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SOIL CONSERVATION IN ALPINE CATCHMENTS

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THE stabilization of erosion in the highest areas of the Australian Alps presents many problems not encountered in more favourable locations. Climatic conditions are such that all treated areas need to be covered with straw mulch and tied down with netting. This requires that some 4–5 tons of materials have to be taken to the site for each acre to be treated. In an area inaccessible to normal wheeled vehicles, transport of these materials and provisioning of the work force becomes a major problem.

The Australian Alps which include the headwaters of the Snowy, Murray, and Murrumbidgee river systems, comprise the nation's major snow-fed catchments (figure 1). In a continent as dry as Australia, the optimum development of the nation's resources will eventually be limited by the availability of water and will require that the limited area of snow-fed catchments be maintained in a stable condition (figure 2).

Detailed erosion surveys carried out by the Soil Conservation Service (Greenup, 1964) show that there are some 12,560 acres classified as minor sheet erosion and 1,340 acres of moderate and severe sheet erosion in the section of the Main Range between Dead Horse Gap on the Alpine Way and the Schlink's Pass Road.

Minor sheet erosion in the alpine context is shown by small bare spaces between individual tussocks of snowgrass (*Poa caespitosa*). Country in this condition will regenerate naturally in the absence of grazing animals. After 8 years of freedom from grazing, the country so affected is now in reasonable condition as the inter-tussock spaces have been occupied by herbaceous species or covered with snowgrass foliage.

Areas mapped as suffering from moderate sheet erosion are generally similar in nature to those affected by minor sheet erosion, but erosion has proceeded to the stage where bare spaces have been enlarged, the intervening tussocks have died out (Durham, 1959), exposing frequent bare eroding patches up to 1–2 chains in diameter, from which 1–6 inches of soil have been lost. The larger areas (more than 5 yards in diameter) need treatment to stabilize. Small bare areas may stabilize naturally if the slope is reasonably flat (less than 10 per cent) and some topsoil still remains.

Severe sheet erosion represents the third stage, where areas suffering from moderate sheet erosion have joined up to form large areas up to several acres extent, from which as much as 2 feet of soil may be lost. The worst of this erosion is concentrated in the area between Carruthers' Peak and Mt Twynam, at elevations ranging from 6,500 feet to 7,200 feet. In this locality, individual areas of several acres have lost from 1 to 2 feet of soil, exposing large rocks and boulders to form an erosion pavement (figure 3).

Erosion of this nature in such a harsh environment constitutes a considerable threat to catchment stability. This article describes the soil conservation measures carried out by the Soil Conservation Service in the Carruthers' Peak-Mt Twynam area, some 4–5 miles north-northeast of Mt Kosciusko.

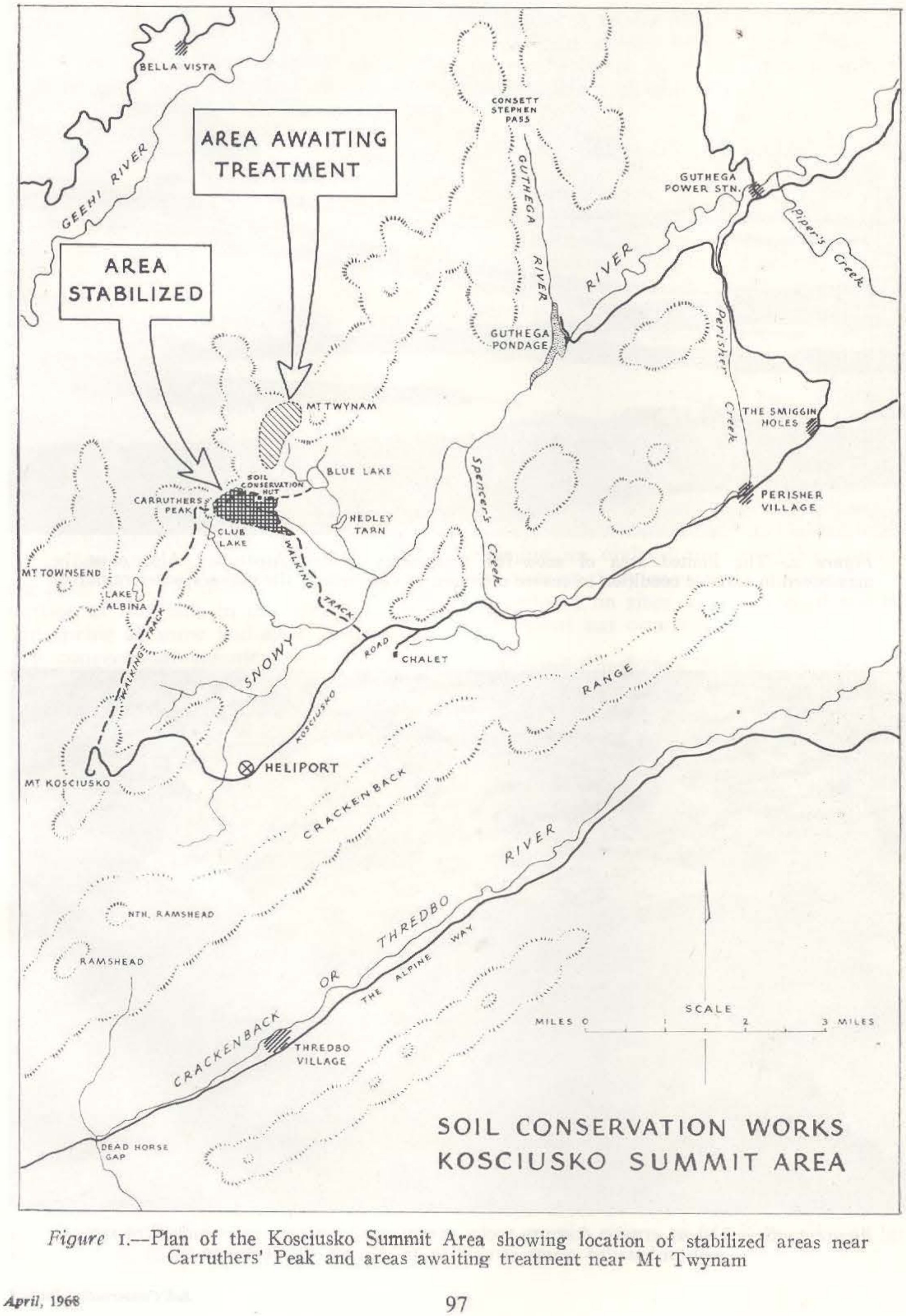

Figure 1.—Plan of the Kosciusko Summit Area showing location of stabilized areas near Carruthers' Peak and areas awaiting treatment near Mt Twynam

Figure 2.—The limited area of snow-fed catchments of the Australian Alps must be maintained in a stable condition to ensure optimum development of the nation's water resources

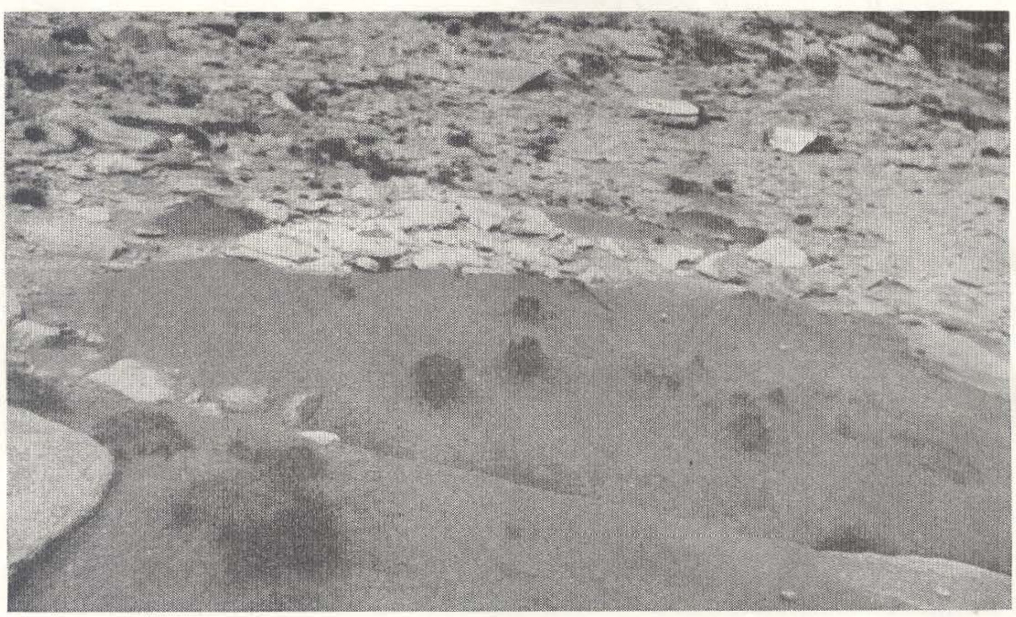

Figure 3.—Severe sheet erosion down to rocky pavement shows the small remnant of sub-soil with pedestalled plants struggling to survive—Mt Twynam

TOPOGRAPHY

The term Kosciusko Massif has been used to describe the general summit area, running northeast from Mt Kosciusko, some 8–10 miles long by 3–4 miles wide. Viewed from the north and west the precipitous terrain gives the impression of grandeur and massive mountains. When approached along the main road from the east, the terrain is plateau type with glacial cirques and well-established drainage patterns from previous glaciations. Within this broad plateau area there is much steep country in excess of 30° slope.

CLIMATE

Long-term meteorological records for the Carruthers' Peak area are not available. Records from the Spencer's Creek weather station, operated by the Snowy Mountains Hydro-Electric Authority at an elevation of 5,800 feet, show annual precipitation ranging from 60 to 111 inches. The greater proportion of this falls in the autumn, winter, and spring as snow and sleet. High intensity convectional summer storms are also experienced as a result of east-moving air masses being forced upward by the steep western escarpment. By extrapolating from the general relationship between elevation and precipitation, annual precipitation at Carruthers' Peak could be expected to range from 90 to 130 inches.

Extreme daily temperature fluctuations are also experienced during the warmer part of the year. At Spencer's Creek, for the ten-year period 1956 to 1965, minimum and maximum temperatures for January were 24°F and 79°F.

Under these climatic conditions the formation of needle ice on bare, moist soils throughout the spring, summer, and autumn is common. Pack snow, with frozen topsoil horizons and surface vegetation, generally occurs for periods of five to seven months each year, with snowdrifts persisting to February and March in sheltered situations. Following heavy snow seasons, as experienced in 1964, some snowdrifts carry through into the following winter.

Galeforce winds occur frequently on the ridges and saddles of the steep divide between the Geehi River on the west and the Snowy River on the east.

GEOLOGY AND SOILS

The dark alpine humus soil is the main soil type in the area and occurs generally to a depth of 1–3 feet. These soils overlay parent materials of granitic origin. A narrow belt of slate and schists runs roughly north-northeast through the area from Etheridge Range through Mt Lee and Carruthers' Peak to Mt Twynam.

VEGETATION

To an elevation of about 6,200 feet, the vegetation is a sub-alpine woodland dominated by snow-gum (*Eucalyptus niphophila*), with a wide range of shrub species forming an understorey on rocky moraine deposits or stony sites, with snowgrass (*Poa caespitosa*) on sites on which good soil development has occurred.

Beyond Charlotte's Pass at 6,030 feet, the country is largely treeless. The tall alpine herbfield alliance of snowgrass and silver snow daisy (*Celmisia longifolia*) forms a green and grey patchwork broken by specialized communities such as heath-forming shrubs in rocky shallow soils, bog communities in groundwater areas, snow-patch communities at the base of snowdrifts, and the "feldmark" communities of sparse, ground-hugging species on the windswept ridges and saddles of the Main Range.

The vegetation and soils have been described in detail by Costin (1950), Taylor (1957–58), and Morland 1958–59).

EROSION

Prior to 1943 the area was open to summer grazing by cattle and, although grazing was banned on some 10,000 acres around Mt Kosciusko from 1944, and from a further 54,290 acres in 1950, cattle were frequently seen on the slopes of Mt Kosciusko as late as 1957.

In such an environment the balance of nature is very delicate. Disturbance of the native vegetation by grazing and uprooting of plants, by burning, and by trampling on frequently sodden soils, has led to serious erosion of many areas.

Once the insulating effect of the previously stable vegetal cover is disturbed, needle ice forms in the moist soil (figure 4). Dependent upon diurnal temperature fluctuations, and other factors such as soil moisture, this needle ice has the effect of lifting and pulverizing the bare soil surface to a depth of ½ inch or more (Costin, 1950, and Durham, 1959.) As the ice needles thaw, the loosened soil rolls downslope or is blown away by strong winds. Seedlings, which may establish themselves during frost-free periods are wrenched out and left lying on the pulverized surface. The roots of established plants around the edge of the bared areas are undermined until the surface sod collapses, breaks off and slides down the slopes.

With the repeated removal of seedlings and undermining of adjacent vegetation it is impossible for bared areas to stabilize naturally. Adjoining bared areas link up over areas of 5–10 yards square. Once bare areas reach this size, down-cutting and undermining of adjacent non-eroded areas proceeds rapidly.

There are now hundreds of acres from which 2–3 feet of soil have been removed, exposing boulders and a stony sub-soil or erosion pavement (figure 5). When individual areas become large the concentrated run-off results in gullying which is normally rare in alpine areas.

The removal of such large quantities of soil by deep sheeting and gullying also results in the burial of large patches of otherwise stable areas in situations downslope.

The old walking track, running along the ridge of the divide from near Rawson's Pass to Blue Lake and back to Charlotte's Pass, has also become seriously eroded in many sections where it has departed from the ridge line. The track has diverted the flow

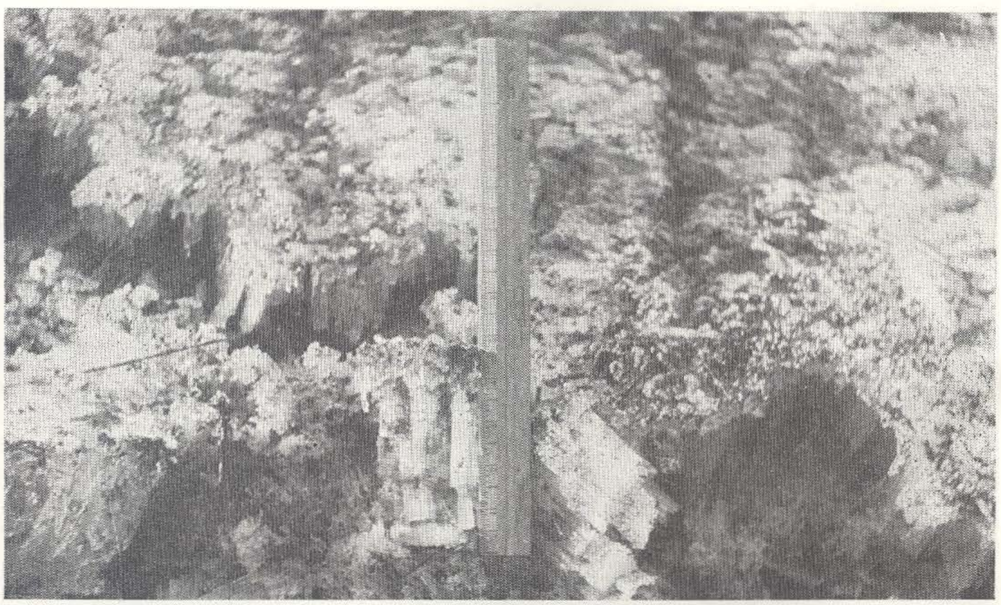

Figure 4.—Soil aggregates lifted off the surface by needle ice. The alternate freezing and thawing on bare areas pulverizes the surface soil, allowing it to be removed by water, wind, or gravity

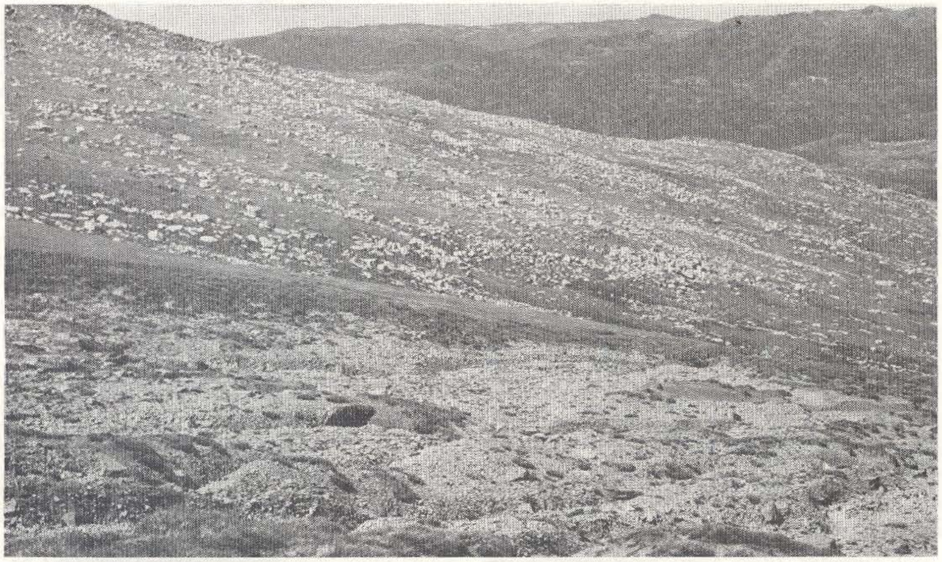

Figure 5.—Extensive area of sheet erosion from which 2–3 feet of soil has been removed, exposing boulders and a stony erosion pavement—Mt Twynam

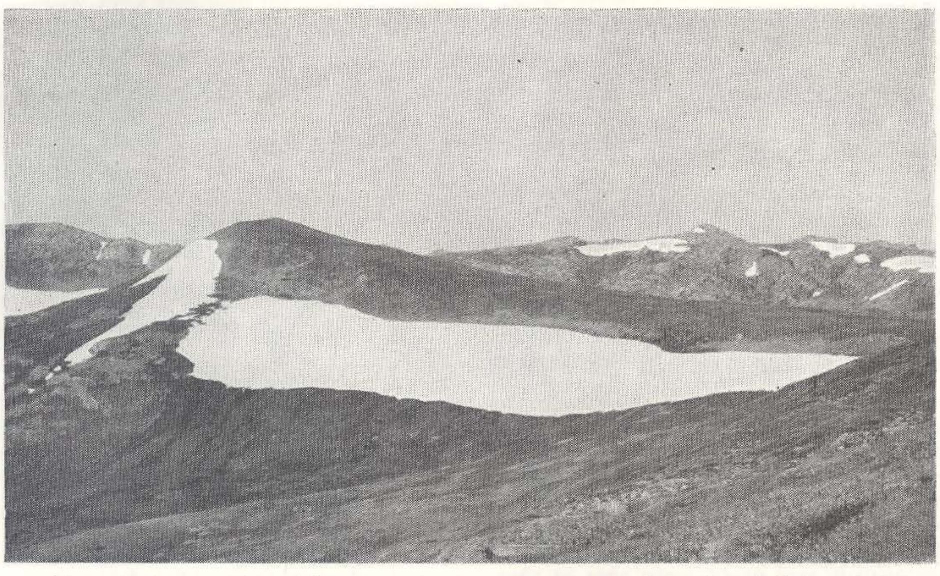

Figure 6.—Large patches of bare ground occur on steep east-facing and south-facing slopes where snowdrifts lie well into the summer as a result of being sheltered from the direct rays of the sun and the hot, dry, westerly winds—Mt Lee with Mt Townsend in the background diagonally across the slope, often carrying the accumulated flow of a number of streamlets for up to half a mile across the slope before discharging at a point where it can again follow a natural flow line. In addition to cutting deep gullies, this has had the effect of diverting the surface and ground-water supply from areas downslope, with consequent degenerative changes in the plant communities, especially those dependent on ground-water.

The acreage of severe erosion quoted above does not take into account large patches of bare ground where snow drifts lie well into the summer months. These occur on steep east-facing and south-facing slopes where snow has accumulated to great depths during the winter, and which are sheltered from the direct rays of the sun and the hot dry westerly winds during the summer (figure 6).

Being free of snow for only a short period each summer, these areas have little chance of establishing vegetation on the precipitous slopes. Patches where drifts are most persistent are characterized by a surface layer of six inches of stone and gravel through which the snowmelt water trickles while ever snow remains. Upslope from this zone soil development has taken place. There is no doubt that areas normally kept bare by snowdrifts have been extended very considerably both outward and upslope by removal of the protective vegetative cover and subsequent erosion. Where this effect is extensive, run-off from summer storms has dissected snow-patch communities and the associated peaty bench which normally occurs at the base of persistent snowdrifts and has cut gullies through or buried the grassed slopes below with soil and rock debris.

EARLY STABILIZATION WORKS

Under the Soil Conservation Act, 1938, the catchment of the Snowy River was declared an area of erosion hazard. Special attention has been paid to erosion problems in this area since the inception of the Soil Conservation Service in the same year. Reports following surveys carried out by Costin (1950) and Taylor (1957–58), and Morland (1958–59) give detailed descriptions of the area.

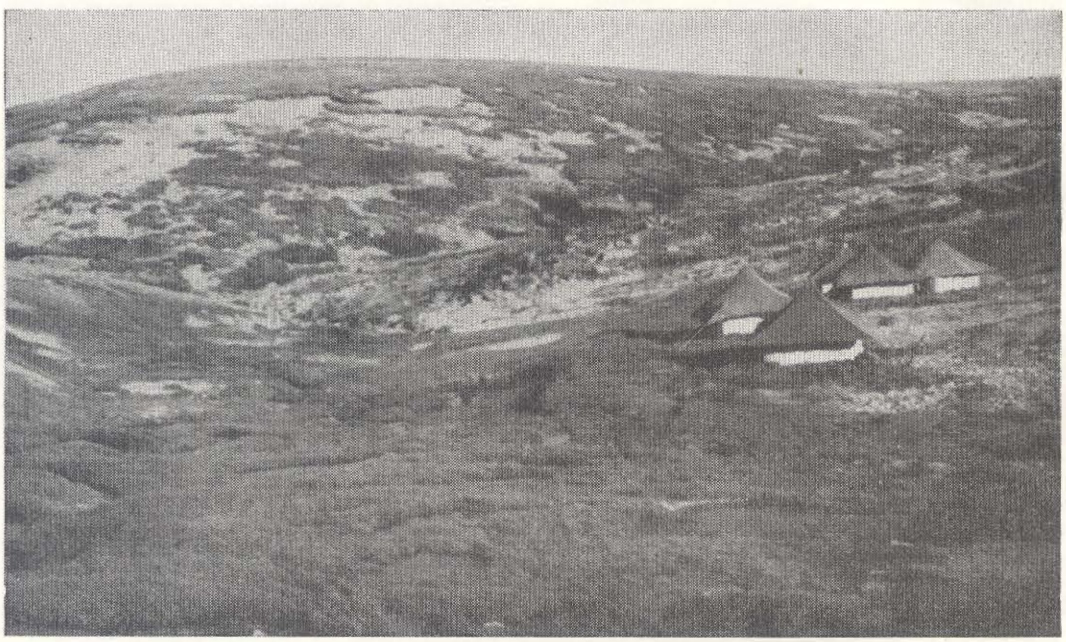

Figure 7.—The tent camp which was established on one of the relatively few flat sheltered areas below Carruthers' Peak. It was subsequently destroyed in a storm in February, 1957. The serious erosion shown in the background has now been stabilized.

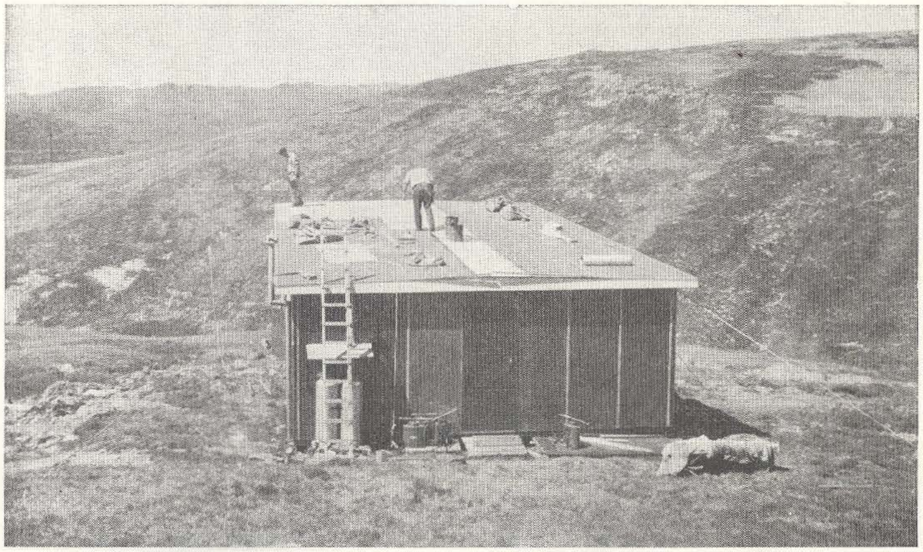

Figure 8.—This hut built in a sheltered spot near Carruthers' Peak was prefabricated and sections flown in by helicopter in 1961

Early in 1957 the first species and fertilizer trials were implemented in the Carruthers' Peak area with the object of determining the requirements necessary for successful stabilization of eroded areas. To carry out this work a tent camp (figure 7) was established on one of the relatively few flat sheltered areas below Carruthers' Peak. A violent thunderstorm struck early one February morning in 1957 leaving the camp in a shambles and forcing the work team to trudge through the storm-lashed pre-dawn to security at the Spencer's Creek weather station. Subsequently, experimental soil conservation work was confined to more accessible areas pending construction of more secure accommodation.

In February, 1961, a hut sufficient to accommodate twelve men was built in a sheltered spot near Carruthers' Peak (figure 8). The design of this hut made special provision for snow and wind loadings, and prefabrication in sections small enough to be carried in the cabin of a helicopter. With the completion of the accommodation hut it was possible to carry out a regular programme of soil conservation work each summer.

ACCESS AND TRANSPORT

Road access is available from Cooma via Jindabyne along the Kosciusko Road to Charlotte's Pass and beyond to Mt Kosciusko. When this road was cleared of snowdrifts (normally in November or December, depending on the depth of winter snow) there still remained a 3–4 mile walk from Charlotte's Pass to the work sites located between Carruthers' Peak and Mt Twynam.

Past experience had shown that wheeled or tracked vehicles, transporting heavy loads, did much damage to the natural surface, creating a serious erosion hazard. Intensive use of packhorses would also create a serious erosion problem on routes used regularly.

To avoid damage to the ground surface it was decided initially to transport all materials and equipment into the area by helicopter and supply the work force with perishable foodstuffs by packhorse limited to three trips per fortnight. Each year from 1961 to 1965 some 30–40 tons of materials were assembled in January at a site beside

Figure 9.—Sling load of wire netting being transported by helicopter to Carruthers' Peak

Figure 10.—Seriously gullied section of the Blue Lake track on the ridge down to Carruthers' Creek the Kosciusko Road, about 2 miles beyond Charlotte's Pass, and airlifted by helicopter over a distance of 4–5 miles to the work sites.

The smaller type aircraft with a payload capacity of 550–600 lb were chartered. This payload capacity depended on wind conditions, type of materials, and availability of suitable loading and unloading sites. The internal loading technique used initially was subsequently discarded in favour of sling loading (figure 9), by which return flights totalling 8–9 miles and including loading and unloading, could be made in 8–10 minutes.

A wide-gauge crawler tractor has been used each year for the construction of banks and small earthworks. To avoid undue damage to the ground surface the route into the work sites was very carefully selected and the grouser plates forming the tracks of the dozer have been fitted with wooden cleats whenever the dozer is required to "walk" any distance over non-eroded ground.

For the 1965 programme, the Snowy Mountains Authority was unable to provide packhorses for the thrice-fortnightly provisioning of the work force. This problem of provisioning, together with the operational problems of helicopter airlifts, prompted the decision to purchase a small jeep-type vehicle of narrow gauge and very light weight, able to operate in rough conditions and on very steep slopes without tipping over. This vehicle successfully transported "rations" and emergency stores and materials along the old Blue Lake walking track. When fully loaded, and fitted with special low-pressure tyres, it gave a ground pressure of 2.5 lb/sq in and was able to operate freely without damage to the ground surface, providing care was exercised in choosing a route. This vehicle was also able to save much back-breaking toil in manhandling bales of hay, rolls of netting, and bags of fertilizer over steep, rough, and rocky slopes from helicopter dumps to work sites.

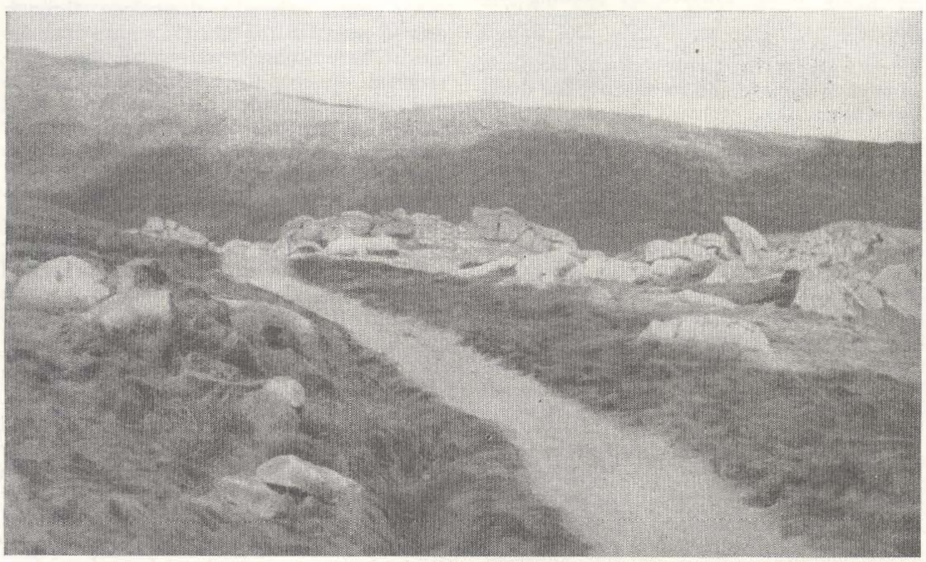

Figure 11.—The areas of serious sheeting and gullying which were on each side of this section of the Blue Lake track have been reclaimed and stabilized

The success of this vehicle in handling up to ½-ton loads under these conditions gave it many considerable advantages over helicopter airlifts for transporting materials from the Kosciusko Road. In view of the seriously gullied condition of the old walking track it was decided to reconstruct this in stages to a condition suitable for operating the vehicle, to provide a stable surface for walking and riding, and at the same time stabilize a serious erosion problem created by the old track (figure 10). This was discussed with and agreed to by the Kosciusko State Park Trust.

The downhill side of the old gully was pushed in with a dozer blade to provide a track surface with a table-drain against the "uphill" wall of the gully. Cross-drains were constructed every chain or so to take water from the table drain and the road surface, and discharge it safely on the downhill side. In this way, streamlets formerly diverted by the gully have been returned to their original courses. Where circumstances warranted small culvert pipes have been laid under the track to return streamlets to their original courses. All disturbed or denuded surfaces are being grassed by seeding and fertilizing, and, if necessary, mulching. Maintenance work is carried out each autumn and spring to prevent any likelihood of erosion damage and to improve the drainage (figure 11).

This reconstruction work, including the relocation of part of the track to a more direct ridge-line route to Carruthers' Peak, has been approved by the Kosciusko State Park Trust on the understanding that the Service restores all damage to the ground surface caused by the operation of the vehicle. In three years of operation no damage has been done to ground surface or vegetation away from established tracks.

STABILIZATION MEASURES

The reclamation of denuded areas in any site, temperate, tropical or alpine, requires the establishment of a stable vegetative cover to protect the surface and, in some circumstances, structures to control run-off. In the alpine environment establishment of vegetation requires some form of physical surface protection to provide the best possible conditions for germination and establishment, and to insulate the soil surface against frost-heave. Meadow hay was used as a mulch to provide this protection.

The steps in stabilizing an eroded area in an alpine situation are detailed below.

Run-off control

The need for structures to control run-off depends on the size of the area being treated. Where run-off control is necessary, small banks, or more correctly large furrows, are constructed with a large furrowing device attached to the ripper frame of a bulldozer. In the initial experimental works, these were constructed by hand and reinforced by placing large flat stones on the downhill side of the channel. Because of the limited capacity of these "banks", grades varied from 0.5 per cent to 3 per cent.

Run-off from the banks was discharged where possible on to existing native vegetation. Where this has not been possible, rock-paved drains have been constructed to carry water directly downslope through eroded areas to the nearest stable drainage line. These drains have normally been constructed by shaping existing small gullies and lining the sides and floor with local large flat stones. These have been most successful in handling storm flows, spaces between the rocks on the floor being filled with coarse sand carried as sediment by storm flows. Small sections have occasionally been damaged by excessive flows following storms. Providing these are repaired promptly the channels continue to function efficiently (figure 12).

Snowdrifts can create problems on structures by reducing designed capacities and causing banks to overtop. This occurs particularly when a snowdrift is located toward the outlet end of banks. As pack snow thaws from the bottom there may only be a 3 inch to 6 inch deep channel capacity under the snow compared to the constructed capacity of one foot depth. Consequently banks have overtopped at the point where the snowdrift crosses the channel. This gen-

Figure 12.—The application of mulch and holding it down with netting is essential to provide suitable conditions for germination and establishment; paved drains are used for safe disposal of run-off

erally occurs during the late spring thaws or following a "warm" rainfall when run-off in excess of 100 per cent may be experienced.

If the position of the drifts is constant each year, the design of banks can be arranged to carry water away from the snow drift. The banks can thus serve to distribute snowmelt run-off as well as storm run-off. In some sites the position of drifts changes from year to year and design of run-off structures is made difficult.

Experience has shown that rapid revegetation of eroded surfaces reduces the need for structural measures to control run-off Thus, as the understanding of the area has increased, stabilization techniques have improved and the degree of run-off control has been reduced. However, there will always be need for flumes or waterways to carry storm and snowmelt flows directly down slope. Trials are being conducted with special materials such as jute-mesh (a coarse-weave hessian material), fibreglass matting and other materials as liners for flumes and waterways. Trials have also been conducted with snowgrass sods for lining the floor and walls of flumes.

Site preparation

The need for special preparation of the surface prior to seeding depends on the degree of erosion and the condition of the surface. Where deep erosion has left a large proportion of the surface area covered by stones and rocks, these have been dozed aside and incorporated in bank construction or left as windrows on the contour. Areas on which remnants of the former organically-rich surface horizon remain will benefit by spreading such material over the area to be treated. Areas dissected by shallow rills need smoothing. Areas with a smooth slaked surface need roughening up by a light cultivation as part of seed bed preparation. In the absence of suitable implements due to steepness of terrain or smallness of area, this can only be done by hand tools.

Banks for run-off control are generally built at this stage although if there is no great dissection of the surface by rills or gullies, they may be commenced beforehand and finished off by hand during site preparation.

As there is not sufficient work to keep a bulldozer occupied for more than a few hours each day, all work requiring the use of a dozer is carried out at one time and the machine withdrawn from the area. A highly skilled operator, well-versed in conservation concepts, is necessary for this phase of the work.

Seeding

When the site has been prepared by cultivation or smoothing and filling, seed is generally sown separately to the fertilizer. Distribution may be by hand broadcasting (on small areas) or by back-pack blower.

Seed of suitable native species is not available in quantities large enough for use in seed mixtures. It was also doubtful that indigenous native species could provide the rapid cover necessary to effect rapid stabilization. Testing and selection of native species to a point where they could be used confidently in a stabilization programme would require years of painstaking research with no guarantee of success. On several occasions small quantities of seed, hand harvested from native species, have been incorporated in a seed mixture without any observed benefit.

It was considered preferable to stabilize eroded areas by using suitable species which were commercially available. As in numerous other examples of stabilization in difficult environments, it was expected that the indigenous native species would migrate into stabilized areas. This is now occurring commonly in the older treatments. However, due to the harsh conditions and radically altered environment, this is a slow process.

A wide range of species is used to give the best possible chance of at least two or three of the selected species being successful. Heavy seeding rates, totalling up to 100 lb per acre, were used with the object of getting a rapid development of cover when germination takes place and also to counteract variable germinations. Some commercial species tested over a twenty-eight-day period have shown germination percentages as low as 3–5 per cent.

The more recent basic seed mixture used has been:

CLOVERS (multi-step inoculated)	lb/ac.
Trifolium repens (White clover), Cert. N.Z. mother	5
Trifolium repens (White clover), N.Z. mother Tasmanian grown	5
Trifolium repens var. Ladino, U.S.A. grown	5
Trifolium repens var. Idaho, U.S.A. grown	5
	20
GRASSES	
Lolium perenne—Perennial rye grass, Tasmanian grown	10
Festuca rubra var. *commutata*, Chewings fescue-Oregon, U.S.A. grown	3
Festuca rubra var. creeping red fescue, Canadian grown	3
Agrostis tenuis Highland bent, Oregon U.S.A. grown	3
Agrostis tenuis Browntop bent, N.Z. South Island grown	2
Agrostis palustris—Huds. var. Toronto creeping bent grass, Canadian grown	2
Poa pratensis—Kentucky blue, Oregon U.S.A. grown	3
Dactylis glomerata—Cocksfoot N.Z. cert. ..	
Dactylis glomerata—Cocksfoot Danish species certified	3
	32
CEREALS	
Avena sativa—Avon oats, locally grown	15
Avena sativa—Cooba oats, locally grown	15
Secale cereale—Black winter rye	12
	42
Total	94

These rates are equivalent to approximately 2 lb per 100 sq yd or 1/3 oz per sq yd. In past years, perennial rye grass has shown up well in the early stages with the bents and fescues becoming dominant in the third and fourth years. White clover has given variable results with a good initial germination generally being achieved, but persistence past the first season has not been satisfactory. In later years all clover seed has been inoculated with rhizobia, using the three-step process of pelleting large amounts of inoculum on to the seed with lime. Research is being conducted on problems associated with rhizobium inoculation.

The seed mixture listed above may be varied in composition or quantities, because one or more species may not be obtainable when required, or because a new species or strain may be added for trial. The search for improved species and strains has been and will be a continuing process.

Fertilizing

Due to the poor fertility level of the granitic sub-soil material on which most of the stabilization measures were carried out, a complete nitrogen, phosphate, and potash fertilizer is used. This is applied at the rate of 5 cwt per acre.

Finely-ground agricultural lime has also been applied in more recent years at 400 lb per acre. The lime and fertilizer were mixed generally by hand immediately before broadcasting.

Heavy amounts of fertilizer have been applied in the initial treatment to meet nutrient requirements and to minimize the need for further applications in later years. Experience has shown that where clover has not done well it has been necessary to apply further fertilizer to maintain a vigorous sward.

As with seed, fertilizer may be broadcast by hand (on small areas) or by back-pack blower.

Investigations are being conducted into the nutrient status of the surface and subsoil in various sites with the view to having the application of fertilizer tailored to fit as closely as possible the nutrient requirements of the site and the proposed vegetation.

Mulching

The application of mulch and holding it down are the most important and most costly part of the stabilization operation. A mulch is essential to insulate the soil against the pulverizing action of frost-heave and to provide suitable conditions for germination and establishment (figure 13).

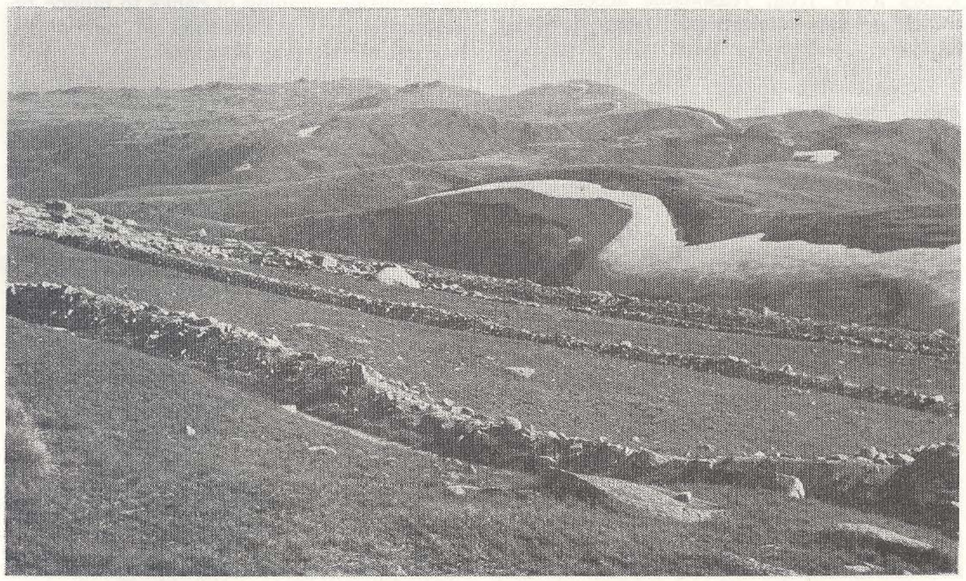

Figure 13.—Excellent establishment of grass following complete treatment between small banks on Mt Twynam, March, 1965

Fine meadow hay, with a large proportion of grass, is the best of the various types of straw mulch available. It is easier to handle and gives greater and more effective coverage per unit weight than cereal hays. It is important that the mulch be thick enough to provide insulation but not so thick as to smother seedlings germinating beneath it.

It is difficult to indicate what thickness of mulch should be used. Optimum amounts range from 2 tons per acre for fine meadow hay to 3 tons per acre for coarser cereal hays. This is equivalent to approximately 1 lb per sq yd for the finer hay to approximately 1½ lb per sq yd for coarser hays. In general terms a 45-lb bale of fine meadow hay should cover approximately 50 sq yds while a 45-lb bale of cereal hay should cover 35 sq yds.

It is important that the hay should be teased out to give a uniform depth of 1-1½ inches. Plants will not establish where the mulch is left in thick clumps.

Mechanical mulching equipment is available but is not suited for operations on steep slopes away from reasonable access. All mulching has consequently been done by hand.

Because high velocity winds are experienced frequently it is necessary to tie the mulch down to prevent it blowing away. This has been done with ungalvanized wire netting or cheaper reject netting when available. To overcome the problem of achieving maximum contact with the ground, the netting is laid out across the slope, working upslope from the lowest point first to obtain correct overlapping of the selvedge, and cutting the tight selvedge where necessary. A patent "ring fastener gun" is used to clip the strips of netting together. The netting is then pinned to the ground by driving "U" (rabbit bows) or "J" pegs of No. 8 wire into the ground at 3–8 feet spacings depending upon the terrain. Local stone was also used if it was readily available.

Other forms of netting have been tried at various times including fishing net and paper mesh, but have not been as satisfactory as the wire netting. On very steep slopes where it is unsafe for men to work, spreading straw becomes a major problem. In these situations jute-mesh, a coarse weave hessian, is used to provide a mulch and to hold seed on the surface.

On small and irregularly shaped areas, or areas containing scattered large rocks or non-eroded islands, cutting and shaping the netting becomes a major problem. In such situations it has been found preferable to use bitumen emulsion as a tacking agent, applied with a power sprayer where small spraying equipment can be got to the site, or by watering can. Although application of precise quantities is difficult under these conditions, about 500 gal per acre (or 1 gal per 10 sq yd) is required to satisfactorily tack the straw.

DRAINAGE LINES

As stabilization progressed from sub-catchment to sub-catchment, the semi-permanent and permanent drainage lines, suffering varying degrees of accelerated erosion, required treatment. Prevention of further undercutting, shaping of banks to induce re-vegetation and stabilization of minor bed load movement was desirable.

Groynes or "rock sausages" were constructed in and along the drainage lines to prevent undercutting, by using local rock with galvanized netting as an envelope. A similar technique was used to construct minor rock weirs to assist in the stabilization of bed load, care being taken that flows passed over the centre of the weirs to prevent by-passing and subsequent failure during high flows.

Shaping of stream banks and peat benches to assist native species to regenerate or revegetate was carried out and further assisted by the laying of jute mesh. This mesh acted as a surface stabilizer and mulch, assisting primary colonizer native species such as alpine purslane (*Montia australasica*) to establish.

This jute type material has been effective in maintaining surface stability for up to three seasons.

Figure 14.—Excellent vegetative cover stabilizing a formerly eroded area in the vicinity of the Blue Lake track, below Carruther's Peak. Invasion by native species is taking place

RESULTS

Observations to date indicate that almost complete cover and surface stability is achieved for the first one to two seasons. Over the succeeding 4–6 years a gradual decline of vegetal basal ground cover to levels varying between 40 and 80 per cent and predominantly of grass species, does occur. Assessment of plant nutrient requirements and continued fertilizer application is necessary to maintain a stable cover of exotic species and allow the continuing migration of native species into the sward.

Reinvasion by native species on treated areas has taken place and has been quite marked in some instances (figure 14). However, complete surface stability by vegetal establishment and regeneration of native species has not been achieved in all areas.

It is expected that current experimental work on rhizobium inoculation, species and strains of pasture plants, and also plant nutrition will improve on the variable results that have been achieved to date. Applied research in problem areas such as these is essential.

By the end of the early 1968 summer, all eroded areas in that part of Carruthers' Creek catchment extending from the summit of Carruthers' Peak to the point where the Blue Lake walking track crosses the creek, had been treated. A small percentage of this will need retreatment.

The stabilization work has had a marked effect on the clarity of the water flowing down Carruthers' Creek. Whereas the flow after heavy rains previously carried a heavy silt load, it now runs clear after a heavy storm.

COSTS AND BENEFITS

The need for mulching and netting, the use of hand labour for a large proportion of the operations, and transport of materials by helicopter has made reclamation in alpine situations a costly operation. Annual expenditure has approximated $20,000 for the treatment of an average of 10 acres of bare eroded ground, and including the construction of rock-paved drains. This cost also includes provision of storage and handling facilities which are being continually improved, and the purchase of tools, and specialized machinery, foodstuffs and many other items of overhead.

Depending on the severity of erosion and the need for special measures for run-off control, actual costs of treatment range from $1,200 to $2,000 per acre, equivalent to 25 to 40 cents per square yard. This apparently high cost needs to be considered in relation to the area which would, in time, be brought to a similar condition if eroded areas were left untreated. On this basis it would be reasonable to divide the present cost by a factor of 5. Allowance must also be made for continuing damage downslope by gullying of drainage lines, siltation of streams, undercutting of stream banks and general deterioration in catchment condition if erosion is left untreated.

These costs have to be weighed against the value of the land primarily as a water catchment, other possible multiple land use factors and the risk of irreversible damage to catchment and stream conditions if seriously eroded areas are left untreated. The almost catastrophic damage which has occurred on the slopes of the ridge running southwest from the summit of Mt Twynam is an indication of what can happen if erosion is allowed to proceed unchecked. Existing erosion must be checked and the area stabilized to prevent it from jeopardizing any part of the extensive hydro-electric scheme.

The area currently being treated is part of the Kosciusko Primitive Area, set aside by the Kosciusko State Park Trust to preserve an area of unique glacialogical, geological, ecological, and scenic features. Serious erosion in the past has destroyed many unusual samples of alpine environments. Stabilization of existing erosion is necessary to preserve a very delicate environment in a stable condition.

The Service is continually looking for ways of reducing costs. The replacement of the helicopter airlift by special wheeled transport has reduced the cost of transporting materials from the Kosciusko Road to the works site from $120 per ton to $40 per ton, a saving of $320 per acre treated. Methods of mechanizing operations are continually being tested to reduce the amount of hand labour. Most attention is being directed to testing special materials and new techniques for mulching and for providing temporary protection to flumes. If special mulching materials now being tested are successful, the amount of materials to be transported may be reduced from 4–5 tons per acre to one ton per acre and the effectiveness of labour increased five times.

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