The Australian Alps
Rehabilitation Manual

A guide to ecological rehabilitation in the Australian Alps

July 2006

Prepared by Roger Good for the Australian Alps Liaison Committee
Dedication

This Manual is dedicated to the life of Amanda Carey, Namadgi National Park Ranger, who was totally committed to the conservation and rehabilitation of the Alps ecosystems.

Amanda had a special affinity with alpine and subalpine bogs and fens and exhibited a motivation, enthusiasm and commitment to their rehabilitation that most of us can only aspire to emulate.

Australian Alps park staff and other personnel involved in the bog and fen rehabilitation program have faced a great challenge in the rehabilitation work but all have been driven to continue the work by the enthusiasm of Amanda, even in her own difficult times over recent years.

The challenge for all of us now, is to complete the work for and in the memory of a wonderful friend, dedicated mountain conservationist, bog and fen specialist and convenor of the Australian Alps Natural Heritage Working Group.

31 July 1962 – 13 November 2005
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A Introduction

A.1 The purpose and scope of this Manual

The unique natural and cultural values of the Australian Alps are among the most significant in the world. The high catchments of the Alps supply some of our most important rivers and irrigation areas. The alpine landscape is rare, beautiful and features prominently in the cultural life of Australia.

While the environment of the high Alps is harsh, it is also extraordinarily fragile. The Alps have a history of considerable disturbance since European settlement. Mining, grazing, hydro-electricity schemes, ski resort development and bushfires have impacted soils, watercourses, wetlands and biodiversity. Degrading processes such as weed invasion, bog desiccation and soil erosion continue to operate.

Many sites remain degraded and unsightly. With increasing visitation, ongoing development pressures and climate change, new disturbances are inevitable. The managers of the alpine national parks carry a responsibility to rehabilitate sites affected by these past and new disturbances.

Figure A.1 Rawsons Pass, near Mount Kosciuszko, 2005

Although the national parks of the Alps cover a wide range of ecosystems, this Manual focuses primarily on the alpine and subalpine zones. These ecosystems are different to those in lowland areas, and different to mountain ecosystems elsewhere in the world. We need to know how these ecosystems work, before we can start to put them back together. Rehabilitation must be guided by ecological science.

This Manual has been produced by the Australian Alps Liaison Committee (AALC) to assist managers with the difficult task of protecting and repairing the Alps environment. The Manual provides principles, procedures and best-practice guidelines for rehabilitation projects.

The aim is to ensure that rehabilitation is based on the best science and technology, and that an ecological approach to rehabilitation is applied consistently across the Australian Alps.
A.2 The structure of the Manual

Section A introduces the Manual and the rehabilitation challenge. Section B provides background on the unique environment of the Australian Alps, and implications for rehabilitation. Section C outlines the history of rehabilitation in the Alps, with notes on key examples and lessons. Section D provides best-practice principles and procedures to assist with the planning of ecological rehabilitation projects.

Sections E and F provide general advice on the rehabilitation of new development sites and existing disturbed areas. Section G provides more detailed guidelines for specific development types and rehabilitation situations. The case studies in Section H provide examples of methods used to rehabilitate alpine communities.

A.3 Using the Manual

The Manual is intended primarily for use by park agency staff actively involved in planning and implementing rehabilitation works. The Manual may also be of use to others undertaking rehabilitation in the Alps, including road agencies, electricity and telecommunications utilities, hydro-electricity generators, private developers and ski resort managers.

The background sections of the Manual distil information of particular relevance to understanding and rehabilitating the ecosystems of the Alps. The principles and standards outlined in the Manual can be used in formulating rehabilitation objectives.

The Manual provides a checklist of procedures and requirements for site assessment, and project planning and administration. Practitioners can use the review of techniques, design specifications and case studies to select appropriate methods for their projects. Agencies may use the Manual to develop their own manuals for specific jurisdictions, areas and project types.

The Manual can also provide development approval authorities with a set of standard guidelines to use as a reference in applying assessment requirements and approval conditions. It can be used to inform contractors of expected performance standards and the rationale of a project task within the broader rehabilitation context. The Manual may further be a useful resource for staff induction and training.

Rehabilitation is a huge and burgeoning field, and this Manual cannot hope to provide the level of detail required by practitioners. This Manual is part of the manager's toolkit and should be used in conjunction with more specialised references, covering, for example, flora and fauna, revegetation, restoration ecology, soil assessment and survey and monitoring program design. Sources of more detailed information are provided in Section I (Resources and References).

A.4 Some working definitions

Objectives in land repair activities form a spectrum from basic soil stabilisation (or ‘reclamation’) to the reconstruction of pre-disturbance biological and physical conditions. This Manual uses the following definitions.

Restoration

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society of Ecological Restoration 2004). An ecosystem has ‘recovered’ - and is restored - when it contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy (Society of Ecological Restoration 2004).
Rehabilitation

Rehabilitation overlaps with restoration in aiming to recreate all or some pre-disturbance conditions. Rehabilitation emphasises the repair of ecosystem processes, productivity and services (Society of Ecological Restoration 2004). Rehabilitation also recognises that some forms of disturbance will not be reversible. For example, peat soil may change irrecoverably on drying and flora-fauna relationships may be permanently lost in some degraded areas.

While ‘rehabilitation’ is generally used as the default term throughout this report, some projects may aim to achieve the complete restoration of a disturbed site.

Ecological rehabilitation

For the purposes of this Manual, ecological rehabilitation refers to scientifically-based rehabilitation which aims to achieve a self-sustaining natural community by re-creating or regenerating pre-disturbance ecological functions and processes at a site.

Ecological rehabilitation is a new and evolving science. The principles and techniques described in the Manual, like the science, are provisional and subject to ongoing testing and revision. Good project design, effective monitoring and evaluation and communication of results will be critical to the evolution of ecological rehabilitation in the Australian Alps.

The Australian Alps Liaison Committee

The Australian Alps Liaison Committee (AALC) has been established under an intergovernmental Memorandum of Understanding (MOU) to oversee the cooperative management of the Australian Alps national parks and reserves. The AALC comprises senior representative of the conservation agencies from the Commonwealth Government and the three State and Territory jurisdictions.

The Australian Alps national parks include Namadgi National Park and Tidbinbilla Nature Reserve (ACT), Kosciuszko and Brindabella national parks and Bimberi and Scabby Range nature reserves (NSW) and Alpine, Mt Buffalo, Snowy River and Mt Baw Baw national parks (Victoria). Together, the parks cover 1.6 million hectares and contain most of the montane, sub-alpine and alpine areas in the Australian Alps bioregion.

The objectives of the MOU are to:

1. protect the unique mountain landscapes;
2. protect natural and cultural values;
3. protect mountain catchments; and
4. provide outdoor recreation and tourism opportunities to encourage enjoyment and understanding and conservation of the alpine environment.

The MOU recognises the importance and role of the Australian Alps as part of the greater catchments of the Snowy, Murrumbidgee and Murray Rivers.
B The Alps environment

B.1 Physical environment

B.1.1 Climate

The climate of the mid latitude, high elevation Alps environment is characterised by high precipitation and low temperatures.

Weather in the Alps is dominated by a strong and cool westerly air stream during the winter months. In summer, precipitation generally results from local thunderstorms and occasional depressions of tropical origin which carry moisture inland from the coast.

Orographic uplift is also a significant climatic factor. The north-south orientation and the steep westerly side of the Dividing Range causes a rapid uplift of the prevailing east moving air masses. This rising air cools, moisture condenses and precipitation falls as snow at higher elevations and as rainfall at lower elevations. The drying effect of warming, descending air on the eastern side of the Divide produces ‘rainshadow’ areas of reduced rainfall in the eastern foothills and valleys.

Precipitation generally increases with elevation, reaching a maximum of approximately 3,000 millimetres per year.

While evaporation in the Alps is less than in lower areas, it is still a significant factor affecting plant growth. Average monthly summer evapotranspiration losses are in the order of 100-250 millimetres per month, depending on altitude and aspect. These evaporation losses can exceed the summer rainfall, subjecting mountain vegetation to periods of moisture deficit. This is a particular feature of the lower montane and tablelands rainshadow areas, but can also occur for short periods at higher elevations, where plants are less adapted to moisture stress. Moisture deficits are exacerbated by the shallow and free draining soils in many parts of the Alps. Soil exposure caused by disturbance can quickly lead to vegetation desiccation and death.

Temperatures generally reduce with increasing altitude, at an average rate of 7.5°C per 1000 metres. This produces a short growing season with cold to mild growing conditions. In the alpine and subalpine zones, cold air drainage is a significant local climatic factor influencing plant growth and survival. During the colder months, cold, dense air accumulates in shallow depressions and valleys each night. Valley floor temperatures can be up to 10°C lower than points on adjacent slopes as little as 20 metres above the valley floor. These low temperatures may be lethal to young plants, evidenced by the death of tree seedlings each autumn and spring. Around some larger shallow valley sites, an ‘inverted treeline’ has developed in response to the regular inversion of the local temperature profile.

Snow cover is important for plant survival and growth. Snow provides an insulating blanket which maintains a temperature slightly above 0°C in the subnivial space (between the snow layer and the soil/vegetation).

The prevailing cold southwesterly winds during the winter and hot northwesterlies in summer have a considerable influence on plant growth and distribution. For example, windswept feldmark occurs on harsh sites where snow is continually removed by wind, exposing the community to the effects of frost heave and wind erosion.

The impacts of climate change may be first exhibited in alpine areas. Average summer temperatures have increased at Charlotte Pass by about 1°C, compared with the previous 25 years. Similarly, ultraviolet light levels and day length have increased. Ultraviolet light levels have increased by as much as 15 percent.
B.1.2 Soils

Some 18 Great Soil Groups are recognisable in the Alps, reflecting to some degree the underlying parent materials. In the alpine zone however, geology has had only a minor influence on soil formation. The alpine humus soils have formed on both acidic (granitic) and basic (basaltic) parent materials. In these higher elevations, the many climatic changes, especially since the Pleistocene, have been the major influence on soil formation. The depth of alpine soils in the Alps is significant, compared to the considerably shallower soil mantles on mountains elsewhere in the world.

The higher elevations are dominated by organic alpine humus soils, which are climatic climax soils. Although strongly acid and low in nutrients, alpine humus soils are maintained by the recycling of nutrients produced by vegetation decomposition and earthworm activity. Soil mycorrhizal fungi are very active in alpine humus soils and play a major role in assisting the uptake and utilisation of limited nutrients.

Given the high level of precipitation at these elevations, the absence of podsolisation – the leaching and deposition of clay and organic colloids into a distinct B horizon – is striking. Soil nutrients and colloids accumulate in the surface soil due to the recycling by deep-rooted vegetation, vigorous activity of soil invertebrates and the accretion of windblown dust. Conversely, lower rainfall tablelands soils on the same parent material often have marked podsolisation.

Soils in the alpine and subalpine zones show a well developed micro-sequence in response to watertable levels. Alpine humus soils occupy upper slopes grading to acidic bog and fen peats on saturated valley floors. Valley floor areas which are not flat have poorly developed podsols (gley podsols) and silty bog soils replacing the raised fen and bog peats.

Soils associated with spring and early summer snowpatches show a different wet-dry micro-sequence. Fen peats supporting short alpine herbfield grade to snowpatch meadow soil, then alpine humus soil supporting tall alpine herbfields. Where the snowpatches are long lasting and soil development is minimal, gravely lithosols replace the snowpatch meadow soils. Feldmark occurs on more exposed areas of gravelly lithosols, where strong winds have carried off the finer particles and organic matter.

B.2 Ecological communities in the Alps

The distribution of ecosystems in the Alps strongly reflects altitudinal and climatic gradients. Often very discrete boundaries exist between vegetation communities.

Four biophysical zones are recognised in the Australian Alps:

- Alpine zone;
- Sub-alpine zone;
- Montane zone;
- Tablelands zone.

Below is a brief summary of these biophysical zones and the vegetation communities they support. Further information can be found in references listed in Section I.

B.2.1 Alpine zone

The alpine zone occurs above the treeline, which is the altitudinal and climatic limit to tree growth. Throughout the world, the treeline occurs where the mean summer temperature is approximately 10°C or less, regardless of altitude. The treeline occurs at about 1800-1830 metres above sea level (ASL) in NSW and 1700-1750 metres in Victoria.
The alpine zone occupies a very small area (approximately 25,000 hectares) in New South Wales and Victoria. The zone supports an array of significant communities including herbfields, heaths, bogs, fens, feldmark and sod-tussock grasslands, many rare and endemic flora and fauna species, and unique geological features.

A well developed mantle of soil covers the alpine zone to the highest peaks, and is only absent from the most exposed rocky outcrops. The alpine humus soils are organic soils and very prone to wind and water erosion when exposed. These soils are low in nutrients but support vegetation growth through rapid nutrient recycling.

The alpine zone supports several vegetation communities which have significant hydrological and biological conservation values.

**Bogs and Fens**

Bogs and fens are groundwater communities dominated by hummock forming mosses (*Sphagnum* spp) and acidophilous shrubs. These communities develop in sites where partially decomposed organic matter accumulates and is colonised by water-loving species such as *Carex* sedges. The growth and decomposition of these species over hundreds of years produces an organic ‘dam wall’ and a pool of surface water.

Bogs and fens occur throughout the Alps, but predominantly in the alpine and subalpine zones. They exist in two forms. Raised bogs occur as physiographic climax communities on the mid to lower slopes of valleys, dominated by the heath *Epacris paludosa* and the moss *Sphagnum cristatum*. Raised bogs are more common in the Victorian Alps.

Valley bogs dominated by *Carex gaudichaudiana* and *Sphagnum cristatum* occur on valley floors where free-standing water and acid soil conditions prevail. The valley bog community is considered to be transitional between the raised bog and acid fen communities. Acid fens dominated by *Carex gaudichaudiana* occur along watercourses in relatively level sites where surface water is retained. Acid fens depend on continual small inputs of nutrients or mineral matter from surrounding areas. This distinguishes fens from the raised bog community which occurs under saturated, nutrient-deficient conditions. The acid fen community only occurs in Kosciuszko National Park and a small area in Namadgi National Park.

The slow release of water from the saturated peatbeds of the bogs and fens is of considerable importance to the surrounding alpine humus soils, streams and other alpine communities. In Kosciuszko and Namadgi National Parks, the bogs and fens provide important habitat for the Corroboree Frog (*Pseudophryne corroboree*) and the Alpine Water Skink (*Eulamprus kosciuskoi*). The bogs also play a role in carbon sequestration and the filtering of pollutants from subsurface flows. They will be one of the first alpine communities to be affected by climate change and are being monitored as an indicator of change. Considering the long period of peat deposition in the Alps, the remaining peatbeds represent a storehouse of botanical and climatic history.
The many years of snow lease and high country stock grazing has disturbed the bogs and fens more than any other community in the Alps. Only about half of the original 5,500 hectares of bog and fen area remains in Kosciuszko National Park and less than half of the original 2,500 hectares remains in the Victorian alpine parks. Small areas remain functional in the ACT; the Ginini bog complex is listed as a Ramsar site.

**TALL ALPINE HERBFIELD**

The tall alpine herbfield dominated by *Celmisia* and *Poa* species is the climatic vegetation climax and the most widespread community in the alpine zone. It occurs where alpine humus soils are well developed. It is best represented in the Kosciuszko alpine zone but also occurs extensively, although less continuously, in the Victorian Alps at Mt Buller, Stirling, Pinnabar, Cobberas and small areas at Mt Speculation, Howitt, Lovick and Snowy Bluff. There is also a small area of tall alpine herbfield in Namadgi National Park.

Tall alpine herbfield and associated alpine humus soil occur on all bedrock types. This contrasts with the alpine herbfields of Europe, which develop only on soils with adequate mineral nutrient status. The Australian tall alpine herbfields are maintained on the nutrient-deficient alpine humus soils by the rapid release and cycling of the limited available nutrients.

The tall alpine herbfields are the most diverse of all the alpine communities, and in summer provide the colourful mass flowering for which the Alps are renowned. Several herbfield species were reduced almost to the point of extinction during the grazing era in Kosciuszko National Park, including Robust Wallaby Grass (*Chionochloa frigida*), Mountain Celery (*Aciphylla glacialis*), Mountain Aciphyll (*Aciphylla simplicifolia*) and Anemone Buttercup (*Ranunculus anemoneus*). With the long continuation of grazing in the Victorian Alps, several species are now considered to be extinct in Victoria, including the Anemone Buttercup.

In some steeper and rockier areas, tall alpine herbfield is replaced by the smaller and fragmented *Brachyscome nivalis-*Austrodanthonia alpica* community. This community has much in common physiognomically with the rock-ledge arctic/alpine communities of Europe.

Some 30 endemic plant species occur in the tall alpine herbfields of the Alps, the result of a long period of isolation and speciation. Interestingly, speciation can also be triggered by human impacts, as seen in Buttercups during the grazing era. Climate change is also expected to influence speciation in alpine plants.
Several tall alpine herbfield species exhibit unique flowering characteristics. The Sky Lily (*Herpolirion novae-zelandiae*) produces a few minute flowers which last only a few hours, while the Marsh Marigold (*Caltha introloba*) has adapted to flowering under translucent snow cover.

A discussion of succession and sustainability in tall alpine herbfields is presented in Attachment 1.

**Figure B.2 Tall alpine herbfield**

**SHORT ALPINE HERBFIELD**

This community occurs immediately below snowpatch areas. The community supports a specialised ground-hugging vegetation complex of Star Plantain (*Plantago muelleri*) and White Purslane (*Neopaxia australasica*) that is maintained by a continuous flow of cold water and nutrients from the melting snowpatches above them. The community also supports a number of species of botanical interest, including Snow Pennywort (*Diplaspis nivis*), Wreath Pennywort (*Dichosciadium ranunculaceu*) and Marsh Marigold (*Caltha introloba*).

Little short alpine herbfield now remains and recent research indicates continuing decline. Cattle grazing has damaged many short alpine herbfield areas resulting in soil channelling and erosion and the drying out of the herbfield community.

**Figure B.3 Short alpine herbfield**

**FELDMARK**

Feldmark is confined to the Kosciuszko region, which is of phytogeographical significance. It exists as two distinct communities; snowpatch feldmark and the cold-feldmark or windswept feldmark of exposed ridges.
The Snowpatch Coprosma (*Coprosma niphophila*) – Snowpatch Cushion Plant (*Colobanthus nivicola*) snowpatch feldmark community occurs on the upper edges of snowpatches where the dry gravelly soils are permanently exposed. This community is moisture-stressed for the greater part of the snow-free period. When soil moisture is present, they are exposed to wide diurnal temperature ranges and considerable frost-heave.

The fragile windswept feldmark occurs in exposed areas with very shallow gravelly soils and harsh weather conditions. One of the greatest threats to its survival is siltation and deposition from the disturbance of adjacent areas. The impact of recreation and tourism is a further threat; a high-use permanent walking track passes through feldmark areas in Kosciuszko National Park.

![Figure B.4 Exposed windswept feldmark community](image)

**SOD TUSSOCK GRASSLANDS**

Sod tussock grasslands are widely distributed within the alpine and subalpine zones of the Alps, particularly in Victoria. They are dominated by the Snow Grasses (*Poa* spp) and Wallaby Grass (*Rytidosperma nudiflorum*). They commonly occur in subalpine cold-air drainage basins where temperatures are lowered by the overnight pooling of cold air. The low temperatures through late autumn and winter limit the growth of woodland species.

The sod-tussock grasslands have been heavily degraded by past stock grazing but are now more likely to be damaged by the development of ski-resort and tourism infrastructure.
HEATHLANDS

Extensive heaths of woody shrubs dominate alpine sites with very free drainage, such as boulderfields and glacial moraines, and also poorly drained sites where inadequate soil aeration limits the growth of herbaceous species.

Heaths have developed on previously disturbed and eroded sites where the underlying gravels have been exposed. The Common Shaggy Pea (*Oxylobium ellipticum*) - Mountain Plum Pine (*Podocarpus lawrencii*) community naturally occurs on boulderfields and screes and has also colonised extensive areas of tall alpine herbfield. This seral (transitional) heath community will predictably senesce and slowly return to tall alpine herbfield as the alpine humus soils reform.

The *Oxylobium - Podocarpus* tall heath is associated with shrub species which are rare in form and distribution. Ovate Phebalium (*Nematolepis ovatifolia*) is an alpine and subalpine endemic, and the Mountain Plum Pine is the only conifer of the alpine zone.

The *Oxylobium - Podocarpus* tall heath is replaced in some areas by *Epacris gunnii - Kunzea muelleri* short heath. The short heath also borders the feldmark communities in exposed sites, and the *Epacris glacialis* heaths in damp soil areas around bogs and fens. The transition from feldmark to heathland and herbfields reflects variation in soil depth, soil moisture and exposure.

The dominance of leguminous species (such as *Oxylobium, Hovea, Bossiaea* and *Acacia* species) in heathlands in the Alps contrasts with alpine zones elsewhere in the world, where leguminous species are absent or only a minor component. The many years of grazing and burning in the Alps has favoured the establishment and spread of leguminous shrubs.
B.2.2 Subalpine zone

The subalpine zone occurs between 1450 metres and 1850 metres ASL in NSW and the ACT, and between 1300 metres and 1750 metres in Victoria. It is the largest bioclimatic zone in the parks of the Alps (but not in the Alps bioregion), covering approximately 40 - 45% of the area of the parks.

The zone is dominated by Snow Gum (*Eucalyptus niphophila*) woodland. This community frequently supports a well developed shrub layer. However, the dense shrub understorey is a transitional (seral) formation resulting from regrowth following many years of domestic stock grazing and regular burning by graziers to promote ‘green pick’.

Figure B.6 Alpine heathlands interspersed with tall alpine herbfield

Figure B.7 Subalpine Snow Gums near the treeline
B.2.3 Montane zone

The montane zone comprises the steep rising slopes emerging from the flat plains and low valleys. The lower limit of the zone lies at either the tablelands or valley floors at elevations ranging from 300 to 800 metres ASL. The upper limit is marked by mean mid winter temperatures of approximately 0°C, and occurs at approximately 1500 metres in NSW and about 1350 metres in Victoria.

The vegetation of the montane zone is dominated by wet sclerophyll forests. The Alpine Ash (Eucalyptus delegatensis) – Mountain Gum (E. dalrympleana) alliance occurs at the higher part of the altitudinal range, above the Brown Barrel (E. fastigata) – Ribbon Gum (E. viminalis) alliance.

The fire sensitive Alpine Ash occurs as a single species dominant in the moister southerly and south-easterly aspects between about 1100 and 1250 metres. This species is not adapted to survive fire, regenerating only from seed after fire has removed the heavy ground litter cover and understorey.

Some species also occur as small remnants of a much wider distribution, such as Bogong Gum (E. chapmaniana). Several other genera and species representing vegetation of past climatic regimes also occur in the montane zone, including Southern Sassafras (Atherosperma moschatum) cool temperate rainforest.

Figure B.8 Alpine Ash forest in the upper montane zone

B.2.4 Tablelands zone

The tablelands occupy the undulating plateau country from which the steeper mountain landscape arises. In the Australian Alps, the tablelands occur between 300 metres and 800 metres ASL. The Monaro tablelands lie to the east of the Main Range in NSW. To the south and west of the Range, the terrain is dissected and the boundary between montane and tableland zones is indistinct.

The most significant area of tableland environment in the national parks of the Alps occurs in the dry ‘rainshadow’ area around the mid reaches of the Snowy River in NSW and Victoria. This area supports the botanically interesting White Box (Eucalyptus albens) – White Pine (Callitris glaucophylla) woodland, which is an eastern outlier of a very extensive western woodland community.

Other communities of significance also continue to survive in the rainshadow area as relics of past climatic regimes. For example the ‘black scrubs’ (Acacia sylvestris – Philotheca trachyphylla community) are of biogeographical interest as they are remnant of a fringing rainforest community that occurs more widely on the eastern coast.

The valley vegetation of the tablelands has been heavily impacted by agriculture, rabbits and weeds, and intact samples are rare. The widespread and continuing degradation of these communities increases the conservation value of areas included in the Alps park system.
B.3 Environmental implications for rehabilitation

The unique Alps environment imposes a special set of constraints on rehabilitation. Some of the key environmental factors which need to be considered in undertaking rehabilitation activities are identified below.

B.3.1 Climate

While precipitation is high in the alpine and subalpine zones, summer rainfall events can be irregular. The strong westerly winds which prevail in the alpine and subalpine zones contribute to desiccation and short-term drought conditions in summer and wind chill and ‘physiological drought’ in winter.

The length of the growing season and species suitable for use are limited by long periods of near-freezing ambient air temperatures. This limitation is most extreme in the alpine and subalpine zones during autumn and winter when the insulating benefits of snow cover are absent or reduced. In the montane and tablelands zones, temperature is a constraint throughout the autumn, winter and spring.

Below the snowline, freezing temperatures and near-frozen soils during autumn and spring can also contribute to ‘physiological drought’: when plants are still growing but are unable to fully utilise soil moisture and hence nutrient uptake. Cold air drainage is a limiting factor for tree growth in alpine and subalpine valley floor locations (such as some ski resort sites).

In alpine and subalpine areas, frost heave has the potential to exacerbate soil exposure and disturbance. Frost-heave occurs when exposed soils at field capacity are exposed to sub-zero ambient temperatures. Soil moisture forms ice crystals (‘needle ice’) that physically lift topsoil and remnant vegetation. During the day, the needle ice melts and the soil and vegetation resettles in a loose and open condition which is prone to erosion. Needle ice can uproot young seedlings and inhibit revegetation activities. Frost heave is especially prevalent during autumn and spring when snow cover is absent.

Short-term drought conditions and frost heave can be countered using mulching, however watering may also be required during dry periods. The mulch should ideally have an insulating capacity equivalent to the natural vegetation cover. Some form of mulch retention/adhesion material is generally required to secure mulch against strong winds (refer Section F).

Several weeks of no rainfall can be followed by high intensity storms. Coupled with free-draining and erodible soils, this pattern has implications for vegetation establishment and growth, and erosion potential at exposed sites. Erosion controls must be designed to account for intense storm events.

The low rainfall of the rainshadow areas must be considered in the selection of species and techniques used in rehabilitation projects on the tablelands.

The predicted effects of climatic change, particularly in the alpine and subalpine zones, also need to be considered in rehabilitation projects. Currently occurring native plant species may not be those that will survive under changed climatic conditions and may not be used for future rehabilitation activities. As well as temperature changes, increased intensities of UV light and increases in day length may affect the choice of species and techniques in future rehabilitation programs.
B.3.2 Soils

Soil forming processes occurring over a very long period have resulted in a deep and almost complete soil cover in the Alps. The heavy vegetation and seasonal snow cover insulates the soil against freezing. Soil moisture conditions are seldom below field capacity for more than a few days. They can however dry very rapidly if rainfall does not occur over a two to three week period during summer.

In alpine and subalpine areas, exposed soils must be protected from the effects of frost heave using a mulch layer (refer Section F). A hay mulch must be loose and open and sufficient only to insulate, not as a thick mat as would be applied at lower elevations to assist soil moisture retention.

The combination of relatively high soil temperatures and soil moisture favour the continuous activities of soil organisms and their role in nutrient recycling and soil profile development. It should be noted, however, that hay mulch may foster fungal blooms which compete with the naturally occurring mycorrhizal fungi and interfere with rehabilitation.

Alpine humus soils maintain their fertility through the rapid recycling of nutrients through the decomposition and humification process (Costin 1954, Good 1972, 1992). If this process is disturbed, vegetation decline occurs quickly and soils can rapidly erode. When exposed, the organic matter which makes up most of the soil rapidly dries out and the soils become very difficult to stabilise and restore.

Native alpine vegetation is adapted to soils with an extremely low micro-nutrient status. The use of high analysis fertilisers can inhibit the establishment of a stable natural vegetation cover and result in the spread of weeds and eutrophication of waterways. Rehabilitation can benefit from applications of artificial fertilisers during rehabilitation works although careful consideration must be given to chemical content and quantity of fertiliser applications. Fertilisers used in rehabilitation works must be slow release and have a good balance of both macro and micro-nutrients.

Wind erosion can be very active in areas of exposed alpine humus soil, blowing away the fine soil material, leaving the larger gravels to accumulate on the down-wind side of any 'blow-out' site. The larger, coarser materials undercut the remaining vegetation (wind ablation) leading to further decline of the vegetation and expansion of the erosion scald.

B.3.3 Significant alpine zone communities

The alpine zone supports highly significant vegetation communities, flora and fauna populations and geological features. Rehabilitation works must consider the need to identify and protect these features at the site.

BoGs and FenS

The rehabilitation of fens and bogs may involve the re-establishment of physical structure and processes at the site. Bog rehabilitation is a slow process, dependent on replicating natural processes. Raised bogs are a dynamic community which oscillates naturally through a cycle of shrubs and herbs, hummocks and hollows.

The peat soils underlying bogs have specific ecological and hydrological roles and conservation values. The peatbeds have taken thousands of years to develop with the last peat-forming climatic conditions occurring some 3,000 to 9,000 years ago. The ancient peatbeds represent a valuable and irreplaceable storehouse of botanical and climatic history. Any disturbance of the peat in a rehabilitation program must recognise the risk of further irreversible degradation of the bog soils and ecosystem.
TALL ALPINE HERBFIELD
The tall alpine herbfields have been extensively impacted by grazing in the past, and severe erosion has occurred. Large areas of gravely lithosol soils have replaced deep alpine humus soil. Some of these areas have become stable but artificial ‘erosion feldmarks’, supporting a number of species typical of natural feldmark communities.
Rehabilitation requires an assessment of the extent of soil loss, soil nutrient status and micro-climatic conditions of the degraded areas. Given the concentration of nutrients in the upper layers of the soil profile, the protection and reinstatement of topsoil and the soil ecosystem is critical to the recovery of tall alpine herbfield.

SHORT ALPINE HERBFIELD
Ecological rehabilitation of this community requires the protection and management of snowpatches with which short alpine herbfields are associated.

FELDMARK
A key element in the rehabilitation of this community is the control of impacts from recreation and tourism. The micro-ecological and biological factors (wind run, exposure, soil nutrient deficiency and down-wind, vegetative spread of plants) that control the occurrence and distribution of the feldmark must be considered in the planning and implementation of track maintenance and feldmark rehabilitation works.

SOD TUSSOCK GRASSLAND
Sod tussock grasslands are dependent on wet soil conditions from groundwater or continual runoff from adjacent areas such as snowpatches. Rehabilitation is difficult and must entail the protection and restoration of appropriate soil moisture conditions and surface flow regimes.
Sod tussock grassland also frequently coincides with valley frost hollows where cold air drainage inhibits the growth of trees. Revegetation objectives must take into account natural limitations on plant growth.

HEATHLANDS
The present distribution of heath communities has been heavily influenced by past disturbances. Further disturbance may stimulate the expansion of heath in the Alps.

B.3.4 Subalpine zone
In many parts of the subalpine zone, the well developed shrub layer in the Snow Gum (Eucalyptus niphophila) woodlands is the result of past grazing and burning practices. This seral vegetation complex now presents a significant conservation management problem which has implications for rehabilitation projects.
The majority of the Snow Gum woodlands have been burnt during the past 150 years, with the 2003 fires burning all but a very few protected areas. This leaves the woodland with low stem age and structural diversity that will require protection from fire and other major disturbances for at least 50 to 100 years. The current rarity of old-growth and hollow-bearing Snow Gums is a significant conservation issue.

B.3.5 Lower zones
The montane zone presents few constraints to ecological rehabilitation approaches and techniques. An appreciation of the role of soils and soil moisture regimes is essential
particularly where these have been altered by site disturbance. An appreciation of the natural distribution of species and communities is similarly important for revegetation.

The main environmental considerations for ecological rehabilitation in the tablelands zone are low precipitation, extremes of temperature, lethal frosts, regular seasonal and physiological drought and the diversity of soil types.

The high level of human impact to valley and plain communities throughout this zone heightens the value and sensitivity of intact examples of this vegetation. Grasslands and grassy woodlands in particular support a large number of rare, threatened and declining flora and fauna.
C History of rehabilitation in the Alps

C.1 Ecological research

Early scientific studies in the Alps focused on native plant taxonomy and distribution (Von Mueller, Helms, Maiden and others). A range of catchment oriented studies were undertaken from the 1930s to the 1960s (Byles, Carr, Costin, Wimbush et al). With the commencement of hydro-electric schemes in the Alps, specific catchment studies were established by Raeder Rotisch, Phillips, Taylor, Neuman and others.

Studies were undertaken by Maise Carr, Alec Costin and Dane Wimbush in the context of catchment grazing, water yields and stability, together with nature conservation. It was this work that established an ecological basis for the management of the Alps catchments, including rehabilitation and revegetation.

![Image](image.png)

Figure C.1 Runoff and erosion studies, 1954

C.2 Early rehabilitation efforts

Rehabilitation programs undertaken in the Alps since the late 1950s have contributed much to our present day knowledge of ecological rehabilitation and the maintenance of many sensitive ecological communities.

Between 1959 and 1974, the NSW Soil Conservation Service implemented its summit area works program to address extensive erosion and vegetation loss resulting from many years of ‘snowlease’ grazing. Road batter and construction site revegetation techniques were also researched, developed and implemented.

Much of the work in NSW was undertaken collaboratively between the Soil Conservation Service and the Snowy Mountains Authority. These field rehabilitation works were arguably the first major attempts at soil erosion control, revegetation and ecosystem rehabilitation in the Alps.

In conjunction with this work, Bryant et al. undertook important revegetation and rehabilitation research, drawing on the ecological research of Carr, Costin and Wimbush. Monitoring and assessment points were established to assess the success of the program and the techniques.
Initially, the early summit rehabilitation works were very much trial and error. Extensive and very costly rehabilitation works were implemented in the Mt Kosciuszko to Mt Anderson, Mt Gungarten and Bulls Peaks areas in the 1960s and 1970s. Many mistakes were made but many were lessons learnt, such as the problems of over-mulching and disturbance to sensitive nutrient regimes from rehabilitation materials (refer Figure C.3).

Techniques were largely agriculture-based with the use of exotic plant colonising species, standard approaches to mulching and the use of artificial fertilisers. In most situations, these techniques came to be regarded as inadequate and inappropriate for use in alpine/sub-alpine situations and significant conservation reserves. In Victoria, the Soil Conservation Authority commenced similar studies and made recommendations on the use of agricultural pasture species for construction site rehabilitation in the Alps. Over time, it was realised that some of these species were becoming invasive environmental weeds.

Figure C.2 Original mulching and soil loss trials for the post-grazing rehabilitation program on the Main Range, Kosciuszko National Park

Figure C.3 Rehabilitation area suffering dieback from zinc toxicity where galvanised wire had been used in stabilisation works
C.3 Evolution of ecological rehabilitation

Studies shifted to more appropriate practices, such as the use of native plant species, the type and amount of mulch material and the impacts of high analysis artificial fertilisers. Workers came to realise that Australian native species adapted to alpine conditions were generally preferable to introduced species, although some fast-growing introduced annual species may still have a role as temporary cover crops.

By the late 1970s, interest in best practice rehabilitation based on research findings was well established. Unfortunately, rehabilitation works continued with little or no consideration of long-term sustainability. Since the late 1980s, the use of more ecologically based rehabilitation practices in the Alps has become widespread. However, there has not to date been a universal acceptance or adoption of ecological principles in rehabilitation and development control.

Rehabilitation programs have now been undertaken in a wide range of natural environments across the Alps. Programs have involved disturbed sites associated the hydro-electric schemes, ski resorts, roads and highways and park infrastructure. Ecosystem rehabilitation projects have been undertaken following major bushfires, such as bog and fen rehabilitation following the 2003 fires. The planning and implementation of these projects has continued to increase our understanding of ecosystem functions and processes and techniques to restore them.

C.4 Guidelines and manuals

During the NSW summit works program, a number of research papers and technical reports on rehabilitation techniques and equipment were published. Several site-specific and prescriptive stabilisation and revegetation manuals were also written for
construction sites, roadside batters and streambank stabilisation eg Snowy Mountains Hydroelectric Authority manual for site stabilisation.

In 1986, the first *Manual of Rehabilitation and Revegetation of Alpine and Subalpine Areas* was prepared, to summarise the state of knowledge of restoration, revegetation and rehabilitation. This manual was also prescriptive and outlined a range of basic rehabilitation techniques with little background information on the development of the techniques, or consideration of ecological principles. In 1998, the Australian Alps Liaison Committee produced a working draft of an Alpine Rehabilitation Manual (Parr-Smith and Polley 1998).

In 2006, the NSW National Parks and Wildlife Service prepared Rehabilitation Guidelines for the Resort Areas in Kosciuszko National Park (NPWS 2006). These guidelines provide a valuable adjunct to the AALC Alps-wide Manual and contain a thorough treatment of propagation and revegetation techniques.
D Ecological rehabilitation

D.1 Principles of ecological rehabilitation

The following principles cover planning, assessment, implementation, administration and evaluation aspects of rehabilitation.

D.1.1 Rehabilitation principles

1. The capacity of the site to regenerate naturally should be protected and enhanced wherever possible.

2. Rehabilitation should aim to protect and restore key ecological functions and processes, which will enable the ecosystem to be self-sustaining and continue to develop stability, diversity and integrity. Physical and biological processes are interdependent.

3. Rehabilitation should be based on a thorough assessment of site values and condition and degrading processes and impacts.

4. Rehabilitation should be based on clear and achievable objectives and measurable environmental outcomes. Objectives should consider the full range of environmental, social and economic values of a site.

5. Indigenous plant species should be used in revegetation where practicable. Propagules should be sourced as locally as possible and contain as much genetic diversity as possible.

6. Rehabilitation objectives should consider the ecological relationship of the site with the surrounding landscape, including off-site degrading processes and impacts.

7. The results of rehabilitation can be unpredictable. Regular monitoring of key indicators and an adaptive management approach should be employed.

D.1.2 Project management principles

1. Rehabilitation planning timelines should account for the need for survey and assessment prior to works, the acquisition of materials (including plant stock), and post-works audit, monitoring and evaluation.

2. Rehabilitation planning should identify roles and responsibilities for all involved and interested parties.

3. All staff involved in a project should be trained in the identification and protection of significant site values and processes, and have a sound understanding of the principles and practice of ecological rehabilitation.

4. Practitioners should foster the continuing development of ecological rehabilitation by carefully monitoring rehabilitation results and communicating these results to other managers and the community.
D.1.3 Development control principles

1. Approval authorities should require rehabilitation measures to be integrated into all stages of the development process.

2. Prevention is better than rehabilitation. Development planning should aim to avoid environmental impacts using site location and development design, rather than rely on rehabilitation.

3. Rehabilitation should be undertaken progressively during a development project, wherever possible and practicable. Soil should be protected at all times.

4. Specific contingency planning during development should account for the possibility of extreme events such as heavy or prolonged rainfall, drought, extremely low temperatures, extreme winds and fire.

5. Developers undertaking rehabilitation as part of development works should be held accountable for site rehabilitation using clear and measurable compliance targets, formal monitoring, audit and reporting processes, and significant penalties for non-compliance.

D.2 Planning a rehabilitation project

Planning a rehabilitation project involves:

- assessing the site;
- defining your objectives and outcomes;
- selecting appropriate rehabilitation techniques;
- preparing the rehabilitation plan.

In addition, a rehabilitation project will require a variety of administrative and project management tasks. Many of these tasks can be managed and recorded via the rehabilitation plan.

D.2.1 Assessing the site

The site should be thoroughly surveyed and assessed prior to any rehabilitation or development works. For new developments, much of this information will be required anyway for development planning and approval.

Site assessment should cover the following:

- background research relating to site history and potential site values, including land uses and impacts;
- significant biological and cultural conservation values on and near the site that may be impacted during the works. Note that certain flora and fauna values may require surveys during particular times of the year;
- soils, hydrology and other relevant physical attributes. Specialist hydrological and geotechnical assessments may be required;
- degrading processes operating at the site, including processes affecting the site but originating off-site. Degrading processes include weeds, pest animals, water/wind erosion, habitat fragmentation;
The presence of seed/cutting collection resources at or near the site and potential for enhancing on-site natural regeneration;

- the location, description and condition of environmental reference sites;
- site boundaries, access arrangements and any physical or structural impediments to the works;
- potential human safety hazards and vandalism risks;
- existing pollution or rubbish requiring remediation at the site;
- potential noise, visual or cultural sensitivities.

The assessment of values and processes at the subject site and the reference site may require monitoring over an extended period.

There are a number of methodologies available to assess and understand degradation and recovery at a site. Two approaches, the State and Transition Model (STM) and Landscape Function Analysis (LFA), are outlined in Attachments 1 and 2. The LFA technique has also been used as a monitoring tool to identify whether ecological function has been re-established following rehabilitation. The technique could be applied to the monitoring of some project outcomes.

For riparian ecosystems, Land and Water Australia has developed a procedure for Rapid Assessment of Riparian Condition (RARC) which is applicable to the larger streams of the Australian Alps (Jansen et al. 2004).

D.2.2 Defining objectives and outcomes

Project objectives and outcomes may cover a range of site values including biodiversity, geological values, catchment protection, cultural heritage and other human interests such as safety, accessibility and amenity.

Large or complex sites may need to be divided into sub-sites with varying objectives, outcomes and techniques.

OBJECTIVES

The statement of objectives should be a succinct and unambiguous qualitative statement. It should also include a general description of the restored, rehabilitated, modified or replacement ecosystem that the works are intended to achieve.

While objectives may be wide-ranging, the statement of objectives should indicate the relative priorities for the project site. Key objectives may include biodiversity and catchment protection, and the control of any active degrading processes. Secondary objectives may include the trialling and evaluation of new materials or techniques.

The objectives should be consistent with relevant plans, policies and regulations, and the future uses of the site. The objectives will need to be developed in conjunction with the site assessment and perhaps consultation with experts and interested parties.

OUTCOMES

The high priority objectives for the project should be developed into a set of quantitative, easily measurable environmental outcomes.

Outcomes describe specific environmental conditions, such as water quality, flow pattern, soil depth and stability, vegetation cover, plant diversity, and the presence and abundance of particular target native or pest species.

The identified outcomes will be the criteria used to evaluate the success of the project.
It is generally better to select a limited number of outcomes to measure and evaluate, than to stretch scarce resources covering the full range of parameters.

Identifying environmental outcomes may require a reference site to establish target environmental characteristics. Historical information, such as personal recollections, survey records or old photographs may be needed to determine the pre-disturbance conditions at a site.

At highly disturbed sites, restoration of the original ecosystem may not be possible. In these cases, an alternative target ecosystem or set of target conditions needs to be adopted. A reference site may be selected which reflects the new site conditions, rather than the original community.

The Society for Ecological Restoration (2004) has compiled a list of nine attributes which describe ‘restored’ ecosystems; refer Box D1. These attributes provide a basis for determining when restoration has been accomplished. Note that success depends on initiating a robust trajectory toward a restored state, rather than necessarily achieving all of the restoration attributes in the short term.

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**Box D1. Nine attributes of restored ecosystems**

1. The restored ecosystem contains a species assemblage and structure which reflect the reference ecosystem.

2. The restored ecosystem consists of indigenous species to the greatest practicable extent.

3. All functional groups necessary for the continued development and/or stability of the ecosystem are represented or, have the potential to colonise naturally.

4. The physical environment of the ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development.

5. The ecosystem apparently functions normally for its ecological stage of development, and signs of dysfunction are absent.

6. The restored ecosystem is suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges.

7. Potential threats to the health and integrity of the ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.

8. The restored ecosystem is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem.

9. The restored ecosystem is self-sustaining to the same degree as its reference ecosystem, and has the potential to persist indefinitely under existing environmental conditions. Some changes will continue to occur as a result of natural disturbance events and evolution in response to change.

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D.2.3 Selecting rehabilitation techniques

The techniques selected will be those that are best able to achieve the identified objectives and outcomes, having regard to:

- the condition and natural/cultural sensitivity of the site;
- the accessibility of the site;
- the nature and extent of degrading processes;
- availability of key resources (equipment, propagules, water etc);
- time and financial constraints.

Where significant uncertainty exists regarding the suitability of a technique, small-scale pilot programs may be useful to test a particular technique or compare the results of a number of potential techniques.

A number of proven and experimental techniques are described in Section G and the Case Studies in Section H.

D.2.4 Preparing a rehabilitation plan

A rehabilitation plan is used to guide the implementation of a specific project or group of related projects. The content and complexity of plans will vary between projects; simple projects are likely to require brief, simple plans. A more comprehensive plan will be needed for large, long term projects which may see many staff changes and require a series of interventions and agency approvals.

For new developments, the rehabilitation plan may form part of the project Environmental Management Plan. Timelines for rehabilitation and development works must be fully integrated.

The following elements may be included in the rehabilitation plan.

1. Site description and background

- site description with maps, aerial photographs and ground-based photographs, including existing condition, ecosystem or vegetation types, sub-sites, degrading processes, significant conservation values and sensitive features, safety hazards or human interests;
- relevant background information sources and references including ecosystem descriptions, existing survey data and site disturbance and land use history;
- description and location of a proposed reference site;

2. Description of rehabilitation works

- a statement explaining why the rehabilitation works are needed;
- project objectives and timeframe with quantified outcomes;
- description of the proposed rehabilitation works, identifying technical specifications, materials, techniques and equipment.

A number of specialised sub-plans and maps may be required, including;
- plan detailing revegetation treatments and requirements,
- soil and landform restoration plan,
- erosion and sedimentation control plan and maps, with access routes, stockpile sites, permanent and temporary site drainage and erosion control works,
- consultation and communications plan,
- monitoring, evaluation and review strategy (covering works performance standards and environmental outcome targets),
- traffic management plan,
- plan showing safety hazards and detailing management of hazardous materials,
- impact avoidance and mitigation measures for significant natural or cultural features.

- an assessment of any potential negative environmental impacts of the proposed rehabilitation works, both on- and off-site;
- expected post-project site protection and management requirements.

3. Planning context

- consistency with relevant legislation, plans and policies;
- planning and other government approval requirements, statutory and policy consultation requirements;

4. Timeline for the rehabilitation works

- detailed project timeline and works schedules covering all phases of the project, including propagation, site assessment, consultation, works periods for contractors, funding and financial reporting actions, monitoring and evaluation etc;

5. Personnel and organisation

- staff and stakeholder roles, responsibilities and contact details, with an organisation and reporting chart;
- the composition of a multidisciplinary reference group or representative steering committee (large or complex projects);
- appointment, induction and training measures;
- contractor engagement, supervision and audit arrangements;
- project occupational health and safety plan;

6. Budget and financial planning

- funding sources, budget information and financial reporting requirements.

D.2.5 Project management

Most project management tasks can be coordinated and documented in the rehabilitation plan (refer above).

Project management tasks include:

- developing the project timeline (incorporating consultation and approval processes, plant propagation, ordering of materials and specialised equipment, site survey, monitoring and post-works auditing, evaluation and maintenance);
- arranging environmental and archaeological assessments;
- identifying any legal issues, including State/Territory and Commonwealth Government agency approval and consultation requirements;
- securing funds, preparing a budget and financial reporting;
- staff/contractor selection, appointment, training and supervision as required;
- project publicity, notification and involvement of interest groups, neighbours, schools and the wider community as appropriate;
- providing for long term monitoring, protection and management beyond the immediate term of the project.

In planning rehabilitation projects, managers should also look for opportunities to combine or coordinate rehabilitation efforts on neighbouring or similar sites.
E  New construction sites

E.1  Basic steps and practices

E.1.1  Integration in project design and planning

A rehabilitation plan should be developed alongside the development design plan for proposed construction projects. The rehabilitation plan may be incorporated in a project Environmental Management Plan (EMP).

Some rehabilitation-related measures, such as ordering tubestock for revegetation, weed control, site survey and soil conservation planning will need to occur well in advance of the actual development construction period.

Development control authorities should ensure that rehabilitation is thoroughly addressed in proposal documentation, including the description of proposed works and mitigation measures. Detailed rehabilitation requirements should be included in development approval conditions, with independent audit and reporting.

The environmental impacts of the rehabilitation work itself should also be addressed in impact assessment reports. Development proposals should justify location and design in terms of environmental impact avoidance. The proponent should, wherever possible, minimise the area, intensity and duration of disturbance. Works should, where possible, be staged to allow rehabilitation to occur progressively during a development project.

E.1.2  Site protection and stabilisation

REMOVAL AND STOCKPILING OF TOPSOIL

The conservation of topsoil is an essential factor in successful rehabilitation programs. ‘Topsoil’ refers to the A horizon of the soil which is usually darker than the underlying soil because of the accumulation of organic matter.

Topsoil contains reserves of seed and vegetative fragments, organic matter and nutrients which are vital in achieving a stable self-sustaining vegetation cover. Topsoil is of prime importance in alpine humus soils, which are characterised by a concentration of nutrients and colloids in the surface layer. The topsoil nutrients, organic matter and micro-organisms that are essential to plant growth are generally very slow to regenerate if lost.

Topsoil at a construction site must be removed prior to construction, stockpiled and managed to preserve its fertility and revegetation value.

Topsoil management involves the following steps:

- before stripping topsoil, the vegetation should be removed and where appropriate, subsequently used as a mulch cover in the rehabilitation works;
- the top 150–400 millimetres of soil should be stripped and stored in two separate stockpiles. The uppermost organic layer (usually about 50 millimetres deep) is removed and stockpiled first, followed by removal of the remaining topsoil down to the subsoil (B horizon);
- plan to re-use the topsoil as soon as possible to minimise leaching of nutrients;
- topsoil should be stored in a low flat mound no more than 1.5 metres high;
• stockpiles should be covered with a protective mesh, such as Sarlon™, to minimise erosion.

• stockpiles should be located in areas convenient for re-use, avoiding traffic pathways, drainage lines and sensitive areas. A filter-fence should be installed around the base of the stockpile to intercept any sediment moving from the stockpile;

• where soil is stored for an extended period (in excess of twelve months), stockpiles should be revegetated to protect the soil from erosion, discourage weeds and maintain active populations of beneficial soil micro-organisms;

• topsoil should be removed when moist, but not saturated, to reduce damage to soil structure. Stripping and spreading topsoil which is too dry will pulverise soil structure and if too wet will lead to compaction.

E.1.3 Rehabilitation during and following the works

RESTORATION OF TOPOGRAPHIC FEATURES
Where possible, the natural topographic conditions of the site should be recreated by reshaping the slopes and micro-topographic conditions. Part of the restoration involves the reconstruction of drainage lines as close as possible to their original location. Constructed drainage line surfaces should form a sound base for any lining treatment, such as jute mesh and other permanent and semi-permanent drain lining materials.

As with topsoil stockpiling and replacement this reshaping provides conditions suitable for plant growth and revegetation. Good topographic restoration will reduce post-rehabilitation maintenance and improve revegetation success.

INSTALLATION OF PHYSICAL SUPPORT STRUCTURES
Physical support structures and materials may be required to mitigate mass movement at unstable sites. Physical support at the base of slopes in particular may be required to prevent mass movement or slumping. The form of these structures varies from simple temporary filter-fences to timber retaining walls, permanent rock-filled gabions or large structural concrete supporting walls. Gabions are widely used in roadside batter stabilisation and revegetation while timber retaining walls are a feature of many landscaped tourism and recreation sites. The inadequate control of mass movement has contributed to the failure of many rehabilitation projects in the Alps.

REPLACEMENT OF TOPSOIL
The replacement of topsoil is not simply a matter of covering the disturbed site with a layer of topsoil. The depth of topsoil influences vegetation that can be established on the site, and is limited by slope. On steep sites such as some road batters with slopes of 1:3 or greater, deep topsoiling eventually results in batter face slippages, loss of vegetation cover and batter erosion. On slopes steeper than 1:3, the depth of topsoil should not exceed 5 to 6 centimetres at the top of the batter. Deeper topsoil can be applied where supporting materials are used eg Geoweb™, MaxJute™, Recover™, MaxBio™, and Soil Saver™.

DRAINAGE AND RUNOFF CONTROL FROM THE SITE
Site drainage is a vital factor in rehabilitation. On poorly drained sites, high intensity rainfall events have the potential to damage rehabilitation works and development structures, extend the area of disturbance and introduce ongoing maintenance issues.
Drainage works must be planned and installed early in the development, either before or as soon as possible after the replacement of topsoil. All runoff water must be managed at non-erosive velocities. The total catchment area around a site that contributes runoff to the site must be used as the basis for stormwater management.

If permanent rehabilitation is delayed, temporary erosion control structures will also be required. Where possible, these should be planned and implemented as part of the permanent site drainage and sediment control plan.

**Diversion banks and channels**

Run-off from adjacent land can be diverted around the site using contour or graded banks on moderate or gentle slopes (<8°), or catch drains, batter drains, channels and waterways on steeper slopes.

Longitudinal profiles of diversion structures should be similar to slope profiles - even or concave. Convex profiles should be avoided. Channels should have trapezoidal or parabolic cross sections. Avoid rectangular or v-shaped channels as these are unstable and rapidly incise. The dimensions of diversion channels (slope and cross section) need to ensure flow velocities which will not scour the channel. In erodible soils, the maximum safe velocity is approximately 0.5 m/sec increasing to 1.0 m/sec for erosion resistant soils. Where the channel is grassed or covered by other vegetation, these velocities can be increased up to double that for unvegetated channels. Where flow velocities cannot be reduced to a safe level it will be necessary to protect the channel with erosion resistant lining materials.

![Figure E.1 Rock-lined drains diverting flows from an alpine rehabilitation site](image)

Channel lining materials should be selected to match the expected life of the diversion structure. Suitable materials may include rock, fibre mats, synthetic mats, and timber (Figures E.1, E.2). Other options may include plastic or rubber sheeting for temporary erosion control or concrete which will provide effective stabilisation, but often at the expense of natural processes and aesthetic appeal. In-channel dissipators can be used to intercept sediment and reduce flow energy (Figure E.2).
Mulches

Organic mats and mulches are used as part of revegetation treatments. Mulches or mats can provide a high level of erosion protection. However, ultimately stabilisation will be provided solely by the vegetation cover. Consequently, the designed peak runoff velocities must match the capabilities of the longer term vegetation cover and soil type. Mulch should be carefully secured to ensure that it does not wash or blow off the site.

Note that mulches should be used with care as they can have negative impacts such as introduction of weeds, entrapment of fauna (particularly where mulch has a synthetic net core) and prevention of effective seed germination, if thickly applied.

Protection of natural drainage patterns

Where possible, natural drainage patterns and flow regimes should be maintained on large sites. Drainage should be divided into smaller manageable catchment units and flow volumes.

Management of runoff flow velocities

Overland runoff velocities should be maintained below the erosive potential for the relevant vegetation cover. Well established grass can carry approximately 2.0 m/s, poor grass cover 1.2 m/s.

Provide sufficient hydraulic capacities

Drainage works should provide for sufficient hydraulic capacity to cope with peak discharge events, such as spring snow melts and flood flows, and summer storms.

Minimise flow concentration

Flows should be dispersed whenever possible to minimise erosion potential.

Sediment and pollution control

The release of sediment or pollutants from the site should be minimised using, for example, sediment fencing, settling ponds, wetlands or sediment traps. Clean runoff should be kept separated from sediment laden runoff.

Sediment laden water should be directed into appropriately designed sediment containment and settlement structures before release into streams and rivers.
Any pollutants generated on a construction site, such as oil and heavy metals, should be handled in a similar manner to sediment capture. These pollutants need to be collected in settlement ponds or structures which can be easily cleaned out and the sediments and pollutants removed to appropriate disposal areas. Hydrocarbon spill kits, designated re-fuelling and fuel storage sites and appropriate staff training will help to minimise the potential for pollution during development or rehabilitation works.

Fertilisers can also pollute hydrological systems, particularly in alpine areas where natural nutrient levels are low. Fertilisers should be used with restraint and, preferably, applied directly to the root system of plants, rather than via broadcasting.

**Minimise visual impact**

Where possible, drains should be visually compatible with the natural drainage system.

**Interface with natural drainage lines**

Drainage discharge points should be stable and capable of receiving discharge flows. Suitable discharge points may be distant from the project site. Reconnection with the natural drainage system should involve minimal disturbance to the natural features at the discharge point and the overall hydrology of the area.

**REVEGETATION**

Revegetation is the most cost effective and environmentally sustainable method of stabilisation. The rehabilitation of a disturbed site should aim to minimise the length of time the site is exposed to potential erosion and sedimentation. Works areas should be progressively stabilised and revegetated immediately following any earthworks. Revegetation is addressed in more detail in Section F.3.

At some sites, revegetation will be difficult or impossible, such as very steep or unstable sites, sites receiving excessive run-on or heavily trafficked areas. Options for these sites include rock facing, gabions and rock mattresses, loose rock placement/facing (rip rap), synthetic stabilising mats, insulating mats and mulches or concrete facing. The best materials will be determined by the potential for maximising surface stability, long term viability and maintenance requirements, visual impact and cost/risk considerations.

**MONITORING AND MAINTENANCE**

Climatic conditions in the Alps make revegetation and rehabilitation a slow process. All rehabilitation works will require maintenance and monitoring over an extended period until degrading processes have ceased and vegetation at the site has become self-sustaining. Experience from the Kosciuszko post-grazing rehabilitation works has shown that alpine herbfields may take up to 20 years, and groundwater communities more than 30 years, to achieve self-sustainability.
E.1.4 Post-rehabilitation auditing

Rehabilitation associated with development works should be independently audited to assess the performance of rehabilitation measures and compliance with development approval conditions. For large or sensitive projects, auditing may be required at intervals during the works, and for an extended period following the works.
F Existing disturbed sites

F.1 Basic steps and practices

Large-scale degradation now occurs infrequently in the Alps, but extensive areas impacted by past activities require rehabilitation. Disturbed sites may be associated with hydro-electric infrastructure, resort developments and slope grooming sites, road construction sites and small borrow pit sites. These sites generally require some restoration of local soil and landform features and revegetation.

Degraded sites may exhibit loss of biodiversity, altered topography, soil loss or degradation, sedimentation and altered drainage. In severely disturbed sites, it will not be possible to restore the original pre-disturbance community or revegetate the site with plant material indigenous to the original community. Figures F.1 and F.2 show sites with greatly altered soil and hydrological conditions.

To rehabilitate these areas, the degraded ecosystem must be compared with its undisturbed state to determine pre-disturbance soil properties and vegetation cover. These pre-disturbance attributes can be used to frame target outcomes for rehabilitation, and inform the selection of plant species, soil treatments and mulching requirements.

The key physical processes and functional roles of the original community also need to be identified, and factored into rehabilitation objectives, outcomes and practices.

For example, the bogs and fens of the Alps have a very significant role in catchment water yield and stream-flow regimes. These hydrological functions rely on both the vegetation and underlying peatbeds. Hence, rehabilitation must address peatbed condition as well as revegetation (refer Case Study 2, Section H).

The main steps to rehabilitating degraded sites are as follows.

1. Assess and quantify the degradation (soil loss, plant species loss etc) and the status of the community at the site. Determine the soil nutrient status of the site compared with that of the undisturbed adjacent soil/vegetation complex.

2. Determine which pre-disturbance site conditions can be recreated, and identify and describe those conditions. Identify the target ecosystem to be restored and derive environmental outcomes based on this objective.

3. If the site is severely eroded, restore the micro-topographic features as far as possible. For example, remove steep eroded edges and reshape flowlines where these have been incised or changed.

4. On slopes greater than 5°-8°, plan and implement runoff control works required to safely transfer and dispose of runoff water that would otherwise affect the stability of the site.

5. Where some soil remains (at least 3 to 4 centimetres deep), lightly cultivate the remnant soil to provide an aerated and roughened seedbed. If adequate soil is not available, it may be appropriate to use weed and pathogen free soil from another source or manufactured soil.

6. If the soil nutrients and organic matter are very low, apply a fast-release high analysis, NPK balanced fertiliser (refer section F.3.1).

7. Sow appropriate initial stabilising vegetation (a ‘cover’ or ‘nurse’ crop). This may be exotic or native species but site conditions generally demand a non-indigenous species (refer section F.3.1).
8. Provide an insulating mulch cover to the sown grasses (refer section F.3.1).
9. In high velocity wind sites, apply a holding or binding medium to the mulch, such as anionic water soluble bitumen or plastic polymers.
10. In high velocity wind sites, place coir logs across the slope and the prevailing winds to break-up wind-flows. If well designed and keyed into the soil, these can also function as low capacity diversion banks directing runoff to safe disposal areas.
11. Following the establishment of the initial stabilising cover crop over-sow or over-plant with the desired native herbaceous or shrub mix (refer Section F.3).
12. Maintain the rehabilitation works for at least 3 years or until a stable self-sustaining native vegetation cover is achieved.

F.2 Soil and landform restoration
At the most basic level of site stabilisation, techniques may involve engineered slope supporting structures and site specific revegetation measures. The benching of sites such as spoil heaps or unstable screes is generally achieved by the placement of some material on the scree slope behind which moving scree material accumulates, not by creating a bench by cutting into the slope.

Figure F.1 Tunnel spoil dumps requiring engineered batter scree supporting structures and site specific revegetation works

The selection of techniques must consider the visual context of the site. Large artificial structures or exotic vegetation may not be appropriate in a visually sensitive natural setting.
F.3 Revegetation

Revegetation - encompassing species selection, seed/cutting collection and treatment, propagation, sowing/planting, sodding and transplantation, mulching, fertilising, plant protection and weed control - is a specialist field. This section contains brief guidelines on common techniques and practices. For specific projects, practitioners are advised to consult available reference sources, many of which are listed in References and Resources (Section I). In particular, the recently developed guidelines for rehabilitation in the Kosciuszko resort areas (NPWS 2006) has a useful coverage of propagation and revegetation techniques in an alpine/subalpine context.

F.3.1 Temporary stabilising or ‘cover’ crops

Non-invasive, short-lived and non-persistent exotic or native grass species may be valuable in providing short term soil cover until permanent native vegetation can be established. However, if the site has a weed problem, or is adjacent to a weed infested area, it may be best to refrain from fertiliser use for the first few years to avoid selectively advantaging weed species.

Seed should be sown into lightly cultivated soil, with a light application of fast-release high analysis, NPK balanced fertiliser if nutrient levels are low. Application rates should be sufficient to encourage good growth of the initial stabilising planting/sowing in the first growing season, but leave no residual effects in following seasons. Such rates are generally in the order of 50 to 100 kg/ha (refer Case Study 1, Section H).

A sterile exotic such as ryecorn or native grasses are commonly used as cover crops. The rate of seed application will vary with the soil conditions and slope. Ryecorn is generally sown at 10 to 30kg/ha. Heavier rates would deplete soil nutrients to the detriment of oversown/planted or naturally regenerating native species. Further information, including case studies on the use of Rye Corn can be found in the KNP resorts rehabilitation guidelines (NPWS 2006).

F.3.2 Permanent vegetation

Permanent native vegetation can be sown or planted during or following the establishment of the cover crop.
NATIVE SPECIES SELECTION

Some general guidelines for native species selection for rehabilitation are as follows.

1. Species used should be adapted to the site conditions. Select natural colonisers - these are species adapted to growing rapidly in spaces created by natural disturbance. Observe plant species growing naturally on any old disturbance areas near the rehabilitation site so that the effective colonising species can be identified.

2. Use at least some fast growing species as soil stabilising plants. Slower growing species can be included or over-sown or planted to add diversity.

3. Include deep-rooted and long-lived species in the species mix if possible.

4. Use easily propagated species - they may be natural colonisers or species producing large quantities of seeds. Some species cannot easily be propagated from seed but can be propagated by division (such as Neopaxia, Astelia).

5. Where possible, local provenance seed or cutting material should be collected from the site or local area before development. As a general rule, the closer to the rehabilitation site, the better. Use plant species that produce sufficient viable seed to harvest economically.

6. As far as possible, attempt to replicate the original or target community in terms of species diversity and relative abundance.

7. Consider habitat requirements in cases where the return of wildlife to the area is a desired outcome of rehabilitation (refer Section F.4).

On grossly disturbed and unstable scree slopes, such as tunnel spoil heaps and major borrow pits, deep-rooted exotic shrub and tree species may be an appropriate choice to achieve basic site stabilisation objectives. Alders, Acers and Elms have been used in the past by the Snowy Mountains Authority and are widely used in the New Zealand Alps to stabilise massive scree slopes. Willows and Poplars have also been used but have proven to be highly invasive are not suitable for use in the Alps. Where exotics are the only species available for revegetation, sterile hybrid stock must be used.

F.3.3 Establishment techniques

Free-seeding or direct seeding is the most common method of establishing cover crops and some native species. Direct seeding is particularly useful in establishing an initial cover crop, which would be followed up by planting of tubestock to provide a more permanent cover.

The sowing of species of the Asteraceae, or daisy, family (such as Craspedia and Celmisia) has been found to be successful at rates in the order of a few grams per square metre.

Direct seeding works best on relatively flat sites that provide good growing conditions (adequate warmth, moisture, soil etc.). In general, the higher the altitude and the steeper the site, the less likely it is that direct seeding will be successful. In these, more difficult situations, it is recommended that tubestock is used, or a combination of tubestock and seed.
EX-SITU PROPAGATION

The use of good quality tubestock\(^1\) is generally the most reliable method of re-establishing vegetation on a disturbed site, however it is also expensive. A reasonable alternative is to use a combination of tubestock and seed, or to follow-up direct seeding with over-planting of tubestock.

The use of native species tubestock usually requires the local field collection of selected native grass and shrub seed and ex-situ propagation. Propagation of native shrub species from seed can be difficult and specialist treatments are often required.

Shrubs that can be effectively propagated from seed include the following genera: *Podolobium, Olearia, Hovea* and *Bossiaea*. Cutting propagation has been found to be more effective for *Baeckea, Grevillea, Podocarpus, Prostanthera* and *Tasmannia*. These species generally establish well from tubestock, if appropriate rehabilitation methods and follow-up work is undertaken.

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\(^1\) Notes on quality control of tubestock are included in the rehabilitation guidelines for KNP resorts (NPWS 2006).
Seed collection
Seed may be used either for the propagation of tubestock or direct seeding. Points to consider when collecting seed include the following.

1. Collect seed from as close to the rehabilitation site as possible. Target species and good seed collection sites should be identified well before seed matures.
2. Collect seed from at least 10 different plants, to ensure there is genetic diversity, and avoid stripping too much seed from one plant.
3. Seed cases that show signs of insect attack or fungal infestation should be avoided.
4. Seed should only be collected when it is mature. Differential ripening within a species or even on a single plant may require several visits to the collection area.
5. Many seed cases or cones are ripe when they have changed colour (normally green to brown) and become hard. Fleshy fruits and winged cases become harder and change colour when ripe. Pods change colour from green to brown and become brittle on the winged portion of the seed case when mature.
6. Avoid collecting seed or seed cases in plastic bags – use cloth or paper bags.
7. Accurately record the area and date of collection.

Seed treatment
The seed of many native species, particularly the pea shrubs and wattles, require some form of seed scarification (hot water soaking, sand-paper rubbing etc). Many other species, such as Mountain Celery (Aciphylla glacialis) and native grasses, require other pre-sowing treatments (cold treatment – vernalisation and smoke immersion). Plant growth regulators such as gibberellic acid can also assist the rate of germination.

Significant research into the germination of native species has been carried out. Two potentially useful sources of information on growing native species are highlighted below. However, there is still much to be learnt regarding germination and growth factors in native high country species. Where practicable, small scale germination trials should be a part of rehabilitation programs.

**Information sources for growing native plants**

Association of Societies for Growing Australian Plants (ASGAP):
http://farrer.csu.edu.au/ASGAP/

Australian Network for Plant Conservation (ANPC):
Seed storage
Points to be considered to maintain maximum viability when storing native seed include the following.

1. Seed should be cleaned to remove as much debris as possible before storage. Failure to do so may result in fungal infection.
2. Seed should be stored in dry insect and vermin proof containers labelled with species, date collected, location etc. The use of insecticide, mothballs etc. is also advantageous.
3. For most species, storage at 1-4°C in airtight containers at less than 10% humidity should maintain seed viability. The loss of some seed viability during storage is normal, but most species should keep for several years.
4. Dormancy in many native Australian species can be affected by changes in light, temperature and moisture conditions, so it is important to store seed in a stable environment.

F.3.4 Mulching
An insulating covering of mulch should be used to protect the sown cover crop. This usually involves a hay mulch in the order of 4 to 10 centimetres deep (8 to 10 t/ha). Biodegradable fibre mats are now commercially available, but are not cost effective for large area works.

At high elevations, mulches are applied to insulate as well as to retain moisture. In the alpine and subalpine zones, mulches are necessary to protect the cover crop against frost heave. Frost-heave occurs when exposed soils at field capacity are exposed to sub-zero temperatures. Frost heave is most prevalent during autumn and spring when snow cover is absent. If possible, the insulating capacity of the mulch should be equivalent to natural vegetation and litter cover.

Meadow hay, rice straw or other fibrous material (coconut or sugar cane fibre) has been the most commonly used mulch material. To minimise weed risks, there is increasing use of sterile, manufactured mulches. If straw mulch is used, care should be taken ensure that it is sourced from a reliable producer of weed free mulch.

Mulch which mats or which is applied too heavily can promote fungal blooms which disturb important associations between natural mycorrhizal fungi and native plants. Thick application of mulch may also inhibit the germination of native seed.

Very windy or steep sites will require a holding or binding medium applied to the mulch, such as anionic water soluble bitumen or plastic polymers or the use of jute netting such as Treemax SoilSaver™. Coir logs and material removed from the site, such as logs or rocks, placed across the slope can also protect the mulch and cover crop against wind and runoff.

F.3.5 Maintenance and protection
The rehabilitation plan should provide for the monitoring and management of revegetation works beyond the planting date. These activities include:

- plant protection from native and introduced herbivores, for example, using tree guards or fencing;
- mulch may degrade or be removed by wind, and need further applications;
dead or poorly performing plants may need to be replaced, possibly using different species or establishment techniques;

plants may require watering during the summer;

erosion and sediment control structures are likely to need maintenance. Intense rainfall events may require further permanent or temporary erosion control measures;

weed control at some sites is likely to be ongoing;

when plants have become well established and the site is adequately stabilised, any synthetic rehabilitation materials should be removed from the site.

F.4 Fauna habitat restoration

Ecological rehabilitation of habitats requires an understanding of:

- the habitat requirements of the target flora and fauna species; and
- the ecological requirements of the habitat components.

This section outlines some of the key factors to be considered in designing rehabilitation projects for wildlife.

F.4.1 Territory and movement

Fauna cope with changing seasons and fluctuating resource availability by defending a permanent territory or moving around to find resources. Movement may be in the form of regular seasonal migration or random and unpredictable nomadism. The strategy adopted gives an indication of the distribution and permanence of resources.

 Territory size relies on several factors, including the size of the animal, the type of food it requires and the size of the group. For rehabilitation, it is essential to be aware of the territorial requirements of target fauna species, including minimum areas in relation to the habitat concerned.

In the Alps, two types of migration occur; between the Alps and areas to the north, and between the Alps and lower elevation valleys and ranges. Migratory fauna generally arrive in early spring and leave in autumn as soon as the young are ready to travel. Rehabilitation for migratory fauna must consider territorial needs for breeding, including habitat size and complexity.

F.4.2 Habitat requirements

There are four essential things that an animal requires from its habitat:

1. food sources
   - continuity of food supplies is critical. Food sources may change with seasons.

2. shelter from predators
   - the smaller the species, the more relevant this is likely to become. Small birds, mammals, lizards and invertebrates are at constant risk of predation and need hollows, litter, dense shrubbery or grass clumps in which to hide.

3. shelter from the weather
   - shelter is particularly relevant to those species which stay in the Alps all year round. Reptiles, frogs, echidnas and many invertebrates survive winter in a
torpor, but they need to be able to shelter in a suitable tree hollow, or a log, or spaces underneath logs or rocks where the cold is not so intense.

4. breeding sites

- these may be different from shelter sites. For example, many species require tree hollows in which to breed, although at other times may shelter elsewhere.

The best way to ensure an adequate food supply for any given species is to maximise the size and complexity of the habitat. Rehabilitation should aim to replicate natural vegetation structure and species diversity. Non-living structural elements, such as fallen branches, logs and rocks should also be restored if possible. This material may be available from other development sites. Some durable habitat materials, such as large logs and rocks, may be stockpiled by agencies for use in future rehabilitation projects.

Where mature trees have been removed, crucial nesting and roosting hollows will be absent. In this situation it is worth considering providing artificial nesting hollows attached to trees. The best such hollows are natural ones, obtained from fallen or lopped tree limbs, for instance where trees have been trimmed for essential safety purposes. If these are not available, artificial nesting boxes are perfectly adequate but it is important to understand that each species has very specific requirements for its hollows. The Birds Australia web site has specifications for nest boxes, and is recommended (http://www.birdsaustralia.com.au/infosheets/05_nestboxes.pdf). Nest boxes should be monitored and pest species such as starlings, mynas and feral honey bees evicted as required.

The removal of rocks and logs from the ground also reduces available habitat. It is worth retaining these materials during construction activities and redistributing them following rehabilitation. Rocks and logs can also be useful to protect mulch and soils.

F.4.3 Shape of habitat

The edge of a natural habitat adjoining cleared or otherwise altered habitat is the least valuable part of it. The edge may be prone to weed invasion, roaming predators, trampling and other human disturbances, drifting fertiliser and other chemicals, and drying effects from increased exposure to wind and sun. The depth of the effective edge is likely to be at least 25 metres, so a strip less than 50 metres wide, or a patch less than 25 metres in radius, is effectively ‘all edge’. For habitat purposes, the rehabilitation site should minimise the proportion of edge (perimeter) to area. Habitat areas should be compact; circles provide the optimum edge:area ratio.

F.4.4 Size of habitat

The minimum area of habitat which may be regarded as useful varies greatly from species to species. For a species which utilises the same area for an entire breeding season, or even all year round, the area required to support it must be much larger. Hooded Robins for example appear to require an area of suitable woodland habitat of at least 100 hectares (Freudenberger 1999). For Brown Treecreepers, the minimum area seems to be closer to 300 hectares (Garnett and Crowley 2000).

For long-term survival however, a much larger population is required to ensure adequate genetic variability and to respond to environmental change. Such a population is also necessary to safeguard against chance fluctuations and natural catastrophes such as storms, fires or disease. It is very dangerous to generalise, but a commonly cited number for the lowest desirable population is 1000 mature individuals.
It is unlikely that any but the smallest animals will have a viable population living entirely within a single rehabilitation site or habitat patch. Connectivity between habitat areas is an important consideration.

**F.4.5 Connectivity and corridors**

An isolated population is ultimately doomed by inevitable natural catastrophes – fire, storm, flood, disease – or by further habitat loss, or by eventual decline in genetic variability and random genetic factors. Individuals must be able to move between populations if all of those populations are to survive. They must also do so to recolonise habitat from which a population has been lost through natural causes.

In a natural landscape, features such as streamlines and ridges provide important movement corridors through areas of otherwise unsuitable habitat for dispersing animals. In view of the edge problem discussed above, the wider the corridor the better. Long corridors mean more time spent within the corridor, so the corridor must supply more essential habitat resources. For a major regional corridor this means a full complement of strata (trees, shrubs, groundcover as appropriate) and a width that is greater than – and preferably double – the average diameter of the animal’s home range. A figure of half a kilometre is the minimum width usually suggested for a regional corridor. Where at all possible a corridor should not be less than 50 metres wide.

Stepping stones of habitat – patches of bush or even individual trees – may be adequate for many species. For instance a Hooded Robin population in an isolated remnant (of greater than 100 hectares) can survive as long as they are within, on average, a kilometre of the five nearest woodland patches (Freudenberger 1999).

The planning and design of rehabilitation projects should consider opportunities to improve connectivity. This will require an assessment of habitat located around the rehabilitation site, and the requirements of local fauna species or fauna groups. Natural corridors may be found in stream lines or ridge lines.

The potential for high gains for fauna conservation may justify an expansion of the rehabilitation project to encompass connectivity objectives. There may be opportunities for cooperation with neighbouring landholders.

**F.4.6 Succession**

Disturbance in natural ecosystems triggers a succession of species and habitats until a climax community is reached. In a grassland, the cycle may take only a few years; in a dry forest the period is decades, and in a wet mountain forest it may be centuries. As time goes on the animals specialising in the earlier successional stages must constantly move to nearby ‘younger’ habitat as the area matures.

Rehabilitation also aims to replicate some of the processes of succession. Fauna habitat will change as the rehabilitation site matures. Some elements of climax communities may be able to be restored early in the rehabilitation process. For example, artificial hollows and other forms of shelter or nest sites may be provided to for resident or re-introduced dependent fauna.

**F.4.7 Threatened species and extinction**

The generally accepted definition of extinction is that the species has not been unequivocally reported in the wild for at least 50 years. Threatened species face extinction unless circumstances improve. In many cases, threatened species are an indicator of the conservation status of an ecosystem. The conservation of species is a central management objective in the national parks and reserves of the Alps.
The prevention of local extinctions should be a prime consideration in rehabilitation. The site assessment should reveal any opportunities to assist the protection or recovery of threatened species as part of the rehabilitation project.

F.4.8 Exotic plant species

Exotic plant species may affect native animal species in a variety of ways:

- by direct competition with favoured food plants;
- by reducing the diversity of native plants, thus diminishing the opportunities to change food sources opportunistically during the year;
- by smothering native regeneration, thus preventing normal succession from taking place and eventually destroying the habitat entirely;
- by providing extra cover for predators.

Weed control is therefore essential for the protection and restoration of fauna habitat, as well as for revegetation and soil stabilisation.
G Guidelines for specific project types

G.1 New development sites

G.1.1 Roads and tracks

This section provides design and operational guidelines relevant for the construction and maintenance of roads and tracks. Sections G.5.3 and G.5.4 provide guidelines on the rehabilitation of closed tracks and fire control lines.

This section incorporates track rehabilitation guidelines developed by the Victorian Department of Sustainability and Environment following the 2003 fires in north-eastern Victoria (DSE 2003).

SAFETY

Steep slopes may not allow machines to work safely, particularly on steep breaks where trees have been removed. If in doubt – don’t do it!

Ripping across the slope may also not be possible due to steepness. Consider the use of hand tools to install bars and runoffs in very steep areas.

VEHICLE HYGIENE

Machinery and vehicles can transport pest plants and soil pathogens; extreme care must be taken when moving into and around natural areas. Within the site, work should start at weed-free areas before moving on to weed infested areas.

Vehicles must be washed and cleaned of soil and vegetation using high-pressure washing/steam cleaning before moving into or out of an area. Machinery should be inspected prior to entry to the site.

ROAD SHAPE

For unsealed roads and tracks, it is important to maintain the cross-sectional shape of the road surface to disperse runoff and prevent pooling. There are three types of road surface formations (Figure G.1):

Crowned: road surface forms a convex shape;
- used on flat terrain to disperse runoff away from the road surface
- used on steep terrain side slopes with high volume traffic
- uses table drains which require culverts or crossdrains.

Insloped: sloped into the cut side of the road;
- used only in short sections
- used in steep terrain
- uses a table drain
- keeps water away from unstable fill slopes.

Outsloped: sloped towards the fill-side of road;
- used on moderate slopes, generally sidecuts or contour roads
- used where fill slopes are reasonably stable
- crossdrains are still required
- used on low volume 4WD tracks only
should not be a regularly used option – can be very dangerous particularly when the road surface is wet.

Figure G.1 Unsealed road and track surface and drain cross-sectional profiles

ROAD AND TRACK DRAINAGE

Well planned and constructed drainage is important in minimising the need for rehabilitation and maintenance. Drainage should be installed on the road to ensure runoff is shed regularly and efficiently to avoid large volume and high runoff.

Crossdrains

Crossdrains are commonly used on low volume four wheel drive public access and service vehicle tracks. There are two types:

- rolling dips (Figure G.2);
  - generally used with outsloped tracks
  - the dip and bar are angled approximately 15-30° to the road

- overland bars (Figure G.3);
  - used on tracks which are level with the surrounding natural surface level
  - fill is pushed up to form a bar on top of the track surface. No fill is removed from the track surface to create the dip; fill is obtained from soil windrows.
  - the bar is angled approximately 15-30° to the road.

Bar height above the track surface should generally range from 20 centimetres on gradual slopes to 50 centimetres on steep slopes. Rolling dips or overland bars should not be installed on high-class roads used for logging traffic or 2WD vehicles. Culverts should be installed if drainage is required on logging/2WD roads.
The rolling dips generally have a base 5 to 10 metres long (refer Figure G.5). The spoon drain behind the bank should be 5 to 15 centimetres deep and 2.5 to 5 metres wide. Spacings between cross drains and culverts depend on the track slope and soil erodibility. General recommendations for maximum spacings for rollover drains are indicated on Table G-1.
<table>
<thead>
<tr>
<th>Slope (°)</th>
<th>1°</th>
<th>2°</th>
<th>3°</th>
<th>5°</th>
<th>6°</th>
<th>7°</th>
<th>9°</th>
<th>11°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (%)</td>
<td>2%</td>
<td>4%</td>
<td>6%</td>
<td>8%</td>
<td>10%</td>
<td>12%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Spacing (m)</td>
<td>160</td>
<td>130m</td>
<td>110m</td>
<td>95m</td>
<td>80m</td>
<td>65m</td>
<td>50m</td>
<td>30m</td>
</tr>
</tbody>
</table>

**Note:** A useful rule of thumb is that if low range 4WD is required, the cross drains should be spaced no further apart than 30 metres.

For access tracks on ski-slopes, roll-over banks and drains are required but a modified design is recommended (Figure G.5). In this case, spoon drains are constructed on both sides of the roll-over bank.

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![Figure G.5 Diversion and rollover bank dimensions for tracks and ski slopes](image)

**Runoff drains**

Runoff drains (mitre or cutoff drains) should be installed regularly and as often as possible (Figure G.6).

Runoff drains should not be pushed into a stream or drainage line; allow a minimum 20 metre buffer between the runoff outlet and the watercourse. Buffers must be vegetated; if not, place barriers (logs, rocks, etc) at the drain outlet to disperse runoff and dissipate flow energy.

The drain outlet should be lower than the table drain to prevent backflow and ponding on the track surface. Saddles and other low or level areas should be drained to prevent water ponding.
Figure G.6 Runoff drains on a ridgeline disperse runoff either side of road

**Drain outlets**

Drain runoff should not discharge directly into waterways. Ensure there is always a minimum 20 metre buffer between the drain outlet and the waterway.

Place material (straw bales, logs, rocks, scrub) along the flowpath of the drain outflow to disperse runoff and dissipate the flow energy (Figure G.7). Straw bales should be certified weed free. Where necessary, drain outlets should be armoured with rocks or flumes to prevent scouring and erosion at the outlet.

Figure G.7 Drain outlet flow dispersal and dissipation structures

**Soil windrows**

Soil windrows created during track construction or maintenance should be reclaimed and pulled back onto the track surface. Windrows around trees >15 centimetres in diameter at breast height are to be removed either by hand or excavator to prevent collar rot.

Soil windrows along the side of the track which cannot be reclaimed should be breached every 10 metres to allow runoff to drain away from the track surface.

**Sediment traps**

Sediment traps in the form of silt fencing may need to be installed on tabledrains and runoffs discharging near waterways. Sediment traps need to be installed on tabledrains entering road drainage culverts. Sediment traps are also needed on runoff outlets that discharge within 10 metres of a waterway, or within 20 metres when the buffer consists of disturbed or exposed soil and/or a steep slope.
Sediment traps may be required at outlet points further from waterways where one or more of the following site factors operate:

- the buffer is very steep;
- the buffer soil is exposed;
- large volumes of sediment are expected from the track surface;
- the cut batter is new or eroding.

Straw bales should not be used in table drains; these will force water to flow around the bale causing scouring of the track surface.

All sediment trap devices must be trenched into the ground so runoff will not flow under the structure. The sediment trap must be wide enough to contain the flow; any runoff flowing around the structure can cause further scouring. If runoff is likely to flow around the structure, armour the flowpath with rock to prevent scouring and disperse the flow.

The following types of sediment traps can be used alone or in combination.

**Silt fencing**
- use geo-textile material, trenched into the ground 10 centimetres, supported by metal/wooden pickets spaced 50 centimetres apart.
- use two to three, depending on soil type.

**Course type traps**
- must be quite porous with openings approximately 5 millimetres in diameter.
- should be used with a silt fence following.
- can be used alone on sandy/course grained soils.

**Leaf litter trap**
- use metal/wooden pickets, 3 x 10 centimetres apart, across the tabledrain.
- allow sufficient height (approximately 30-40 centimetres) so that it is visible to vehicles.
- will trap and hold leaf litter, twigs and branches and allow runoff to flow through.

**Sediment pits**
- a pit/holding pond constructed at the end of the runoff.
- the outlet must be lower than runoff inlet to prevent backflow onto road.

**Straw bales**
- installed toward the end of the runoff.
- care must be taken to ensure top of bale is lower than the runoff outlet to prevent backflow.
- should be trenched into the ground to prevent water flowing under the bale.
- rock or geo-textile may be required to prevent scouring on the downstream side (from runoff flowing over the bales) and upstream side (from back eddying).

**Rock**
- rock can be placed at runoff outlet as well culvert inlets.
- this will disperse the runoff flow, slow the velocity of the runoff and prevent erosion.

**Logs/debris**
- place logs/branches/scrub across the flowpath of the runoff discharge.
- arrange so flow is dispersed and slowed by the debris. Avoid concentrating the flow into a single flowline.
**Sediment traps on crossdrains and runoffs**

Sediment traps should be installed in the runoff outlet of crossdrains that discharge within 20 metres of a waterway. In highly erodible or dispersive soils, 2 to 3 sediment traps may be required.

**Sediment traps on tabledrains**

Sediment traps should be installed in tabledrains greater than 40 metres in length that discharge directly into streams. Sediment traps should also be installed in tabledrains that enter road drainage culverts that discharge within 20 metres of a waterway.

**Sediment traps in combination**

A series of three different styles of sediment traps can be used for each drainage discharge point:

- install a leaf litter trap 20 metres from the discharge point (Figure G.8);
- install a silt trap to catch course material 10 metres from the discharge point (mesh with a gauge of approximately 5 millimetres)(Figure G.9);
- install a silt trap to catch fine sediment material 4 metres from the discharge point (silt fence material) (Figure G.11).

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**Figure G.8 Leaf litter trap**

**Figure G.9 Coarse type sediment trap**
SITING NEW ROADS AND TRACKS

The location of roads and tracks is important in minimising degradation and the need for rehabilitation and maintenance. Park tracks often follow old stock paths and bridle trails and hence may not always be located in the most appropriate locations.

In general, the following criteria should be applied to the siting of vehicle tracks:

- tracks should be located on or near the contour as far as possible;
- boggy areas and areas with deep organic soils are to be avoided because of high construction and maintenance costs. Bog and fen communities must be protected from any track development;
- track alignments should avoid steep gradients (>10°) as steep tracks require more extensive drainage works and maintenance;
- long steep slopes should be avoided as tracks on such sites will require larger cut and fill batters, with an increased area of disturbance and increased rehabilitation requirements;
- it is preferable to locate tracks along ridgelines. Such sites are drier and not affected by run-on water. Tracks located further down the slope will have a larger run-on catchment requiring larger drainage works to protect the track and to transfer runoff to stable discharge points.
**WALKING TRACKS**

As with roads, effective drainage is critical for the protection and maintenance of walking tracks. Walking track designers should also consider use levels, user types and track surfacing materials. A track designed with inadequate capacity will result in off-track disturbance to vegetation and soils during peak use periods.

The siting guidelines outlined above also apply to walking tracks. In the alpine zone, grasslands, heath and woodlands are more resistant to the impact of trampling than other communities.

A number of specialist guidelines relating to the design, construction, maintenance and rehabilitation of walking tracks have been produced, including (IMBA 2001) and (PWS 2001) – refer sections I.2.6 and I.2.7.

**G.1.2 Road and construction site batters**

Road and construction site batters comprise excavated cut batters and deposited fill batters. In many situations, the excavated material from the upslope cut is deposited downslope to create the fill batter. Both batter types have their problems and issues to be considered in rehabilitation.

The following factors should be considered when planning and designing batters:

- the erosion potential of the site needs to be assessed. A geotechnical engineer’s report may be required. Steep and long slopes allow surface runoff to accelerate, resulting in erosion. Shallow slopes are less erodible and vegetation is more easily established. Consider the natural slopes in the area as these have evolved to a relatively stable state under natural erosion processes;

- slopes should be designed to reduce the velocity of runoff as the catchment area increases. Where limitations prevent the formation of a stable slope profile, contour benches or similar erosion control methods may be required. Slopes with an overall convex profile should always be avoided;

- batters should be appropriate to the visual sensitivity of the site;

- the drainage pattern for the overall site must be planned as part of the landscaping and rehabilitation.

**CUT BATTERS**

These batter types are generally cut into the B and C horizon soils and sometimes the underlying rock. The batter faces may be steep, hard and smooth as a result of finishing with a grader or dozer blade. The faces may also be very long and high. Long, steep batters are inherently unstable and prone to rilling and slumping. These conditions are harsh for plants, and revegetation without prior remediation is almost impossible.

The rehabilitation and revegetation of cut batters generally requires the following works.

1. Batters should be effectively drained with a catch drain on stable vegetation above the batter and a catch drain at the base (toe) of the batter. Generally the catch drain at the toe of the batter requires lining with jute mesh\textsuperscript{tm} or similar material, and/or rocks.

2. Steep batters may need to be laid back or reshaped to a stable batter slope. The general standard in road construction has adopted a recommended maximum grade of 18° (1:3) for batters to be topsoiled and revegetated. In the Alps, the
natural slopes are often well in excess of 18° and this recommended maximum cannot be achieved.

3. Very high batters require benching to provide drainage from the batter face (Figure G.12). Benches should be formed at 4 to 5 metre intervals up the batter face. Spacing may vary depending on soil and subsoil type. The benches should be shaped so that any runoff collected is drained from the batter in a catch drain at the toe of each bench.

![Profile of batter and slope benching](image)

**Figure G.12 Profiles of batter and slope benching**

Benches are best located in the middle of the slope. Where long slopes cannot be avoided, several benches may be required and their spacing will need to consider slope and runoff characteristics. Table G-1 provides a guide for the spacing of benches along slopes.

4. Batter faces should be roughened or ripped across the contour with a backhoe or similar machine. This will assist topsoil to ‘grip’ the batter face and not slip off before vegetation is established.

**Note:** batter drainage, reshaping and benching and ripping should be planned for implementation during the initial construction of the cut batters. Forming benches on very high batters after construction is both difficult and costly.

5. To achieve revegetation, batters need to be covered with a layer of topsoil. The maximum depth at the top of the batter should be 7-10 centimetres, with greater depth towards the toe of the batter to provide a solid support to the weight of topsoil on the batter face.

6. If a cut batter cannot be ripped and benching a supporting fabric to hold topsoil would be required, such as honeycomb Geoweb®, jute mesh, straw and wire netting (Figure G.13). The careful and effective installation of these supporting materials is essential for the stability of the topsoil and vegetation cover.

7. The batter is then sown to a seed mix appropriate to the site and long-term stability. This may require initial sowing or planting with non-indigenous species to provide a stabilising cover crop and subsequent sowing with suitable native plant species.

8. Seed sowing may be undertaken using a hydroseeder, a Finn batter mulcher™, or manually (Figures G.14, G.15). Where a hydroseeder or batter mulcher machine is used, fertiliser and mulch is applied at the same time. The batter mulcher applies a meadow or straw hay mulch, while the hydroseeder can use a range of organic materials (such as shredded pine fibre and recycled paper). Both application methods may use a bonding agent to hold the mulch, seed and fertiliser on the batter. Bonding material options include anionic bitumen or clear liquid polymers.
9. Batters should be mulched and fertilised according to soil testing for nutrient status. The amount of mulch material applied is largely determined by the steepness of the batter face. As with topsoil application, large amounts of mulch (by weight) may result in slippage from the batter face. The general rule is the minimum required to provide for soil moisture retention during the germination and seedling establishment period. As a very general guide, batter mulching rates should not exceed 1.5 to 2 tonnes/hectare unless supported (as outlined above).

10. Where batter substrates are unstable and the potential for slumping exists, some form of physical support barrier or wall should be constructed at the toe of the batter. These may be concrete and rock walls, wooden walls, mesh fences or gabions. The latter are extensively used in road batter stabilisation and construction site rehabilitation and landscaping.
Figure G.15  Finn™ application of hay mulch to a road batter

Figure G.16  Batter stabilisation using supporting materials and retaining wall
11. Where the topsoil placed on the face of a batter has a high potential for slippage under its own weight, the placement of grass sods, the use of brush matting, or cellular plastic (Geoweb™) soil support will be required. Sods should be taken from flat stable native grass areas, which can be readily revegetated. Sods are taken in roll form, the length of each roll equalling height of the batter. The sods are held in place with commercially available metal u-shaped pins made of 2 millimetre steel rod.

Figure G.17 Rolled grass sods cut with a sod cutter for use on a steep cut batter

**FILL BATTERS**

Fill batters require the same basic drainage works as cut batters. Revegetation is easier because fill batter face material is generally loose and rough, deeper and more fertile. Fill batters are initially less stable than cut batters and often require support to hold the batter face and revegetation materials in place. Similar techniques and materials to support topsoil on cut batters (refer above) can be used for unstable fill batters.

A road drain is required at the top of each batter to divert road surface runoff to a safe disposal site beyond the batter or to drop-down drains constructed on the batter face. Drop-down drains take many forms, and may be constructed of Armco™ half-round corrugated iron, rock, prefabricated interlocking concrete flume sections, or mesh lined structures.

The type of drop-down drain is determined by the steepness of the batter. In the Alps, rock-lined and mesh-lined drains and flumes should be used where possible. Prefabricated concrete and corrugated iron drain materials are aesthetically obtrusive and require regular and on-going maintenance.
Figure G.18  Grass lined and corrugated steel lined drains
Water flows diverted by drains and culverts will be concentrated with potentially high flow velocities, volumes and erosion potential at discharge points. Energy dissipators should be constructed at the outlet points to slow the velocity of the water and dissipate flow energy before the water enters the natural drainage system. Rock lined (‘rip rap’) aprons or reno-mattresses™ are the simplest and most widely applicable structures. Rock and concrete dissipators and deflectors may be required in very high discharge culverts and batter drains (Figures G.20 and G.21).
G.1.3 Ski slopes

Downhill ski slopes and infrastructure are major developments in the Alps, with significant local environmental impact. The grooming of slopes impacts natural drainage systems, alters topography and often removes native vegetation and microhabitats.

Ski-slope construction and grooming should ensure:

- minimal removal of vegetation;
- highly sensitive areas such as deep organic soils and bogs are avoided;
- significant buffer strips are retained along drainage lines (>20 metres wide);
- patches of native vegetation communities are retained to allow for natural regeneration;
- any remaining trees are retained. The design of tree lots should be optimal for habitat connectivity and drainage line protection, rather than for the convenience of skiers. Isolated islands of trees on groomed slopes generally die due to changes in soil hydrology and nutrients, and exposure to wind throw;
- soils are not compacted, particularly where soil is removed from one area and used to fill depressions in another;
native plant material is used for revegetation of sites where the landscape features have been changed by grading, rock outcrop removal etc.

- ecologically-based revegetation programs are implemented immediately after slope earthworks and clearing. Soil and slope hydrology surveys are a prerequisite of any post-grooming revegetation and rehabilitation work. Rehabilitation techniques should be consistent with rehabilitation practices for alpine and subalpine herbfields. For sites that will be slow to recover or prone to heavy use, the laying of sods is recommended.

Indigenous grasses and low-growing shrubs offer several advantages over exotic grasses. Indigenous species are generally very hardy and resistant to the impacts of slope grooming and snow accumulation. They produce a long lasting, resilient and self-sustaining ground cover. Furthermore, air layer created between snow and the shrub canopy helps to prolong snow cover by allowing water to flows beneath the snow. A ski slope revegetated with native shrubs and grasses is shown on Figure G.22.

![Photo courtesy Liz MacPhee](image)

**Figure G.22** ‘Rollercoaster’ ski run at Perisher revegetated with native shrubs and grasses

### G.2 Existing disturbed sites

#### G.2.1 Borrow pits

The rehabilitation techniques applicable to borrow pits are similar to those for cut batters on roads (Section G.1.2). Borrow pits are likely to require some site preparation, such as reshaping the topography. In particular, any undercutting of the crest will need to be removed (Figure G.23).
Very large borrow pits often require engineered rehabilitation techniques and structures, and revegetation with hardy plant species which may not have been present in the original, pre-disturbance community. In some sites, where borrow pits have steep, solid rock faces, visual screening with vegetation may be the most practical solution. At visually sensitive sites, it may be worthwhile planting native species adapted to cliff or exposed environments into crevices on the pit face to soften the visual impact.

Figure G.23  A borrow pit presenting extreme conditions for rehabilitation

Figure G.24  Borrow pit rehabilitation with jute mesh, into which native grasses and forbs will be planted
G.2.2 Gullies and creeks

Many gully lines have been eroded and incised following the use of bridle trails during the grazing era or the construction of access tracks for the hydro-electric schemes. The following steps apply to the rehabilitation of these sites in the Alpes:

1. Redirect runoff flows away from the gully line;
2. Reshape the gully side battens and cut back to a 1:3 slope where possible;
3. Slow high velocity runoff flows in the gully line by the placement of energy dissipators. Dissipators should slow flows and collect sediment. Hay bales have been widely used for this purpose but in large gullies, rock dams and flumes may be required. In very high flow or high velocity sites, gabions may be required (Figure G.27).
4. sow and mulch the batters in a manner similar to road batters. On very steep gully sides, or where the gully carries continuous high flows, the use of vegetation sods (rolls) is the only stabilising and revegetation technique applicable.

![Rock and haybale dam in an eroded gully line. Banks have been stabilised using sods](image)

**Figure G.26** Rock and haybale dam in an eroded gully line. Banks have been stabilised using sods

![Gabion dam and energy dissipator in an eroded alpine gully](image)

**Figure G.27** Gabion dam and energy dissipator in an eroded alpine gully

Sods are most efficiently cut using a specialised sod cutter machine, available commercially or hired. For very small rehabilitation areas, sods can be cut using a spade but this is not generally cost effective. It is essential when removing the sods that soil is kept attached to the root systems. The thickness of grass sods should be in the order of 2.5-5 centimetres. Rolls may be 10 to 15 metres long. Longer rolls make handling difficult due to the bulk and weight when working in step gully lines.

If the sods need to be stored prior to use, they should be regularly watered. Sods should be placed within 3 to 4 days of being cut.

Soil preparation prior to the laying of sods should include the removal of coarse gravel and any loose rocks, light scarification of the area and topsoiling if required.

On slopes steeper than 1.5:1, the sods need to be held in place with wooden or metal pegs. The sodded area should be covered with topsoil to fill any spaces between sods and to prevent sods from drying out at the edges.
The most suitable time for laying sods for most alpine species is in early summer, giving the plants time to re-establish their root systems before winter. At lower altitudes, autumn and spring are feasible when soil moisture is available.

G.2.3 Closed roads and fire control lines

The section incorporates track and control line rehabilitation guidelines developed by the Victorian Department of Sustainability and Environment following the 2003 fires in north-eastern Victoria (DSE 2003).

The rehabilitation of closed roads and fire control lines generally uses the following strategy:

- restore the natural slope profile as far as possible;
- install large drainage bars to discourage public access (ensure that bars provide drainage and don’t dam runoff);
- spread windrowed vegetation and logs over the track to prevent vehicle access, protect soil and disperse runoff; and
- close the ends of the track with log and earth barriers and spread as much vegetation over the track as possible to discourage public access.

LANDFORM

The natural slope and land profile should be restored as far as possible. If natural profiles cannot be restored, outslope the track as much as possible.

DRAINAGE STRUCTURES

The main types of drainage structures used with closed tracks are:

- ‘breach and bar’ structures at either end of the track (to prevent public access and disperse runoff);
- crossdrains for the remainder of the track.

Breach and bar construction

Breaches and bars are installed approximately every 10–20 metres for the first 100–200 metres at each end of the track to discourage public access (Figure G.28).

The structures must be:

- of sufficient height (1.5 metres) to preclude vehicle access;
- able to drain and not hold or pond water;
- angled to the road approximately 15-30°.

Figure G.28 Breach and bar cross-section
Crossdrains

Crossdrains may be of two types; rolling dips and overland bars. Guidelines on the construction of crossdrains are provided in section G.1.1.

Recommended maximum distance between crossdrains and culverts on tracks to be closed and rehabilitated are provided in Table G-1. Optimal spacing will vary according to road grade and soil erodibility.

Table G-2 Maximum drainage spacing for closed roads

<table>
<thead>
<tr>
<th>Drainage spacing</th>
<th>0°-6° 0–10%</th>
<th>7°-11° 11–20%</th>
<th>12°-18° 21–33%</th>
<th>19°-26° 34–50%</th>
<th>&gt;27° &gt;50%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60m</td>
<td>30m</td>
<td>20m</td>
<td>10m</td>
<td>10m*</td>
</tr>
</tbody>
</table>

* road grade not appropriate in areas with high soil erosivity

RIPPING

The track surface should be ripped to a depth of at least 40 centimetres, in lines no more than 2 metres apart, preferably along the contour. Cleared breaks beside tracks should also be ripped if compaction or blading off has occurred.

SOIL WINDROWS

Soil windrows should be reclaimed and pulled back onto the road surface. Windrows around trees should be removed either by hand or excavator. Windrows unable to be reclaimed should be breached every 10 metres to allow runoff to drain away from the track surface. Any stockpiles of soil should be spread evenly over cleared areas or the track surface.

MULCHING AND VEGETATION SPREADING

Any windrowed vegetation should be spread over the track and cleared areas to protect the soil against erosion and frost heave. In areas where little windrowed vegetation is present, logs, rocks or shrubs could be used to spread over the area to protect soils and disperse runoff.

G.2.4 Stream crossings

The section incorporates stream crossing rehabilitation guidelines developed by the Victorian Department of Sustainability and Environment following the 2003 fires in north-eastern Victoria (DSE 2003).

Rehabilitation works affecting watercourse crossings may require consultation with, or approval from, government agencies responsible for aquatic habitat or water resources. Specific guidelines have been developed by these agencies for the construction of crossings, including:

- Culverts: Fish Passage Design Requirements (DNRE 1997);
- Fords: Fish Passage Design Considerations (DNRE 1997); and
- Policy and Guidelines Aquatic Habitat Management and Fish Conservation (New South Wales Fisheries 1999).
GENERAL GUIDELINES

General guidelines include:

- no work should be undertaken in flowing water;
- no excavation should be allowed below the natural bed level of the stream;
- the watercourse should not be deviated;
- disturbance to stream bed and banks should be minimised. Areas of bank that have been disturbed should be reinstated to match existing banks adjacent to the works site;
- works in the bed of the waterway must not impede fish passage (e.g., rock weirs);
- any heaps of excavated soil remaining after the completion of works should be removed from the site. No material should be pushed into the waterway or left in a manner where it can slip or be moved by floodwaters into the waterway;
- logs and boulders removed from the waterway as a result of the rehabilitation should be returned to the waterway and randomly distributed. Logs should be placed with the crown end downstream;
- if woody debris (snags) must be moved from the middle of the waterway, they should where possible be drawn to the bank of the stream and anchored there with the crown end facing downstream. In this position, the debris can still provide shelter and an energy source as the material decays;
- windrows should not be created on the banks of the watercourse;
- consideration should be given to securing logs placed on the floodplain if there is potential for flood flows to move the logs and impact on downstream infrastructure, such as bridges;
- flat blade clean up buckets should not be used; tooth buckets are preferred;
- dozers should not be used for stream works; excavators are preferred;
- no servicing or re-fuelling of machinery should occur in or near the stream channel.

Figure G.29 Track drainage near crossings

CROSSINGS WHICH ARE TO REMAIN OPEN

The rehabilitation of crossings which are to remain open aims to restore pre-disturbance conditions while minimising the release of sediment downstream.

Drainage

Track drainage should be installed on both approaches at least 20 metres before crossings (refer section G.1.1). There should be a 20 metre buffer between the drain outlet and the waterway. Silt fencing should be used where there is inadequate local material. If a 20 metre buffer is not achievable, the track drainage should be more closely spaced so each discharge point carries a smaller volume of runoff.
Crossing fill and abutments

Ensure crossing fill and abutments are armoured and stable. Rock may have to be used to protect unstable fill.

Fords

Fords are generally constructed of rock; the rock should extend up both approaches to the limits of normal flood level. The ford should be as wide as the crossing place will allow. The ford should not project above the bed of the stream or wetland in a way which may prevent the passage of aquatic fauna. The approach battering must not extend into the stream to restrict flow capacity.

Bridge upgrades

General guidelines relating to the upgrading of bridge crossings are as follows:

- the side slopes of any cut excavated into the bank of the waterway to access the crossing should be no steeper than 2 horizontal to 1 vertical. All side slopes should be topsoiled and revegetated;
- runoff from access tracks leading to the crossing, other than from access ramps excavated into the banks of the waterway, should not be allowed to flow directly to the waterway. All such runoff should be diverted away from the waterway or, if this is not possible, into the vegetated verges adjacent to the waterway;
- in the case of access ramps cut into the bank, where runoff from the ramp will flow directly into the waterway, the access ramp should be surfaced with compacted gravel to prevent scouring of the track. Side drains should be protected with rockfill evenly graded from fines to 150 millimetres in diameter;
- any side rails attached to the bridge should be designed to minimise the trapping of flood debris;
- wherever possible and practicable, the waterway should not be deviated. If necessary, the flow should be pumped around the construction site or construction undertaken in stages with flow confined to one portion of the waterway;
- disturbance of the bed and banks of the waterway and the use of construction plant and equipment should be minimised during construction. Removal, destruction or lopping of native vegetation should also be minimised. Suitable conservation measures are to be implemented to prevent vegetation, silt, chemicals and spillage from construction activities either entering the waterway or moving downstream;
- no discharge/dumping of wastewater or other materials to the waterway is permitted, unless specifically authorised by the relevant authority;
- all disturbed bank areas should be graded, topsoiled and revegetated;
- vegetation that has been cleared for construction purposes and any heaps of excavated soil remaining after the completion of the works should be removed from the site. No material should be pushed into the waterway or left in a manner where it can slip or be moved by floodwaters, into the waterway;
- works in the bed of the waterway should not to impede fish passage;
- logs and boulders removed from the waterway as a result of construction activity should be returned to the waterway and randomly distributed.
CROSSINGS WHICH ARE TO BE CLOSED

The existing crossing structure should be removed with an excavator. The removed material should not be allowed to erode and enter the stream.

Drainage

Track drainage should be installed at least 20 metres before the crossing on both approaches, and before the piles of material removed from the waterway (refer section G.1.1).

Removal of crossing fill

Only an excavator should be used to remove the crossing structure or soil from the crossing. Work should begin from the closed end first. The top layer of material should be removed, leaving adequate fill in the crossing to allow the machine to cross the waterway without impacting on the stream bed. The removed material should be spread over the track, ensuring that runoff will not carry the material into the waterway. Works should then move to the other side of the crossing and the remaining fill removed.

Any heaps of excavated soil remaining after the completion of works, except that placed to bar the track, is to be removed from the site. No material should be pushed into the waterway or left in a manner where it can slip or be moved by floodwaters into the waterway.
H Case studies

H.1 Alpine rehabilitation in Kosciuszko National Park

H.1.1 The impacts of grazing and burning

Soil erosion and degradation in the alpine communities was caused by vegetation damage through overgrazing and stock trampling (Clothier and Condon 1968). The exposed soil was subject to frost heave, which increased its vulnerability to water and wind erosion. Frost heave, wind abrasion and desiccation caused erosion scalds to spread by under-cutting surrounding soils and vegetation. Some areas eroded to gravel or rock pavements which had a feldmark-like appearance. This degradation sequence is shown on Figure H.3.

Bog, fen and wet tussock grassland areas were favoured by stock, being sheltered and offering water and palatable grasses. Stock caused considerable damage to these sensitive sites from trampling, pugging soils and disrupting flow patterns. Peat and alpine humus soils were exposed to desiccation and oxidisation, and incision by concentrated runoff. Deep gullies very quickly developed in many fen and bog areas with loss of the functional role that these communities have in catchment hydrology.

The bogs and fens are critical for the retention and slow release of groundwater flows to the streams and surrounding vegetation communities. It was the destruction and loss of these communities that was of greatest concern to the Snowy Mountains Authority. The bogs and fens provide for an even base-flow to the streams and rivers supplying the hydro-electric power stations.

While erosion was most severe in the alpine zone, large areas of erosion also occurred in the sub-alpine woodlands. Approximately 400 hectares of severely eroded land and 1,100 hectares of moderate erosion along the Main Range between Mt Kosciuszko and Mt Tate required rehabilitation.

H.1.2 Background to rehabilitation

As early as 1890, concerns were being expressed that grazing and annual burning was damaging vegetation and soils in the snow-lease area (Helms 1890 and 1893; Maiden 1898). In 1938, the NSW Government declared the upper catchment of the Snowy River an area of ‘erosion hazard’ under the Soil Conservation Act 1938 and initiated surveys to determine the extent of damage.

Grazing was excluded from the Kosciuszko summit area in 1944, with the gazettal of Kosciuszko State Park. Over the following 20 years, grazing was progressively excluded from the rest of the Park. In 1957, the Soil Conservation Service commenced studies on rehabilitation methods and plant species for areas which were degraded beyond the capacity for natural recovery. In 1959, the first and largest ecological landscape restoration and rehabilitation project in NSW was commenced (Good 1976).

H.1.3 The alpine rehabilitation program

The rehabilitation of alpine environments had not been attempted in Australia prior to the Kosciuszko summit rehabilitation program. The project therefore presented many ecological challenges. It was necessary to develop, evaluate and evolve a range of new techniques.
The first attempts to rehabilitate severely eroded sites in tall alpine herbfield areas were based on soil conservation practices developed for agriculture. The eroded areas were manually dug over or disturbed and sown with a soil stabilising cover crop together with a mix of introduced European grasses and clovers. Species included Perennial Ryegrass (*Lolium perenne*), Browntop Bent (*Agrostis capillaris*), Kentucky Blue Grass (*Poa pratense*), Chewings Fescue (*Festuca nigrescens*), Creeping Bent (*Agrostis stolonifera*), Timothy Grass (*Phleum pratense*), Red or Creeping Fescue (*Festuca rubra* ssp *rubra*) and White Clover (*Trifolium repens*).

In later years of the program when the ecological requirements and constraints on the use of native plant material were known, only native seed was sown.

An application of high analysis fertiliser was applied at rates appropriate to each site. A mulch of sterilised hay was placed over the treated area, at a rate of 10 t/ha (Figure G.1). The mulch was held in place with wire netting pegged to the ground.

The use of a mulching agent was based on studies by Costin (1954, 1958), which indicated that a minimum vegetation cover of approximately 10 t/ha of dry matter was required for adequate soil protection, and mitigation of frost heave. The use of mulch was also based on the assumption that it would provide a more constant soil moisture regime and better growing environment for the seedlings, particularly where soils were shallow. The mulch was to replicate the protection from frost and desiccation provided by natural vegetation cover.

![Figure H.1 Hay and anionic water soluble bitumen being applied as a mulch to eroded areas](image)

**H.1.4 The lessons for ecological rehabilitation**

**ZINC TOXICITY FROM GALVANISED WIRE NETTING**

The use of an exotic grass mix, with heavy mulching and wire netting, resulted in very mixed success. Native cover was suddenly lost over large areas five to seven years after revegetation had established a native plant sward.
The reason for the continuing revegetation failures was discovered fortuitously. When the heavy galvanised wire netting was replaced by light gauge black wire netting, revegetation was completely successful. The problem lay in the use of galvanised netting (Good 1976). The galvanised wire broke down after five to seven years, releasing very small but significant levels of zinc into the soil, and leading to zinc toxicity and plant death (Figure G.2).

Alpine humus soils are base unsaturated and strongly acid. Levels of exchangeable zinc are very low compared with soils at lower elevations (0.10 to 0.15mg/kg compared to general levels of up to 300 mg/kg) (Johnston and Good 1996). The areas where galvanised wire netting and wire pegs were used still remain visible today, 30 to 35 years after application. While this is undesirable from a visual impact perspective, it does serve to remind visitors of the historical impacts of grazing and the rehabilitation effort.

Many commercially available materials were trialled as replacements for the heavy and expensive wire netting. These included extruded paper netting, plastic polymers, biodegradable nylon net and water soluble anionic bitumen. The latter was used for much of the later stages of the rehabilitation program. The use of water soluble bitumen as a holding agent had several benefits: it was easier to transport to the sites, was readily applied, provided a black cover which improved the temperature regimes for growth under the mulch, and most importantly, slowly dissolved after two or three years.

**DAMAGE TO FUNGAL ASSOCIATIONS FROM ZINC AND EROSION**

Research by Johnston and Ryan (2000) identified that the root system of alpine herbaceous plants in undisturbed sites support a net of arbuscular mycorrhizal root fungi that assist the uptake of nutrients. At many failure sites, it was found that the fungal associations had not developed due to the zinc released from the wire netting and the loss of topsoil and organic matter.

*Figure H.2 Failure of rehabilitation works around 7 years after treatment, due to zinc toxicity from the breakdown of galvanised wire netting*
FUNGAL IMBALANCES DUE TO HEAVY MULCHING

The hay mulch was also found to maintain a high humidity level which contributed to fungal growth during the growing season. This fungal growth resulted in mortality in the native seed sown for revegetation. The mulching program was adapted to account for these impacts with mixed success, particularly where wire netting was used to hold the hay mulch in place.

TEMPERATURE IMPACTS OF MULCHING

Preliminary investigations of the rehabilitation failures focused on soil temperature and moisture regimes under the mulch cover, and the rates of fertiliser application. The mulch investigations indicated that early spring (October/November) treatment and application of mulch actually kept soil temperatures below required germination temperatures.

DIFFERENT FERTILISER REQUIREMENTS OF INTRODUCED AND NATIVE SPECIES

The trials also indicated that the heavy rates (up to 200kg/ha) and high nutrient content (N-11, P-34, K-11) of the fertilisers used, while necessary for introduced species, were detrimental to the germination and growth of many of the colonising native species.

A threshold point was identified four to five years after initial treatment when the use of fertiliser had to be reduced to almost nil to allow native species to succeed. Some failures occurred at this point as the soil-stabilising introduced species were lost and native species were unable to establish at sufficient densities to ensure soil stability.

SPECIES SUITABLE FOR EX SITU PROPAGATION

While the aim of the rehabilitation was to achieve a stable cover of native plants, it was recognised that recolonisation of native species at some sites would not occur without assistance. Ex situ plant propagation trials were commenced in 1967 to develop propagation techniques for the possible mass production of plants suitable for replanting and over-planting of previously eroded but stabilised sites. Some 35 herbaceous species were trialled, from which a small number were selected for mass production. These included many of the colourful herbaceous species that had been greatly reduced by grazing.

Figure H.3 Degradation states of tall alpine herbfield
H.2 Post-fire 2003 mire community rehabilitation in Kosciuszko and Namadgi National Parks

H.2.1 Introduction

Mires (bogs and fens) are important functional communities in the water catchments of the Alps national parks. The 2003 fires burnt all the major bog and fen areas in the parks, with subsequent impacts on water yield and water quality. The bogs and fens became a priority for post-fire rehabilitation works. An interstate Mire Research and Rehabilitation Group was established very soon after the fires to plan and undertake the rehabilitation program. The program will continue until 2008.

The bogs and fens play a major hydrological role in the storage and release of water to the streams and rivers. However, the drought preceding the 2003 fires had left most bogs and fens in a dry state and vulnerable to burning. With the passage of the fires through the mountains, the *Sphagnum* moss cover of most bogs was destroyed. Large volumes of the underlying peatbeds were burnt, and the remaining unburnt peat subsequently dried out, losing much of its water-holding capacity. Many bog and fen sites now carry little *Sphagnum* cover and flowlines through the mire communities have been deeply incised.

Extensive subsurface tunnelling as a result of peat burning became evident some months after the fires, undercutting the surface layers over large areas. This has lead to the collapse of the peatbeds and the development of deep channels through the bogs and fens. These effectively drained the mire communities, exacerbating the drying effects of the fire. A number of bog areas are now hydrophobic and beyond rehabilitation. An estimated 15 percent of bog and fen areas were destroyed across the Alps national parks as a result of the fires.

H.2.2 Priority bog and fen areas

The severity of the impact of the fires on the bogs is related to the fire intensity and the rate of spread. The greatest impact was caused by low to medium intensity, slow-moving fires. These fires produced a long period of exposure of the bog to the heat of the fire. The fast-moving fires burnt through the *Sphagnum* hummocks but seldom resulted in peat burning.

Based on these observations, bogs and fens that were impacted by medium intensity, slow-moving fires were targeted as the initial priority for rehabilitation works. Bogs and fens were also classified according to the extent of degradation, using the degradation state model shown in Figure H.4.

A set of criteria was established to determine priority areas for a planned three to five year rehabilitation program for the bogs and fens in degradation states 1 and 2. Beyond degradation state 3, the bog and fens were considered to be beyond effective rehabilitation to a stable self-sustaining hydrologically functional ecosystem. Many of these sites could still be rehabilitated with a stable vegetation cover, but not a mire community.
Figure H.4 Degradation states for burnt bogs and fens
H.2.3 Criteria for determining priorities of mire sites for rehabilitation

The following criteria were used to identify priority mire sites for rehabilitation;

**Extent of degradation** – including (a) the amount of vegetation lost during the fires, (b) peat incision had begun (c) the soils had become hydrophobic following the fires.

**Recoverability** – some potential for recovery was evident.

**Size and extent of peat beds** – role in catchment hydrology.

**Significance in terms of catchment value** - part of an extensive complex in a catchment or only in a closed system?

**Location** – within the landscape and the catchment. Valley bottom bog complexes were especially targeted due to their deeper peat soils and the higher drainage volumes.

**Accessibility** – with consideration to the effort required to get to the location in terms of both time and costs.

**Cost benefit of rehabilitation** – rehabilitation of bog and fen areas that would be of greatest benefit for catchment protection over the largest area.

**Past history of damage** – while recovery in these areas may have been occurring since the cessation of grazing, the fires were often found to have exposed earlier degradation.

**Iconic importance** – some areas have significant iconic importance. Examples include Pengilley’s and the Jagungal bog complex in Kosciuszko National Park, and the Cotter source, Rotten, and Ginini bogs in Namadgi National Park.

**Threatened species habitat** - Several bogs have previously had large Corroboree Frog populations and they retain the potential to support reintroductions from captive breeding populations.

**Scientific and education value** - the Prussian Creek bogs have particular value for history of bog and hydrological research. Bogs that could be used to illustrate management issues and functional processes were identified as important for recovery works. Guthrie’s bog in KNP represents the largest bog area outside the Main Range.

**Long term monitoring potential** – essential to undertaking such a program is the ability to measure the success of the works. Issues such as access, location and importance were considered in selecting long term monitoring sites.
H.2.4 Rehabilitation objectives

A number of specific objectives were identified by the Mire Research and Rehabilitation Group. These were to:

- assist and promote the regrowth of *Sphagnum*, *Carex* and other bog and fen vegetation in areas affected by fire;
- slow the rate of water movement both within and into bog and fen communities to reduce the potential for incision and channel entrenchment;
- restore where possible the functional hydrological role of the bog and fen communities in the catchment;
- implement sound ecologically based techniques that will ensure sustainability of the rehabilitated sites;
- implement a research and monitoring program as an integral part of the rehabilitation works such that the success of the program can be assessed in future years.

Experience from the alpine rehabilitation work undertaken in Kosciuszko in the 1960s and 1970s indicated rehabilitated bogs and fens can take 30 to 40 years to achieve recovery of hydrological functions. While the post-fire rehabilitation work has restored vegetation cover and a bog-like appearance to many bogs and fens, it has only just begun the slow process of restoring hydrological function.

H.2.5 Rehabilitation program and techniques

The basic techniques for the rehabilitation of bogs and fens and eroded flowlines were developed in the 1960s by the NSW Soil Conservation Service. These techniques are relatively simple and involve:

- the shading and protection from desiccation of the remnant vegetation (particularly *Sphagnum* moss);
- the construction of straw bale dams in flowlines;
- the construction of absorption ‘trenches’ filled with straw bales; and
- the placement of coir and straw-filled jute mesh ‘logs’ as surface water-spreaders and sediment traps.

The techniques aim to slow surface flows to prevent flowline entrenchment, and to create pools of surface water where *Sphagnum* can regenerate and water can spread laterally through the peatbeds.

Following the installation of any straw bales flow-control structures, sods of *Sphagnum* and *Carex* species are planted into them to encourage the regeneration of the community and the breakdown of the haybales. In some pools, silt deposition has already occurred and *Carex* sods have been planted into the sediment fans. The rehabilitation techniques and materials described below are not necessarily the only, or necessarily the best for mire rehabilitation. Rehabilitation programs should allow for the trialling and use of new and possibly more effective approaches and materials.

**WATER SPREADING**

The initial technique applied to many burnt and degraded mire sites was the positioning of water-spreadin structures (coir logs - coconut fibre wrapped in a jute mesh) on slopes above the bogs. This was done to redirect overland runoff into the bog sites or to restore pre-fire flowline connections with the mires. This was a simple but readily
implemented technique to provide additional water to assist resaturation of the
dessicated bogs and fens.

Figure H.5  Coir log flow diversion and water-spreading structures

VEGETATION SHADING

A range of moisture regimes existed in the various mire areas at the time of the fires. Consequently, not all vegetation was destroyed by the fires. Small areas of live
*Sphagnum* were found in shaded and moister sites. In other sites, the *Sphagnum*
appeared to be recovering from within the core of the hummock, with growth being assisted by shading from overhanging dead shrub material.

In order to further increase the potential for *Sphagnum* recovery, sterile straw mulch was spread over remnant *Sphagnum* hummocks that exhibited some recovery potential. The straw was applied at a rate of approximately 2 tonnes per hectare, loosely spread to a depth of 3-5 centimetres. This rate of application provided approximately 70% shading for the underlying vegetation, a level previously identified as optimal for *Sphagnum* regeneration.

Because of the difficulty of transporting straw bales to remote sites, shade cloth (Sarlon™) was trialled and this was found to be a suitable alternative (refer Figure H.6). It was easier to apply than the straw and lasted longer. Some 5,500 square metres of shade cloth have been placed over mire sites in Kosciuszko and Namadgi National Parks with considerable benefits to plant growth evident after three years. The shade cloth also provides effective protection for seedlings and young plants from the damaging impacts of ultra-violet light, which has increased considerably in the mountains over the past decade.
Runout Flow Reduction

Because of their high organic content, alpine and subalpine soils are sensitive to damage by fire as the organic material within the soil is mineralized or volatilised. The volatilisation of organic materials compounds the problem by inducing water repellence. Soil exposure, structural breakdown from organic matter loss and water repellence combine to create high erosion risks following fires.

Increased erosion and runoff also contributes to the concentration of flows and incision of mire soils. This occurred following the 2003 fires, with deep channel development and the loss of natural pools within bogs and fens. Straw bales were used to reduce the flow rates and volumes in these drainage lines (Figures H.7 and H.8), to recreate chains of pools and to divert the higher flows over larger areas of vegetation. This assisted the regrowth of the extant vegetation while reducing the potential for further flowline incision.
Figure H.8 Haybales inserted into low flow areas to spread water into surrounding peatbeds and form stable pools for the regeneration of fringing *Sphagnum* hummocks

In areas with high flow rates, substantial vertical incision through the peat had occurred. Incised channels were a metre or more in depth. It was also found that once channels had been incised to bedrock, lateral erosion of the peat up to two metres either side of the incised flowline occurred.

Reducing flows in these areas was also achieved through the placement of straw bales into the incised flowlines. Hessian sandbags filled with straw were inserted into areas of undermined lateral peatbed to provide support for the peat.

**GULLY-LINE WEIR AND POOL RECONSTRUCTION**

Where substantial loss of peat had occurred and large gully development had commenced, straw bales were positioned in the gullies to reduce flow rates. The function of these bales was not to replace lost peat, but simply to reduce flows and provide a greater opportunity for the re-establishment of vegetation along bank edges.

Figure H.9 A stable pool constructed in an entrenched and dried out bog
**GULLY BANK PROTECTION**

In sites where deep gullies had developed, the increased flows often resulted in rapid undermining of bank edges. Techniques and materials were required to divert flows away from the banks. Two approaches were taken; pool creation and barrier insertion. While pools acted to slow high flows into an area being actively eroded, diversion barriers acted to divert the flows away from undermined stream banks. Coir logs were placed into the undermined stream banks and fastened with steel pins.

![Coir log used as a barrier in an eroded flowline to prevent further undermining of the bank edge](image)

**SUBSURFACE STRAW-FILLED DAMS**

In several large, drained bog areas, trenches were cut through the peatbed down to the underlying gravels or bedrock and then filled with one to three levels of straw bales. This was done to provide a subsurface ‘dam’ (Figure H.11) to reduce the loss of water from the peat mass and to provide for the re-saturation of the peat. The straw bales were covered with peat and bog vegetation and eventually they will be consumed into the peat mass. This was a drastic measure but was deemed essential if the bogs were to be effectively rehabilitated. To date, this technique has worked effectively at all sites where it was implemented.

![Excavated trench (part left uncovered for study) filled with straw bale ‘dam’ to retain subsurface water in the peatbed](image)
H.2.6 Summary

The successful rehabilitation of alpine and subalpine ecosystems and plant communities requires:

- an understanding of the functional role of the communities being treated;
- an understanding of the ecological requirements of the significant plant species of each community; and
- an appreciation of the level or degree of degradation of each community.

For the bogs and fens at the extremes of degradation, rehabilitation to the pre-fire community has not been possible and restoration to another stable community is all that has been achieved.

Where rehabilitation is identified as possible, the techniques to restore the bogs and fens to their pre-fire condition can be relatively simple and readily implemented. However, the restoration of their full functional role may take several decades of careful maintenance and management. The bog and fen rehabilitation work undertaken after the 2003 bushfires has been demanding of skills, time and funding but has shown that well founded, ecologically based programs can be very successful.

The shading techniques that have been developed have proven to be an effective measure in the protection and regeneration of *Sphagnum* and other aquatic plant species.

Further research on a number of aspects of bog and fen ecology and hydrology and climate change impacts is required. Some of this research is being undertaken by the Mire Research and Rehabilitation Group. Long-term monitoring of the bogs and fens should also be undertaken to assess their recovery as well as their response and adaptation to climate change.
I References and resources

I.1 References


I.2 Further resources

This section lists some of the resources and references which may be applicable to rehabilitation projects in the Australian Alps. The list is intended to be a starting point for research and is not comprehensive.

I.2.1 Flora and fauna values

BOOKS, REPORTS AND PAPERS


Cameron-Smith, B. (1999) Plants and Animals of the Australian Alps. Envirobook, Annandale, NSW


Thomas, V., Gellie, N. and Harrison, T. (2000) *Forest Ecosystem Classification and Mapping for the Southern CRA Region* NSW NPWS, for the NSW CRA/RFA Steering Committee


**WEB DATABASES**


Wetlands International Directory of Wetlands of International Importance:

I.2.2 Physical values

Canadian CMHC (website) - information on some simple soil testing procedures:


Young, A Young, R (2001) *Soils in the Australian Landscape* Oxford University Press

I.2.3 Propagation and revegetation


Greening Australia (undated) *How to Germinate Native Tree and Shrub Seed Enjoyably*. Pamphlet published by Greening Australia with support from the Australian Nature Conservation Agency and Pacific Waste Management

Far South Coast Landcare Association (undated) *Community Seedbank. Notes on seed collection*. Supported by the Southern Rivers Catchment Management Authority


Florabank (1999b) *Guidelines 6: Native Seed Collection Methods*. Florabank, Canberra


WEBSITE


I.2.4 Weed management


**WEBSITES**


CRC for Australian Weed Management: http://www.weeds.crc.org.au

NSW Agriculture weed management site with information on weed identification and control: http://www.agric.nsw.gov.au/reader/weeds

Weeds Australia: http://www.weeds.org.au

**I.2.5 Conservation management**

Australian Network for Plant Conservation Germplasm Working Group (1997) *An introduction to the principles and practices for seed and germplasm banking of Australian Species*. Produced by the Australian Network for Plant Conservation, Canberra


**I.2.6 Rehabilitation, monitoring and assessment**


Nature, in association with the British Upland Footpath Trust and the Countryside Commission.


Papst, W., Morgan, J., Wahren, H. and MacPhee, L. (2005) Alpine Rehabilitation and Vegetation Management in The Alpine Rehabilitation Course Notes. Course presented by the Centre for Applied Alpine Ecology, La Trobe University, Melbourne at Falls Creek, 14-17 February 2005


I.2.7 Construction and maintenance guidelines


Department of Natural Resources and Environment (DNRE) (Vic) (1997) *Culverts: Fish Passage Design Requirements*

Department of Natural Resources and Environment (DNRE) (Vic) (1997) *Fords: Fish Passage Design Requirements*


I.2.8 Training

Alpine Rehabilitation Course – training course run in alternate years by the Centre for Applied Alpine Ecology, Latrobe University.

I.2.9 Miscellaneous


### J Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘A’ horizon</td>
<td>The top layer of a soil profile which stores much of the nutrient base and is the medium for the majority of plant growth, particularly herbs and shrubs</td>
</tr>
<tr>
<td>Accelerated erosion</td>
<td>Erosion occurring at a greater rate than the natural condition primarily induced by the activities of human use</td>
</tr>
<tr>
<td>Soil Acidity</td>
<td>A soil exhibiting a pH of less than 7. Acidic soils become a rehabilitation problem when the pH is less than 5.5 but all alpine soils are acidic with organic alpine soils in groundwater sites being as low as pH 4.</td>
</tr>
<tr>
<td>Anaerobic soils</td>
<td>Soils having little or no free oxygen in their profile. A soil condition of high water table areas and groundwater communities</td>
</tr>
<tr>
<td>Aerobic soils</td>
<td>Soils having free oxygen in their profile and where oxidising and humification processes prevail</td>
</tr>
<tr>
<td>‘B’ horizon</td>
<td>The layer of soil below the A horizon which is usually finer in texture, more massive in structure (clayey) and stronger in colour. It is usually a poor medium for plant growth</td>
</tr>
<tr>
<td>Batter</td>
<td>The excavated or constructed face of an embankment such as a road batter</td>
</tr>
<tr>
<td>Bench</td>
<td>A level strip constructed across a slope or batter to reduce the continuity and height of a batter and hence the length of flow of runoff over a slope. A bench often is constructed to act as a drain to divert water across a batter</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>The variety of living organisms, the genes they contain and the ecosystems they form.</td>
</tr>
<tr>
<td>Biomass</td>
<td>The total weight of living organic matter existing on a given area at any given time</td>
</tr>
<tr>
<td>Biota</td>
<td>All flora and fauna of a given area or site</td>
</tr>
<tr>
<td>Calcareous soils</td>
<td>Soils containing significant amounts of calcium carbonate and usually exhibiting neutral to alkaline conditions (pH 7 +)</td>
</tr>
<tr>
<td>Catch drains</td>
<td>Drains constructed on the high side of a construction / development site such as a cut batter of a road</td>
</tr>
<tr>
<td>Check bank</td>
<td>A short level earth bank constructed to slow and spread runoff flows from other structures</td>
</tr>
<tr>
<td>Cold air drainage hollow</td>
<td>A natural depression in the landscape where cold air settles or pools after flowing downslope from higher surrounding lands (cold air drainage).</td>
</tr>
<tr>
<td>Community</td>
<td>A natural complex of plants occurring on a specific biophysical site</td>
</tr>
<tr>
<td>Compaction</td>
<td>The reduction of the volume and the increase in the density of a soil in the preparation of a site for infrastructure development, road surface etc, or as a result of vehicular movements and recreation activities etc. Soil compaction results in lower soil permeability, change in structure and poorer soil aeration with consequence loss of capacity of plant growth</td>
</tr>
<tr>
<td>Corridor</td>
<td>A linear area of vegetation linking other larger remnants of vegetation. It forms a link for the movement mainly of animals, but also a relatively natural area for plants to establish or re-establish. Corridors, therefore, form a vital part of the ecosystem in highly disturbed areas.</td>
</tr>
<tr>
<td>Cover crop</td>
<td>A short-term or temporary vegetation cover grown to provide soil protection and a modified micro-environment for the establishment of more permanent plant species. A cover crop eventually becomes part of</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Cross-slope</td>
<td>The slope of the land surface sat right angles to the dominant slope</td>
</tr>
<tr>
<td>Cross-fall drainage</td>
<td>Drainage from a road surface to the sides of the road or track but not along it. Where the flow is towards the toe of a cut-batter it is referred to as an infall flow, while flows to the fill-batter side are referred to as outfall flows</td>
</tr>
<tr>
<td>Cut-batter</td>
<td>A batter on the high side of a road or construction site where a hill slope is cut into to level a site or to reduce the gradient of a road. As the lower soil horizons and geology are exposed revegetation and rehabilitation is always difficult</td>
</tr>
<tr>
<td>Cuttings</td>
<td>Used as a means of propagation, parts of the parent plant are cut away and re-planted, generally after dipping in plant hormones to encourage roots to develop. Once roots have formed the plant is said to have `struck' and growth of the upper parts will follow. Once the cutting has struck and is growing well, it is ready to plant out.</td>
</tr>
<tr>
<td>Degradation</td>
<td>Lowering the functionality and sustainability of a landscape</td>
</tr>
<tr>
<td>Direct Seeding</td>
<td>The practice of sowing seed directly onto the soil. In practice this technique is mostly used for grasses, however, other species that produce seed prolifically may also be suited to direct seeding, particularly many of the alpine forbs.</td>
</tr>
<tr>
<td>Division</td>
<td>In clump-forming species, division is sometimes used as a means of propagation. It involves dividing up the clump, or cutting part of it off with roots intact, and replanting this (also referred to as `clump separation').</td>
</tr>
<tr>
<td>Dysfunctional</td>
<td>An area or landscape that is no longer self-sustaining</td>
</tr>
<tr>
<td>Direct seeding</td>
<td>The sowing of seed material directly onto a disturbed soil often through hydroseeding or hay mulching using a Finn batter mulcher</td>
</tr>
<tr>
<td>Discharge</td>
<td>The runoff and suspended materials from a degraded site</td>
</tr>
<tr>
<td>Drop structure</td>
<td>A structure for carrying runoff from a road drain or site drain to a lower level on a steep slope</td>
</tr>
<tr>
<td>Duplex soil</td>
<td>A soil exhibiting a defined (sharp) change in texture between the A and B horizons in the profile</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>A community of organisms, interacting with one another, plus the environment in which they live</td>
</tr>
<tr>
<td>Ecotone</td>
<td>A transitional zone or marginal area between two plant communities. Often very rich in plant and animal species.</td>
</tr>
<tr>
<td>Edaphic</td>
<td>Varying climatic or environmental conditions</td>
</tr>
<tr>
<td>Energy dissipater</td>
<td>A structure built to slow the rate of flow of runoff discharge water and hence its erosive capacity</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>The natural and artificial addition of nutrients to lakes, streams and estuaries and the effects of this addition.</td>
</tr>
<tr>
<td>Fetch</td>
<td>See inter-patch</td>
</tr>
<tr>
<td>Field capacity</td>
<td>The total amount of water held in the soil after surface runoff and drainage following saturation. Soils are generally at field capacity about 48 hours after a rainfall event that results in soil saturation</td>
</tr>
<tr>
<td>Fill batter</td>
<td>A batter on the downslope side of a road constructed from excavated material from a cut batter or imported from elsewhere and deposited as `fill' material</td>
</tr>
<tr>
<td>Finn batter mulching</td>
<td>The process of applying a vegetative mulch material and a liquid tacking agent (usually anionic bitumen) to the batters of a construction site using a Finn batter mulcher</td>
</tr>
<tr>
<td>Frost heave</td>
<td>The diurnal freezing of soil moisture into ice crystals in an exposed soil surface and the subsequent melting (and evaporation) resulting in continual lifting of the soil surface together with any plant material, leaving</td>
</tr>
</tbody>
</table>
the area subject to runoff and wind erosion

**Functional**
An area or landscape that controls and uses its resources in a sustainable way

**Gabions.**
Wire mesh baskets that are filled with rock and used as physical supporting structures at the base (toe) of large batters or sites subject to slumpage/mass movement. They are also used as small dam structures in flowlines reducing the flow rate, as stepping structures to drop flows down a steep watercourse or as structures to assisting sediment deposition in eroding gully lines

**Gabion mattresses.**
Thin rock mesh baskets used to line flowlines to prevent entrenchment

**Geofabric, Geoweb Geofilter, Filtercloth etc**
Commercial fine mesh products commonly used in construction site rehabilitation and erosion control structures

**Gradational Soil**
A soil where there is a gradual texture change between the A and B horizons

**Graded bank.**
A soil bank constructed to a specified gradient to divert runoff from a site

**Groundwater**
Subsurface water in the soil and rock substrate that fills all available pores and cracks. The upper level of this water is referred to as the water table and in groundwater communities the watertable occurs at or above the ground surface. e.g. bogs and fens

**Habitat**
The place or environment where a species naturally occurs.

**Homologue**
Having the same type of structure but not the same functionality

**Hydraulic capacity**
The capacity of natural or constructed flowlines to carry a given discharge

**Hydraulic pressure**
In terms of natural communities such as bogs and fens this is the pressure gradient between the inflow site and the discharge point. In bog rehabilitation every endeavour is to have this pressure forcing water laterally into peat areas adjacent to the main flowlines

**Hydro-mulching**
The application of a slurry of water, seed, fertiliser and an organic mulch material (pine fibre, paper mash etc) to road batters and other construction sites through a Hydromulcher™ machine

**Indigenous**
Species naturally distributed within a specific geographic area, e.g., KNP or the Perisher Range (cv native species).

**Infiltration Index**
An index of the ability of the landscape to absorb incident rain and flowing water

**Inter-patch**
An area that tends to lose resources such water, soil, that feeds patches further down slope

**Landscape Function Analysis**
The central core of the procedure where the monitoring transects is stratified into patch/inter-patch zones. These patch/inter-patch zones are subsequently assessed by the Soil Surface Assessment indicator procedure to generate indices of stability, infiltration and nutrient cycling

**Landscape Health**
A subjective term commonly use to describe the condition and sustainability of a landscape, i.e. good, fair, poor etc

**Landscaping**
Can be a type of rehabilitation where the focus is more on aesthetics, rather than ecosystem processes. Indigenous or non-indigenous plants may be used, however, when indigenous species are used these are often confined to the creation of a representative rather than a realistic ecosystem.

**LFA**
See Landscape function analysis

**Local provenance**
The genetic variant of a species found in a particular locality. To maintain genetic integrity local provenances are preferred in all parks rehabilitation work

**Native Species**
Term normally applied to any species that naturally occurs, or is
Australian Alps Rehabilitation Manual

indigenous to Australia (cv indigenous).

**Needle ice**

Ice crystals formed in exposed soil often resulting in ‘frost heave’

**Nutrient Cycling Index**

An index of the return of vegetative material to the soil to provide nutrients for plant growth

**Organic soil**

A soil in which organic matter dominates the profile

**Patch**

An area that tends to trap and accumulate resources from the upslope inter-patch

**Peak flow**

The greatest flow rate in a channel, drain or culvert

**Peat**

Consolidated organic matter formed by the breakdown of Sphagnum and Carex spp in acidic and anaerobic conditions

**Propagule**

Any part of a plant that is capable of growing independently from the parent plant, e.g., a seed, cutting, sections divided from a clump forming plant etc.

**Query zone**

Portion of a patch/inter-patch zone where the soil surface features are accessed by the SSA indicators. (LFA)

**Resources**

Components that contribute to the functionality and production of a landscape such as water, soil, nutrients and seed.

**Riprap**

A surface of rocks placed manually or by machine usually to form a waterway or flume

**Roll-overs / roll bars.** Slightly raised soil bars or banks placed across a trail or track to reduce flow along the surface of a track or trail.

**Runoff**

An area that loses resources – see inter-patch. (LFA)

**Run-on**

An area that accumulates resources – see patch. (LFA)

**Sediment Fence**

Term used to describe a fence-like structure designed to prevent the downslope movement of sediment.

**Sediment trap**

A structure or barrier to collect or trap sediment in a drain or culvert outlet

**Seral**

A stage in the successional development of community. Seen as a transitional community that, providing it is not disturbed, is likely to change into a new or climax community over time.

**Slope grooming**

The reshaping and / or removal and replacement of vegetation on a ski-slope

**Sod/Sodding**

The term sod is applied to a square or chunk of material that is stripped from a site with vegetation, soil and roots all intact. Theoretically this material can be stored and later replanted on the site or transplanted to another location. In practice, however, it may be difficult to get native vegetation to re-establish from sods therefore special care is required to maximise the chances of success with this technique.

**Soil Surface Assessment**

The procedure whereby the soil surface is assessed by 10 visual indicators and soil texture. These indicators are combined in various ways to generate indices of stability, infiltration and nutrient cycling. (LFA)

**Spoil**

Material for mining that has to be removed to gain access to the ore body

**SSA**

See Soil Surface Assessment.

**Stabilisation**

Implementing strategies designed to prevent a site from degrading, eg, using mulch, plants and other sediment and erosion controls to protect soil and prevent erosion and sedimentation.

**Stability Index**

An index of the ability of the landscape to withstand the erosive forces of water and wind

**Stockpile**

A temporary placement of topsoil from a site

**Sward**

A grassland or grassy patch within which there are no visible signs of resource (litter and/or alluvium) transport between or around grass plants. (LFA)
<table>
<thead>
<tr>
<th><strong>Table drain</strong></th>
<th>A drain constructed on the inside of a road at the base of a cut batter, or along the top of a fill batter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transect log</strong></td>
<td>The dividing of the monitoring transect into zones of like functionality, (LFA).</td>
</tr>
</tbody>
</table>
Function, sustainability and succession in tall alpine herbfields

Introduction

The tall alpine herbfield ecosystem is a self-sustaining complex and mosaic of vegetation (Good 1992; Costin et al. 2000). The interactions of the physical environment and the genetic structure of a cold adapted flora control plant metabolism, growth and reproduction in the Kosciuszko alpine area (Costin 1989).

In its natural condition, the tall alpine herbfield ecosystem functions as a conservative system; i.e. it works to efficiently capture, retain, recycle and utilise scarce resources (water and nutrients) (Costin et al. 1969; Billings 1978; Costin et al. 2000).

Plant growth is constrained primarily by low air and soil temperatures, nutrient deficiencies, and periods of physiological winter and summer moisture stress (Billings 1978; Oberbauer and Billings 1981; Johnston and Ryan 2000). Similar mechanisms for maintaining scarce water and nutrient resources have also been proposed for ecosystems in arid and semi-arid rangelands (Anderson and Hodgkinson 1997). These ecosystems are also sustainable through their efficient functioning and use of resources in a harsh environment.

A sustainable tall alpine herbfield ecosystem is a complex that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional vegetation groups, productivity and rates of biogeochemical cycling (Costin et al. 1969; Billings 1978; Chapin et al. 1996).

The diversity of major functional vegetation groups and the rates of biogeochemical cycling are determined by a set of four interactive controls:

- climate;
- soil resources;
- the major functional groups; and
- disturbance regimes.

These controls both govern and respond to alpine ecosystem processes and oscillate between stable bounds (Chapin et al. 1996). However, the ecosystem cannot be sustained if the interactive controls move outside these stable bounds (e.g. if excessive amounts of water, soil, biomass and nutrients are lost from the system). If this occurs, the equilibrium between component entities within the tall alpine herbfield ecosystem becomes dysfunctional (Billings 1978).

A dysfunctional ecosystem has been defined as one in which there is an excessive flow of moisture and nutrients out of the system (Ludwig et al. 1997).

Interactive controls on ecosystem variables

A sustainable ecosystem maintains its characteristic diversity of major functional groups, productivity, soil fertility and rates of biogeochemical cycling. This incorporates all stages of succession, including disturbance colonisation and successional development (McNaughton 1977; Chapin et al. 1996). These ecosystems are not static. Plant and animal composition, productivity, and nutrient cycling all change in response to stochastic events and successional change (Chapin et al. 1996). Each interactive control changes over the course of a disturbance-succession cycle.
However, within a stable ecosystem, the interactive controls operate within limits that are representative for that ecosystem and form negative feedbacks preventing larger changes in the interactive controls, therefore maintaining these traits within stable bounds (Chapin 1991; Chapin et al. 1996). The interactive controls need to be conserved and maintained if the ecosystem is to be conserved. Any major changes to the interactive controls will lead to a new ecosystem (state) with distinctly different properties (Chapin 1991; Ludwig et al. 1997).

The alpine areas of Australia are a very small biogeographical zone and are recognized as being biologically significant and most at risk from disturbance and subsequent degradation (Costin 1954; Costin et al. 2000). To maintain the long-term viability of these ecosystems, it is critical to balance the concepts of stability, sustainability and fragility with their use and management.

The local interactive controls for tall alpine herbfields in the Kosciuszko alpine area and how they govern ecosystem processes are now outlined.

**Climate**

Climate strongly affects the structure, productivity of the major functional groups, and rates of biogeochemical cycling in the tall alpine herbfields. The climate of the alpine area is cold with mean mid-summer temperatures of less than 10°C, the physiological limit to tree growth (Park 1975; Green and Osborne 1994; Costin et al. 2000). Patterns of soil and vegetation strongly reflect the very close relationship of the climate to the local topography and the regional physiography (Costin, 1954; Park, 1975; Good 1992). Like most of the Australian continent, there are considerable fluctuations in the mean and extreme annual precipitation and temperatures producing essentially a cool maritime climate (Costin 1954; Galloway and Jennings 1972). These fluctuations, particularly through the short growing season, exert the greatest influence on the distribution of alpine vegetation (Park 1975; Costin 1989; Good 1992).

Disturbance of the alpine vegetation that exposes the ground cover to both the diurnal soil surface frost action (frost heave) and the accumulation of surface heat will result in sustained bare areas. These bare areas are subsequently exposed to wind and water action, which can erode them to such an extent that vegetation re-establishment is limited or delayed. This is an important consideration for Australian alpine land use and conservation (Chapin and Körner 1995).

**Soil resources**

The soil resource determines the maximum productivity and structural diversity of the vegetation. Australian alpine soils differ from alpine soils elsewhere in the world. (Costin 1954; Billings 1978; Costin 1986; Johnston and Ryan 2000; Johnston 2001). The podsol features typical of soils of oceanic moorlands on other continents are absent or poorly developed in the Australian Alps, especially in the dominant alpine humus soil.

The development of alpine humus soils has several origins (Johnston 2001). These include: current chemical weathering, weathering prior to periglaciation, the decomposition of deep-rooted alpine/subalpine vegetation to produce colloid sized sesquioxides at the soil surface, bioturbation and dusts (resembling parna) blown in from the semi-arid and arid zones of Australia (Costin et al. 1952; Walker and Costin 1971; Costin 1986; Johnston 2001). The latter three processes are considered to be the major factors in these soils resisting podsolisation, and are extremely important in the internal nutrient cycling of the Australian alpine soils (Walker and Costin 1971).

The Australian alpine humus soil has developed to become the climatic climax soil, although the organo-mineral solum is acid throughout and base unsaturated (Costin 1954; Costin 1986; Good 1992; Johnston and Ryan 2000).
Functional groups

A gain or loss of key functional groups (e.g. the introduction or loss of species) can permanently change the character of an ecosystem (Chapin 1991; Ludwig et al. 1997). This change to a functional group can change the resource supply or disturbance regime. Changes in functional groups can often influence Australian alpine ecosystem processes as strongly as changes in local climate (Chapin et al. 1996).

In particular, the role of meso fauna and flora is critical in maintaining ecosystem health. For example, the loss of vesicular arbuscular mycorrhizal fungi (VAM) has enhanced the vulnerability of tall alpine herbfields to stress (Johnston and Ryan 2000). VAM are particularly important in the uptake of phosphorous and moisture by plants in the ecosystem (Ryan 1998; Johnston and Ryan 2000). Given the slow growth, short growing season and limitation of nutrients, a plants symbiotic relationship with VAM may be extremely important in the tall alpine herbfield. The loss of the fungi could permanently change the characteristic of the ecosystem through changes in resource supply (e.g. P) or the ability of the ecosystem to recover from disturbance (Johnston and Ryan 2000). Therefore, functional groups, such as VAM, respond to and affect most interactive controls and alpine ecosystem processes.

Disturbance regime

Natural disturbance

Disturbance is integral to all plant communities (Pickett and White 1985). It is critical to sustaining the natural structure and rates of processes in ecosystems (Sousa 1985). In particular, alpine ecosystems are subject to recurrent disturbance because of the severe climate (Williams and Costin 1984). For example, insect herbivores, frost, wind, drought and other extreme climatic events are natural disturbances that commonly occur in Australian alpine ecosystems (Wimbush and Costin, 1979; Williams 1990). However, in contrast to lower altitude ecosystems found within Australia, the soils and biota of the Australian alpine area have evolved mostly in the absence of significant grazing by vertebrates and the effects of regular fires (Wimbush and Costin, 1979; Banks 1989; Williams and Costin 1994).

In response to the natural disturbance regimes, the natural patterns of dominance in the vegetation communities may alternate between plant species (Sousa 1985; Pickett and White 1985). However, a change in intensity, type or frequency of disturbance may cause long-term ecosystem change outside the natural bounds (Sousa 1985; Chapin 1991; Ludwig et al. 1997).

Human disturbance

The history of human disturbance in the Kosciuszko alpine area over the last 200 years has been one of accumulated European impacts, including summer grazing and burning, and tourism (Costin 1954; Costin 1957; Good 1976; Good 1987; Good 1992; Johnston 1998). These activities have resulted in long-term damage or irreversible change to the soils and vegetation communities of the area (Clothier and Condon 1968; Good 1987; Arkle 2000). Anthropogenic climate change may further exacerbate the impacts resulting in further loss of vegetation and increased erosion.

Conceptual State and Transition Model for alpine herbfields

The state-and-transition model was originally developed by Westoby et al. (1989) for arid and semi arid rangelands as a practical way to understand successional processes and to organise information for management. In this model, any rangeland system may exist in a range of states, where a state is usually defined as a stable plant community. However, these states are not static, and transition states between the stable states were also identified.
Transitions between the states can be triggered by natural events such as changes and fluctuations in climate or fire or by management (disturbance) actions such as overgrazing, destruction of plant cover etc. (Westoby et al. 1989). The Westoby et al. (1989) model can incorporate impacts of climate and management on the life history identified in Groves and Williams (1981), along with catastrophic climatic events (i.e. droughts) which typify much of Australia’s extensive grassland areas (Mott and Groves 1994).

Groves and Williams (1981) have described difficulties in applying classical successional concepts and philosophies to the dynamics of Australian grassland communities. They proposed the concept that grasslands could exist in several ‘variations’. This is supported by Westoby (1980) who described variations in composition of grass swards over time, emphasising the importance of the interaction with the environment that may cause changes in the composition of the vegetation. This concept has been articulated by a number of other researchers around the world and represents the basis of the ‘non-equilibrium’ hypothesis for ecosystem function (DeAngelis and Waterhouse 1987). The importance of the non-equilibrium model for grasslands has also been argued forcefully in Australia by Westoby et al. (1989) who proposed a state-and-transition model for grassland ecosystems.

It is postulated that, in addition to its use in rangelands, the Westoby et al. (1989) model can also be used to understand the successional dynamics of the tall alpine herbfield ecosystem of the Kosciuszko alpine area. Furthermore, the dynamics of tall alpine herbfield ecosystems can be described as a set of discrete states with a set of discrete transitions between these states.

Disturbance to the tall alpine herbfield ecosystem in the Kosciuszko alpine area has resulted in extensive areas of tall alpine herbfield changing from a self-sustaining natural grassland system with a well developed climax alpine humus soil (i.e. state 1), to a sparsely vegetated erosion-feldmark with a stony skeletal soil (i.e. state 2). The natural system in state 1 consists of an intact soil profile (~95 cm) with a high organic matter content, high moisture availability, good nutrient availability and a 100 percent cover of vegetation. However, in state 2 (erosion-feldmark), the soil profile has been eroded down to approximately 14 cm with a high stone content, low organic matter content, low moisture availability, poor nutrient availability and a vegetation cover of approximately 20 percent.

The change from one state to another can involve a number of events or a single event, depending on the change, duration and effects on the interactive controls, leading to a series of transition states between the stable states (Figure A1.3). Similar approaches are relevant for other disturbed alpine ecosystems in the Kosciuszko alpine area, such as the bogs, fens and short alpine herbfield systems in which stream entrenchment has lowered the water tables.

**Implications for management**

The critical step in enhancing the sustainability of Kosciuszko alpine ecosystems is to preserve or manage the interactive controls so that they form negative feedbacks that will maintain the optimum alpine ecosystem characteristics. These negative feedbacks can be strengthened by maintaining historic links among ecosystems and by using regulations and intervention to produce negative feedbacks where human impacts strongly influence the interactive controls of the alpine ecosystems in the Kosciuszko alpine area.

Where interactive controls cannot be maintained, the framework of this model suggests that management should create a new stable set of interactive controls that will sustain the desired ecosystem without relying on continued intensive intervention.
management should attempt to re-establish a stable erosion-feldmark community that does not subsequently impact on the surrounding areas.

SUSTAINABLE ECOSYSTEMS  
**CYCLIC**  
Time  
Interactive controls

UNSUSTAINABLE ECOSYSTEMS  
**UNSTABLE**  
Time  
Interactive controls

**NEARLY CONSTANT**  
Time  
Interactive controls

**TRENDED**  
Time  
Interactive controls

---

**Figure A1.1** Examples of fluctuations in ecosystem traits for sustainable (1) and (2) and unsustainable (3) and (4) ecosystems (adapted from Chapin et al. 1996; 1973)

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**Figure A1.2** Biological, chemical and physical properties that were investigated and used to identify the properties of the states
Figure A1.3 State and Transition Model for the tall alpine herbfield community, Kosciuszko National Park
Table A1-1 Characteristics of States 1 and 2 for tall alpine herbfield ecosystems, Kosciuszko alpine area (adapted from Johnston and Ryan 2000; Johnston 1998 and Johnston 2001)

<table>
<thead>
<tr>
<th></th>
<th><strong>State 1: Natural</strong></th>
<th><strong>State 2: Erosion-feldmark</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant cover (%)</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Range of maximum rooting</td>
<td>28-43</td>
<td>2-8</td>
</tr>
<tr>
<td>depth (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average daily summer soil</td>
<td>5.9</td>
<td>16.9</td>
</tr>
<tr>
<td>temperature (°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range of organic horizon</td>
<td>26-44</td>
<td>0-5</td>
</tr>
<tr>
<td>thickness (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average depth of soil profile</td>
<td>95</td>
<td>14</td>
</tr>
<tr>
<td>(cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Organic horizons</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steady state infiltration</td>
<td>196</td>
<td>35</td>
</tr>
<tr>
<td>(mm hr-1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>4.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>17.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>18.4</td>
<td>7.1</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>8.9</td>
<td>18.2</td>
</tr>
<tr>
<td>Fine sand (%)</td>
<td>26.8</td>
<td>31.7</td>
</tr>
<tr>
<td>Coarse sand (%)</td>
<td>45.9</td>
<td>43.0</td>
</tr>
<tr>
<td>pH</td>
<td>4.5</td>
<td>4.7</td>
</tr>
<tr>
<td>EC ( s)</td>
<td>63.5</td>
<td>51.0</td>
</tr>
<tr>
<td>Nitrogen (mg.kg-1)</td>
<td>123.4</td>
<td>38.4</td>
</tr>
<tr>
<td>Phosphorus (mg.kg-1)</td>
<td>31.6</td>
<td>7.3</td>
</tr>
<tr>
<td><strong>Sub-surface horizons</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>2.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>11.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>9.3</td>
<td>8.3</td>
</tr>
<tr>
<td>Fine sand (%)</td>
<td>31.8</td>
<td>10.2</td>
</tr>
<tr>
<td>Coarse sand (%)</td>
<td>47.8</td>
<td>78.3</td>
</tr>
<tr>
<td>pH</td>
<td>5.5</td>
<td>6.2</td>
</tr>
<tr>
<td>EC ( s)</td>
<td>9.7</td>
<td>72.0</td>
</tr>
<tr>
<td>Nitrogen (mg.kg-1)</td>
<td>38.1</td>
<td>18.5</td>
</tr>
<tr>
<td>Phosphorus (mg.kg-1)</td>
<td>9.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Landscape function analysis

Landscape function analysis (LFA) is a versatile monitoring procedure which uses simple and easily assessed environmental indicators to determine the health of a biophysical system. The techniques have been developed from data and field trials from many years of research work across a number of disciplines.

It is based mainly on processes involved in surface hydrology: rainfall, infiltration, runoff, erosion, plant growth and nutrient cycling.

LFA comprises four components:
1. a conceptual framework;
2. field data acquisition;
3. data reduction and tabulation; and
4. an interpretational framework.

The LFA conceptual framework

The concept of landscape function has been fully described in Ludwig et al. (eds) (1997) and Whisenant (1999). Both of these books describe a similar approach that deals with ecosystems in terms of processes involved in the transport, utilisation and cycling of scarce and limiting resources, such as water, topsoil, organic matter and propagules, in space and time. Figure A2.1 lists some of the processes operating at different locations in the framework.

![Figure A2.1 The conceptual framework representing sequences of ecosystem processes and feedback loops](image-url)
This approach specifically examines the functioning of a landscape, differing from more traditional approaches which assess biological composition and structure. Ludwig and Tongway (1997) proposed a conceptual framework representing landscape function similar to that outlined in Figure A2.1.

This framework represents a sequence of processes (Trigger-Transfer-Reserve-Pulse) operating to maintain the biogeochemical ‘engine-room’ of a landscape. Resource losses from the system are assessed against both inputs and feedback mechanisms. Loss of landscape function means that the system ‘leaks’ resources beyond its boundaries, whereas a gain in function means that control over resource loss is increased, as results from successful rehabilitation.

To summarise this framework model, a trigger, such as rainfall, may result in runoff that is spatially relocated (transferred, 1) across the landscape. Some resources may be lost to the system by runoff (3) and some may be absorbed into the soil (the reserve - 1). In addition, some parts of the landscape absorb more of the water than other parts, due to differential inter-patch/patch characteristics. A pulse of plant growth and of mineralised nutrients (2) may ensue depending on the status of the reserve. Some of the growth may be lost from the system (4) by fire or herbivory and the remainder is cycled back (5) to the reserve. A growth pulse may also feed back (6) to modify subsequent transfer processes by physical means.

The framework recognises:

- the overt spatial redistribution of resources and hence functional connectivity between the ecosystem components in the landscape;
- the importance of considering spatial sequences of processes, rather than composition or structure per se in the ecosystem components;
- the importance of feedback processes in regulating ecosystems in the long term. Key or ‘framework’ species may provide major regulatory services to the system;
- the concept of the ‘economics’ of vital resources;
- that specific simulation models can be developed from this general framework (e.g. hydrological, nutrient cycling);
- this framework is generic and summarises the processes by which scarce/vital resources are retained and utilised in the landscape.

Further, the conceptual framework implies that:

1. landscapes are often highly patterned, with well-defined source/sink or inter-patch/patch sequences, which are responsible for mediating the system processes. This pattern is most efficiently assessed by locating a line transect directly downslope and identifying sequences of inter-patch and patch that are linked by hydrological processes. This is an example of the gradsect approach to understanding ecosystem behaviour (Gillison and Brewer 1984);

2. the scale at which the landscape pattern is monitored comes from the landscape itself i.e. the scale at which the processes are taking place. This can vary from fractions of a metre in grasslands to many tens of metres in semi-arid woodlands. No particular spatial scale is assumed; observation of surface processes establishes the scale.
Uses of the LFA technique

LFA can be used in the following ways:

- to objectively assess landscape desertification/degradation;
  - is there genuine degradation or just utilisation: role of weeds?
- designing rehabilitation procedures, based on system function;
  - what 'engineering' processes are needed vs 'biological'?
- monitoring rehabilitation or desertification over time in response to objectively assessed stress/disturbance regimes;
  - what is the trend over time?
- defining 'edaphic habitat' requirements for plants of interest: physics, chemistry, soil biology and microclimate, ie niche habitats.
- looking at the relative effects of different environmental stressors
  - eg crop-woodland interfaces

Procedure for using LFA

LFA is a simple but effective method of assessing soil health, involving:

- the landscape context: overland flow and resource transport;
- plant induced soil properties, including below-ground biota.

Data are collected at two linked scales:

1. Landscape organisation – factors which influence the retention or loss of resources; and
2. Soil surface assessment – factors at the individual plant scale affecting the soil's habitat value.

Landscape Function Analysis manual

A CD ROM manual describing the LFA program and the procedures for its use is available from David Tongway, CSIRO Sustainable Ecosystems:

Phone (02) 6254 7162
Email dtongway@iinet.net.au

The manual includes Excel templates that calculate and summarise the data as well as worked examples for each assessment type.