

Before the Fast-track Panel

Under: Fast-track Approvals Act 2024

In the matter of: FTAA-2605-1236 – Remarkables Ski Area Upgrade and Doolans Expansion

Statement of advice: Susan Walker

Terrestrial flora, vegetation and ecosystems

Independent consultant

7 October 2026



Department of
Conservation
Te Papa Atawhai

**Te Kāwanatanga
o Aotearoa**
New Zealand Government

SUMMARY

Part 1. Values

1. The Applicant's assessment of **values** in the Terrestrial Ecological Impact Assessment (TEIA) is inadequate in several ways.
2. The assessment of significance and values has been undertaken only at an inappropriately fine scale of individual 'vegetation communities', using criteria that were not designed for that scale of assessment. Significance criteria produce spurious results at that scale, and disaggregated scores logically cannot be 'added up' to an overall assessment.
3. There is no assessment of the significance of the values at the site and area scale as required by the National Policy Statement for Indigenous Biodiversity (NPSIB), Otago Regional Policy Statement (ORPS) and DOC guidelines. Consequently, crucial ecological context is missing from the assessment, and the ecological significance, irreplaceability and vulnerability of the values are not properly identified.
4. Naturally uncommon ecosystems ('NUEs', also known as 'historically rare ecosystems') are key values that specifically require avoidance in the ORPS but are not mapped. Some NUEs (moraine, ephemeral wetland, alpine deflation surfaces) are not identified at all, and they do not correspond to mapped vegetation communities. Consequently, ecological values associated with NUEs are inadequately identified and effects on them are not assessed.
5. Three practical area units for assessing significance across the Project Site are the Rastus Burn, Sugarbowl, and Doolans Basin. All three areas meet criteria for ecological significance despite significant modification of key ecological features in the Rastus Burn.
6. The ecological significance of the Doolans Basin is exceptionally high. Key attributes not described in the TEIA include
 - a. **Representativeness:** extremely high ecological integrity and wholly intact representation of the natural character of the Ecological District (ED); likely to be the only alpine basin in the ED representing ecosystems

that were never historically under deliberate pastoral grazing, and therefore a unique baseline.

- b. **Diversity and pattern:** outstanding ecological diversity and pattern of a character unreplicated in the ED; the only major basin supporting intact connected habitats across the full range of west, south, east, and north aspects across this elevation range; extensive mosaics of terrestrial and wetland vegetation on diverse naturally uncommon ecosystems.
- c. **Rarity and distinctiveness:** much of the area comprises indigenous vegetation and habitat on naturally uncommon ecosystems (NUEs), including (terrestrial) moraines, screes of acidic rock, alpine deflation surfaces, and six different wetland NUEs. There is a large At Risk rare vascular flora and a rare and poorly known invertebrate fauna. The whole area is highly distinctive with a combination of characteristics unreplicated in the ED. There are moraines, tarns and other glacial features formed during repeated late-glacial advances, providing evidence of landscape stability and past climate conditions. Highly distinctive individual features (NUEs) that are rare or not represented elsewhere in the ED include an extreme alpine deflation surface on Helicopter Ridge, a late-glacial moraine; an extensive low relief tussock-clad moraine bench; a wind 'touch down' alpine deflation surface on the moraine bench margin; a wetland string mire, and Tarn 3, which is the only ephemeral wetland in the Project site.
- d. **Ecological context:** unequalled value for the adaptation of the flora and fauna of the ED to maintain indigenous biodiversity through climate change, due to compact shape and large extent combined with the intactness, diversity, and completely unmodified connectivity of vegetation and unvegetated habitats.

Part 2. Effects

7. I found the Applicant's assessments of effects to be inadequate in several ways.
8. The scale for assessment of effect magnitude in the TEIA (the ED above 1100 m) is orders of magnitude larger than that of the scale of values assessment. That approach minimises the apparent magnitude of effects, deviates from unambiguous industry guidance that magnitude of effects should be assessed at the same scale as ecological value, and contrasts with the FEIA.
9. The TEIA uses a flawed application of the random forests ('RF') GIS tool to enlarge the assessment scale to the ED above 1100 m. The model outputs are invalid principally because predicting beyond the range of the training data violates the key limitation of such models and automatically inflates predicted extent of input communities.
10. The extent of loss of terrestrial naturally uncommon ecosystems (NUEs) is not documented. It appears that most of the direct disturbance footprint in the Doolans Basin will result in the loss of NUEs, which cannot be offset or compensated for. There will be complete destruction or significant loss and fragmentation of the extreme 'Helicopter Ridge' alpine deflation surface (a scree of acidic rock) for the Doolans Mid Station; the late-glacial moraine for the main trail; the moraine bench for the Doolans Base Area and Learners Slope; the moraine-margin wind deflation surface for the Doolans Base Area; and the Tarn 3 ephemeral wetland. NUEs (scree of acidic rock) in the Rastus Burn will also be impacted by access and service routes.
11. Many of the most important and largest-scale effects of project activities on vegetation and ecosystems in Doolans Basin are missing from both the TEIA and the FEIA. Serious omissions include effects from:
 - a. Snowmaking (soil compaction and saturation, nutrient enrichment/eutrophication of receiving environments, greater snowmelt and runoff causing erosion and sedimentation, and delayed snowmelt leading to below- and above-ground ecosystem compositional shifts).
 - b. Snow grooming (progressive soil compaction, loss of insulation hence deep soil freezing and nutrient mineralisation, altered soil subsurface

melt patterns, delayed snowmelt leading to degraded below- and above-ground ecosystem properties and vegetation compositional changes).

- c. Skiing and snowboarding (like those of snow grooming, but with a different spatial distribution with concentration at pinch points, and PFAS and microplastic pollution impacts).
- d. Visitor impacts in summer increased from negligible to 4 days per week by gondola and unconstrained mountain bike access (creation of off-trail tracks and foot and bike trampling, compounded biosecurity threats, escalated anthropogenic pollution and eutrophication, concentrated 'honeypot' impacts, and elevated wildfire risk, all with potentially for severe effects on flora, fauna and ecosystems).
- e. Summer road use impacts (ecological consequences of wide scale plant dust coating with mineral dust, as well as heavy metal and micro-rubber residues).

12. Deficiencies in the TEIA also contribute to considerable underestimation of the magnitude of adverse effects, especially:

- a. Limited consideration of edge effects from the direct disturbance footprint, unsupported by data or ecological observation, and orders of magnitude smaller than the scale of effects that can be reasonably anticipated.
- b. Unrealistic expectations of weed invasion mitigation, not supported by outcomes in the Rastus Burn or adequate minimisation measures.
- c. Major underestimation of the scale and types of future fragmentation through considering only the within-community scale fragmentation, and only a fraction of the relevant fragmenting processes.

13. Cumulative effects¹ of the activities across Doolans Basin are therefore greatly understated, and in particular:

¹ effects arising over time, and effects arising in combination with other effects (which can include landscape-scale and off-site effects)

- a. The widespread (basin-wide) extent of fragmentation and degradation of terrestrial ecosystems and ecosystem functioning across the period of the activity (which will increase further if greater snowmaking is used to combat foreseeable climate change effects on economic viability)
- b. That the ecosystem will be blocked from naturally adapting its phenology² and stress traits to match the actual climate shift through snowmaking, snow grooming and skiing. Having been denied the opportunity to progressively adapt through advanced phenology or the expression of stress-tolerant traits, the ecosystem will be highly vulnerable to abrupt collapse when artificial management ceases or alters.
- c. Cumulative degradation and maladaptation would have district-wide effects on indigenous biodiversity, because a key stronghold against climate impacts would be lost from the wider ED.

Part 3. Adequacy of avoidance, mitigation, rehabilitation and management measures, and potential additional measures

- 14. Because neither values nor effects have been fully and adequately identified, the Applicant's proposed avoidance, mitigation, rehabilitation and management measures as they relate to terrestrial ecology are partial and deficient.
- 15. I suggest some potential measures that might reduce the unrecognised effects of snowmaking, snow grooming, skiing, visitor impacts, roading impacts and weed invasion. However, I expect residual effects would remain very high even after all possible measures are taken.
- 16. Proposed avoidance, mitigation, rehabilitation and management measures for recognised effects are inadequate (see also Part 5 of this statement).

Part 4. Offsetting and compensation

- 17. Offsetting and compensation for residual ecological effects in the Doolans Basin is not appropriate or possible.

² i.e. the timing of periodic biological events, such as emergence, flowering and mast seeding, pollination, fruiting, ripening, nesting, breeding, moulting, migration and dormancy.

18. Should the panel determine to grant consent despite this, remaining principles of compensation indicate that scale of the compensation should achieve outcomes that outweigh the adverse effects. The limited initiatives proposed by the Applicant fall far short of that standard.

Part 5. Conditions and management plans

19. Conditions and management plans for recognised effects are inadequate, especially in the context of the exceptionally high ecological value and near-pristine baseline condition of the Doolans Basin. Three key inadequacies are:
 - a. Avoidance of ecologically sensitive areas and high-value vegetation cannot be achieved with the proposed footprint. Avoiding ecologically sensitive areas and high value vegetation requires that NUEs are identified and mapped, and that conditions specify that those areas are avoided.
 - b. Measures to protect wetlands and terrestrial vegetation through exclusion zones, erosion and sediment controls, and hydrological management. Proposed sedimentation control and drainage measures fall far short of best alpine practice and will lead to permanent loss.
 - c. Biosecurity procedures to prevent the introduction and spread of invasive plants and organisms such as didymo. The measures proposed are inadequate to prevent widespread incursions.
20. New and additional conditions, and amended management plans, will also be needed to manage the unrecognised effects that are not avoided, and to adequately specify and manage compensation.
21. In my experience enforceable conditions have quantitative and time bound targets and triggers and specify remedial actions when targets and triggers are not met. The proposed conditions largely lack those targets, triggers and actions.

INTRODUCTION

22. My full name is Susan Walker.

Instruction

23. I have been requested to provide expert advice to the Director-General of Conservation (DOC/the Department) for the purposes of his comments on the Remarkables Ski Area Upgrade and Doolans Expansion Project Fast-track application.
24. My advice will be used to inform DOC's s51 reporting and s53 comments on the application.

Qualification and Experience

25. I am a terrestrial conservation ecologist and Principal Researcher based in Dunedin in the Manaaki Whenua Group within the crown owned Bioeconomy Science Institute (BSI, formed July 2025). I have 29 years of professional experience as an ecologist, having also worked for BSI's predecessor organisation Manaaki Whenua – Landcare Research from 1997 to June 2025.
26. I have MSc (1994) and PhD (1997) degrees from the University of Otago. I have published more than 60 peer-reviewed scientific journal papers and book chapters in international and national literature and produced more than 50 internally peer-reviewed contract reports.
27. My fields of expertise relevant to this application include:
- a. The botany, ecology, and conservation management of indigenous ecosystems of the eastern South Island.
 - b. Quantitative field sampling and measurement of biodiversity components and assessment of ecological significance.
 - c. Biodiversity assessment, including measurement and reporting of the biodiversity and conservation outcomes and achievements of policies (and incentives), and biodiversity offsetting and compensation.
 - d. The effects of fragmentation and edge effects on terrestrial vegetation.

- e. The effects of climate change on New Zealand's indigenous biodiversity and rodent pests.
28. I have also researched and published scientific papers and written peer reviewed reports about the ecology and conservation of threatened plants, national and regional long-term changes in New Zealand's land cover and indigenous bird fauna, the temporal dynamics of introduced rodents across New Zealand, evolutionary patterns of plant richness, radiation and endemism, and movements of inland-migrant birds, among other topics.
 29. I routinely use modern quantitative modelling in my peer-reviewed research, and I have experience in spatial analyses and machine learning techniques.
 30. I have worked with geomorphologists and geomorphology datasets to support identification of naturally uncommon (historically rare) ecosystems (NUEs). I have a strong understanding of glacial geomorphology through my work on glacially-derived NUEs across the inland eastern South Island.
 31. Throughout my career I have prepared expert evidence on indigenous biodiversity and ecology for council hearings and Environment Court and High Court proceedings and more recently for Fast Track proceedings. I am often engaged to provide independent ecological advice to central and local government agencies on matters of ecology and biodiversity assessment and protection. For example, in 2018 I and other national experts advised the Biodiversity Collaborative Group on the effects that must be avoided, remediated or mitigated to halt biodiversity loss across New Zealand, to underpin the National Policy Statement for Indigenous Biodiversity (NPS-IB)³; and I was engaged last year to provide advice to the Ministry for the Environment (MfE) on technical aspects of limits for indigenous ecosystems and biodiversity under new resource management legislation.

³ Walker S, Lee W, Bellingham P, Kaine C, Richardson S, Brown MA, Greenhalgh S, Simcock R 2018. Critical factors to maintain biodiversity: what effects must be avoided, remediated or mitigated to halt biodiversity loss? Manaaki Whenua Contract Report: LC3116. Prepared for The Biodiversity Collaborative Group.

32. I am familiar with and have published on biodiversity offsetting and compensation. For example, my 2009 paper on biodiversity offsetting⁴ has been cited widely internationally; and in 2022 I developed a comprehensive framework for biodiversity compensation and offsets for harm to indigenous biodiversity under the Natural and Built Environment Act⁵ under contract to MfE, alongside policy and legal experts.
33. In 2018, I received the New Zealand Ecological Society's Ecology in Action award which recognises contribution to the application of ecological knowledge, including communication, education and transfer of ecological science.
34. I have visited the site and understand its terrestrial ecological context of the Central Otago and Queenstown Lakes Districts very well. I have spent my career based in the region and undertaking fieldwork, including very large landscape scale field studies covering substantial parts of those districts.
35. My role in this project to date has included review of both draft and substantive terrestrial ecology impact assessment documents, and attendance at various meetings with the applicant's ecologists.

Code of conduct

Although this is not an Environment Court Proceeding, I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2023. I have complied with the Code of Conduct in the preparation of this advice. Unless I state otherwise, this advice is within my area of expertise, and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

⁴ Walker S, Brower AL, Stephens RT, Lee WG 2009. Why bartering biodiversity fails. *Conservation Letters* 2: 149-157.

⁵ Greenhalgh S, Walker S, Simcock R, Gepp S, Wright M 2022. A framework for Biodiversity Compensation and Offsets for harm to indigenous biodiversity in Aotearoa-New Zealand under the Natural and Built Environment Act. Manaaki Whenua Contract Report: LC4131 prepared for the Ministry for the Environment.

Scope of advice and expert opinion

36. My expert advice relates to the following:

- i. Adequacy of the Applicant's assessment of terrestrial flora, vegetation and ecosystems, including identification of any values that have not been assessed or have been insufficiently characterised (Part 1).
- ii. Adequacy of the Applicant's assessment of effects on terrestrial flora, vegetation and ecosystems with specific reference to any effects that are incomplete, understated, or not addressed (Part 2).
- iii. Adequacy of the Applicant's proposed mitigation, rehabilitation and management measures as they relate to terrestrial ecology (Part 3), and potential additional measures.
- iv. Offsetting and compensation (Part 4).
- v. Comments on proposed conditions (Part 5).

37. In these comments, I refer to the Remarkables Ski Area Upgrade and Doolans Expansion Project as 'the Project'. I refer to the Project Site as comprising three areas:

- a. The 'Rastus Burn' comprising the area of the existing Remarkables Ski Area shown on Sheet E101 that falls within the Queenstown Lakes District Council area ('QLDC').
- b. The 'Doolans Basin' comprising the Doolans Basin Ski Expansion Area as shown on Sheet E101, and the area of Helicopter Ridge immediately to the west that falls within the Central Otago District Council area ('CODC').
- c. The 'lower carpark area' (not addressed in these comments).

Material Considered

38. In preparing this advice I reviewed the following documents.

Part A – Substantive Application - Updated documents 4 September 2026	Abbreviation
A-10 – Substantive Application Report Section 3 - Project Description updated 3 September 2026	A-10
A-13 – Substantive Application Report Section 6 - Assessment of Environmental Effects updated 3 September 2026	A-13
A-14 – Substantive Application Report Section 7 – Management and Monitoring of Actual and Potential Effects updated 3 September 2026	A-14
A-16 – Substantive Application Report Section 9 – Approvals Relating to the Resource Management Act 1991 Effects updated 3 September 2026	A-16
A-17 – Substantive Application Report Section 10 – Approvals Relating to the Conservation Act updated 3 September 2026	A-17
A-21 – Effects Management and Compensation Overview Addendum	A-21
Part B – Technical Reports Updated documents 4 September 2026	
B-06 – Remarkables Ski Area Upgrade and Doolans Expansion - Heritage Assessment	B-06
B-08 – Doolans Creek Water Take Assessment of Effects 26 Aug 26	B-08
B-09 – Freshwater Ecological Impact Assessment 27 Aug 26	FEIA
B-11 – Wastewater Discharge Impact Assessment 28 Aug 26	B-11
B-12 – Terrestrial Ecology Impact Assessment 26 Aug 26	TEIA
B-14 – Tracks, Crossings, Stormwater Freshwater Ecological and Hydrological Impact Assessment updated 27 Aug 26	B-14
Part B – Technical reports and drawings	
Remarkables Ski Area Upgrade and Doolans Expansion – Heritage assessment (May 2026)	HA
Remarkables Ski Area Upgrade and Doolans Expansion – Recreation assessment (May 2026)	RA
Remarkables Ski Area Upgrade and Doolans Expansion – Natural hazards assessment (April 2026)	NHA
Part C	
Project Maps and Drawings C-00 – C-11	C-00 to C11
Part F	
F.02 – Remarkables Ski Area Upgrades and Doolans Expansion – Construction Environmental Management Plan (May 2026)	F-02
F.03 – Remarkables Ski Area Upgrade and Doolans Expansion – Terrestrial Ecology Management Plan (May 2026)	TEMP
Part H – Proposed Conditions - Updated application documents	
H.02 – Resource Consent Conditions updated 3 September 2026	RCC

39. I rely on the statements of advice of Dr Kavazos on wetland and freshwater ecology, Dr Watts on terrestrial invertebrate ecology, Dr Maseyk on ecological offsetting and compensation, and Mr Barrell on geomorphology.
40. Polygon shapefiles of the mapped vegetation communities and line shapefiles of project features used to prepare maps in this statement of advice were provided by the Applicant on request.

Site Visit

41. I undertook site visits to the Doolans Basin and Rastus Burn on 30 April and 1 May 2026 respectively. The Doolans Basin was visited in the company of e3s and Applicant representatives as well as DOC representatives. On the Rastus Burn visit I was accompanied by John Roberts (DOC).
42. These visits briefly traversed the sites as far as time and snow and ice conditions allowed. They were for general location familiarisation, and insufficient to undertake any botanical assessment, plant collection and identification, inventory or survey.
43. The timing of the application coincided with the start of winter just before snow covered the basins. There was no opportunity for me to undertake adequate botanical investigation or weed inventory or to field-check the vegetation community maps prepared by e3s for the Applicant.

Feedback to and meetings with the applicant

44. I provided preliminary comments to the applicant on an earlier draft of their terrestrial ecology report. I attended meetings facilitated by the applicant to discuss those pre-application comments with the applicant's ecologists. These meetings were on 4 August (feedback on Wetlands, Streams and Crossings; 2 hr) and 7 August (feedback on terrestrial ecology; 1.5 hr) and 21 August (feedback on lizards; 1 hr). I also attended the applicant's presentation of their effects management hierarchy and the compensation package (15 September, 1 hr).

PART 1 ADEQUACY OF THE APPLICANT'S ASSESSMENT OF TERRESTRIAL ECOLOGY.

45. The Applicant's assessment of **values** in the Terrestrial Ecological Impact Assessment (TEIA) is inadequate.

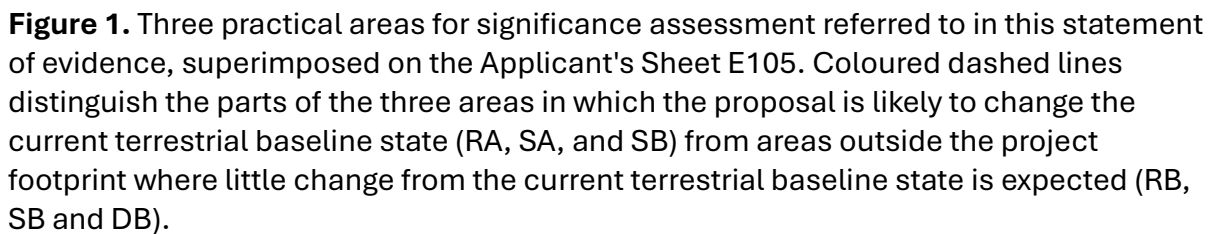
Ecological significance assessment

46. The assessment of significance was undertaken only at the scale of 'vegetation communities' (vegetation types). This is problematic because:
- a. Ecological significance criteria are explicitly designed to identify significant natural areas, and are designed for application to areas (or alternatively 'sites') containing multiple vegetation communities. They are not designed for assessments at the scale of an individual vegetation community within, or scattered across, an area or site⁶.
 - b. Ecological significance assessment at the area (or site) scale is required by the National Policy Statement for Indigenous Biodiversity (NPSIB), Otago Regional Policy Statement (ORPS) and DOC guidelines⁷.
47. I suggest three practical areas for significance assessment within the Project Site are the Rastus Burn, Sugarbowl, and Doolans Basin (Figure 1). The currently unmodified saddle and ridge features on Helicopter Ridge are included with the ecologically contiguous Doolans Basin, consistent with district plans and DOC parcel boundaries. The relatively small Sugarbowl area is distinguished as a remaining unmodified unit in the upper Rastus Burn. All three areas probably meet

⁶ See paragraphs 52 to 54 of this statement of advice, below.

⁷ the NPSIB criteria are in Appendix 1 at <https://environment.govt.nz/assets/publications/npsib-2023-amended-december-2025.pdf>. The NPSIB criteria and guidance are reproduced with little amendment Appendix 2 of the Otago Regional Policy Statement (ORPS) <https://www.orc.govt.nz/media/02jlmga/otago-regional-policy-statement-2021-web-version-with-seal-page.pdf>.

The DOC criteria and guidelines are at <https://www.doc.govt.nz/documents/science-and-technical/sfc327entire.pdf>.



- ⁸ Information in the TEIA is not sufficient to fully assess the significance of the Rastus Burn or Sugarbowl areas. However, the Rastus Burn will satisfy the Rarity criterion because it contains numerous naturally uncommon wetlands and Threatened and At Risk species, including the recently described Threatened - Nationally Critical plant *Montia miniscula* (Heenan 2026). The Sugarbowl also satisfies the Rarity criterion, being made up of NUEs (including screes of acidic rock, and cliffs and bluffs of acidic rock, cushion bog and tarn).

Table 1. Assessment of the ecological significance of the Doolans Basin, following the DOC and NPSIB criteria.

Criterion	Attributes meeting the criterion
Representativeness: the extent to which indigenous biodiversity is typical of the natural diversity of the relevant ED (DOC) or the extent to which the indigenous vegetation or habitat of indigenous fauna in an area is typical or characteristic of the indigenous biodiversity of the relevant ecological district (NPSIB)	The indigenous vegetation across the area has exceptionally high ecological integrity and is wholly representative of the natural character of the ED. It is likely to be the only alpine basin in the ED (and Central Otago more widely) never subject to regular or deliberate pastoral grazing, and therefore a unique baseline. All habitat types support at least a typical suite of indigenous fauna for the ED (and generally higher because of the highly intact state) and retain at least a moderate range of the fauna species expected.
Naturalness: the relative absence of human disturbance or modification within the ED (DOC only)	The most intact basin in the Remarkables ED, with limited historical pastoral grazing and never having experienced fire. It is the only basin with no visible effects of human disturbances. Sign of animal browse is minimal. The avifauna is depleted but typical of, or higher than, across the remainder of the ED.
Rarity and distinctiveness (NPSIB): the presence of rare or distinctive indigenous taxa, habitats of indigenous fauna, indigenous vegetation or ecosystems Rarity and special features (DOC): the natural or induced scarcity of biological, physical and ecological features within an area, and unusual or distinctive features of an area.	A high proportion of the area is comprised of indigenous vegetation or habitat of indigenous fauna on naturally uncommon ecosystems⁹ ('NUEs') being Inland and alpine NUEs • Moraines (recently formed/recent) • Screes of acidic rock • Alpine deflation surfaces • Cliffs, scarps and tors of acidic rocks Wetland NUEs • Cushion bogs • Ephemeral wetland • String mires • Tarns • Seepages and flushes • Snow banks The vascular flora includes at least 38 Nationally and a further 38 Regionally Threatened, At Risk or Data Deficient vascular plant species. There are two Threatened or At Risk bird species and at least 25 invertebrate species unclassified or classified as Data Deficient, At Risk, or Threatened. Other taxonomic groups (e.g. non-vascular flora) were not surveyed or documented and are also likely to include rare species.

⁹ Williams et al. (2007), Holdaway et al. (2012), Brownstein et al. (2025); Brownstein et al. in review

Criterion	Attributes meeting the criterion
	The whole area is highly distinctive, being the most northern alpine basin in the Remarkables ED, with the most extensive continuous tracts of unmodified alpine vegetation and habitats in the Remarkables ED, and the most ecologically intact basin in the Remarkables ED. Within the Basin moraines, tarns and other glacial features formed during repeated late-glacial advances indicate long-term stability in that part of the landscape and provide evidence of past climate conditions. Elsewhere in the Remarkables and Hector Mountains, mobile slopes, creeping deformation and landslides have removed or obscured much of the former glacial record. Highly distinctive features include the Helicopter Ridge alpine deflation surface (formed by exceptional windspeeds), a late-glacial moraine (also a rare or unusual geomorphological feature), an extensive tussock and wetland mosaic across low-relief moraine bench of glacial till and wind ‘touch down’ deflation surfaces on it, a wetland string mire, and ‘Tarn 3’ - the only ephemeral wetland in the Project Site with indications of lake-ice conveyor processes.
Diversity and pattern (the extent to which the expected range of diversity and pattern is present)	Ecological diversity and pattern are not duplicated in other basins in the Remarkables ED. This is the only major basin supporting extensive continuous and connected areas of vegetation across the full range of west, south, east, and north aspects, and across all major microclimates and habitats (including the distinctive late-glacial features listed above) across a significant elevation range. Diverse and extensive interconnected elevation sequences and intricately interwoven mosaics of both terrestrial and wetland vegetation occur on naturally uncommon and other ecosystems.
Ecological context: The extent to which the size and configuration of an area and its degree of buffering from a surrounding landscape affects its ability to maintain its indigenous biodiversity (DOC). Characteristics that help maintain indigenous biodiversity within the area and the wider landscape (NPSIB)	The area is of large extent, with a compact shape containing completely natural and unmodified connected sequences and mosaics of vegetation and unvegetated habitats. The basin is buffered from many surrounding landscape pressures by natural barriers to access. These features together make the Doolans basin exceptionally valuable for the adaptation of the flora and fauna of the ED under climate change.

49. Several features support my opinion that the Doolans Basin was never subject to regular or deliberate pastoral grazing, and in this regard is exceptional in the ED:
- a. The vegetation is unusually intact and in an advanced climax state.
 - b. Although the basin was formerly part of large pastoral lease estates, no physical evidence of historical shepherd huts or fencing has been found in the basin¹⁰.
 - c. There is no evidence of any historic stock tracks within the basin¹¹, which is a distinction from other high-elevation basins in the Remarkables ED where stock tracks are visible. Historic stock tracks in alpine environments can remain discernible for generations due to the slow growth rates in the alpine flora and protracted recovery times in the alpine ecosystems¹².
 - d. The high elevation and southern aspect of the main basin combine to create a particularly short growing season, limiting potential benefit from seasonal pasturage.
 - e. The physical difficulty of access and the incidence of early and late snows are likely to have put stock driven or wandering into the basin at high risk of loss. Therefore, any deliberate historic grazing would have been limited in seasonal duration¹³.

¹⁰ Applicant's report B-06 (Heritage) and statement of advice of Dr Matt Schmidt for DOC.

¹¹ This was my personal observation in the field and matches the Applicant's Heritage assessment (Pages 56 to 58 and Figure 9-12) which points out the only two visible tracks on aerial imagery. Both occur outside the Doolans Basin area (to the south of the intake area) and are interpreted as hiking tracks or walking tracks rather than sheep tracks.

¹² Intact native alpine climax vegetation takes decades or even centuries to recover. Unlike lowland communities where pioneer species exist and quickly colonise disturbed sites, exposed alpine soils lack protective canopies for protracted periods. In addition, compacted soils constrain root systems of slow-growing seedlings, and sheep tracks alter snow meltwater flows and drainage which accelerates erosion in places, preventing plants from recolonising the scar. Freeze-thaw cycles continuously push loose soil around, so that track lines remain as bare, self-perpetuating physical grooves.

¹³ This matter is not directly addressed in statements on Heritage, so I consulted with Dr Matt Schmidt (the Department of Conservation's Heritage expert) on it. Dr Schmidt agreed and noted that *'You don't want your sheep up that high. The loss of hundreds of sheep in the Upper Nevis drove the sheep farming*

- f. Sheep are likely to have strayed into the basin from surrounding runs.

However, there would also have been incentive for pastoralists to actively remove straying stock to preserve them from loss.

50. Ecological significance assessment in context shows that Doolans Basin is an unparalleled ecological baseline for the ED. Key features are its large size and compact shape, the diverse representation of all major physical environments (all aspects and microhabitats), the uniquely intact and undisturbed interconnected vegetation sequences and mosaics present across a significant elevation range, and the buffering provided by strong natural barriers to access. No other basin in the ED provides these characteristics in combination: all show evidence of past grazing, and none provides the equivalent range and scale. These features mean the basin is uniquely capable of maintaining indigenous biodiversity that is characteristic of the ED through climate change.
51. In 1977, 1982, 1990 and most recently in 2019¹⁴ the Doolans Basin has been proposed as part of a wider National Park. Ecological significance assessment in context shows the values of the Doolans Basin meet the National Parks Act s4(1) standard of *‘ecological areas of New Zealand that contain ... ecological systems, or natural features so beautiful, unique, or scientifically important that their preservation is in the national interest ...’*.

down to the Lower Nevis in the 19th century. Sheep still wandered high, but few were allowed to stray higher up the valley particularly when it was getting cold’ (Dr Matt Schmidt, pers. comm. 6 October 2026).

¹⁴ <https://www.doc.govt.nz/get-involved/have-your-say/all-consultations/2020-consultations/kawarauremarkables-conservation-area-reclassification-consultation/>

Application of ecological significance to individual vegetation communities

52. Applying ecological significance criteria only at the level of individual vegetation communities (as in Table 9 of the TEIA) leads to incomplete assessment of ecological significance and value (including irreplaceability).
53. Disaggregation of complex interconnected mosaics and sequences into smaller units:
 - a. omits essential context for interpreting the **representativeness**, **distinctiveness**, and **ecological context** criteria of the assessment¹⁵
 - b. necessarily depresses assessment attributes. For example, fewer species, habitats and features are always present in smaller areas, and therefore fewer rare species, naturally uncommon ecosystems and habitats, and other special features will automatically be present. This downgrades interpretations of **rarity and distinctiveness**;
 - c. leads in the TEIA to spurious comparisons of numbers of species in different communities under **rarity and distinctiveness**. This criterion is met if the diversity and pattern are those *expected* for an area within the context of an ED¹⁶. However, the TEIA incorrectly compares the amount of internal patterning, or numbers of species, among different communities as indications of their *relative* value¹⁷. This approach lacks ecological grounds: different communities naturally have different amounts of internal diversity and support different numbers of species, and relative numbers have nothing to do with relative value;

¹⁵ See Table 1 and paragraphs 50 to 51 of this statement of advice, above.

¹⁶ NPSIB Appendix 1B(1) states that ‘*Diversity and pattern is the extent to which the expected range of diversity and pattern of biological and physical components within the relevant ecological district is present in an area*’.

¹⁷ For example naturally relatively less species rich and less naturally internally variable snow tussock grassland, rockfield and *Dracophyllum* scrub are given only ‘moderate’ value for diversity and pattern compared to (for example) riparian wetland communities which naturally occur across a wider range of environments and support larger numbers of species.

- d. leads to spurious interpretations of **diversity and pattern**, because the very diversity and patterns (including ecotones, gradients and sequences) that are central to assessment of this criterion have been removed by subdivision into vegetation communities; and
 - e. produces defective conclusions about **ecological context** (which are the characteristics that maintain indigenous biodiversity and contribute to protecting an area's biodiversity) because the coherence, connectivity and size and shape characteristics that define the assessment area are excluded from consideration by artificially considering parts in isolation¹⁸.
54. In sum, I consider that the ecological significance and value assessments of individual vegetation classes presented in Table 9 of the TEIA are unreliable because they omit key assessment context, produce ecologically defective conclusions, and downplay ecological value by making spurious comparisons among communities and considering interconnected components in isolation.

Naturally uncommon ecosystems

55. The TEIA relies mainly on maps of vegetation communities. While those maps describe broad vegetation pattern and character across the Project Site, they are insufficient to document the ecological patterns and ecological systems (ecosystems) that will be affected, including those that are irreplaceable.

¹⁸ For example, the TEIA notes that '*occurrences of north facing tussock grassland within the Doolans catchment are isolated forming small disjunct communities*' and that snow banks are '*comparatively small in size and compact in shape, occurring in isolated unconnected patches throughout the landscape*' and accordingly ranks them moderate or low for context. Yet both communities are entirely able to maintain indigenous biodiversity and contribute to protecting an area's biodiversity – they are of wholly natural extents, sizes and shapes, and all occurrences are fully connected to and embedded within mosaics of other communities across the assessment area. Their significance for context is therefore the highest possible.

56. Naturally uncommon ecosystems (NUEs) (Williams et al. 2007; Holdaway et al. 2012; Brownstein et al. in review) are key values that confer ecological significance¹⁹ and also define where biodiversity offsetting and compensation is not appropriate.²⁰ The value assessments for vegetation communities in Table 9 of the TEIA note that some NUEs occur in or are synonymous with some vegetation communities. However, NUEs do not correspond to the vegetation communities mapped in the TEIA, but instead their defining features are physical character and process.²¹ NUE identification in this context requires consideration of geomorphology and physical character, and separate mapping, neither of which is provided in the TEIA.
57. Some types of NUE that occur within the Project Site are not specifically mentioned or identified in the TEIA at all. These include:

¹⁹ In the NPSIB Appendix 1C(6) *'An area that qualifies as an SNA under this criterion has at least one of the following attributes: ... (e) indigenous vegetation or habitat of indigenous fauna occurring on naturally uncommon ecosystems'*

In the ORPS *'An area qualifies as an SNA if it meets any one of the attributes of the following four criteria: representativeness: diversity and pattern: rarity and distinctiveness: ecological context. An area that qualifies as an SNA under this criterion has at least one of the following attributes: ... (e) indigenous vegetation or habitat of indigenous fauna occurring on naturally uncommon ecosystems'*

²⁰ Principle 2 In the NPSIB Appendix 4 Principles for Biodiversity Compensation is *'When biodiversity compensation is not appropriate: Biodiversity compensation is not appropriate where indigenous biodiversity values are not able to be compensated for. Examples of biodiversity compensation not being appropriate include where:*

(a) the indigenous biodiversity affected is irreplaceable or vulnerable ...'

In the ORPS NUEs are mentioned in the Principles for biodiversity offsetting (Appendix 3) and the Principles for biodiversity compensation (Appendix 4). In both appendices, the following is given as an example of a case where biodiversity offsetting/biodiversity compensation is not appropriate: *'the removal or loss of ecological integrity and resilience of a naturally uncommon ecosystem type that contains indigenous vegetation or habitat for indigenous fauna'.*

²¹ For example a scree of acidic rock may be covered partly by rockfield vegetation and partly by cushionfield; moraine may be partly tussock grassland, partly cushionfield and partly rockfield.

- a. **Ephemeral wetland**²², of which the only example in the Project Site is ‘Tarn 3’ (Figure 2) which is proposed to be converted to a reservoir. Tarn 3 is also distinct from the other tarns in Doolans Basin because it is higher in elevation, with a rock-strewn beach²³, and is part of a rare late-glacial moraine geomorphic sequence²⁴. Rather than a tarn of lower ecological value than others in the Doolans Basin²⁵, this ephemeral wetland appears to be of a type, ecological character, and geomorphic origin that is unusual in the ED, and therefore of unusually high value.



Figure 2. Tarn 3, showing the intermittent dryness and mineral substrate that defines an ephemeral wetland, and the rock-strewn beach (DOC 2026).

²² ‘...a wetland class, typically occupying a closed depression that lacks a permanent surface outlet channel, having mineral soil and a marked seasonal alternation between being ponded and dried, the wetness and the wetland tending therefore to be ephemeral’ (Johnson & Gerbeaux 2004)

²³ Beaches are not generally characteristic of tarns because there is limited wave fetch. Formal geomorphological interpretation may determine that the rocky beach is formed by ‘lake-ice conveyor’ processes more characteristic of Antarctic Dry Valley systems (Hall et al. 2006). The process would be that rockfall deposition from the cliff above becomes embedded in winter ice and is ice-rafted across the tarn surface as water level rises or winds shift.

²⁴ Statement of advice of Mr David Barrell for the Department of Conservation Fig. 1 and paragraph 35.

²⁵ The FEIA does not recognise these distinctive and unusual attributes, and instead suggests that ‘Tarn 3 was found to have the lowest ecological values of the surveyed tarns’.

- b. **Moraine**, which was not identified as a type of NUE present in the assessment area at all²⁶. Moraine ecosystems account for sizeable areas of Doolans Basin that will be removed and/or fragmented by earthworks for the proposed Doolans Access Road, Doolans ski trail, Doolans Base Area and Learners Slope. For example, the feature described as a *‘significant and spectacular ancient ‘Rock Glacier’ feature’* in the Natural hazards assessment²⁷ is a late-glacial moraine²⁸, and the large, gently sloping tussock-covered landform at around 1600 m that contains the basin’s major cushion bog and string bog wetlands is a moraine bench²⁹ (the largest of such features in the ED). Indicative locations of these two prominent moraine features are mapped in Figure 3. The water take access track is likely to cross further (unidentified) moraine landforms which are also NUEs. The late glacial moraine has value beyond being a naturally uncommon ecosystem, because it is a rare and unusual geomorphological feature that is unusually well-preserved and therefore has scientific importance as a climate archive³⁰.

²⁶ There is a single mention of till (depositional material that makes up moraine) being mapped in GNS Science’s QMAP on page 31 of the TEIA.

²⁷ Fig. 53 and p. 56 of the Applicant’s Natural hazards assessment (NHA)

²⁸ This is the late-glacial moraine feature described in the statement of evidence of Mr David Barrell for the Department of Conservation.

²⁹ GNS Science’s 1:250,000 (quarter-million) geological map (‘QMAP’) identifies this moraine bench landform as till, which is the depositional material that makes up moraine. The presence of this till, but not its location or its identity as moraine, is also noted on page 31 of the TEIA. The moraine bench is distinct from the late-glacial moraine described in the statement of advice of Mr David Barrell for the Department of Conservation. Instead, it is one of the relict glacial-episode landforms listed in paragraph 16 of Mr Barrell’s statement.

³⁰ Statement of advice of Mr David Barrell for the Department of Conservation.

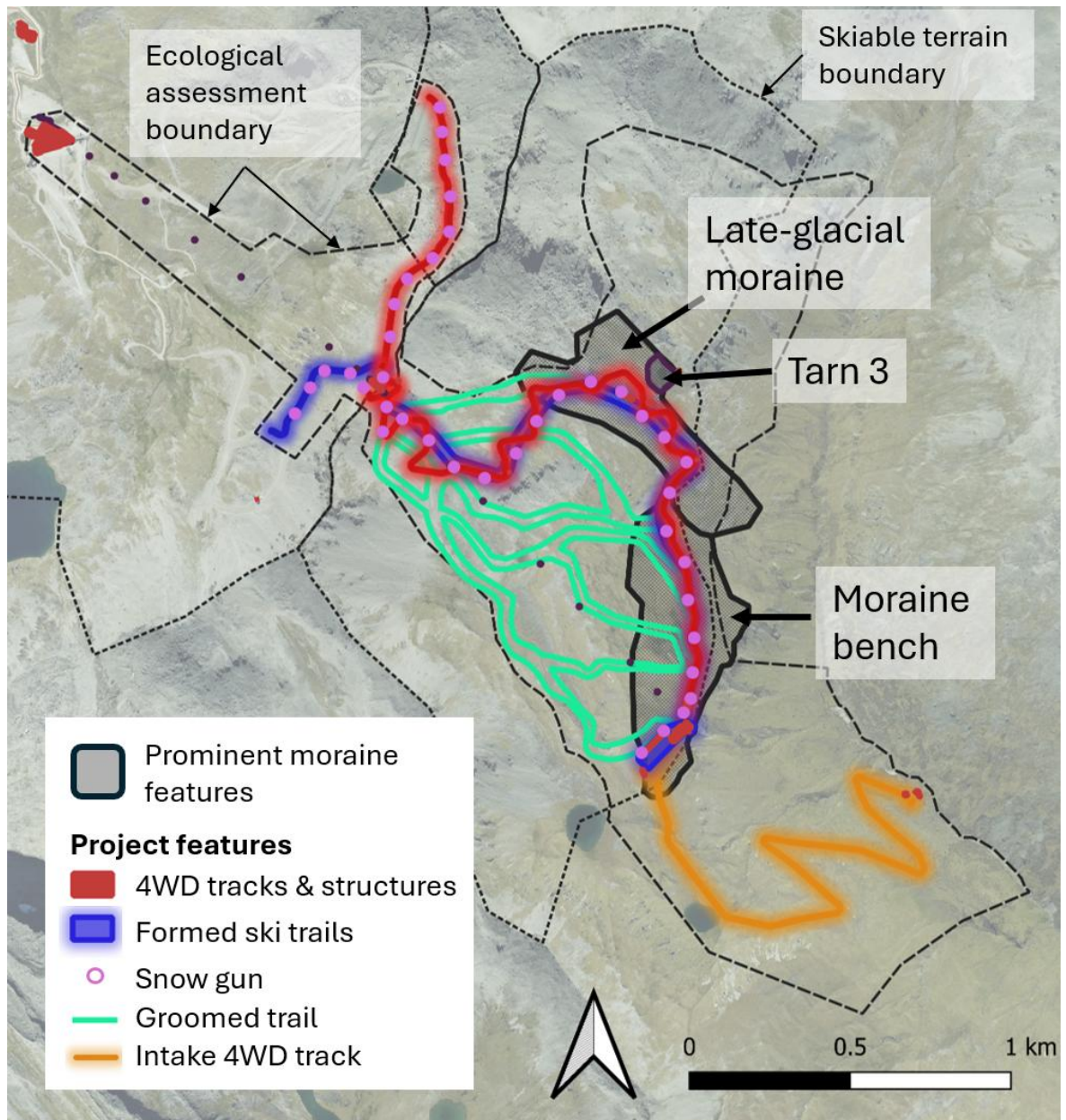


Figure 3. Indicative locations of two prominent moraine features (Late-glacial moraine and Moraine bench, shown as grey shaded polygons outlined in bold) impacted by the Project in Doolans Basin, in relation to major project features. Other areas of moraine are likely to be present across the Project site but are not mapped in this figure.

- c. **Alpine deflation surfaces**³¹, which are wind-scoured fell-fields that are regularly blown free of snow in the winter, often where wind is funnelled and strips snow from exposed saddles and localised sites in leeward valleys, subjecting the vegetation to unusually severe winter cold stress. The most spectacular example of an alpine deflation surface in the Project Site (part of the 'screes of acidic rock' NUE) forms the Helicopter Ridge location which is proposed to be destroyed by earthworks to create the proposed Gondola Mid Station (Figure 4). A related wind 'touch down' surface (indicated by an abrupt transition from tussock grassland to cushionfield) occurs on the margin of the moraine bench at about 1600 m (Figure 5). This NUE would also be destroyed by the Project because it is the proposed site of the Lift Station in the Doolans Base Area.

³¹ Alpine deflation surfaces are not one of the 72 types listed in Williams et al. (2007) but are noted in the Discussion of the recent revision (Brownstein et al. in review) as a potential future addition to that list. In the Doolans Basin, alpine deflation surfaces are already considered NUEs because they occur on two other listed NUE types (screes of acidic rock and moraine).

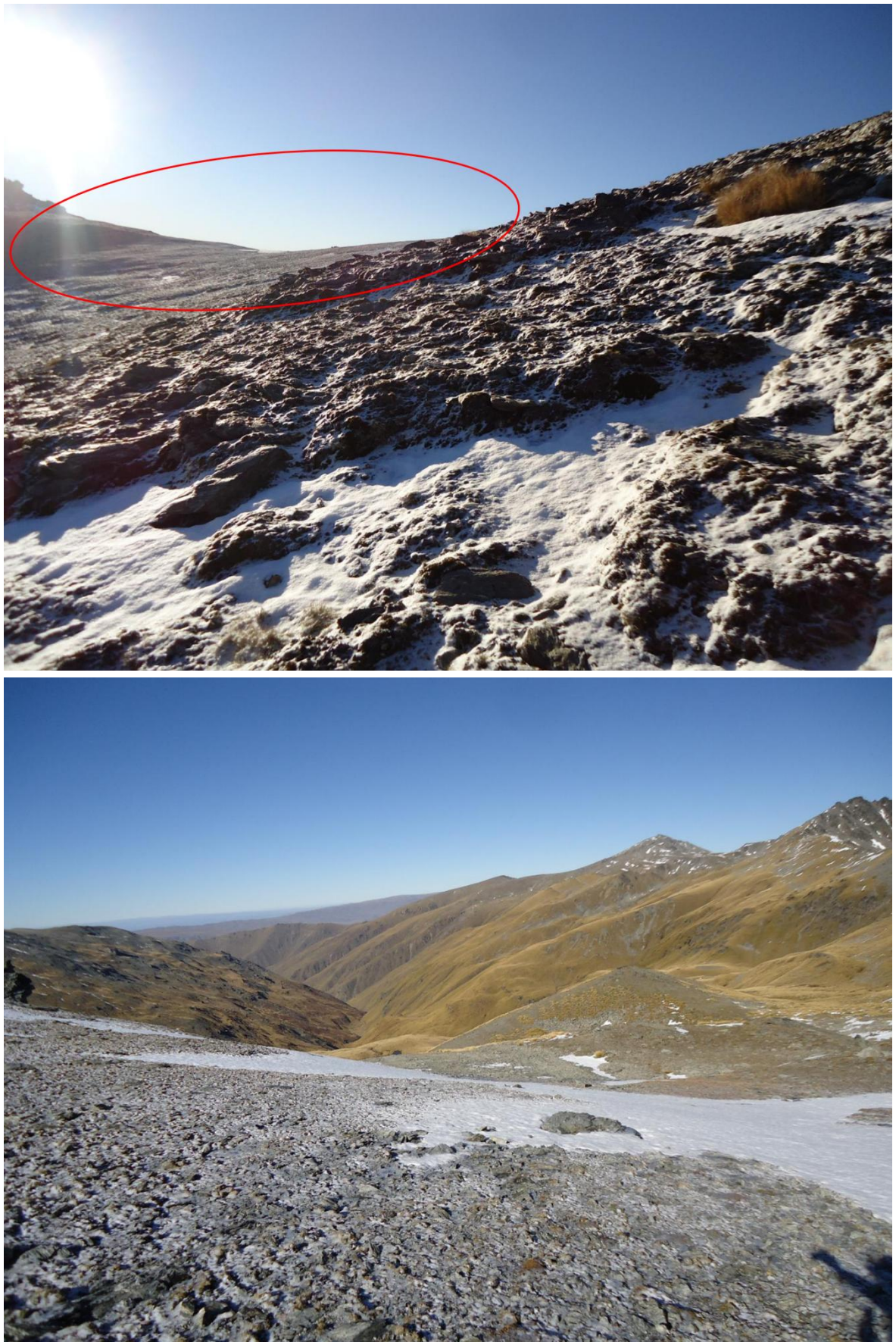


Figure 4. Alpine deflation surface formed by extreme windspeed on screes of acidic rock on Helicopter Ridge (the site of the proposed Gondola Mid Station), seen when on approach from the Rastus Burn (above, deflation surface circled), and standing on the saddle looking south (below, deflation surface in foreground). (Susan Walker 2026).



Figure 5. The ‘wind touch down’ alpine deflation surface (circled in red) in the southern lee of Helicopter Ridge is decipherable as an abrupt transition from snow tussock grassland (left) to cushionfield (right). The deflation surface and cushionfield is the proposed site of the proposed Lift Station in the Doolans Base Area, and is part of the larger moraine bench NUE (outlined by yellow dashed line) that will also support the proposed Doolans Ski Trail and Learners Slope. (Susan Walker 2026).

58. The most extensive vegetation community mapped on the moraine NUEs in the TEIA is snow tussock grassland. The moraine bench (Figure 5) is mapped largely as a mosaic of snow tussock grassland, seepage wetland, and cushion bog vegetation, with areas of cushionfield vegetation mapped on the eastern margin of the moraine bench where there are wind deflation surfaces. The TEIA descriptions³² do not identify that either snow tussock grassland or cushionfield communities occur on naturally uncommon ecosystems.
59. The ‘scree of acidic rock’ NUE is partly mapped as ‘rockfield’ (which is likely to be wholly scree of acidic rock NUE) and partly as cushionfield and high alpine cushionfield (both of which occur on the scree of acidic rock NUE, on the

³² TEIA Table 9

moraine NUE, and on other landforms). Therefore, boundaries of the ‘scree of acidic rock’ NUE cannot be identified from the vegetation community map in the TEIA.

60. In summary, NUEs and their ecological values which require avoidance under the ORPS cannot be adequately identified from the information provided in the TEIA. Effects on key NUEs were not identified by the Applicant, and as a result, effects management was not applied to them.
61. The Applicant states that ecologists informed the avoidance of certain vegetation communities in the alignment selection³³. Some plant communities may have been avoided in design, but because the distinctive ephemeral wetland, moraines and alpine deflation surfaces were not recognised and were not mapped, they were not avoided. Instead, it is proposed to heavily impact or wholly remove those features for the construction of the Doolans Ski Trail, Gondola Mid Station, Doolans Base Area and Learners Slope.

PART 2. ASSESSMENT OF EFFECTS

62. The Applicant’s assessment of effects is inadequate in several ways.

Wrong scale of assessment of effect magnitude

63. The assessment of effect magnitude in the TEIA is repeatedly understated and diluted by placing it in an incorrect (inflated) context.
64. In Table 9 of the TEIA, ecological value was assessed at the scale the vegetation community within the field assessment area. But in Table 14 of the TEIA the scale chosen to determine the magnitude of effect is the estimated full extent of that

³³ A-21 – Effects Management and Compensation Overview Addendum page 6. The addendum states (p. 6) that priority for avoidance was wetlands, watercourses or flow paths, ‘high value snowbank habitats’ and ‘high-value cushionfield areas’. Appendix A to A-21 says that they also sought to avoid *Dracophyllum* shrubland, cushionfield, and wetlands. Rockfield and tussock grassland were considered to be some of the lower value vegetation communities within the Project area, and were targeted for infrastructure because they were judged to be more resilient, not recognising that these communities occur on NUEs.

vegetation community across the whole ED above 1100 m³⁴. The scale chosen for assessment of effect magnitude in the TEIA is on average 65 times the scale of values assessment (and >100 times the value-assessment scale for tussock grasslands and rockfield-dominant communities)³⁵.

65. The scale mismatch:

- a. minimises the apparent magnitude of effects;
- b. is directly contrary to industry (EIANZ) guidance which has clarified³⁶ that ***‘[t]he magnitude of effect should be assessed at the same scale as the ecological value assessment, with wider district, regional or national context informing, but not supplanting, that assessment’***; that *‘[w]ider ecological context remains important but should not be used to dilute or amplify effects by substituting a different spatial scale for that used in the value assessment’* and that such amplification of scale *‘deviates substantially from the guidance’*; and
- c. contrasts with the FEIA where the denominator for effect magnitude for each feature was the extent of that feature within the Doolans Basin (consistent with EIANZ guidance).

³⁴ This denominator is not applied entirely consistent within the TEIA. For example, the magnitudes of effects of weeds and sedimentation appear to have been assessed at the same scale as the assessment of values and not the whole ED above 1100 m.

³⁵ TEIA Table 13

³⁶ EIANZ 2026. Explanatory note. Ecological Impact Assessment EIANZ Guidelines for use in New Zealand terrestrial and freshwater ecosystems. Interpretation of scale in assessment of ecological values and magnitude of ecological effects. <https://www.eianz.org/document/item/8955>.

The note states that *‘contextual information about the wider landscape should not replace the scale at which the ecological values were assessed, particularly where the wider habitat has not been surveyed, mapped or valued to an equivalent level of detail. Nor should the existence of additional habitat elsewhere be used to dilute the permanent loss or modification of a rare, threatened or otherwise important ecological feature within the site or zone of influence. ...*

EIANZ’s concern with such an example is that amplification of the assessment scale may understate a detectable ecological loss. This may result in the effects assessment being discontinued before appropriate consideration is given to avoidance, minimisation, remediation, mitigation, offsetting, compensation and possibly monitoring’.

66. The application of the random forests ('RF') GIS application³⁷ used to widen the frame of reference to the whole ED above 1100 m is flawed. The predictions of that RF model are unsound because³⁸:
- a. RF and other similar machine learning models cannot be used to predict beyond the area of survey data (limited here to the training data extent in Fig. 7 of the TEIA). A model that has never 'seen' data in the new territory will assume the patterns it learned will continue infinitely, which is rarely true in the real world. The model can only predict the communities that are input, so any 'unseen' community is incorrectly assigned to a 'seen' community, automatically inflating the predicted extent of 'seen' communities across the ED;
 - b. abrupt linear artefacts interpreted as vegetation shifts are caused by spectral variation among tiled aerial photographs in the predictor data (these abrupt predicted vegetation shifts at photograph boundaries are incorrectly referred to as 'edge effects' in the TEIA)³⁹;
 - c. the precision of the RF predictions will consequently be some orders of magnitude lower than the one hundredth of a hectare suggested by 2 decimal places, even without accounting for any error in field mapping for the training dataset⁴⁰; and

³⁷ TEIA pp 12 to 16 (Section 2.2.3 Estimating the Extent of Ecological Communities Across the Ecological District).

³⁸ The predictions are invalid because models like this cannot be used to predict beyond the scope of surveyed input data (as was done here) because they can only identify those communities that are input. Any different community that occurs in reality will be incorrectly assigned.

³⁹ Different image tiles (different photographs tiled together to make up a composite aerial image) have different lighting, atmospheric conditions, and camera angles, and the model incorrectly interprets these sudden shifts as distinct features rather than continuous terrain. These are not 'edge effects'.

⁴⁰ In my experience no field mapping can be perfectly accurate. Appropriate rounding should be incorporated into all mapping estimates for transparency and so as not to imply an unrealistic level of precision.

My inspection of the GIS mapped polygons supplied by the Applicant suggests that the mapping accuracy is much lower than implied in the TEIA tables (e.g. Table 14) which round areas to the nearest one hundredth of a hectare. That rounding implies that the likely error in the area estimate for each vegetation

d. these limitations are not stated in the TEIA.

Effects on terrestrial naturally uncommon ecosystems not assessed

67. The extent of loss of terrestrial naturally uncommon ecosystems (NUEs) (i.e. moraine, screes of acidic rock, and alpine deflation surfaces on them) is not documented. This is because those NUEs are neither identified nor mapped, and areas of direct disturbance are estimated only for vegetation communities (which NUEs do not correspond to⁴¹).
68. The correct scale at which to determine the magnitude of effects on NUEs would be their extent across each assessment area (i.e. Doolans Basin, Sugarbowl, and Rastus Burn; see Figure 1). Effect magnitudes are likely to be very high, especially in the Doolans Basin area, where it appears that most of the direct disturbance footprint would result in the loss of NUEs.
69. I have shown the general locations of the unidentified NUEs on Figure 6, using Figure 26 from the TEIA as a base map to provide a high-level indication of the full extent of proposed impact. In Figures 7 and 8 I show the locations of selected NUE features and project features at somewhat higher resolutions.

type across the TEIA mapping area is expected to be less than 100 m² (equivalent to a single 10 x 10 m square area on the ground). Given the coarse mapping scale, I estimate that many individual polygons would have had mapping errors of 100 m² and likely greater. Therefore, mapping uncertainty for a vegetation community across the whole mapping area will have been in the tens to hundreds of hectares (depending on the extent of that community). Area estimates should have been rounded up to the nearest ten or one hundred hectares to acknowledge and reflect this uncertainty.

⁴¹ As explained in paragraph 58 and 59 in this statement of advice

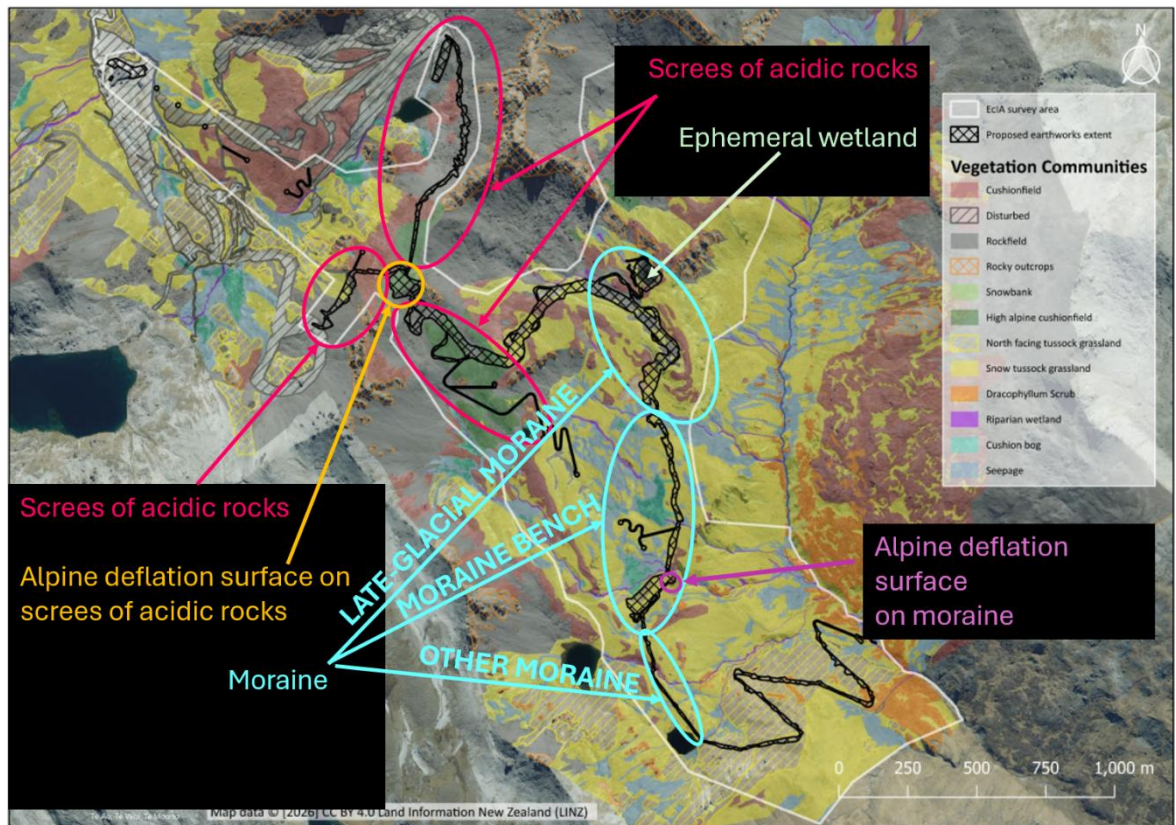


Figure 6. General locations where naturally uncommon ecosystems (NUEs) that were not identified in the TEIA will be directly impacted by the project.

70. In the Doolans Basin, the Project would result in complete destruction or considerable modification of distinctive NUEs that have not been identified in the TEIA (Figure 6).
71. These effects would include permanent loss of the extreme alpine deflation surface on Helicopter Ridge (screes of acidic rock NUE) for the excavation and construction of the Doolans Mid Station and its platform (Figure 7).

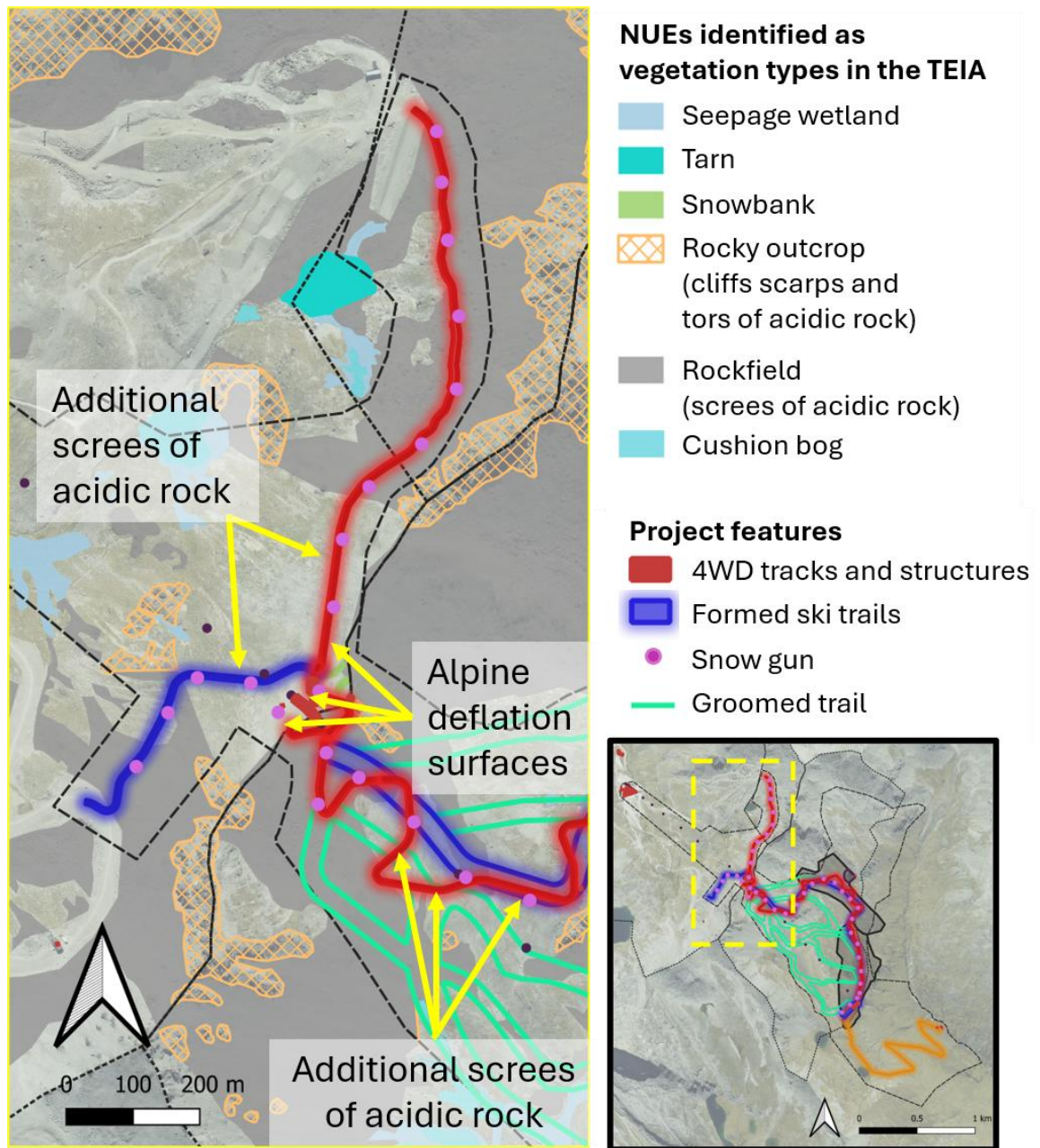


Figure 7. Detail of the Helicopter Ridge divide between the Rastus Burn and Doolans catchments, showing some locations (identified by yellow arrows with labels) where screes of acidic rock and alpine deflation surfaces (naturally uncommon ecosystems or NUEs) were not identified in the TEIA and are intersected by project features. The ‘Rockfield’ vegetation community (screes of acidic rock NUE) and other vegetation communities that are identified as NUEs, or correspond with NUEs, are also shown. The yellow dashed polygon on the inset map shows the location of the detail area within the Project site.

72. There would also be significant, irreversible loss and fragmentation of the late-glacial moraine landform for the excavation and construction of the proposed Doolans Ski Trail; and of the intact, interconnected terrestrial-wetland complex on the moraine bench for the excavation and construction of the proposed Doolans Ski Trail, Doolans Base Area and Learners Slope. The wind deflation surface on the margin of the moraine bench would be completely cleared for the construction of the Doolans Base Area (Figure 8).

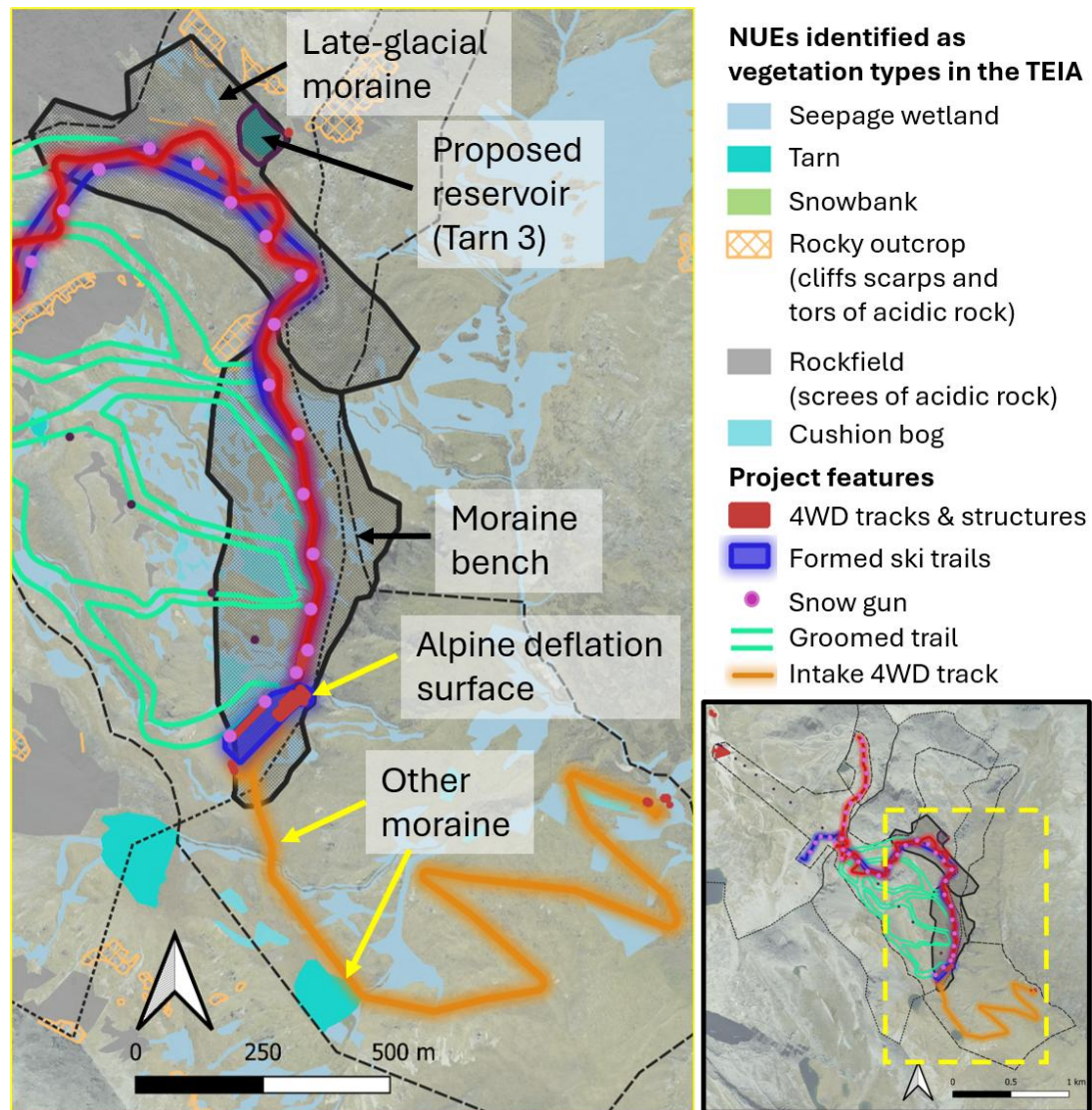


Figure 8. Detail of part of Doolans Basin, showing locations where naturally uncommon ecosystems (NUEs) are intersected by project features. The late-glacial moraine and moraine bench features are shown as labelled grey shaded polygons (indicated by arrows). Tarn 3 (both an ephemeral wetland and tarn NUE) is the site of the proposed reservoir. Yellow arrows show the location of the alpine deflation surface (under the proposed Doolans Base Area) and where the route of the intake 4WD track may intersect other moraine landforms. Vegetation communities from the TEIA that are identified as NUEs or correspond to NUEs are also shown. The yellow dashed polygon on the inset map shows the location of the detail area within the Project site.

73. In the Rastus Burn catchment, there would also be loss and modification of NUEs (screes of acidic rock) for the temporary construction access above the current Sugarbowl ski area north of Helicopter Ridge, and for the permanent access and service route between Helicopter Ridge and Curvey Basin⁴².
74. Excavation of and construction on the late-glacial moraine would also irreversibly disturb scientifically important well-preserved glacial features and reduce the ability to investigate them to address regional and global climate questions⁴³.

Key wide-scale ecological effects of ski-field management are not described

75. Many of the most important effects of the proposal on terrestrial and freshwater ecosystems are missing from both the TEIA and the FEIA. Key effects that are missing or understated are those of (winter) snowmaking, snow grooming and skiing, and summer visitors and road use, especially as they affect the Doolans Basin ecosystem.
76. With respect to winter activities, there is a scientific literature documenting how winter snowmaking, snow grooming, skiing cause ecological degradation to alpine soils through inducing physical compaction, increasing soil frost depth, altering moisture regimes, elevating nutrient loads, and causing erosion and sedimentation. These activities impact mountain vegetation communities through delayed springs and shortened growing seasons, and numerous shifts in below and above-ground community character and composition, in addition to mechanical plant damage. The emergent effects are cumulative ecological degradation and maladaptation of the ecosystem to climate change.
77. The scientific source references for my paragraphs on the effects of snow making and snow grooming are:
 - a. The scientific literature contained in the review of Meijer zu Schlochtern et al. (2014) (appended to this statement of advice as **Attachment 1**).

⁴² Mapped as cushionfield and therefore not identified as a NUE.

⁴³ Statement of advice of Mr David Barrell for the Department of Conservation.

- b. Relevant scientific literature since the Meijer zu Schlochtern et al. review (appended to this statement of advice as **Attachment 2**).

Snow making (artificial snow)

78. Key physical effects of **snowmaking** (and the artificial snow it produces) on ecosystems are soil compaction and saturation, greater snowmelt and runoff, erosion and sedimentation, delayed snowmelt, and the nutrient enrichment/eutrophication of receiving environments, as follows:
- a. **Accelerated compaction, soil surface ice and soil saturation:** healthy alpine soils rely on a network of open macro-pores for roots, invertebrates and microbes to breathe. Natural snow is light and insulating but artificial snow has higher static weight (135% of natural snowpack) which compacts soil. Solid layers of basal ice on the soil surface block oxygen transfer, causing soil anoxia. Artificial snow introduces up to four times the water mass of natural snow. Prolonged soil waterlogging results, making soils more susceptible to compaction both by snowpack and by snow groomers.
 - b. **Greater, later spring melt:** under natural conditions, alpine meltwater slowly percolates through soil, but the artificial snowpacks add significantly more water (2 to 4 times as much) and delays the melt of dense heavy artificial snow by 2 to 4 weeks. This combines with compacted and saturated soils to create a later, more rapid, higher-velocity runoff across the surface that can scour and create erosion.
 - c. **Delayed snowmelt:** delayed melt of dense heavy artificial snow means the growing season and carbon fixation is compressed. Additionally, soils that cannot drain or breathe properly stay frozen and cold longer into the spring and summer.
 - d. **Nutrient enrichment and pH alteration:** the higher-conductivity water from the lower-elevation Doolans Creek⁴⁴ would increase ion input,

⁴⁴ Table 4 of the FEIA (report B09) shows higher conductivity (Doolans Creek sites DC1 60.7, DC2 66.8, Weir 47.3) vs Tributary ('Trib') sites (Trib A 12.9 and Trib C 12.6). Water in the Doolans Creek also have higher pH (DC1 7.55, DC2 7.41, Weir 7.42 vs Trib A 7.30 and Trib C 7.09). Conductivity and pH at DC3 (35

artificially elevating nutrients and pH. Nutrients from the creek water would be distributed, and pH altered, throughout the receiving drainage network below the main trail, including wetlands. Dr Kavazos addresses the quantum and likely effects of this transfer on the Doolans Basin freshwater ecosystems in his statement of advice⁴⁵.

79. In terrestrial ecosystems, the combination of heavy, nutrient-rich, lower-pH runoff and prolonged soil wetness and snow cover can lead to many biological shifts above and below ground, including reduced decomposition of organic matter; root suffocation and rot, and vegetation and soil fauna die back, and loss of invertebrate habitat.
80. Other effects recorded in scientific studies are the replacement of aerobic soil nutrient cycling bacteria and fungi by anaerobic soil microbes, and a shift from fungal-dominated soil microbial communities of relatively infertile soils towards bacterial-dominated soil communities. These changes accelerate soil nutrient turnover, creating further positive feedback to a nutrient cycle already enhanced by snowmaking water from lower elevations.
81. Overseas studies have also recorded plant composition changes to slow-starting, late flowering, snow-bed species and short-season generalist species (including weeds) that tolerate saturated compacted soils and capitalise on eutrophic conditions. They have recorded decreases in abundance of early emerging native alpine invertebrates, of flowering plants adapted to well-drained, early-thawing soils, and of wind-edge species and ecotypes adapted to lower and briefer winter snow cover. The life span, life form, strategy type, leaf persistence, and elevational affinity of plants in the community are all affected.
82. The TEIC notes⁴⁶ that in the Doolans Basin *‘the proposed ski trails (which have snowmaking) will be established atop areas proposed to be disturbed to establish the ski-field expansion. Therefore, the compaction of snow within these areas will*

and 7.15, respectively) are not as distinct due to dilution effects of Trib B which is immediately upstream (Figure 5 on p. 17 pf of report B09).

⁴⁵ Statement of advice of Dr Kavazos, **PART 3: Assessment of effects** under *Ongoing operational effects on freshwater environment*

⁴⁶ TEIA page 131 in Section 6.8.4 Increased Human Presence and Ski-field Operation

not have additional loss of vegetation within an area that will be fundamentally different post disturbance’.

83. If artificial snow is not discharged, moved by grooming or blown off the engineered Doolans Ski Trail (which seems unlikely) the TEIA would be correct, but with respect to soil and snow compaction only. There would be additional and more widespread effects of increased late, nutrient enriched runoff onto and into all indigenous freshwater and terrestrial ecosystems that receive meltwater, which are not considered in the TEIA or the FEIA.
84. I have assumed that neither biological nor inorganic ice nucleation additives (‘INA’)⁴⁷ will be used for snowmaking. If they are used, INA could have further negative effects not addressed in this statement⁴⁸. The Applicant has said that ‘*in most cases natural refrigerants can be used*’⁴⁹ but does not say what those are, how or when they will be used, nor described their ecological effects.

Snow grooming

85. Effects of **snow grooming** (proposed widely within the Doolans Basin⁵⁰) on ecosystems also include delayed spring melt. Although there is no added water or nutrient enrichment, grooming on natural snow instead causes a loss of insulation and hence deeper frost penetration into soils, and the resultant effects on soils and vegetation are different and more complex. Notable effects on ecosystems not mentioned in the TEIA are:

⁴⁷ I understand there are three potential types: (1) biological nucleators (bacterial proteins) containing freeze-dried, sterilized cells of the plant-pathogenic bacterium *Pseudomonas syringae*; (2) mineral nucleators (clays) which are fine, naturally occurring aluminosilicate minerals such as kaolin clay or montmorillonite; and (3) hardening salts (not always classified as ‘natural’) which are mineral compounds like ammonium nitrate, urea, or chloride salts that harden the snow surface.

⁴⁸ For example, surviving bacteria or toxins in dead bacteria could adversely affect plants, and laboratory tests have shown that sterilized *P. syringae* proteins can affect plant growth due to their ability to induce ice formation at temperatures below the ice melting point. Precautionary bans in countries like Austria, France, and Germany since 1997 have denied researchers of “active” INA-treated fields to study, so that the extent to which INAs are ecological threats under real-world conditions remains unknown.

⁴⁹ Response to the Panel’s RFI https://www.fasttrack.govt.nz/_data/assets/pdf_file/0018/30168/FTAA-2605-1236-Remarkables-and-Doolans-RFI-Response-Climate-Change.pdf at final bullet point on page 6.

⁵⁰ See Map Sheet E105 in C-00 General Arrangement

- a. **Snow compaction drives loss of insulation:** when natural snow is altered and compacted by grooming it loses its natural insulating properties which hold the soil surface at zero degrees⁵¹. Under compacted groomed snow, alpine plants and the soil microbes can be subjected to below-zero (freezing) conditions more than half a metre underground, rather than just at the very surface, and there is increased net ammonification and net N mineralisation in soils over winter.
 - b. **Delayed springs accompanied by nutrient leaching:** the denser groomed snow also melts 2 to 4 weeks later than normal, releasing a late surge of water and mineralised nutrient leaching into receiving wetlands and streams.
 - c. **Surface soil over-wetting:** with deep-frozen soils, spring meltwater gets trapped in a layer above the frozen sub-surface layers, causing surface soil over-wetting, surface runoff, and exacerbated erosion.
86. Deeper freezing has complex adverse effects on soils. It inhibits the microbial community and reduces microbial activity, also impacting the soil aggregate stability, litter decomposition processes and soil carbon (C) and nutrient dynamics, including net nitrogen (N) mineralization. Increased root mortality and reduced plant nitrogen uptake induced by soil freezing can also increase soil nitrate levels, even without an increase in net mineralisation or nitrification. The net result is depleted soil structure, altered nutrient and microbial regimes, and diminished primary productivity and soil C stocks.
87. Delayed melt-out delays the flowering phenology of early-flowering species because cold soils under compacted snow delay their development⁵². There are also changes in functional composition from more frost-sensitive to more frost-tolerant species.

⁵¹ For example, Rixen et al. (2008) found that the temperature conductivity of snow on ski slopes (the rate at which it loses heat) is 2.5 times higher for compacted artificial snow and twice as high for compacted natural snow, compared with uncompacted natural snow.

⁵² The biological delay for the plants stretches even longer than the physical snowmelt delay: plant growth and flowering cycles are set back by up to five weeks relative to undisturbed natural areas even after the snow has completely melted (Rixen et al. 2008).

88. The TEIA does not address the above systemic effects of snow grooming on the ecosystem's soils, biota and ecosystems at all. It mentions only that '*thin snow coverage-imposed equipment damage*' to vegetation and soils '*is likely restricted to isolated locations, particularly convex slopes ...*'⁵³.
89. Direct mechanical damage to vegetation by grooming is likely to occur in addition to the effects I have listed above. However, local mechanical vegetation damage will not be the most consequential or widespread ecological effect. Because the TEIA overlooks those other effects on soils and ecological communities, it considerably understates the types, extent and magnitude of effects that snow grooming would have on the Doolans Basin ecosystem.

Skiing and snowboarding

90. Skiing and snowboarding cause similar effects of snow compaction and direct mechanical damage to vegetation to those of snow grooming, but with a different spatial distribution (concentrated at pinch points⁵⁴).
91. In addition, skiers introduce pollution from:
- a. Per- and polyfluoroalkyl substances (PFAS) in ski waxes⁵⁵ rub off onto the snowpack and flush directly into alpine soils and water with snowmelt. In highly organic alpine turf, long-chain perfluoroalkyl carboxylic acids (CL-

⁵³ The TEIA also assesses the effect at the scale of the whole Ecological District to be negligible in magnitude and low in effect. As noted earlier that scale is inappropriate and contrary to EIANZ guidance.

⁵⁴ Skier traffic tends to funnel into the same narrow physical pathways and concentrated traffic strips away vegetative cover in narrow bands where they traverse hillslopes and at the base of moguls (Wardle & Fahey 2002). Roux-Fouillet et al. (2011) showed lower plant cover, higher soil pH and lower organic matter developed over 8 years on ungraded ski pistes compared with control plots.

⁵⁵ For scientific literature see Vogel et al. (2024), Plassmann & Berger (2013), Carlson & Tupper (2020), Grønnestad et al. (2019). Informal accounts include <https://www.innovationnewsnetwork.com/swiss-ski-slopes-contaminated-with-forever-chemicals-from-ski-wax/63869/> and [EMPA \(2025\) PFAS in ski wax - forever chemicals on the ski trail](#). There is no direct domestic ban on PFAS in New Zealand, and while overseas manufacturers are phasing out PFAS, they will be legacy effects from older consumer inventory.

PFCAs, a subgroup of PFAS) bind to soil organic matter and bioaccumulate in the food chain⁵⁶.

- b. Ultra-High Molecular Weight Polyethylene (UHMWPE) particles and fibres abrade off synthetic bases of skis and snowboards, and synthetic microfibers (polyester and polyamide) shed from technical outdoor apparel⁵⁷. These microplastic fragments can significantly change soil physical and chemical properties, and microbial communities, indirectly or directly affecting plant growth and stress resistance, mycorrhizal colonisation and community composition⁵⁸.

Maladaptation to climate change

- 92. Climate change is changing temperatures and precipitation patterns and is predicted to decrease natural snow cover and reduce snow seasons in the New Zealand mountains (Table 2). Thinner snow cover is predicted, which will melt earlier, causing a longer plant growing season. This will drive adaptations in the flora, fauna and ecosystems in the opposite direction to those in response to prolonged snow-lie and more extreme soil freezing associated with groomed and artificial snow on ski slopes.
- 93. Where slopes are groomed and where there is snow making, ecosystems will not only be degraded⁵⁹, but also effectively blocked from naturally adapting their phenology and stress traits to match the actual climate shift. Therefore, when winter temperatures rise past the point where artificial snow making can keep the ski-field viable, the remaining ecosystems will be unequipped to survive the

⁵⁶ For scientific literature see Wang et al. (2025). A comprehensive [summary of the literature and known ecological effects](#) of PFCAs informed restrictions under the Stockholm Convention on Persistent Organic Pollutants.

⁵⁷ For scientific literature see Dassie et al. (2025), Eraslan et al. (2026), and Carney et al. (2018).

⁵⁸ For scientific literature see de Souza Machado et al. (2018, 2019), Hu et al. (2026), Rillig & Lehmann (2020), and Zhao et al (2024).

⁵⁹ As described in the sections on effects of snow making and snow grooming in this statement of advice.

sudden stresses of a warmer, drier alpine environment. There will be no practical remedy for these effects⁶⁰.

Table 2 Summary of expected climatic changes and effects⁶¹

Winter warming: Across the new skiable terrain (largely 1600 to 1800 m elevation) climate change is expected to increase average annual temperature increase of 1.5°C to 2.5°C over the next 35 to 40 years. Frost days will greatly decrease, so winter soil freezing becomes intermittent, and daily winter freezing level (currently averaging around 1200–1400m) will regularly lift above 1600m, so precipitation more often falls as rain between 1600 and 1800m.
Precipitation and wind: Winters are predicted to be wetter (by 10 to 20%) and summers drier, but there will be more extreme heavy deluges with significantly higher volumes of water over short periods. Intense unseasonal winter rain-on-snow events will also likely trigger rapid snowmelt, flash runoff, and erosion. NIWA has also predicted substantial increases in average and extreme wind speeds during winter and spring.
Snow cover: The natural snow season is expected to contract at both ends, arriving later in winter and melting 2 to 3 weeks earlier. There is also likely to be extreme inter-annual volatility (feast or famine) with one winter experiencing severe snow droughts with entirely bare rock at 1800m, and the next possibly featuring heavy, wet, cyclical snowstorms.
Summer conditions: Many summers will exceed historic heat and drought records, some causing extremes of desiccation.

⁶⁰ In response to the Panel's RFI https://www.fasttrack.govt.nz/_data/assets/pdf_file/0018/30168/FTAA-2605-1236-Remarkables-and-Doolans-RFI-Response-Climate-Change.pdf, the Applicant points to conditions in the present concession that require it to 'make good any damage' and 'replant the affected Land with indigenous vegetation of a similar abundance and diversity as that which existed generally in the vicinity prior to the structures or improvements being installed'. It will not be practically possible to make good this type of damage (decades of maladaptation). The extent of damage may also be beyond the scale of practical repair. For example, landscape scale replanting with ecotypes grown from lower elevations would not restore the adapted complex ecosystem with its soil structure, soil and invertebrate biota, and natural ecological interactions. It would be able to involve only a fraction of the hundreds of species present, would be experimental and may not succeed.

⁶¹ This table is compiled from the published projections [Climate projections map | Ministry for the Environment](#); [Updated national climate projections for New Zealand | Earth Sciences New Zealand | NIWA](#); and [Downscaled CMIP6 future climate projections for New Zealand: climatology and extremes - ScienceDirect](#)

94. The Applicant⁶² has referred to papers published in 2012 which conclude that ski-fields such as the Remarkables will remain viable but only provided fields can make snow⁶³. I have read those papers and consider the reliability of their projections are undermined by their caveat (which is clearly stated) that the model did not allow for any melting of artificial snow⁶⁴. Not allowing for artificial snow to melt is a fundamental (and increasingly problematic) limitation of the models and conclusions because there is a present trend towards intense unseasonal winter rain-on-snow and associated rapid melt events⁶⁵. In my opinion newer models are needed, using more up-to-date and realistic climate predictions, models, and assumptions.
95. Snow making proposed in Doolans Basin within this application is limited to the main trail only. Snow grooming on natural snow alone is presently proposed on off-trail runs⁶⁶. The Hendrikx model predicts between 52 and 68 days of natural snow exceeding 0.30 m for existing Rastus Burn ski-field in 2040. Hendrikx and Hreinsson (2012) assumed a ski-field viability threshold of 90 days exceeding 0.30 m. I understand that 0.50 m is the operational minimum for snow grooming. The Applicant has said that Doolans Basin collects and retains more snow than the Rastus Burn but has not provided site-specific predictions.

⁶² Response to the Panel's RFI https://www.fasttrack.govt.nz/_data/assets/pdf_file/0018/30168/FTAA-2605-1236-Remarkables-and-Doolans-RFI-Response-Climate-Change.pdf

⁶³ Hendrikx et al. (2012) and Hendrikx & Hreinsson (2012). Hendrikx & Hreinsson (2012) estimated that under the 'moderate' A1B warming scenario on the Remarkables ski-field at 1,900m and 1,640 m the number of days with snow depths exceeding 0.30 m would be increased from 68 to 126 and 52 to 114 days respectively. Their assumption was that depths exceeding 0.30 m for three months would be viable.

⁶⁴ i.e. '*...we must still urge some caution in their use. Foremost is that the snowmaking analysis may be overly optimistic given that we have not calculated losses incurred from melt in the snow made from snowmaking.*' (Hendrikx & Hreinsson 2012 p 629).

⁶⁵ Extreme rain on snow is described by Miller et al. (2023) from a natural hazards perspective and detailing the sequence of events from the July 2022 storm. Boedeker Scientific (2019) state '*Precipitation that would previously have fallen as snow and been stored in the snowpack will instead be more likely to fall as rain...*'.

⁶⁶ These off trail runs are marked as 'Groomed Trails' and shown in pink on Sheet E105 of C-00 (Remarkables Ski Area Upgrade and Doolans Expansion - General Arrangement)

96. Further snowmaking in the Doolans Basin in future would materially increase the magnitude of adverse effects on freshwater and terrestrial ecosystems. For example, there would be:
- a. increased direct effects on freshwater and terrestrial ecosystems from water take, water storage needs⁶⁷ and associated infrastructure;
 - b. more widespread realisation of the associated adverse effects, including soil compaction, late rapid high-velocity runoff, nutrient enrichment, reduced carbon storage, and cumulative degradation of terrestrial and freshwater ecosystems;
 - c. even more widespread ecological climate maladaptation, through more comprehensive removal of the climatic selection pressure for climate-resilient, drought-tolerant, or thermophilic (warm-adapted) genotypes that are required for the system's long-term survival.
97. Climate changes will affect both the Project viability and the ecology of the site. Expert assessment on the climate changes anticipated and their effects on snow in the Doolans Basin have not been provided. The Applicant has said that it will need to make more snow in Doolans Basin to realise the economic benefits of the project⁶⁸, and the science relied on by both the Applicant⁶⁹ and the industry⁷⁰ anticipate that requirement. If that need can be anticipated now, in my opinion that additional activity and its effects should also be considered now, or the environmental effects of the proposal will be underestimated.

⁶⁷ For example, the Water Take Assessment of Effects (B-08) assessed effects based on only extracting the specific water quantities needed for the planned activities (i.e. 26 snow guns); utilising water storage to buffer overall demand, and maintaining flow during low flow periods. Those mitigations would be void if more snowmaking is undertaken. Furthermore, Appendix B to that assessment (Snow Making Water Demand Calculations) refers to 'Doolans Stage 1' which implies anticipation of further stages.

⁶⁸ⁱ For example, in their response to the Panel's RFI the Applicant (p. 7) states that '*Advancements in snow making technology will therefore continue to support the longevity of alpine ski fields, including the Doolans Basin expansion, in the face of changing climate conditions*'.

⁶⁹ Hendrikx et al. (2012) and Hendrikx & Hreinsson (2012).

⁷⁰ See for example <https://snowfall.co.nz/snowmaking-new-zealand-ski-fields/>

Summer visitor use

98. In my opinion the TEIA underestimates foreseeable summer visitor use and overlooks literature describing how visitor use and road use in the summers may impact the presently near-pristine alpine ecosystem in the Doolans Basin.
99. The TEIA states that *‘the Doolans will remain highly inaccessible to the average summer user’*; and states that the trampling effect would represent a *‘largely indistinguishable shift in baseline conditions’*. It dismisses the effects as minor⁷¹. However, the statement that the basin *‘will remain highly inaccessible’* is at odds with the Project Description, which anticipates gondola transport for summer visitors up to 4 days per week⁷² and unlimited mountain bike access (including e-mountain bike access) over the new trail⁷³.
100. There is presently very little summer foot traffic and no mountain biking in the Doolans Basin⁷⁴, and no visible sign of human tracking. While I have no expertise in predicting visitor numbers, the Applicant’s material shows that the new infrastructure may be leveraged to transport a sustained volume of day walkers, trampers, sightseers, and mountain bikers into the basin. If that is the outcome, I would expect a range of cumulative ecological degradation effects, including both visually obvious effects on vegetation and more subtle effects on soils and ecosystem functioning⁷⁵.
101. New tracking and trampling effects may become widespread, with locally severe effects that are slow to reverse because alpine soils and vegetation are poorly

⁷¹ Section 6.8.4 Increased Human Presence and Ski-field Operation on p. 128 of the TEIA

⁷² Section 3.5.5 and p. 129 of the Project Description (Document A-10) states that *‘Summer operations’ of the Doolans Gondola (for customers) between 7.00 am and 6:30pm on up to four days a week, with hours extending up to three days per week until 9.00 pm’*.

⁷³ Table 5 on p 37 of the Recreation assessment report (RA) states that *“... there will be no restriction on private access to the Doolans Basin and mountain bikers and walkers may choose to use field access formations”*.

⁷⁴ Figures 9 and 10 on pp 26 and 27 of the Recreation assessment report (RA) and analysis of interviews.

⁷⁵ e.g. Hammit et al. (2003), Pickering & Buckley (2003), Cole (2004).

equipped to withstand structural shear forces⁷⁶. Many alpine terrestrial and wetland ecosystems are especially fragile, with short windows for the slow-growing plants to photosynthesise, reproduce, and fix carbon, and current research into trampling effects is limited⁷⁷. What is known is that:

- a. foot traffic would create new informal trails and tracks which compact topsoils, raising soil bulk density and destroying soil macro-porosity, and reducing water infiltration rates⁷⁸. Compacted pathways would act as artificial drainage channels. Water flowing down trails would scour out topsoils and trigger rill and gully erosion, washing sediment loads downstream into waterbodies. Soil chemistry (pH, carbon) and biota would be altered as well as the above-ground vegetation (reductions in vegetation height, species richness, and changes in species and functional composition). Trail creation in forest fragments has been shown to reduce soil microbial biomass and shift soil pH up to 20 metres away from an actual trail edge⁷⁹;
- b. off-trail mountain biking exerts dual forces⁸⁰, can significantly increase trail width and depth⁸¹, and is especially damaging in streams and in seepages⁸². A major physical-impact implication from the advent of mountain biking lies in the increase in user numbers they represent⁸³.

⁷⁶ See Crisfield et al. (2012)

⁷⁷ For example, the global review of Ballantyne & Pickering (2015) highlights that research on vegetation and soil impacts of recreational trails is limited; current research is biased to only a few ecosystems in protected areas in developed nations, most responses measured are compositional and are measured at local scales, there is a need for more landscape-scale, temporal and comparative research on trail impacts and a greater geographical spread of research is needed.

⁷⁸ See Crisfield et al. (2012), Jorge et al. (2026)

⁷⁹ Malmivaara-Lämsä et al. (2008)

⁸⁰ Mountain bikes exert dual forces—normal force (causing compaction) and shear force (displacement through tire skidding) which combine to cause tread incision (Cessford 1995).

⁸¹ e.g. Evju et al. (2021): bikers trying to avoid deep mud, puddles, or stream pools ride around the edges, progressively widening the trail footprint.

⁸² Evju et al. (2021)

⁸³ Cessford (1995)

Those greater numbers expand informal trail creation and hence fragmentation and edge effects, which also exacerbate the observed reductions in vegetation height, species richness, and species and functional composition changes⁸⁴;

- c. Off-trail e-mountain bikes can create even more cumulative damage through hardening and increases in informal trail creation by encouraging riding of longer distances and steeper slopes, and their heavier weights⁸⁵.

102. Biosecurity incursions and their effects would be compounded by the operation of lifts multiple days a week and all-weather trail access for mountain bikes. Those mechanisms are ecological conveyor belts transporting sustained volumes of lowland pathogens and invasive weeds. Visitors accumulate and transport weed seeds, fungal spores, other pathogens and organic debris from modified environments on boot treads, socks, and velcro straps. Foot and bike passage creates continuous micro-disturbances along new trails which are competition-free seedbeds for invasive species. E-mountain bikes would travel further than other bikes, increasing the penetration of invasions.
103. Pollution and eutrophication would also increase and covertly degrade ecosystem functions and processes. Additions of chemical and material contaminants to the catchment would include microplastics and synthetic microfibers and sunscreen leaching. There would be off-trail littering and localised nutrient overloading from human waste, introducing *E. coli* and foreign nitrogen spikes into soils and waterways.
104. Concentrated heavy impacts may develop at popular shared sites and viewpoints. These localised concentrations of human activities and extreme impacts are known as ‘honeypot’ effects in recreational ecology⁸⁶.
105. Climate shifts combined with summer tourism would raise the baseline risk of wildfires.

⁸⁴ Pickering et al. (2011)

⁸⁵ Kuwaczka et al. (2023)

⁸⁶ Pickering & Buckley (2003)

Summer road use impacts

106. Opening the near-pristine Doolans Basin to summer maintenance vehicle traffic via unsealed, gravel roads and trails introduces a pollution corridor likely to alter the ecosystem far beyond the trail verge:

- a. vehicles in dry summer conditions generate ‘fugitive dust’ plumes carried several hundreds of metres to settle on leaves, blocking stomata while forming opaque layers that reduce photosynthetic rates, reversing plants natural albedo (reflectivity of pale alpine leaves) and raising leaf temperature leading to transpiration stress⁸⁷;
- b. vehicle-derived heavy metal residues such as copper, zinc, and lead from brakes, tires, and mechanical wear, and micro-rubber fragments travel alongside raw mineral silt to settle on leaf and soil surfaces. These residues accumulate over time and have diverse adverse effects ranging from localised tissue necrosis (dead spots) and stunting seasonal growth in plants to reduced enzymatic activity in the soil⁸⁸.

Ecological edge effects of earthworks are underestimated

107. The TEIA suggests edge effects are likely to occur beside proposed earthworks, but it estimates that edge effects would be ‘observable’ only within the first two metres of the works and would affect less than 50% of the vegetation cover. This approach to edge effect assessment is:

- a. simplistic because change in vegetation cover is only one of many indicators of an edge effect, and
- b. deficient because no field measurement is provided to support an expectation of an effect only within 2 metres and not beyond. Some of the actual and realised edge effects of earthworks and structures could have been measured in the Rastus Burn to inform this assessment.

⁸⁷ Thompson et al. (1984), Farmer (1993), Doley (2006)

⁸⁸ Uka et al. (2021), Bartkowiak et al. (2024), Kang et al. (2025)

108. In the ecological literature, and in my experience⁸⁹, edge effects that are properly measured in the field typically extend at least tens of metres from artificial edges, and some are detectable over hundreds of metres (depending on system and parameters measured). In addition to the processes described in the TEIA, in the Doolans Basin environment I would expect edge effects involving (at a minimum):
- a. effects of sedimentation extending the distance of drainage pathways away from the main trail⁹⁰;
 - b. soil compaction and reduced carbon fixation extending the distance of artificial snow spillover from the main trail⁹¹;
 - c. (assuming snowmaking water from the enriched, higher-pH Doolans Creek) nutrient enrichment, pH change and potentially biological invasions⁹² from artificial snow runoff extending the distance of drainage pathways away from the main trail⁹³;
 - d. effects of accelerated erosion from the later and greater melt of artificial snow extending the distance of drainage pathways away from the main trail⁹⁴;

⁸⁹ Walker et al. (2019) and Walker (2020).

⁹⁰ The proposed construction management plan will enable discharge of sediment laden runoff with turbidity up to 150 NTU (Nephelometric Turbidity Units) which is 400 to 750-fold increase in turbidity over the current NTU of 0 to 0.35 NTU. This will cause immediate and long term irreversible ecological degradation in terrestrial as well as freshwater systems. Terrestrial alpine plants grow slowly and rely on clear leaf surfaces and fine sediment blocks photosynthesis and leads to localised die-off. Highly organic, porous, and well-leached alpine soil pore spaces are filled with fine silts, causing compaction, reducing oxygen availability to plant roots, and altering sub-surface hydrology. Intact leaf litter and rocky scree are porous habitats for endemic terrestrial invertebrates: sediment deposition fills micro-crevices, burying habitats and disrupting the food web. Sediment deposits act as fertile disturbed and compacted seedbeds and vector for weeds like exotic *Juncus* species.

⁹¹ Paragraph 78(c) of this statement of advice

⁹² For example, didymo and other water-borne organisms with dispersal stages that may survive snowmaking

⁹³ Paragraphs 78d of this statement of advice

⁹⁴ Paragraph 78b of this statement of advice

- e. effects of pollutants from winter trail use by machines and skiers extending as far as meltwater off the trail⁹⁵;
 - f. altered snow persistence zones leading to soil biota and plant compositional and phenological changes⁹⁶;
 - g. effects of summer dust extending hundreds of metres from the main trail and roads⁹⁷.
109. Ski infrastructure earthworks can alter soil erosion processes across hillslopes, and these changes are also edge effects. New patterns of erosion and accumulation above and below earthworks create new landforms, drainage systems, and land stability patterns with hillslope-wide consequential effects on ecosystems⁹⁸.
110. Impeded or accelerated drainage alone can have both upslope and downslope consequences. Waterlogging, ponding, inundation and stagnant flooding can occur upstream due to backwater effects, surcharging and impoundment, leading to vegetation dieback, habitat loss and community shifts through root anoxia and altered soil and water chemistry. Acceleration of drainage can cause stream channelisation, wetland drawdown, dewatering or desiccation, subsidence, peat oxidation, and vegetation and fauna community shifts to drought-tolerant species. Those effects can be spatially extensive and worsen over time in complexes of hydrologically interconnected habitats and ecosystems.
111. In my opinion such effects are very likely to occur on the moraine bench in Doolans Basin where the proposed ski trail bisects a continuous and hydrologically integrated mosaic of wetlands and terrestrial vegetation communities. For example:

⁹⁵ Paragraph 91 of this statement of advice

⁹⁶ Microhabitats where snow lie is reduced may dry out and warm prematurely increasing frost susceptibility, while those with extended snow-lie experience delayed emergence and shortened growing seasons.

⁹⁷ Paragraph 106 of this statement of advice

⁹⁸ These effects have been documented on skifields internationally, for example by Piątek & Bernatek-Jakiel (2024).

- a. Dr Kavazos⁹⁹ describes reliance on permeable track sections to maintain seepage flow across the corridor, uncertainty whether these will maintain subsurface flows that sustain wetlands, and downslope consequences if the permeability underperforms. He notes changes in water level range and hydroperiod, with downslope desiccation, peat oxidation and shrinkage of peat forming and cushion bog communities, compositional shifts toward drought-tolerant species if upslope water is impeded.
- b. Dr Kavazos highlights the risk that the services trench becomes a preferential drainage path¹⁰⁰. The consequence would be dewatering of upslope communities and downslope erosion, sedimentation and siltation with associated losses of ecosystem condition and functioning.

112. Because the TEIA does not consider any of the above edge effect processes, it has greatly underestimated the extent and scale of the edge effects that would result from the earthworks and structures footprint, in my opinion.

Weed effects are underestimated

113. The TEIA states that compared to the Doolans catchment '*[d]isturbed areas in the Rastus Burn' catchment 'have a slightly higher prevalence of exotic species in adjoining trails and within or fringing disturbed habitat'* and comments that '*Notwithstanding this point, weeds remain at low levels in the Rastus Burn*'.

114. No weed list and no distribution and trend data for weeds in the Rastus Burn have been provided. As a result, the key information needed to assess the weed invasion that can be expected in Doolans Basin is missing from the TEIA¹⁰¹.

115. Although extreme alpine environments filter potential invaders, research suggests receiving alpine ecosystems are more susceptible to invasion by those few weeds

⁹⁹ Statement of advice of Dr Kavazos, **PART 3: Assessment of effects** under *Wetland loss, fragmentation and hydrological disconnection*

¹⁰⁰ Statement of advice of Dr Kavazos, **PART 3: Assessment of effects** under *Wetland loss, fragmentation and hydrological disconnection*

¹⁰¹ Trend data are important because weed invasions are non-linear, often with extended lag phases before triggers (such as disturbances or climate changes) result in exponential increases and spread (Kowarik 1995; Crooks and Soule 1999).

capable of invading¹⁰². I therefore agree with the TEIA that the likely magnitude of effect of weeds on the Doolans Basin vegetation is ‘Very High’.

116. I do not agree, however, that the residual effect level will be reduced to ‘Low’ by future weed management. The management plan is expected to achieve no new exotic species introductions to the wider landscape, and to control all existing exotic species to ensure no increase in current populations/distributions. Those goals are unrealistic in my opinion, and, relevantly, have not been achieved in the Rastus Burn.
117. For example, during my field visit I observed exotic *Juncus* and grass species along tracks and trails in the Rastus Burn but not present in the untracked, undisturbed Doolans Basin vegetation. Ecological characteristics mean it will not be plausible to eradicate or control such species¹⁰³ in the Doolans Basin once they are introduced and promoted by the proposed disturbances and nutrient enrichment.

Fragmentation is underestimated

118. Fragmentation is the break-up of continuous areas of natural vegetation or habitat into smaller, isolated patches separated by human-transformed communities or cover. The loss of area, increase in isolation, and greater exposure to human human-transformed edges initiate long-term changes to the composition, structure and function of the remaining fragments. Changes occur chiefly through three mechanisms which unfold over time: (i) edge effects; (ii) loss of connectivity for species and ecological processes¹⁰⁴; and (iii) directional losses of species (because smaller, more isolated patches can support fewer species and receive fewer immigrants).

¹⁰² Lembrechts et al. (2004)

¹⁰³ For example, these weeds are small and have traits such as large, long-lived seed banks, dormancy, long distance dispersal mechanisms (e.g. mucilaginous coatings and hairs for hitchhiking, water dispersal). I am not aware of any successful attempts to eradicate them once they have established in natural areas where human disturbance traffic is ongoing.

¹⁰⁴ Examples of the ecological processes that can be disrupted are gene flow and meta-population dynamics, fauna migrations and seasonal ranging, herbivory and host-plant synchronisation, plant seed dispersal and recruitment, hydrological cycles and nutrient flows.

119. The TEIA considers fragmentation of terrestrial vegetation as only occurring *within* individual vegetation communities and only involving species exclusive to them¹⁰⁵. This is not a meaningful scale at which to consider fragmentation because ecological communities are not ‘sealed units’ but occur in connected, mutually dependent mosaics sharing taxa and processes¹⁰⁶. Fragmentation must be considered across connected areas with vegetation sequences or mosaics.
120. The project would divide up the Doolans Basin ecosystem and vegetation sequences and mosaics into smaller fragments through diverse activities, and not only the direct infrastructure and trail footprints. Effects of both winter and summer operations¹⁰⁷ would create additional fragmentation through habitat division and isolation, for example through:
- a. *Asynchronous isolation*: later snow-lie on grooming trails and skier-compacted tracks across Doolans Basin, which would create bands of phenological¹⁰⁸ ‘suspension’ where soil remains frozen weeks longer than the surrounding areas. Ungroomed zones that melt out early would be effectively isolated into disconnected fragments.

¹⁰⁵ For example, in the TEIA the fragmentation of snow tussock grassland is considered only insofar as whether there will be ‘observable reduction of the population and dispersal ability of species *within* it’. Snowbanks are suggested to be not subject to fragmentation because they occur in discrete patches.

¹⁰⁶ For example

- pollinator species may use continuous seasonal gradients of resources; depending on early-emerging plants in early-exposed communities to initiate their lifecycle, and late-flowering species in persistent snowbanks to sustain and extend their active season.
- a cushion bog community may be fed by oligotrophic flow from seepage wetlands
- a diversity of vegetation communities confers resilience to demographic and environmental stochasticity and slow species loss (e.g. plant communities in high-moisture zones act as refuges for species during severe drought years, and naturally drier microsites are safe havens in exceptionally wet years).

¹⁰⁷ Described in paragraphs 75 to 106 of this statement of advice

¹⁰⁸ Phenology refers to seasonal and periodic biological life cycle events in plants and animals, such as flowering, migration, or hibernation, and how these activities relate to seasonal weather and climate.

b. *Physical isolation*: corridors of physically altered substrates and plant communities separating remaining core patches developed through, for example:

- i. greater and enriched runoff from snowmaking along the main trail which would scour, alter soil properties, and alter the composition of the original nutrient-poor plant communities along melt pathways;
- ii. ecosystem alterations extending unknown distances either side of walking and biking trails, and contaminants on dust from vehicle and bike use, which would travel hundreds of metres from the Doolans Ski Trail and 4WD track.

121. Asynchronous isolation is likely to disrupt pollination and geneflow, reducing outcrossing rates and diminishing genetic resilience of flora and fauna species over successive generations. Physical isolation would lead to cumulative degradation of core patches through expanding edge effects, structural barriers to fauna movement, and the non-random, directional loss of habitat-specific species over time.

Cumulative effects are underestimated

122. Cumulative effects are effects arising over time, and effects arising in combination with other effects (which can include off-site and landscape-scale effects). In my opinion, the deficiencies in the TEIA and FEIA have led to incomplete description and underappreciation of cumulative and irreversible ecological effects that would result from the proposed activities in the Doolans Basin¹⁰⁹.

123. Cumulative ecological degradation is underestimated because the TEIA and FEIA did not identify key direct effects such as significant damage to and loss of distinctive and high-value NUES; did not describe important effects of operational activities (snow making, snow grooming, skiing); understated or overlooked

¹⁰⁹ Assessment of cumulative effect in the TEIA considered only direct disturbance of terrestrial communities, omitting even the (inadequate) estimates of edge effects and fragmentation. The context for magnitude of cumulative effect is also expanded to the entire ED above 1100m, contrary to explicit EIANZ guidance.

summer road use impacts, edge effects, fragmentation, and weed ingress; and potentially understated summer visitor impacts; all of which are synergistic effects that will worsen over time. The TEIA and FEIA also did not identify that further ecological degradation will result from any additional snowmaking used in future to combat foreseeable climate change effects on economic viability.

124. Cumulative degradation has potential to reduce population sizes and therefore likelihood of persistence in all of the listed¹¹⁰ plant species that occur in the Project site. At particular risk from adverse effects of snowmaking, snow grooming, fragmentation and edge effects (especially altered drainage and sedimentation) on wetland habitat integrity are:
 - a. *Craspedia uniflora* var. *uniflora* (a Threatened – Nationally Endangered and Regionally Data Deficient plant) which occurs in cushion bogs, riparian wetlands and seepages; and
 - b. the recently described *Montia miniscula* (a Threatened – Nationally Critical plant) (Heenan 2026). Tiny, cryptic *M. miniscula* occurs in palustrine fen ('Seepage' in the TEIA) and string mire wetlands. It is currently known from only two sites (both in Otago, one of them the Rastus Burn) and may be present in the Doolans Basin wetlands, but was not expressly searched for in the TEIA surveys.
125. The TEIA also fails to evaluate the cumulative ecological effects of the climate maladaptation that will result from extending the natural snow lie (through snow making and snow grooming) at both local ecosystem and broader Ecological District (ED) scales.
126. In its current undisturbed state, Doolans Basin is a key stronghold for the ED's flora and fauna against climate impacts. It has exceptional capacity to support natural climate adaptation because of its present intactness, high ecological connectivity, and the outstanding variety of habitats and refugia that occur across

¹¹⁰ That is, species listed as Threatened, At Risk, or Data Deficient in the New Zealand Threat Classification System, or in the Regional Threat Classifications.

all elevations and aspects within its compact boundary¹¹¹. Modification by the Project will compromise that natural resilience.

127. Under unmodified conditions, the native alpine flora and invertebrate community of Doolans Basin would adapt to the warming trend¹¹² through natural selection. Natural selection would favour plant genotypes that green and flower earlier, and invertebrate genotypes that emerge earlier in the season. Those phenological shifts would allow native species to avoid late-summer droughts and food shortages, and would favour the progressive development of drought- and stress-tolerant ecotypes.
128. Artificially delaying snowmelt, snow grooming and snow-making would remove the selection pressures needed to develop climate-resilient, drought-tolerant, or thermophilic (warm-adapted) genotypes. Those activities would lock the flora, fauna and ecosystems into an artificial, late-melting microclimatic regime that opposes regional climate trajectories.
129. Having been denied the opportunity to progressively adapt, the ecosystem would be unequipped to withstand a transition to a warmer, drier alpine environment when artificial management ceases. Diebacks of maladapted vegetation and collapses of ecological communities on abandoned runs might result, with no viable path for remediation.
130. Together the cumulative degradation and maladaptation would represent a fundamental alteration of the present ecological attributes of Doolans Basin. However, they would also have district-wide effects on indigenous biodiversity, because a key stronghold against climate impacts would be lost from the wider ED.

¹¹¹ Table 1 and paragraph 50 in this statement of advice

¹¹² Paragraph 92 and Table 2 of this statement of advice

PART 3. ADEQUACY OF THE APPLICANT'S PROPOSED MITIGATION, REHABILITATION AND MANAGEMENT MEASURES, AND POTENTIAL ADDITIONAL MEASURES

131. Because neither the values nor the effects have been adequately identified, the Applicant's proposed avoidance, mitigation, rehabilitation and management measures as they relate to terrestrial ecology are partial and deficient.
132. Specifically, sequential avoidance, minimisation, and remediation, offsetting and compensation¹¹³ has not been demonstrated for:
- a. damage to and loss of distinctive and high-value NUEs that were not identified;
 - b. unidentified effects of operational activities (snow making, snow grooming, and skiing), including further snowmaking that can reasonably be anticipated in future;
 - c. reasonably foreseeable impacts of summer visitor and road use; and
 - d. the extent of edge effects, fragmentation, and weed ingress that can be reasonably expected.
133. Table 3 (below) suggests some potential measures that might reduce some of the predicted effects of snowmaking, snow grooming, skiing, summer visitor, summer roading and incursions of invasive plants (and thereby limiting edge effects and fragmentation). I have not attempted to investigate the feasibility or effectiveness of these measures, and some may be neither possible nor practical. Even with the adoption of these measures, I expect adverse effects would remain that cannot be remedied, mitigated, offset or compensated for.

¹¹³ As set out in the NPSIB. In the Conservation Act s17U '*Consideration is given to any practical measures that can avoid, remedy, or mitigate any negative environmental impacts*'.

Table 3. Potential measures to reduce effects

Category	Effects	Potential reduction measure
A. Snowmaking	• Soil compaction and saturation • Nutrient enrichment / eutrophication • Greater snowmelt and runoff • Erosion and sedimentation • Delayed snowmelt leading to ecosystem shifts	• Use an alternative high elevation source for snowmaking water, with similar ion and pH levels to natural snow • Mechanisms to collect runoff and filter nutrients from artificial snow to prevent discharge onto and into native vegetation • Establish moraines and wetlands as permanent ‘no-snowmaking’ zones • Zero-additive policy banning chemical and biological (including so called ‘natural’) additives • Climate shut-offs to prevent wind drift of artificial snow onto off-piste flora • Advanced water treatment to remove nutrients at intakes and reservoirs
B. Snow Grooming	• Progressive compaction • Insulation loss causing deep soil freezing • Accelerated nutrient mineralisation • Altered soil subsurface melt patterns • Degraded below- and above-ground properties	• Limit snow grooming to the main (engineered) trail, or to unvegetated areas. • Establish moraines and wetlands as permanent ‘no-groom’ zones
C. Skiing & Snowboarding	• Similar to grooming but concentrated at topographic pinch points • Vegetation stripping • PFAS and microplastic chemical pollution	• Off-trail closures until snowpack is deep enough to prevent edges hitting soil as well as late-season • Rope off pinch points during low-snow conditions or permanently • Resort-wide ban on fluorinated waxes at entry
D. Summer Visitor Impacts	• Off-trail track creation • Foot and bike trampling • Compounded biosecurity threats • Anthropogenic pollution / eutrophication • Concentrated ‘honeypot’ impacts • Elevated wildfire risk	• Limit summer visitors to current levels through (a) summer gondola shut down and (b) wheeled vehicle access prohibition or limits (i.e. limit bikes to the engineered trail)

		• Fire closures that automatically shut down access during extreme drought and high wind days.
E. Summer Road Use	• Wide-scale plant dust coating (mineral dust) • Heavy metal residues • Micro-rubber tire residues	• Wheeled vehicle restrictions, summer staff and maintenance transport restricted to aerial lifts or lightweight electric UTVs.
F. Biosecurity and weed invasions	• Small sizes making early detection difficult; large, long-lived dormant seed banks • Dispersal vectors: long-distance hitchhiking and water dispersal	• Zero-introduction boundary controls (including wash stations) for ski-field construction machinery, summer utility vehicles, and commercial equipment • Vehicle fleet separation between Doolans Basin and Rastus Burn • Staff footwear separation between Doolans Basin and Rastus Burn • Mandatory high-pressure boot and bike wash station for staff and visitors, with collection and offsite disposal of runoff • Advanced water filtration for didymo and other organisms at intakes and reservoirs

PART 4. OFFSETTING AND COMPENSATION

134. Offsetting and compensation for residual terrestrial ecology effects in the Doolans Basin are not appropriate under the NPSIB and ORPS¹¹⁴. Avoidance is directed because effects include diverse, large, permanent and irreversible effects on irreplaceable and vulnerable ecological values; several effects are uncertain, unknown, or little understood; and there are no technically feasible options by which to secure net gains within acceptable timeframes.
135. Should the panel determine to grant consent despite this, Principle 3 of compensation indicates ecological outcomes sought should outweigh the adverse effects. That is, while it is not possible to replace the losses that will occur ‘in kind’, compensation should achieve positive ecological outcomes that

¹¹⁴ Statement of advice of Dr Fleur Maseyk for the Department of Conservation

are greater in scale and magnitude to the effects of the Project (once those effects have been adequately identified and quantified).

136. Because of the scale and the variety of anticipated effects of this Project¹¹⁵, it will be demanding - and a package will be unlikely - to achieve 'proportionate' or 'comparable' outcomes through compensation. To approach that standard, compensation would need to involve a diverse package of very large landscape scale projects, each giving effect to the remaining principles for compensation¹¹⁶.

137. I agree with Dr Maseyk¹¹⁷ that the Applicant has not offered compensation that is 'proportionate' or 'comparable' to the effects.

PART 5. CONDITIONS AND MANAGEMENT PLANS.

138. Conditions and management plans for recognised effects are deficient and insufficiently developed, especially in the context of the near-pristine baseline condition and exceptionally high ecological value of the Doolans Basin. Some important inadequacies are summarised below.

139. A post-consenting process to identify and avoid 'ecologically sensitive areas' and 'high-value' vegetation¹¹⁸ is inadequate, because it is clear that key infrastructure will not avoid these values¹¹⁹. Moraine, scree, and alpine deflation surfaces are ecologically sensitive areas and the vegetation on them is, by definition, highly valuable (and ecologically significant), but the TEIA failed to recognise them.

¹¹⁵ As described in this statement of advice, and in the statements of advice of Drs Kavazos and Watts.

¹¹⁶ As set out in the NPSIB, these principles include. scale, additionality, leakage, long term outcomes, landscape context, time lags, trading up, financial contributions, science and mātauranga Māori, tangata whenua and stakeholder participation and transparency.

¹¹⁷ Statement of advice of Dr Fleur Maseyk for the Department of Conservation

¹¹⁸ The TEMP states that '*Key management measures incorporated within the TEMP include: > Protection of wetlands and ecologically sensitive areas through exclusion zones, erosion and sediment controls, hydrological management and staged construction methodologies;*

>Avoidance and minimisation of indigenous vegetation clearance wherever practicable, including retention of high-value vegetation, clearly defined disturbance footprints and rehabilitation of temporarily disturbed areas...'. The TEMP Table 6.1 describes those measures.

¹¹⁹ Furthermore, by my reading. the conditions do not require avoidance of areas and vegetation as suggested by the management plan, but only the salvage and translocation of some flora species.

Consequently, the project layout targets these sensitive landforms for heavy disturbance. Avoiding ecologically sensitive areas and high value vegetation requires that NUES are identified and mapped, and that conditions specify that those identified areas are avoided.

140. Measures proposed to protect wetlands and terrestrial vegetation through erosion and sediment controls and hydrological management fall far short of best alpine practice. They will allow avoidable and permanent degradation of terrestrial and wetland ecosystems¹²⁰.
141. The generic conditions and management plans do not take account of the sensitivity and high value of the environment and must be replaced by more rigorous, bespoke and tailored instruments. For example:
 - a. for sediment, at a minimum there should be a trigger-level framework tied to the natural background variation ¹²¹, backed by a continuous monitoring regime¹²².
 - b. for drainage, at all track crossings there needs to be prior baseline validation of flows, continuous upstream and downstream monitoring,

¹²⁰ Limitations in sediment management are described in paragraph 108a and associated footnote 82 of this statement and in the statement of advice of Dr Kavazos (**Part 3: Assessment of effects** under *Wetland loss, fragmentation and hydrological disconnection*). The proposed construction management plan will enable discharge of sediment laden runoff with turbidity up to 150 NTU (Nephelometric Turbidity Units) which is 400 to 750-fold increase in turbidity over the current NTU of 0 to 0.35 NTU.

Limitations in drainage management are described in paragraph 111 of this statement and the statement of advice of Dr Kavazos (**Part 3: Assessment of effects** under *Wetland loss, fragmentation and hydrological disconnection*)

¹²¹ For example, no change in turbidity greater than 10% to 20% above the background baseline.

¹²² For example, automated, continuous monitoring stations both upstream (control site) and downstream (impact site) of the construction zone to isolate construction-related discharges from natural fluctuations caused by heavy rain; continuous telemetered sensors recording data every 15 minutes providing live alerts (both investigation and cease work triggers) as soon as a threshold is breached; supplementary sediment deposition monitoring (e.g. weekly) in downstream pools to also be used track and manage cumulative physical accumulation.

pre-emptive trigger levels, and enforceable structural interventions to ensure and confirm that subsurface hydrology remains unaltered¹²³.

142. The construction layout creates concurrent biosecurity threats by moving traffic between a modified, weedy catchment and a near-pristine alpine zone, while simultaneously pumping and spreading water from a didymo-infested lower creek¹²⁴. The proposed generic biosecurity conditions and management plans insufficiently recognise the sensitivity and value of the environment and will be inadequate to prevent basin-wide incursions and spread.
143. For small-seeded terrestrial and wetland weeds there needs to be a single-point-of-entry quarantine station separating the Rastus Burn and Doolans catchments, two-stage mechanical decontamination (the 2013 "Keep It Clean" guidelines are inadequate) with washdown transported offsite, and strict footwear and small-tool quarantine¹²⁵.
144. Terrestrial and wetland weed monitoring should use monthly systematic gridded field searches (rather than casual visual inspections) across high-risk corridors for the duration of the consent. All detections should be GPS logged, mapped and photographed at permanent photo-points to track infestation extent, seedling

¹²³ For example, paired, automated groundwater monitoring upslope and downslope of the proposed track alignment with a minimum of 12 months of continuous hourly data to map the natural seasonal water level range, water table depth, and hydroperiod dynamics of the cushion bog and peat systems; condition thresholds (e.g. groundwater levels and soil moisture content remaining within a percentage of natural seasonal variance at all times, and no artificial upslope water ponding or water table elevation exceeding natural baseline ranges); investigation and action (i.e. cease-work and engineering remedy) triggers at 10-day and 20-day changes, respectively, in water table or soil moisture levels from the natural seasonal baseline (independent of regional weather patterns).

¹²⁴ Dr Kavazos addresses the unaddressed threat of didymo in his statement of advice, in **Part 3. Assessment of effects** under *Freshwater biosecurity*.

¹²⁵ For example, no vehicle or machinery to pass into the Doolans Basin without physical, signed biosecurity clearance. The quarantine station to feature a dedicated high-pressure washdown pad with an integrated sediment trap, collected and trucked offsite to a suitable disposal facility to prevent runoff from escaping. All tracked excavators, grooming fleets, and support vehicles to undergo a two-stage process: mechanical scrape followed by high-pressure thermal washing (>60°C) to blast seeds from structural recesses, undercarriages, and tracks. Construction and other personnel to step through a dedicated boot-scrubbing station utilizing a broad-spectrum agricultural disinfectant prior to crossing the saddle boundary. Tools, surveying equipment, and personal gear to be inspected and cleared of all organic debris prior to entry.

presence, and treatment efficacy over time¹²⁶. Conditions specifying zero-tolerance for both new invasive species and for spread and remediation to achieve zero levels should be accompanied by cessation of works and traffic movement if an incursion is not contained within a stated timeframe.

145. New and additional conditions and amended plans will also be needed to

- a. manage the unrecognised effects that are not avoided, and
- b. to adequately specify and manage compensation for the full suite of effects.

146. In my experience conditions that are adhered to and enforceable have set quantitative and time bound targets and triggers. They identify and specify remedial actions when these are not met or exceeded. They do not leave targets, triggers and mandated remedial actions to flexible management plans and post-consenting determination, as in the current proposed conditions.

Susan Walker

7 October 2026.

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¹²⁶ For example, control measures to be completed within 20 working days of detection, ensuring plants are completely destroyed prior to reaching their fruiting or seeding phase, using named targeted, low-impact control methods; treated areas to be re-surveyed 4 weeks after treatment to verify complete eradication and check for secondary seedling germination; annual report to the regulatory authority detailing all survey routes, weed species encountered, total area affected, and the precise control methods deployed.

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ATTACHMENTS

Attachment 1 Meijer zu Schlochtern et al. (2014)

Attachment 2. Relevant scientific literature since the Meijer zu Schlochtern et al. review

Attachment 1 Meijer zu Schlochtern et al. (2014)

Melanie P. Meijer zu Schlochtern · Christian Rixen
Sonja Wipf · Johannes H. C. Cornelissen

Management, winter climate and plant–soil feedbacks on ski slopes: a synthesis

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Abstract Owing to the increasing popularity of skiing and the upslope movement of the snow reliability line in mountain regions, more and more alpine environments are being turned into skiing areas, with strong impacts on ecosystem functions and biodiversity. Creation and management of ski slopes cause physical disturbance to soil and vegetation, while (artificial) snow supplements affect soil structure, chemistry, moisture and temperature regimes as well as shifts in snow season and growing season length. Vegetation–soil feedbacks may influence the outcome of these interactive effects on soil and vegetation, with possible consequences for soil erosion. Moreover, climate warming will lead to changing snow cover and duration, which will interact with ski slope management effects on soil and vegetation and its feedbacks. Based on a conceptual framework we review the main elements of these interactive effects on soil and vegetation on new and established ski slopes. We also set a research agenda with specific studies that could further advance our understanding of interacting ski slope management, winter climate, vegetation–soil feedbacks and ecosystem functioning. In such new investigations, alpine climate change ecology can probably learn much from the “experimental” disturbance and snow manipulations on ski slopes and vice versa.

Keywords Alpine ecosystems · Disturbance regimes · Land-use · Ski slope · Snow regime · Vegetation–soil feedback · Winter climate

Introduction

Recreational activities including tourism in nature have greatly increased worldwide over the last decades (Abegg et al. 1997; Patthey et al. 2008; Kangas et al. 2012; Steiger 2013). Many mountain regions host large skiing areas, with their ski resorts, which attract millions of visitors each year, giving them significant economic value (Rixen et al. 2011). However, skiing areas are also considered to be among the main causes of environmental degradation in mountain regions (Kangas et al. 2009; Rixen 2013). The creation and management of these skiing areas represent a significant source of disturbance to alpine ecosystems (Burt and Rice 2009; Rixen 2013). This impact is still rising, through the enlargement of skiing areas to support the increasing popularity of outdoor winter activities (Wipf et al. 2005; Kangas et al. 2009) on the one hand. On the other hand, the use of artificial snow for the preparation of ski slopes will be increasing (Keller et al. 2004; Steiger and Mayer 2008) as climate warming reduces snow amounts and predictability in the alpine belt, especially at lower altitudes (IPCC 2007; Wipf and Rixen 2010; Steiger 2010).

Alpine habitats are a unique component of alpine biodiversity and can be exceptionally rich in species both at the landscape scale and the plot scale. Moreover, in these harsh and extreme environments, plant and associated animal communities consist of a high proportion of extreme climate specialists (Körner 2003; Onipchenko et al. 2009), which are likely to be sensitive to environmental change and disturbance by ski slope management (Wipf et al. 2005; Björk and Molau 2007; Rixen 2013). The intensity of disturbance that ski slope management exerts on these fragile high mountain ecosystems, however, varies between methods applied (Burt and Rice 2009); see Fig. 1. Firstly, ski resorts affect the alpine ecosystem through physical disturbance, imposed by (a) the creation of ski slopes through removal of tall original vegetation, (b) machine grading (causing major damage to the soil surface), (c) grooming of the ski

M. P. Meijer zu Schlochtern · J. H. C. Cornelissen (✉)
Systems Ecology, Department of Ecological Science, Faculty of
Earth and Life Sciences, VU University, De Boelelaan 1085, 1081
HV Amsterdam, The Netherlands
E-mail: j.h.c.cornelissen@vu.nl

C. Rixen · S. Wipf
WSL Institute for Snow and Avalanche Research SLF,
7260 Davos, Switzerland

slopes (compaction of snow). Second, snow supplements, whether with natural or artificial snow (Wipf et al. 2005; Rixen 2013), will cause changes of the chemical and physical characteristics of the soil, for example due to chemical compounds in artificial snow or compaction of soil by machine grooming (Delgado et al. 2007).

Vegetation and soil strongly interact, resulting in important plant–soil feedbacks (e.g. Bardgett and Wardle 2010; van der Putten et al. 2013; Freschet et al. 2013). In one direction, the abiotic soil conditions, such as soil nutrient and water availability, and soil organisms (e.g. mycorrhizal fungi, soil pathogens) have a strong influence on plant growth and on plant species composition. In the other direction of the feedback loop, the traits of different plant species in turn have a strong influence on the soil abiotic and biotic environment (e.g. Finzi et al. 1998a, b). Indeed, the plant species composition, and thereby trait composition, can affect the availability of nutrients or carbon storage in the soil, for example through decaying roots and root exudates (Burke et al. 1998; De Deyn et al. 2004; Van de Voorde et al. 2011; Freschet et al. 2012) or through the decomposability of leaf litter, which differs between species or functional types (Cornelissen et al. 2007; Cornwell et al. 2008). Through such strong plant–soil feedbacks, changes or manipulations in either plant species composition or in the soil can have profound consequences for the other component (Burke et al. 1998). More specifically, changes in either soil or vegetation induced by ski slope management can, through these feedbacks, have profound consequences for the entire alpine ecosystem, both above- and belowground (Fig. 1).

There is substantial literature about the impacts of ski slope management on the natural vegetation, reporting for example declines in biodiversity and changes in plant species composition (Keller et al. 2004; Burt and Rice 2009; Roux-Fouillet et al. 2011; Rixen 2013). However, few studies incorporate changes in soil ecology, and the feedbacks between alpine vegetation and soil as affected by ski slope management have not yet been well synthesised. Moreover, ski slope management and its effect on vegetation–soil feedbacks is likely to interact with the changing alpine climate. For example, changing snow cover is one of the fastest emerging consequences of climate change, generally resulting in a decrease in snow cover due to a warming climate in spite of strong spatial heterogeneity (Rixen et al. 2008; Wipf and Rixen 2010; Makoto et al. 2014). This trend is triggering an increased use of artificial snow (Steiger 2010), however the implication and impacts for the soil–vegetation interactions induced by climate change are unclear (Roux-Fouillet et al. 2011).

Here we take on the challenge to synthesise the currently available literature and our own observations on the various influences of ski slope management on vegetation–soil feedbacks, and on their future in a warmer mountain world.

In doing so we address the following questions:

- Do vegetation–soil feedbacks exacerbate the impacts of physical disturbance and snow supplements on vegetation or soil? In other words, are there important effects of ski slope management on vegetation and soil through other drivers of plant–soil feedbacks, e.g. snow cover, soil properties and vegetation composition?
- How will vegetation–soil feedbacks be influenced by interactions of ski slope management and changing natural snow cover as induced by climate warming?

These questions will be held against the currently available literature, through a conceptual framework of interactions between ski slope management and biotic and abiotic drivers of vegetation and soil properties (see boxes and numbered arrows in Fig. 1). To answer these questions, we searched the ISI Web of Science database for relevant literature, by searching for combinations (connected with ‘AND’) of two or three of each of the following keywords: artificial, avalanche, chemicals, chemistry, climate change, climate warming, compounds, construction, creating, erosion, feedback, formation, global warming, grading, grooming, interaction, lift, machine, making, plant, pollution, preparation, resort, ski, skiing area, ski piste, ski run, slope, snow, soil, structure, vegetation and vehicle. Moreover, references cited in the selected papers were searched for additional relevant literature, while we also used papers and reports already in our own literature bases. We only selected papers or reports that we judged methodologically sound and relevant to our concept, and which were published by authors connected to a non-commercial research institution. We will first discuss impacts and feedbacks of physical disturbance associated with ski slope creation and management, then on those of snow supplementation. Finally we will discuss these feedbacks in the context of soil erosion, alpine climate warming and will wrap up with recommendations for a new research agenda.

Physical impacts of ski slope management on plant–soil interactions

The impacts of physical disturbance associated with ski slope management on vegetation and soil have been relatively well studied (Wipf et al. 2005; Barni et al. 2007; Kangas et al. 2009; Roux-Fouillet et al. 2011; Rixen 2013). Here we only briefly summarize the main consequences of the physical aspects of ski slope management activities as far as they also operate through plant–soil interactions.

Creation and machine-grading of ski slopes

The creation of ski slopes (Fig. 1a) by cutting and clearing of vegetation causes changes in the species composition (arrow 1 in Fig. 1; Kubota and Shimano

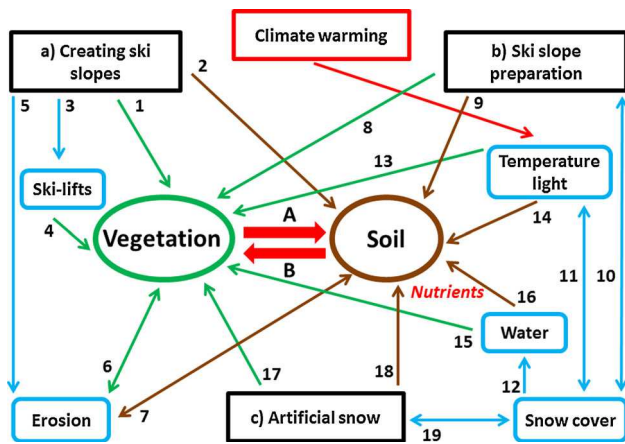


Fig. 1 The conceptual framework of the influence of ski slope management on vegetation and soil. Three management techniques are distinguished; *a* Creating ski slopes, *b* Ski slope preparation and *c* Supplements of artificial (or natural) snow. The important interaction between vegetation and soil is shown with large red arrows (A and B), influences on vegetation with green arrows and on soil with brown arrows. The blue arrows show the indirect influence of a factor (i.e. via another factor) on vegetation and soil. The arrow numbers and letters are referred to in the text

2010). Also for the creation of ski lifts (arrow 3) vegetation such as trees and shrubs, needs to be removed, using heavy machinery. There is little information about the impacts of ski lifts on vegetation (arrow 4). However, one study reported high plant species diversity and occurrence of uncommon, tall herb species in areas where the canopy closure was low, such as under gondola lifts, at the edge of ski-slopes and on ski slopes, as opposed to nearby undisturbed forest (Kubota and Shimano 2010). Ski slopes can still have some ecological similarity, in terms of species and functional diversity, to nearby forest (Burt and Rice 2009), but landscape fragmentation can be substantial (Ristic et al. 2012).

Grading of ski slopes by heavy machines (Fig. 1a), whether initial grading (after ski slope creation) or subsequent annual grading, removes vegetation, tree stumps, rocks and other obstacles, damages or even removes top soil and smoothes uneven surfaces (Wipf et al. 2005; Burt and Rice 2009). Removing the upper soil layer (Kangas et al. 2009) can cause vegetation gaps and affects vegetation in the long-term, as major alteration of soil biotic, physical and chemical properties hamper establishment and growth of the original plant species (arrows 1, 2 and B; Barni et al. 2007; Roux-Fouillet et al. 2011). Moreover, their seed bank is lost, thereby greatly reducing the resilience of the original species (arrow B; Burt and Rice 2009). Subsequent seeding of non-local species can result in high proportions of species not native to the ski slope area (Barni et al. 2007). Some of these seeded species, or spontaneously established alien plants, may outcompete remaining native species or hamper their re-establishment. One of the mechanisms involved is that of 'natural enemy release'; soil-borne pathogens or root herbivores adapted to the native flora are often not able to infect or

consume belowground plant parts (Callaway et al. 2004; van der Putten et al. 2013; Maron et al. 2014). This way they can gain a competitive advantage over native plant species, which tend to be hampered in their performance considerably by soil-borne enemies.

Species diversity, plant cover and productivity were decreased on graded ski slopes (productivity reduced by more than 75 % compared with ungraded ski slopes), and the abundance of early flowering and woody plants was found to be lower (Wipf et al. 2005; Roux-Fouillet et al. 2011). Plant communities on graded ski slopes are mostly species-poor and dominated by early-successional species, such as annual herbs, grasses and herbaceous legumes (Wipf et al. 2005; Burt and Rice 2009; Kangas et al. 2009). An increase in grasses and forbs relative to the original vegetation dominated by woody plants can generally lead to higher quality leaf matter turning into litter that is more decomposable by broadly 30–40 % (Cornelissen et al. 2007). This drives an important plant–soil feedback, as faster litter decomposition will accelerate litter nutrient release and thereby potential nutrient losses through downward export (arrow A). However, it matters which growth form dominates the new herbaceous vegetation, as forbs generally decompose 30–50 % faster than graminoids (Quested et al. 2003; Cornelissen et al. 2007; Cornwell et al. 2008).

Grading of ski slopes affects the physical characteristics of the soil and causes changes in soil texture (arrow 2); for instance fine soil particles such as clay may decrease or swell (Barni et al. 2007). Soil compaction due to work with heavy machinery can lead to soil density increases by more than 50 %. Chemical changes may include a higher soil pH, and soil organic C concentration is usually decreased (Barni et al. 2007; Roux-Fouillet et al. 2011). Concentrations of phosphorus and base cations such as potassium, calcium and magnesium have been recorded to be higher in soils of machine graded ski slopes than next to them (Kangas et al. 2009). Most of these changes result from the disturbance of the soil (younger soils with higher pH etc.), or from treatments after grading when ski slopes are filled with peat or fertilised. All these changes in soil structure, pH, carbon and nutrient status, which are key determinants of plant performance, will greatly influence vegetation composition (arrow B).

Ski slope snow preparation

In winter, ski slopes need to be maintained for downhill skiing in ski resorts through daily snow-grooming (Fig. 1b). The heavy vehicles for snow grooming can cause mechanical damage to the vegetation and compaction of the underlying soil by frequently driving over the ground (arrows 8 and 9; Kammer 2002; Wipf et al. 2005), especially when the snow cover is thin (Rixen et al. 2003). The ski slope management decreases the vegetation height and the cover of woody plants by more than 50 % (dwarf shrubs of the Ericaceae family);

probably the size, growth form and slow growth rates of woody plants make them more susceptible and less resilient to damage by machines (Kammer 2002; Wipf et al. 2005; Roux-Fouillet et al. 2011).

Influences on the soil by snow grooming include (arrow 9) changes in the soil aggregate stability, particle size distribution, carbon and nitrogen content and porosity (Delgado et al. 2007; Pohl et al. 2009). However, these changes are hard to quantify as ungraded control sites are often missing in previous studies (Martin et al. 2010). Ski slope preparation causes a decrease in the soil pore space, both for macropores and micropores, which may lead to a greater pore aggregate stability, but a lower water storage capacity, and as a result, a decrease in microbial biomass inhibiting decomposition. The snow grooming of ski slopes affects also the chemical and physical properties of the soil. For instance, it may decrease organic C content and increase pH, Na^+ content of the exchange complex, electrical conductivity and base saturation (Delgado et al. 2007). Changes in these soil properties induced by machines will feed back to the vegetation (arrow B), in most cases leading to fewer plant species and sparser vegetation cover (Kammer 2002; see also below).

Very interesting soil–plant feedbacks in the context of soil compaction, as described above, may be expected from the fate of alpine ecosystem engineers (Jones et al. 1994). These are organisms that affect key ecosystem functions in a major way and thereby support or provide habitat for a range of other organisms including plants. For instance, alpine marmots (*Marmota marmota*) are medium-sized rodents known for their extensive burrowing activity above the alpine treeline, thereby providing strong soil aeration (as do earthworms, another group of ecosystem engineers). Although we do not have empirical evidence, we expect the soil compaction and intensive human presence on ski slopes to deter alpine marmots. If so, this could be an example of a positive feedback in the direction of increasing soil compaction. The role of ecosystem engineers on plant–soil feedbacks in ski slope areas warrants in-depth research.

Snow additions and plant–soil interactions

Stable snow conditions and snow reliability are very important requirements for ski resorts (Kammer 2002; Steiger 2010; Rixen et al. 2011). The quality and depth of the snow cover determine to a large extent the success of a skiing area (Steiger 2010). Therefore, artificial snow (Fig. 1c) has been used in many ski resorts to create a deeper and more reliable snow cover, to guarantee good skiing conditions especially at lower elevations and early and late season (Lagriffoul et al. 2010). In most resorts this artificial snow production has been intensified over time, and a further increase is expected (Rixen et al. 2003, 2004; Wipf et al. 2005; Steiger 2010). Overall, artificial snow addition doubles the snow water equivalent on ski slopes (natural plus artificial snow) compared

to natural snow on ski slopes without added snow (Rixen et al. 2004; Wipf et al. 2005).

Artificial snow deviates from natural snow in its physical and chemical properties. It consists of spherical particles (Rixen et al. 2008). The artificial snow profile is more homogenous and contains more ice layers. In general, the addition of artificial snow makes the snow pack on ski slopes significantly denser and much deeper (by c. 70 cm, Rixen et al. 2004). As a result, the snow cover is preserved longer due to the increased snow mass and melts usually more than 2 weeks later than in the surrounding landscape (arrow 19; Rixen et al. 2004; Roux-Fouillet et al. 2011).

The use of artificial snow influences vegetation and soil in several ways, which will all potentially interact. It influences soil–plant interactions through biological and chemical additives and by influencing the snow cover regimes (arrow 10 and 19) and the associated microclimates over time. The snow pack impacts the soil and vegetation by influencing the temperature and light availability (arrow 11) and the soil moisture content during the growing season (arrow 12; Wipf and Rixen 2010). Below we will discuss these impacts related to (artificial) snow additions in more detail.

Water composition and additives of artificial snow

The added snow on the ski slopes influences the soil through its nutritional impact (arrows 16, 18). Water for the artificial snow production is often taken from lakes, rivers, reservoirs or groundwater. These water bodies differ from precipitation in their chemical composition, containing more nutrients including base cations for plant growth, more salt (together leading to 4 times higher electrical conductivity) and the pH is often higher (Jones and Devarennas 1995; Wipf et al. 2005; Rixen et al. 2008). Sometimes, biological additives to induce ice nucleation activity (INA) are applied to enhance artificial snow production at temperatures warmer than approx. -3°C . These INA products are derived from plant pathogenic gram-negative bacteria, especially sterilised *Pseudomonas syringae*, and are applied worldwide (Rixen et al. 2003, 2008; Lagriffoul et al. 2010). Their potential impacts on the environment have been controversial, including their possible pathogenic effects on plants (arrow 17; Lagriffoul et al. 2010). Surviving bacteria or toxins in dead bacteria could affect plants and increased ice nucleation activity could also affect plant tissues. Since 1997, some countries in the Alps have banned INA products as a precautionary measure, even though it still remains unclear if and how alpine plants could be affected by INA products (Rixen et al. 2003, 2008).

Locally, artificial snow hardeners, in the form of salts, are used to harden the surface of ski slopes, for example to prepare them for ski races (on artificial or natural snow, Lagriffoul et al. 2010). These chemicals melt the upper layer of the snowpack and change the

snow quality, thereby creating an icy surface. The salts used as snow hardeners are predominately based on chlorides and nitrates (e.g. ammonium nitrate, ammonium chloride, ammonium sulphate, potassium chloride, sodium chloride and phosphates; Rixen et al. 2008; Lagriffoul et al. 2010). The impacts of most salts in artificial snow on the environment have not yet been investigated extensively. However, as some of them (e.g. nitrate salts) are commonly used in concentrations that are, locally, as high as in agricultural fertilisation, they are likely to infiltrate into the soil (arrow 18) and increase the nutrient availability to plants (arrow B). Also the pH may be increased (arrow 18; Kangas et al. 2009). Due to the use of surface water for snow production, and especially due to snow additives and hardeners, plant species that require high nutrient availability, such as grasses typical for nutrient-rich meadows, are probably favoured at the expense of less competitive species (Kammer 2002; Roux-Fouillet et al. 2011). Such shifts in plant strategies tend to have negative impacts on species diversity and could lead to the loss of some rare alpine species (arrow 17; Kammer 2002; Rixen et al. 2003). They may also feed back to the soil (arrow A) through shifts in leaf litter decomposability (see above). A greater proportion of herbaceous, nutrient-acquisitive species would be expected to feed back to soil fertility through greater litter decomposability overall (Aerts and Chapin 2000; Cornelissen et al. 2007; Freschet et al. 2012), although, again, nutrient-acquisitive grasses tend to be somewhat less decomposable than nutrient-acquisitive forbs (Quested et al. 2003; Soudzilovskaia et al. 2007). Also, higher soil nutrient availability and pH may shift originally fungal-dominated microbial communities of relatively infertile soils towards bacterial-dominated communities (Bardgett and Wardle 2010). Such a shift would accelerate soil nutrient turnover, providing positive feedback to the already enhanced nutrient cycle.

Snow cover properties and winter temperature regimes

Snow addition, whether machine produced artificial snow or natural snow imported from outside the ski slope area, increases the depth and duration of snow cover, which will have effects that may be (partly) decoupled from the moderately fertilising effect of artificial snow. Some of these effects will act through the temperature regime, as snow is known to act as a good insulator, owing to the extensive air spaces surrounding the ice particles in snow.

Indeed, deeper snow packs tend to go along with higher winter soil temperatures (arrow 11; Sturm et al. 2005). The supplemented artificial snow enhances the amounts of snow on the ski slopes (arrow 19). In the long term this increased snow cover alone, without concomitant changes in snow quality, would be expected to lead to higher soil temperatures on ski slopes, leading to increased microbial activity and CO₂ and N₂O production (but also denitrification) and increased N min-

eralisation, with consequences for soil N availability and through that the composition of plant species (arrows 13 and 14; Keller et al. 2004; Rixen et al. 2008).

However, we have to take into account the large difference in snow quality on ski slopes as compared to the nearby mountain landscape. In general on ski slopes, the density, hardness and thermal conductivity of the snow have been reported to be higher compared to a normal snow pack (Keller et al. 2004; Delgado et al. 2007). During the winter, slope grooming machines frequently drive over the ski slopes to prepare them, thereby compacting the snow (arrow 10). Furthermore, artificial snow is denser than natural snow from the beginning, due to the spherical shape of its ice particles (arrow 19; Kammer 2002; Keller et al. 2004; Kangas et al. 2009). The density of freshly produced artificial snow ranges from 350 to 600 kg m⁻³, which corresponds to old and wet natural snow. However, density, temperature conductivity and gas permeability on ski slopes with artificial snow do not differ greatly from those on other ski slopes; depth of snow cover and grooming cause more difference in snow properties (Kammer 2002). Indeed, the temperature conductivity of snow on ski slopes is 2.5 times higher for compacted artificial snow and twice as high for compacted natural snow, compared with uncompacted natural snow (Rixen et al. 2008). On ski slopes in snow-rich mountain regions, the temperature under the compacted natural snow cover can be as low as -10 °C, while under normal snow covers the temperature hardly ever drops below 0 °C (Rixen et al. 2004; Wipf et al. 2005). Rixen et al. (2004) found a decrease in soil surface temperature of 1 °C on ski slopes compared to off-piste plots; these lower temperatures can lead to long-term and major soil frost on ski slopes. However, it is the balance between initial snow quality, snow compaction and snow depth that determines the insulation effect and thereby the effect on soil processes. Thus, when artificial snow is used, freezing of the soil occurs less regardless of the high temperature conductivity of the snow, because a larger snow depth enhances the insulation effect of the snow cover (Rixen et al. 2004).

Temperature has been shown to be one of the most important factors influencing the alpine vegetation (arrow 13). First, many studies have reported that temperature is the main driver of phenology in alpine plants (Jonas et al. 2008; Wipf 2010; see also below). Colder temperatures and ice layers under ski slopes can easily damage aboveground and belowground parts of plants, with negative consequences for their performance during the growing season (Roux-Fouillet et al. 2011). This may cause shifts in functional composition from more frost-sensitive to more frost-tolerant species and in a higher proportion of unvegetated ground on the ski slopes (Rixen et al. 2003; Wipf et al. 2005). On ski slopes a decrease in early flowering species had been found, because cold soils under compacted snow delay their development (Wipf et al. 2005; Roux-Fouillet et al. 2011). However, when artificial snow is used on ski

slopes approx. 5–10 % more woody plants may be found, due to the increased snow cover providing more protection against mechanical damage (Rixen et al. 2003, 2004; Wipf et al. 2005). Soil freezing, and subsequent vegetation change can influence the soil properties (arrow A). Specifically, increased root mortality and reduced plant nitrogen uptake induced by soil freezing can increase soil nitrate levels, even without an increase in net mineralisation or nitrification (Rixen et al. 2004, 2008).

Lower temperatures and soil freezing also influence the soil properties and processes (arrow 14). Freezing inhibits the microbial community, resulting in a reduction of microbial activity, and it impacts the soil aggregate stability. These factors affect litter decomposition processes and thereby soil C and nutrient and C dynamics including net N mineralization (Rixen et al. 2004, 2008). The compaction of snow and ice layers also causes a decrease in gas exchange capacity of the snow cover, especially through artificial snow. This can lead to oxygen deficiency, which can influence the vegetation (arrow B), as oxygen deficiency may lower the frost resistance of some species, and may cause damage to plants during cold periods (Kammer 2002; Rixen et al. 2003; Roux-Fouillet et al. 2011).

As a result of the increased snow depth, snowmelt is delayed and the snow cover lasts up to 4 weeks longer on ski slopes compared to the surrounding landscape. This shortens the vegetation growing season correspondingly and impacts the plant species composition (Keller et al. 2004; Rixen et al. 2008; Kangas et al. 2009). A decrease in abundance of early flowering species in response to snow addition has been reported (Rixen et al. 2004; Wipf et al. 2005). Prolonged use of added (artificial) snow may favour woody plants (see above), snow bed species and late-flowering species, at the expense of wind-edge species adapted to low or absent winter snow cover (Rixen et al. 2003; Wipf et al. 2005; Wipf and Rixen 2010). Such changes in the vegetation related to snow cover could induce changes in the soil (arrow A) differently from those related to the fertilising effect. For instance, in those cases where shrubs expand in response to prolonged snow cover, this would result in a shift towards more recalcitrant leaf litter, decomposing slower and releasing nutrients into the soil more slowly (Cornelissen et al. 2007; see also above).

Through the delay in vegetation development, the plants on ski slopes may also be mown in an earlier phenological state than next to ski slopes, i.e. before flowering and fruiting, thereby reducing reproductive output (Kammer 2002).

Water input

The water content and water availability are indirectly increased by snow depth, which in turn depends on snow supplements (arrow 12; Roux-Fouillet et al. 2011). The compaction of the snow cover reduces the water holding

capacity of the snow and enhances water runoff (Kangas et al. 2009) due to reduced infiltration rates and water storage capacity (Roux-Fouillet et al. 2011). These effects are stronger under more intensive disturbance regimes including machine grading on ski slopes (Pintar et al. 2009). Furthermore, soil freezing can limit the water uptake by plants, which hampers plants directly (Rixen et al. 2004). The spring thaw releases the water and nutrients from the snow (see above), which influence the soil moisture and nutrient status till the end of the summer (arrow 16). Soil moisture in turn interacts with the summer temperatures and in combination these factors determine vegetation growth and composition (arrow 15) (Wipf and Rixen 2010). Artificial snow addition doubles the water input compared to natural snow alone (Rixen et al. 2004). The increased water content of the added artificial snow leads to a shift towards more mesic plant species in the vegetation (Roux-Fouillet et al. 2011).

Erosion risk

The creation and machine grading of ski slopes impact the vegetation and soil through the higher susceptibility to erosion (arrow 5; Delgado et al. 2007; Kangas et al. 2012; Ristic et al. 2012), because the removal of vegetation and rocks or removal of the top soil layer removes physical barriers to runoff and damages the soil physical structure (Burt and Rice 2009). Due to the sparser vegetation cover and increased soil density through compaction, especially graded ski slopes are more sensitive to soil erosion and surface runoff. Furthermore, erosion of fine soil including clay (Barni et al. 2007) is also stimulated by the reduction of water infiltration rates and water storage of the snow cover, induced by snow compaction through machines (Roux-Fouillet et al. 2011). The snow supplements cause additional water input and extra melt water, which could exacerbate the soil erosion risk (Rixen et al. 2004). Fluctuations in temperature, like soil freeze–thaw cycles, may cause further soil disturbance and thereby increase the surface runoff and soil erosion (Rixen et al. 2008).

Surface erosion impacts the vegetation and soil, with important feedbacks (arrows 6 and 7). It causes losses of the seed-bank through seed mortality and downhill transport with runoff, with negative effects on regeneration of the vegetation. Thereafter, constraints on seed influx, soil disturbance and compaction will hamper the establishment of a diverse and closed plant cover, which may cause yet more positive feedback enhancing erosion rates (arrow 6; Roux-Fouillet et al. 2011). Reseeding and re-vegetation are common aspects of the management of graded ski slopes (not cleared ski slopes) in attempts to minimize the erosion problem. Non-native species are often used, mostly grasses and legumes, because they are cheaper in the short run, which changes the vegetation composition on ski slopes (Burt and Rice 2009; Kangas et al. 2009). The consequences for soil stability relative

to that below natural vegetation are yet poorly known. Erosion also impacts the surrounding environment, as it causes sedimentation of soil and influx of nutrients downstream (Kangas et al. 2012). This reduces the water quality of rivers and lakes nearby, eutrophication being one important contributor to this (Burt and Rice 2009; Kangas et al. 2009). Indeed, water bodies near skiing areas often have higher variation of nutrient concentrations over time and higher overall nutrient levels than control water bodies (Kangas et al. 2009).

Linking climate change, ski slope management and plant–soil interactions

Climate change will lead to changes in temperature and precipitation (see “[Introduction](#)”), which will have major effects on the snow cover (arrow 11). Ski slope management needs to adapt to changes in snow cover (arrows 10 and 19), and this management adjustment will in turn feed back to the vegetation, soil and their interaction.

The snow cover is probably one of the fastest changing features as a consequence of climatic change and, in spite of great spatial heterogeneity (Makoto et al. 2014), it is likely that the predominant direction of change will be a decrease in snow cover in mountain regions due to a warming climate (IPCC 2007; Wipf and Rixen 2010). Predictions for the increase in the mean annual temperature range from 1.4 to 5.5 °C in the Alps (Kammer 2002; IPCC 2007). Most scenarios of climate change also predict shifts and abnormalities in snowfall pattern, whereby the start of the snow season will be later and the melt-out earlier (Wipf et al. 2005, 2009; Rixen et al. 2012). Because of the higher winter temperatures, a higher percentage of precipitation will fall as rain instead of snow, therefore the snow cover will be thinner and melt earlier. This will cause a longer plant growing season and goes against the effects of the prolonged soil frost associated with artificial and compressed snow on ski slopes (see above). It is also likely that the snow density will increase as more rain will lead to wetter snow (Rixen et al. 2008). However, changes in snow fall patterns will depend on the altitude: at higher altitudes the snow fall may be enhanced due to a predicted increase in precipitation, whilst lower altitudes might experience a decrease in snow-to-rain ratio due to warmer temperatures (Rixen et al. 2004; Wipf and Rixen 2010).

Together with this probable upwards shift of the snow line, the minimum altitude with reliable snow conditions for skiing in the Alps will rise to at least 1,500 m, causing snow shortage problems for many ski resorts at elevations between 1,200 and 1800 m (Kammer 2002; Marty 2008; Lagriffoul et al. 2010). Because the tourists request excellent skiing conditions already early in the season, i.e. November or early December in the northern hemisphere, the ski resort will have to

adapt to these changes (Lagriffoul et al. 2010). Consequently, ski resorts will extend the production of artificial snow to maintain their winter sport function into the future, especially at elevations between 1200 and 1,800 m (Kammer 2002; Rixen et al. 2008). Consistent with the effects of artificial snow discussed earlier, increased application could amplify the moisturizing and fertilizing effects, causing further associated shifts towards more mesic and nutrient-acquisitive vegetation, leading to further expansion of competitive species at the expense of species diversity and specific rare alpine species.

Based on our current knowledge of soil temperature regimes on ski slopes (see above), the warmer climate will probably not lead to higher winter soil temperatures. Because the (artificial) snow cover will become thinner and denser, its insulation will decrease, which very likely leads to soils becoming colder on ski slopes in a warmer climate in the Alps (Rixen et al. 2008; see also Groffman et al. 2001), especially at lower altitudes. However, at higher elevations higher precipitation and low temperatures may lead to deeper snow cover with stronger temperature insulation and less damage to vegetation. It is difficult to predict the effects on vegetation and soil properties in this system with many interacting external drivers, especially the (artificially maintained) minimum snow depth, extended growing season length, increases in freeze–thaw cycles in autumn and spring, intensified nutrient and water input, and possibly increased soil erosion due to greater soil compaction, reduced infiltration and greater runoff. All these interactions will in turn be influenced strongly by local topography and soil type as well as by the exact management practice to maintain snow regimes on ski slopes.

Research agenda

It will be a major challenge for future research (Table 1) to take into account all these interactions and feedbacks for application in particular skiing regions or sites. Future research directions (not only on ski slopes) should therefore aim at understanding climate change effects on the interactions of snow cover, soil and vegetation. A specific research gap is to understand how disturbed sites at high elevation can be restored by using site-specific and locally adapted plant material. Aspects of interest should also include issues beyond this review, such as effects of extreme events (freezing events, storms) and their possible link with soil erosion. Extreme climatic events such as strong drought or extreme rainfall have recently been shown to affect soil biota, leaving legacy effects that may promote the establishment of exotic invasive species (Meisner et al. 2013). This is a new research direction of relevance to ski slopes, which are already vulnerable to plant invasion owing to their relatively low plant cover due to high disturbance (Burke

Table 1 Research agenda for improved understanding and prediction of interactive impacts of ski-slope management and climate warming on alpine ecosystems through soil–plant feedbacks

Impact of seeding, soil disturbance and canopy opening and/or possible release from soil-borne pathogens on the establishment and competitiveness of plant species alien to the original plant community; and their knock-on effects on soil properties
Impact of soil–plant feedbacks through ecosystem engineers such as alpine marmots (or invertebrates like earthworms), the decline or disappearance of which may exacerbate soil compaction impact
Possibilities and feedbacks of restoration of disturbed ski slope areas by seeding or planting native as opposed to alien plant species, particularly on vulnerable slopes at high elevations
Impacts, through plant–soil feedbacks, induced by shifts from fungal-dominated to bacterial-dominated energy channels in soils with increasing nutrient availability and pH (e.g. through application of artificial snow)
Effects of extreme climatic and erosion events (e.g. extremes of precipitation and temperature, increased frequency of freeze–thaw cycles, storms, avalanches, landslides) on ski slope areas and their downhill zone of influence
Effects of extreme climatic events through soil legacies via changing microbial communities
Knock-on effects through plant–soil feedbacks of shifts between the type of precipitation (snow versus rain) at lower versus higher altitude ski slopes as affected by climate warming
Developing lower impact ski slope management practice
Building and applying a spatially explicit model that will allow the incorporation of initial environmental site variables and specific management regime on ecosystem response variables subject to plant–soil feedbacks

and Grime 1996) and may be even more so under climate warming and its associated extreme climatic fluctuations. Shifts in soil microbial communities may also feed back to aboveground vegetation performance, because of possible shifts in mycorrhizal symbiosis or in the fungal-to-bacterial ratio (Bardgett and Wardle 2010). Such shifts may accompany increases in nutrient availability and pH in response to the use of artificial snow (see above). Research in alpine climate change ecology can probably learn much from the “experimental” snow manipulation on ski slopes and vice versa, since both approaches share a main research focus on effects of changing snow cover on plants and soils. On ski slopes and in alpine vegetation in general, it is important to understand how effects of changing snow cover (and respective soil temperatures and season length) on vegetation performance and soil–plant interactions depend on initial environmental conditions. Indeed the strong context dependence of such effects on topography, climate, initial soil and vegetation properties is one of the key findings of this paper, but also makes it difficult to make broad generalisations and quantifications at this current stage of knowledge. So what is the most efficient way to make further progress on this?

Probably a fruitful way forward will be to build a spatially explicit model, for instance based on the framework and plant–soil feedbacks presented here, with the possible application of structural equation modelling (SEM) to quantify the contributions of individual cause-effect arrows. There are relevant SEM-based examples involving soil–plant feedback in the literature that show the potential usefulness and practicalities of such models, for instance in the context of roadside grassland succession (Garcia-Palacios et al. 2011), or *Sphagnum* peatland warming (Jassey et al. 2013). The ski slope model should be able to predict, for a given alpine site, impacts of a series of concrete ski slope management regimes on response variables such as productivity, vegetation functional type composition, soil properties, runoff quantity and quality. Based on topographic, climatic (including snow dy-

namic), initial vegetation and soil properties, such a model should be able to incorporate the main impacts and interactions reported in our review. Since we have seen that the responses of alpine ecosystems to ski slope management are so dependent both on initial environmental conditions and on the exact management regimes, only such a model may be able to incorporate this context dependency of response. Moreover, future scenarios under climate warming might be incorporated relatively easily into such a model, because it could be treated as a special (new) case of initial climatic conditions for each given site. Once such a model has been built adequately, it may also serve as a tool to identify which types of ecosystems, soils and climates need further empirical study to improve parameterisation of relationships within the model. It may also help to explore how specific aspects of ski slope management can be optimized so as to make the ski culture more environmentally sustainable, both at present and in a warmer future. Indeed, we need to apply our insights in plant–soil feedbacks to help switch the ski culture focus from snow reliability lines to ecosystem sustainability lines in the alpine landscape.

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Attachment 2. Relevant scientific literature since the Meijer zu Schlochtern et al. review

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