APPENDIX I

GEODIVERSITY REVIEW

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To	Duncan Peake
From	Scott Lawson, Associate Hydrogeologist
Subject	–Exploratory Works - Geodiversity

1 Introduction

Geodiversity refers to the natural diversity of rocks, minerals, fossils, sediments and soils, and the processes that have shaped these features over time. This literature review and preliminary assessment has been undertaken to:

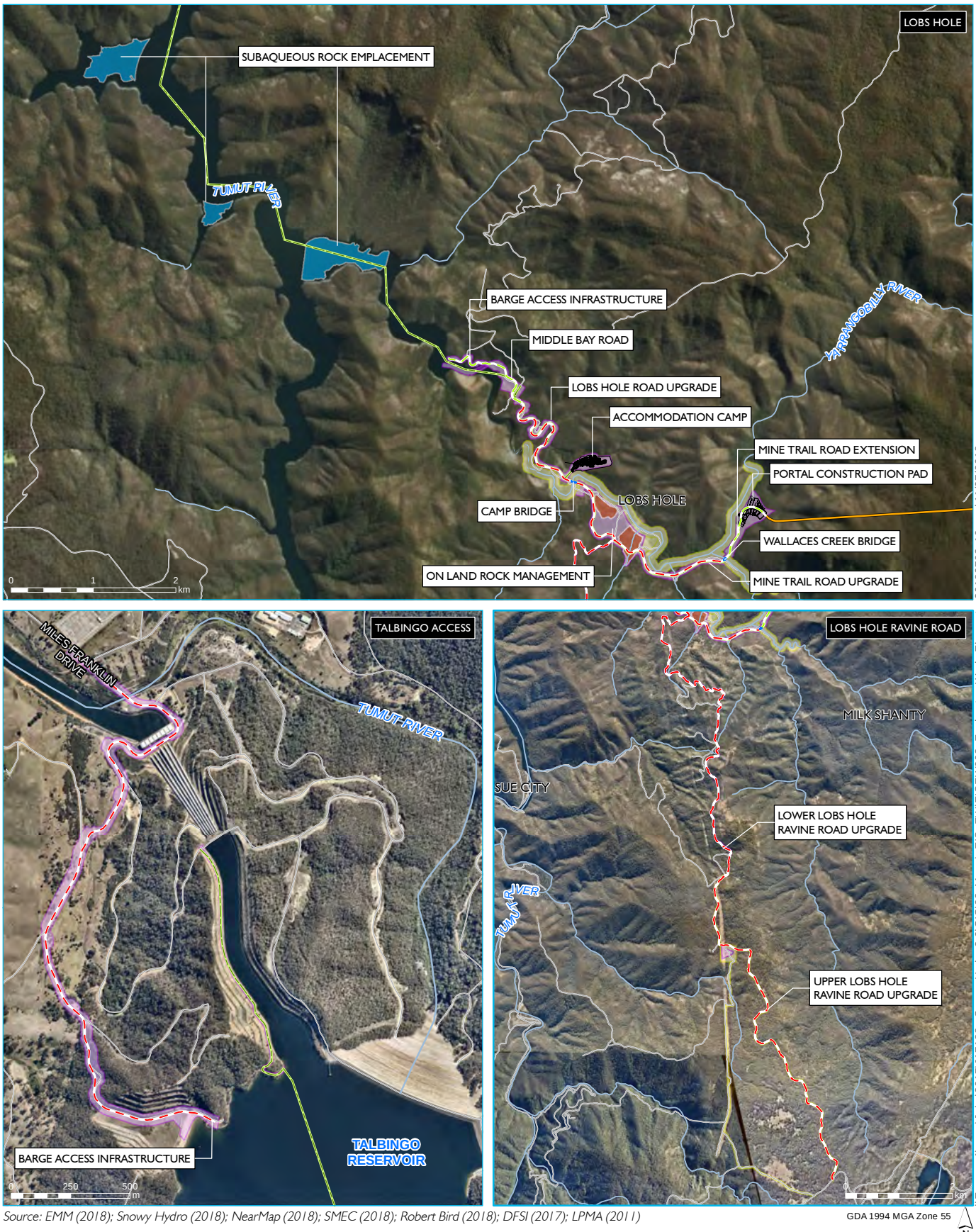
- identify significant geodiversity features of Kosciuszko National Park (KNP) within the area of Exploratory Works, and
- identify and evaluate the risks that Exploratory Works pose to identified geodiversity features.

The assessment has been informed by and aims to meet the requirements of the Kosciuszko National Park Plan of Management (KNP PoM) (DEC NSW 2006). The assessment has involved a literature review of relevant and available documentation, as well as geographic information system analysis and a visual site inspection to confirm the location and condition of geodiversity features relevant to Exploratory Works. It is noted that in line with the management objectives of the KNP PoM (section 6.3.1 of the KNP PoM), the site location of assessed geodiversity features has not been published in this report.

2 Overview of Exploratory Works

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

- establishment of an exploratory tunnel to the site of the underground power station for Snowy 2.0;
- horizontal and other test drilling, investigations and analysis in situ at the proposed cavern location and associated areas, and around the portal construction pad, access roads and excavated rock management areas all within the disturbance footprint;
- establishment of a portal construction pad for the exploratory tunnel;
- establishment of an accommodation camp for the Exploratory Works construction workforce;
- road works and upgrades providing access and haulage routes during Exploratory Works;



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

GDA 1994 MGA Zone 55

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KEY

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

Exploratory Works elements

Snowy 2.0
Geodiversity
Exploratory Works
Figure 1

snowy 2.0 EMM

- establishment of barge access infrastructure, to enable access and transport by barge on Talbingo reservoir;
- excavated rock management, including subaqueous placement within Talbingo Reservoir;
- establishment of services infrastructure such as diesel-generated power, water and communications; and
- post-construction revegetation and rehabilitation, management and monitoring.

3 Geodiversity values of Kosciuszko National Park

3.1 Literature review

3.1.1 Kosciuszko National Park Plan of Management

Kosciuszko National Park (KNP) contains the highest mountains on the Australian continent, unique glacial landscapes, and unusual assemblages of plants and animals, a number of which are found nowhere else. It also encompasses significant water catchments, the principal seasonally snow-covered region in Australia, and extensive tracts of forest and woodland in the most densely populated corner of the nation (DEC NSW 2006).

An Independent Scientific Committee (ISC) was formed as part of a review process for the KNP PoM which was announced in 2001. The ISC was tasked with providing independent and objective advice on the values of KNP, which was ultimately documented in a report to NSW National Parks and Wildlife Service (NPWS) (NPWS 2004). The information was used to provide key findings and recommendations that should be adopted in a revised plan. The revised plan was finalised in 2006.

The KNP PoM has been prepared under the *NSW National Parks and Wildlife Act 1974* to provide a framework of objectives, principles and policies to guide the long-term management of the broad range of values contained in the park. This framework is translated into a suite of specific actions to be undertaken by the NPWS and other organisations during the life of this plan.

The plan contains a set of actions concerning the management of the geodiversity (non-living components) and biodiversity (all living things) of the park. Actions for managing geodiversity include developing a geodiversity conservation strategy aimed at protecting all rocks, landforms and soils at risk of disturbance. A number of these actions have since been implemented, including the preparation and implementation of the *KNP Geodiversity Action Plan 2012-2017* (KGAP) which came into effect in 2012 (see Section 2.1.2).

Management objectives in the KNP PoM relating to geodiversity have been developed for both 'Rocks and Landform' and 'Karst' categories. Relevant objectives and their actions are listed in Table 1.

Table 1 KNP PoM management objectives relevant to Exploratory Works

Management Objective	Policies and actions
Rocks and Landform	
6.3.1: The rocks, landforms and geological processes of the park are protected and, where necessary, managed within the bounds of acceptable limits of disturbance.	1. Provide maximum protection to rocks, landforms and geological processes that are of national significance and sensitive to disturbance by current human activities. This will include items listed in Schedule 1. Such places will not be publicised or promoted unless management regimes are in place to protect them from likely damage associated with increased visitation.
6.3.2: Rehabilitation and construction works are undertaken in ways that protect significant rocks, landforms and geological processes.	1. Prohibit developments likely to significantly impact on the integrity of geodiversity features of national significance. 2. Assess potential impacts on geodiversity values as part of the approval process for proposed developments or activities, including restoration works. 3. Undertake the rehabilitation of disturbed sites in accordance with Section 11.2 (of the KNP PoM).
Karst	
6.4.1: The quality and quantity of air and water movement through the surface and subterranean environments of karst areas are maintained within the bounds of natural variability.	8. Minimise the use of earth-moving machinery in karst catchments. 9. Minimise surface and groundwater pollution within karst catchments.
6.4.2: Impacts associated with visitation to karst areas and features are managed within acceptable limits of disturbance.	2. Minimise adverse impacts of road drainage structures and materials used for roadworks and car parks in karst areas.

3.1.2 Kosciuszko National Park geodiversity action plan

The KGAP was prepared in response to the issues and conservation strategies for geological and geomorphological features, as outlined in the KNP PoM. The KGAP went into effect in July 2012 and outlines the condition and threats to condition of key landforms, karst areas, rocks, minerals, fossils and soils within KNP. The focus of the KGAP is to guide the Office of Environment and Heritage (OEH) on how to better protect, conserve and promote the key features in the park (OEH, 2012), and to identify a range of actions for protecting, conserving and promoting these features to park visitors.

3.1.3 Kosciuszko National Park geodiversity monitoring program

The KNP geodiversity monitoring program (KGMP) responds to the actions identified in the KGAP and outlines the methods and timeframes for the features listed.

The basis for monitoring is to improve understanding of the condition and pressures, evaluate how well management is undertaken against objectives and outcomes, inform planning and decision-making at all levels of management, assist in the allocation of funding and resources and support effective communication of our management performance.

Monitoring is primarily performed through rapid condition assessments, which involve a visual assessment of the feature to identify individual features and derive a general assessment of condition against predetermined criteria (DEC NSW 2006). Other forms of monitoring are to be performed through photo-monitoring, remote sensing, or from visitor data and trip reports.

3.2 Sites or features within the Exploratory Works project area

3.2.1 Periglacial landforms

The Pleistocene glacial landforms in KNP are the only examples of this landform on the mainland of Australia and are of national and international significance (OEH 2012). Periglacial features of the park include terracing, solifluction lobes, sliding and shattered boulders and block streams (also known as scree slopes or boulder streams). Periglacial features are more extensive than glacial features in KNP, considered to be widespread across the KNP. Periglacial evidence can be found in most areas above 1,000 m and possibly as far down as 600 m.

Block streams (or scree slopes) are listed under 'Rocks and Landforms' in Schedule 1 (Significant Natural and Cultural Features) of the KNP PoM. They are defined as a 'river' or field of rocks that has moved downhill in mass and which was held together by ice, and occur in various areas of KNP, including the Exploratory Works project area, where they occur along a section of Lobs Hole Ravine Road. The block stream at this location is dated to about 20,000 years ago. Rapid condition assessments are assigned to the Ravine block stream every three years, in accordance with the KGAP. This is the only periglacial feature in the project area listed in the KGAP.

3.2.2 Karst areas

Karst formations, being landforms produced by the action of natural waters on soluble rocks (most commonly, limestone and dolomite) occur in various areas of KNP, and are well known and visited in the Yarrangobilly area. Eight karst areas are identified in the KNP PoM, recognised as areas of local, regional, state or national significance. Each of the areas has distinctive characteristics in terms of topographic setting, broad vegetation type, degree of karstification and degree of karst hydrological integration. Three karst areas are in the vicinity of Exploratory Works. They are:

- Cooleman Plain karst area, about 10 km north of Tantangara Reservoir and 25 km north east of the exploratory tunnel;
- Yarrangobilly karst area (which includes Yarrangobilly Caves), about 6.5 km north of the Snowy 2.0 main tunnel and 8.5 km north east of the exploratory tunnel; and
- Ravine karst area, the area surrounding Lobs Hole Ravine Road about 1 km south of the exploratory tunnel portal.

A groundwater assessment carried out for Exploratory Works considered Yarrangobilly Caves, a well visited geodiversity site that is also a groundwater dependent ecosystem. The assessment concluded that there would be no impact to the caves as a result of Exploratory Works. The Ravine karst area is the only karst area relevant to Exploratory Works.

There are numerous occurrences of limestone at Ravine, however it is mostly thinly-bedded, flaggy or impure (DEC NSW 2006). This includes limestone in this area of Exploratory Works, which occurs as a component of the Lick Hole Formation.

The karst significance of Ravine appears to reside entirely in the massive tufa deposits (see below) and caves. The KNP PoM suggests that the tufa deposits and fossil sequence at Ravine are considered to have national or regional significance (DEC NSW 2006), preserving records of vegetation and climate change.

Ravine Basin Devonian sediments

The Devonian strata may be of greater interest for its fossils (which include corals, trilobites, brachiopods and molluscs; Geoscience Australia 2017) than for its karst features. Fossiliferous rock is evident in the Lick Hole Formation outcrop within the Exploratory Works project area. The outcropping and potentially disturbed area of this formation is in an area adjacent to Lobs Hole Ravine Road. It is noted that the outcrop at this location is exposed most likely as a result of previous road construction, and is in a disturbed condition (see Appendix 1).

Tufa deposits

The KGAP states that the Ravine karst area (Lobs Hole area) contains one of the largest tufa deposits in southern Australia (OEH 2012). Tufa is defined as a porous deposit of calcium carbonate, often with a spongy like appearance, deposited in solution from spring or surface water in karst areas. Most of the limestone/tufa at Lobs Hole is thinly-bedded, flaggy or impure (DEC NSW, 2006) and karst features are rare though a number of small caves exist (DEC NSW 2006).

The KGAP identifies three tufa deposits in the Exploratory Works project area:

- Cave Gully Tufa deposit: in a small gully 1 km upstream of the Lobs Hole copper mine. The KGMP recommends rapid assessments be completed every three years with no photo-documentation required unless significant impacts are observed.

- The Lick Hole Gully Tufa: two tufa deposits near the headwaters of Lickhole Gully that are visible from Ravine Road. Rapid assessments are completed every three years, to monitor for weed cover. This formation is also one of two sites identified as 'Geological Sites of Significance' by the Geological Society of Australia (NSW Division) within KNP.

At present, there is no interpretation signage at Ravine, which identifies or discusses the significance of these features. While the tufa deposits are within the Exploratory Works project area, they are not within the expected disturbance footprint.

3.2.3 Geoheritage site

The Ravine Copper Mine (Lobs Hole Mine) is identified as a geoheritage site in the KGAP. Rapid condition assessments are prescribed by the monitoring program for the mine, with actions and attention given to the creation of informal access tracks, illegal camp fires and the removal of mining heritage (eg bricks and mining remnants). The geoheritage assessment of Lobs Hole Mine is addressed separately by NSW Archaeology (2018), and is not considered further in this report.

3.3 Site inspection

Geodiversity features located along Lobs Hole Ravine Road were inspected by Scott Lawson (Associate Hydrogeologist) on 10 May 2018. The inspection focused on those sites and features within or adjacent to the Exploratory Works disturbance footprint only, with potential to be impacted by construction activities. These sites are the periglacial block streams along Lobs Hole Ravine Road, and where an outcrop of the Ravine karst area occurs along Lobs Hole Ravine Road. Photographs of the features are provided at Appendix 1.

3.3.1 Block streams (boulder scree)

Block stream, or boulder scree, sites are along Lower Lobs Hole Ravine Road, approximately 5 km from the intersection with Link Road. The geology of this area comprises Cainozoic age basalt overlying Devonian age Milk Shanty Formation (conglomerate, sandstone and siltstone) and the Silurian age Tumut Pond Group (sandstone, quartzite, slate and phyllite).

The block stream was observed as mostly angular rocks and small boulders spread and layered on the steeply sloping ground surface in about six landslide scree zones. Individual zones vary in size but are mostly about 20 to 40 m across (perpendicular to the slope), and 100 to 200 m in length (parallel to the slope). The boulders are dark grey, fine grained and assumed to be Cainozoic basalt. Individual boulders are very hard and strong, and range in size from about 20 to 50 cm.

The block stream is well exposed from the surrounding dense vegetation (undergrowth with tall eucalypts). Most of the stream does not support any vegetation growth apart from lichen on the rock surfaces. In addition, Lower Lobs Hole Ravine Road passes adjacent to / beneath the toe of some slopes, providing easy viewing upslope to the toe and higher levels of the scree. The road also cuts through one of the larger deposits, providing both upslope and downslope views.

The upper, source areas of the block streams were not visited due to access and safety constraints.

3.3.2 Ravine karst area (Lick Hole Formation)

Outcropping strata of the Devonian age Lick Hole Formation (Geoscience Australia 2017) is along Lower Lobs Hole Ravine Road, approximately 12 km from the intersection with Link Road.

The geological formation was formerly known as the Lick Hole Limestone (Geological Survey of New South Wales 1966). It is exposed in a hill slope road cutting which ranges up to about 2 m in height. Additional local exposures were not detected (however exploration was hampered by dense regrowth and blackberry bushes).

The strata consists of grey friable shale with a high density of calcareous, rounded nodules. The nodules are light brown in colour, hard and brittle, and slightly elongated with dimensions typically of about 2 to 3 cm in diameter and 4 to 10 cm in length. Some appear to display the remains of branching structure, and are assumed to be corals. Less abundant shell fish fossils were also observed.

The Australian Stratigraphic Units Database (Geoscience Australia, 2017) describes the Lick Hole Formation as a *'fossiliferous well-bedded marine limestone with a pronounced rubbly appearance to spheroidal concretions to 10 cm, and calcareous shale; fossils include corals, trilobites, brachiopods and molluscs'*. This is consistent with observations made on site (however no trilobites were noted).

Karst features appear to be rare within the Devonian strata along Lobs Hole Ravine Road, and given the nature of the strata at the outcropping inspection site, which is mostly shale with no massive limestone, significant karst features cannot be expected. No karst features or caves were identified during the site inspection.

4 Potential impacts of Exploratory Works

4.1 Areas of disturbance

The main areas of disturbance associated with Exploratory Works that have potential to impact geodiversity features within the KNP are along Lower Lobs Hole Ravine Road. The works along Lower Lobs Hole Ravine Road are shown on Figure 2 and include:

- road upgrade to allow one-way access for construction traffic. Road works will include maintaining drainage lines, minor road widening to provide 4 m lane width, gravel pavement overlay, installation of guideposts and snow poles above the snow line; and
- geophysical and geotechnical investigation within the existing road width. The works will involve:
  - seismic survey using a hammer and plate or blasting method; and
  - excavating test pits and drilling boreholes.

4.2 Risks to geodiversity sites and features

4.2.1 Threats to geodiversity

The KGAP identifies the threats to geodiversity as human activities including clearing and cultivation of land, mining, poorly designed and located infrastructure, fossicking, waste disposal, urban development, climate change and a range of recreational pursuits. These activities can adversely impact geodiversity leading to:

- complete/partial loss of an element of geodiversity;
- physical damage to geological features and attributes;
- interruptions to natural land forming processes;
- impeded or lost access to significant/interesting sites;
- increase/decrease in erosion; and
- pollution of water bodies.

4.2.2 Block stream (boulder screes)

The proposed road upgrades are necessary to ensure road stability and safety. The upgrades will be designed to minimum requirements in order to minimise earthworks where possible. The majority of the block stream has predominantly been avoided. However, there is a minor encroachment on the block stream in one section of Lower Lobs Hole Ravine Road, where the existing road has cut through the block stream by some 3.5 m. The geodiversity element will remain intact, and works will not further interrupt or impede natural land forming processes or access to the site. Environmental management measures will be incorporated to control erosion and runoff during and after construction at the site.

4.2.3 Ravine karst area (Lick Hole Formation)

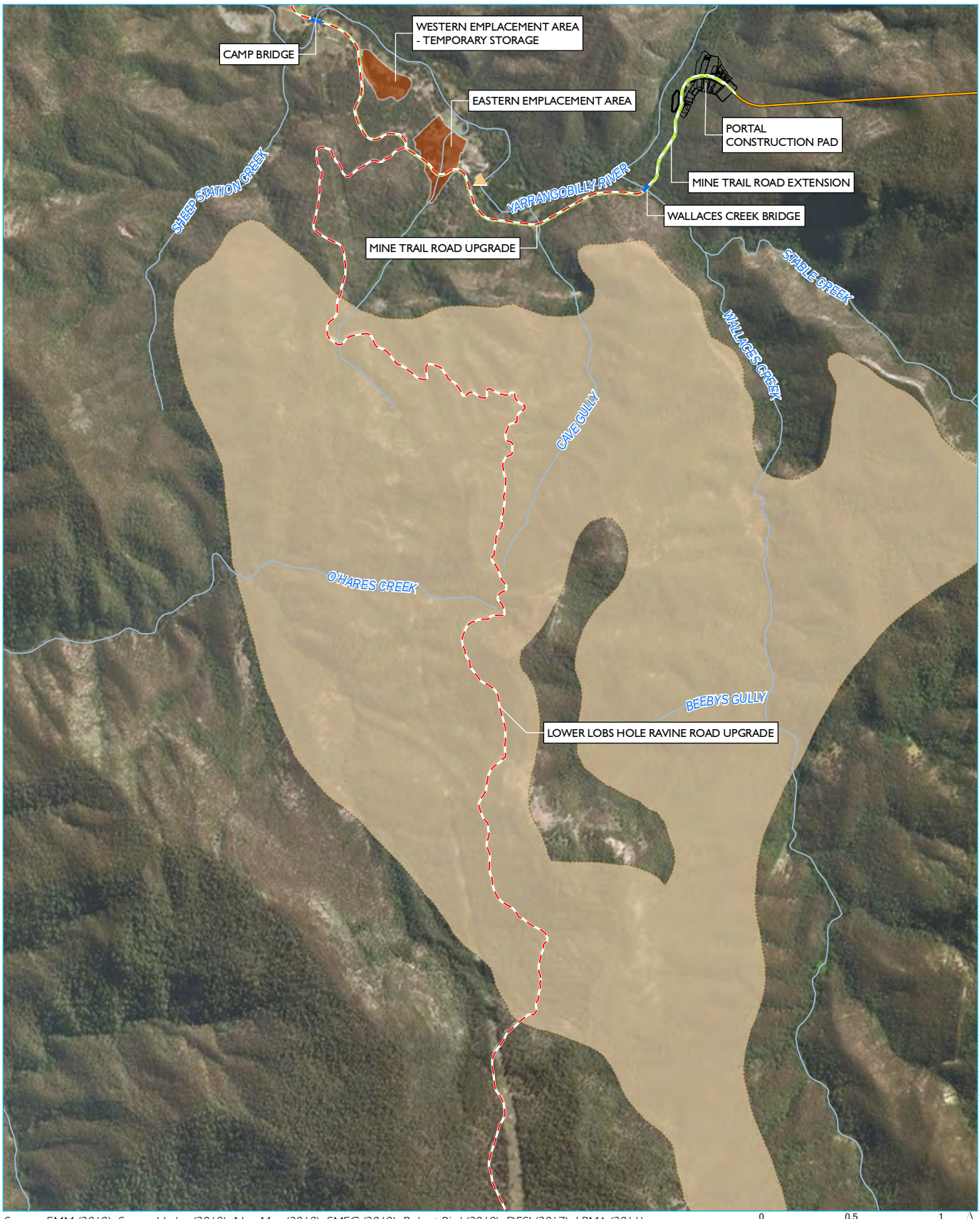
Karst features associated with the Devonian strata appear to be minimal and not of high significance at this location. The outcrop is in a disturbed condition and continues to degrade as a result of its exposure.

Road improvement may require some removal of fossiliferous rock on the upslope side of the road, and construction works and associated increased heavy vehicle traffic may result in indirect vibration impacts. Further expert opinion could be sought on the significance of the fossils present, however it is likely that removal of fossiliferous rock will simply expose more fossiliferous rock. Removal and/or salvage may also provide an opportunity for expert cataloguing of the fossil suite.

The additional tufa features identified in the Lobs Hole area (Cave Gully and Lick Hole tufa deposits) are in avoidance areas of the project, and will not be disturbed as part of Exploratory Works.

4.2.4 Geoheritage site

With the exception of an adit, the Lobs Hole Mine is in the avoidance area of the project and will not be disturbed as part of Exploratory Works. Consideration of the heritage values of Lobs Hole Mine is addressed separately by NSW Archaeology (2018).



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

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KEY

- Exploratory tunnel
- Portal construction pad conceptual layout
- Access road upgrade
- Access road extension
- Permanent bridge
- Communications cable
- Watercourse
- Lobs Hole Mine
- On land rock management
- Karst areas

Exploratory Works – Lower Lobs Hole Ravine Road

Snowy 2.0
Geodiversity
Exploratory Works
Figure 2

snowy 2.0 EMM

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5 Outcomes and recommendation

The geodiversity features identified are valuable components of the natural character of the KNP, and impacts to them will be able to be kept to minimal levels, subject to construction requirements, environmental controls (such as erosion and sediment controls), and options for further minimising disturbance through design refinement. Where possible, the design of Lobs Hole Ravine Road and the required disturbance footprint have been reduced as much as possible to minimise impacts to geodiversity.

The construction environmental management plan (CEMP) developed for Exploratory Works is to consider the management objectives and implementation actions identified in the KNP PoM and KGAP that have been discussed in this report. The rocks, landforms and geological processes are to be managed within the bounds of acceptable limits of disturbance. Recommendations for construction include:

- installing rock protection measures to protect identified periglacial features and limit direct and indirect impacts to the features as far as possible;
- cataloguing the fossiliferous rock if removed during upgrade of Lower Lobs Hole Ravine Road;
- minimising surface water pollution within the Ravine karst catchment by installing erosion and sediment controls to manage water quantity and quality; and
- monitoring the effectiveness of environmental controls during construction.

Monitoring of geodiversity features is recommended as part of the KGAP. However, the KGAP also states that a reasonable portion of the park's geodiversity is of a sufficient scale, level of abundance and degree of robustness to not warrant its routine monitoring (Appendix 3 of KGAP). It is recommended that any additional ongoing monitoring required for impacted features be discussed and implemented as agreed with NPWS.

6 References

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Appendix 1

Site photographs

Rocks and Landform

Photograph 1 **Large area of a boulder stream – looking uphill**

Photograph 2 **Scree boulders**

Photograph 3 **Lower Lobs Hole Ravine Road – cut into the lower end of the block stream**

Photograph 4 **Boulder stream terminated by Lobs Hole Ravine Road**

Ravine Karst outcrop

Photograph 5 **Devonian Lick Hole Formation outcrop in a road cutting of Lobs Hole Ravine Rd.**

Photograph 6 **Stratification of the Lick Hole Formation**

Photograph 7 **In situ calcareous fossils of the Lick Hole Formation (note: fossils are about 2 to 3 cm in diameter and 4 to 10 cm in length, an are presumed to be corals)**

Photograph 8 **Loose calcareous fossils of the Lick Hole Formation**