APPENDIX D

GEODIVERSITY ASSESSMENTS OF SIGNIFICANCE

ASSESSMENT OF POTENTIAL IMPACTS TO THE RAVINE BLOCK STREAMS FROM EXPLORATORY WORKS MODIFICATION 1, SNOWY 2.0

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1. PURPOSE AND SCOPE OF THIS REPORT

The purpose of this report is to assess potential impacts on the geodiversity values of the Ravine periglacial block streams as a result of proposed modifications to the Exploratory Works (EW) for Snowy 2.0, hereafter described as Modification 1. Modification 1 includes a proposal to undertake additional road widening on the block stream sections of Lobs Hole Ravine Road. This report presents an analysis of the potential impacts of Modification 1 on the block streams and recommendations for managing any impacts so as to minimise any damage and provide benefits to the geodiversity values of the features. A summary of previous geodiversity assessments of the site, observations from a site visit and a map of Ravine area block stream extents are provided for context.

2. PREVIOUS ASSESSMENTS OF THE FEATURES

Previous assessment of the blocks streams was provided for the EW Environmental Impact Statement (EIS) and comprised a geodiversity report prepared by EMM, dated 13 July 2018, and additional assessment provided by Dr Bradley Opdyke in September 2018. Together these reports provide a description of the block streams, outline their geodiversity values and significance, describe the potential impacts of the EW on the features, and provide guidance for the management and amelioration of these impacts, as summarised below.

2.1 Overview of the Ravine block streams

Block streams can form in alpine areas affected by periglacial conditions, where freeze-thaw activity is able to modify the landscape in a significant way. They consist of angular cobbles (6-25 cm diameter) and boulders (>25 cm diameter) that have broken off rock outcrops by frost-shattering, and been transported down-slope in association with interstitial ice. Block streams typically occur on steep slopes in shallow depressions in the landscape. In Australia they are relict features formed when the climate was much colder than present, mostly during the peak of the last ice age (last glacial maximum), between around 22 to 16 thousand years ago.

The Ravine block streams are located in the vicinity of Lobs Hole Ravine Road in northern Kosciuszko National Park (KNP), approximately 7 km from the intersection with Link Road to the south. They occur mostly on the steep, eastern, up-slope side of the road, with the lower reaches of several block streams bisected by the road.

The block streams are distributed in around six zones which are elongate parallel to the steep slope on which they lie. The zones vary in size but are typically 20 m to 40 m across and 100 m to 200 m long. The blocks are composed of dark grey, hard, fine-grained basalt inferred to have been sourced from outcrops of Cenozoic basalt occurring on the ridge-top to the east. The blocks have a typical size range of 20-50 cm.

The block streams are striking landforms, readily viewed from Lobs Hole Ravine Road in a number of locations. They stand out clearly from surrounding thickly forested slopes, being largely unvegetated.

Current impacts on the block streams are confined to the areas where the road bisects the block streams. At these sites, sections of the block streams have been excavated on the upslope side of the road and filling placed below that on the block streams to build up a level road surface. The road dates originally from the late 19th century and is currently a single-lane unpaved road.

2.2 Geodiversity significance of the block streams

Geodiversity is defined as the natural range of geological, geomorphological and soil features, assemblage, systems and processes (Commonwealth of Australia 2002). Guidelines for geodiversity preservation and management within KNP are provided in the KNP Plan of Management 2006 (PoM) and KNP Geodiversity Action Plan 2012-2017 (KGAP). The PoM specifies periglacial features as significant geodiversity features that occur within the park, and periglacial block streams are listed in Schedule 1 of that plan which defines 'Significant Natural and Cultural Features'. The KGAP outlines issues and conservation strategies associated with specific geodiversity features including the Ravine block streams. The block streams are subject to condition assessments every three years in accordance with the KNP Geodiversity Monitoring Program which was initiated in response to issues raised in the KGAP. In summary, the Ravine block streams are seen as significant geodiversity features within KNP.

While not common, periglacial block deposits have been identified in a number of highland areas of southeastern Australia (Slee & Schulmeister 2015). These deposits have regional significance based on their contribution to the understanding of climate conditions at the time of their formation during the last glacial period, which peaked at around 20 thousand years ago. The Ravine block streams have additional significance related to their occurrence within a protected area (KNP) and their potential accessibility to the public for the purposes of geological education.

2.3 Impact of Exploratory Works

In the original approved plan for the Exploratory Works, impacts on the block streams relate to minor widening of Lobs Hole Ravine Road to enable access to Lobs Hole for EW construction traffic. The impact on the block streams was described as being limited to three locations where the features have been bisected previously by Lobs Hole Ravine Road. The works are described as including a road upgrade to allow single lane access for construction traffic, and geophysical and geotechnical investigation within the existing road width (EMM 2018).

The previously proposed road design, as described in Opdyke (2018), involved building a retaining wall on the downslope side anchored into the existing road surface for stabilisation, and building up the road surface vertically enabling slight widening of the road (approximately 2 metres). Impacts on the block streams would include some encroachment on the upslope side, mainly through filling, but disturbance downslope into the block streams would be avoided.

Opdyke (2018) noted that the very angular nature of the rock boulders and cobbles of which the block streams are comprised enables them to interlock and resist movement, even on steep slopes.

He surmised that, as a result, if road works are undertaken carefully and did not cut too deeply, block stream stability should not be compromised.

2.4 Recommendations for management of impacts from Exploratory Works

The prior reports outline a number of recommendations for managing impacts of the Exploratory Works on the block streams in order to minimise or avoid damage to the features, and provide future benefits, as listed below.

1. Minimise earthworks where possible.
2. Implement environmental management measures to control erosion and runoff during and after construction.
3. In the case that upslope sections of the block streams require stabilisation, that open mesh wire fencing is used so that the deposits remain visible for the purposes of public and scientific interpretation. Building a solid wall or spraying concrete on the upslope side should be avoided.
4. Additional covering of the deposits on the downslope side should be avoided where practical.
5. Digging the road deeper into the block streams should be avoided where practical.
6. In relation to design and construction of drainage, consideration should be given to the extremely porous and permeable nature of the block streams and their likely locations overlying minor depressions in the landscape, in particular to ensure build up of water does not occur on the upslope side of the road during heavy rain.
7. Ensure road widening is only done to the width needed to accommodate safe single lane access for construction vehicles.
8. Monitor the effectiveness of environmental controls during construction.
9. Provide signage in a nearby suitably widened area explaining the nature and significance of the periglacial block streams.

The reports conclude that the road could be widened and strengthened with only minor additional impacts to the block streams and associated landscape if the above recommendations are followed, and that these works potentially provide an opportunity to enhance the value of the site within KNP and provide a public education benefit if subsequently developed as a geoheritage site.

3. SITE VISIT, MAPPING AND OBSERVATIONS

3.1 Site visit

A site visit was undertaken by the author on 30 May 2019 facilitated by EMM and Snowy Hydro Pty Ltd. Conditions were snowy, but generally this did not hinder visibility of the features. The purpose of the site visit was to make observations of block stream characteristics, extent and condition, and enable visualisation of potential impacts of the proposed road works on the features. Field activities included examination of features in the vicinity of the road, note taking, recording of waypoints at observation sites using a hand-held GPS unit, and photography. These activities were confined largely to roadside areas where the features could be examined most easily and future impacts are likely to be greatest.

3.2 Block stream mapping

Figure 1 shows a map of inferred block stream extents. This map is modified from an earlier version which was based on aerial image interpretation and vegetation mapping and used in the previous geodiversity reports. Changes include recognition of additional block streams and expanded extents of some previously mapped block streams, and were based on additional remote interpretation of aerial and DEM imagery, ground-truthing of approximate locations of some road/block stream intersections during the site visit, and field mapping by SMEC geologists. It is possible that some limited additional areas of block stream remain undetected, in particular where vegetation obscures remote interpretation. The mapped boundaries along the road corridor are inferred from the DEM and coincide with the base of the existing road batter on the downslope side and the road surface edge on the upslope.

Five block streams, labelled A to E, are intersected by the road (Figure 1). One additional block stream, labelled B2, appears to terminate just upslope of the road. The inferred extent of ridge-capping basalt from which the blocks were sourced is also shown in Figure 1.

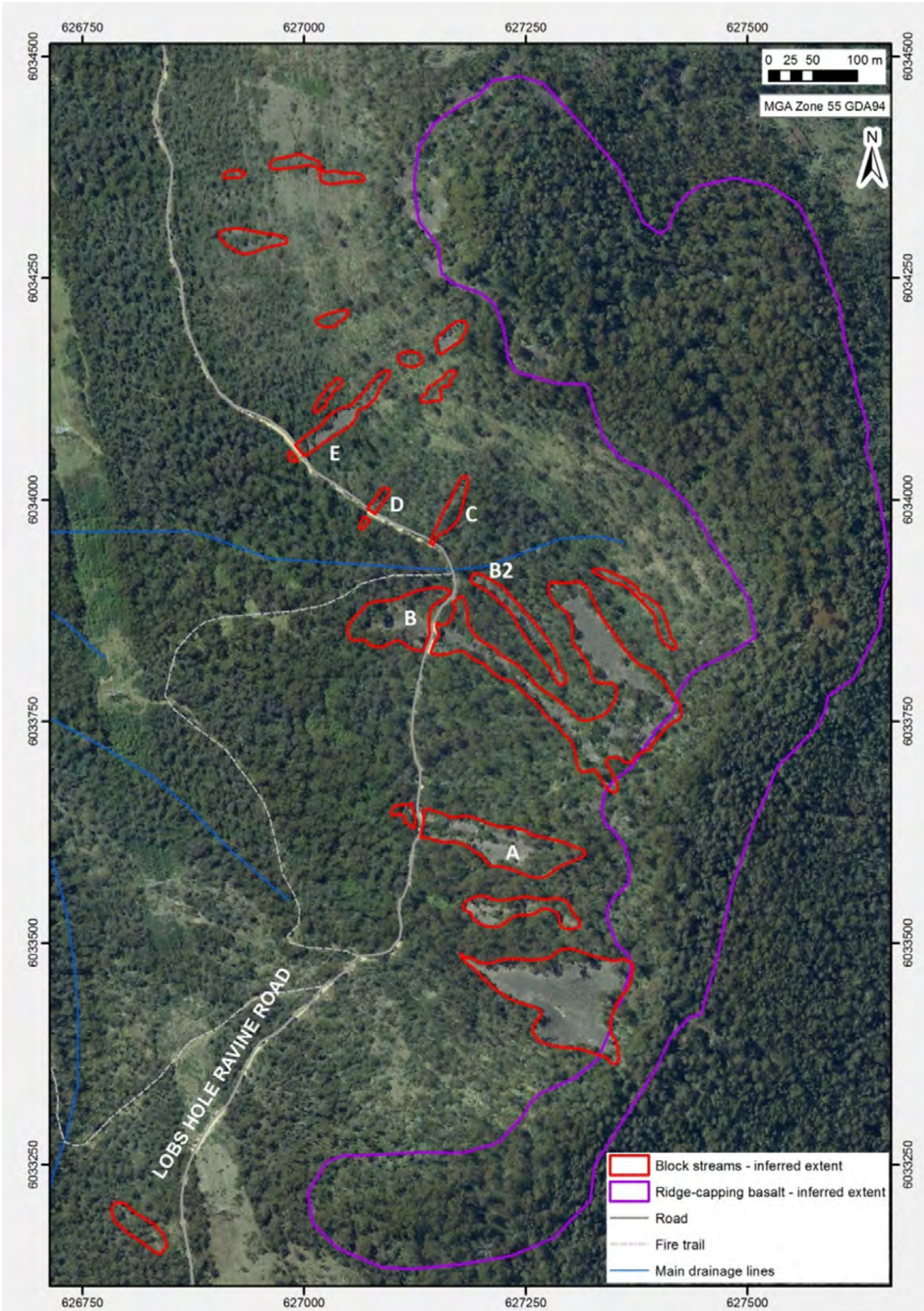

Figure 1. Aerial image showing inferred extents of periglacial block streams adjacent to Lobs Hole Ravine Road. Five block streams, labelled A to E, are intersected by the road. Block stream B2 appears to stop just short of the road. The approximate extent of ridge-capping basalt from which the blocks were sourced is also shown.

3.3 Field observations

Key field observations are listed below and field photos are provided at the end of this report.

1. As documented previously, the deposits comprise interlocking basalt blocks in the cobble to boulder size range, which are mainly sub-angular to sub-rounded.
2. Where they are unvegetated the block streams are very striking features (e.g. Photo 1), clearly visible in aerial imagery. There are, however, other areas of block stream which are vegetated, particularly around the edges of the features, making the full extent of the deposits hard to determine precisely from aerial imagery.
3. Block Streams D and E may extend further downslope of the road beyond what is mapped in Figure 1. These sites are very steep and hard to access with thick vegetation cover obscuring the view downslope below the road (e.g. Photo 2). In contrast, Block streams A and B have substantial unvegetated expanses below the road, with a shallower gradient.
4. On the upslope side of the road, Block Stream B is not continuous but has two parts separated by a small ridge of block-free colluvium and/or residuum.
5. The mapped block stream extents are confined to areas of matrix-free blocks (i.e. boulders and cobbles with no interstitial finer-grained material). Basalt blocks buried in the upper soil profile to a variable depth, but in places exceeding 1 m deep, were observed in some road cuttings both underlying matrix-free blocks and adjacent to some block stream edges where surficial matrix-free blocks are absent (Photos 3 & 4). The buried blocks may represent a lower layer of the block stream structure, or (less likely) may be older colluvial slope deposits. It is unclear whether matrix-free blocks are invariably underlain by such deposits as it is only possible to observe the substrate underlying the block streams in a few localities where there are existing road cuttings; however, such deposits have been reported to underlie block streams elsewhere in KNP (Caine & Jennings 1968).
6. Block sizes are quite variable, ranging from around 0.08 m to greater than 1 m in diameter, but are typically in the 0.2-0.5 m range. Some very large blocks (>0.8 m) were observed in places, but only at the surface (e.g. Photo 5). Where the subsurface was visible no size sorting of blocks was noted.
7. Block stream thickness can be hard to estimate accurately due to uncertainty around depth to the underlying substrate. Where block stream bases could be observed at road cuttings or intersections the features are typically 1-2 m thick, as previously estimated by Barrows et al. (2004); however, a range in thickness was observed from around 0.2-0.5 m (one layer of boulders) at block stream edges, to greater than 4 m in the central part of Block Stream B.
8. All five of the block streams bisected by Lobs Hole Ravine Road occupy shallow gullies at the road intersection. The gullies occupied by Block Streams C, D and E may be no more

than 1.5-2 m deep centrally, while those occupied by Block Streams A and B appear deeper (perhaps up to 4-6 m).

9. Vegetation around the block is largely eucalypt forest with a variable understory of smaller trees and shrubs. It seems likely that where block stream deposits are relatively thick, vegetation is absent to sparse, with vegetation colonising areas of block stream where the deposits are relatively thin or interstitial soil occurs close to the surface.

10. The assumed source for the blocks is a Miocene basalt deposit capping the ridge to the east of Lobs Hole Ravine Road. The inferred extent of this deposit, based largely on interpretation of remotely sensed data, is shown in Figure 1. On the regional geology map Cenozoic basalt is not shown to extend this far north along this ridge (Colquhoun et al. 2018), but discontinuous basalt is shown on unpublished Snowy Mountains Authority maps produced in the 1950s (e.g. Drawing B1, reproduced in SMEC (2018)).

11. In places, low relief curved ridges perpendicular to the slope and other surface micro-topography are visible on the block streams. From the road, these are best observed on lower Block Stream B (Photo 6). Such features are characteristic of periglacial block streams (Wilson 2007), and have been described previously from the Ravine block streams and attributed to block flow (Barrows et al. 2004). The preservation of such features, which likely date from the time of deposition of the features during the last glacial period (ice age) between 22 to 17 thousand years ago (Barrows et al. 2004), suggests that the block streams are inherently stable features.

12. Current impacts on the block streams are confined to the existing road corridor in the five areas where it bisects the features. As noted previously, Lobs Hole Ravine Road is currently an unpaved single lane road with a simple cut and fill construction. Typical impacts on the block streams are illustrated in Photos 7 and 8, and can be summarised as follows:

    a) On the upslope side of the road, block stream deposits have been excavated, in some cases into the underlying substrate, in places forming road cuts up to ~ 2m high;

    b) Filling has been placed on top of block stream deposits below the excavated areas to build up a level road surface with a down-slope batter angle ranging from ~26° to 44°.

4. IMPACT ASSESSMENT OF PROPOSED MODIFICATIONS

4.1 Proposed modifications to Exploratory Works

Modification 1 includes revisions to the road design and additions to the construction footprint from that approved previously for the EW. It is understood that the proposed modifications are required to accommodate an increase in the maximum vehicle size and load width requiring passage along Lobs Hole Ravine Road during the EW.

The proposed road design for widening the block stream sections involves excavation on the upslope side of the road with stabilisation achieved by cut and fill to a stable batter slope (Figure 2). Where required, local stabilisation works may be undertaken using methods with low visual impacts such as wire netting. Additional elements of the design include an open drain on the upslope edge of the road and an earth mound on the downslope edge of the road, as indicated in Figure 2. It is understood that the earth mound is a temporary safety barrier to be installed during construction prior to installation of permanent guardrails and may be stabilised with grass seed or polymer spray. The road surface would have a crossfall into the cut side to capture water and control runoff. This design differs from that proposed originally for the block stream sections which involved raising the road surface and building a retaining structure on the downslope side of the road.

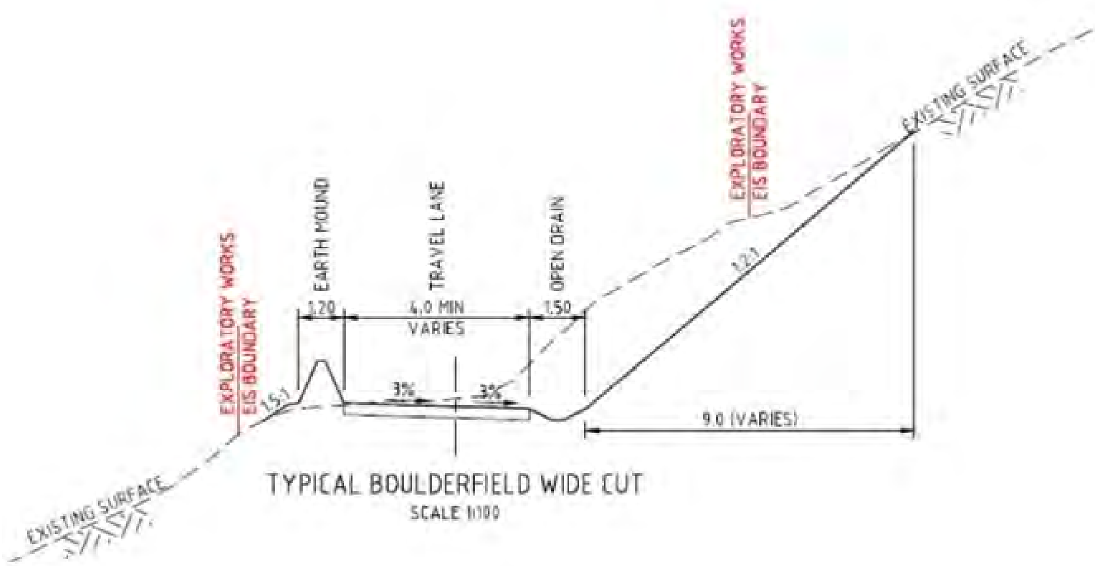

Figure 2. Proposed road design for the block streams sections. (Source: Snowy Hydro Ltd)

Figure 3 shows the previously approved construction footprint in purple and the additional footprint required in blue. The additions are mostly on the upslope and extend through the block stream areas and some adjacent road sections. On the downslope side, additions are minor and lie almost wholly outside the block stream extents.

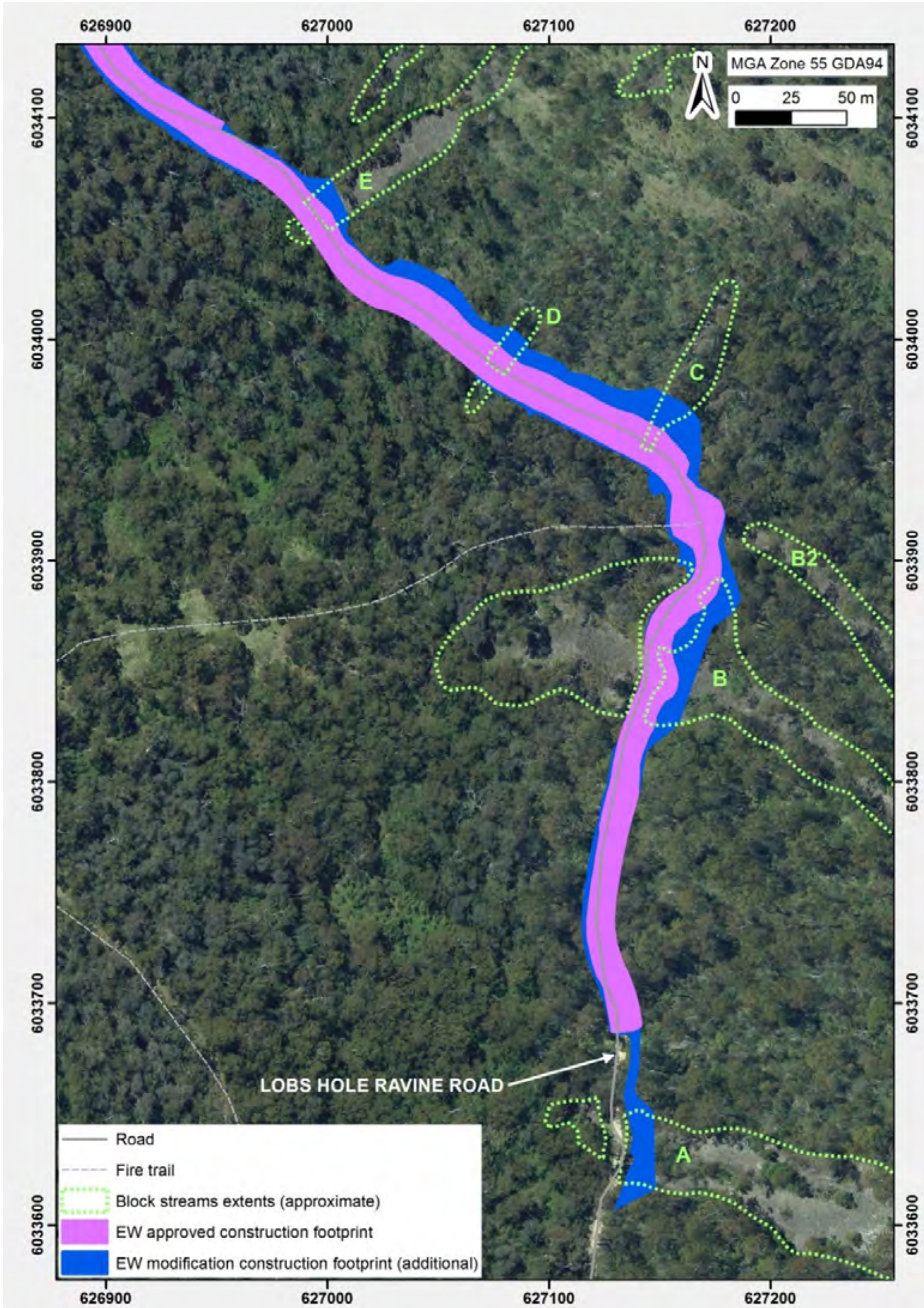

Figure 3. Aerial view of the Ravine block streams showing the approved EW construction footprint and proposed Modification 1 additions to that footprint along Lobs Hole Ravine Road.

Figures 4, 5 and 6 provide a closer view of the proposed construction footprint and an indication of the road design through the various block streams. The orange lines of the road design drawing show the extent to which excavation would occur. In the area beyond that but within the modified construction footprint, local stabilisation with wire netting or similar may be undertaken to secure boulders and there may also be impacts during construction, for example, the area may be used for stationing of equipment and materials.

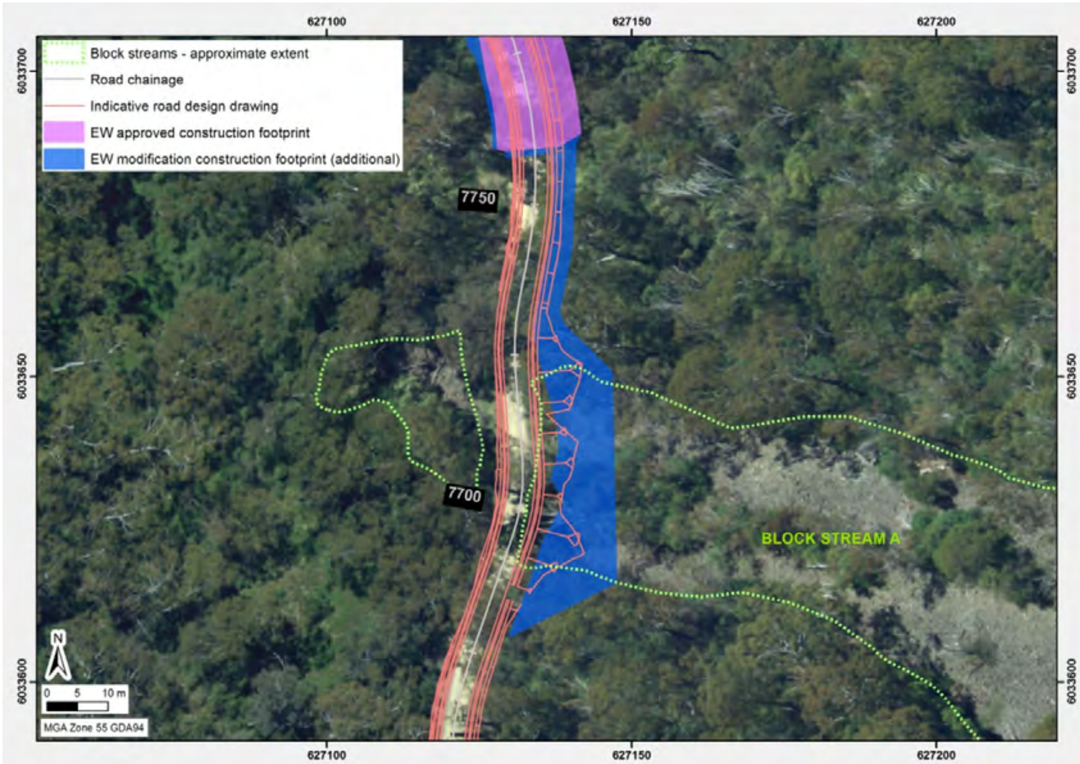

Figure 4. Aerial view of Block Stream A, at Lobs Hole Ravine Road, showing the extent of the proposed additional construction footprint and the indicative road design drawing for this section.

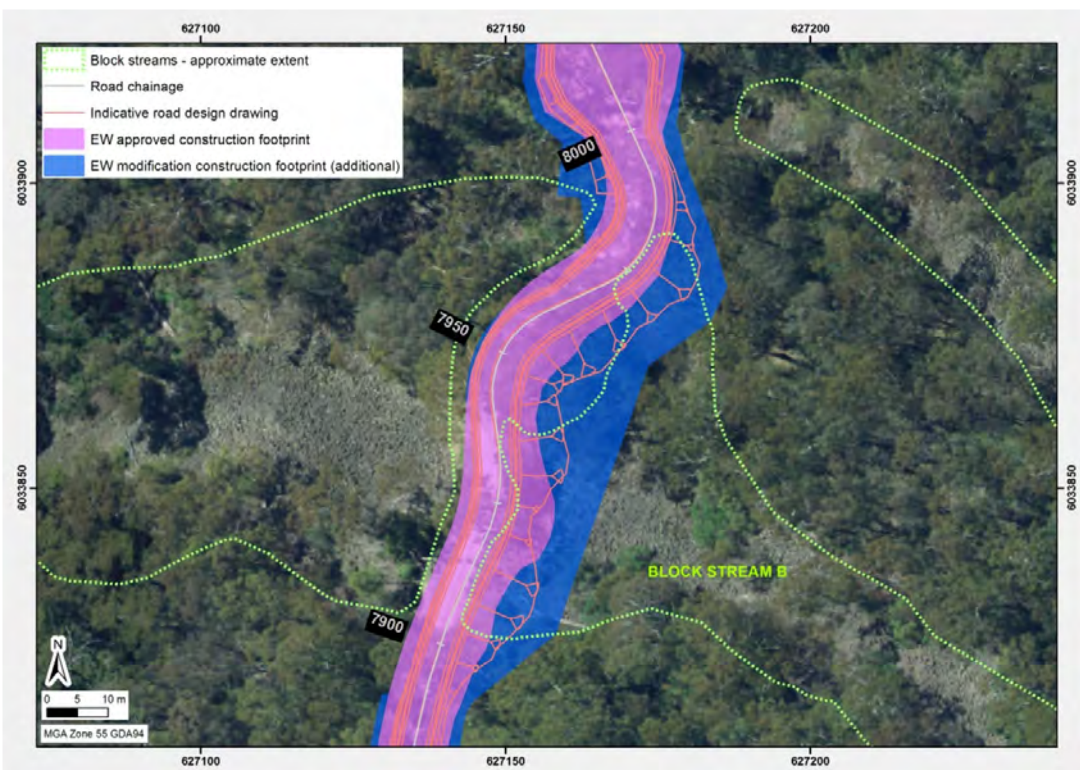

Figure 5. Aerial view of Block Stream B, at Lobs Hole Ravine Road, showing the extent of the proposed additional construction footprint and the indicative road design drawing for this section.

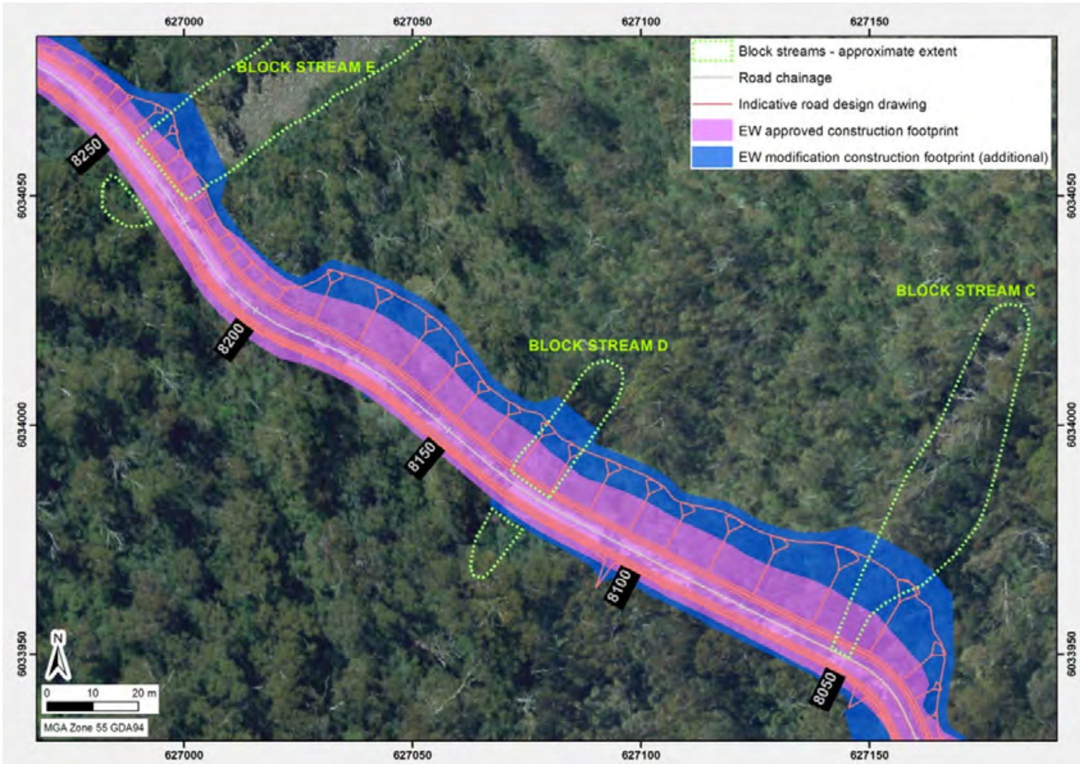

Figure 6. Aerial view of Block Streams C, D and E, at Lobs Hole Ravine Road, showing the extent of the proposed additional construction footprint and the indicative road design drawing for this section.

Table 1 provides estimates of maximum upslope impacts widths for each of the five block streams bisected by the road. Compared to the approved construction footprint, the maximum additional upslope width of the modified footprint ranges between around 10 to 15 m through the block stream sections. The proposed width of upslope excavation within this area ranges from around 5 to 10 metres. Drawings provided to the author indicate that the maximum thickness of excavation in the block stream sections would range from around 1.6 m to 3.1 m at the base of the batter slope, tapering upslope at a typical 1.2:1 slope to the extent of excavation (see Figure 2).

Block Stream ID	Additional construction footprint (m)	Additional excavation beyond approved footprint (m)
A	13.6	6.8
B	15.4	6.1
C	15.3	10.2
D	10.1	4.8
E	10.6	5.4

Table 1. Estimates of maximum upslope impact widths for individual block streams.

4.2 Potential impacts of proposed Exploratory Works modifications on the features

The main impact on the block streams from Modification 1 would be from the additional upslope excavation of the features. The increased excavation would undoubtedly have a negative aesthetic impact on the features. It does, however, represent a small proportion of the overall block stream extents (see Figures 1 and 2), and the features would remain substantially intact. In all cases the excavation would involve further cut into existing batters adjacent to the road, thereby extending an existing impact. It could be expected that the remaining blocks and underlying substrate in the batter area would form a relatively natural-looking surface, although it may need to be retained with local stabilisation works in some areas to maintain block stability and ensure safe use of the road. The use of wire-netting is preferable to other alternatives, such as shotcrete, which would be more unsightly and would cover up the blocks from view.

Despite the increased construction footprint and excavation width, the proposed modification may have some advantages over the previously approved plan to raise the road surface with filling and build a retaining structure on the road downslope, which could have a more prominent visual impact.

There do not appear to be any impacts on the block streams downslope of the existing road from Modification 1.

4.3 Potential opportunities

Opdyke (2018) indicated that a potential benefit of Snowy 2.0 relates to future development of the Ravine block streams for geoheritage tourism, which is also foreshadowed in the KNP Geodiversity Action Plan (OEH 2012). Widening and upgrade of Lobs Hole Ravine Road would help facilitate this benefit, but public access and any associated tourism infrastructure such as a parking bay and signage would likely need to wait until after construction work on Snowy 2.0 is completed. Any road design considerations that would enable this opportunity to be realised might be more appropriately addressed during Snowy 2.0 Main Works. Should the Snowy 2.0 Main Works not proceed, opportunities to enhance the geotourism potential of the Ravine block streams should be considered as part of the Exploratory Works Rehabilitation Plan.

Aspects of periglacial block stream formation and structure remain poorly understood and are hard to study due to the nature of the features. The creation of fresh road cuts through the Ravine block streams and their substrate may provide new information on the nature of these features which would be of interest to scientific specialists, if the cuts are left exposed to view post-construction. Such studies would be greatly enhanced if the data generated and acquired during Snowy 2.0 (e.g. geotechnical reports, and remote sensing data) was shared with suitably interested scientific researchers. Findings from such a study would contribute to the scientific and educational value and significance of the features.

5. RECOMMENDATIONS

As ascertained previously, the Ravine periglacial block streams are significant geodiversity features within KNP, and roadworks for Snowy 2.0 EW should be designed and managed to minimise impacts to the geodiversity values of the block streams as much as practical (EMM 2018; Opdyke 2018). The main risks and sensitivities around these features are impacts on visual amenity, maintenance of landscape integrity, block stability, and future access to the features for viewing and study. Specific recommendations for minimising potential impacts of Modification 1 on the features are listed below.

1. If not already undertaken, carry out field mapping of block stream extents and morphology within the construction footprint prior to works. Use this data to assist preparation of final design and construction plans which minimise potential impacts on these features and enable management of impacts during construction.
2. Consider visual amenity in the final road design and aim, where possible, to avoid the use of construction methods and materials that detract from the landscape values of the block streams and their surrounds.
3. In order to maintain feature integrity in a near-natural state, construction activities should, where practical:
    - minimise the extent of excavation into the upslope block streams;
    - minimise moving or damaging blocks in areas beyond the excavation zone;
    - minimise the placement of outside materials onto the block streams (e.g. soil or fill);
    - minimise use of any stabilisation measures that permanently cover the block streams, for example with shotcrete or other construction materials, which would preclude their future viewing and study.
4. Road design should incorporate adequate drainage controls to ensure water flow through the upslope block streams is not impeded as this may impact local stability of the features.
5. Sediment and erosion control measures should be implemented during and after construction with the aim to minimise adverse impacts on and around the block streams. Sediment and erosion impacts of the proposed works were assessed in the water impact assessment section of the Modification 1 assessment report.
6. The proposed works should implement controls in accordance with the Biodiversity Management Plan to ensure they do not promote the spread of weeds near the boulder streams, and thereby reduce their visibility.
7. Particular care should be taken to avoid impacts on the downslope section of Block Stream B which features well-preserved evidence of ice age block flow in the form of ridges and other low relief surface topography.
8. Undertake monitoring of block stream sections during construction to ensure that works are being carried out within design parameters and environmental controls are effective.

If these recommendations are followed, it should be possible to maintain the integrity of the features in a reasonably natural state and preserve their geodiversity values for the future, despite the additional impacts of Modification 1.

REFERENCES

Barrows T.T., Stone J.O. & Fifield L.K. 2004. Exposure ages for Pleistocene periglacial deposits in Australia. Quaternary Science Reviews **23**, 59-708.

Caine N. & Jennings J. N. 1968. Some block streams of the Toolong Range, Kosciusko State Park, New South Wales. Journal and Proceedings, Royal Society of New South Wales **101**, 93–103.

Colquhoun G.P., Hughes K.S., Deyssing L., Ballard J.C., Phillips G., Troedson A.L., Folkes C.B. & Fitzherbert J.A. (2018). New South Wales Seamless Geology dataset, version 1 [Digital Dataset]. Geological Survey of New South Wales, NSW Department of Planning and Environment, Maitland.

Commonwealth of Australia 2002. Australian Natural Heritage Charter for the conservation of places of natural heritage significance. Australian Heritage Commission. Second edition.

NSW National Parks and Wildlife Service (NPWS) 2006. Kosciuszko National Park Plan of Management 2006. Department of Environment and Climate Change, Sydney.

EMM 2018. Geodiversity review. Snowy 2.0 Exploratory Works Environmental Impact Assessment, Appendix I.

Opdyke B.N. 2018. Characteristics of periglacial rock streams along Lobs Hole Ravine Road. Supplement to geodiversity review for Snowy 2.0 Exploratory Works Environmental Impact Assessment, September 2018.

Office of Environment and Heritage (OEH) 2012. Kosciuszko National Park Geodiversity Action Plan, 2012-2017.

SMEC 2018. Geological Interpretive Report for Snowy 2.0, November 2018. S2-4100-REP-000012-B.

SMEC 2019. Early Works Roads – Stabilisation of Boulder Field batters using Soil Nail Wall, Snowy 2.0 Reference Design, 28 June 2019. S2-6130-TCN-000001.

Wilson P. 2007. Periglacial landforms, rock forms: block/rock streams. In: Elias S. A. (ed.) Encyclopedia of Quaternary Science, Elsevier, pp.2217-2225.

SITE PHOTOS

Photo 1. Block Stream E immediately upslope of Lobs Hole Ravine Road showing a typical view of unvegetated matrix-free blocks up the main axis of the block stream.

Photo 2. The view immediately below Lobs Hole Ravine Rd at Block Stream E. Some boulders are visible at the base of the road batter but thick vegetation obscures the view beyond that point, and the downslope extent of the block stream is uncertain.

Photo 3. Road cut at the northern edge of Block Stream E, upslope of Lobs Hole Ravine Road. In the foreground, basalt blocks are embedded in soil. Matrix-free surface blocks occupy a shallow gully beyond that to the right; pink streamers mark the roadside extent of surface blocks.

Photo 4. A layer of basalt blocks within the upper soil profile adjacent to the southern edge of Block Stream B, where matrix-free surface blocks are absent. The camera case is 14 cm long.

Photo 5. Block sizes are mainly in the 0.2-0.5 m diameter range but a few are much larger including this elongate boulder around 1.2 m long at the surface of Block Stream A on the upslope side of Lobs Hole Ravine Road.

Photo 6. Block Stream B immediately downslope of Lobs Hole Ravine Road. Low relief surface topography on the block stream is subtly delineated by variations in snow cover, and includes across-slope ridges. These features were probably formed by block flow at the time of deposition, ~22-17 thousand years ago.

Photos 7 & 8. Block Stream B where it is bisected by Lobs Hole Ravine Road showing an example of current impacts of the road on the block streams. On the upslope side the block stream and in places the underlying substrate, have been excavated. Fill has been placed on the block stream below the cutting to create a level road surface with a steep batter sloping down to the lower section of the block stream.

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Dr Alexa Troedson is a geologist with expertise in sedimentology, stratigraphy, geological and geomorphic mapping of Cenozoic deposits, palaeoenvironmental interpretation, and Geographic Information Systems (GIS). She has worked for government agencies in Australia and the UK, for a geotechnical and environmental engineering consultancy based in Sydney, and most recently as a self-employed consultant. Her qualifications include a Bachelor of Science Honours degree (First Class) majoring in geology and a PhD in sedimentology, both from the University of Sydney. She has also undertaken environmental law, management and GIS subjects at Macquarie University, gaining distinctions. She has experience interpreting Cenozoic deposits from a range of environments including specific experience in glacial deposits gained from research on Antarctic glacial rocks; she was first author on two papers published in international scientific journals on this work (see below). More recent work has included studies and mapping of Cenozoic deposits in NSW. Some publications associated with these projects are also listed below.

Selected publications:

Troedson A.L. & Smellie J.L. 2002. The Polonez Cove Formation of King George Island, Antarctica: stratigraphy, facies and implications for mid-Cenozoic cryosphere development. *Sedimentology* 49, 277-301

Troedson A.L. & Riding J.B. 2002. Upper Oligocene to lowermost Miocene strata of King George Island, South Shetland Islands, Antarctica: stratigraphy, facies analysis and implications for the glacial history of the Antarctic Peninsula. *Journal of Sedimentary Research* 72, 510-523.

Troedson A.L. & Hashimoto T.R. 2008. Coastal Quaternary Geology - north and south coast of NSW, Bulletin 34, Geological Survey of NSW, NSW Department of Primary Industries, Mineral Resources.

Troedson A.L., Hashimoto T.R., Colquhoun G.P. & Ballard J.C. 2015. Coastal Quaternary Geology Data Package for NSW [Digital Dataset]. Geological Survey of New South Wales, Maitland.

Troedson A.L. & Deyssing L. 2015. Coastal Quaternary mapping of the southern Hunter to northern Illawarra regions, New South Wales. *Quarterly Notes of the Geological Survey of New South Wales* 146.

Troedson A.L. & Bull K.F. 2018. Geology of Warrumbungle National Park and environs. NSW Office of Environment & Heritage and Geological Survey of New South Wales, Maitland. Geological Survey of New South Wales Report GS2018/0575.

Colquhoun G.P., Hughes K.S., Deyssing L., Ballard J.C., Phillips G., Troedson A.L., Folkes C.B. & Fitzherbert J.A. 2018. New South Wales Seamless Geology Dataset, v 1 [Digital Dataset]. Geological Survey of NSW, NSW Dept of Planning and Environment, Maitland.

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