure 1.3.

1.1 Purpose of this report

The purpose of this report is to:

- describe proposed works that will be undertaken on or in close proximity to flood prone land, and identify potential flood impact mechanisms;
- establish baseline flooding characteristics for key project areas;
- describe potential flood impacts and residual risks, including public safety risks; and
- identify additional mitigation and flood risk management controls that are recommended.

This report references:

- project information in regards to design and construction of temporary and permanent infrastructure, as well as the proposed operation of Snowy 2.0;
- water management measures that are described in detail in the water management report (WMR) (Annexure D to the water assessment);
- a rehabilitation strategy (Appendix F) has been prepared as an appendix to the Snowy 2.0 Main Works EIS; and
- previous studies undertaken on behalf of Snowy Hydro to investigate flooding characteristics for Talbingo and Tantangara reservoirs.

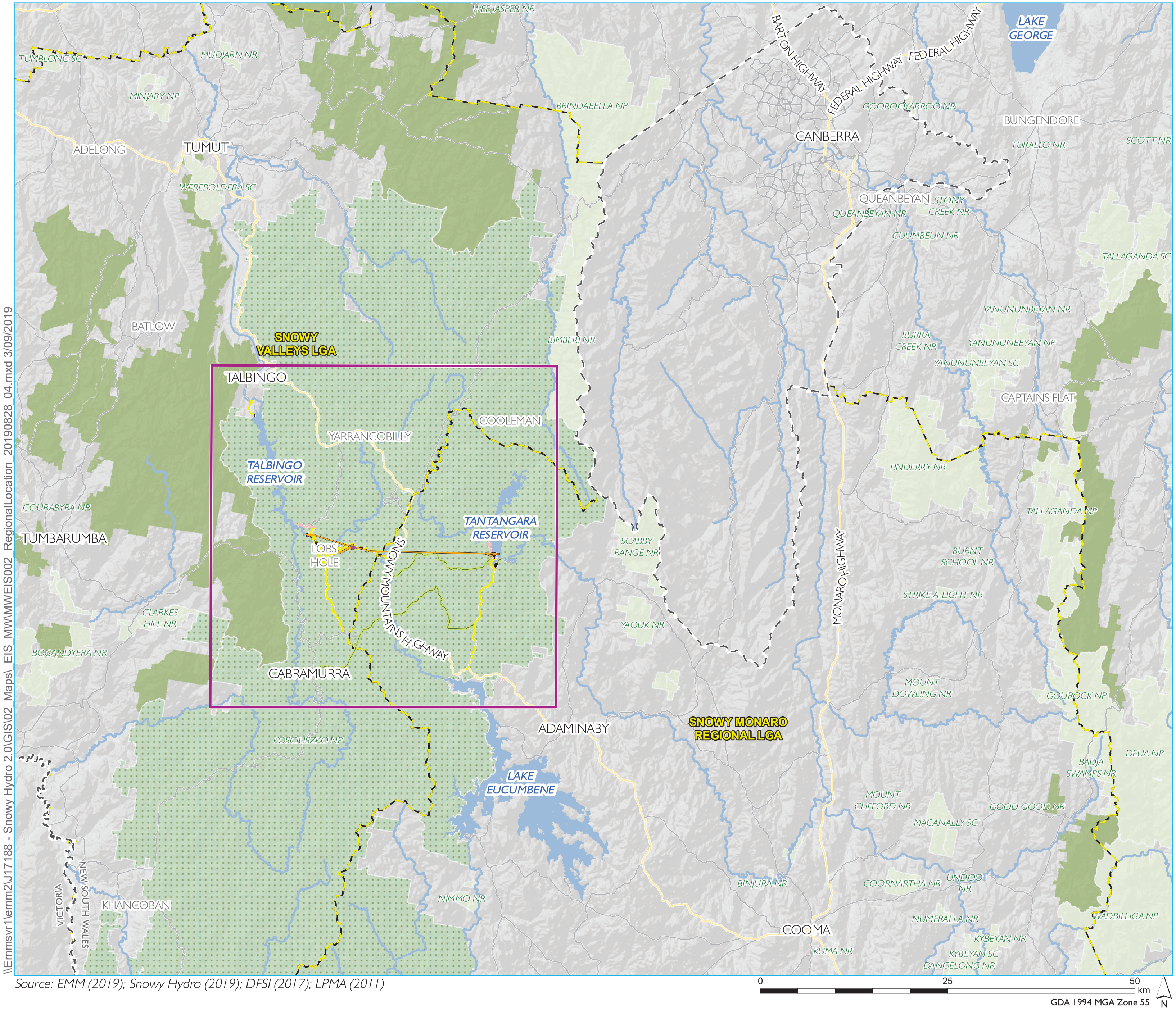
1.2 Structure of this report

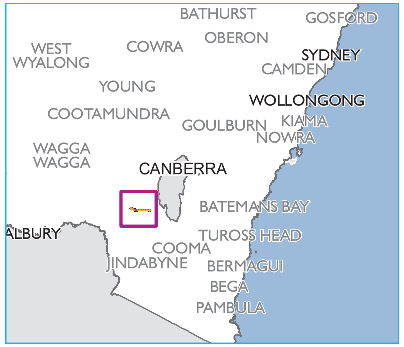
The report is structured as follows:

- Chapter 2 describes the framework of this FRA, including relevant project information, potential flood risks and impact mechanisms, assessment methods, and assessment requirements and guidelines.
- Chapter 3 summarises baseline flooding characteristics for key project areas.
- Chapter 4 describes flood impacts and residual risks, including public safety risks.

Attachment A contains a set of figures showing key project elements for both construction and operational phases.

A flood study for Snowy 2.0 Main Works, including flood mapping for several key project areas, has been prepared by GRC Hydro (2019) and is provided in Attachment B.





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

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KEY

- Project area

Snowy 2.0 Main Works operational elements

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

Snowy 2.0 Main Works construction elements

- Temporary construction compounds and surface works
- Temporary access road

Existing environment

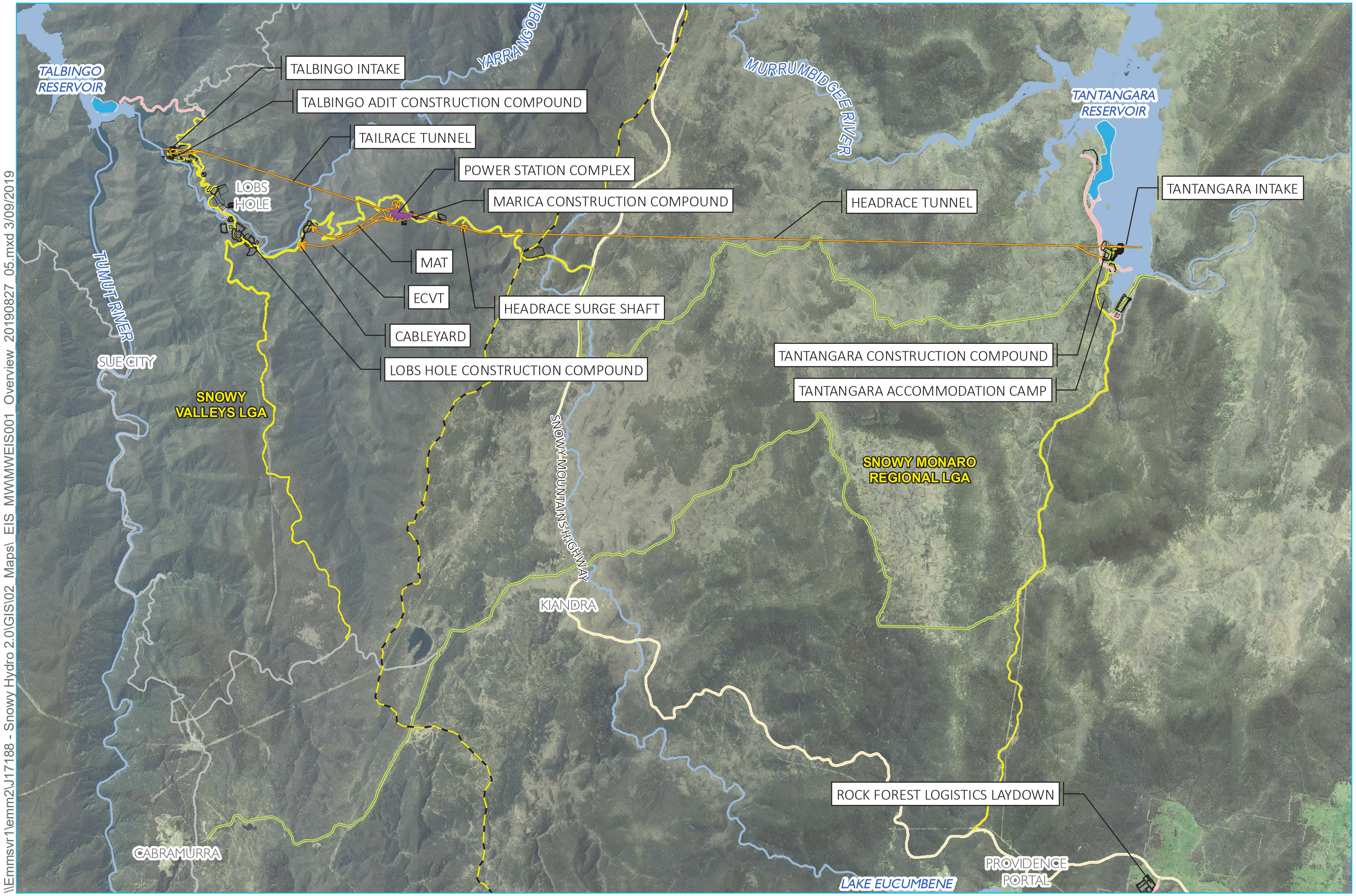
- Main road
- Local road
- Watercourse
- Waterbodies
- Kosciuszko National Park
- NPWS reserve
- State forest
- Local government area boundary
- State boundary

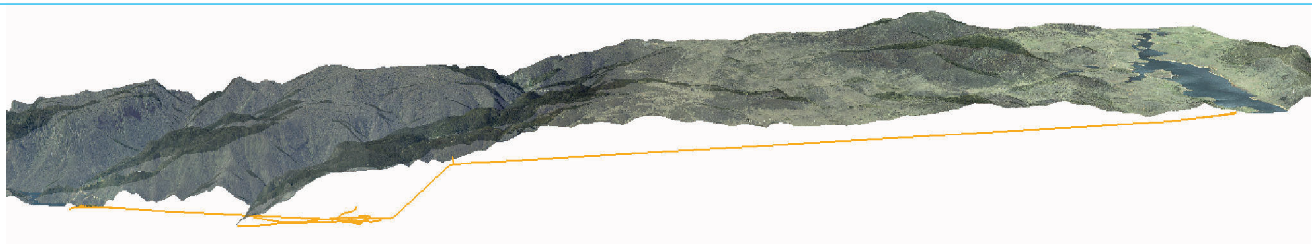
Regional setting

Snowy 2.0
Flood risk assessment
Main Works
Figure 1.1

snowy 2.0

EMM creating opportunities





KEY

Existing environment

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

Snowy 2.0 Main Works operational elements

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

Snowy 2.0 Main Works construction elements

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

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

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Snowy 2.0 project elements

Snowy 2.0
Flood risk assessment
Main Works
Figure 1.2

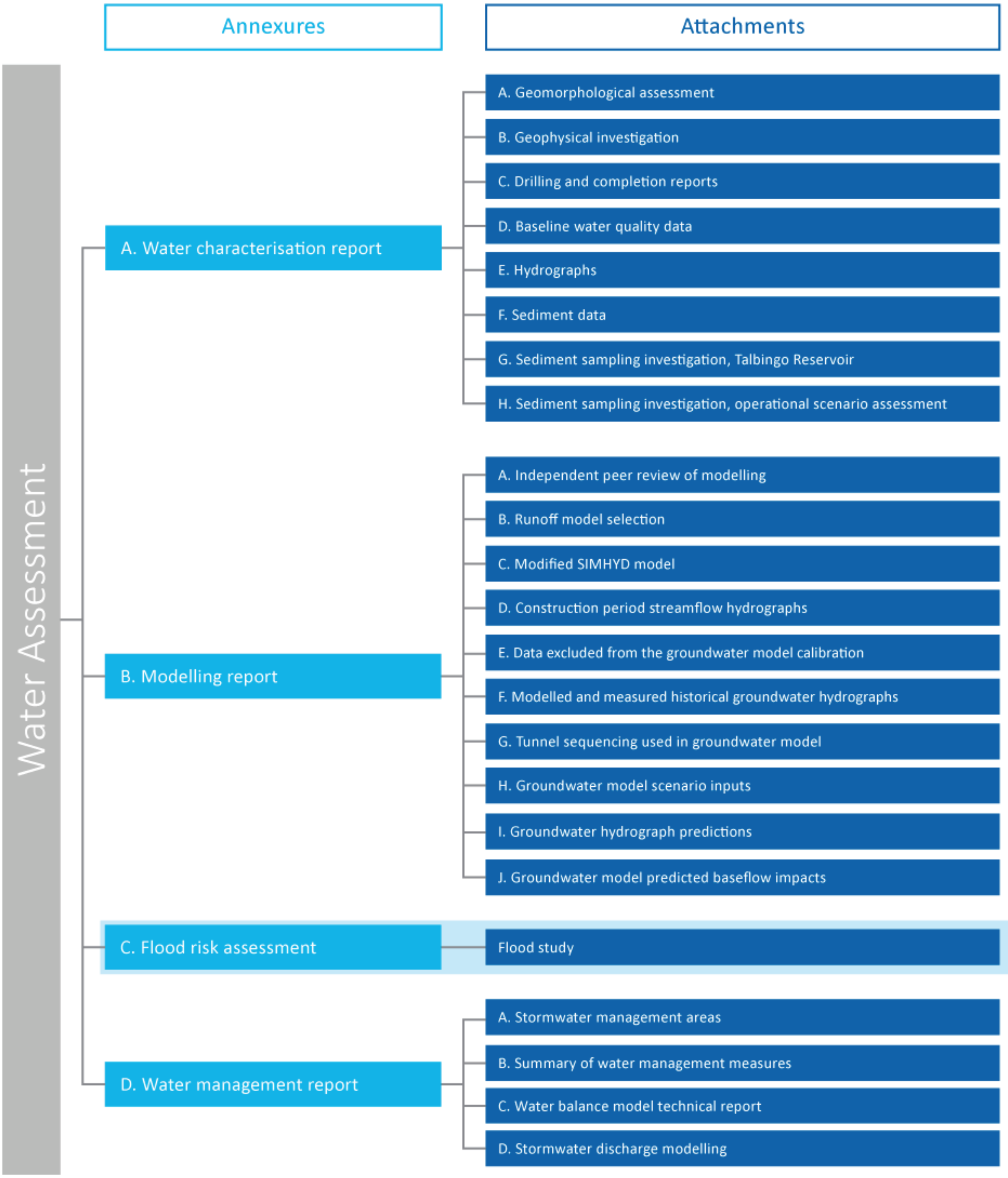


Figure 1.3 Water assessment and FRA structure

2 Assessment framework

2.1 Overview

This chapter describes the framework of this FRA and relevant project information and is structured as follows:

- Section 2.2 describes project information that is referenced in this report, including project phasing, concept design information and relevant hydrologic design standards;
- Section 2.3 describes potential flood impact mechanisms during the construction and operational project phases;
- Section 2.4 describes assessment requirements and relevant guidelines that have been considered in this FRA; and
- Section 2.5 sets out the methodology used to describe and assess residual flood impacts.

2.2 Project information

This section describes project information that is referenced in this report.

2.2.1 Project phases

Snowy 2.0 will comprise a construction phase and an operational phase, both of which are addressed in this report.

Chapter 2 of the EIS describes the Snowy 2.0 Main Works construction phase comprising three broad but overlapping sub-phases, being pre-construction works, construction works (including progressive rehabilitation) and testing and commissioning of permanent infrastructure. For the purpose of describing potential flood impacts and residual risks in this report, these are considered simply as a single phase of construction. The overall construction period is expected to be about 6 years.

The operational phase of Snowy 2.0, including operation and maintenance of permanent infrastructure for the purposes of power generation and pumped storage, will be ongoing.

2.2.2 Concept design information

The following concept design information has been developed for Snowy 2.0 Main Works:

- Disturbance area – describes the maximum extent of surface disturbance. The actual disturbance footprint is expected to be less than the disturbance area.
- Conceptual layout – describes the possible location and footprint of temporary and permanent infrastructure. The conceptual layout will be refined at detailed design but will be within the disturbance area.
- Water management system – a description of the proposed water management approach, including stormwater management, for construction and operational phases.
- Rehabilitation Strategy – a description of the proposed locations and treatments for rehabilitation of disturbed land, prepared by SLR (2019). This forms Appendix F to the Snowy 2.0 Main Works EIS.

Further description of key project elements is provided below, with a focus on surface infrastructure where potential interaction with floodwaters will occur.

2.2.3 Description of key project elements

i Temporary surface infrastructure

Snowy 2.0 Main Works will require multiple construction activities to be carried out concurrently, and across several different sites. Specific details on all Snowy 2.0 Main Works construction activities, as well as a detailed indicative schedule, is provided in Chapter 2 (project description) of the EIS.

Table 2.1 provides an overview of major construction activities and sites for each project location, and provides a reference to a set of figures contained in Attachment A that show the location and layout of temporary (and permanent) infrastructure.

Table 2.1 Summary of proposed construction phase surface infrastructure

Location	Major construction sites and activities	Figure reference
Talbingo Reservoir	• Talbingo Emplacement Area • Talbingo Intake • Talbingo Portal and Construction Compound • Talbingo Adit • Middle Bay Barge Ramp • Access roads and utilities	Figure A1
Lobs Hole	• Main Works Camp • Exploratory Camp • Lobs Hole Substation • Main Yard • Excavated Rock Stockpiles • ECVT Portal and Cableyard • MAT Portal and Buildings • Access roads and utilities	Figure A2
Marica	• Ventilation Shaft • Surge Shaft Yard • Marica Accommodation Camp • Access roads and utilities	Figure A3
Plateau	• Instream barrier • Access roads and utilities	Figure A4
Tantangara Reservoir	• Tantangara Emplacement Area • Tantangara Intake, Portal and Construction Compound • Barge Launch • Tantangara Adit • Tantangara Accommodation Camp • Tantangara Laydown Area • Access roads and utilities	Figure A5

Table 2.1 Summary of proposed construction phase surface infrastructure

Location	Major construction sites and activities	Figure reference
Rock Forest	• Rock Forest Logistics Yard • Access road	Figure A6

ii Permanent surface infrastructure

The following permanent surface infrastructure will be maintained to support the operation of Snowy 2.0:

- water intake structures and surface buildings at Tantangara and Talbingo reservoirs;
- access tunnels (and tunnel portals) to the underground power station comprising the main access tunnel (MAT) and Emergency egress, Communication, and Ventilation tunnel (ECVT). A portal building and helipad will be established 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;
- fish control structures in proximity to Tantangara Reservoir; and
- access roads, permanent bridge structures and barge launch ramps needed for the operation and maintenance of Snowy 2.0 infrastructure.

The majority of surface infrastructure established to support construction activities such as construction pads and accommodation camps will be decommissioned and rehabilitated in accordance with the Rehabilitation Strategy. This will substantially reduce the disturbance area and associated water management risks, including the potential for flood impacts over the longer term.

Rehabilitation in most project areas will result in revegetation of disturbed surfaces. However, indicative final landform designs for several construction sites in the Lobs Hole Main Yard construction compound have been prepared as part of the Rehabilitation Strategy and will involve reshaping of construction work sites, building pads and other temporary landforms prior to revegetation.

Following decommissioning of temporary buildings and infrastructure, accommodation camps at Lobs Hole and Tantangara are intended to be retained for recreational purposes (eg remote campsites). It is expected that any changes to construction phase landforms would be minor only in these areas to support the proposed final land use.

The design of all proposed landform reshaping works will be further developed and finalised and part of detailed design.

Table 2.2 provide a summary of proposed retained infrastructure and recreation sites.

Table 2.2 Summary of proposed retained infrastructure and recreation sites

Location	Retained infrastructure	Recreation sites
Talbingo Reservoir	• Talbingo Intake • Middle Bay Barge Ramp • Access roads and utilities	N/A
Lobs Hole	• Substation • ECVT Portal and Cableyard • MAT Portal • Access roads (including Camp Bridge and Wallaces Creek Bridge) and utilities	• Lobs Hole Accommodation Camp
Marica	• Ventilation Shaft • Surge Shaft Yard • Access roads and utilities	N/A
Plateau	• Access roads and utilities	N/A
Tantangara Reservoir	• Tantangara Intake • Access roads	• Tantangara Accommodation Camp
Rock Forest	N/A	N/A

2.2.4 Water management approach

The proposed water management approach, including stormwater management, is described in detail in the WMR (Annexure D to the water assessment). Project level categories are established to describe each unique aspect of proposed stormwater management approaches. Categories relevant to the scope of this FRA in terms of minimising potential flooding impacts are summarised in Table 2.3.

Table 2.3 Water management categories relevant to flood risk assessment

Phase	Water management category name	Category ID
Construction	Clean water management	WM 1.1
	Temporary watercourse diversions	WM 2.1
	Accommodation camps	WM 2.2
	Construction pads	WM 2.3
	Access roads	WM 2.4
	Large temporary stockpiles	WM 2.5
	Large surface excavations	WM 2.7
Operation	Permanent watercourse diversions	WM 3.1
	Permanent surface infrastructure	WM 3.2
	Permanent access roads	WM 3.3

In summary, and to provide context, stormwater management measures in the above categories include principles and/or design objectives such as:

- establishing hydrologic design standards for temporary and permanent drainage systems;
- avoidance of increasing flow rates in watercourses, where practical;
- provision for scour protection;
- consideration of potential blockage; and
- provision for overland flow paths to convey bypass flows and for flows that exceed the capacity of the drainage system.

The WMR (Annexure D to the water assessment) should be referred to for details of these categories including proposed stormwater management measures.

2.3 Potential flood impact mechanisms

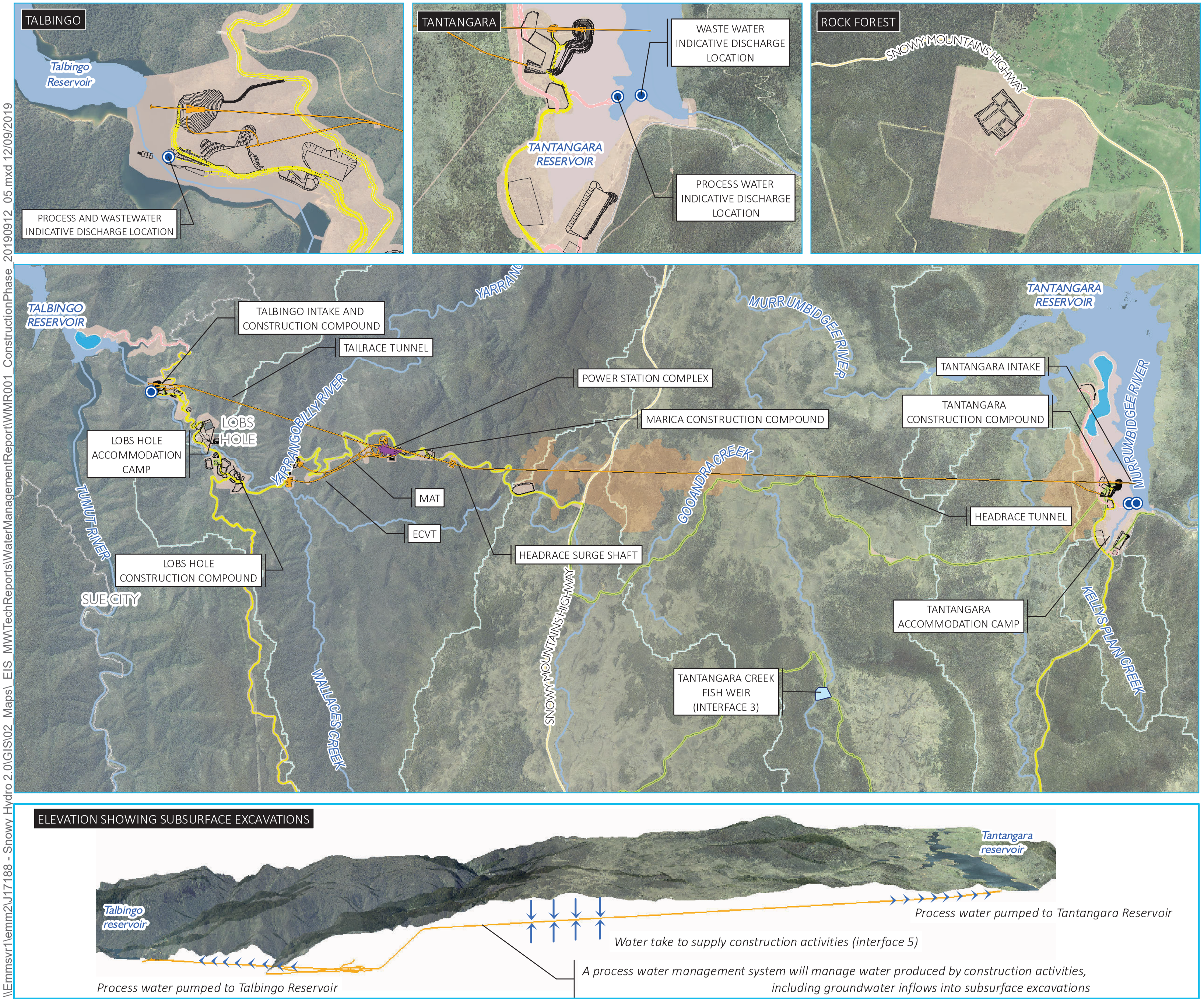
This section conceptually describes expected project interfaces with the water cycle (ie both groundwater and surface water) during the construction and operational project phases, and identifies those interfaces associated with potential residual flood impacts.

2.3.1 Construction phase

Table 2.4 describes the key water cycle interfaces during the construction phase of the project, and identifies those interfaces associated with potential residual flood impacts. Information on the interface locations and mechanisms is also provided. Figure 2.1 shows the location of interfaces relative to the conceptual project layout.

Table 2.4 Water cycle interfaces – construction phase

Interface	Mechanisms	Locations	Potential for flood impacts and where addressed in this report
1 – Impacts to groundwater and connected surface water systems due to subsurface excavations	• Impacts to the shallow groundwater system due to groundwater inflows into subsurface excavations	• Some areas in the plateau	Nil
2 – Stormwater discharges	• Stormwater discharges from areas disturbed by construction of surface works • Stormwater discharges from surface infrastructure that will support broader construction activities	• All watercourses downstream of disturbance areas • Talbingo and Tantangara Reservoirs	No – stormwater management is addressed in the WMR (Annexure D to water assessment).
3 – Instream works and disturbance of waterfront land / flood prone land	• Watercourse diversions • Instream fish barrier • Watercourse crossings (ie bridges and culverts) • Temporary works/sites located on flood prone land	• Some watercourses that are in proximity to the disturbance boundary	Yes – refer Section 4.2
4 – Excavated rock placement	• Reduced storage from spoil placements into Talbingo and Tantangara reservoirs	• Talbingo and Tantangara reservoirs	Yes – refer Section 4.2
5 – Water take to supply construction activities	• Potable water supply • Water supply to construction activities	• Talbingo and Tantangara Reservoirs • Groundwater resources	Nil
6 – Controlled discharges to reservoirs	• Discharges of treated wastewater (ie sewage) • Discharges of treated process or tunnel affected water	• Talbingo and Tantangara Reservoirs	Nil



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

KEY

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

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

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

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

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

Water cycle interfaces - construction phase

Snowy 2.0
Flood risk assessment
Main Works
Figure 2.1

snowy2.0

EMM creating opportunities

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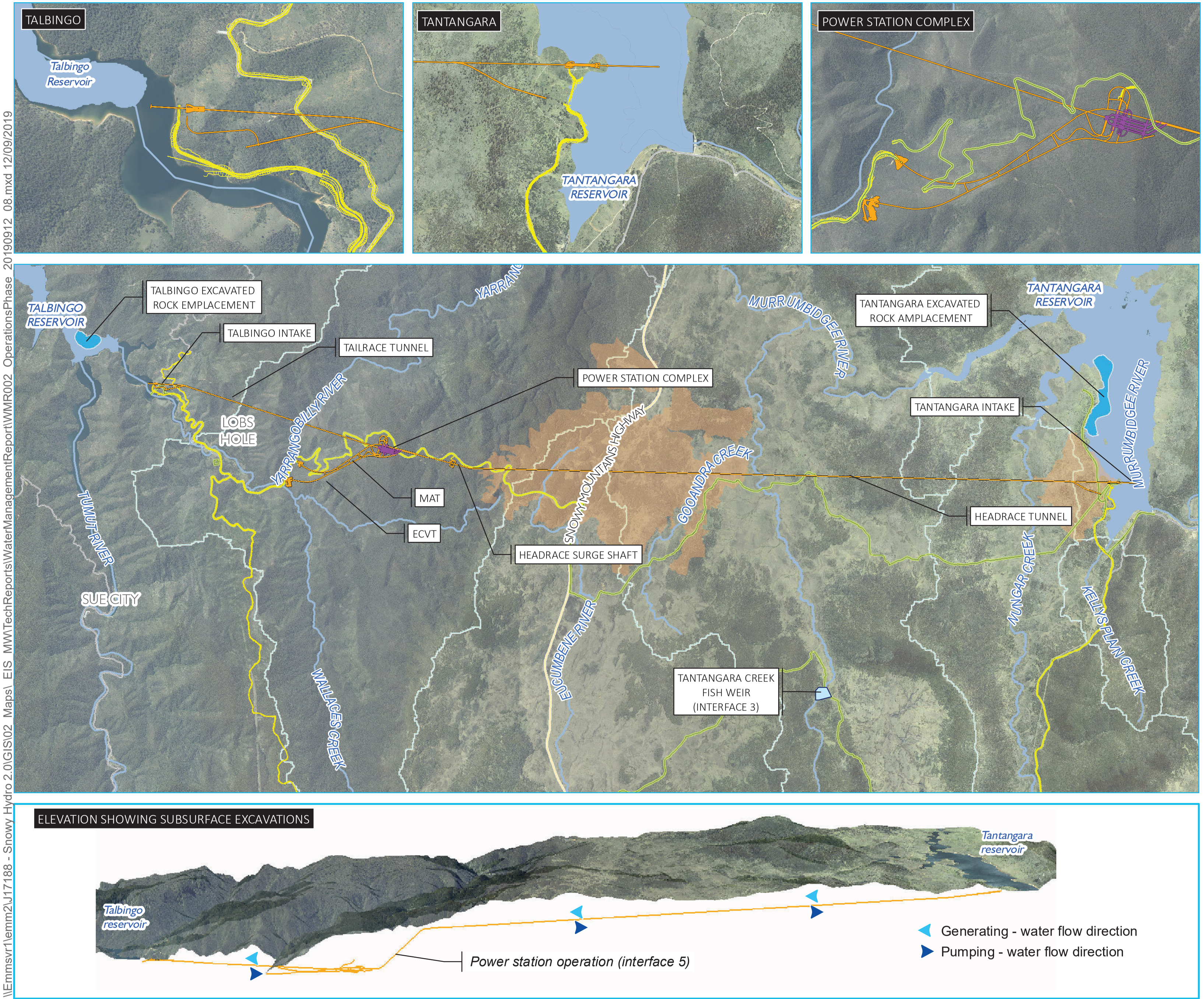
2.3.2 Operational phase

Table 2.5 describes the key water cycle interfaces during the operational phase of the project, and identifies those interfaces associated with potential residual flood impacts. Information on the interface locations and mechanisms is also provided. Figure 2.2 shows the location of interfaces relative to the conceptual layout of permanent infrastructure.

Table 2.5 Water cycle interfaces – operational phase

Interface	Mechanisms	Locations	Potential for flood impacts and where addressed in this report
1 – Impacts to groundwater and connected surface water systems due to subsurface excavations	• Impacts to the shallow groundwater system due to groundwater inflows into subsurface excavations	• Some areas in the plateau	Nil
2 – Stormwater discharges	• Stormwater discharges from permanent infrastructure (ie access roads and tunnel portals)	• All watercourses downstream of permanent infrastructure • Talbingo and Tantangara Reservoirs	No – stormwater management is addressed in the WMR (Annexure D to water assessment).
3 – Instream works and disturbance of waterfront land / flood prone land	• Permanent watercourse diversions • Instream fish barrier • Permanent watercourse crossings (ie bridges and culverts) • Permanent works/sites located on flood prone land	• Some watercourses that are in proximity to the disturbance boundary	Yes – refer Section 4.3
4 – Excavated rock placement	• Reduced storage from spoil placements into Talbingo and Tantangara reservoirs	• Talbingo and Tantangara reservoirs	Yes – refer Section 4.3
5 – Power station operation	• Water exchange between Talbingo and Tantangara reservoirs	• Talbingo and Tantangara Reservoirs	Yes – refer Section 4.3
	• Tailrace tunnel dewatering to enable maintenance access	• Yarrangobilly River	No – tailrace dewatering is addressed in the WMR (Annexure D to water assessment)



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

KEY

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

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

Snowy 2.0 Main Works operational elements (interface 2)
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

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

Water cycle interfaces - operations phase

Snowy 2.0
Flood risk assessment
Main Works
Figure 2.2

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2.4 Assessment requirements and guidelines

2.4.1 Assessment requirements

This FRA has been prepared to address the Secretary's Environmental Assessment Requirements (SEARs) for the project which were issued in July 2019. The SEARs identified the following related to flooding:

- assessment of potential flooding impacts; and
- assessment of public safety risks, including flooding risks.

The level of assessment of these issues in this FRA is proportionate to the likely significance of impacts.

2.4.2 Relevant guidelines

The following guidelines are referenced in this report.

i Australian Rainfall and Runoff

Australian Rainfall and Runoff (Ball et al, 2016) is a national guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia. This guideline is referred to as ARR2016 in the remainder of this document.

ii Floodplain Development Manual

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

2.5 Assessment methodology

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

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

This work was undertaken by GRC Hydro (2019) and is documented in a flood study for Snowy 2.0 Main Works that is provided in Attachment B, which should be referred to for details of the adopted hydrologic and hydraulic analysis methods.

Assessment of potential flood impacts for Lobs Hole during construction of Snowy 2.0 Main Works was also informed by flood modelling, and is documented in GRC Hydro (2019).

This FRA presents and interprets the key findings of GRC Hydro (2019), and describes potential flood impacts outside of Lobs Hole where appropriate on the basis of additional qualitative assessment and through reference to proposed water management measures that form part of the project design. Water management measures are described in detail in the WMR (Annexure D to the water assessment).

3 Baseline conditions

3.1 Overview

This chapter describes baseline flooding characteristics for several key project areas, and is structured as follows:

- Section 3.2 deals with key areas within the ravine, including Talbingo Reservoir and Lobs Hole;
- Section 3.3 deals with key areas on the plateau, including Tantangara Reservoir and Kellys Plain Creek; and
- Section 3.4 deals with Rock Forest.

For Talbingo and Tantangara reservoirs, flooding characteristics are described in terms of peak water levels for flood frequencies up to the PMF.

For flooding at Lobs Hole, Rock Forest and along Kellys Plain Creek, flood mapping is presented for a range of flood frequencies up to the PMF to show flooding characteristics in terms of extent, depth and level. Flood hazard mapping is also presented for these locations based on the hazard classifications and associated vulnerability thresholds documented in AIDR (2017), consistent with guidance in ARR2016. Table 3.1 provides a summary of the hazard classifications and associated vulnerability descriptions.

Table 3.1 Flood hazard classifications and vulnerability descriptions

Hazard classification	Description
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

Source: AIDR (2017)

3.2 Ravine

3.2.1 Talbingo Reservoir

Peak water levels for Talbingo Reservoir for a range of design flood events and scenarios are documented in SKM (2011) and are summarised in Table 3.2. Reservoir key operating levels and spillway crest level are also shown for reference.

Table 3.2 Talbingo Reservoir – existing operating and peak water levels

Characteristic	Water level (m AHD)
MOL	534.3
FSL	543.2
Spillway crest level	544.7
Peak water level - 2% AEP	545.8
Peak water level - 1% AEP	546.1
Peak water level - PMF	552.1

Source: Peak water levels extracted from Figure ES-2 for zero drawdown scenario in SKM, 2011. Other reservoir characteristics provided by Snowy Hydro.

As the analysis presented in SKM (2011) predated ARR2016, GRC Hydro (2019) undertook a review of previously estimated peak water levels to consider whether recent changes to design rainfall data and flood estimation methods for extreme events may significantly influence peak water level estimates for the reservoir. This review found that for the 1% AEP and PMF events, the maximum difference in peak water levels was in the order of +/- 0.1 m. On the basis of these relatively minor differences, the peak water levels shown in Table 3.2 are considered representative of baseline conditions.

3.2.2 Lobs Hole

Flood mapping that presents baseline flooding characteristics for Lobs Hole in terms of flood extent, depth, level and hazard is contained in GRC (2019) in Attachment B. Table 3.3 provides relevant figure references.

Table 3.3 Flood characteristics figure references – Lobs Hole – baseline conditions

Event	Flood extent, depth and level	Flood hazard
20% AEP	Figure A1	Figure A7
5% AEP	Figure A2	Figure A8
1% AEP	Figure A3	Figure A9
0.2% AEP	Figure A4	Figure A10
0.05% AEP	Figure A5	Figure A11
PMF	Figure A6	Figure A12

The flood model results indicate that:

- for the lower magnitude flood events such as the 20% and 5% AEP events, flooding is predominantly confined to the channel and immediate floodplain areas. Full inundation of the floodplain occurs in the 1% AEP and greater magnitude events; and
- for all events except the PMF, most of the flow conveyance occurs within the channel and immediate floodplain areas.

3.3 Plateau

3.3.1 Tantangara Reservoir

Peak water levels for Tantangara Reservoir for a range of design flood events and scenarios are documented in Jacobs (2015) and are summarised in Table 3.4. Reservoir operating levels and spillway crest level are also shown for reference.

Table 3.4 Tantangara Reservoir – existing operating and peak water levels

Characteristic	Level (m AHD)
MOL	1205.8
FSL	1228.7
Spillway crest level	1228.7
2% AEP – peak water level	1230.1
1% AEP – peak water level	1230.3
PMF – peak water level	1236.3

Source: Peak water levels extracted from Figure 6-3 and Table 7-1 for no drawdown scenario in Jacobs, 2015. Other reservoir characteristics provided by Snowy Hydro.

As the analysis presented in Jacobs (2015) predated ARR2016, GRC Hydro (2019) undertook a review of previously estimated peak water levels to consider whether recent changes to design rainfall data and flood estimation methods for extreme events may significantly influence peak water level estimates for the reservoir. This review found that for the 1% AEP and PMF events, the maximum difference in peak water levels was in the order of +/- 0.2 m. On the basis of these relatively minor differences, the peak water levels shown in Table 3.4 are considered representative of baseline conditions.

3.3.2 Kellys Plain Creek

Flood mapping that presents baseline flooding characteristics for Kellys Plain Creek in terms of flood extent, depth, level and hazard is contained in GRC (2019) in Attachment B. Table 3.5 provides relevant figure references.

Table 3.5 Flood characteristics figure references – Kellys Plain Creek – baseline conditions

Event	Flood extent, depth and level	Flood hazard
1% AEP	Figure B1	Figure B3
PMF	Figure B2	Figure B4

The flood model results indicate that:

- floodwaters generally follow the alignment of Kellys Plain Creek for all events up to the PMF, with no major breakouts or flow diversions;
- peak flood levels in the lower reaches of Kelly Plain Creek are influenced by reservoir water levels;
- shallow overland flows approach Kellys Plain Creek from the east in several locations; and

- flood hazard is classified generally as H5 along Kellys Plain Creek for the 1% AEP event, rising to H6 for the PMF. Shallow overland flows the approach Kellys Plain Creek from the east are classified generally as H1 flood hazard.

3.4 Rock Forest

Flood mapping that presents baseline flooding characteristics for Rock Forest in terms of flood extent, depth, level and hazard is contained in GRC (2019) in Attachment B. Table 3.6 provides relevant figure references.

Table 3.6 Flood characteristics figure references – Rock Forest – baseline conditions

Event	Flood extent, depth and level	Flood hazard
1% AEP	Figure C1	Figure C3
PMF	Figure C2	Figure C4

The flood model results indicate that:

- floodwaters generally follow the alignment of watercourses for all events up to the PMF, with no major breakouts or flow diversions; and
- flood hazard is classified generally as H1 in the vicinity of Rock Forest for all events up to the PMF, with some isolated areas of greater hazard (up to H5).

4 Flood impacts and residual risks

4.1 Overview

This chapter describes predicted flood impacts and residual risks for several key project areas, and is structured as follows:

- Section 4.2 deals with construction phase impacts and risks; and
- Section 4.3 deals with operational phase impacts and risks.

4.2 Construction phase

4.2.1 Flood impacts

i Ravine

a Talbingo Reservoir

During construction approximately 2.8 million m^3 of excavated material will be placed in Talbingo Reservoir in dedicated emplacement areas ranging between the bed of the reservoir to just above FSL. This volume of material corresponds to about 0.3% of the total storage currently available in the reservoir.

Accordingly, no significant change to flooding characteristics for Talbingo Reservoir is anticipated as the volume of excavated material to be placed in the reservoir is very small in comparison to the existing storage.

During construction there is also potential for Talbingo Reservoir to be held at lower levels within the current operating range to facilitate construction activities. The impact (if any) on flood levels in the reservoir would be to lower peak water levels for any given frequency of flooding.

b Lobs Hole

Flood modelling was undertaken to predict changes to existing flooding characteristics along the Yarrangobilly River in Lobs Hole as a result of proposed construction phase works. This work was undertaken by GRC Hydro, and a detailed methodology is presented in GRC Hydro, 2019 in Attachment B. In summary:

- The hydraulic model developed to represent baseline conditions was modified to include details of proposed temporary landforms. This was based on available concept design data and required some interpretation of that data and reasonable assumptions to fill gaps in understanding, noting that design details are still preliminary and subject to further design development.
- The modified hydraulic model was rerun for design flood events ranging from 20% AEP to the PMF.
- For each design event, impacts to baseline flooding characteristics were quantified by calculating the difference in peak flood levels and flood hazard.

Results for both construction phase flooding characteristics (in terms of flood extent, depth, level and hazard) and impacts (change in flood level and hazard) are presented spatially in flood mapping, which is contained in GRC (2019) in Attachment B.

Table 4.1 provides relevant figure references for construction phase flooding characteristics.

Table 4.1 Flood characteristics figure references – Lobs Hole – construction phase conditions

Event	Flood extent, depth and level	Flood hazard
20% AEP	Figure A13	Figure A19
5% AEP	Figure A14	Figure A20
1% AEP	Figure A15	Figure A21
0.2% AEP	Figure A16	Figure A22
0.05% AEP	Figure A17	Figure A23
PMF	Figure A18	Figure A24

Table 4.2 provides relevant figure references for construction phase flood impacts.

Table 4.2 Flood impacts figure references – Lobs Hole – construction phase

Event	Change in peak flood level	Change in flood hazard
20% AEP	Figure A25	Figure A31
5% AEP	Figure A26	Figure A32
1% AEP	Figure A27	Figure A33
0.2% AEP	Figure A28	Figure A34
0.05% AEP	Figure A29	Figure A35
PMF	Figure A30	Figure A36

The flood model results indicate that:

- For floods up to the 5% AEP event, flood impacts along the Yarrangobilly River are negligible. Localised increases in peak flood level around proposed infrastructure (eg access roads, bridges and construction pads) of up to about 0.5 m occur in several locations on the floodplain or along minor tributaries.
- For the 1% AEP event, increases in peak flood level remain localised around proposed infrastructure including the proposed Camp Bridge crossing of the Yarrangobilly River and Wallaces Creek bridge, and are limited to about 0.5 m.
- For larger magnitude flood events, increases in peak flood level are more widespread and affect greater length of the Yarrangobilly River.

The flood model results also indicate that changes to flood hazard are typically minor and/or localised across the full range of modelled events.

The impacts described above are not anticipated to impact on existing infrastructure or other areas of significance, however the detailed design of temporary and permanent works will need to consider and accommodate the changed flooding characteristics.

It is noted that potential changes to local catchment runoff regimes in Lobs Hole that may occur due to construction activities and proposed water management practices were not represented in the flood modelling. However, changes to local runoff regimes will have negligible influence on Yarrangobilly River flooding characteristics given its large upstream contributing catchment area in comparison to the relatively smaller disturbance area. Management of stormwater discharges from temporary (and permanent) infrastructure and residual impacts is addressed in the WMR (Annexure D to water assessment).

ii Plateau

a Tantangara Reservoir

During construction approximately 2.8 million m^3 of excavated material will be placed in Tantangara Reservoir in dedicated emplacement areas ranging between the MOL to just above FSL. This volume of material corresponds to about 1.1% of the total storage currently available in the reservoir.

Accordingly, no significant change to flooding characteristics for Tantangara Reservoir is anticipated as the volume of excavated material to be placed in the reservoir is small in comparison to the existing storage.

During construction there is also potential for Tantangara Reservoir to be held at lower levels within the current operating range to facilitate construction activities. The impact (if any) on flood levels in the reservoir would be to lower peak water levels for any given frequency of flooding.

b Kellys Plain Creek

With reference to Figure B2 in Attachment B, temporary surface infrastructure in the vicinity of Kellys Plain Creek (eg Tantangara accommodation camp and laydown area) largely avoids flood prone land and therefore will not significantly impact on existing flooding characteristics. It is noted that shallow flooding shown across the laydown area can be attributed to minor overland flows that can be readily managed through implementation of temporary drainage and runoff controls, with no potential for significant flood impacts.

Minor increases to peak flood levels along Kellys Plain Creek are expected to occur from the proposed upgraded road crossing of this watercourse, however these impacts would be localised are not anticipated to impact on existing infrastructure or other areas of significance.

iii Rock Forest

With reference to Figure C2 in Attachment B, temporary surface infrastructure associated with the proposed logistic yard at Rock Forest largely avoids flood prone land and therefore will not impact on existing flooding characteristics.

iv Other project areas

The potential for adverse flood impacts in other project areas is considered minor and manageable with the implementation of proposed management measures relevant construction phase water management categories identified in Section 2.2.4, which include:

- clean water management (WM 1.1);
- temporary watercourse diversions (WM 2.1);
- accommodation camps (WM 2.2);
- construction pads (WM 2.3);
- access roads (WM 2.4);
- large temporary stockpiles (WM 2.5); and

- large surface excavations (WM 2.7).

4.2.2 Residual flood risks and public safety

Whilst temporary works avoid flood prone land where possible, some infrastructure will unavoidably need to be constructed on flood prone land. Management of residual flood risks to the construction workforce is an important consideration, in particular to ensure that effective evacuation and refuge is possible in the event of a major flood occurring.

With reference to Figures A18 and B2 in Attachment B, flood refuge above the level of the PMF will be available at several sites (including Lobs Hole and Tantangara accommodation camps) in key flood risk areas around Talbingo and Tantangara reservoirs, Lobs Hole and Kellys Plain Creek.

Snowy Hydro routinely monitor weather conditions and have sufficient expertise, systems and monitoring equipment in place to identify weather systems that have potential to produce flood producing rainfall. Accordingly, it is expected that adequate warning will be provided to enable to safe and orderly evacuation of all site personnel to designated flood refuge locations above the level of the PMF. A flood emergency response plan to describe and document flood warning and evacuation will be prepared as part of the broader Snowy 2.0 Main Works emergency response plans.

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

4.3 Operational phase

4.3.1 Flood impacts

i Ravine

a Talbingo Reservoir

As described for construction phase impacts, no significant change to flooding characteristics for Talbingo Reservoir due to the placement of excavated material is anticipated.

Proposed Snowy 2.0 scheme operation, including reservoir management, is described in Chapter 2 (project description) of the EIS. Talbingo Reservoir will have additional operational functions owing to it acting as a tail storage for Snowy 2.0 power generation, and this will likely result in variations to longer term water level trends and rates of rise and fall when compared to historic operations. However, reservoir levels will continue to be operated within the MOL and FSL approved for the existing Snowy Scheme. On this basis, no significant change to flooding characteristics is anticipated.

b Lobs Hole

Flooding impacts relative to baseline conditions in Lobs Hole during operation of Snowy 2.0 are anticipated to be similar to construction phase impacts, though reduced in both extent and magnitude as a result of rehabilitation works and associated permanent landform changes.

Flood modelling will be necessary to inform future detailed design of associated landform changes and associated rehabilitation activities.

ii Plateau

a Tantangara Reservoir

As described for construction phase impacts, no significant change to flooding characteristics for Tantangara Reservoir due to the placement of excavated material is anticipated.

Proposed Snowy 2.0 scheme operation, including reservoir management, is described in Chapter 2 (project description) of the EIS. Tantangara Reservoir will have 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. This will likely result in variations to longer term water level trends and rates of rise and fall when compared to historic operations. However, reservoir levels will continue to be operated within the MOL and FSL approved for the existing Snowy Scheme. On this basis, no significant change to flooding characteristics is anticipated.

b Kellys Plain Creek

As described for construction phase impacts, permanent infrastructure will not significantly impact on existing flooding characteristics. Expected minor and localised flood impacts along Kellys Plain Creek during construction would be permanent as the upgraded Quarry Trail is intended to be retained to support Snowy 2.0 operations. Other temporary works in this project areas would be rehabilitated.

iii Rock Forest

There will be no permanent flooding impacts at Rock Forest as this site will not be used for operational purposes.

iv Other project areas

The potential for adverse flood impacts in other project areas is considered minor and manageable with the implementation of proposed management measures for relevant operational phase water management categories identified in Section 2.2.4, which include:

- permanent watercourse diversions (WM 3.1);
- permanent surface infrastructure (WM 3.2); and
- permanent access roads (WM 3.3).

4.3.2 Residual flood risks and public safety

Similar to the construction phase, a flood emergency response plan will be required to support Snowy 2.0 operations, including to address flood risk to the operational workforce. It is anticipated this will be prepared by Snowy Hydro.

New permanent recreational sites that are proposed to be established at Lobs Hole and Tantangara accommodation camps as part of rehabilitation lie above the level of the PMF. The proposed use of these sites is therefore considered broadly compatible with flooding conditions. Flood risk and emergency response will be considered during future detailed design of proposed final landform changes and associated rehabilitation activities.

4.4 Summary of proposed mitigation measures

A summary of proposed additional mitigation measures to reduce flood-related impacts of the construction and operational activities of Snowy 2.0 Main Works is provided in Table 4.3.

Table 4.3 Mitigation measures for flood impacts and residual risks

Impact/risk	Measure(s)	Timing	Responsibility
Flooding conditions and impacts	Further consideration of flooding conditions and impacts, including flood modelling where necessary, will be undertaken to support future detailed design of both temporary and permanent works.	Construction Operation	Contractor Snowy Hydro
Residual flood risk	Flood emergency response plans will be developed for both construction and operational phases.	Construction Operation	Contractor Snowy Hydro

References

AIDR 2017, *Australian Disaster Resilience Handbook 7 – Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia*, 3rd edition, edited and published by the Australian Institute for Disaster Resilience on behalf of the Australian Government Attorney-General's Department.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I (Editors) 2016, A*ustralian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia.

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Jacobs 2015, *Tantangara Dam Update of Hydrology and Spillway Capacity Assessment*, prepared for Snowy Hydro Limited by Jacobs.

NSW Department of Infrastructure, Planning and Natural Resources (DIPNR), 2005, *Floodplain Development Manual*, NSW Government.

SKM 2011, *Talbingo Dam Flood Hydrology*, prepared for Snowy Hydro Limited by SKM.

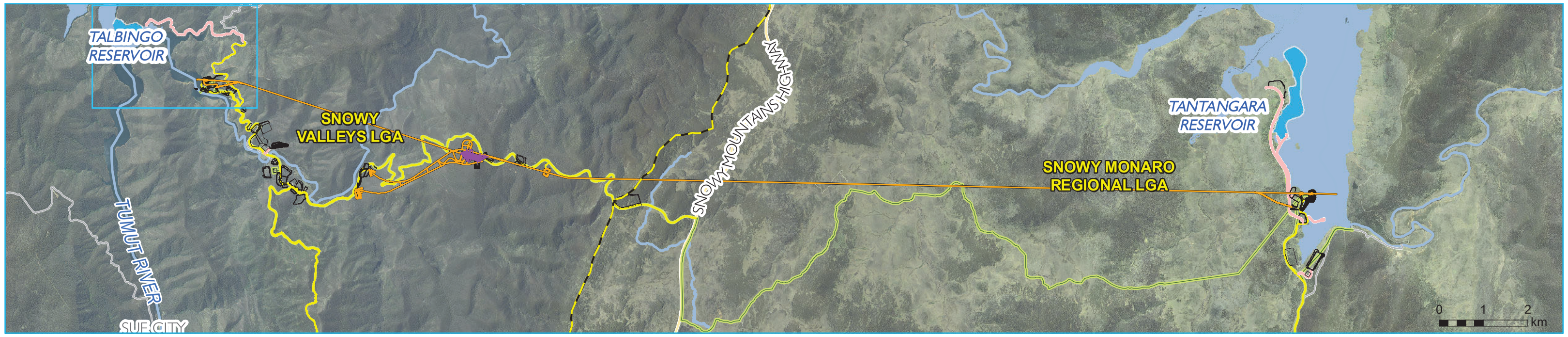
SLR 2019, *Snowy 2.0 Main Works Rehabilitation Strategy*, prepared for Future Generation Joint Venture by SLR Consulting Australia Pty Limited.

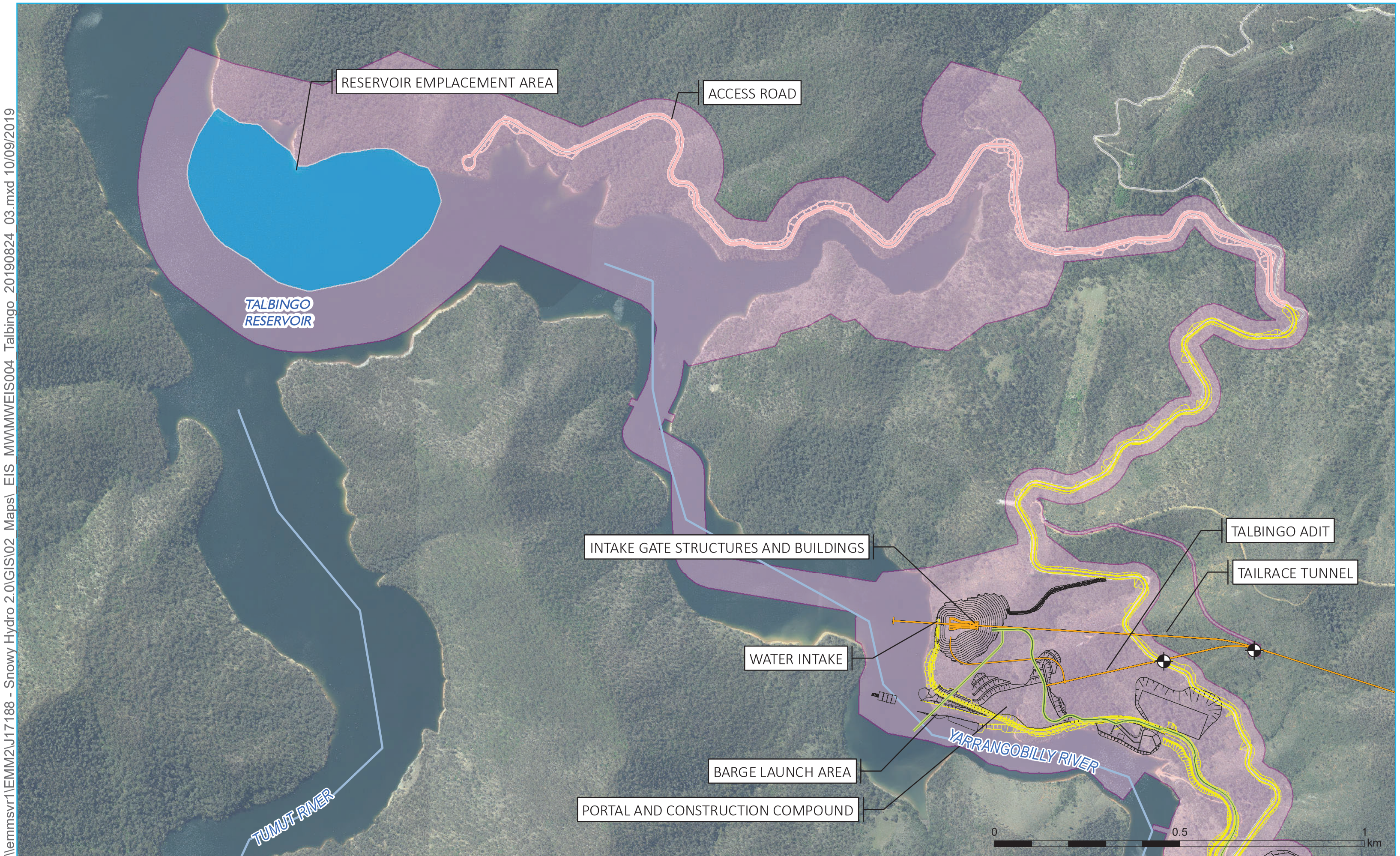
Abbreviations

Abbreviation	Description
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ECVT	Emergency Egress, Communication and Ventilation Tunnel
EIS	Environmental Impact Statement
FSL	Full supply level
km	Kilometres
KNP	Kosciuszko National Park
m	Metres
MAT	Main Access Tunnel
MOL	Minimum operating level
MW	Megawatts
MWh	Megawatt hours
NEM	National Electricity Market
NSW	New South Wales
PMF	Probable Maximum Flood
SEARs	Secretary's Environmental Assessment Requirements

Attachment A

Figures showing key project elements





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.

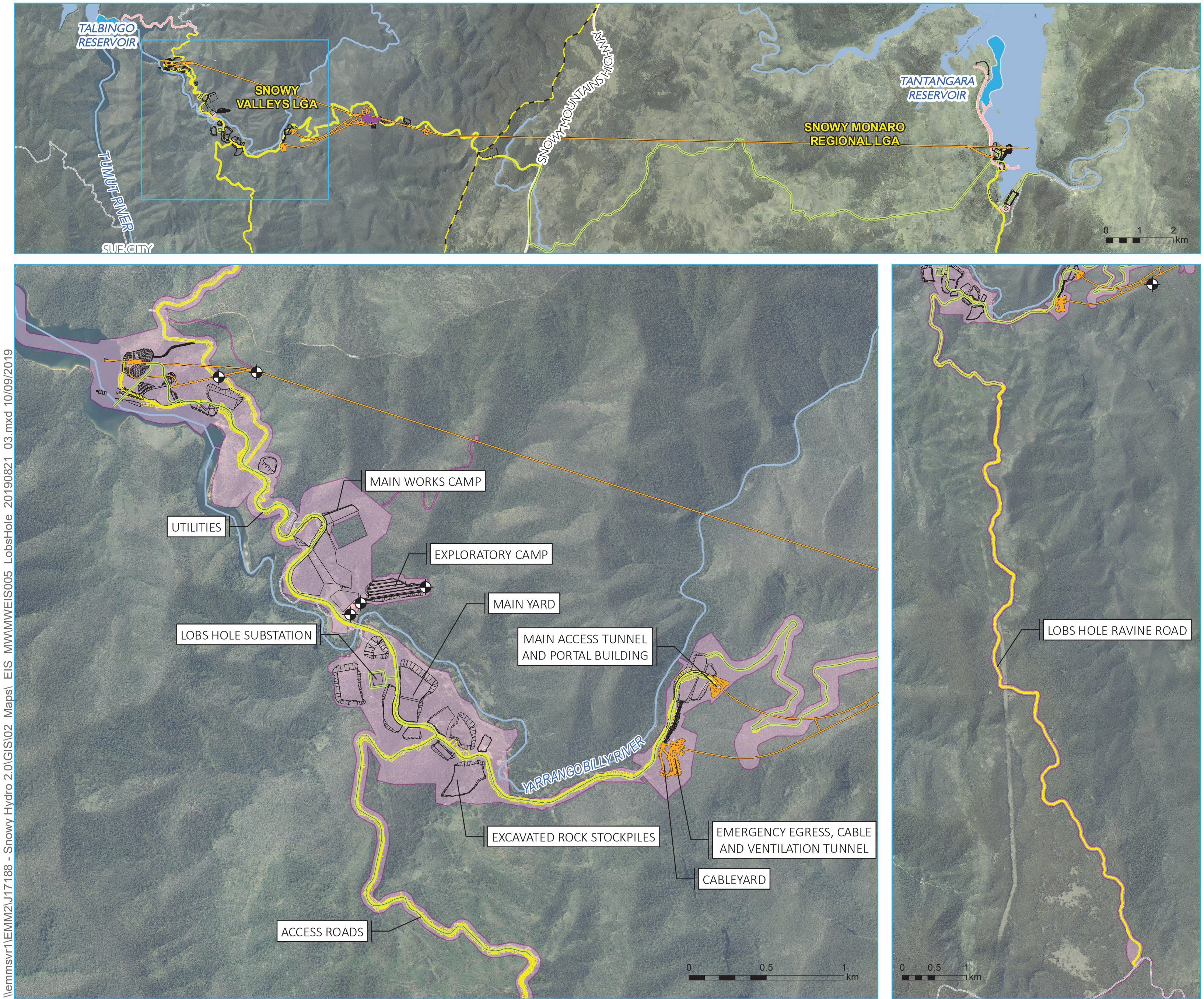
Talbingo Reservoir - project elements

Snowy 2.0
Flood risk assessment
Main Works
Figure A1

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWMWEIS004_Talbingo_20190824_03.mxd 10/09/2019

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

GDA 1994 MGA Zone 55



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

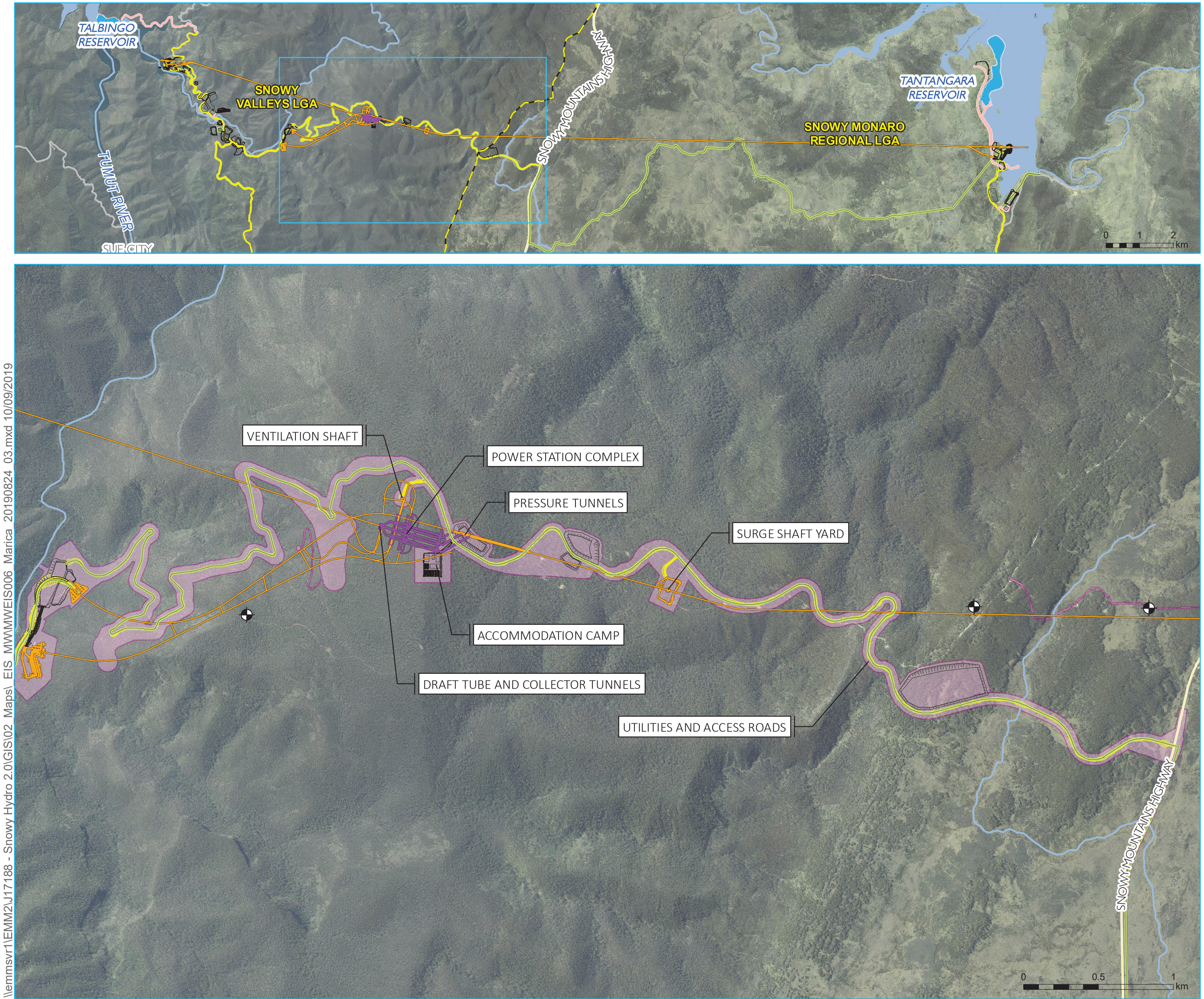
Snowy 2.0 Main Works construction elements
- Temporary construction compounds and surface works
- Temporary access road
- Geotechnical investigation
- Indicative rock emplacement area
- Disturbance area*

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
Flood risk assessment
Main Works
Figure A2

snowy 2.0
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

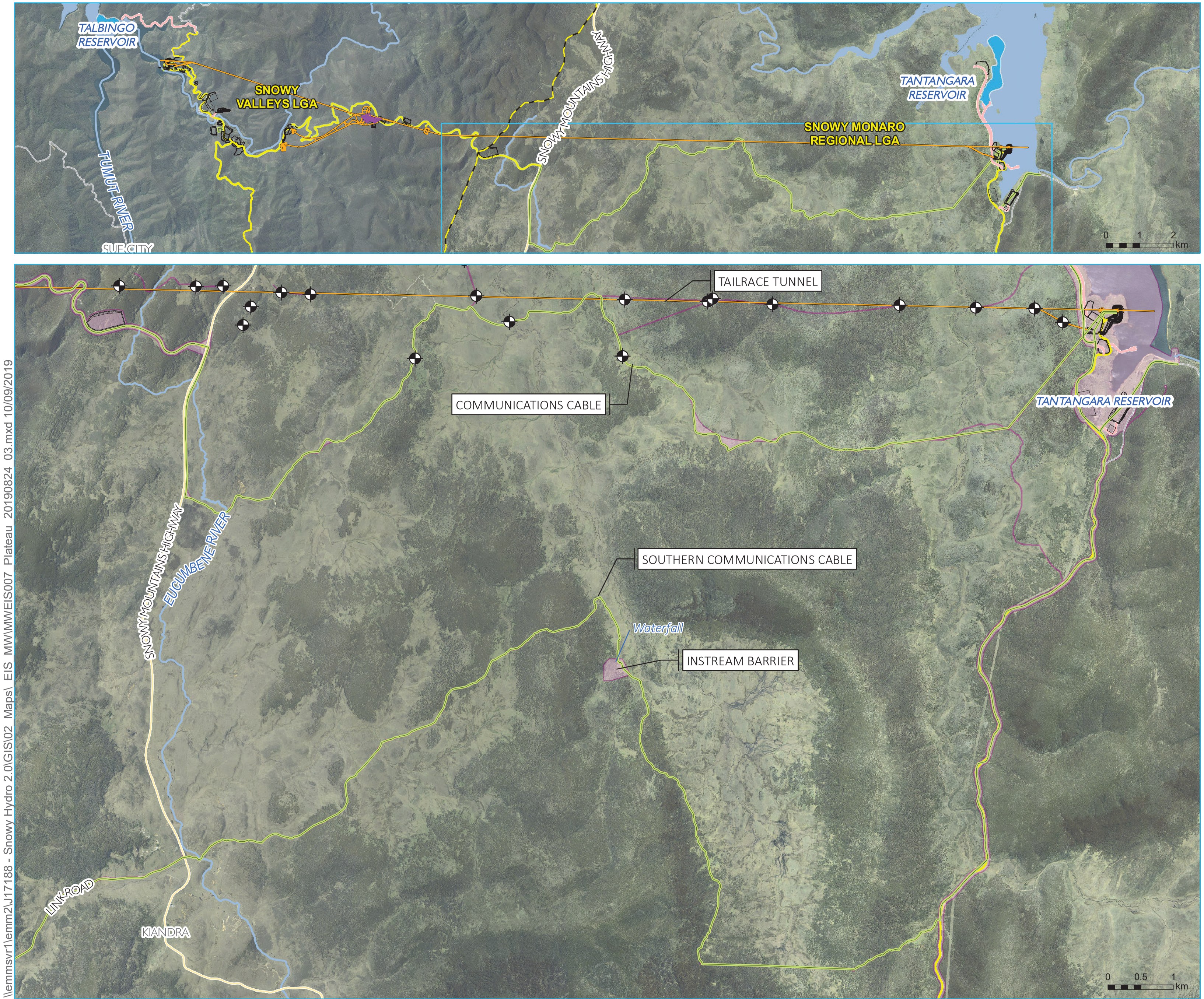
Snowy 2.0 Main Works construction elements

- 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.

Marica - project elements, purpose and description

Snowy 2.0
Flood risk assessment
Main Works
Figure A3



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

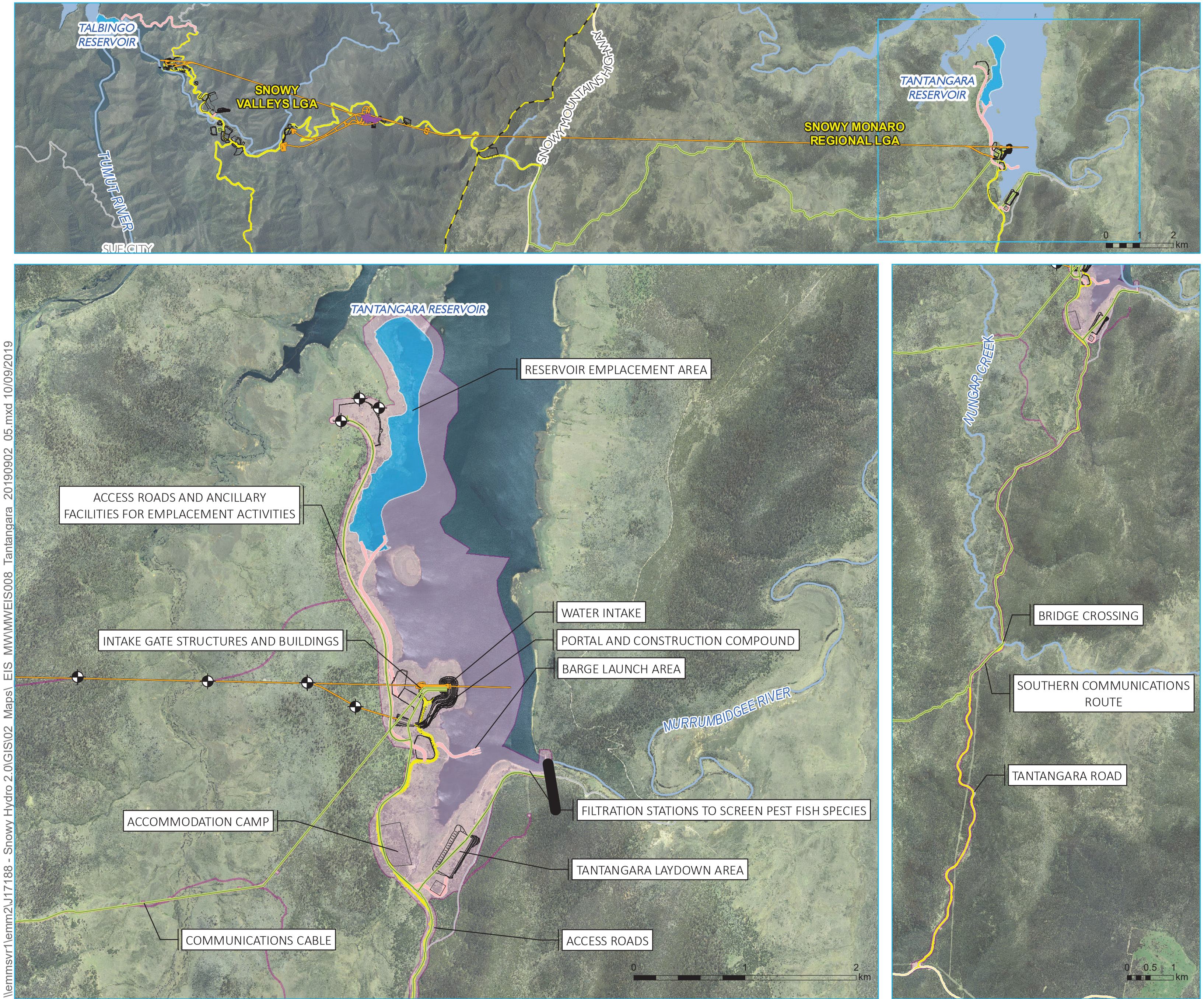
Snowy 2.0 Main Works operational elements
- Tunnels, portals, intakes, shafts
- Power station
- Utilities
- Permanent road

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.

Plateau - project elements

Snowy 2.0
Flood risk assessment
Main Works
Figure A4



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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.

Tantangara Reservoir - project elements, purpose and description

Snowy 2.0
Flood risk assessment
Main Works
Figure A5

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

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KEY

Existing environment

- Main road
- Local road
- Watercourse

Snowy 2.0 Main Works operational elements

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

Snowy 2.0 Main Works construction elements

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

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

Rock Forest - project elements

Snowy 2.0
Flood risk assessment
Main Works
Figure A6

Attachment B

Flood study

SNOWY 2.0 MAIN WORKS – FLOOD STUDY

Draft Report

AUGUST 2019

Snowy 2.0 Main Works – Flood Study

Project Number: 190014

Client: EMM Consulting Pty Ltd

Client Contact: Nick Bartho

Report Author: Zac Richards, Beth Marson, William Tang

Date: 30 August 2019

Verified By: Zac Richards

Date	Version	Description
30 August 2019	1	Snowy 2.0 Main Works – Flood Study - DRAFT

Filepath: J:\190014\Admin\Reporting\SEARs_Report\Snowy2_Flood_Study_GRC_Hydro_Draft.docx

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Appendix C: Figures – Rock Forest

EXECUTIVE SUMMARY

Introduction

This report has been prepared by GRC Hydro Pty Ltd on behalf of EMM Consulting Pty Ltd (EMM) for submission to Snowy Hydro Limited (Snowy Hydro) as part of the Snowy 2.0 Main Works, Environmental Impact Statement (EIS).

The report comprises flood studies for three sites within the Snowy 2.0 Main Works project area. The studies aim to produce information used to address the relevant Secretary's Environmental Assessment Requirements (SEARs) for the project, which include the assessment of hydrologic flows, potential flooding impacts and flood hazard.

The three sites are listed below, along with reference to the pertinent sections of this report:

- **Lobs Hole (Section 2)** - situated in the Yarrangobilly River catchment, to the west of Talbingo Dam;
- **Kellys Plain Creek (Section 3)** – situated on the plateau, to the south of Tantangara Dam; and
- **Rock Forest (Section 4)** – situated outside of Kosciuszko National Park, to the west of Adaminaby.

Existing Conditions (e.g. baseline conditions, prior to commencement of the Exploratory Works) design flood behaviour has been defined for a range of events and Proposed Conditions (i.e. during the construction phase of the project) flood behaviour has been analysed where appropriate.

Due to significant differences in geographic, hydrologic, flood mechanism and proposed infrastructure characteristics, this report has been prepared as three discrete flood studies for each of the sites (Sections 2, 3 and 4), each of which can be examined in isolation.

Lobs Hole Flood Study

A flood study was undertaken for Lobs Hole, situated within the Snowy 2.0 Main Works project area. Lobs Hole is subject to flooding from the Yarrangobilly River, Wallaces Creek and other unnamed tributaries, and in the lower reaches of the site, Talbingo Dam.

Flood behaviour for Lobs Hole was assessed as part of the '*Yarrangobilly River Flood Study*' (GRC Hydro, 2018) undertaken for the Snowy 2.0 Exploratory Works EIS. The current study builds on the GRC Hydro (2018) study, by first reviewing the modelling methods and parameters to confirm suitability for use in the current study, and then extending the models to assess Talbingo flood levels which can also affect the lower reaches of Lobs Hole.

An XP-RAFTS model was developed as part of the GRC Hydro (2018) study and ARR2016 methods and parameters were applied. The model was calibrated to Flood Frequency Analysis (FFA) developed for the Yarrangobilly@Ravine (410574) stream gauge and validated to regional flow estimates. Review of the calibration process indicated that the model was suitable for use in the current study. Additionally, validation of the Yarrangobilly@Ravine stream gauge rating was undertaken as part of the current study. The calibration/validation process found that the XP-RAFTS model is producing robust design flow estimates, as presented in Table ES 1.

Table ES 1: Comparison of RFFE, FFA and XP-RAFTS Design Flow Estimates (m^3/s), Yarrangobilly@Ravine Gauge

AEP (%)	RFFE* (m^3/s)	FFA (m^3/s)	XP-RAFTS (m^3/s)
5	58	83	92
20	114	142	154
1%	205	233	244

* ARR2016 Regional Flood Frequency Estimation (RFFE)

Design flows were developed for the 20%, 5%, 1%, 0.2% and 0.05% AEP events and the PMF. Flows from the XP-RAFTS model were then applied to a TUFLOW hydraulic model.

Talbingo Dam design flood levels were obtained from the *'Talbingo Dam Flood Hydrology'* (SKM, 2011) study. The current study undertook hydrologic analysis for the dam by implementing ARR2016 methods and techniques to validate the finding of the SKM (2011) study. The analysis was undertaken to ensure that changes to Australian Rainfall and Runoff associated with the 2016 revision have not significantly affected Talbingo Dam design flood levels. The results of this analysis are presented in Table ES 2 for both the 1% AEP and PMF events, with a maximum difference of 0.1 m noted.

Table ES 2: Talbingo Dam Flood Levels - Current Study vs SKM (2011) Study

AEP	Current Study Dam Level (mAHD)	SKM (2011) Dam Level (mAHD)
1%	546.2	546.1
PMF	552.1	552.1

The TUFLOW hydraulic model developed as part of the *'Yarrangobilly River Flood Study'* (GRC Hydro, 2018) study was updated for the current study. The model was used to determine design flood characteristics for Lobs Hole in the vicinity of the site. Flows from the XP-RAFTS model and Dam levels from the SKM (2011) study were applied to the TUFLOW model to examine design flood behaviour for Existing Conditions at the site.

Validation of design flood levels at the Yarrangobilly@Ravine stream gauge was undertaken by comparing hydraulic model results to stage frequency analysis. The results of this analysis (see Table ES 3) indicates good agreement between the two methods, providing confidence in model results.

Table ES 3: Comparison of TUFLOW design levels to Stage Frequency Analysis, Yarrangobilly@Ravine Gauge

AEP (%)	TUFLOW Stage (m)	Stage FFA (m)
5	2.31	2.24
20	2.85	2.82
1%	3.46	3.34

* Note that gauge stage has been estimated by assuming a gauge zero of 561.48 mAHD based on interrogation of available LiDAR.

A Proposed Conditions model was produced by modifying the Existing Conditions TUFLOW model to incorporate works proposed for the construction phase of the Snowy 2.0 Main Works project. Available design information was provided by Future Generations Joint Venture (FGJV) for this purpose, and required some interpretation and development of reasonable supporting assumptions to produce a model that was considered representative of Proposed Conditions.

Existing and Proposed Conditions flood characteristics are presented in Appendix A. The mapping presents flood depths, levels and hazard for the 20%, 5%, 1%, 0.2%, 0.05% AEP and PMF events. Flood level and flood hazard impact maps are also provided to inform the impact of the Snowy 2.0 Main Works on flood behaviour, during the construction phase.

Kellys Plain Creek Flood Study

A flood study was undertaken for the Kellys Plain Creek site within the Snowy 2.0 Main Works project area. The site is subject to flooding from Kellys Plain Creek and Tantangara Dam.

An XP-RAFTS model was developed for the Kellys Plain Creek catchment and ARR2016 methods and parameters were applied. Continuing losses were based on those determined via model calibration in the nearby '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) as per the methods outlined in the OEH guidelines (Floodplain Risk Management Guide, 2019).

The Kellys Plain Creek 1% AEP flow estimate of 49.4 m^3/s was validated by comparison to design flow estimates from surrounding gauges, increasing confidence in design flow results. The PMF flow estimate of 606 m^3/s was developed through application of the Generalised Short Duration Method (GSDM).

Tantangara design flood levels were obtained from the *'Tantangara Dam Update of Hydrology and Spillway Capacity Assessment'* (Jacobs, 2015) study. The current study undertook hydrologic analysis for Tantangara Dam by implementing ARR2016 methods and techniques to validate the finding of the Jacobs (2015) study. The analysis was undertaken to ensure that changes to Australian Rainfall and Runoff associated with the 2016 revision have not significantly affected design flood levels for the Dam. The results of this analysis found that design flood levels are within ± 0.2 m when comparing the two studies for both the 1% AEP and PMF events (see Table ES 4).

Table ES 4: Tantangara Dam Flood Levels - Current Study vs Jacobs (2015) Study

AEP	Current Study Dam Level (mAHD)	SKM (2011) Dam Level (mAHD)
1%	1230.5	1230.3
PMF	1236.1	1236.3

A TUFLOW hydraulic model was developed for the Kellys Plain Creek floodplain in the vicinity of the site. Flows from the XP-RAFTS model and Dam levels from the Jacobs (2015) study were applied to the TUFLOW model to examine 1% AEP and PMF design flood behaviour.

Existing Conditions flood characteristics are presented in Appendix B. The mapping presents flood depths, levels and hazard for the 1% AEP and PMF events.

Rock Forest Flood Study

A flood study was undertaken for the Rock Forest site within the Snowy 2.0 Main Works project area. The site is subject to flooding Camerons Creek and an unnamed tributary of the Goorudee River (named Watercourse RF1 for the purpose of this assessment).

An XP-RAFTS model was developed for catchments upstream of the site and ARR2016 methods and parameters were applied. Continuing losses were based on those determined via model calibration in the nearby '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) as per the methods outlined in the OEH guidelines (Floodplain Risk Management Guide, 2019).

The Camerons Creek 1% AEP flow estimate of 40 m^3/s at the site was validated by comparison to design flow estimates from surrounding gauges, increasing confidence in design flow results. The PMF flow estimate of 590 m^3/s was developed through application of the GSDM.

A TUFLOW hydraulic model was developed for the Camerons Creek and Goorudee Rivulet floodplains in the vicinity of the site. Flows from the above-mentioned XP-RAFTS model were applied to the TUFLOW model to examined 1% AEP and PMF design flood behaviour.

Existing Conditions flood characteristics are presented in Appendix C. The mapping presents flood depths, levels and hazard for the 1% AEP and PMF events.

1. INTRODUCTION

This report has been prepared by GRC Hydro Pty Ltd on behalf of EMM Consulting Pty Ltd (EMM) for submission to Snowy Hydro Limited (Snowy Hydro) as part of the Snowy 2.0 Main Works, Environmental Impact Statement (EIS).

Flood characteristics for three sites (see Section 1.2 for further details) within the Snowy 2.0 Main Works project area have been assessed. Existing Conditions (e.g. baseline conditions, prior to commencement of the Exploratory Works) design flood behaviour has been defined for a range of events and Proposed Conditions (i.e. during the construction phase of the project) flood behaviour has been analysed where appropriate.

Due to significant differences in geographic, hydrologic, flood mechanism and proposed infrastructure characteristics, this report has been prepared as three discrete flood studies (Sections 2, 3 and 4), each of which can be examined in isolation.

1.1 The Project

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

The NSW Department of Planning and Environment requires Secretary's Environmental Assessment Requirements (SEARs) to be undertaken for critical infrastructure. The current flooding assessment has been undertaken to address the relevant SEARs for the project, which include the assessment of hydrologic flows, potential flooding impacts and flood hazard considerations for the Snowy 2.0 Main Works.

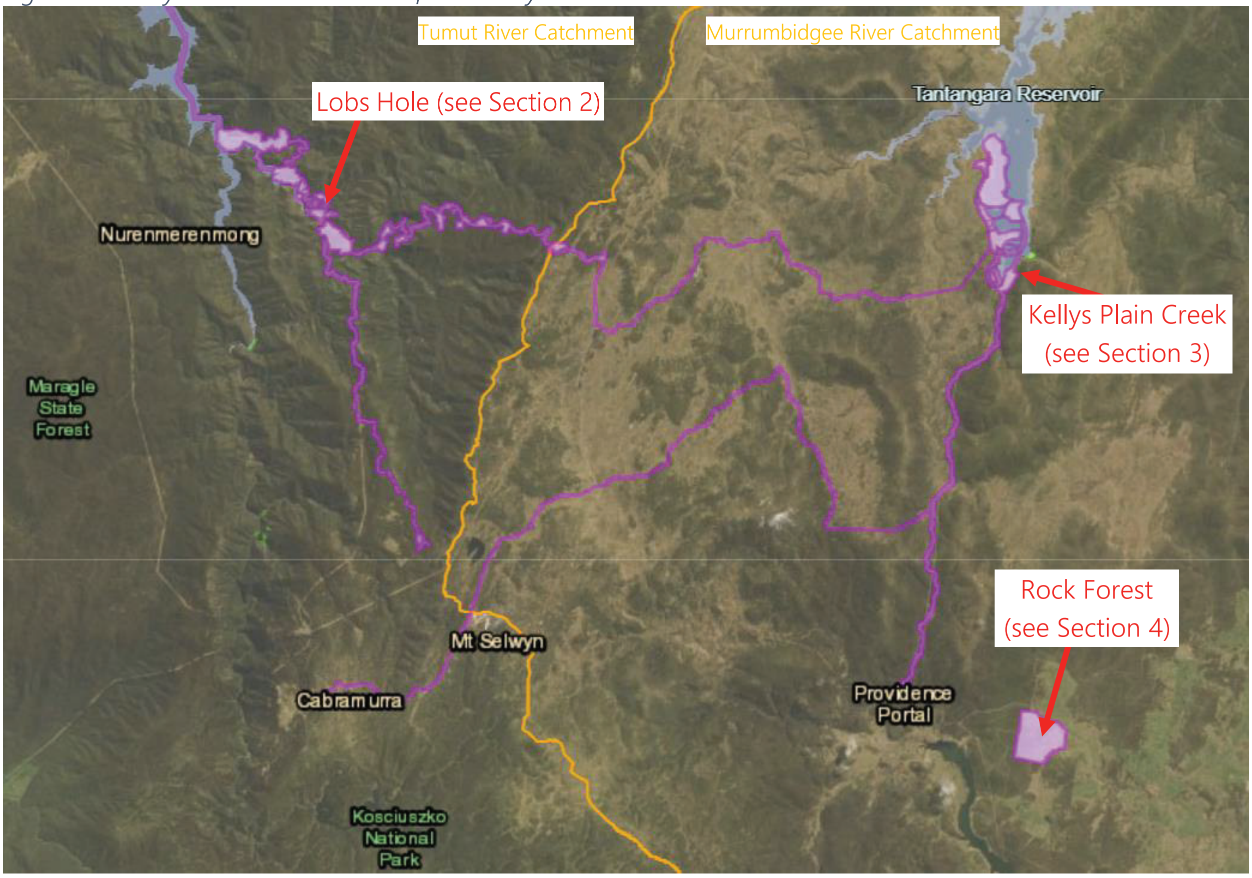
1.2 Background

EMM have requested that flood studies be undertaken for three sites within the Snowy 2.0 Main Works project area. The sites are listed below with the locations presented in Figure 1:

- Lobs Hole (Section 2) - situated in the Yarrangobilly River catchment, to the west of Talbingo Dam;
- Kellys Plain Creek (Section 3) – situated on the plateau, to the south of Tantangara Dam; and
- Rock Forest (Section 4) – situated outside of Kosciuszko National Park, to the west of Adaminaby.

A description of each site, along with pertinent characteristics related to flooding, are presented in Sections 2.1.1, 3.1.1 and 4.1.1.

Figure 1: Snowy 2.0 Main Works and flood study assessment areas



1.3 Terminology

1.3.1 Acronyms and Terminology

Table 1 presents a list of acronyms and terminology used in the report.

Table 1: List of Acronyms and Terminology

Abbreviation	Description
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
AEP	Annual Exceedance Probability (see Section 1.3.2)
AHD	Australian Height Datum – national surface level datum corresponding to mean sea level
ARF	Areal Reduction Factor - is a value which can be applied to a point rainfall to give the reduced areal rainfall over a given catchment area.
ARI	Average Recurrence Interval (see Section 1.3.2)
ARR87	Australian Rainfall and Runoff, 1987 Edition – ARR is a national guideline document that is used for the estimation of design flood characteristics in Australia.
ARR2016	The latest revision of Australian Rainfall and Runoff.
DEM	Digital Elevation Model - is a 3D representation of a terrain's surface

Abbreviation	Description
EIS	Environmental Impact Statement
FFA	Flood Frequency Analysis – statistical analysis of stream flows at a gauge
FSL	Full Supply Level – referring to a dam's capacity
GEV	Generalised Extreme Value – a continuous probability distribution
GL	Gigalitres – a measurement of volume equivalent to 1 x 10^9 Litres
GSAM	Generalised Southeast Australia Method – a method of calculating the PMF
GSDM	Generalised Short Duration Method – a method of calculating the PMF
Hydraulic	Term given to the study of water flow; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs.
LiDAR	Light Detection and Ranging - is a remote sensing method that uses light in the form of a pulsed laser to measure ranges. This data is typically used in the creation of a DEM.
LPIII	Log-Pearson type-III – a continuous probability distribution
m^3/s	Cubic metres per second - a measurement of flow rate
Model	Computer model - The mathematical representation of the physical processes involved in runoff generation and flow. These models are run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
PMF	Probable Maximum Flood - The PMF is the largest flood that could conceivably occur at a particular location. The PMF defines the extent of flood prone land, that is, the floodplain. Generally, it is not physically or economically possible to provide complete protection against this event.
PMP	Probable Maximum Precipitation - the greatest possible depth of precipitation for a given duration at a particular location.
Probability	A statistical measure of the expected chance of flooding (see AEP).
RFFE	Regional Flood Frequency Estimation
SEARs	Secretary's Environmental Assessment Requirements
SRTM	Shuttle Radar Topography Mission – is an international research effort that obtained digital elevation models on a global scale
TUFLOW	A 1D/2D hydraulic model typically used for assessing flood behaviour
WBNM	A type of hydrologic model typically used for flood hydrology
XP-RAFTS	A type of hydrologic model typically used for flood hydrology

1.3.2 Adopted Probability Terminology

Event probability is often described in terms of:

- *Annual Exceedance Probability (AEP) - the probability of an event being equalled or exceeded within a year; or*
- *Average Recurrence Interval (ARI) - the average time period between occurrences equalling or exceeding a given value.*

This study has used the 'AEP' terminology when describing event probability as is recommended in Australian Rainfall and Runoff 2016 (ARR2016). The relationship between 'AEP' and 'ARI' is presented in Table 2.

Table 2: Relationship between AEP and ARI

AEP (%)	ARI (years)
10	10
5	20
2	50
1	100
0.2	500
0.05	2,000

2. LOBS HOLE – FLOOD STUDY

2.1 Lobs Hole - Introduction

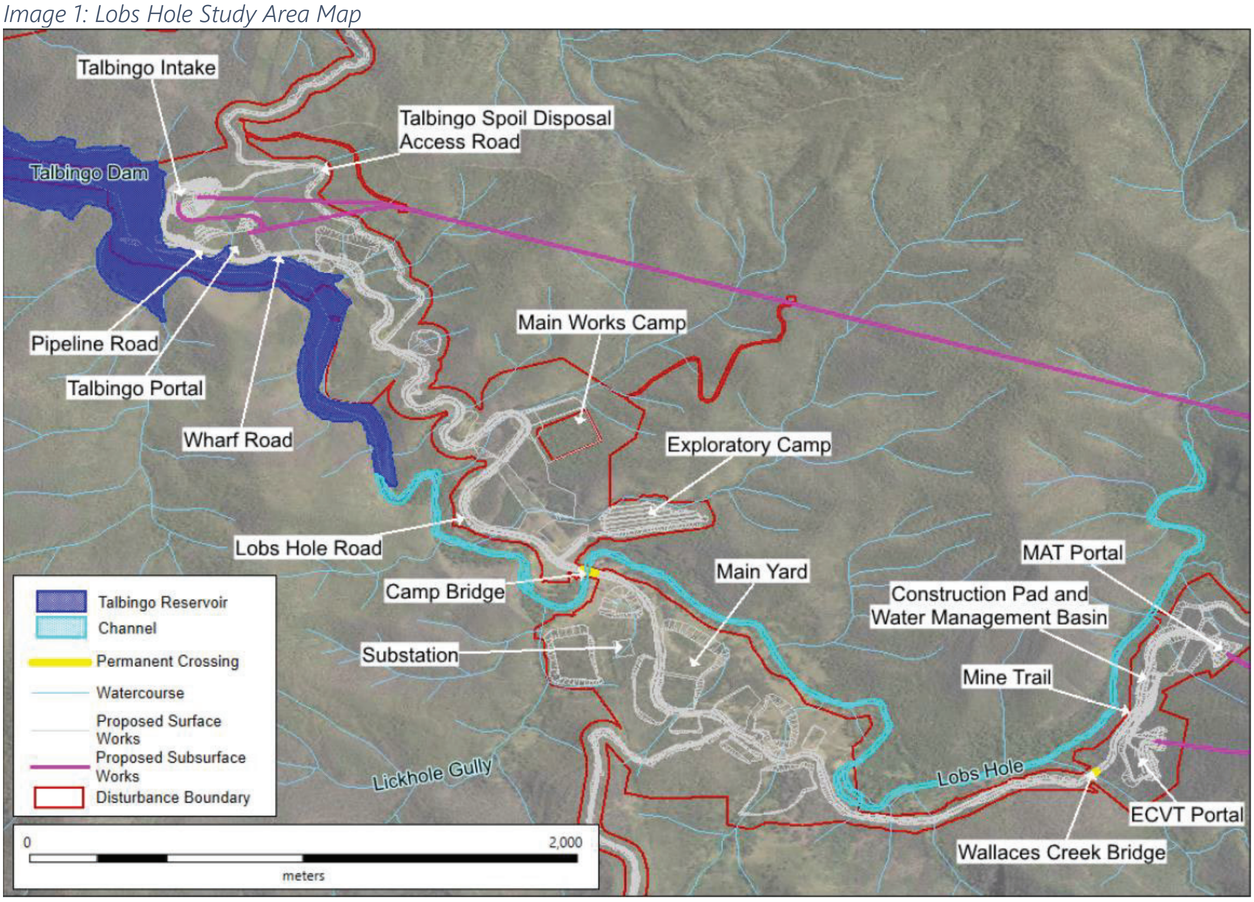
This section comprises 'The Lobs Hole Flood Study' which defines design flood behaviour for the Lobs Hole. The Lobs Hole Flood Study is an update of the '*Yarrangobilly River Flood Study*' (GRC Hydro, 2018) undertaken as part of the Snowy 2.0 Exploratory Works EIS. The modelling methods and applied parameters are generally consistent with the '*Yarrangobilly River Flood Study*' (GRC Hydro, 2018), however the hydrologic model has been extended to assess Talbingo Dam flood levels. Additional calibration works and parameter refinement has been undertaken for the Tumut River catchment to Talbingo Dam.

Flood behaviour for Yarrangobilly River, Wallaces Creek, major Yarrangobilly River tributaries and Talbingo Dam has been considered.

2.1.1 Study Area

Lobs Hole is situated in the Yarrangobilly River catchment which is a tributary of the Tumut River. A study area map with proposed works is presented in Image 1.

Image 1: Lobs Hole Study Area Map



The Yarrangobilly River flows through Lobs Hole in a westerly direction before flowing into Talbingo Dam. Wallaces Creek, a tributary of the Yarrangobilly, flows into the River from the south. The Yarrangobilly catchment area to Talbingo Dam is 280 km^2.

Flood levels in Lobs Hole are typically defined by the Yarrangobilly River, however Wallaces Creek and other unnamed tributaries may also define design flood levels in areas away from the Yarrangobilly River floodplain. In the lower reaches of the Yarrangobilly River, design levels are defined by Talbingo Dam flood levels.

Table 3 presents observations of Lobs Hole characteristics based on findings from a site visit undertaken on in March 2019. These findings have been considered during model update and development.

Table 3: Lobs Hole Characteristics

Observation	Photographs
Topography in Lobs Hole is characterised as 'steep', with average grades in the upper catchment estimated to exceed 40% in many locations. Tributaries flowing to the Yarrangobilly are deeply incised through the steep terrain before opening up to a relatively narrow floodplain in the lower catchment.	
Dense vegetation is present throughout the catchment, particularly in the understory. High Manning's values ranging from 0.07 to 0.12 are present based on assessment of Chow (1959) and ARR2016 guidelines.	
The floodplain is a combination of moderate to dense vegetation and open grasslands. Mannings values are estimated to range from 0.05 to 0.07 (Chow, 1959).	

The Yarrangobilly River channel is comprised of a series of shallow pools with rocky (boulder) base and a dense riparian corridor immediately proximate to the river channel. River channel Mannings estimated to be 0.04 to 0.05, with riparian vegetation Mannings of approximately 0.1 to 0.12 (based on Chow, 1959).	
The Wallaces Creek channel is similar to the Yarrangobilly channel, however with large boulders and a poorly defined floodplain. Wallaces Creek channel Mannings of approximately 0.06 to 0.07 (based on Chow, 1959).	
The catchment is largely undisturbed and has not been grazed (with the exception of the lower floodplain) indicating the soil compaction due to hoven animals has not occurred. The combination of dense vegetation and uncompacted soils are consistent with high rainfall losses.	
A hardwood trunk laying across the river was noted to form a local control, resulting in a deep pond at the location of the Yarrangobilly@Ravine (410574) stream gauge. The gauge reading was recorded at 0.4 m at the time of the site visit (28 March 2019, 11:00 am), with ~0.1 m of water noted above the control level. Gauge readings lower than 0.3 m are not frequently expected due to the presence of the control, unless during extended dry periods.	
Various rocky outcrops were noted proximate to the river that have the potential to create significant flow controls. The most notable control (pictured right) is situated ~300 m downstream of the Washington Hotel ruins.	

2.1.2 Objectives

The key objective of the Lobs Hole Flood Study is to define design flood characteristics for Lobs Hole due to the Yarrangobilly River, local tributaries and Talbingo Dam flood events. The analysis has applied the methods outlined in ARR2016 for the 20%, 5%, 1%, 0.2% AEP, 0.05% and Probable Maximum Flood (PMF) events. Flood level, depth, extent and flood hazard have been produced for each event.

To satisfy the key objective outline above, the following analysis has been undertaken:

- Review of the analysis undertaken as part of the Snowy 2.0 Exploratory Works EIS (*Yarrangobilly River Flood Study*, GRC Hydro, May 2018), to confirm suitability for implementation in the current study. This analysis includes, review of:
    - The Yarrangobilly River XP-RAFTS hydrologic model;
    - Flood Frequency Analysis (FFA) for the Yarrangobilly@Ravine (410574) stream gauge;
    - Calibration of the XP-RAFTS model to Yarrangobilly@Ravine (410574) FFA;
    - Validation of the 1% Annual Exceedance Probability (AEP) flow estimate using the ARR2016 Regional Flood Frequency Estimation model; and
    - The TUFLOW hydraulic model for the site.
- Extension of the Yarrangobilly River XP-RAFTS model to include the Tumut River catchment to Talbingo Dam;
- FFA for the 'Happy Jacks River above Happy Jacks Pondage' (410534) and 'Tumut River above Happy Jacks Pondage' (410533) stream gauges;
- Calibration of the extended XP-RAFTS model to the above mentioned FFA;
- Derivation of design flow hydrographs for Lobs Hole and Talbingo Dam, using ARR2016 methods for the 20%, 5%, 1%, 0.2% AEP, 0.05% and Probable Maximum Flood (PMF) events;
- Analysis of Talbingo flood levels for the 1% AEP and PMF events. This analysis has been undertaken to validate the findings of the *'Talbingo Dam Flood Hydrology'* (SKM, 2011) report, and ensure changes associated with ARR2016 have not significantly impacted on design flood levels in the Dam;
- Validation of the Yarrangobilly@Ravine (410574) rating by comparison of TUFLOW model results; and
- Modelling design flood behaviour for the above-mentioned events, incorporating Talbingo flood levels.

2.1.3 Modelling Methodology

Flood behaviour for Lobs Hole was assessed as part of the *'Yarrangobilly River Flood Study'* (GRC Hydro, 2018) undertaken for the Snowy 2.0 Exploratory Works EIS. A key component of these works was the development of a hydrologic and hydraulic computer modelling system. The modelling system was used to firstly convert rainfall into flow via the hydrologic model, and then the hydrologic model flows were applied to the hydraulic model to define flood levels, depths, extents and flood hazard. The current study builds on the GRC Hydro (2018) study, by first reviewing the modelling methods and parameters to confirm suitability for use in the current study, and then extending the models to assess Talbingo flood levels which can also affect the lower reaches of Lobs Hole.

The details of the hydrologic analysis are presented in Section 2.2, and the hydraulic analysis is discussed in Section 2.3.

2.2 Lobs Hole - Hydrology

2.2.1 Hydrology Approach

A two-part hydrologic analysis was undertaken:

1. The XP-RAFTS hydrologic model produced as part of the Snowy 2.0 Exploratory Works (*Yarrangobilly Flood Study*, GRC Hydro 2018) was reviewed and found to be suitable for defining design flows for the Yarrangobilly River at Lobs Hole. A summary of the applied methodology is discussed in Section 2.2.2; and
2. The above-mentioned XP-RAFTS model was extended to include the catchment upstream of Talbingo Dam to assess dam inflows. Additional validation to FFA at two gauges in the upper Tumut River catchment was undertaken and the model was used to calculate 1% AEP and PMF event dam inflows. The results of this analysis confirmed the suitability of the *'Talbingo Dam Flood Hydrology'* (SKM, 2011) report for flood levels for defining tailwater levels for the hydraulic model.

The following sections outline the implemented approach.

2.2.2 Yarrangobilly Catchment Hydrology

This section discusses the methods, parameters and calibration process used in the development of a XP-RAFTS hydrologic model for Lobs Hole. A discussion of the analysis for the extended Talbingo Dam XP-RAFTS model is presented in Section 2.2.3.

2.2.2.1 Yarrangobilly River Flood Frequency Analysis

FFA was performed on the annual maximum series of flows recorded at the Yarrangobilly@Ravine (410574) stream gauge (the Gauge). The gauge was commissioned in March 1972 and has a largely continuous and homogenous record period suitable for FFA. FFA was undertaken on the maximum annual flow for the 46 years of record from 1972 to 2017 (see Table 4). The review process found that the 2018 annual maximum flow was 14.2 m^3/s and inclusion of a flow of this magnitude (~1 EY) in the analysis is not expected to significantly influence design event estimates. Accordingly, the *'Yarrangobilly Flood Study'* (GRC Hydro, 2018) FFA did not require revision for the current study.

Table 4: Yarrangobilly@Ravine Annual Series Flows (m³/s)

Year	Flow	Year	Flow	Year	Flow
1972	30	1988	96	2004	47
1973	61	1989	29	2005	92
1974	62	1990	60	2006	3
1975	126	1991	38	2007	40
1976	75	1992	66	2008	36
1977	44	1993	77	2009	14
1978	57	1994	11	2010	210
1979	42	1995	119	2011	64
1980	45	1996	78	2012	163
1981	94	1997	25	2013	28
1982	6	1998	50	2014	31
1983	58	1999	37	2015	19
1984	102	2000	75	2016	62
1985	41	2001	27	2017	49
1986	50	2002	27		
1987	39	2003	67		

The Yarrangobilly@Ravine (410574) stream gauge rating was validated by comparison of the stage/discharge relationship of historic events, to the stage/discharge developed in the TUFLOW hydraulic model. This analysis is discussed further in Section 2.4.1.2.

The extreme value analysis software package 'FLIKE' was used for FFA, following the procedures outlined in ARR2016. A Log-Person Type 3 (LPIII) distribution was fitted to the annual series. Other distributions were also examined, however the LPIII distribution was noted to have the best fit to the annual series data. The Grubbs-Beck Test for statistical outliers was applied, with five events with a peak flow less than 25 m^3/s censored from the record during analysis. Application of the Grubbs-Beck test was undertaken in unison with visual assessment of the applied distribution. FFA design flow estimates for the gauge are presented in Table 5 and the FFA plot is presented in Chart 4.

Table 5: FFA Design Flow Estimates, Yarrangobilly@Ravine

AEP	Expected Parameter Quantile (m³/s)	90% Confidence Limits (m³/s)	
0.2EY	83	69	101
10%	111	90	144
5%	142	111	201
2%	191	137	312
1%	233	157	428

2.2.2.2 Hydrologic Modelling

Model Schematisation and Parameters

An XP-RAFTS model was developed for the Yarrangobilly River catchment downstream to Talbingo Dam. Details of the XP-RAFTS model schematisation are presented in Table 6 with sub-catchment delineation presented in Image 2.

Table 6: Yarrangobilly River, XP-RAFTS Model Schematisation

Total model catchment area (km²)	Area of catchment at the Gauge (km²)	Number of Catchments	Average catchment size (km²)
280	271	78	3.6

XP-RAFTS model parameters were determined via inspection of available data including photographs, aerial imagery and SRTM DEM. This information was used to inform sub-catchment Mannings, slope and lag times.

A global Mannings value of 0.07 was implemented which is consistent with moderate to dense vegetation. The site-visit findings (see Table 3), indicate that this is on the lower range of appropriate roughness coefficients for the Yarrangobilly River catchment, however use of a lower Mannings value will results in a higher flow estimate, which when coupled with the calibration process indicates that applied Mannings values are acceptable.

Sub-catchment slopes were determined via methods outlined in the XP-RAFTS user manual, whereby the 'equal angle slope' was calculated based on a sub-catchment's minimum and maximum elevation and maximum stream length. Lag times for inter-catchment routing were determined using the major flow path length (L) and slope (S) and the formula outlined in the Laurenson's method (lag time = $L / S^{0.5}$).

Design Rainfall

ARR2016 design rainfall depths for various durations were obtained from the Bureau of Meteorology (BoM). Due to a significant design rainfall gradient across the Yarrangobilly River catchment, a single uniformly applied rainfall depth was not appropriate for modelling of design rainfall. Instead, spatially varying design rainfalls were applied across the catchment with each sub-catchment receiving a unique rainfall depth. The Yarrangobilly River catchment's minimum, maximum and average rainfall depths are presented in Table 7.

Table 7: Design Rainfall Depths (Average / Minimum / Maximum), Yarrangobilly River Catchment

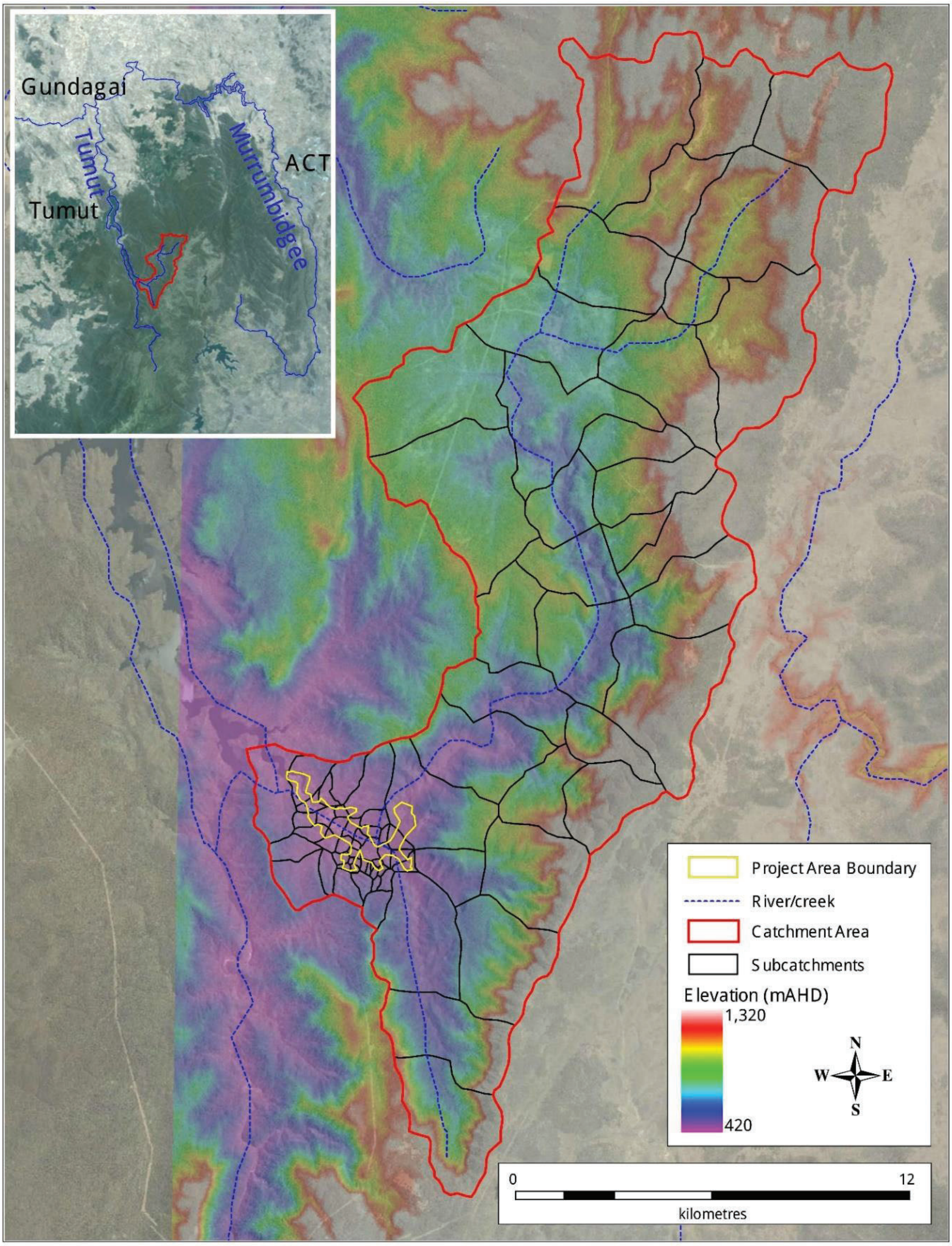
Duration (min)	20% AEP Event (mm)	10% AEP Event (mm)	5% AEP Event (mm)	2% AEP Event (mm)	1% AEP Event (mm)	0.2% AEP Event (mm)	0.05% AEP Event (mm)
720	64 / 60 / 76	74 / 69 / 88	83 / 78 / 100	97 / 90 / 116	108 / 100 / 130		
1080	75 / 70 / 91	87 / 80 / 106	99 / 91 / 121	116 / 106 / 142	129 / 118 / 160		
1440	84 / 77 / 104	97 / 89 / 121	111 / 101 / 139	130 / 117 / 164	145 / 131 / 185	188 / 169 / 244	255 / 203 / 300
2160	97 / 88 / 122	112 / 101 / 142	127 / 115 / 163	150 / 134 / 193	167 / 149 / 218	212 / 186 / 283	304 / 220 / 345
2880	105 / 95 / 134	122 / 109 / 157	138 / 123 / 180	163 / 144 / 214	182 / 160 / 242	224 / 194 / 311	287 / 225 / 373

Probable Maximum Precipitation (PMP) rainfall depths were determined using the methods outlined in the GSDM. The catchment is defined as 100% 'Rough' and a Moisture Adjustment Factor of 0.64 was applied. PMP rainfall depths for 'Ellipse A' for various durations are presented in Table 8.

Table 8: PMP Rainfall Depths, Yarrangobilly River Model

Duration	1 hour	2 hour	3 hour	4 hour	5 hour	6 hour
Rain (mm)	320	480	580	660	730	770

Image 2: Yarrangobilly Sub-catchments, Project Area Boundary and Locality Map



Areal Reduction Factor

Areal Reduction Factors (ARF) were applied to design rainfall depths to adjust for the Catchment's areal average rainfall intensity. The ARFs were determined following the methods outlined in

ARR2016 for the 'Southern Temporal' region. Calculated ARFs were based on the catchment's area and event's duration and probability. Applied ARFs are presented in Table 9.

Table 9: Areal Reduction Factors, Yarrangobilly River Model

Duration (min)	20% AEP Event	10% AEP Event	5% AEP Event	2% AEP Event	1% AEP Event	0.2% AEP Event	0.05% AEP Event
720	0.91	0.90	0.90	0.89	0.88		
1080	0.92	0.92	0.92	0.91	0.91		
1440	0.94	0.94	0.94	0.94	0.93	0.93	0.93
2160	0.95	0.94	0.94	0.94	0.94	0.94	0.94
2880	0.95	0.95	0.95	0.94	0.94	0.94	0.94

<u>Rainfall Losses</u>

Applied losses have been kept consistent with the losses determined in the *'Yarrangobilly River Flood Study'* (GRC Hydro, 2018).

An Initial and Proportional Loss (IL / PL) model was implemented for events up to an including the 1% AEP. ARR2016 notes that studies undertaken by Dyer et al (1994) and Hill et al (1996) found that 'the IL/PL model resulted in generally improved calibrations'.

It must be noted that calibration to FFA was first attempted using an Initial and Continuing Loss (IL / CL) model. The calibration was unsuccessful and required that CL's were increased with event magnitude. This is in contradiction with ARR2016 which notes that the 'majority of Australian studies of losses at catchment scale have concluded that both ILs and CL do not vary systematically with the severity of the event; that is loss is independent of AEP.' ARR2016 recommends 'to keep the ILs and CL values the same for AEPs unless there is specific evidence to suggest that there is a systematic variation of loss with AEP.' However, the opposite is true for the IL / PL model, with ARR2016 noting that the PL component of this model is noted to 'vary with the AEP of the event'.

For events up to and including the 1% AEP, an IL of 26 mm has been adjusted to account for pre-burst as per ARR2016. For comparative purposes, the average design initial loss implemented in the *'Snowy Monaro Flood Studies Draft Final Report'* (SMEC/GRC Hydro, 2019) is 26.5 mm. The burst initial losses used in design flood modelling are presented in Table 10. Pre-burst adjusted initial losses range from 15 to 26 mm depending on the event duration and AEP. 0.2% and 0.05% AEP losses have been determined via interpolating between 1% AEP and PMF losses which follows methods outlined in ARR2016.

Table 10: Applied Initial Losses (incorporating pre-burst), Yarrangobilly River Model

Duration (min)	20% AEP Event	10% AEP Event	5% AEP Event	2% AEP Event	1% AEP Event	0.2% AEP Event	0.05% AEP Event
720	23.9	23.7	23.5	18.8	15.3		
1080	25.2	24.7	24.1	21.1	18.9		
1440	25.7	25.5	25.4	24.6	24.1	7.8	2.9
2160	26.0	26.0	26.0	25.9	25.9	8.3	3.1
2880	26.0	26.0	26.0	26.0	26.0	8.3	3.1

The NSW Office of Environment and Heritage (OEH) released the 'Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in Studies' in early 2019 to provide additional guidance for the application of ARR2016 in NSW catchments. These guidelines provide a hierarchical approach to loss and pre-burst estimation in NSW, however, analysis undertaken as part of the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, July 2019) found that the proposed methodology did not provide more robust design flow estimates when compared to FFA, and in some instances, resulted in underestimation of frequent event flows. Accordingly, initial losses as recommended by ARR2016 have been used for design flood modelling, with the calibration process (see Section 2.2.2.3) indicating that the applied losses are appropriate.

A variable proportional loss has been applied for each design event. The applied PL for design events up to and including the 2% AEP event were determined via calibration to the FFA. Due to the relative short record period of available gauge data, reduced confidence is held in FFA design flow estimates for events rarer than the 2% AEP. For events larger than the 5% AEP, the PL was calculated following methods outlined in ARR2016, whereby it was assumed that PL vary linearly on a log-log plot of losses versus AEP, up until the recommended PMF loss. As the IL / CL model is recommended for the PMF, a conservative PL estimate of 0.01 was used in this interpolation. This method of determining loss values is more consistent with the interpolation procedure used for design rainfalls in ARR2016. The applied PL's are presented in Table 11.

Table 11: Applied Proportional Losses, Yarrangobilly River Model

Event AEP	20%	10%	5%	2%	1%	0.2%	0.05%
Proportional Loss	0.69	0.66	0.64	0.61	0.59	0.53	0.48

ARR2016 recommends caution for implementation of IL / PL model for estimating 'Very Rare' or 'Extreme' events. Accordingly, modelling was also undertaken using an IL / CL model for events exceeding the 1% AEP. A CL of 4.2 mm/hr was applied as per recommendations in ARR2016. ARR2016 recommends a method of estimating 'Very Rare' floods via interpolation methods between 'Rare' floods and the PMF. These methods were used to determine which loss model was most appropriate for implementation for the 0.2% and 0.05% AEP events. This analysis is discussed in the Section 2.2.2.3.

It should be noted that the Yarrangobilly River catchment rainfall losses are noted to be typically higher than the losses determined for surrounding catchments (2.0 mm/hour on average, see '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, July 2019), Talbingo Dam Hydrology (Section 2.2.3, Kellys Plain Creek Flood Study (Section 3) and Rock Forest Flood Study (Section 4)). The higher losses are due to the catchment's high vegetation density and pristine condition (i.e. it has not been grazed by hoven animals, resulting in reduced soil compaction, see Table 3). The combination of dense vegetation and uncompacted soils are consistent with high rainfall losses.

PMF rainfall losses have been applied as an IL / CL model (IL = 0 mm, CL = 1 mm/hr) as per the methods outlined in the GSDM.

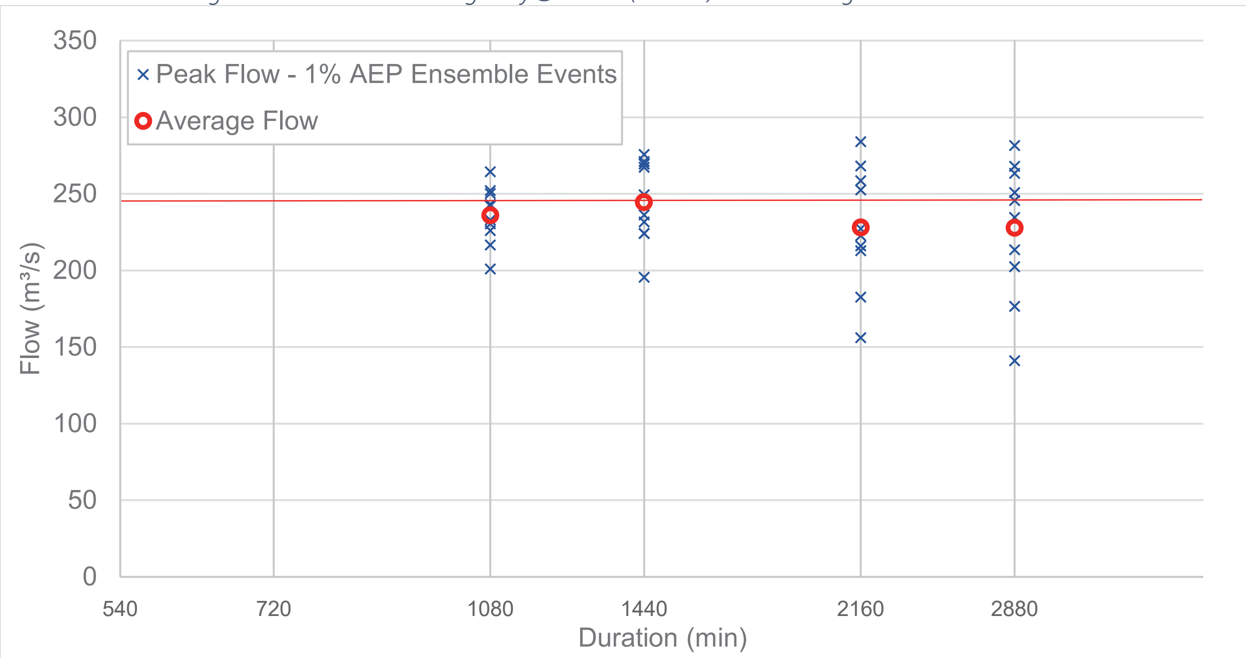
<u>Rainfall Temporal Patterns</u>

Rainfall temporal patterns are used to describe how rainfall is distributed as a function of time. The recommended ARR2016 ensemble approach to applying temporal patterns has been utilised in the current study. The ensemble approach to flood modelling applies a suite of 10 different temporal patterns for each duration. Areal Temporal Patterns have been implemented due to the catchment size exceeding 75 km². The temporal patterns were obtained from ARR2016 for the 'Murray Basin' region for a theoretical catchment area of 200 km². The implementation of the ensemble approach required the modelling of 300 design flood events (5 durations x 6 AEP x 10 temporal patterns) in the hydrologic model using the varying design rainfall depths, ARF and losses as presented above.

Hydrologic model design flows are presented in Chart 1 to Chart 3 for the 1%, 5% and 20% AEP events at the Yarrangobilly@Ravine (410574) stream gauge. Each blue 'x' indicates the peak flow of a modelled event. The red circle is the average flow for each duration. The ensemble method identifies the critical duration as the duration with the highest mean flow and each AEPs design event is selected as the event which is closest to, but above the mean.

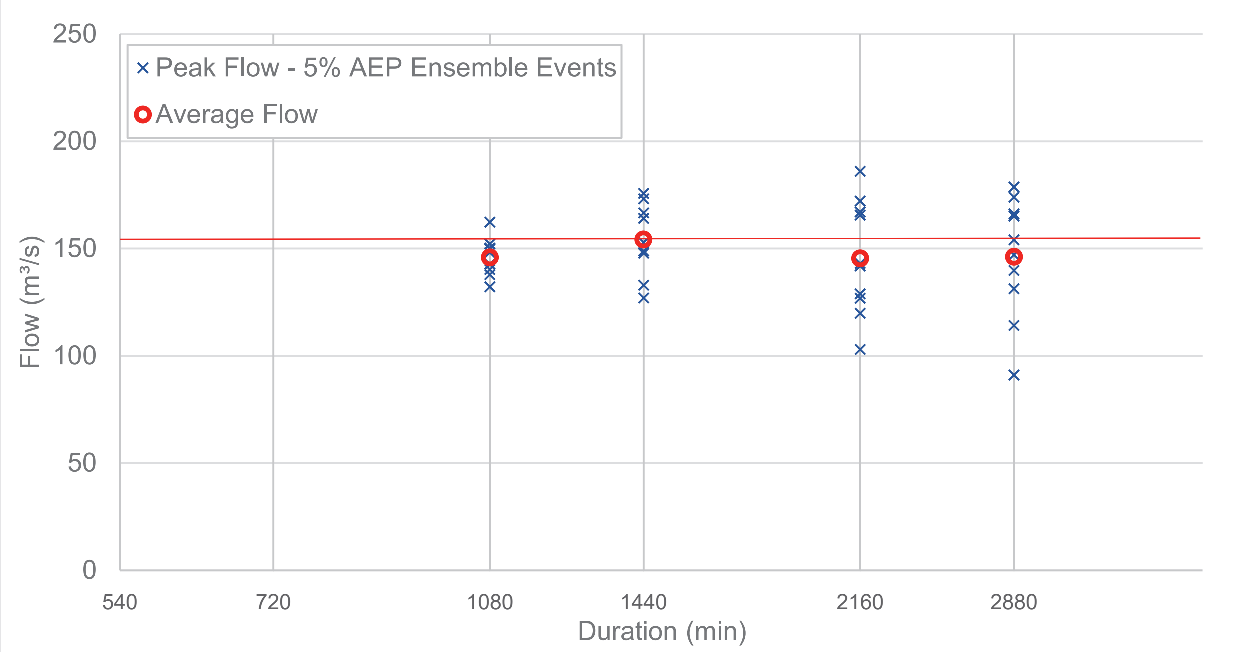
For the 1% AEP event the critical duration at the gauge is the 24 hour event with an ensemble average flow of 244 m^3/s.

Chart 1: 1% AEP Design Flow Results at Yarrangobilly@Ravine (410574) Stream Gauge Location



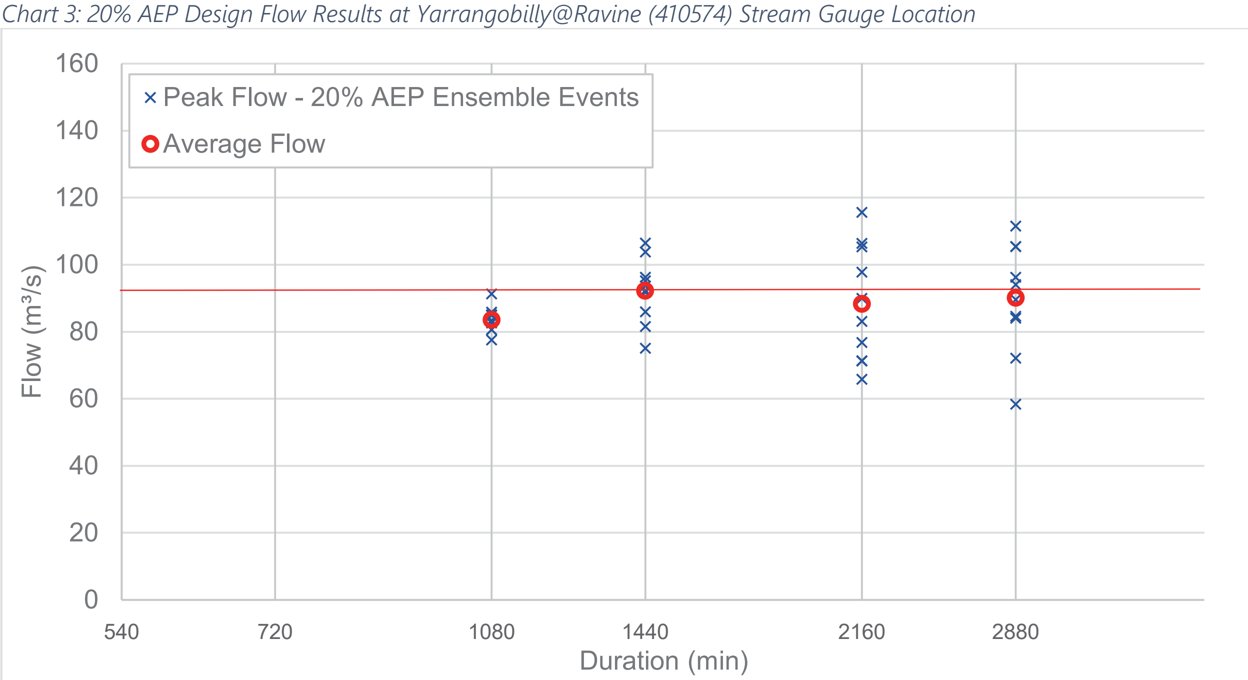
For the 5% AEP event the critical duration at the Site is the 24 hour event with an ensemble average flow of 154 m^3/s.

Chart 2: 5% AEP Design Flow Results at Yarrangobilly@Ravine (410574) Stream Gauge Location



For the 20% AEP event the critical duration at the Site is the 24 hour event with an ensemble average flow of 92 m^3/s.

Chart 3: 20% AEP Design Flow Results at Yarrangobilly@Ravine (410574) Stream Gauge Location



The critical duration of the 10%, 2%, 0.2% and 0.05% AEP events were determined to be 24 hours. The PMF critical duration was determined to be 6 hours.

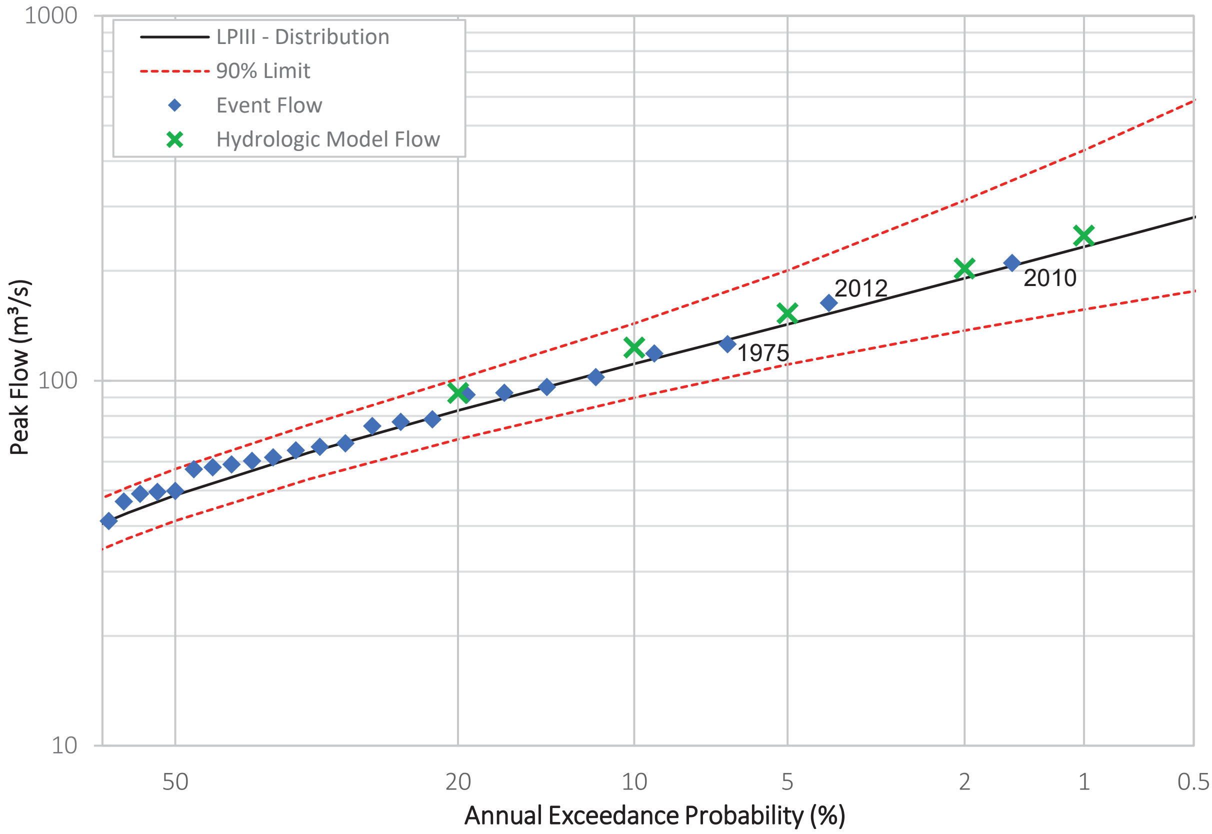
2.2.2.3 Calibration of the XP-RAFTS Model to FFA

Calibration of the XP-RAFTS model was undertaken by comparing model flows to FFA undertaken at the Yarrangobilly@Ravine (410574) stream gauge. Adjustment of applied proportional losses in the hydrologic model were made to obtain a good fit to the FFA design flows.

Chart 4 presents the Yarrangobilly@Ravine (410574) stream gauge FFA along with flows obtained from the XP-RAFTS hydrologic model (green 'X'). Hydrologic model flows for events from the 20% to the 1% AEP are a close match to the LPIII distribution expected quantile (black line) and within the 90% confidence interval limits (hashed red lines) increasing confidence in design flow estimates for these events.

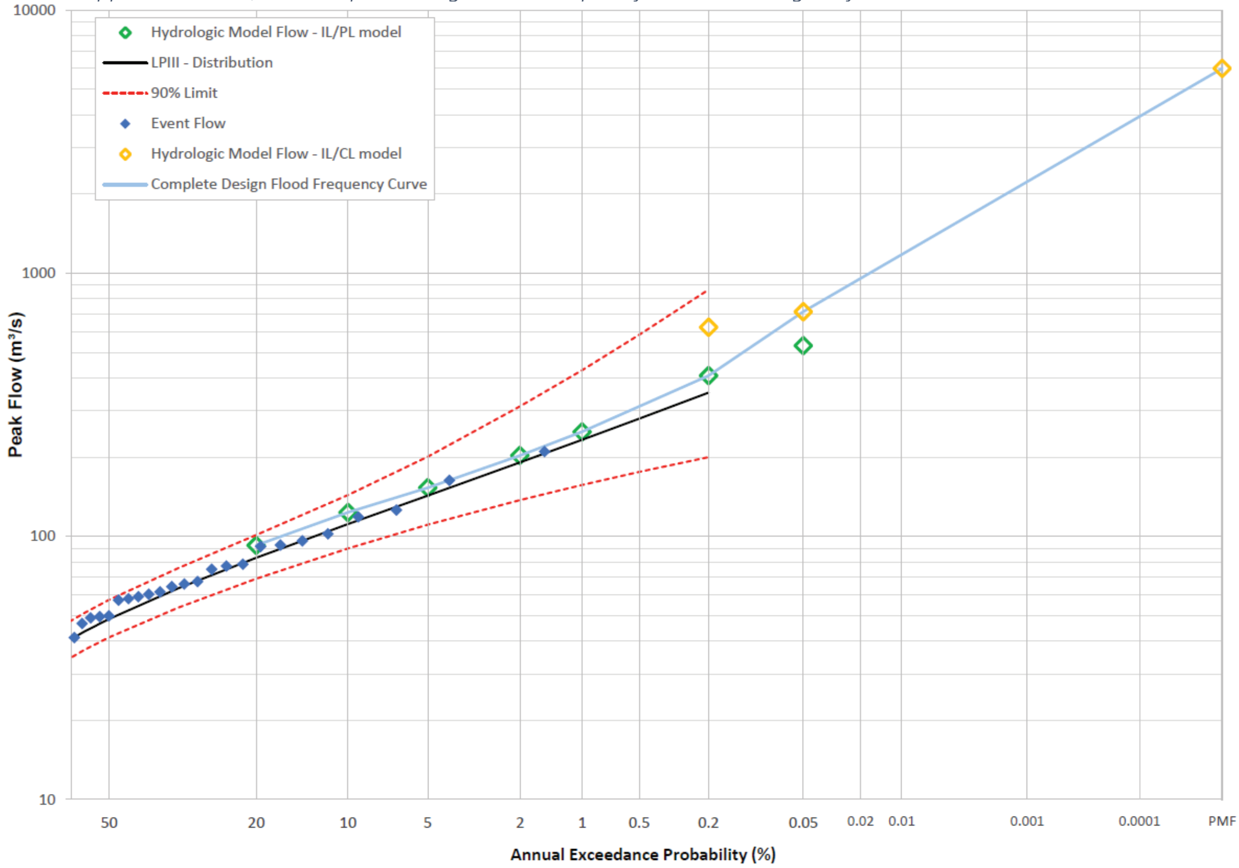
The calibration process indicates that the XP-RAFTS model is providing robust design flow estimates.

Chart 4: Yarrangobilly@Ravine - Comparison of Hydrologic Model Flows to FFA



ARR2016 outlines a method of estimating 'Very Rare' floods via interpolation methods between 'Rare' floods and the PMF. This method was used to determine the preferred loss model for calculation of the 0.2% and 0.05% AEP events. An approximation of the complete design flood frequency curve was derived by interpolating between the 'Rare' events and the PMF (see Chart 5). The findings from this analysis indicated that use of the recommended ARR2016 CLs overestimated 0.2% AEP flows and the IL/PL loss method underestimated the 0.05% AEP event. Accordingly, the IL/PL method was applied for events up to and including the 0.2% AEP event and the IL/CL method was applied for the 0.05% AEP event. Both the 0.2 and 0.05% AEP event flow are noted to diverge from the LPIII distribution and exceed FFA design flow estimates, however are well within the 90% confidence intervals.

Chart 5: Approximation of the Complete Design Flood Frequency Curve, Yarrangobilly@Ravine



2.2.2.4 Yarrangobilly River Catchment Design Flow Results

Design flows determined from the XP-RAFTS model at the Yarrangobilly@Ravine (410574) gauge and the Wallaces Creek outlet are presented in Table 12.

Table 12: Hydrologic Model flows at Yarrangobilly@Ravine gauge and Wallaces Creek outlet

AEP	Yarrangobilly Model Flows (m^3/s)	Wallaces Creek Flows (m^3/s)
20%	92	20
5%	154	31
1%	244	58
0.2%	408	89
0.05%	714	236
PMF	6,000	1,146

Design flows obtained from the XP-RAFTS model have been implemented in the TUFLOW model.

2.2.2.5 Validation of Design Flow Estimates to RFFE

To improve confidence in design flow estimates, comparison has been made to design flow estimates from the ARR2016 Regional Flood Frequency Estimation (RFFE) model. The comparison is presented in Table 13.

The results indicate that the XP-RAFTS design flow estimates are higher, yet comparable, to the RFFE flow estimates.

Table 13: Comparison of RFFE, FFA and XP-RAFTS Design Flow, Yarrangobilly@Ravine Gauge

AEP (%)	RFFE (m^3/s)	FFA (m^3/s)	XP-RAFTS (m^3/s)
5	58	83	92
20	114	142	154
1%	205	233	244

It is important to note the ARR2016 states 'that the relative accuracy of regional flood estimates using the RFFE model is likely to be within ± 50% of the true value' and as such, RFFE design flows estimates should be carefully considered. Accordingly, the 'output_nearby.csv' file was downloaded from the RFFE website (https://rffe.arr-software.org/) and assessed to for discrepancies that could affect RFFE results. The analysis indicated that there are at least two gauges (401009, 401017), within 50 km of the Yarrangobilly catchment, of similar size (220 km^2 & 197 km^2 respectively) with comparable runoff coefficients (0.8 & 1.1 $m^3/s/km^2$ respectively). The Yarrangobilly runoff coefficient based on the XP-RAFTS flows is 0.9 $m^3/s/km^2$. This provides some confidence in the RFFE model flow estimates for the site.

2.2.3 Talbingo Dam Hydrology

Design flood levels for Talbingo Dam have previously been determined in the '*Talbingo Dam Flood Hydrology*' (SKM, 2011) report. The current study has undertaken hydrologic analysis for the dam by implementing ARR2016 methods and techniques. This analysis was undertaken to validate the finding of the SKM (2011) study and ensure that changes to Australian Rainfall and Runoff associated with the 2016 revision have not significantly affected design flood levels in Talbingo Dam.

The current study dam analysis was focused on determining design flood levels for Lobs Hole, and accordingly the SKM (2011) study was noted to have applied a more rigorous approach to dam flood hydrology. As such, the results from the SKM (2011) study have been used in preference to the current study results. Notwithstanding, the results from the two studies are similar (±0.2 m), thus providing confidence in the SKM (2011) study results. A comparison of the current study and SKM (2011) study, Talbingo Dam levels for the 1% AEP and PMF events is presented in Section 2.3.1.3.

2.2.3.1 Talbingo Dam XP-RAFTS model extension

Design inflows for Talbingo Dam were determined by extending the Yarrangobilly catchment XP-RAFTS model discussed in Section 2.2.2.2.

The model build approach and applied parameters are generally consistent with the Yarrangobilly catchment XP-RAFTS model. Notable exceptions are presented in the following sections.

<u>Model Schematisation and Parameters</u>

The extended model sub-catchment layout is presented in Image 3, with a summary of sub-catchment details presented in Table 14. XP-RAFTS model parameters, such as Mannings, slope and lag times, were determined as per the methods outlined in Section 2.2.2.2. The PMF lag times were reduced to account for increased celerity associated with increases in flow. A course rainfall on grid model was developed for the catchment to determine the decrease in lag time from the 1% AEP to the PMF event. An average ratio of 0.45 was determined and PMF lags were factored accordingly.

Table 14: Talbingo Dam, XP-RAFTS Model Schematisation

Total model catchment area (km²)	Number of Catchments	Average catchment size (km²)
1,080	112	9.6

Design Rainfall

ARR2016 design rainfall depths for various durations were obtained from the Bureau of Meteorology (BoM) and were applied as spatially varying design rainfalls depths. The Tumut River catchment upstream of Talbingo Dam's, minimum, maximum and average rainfall depths are presented in Table 15.

Table 15: Design Rainfall Depths (Average / Minimum / Maximum), Talbingo Dam Catchment

Duration (min)	1% AEP Event (mm)
720	108 / 96 / 130
1080	129 / 118 / 160
1440	146 / 124 / 185
2160	167 / 149 / 218
2880	185 / 151 / 251
4320	204 / 164 / 288
5760	216 / 172 / 312
7200	226 / 178 / 330

Probable Maximum Precipitation (PMP) rainfall depths were determined using the methods outlined in the Generalised Southeast Australia Method (GSAM). PMP rainfall depths are presented in Table 16.

Table 16: PMP Rainfall Depths

Duration	9 hour	12 hour	18 hour	24 hour	36 hour	48 hour
Rain (mm)	550	610	720	760	900	960

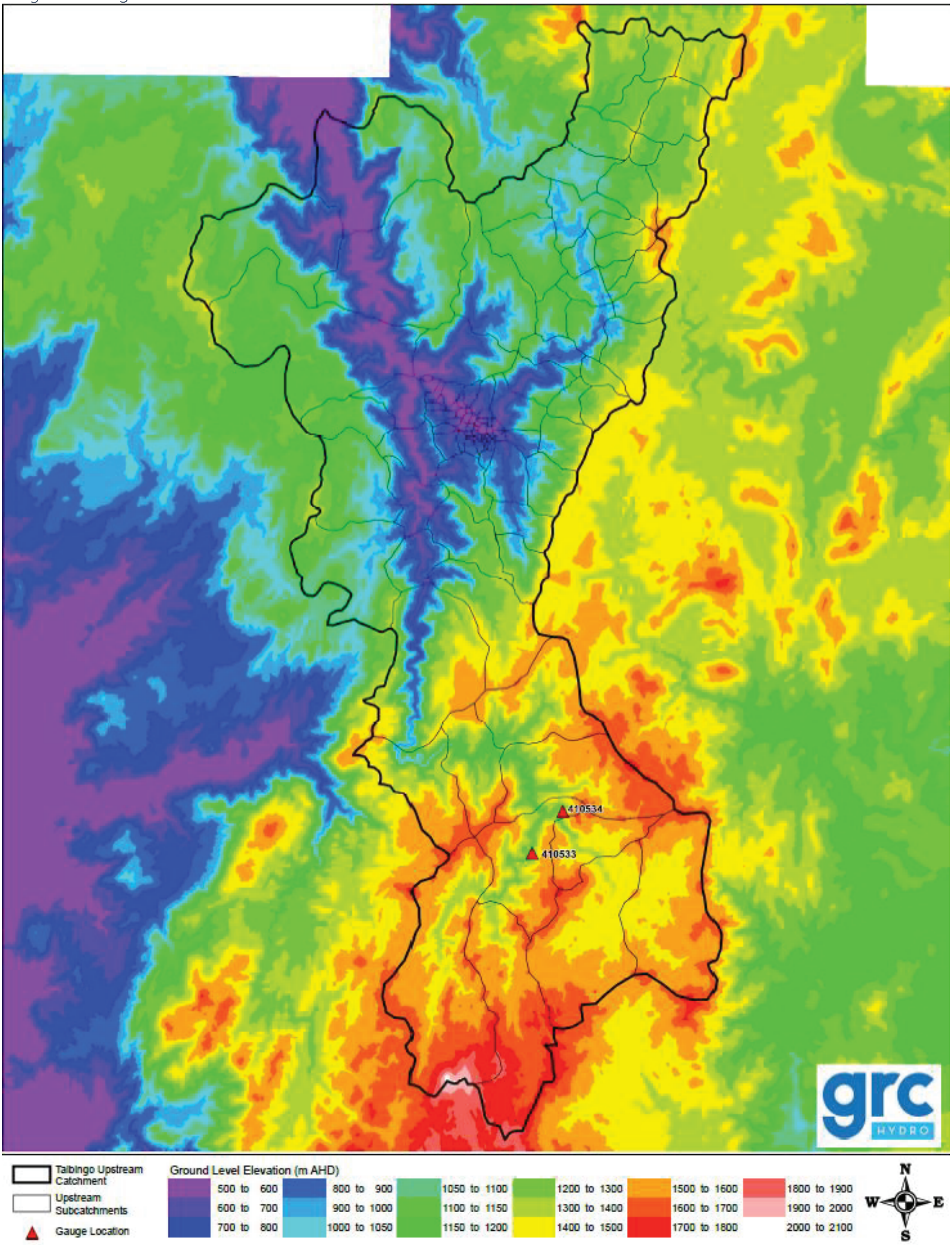
Areal Reduction Factor

Areal Reduction Factors (ARF) were applied to design rainfall depths to adjust for the Catchment's areal average rainfall intensity. The ARFs were determined following the methods outlined in ARR2016 for the 'Southern Temporal' region. Calculated ARFs were based on the catchment's area and event's duration and probability. Applied ARFs are presented in Table 17.

Table 17: Talbingo Dam - Areal Reduction Factors

Duration (min)	1% AEP Event
720	0.82
1080	0.86
1440	0.90
2160	0.91
2880	0.91

Image 3: Talbingo Dam Sub-catchments



Rainfall Losses

The '*Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in Studies*' (OEH, 2019) guidelines provide a hierarchical approach to loss and pre-burst estimation in NSW. The approach recommends the use of 'the average of calibration losses from the actual study on the catchment if available'. Accordingly, continuing loss values have been determined via calibration to FFA at two gauges in the upper Tumut River catchment, with the average continuing loss determined to be 2.0 mm/h. Details of this analysis is presented in 2.2.3.3.

The applied continuing loss was found to be consistent with the average continuing loss in nearby catchments assessed as part of the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, July 2019). Table 18 presents the calibrated continuing loss parameters adopted in the GRC Hydro (2019) studies. The analysis determined lower rainfall losses than that determined for the Yarrangobilly River catchment, however as previously discussed this is due to the Yarrangobilly catchment's high vegetation density and pristine condition which are consistent with high rainfall losses (see Section 2.2.2.2, 'Rainfall Losses').

Table 18: Calibrated continuing loss - Snowy Monaro Flood Studies (GRC Hydro, 2019)

Town	Continuing Loss (mm/h)
Cooma	0.5
Bredbo	2.0
Berridale	2.0
Michelago	3.5
Average	2.0

Initial losses have been applied as per the methods outlined in Section 2.2.2.2, 'Rainfall Losses'.

Rainfall Temporal Patterns

The recommended ARR2016 ensemble approach to applying temporal patterns has been utilised in the current study. Areal Temporal Patterns were obtained from ARR2016 for the 'Murray Basin' region for a theoretical catchment area of 1,000 km².

2.2.3.2 Upper Tumut River Catchment Flood Frequency Analysis

FFA was performed on the annual maximum series of flows recorded at the 'Happy Jacks River above Happy Jacks Pondage' (410534) and 'Tumut River above Happy Jacks Pondage' (410533) stream gauges. Both gauges have a largely continuous and homogenous, 60 year record period, between 1959 to 2018. FFA was undertaken on the maximum annual flow for the period of record (see Table 19 and Table 20).

The extreme value analysis software package 'FLIKE' was used for FFA, following the procedures outlined in ARR2016. A Log-Person Type 3 (LPIII) distribution was fitted to the annual series. Other distributions were also examined, however the LPIII distribution was noted to have the best fit to the annual series data. The Grubbs-Beck Test for statistical outliers was applied, censoring low flow events from the analysis. Application of the Grubbs-Beck test was undertaken in unison with visual assessment of the applied distribution.

Table 19: Tumut River above Happy Jacks Pondage (410533) Annual Series Flows (m^3/s)

Year	Flow	Year	Flow	Year	Flow
1959	92	1979	56	1999	54
1960	172	1980	3	2000	63
1961	25	1981	207	2001	54
1962	38	1982	0	2002	61
1963	43	1983	45	2003	213
1964	119	1984	61	2004	144
1965	58	1985	27	2005	102
1966	42	1986	74	2006	12
1967	21	1987	35	2007	57
1968	128	1988	42	2008	180
1969	99	1989	56	2009	59
1970	199	1990	77	2010	164
1971	85	1991	66	2011	137
1972	47	1992	171	2012	408
1973	80	1993	47	2013	62
1974	169	1994	29	2014	33
1975	162	1995	142	2015	32
1976	86	1996	87	2016	141
1977	38	1997	50	2017	110
1978	48	1998	66	2018	26

Table 20: Happy Jacks River above Happy Jacks Pondage (410534) Annual Series Flows (m^3/s)

Year	Flow	Year	Flow	Year	Flow
1959	31	1979	29	1999	20
1960	91	1980	2	2000	42
1961	17	1981	76	2001	34
1962	17	1982	0	2002	27
1963	17	1983	17	2003	64
1964	77	1984	47	2004	76
1965	31	1985	23	2005	48
1966	22	1986	58	2006	6
1967	12	1987	14	2007	20
1968	88	1988	26	2008	71
1969	35	1989	21	2009	39
1970	53	1990	44	2010	85
1971	37	1991	31	2011	43
1972	24	1992	70	2012	205
1973	12	1993	21	2013	26
1974	39	1994	13	2014	18
1975	109	1995	58	2015	21
1976	40	1996	33	2016	69
1977	15	1997	27	2017	65
1978	35	1998	39	2018	14

For both gauges, the 2012 event flow was noted to be almost twice as large as the second highest flow event in 60 years of record. This coupled with rainfall depths that were noted to have far exceeded 1% AEP estimates for various durations, indicates that the 2012 event had a probability significantly rarer than 1% AEP. To reduce bias associated with incorporating an unusually rare event into the FFA with a relatively short record period, prior regional information was applied as 'Gaussian prior distribution'. The prior distribution covariants were extracted from the ARR2016 RFFE website for both catchments and applied to Flike.

FFA design flow estimates for gauges 410533 and 410534 are presented in Table 21 and Table 22, with FFA plots presented in Chart 6 and Chart 7.

Table 21: Tumut River above Happy Jacks Pondage (410533) - FFA Design Flow Estimates

AEP	Expected Parameter Quantile (m^3/s)	90% Confidence Limits (m^3/s)	
0.2EY	107	93	126
10%	147	125	177
5%	192	160	238
2%	260	210	334
1%	319	253	422

Table 22: Happy Jacks River above Happy Jacks Pondage (410534) - FFA Design Flow Estimates

AEP	Expected Parameter Quantile (m^3/s)	90% Confidence Limits (m^3/s)	
0.2EY	53	46	62
10%	72	61	86
5%	93	77	114
2%	123	100	158
1%	150	119	197

2.2.3.3 Calibration of the Talbingo Dam XP-RAFTS Model to FFA

Calibration of the XP-RAFTS model was undertaken by comparing model flows to FFA at the 'Happy Jacks River above Happy Jacks Pondage' (410534) and 'Tumut River above Happy Jacks Pondage' (410533) stream gauges. Adjustment of applied continuing losses in the hydrologic model were made to obtain a good fit to the FFA design flows. A continuing loss of 1 mm/hour was found to provide the best fit to the FFA for gauge 410533, whilst a loss of 3 mm/hour was determined for gauge 410534. For both gauges, hydrologic model flows are a good match to the LPIII distribution expected quantile (black line) and within the 90% confidence interval limits providing confidence in the calibrated loss parameters.

When modelling design inflows for Talbingo Dam, an average continuing loss of 2.0 mm/hour has been applied as per recommendations in the 'Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in Studies' (OEH, 2019).

Chart 6: Tumut River above Happy Jacks (410533) - Model vs FFA Flow Comparison

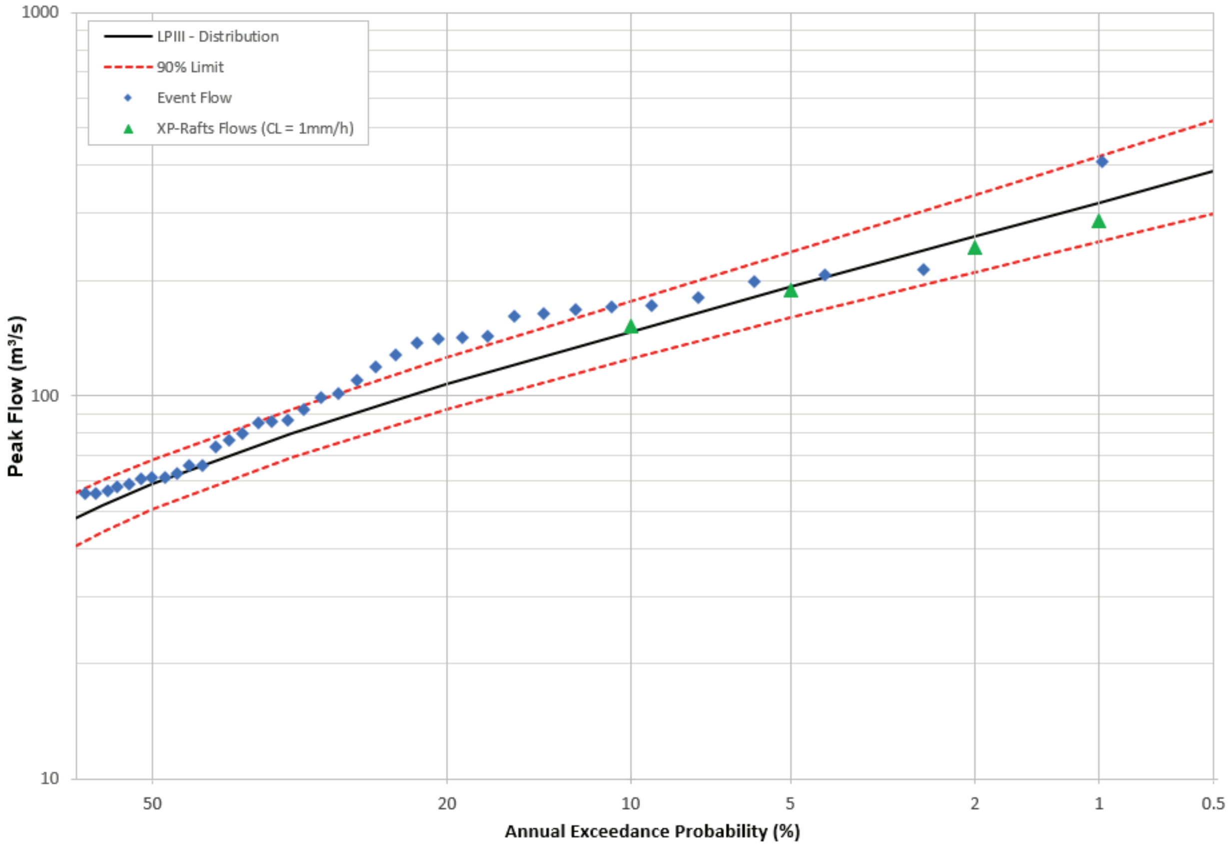
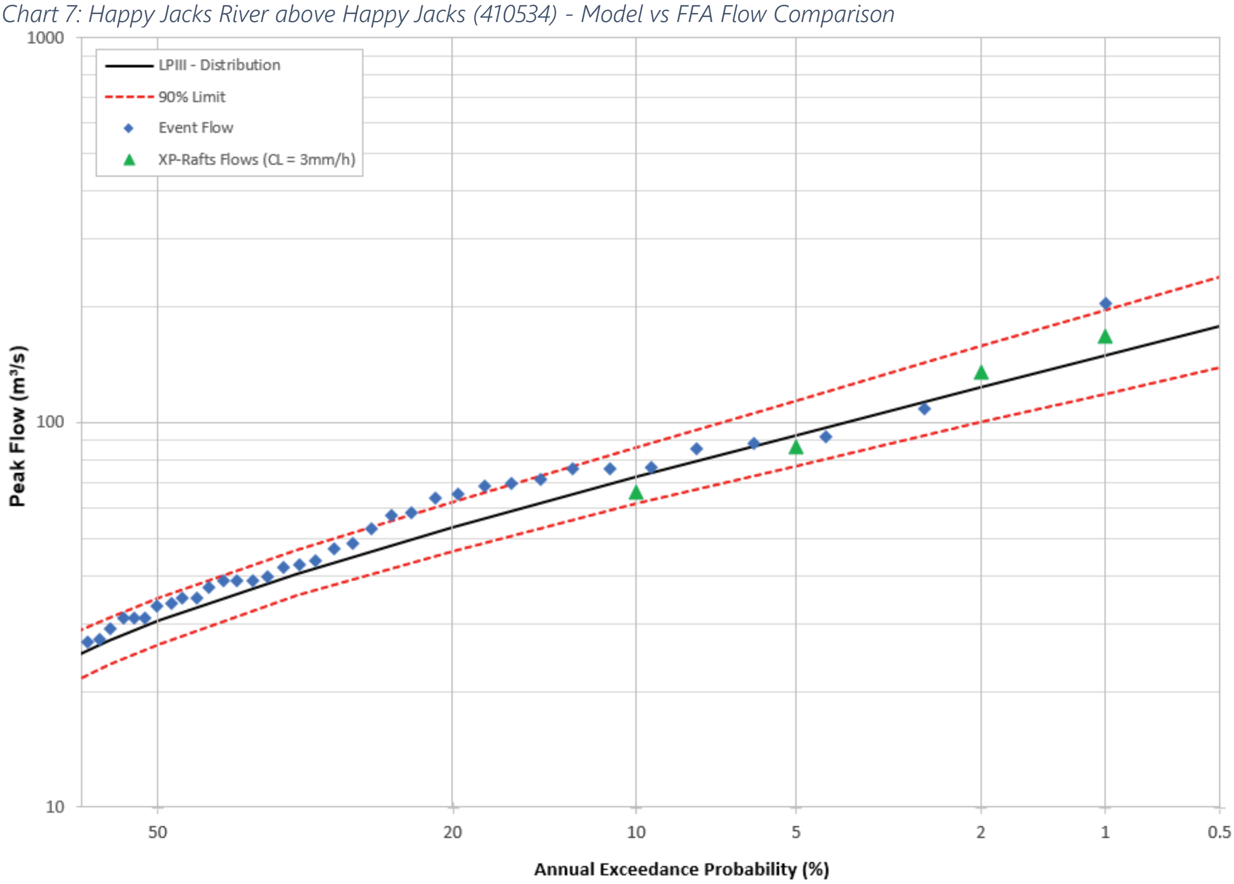


Chart 7: Happy Jacks River above Happy Jacks (410534) - Model vs FFA Flow Comparison



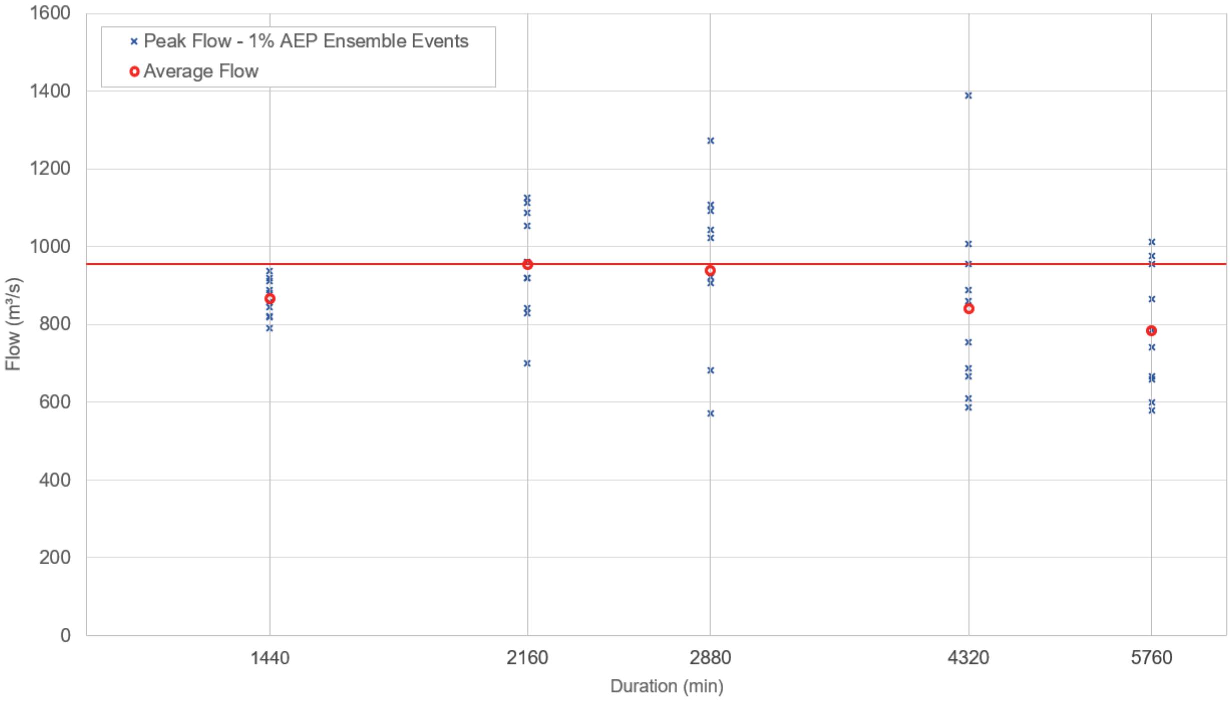
2.2.3.4 Talbingo Dam Inflow Results

Talbingo Dam design inflows determined from the XP-RAFTS model are presented in Table 23. The temporal pattern ensemble for the 1% AEP event is presented in Chart 8. The design inflows were routed through a conceptual storage in XP-RAFTS to determine dam flood levels. Details of this analysis are presented in Section 2.3.1.

Table 23: XP-RAFTS Model Talbingo Dam Inflows

AEP	Current Study XP-RAFTS Dam Inflow (m^3/s)	Critical Duration (hours)
1%	960	36
PMF	13,000	12

Chart 8: Talbingo Dam 1% AEP Design Inflows, Ensemble Results



2.3 Lobs Hole - Hydraulic Modelling

Similar to the hydrologic analysis undertaken as part of the current study, the hydraulic analysis was undertaken in two parts:

1. Talbingo Dam design levels were estimated by applying the previously discussed design inflows to a conceptual storage in XP-RAFTS. This analysis has been undertaken to validate the findings of the *'Talbingo Dam Flood Hydrology'* (SKM, 2011) report, and ensure changes associated with ARR2016 have not significantly impacted on design flood levels in the Dam. The SKM (2011) dam flood levels were then applied to the downstream boundary of the TUFLOW model discussed below; and
2. The TUFLOW model developed for Lobs Hole as part of the *'Yarrangobilly River Flood Study'* (GRC Hydro, 2018) was reviewed and updated. Some modifications to the model were made as part of the current study to better emulate existing catchment conditions.

Details are discussed in the ensuing sections.

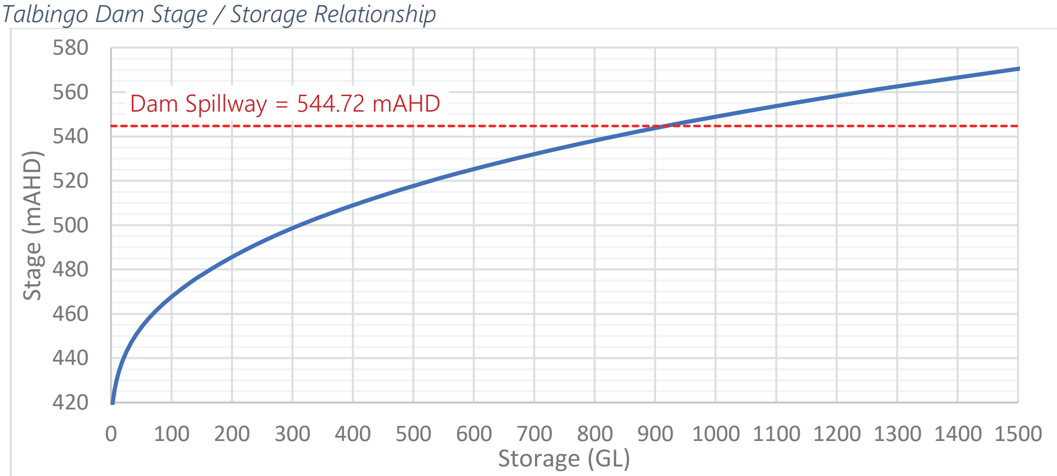
2.3.1 Talbingo Dam Flood Level Estimation

Talbingo Dam is a rockfill dam with an ogee type spillway. The Dam is the largest dam in the Snowy Mountains scheme with a gross capacity of 924 GL, and has been modelled as a conceptual storage in XP-RAFTS. Stage/discharge and stage/storage relationships have been developed for implementation in the model.

2.3.1.1 Talbingo Dam Stage/Storage Relationship

A stage/storage relationship was developed by interrogation of available 1s-SRTM DEM data obtained from the NSW Spatial Services website. The SRTM data was merged with bathymetry survey (provided by Snowy Hydro) for the dam to determine storage volume below the full supply level. The Talbingo stage/storage relationship is presented in Chart 9.

Chart 9: Talbingo Dam Stage / Storage Relationship



2.3.1.2 Talbingo Dam Stage/Discharge Relationship

A stage/discharge relationship has been developed for the Talbingo Dam. The relationship considers flow through the spillway, and for extreme events, flow overtopping the dam wall. The headrace and diversion tunnel capacities have not been considered.

Talbingo has an ogee spillway type, which aims to increase weir efficiency by shaping the spillway nappe surface to be approximately parabolic for a specific design head. Spillway discharge has been calculated such that an estimate of water levels within Talbingo Dam can be made for a given inflow.

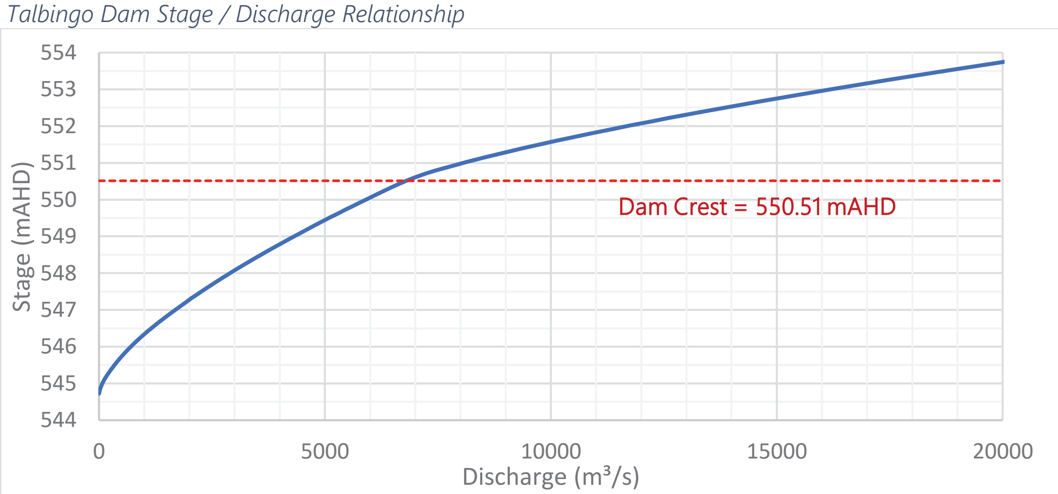
The dam has the following pertinent characteristics relevant to estimating upstream water levels:

- Dam Embankment Length (B) = ~701 m
- Spillway Length (b) = 230 m
- Dam Height (P) = ~161.5 m
- Spillway invert to Dam Crest level = 5.8 m
- Spillway crest level (Z) = 544.7 mAHD

Due to the dam's significant height relative to overtopping depth (P/H > 1.33), it can be assumed that the velocity head is negligible and does need not be considered in calculations. The spillway coefficient (Cw) has been determined considering the contracted weir form and ogee profile with a Cw = 0.72 determined. For extreme event flows overtopping the dam wall, a broad crest weir coefficient of 0.57 has been used.

Chart 10 present the Talbingo Dam stage/discharge relationship.

Chart 10: Talbingo Dam Stage / Discharge Relationship



2.3.1.3 Talbingo Dam Design Flood Levels

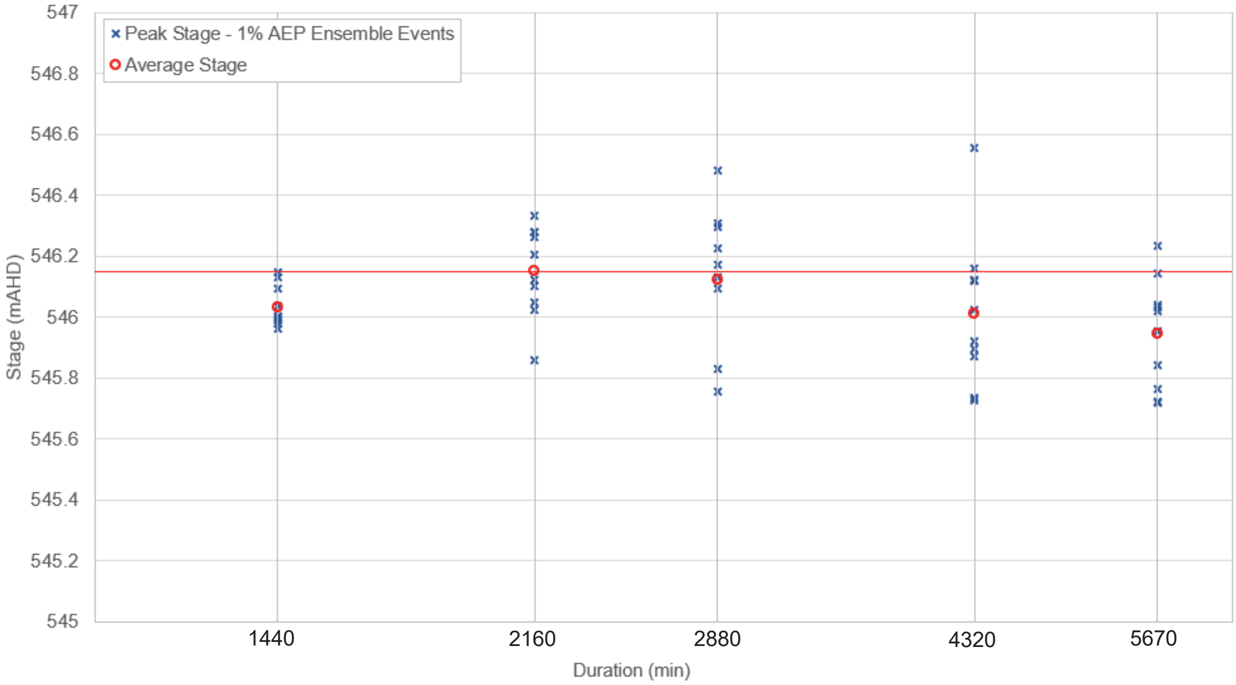
Design flood levels for Talbingo Dam have been determined by routing the dam inflow discussed in Section 2.2.3.4, through a conceptual storage in XP-RAFTS and applying the previously discussed stage/storage and stage/discharge relationships. The 1% AEP ensemble flood levels results are presented in Chart 11, with the 36 hour duration noted to be critical.

Table 24 presents the Talbingo Dam design flood levels for the 1% AEP event and PMF. Comparison to the '*Talbingo Dam Flood Hydrology*' (SKM, 2011) study results for the 'Updated Model With Zero Drawdown and Original Spillway Rating' scenario, indicate that the current study analysis provides a close match to the SKM (2011) study results. This analysis indicates that the changes to Australian Rainfall and Runoff associated with the 2016 revision have a limited effect on Talbingo Dam flood levels. The results of this analysis confirmed the suitability of the '*Talbingo Dam Flood Hydrology*' (SKM, 2011) report for flood levels for defining tailwater levels for the hydraulic model. The SKM (2011) study also provides results based on a Monte Carlo framework which incorporates dam drawdown into the analysis and provides significantly reduced design dam flood levels. Notwithstanding, results for the 'Zero Drawdown' scenario have been implemented to the TUFLOW model for the current study as a conservative approach to flood hydrology.

Table 24: Talbingo Dam Flood Levels - Current Study vs SKM (2011) Study

AEP	Current Study Dam Level (mAHD)	SKM (2011) Dam Level (mAHD)
1%	546.2	546.1
PMF	552.1	552.1

Chart 11: Talbingo Dam 1% AEP Flood Level, Ensemble Results



2.3.2 Lobs Hole Hydraulic Model Setup

The TUFLOW model developed for Lobs Hole as part of the *'Yarrangobilly River Flood Study'* (GRC Hydro, 2018) was reviewed and updated. TUFLOW is 2D numerical modelling package which is suitable for modelling complex flood behaviour of channels and floodplains such as those in Lobs Hole. Some modifications to the model (as discussed in Section 2.3.2.1) were made as part of the current study to better emulate existing catchment conditions and to develop a suitable Existing Conditions model. Further modification of the model to incorporate proposed Snowy 2.0 Main Works was undertaken to develop a Proposed Conditions model (see Section 2.3.2.2). The Proposed Conditions model was used to analyse flood behaviour for the construction phase of the project.

2.3.2.1 Existing Conditions Model Setup

The various data and parameters implemented in the Existing Conditions TUFLOW model are discussed below and are presented in Image 4:

- Model Domain and Grid Size – The hydraulic model domain covers an area of 4.5 km^2, extending from 500 m upstream of the construction pad on Yarrangobilly River, and 400 m upstream on Wallaces Creek. The downstream boundary is situated approximately 4 km downstream of the accommodation camp. A model grid size of 5 m x 5 m has been implemented which is considered suitable for adequately modelling key hydraulic features of the Yarrangobilly River. Section 2.4.1.2 presents a comparison the stage/discharge relationships for the Yarrangobilly@Ravine gauge and the TUFLOW hydraulic model which provides confidence in the selected grid size. For the PMF event, a 10 m grid cell size has been implemented due to flow depths significantly exceeding the cell size as well as to improved model stability;

- Digital Elevation Model (DEM) – A 1 m DEM provided by EMM (based on available LiDAR data supplied by Snowy Hydro) has been used to inform the topography of the 2D hydraulic model;
- Mannings Roughness – Mannings values were selected based on inspection of aerial imagery and the site visit (see Table 3). Selected Mannings values are consistent with Chow (1959) and ARR2016 and are presented in Table 25. These roughness values have been revised slightly relative to the '*Yarrangobilly River Flood Study*' (GRC Hydro, 2018);

Table 25: Lobs Hole, Mannings roughness values

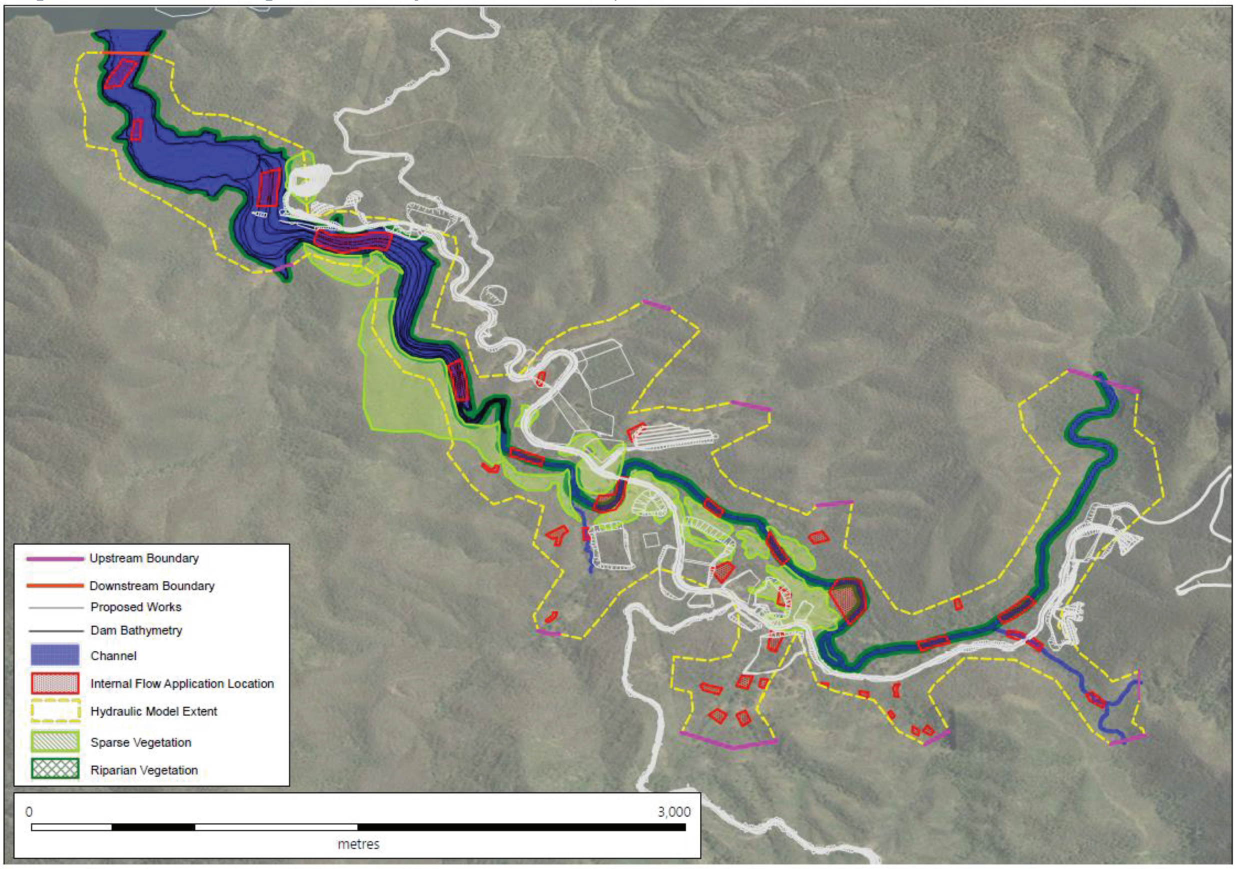
Land Use	Mannings
Yarrangobilly River channel	0.055
Wallaces Creek channel	0.06
Sparse vegetation	0.06
Dense vegetation	0.09
Riparian Vegetation	0.11

- Boundary Conditions – The inflows to the TUFLOW model were obtained from the XP-RAFTS model discussed in Section 2.2.2.2. The downstream boundary was set as a fixed water level boundary in Talbingo Dam. The following levels were implemented:
  - 20% to 2% AEP events – Full Supply Level (FSL) of 543.3 mAHD;
  - 1% to 0.05% AEP events – 1% AEP level of 546.1 mAHD based on the SKM (2011) study (see Section 2.3.1.3); and
  - PMF event – PMF level of 552.1 mAHD based on the SKM (2011) study (see Section 2.3.1.3);

Implementing the various details discussed above, an Existing Conditions model was developed to model baseline conditions (e.g. prior to commencement of the Exploratory Works) flood behaviour for Lobs Hole.

Existing Conditions model results are discussed in Section 2.4.1, with figures presented in Appendix A.

Image 4: Lobs Hole, Existing Conditions Hydraulic Model Setup



*Note: the proposed development works are presented in white. These have not been included in the Existing Conditions TUFLOW model and are shown purely for representational purposes.

2.3.2.2 Proposed Conditions Model Setup

A Proposed Conditions model was produced by modifying the Existing Conditions TUFLOW model to incorporate works proposed for the construction phase of the Snowy 2.0 Main Works project. Available design information was provided by Future Generations Joint Venture (FGJV) and required embellishment/assumptions to develop the Proposed Conditions scenario.

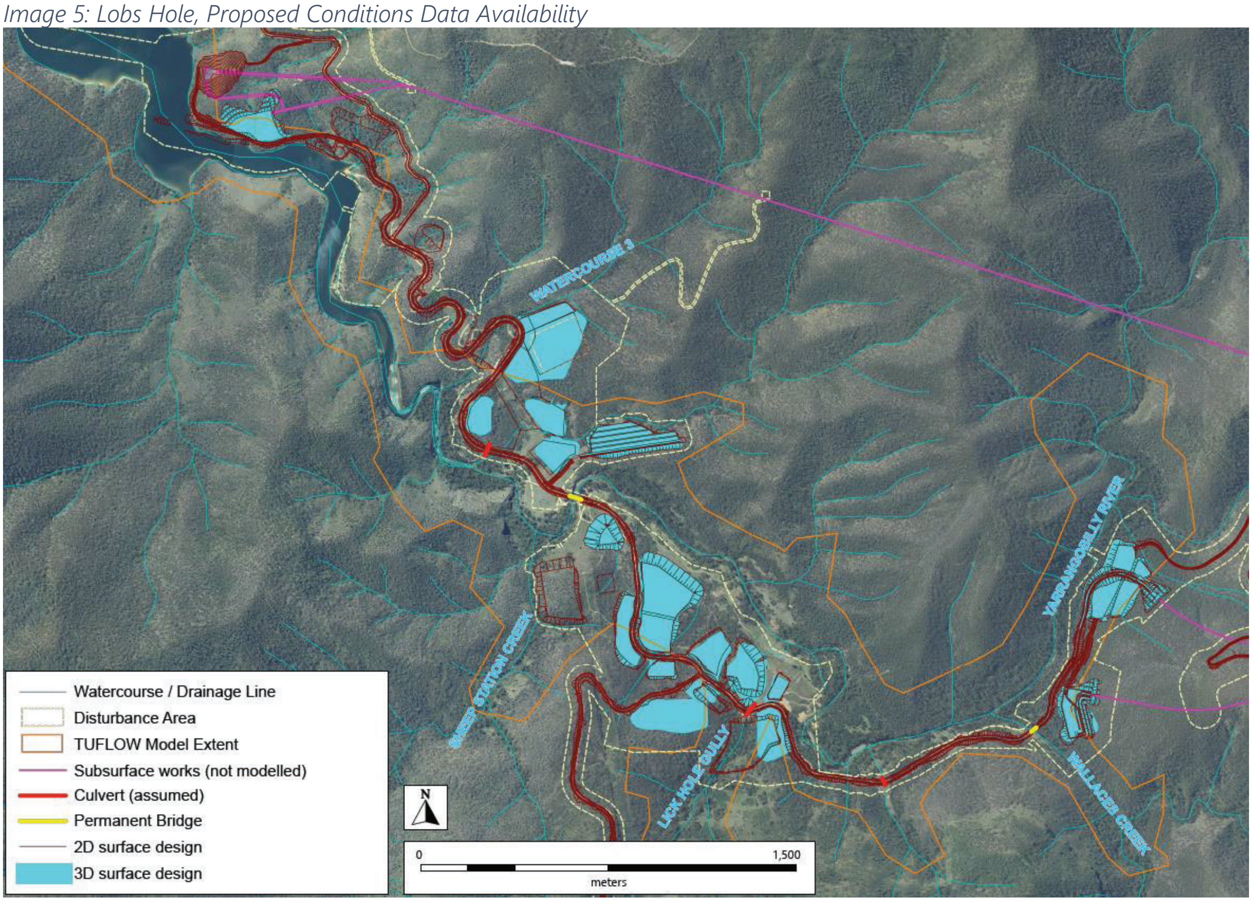
Image 5 presents available data for the FGJV design for use in the current assessment. The data can be categorised into five groups which are outlined below:

- 3D surface design – provided as a Triangulated Irregular Network (TIN). The provided 3D design typically represented rock emplacement and areas of bulk earthworks such as the accommodation camp;
- 2D surface design – provided as a 2D GIS compatible format. The provided 2D design typically represented roads and in some instances rock emplacement areas, where 3D design surfaces were not available. For implementation of the design into the TUFLOW model, a 3D design was developed by GRC Hydro based on the interpretation of the 2D surface design and available LiDAR data;
- Assumed culverts – at three locations the proposed 3D and 2D surface designs resulted in the obstruction of Yarrangobilly River tributaries. In these cases, it was assumed that culverts are proposed, and that the sizing of these culverts will be determined during detailed design.

For the current assessment the three culvert crossings were assumed to be 2 x 1200 mm diameter pipes;

- Permanent Bridges – concept drawings were provided as part of the Snowy 2.0 Exploratory Works. The drawings provided design information, inclusive of design levels, suitable for incorporating bridge details into the Proposed Conditions model. Bridge approach embankments were also available as part of this information; and
- Subsurface works – have not been modelled as they will not impact on Proposed Conditions flood behaviour.

Image 5: Lobs Hole, Proposed Conditions Data Availability



Further consideration of flooding conditions and impacts under both construction and operational phases will be required as part of future design development. This should also include consideration of flooding conditions along minor tributaries of the Yarrangobilly River, which have not been the focus of the current assessment.

Proposed Conditions model results are discussed in Section 2.4.2, with figures presented in Appendix A.

2.4 Hydraulic Model Results

Hydraulic model results are presented in Sections 2.4.1 and 2.4.2 for Existing and Proposed Conditions respectively.

2.4.1 Existing Conditions Results

Existing Conditions have been assessed using the TUFLOW model discussed in Section 2.3.2.1. Results are presented in Appendix A for the 20%, 5%, 1%, 0.2% AEP events and the PMF. Peak flood depths and levels are presented in figures:

- *Figure A 1:* *Lobs Hole, peak flood depths and levels – Existing Conditions – 20% AEP*;
- *Figure A 2:* *Lobs Hole, peak flood depths and levels – Existing Conditions – 5% AEP*;
- *Figure A 3:* *Lobs Hole, peak flood depths and levels – Existing Conditions – 1% AEP*;
- *Figure A 4:* *Lobs Hole, peak flood depths and levels – Existing Conditions – 0.2% AEP*;
- *Figure A 5:* *Lobs Hole, peak flood depths and levels – Existing Conditions – 0.05% AEP*;
- *Figure A 6:* *Lobs Hole, peak flood depths and levels – Existing Conditions – PMF*.

Design flood levels at the Yarrangobilly@Ravine (410574) gauge location are presented in Table 26.

Table 26: Flood Level and Gauge Stage at the Yarrangobilly@Ravine (410574) Gauge

AEP	Hydraulic Model Gauge Level (mAHD)	Estimated Gauge Stage (m)*
20%	563.79	2.3
5%	564.33	2.8
1%	564.94	3.5
0.2%	565.55	4.1
0.05%	566.34	4.9
PMF	572.31	10.8

* Note that gauge stage has been estimated by assuming a gauge zero of 561.48 mAHD. The gauge zero has been estimated via interrogation of the LiDAR and is subject to an accuracy of approximately ±0.3 m, however the gauge zero level is not likely to exceed a level of 561.48 mAHD (see Table 3).

ARR2016 flood hazard based on the *'Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia'* (AIDR 2017) is presented in figures:

- *Figure A 7:* *Lobs Hole, flood hazard – Existing Conditions – 20% AEP*;
- *Figure A 8:* *Lobs Hole, flood hazard – Existing Conditions – 5% AEP*;
- *Figure A 9:* *Lobs Hole, flood hazard – Existing Conditions – 1% AEP*;
- *Figure A 10:* *Lobs Hole, flood hazard – Existing Conditions – 0.2% AEP*;
- *Figure A 11:* *Lobs Hole, flood hazard – Existing Conditions – 0.05% AEP*; and
- *Figure A 12:* *Lobs Hole, flood hazard – Existing Conditions – PMF*.

Flood hazard is defined as a source of potential harm or a situation with the potential to result in loss (ARR2016). AIDR (2017) flood hazard considers the threat to people, vehicles and buildings based on flood depth and velocity at a specific location. Chart 12 and Table 27 present the relationship between the velocity and depth of floodwaters and the corresponding classification.

Chart 12: Flood Hazard Curves (AIDR, 2017)

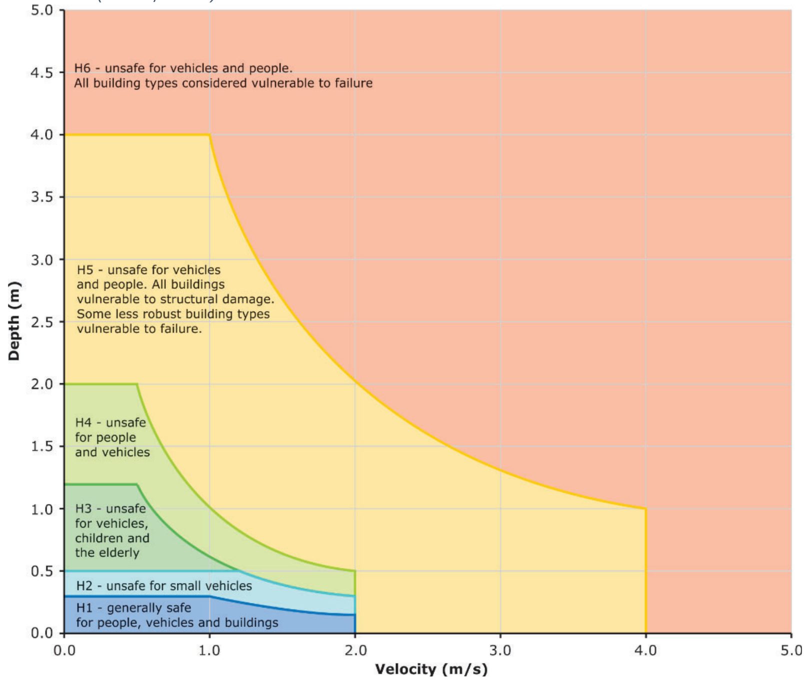


Table 27: Flood Hazard – Vulnerability Thresholds

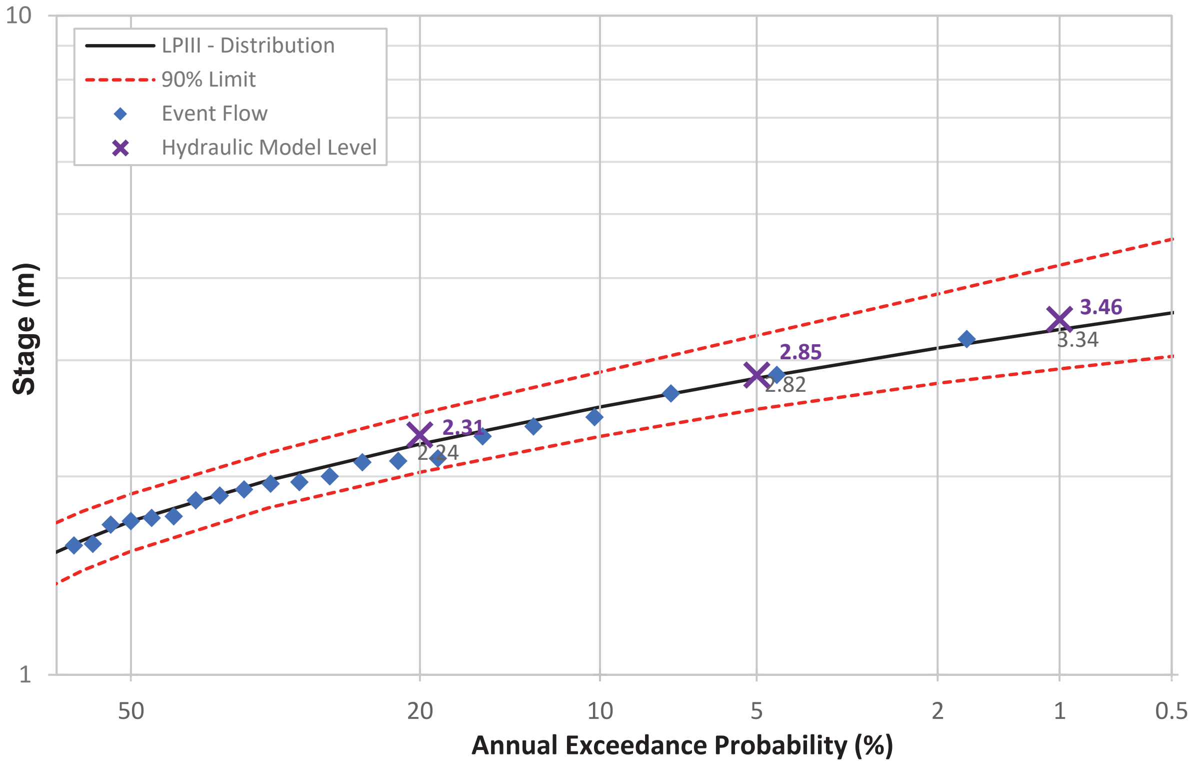
Hazard Classification	Description
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

2.4.1.1 Validation of Hydraulic Model Results

Frequency analysis was performed on the annual maximum series of gauge stages' at the Yarrangobilly@Ravine (410574) stream gauge. The frequency analysis was undertaken for the period of 1982 to 2017 as gauge levels were not available for the period prior to 1982. The analysis was undertaken using the same methods outlined for the flow FFA (see Section 2.2.2.1).

A comparison of hydraulic model stage and frequency analysis stage is presented in Chart 13. Results indicate an excellent match to the LPIII distribution expected quantile (black line) indicating that the model is accurately reproducing design flood levels at the gauge location.

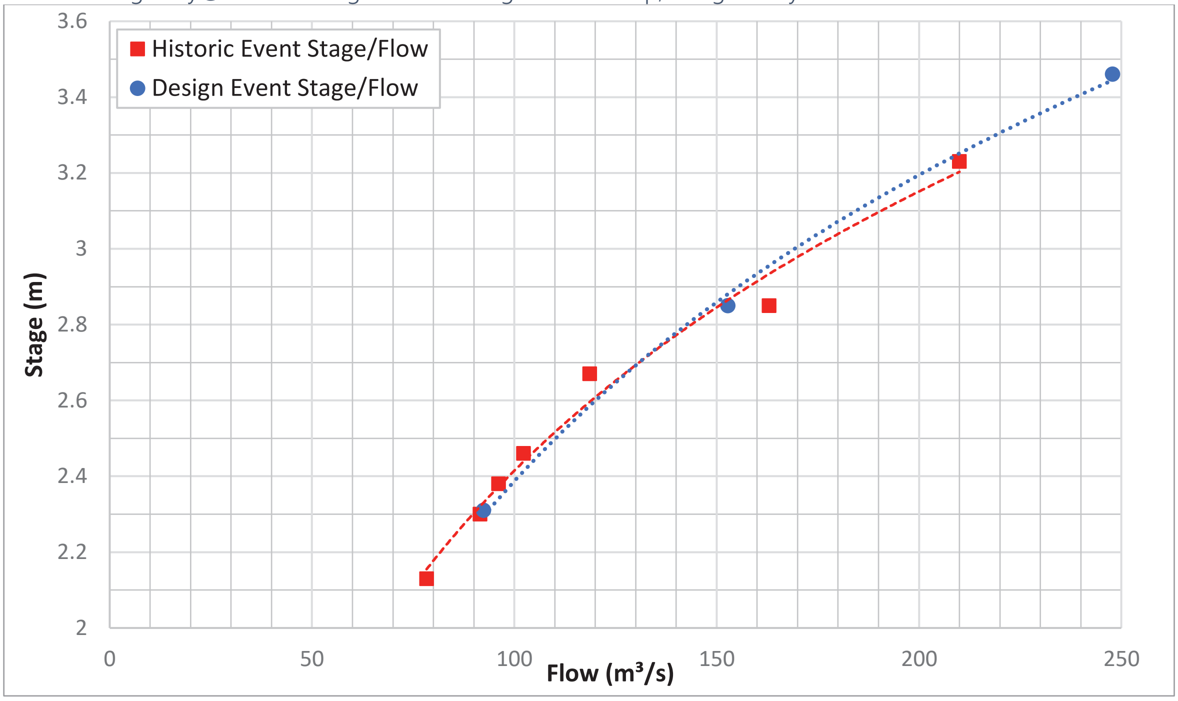
Chart 13: Comparison of Stage FFA to the Hydraulic Model at Yarrangobilly@Ravine



2.4.1.2 Validation of Yarrangobilly@Ravine Rating Curve

The stage/discharge relationship at the Yarrangobilly@Ravine gauge has been examined in the TUFLOW model to assess the validity of the gauge's rating curve. The Yarrangobilly@Ravine rating was not available for review at the time of the study, however an approximation of the rating has been inferred by examining historic event peak stage and discharges. The peak stage and discharge recorded for the seven largest events on recorded at the gauge have been plotted in red on Chart 14, with a trendline fitted to approximate the rating curve. Peak stage and flows for the 20%, 5% and 1% AEP events extracted from the TUFLOW model have been plotted in blue, again with a trendline fitted to approximate the stage/discharge relationship of the TUFLOW model at the gauge. Comparison of the historic event and design event relationships indicates that the TUFLOW model is reproducing a similar stage/discharge relationship to the gauge rating. This gives confidence in the historic event flow estimates and FFA results, as well as the TUFLOW model design flood levels.

Chart 14: Yarrangobilly@Ravine – Stage and Discharge Relationship, Gauge vs Hydraulic Model



2.4.2 Proposed Conditions Results

Proposed Conditions have been assessed using the TUFLOW model discussed in Section 2.3.2.2. Proposed Conditions results are presented in Appendix A for the 20%, 5%, 1%, 0.2% AEP events and the PMF. Peak flood depths and levels are presented in figures:

- *Figure A 13: Lobs Hole, peak flood depths and levels – Proposed Conditions – 20% AEP*;
- *Figure A 14: Lobs Hole, peak flood depths and levels – Proposed Conditions – 5% AEP*;
- *Figure A 15: Lobs Hole, peak flood depths and levels – Proposed Conditions – 1% AEP*;
- *Figure A 16: Lobs Hole, peak flood depths and levels – Proposed Conditions – 0.2% AEP*;
- *Figure A 17: Lobs Hole, peak flood depths and levels – Proposed Conditions – 0.05% AEP*;
- *Figure A 18: Lobs Hole, peak flood depths and levels – Proposed Conditions – PMF*.

ARR2016 flood hazard (see Section 2.4.1 for further details) based on the *'Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia'* (AIDR 2017) is presented in figures:

- *Figure A 19: Lobs Hole, flood hazard – Proposed Conditions – 20% AEP*;
- *Figure A 20: Lobs Hole, flood hazard – Proposed Conditions – 5% AEP*;
- *Figure A 21: Lobs Hole, flood hazard – Proposed Conditions – 1% AEP*;
- *Figure A 22: Lobs Hole, flood hazard – Proposed Conditions – 0.2% AEP*;
- *Figure A 23: Lobs Hole, flood hazard – Proposed Conditions – 0.05% AEP*; and
- *Figure A 24: Lobs Hole, flood hazard – Proposed Conditions – PMF*.

2.4.3 Assessment of Flood Impacts

The Existing and Proposed Conditions model results have been compared to assess the likely impact on flood behaviour due to the Snowy 2.0 Main Works during the construction phase of the project.

Flood level impact maps that compared the change in water level between Existing and Proposed Conditions are presented in figures:

- *Figure A 25:* *Lobs Hole, flood level impact mapping – 20% AEP*;
- *Figure A 26:* *Lobs Hole, flood level impact mapping – 5% AEP*;
- *Figure A 27:* *Lobs Hole, flood level impact mapping – 1% AEP*;
- *Figure A 28:* *Lobs Hole, flood level impact mapping – 0.2% AEP*;
- *Figure A 29:* *Lobs Hole, flood level impact mapping – 0.05% AEP*; and
- *Figure A 30:* *Lobs Hole, flood level impact mapping – PMF*.

Flood hazard impact maps that compared the change in flood hazard between Existing and Proposed Conditions are presented in figures:

- *Figure A 31:* *Lobs Hole, flood hazard impact mapping – 20% AEP*;
- *Figure A 32:* *Lobs Hole, flood hazard impact mapping – 5% AEP*;
- *Figure A 33:* *Lobs Hole, flood hazard impact mapping – 1% AEP*;
- *Figure A 34:* *Lobs Hole, flood hazard impact mapping – 0.2% AEP*;
- *Figure A 35:* *Lobs Hole, flood hazard impact mapping – 0.05% AEP*; and
- *Figure A 36:* *Lobs Hole, flood hazard impact mapping – PMF*.

2.5 Lobs Hole - Conclusions

A flood study was undertaken for Lobs Hole, situated within the Snowy 2.0 Main Works project area. Lobs Hole is subject to flooding from the Yarrangobilly River, Wallaces Creek and other unnamed tributaries, and in the lower reaches of the site, Talbingo Dam.

Flood behaviour for Lobs Hole was assessed as part of the *'Yarrangobilly River Flood Study'* (GRC Hydro, 2018) undertaken for the Snowy 2.0 Exploratory Works EIS. The current study builds on the GRC Hydro (2018) study, by first reviewing the modelling methods and parameters to confirm suitability for use in the current study, and then extending the models to assess Talbingo flood levels which can also affect the lower reaches of Lobs Hole.

An XP-RAFTS model was developed as part of the GRC Hydro (2018) study and ARR2016 methods and parameters were applied. The model was calibrated to FFA developed for the Yarrangobilly@Ravine stream gauge and validated to regional flow estimates based on RFFE. Review of the calibration process indicated that the model was suitable for use in the current study. Validation of the Yarrangobilly@Ravine stream gauge rating was undertaken. The calibration/validation process indicates that the XP-RAFTS model is producing robust design flow estimates.

Design flows were developed for the 20%, 5%, 1%, 0.2% and 0.05% AEP events and the PMF. Design flows from the XP-RAFTS model were applied to the TUFLOW model discussed below

Talbingo Dam design flood levels were obtained from the *'Talbingo Dam Flood Hydrology'* (SKM, 2011) study. The current study undertook hydrologic analysis by implementing ARR2016 methods and techniques to validate the finding of the SKM (2011) study. The analysis was undertaken to ensure that changes to Australian Rainfall and Runoff associated with the 2016 revision have not significantly affected design flood levels for the Dam. The results of this analysis found that design flood levels are within ± 0.1 m when comparing the two studies for both the 1% AEP and PMF events.

The TUFLOW hydraulic model developed as part of the *'Yarrangobilly River Flood Study'* (GRC Hydro, 2018) study was updated for the current study. The model was used to determine design flood characteristics for Lobs Hole in the vicinity of the site. Flows from the XP-RAFTS model and Dam levels from the SKM (2011) study were applied to the TUFLOW model to examine design flood behaviour for the 20%, 5%, 1%, 0.2% and 0.05% AEP events and the PMF.

Existing and Proposed Conditions flood depths, levels and flood hazard for the 20%, 5%, 1%, 0.2% AEP and PMF events are presented in Appendix A, along with flood level and hazard impact mapping.

3. KELLYS PLAIN CREEK – FLOOD STUDY

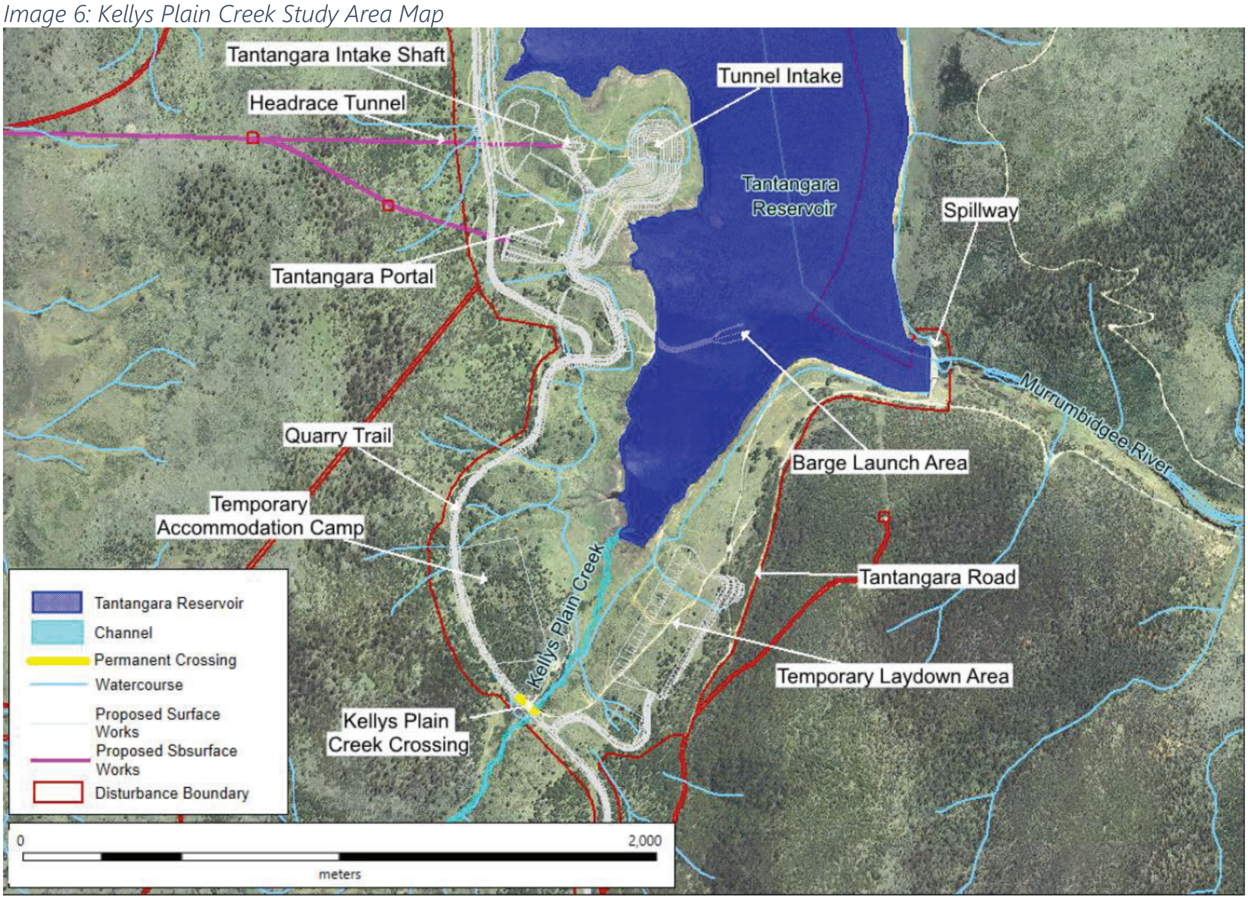
3.1 Kellys Plain Creek Introduction

This section comprises the 'Kellys Plain Creek Flood Study' which defines design flood behaviour for the Kelly Plain Creek site. Flood behaviour for Kellys Plain Creek and Tantangara Dam has been considered.

3.1.1 Study Area

Kellys Plain Creek flows into Tantangara Dam to the south of the dam spillway and has a catchment area of ~11 km^2. Due to the close proximity of the Dam, flood levels for the lower reaches of the site are dominated by water levels in Tantangara. A study area map is presented in Image 6.

Image 6: Kellys Plain Creek Study Area Map



3.1.2 Objectives

The key objective of the Kellys Plain Creek Flood Study is to define design flood characteristics for the Kellys Plain Creek site due to the Creek and Tantangara Dam flood events. The analysis has applied the methods outlined in ARR2016 for the 1% AEP and PMF events. Flood level, depth, extent and flood hazard have been produced for both events.

To satisfy the key objective outline above, the following analysis has been undertaken:

- Development of an XP-RAFTS hydrologic model for the catchment upstream of Kellys Plain Creek;

- Modelling of Creek design flows for the 1% AEP (ARR2016) and the PMF (GSDM) events;
- Validation the 1% AEP flow by comparison to regional estimates derived for surrounding areas;
- Analysis of Tantangara Dam flood levels using the WBNM model developed as part of the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019). This analysis has been undertaken to validate the findings of the *'Tantangara Dam Update of Hydrology and Spillway Capacity Assessment'* (Jacobs, 2015) report, and ensure changes associated with ARR2016 have not significantly impacted on design flood levels in the Dam;
- Development of a TUFLOW hydraulic model for Existing Conditions (e.g. baseline conditions) flood behaviour at the Kellys Plain Creek to Tantangara Dam;
- Modelling the 1% AEP event and the PMF in TUFLOW, incorporating Tantangara Dam design levels based on the Jacobs (2015) study.

The purpose of this report is to describe the data analysis and modelling methodologies that have been applied to the Kellys Plain Creek Flood Study. Model results are presented and discussed herein.

3.2 Kellys Plain Creek - Hydrology

3.2.1 Hydrology Approach

A two-part hydrologic analysis was undertaken:

1. An XP-RAFTS hydrologic model was produced to assess Kellys Plain Creek design flows. Due to the absence of a stream gauge within the catchment, Flood Frequency Analysis (FFA) and event-based model calibration could not be undertaken. Accordingly, 1% AEP flow estimates were validated to regional design flow estimates from nearby studies; and
2. Design inflows for Tantangara Dam were calculated using a WBNM hydrologic model produced as part of the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019). Additional validation to FFA from a gauge in the upstream Tantangara Dam catchment was undertaken and the model was used to calculate 1% AEP and PMF event dam inflows. The results of this analysis confirmed the suitability of the *'Tantangara Dam Update of Hydrology and Spillway Capacity Assessment'* (Jacobs, 2015) report for flood levels for defining tailwater levels for the hydraulic model.

The following sections outline the implemented approach.

3.2.2 Local Catchment Hydrology – Kellys Plain Creek

Hydrologic model design flows have been determined using ARR2016 guidelines. Selected model parameters and inputs are described in the ensuing sections.

3.2.2.1 Model Schematisation and Parameters

An XP-RAFTS model was developed for the Kellys Plain Creek catchment to Tantangara Dam. Details of the XP-RAFTS model schematisation are presented in Table 28 with sub-catchment delineation presented in Image 7.

Table 28: XP-RAFTS Model Schematisation – Kellys Plain Creek

Total model catchment area (km^2)	Number of Catchments	Average catchment size (km^2)
11	26	0.4

XP-RAFTS model parameters were determined via inspection of available data including photographs, aerial imagery and a 2 m DEM data obtained from the NSW Government Spatial Services. This information was used to inform sub-catchment Mannings, slope and lag times.

The Kellys Plain Creek catchment at the site was found to be predominantly grazed grasslands with pockets of moderate to low density vegetation in the lower catchment, with increased vegetation density in the upper catchment areas. Manning's values ranging from 0.04 in grasslands to 0.07 in the vegetated upper catchment areas were applied to the XP-RAFTS model.

Sub-catchments slopes and stream lengths were calculated for each sub-catchment via interrogation of the 2 m LiDAR data.

Lag times for inter-catchment routing were determined using the major flow path length (L) and slope (S) and the formula outlined in the Laurenson's method (lag time = $L / S^{0.5}$).

3.2.2.2 Design Rainfall

ARR2016 design rainfall depths for various durations were obtained from the Bureau of Meteorology (BoM). Analysis of design rainfall depths across the Kellys Plain Creek catchment was undertaken to identify potential design rainfall gradients. The analysis indicated that there is no significant design rainfall gradient present and accordingly, a single-uniformly applied rainfall depth was appropriate for modelling of design rainfall for the study area. Catchment design rainfall depths applied to the XP-RAFTS model are presented in Table 29.

Table 29: Design Rainfall Depths, Kellys Plain Creek

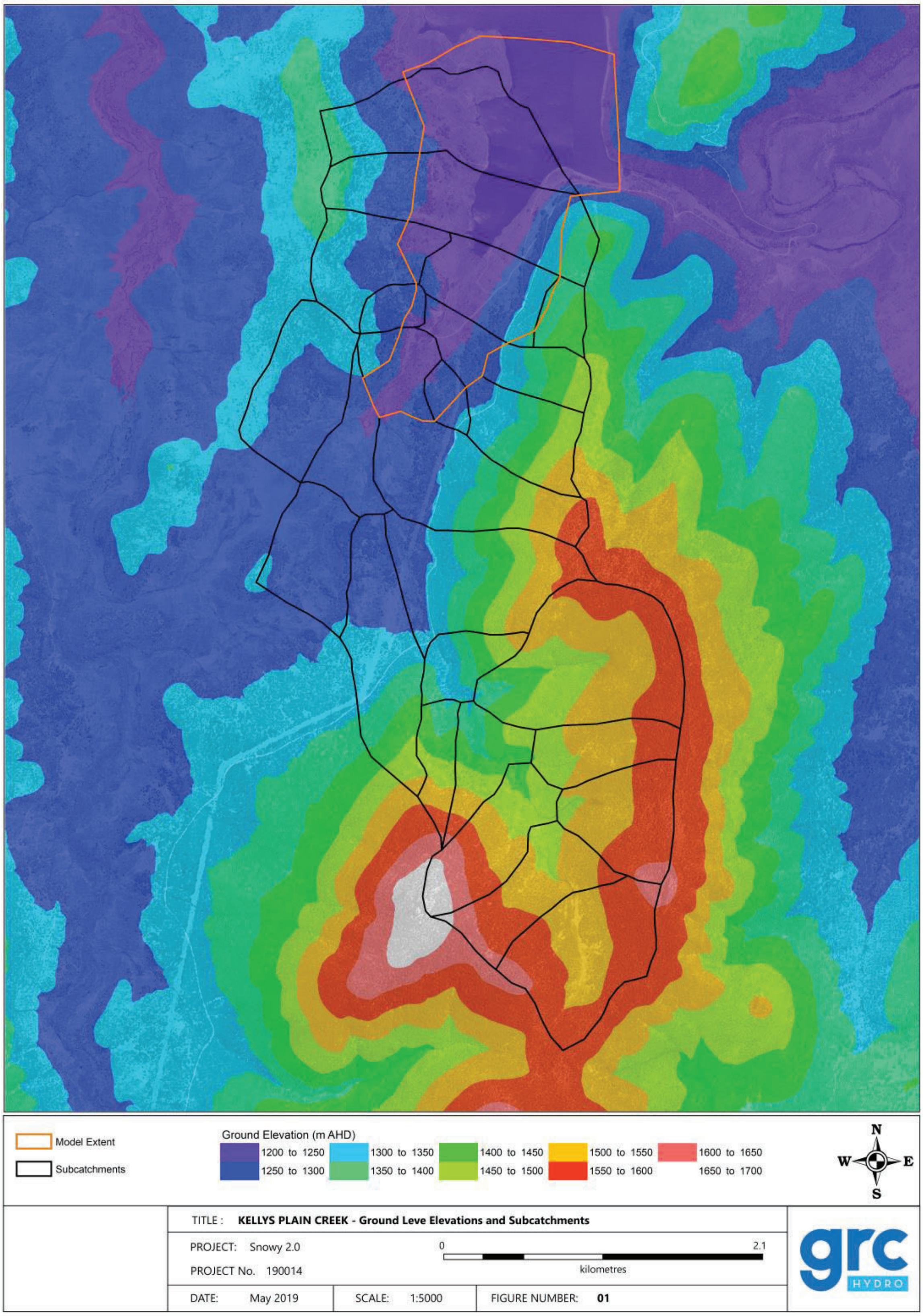
Duration (min)	1% AEP Event
180	59.2
270	70.6
360	81.2
540	100
720	117

Probable Maximum Precipitation (PMP) rainfall depths were calculated using the XP-RAFTS software which uses the methods outlined in the GSDM. The catchment is defined as 60% 'Rough' and a Moisture Adjustment Factor of 0.62 was applied. The Elevation Adjustment Factor was not applied as catchment elevations typically do not exceed 1500 mAHD. PMP rainfall depths for various durations are presented in Table 30.

Table 30: PMP Rainfall Depths, Kellys Plain Creek

Duration	45min	1 hour	1.5 hour	2 hour	3 hour
Rain (mm)	250	290	350	440	480

Image 7: Kellys Plain Creek Sub-catchments, Topography and TUFLOW Model Boundary



3.2.2.3 Areal Reduction Factor

Areal Reduction Factors (ARF) were applied to design rainfall depths (with the exception of the PMF) to adjust for the catchment's areal average rainfall intensity. The ARFs were determined following the methods outlined in ARR2016 for the 'Southern Temporal' region. Calculated ARFs were based on the Kellys Plain Creek catchment area and event duration and probability. Applied ARFs are presented in Table 31.

Table 31: Areal Reduction Factors, Kellys Plain Creek

Duration (min)	1% AEP Event
180	0.93
270	0.94
360	0.96
540	0.97
720	0.97

3.2.2.4 Rainfall Losses

ARR2016 recommends a continuing loss of 4.1 mm/h at the study area. The recommended ARR2016 continuing loss was found to be relatively high compared to nearby catchments with similar land uses and topographic characteristics. Table 32 presents the calibrated continuing loss parameters adopted in the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019).

Table 32: Calibrated continuing loss from the Snowy Monaro Flood Studies (GRC Hydro, 2019)

Town	Continuing Loss (mm/h)
Cooma	0.5
Bredbo	2.0
Berridale	2.0
Michelago	3.5
Average	2.0

The NSW Office of Environment and Heritage (OEH) released the '*Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in Studies*' in early 2019 to provide additional guidance for the application of ARR2016 in NSW catchments. These guidelines recognised that loss values for NSW from the ARR Data Hub have resulted in "a significant bias toward underestimation of flows". These guidelines provide a hierarchical approach to loss and pre-burst estimation in NSW. This approach recommends the application of an average calibration loss from other studies in similar adjacent catchments if suitable calibration of losses is not possible. Based on this approach an average continuing loss of 2.0 mm/h (see Table 5), derived in the *'Snowy Monaro Flood Studies Draft Final Report'* (SMEC/GRC Hydro, 2019), has been adopted in the current study.

An ARR2016 Initial loss of 28 mm has been used for design flood modelling with adjustment for pre-burst. For comparative purposes, the average design initial loss implemented in the *'Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) is 26.5 mm. Pre-burst adjusted initial losses used in the current study design flood modelling are presented in Table 33 and range from 16.6 to 28 mm depending on the event duration.

Table 33: Applied 1% AEP Initial Losses (incorporating pre-burst)

Duration (min)	1% AEP Event
180	28.0
270	26.1
360	24.2
540	20.4
720	16.6

PMF rainfall losses have been applied as an IL / CL model (IL = 0 mm, CL = 1 mm/hr) as per the methods outlined in the GSDM.

3.2.2.5 Rainfall Temporal Patterns

Rainfall temporal patterns are used to describe how rainfall is distributed as a function of time. The recommended ARR2016 ensemble approach to applying temporal patterns has been utilised in the current study. The ensemble approach to flood modelling applies a suite of 10 temporal patterns for each duration. Point Temporal Patterns have been implemented as the catchment size is less than 75 km^2. The temporal patterns were obtained from ARR2016 for the 'Murray Basin' region.

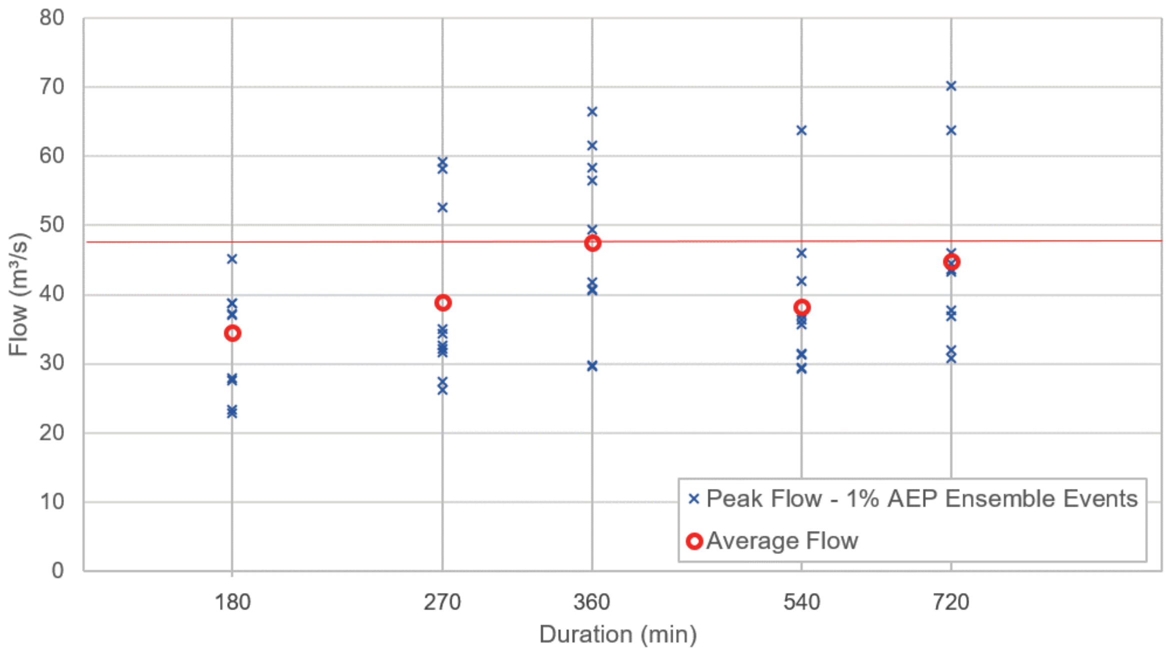
The GSDM temporal pattern was used in analysis of the PMF.

3.2.2.6 Hydrologic Results

Hydrologic model design flows are presented in Chart 15 for the 1% AEP event on Kellys Plain Creek at the site. Each blue 'x' indicates the peak flow of a modelled event. The red circle is the average flow for each duration. The ensemble method identifies the critical duration as the duration with the highest mean flow and the temporal pattern, which is closest to, but above the mean is selected.

For the 1% AEP event the critical duration at the site is the 6 hour event with an ensemble average flow of 47.5 m^3/s. Storm 6 with a peak flow of 49.4 m^3/s was used for the ensuing analysis.

Chart 15: 1% AEP Design Flow Results on Kellys Plain Creek at the subject site



A similar process was implemented for the PMF with a range of PMP durations from 0.5 to 3 hours assessed. The PMF critical duration was determined to be 1 hour with a peak flow of 606 m^3/s.

3.2.2.7 Validation of Design Flow Estimates

To improve confidence in the 1% AEP design flow estimate, a validation process was undertaken.

As a first pass, comparison of the XP-RAFTS flow estimate to the ARR2016 RFFE flow estimate was undertaken (see Table 34). However, review of ARR2016 RFFE for the site revealed a lack of confidence in the RFFE design flows. Accordingly, design flow estimates were validated via other means.

Table 34: Comparison of 1% AEP Hydrologic Model Flow and RFFE Estimates – Kellys Plain Creek

Location	Hydrologic Model 1% AEP Flow (m^3/s)	RFFE Design Estimates (m^3/s)		
		1% AEP Estimate (m^3/s)	Upper Confidence Limit	Lower Confidence Limit
Kellys Plain Creek	47.5	15	42	6

Results presented in Table 34 show a clear disparity between the 1% AEP design estimates from the current study and the RFFE model. When considering RFFE flow estimates, it is important to note the ARR2016 states 'that the relative accuracy of regional flood estimates using the RFFE model is likely to be within ± 50% of the true value' and as such, RFFE design flows estimates should be carefully considered. This is particularly the case for smaller catchments as ARR2016 states 'there are only a few gauged catchments smaller than 10 km^2 included in the data base to develop the RFFE Model' and as such 'it is likely that there will be a greater degree of error in the quantile estimates for these smaller catchments'. The Kellys Plain Creek catchment at the site is ~8 km^2 and accordingly, the RFFE estimates are likely have a higher degree of error.

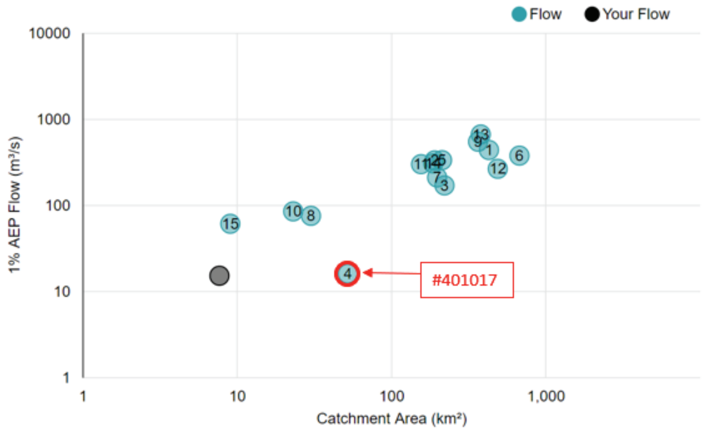
Comparison of RFFE design flow estimates to those derived in the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) via event-based calibration and validation to FFA, indicate that on average the difference is 50%, however the maximum difference from four examined gauges was -120%. This finding further reduced confidence in the veracity of the RFFE estimates in the vicinity of the subject site.

Given the uncertainty associated with the RFFE results in the region, further analysis of RFFE input parameters was undertaken. It was noted that Welumba @ The Square (401017) gauge 1% AEP flow estimate is significantly lower than the surrounding gauges with comparable catchment areas. The 1% AEP Flow vs Catchment Area plot extracted from RFFE is presented in Chart 16.

Details of the surrounding gauges on which the RFFE analysis is based, were extracted from the 'output_nearby.csv' from the RFFE website. Review of the Welumba gauge (401017, area of 52 km^2) confirmed a low runoff coefficient for the catchment of 0.3 $m^3/s/km^2$. This is significantly lower than the average runoff coefficients calculated for catchment areas (average catchment area of 260 km^2) examined in the '*Snowy Monaro Flood Study Draft Final Report*' (SMEC/GRC Hydro, 2019) of 1.6 $m^3/s/km^2$. This is contrary to what would typically be expected as larger catchment areas (52 km^2 vs 260 km^2) have smaller runoff coefficients due to flow attenuation, spatial distribution of rainfall and other hydrologic and hydraulic factors. This strongly indicates that the Welumba gauge (401017) 1%

AEP flow is underestimated, or at least, is not representative of design flow estimates in surrounding catchments.

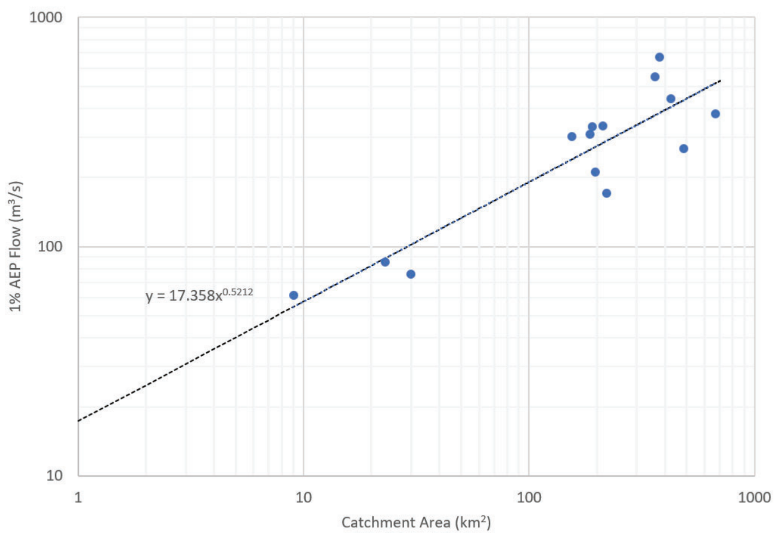
Chart 16: ARR2016 RFFE - 1% AEP Flow Results vs Catchment Area, Kellys Plain Creek



Due to lack of confidence in the RFFE derived flow estimate, another method of testing the robustness of the 1% AEP flow estimate has been applied. This analysis used gauge details and design flows presented in the RFFE 'output_nearby.csv' to develop a relationship (power curve) between the 1% AEP estimates and catchment area. Table 35 presents details extracted from the 'output_nearby.csv' along with the relationship developed for this data. Due to the unexpectedly low runoff coefficient determined for Welumba gauge (401017), this gauge was not used in the analysis.

Table 35: RFFE Catchment Area vs 1% AEP Flow, Kellys Plain Creek

Gauge ID#	Area (km^2)	1% AEP Flow (m^3/s)
401016	52	16
410152	9	61
410149	30	76
410114	23	85
401009	220	171
401017	197	212
401229	487	267
410061	155	302
410107	186	308
410141	190	334
410076	212	336
410057	673	380
410088	427	441
401230	363	551
401013	378	668



Using this relationship and the Kellys Plain Creek catchment area at the site (7.7 km^2), a 1% AEP flow estimate of 50 m^3/s was determined for the subject site via extrapolation of the power curve. This flow is comparable to the hydrologic model 1% AEP flow of 49 m^3/s which provides confidence in the 1% AEP design flow estimate.

3.2.3 Tantangara Dam Hydrology

Design flood levels for Tantangara Dam have previously been determined in the '*Tantangara Dam Update of Hydrology and Spillway Capacity Assessment*' (Jacobs, 2015) report. The current study has undertaken hydrologic analysis for the dam by implementing ARR2016 methods and techniques. This analysis was undertaken to validate the finding of the Jacobs (2015) study and ensure that changes to Australian Rainfall and Runoff associated with the 2016 revision have not significantly affected design flood levels in Tantangara Dam.

The current study dam analysis was focused on determining design flood levels for the Kellys Plain Creek site, and accordingly the Jacobs (2015) study was noted to have applied a more rigorous approach to dam flood hydrology. As such, the results from the Jacobs (2015) study have been used in preference to the current study results. Notwithstanding, the results from the two studies are similar (±0.2 m), thus providing confidence in the Jacobs (2015) study results. A comparison of the current study and Jacobs (2015) study, Tantangara Dam levels for the 1% AEP and PMF events is presented in Section 3.3.1.3.

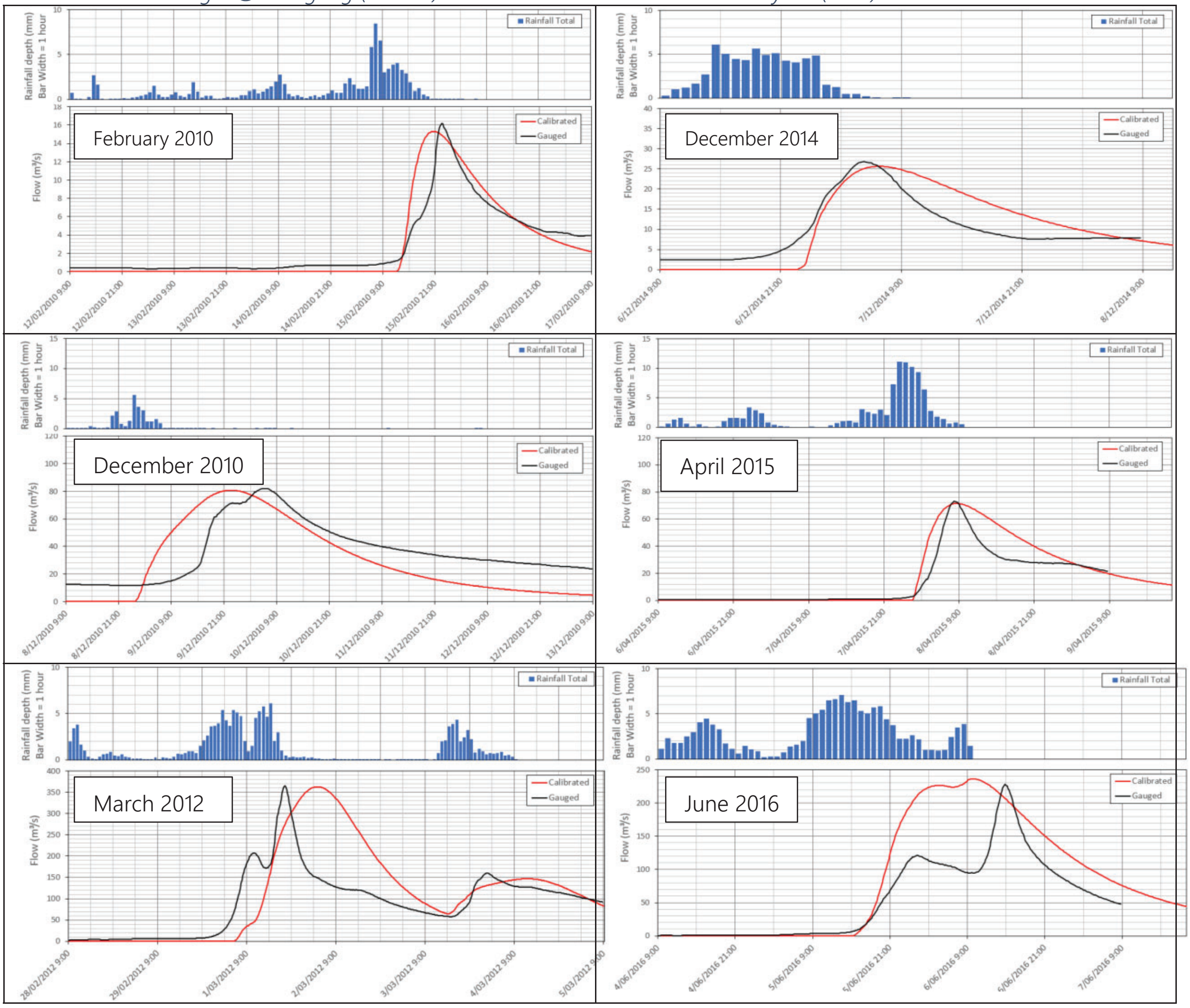
Design inflows for Tantangara Dam were calculated using a WBNM hydrologic model produced as part of the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019). Additional validation to FFA for a gauge in the upstream Tantangara Dam catchment was undertaken and the model was used to calculate 1% AEP and PMF event flows.

3.2.3.1 Snowy Monaro Flood Studies Hydrology Summary

Focus of the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) was for flooding in the townships of Cooma, Bredbo, Michelago and Berridale. Of these towns, only Bredbo experiences flooding due to the Murrumbidgee River (for a catchment area of ~4,900 km^2), and only due to backwatering of the Bredbo River during major Murrumbidgee River floods. Accordingly, calibration efforts were focused on calibration of Murrumbidgee River tributaries in each of the towns, rather than the Murrumbidgee. However, calibration to six events at Murrumbidgee River at Mittagong gauge (410033) (catchment area of 1,890 km^2) was undertaken with the results presented in Chart 17. Note that this document only discusses results for the Murrumbidgee River calibration, for a full set of results for tributaries, please refer to the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019). For all events, a WBNM routing parameter (C) of 1.6 and a continuing loss of 2 mm/hr were implemented. Only the Initial Losses were varied between events, which would be expected due to variations in antecedent conditions.

The calibration process achieved a good match to peak flow for all events, however hydrograph shape and timing of peak were generally fair to poor. Calibrated event volumes were noted to be good for five of the six events examined. Event based calibration efforts were hampered due to a paucity of rainfall data. Whilst the total number of gauges analysed was high (63 daily and 28 sub-daily rainfall gauges), the rainfall gauge distribution was sparse with on average less than one gauge per 200 km^2.

Chart 17: Murrumbidgee@Mittagong (410033) Historic Event Calibration - GRC Hydro (2019)



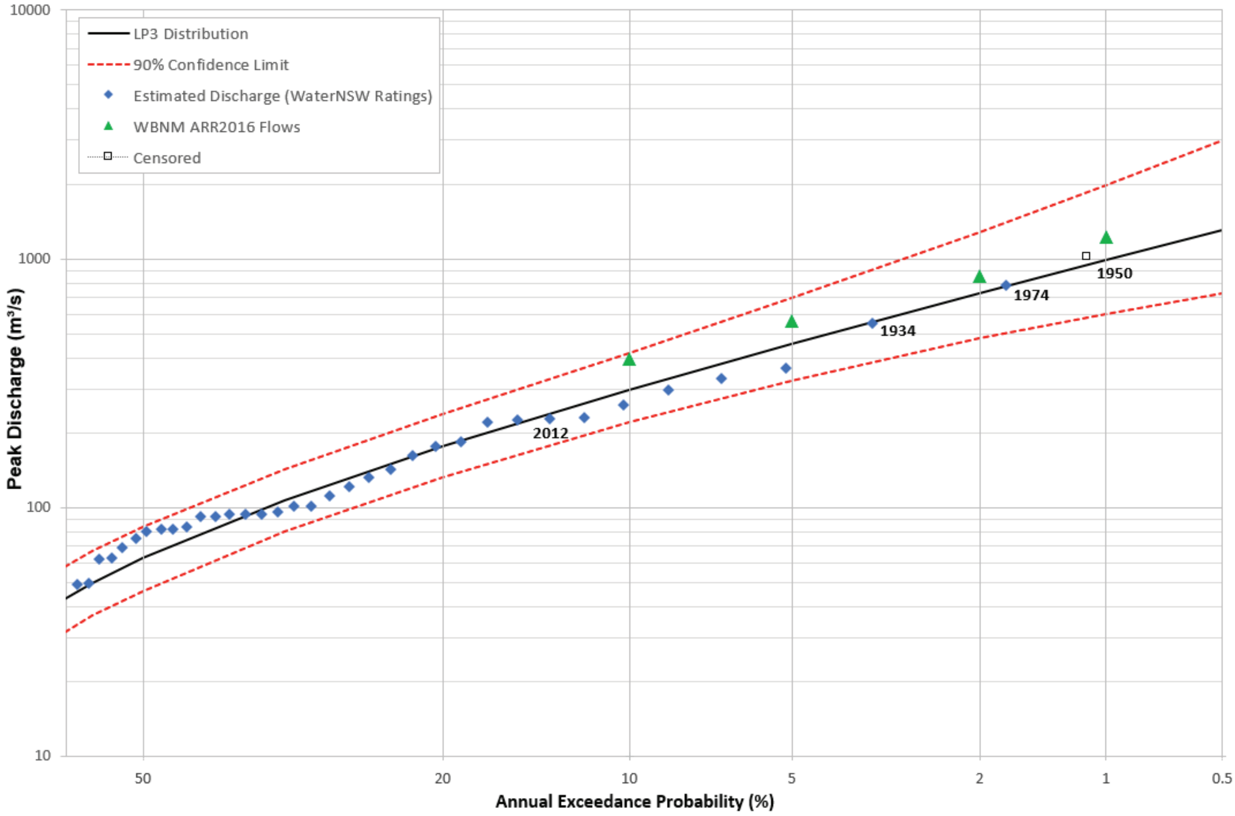
Design event modelling was undertaken using the methods outlined in ARR2016, using the calibrated parameters discussed above (C = 1.6, CL = 2 mm/hr). Initial Losses were applied as per the methods outlined in ARR2016. Rainfall was applied as spatially varying to incorporate the effects of design rainfall gradients across the catchments, with 'Murray Basin' region temporal patterns applied.

Validation of design flow estimates to FFA was undertaken for each of the gauges in the study area. Comparison of WBNM results to the Murrumbidgee River at Mittagong gauge (410033) FFA is presented in Chart 18 (extracted from the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019)).

The FFA was performed on the annual maximum series of flows for the period 1926 to 2017. Construction of Tantangara Dam (completed in 1960), meant that the data series was not homogeneous. To account for the impact of Tantangara Dam on the annual series, data prior to construction of the dam (1960) was incorporated into the analysis as 'censored' data using FLIKE's Bayesian inference methods. It was assumed that the 1950 event (1,018 m^3/s) was the largest event to have occurred in this period and this event would have exceeded the magnitude of the 1974 event (786 m^3/s) had it occurred post construction of the dam. The 1974 event flow was set as the censored threshold, with 33 years below the threshold (1926 to 1959) and one event above the threshold (1950 event). The extreme value analysis software package 'FLIKE' was used for analysis, following the procedures outlined in ARR2016. Log-Pearson Type 3 (LPIII) distributions were fitted to the annual series data. Other distributions were also examined, however the LPIII distribution was noted to have the best fit to the annual series data for each of the gauges

Comparison of WBNM and FFA design flows at the Murrumbidgee River at Mittagong gauge (410033) indicates a reasonable match, with WBNM flows contained within the 90% confidence limits, and noted to be typically being higher than FFA estimate.

Chart 18: WBNM Flows vs FFA at Murrumbidgee@Mittagong (410033) – GRC Hydro (2019)



As previously discussed, the focus of the *Snowy Monaro Flood Studies Draft Final Report'* (SMEC/GRC Hydro, 2019) was predominantly Murrumbidgee River tributaries, and to a lesser degree, the Murrumbidgee River at Bredbo (catchment area 4,900 km^2). Tantangara Dam is situated in the headwaters of the Murrumbidgee River catchment, and accordingly was not the focus of the Council study. To provide additional robustness in design inflow estimates for Tantangara Dam, validation of the Council WBNM model has been undertaken by comparison of model estimates to FFA undertaken for a gauge upstream of Tantangara Dam.

3.2.3.2 Murrumbidgee River @ Above Tantangara Dam (410535) - Flood Frequency Analysis

FFA was performed on the annual maximum series of flows recorded at the Murrumbidgee River @ Above Tantangara Dam (410535) (catchment area of ~210 km^2). The gauge was commissioned in 1958. A largely homogenous dataset was provided by Snowy Hydro for the period of 1958 to 1980, with data post 1980 obtained from the Bureau of Meteorology (see Table 36). FFA was undertaken on the maximum annual flow for the 59 years of record.

Table 36: Murrumbidgee River @ Above Tantangara Dam (410535) Annual Series Flow (m^3/s)

Year	Flow	Year	Flow	Year	Flow
1960	184	1980	50	2000	57
1961	27	1981	103	2001	35
1962	28	1982	6	2002	28
1963	22	1983	38	2003	62
1964	120	1984	72	2004	41
1965	55	1985	48	2005	72
1966	39	1986	60	2006	4
1967	14	1987	34	2007	58
1968	97	1988	84	2008	47
1969	28	1989	24	2009	24
1970	106	1990	57	2010	129
1971	29	1991	54	2011	84
1972	27	1992	62	2012	169
1973	52	1993	48	2013	38
1974	88	1994	15	2014	39
1975	244	1995	132	2015	26
1976	65	1996	67	2016	65
1977	49	1997	33	2017	55
1978	64	1998	36	2018	23
1979	53	1999	29		

The extreme value analysis software package 'FLIKE' was used for FFA, following the procedures outlined in ARR2016. A Generalised Extreme Value (GEV) distribution was fitted to the annual series. FFA design flow estimates for the site are presented in Table 37 and the FFA plot is presented in Chart 19.

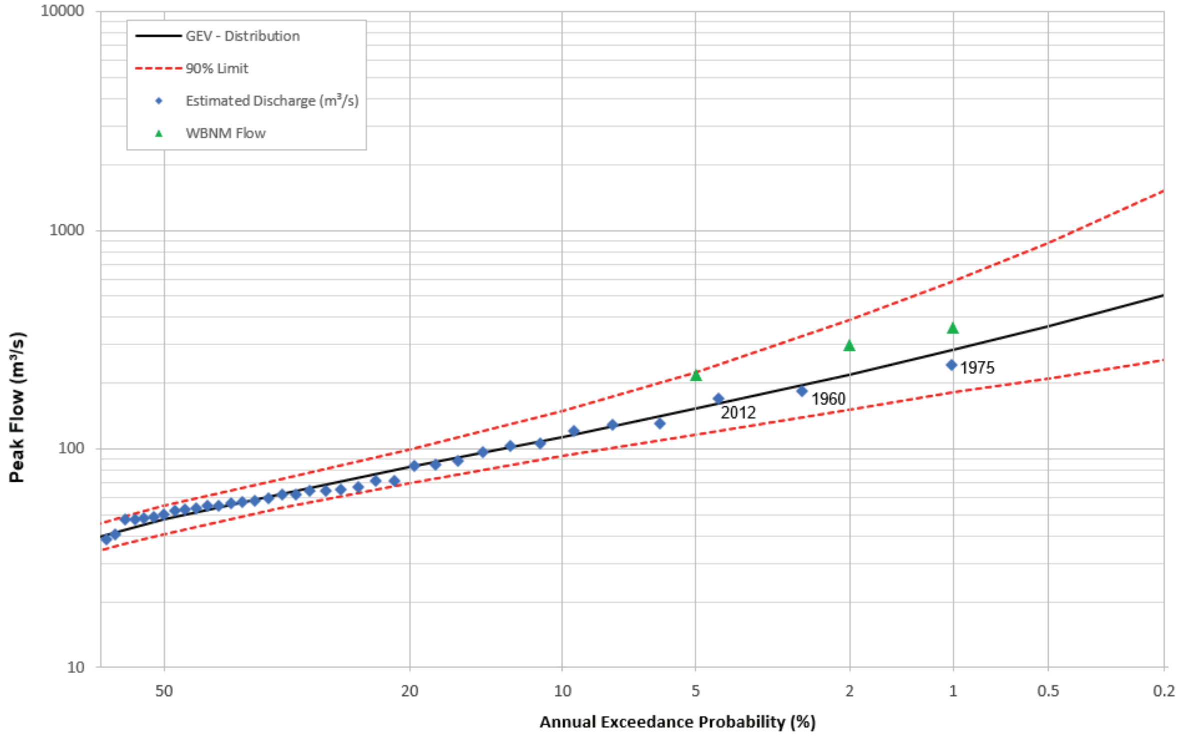
Table 37: FFA Design Flow Estimates - Murrumbidgee River @ Above Tantangara Dam (410535)

AEP	Expected Parameter Quantile (m^3/s)	90% Confidence Limits (m^3/s)	
0.2EY	82	70	150
10%	114	93	225
5%	152	117	387
2%	219	152	583
1%	284	181	883

Comparison of WBNM and FFA flows at the Murrumbidgee River @ Above Tantangara Dam (410535) noted WBNM flows within the 90% confidence limits, indicating reasonable agreement between the two methods (see Chart 19). Again, WBNM flows are noted to be typically being higher than FFA estimates indicting conservative results.

PMF inflow estimates were determined by applying the GSDM and GSAM methods to the WBNM model. The PMF critical duration was determined to be 9 hours, with a peak flow of 6,700 m^3/s.

Chart 19: WBNM vs FFA flows at Murrumbidgee River@Above Tantangara Dam (410535)



3.2.3.3 Tantangara Dam Inflow Results

Tantangara Dam design inflows determined from the WBNM model are presented in Table 38. The design inflows were routed through a conceptual storage in WBNM to determine dam flood levels. Details of this analysis are presented in Section 3.3.1.

Table 38: WBNM Tantangara Dam Inflows

AEP	Current Study XP-RAFTS Dam Inflow (m^3/s)	Critical Duration (hours)
1%	760	48
PMF	6,700	9

3.3 Kellys Plain Creek - Hydraulic Analysis

Similar to the hydrologic analysis undertaken as part of the current study, the hydraulic analysis was undertaken in two parts:

1. Tantangara Dam design levels were estimated using the WBNM design inflows and a conceptual storage in WBNM. This analysis has been undertaken to validate the findings of the *'Tantangara Dam Update of Hydrology and Spillway Capacity Assessment'* (Jacobs, 2015) report, and ensure changes associated with ARR2016 have not significantly impacted on design flood levels in the Dam. The Jacobs (2015) dam flood levels were then applied to the downstream boundary of the TUFLOW model discussed below; and
2. A TUFLOW model was developed for Kellys Plain Creek from Tantangara Dam to upstream of the site.

Details are discussed in the ensuing sections.

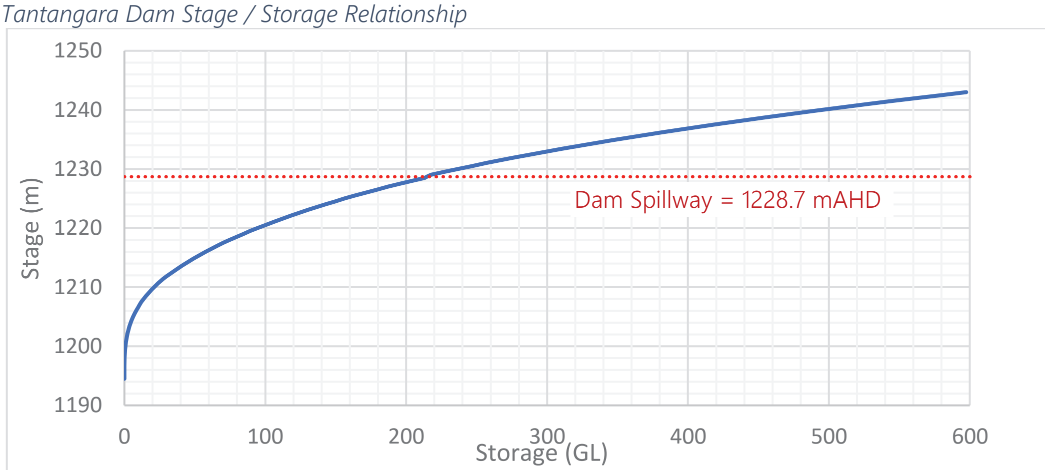
3.3.1 Tantangara Dam flood level estimation

Tantangara Dam is a concrete gravity dam. The Dam is part of in the Snowy Mountains scheme with a gross capacity of 254 GL and has been modelled as a conceptual storage in WBNM. Stage/discharge and stage/storage relationships have been developed for implementation in the model.

3.3.1.1 Tantangara Dam Stage/Storage Relationship

A stage/storage relationship was developed by interrogation of available 1s-SRTM DEM data obtained from the NSW Spatial Services website. The SRTM data was merged with bathymetry survey (provided by Snowy Hydro) for the dam to determine storage volume below the full supply level. The Tantangara stage/storage relationship is presented in Chart 20.

Chart 20: Tantangara Dam Stage / Storage Relationship



3.3.1.2 Tantangara Dam Stage/Discharge Relationship

Tantangara Dam spillway characteristics are of a contracted rectangular weir, with an approximate ogee profile. The ogee profile aims to increase weir efficiency by shaping the spillway nappe surface to be approximately parabolic for a specific design head, whilst the contracted spillway arrangement leads to decreased efficiency. Estimates of the spillway efficiency have been calculated such that water levels within Tantangara Dam can be estimated for a given outflow. The dam has the following pertinent characteristics relevant to estimating spillway discharge:

- Dam Embankment Length (B) = ~216 m
- Spillway Length (b) = 61 m
- Dam Height (P) = ~45.1 m
- Spillway invert to Dam Crest level = 5.2 m
- Spillway crest level (Z) = 1228.7 mAHD

Due to the dam's significant height relative to overtopping depth (P/H > 1.33), it can be assumed that the velocity head is negligible and does need not be considered in calculations. However, the effects of the contracted rectangular weir form and ogee profile need be considered in determining an appropriate spillway coefficient (Cw). The following considerations have been made:

- The impact of expansion and contraction at the spillway crest due to B > b, has been considered as this reduces spillway efficiency. French (1986) proposed a generalised equation for sharp crested weirs that considers local geometry (B, b, P, H) to determine an appropriate

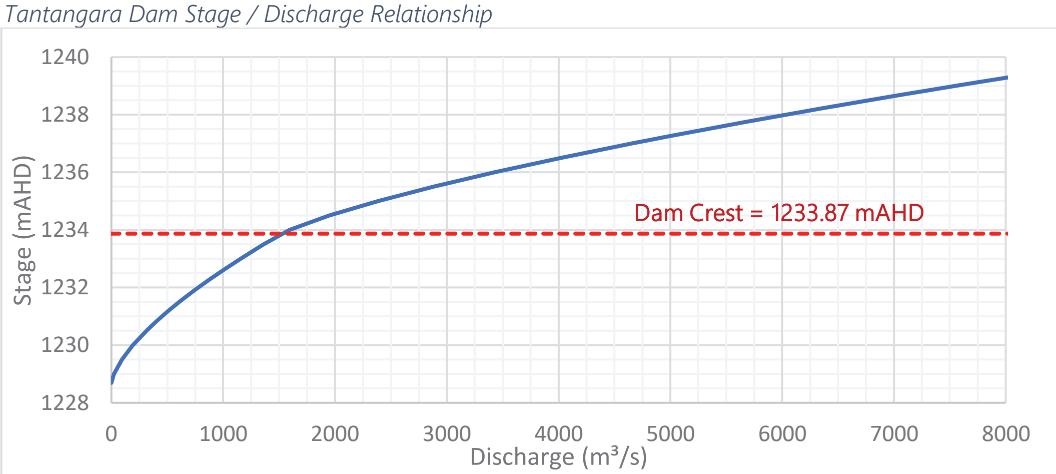
Cw for the contracted weir type. Dependant on the dam water level (H), the Cw varies, however the reduction in Cw associated with the contracted weir type is calculated to be ~95% for Tantangara Dam;

- Due to the ogee profile, the efficiency of the spillway is increased when compared to a sharp-crested weir. Elementary Fluid Mechanics, J.k. Vennard (1961) suggests that assuming the water level is equal to the design head (Dh), and H/P = ~0, then Cw = 0.75. If the water level exceeds the design head (Dh), the Cw increases. Similarly, if the flow head is less than the design head, Cw is decreased. The Tantangara Dam spillway design head (Dh) is unknown.

With the current study's focus on major flood events (1% AEP and PMF), it is assumed that the design head (Dh) of the spillway is ~ 1% AEP event level and a Cw of 0.75 is appropriate. The Cw has been factored to consider the spillway contraction, thus resulting in an applied Cw = 0.72.

Chart 21 present the Tantangara Dam stage/discharge relationship.

Chart 21: Tantangara Dam Stage / Discharge Relationship



3.3.1.3 Tantangara Dam Design Flood Levels

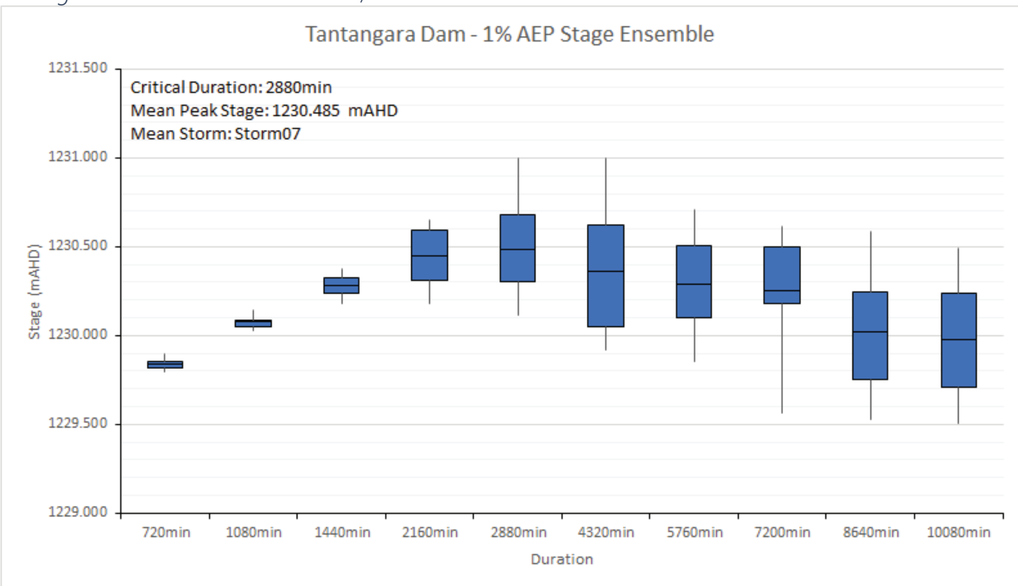
Design flood levels for Tantangara Dam have been determined by routing the dam inflow discussed in Section 3.2.3.3, through a conception storage in WBNM and applying the previously discussed stage/storage and stage/discharge relationships. The 1% AEP and PMF flood levels are presented in Table 24, along with a comparison to '*Tantangara Dam Update of Hydrology and Spillway Capacity Assessment*' (Jacobs, 2015) design flood levels.

Table 39: Tantangara Dam Flood Levels - Current Study vs Jacobs (2015) Study

AEP	Current Study Dam Level (mAHD)	SKM (2011) Dam Level (mAHD)
1%	1230.5	1230.3
PMF	1236.1	1236.3

Comparison to the *Jacobs (2015)* study results for the 'Updated Model With Fixed FSL Drawdown' scenario, indicate that the current study analysis provides a close match to the Jacobs (2015) study results. This analysis indicates that the changes to Australian Rainfall and Runoff associated with the 2016 revision have a limited effect on Tantangara Dam design flood levels. The results of this analysis confirmed the suitability of the *'Tantangara Dam Update of Hydrology and Spillway Capacity Assessment'* (Jacobs, 2015) report flood levels for defining tailwater levels for the hydraulic model. The Jacobs (2015) study also provides results based on a Monte Carlo framework which incorporates dam drawdown into the analysis and provides significantly reduced design dam flood levels. Notwithstanding, results for the 'Zero Drawdown' scenario have been implemented to the TUFLOW model for the current study as a conservative approach to flood hydrology.

Chart 22: Tantangara Dam 1% AEP Flood Level, Ensemble Results



3.3.2 TUFLOW Hydraulic Model Setup

A TUFLOW hydraulic model was developed for the site. TUFLOW is 2D numerical modelling package which is suitable for modelling complex flood behaviour of channels and floodplains such as those noted on Kellys Plain Creek.

Various data and parameters implemented in the TUFLOW model are discussed below and are presented in Image 8:

- Model Domain and Grid Size – The hydraulic model domain covers an area of 6.3 km^2, extending from 640 m upstream of the Quarry Trail. The downstream boundary is situated within the Tantangara Dam. A model grid size of 5 m x 5 m has been implemented which is considered suitable for adequately modelling key hydraulic features of the study area.
- Digital Elevation Model (DEM) – A 2 m DEM data obtained from the NSW Government Spatial Services has been used to inform the topography of the 2D hydraulic model.
- Mannings Roughness – Mannings values were selected based on inspection of aerial imagery and knowledge of the typical roughness values used in catchments nearby. Selected Mannings values are consistent with the ranges described in ARR2016 and are presented in Table 40;

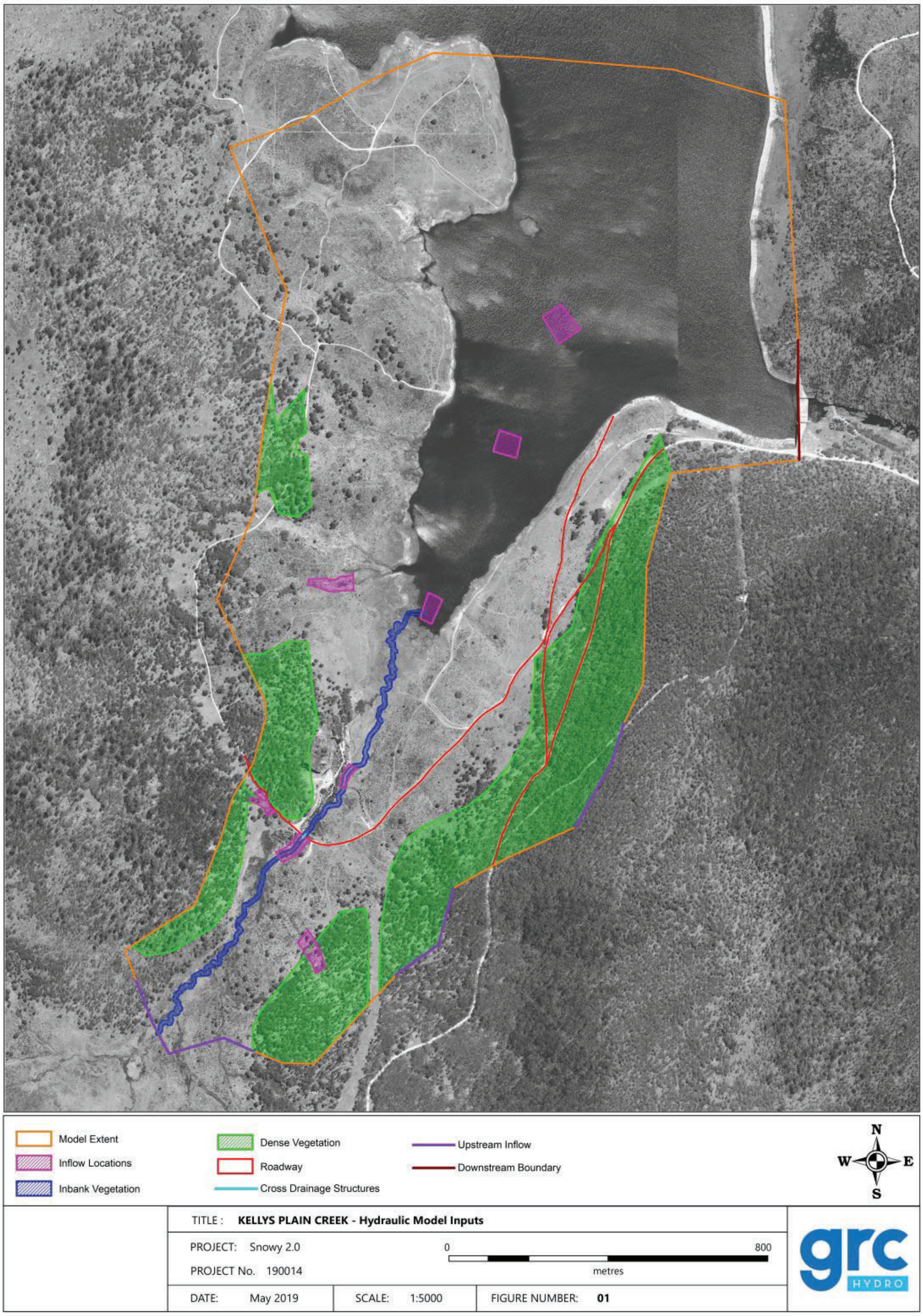
Table 40: Mannings roughness values, Kellys Plain Creek

Land Use	Mannings
Grassland	0.04
Creek Channel	0.05
Dense vegetation	0.07

- Boundary Conditions – The inflows to the TUFLOW model were obtained from the XP-RAFTS model discussed in Section 3.2.2. The downstream boundary was set at the design Tantangara Dam levels determined by the *'Tantangara Dam Update of Hydrology and Spillway Capacity Assessment'* (Jacobs, 2015) study (see Section 3.3.1.3).
- Hydraulic Features – Key hydraulic controls such as road crests have been implemented as breaklines. Cross drainage structures traversing the Quarry Trail have been included in the hydraulic model as 1D elements. The dimension of the cross-drainage structure was estimated based on analysis of the LiDAR and aerial images. A 3 x 0.9 m x 1.2 m box culvert was implemented at this location.

Implementing the various details discussed above, an Existing Conditions model was constructed to model baseline conditions (e.g. prior to commencement of the Exploratory Works) flood behaviour for the Kellys Plain Creek site.

Image 8: Kellys Plain Creek Hydraulic Model Setup



3.3.3 Hydraulic Model Results

Design results have been assessed using the TUFLOW model discussed in Section 3.3.2. Results are presented in Appendix B for the 1% AEP and PMF events. Peak flood depths and levels are presented in figures:

- *Figure B 1:* *Kellys Plain Creek, peak flood depths and levels – Existing Conditions – 1% AEP*;
- *Figure B 2:* *Kellys Plain Creek, peak flood depths and levels – Existing Conditions – PMF*.

ARR2016 flood hazard (see Section 2.4.1 for further details) based on the *'Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia'* (AIDR 2017) is presented in figures:

- *Figure B 3:* *Kellys Plain Creek, flood hazard – Existing Conditions – 1% AEP*; and
- *Figure B 4:* *Kellys Plain Creek, flood hazard – Existing Conditions – PMF*.

3.4 Kellys Plain Creek - Conclusions

A flood study was undertaken for the Kellys Plain Creek site within the Snowy 2.0 Main Works project area. The site is subject to flooding from Kellys Plain Creek and Tantangara Dam.

An XP-RAFTS model was developed and ARR2016 methods and parameters were applied. Continuing losses were based on those determined via model calibration in the nearby *'Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) as per the methods outlined in the OEH guidelines (Floodplain Risk Management Guide, 2019).

The Kellys Plain Creek 1% AEP flow estimate of 49.4 m^3/s was validated by comparison to design flow estimates from surrounding gauges, increasing confidence in design flow results. The PMF flow estimate of 606 m^3/s was developed through application of the GSDM.

Tantangara design flood levels were obtained from the *'Tantangara Dam Update of Hydrology and Spillway Capacity Assessment'* (Jacobs, 2015) study. The current study undertook hydrologic analysis by implementing ARR2016 methods and techniques to validate the finding of the Jacobs (2015) study. The analysis was undertaken to ensure that changes to Australian Rainfall and Runoff associated with the 2016 revision have not significantly affected design flood levels for the Dam. The results of this analysis found that design flood levels are within ± 0.2 m when comparing the two studies for both the 1% AEP and PMF events.

A TUFLOW hydraulic model was developed for the Kellys Plain Creek floodplain in the vicinity of the site. Flows from the XP-RAFTS model and Dam levels from the Jacobs (2015) study were applied to the TUFLOW model to examine 1% AEP and PMF design flood behaviour.

Design flood depths, levels and flood hazard for the 1% AEP and the PMF events are presented Appendix B.

4. ROCK FOREST – FLOOD STUDY

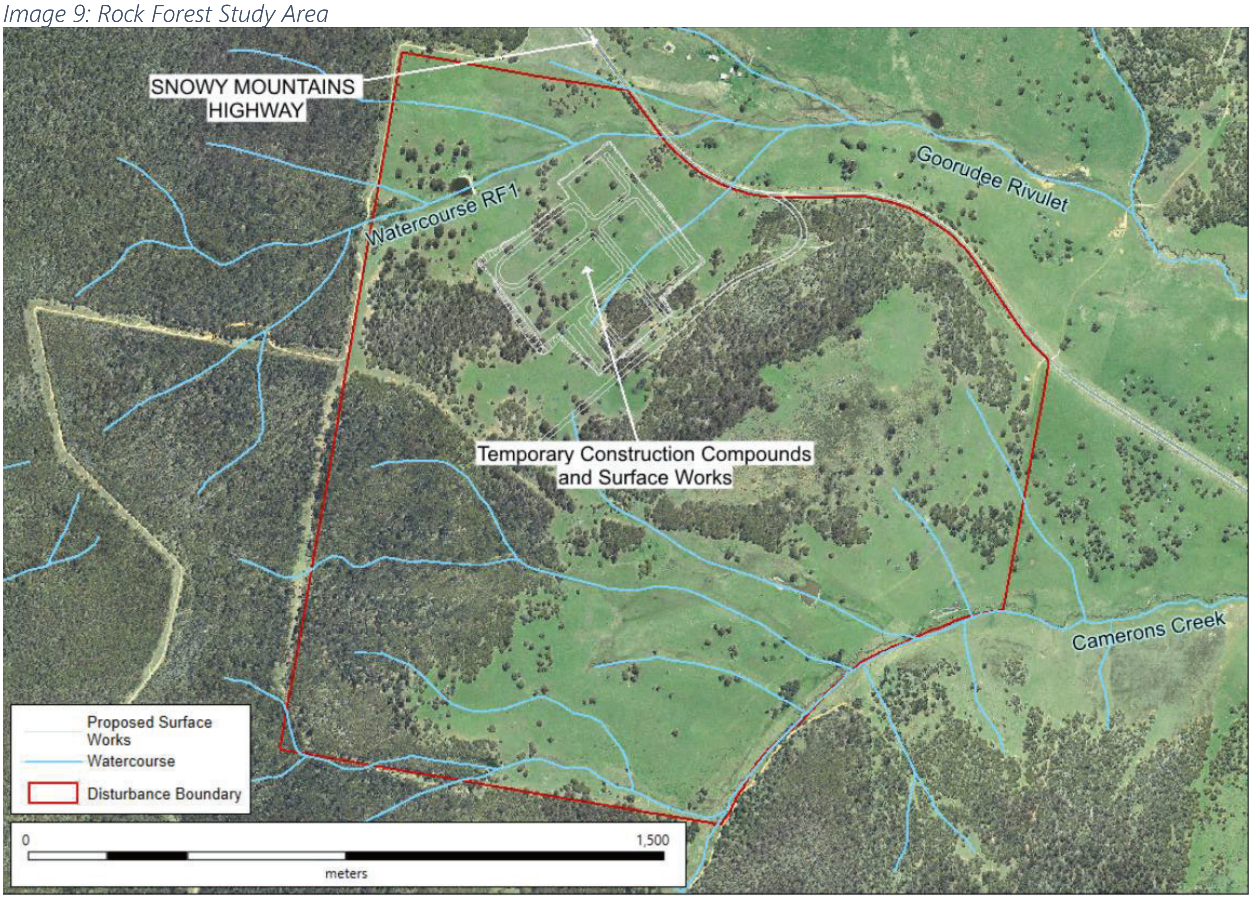
4.1 Rock Forest - Introduction

This section comprises the 'Rock Forest Flood Study' which defines design flood behaviour for the Rock Forest site. Flood behaviour for Camerons Creek, Goorudee Rivulet and an unnamed Goorudee River tributary (named Watercourse RF1 for the purpose of this assessment) within the site, has been considered.

4.1.1 Study Area

Rock Forest is situated to the west of Adaminaby in the Goorudee Rivulet catchment which is a subcatchments of the Murrumbidgee River catchment. A study area map is presented in Image 9.

Image 9: Rock Forest Study Area



The site is flood affected by Camerons Creek and Watercourse RF1. The Camerons Creek catchment area at the subject site is 10.4 km^2 and the Goorudee Rivulet catchment area to downstream of the site is approximately 40 km^2.

Table 41 presents observations of the Rock Forest characteristics based on findings from a site visit undertaken on 27 March 2019. These findings have been considered during model development.

Table 41: Rock Forest Characteristics

Observation	Photographs
Topography at Rock Forest can be characterised as 'low-grade rolling hills' with average grades estimated to generally not exceed 15%. Tributaries of Camerons Creek within the proposed development site are ill-defined and consist of distributed overland flow paths rather than defined channels.	
Sparse vegetation density is noted within the project site, predominantly composed of grazed grasslands and pockets moderate to low density vegetation with clear understory. Low Manning's values ranging from 0.04 to 0.07 are present based on Chow (1959) and ARR2016 guidelines. Vegetation density was noted to increase in the upper catchment, however, did not appear to compare to densities noted in Lobs Hole.	
The Camerons Creek channel is a heavily eroded earthen base with grassed overbank. Channel Mannings estimated to be 0.04 to 0.05, with similar overbank roughness. The capacity of the channel in-bank is noted to be negligible for flood hydraulics.	
The catchment is used for mixed grazing with significant soil compaction expected due to the presence of hoven animals. Combination of sparse vegetation and compacted soils are consistent with low rainfall losses.	

Various Snowy Mountains Highway creek and flow path crossings were examined. Culvert dimensions are presented below: (1) 2 x 750 mm dia. (2) 4 x 1540 mm dia. (3) 3 x 750 mm dia. (4) 4 x 3000 mm x 3000 mm RCBC (1200 mm cover) (5) 1 x 1820 mm dia.	

4.1.2 Objectives

The key objective of the Rock Forest Flood Study is to define design flood characteristics for the Rock Forest site due to Camerons Creek and Watercourse RF1 flood events. The analysis has applied the methods outlined in ARR2016 for the 1% AEP and PMF events. Flood levels, depths, extents and flood hazard have been produced for both events.

The flood study objectives are to:

- Develop an XP-RAFTS hydrologic model for the catchment to downstream of the Rock Forest site;
- Produce design flows for the 1% AEP (ARR2016) and the PMF (GSDM);
- Validate the 1% AEP flow by cross-checking against regional estimates derived for surrounding areas;
- Develop a TUFLOW hydraulic model to model existing conditions flood behaviour of 4 km Goorudee Rivulet reach adjacent to the site and 2 km of Camerons Creek reach through the site;
- Model 1% AEP event and the PMF in TUFLOW;

The purpose of this report is to describe the data analysis and modelling methodologies that have been applied to the Rock Forest Flood Study. Model results are presented and discussed herein.

4.2 Rock Forest - Hydrology

4.2.1 Hydrology Approach

The hydrologic analysis consisted of the development of a XP-RAFTS hydrologic model which was then validated to regional design flow estimates from nearby studies. Due to the absence of a stream gauge within the Rock Forest catchment, Flood Frequency Analysis (FFA) and event-based model calibration could not be undertaken. The following sections outline the implemented approach.

4.2.2 Hydrologic Modelling

Hydrologic model design flows have been determined using ARR2016 guidelines. Selected model parameters and inputs are described in the ensuing sections.

4.2.2.1 Model Schematisation and Parameters

An XP-RAFTS model was developed for the Rock Forest catchment to approximately 1.4 km downstream of the confluence of Camerons Creek and the Goorudee River. Details of the XP-RAFTS model schematisation are presented in Table 42 with sub-catchment delineation presented in Image 10.

Table 42: XP-RAFTS Model Schematisation, Rock Forest

Total model catchment area (km^2)	Number of catchments	Average catchment size (km^2)
41	66	0.6

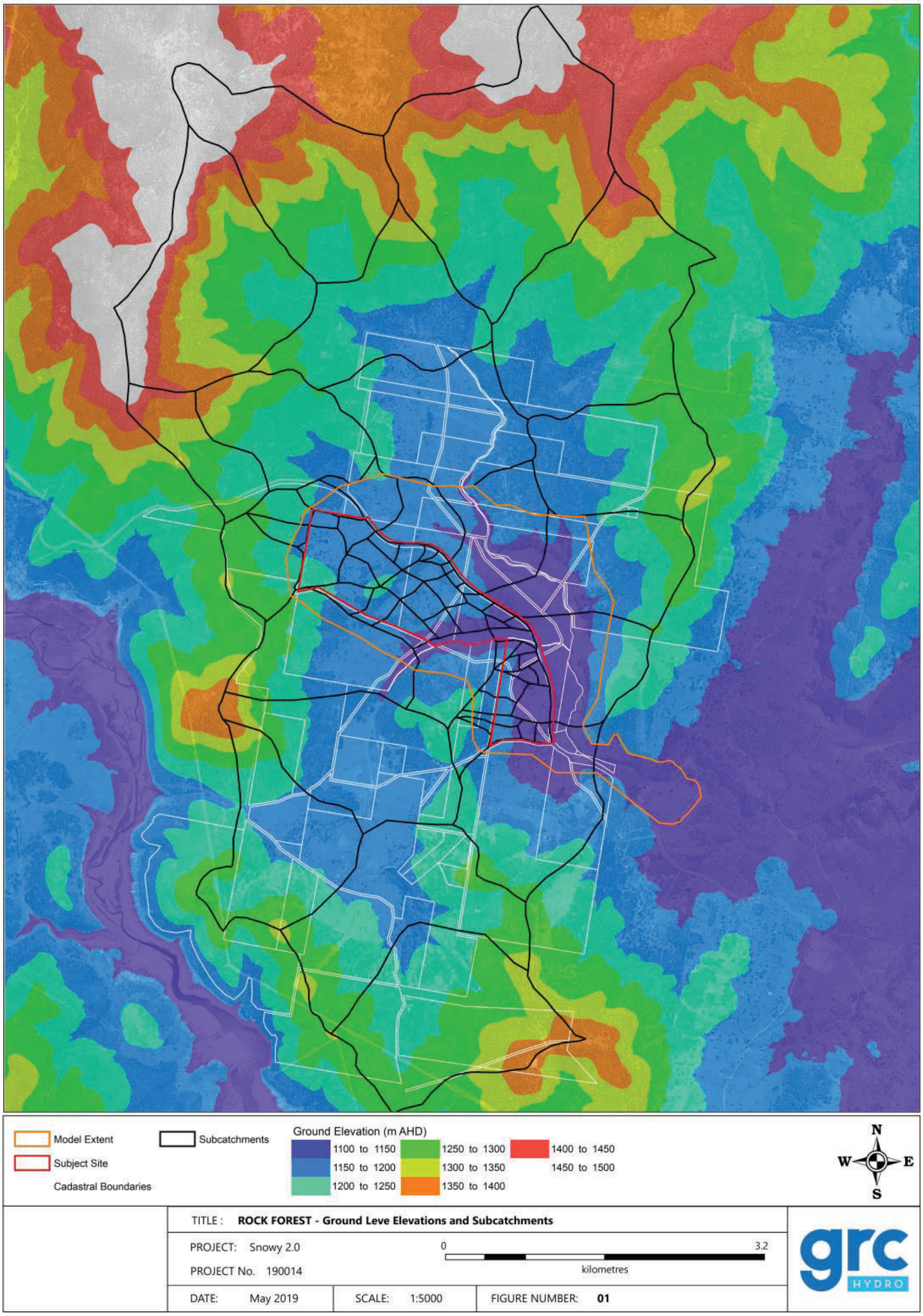
XP-RAFTS model parameters were determined via a site visit and inspection of available data including photographs, aerial imagery and 2 m LiDAR data. This information was used to inform sub-catchment Mannings, slope and lag times.

The Camerons Creek catchment at the site was found to be predominantly grazed grasslands with pockets of moderate to low density vegetation in the lower catchment, with increased vegetation density in the upper catchment areas. Manning's values ranging from 0.04 in grasslands to 0.07 in the vegetated upper catchment areas were applied to the XP-RAFTS model.

Sub-catchments slopes and stream lengths were individually calculated for each sub-catchment via interrogation of the 2 m LiDAR data obtained from NSW Spatial Services (Tantangara and Berridale datasets, 0.3 m and 0.8 m accuracy at the 95% Confidence Interval in the vertical and horizontal respectively).

Lag times for inter-catchment routing were determined using the major flow path length (L) and slope (S) and the formula outlined in the Laurenson's method (lag time = $L / S^{0.5}$).

Image 10: Rock Forest Sub-catchments, Topography and TUFLOW Model Extent



4.2.2.2 Design Rainfall

ARR2016 design rainfall depths for various durations were obtained from the Bureau of Meteorology (BoM). Analysis of design rainfall depths across the Camerons Creek and Goorudee Rivulet catchments was undertaken to identify potential design rainfall gradients. The analysis indicated that there is no significant design rainfall grade present and accordingly, a single-uniformly applied rainfall depth was appropriate for modelling of design rainfall for the study area. Catchment design rainfall depths applied to the XP-RAFTS model are presented in Table 43.

Table 43: Design Rainfall Depths, Rock Forest

Duration (min)	1% AEP Event
360	72.7
540	88.2
720	102
1080	124
1440	142

Probable Maximum Precipitation (PMP) rainfall depths were calculated using the XP-RAFTS software which uses the methods outlined in the GSDM. The catchment is defined as 100% 'Rough' and a Moisture Adjustment Factor of 0.62 was applied. The Elevation Adjustment Factor was not applied as catchment elevations typically do not exceed 1500 mAHD. PMP rainfall depths for various durations are presented in Table 44.

Table 44: PMP Rainfall Depths, Rock Forest

Duration	1 hour	1.5 hour	2 hour	3 hour
Rain (mm)	260	340	390	470

4.2.2.3 Areal Reduction Factor

Areal Reduction Factors (ARF) were applied to design rainfall depths (with the exception of the PMF) to adjust for the catchment's areal average rainfall intensity. The ARFs were determined following the methods outlined in ARR2016 for the 'Southern Temporal' region. Calculated ARFs were based on the Camerons Creek catchment area and event duration and probability. Applied ARFs are presented in Table 45.

Table 45: Areal Reduction Factors, Rock Forest

Duration (min)	1% AEP Event
360	0.95
540	0.97
720	0.97
1080	0.97
1440	0.97

4.2.2.4 Rainfall Losses

ARR2016 recommends a continuing loss of 4.4 mm/h at the study area. The recommended continuing loss of 4.4 mm/h was found to be relatively high compared to flood study findings in nearby catchments with similar land uses and topographic characteristics. Table 46 presents the calibrated continuing loss parameters adopted in the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019).

Table 46: Calibrated continuing loss from the Snowy Monaro Flood Studies (GRC Hydro, 2019)

Town	Continuing Loss (mm/h)
Cooma	0.5
Bredbo	2.0
Berridale	2.0
Michelago	3.5
Average	2.0

The NSW Office of Environment and Heritage (OEH) released the 'Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in Studies' in late 2018 to provide additional guidance for the application of ARR2016 in NSW catchments. These guidelines recognised that loss values for NSW from the ARR Data Hub have resulted in "a significant bias toward underestimation of flows". These guidelines provide a hierarchical approach to loss and pre-burst estimation in NSW. This approach recommends the application of an average calibration loss from other studies in similar adjacent catchments if suitable calibration of losses is not possible. Based on this approach an average continuing loss of 2.0 mm/h (see Table 5), derived in the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019), has been adopted in the current study.

An ARR2016 Initial loss of 27 mm has been used for design flood modelling with adjustment for pre-burst. For comparative purposes, the average design initial loss implemented in the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) is 26.5 mm. Pre-burst adjusted initial losses used in the current study design flood modelling are presented in Table 47 and range from 20 to 26 mm depending on the event duration.

Table 47: Applied 1% AEP Initial Losses (incorporating pre-burst)

Duration (min)	1% AEP Event
360	26.0
540	23.0
720	20.0
1080	20.9
1440	23.4

PMF rainfall losses have been applied as an IL / CL model (IL = 0 mm, CL = 1 mm/hr) as per the methods outlined in the GSDM.

4.2.2.5 Rainfall Temporal Patterns

Rainfall temporal patterns are used to describe how rainfall is distributed as a function of time. The recommended ARR2016 ensemble approach to applying temporal patterns has been utilised in the current study. The ensemble approach to flood modelling applies a suite of 10 temporal patterns for each duration. Point Temporal Patterns have been implemented as the catchment size is less than 75 km^2. The temporal patterns were obtained from ARR2016 for the 'Murray Basin' region.

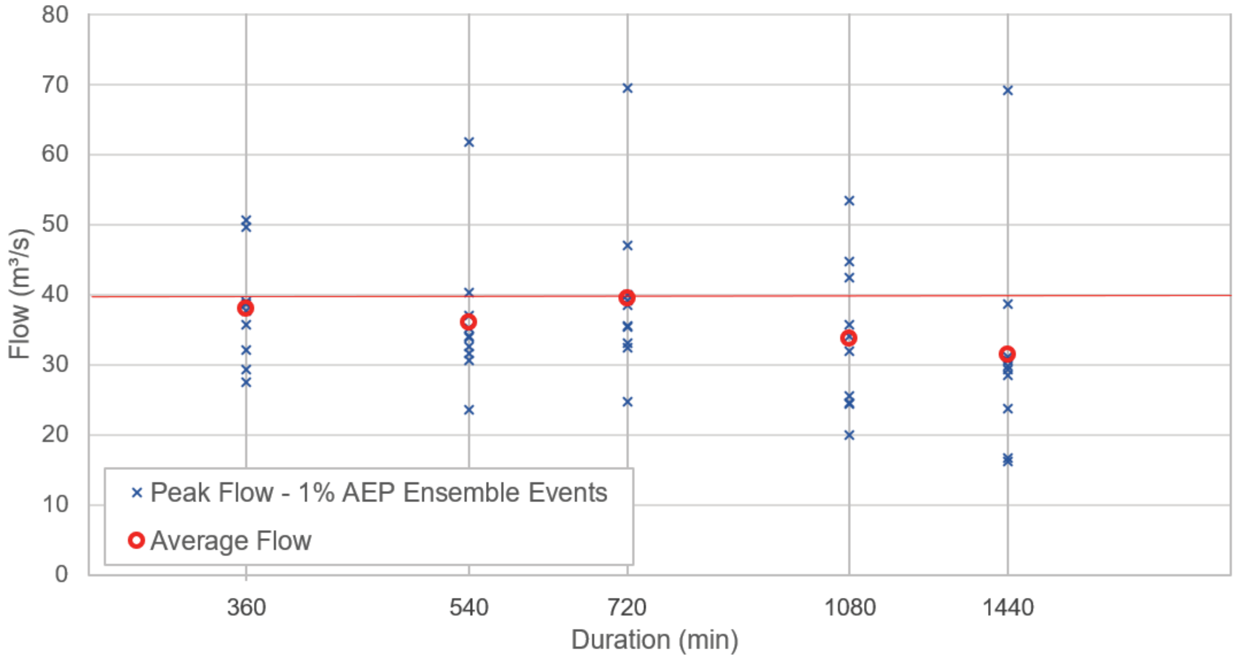
The GSDM temporal pattern was used in analysis of the PMF.

4.2.3 Hydrologic Results

Hydrologic model design flows are presented in Chart 23 for the 1% AEP event on Camerons Creek at the site. Each blue 'x' indicates the peak flow of a modelled event. The red circle is the average flow for each duration. The ensemble method identifies the critical duration as the duration with the highest mean flow and the temporal pattern which is closest to, but above the mean is selected.

For the 1% AEP event the critical duration at the Site is the 12 hour event with an ensemble average flow of 39.5 m^3/s. Storm 6 with a peak flow of 40 m^3/s was used for the ensuing analysis.

Chart 23: 1% AEP Design Flow Results on Camerons Creek at the subject site



A similar process was implemented for the PMF with a range of PMP durations from 0.5 to 3 hours assessed. The PMF critical duration was determined to be 2 hours with a peak flow of 590 m^3/s.

Design flows obtained from the XP-RAFTS model have been implemented in the TUFLOW model.

4.2.3.1 Validation of Design Flow Estimates

To improve confidence in the 1% AEP design flow estimate, a validation process was undertaken.

As a first pass, comparison of the XP-RAFTS flow estimate to the ARR2016 RFFE flow estimate was undertaken (see Table 48). However, review of ARR2016 RFFE for the site revealed a lack of confidence in the RFFE design flows. Accordingly, design flow estimates were validated via other means.

Table 48: Comparison of 1% AEP Hydrologic Model Flow and RFFE Estimates – Rock Forest

Location	Hydrologic Model 1% AEP Flow (m3/s)	RFFE Design Estimates (m^3/s)		
		1% AEP Estimate (m3/s)	Upper Confidence Limit	Lower Confidence Limit
Camerons Creek at Rock Forest	40	16	44	6

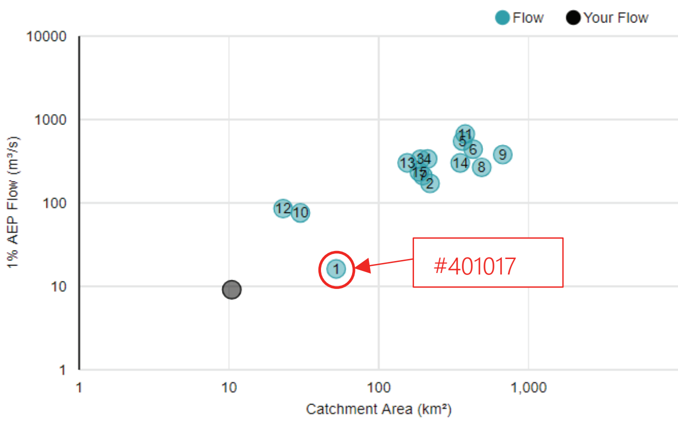
Results presented in Table 48 show a clear disparity between the 1% AEP design estimates from the current study and the RFFE model. When considering RFFE flow estimates, it is important to note the ARR2016 states 'that the relative accuracy of regional flood estimates using the RFFE model is likely to be within ± 50% of the true value' and as such, RFFE design flows estimates should be carefully considered. This is particularly the case for smaller catchments as ARR2016 states 'there are only a few gauged catchments smaller than 10 km^2 included in the data base to develop the RFFE Model' and as such 'it is likely that there will be a greater degree of error in the quantile estimates for these smaller catchments'. The Camerons Creek catchment at the Rock Forrest site is 10 km^2 and accordingly, the RFFE estimates are likely have a higher degree of error.

Comparison of RFFE design flow estimates to those derived in the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) via event-based calibration and validation to FFA, indicate that on average the difference is 50%, however the maximum difference from four examined gauges was -120%. This finding further reduced confidence in the veracity of the RFFE estimates in the vicinity of the subject site.

Given the uncertainty associated with the RFFE results in the region, further analysis of RFFE input parameters was undertaken. It was noted that Welumba @ The Square (401017) gauge 1% AEP flow estimate is significantly lower than the surrounding gauges with comparable catchment areas. The 1% AEP Flow vs Catchment Area plot extracted from RFFE is presented in Chart 24.

Details of the surrounding gauges on which the RFFE analysis is based, were extracted from the 'output_nearby.csv' from the RFFE website. Review of the Welumba gauge (401017, area of 52 km^2) confirmed a low runoff coefficient for the catchment of 0.3 $m^3/s/km^2$. This is significantly lower than the average runoff coefficients calculated for catchment areas (average catchment area of 260 km^2) examined in the '*Snowy Monaro Flood Studies Draft Final Report*' (SMEC/GRC Hydro, 2019) of 1.6 $m^3/s/km^2$. This is contrary to what would typically be expected as larger catchment areas (52 km^2 vs 260 km^2) have smaller runoff coefficients due to flow attenuation, spatial distribution of rainfall and other hydrologic and hydraulic factors. This strongly indicates that the Welumba gauge (401017) 1% AEP flow is underestimated, or at least, is not representative of design flow estimates in surrounding catchments.

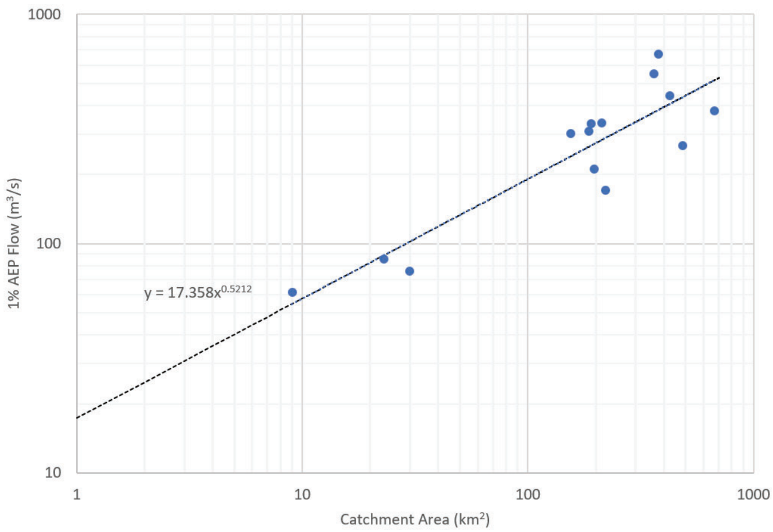
Chart 24: ARR2016 RFFE - 1% AEP Flow Results vs Catchment Area



Due to lack of confidence in the RFFE derived flow estimate, another method of testing the robustness of the 1% AEP flow estimate has been applied. This analysis used gauge details and design flows presented in the RFFE 'output_nearby.csv' to develop a relationship (power curve) between the 1% AEP estimates and catchment area. Table 49 presents details extracted from the 'output_nearby.csv' along with the relationship developed for this data. Due to the unexpectedly low runoff coefficient determined for Welumba gauge (401017), this gauge was not used in the analysis.

Table 49: RFFE Catchment Area vs 1% AEP Flow, Rock Forest

Gauge ID#	Area (km^2)	1% AEP Flow (m^3/s)
401016	52	16
401009	220	171
410141	190	334
410076	212	336
401230	363	551
410088	427	441
401017	197	212
401229	487	267
410057	673	380
410149	30	76
401013	378	668
410114	23	85
410061	155	302
401208	350	301
222015	187	234



Using this relationship and the Camerons Creek catchment area at the site (10.4 km^2), a 1% AEP flow estimate of 53 m^3/s was determined for the subject site via extrapolation of the power curve. This flow is comparable to the hydrologic model 1% AEP flow of 40 m^3/s which provides some confidence hydrologic model results.

4.3 Rock Forest - Hydraulic Analysis

4.3.1 Hydraulic Model Setup

A TUFLOW hydraulic model was developed for the Rock Forest site. TUFLOW is 2D numerical modelling package which is suitable for modelling complex flood behaviour of channels and floodplains such as those at the site.

Various data and parameters implemented in the TUFLOW model are discussed below and are presented in Image 11:

- Model Domain and Grid Size – The hydraulic model domain covers an area of 6.3 km^2, extending from 330 m upstream of the subject site on Camerons Creek. The downstream boundary is situated approximately 2.4 km downstream of the Camerons Creek and Goorudee Rivulet confluence. A model grid size of 5 m x 5 m has been implemented which is considered suitable for adequately modelling key hydraulic features of the study area.
- Digital Elevation Model (DEM) – A 2 m DEM obtained from the NSW Government Spatial Services has been used to inform the topography of the 2D hydraulic model.

- Mannings Roughness – Mannings values were selected based on the site visit undertaken in April 2019, inspection of aerial imagery and photographs of the Site. Selected Mannings values are consistent with the ranges described in ARR2016 and are presented in Table 50;

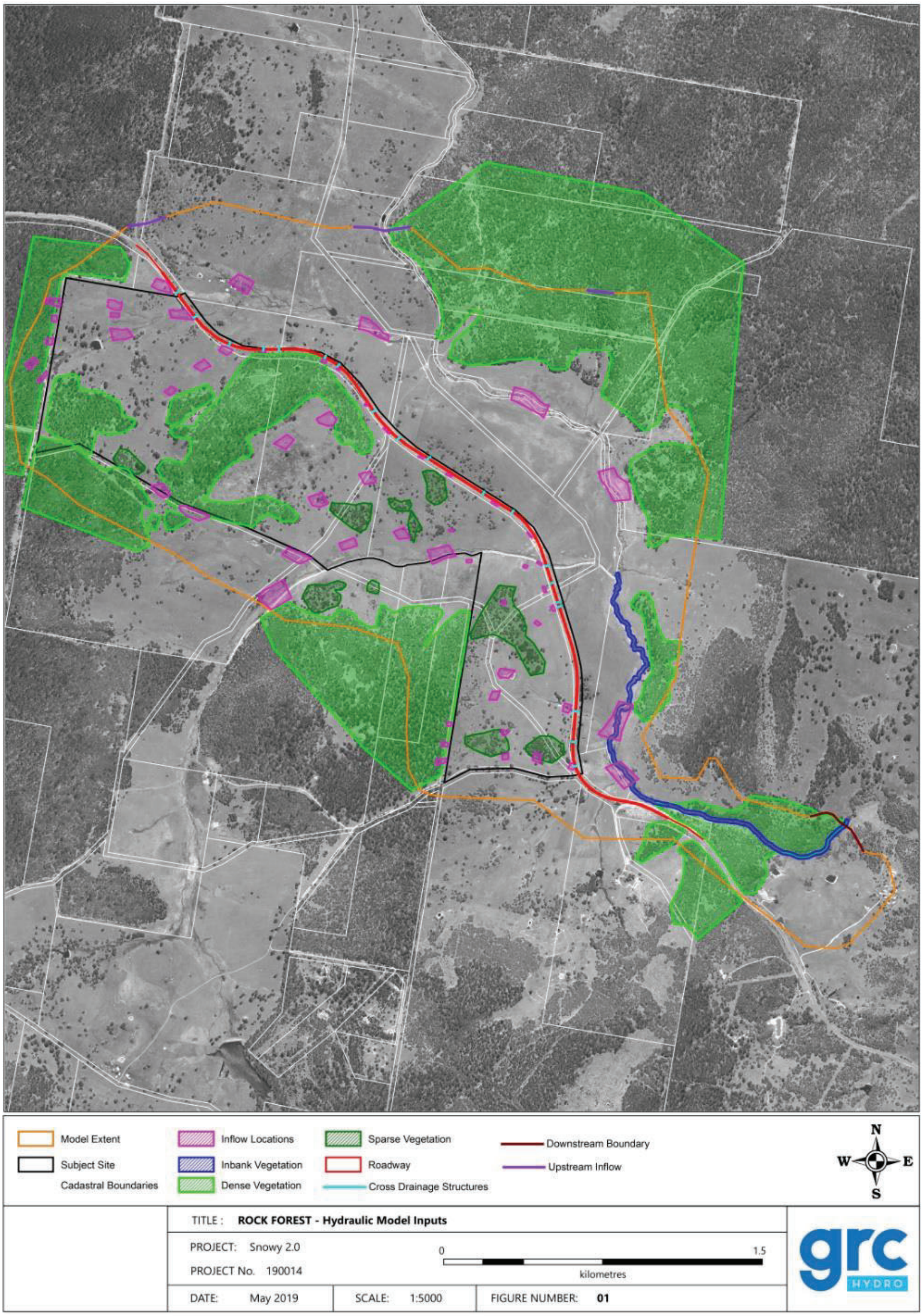
Table 50: Mannings roughness values, Rock Forest

Land Use	Mannings
Grassland	0.04
Inbank Vegetation	0.05
Sparse vegetation	0.05
Dense vegetation	0.07
Roads	0.02

- Boundary Conditions – The inflows to the TUFLOW were obtained from the XP-RAFTS model discussed previously. The downstream boundary was set as a fixed water level boundary. Sensitivity testing has been undertaken on the downstream boundary to ensure that the boundary does not influence the peak flood levels within the study area.
- Hydraulic Features – Key hydraulic controls such as road crests on the Snowy Mountains Highway have been implemented as breaklines. Cross drainage structures traversing the highway have been included in the hydraulic model as 1D elements, with conduit dimensions obtained during the site visit (see Table 41) and inverts estimated from available LiDAR data.

Implementing the various details discussed above, an Existing Conditions model was constructed to model baseline conditions flood behaviour for the Rock Forest site.

Image 11: Rock Forest Hydraulic Model Setup



4.3.2 Hydraulic Model Results

Design results have been assessed using the TUFLOW model discussed in Section 4.3.1. Results are presented in Appendix C for the 1% AEP and the PMF. Peak flood depths and levels are presented in figures:

- *Figure C 1:* *Rock Forest, peak flood depths and levels – Existing Conditions – 1% AEP*; and
- *Figure C 2:* *Rock Forest, peak flood depths and levels – Existing Conditions – PMF*.

ARR2016 flood hazard (see Section 2.4.1 for further details) based on the *'Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia'* (AIDR 2017) is presented in figures:

- *Figure C 3:* *Rock Forest, flood hazard – Existing Conditions – 1% AEP*; and
- *Figure C 4:* *Rock Forest, flood hazard – Existing Conditions – PMF*.

4.4 Rock Forest - Conclusions

A flood study was undertaken for the Rock Forest site within the Snowy 2.0 Main Works project area. The site is subject to flooding Camerons Creek and Watercourse RF1.

An XP-RAFTS model was developed and ARR2016 methods and parameters were applied. Continuing losses were based on those determined via model calibration in the nearby *'Snowy Monaro Flood Studies Draft Final Report'* (SMEC/GRC Hydro, 2019) as per the methods outlined in the OEH guidelines (Floodplain Risk Management Guide, 2019).

The Camerons Creek 1% AEP flow estimate of 40 m^3/s at the site was validated by comparison to design flow estimates from surrounding gauges, increasing confidence in design flow results. The PMF flow estimate of 590 m^3/s was developed through application of the GSDM.

A TUFLOW hydraulic model was developed for the Camerons Creek and Goorudee Rivulet floodplains in the vicinity of the site. Flows from the above mentioned XP-RAFTS model were applied to the TUFLOW model to examined 1% AEP and PMF design flood behaviour.

Design flood depths, levels and flood hazard for the 1% AEP and the PMF events are presented in Appendix C.

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National Flood Risk Advisory Group

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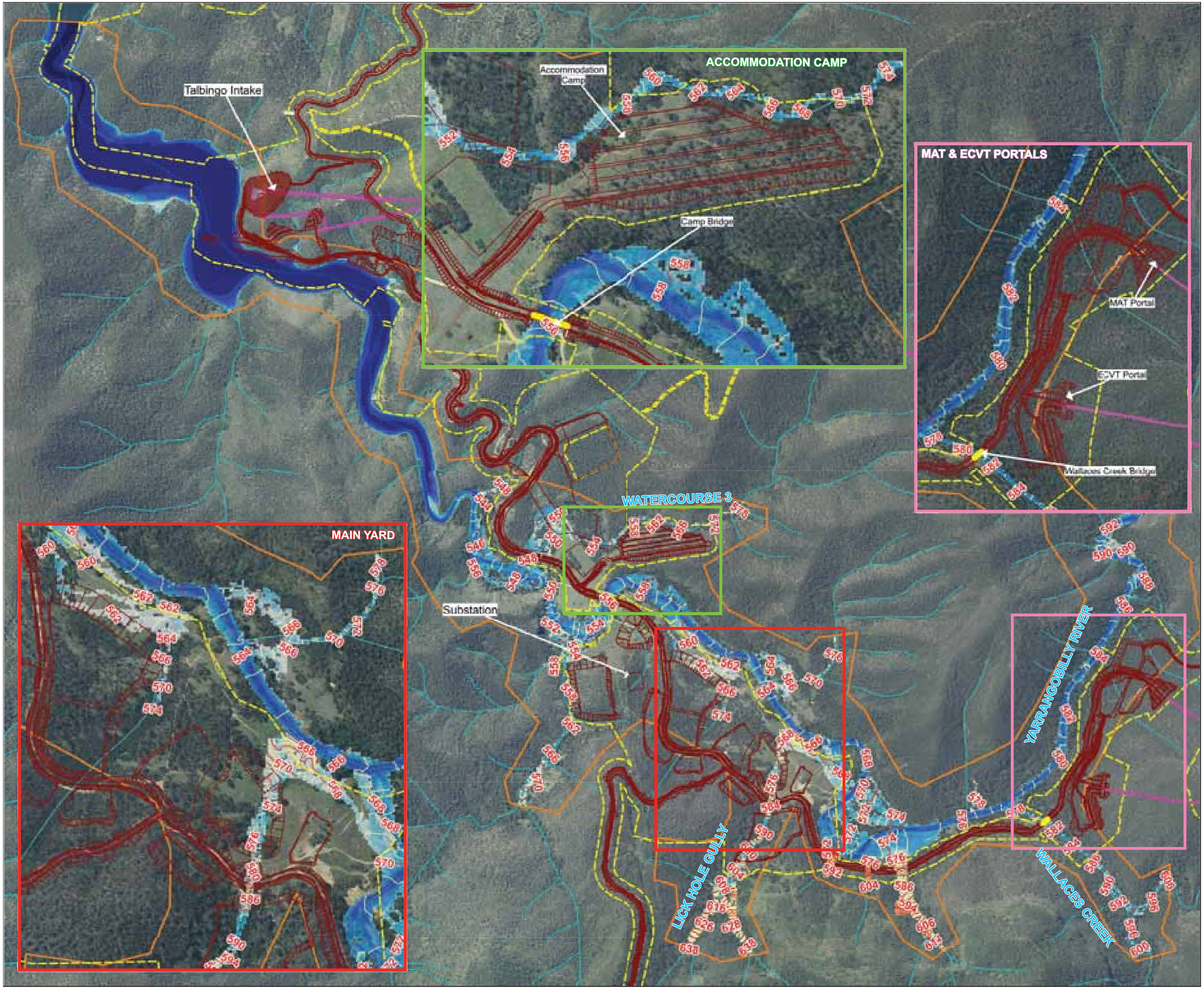
Appendix A:



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

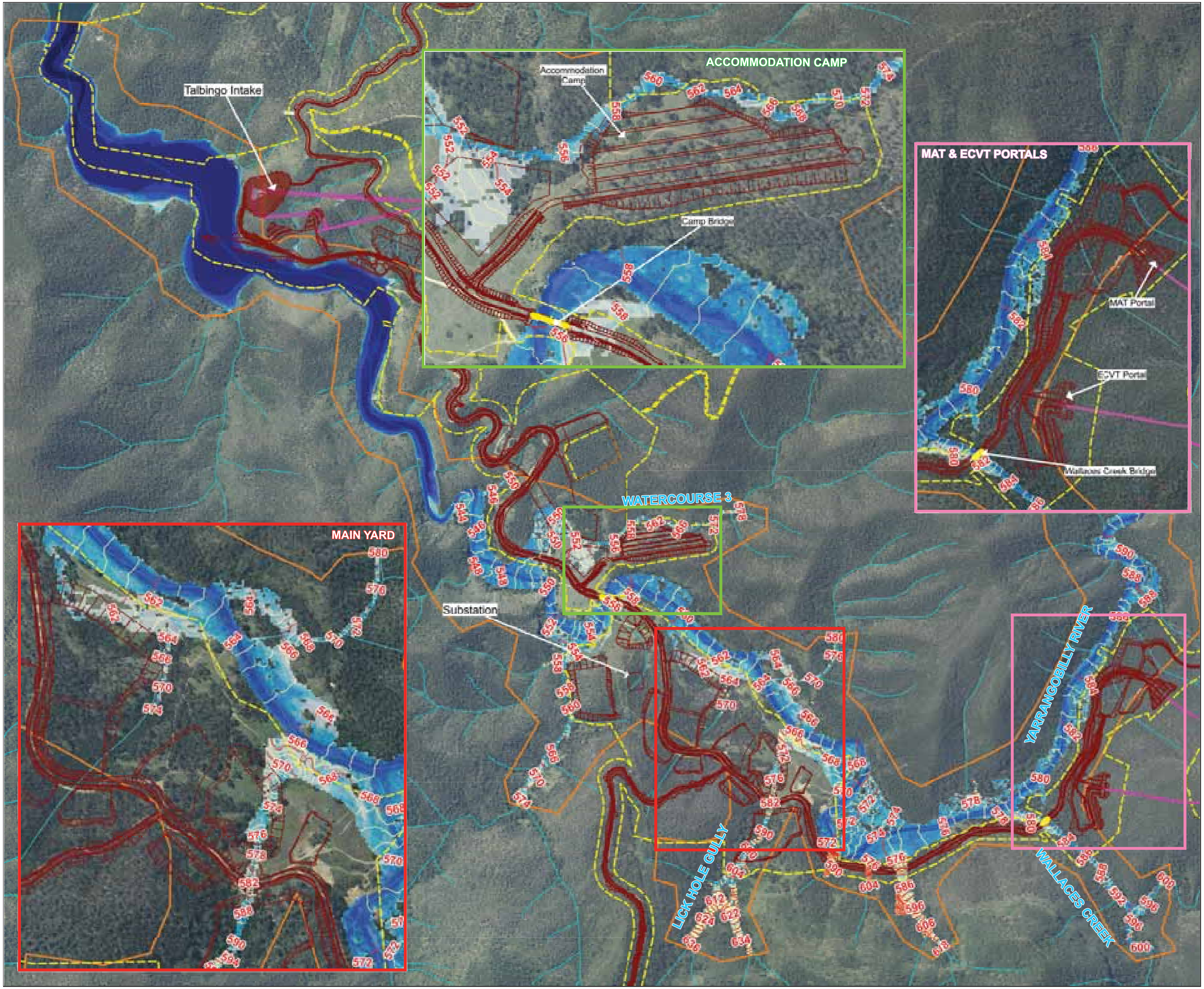
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

20% AEP Event - Peak Flood Depth and Level Existing Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A01



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Peak Flood Depth (m)

0.00 to 0.05
0.05 to 0.1
0.1 to 0.3
0.3 to 0.5
0.5 to 1.0
1.0 to 2.0
2.0 to 5.0
5.0 to 10.0
10.0 to 20.0
20.0 to 30.0
> 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

5% AEP Event -

Peak Flood Depth and Level

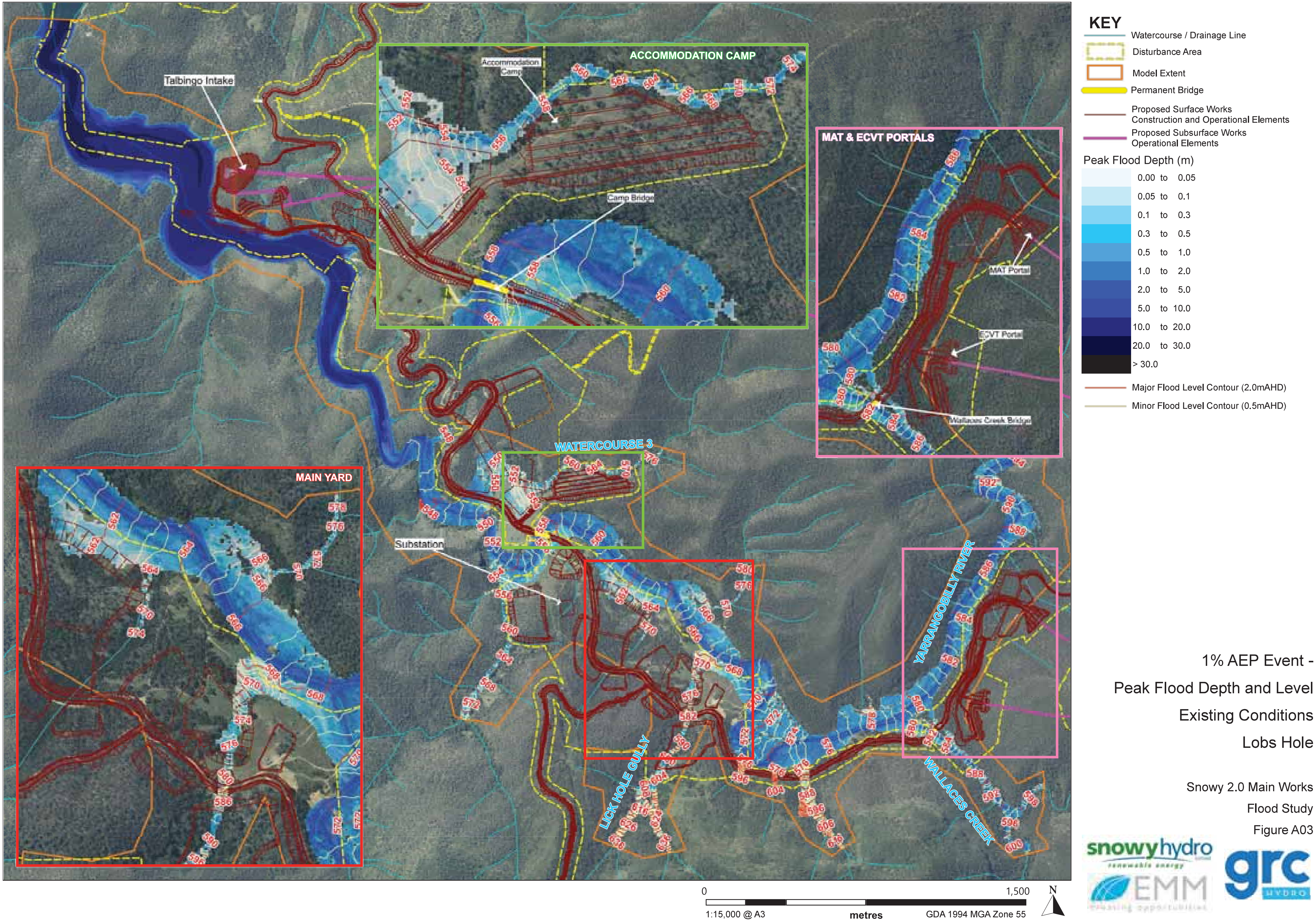
Existing Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A02



1% AEP Event -

Peak Flood Depth and Level

Existing Conditions

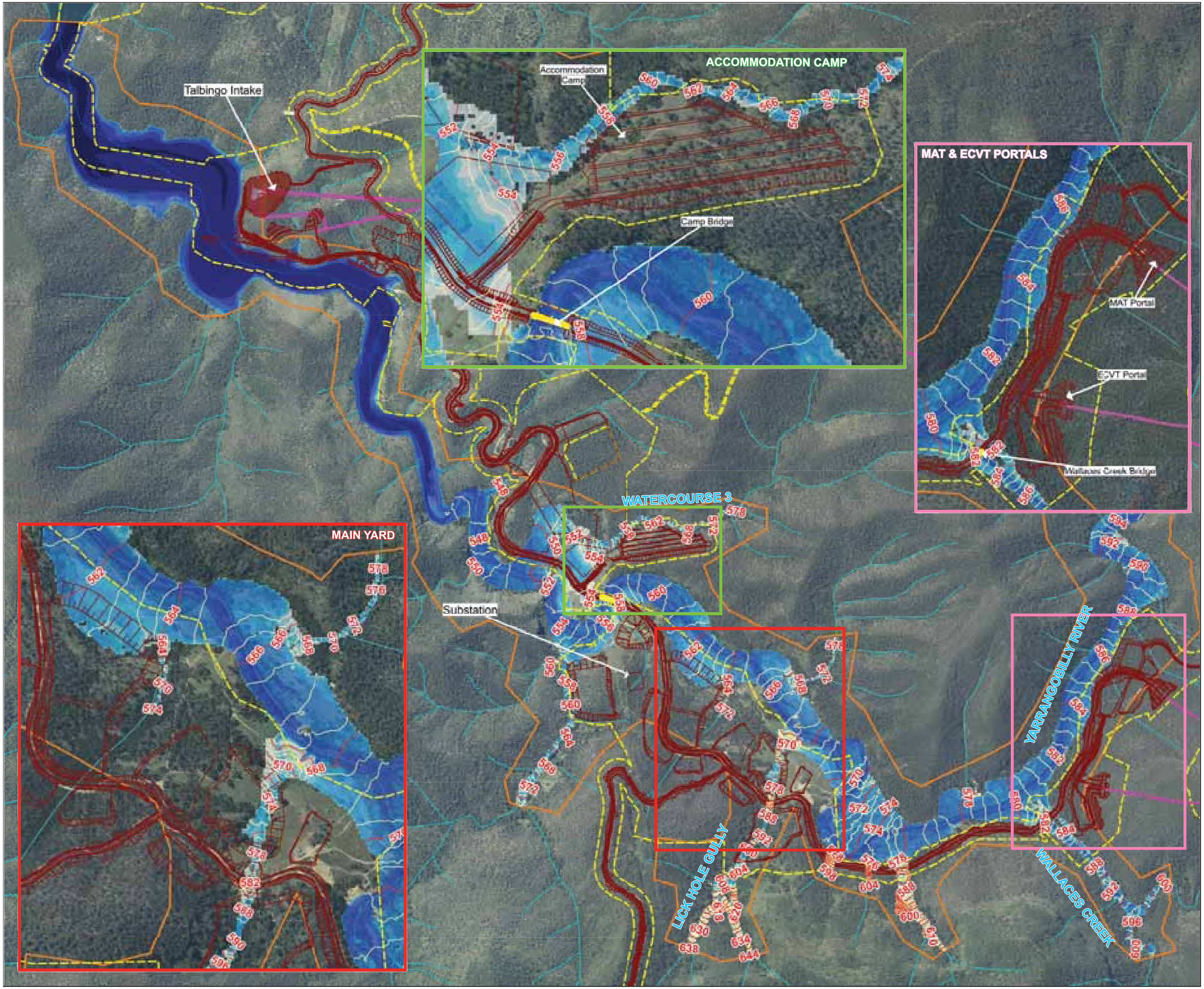
Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A03

snowyhydro EMM grc hydro



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Peak Flood Depth (m)

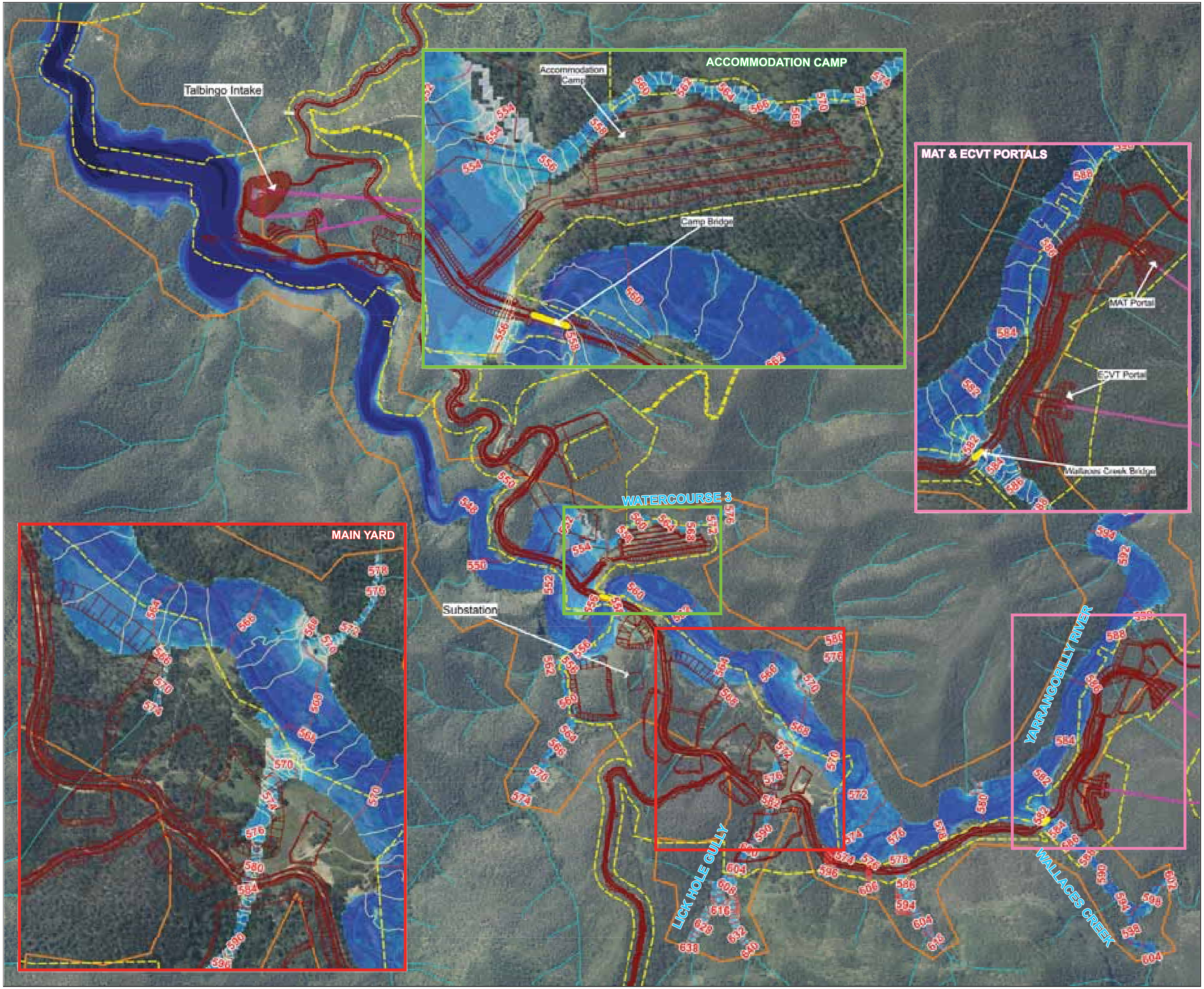
- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

0.2% AEP Event -
Peak Flood Depth and Level
Existing Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A04

snowyhydro renewable energy
EMM
grc hydro



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

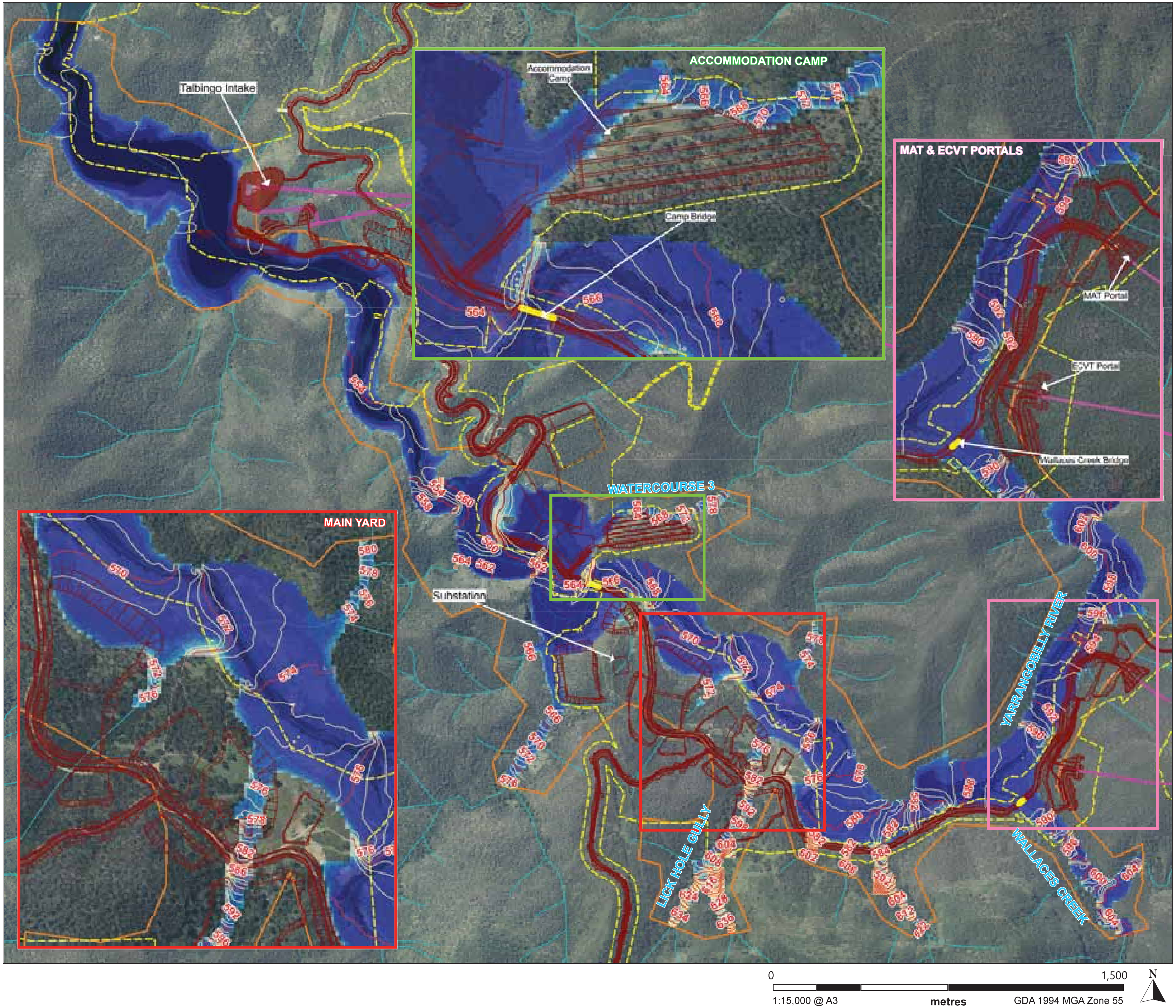
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

0.05% AEP Event -
Peak Flood Depth and Level
Existing Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A05



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

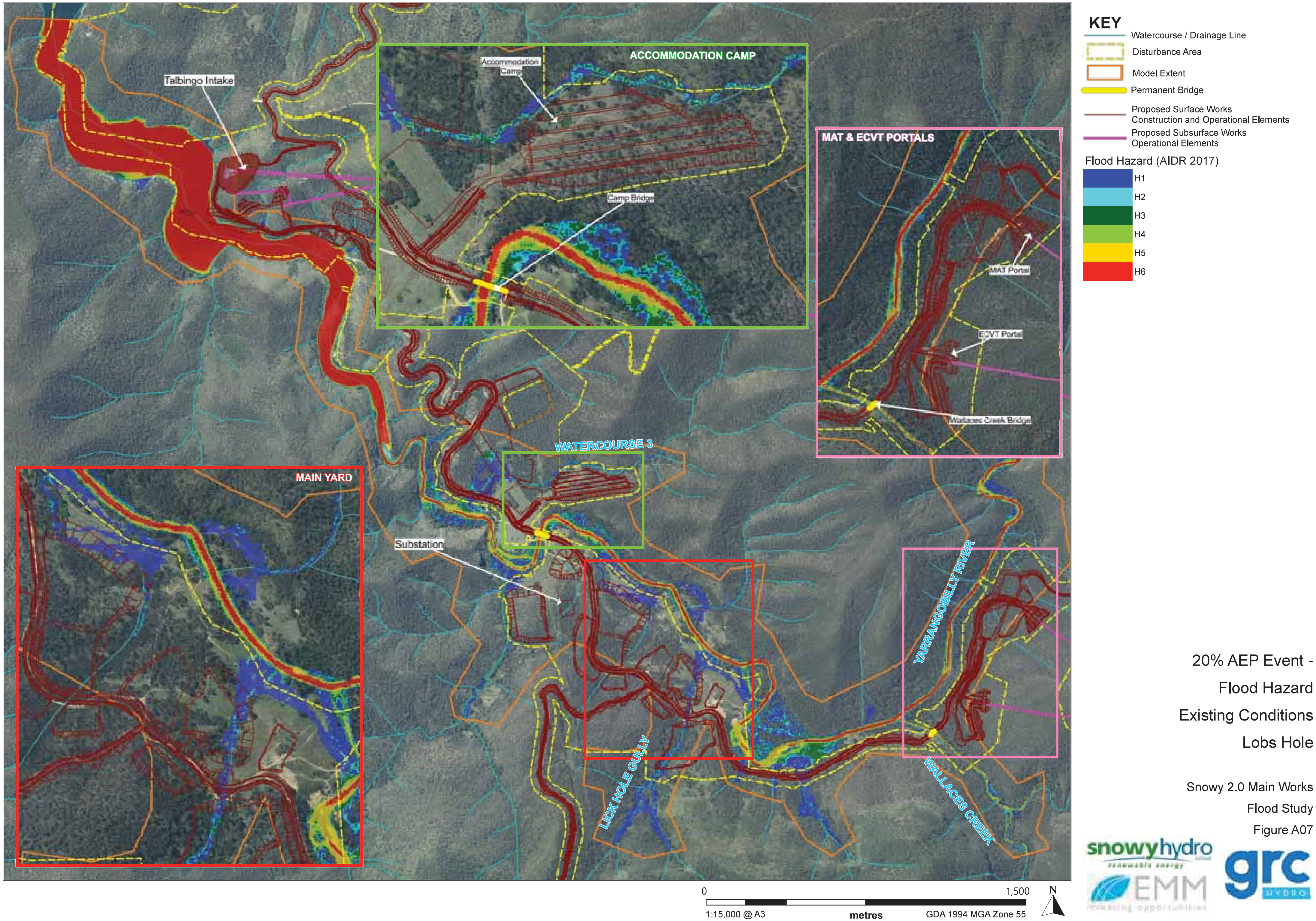
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

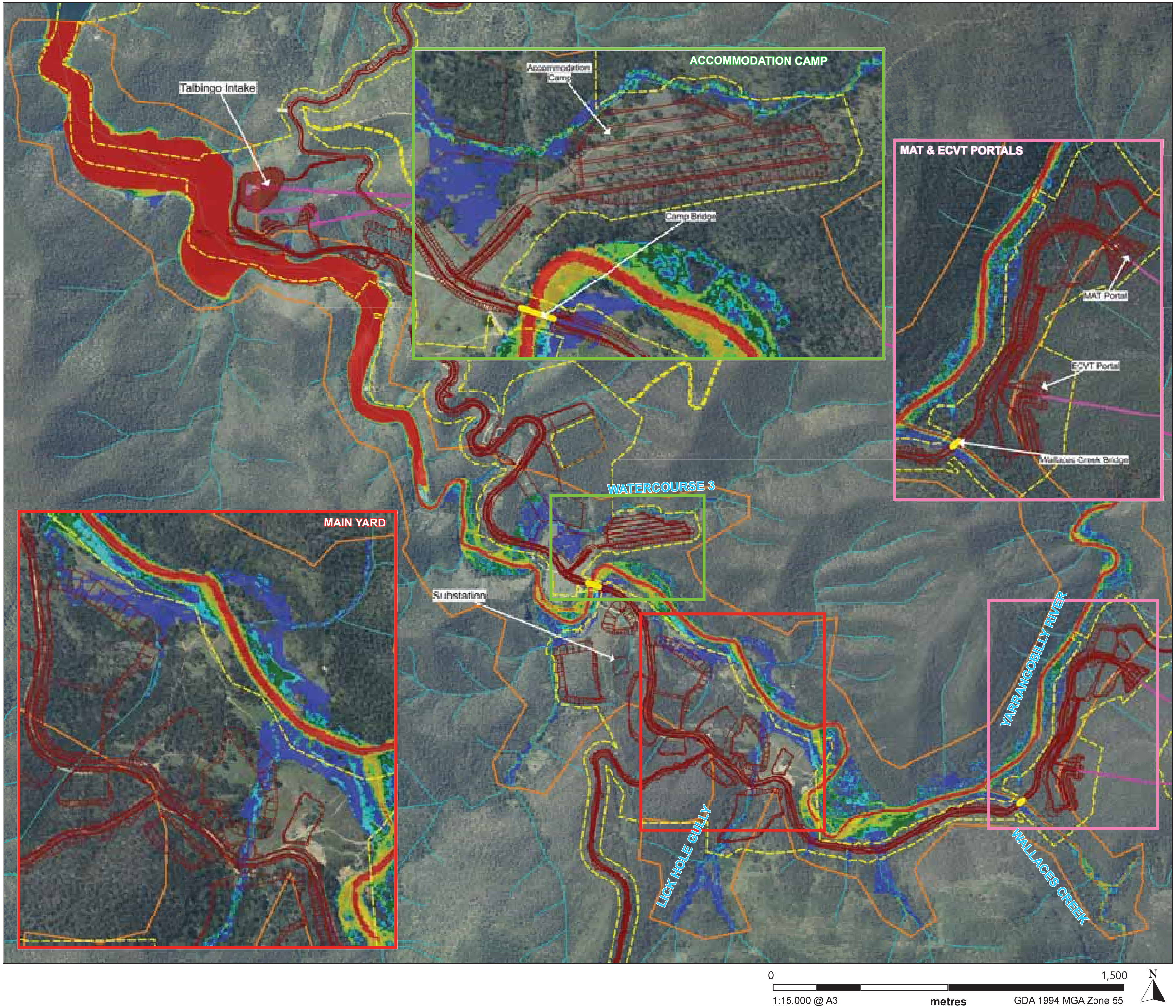
- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

PMF Event -
Peak Flood Depth and Level
Existing Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A06



KEY
Watercourse / Drainage Line
Disturbance Area
Model Extent
Permanent Bridge
Proposed Surface Works Construction and Operational Elements
Proposed Subsurface Works Operational Elements
Flood Hazard (AIDR 2017)
H1
H2
H3
H4
H5
H6
ACCOMMODATION CAMP
Accommodation Camp
Camp Bridge
MAT & ECVT PORTALS
MAT Portal
ECVT Portal
Wallaces Creek Bridge
Talbingo Intake
WATERCOURSE 3
MAIN YARD
Substation
LICK HOLE GULLY
YARRANGOBILLY RIVER
WALLACES CREEK
20% AEP Event -
Flood Hazard
Existing Conditions
Lobs Hole
Snowy 2.0 Main Works
Flood Study
Figure A07
0
1,500
1:15,000 @ A3
metres
GDA 1994 MGA Zone 55
N



KEY

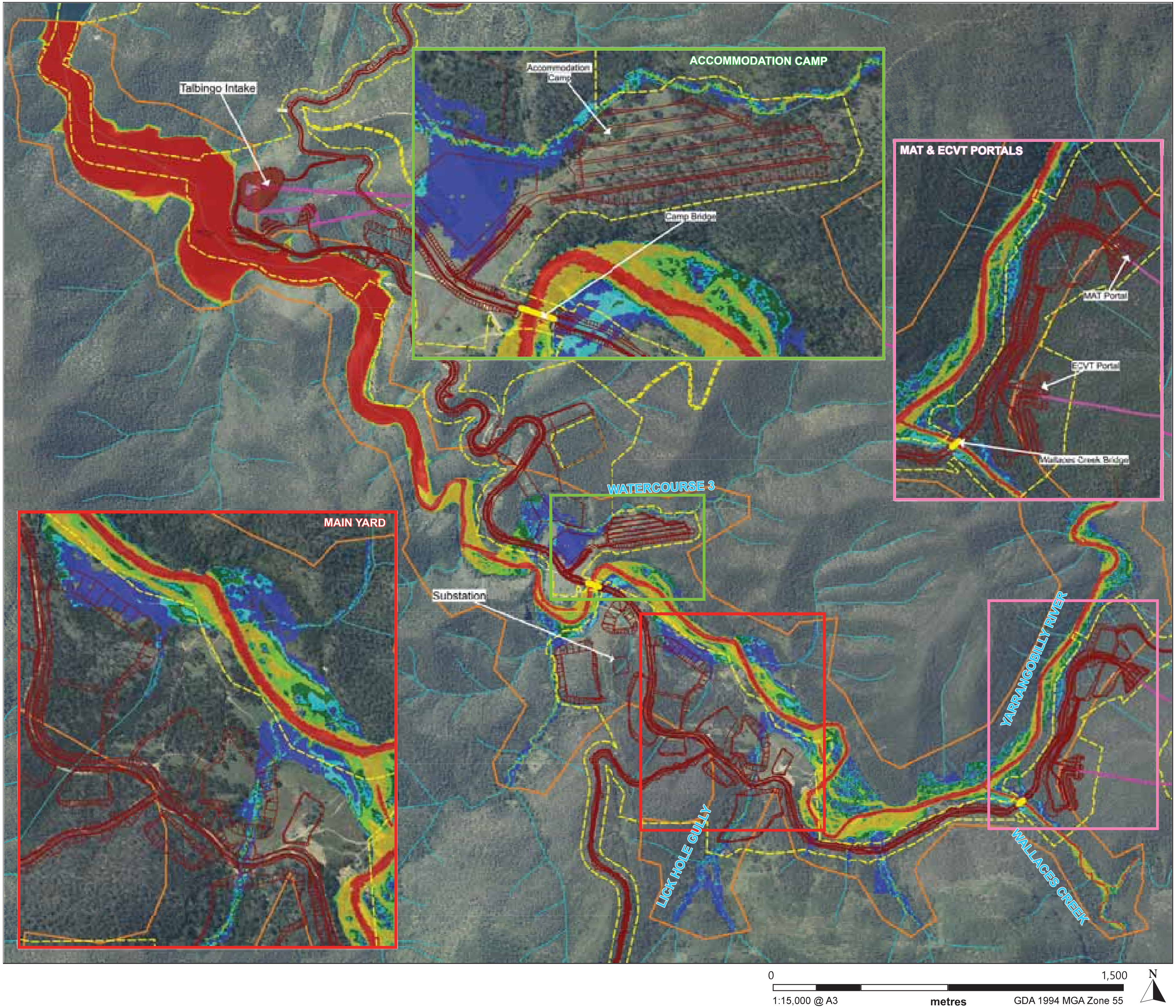
- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

5% AEP Event - Flood Hazard Existing Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A08



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

1% AEP Event -

Flood Hazard

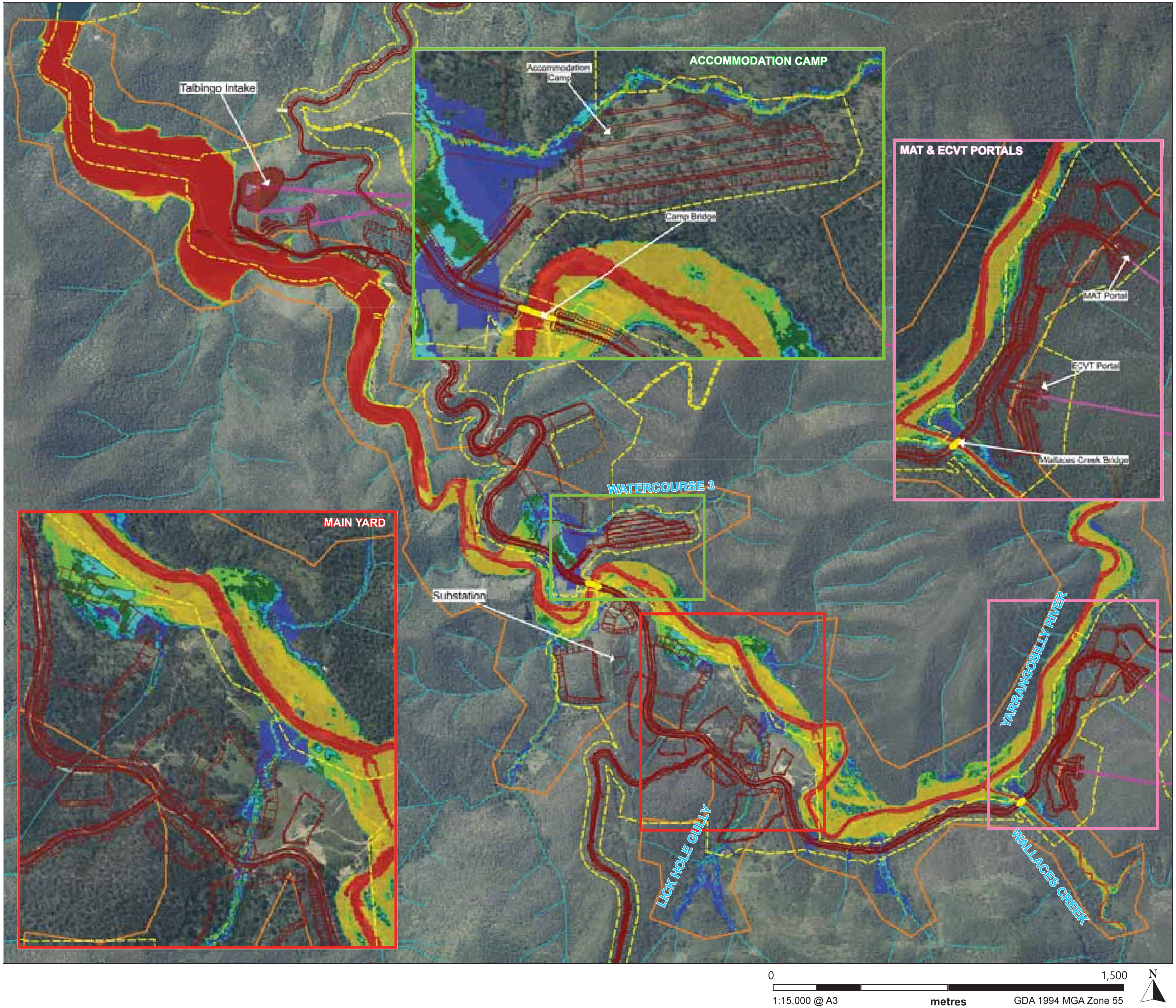
Existing Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A09



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

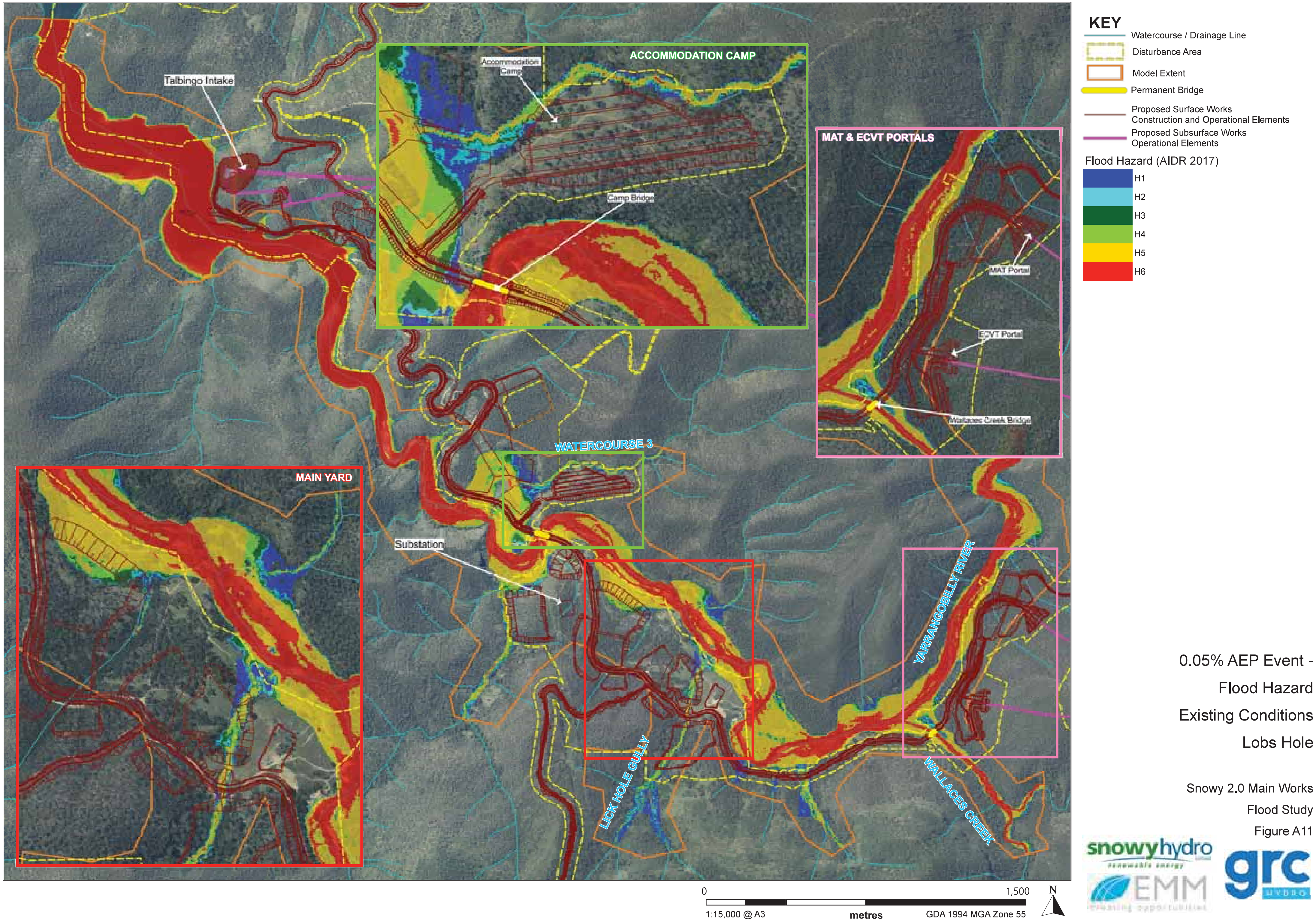
Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

0.2% AEP Event - Flood Hazard Existing Conditions Lobs Hole

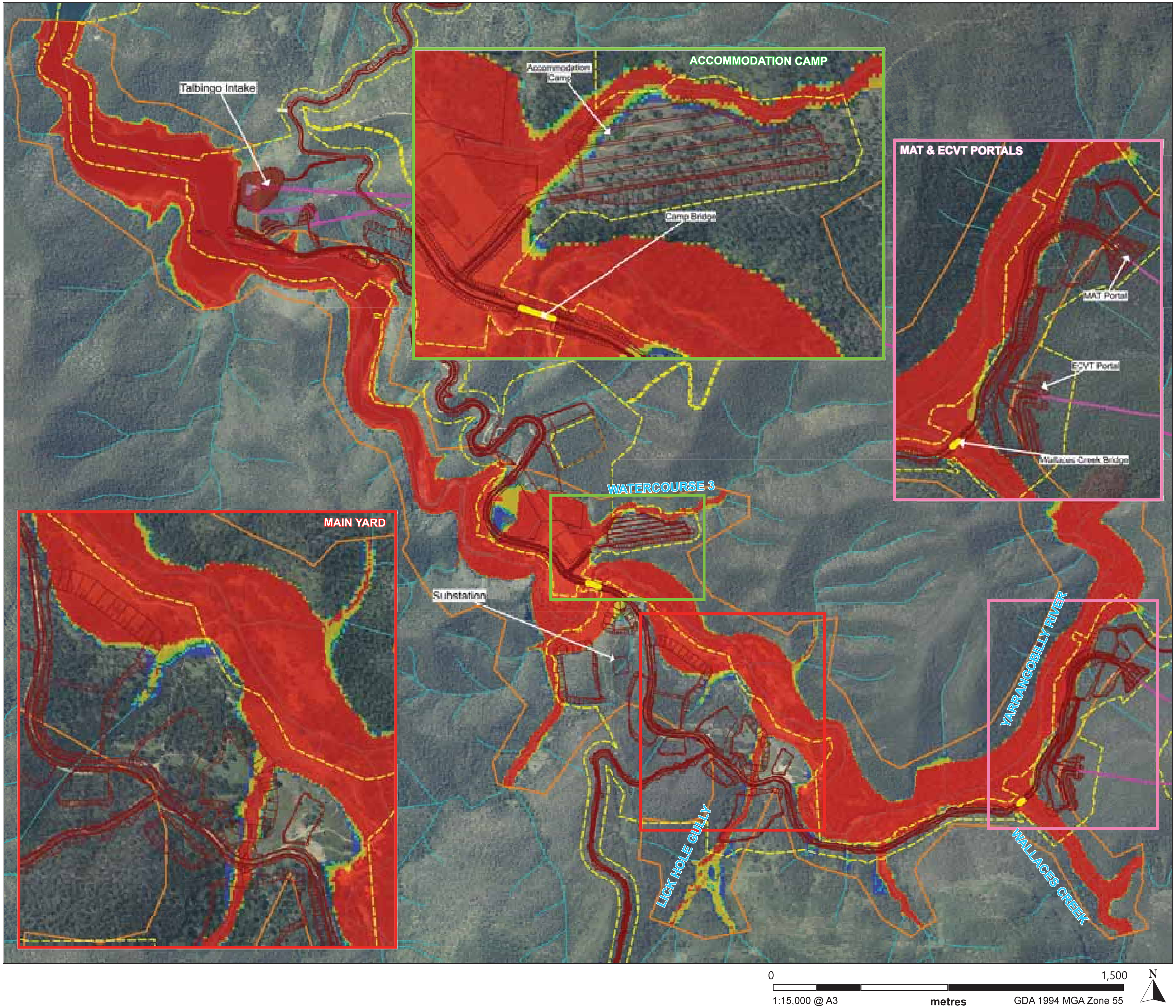
Snowy 2.0 Main Works Flood Study

Figure A10



0.05% AEP Event -
Flood Hazard
Existing Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A11



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

PMF Event -

Flood Hazard

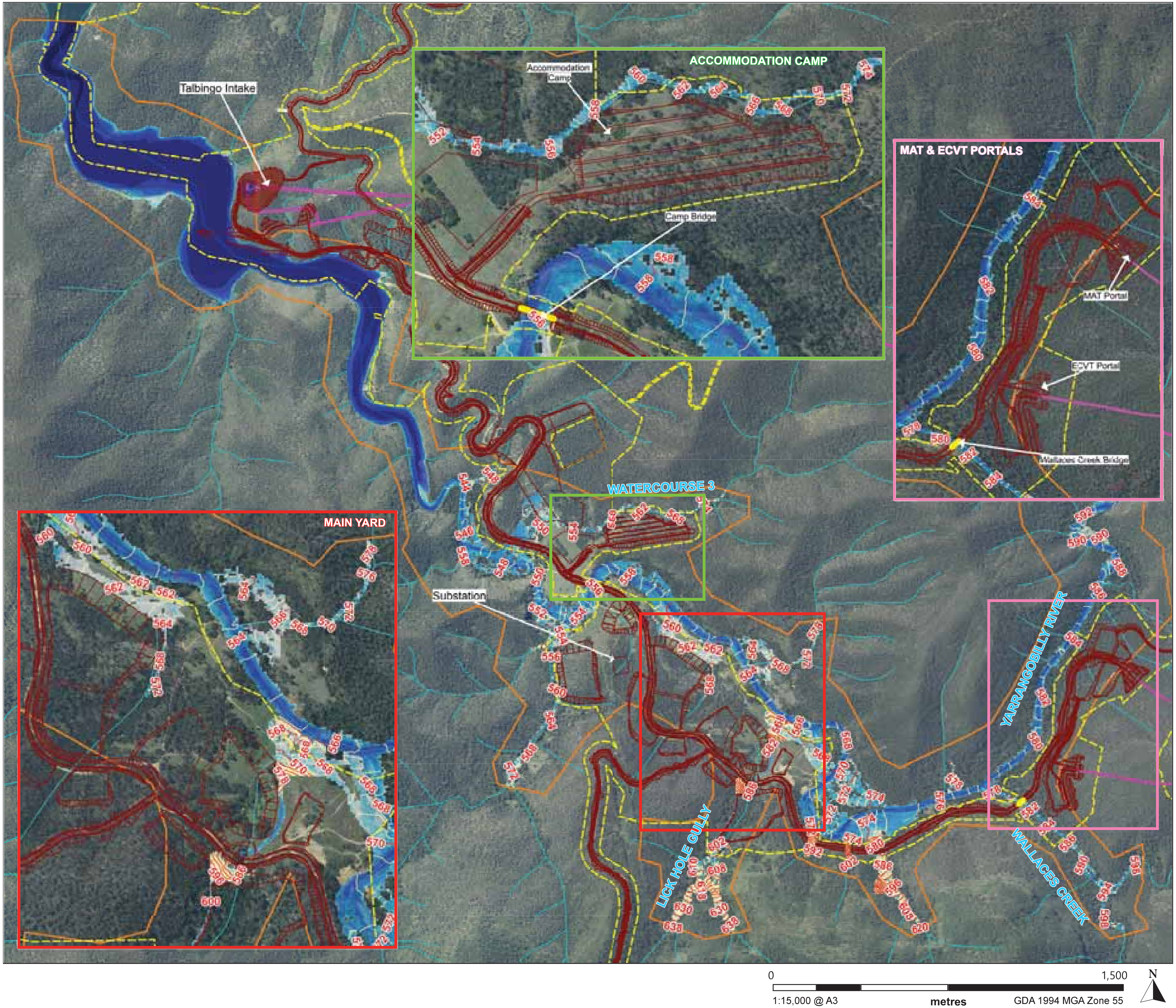
Existing Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A12



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

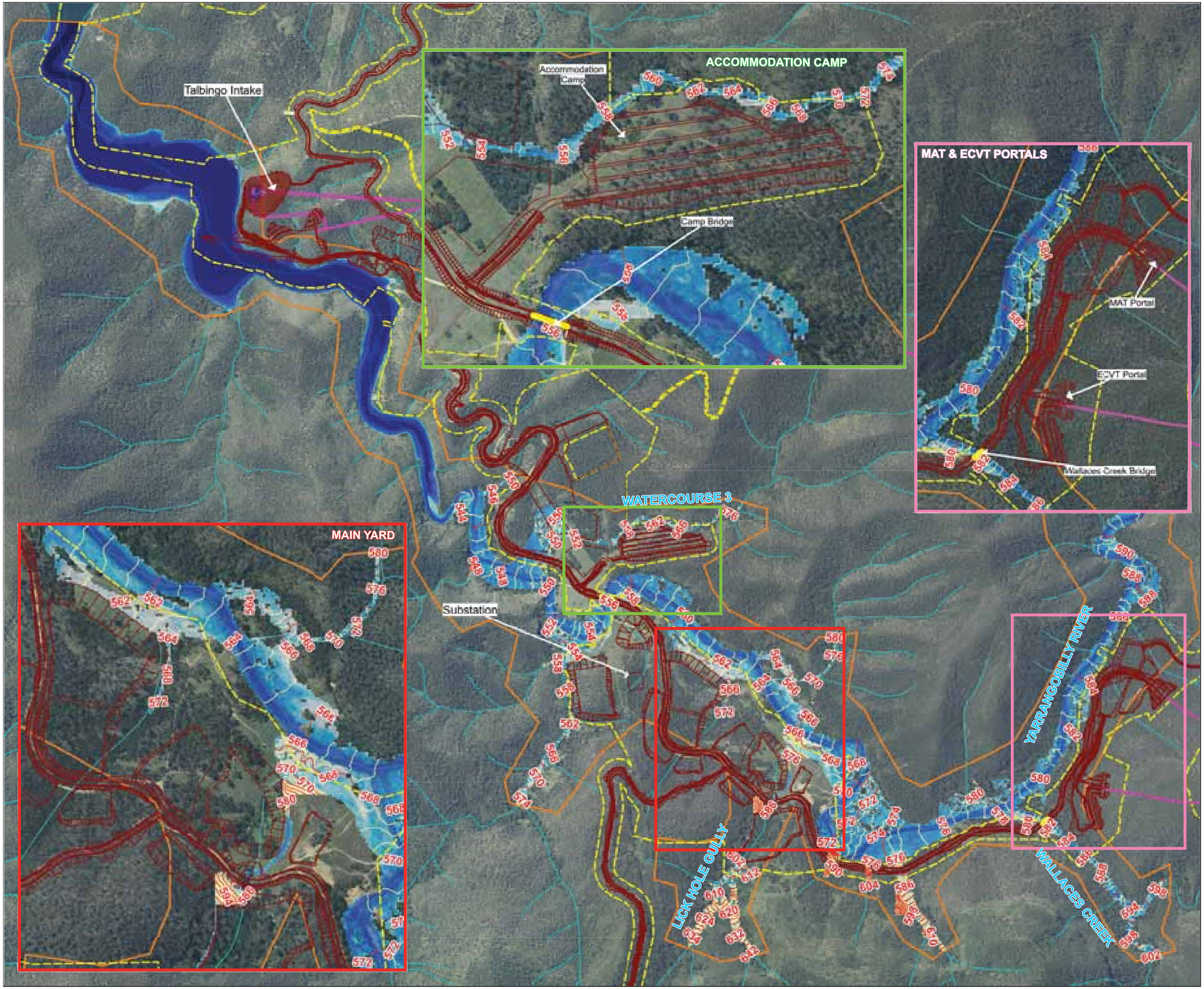
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

20% AEP Event - Peak Flood Depth and Level Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A13



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

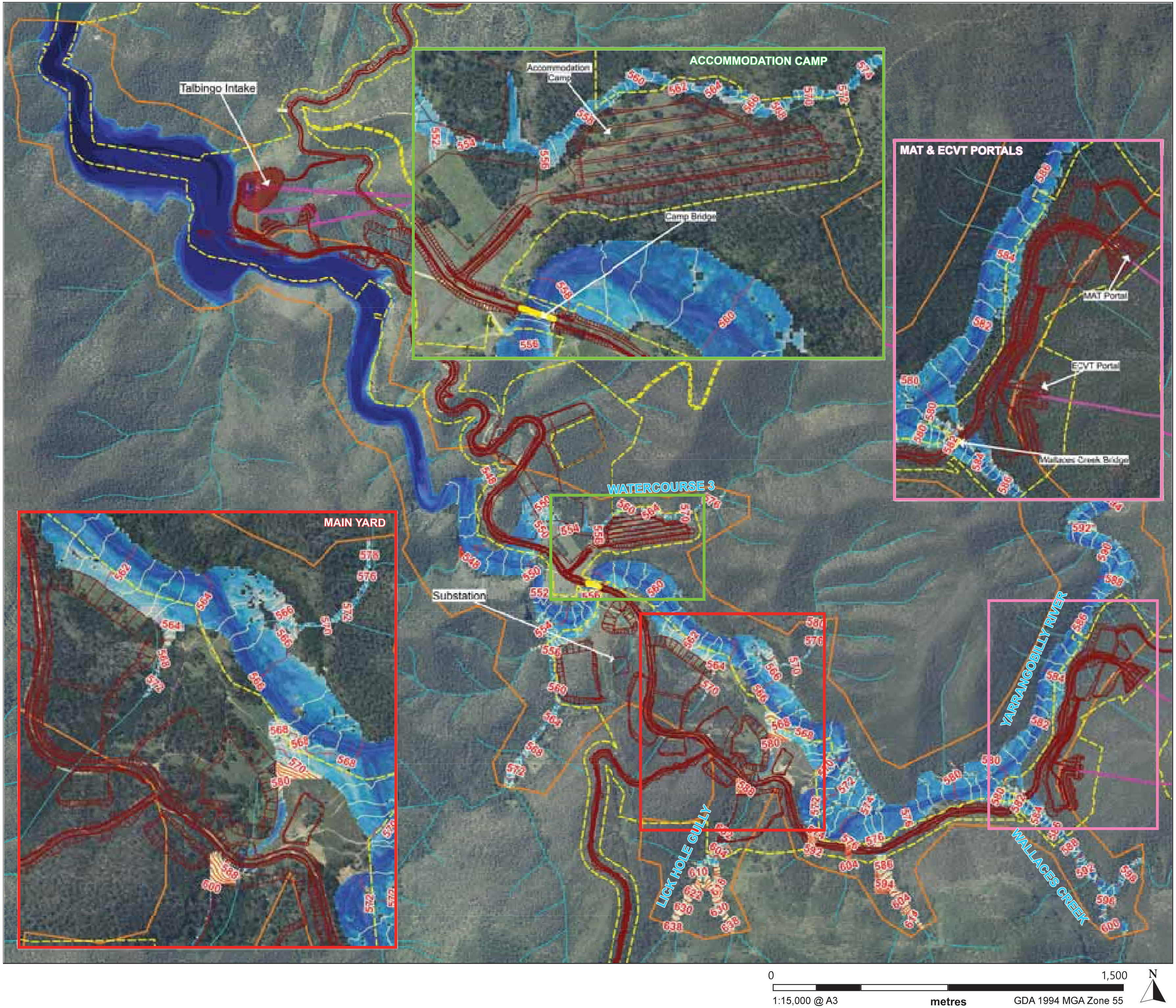
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

5% AEP Event - Peak Flood Depth and Level Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A14



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

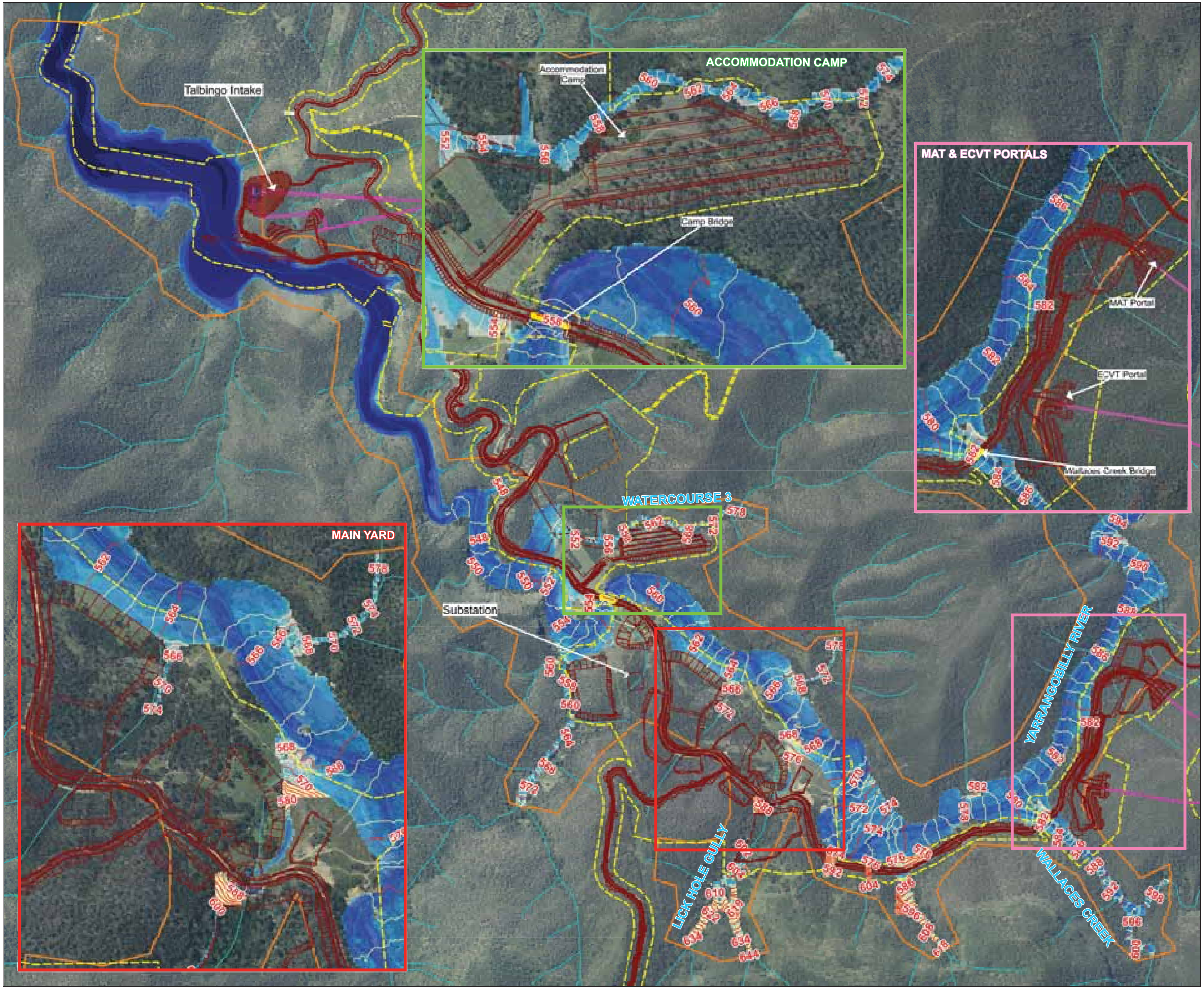
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

1% AEP Event - Peak Flood Depth and Level Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A15



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

0.2% AEP Event -

Peak Flood Depth and Level

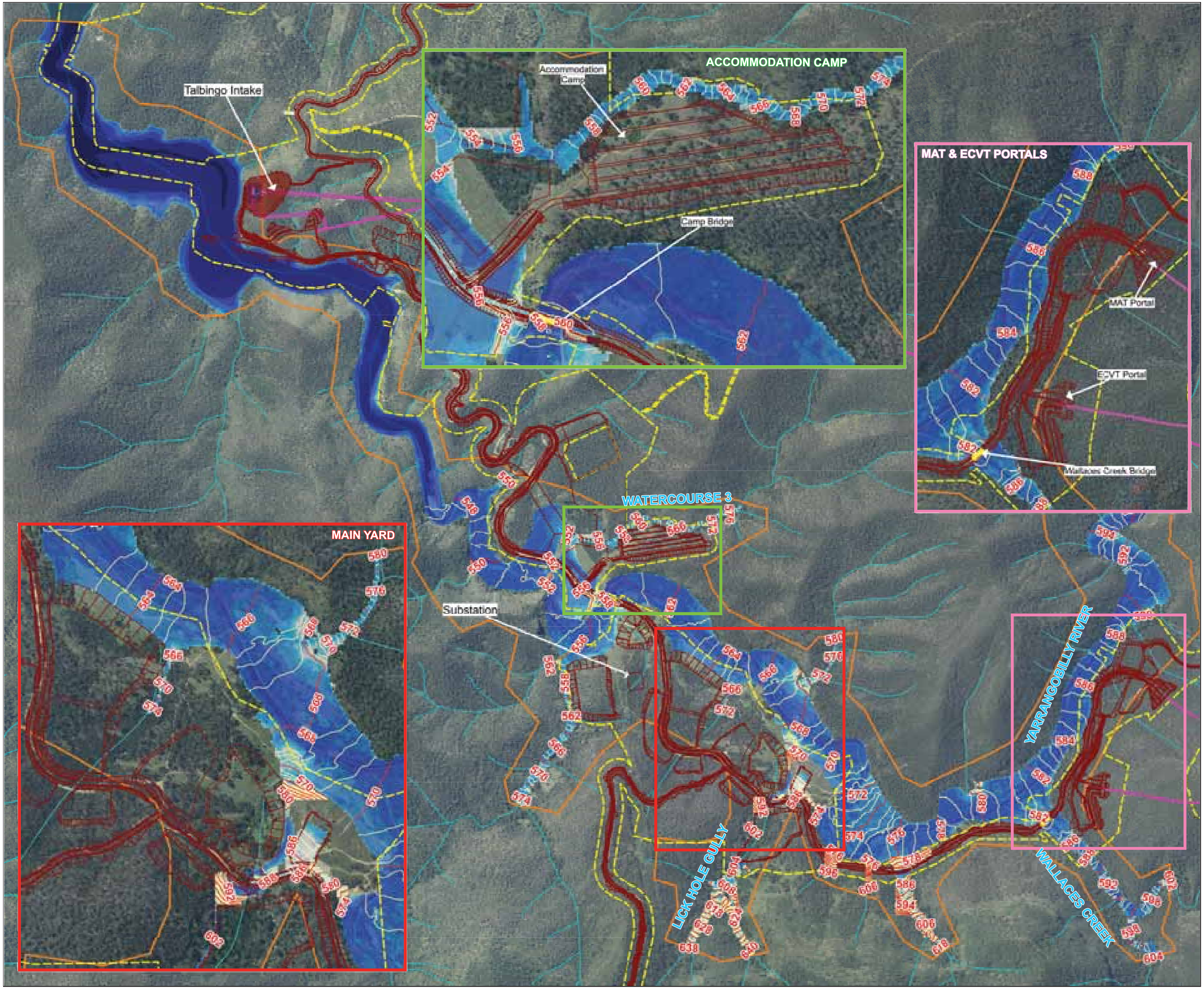
Proposed Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A16



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

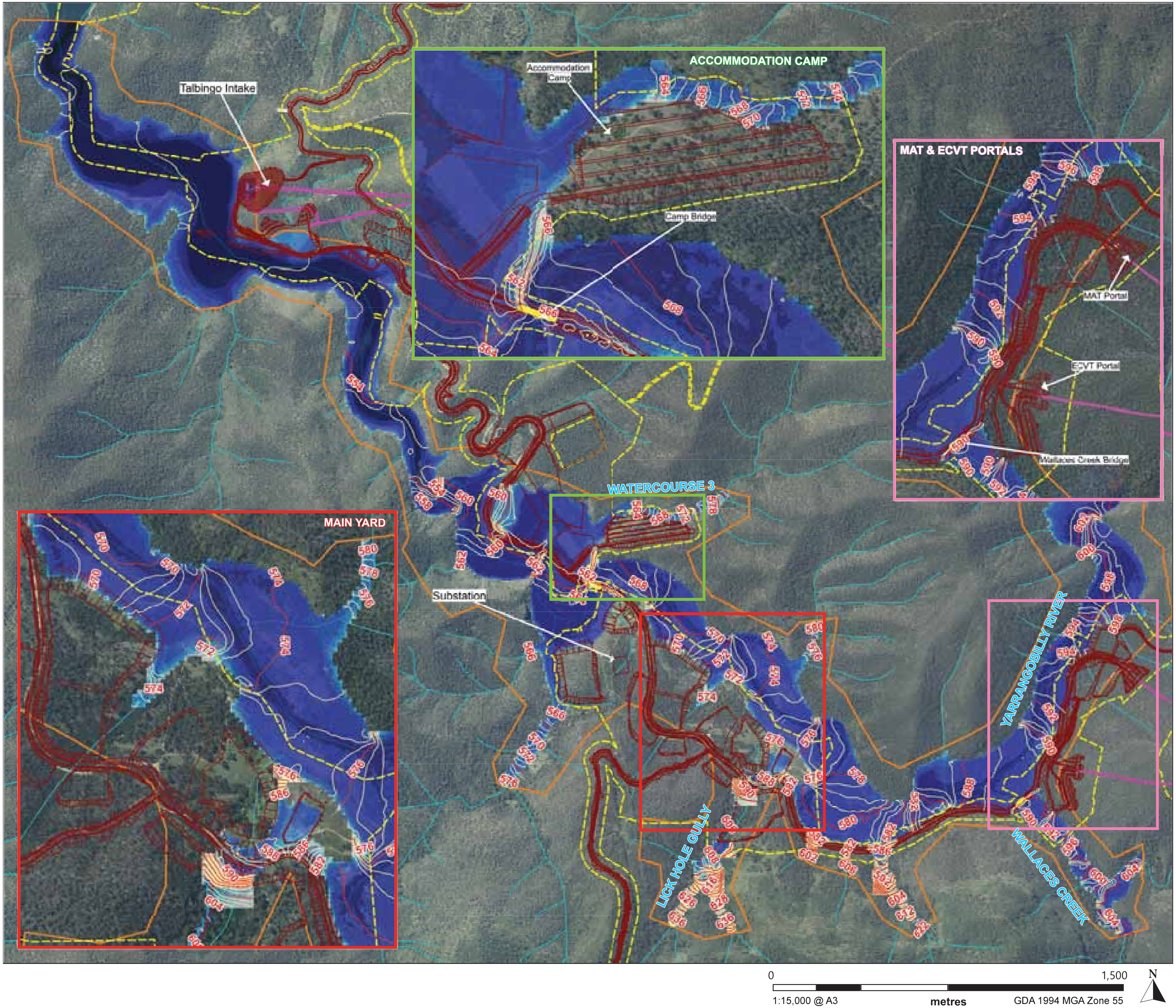
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

0.05% Event - Peak Flood Depth and Level Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A17



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

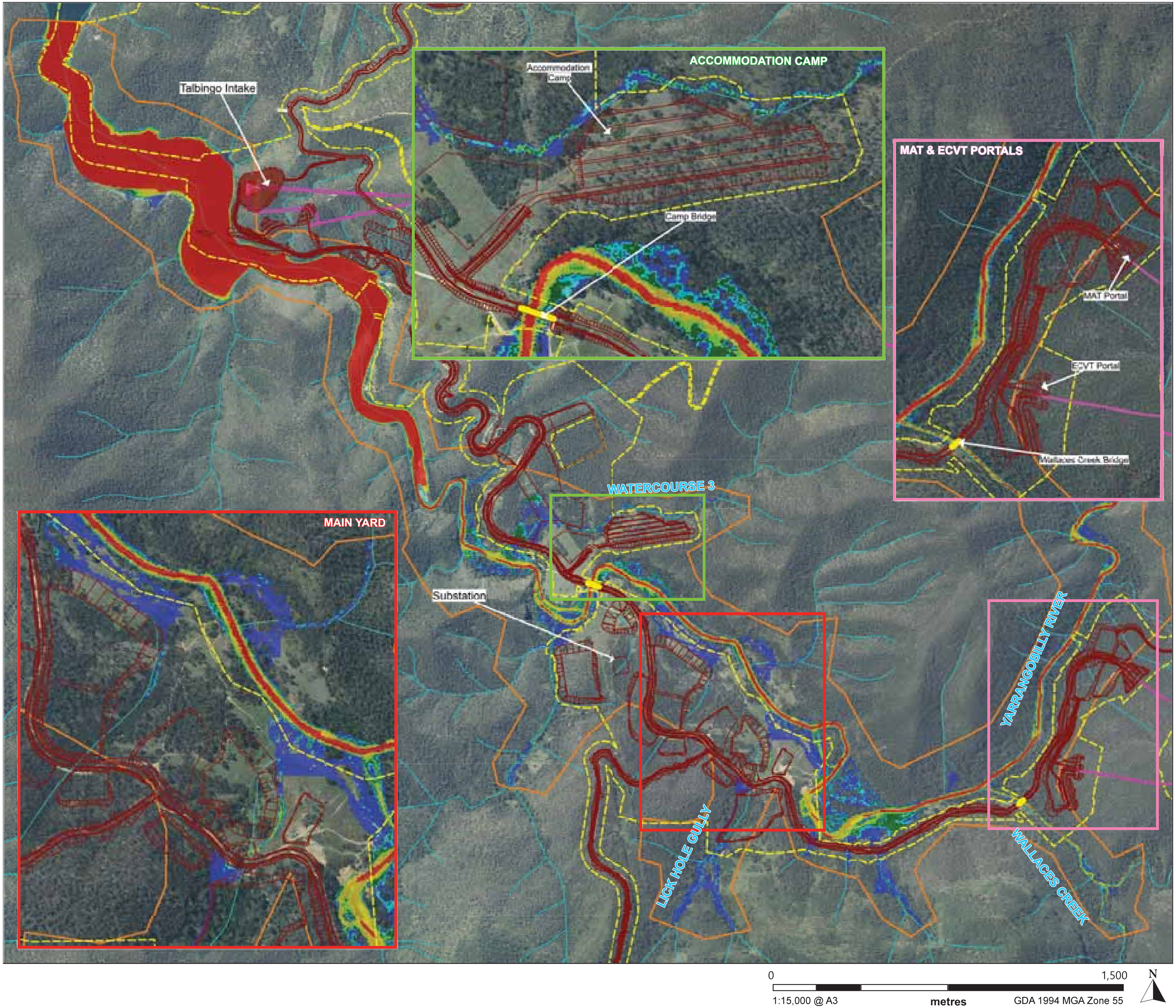
Peak Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Major Flood Level Contour (2.0mAHD)
- Minor Flood Level Contour (0.5mAHD)

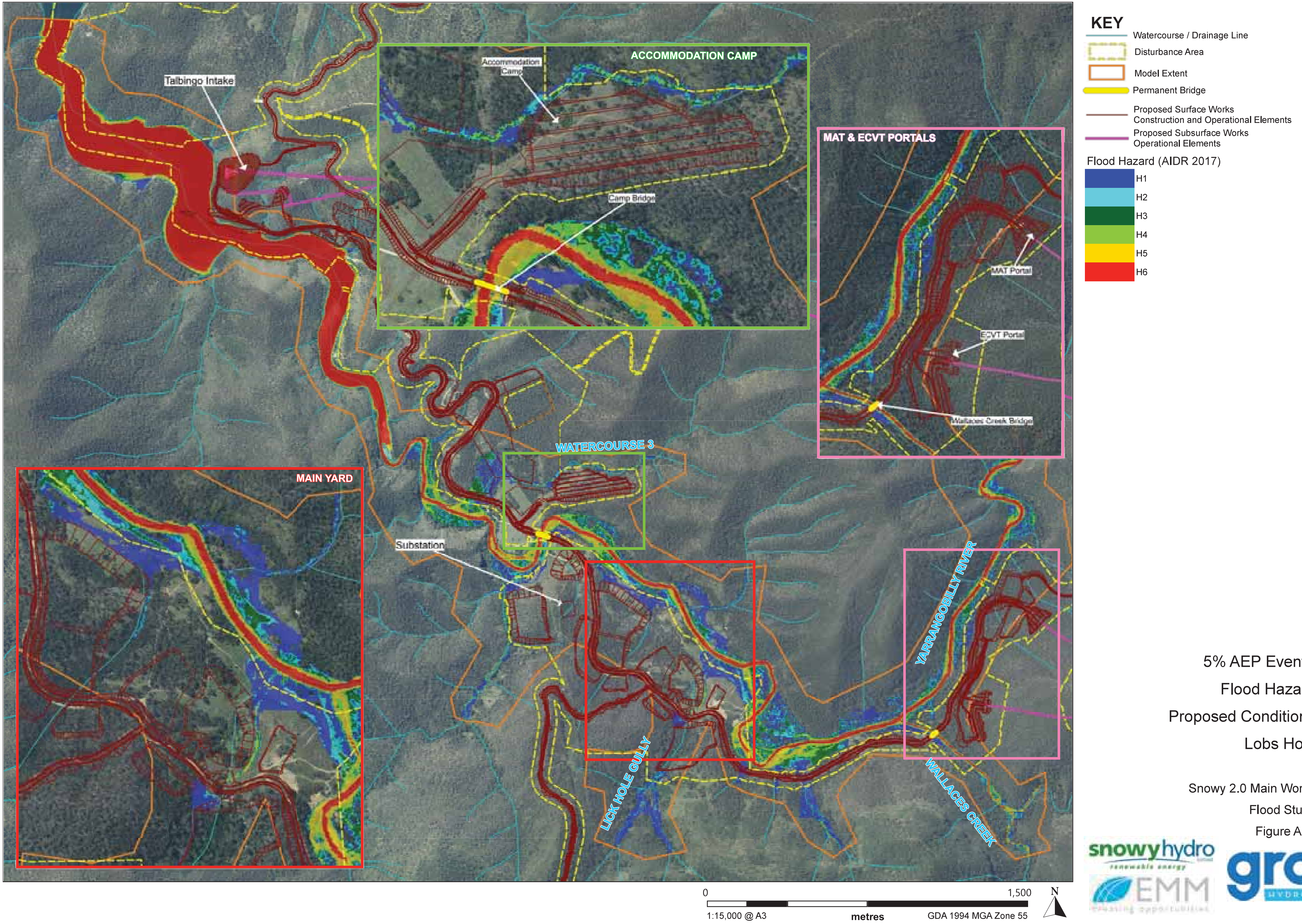
PMF Event -
Peak Flood Depth and Level
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A18



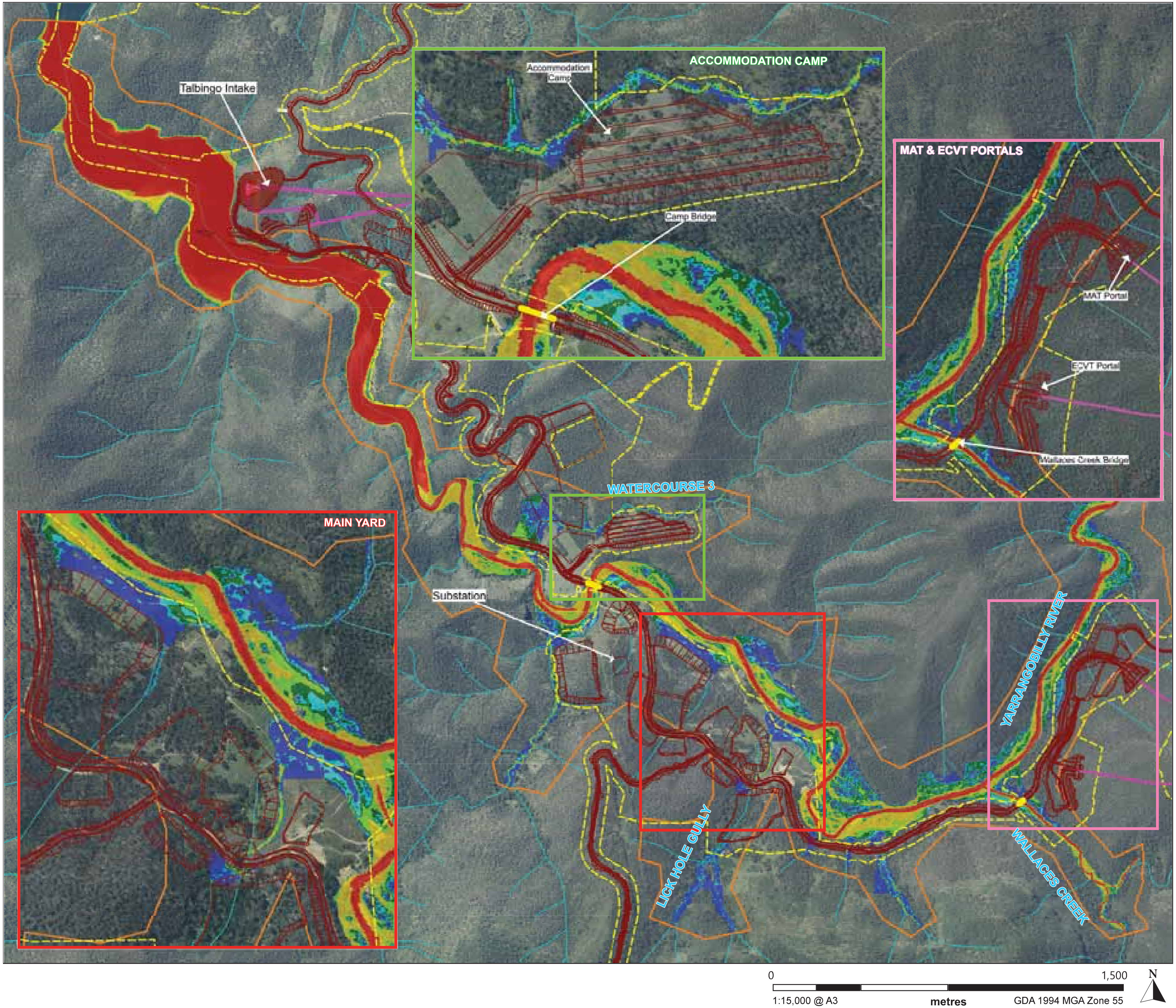
20% AEP Event -
Flood Hazard
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A19



5% AEP Event - Flood Hazard Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A20



KEY

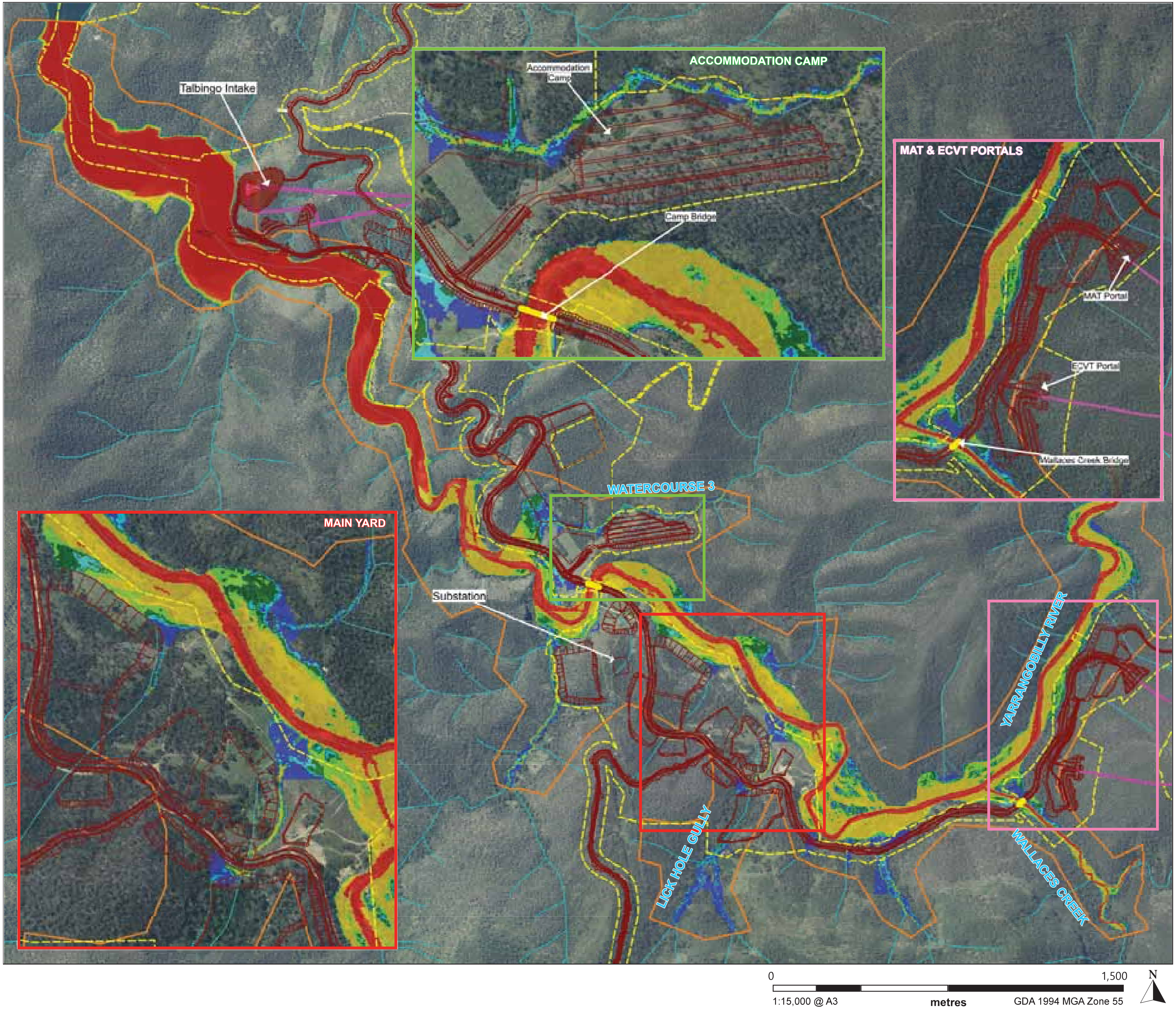
- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

1% AEP Event -
Flood Hazard
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A21



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

0.2% AEP Event -

Flood Hazard

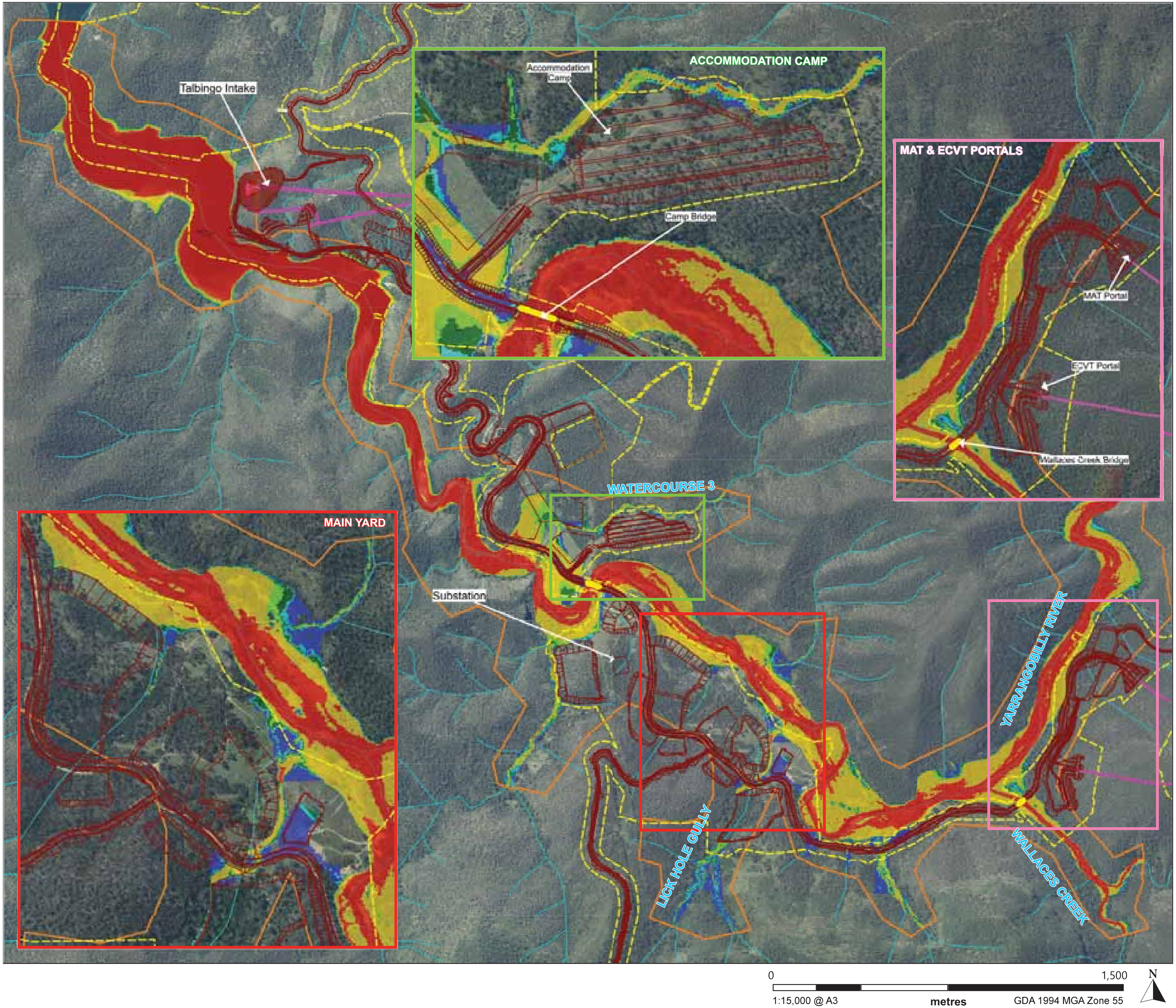
Proposed Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A22



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

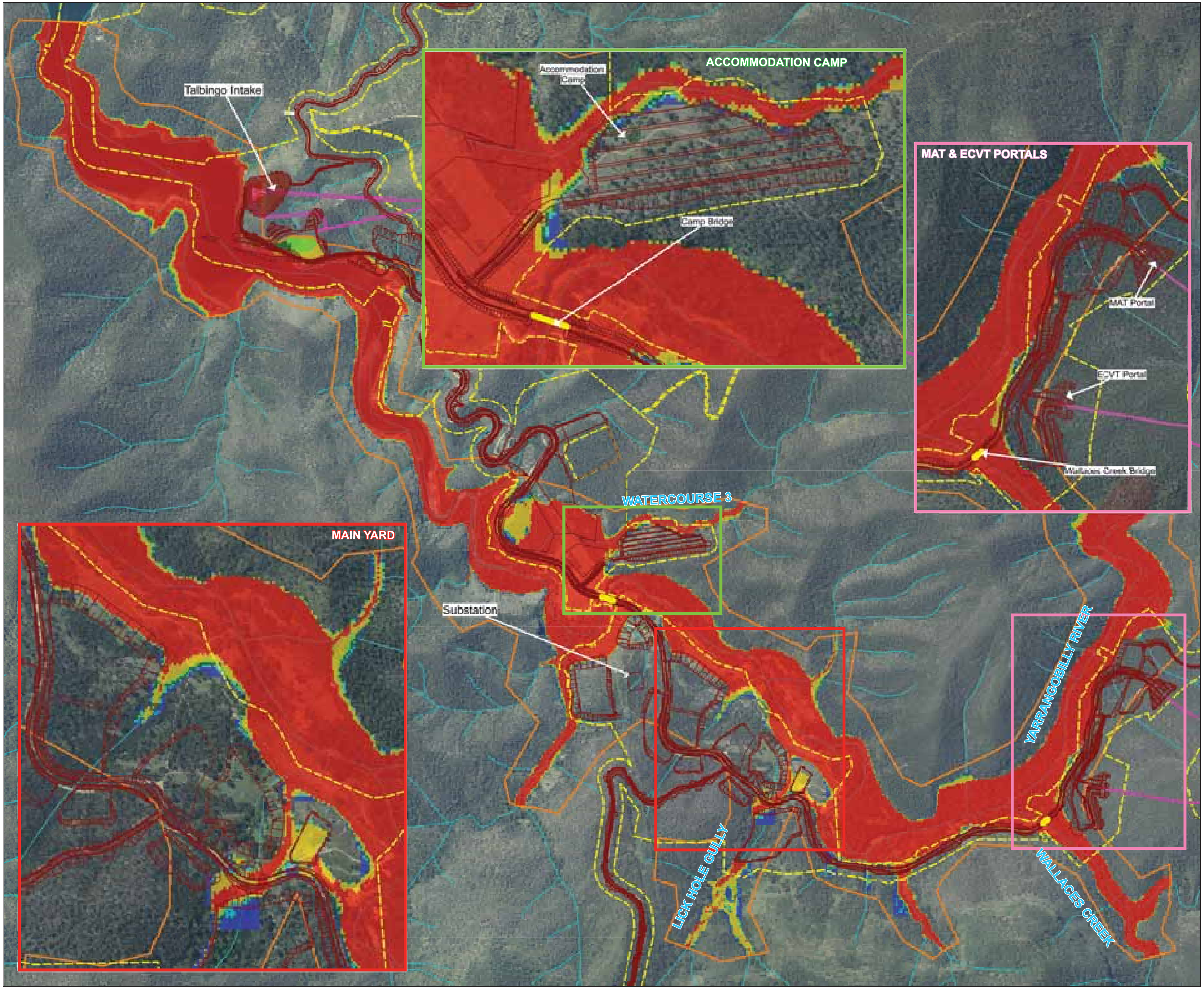
Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

0.05% AEP Event - Flood Hazard Proposed Conditions Lobs Hole

Snowy 2.0 Main Works Flood Study

Figure A23



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

PMF Event -

Flood Hazard

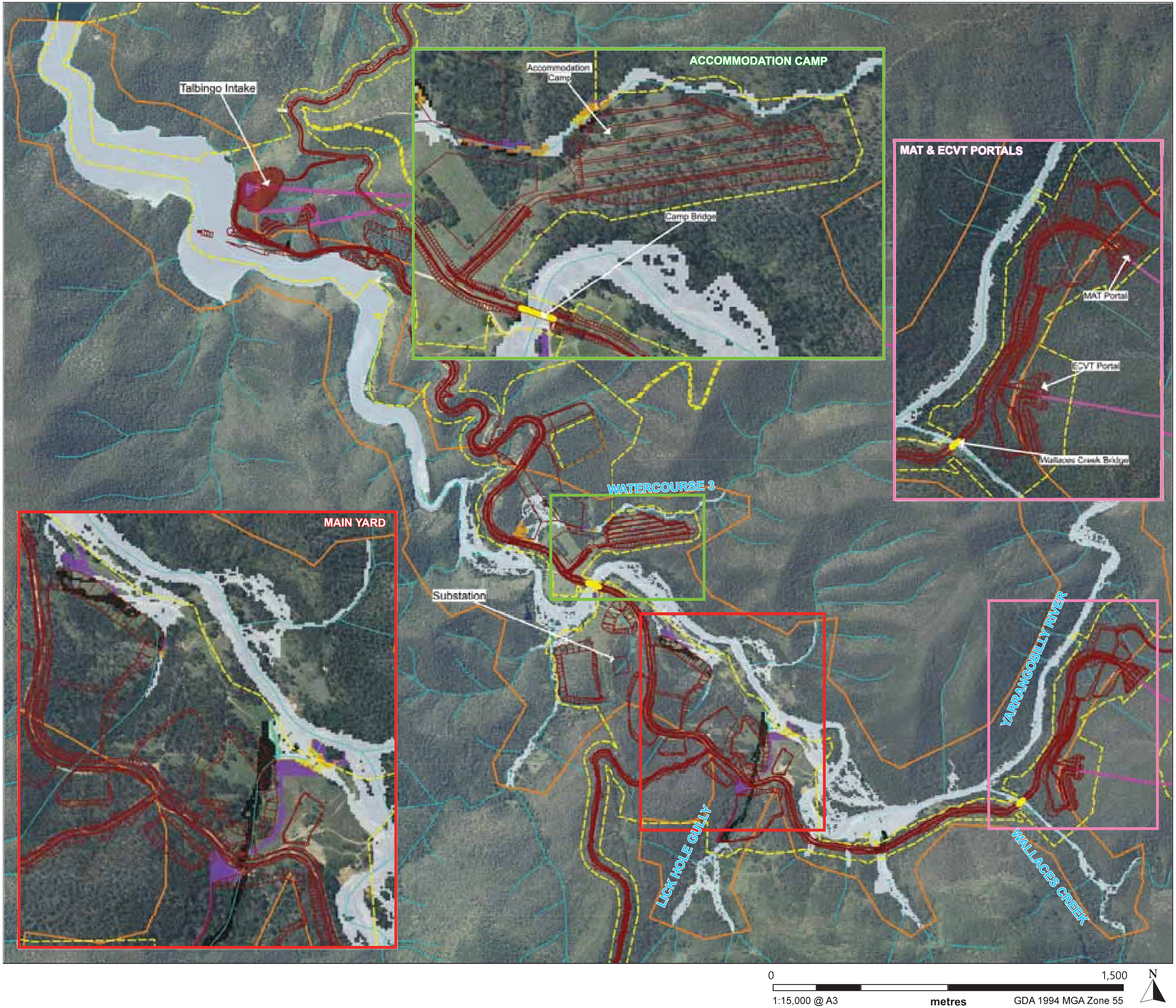
Proposed Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A24



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

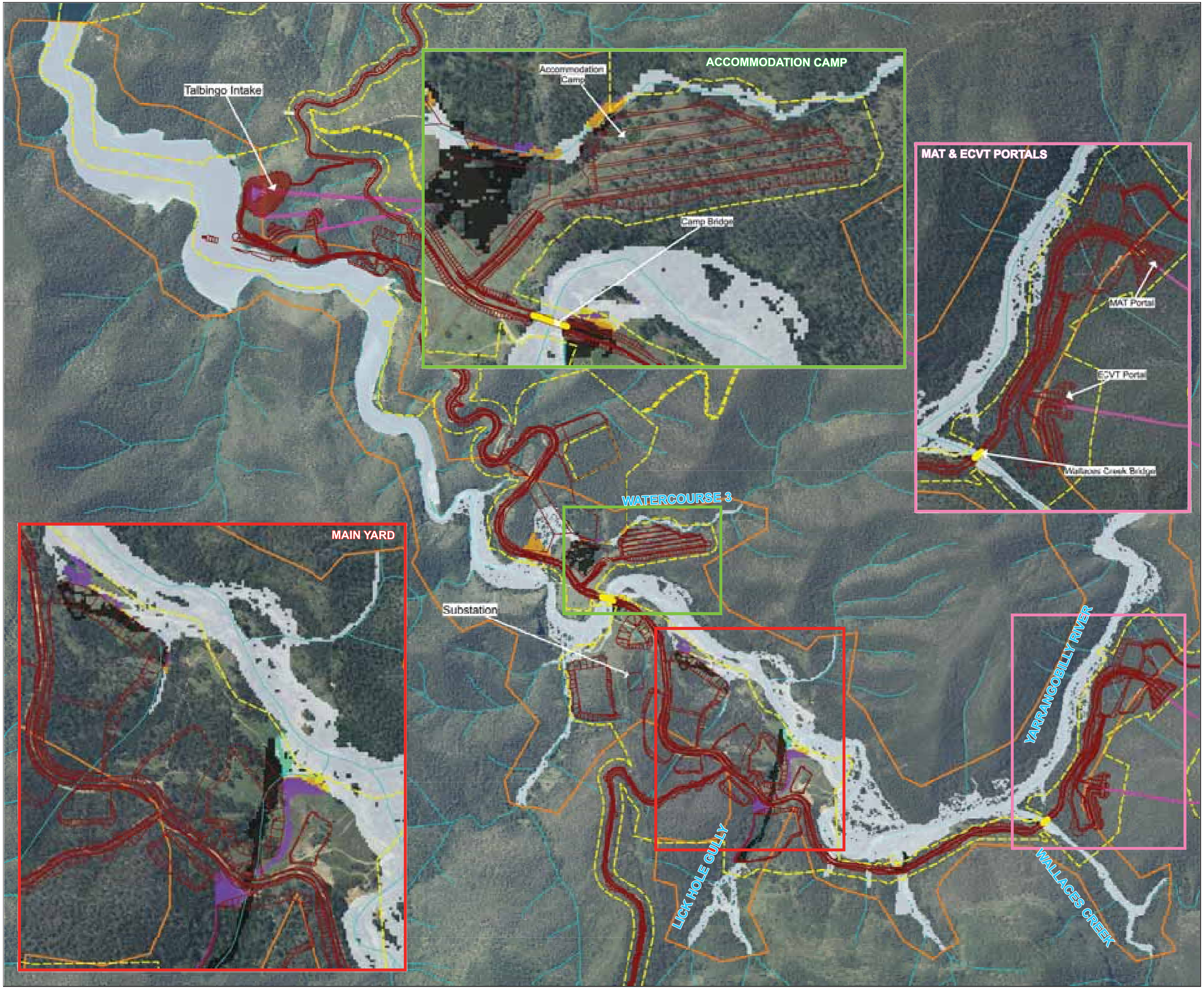
Water Level Difference (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- No Impact
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0
- Newly Flooded
- No Longer Flooded

NOTE:
This flood impact map presents the difference in peak flood level between Existing (pre-works) and Proposed (construction phase) Conditions

20% AEP Event -
Water Level Impacts
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A25



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

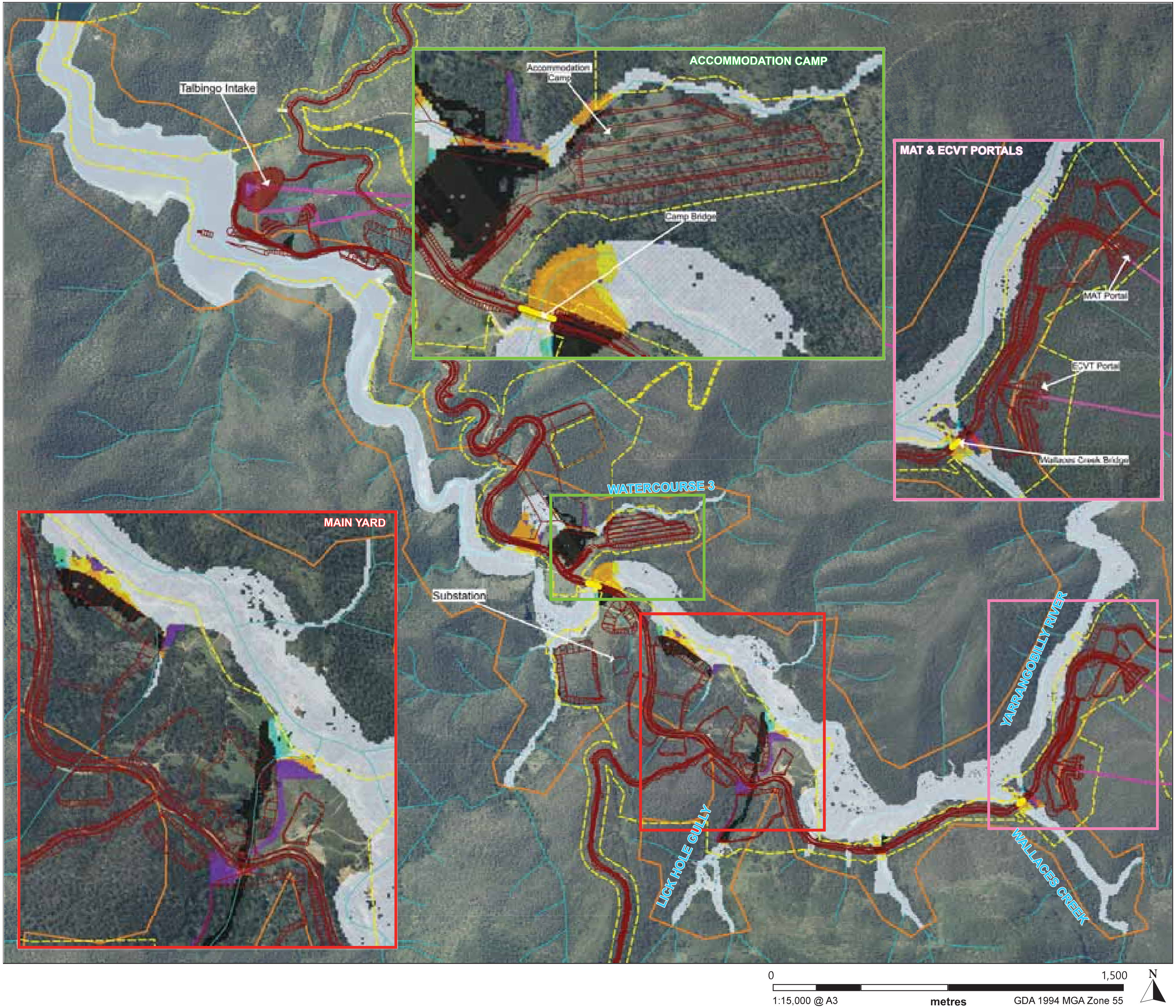
Water Level Difference (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- No Impact
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0
- Newly Flooded
- No Longer Flooded

NOTE:
This flood impact map presents the difference in peak flood level between Existing (pre-works) and Proposed (construction phase) Conditions

5% AEP Event -
Water Level Impacts
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A26



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

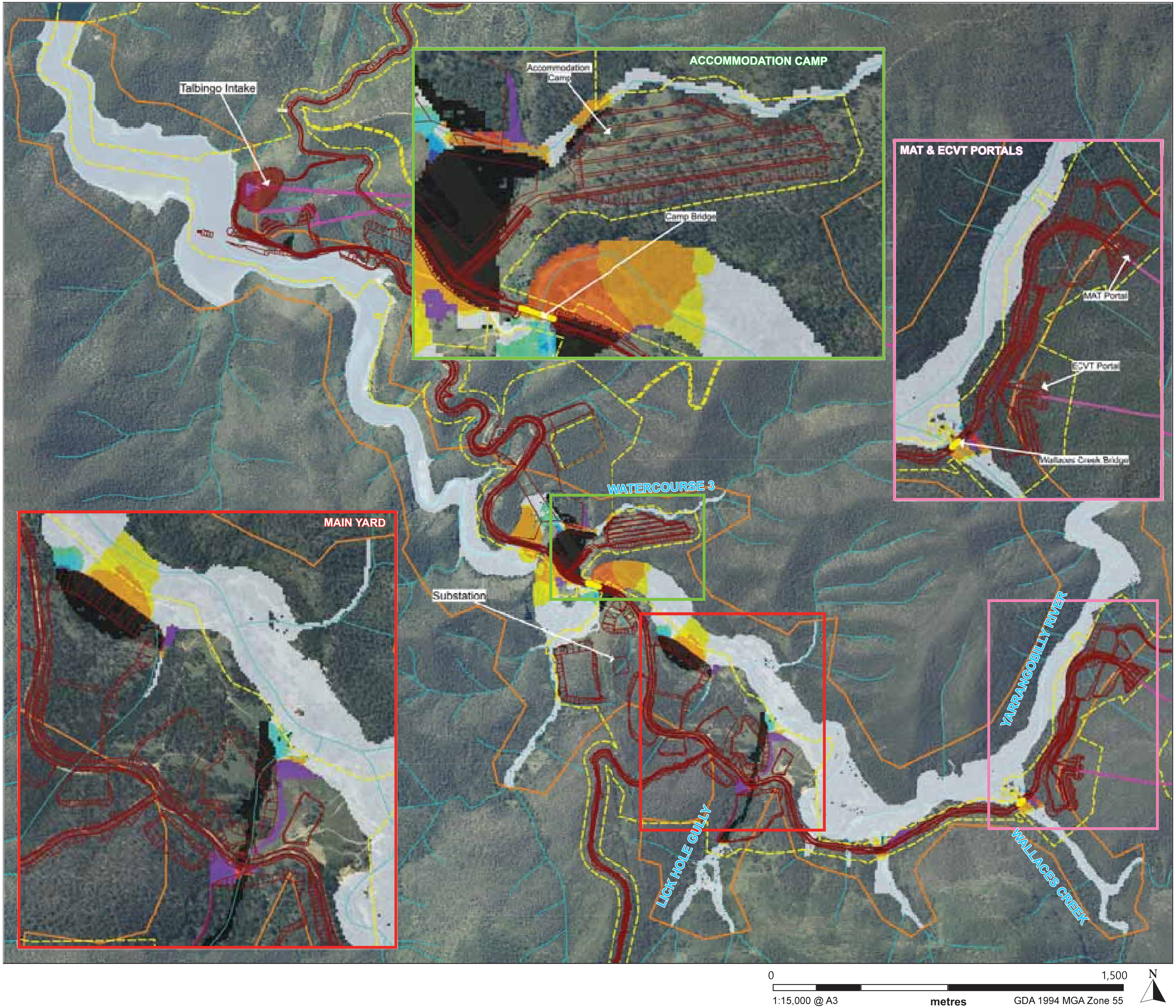
Water Level Difference (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- No Impact
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0
- Newly Flooded
- No Longer Flooded

NOTE:
This flood impact map presents the difference in peak flood level between Existing (pre-works) and Proposed (construction phase) Conditions

1% AEP Event -
Water Level Impacts
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A27



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

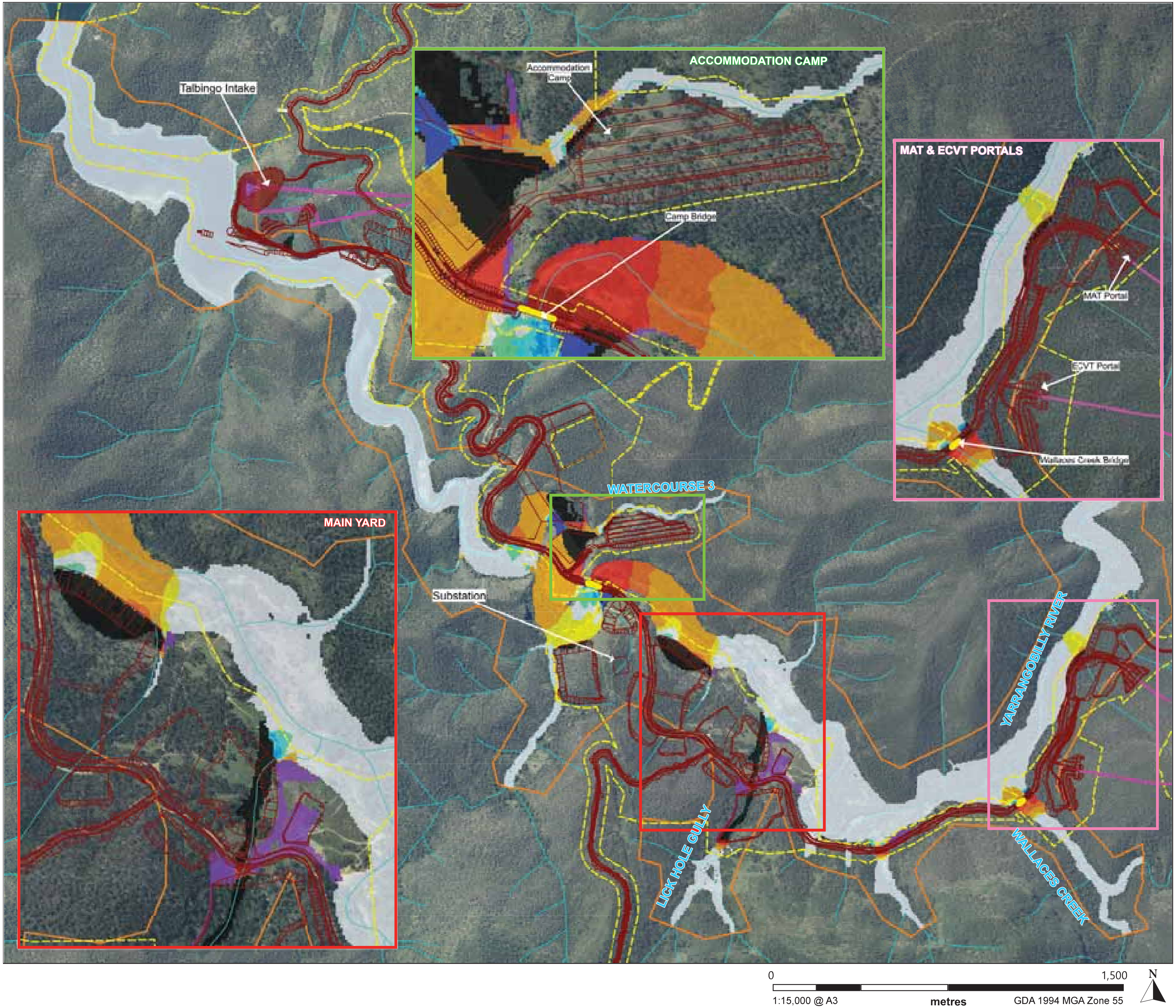
Water Level Difference (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- No Impact
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0
- Newly Flooded
- No Longer Flooded

NOTE:
This flood impact map presents the difference in peak flood level between Existing (pre-works) and Proposed (construction phase) Conditions

0.2% AEP Event - Water Level Impacts Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A28



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

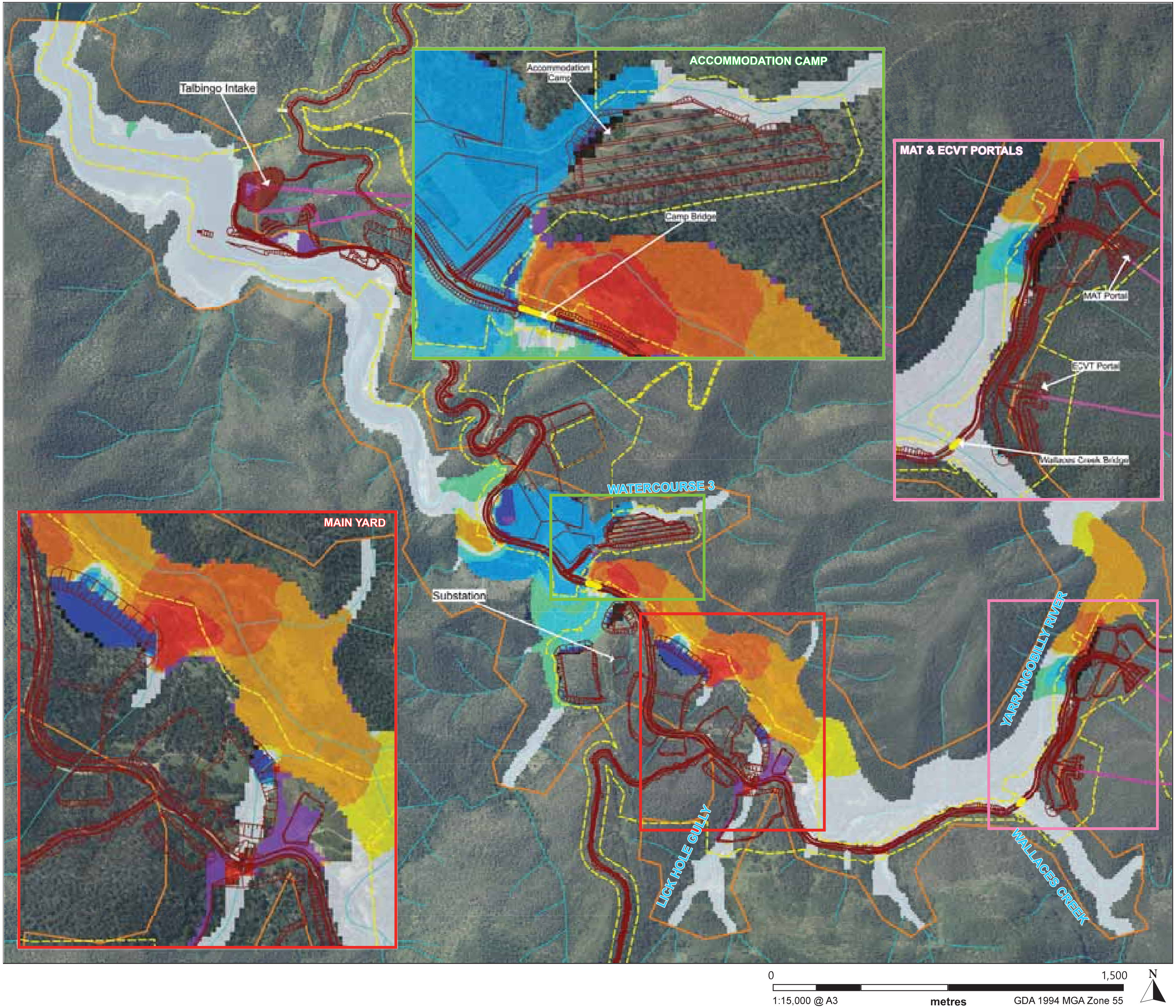
Water Level Difference (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- No Impact
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0
- Newly Flooded
- No Longer Flooded

NOTE:
This flood impact map presents the difference in peak flood level between Existing (pre-works) and Proposed (construction phase) Conditions

0.05% Event -
Water Level Impacts
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A29



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

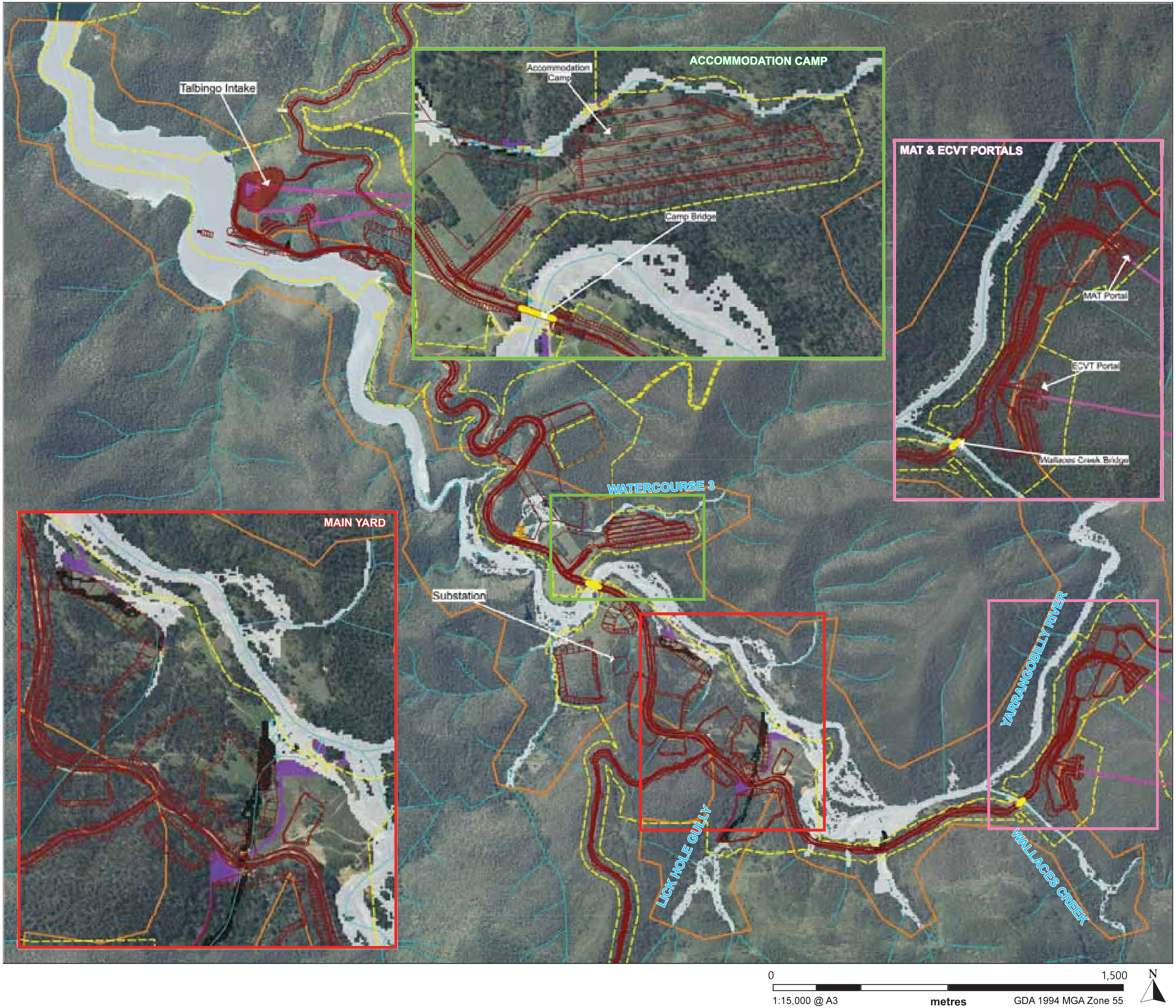
Water Level Difference (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- No Impact
- 0.05 to 0.1
- 0.1 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- > 5.0
- Newly Flooded
- No Longer Flooded

NOTE:
This flood impact map presents the difference in peak flood level between Existing (pre-works) and Proposed (construction phase) Conditions

PMF Event - Water Level Impacts Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A30



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Hazard Category Change

- Increased by more than 3 categories
- Increased by 2 category
- Increased by 1 category
- Same Category
- Decreased by 1 category
- Decreased by 2 category
- Decreased by more than 3 categories
- Newly Flooded
- No Longer Flooded

20% AEP Event -

Flood Hazard Impacts

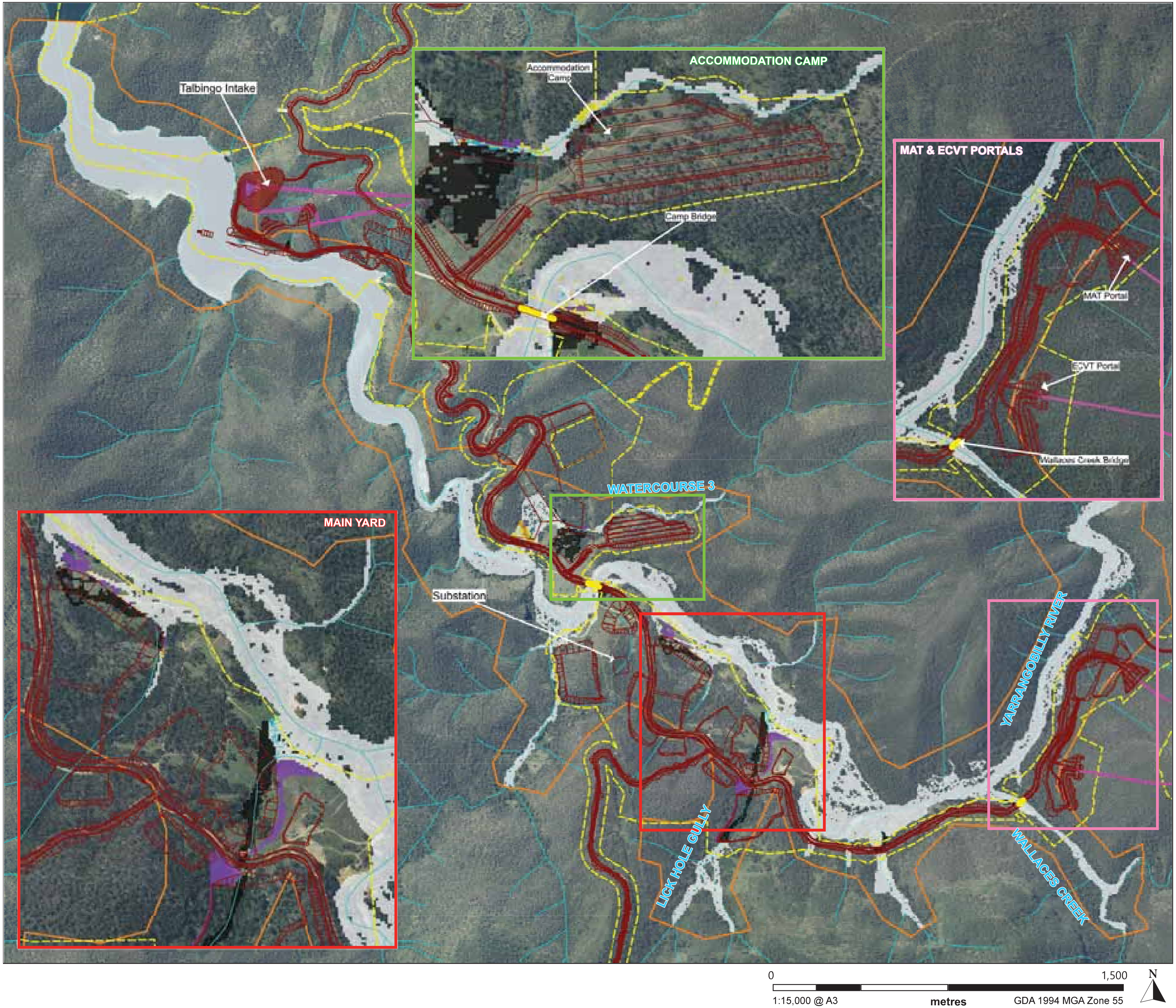
Proposed Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A31



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

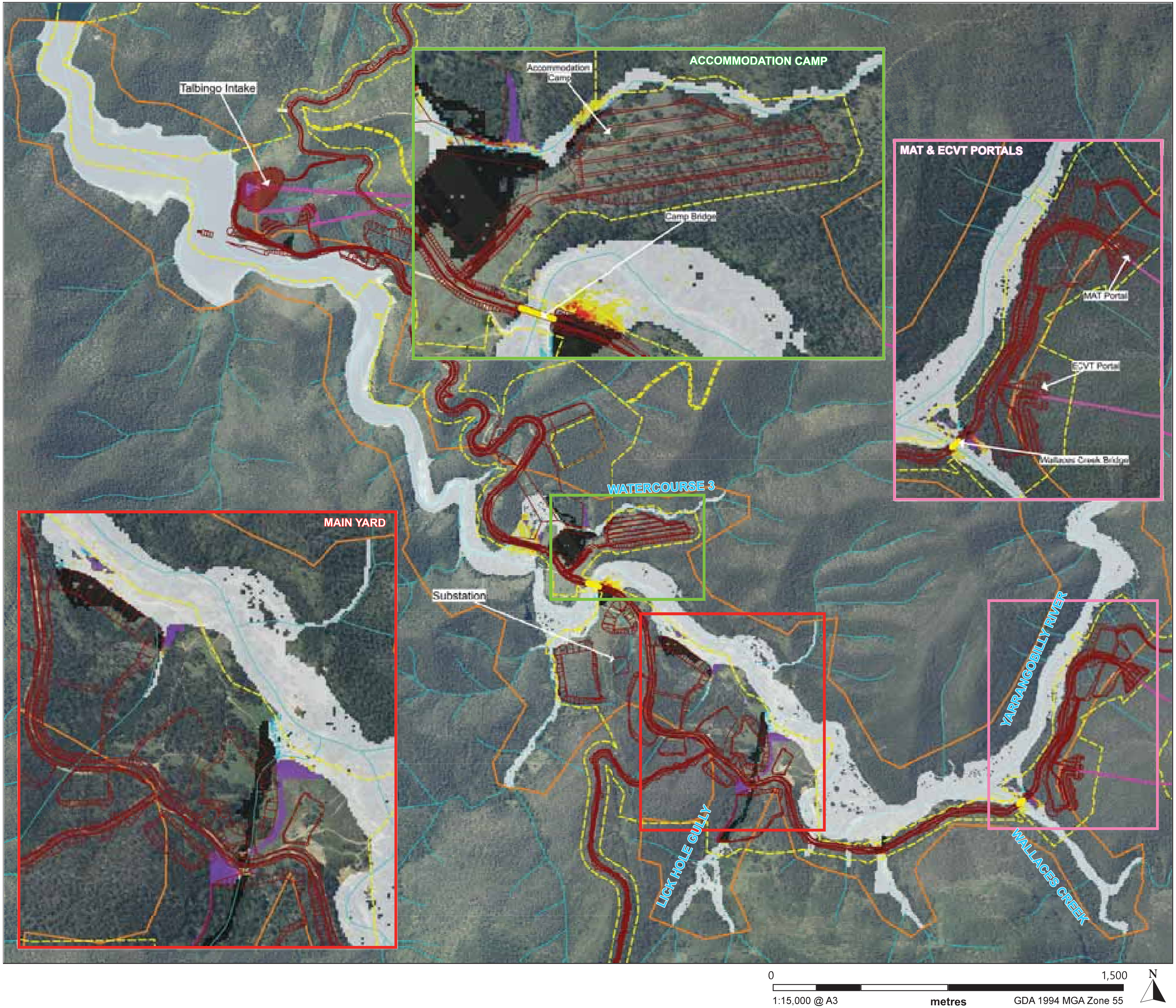
Hazard Category Change

- Increased by more than 3 categories
- Increased by 2 category
- Increased by 1 category
- Same Category
- Decreased by 1 category
- Decreased by 2 category
- Decreased by more than 3 categories
- Newly Flooded
- No Longer Flooded

5% AEP Event - Flood Hazard Impacts Proposed Conditions Lobs Hole

Snowy 2.0 Main Works Flood Study

Figure A32



KEY

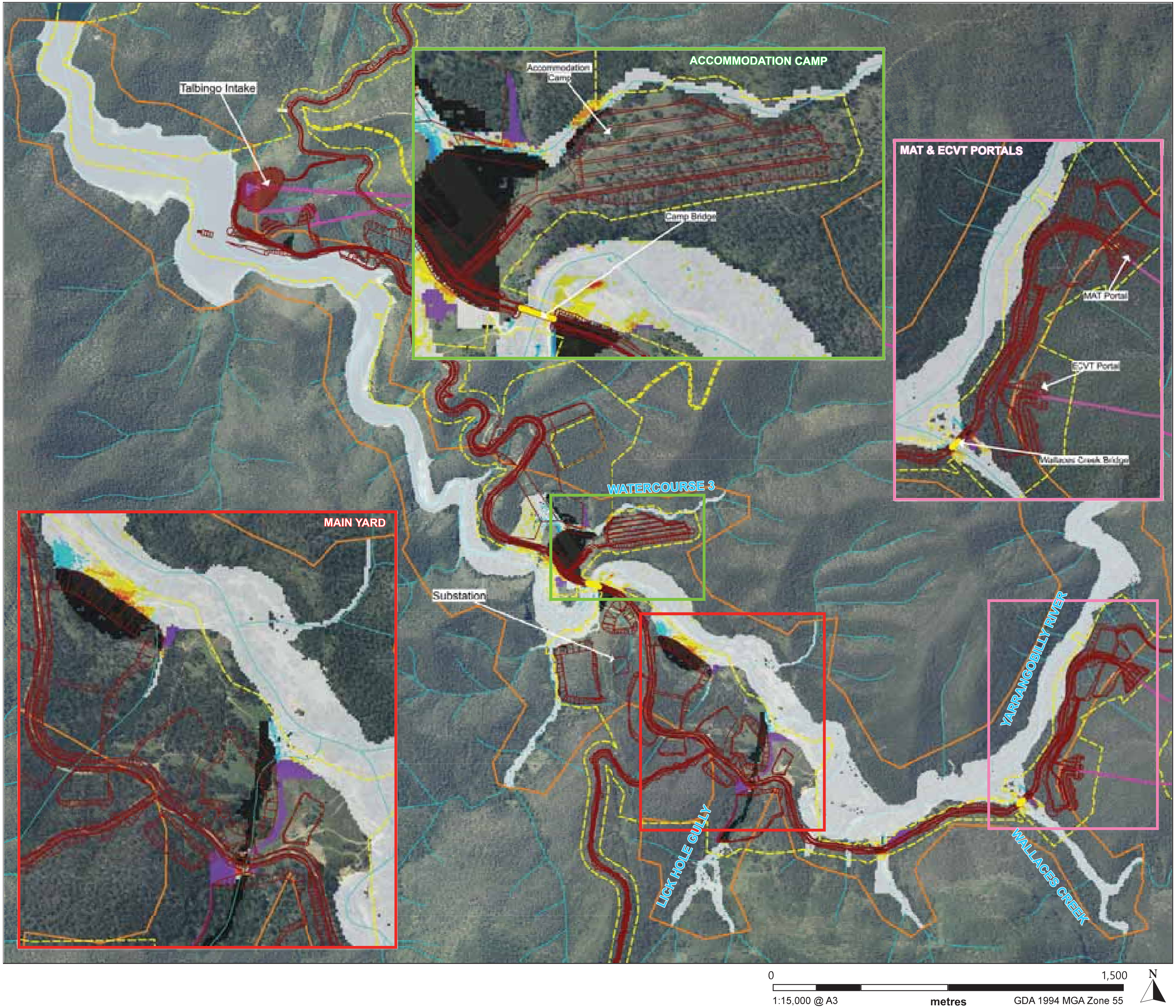
- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Hazard Category Change

- Increased by more than 3 categories
- Increased by 2 category
- Increased by 1 category
- Same Category
- Decreased by 1 category
- Decreased by 2 category
- Decreased by more than 3 categories
- Newly Flooded
- No Longer Flooded

1% AEP Event - Flood Hazard Impacts Proposed Conditions Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A33



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

Hazard Category Change

- Increased by more than 3 categories
- Increased by 2 category
- Increased by 1 category
- Same Category
- Decreased by 1 category
- Decreased by 2 category
- Decreased by more than 3 categories
- Newly Flooded
- No Longer Flooded

0.2% AEP Event -

Flood Hazard Impacts

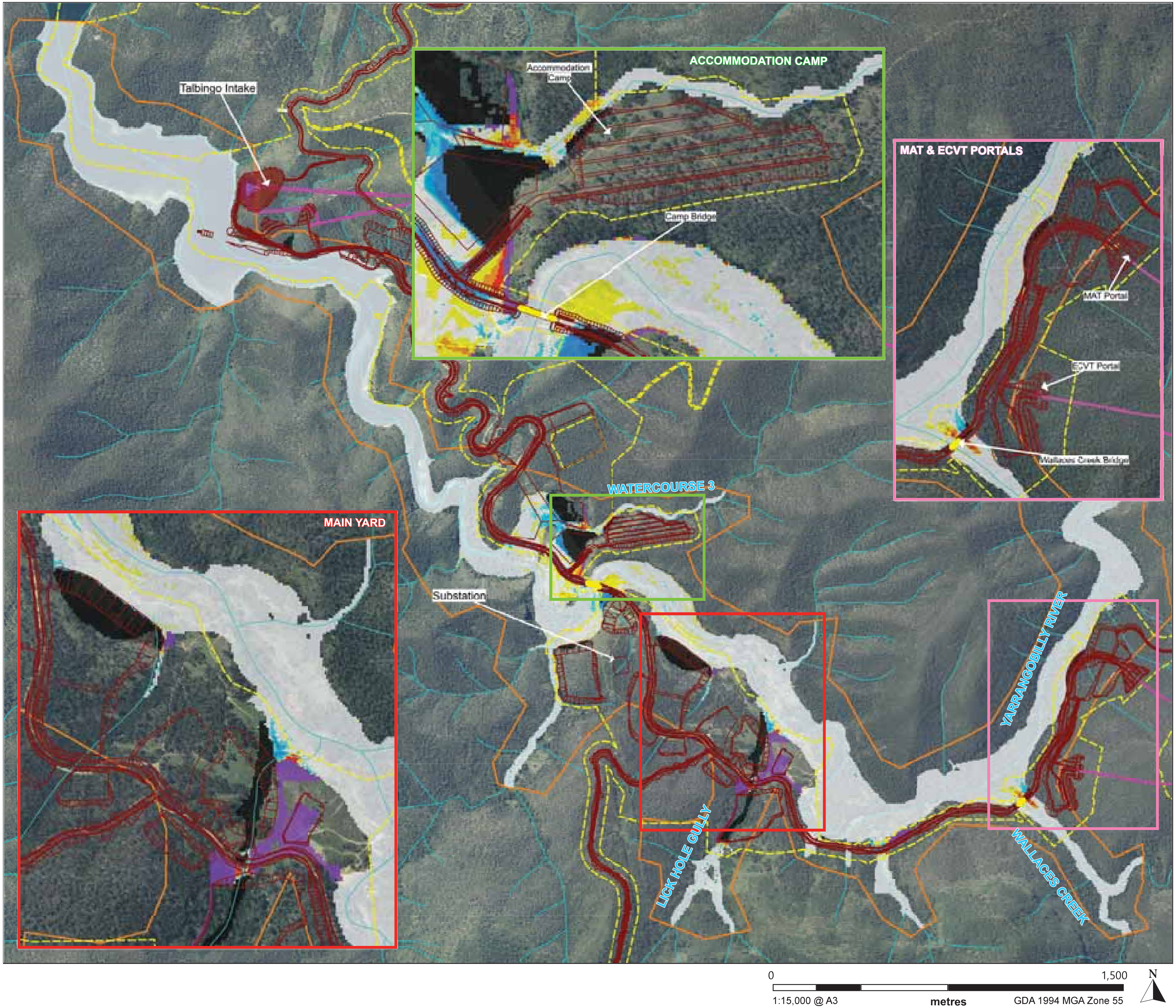
Proposed Conditions

Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A34



KEY

- Watercourse / Drainage Line
- Disturbance Area
- Model Extent
- Permanent Bridge
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

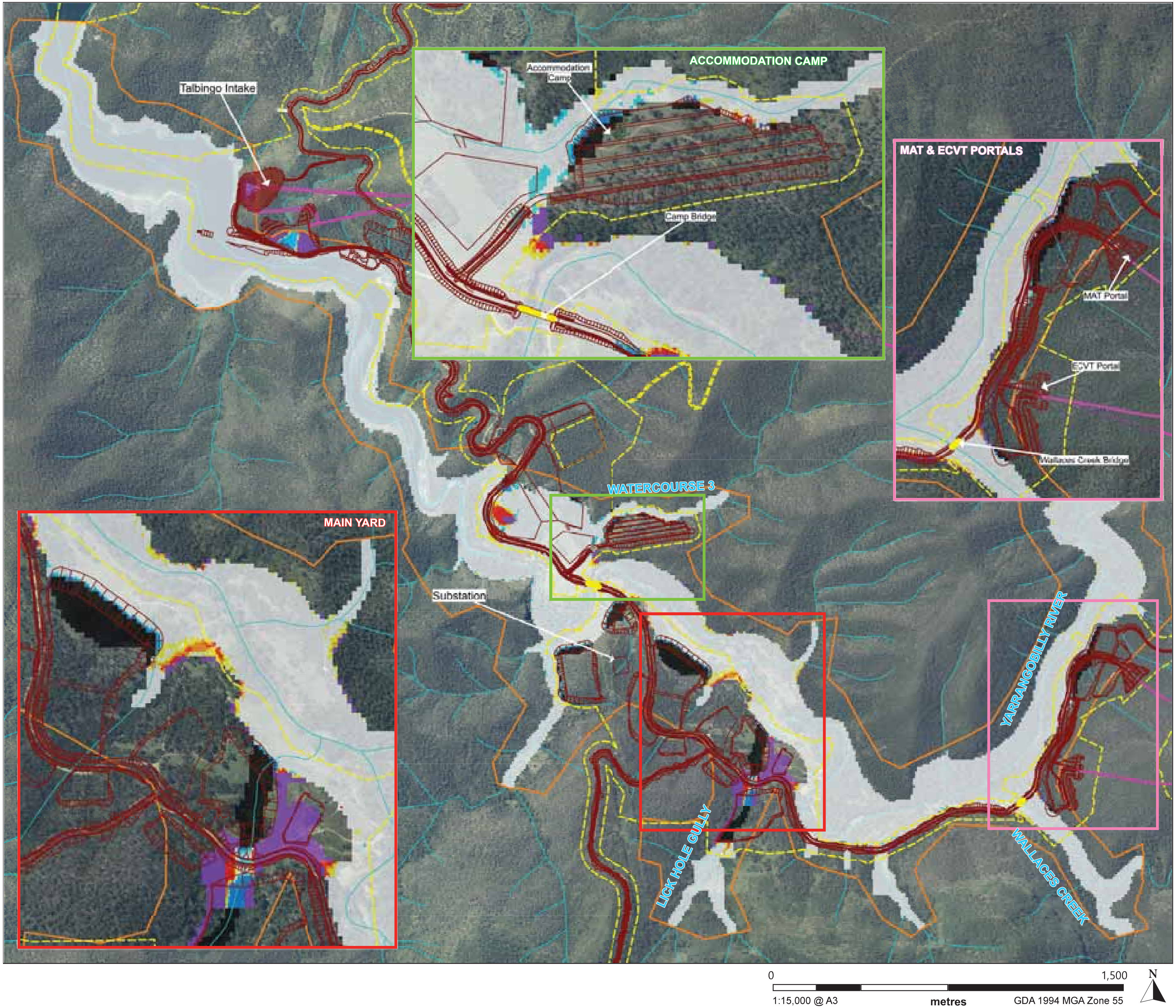
Hazard Category Change

- Increased by more than 3 categories
- Increased by 2 category
- Increased by 1 category
- Same Category
- Decreased by 1 category
- Decreased by 2 category
- Decreased by more than 3 categories
- Newly Flooded
- No Longer Flooded

0.05% AEP Event -
Flood Hazard Impacts
Proposed Conditions
Lobs Hole

Snowy 2.0 Main Works
Flood Study
Figure A35

snowyhydro renewable energy
EMM creating opportunities
grc HYDRO



PMF Event -

Flood Hazard Impacts

Proposed Conditions

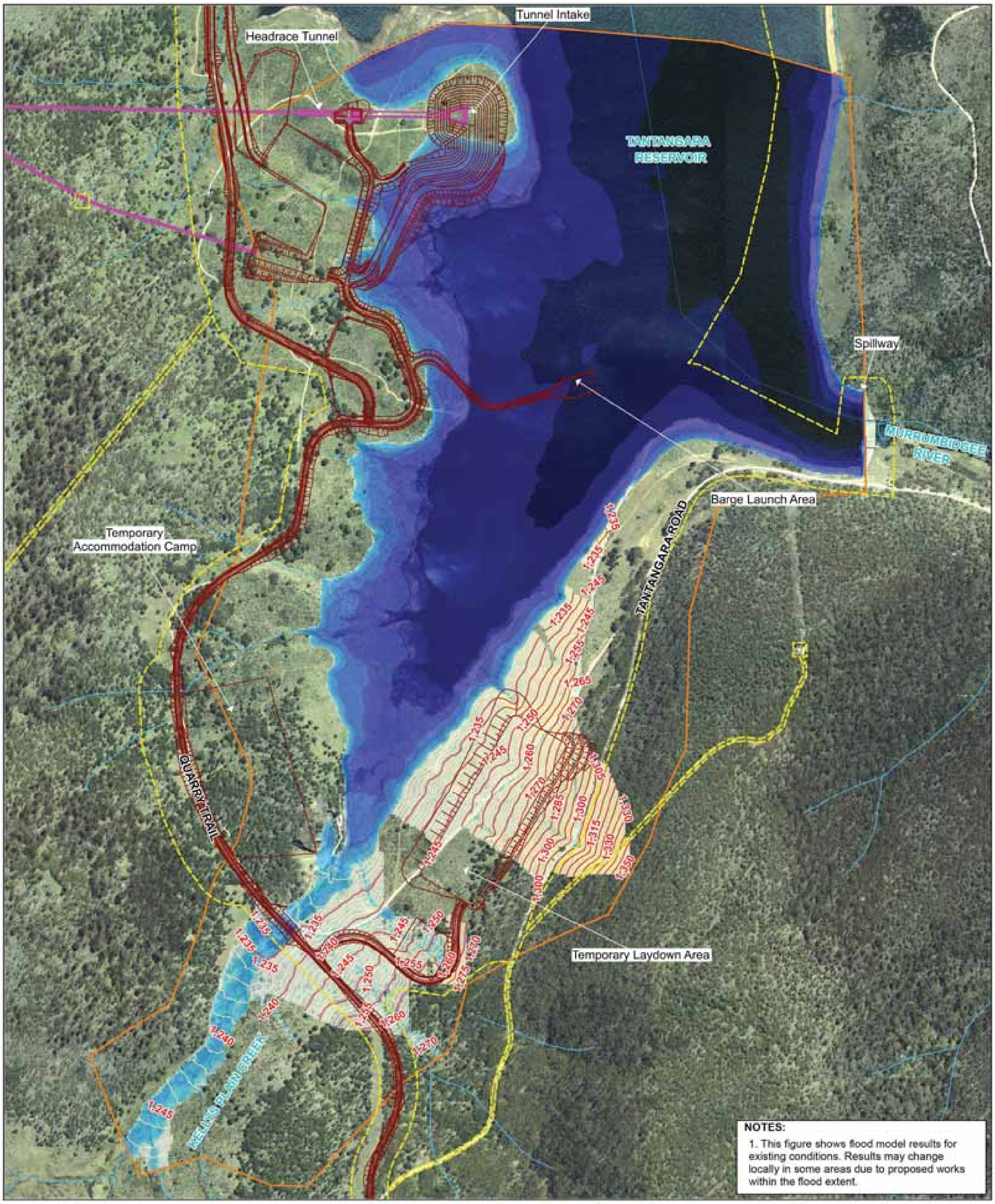
Lobs Hole

Snowy 2.0 Main Works

Flood Study

Figure A36

Appendix B:



KEY

Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Watercourses / Drainage Line
- Disturbance Area
- Model Extent
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements
- Major Flood Level Contour (5.0mAHD)
- Minor Flood Level Contour (1.0mAHD)

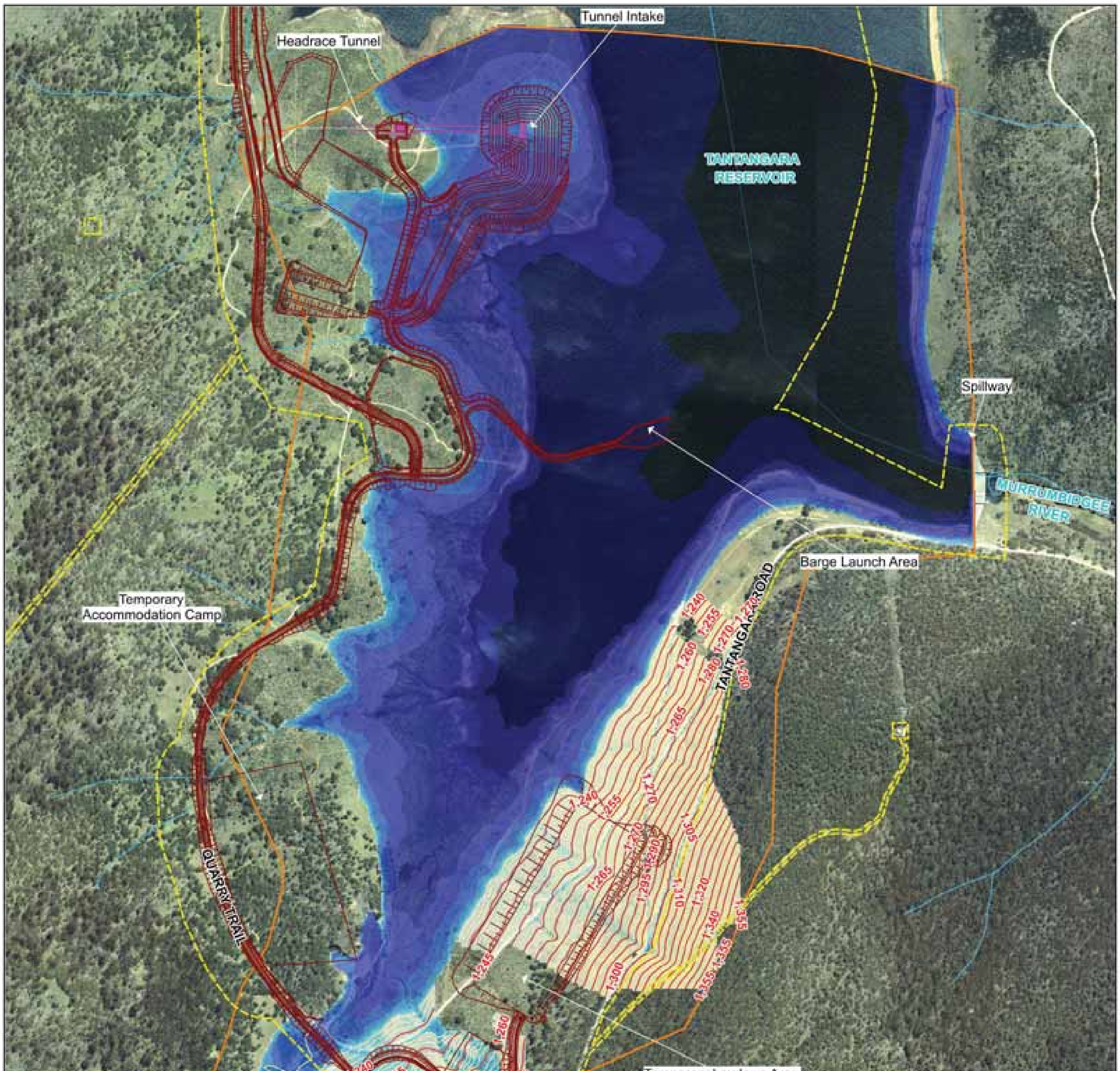
0 750

1:7,500 @ A3 meters

N

1% AEP Event - Peak Flood Depth and Level Existing Conditions Kellys Plain Creek

Snowy 2.0 Main Works
Flood Study
Figure B01



KEY

Flood Depth (m)

0.00 to 0.05	2.0 to 5.0
0.05 to 0.1	5.0 to 10.0
0.1 to 0.3	10.0 to 20.0
0.3 to 0.5	20.0 to 30.0
0.5 to 1.0	> 30.0
1.0 to 2.0	

- Watercourses / Drainage Line
- Disturbance Area
- Model Extent
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements
- Major Flood Level Contour (5.0mAHD)
- Minor Flood Level Contour (1.0mAHD)

0 750

1:7,500 @ A3 meters

N

PMF Event - Peak Flood Depth and Level Existing Conditions Kellys Plain Creek

snowy hydro renewable energy

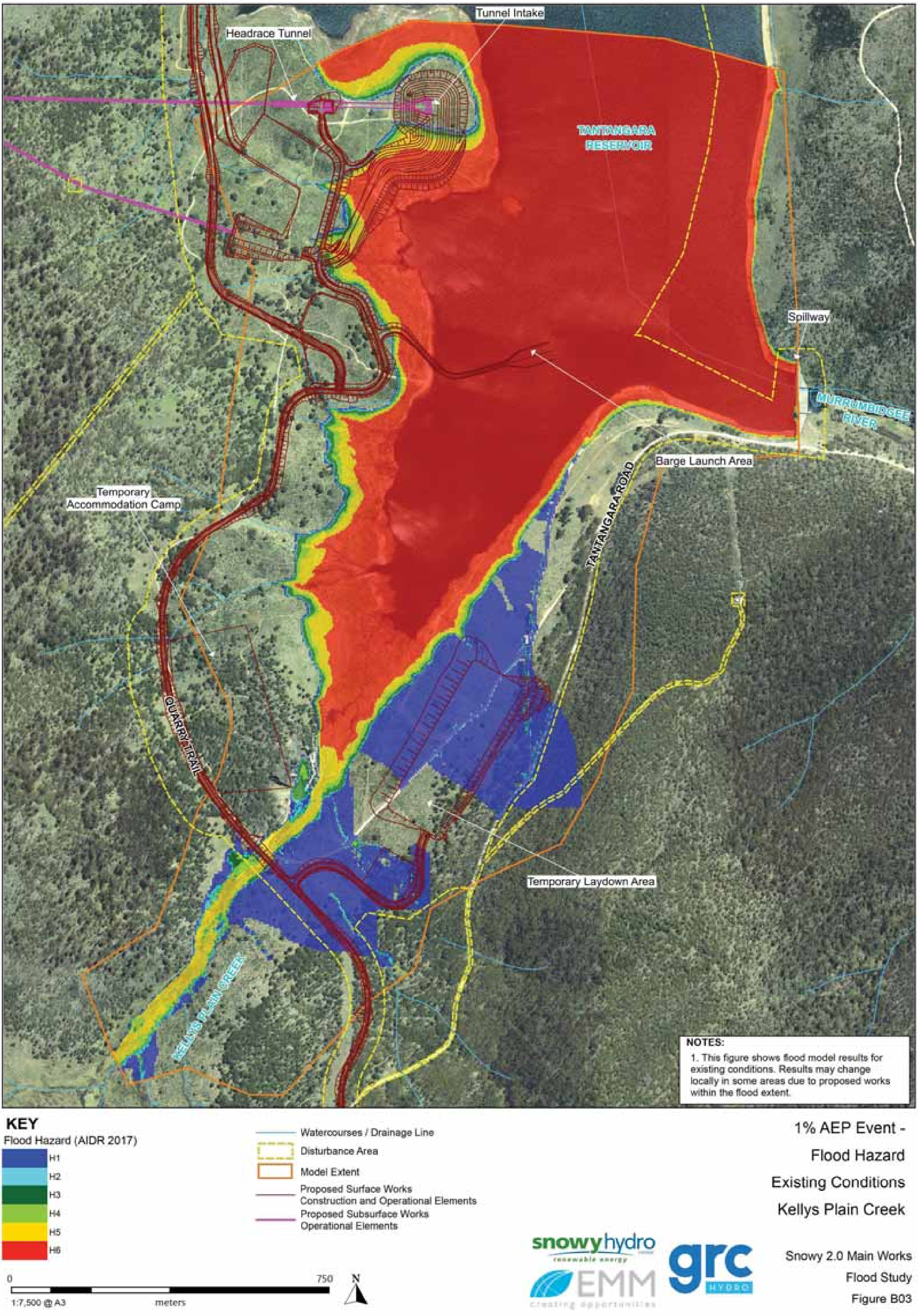
EMM creating opportunities

grc HYDRO

Snowy 2.0 Main Works

Flood Study

Figure B02



1% AEP Event -

Flood Hazard

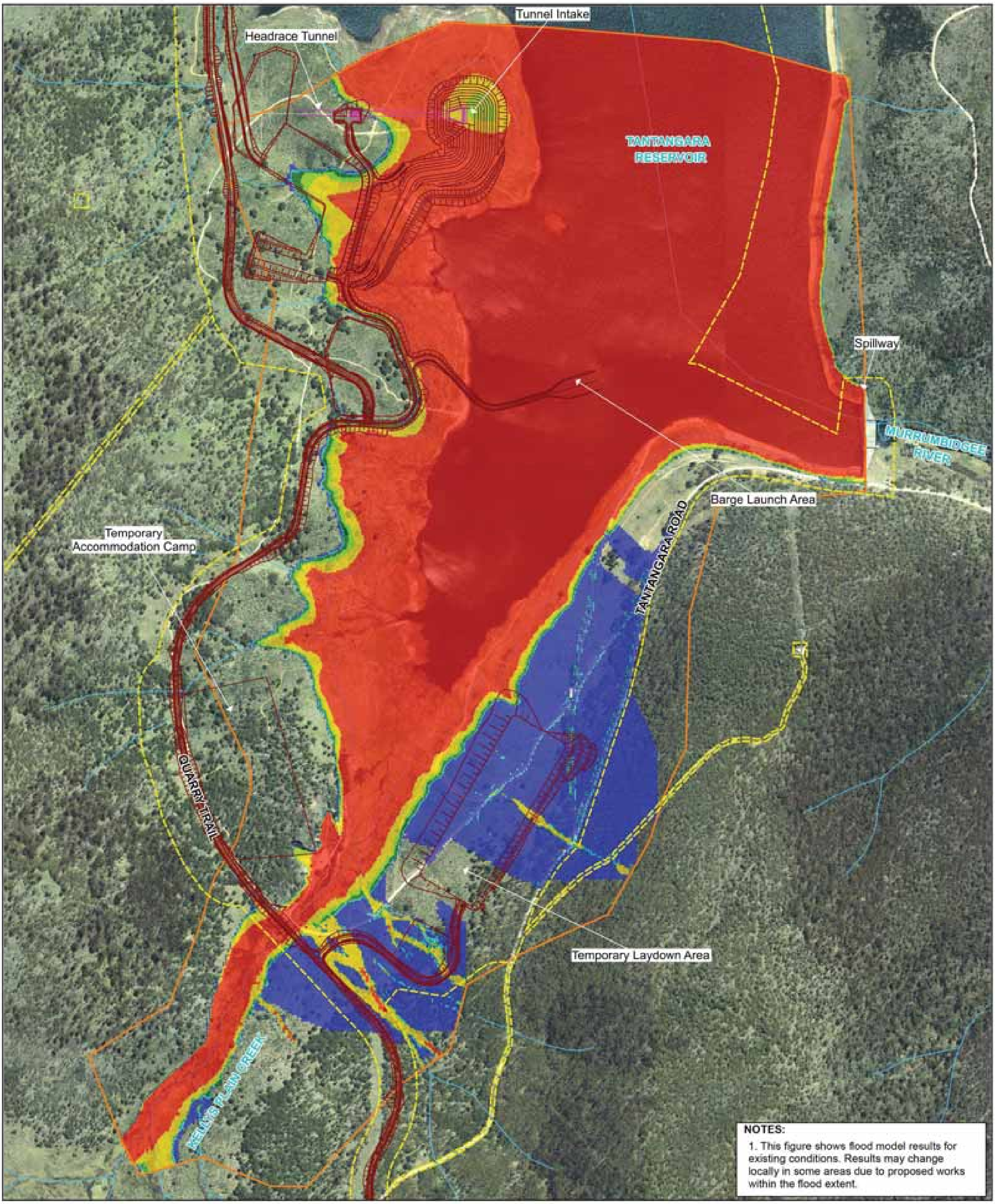
Existing Conditions

Kellys Plain Creek

Snowy 2.0 Main Works

Flood Study

Figure B03



NOTES:

1. This figure shows flood model results for existing conditions. Results may change locally in some areas due to proposed works within the flood extent.

KEY

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

- Watercourses / Drainage Line
- Disturbance Area
- Model Extent
- Proposed Surface Works Construction and Operational Elements
- Proposed Subsurface Works Operational Elements

0 750

1:7,500 @ A3 meters

PMF Event -

Flood Hazard

Existing Conditions

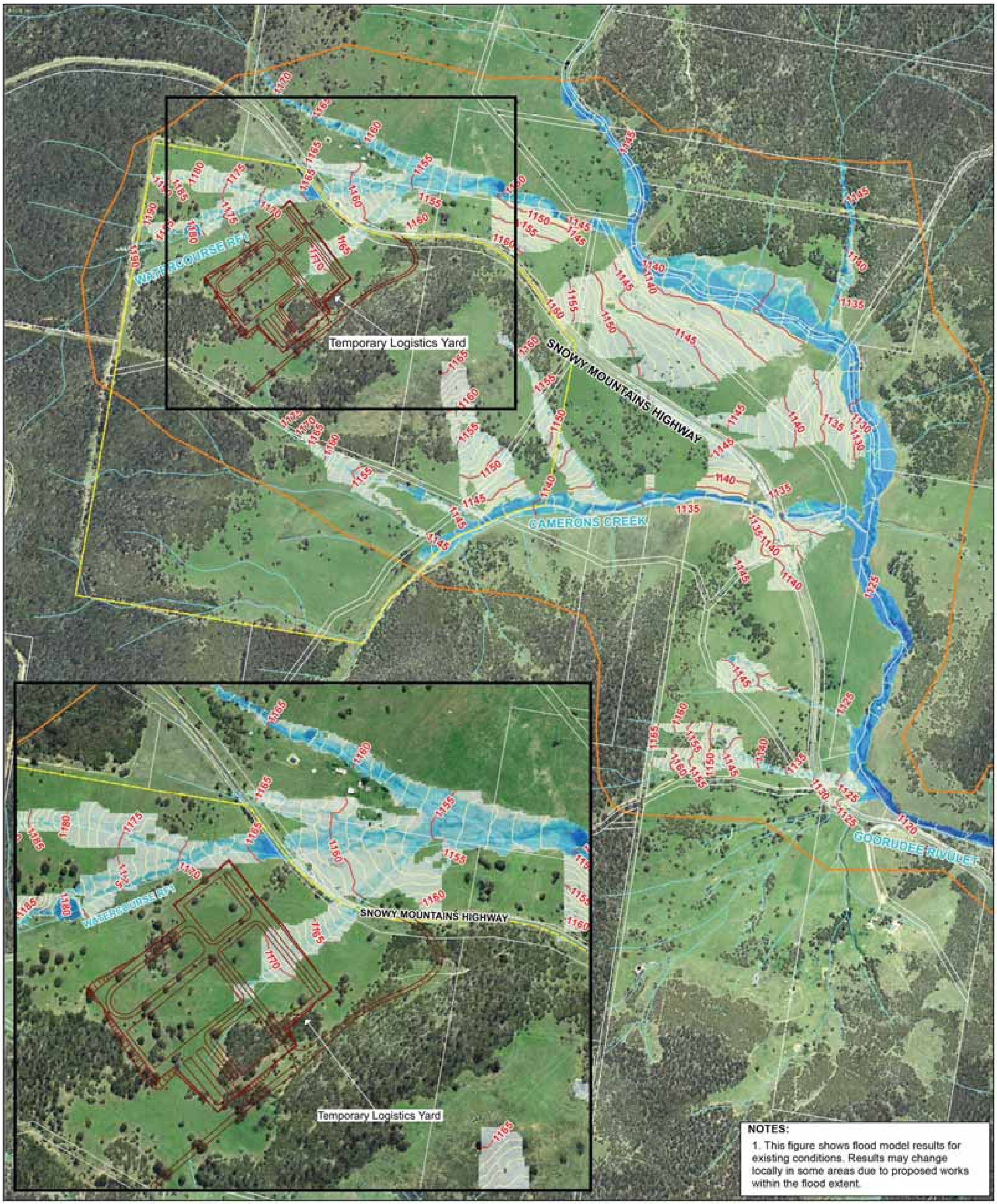
Kellys Plain Creek

Snowy 2.0 Main Works

Flood Study

Figure B04

Appendix C:



KEY

Flood Depth (m)

- 0.00 to 0.05
- 0.05 to 0.1
- 0.1 to 0.3
- 0.3 to 0.5
- 0.5 to 1.0
- 1.0 to 2.0
- 2.0 to 5.0
- 5.0 to 10.0
- 10.0 to 20.0
- 20.0 to 30.0
- > 30.0

- Watercourses / Drainage Line
- Disturbance Area
- Model Extent
- Cadastral Boundaries
- Proposed Surface Works Construction Elements
- Major Flood Level Contour (5.0mAHD)
- Minor Flood Level Contour (1.0mAHD)

0 1,250

1:12,500 @ A3 meters GDA 1994 MGA Zone 55

N

1% AEP Event -

Peak Flood Depth and Level

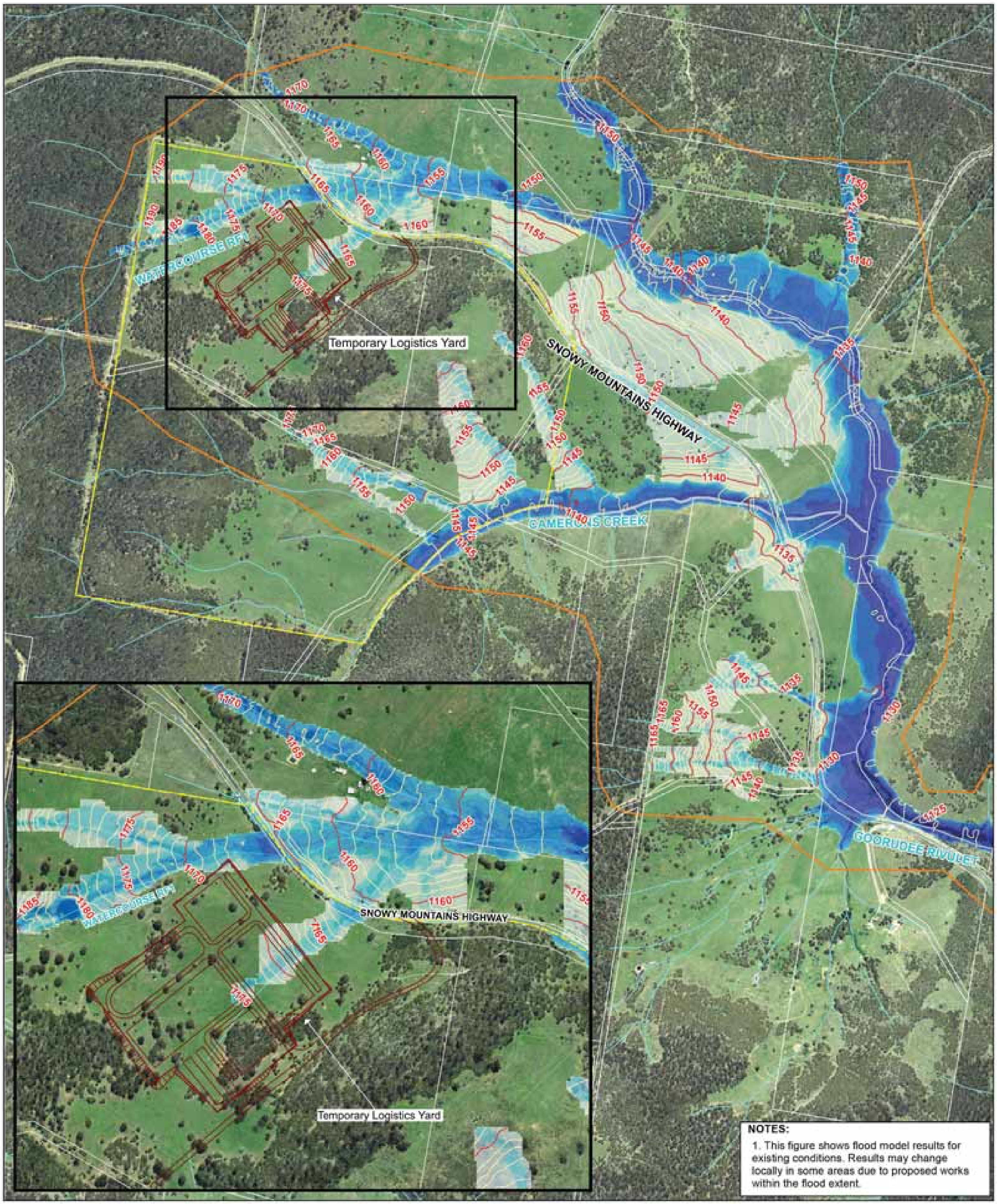
Existing Conditions

Rock Forest

Snowy 2.0 Main Works

Flood Study

Figure C01



KEY

Flood Depth (m)

0.00 to 0.05	2.0 to 5.0
0.05 to 0.1	5.0 to 10.0
0.1 to 0.3	10.0 to 20.0
0.3 to 0.5	20.0 to 30.0
0.5 to 1.0	> 30.0
1.0 to 2.0	

- Watercourses / Drainage Line
- Disturbance Area
- Model Extent
- Cadastral Boundaries
- Proposed Surface Works Construction Elements
- Major Flood Level Contour (5.0mAHD)
- Minor Flood Level Contour (1.0mAHD)

0 1,250

1:12,500 @ A3 meters GDA 1994 MGA Zone 55

N

PMF Event -

Peak Flood Depth and Level

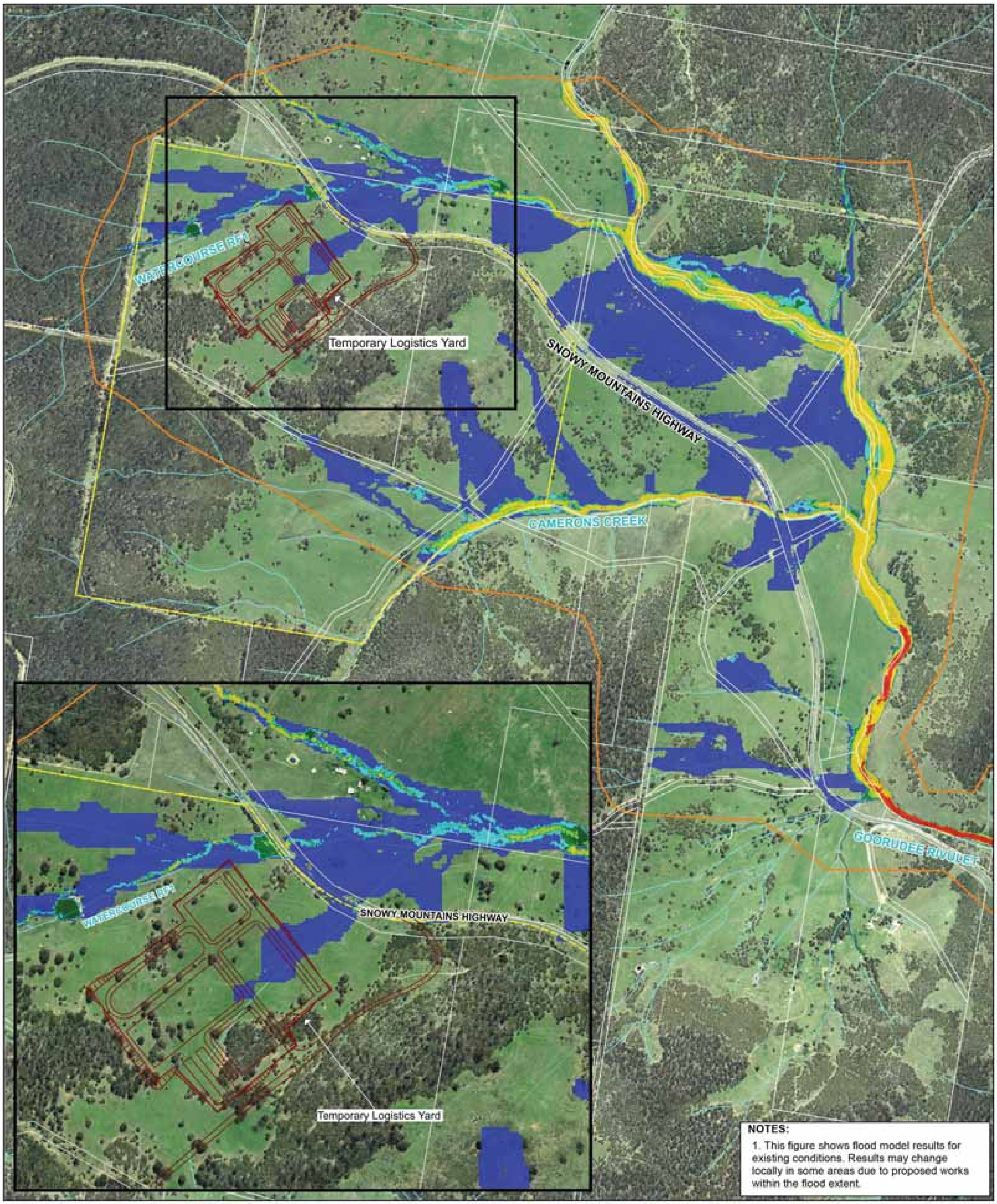
Existing Conditions

Rock Forest

Snowy 2.0 Main Works

Flood Study

Figure C02



KEY

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

- Watercourses / Drainage Line
- Disturbance Area
- Model Extent
- Cadastral Boundaries
- Proposed Surface Works Construction Elements

0 — 1,250

1:12,500 @ A3 — meters — GDA 1994 MGA Zone 55

N

1% AEP Event -

Flood Hazard

Existing Conditions

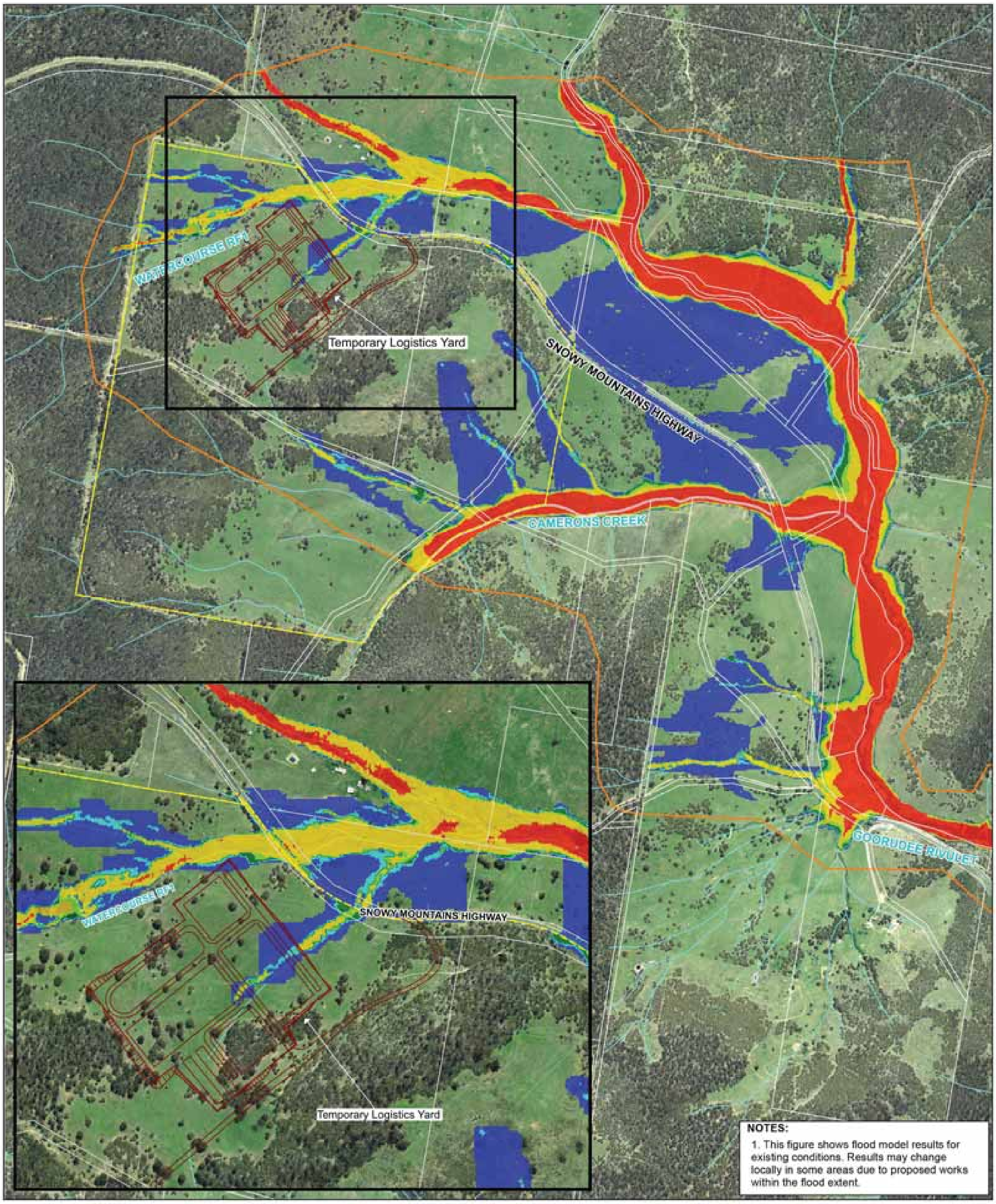
Rock Forest

snowy hydro renewable energy — EMM creating opportunities — grc HYDRO

Snowy 2.0 Main Works

Flood Study

Figure C03



NOTES:

1. This figure shows flood model results for existing conditions. Results may change locally in some areas due to proposed works within the flood extent.

KEY

Flood Hazard (AIDR 2017)

- H1
- H2
- H3
- H4
- H5
- H6

- Watercourses / Drainage Line
- Disturbance Area
- Model Extent
- Cadastral Boundaries
- Proposed Surface Works Construction Elements

0 1,250

1:12,500 @ A3 meters GDA 1994 MGA Zone 55

N

PMF Event - Flood Hazard Existing Conditions Rock Forest

snowy hydro renewable energy

EMM creating opportunities

grc HYDRO

Snowy 2.0 Main Works

Flood Study

Figure C04