# INDICATORS OF LAND DETERIORATION IN THE SNOWY MOUNTAINS CATCHMENTS

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# INDICATORS OF LAND DETERIORATION IN SNOWY MOUNTAINS CATCHMENTS

BY

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## PART I

TO a large extent, the real value of the catchments of the Snowy Mountains lies in their limited area. In an essentially dry continent, they represent—together with the Victorian Alps—our most richly endowed watersheds.

The irrigation areas already established on the dry, but fertile plains to the west of the mountains, together with any future irrigation development, are entirely dependent on the water yield from these catchments. Regardless of all other uses to which the area may be suited, its value as a water producing unit thus remains of paramount importance.

By comparison with other mountains throughout the world, these are not very high. Consequently, there are no areas of permanent snow cover, or glaciers, to act as a continuous reservoir. This rather limited mountain resource can rely only on a fairly substantial annual precipitation, comprised largely of winter snow fall and reaching something in the order of 100 inches at the highest elevation, being 7,314 ft. at Mt. Kosciusko.

The winter snow line corresponds roughly with the lower limit of the sub-alpine tract at about 5,000 feet. After the snow melts during the late spring and early summer of each year, it remains for periodic rainfall and satisfactory catchment condition to ensure the continuity of stream flow during the later summer months. Like most of Australia, rainfall is generally spasmodic and variable in amount, so that maintenance of the catchments in a thoroughly sound condition to ensure a continuous and steady flow is of the utmost importance.

The area has been occupied by white man for just over a century, but already we are faced with the problem of restoring large areas of deteriorated lands. Evidence is presented which indicates that most of this damage has occurred during the past fifty or sixty years. Unfortunately there is a tendency to take this state of affairs for granted. Little thought is given to what the area may be like after the next fifty or sixty years.

The term *land deterioration* denotes some reduction in the quality or value of the land. Depending on the type of land being considered, such loss in value may be a measure of declining soil fertility as expressed in reduced crop yields. On grazing land, it may be indicated by the elimination of valuable species by gross over-grazing and by the subsequent invasion of undesirable species involving a loss in grazing value. In the extreme, however, deterioration is represented by accelerated erosion and when this stage is reached, a serious reduction in all other values is normally implied.

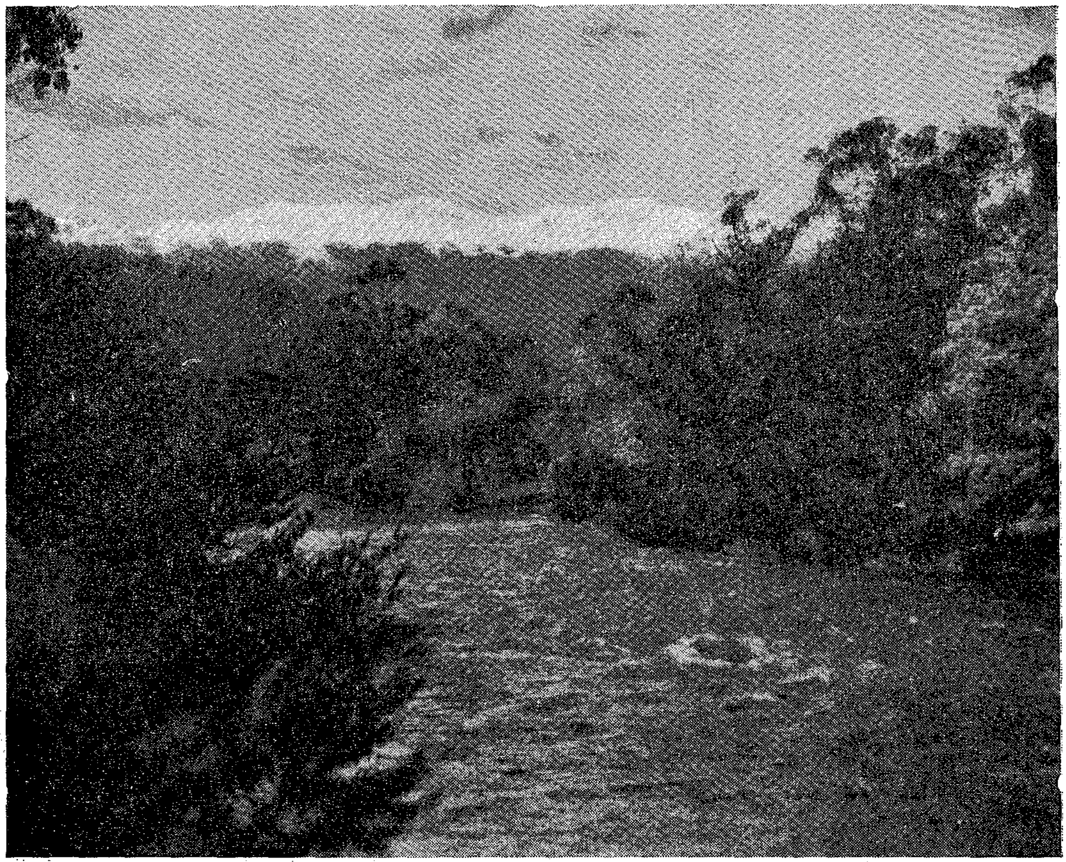

*Fig.* 1.—Water from the Snowy Mountains is the life-blood of irrigation areas already established on the fertile, but dry, plains to the west of the mountains. Further development will be possible as additional water becomes available from the present hydro-electric scheme (Geehi Area). (Photo., S.M.H.E.A.)

As the result of ecological and erosion surveys carried out in recent years, it is now well established that the grazing industry has been responsible for widespread deterioration in the vegetative cover and the onset of accelerated erosion in these catchments. It is doubted whether this position can be overstated, if we give due regard to the very short time that the white man has occupied the area and consider the ultimate consequences of allowing the deterioration to continue.

In order to show that great changes have occurred in the original land systems since the entry of white man, this work is based largely on a survey of a number of early reports published on various aspects of the area. The information contained in these reports has proved a useful guide to conditions in the area up to about the year 1900. Certain well-known principles in soil formation and the development of a primary land system are then described. The decline in the status of certain vegetation, subsequent to human interference, is then traced and reasons are put forward to explain the increasing damage by accelerated erosion.

The extent of this damage can now be recognised in certain signs or indicators that may be seen in the vegetation and the soil, and a number of these are described.

The method of applying these indicators to judge the extent of the deterioration on any particular area and their relationship to all other activities undertaken in the area are also discussed.

This work is offered as further evidence of the extent of the deterioration in these extremely valuable catchments and, perhaps more importantly, as a further recommendation for an urgent re-appraisal of the minimum requirements for catchment protection.

## HISTORY OF THE AREA

The early 1800's witnessed many attempts to locate new pastoral areas to provide for the rapidly expanding colony of New South Wales. These explorations ultimately led to the discovery of some of the high mountain pastures in 1829.

It is probable that the practice of summer grazing in the snow country began shortly afterwards but the extent to which the area was used for many years is by no means clear from early records. It has been asserted[1] that one settler was in the Snowy River country with 400 head of cattle in 1821. The same source reports that a settler looking for pasture land in 1834 found two squatters running cattle as far up as Kiandra, and refers also to sheep and cattle being driven out "on the tops" above the tree line in the summer months from the 1860's onwards.

Apart from occasional expeditions in the area during the intervening years, notable among which was the ascent and naming of Mt. Kosciusko by Strzelecki in 1840, it was not until the 1880's that matters of scientific interest began to receive closer attention. It is from the many reports based on examinations of the geology, glaciology and vegetation, issued during the subsequent two decades, that information relevant to present-day problems can be assembled.

In a report based on an examination of the central part of the Australian Alps in 1885, von Lendenfeld (1885), while apparently attempting to compare this area with certain areas of the European Alps, recorded the opinion that it was not being extensively utilised.

From this it may be inferred that, either von Lendenfeld was endeavouring to draw too close a comparison between this newly found alpine area and the more closely and longer settled areas of the European Alps, or that, in fact the area had not been extensively used up to that time. Whilst it is probable, in the light of all evidence available at the present time, that the matter may be resolved somewhere between these two possibilities, von Lendenfeld's opinion is a basis for suggesting that the widespread evidence of deterioration which exists today is more serious for having occurred in a much shorter time than is generally estimated. Other evidence, which is presented, tends to support this view, although it is recognised that the area was undoubtedly used to some extent in the years immediately following its discovery.

Largely as a result of the Land Act of 1836 which gave some security of tenure to the early squatters, and thus gave impetus to the grazing industry generally in New South Wales, it is apparent that fairly rapid expansion took place in the pastoral industry in districts adjacent to the mountains from about 1840 onwards. Allowing some years for consolidation of the industry in these districts, it is thus logical to assume that the mountain pastures gradually attracted wider attention and that by about 1880 the practice of summer grazing in the snow country was becoming fairly well established. As proof of this, and also of the fact that the time had arrived for some measure of control, an Act of Snow Lease Tenure was introduced in 1889.

The general condition of deterioration in the vegetation and erosion damage which exists at the present time, is therefore seen as the culmination of grazing practices instituted during the early years, but which were rapidly intensified in later years as the

(1) "Snowy Saga". Oswald Zeigler Publications, Sydney, 1956.

onslaught on the vegetation became more sustained with the constant use of fire and greatly increased numbers of stock.

Under the legislation of 1889, the area was envisaged as drought relief country on which to pasture stock drawn from drought stricken areas, not only in adjacent districts but in remote regions of the State. In subsequent years, the practice of regular annual grazing gradually displaced drought relief and in more recent years still, the area was used increasingly by local landholders as part of a home maintenance area.

The Kosciusko State Park Act of 1944 proclaimed the greater part of these catchments as a State Park and vested its "care, control and management" in a Trust. Up till that time there were no restrictions on the number or type of stock carried and leases were generally larger than in subsequent years. Although regulations provided in this Act limited, to some extent, the total number of stock allowed in the area, deterioration had reached such an advanced stage by that time that the effective stocking rates remained exceedingly high.

In the same year, a decision of the Catchment Areas Protection Board, based on extensive evidence of erosion hazard and damage, resulted in approximately 10,000 acres being withdrawn from lease in the Summit area surrounding Mt. Kosciusko. In 1950 this area was enlarged to 54,000 acres and a further 18,000 acres were withdrawn at the head of the Geehi River.

Because of the lack of restriction on stock numbers in previous years, these numbers were at times exceedingly high, particularly during periods of widespread drought. Between August and November, 1888 for example, it was reported that 500,000 sheep had gone through Narrandera towards the mountains for feed and water (Foley, 1957). One million sheep were said to have passed through the Wagga district. In 1897, it was stated that "Never before had the drought been so extensive. On previous occasions stock were moved to the mountain country to the east but even the mountains have felt the effects of the dry season."

It is probable that not all these stock reached the high mountain country, but even allowing for this and then adding the numbers which came from the adjacent tablelands to the east of the mountains, it is quite certain that the mountains were at times subjected to extremely heavy grazing pressures.

A long history of deliberate burning has aggravated this general position and has undoubtedly been responsible for the majority of the ill-effects occasioned by grazing practices. Regular burning of coarse dry growth to promote palatable spring feed, to replace woodland and shrub communities with open grassland, and, to a lesser extent, to prevent summer bushfires, has been widely practised as an adjunct to general grazing practices.

Against this background it is possible to form some idea of the extent of the pressures applied annually to the vegetation for a long number of years, particularly during periods of widespread drought when the mountains like other areas were least able to stand it.

Following a trip to Kosciusko area in March, 1890, Helms (1890) wrote that,

> "On the whole. . . the higher parts of the ranges did not look very attractive. Much of the almost desert-like look was undoubtedly caused through the firing which had been carried on to an unusual extent during the long dry summer. On every peak half burned and dead scrub stared us in the face. . . . Already vast stretches of country are annually burnt off to improve the pasturage, and during summer, when through the devastation of forests, the water gets scarcer in the low-lying parts, and consequently the pasturage parched up, the mountains will be more resorted to."

It is noteworthy that Helms drew attention to this practice nearly seventy years ago, and yet it is regrettable that it was not until 1952 that positive steps were taken to prevent indiscriminate burning. Regulations introduced at that time, provided that all burning must be carried out under permit of the Fire Control Officer for the area.

Helms (1893) perhaps made the position somewhat clearer, when he wrote,

"Up to the present time, the mountains have been, so to say, a free country, and anyone who liked took stock up there. This of course will not be so when the country is leased. (Large areas were then being surveyed for leasehold purposes following the Act of Snow Lease Tenure, 1889). A common and, in my opinion, very improvident practice, will probably be continued as hitherto, viz., the constant burning of the forests and scrubs. This proceeding has only a temporarily beneficial effect in regard to the improvement of pasture by the springing up of young grass in the places so cleared, for after a year or two the scrub and underwood spring up more densely than ever . . . I have seen some very detrimental effects from this practice here, because the heavy rains wash the soil away from the steep declivities, and it is either carried into the creeks and rivers and is entirely lost, or it accumulates in the boggy places and thus becomes useless. The more or less constant diminution of humus in the soil of the slopes is a danger not generally recognised".

*Fig. 2.*—The eastern slope of Carruthers Peak (7,042 feet) on the main range, is extensively eroded. All evidence suggests that this damage is due to past grazing practices. This area comprises part of the Guthega catchment area and, in this condition, is a possible flood and sediment source for the small storage at Guthega Dam (Carruthers Peak).

This early interpretation by Helms has been largely substantiated by recent ecological studies. It is of interest therefore, to ponder the amount of damage which occurred during the subsequent sixty years when these same practices were continued. It is significant also that although Helms here drew attention to erosion hazard, he made no reference to any areas that were already seriously eroded at that time, such as may be seen to-day, for example, in the alpine tract in the vicinity of Carruthers Peak and Mt. Twynam. Judged by the accuracy and detail of his reports for that time, Helms' only reason for failing to describe such damage was that it did not exist. As further evidence of this, in 1896 he described Carruthers Peak thus:

> "The apex of the slate formation is reached about 3 miles from Dividing Peak (now Muellers Peak) and rises to nearly 7,000 feet. I have given this peak the name of Slate Peak (now Carruthers Peak). The approach to it is very gradual along the main range and up to its summit. With the exception of a few protruding masses of barren rock, it is covered with vegetation."

As shown in figure 2, vastly different circumstances exist in this area to-day. Such evidence points conclusively to the fact that the erosion damage which causes concern at the present time has occurred within the past fifty or sixty years. Since this damage is the legacy of an unfavourable influence in the environment in preceding years, it follows that, unless the disturbing influence is removed from those lands which are already seriously deteriorated, the end result can only be a rapid extension of erosion hazard and damage.

In spite of such evidence, some still maintain that grazing and burning are not injurious to the catchments and, in some cases,

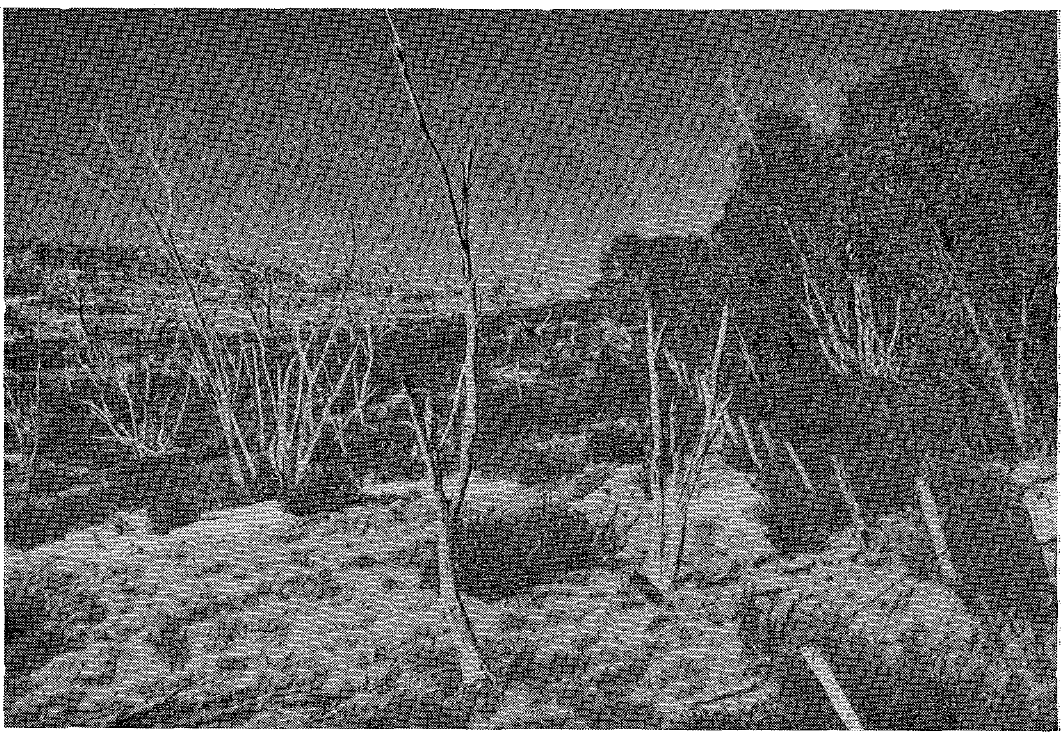

*Fig.* 3.—The whole of this area was burnt during the major fires in 1939. The area to the left of the fence has been grazed since then, whereas the area to the right of the fence has not been grazed (Hotel Kosciusko Water Reserve).

insist that they may even be beneficial. To sustain their arguments they point to damage arising from major bushfires, rabbits, strong winds, snow patch erosion and, latterly, to engineering works. An analysis of these separate factors, however, shows that individually their effects are largely confined within certain limits.

### Fire Damage

Fire scar studies carried out on very old trees in recent years show quite definitely that major fires have become much more frequent since the advent of white man. Although these large fires cause considerable damage, evidence is presented (figure 3) which shows that nature quickly repairs most of the damage, provided other destructive influences are withheld during the period of convalescence.

The early reports referred to above are also valuable in making mention of the fires caused by aboriginal tribes who frequented the area during the summer months in search of "boogongs" or Bogong Moths, which they devoured in great numbers. It was customary to force these insects from their refuge in rock crevices or beneath rock slabs with a burning or smouldering bush and, in so doing, it is apparent that considerable areas of country were occasionally set alight.

There is nothing which suggests that this practice had not occurred for many centuries before the entry of white man, so that arguments which purport to show that these and naturally occurring bushfires are largely responsible for present damage do not stand critical analysis.

In view of the decision by the Government of New South Wales to prohibit grazing in these catchments above the 4,500 feet level as from June, 1958, concern has been expressed that the build-up of fuel in the next few years will present a much greater fire and erosion hazard than the continuance of grazing and controlled burning. This infers that a continuance of grazing and burning will exercise a considerable measure of control in the event of major fires, but, significantly, it leaves unanswered the fact that the disastrous fires of 1939, for example, were not influenced to any great extent by grazing practices which were uncontrolled at that time.

### Snow Patch Erosion

It is often argued that snow patches are a primary cause of accelerated erosion. These snow patches are formed by deep accumulations of snow which occur annually on defined sites on east-facing leeward slopes at higher alpine levels and which persist for at least eight months of the year. Many of the present-day snow patch sites are identifiable with sites mentioned in early reports, and it may be assumed that they have occurred annually to a greater or lesser extent over hundreds or thousands of years.

Whilst erosion undoubtedly occurs on these sites, it is apparent that the natural process of nivation is being confused at the present time with "accelerated nivation" due to other causes.

Because of the severe cold associated with large accumulations of snow and the possible occurrence of freeze-thaw cycles at any time of the year while the supply of moisture remains adequate, the natural process of nivation is most active. Thus the absence of soil on well defined snow patch sites should not be taken to mean that soil has been removed catastrophically during some recent period, but rather that, soil formation has not been possible owing to the lack of essential stability caused by the recurring process of nivation.

Under natural conditions, the small amounts of fine rock and mineral derived from nivation are transported by water from melting snow to the base of the snow patch, where, under more stable conditions and the influence of a constant supply of ice-cold water, snow patch meadow soils supporting a distinctive vegetation of short alpine herbfield are normally developed.

At the present time, it is certain that selective grazing of this palatable snow patch vegetation, and the added effect of stock

*Footnote.—Nivation* refers to the physical weathering of rock fragments by the process of alternate freezing and thawing.

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trampling during the early part of the season when these sites are still very wet, have considerably altered the microtopography and hydrology of many of these sites, thereby initiating accelerated erosion.

There is no evidence to suggest that the natural process of nivation is more severe now than it was in earlier times, or that, of itself it is a primary cause of accelerated erosion. If further evidence is needed, it is found in the fact that snow patch sites make up a very small proportion indeed of the total area which concerns us at the present time.

### Wind Damage

Strong winds, which are a feature of the climate in these elevated lands, are also argued as a major contributory cause of erosion damage.

The ability of high velocity winds to transport soil particles of considerable size, once the protection of the vegetation is lost, is well known and is freely admitted. Yet, despite the probable constancy of strong winds for the past several hundred, or possibly thousands of years, nature has been able to clothe and protect the soil with a highly developed vegetation on all except the most exposed and vulnerable sites.

Again, these typical wind-blown, *fjaeldmark* areas (figure 9) make up an infinitesimally small part of the total area. Hence wind is recognised as a powerful contributory factor in extending erosion damage once the vegetation is destroyed by some other cause, but it cannot be regarded here as a primary cause.

### Animal and Insect Pests

In contrast to the depredations of rabbits in other areas, their effect in these catchments has not been serious. In general, they are limited by climatic environment to below 5,000 feet and their numbers have not reach serious proportions, except on relatively small areas of intensively grazed lands. Since their grazing habits are well known, some damage may be expected wherever they are present, but their effects here cannot be regarded under any circumstances as approaching the widespread devastation caused by burning and the grazing of domestic livestock.

Insect pests are occasionally responsible for damage to the vegetation. Chief among these are the larvae of Case Moths (Psychids) and Swift Moths (Hepialids). The larvae of these moths destroy snow grass by feeding on the plant crowns and leaves and, in the case of severe infestations, large areas may be killed. If these damaged areas are left undisturbed they are normally rehabilitated by secondary succession within a few years, but if burning or subsequent grazing disturbs the litter the areas are left bare and become subject to erosive agencies.

### Engineering Damage

The mountainous terrain and the severe climatic environment of this area, which together furnish the snow and also a considerable head of water, are the bases for the installation and operation of the present hydro-electric scheme. These same forces however, impose many difficulties in conservation.

In providing many miles of new roads and access tracks, transmission lines, aqueducts, reservoirs and camp sites, considerable areas have been opened up and the vegetation disturbed or destroyed. Some of the problems encountered in these works and subsequent remedial measures have been described in greater detail previously (Durham, 1956).

By virtue of the steep terrain, some of this damage, particularly at the outset, is quite spectacular. For this reason it is far more obvious than the general pattern of deterioration over the whole of the area, and hence engineering damage is often argued as being more disastrous than the other insidious forms of deterioration and accelerated erosion.

Under no circumstances could the damage caused by engineering works be overlooked and since the inception of the works, conservation interests have been unanimous in urging that erosion hazard and damage be controlled as soon as possible on the steeply sloping lands in this difficult climatic environment. The Snowy Mountains Authority has given an undertaking that this will be done and already a considerable amount of repair work has been carried out. Although much remains to be done to completely stabilise disturbed areas, it is still a fact that engineering works are confined to about 1 per cent. of the total area and can in no way be held responsible for all other evidence of erosion hazard and damage.

From a survey of early reports on the area, and by analysing arguments put forward in support of grazing, it is thus clear that past grazing practices must be held responsible for most of the deterioration which exists at the present time and that the evidence is overwhelmingly against the continuance of these practices. Subsequent sections in this article enlarge on this evidence and further substantiate it.

## DETERIORATION OF THE VEGETATIVE COVER AND ACCELERATED EROSION

In addition to establishing the reasons for marked changes and damage in the area during the past century, early reports are of added value in illustrating the degree of change which has occurred in the vegetation and the extent of the erosion problem at the present time.

Helms (1893) reported that,

> ". . . on the eastern slopes, they (stock) often find shelter in the high growing patches of *Danthonia robusta*, a grass much liked in spite of its coarseness and which grows tall enough to hide them completely."

Maiden (1898) also commented on the common occurrence of this species, stating that it was to be found "on the plains close to the summit and for a thousand or two feet below". Following intensive ecological surveys, Costin (1954) found that by 1946 the distribution of this species was confined to steep slopes and rocky situations inaccessible to stock.

Maiden also listed the occurrence of the grass *Hemarthria compressa* and it was again recorded in 1927 by McLuckie and Petrie as being "common" in the Kosciusko area. Again, however, Costin found that by 1946 at the very latest, this species had virtually disappeared. A number of other palatable herbs were also recorded as having been reduced from co-dominant status to the stage where they occurred only as minor associates with the snow grass (*Poa caespitosa*).

One effect of grazing has been therefore, a reduction in the occurrence of the more palatable grass and herb species, resulting in the increasing dominance of the rather unpalatable snow grass. Snow grass includes several distinct forms, some of which are occasionally grazed, but the most widespread form is the least attractive and generally it is not grazed except in the seedhead stage or unless stock are particularly hungry.

Although a highly valuable species in catchment protection, the increasing dominance of snow grass led to the regular burning of the coarse, dry tussock to promote a palatable spring growth and to induce the the growth of more palatable herb species in the inter-tussock spaces.

Under this system the requirements for grazing and catchment protection are thus incompatible.

The same practices have resulted in marked changes in the woodlands over the greater part of the sub-alpine tract. On the steeper slopes, these areas were originally relatively open communities of snow gum (*Eucalyptus niphophila*) having in the main a carpet-like floor vegetation of snow grass, with various shrub and bog communities occupying the freely-drained rocky situations and the wetter valley sites respectively.

Burning, to convert these areas to open grassland, seldom had the desired effect. Grass which grows immediately after burning is soon invaded by shrub communities acting as pioneer species for a secondary snow gum community. In this condition, these areas are less attractive and accessible to stock and periodic burning was employed to remove this recurring shrub growth. Had the ultimate objective of an attractive open grassland been readily attained, it is probable that little damage would have resulted from the initial fires, but the fact that areas were burnt again and again, and heavily grazed at the same time, initiated far-reaching changes that seriously disturbed the natural balance built up over great periods of time.

The rapidity with which these changes could occur was clearly outlined by Byles (1932). Following a survey of the mountainous part of the River Murray catchment in New South Wales, he recorded the statements of stockmen who had worked on certain snow leases at the time of their occupation about 1900, that "their first job was to burn and keep on burning the woody shrubs and snow gums," and that the country "is definitely drier now than it was thirty years ago." From the same source it was reported that swamps which had formerly been so wet that "once a horse put his hoof off a tussock of grass it would sink up to its belly in the swamp; now in an average summer a bullock dray can be taken across the former swamps and not sink more than a few inches." Again and again, swamps and creeks were pointed out which were formerly impassable but where a man could now ride without any fear of sinking. All this, in the short space of three decades.

Of the forests, Byles stated "... a degredation process started a long time ago, . . . has in certain areas, reached the stage where Ash (*Euc. gigantea*) trees have completely disappeared and erosion has started in the soft, deep granite soils." He warned that the velocity of this process of degredation "increases in geometrical proportion and will be far and away greater in the next twenty years than it has been in the past twenty years.

In total then, the constant diminution of palatable species by grazing; the gradual reduction in effective surface cover and desiccation of swamps as a result of grazing and burning; and the constant depletion of soil humus and surface litter by burning, have all combined to reduce the protection afforded by the original vegetation, thus initiating accelerated erosion and disturbing stream hydrology.

The fact that only relatively confined areas are, so far, seriously eroded allows no cause for complacency. Accelerated erosion is a dynamic force and from the unobtrusive beginnings of a depleted vegetative cover and the insidious form of sheet erosion, it is normally only a matter of years until gullying or destruction of the whole soil mantle becomes apparent and deposition of erosional debris begins at lower levels.

It is characteristic of these mountain catchments, however, that in most cases, the valleys are fairly broad and relatively flat and it is apparent that for some considerable time, increased run-off and eroded material is withheld by the dense vegetation in these broad valleys. Because of this and because advanced stages of siltation are generally looked for in assessing damage, there has arisen a popular assumption that siltation of streams and reservoirs is not likely to become a problem.

It is most unlikely, however, that this position can obtain for all time. Already, entrenched streams, deposition of sand and gravel, a tendency towards single streamline formation through bogs, humification and erosion of bog peat, and significant siltation in at least one case, all convey clear evidence that stream hydrology has been seriously disturbed in many cases.

Of some of the more seriously damaged areas, it can already be said that, so far as natural rehabilitation is concerned, they have passed "the point of no return." Rehabilitation in such cases, will depend on the success of artificial means of control to help the system attain equilibrium at a new level.

Since all these trends reflect symptoms quite similar to those observed elsewhere if the vegetation is destroyed on sloping land, conservationists accept the circumstances here as due to radically altered conditions in the higher parts of the catchments. Restoration of these higher lands by whatever means available and maintenance of a closed vegetative cover as protection against erosion are therefore necessary first steps towards solution of the whole problem.

## THE EROSION PROCESS

In the broadest sense, erosion may be considered in two classes:—

(*a*) Geologic erosion.

(*b*) Accelerated erosion.

Geologic erosion occurs at all times and is a natural process whereby wind, water and gravity remove rock fragments and soil particles from part of the earth's surface and deposit them in another. Many of the land forms recognised today have been derived in this way.

An essential characteristic of geologic erosion, is that the process occurs in equilibrium with all other factors of the environment. Whilst climate, topography and vegetation thus influence the rate of soil loss by geologic erosion they also influence the rate at which soil is formed, so that a balance or equilibrium is reached where soil cover remains constant.

Accelerated erosion, on the other hand, occurs when this equilibrium is disturbed and results in soil being destroyed much faster than it is formed. Usually this disturbance is brought about by the partial or complete destruction of the vegetative cover as a result of unfavourable human interference. Many other influences may also work to disturb this equilibrium. The alteration of the drainage pattern by stock pads, tracks and roads is a frequent cause of erosion in these catchments.

*Fig.* 4.—Normal or geological erosion occurs on all land surfaces as a natural process. Despite the steepness of these slopes they are relatively stable and partly covered by vegetation (Watsons Crags).

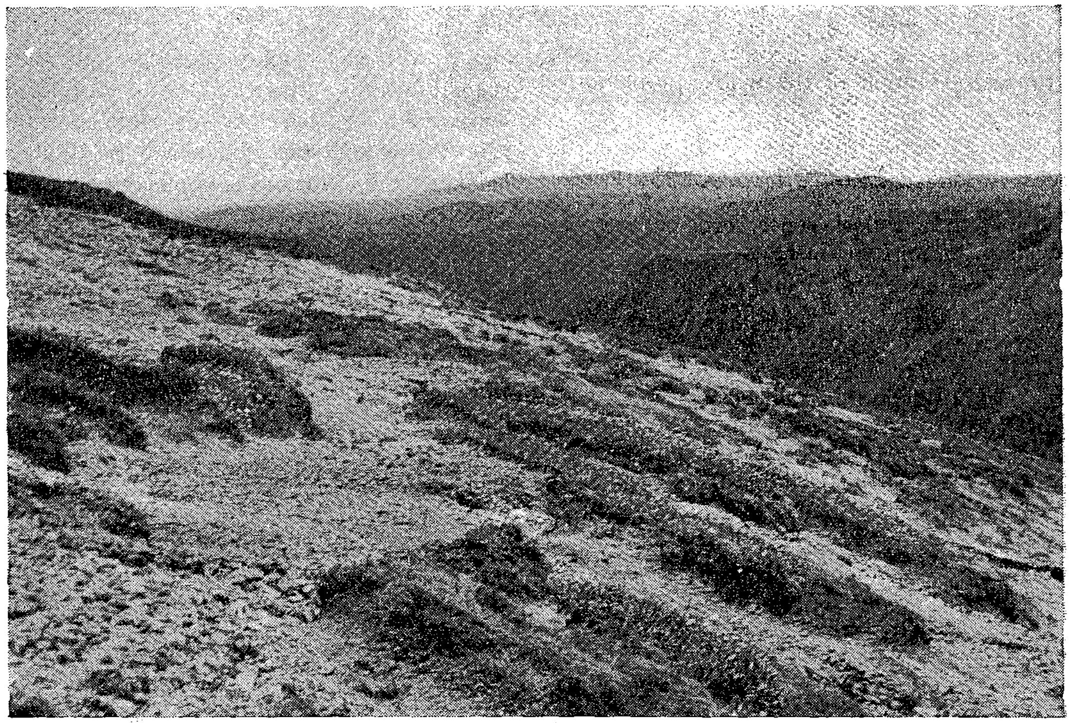


*Fig.* 5.—By contrast with figure 4 the lesser slope in the foreground is severely damaged by accelerated erosion since it is accessible to stock and has been heavily grazed (Carruthers Peak).

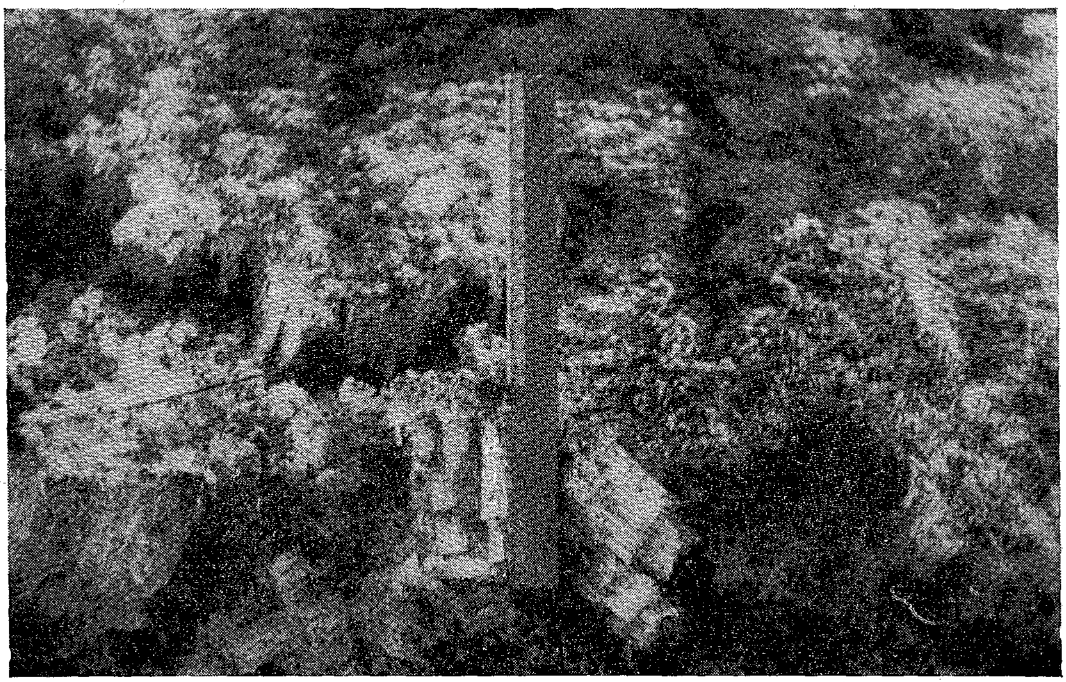


*Fig.* 6.—The formation of massive needle-ice such as this constantly pulverises the soil. The loose soil is then readily removed by wind, water or gravity (Kosciusko).

Wind and water are the principal agencies acting on the land surface to remove soil material. Other agencies also become important in localised areas—alternate freezing and thawing and the production of needle ice are examples of such agencies operating in very cold climates. While the land surface has a protective covering of vegetation, these agencies are unable to operate. It is only when the cover of vegetation is removed or depleted, and the delicate equilibrium in the environment thus destroyed, that erosion is able to take its toll of the soil.

The predisposing causes of frost activity and ice formation are low temperatures, bare soil surface and a soil of high water-holding capacity or one that is not freely drained. A number of different types of ice formations occur, but the most common form here is the needle-ice crystal. These grow out from a bare soil surface, commonly to lengths of 1 to 2 inches (figure 6), and are often bound together in masses in a honeycomb structure.

The effect of this needle-ice formation is to continually pulverise and desiccate the soil so that it is readily removed by wind, water or gravity. The force exerted by these needles is considerable (figure 7) and the effect on bare soil and adjacent vegetation is most severe. Young seedlings and sections of older plants are prised from the soil, plant roots are severed, and soil is continually removed from around the base of the plant.

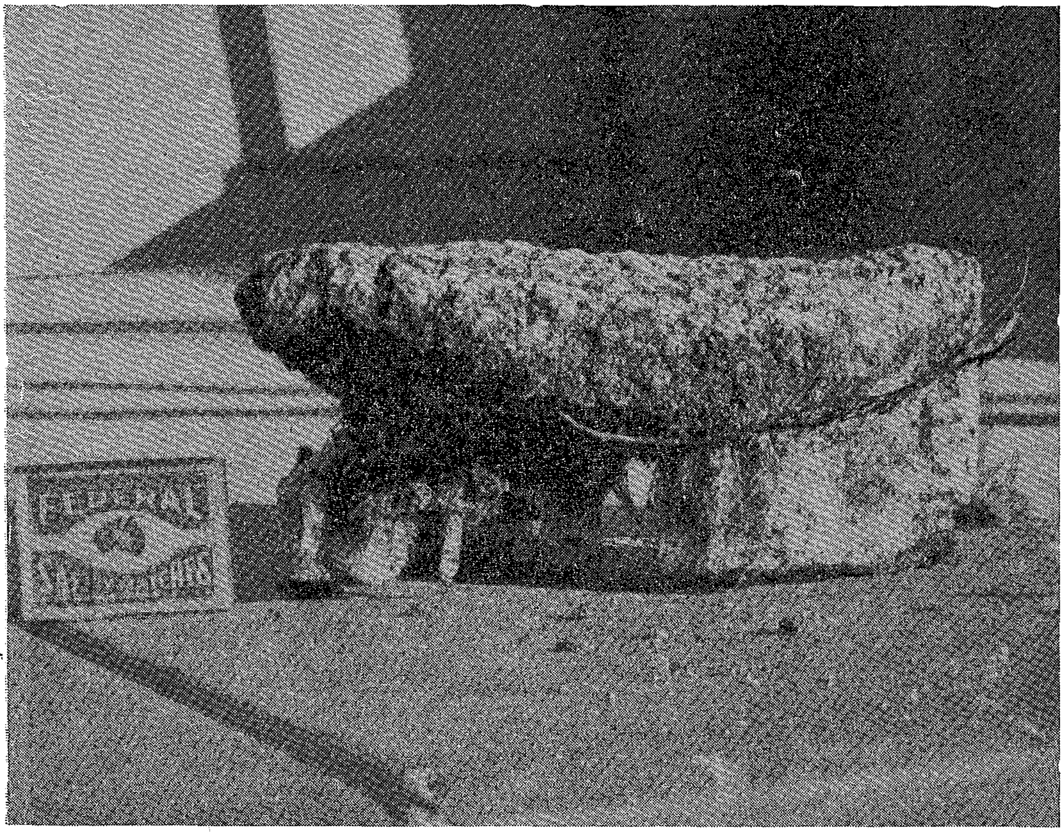


*Fig. 7.*—The force exerted by the growth of these needle-ice crystals was sufficient to raise this stone from the soil surface. The effect of such forces on young seedlings and exposed roots is most severe. (Photo., D. Kerr.)

In combination with wind and water, frost is thus a powerful contributory factor in soil loss and further depletion of the vegetation once the vegetative cover is reduced or opened up.

High velocity winds are a feature of the climate and, where the protection of vegetation is lost, soil particles and pebbles up to half an inch in diameter are readily moved by the wind (figure 8). The finer soil particles are transported by the wind and deposited elsewhere. The heavier particles move by a process of creep or saltation and their main effect is in bombarding adjacent vegetation and in dislodging further soil from denuded areas. In this way depleted areas suffer further damage due to soil loss, burial of vegetation and mechanical damage to plants and their root systems.

Water erodes and transports soil particles by raindrop splash, surface flow and stream flow. Water erosion is now active throughout these catchments and, except for isolated cases of gullying where extensive damage to the vegetation and the soil mantle is evident, sheet erosion is the most widespread form.

Since the rate of soil removal by sheeting may be almost imperceptible, there is a fairly prevalent notion that it presents no problem. Nothing could be further from the truth, for conditions often arise where soil removal becomes very rapid. The constant removal of soil, however slow, from higher to lower regions, means that soil is being lost from those higher areas. Almost invariably, this means that the soil level next to individual plants is being lowered

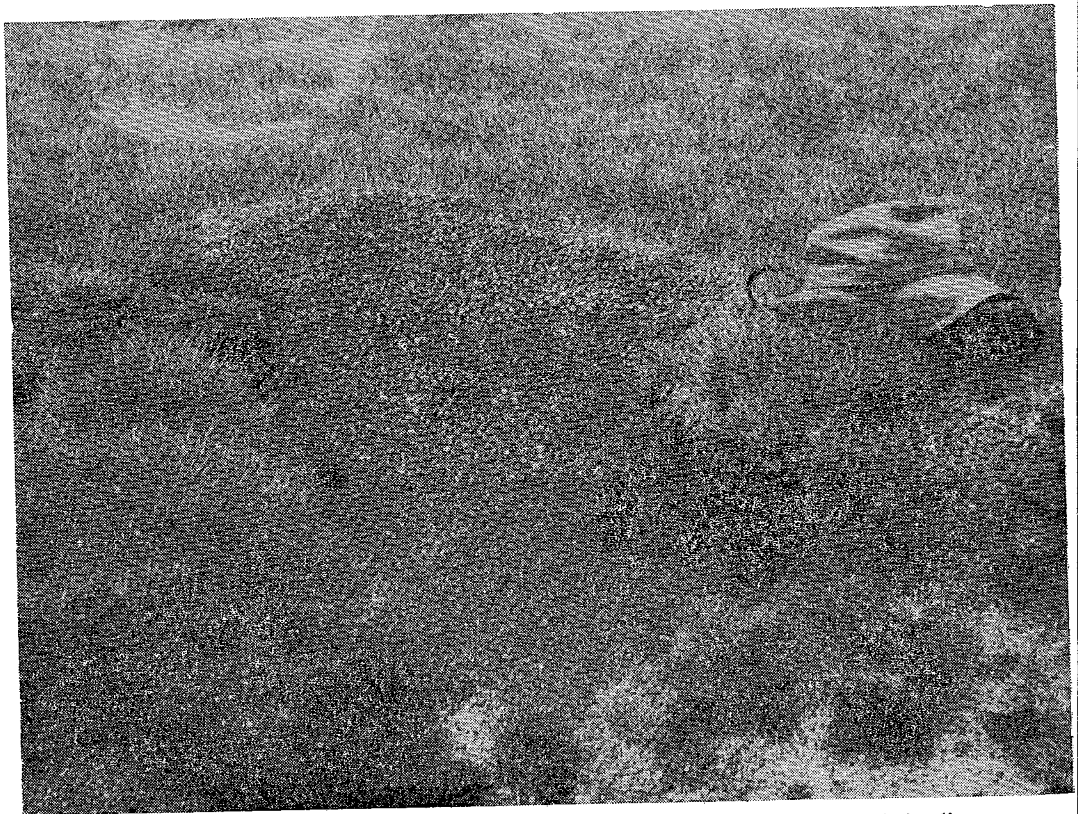


*Fig.* 8.—High velocity winds move soil particles and pebbles up to half an inch in diameter. The bombarding effect of these pebbles dislodges further soil and damages the vegetation by exposing and severing roots (Carruthers Peak—Mt. Twynam). (Photo. A. Costin.)

and consequently, the micro-climate becomes drier, plant roots are exposed and the conditions for plant survival and regeneration become much more critical.

If soil is being moved, it means also that there is sufficient run-off, or that run-off velocity is high enough, to transport that soil. The cumulative effect of this increased run-off then exerts greater pressure on the drainage system at lower levels. Almost without exception, the broad valley bottoms in these mountains, which were formerly bogs or swamp-like in character, have been damaged by burning, grazing, and stock trampling. As a result, water flow has been channelled into single streamlines and in times of heavy run-off, these streams now carry much of the flow which was formerly distributed in a broad shallow flow over the valley floor.

Active stream bank erosion is now taking place along most of these meandering channels. In relation to the size of these small streams, the amount of soil which is being lost due to undermining and slumping of the banks, shows every indication of being proportional to soil losses which occur from the flats adjacent to some of our major creeks and rivers. Since both these instances reflect a degrading process in the catchment system, they should be regarded as equally serious.

Based on the main features described in this process, a series of photographs (figures 11A-11*i*) are included to illustrate more clearly the recognised stages in depletion of the vegetation and ultimate loss of the soil mantle. This particular series demonstrates damage in sod-tussock grassland and while the details may vary for other vegetation units, the fundamental principles remain the same.

*Fig.* 9.—A typical fjaeldmark community of ground-hugging shrubs which occupy the windswept cols along the main range at about 7,000 feet elevation. It is unlikely that soil has ever been formed on these exposed situations (Mt. Lee—Carruthers Peak).

While the vegetation affords protection to the soil there is no problem (figure 11A). When the vegetation is damaged and erosive forces begin to act on the unprotected soil, a chain reaction involving alteration of the micro-climate, death of the vegetation and soil loss is set in motion. In the final stages (figure 11*i*), infiltration capacity is greatly reduced, excess run-off occurs, and erosion debris is transported to lower levels. If the damage is widespread, significant changes will be reflected in the stream hydrology of the whole area.

## THE SIGNIFICANCE OF LAND DETERIORATION

The real significance of land deterioration is readily found in a comparison of the great length of time needed for the development of a soil mantle and the rapidity with which it may be destroyed by exploitative land practices. All estimates of the rate of soil formation are that it is extremely slow. On the other hand, evidence of serious soil loss and wastage within the the space of a few years, or even in a matter of hours in extreme cases, is all too readily observable.

A statement by Chamberlin (1908) regarding the rate of soil formation is very appropriate here, despite the intervening years, and is reproduced in part below.

> "We have as yet no accurate measure of the rate of soil production. We merely know that it is very slow . . . Without any pretensions to a close estimate, I should be unwilling to name a mean rate of soil formation greater than 1 foot in 10,000 years on the basis of observation since the glacial period. I suspect that if we could positively determine the time taken in the

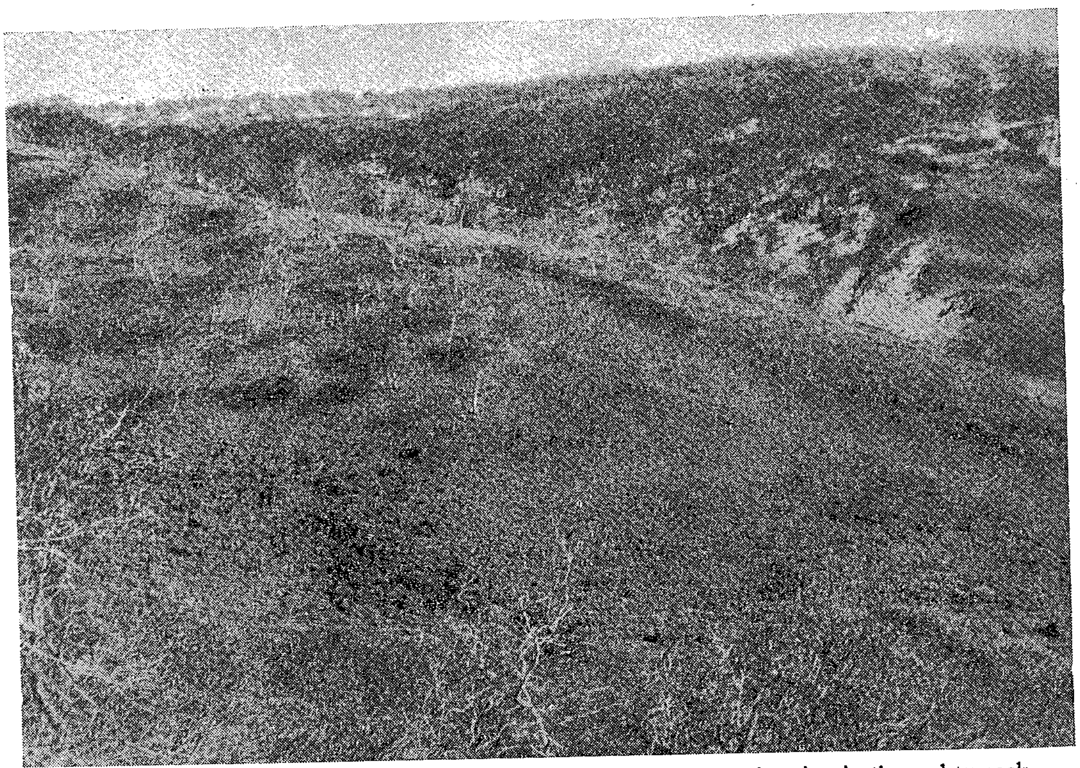


*Fig.* 10.—This slope in the subalpine tract is showing serious deterioration in the sod-tussock grassland community. The depleted surface cover permits rapid soil loss due to frost, wind and water action (Kiandra).

formation of the 4 feet of soil next to the rock over our average domain, where such depth obtains, it would be found above rather than below 40,000 years. Under such an estimate, to preserve a good working depth, surface wastage should not exceed some such rate as 1 inch in a thousand years. . . . It must be noted that more than loss of fertility is here menaced. It is the loss of the soil body itself, a loss almost beyond repair. When our soils are gone, we too must go, unless we shall find some way to feed on raw rock or its equivalent. . . ."

Since geologists estimate that the last glaciation of the Kosciusko area occurred some 10-20,000 years ago, there is good correlation between the estimates given by Chamberlin and the average depth of 1 to 2 feet of top-soil over the higher parts of these catchments. Over the whole area however, the rate of soil wastage appears far in excess of the desirable 1 inch per thousand years.

What then are the reasons for land deterioration and how does it begin? The answers to this question vary in detail according to the area being considered and the type of land use which has been imposed, but again the fundamental principles remain the same. In any discussion concerning deterioration of the land however, the fact of paramount importance is that soil is our basic resource. If it is being destroyed as a result of land use methods imposed during our time, we are clearly failing in our duty as custodians of a natural heritage.

### *Nature as a Complex*

As the result of our increasing knowledge of plant and animal ecology, of the relationship of organisms to each other and to the factors of their environment, it is now possible, if not essential, to look on nature as a single system or complex. It is thus recognised that this complex is comprised of numerous factors so closely inter-related that what affects one affects all. For convenience these factors may be grouped as animals, plants, soil, climate and topography.

Historical evidence and experience the world over, as attested by accelerated soil erosion and abandonment of the land, has shown that it is impossible to disrupt the balance between these factors with impunity. A knowledge of the mutual dependence of the plants, the animals and the soil in any particular climatic environment is thus essential to a correct understanding of the significance of land deterioration and accelerated erosion.

### *Primary Succession*

The development of any natural land system occurs by primary succession and begins with the invasion of vegetation on bare areas not formerly occupied by plants. From the earliest and rudimentary stages, it proceeds by orderly successional change and continues by normal development of vegetation and soil towards a climax or mature state determined largely by climate.

An example of the initial stages in primary succession, as the result of the invasion of vegetation on a steep talus slope is shown in figure 12. A later stage in the succession on a similar slope, as indicated by the presence of some soil and the stabilising of the slope by vegetation, is shown in figure 13.

In the earliest stages, the complex, or system, is relatively simple. There is little or no soil. The vegetation is represented only by the lower forms of plant life such as lichens and mosses. Animal life is limited.

By degrees however, and as the centuries pass, small amounts of soil formed by the decay of pioneer plants, or washed or blown in from elsewhere, accumulate between the rock fragments. Under the influence of physical and chemical weathering, small rock fragments break down into finer particles, and so the gradual accretion of soil material makes possible the growth of larger plants. In turn, these larger plants, the grasses, shrubs and trees, return greater amounts of litter and humus to the soil and more successfully anchor it against the agencies of erosion.

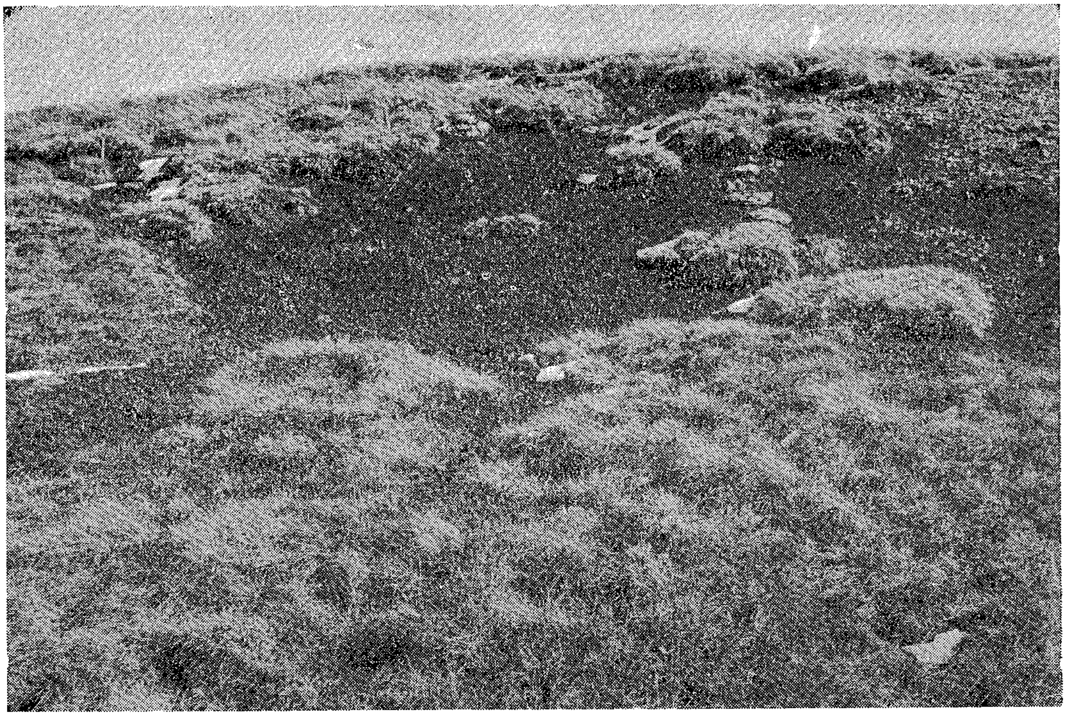


*Fig.* 11.—An advanced stage in the destructive process of accelerated erosion following death and removal of the vegetative cover. The successive stages leading to this condition are shown in figures 11A-I (Kiandra).

At the same time changes take place in the animal kingdom. The larger plants provide a more suitable habitat and increased food supply for greater numbers and larger animals. The plant species on which they feed suffer greater competition and may die out or be replaced by non-edible species. Fluctuations thus occur in the animal population as a result of increased or depleted food reserves, or perhaps as a result of disease or increased predator attack. And so these changes continue, with vegetation influencing soil development; local microclimate being modified by increased vegetation and, in turn, influencing animal distribution; topographic features such as aspect and drainage determining soil type, and so on. The important point, however, is that these changes are always gradual and always working towards maintenance of an equilibrium between all the factors involved.

This essential stability or balance in the complex must pertain at all times, for how else could deep soils develop and steep mountain slopes become clothed in vegetation? The steeper the slope, the more certain it is that soil and vegetation developed concurrently and interdependently. Proof of this resides in the fact that if the vegetation is removed the soil erodes rapidly.

Had he understood all this, white man's reaction on seeing these mountain lands for the first time should therefore have been, that here was a land system which had taken many thousands of years to develop and which was now in harmony with its harsh climatic environment. The fact that he failed to do so, as, indeed, he failed in almost all Australian environments, has meant far-reaching changes in the stability of the land. By introducing his domestic animals, of different feeding habits and in greater numbers than the native fauna, man has completely disrupted the balance set up by slow evolution under natural conditions. In conjunction with heavy grazing in these mountains, he also attacked and destroyed the vegetation by burning.

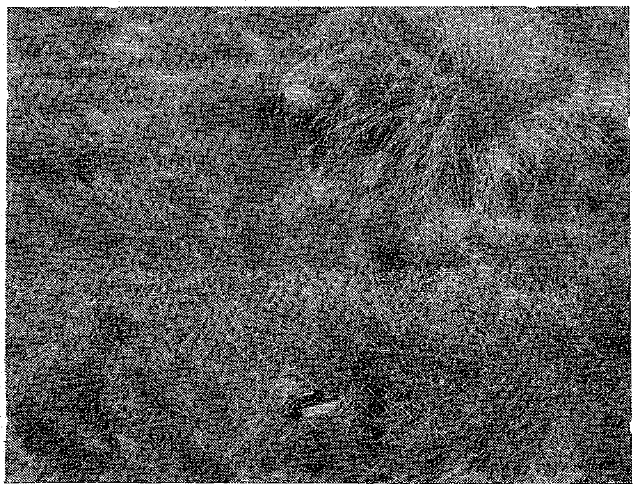


*Fig.* 11A.—A localised area of sod-tussock grassland in good condition, adjacent the area in figure 11. Surface cover is complete, but the vegetation is not particularly attractive to stock for grazing

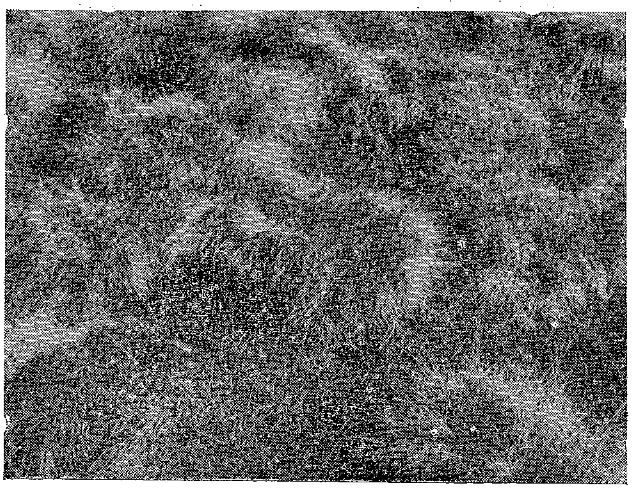


*Fig.* 11B.—An early stage in deterioration. The inter-tussock spaces have been enlarged and are being heavily grazed. The constant depletion of these herbaceous mat plants permits increased activity by frost and other erosive agencies.

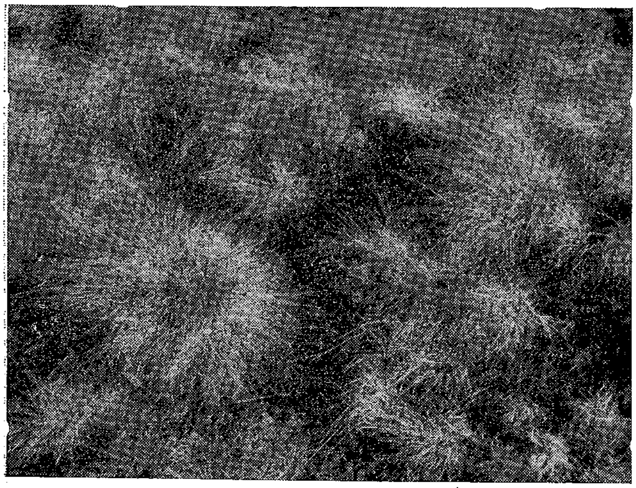


*Fig.* 11C.—Further depletion of the inter-tussock vegetation initiates soil loss. Here, soil loss has proceeded to the stage where the individual tussocks are becoming pedestalled, roots are exposed and the micro-climate is becoming drier due to a lowered ground water table.

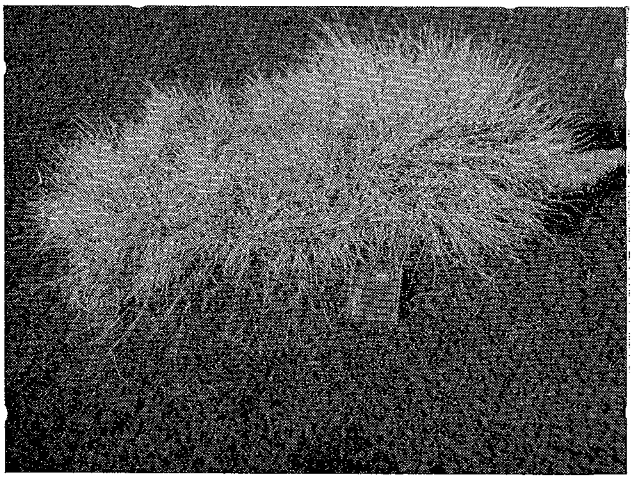


*Fig.* IID.—As individual tussocks become isolated, their chances of survival are remote. The adjacent bare area is constantly desiccated by frost action and the tussock is undermined to expose more of the root system.

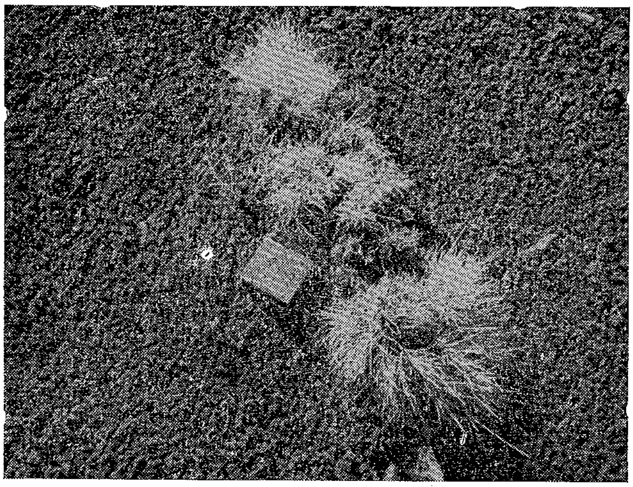


*Fig.* IIE.—Condemned to death, the tussock begins to disintegrate. As a result the bare areas become larger and the adjacent vegetation is further exposed and isolated.

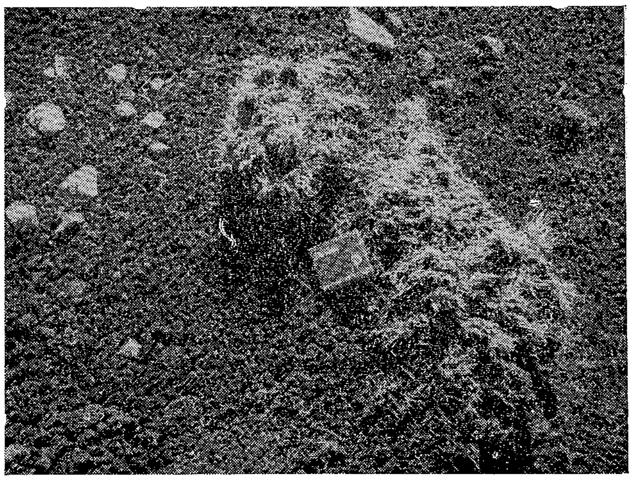
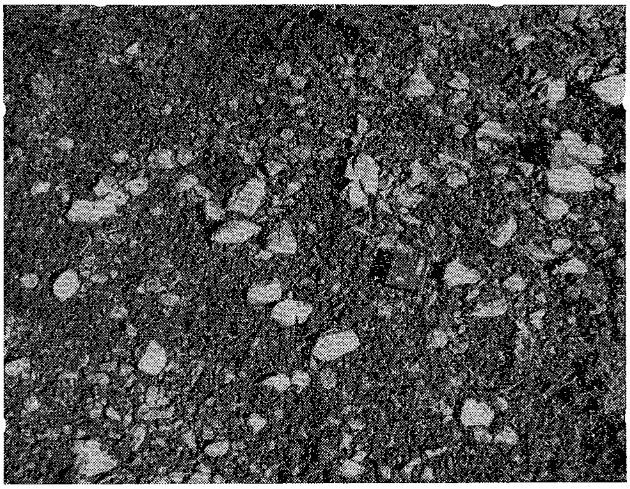


*Fig.* IIF.—The unequal contest of a single plant against the combined agencies of erosion is almost over and the death of this tussock is clearly in sight. At the same time, continued soil loss on the bare areas has exposed the gravel layer below the soil mantle.

*Fig.* 11G.—All that remains of a once healthy tussock—a small mound of soil and the basal remnants of the plant.

*Fig.* 11H.—With the vegetative cover gone, erosion proceeds at a rapid rate destroying the soil mantle and exposing a gravel erosion pavement.



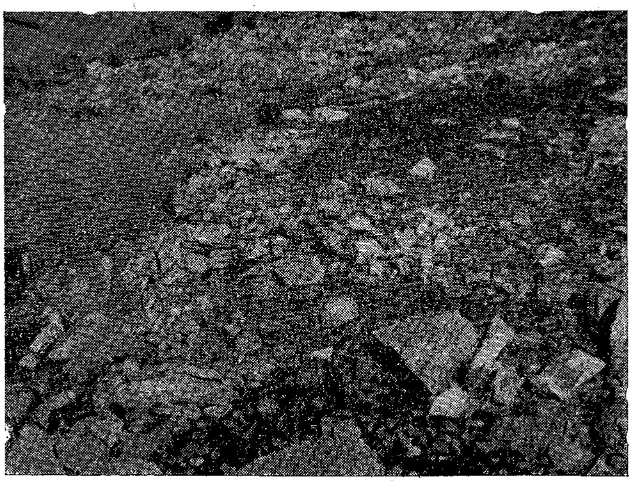


*Fig.* 11*i*.—With the vegetation and most of the soil gone, run-off proceeds unchecked and now carries soil and erosional debris downslope. Vegetation is buried and the continuity of stream flow is threatened at lower levels if this condition is sufficiently widespread.

*Fig.* 12.—An early stage in the primary successional process as shown by the invasion of vegetation on a steep talus slope (Happy Jack's River).

*Fig.* 13.—An adjacent scree slope, exposed by a road cutting, on which the successional process has advanced to a much later stage. Some soil has been developed and the slope was formerly stabilised by vegetation (Happy Jack's River).

Such changes are violent and unlike the gradual changes which occur during orderly primary succession, and they have not been absorbed by gradual modification of the system as a whole. The existence of accelerated erosion, as a result of this disturbance, is evidence of disintegration between the components of the environment and indicates that stresses of greater magnitude than those normally applying have been placed upon the environment in recent times.

It is thus necessary to distinguish between primary succession, which originates and proceeds independently of man, and secondary succession or other drastic changes which occur as a result of human intervention.

*Secondary Succession*

Secondary succession may be caused by any influence which completely or partially disturbs the original vegetation, such as fire, grazing, cultivation or engineering works. Depending on the degree of disturbance to the original vegetation, it may involve the reinvasion of vegetation on bared areas or consist merely of successive changes in the vegetation as marked by the elimination of certain species and their replacement by others.

Like primary succession, it occurs by orderly successional change and if the environment is freed of human interference, or other disturbance such as fire, the secondary changes normally become submerged in the primary successional process and the vegetation again moves towards the climax, as does the system as a whole.

Secondary succession, however, differs in two main respects from primary succession. The first of these is time. Primary succession involves the development of a soil mantle and the creation of a land system in

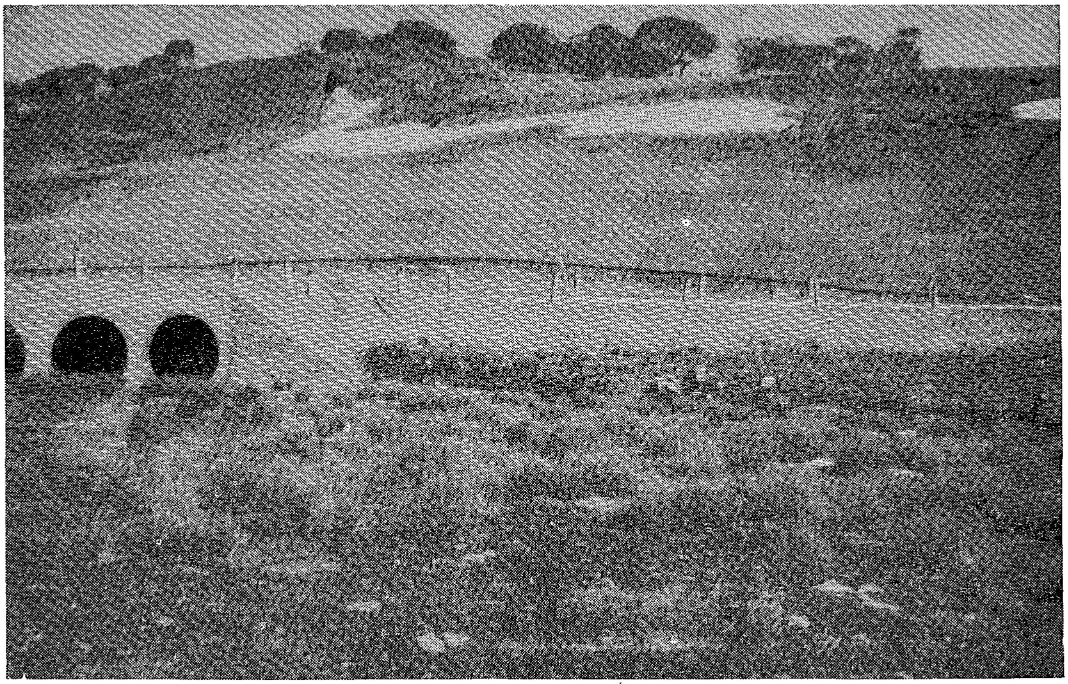


*Fig.* 14.—The area in the foreground has been disturbed by road construction and has been reinvaded by a secondary community of shrub species. The original grassland shows in the background.

which all the natural factors of the environment play a part. Time in this instance is probably to be reckoned in thousands of years. Secondary succession, on the other hand, taking place where soil is already in existence, is relatively rapid. Depending on the degree of disturbance, significant changes may therefore be recognised in a few years.

The second important difference is that, whereas primary succession normally follows a set pattern determined by the natural factors of the environment, secondary succession may follow a number of courses depending on the type of disturbance or the pressure applied. Change which takes place in the vegetation as a result of grazing, for example, may therefore be either desirable or undesirable for subsequent grazing. Under favourable circumstances, management can direct these changes for the betterment of grazing, or to accomplish other particular purposes, by controlling the type of grazing animal, the length of the grazing period or perhaps by deferring grazing until the most valuable species has set seed.

If based on exploitation, however, as grazing practices in the mountains have been, problems usually arise in subsequent grazing and, more often than not, the whole problem becomes manifest in a serious threat to the stability of the land. As already mentioned, changes in this area have been marked by a reduction in the occurrence of palatable species and the increased dominance of unpalatable ones. The remaining palatable species therefore suffer greater utilisation. Other areas, subjected to greater disturbance, have been invaded by woody perennials which required regular burning to allow of easier access for stock and to provide better grazing. Herbaceous and mat-forming plants which invade bared areas following damage in the grasslands and woodlands, and which represent an early stage in the secondary successional process, now provide the bulk of the grazing available in the mountains. Hence the incompatibility of recent grazing practices and the essential requirements for stability in the catchments.

Despite these two main differences between primary and secondary succession, namely, time and the existence of soil, there is still a similarity between them in that the changes which occur in both are orderly and vegetative control of the soil surface is maintained. If the disturbance which initiates secondary succession allows of some soil loss, normally the vegetation increases rapidly and soon regains control of the soil surface.

Secondary succession, however, does not include these changes if the vegetation is unable to regain control of the soil surface and they are accompanied by accelerated erosion. To describe the changes which take place when vegetative control of the soil surface is lost, Ellison (1949) used the term destructive change, stating that such " . . changes are no longer evolutionary, but revolutionary in character".

*Destructive Change*

Since the existence of a well-developed soil mantle is evidence of the successful integration of all the factors of the environment, accelerated erosion, which rapidly destroys that soil and which occurs as the result of some drastic change within the environment, must indicate degeneration.

Almost without exception, the changes responsible for accelerated erosion are imposed by man, violent fluctuations in climate or the other factors of the environment being abnormal. The presence of deep soils alone proves this, or at least indicates that stability has reigned in the environment for the greater part of the time. To have soil developed at all, the rate of soil formation must at least equal its rate of loss due to normal erosion.

Evidence of serious soil loss in these catchments within the past fifty or sixty years can only mean therefore that excessive pressure has been applied to the vegetation before and during that time and that man's use of these mountain lands has been exploitative. With the whole of the soil gone from some areas there is little that can now be done about it, for its replacement will certainly not be achieved by natural means for many thousands of years

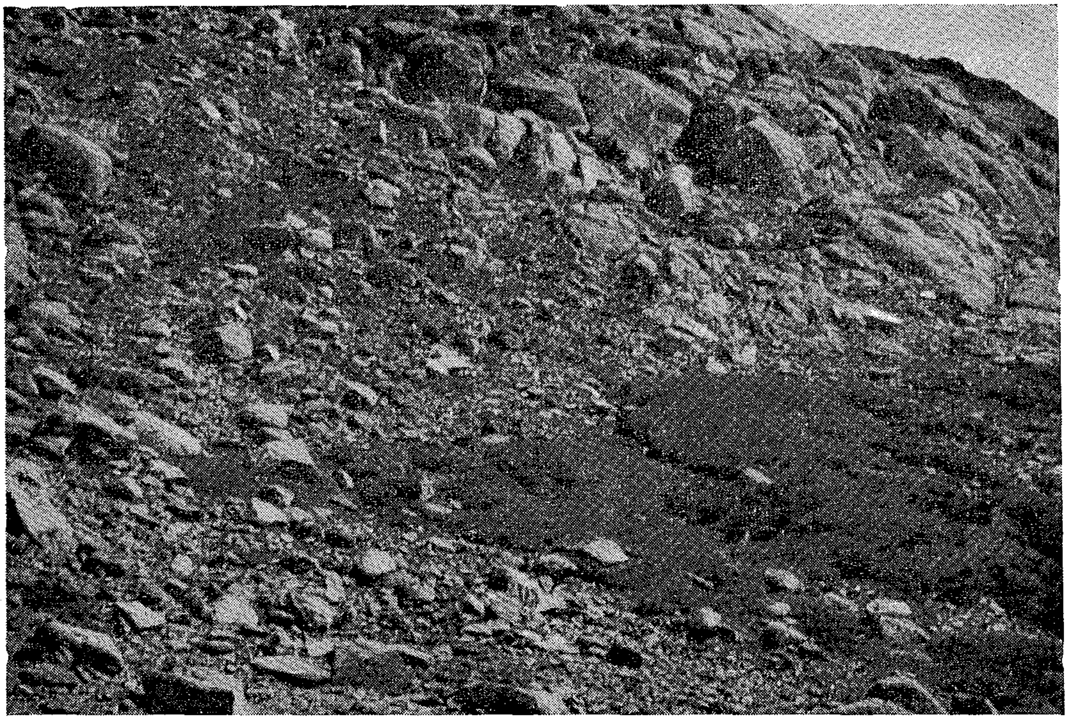


*Fig.* 15.—Destructive change is indicated on this slope by the fact that a snow patch meadow soil, developed under finely balanced conditions, is now being destroyed by erosion. Soil remnants occur in places in the left background (Perisher Range).

The problem now is to stabilise these areas by artificial means and to prevent further loss of soil from adjacent areas.

The real problem with accelerated erosion is that, in most instances, it is not recognised early enough. By the time whole areas are incised with deep gullies or the complete soil mantle is threatened with destruction, the signs are abundantly clear. The early stages of erosion, however, may still be very rapid and yet remain unrecognised.

The reason for this is simply that the untrained observer does not appreciate the principles involved in soil formation and that when accelerated eroson is taking place soil is being destroyed. Nor does he realise that the earliest stages of deterioration may be marked by certain signs or indicators in the vegetation and the soil, which show quite definitely that undesirable changes are overtaking the environment and that if allowed to continue, the end-point of these changes will undoubtedly be serious erosion hazard and damage.

Throughout these catchments, there are a number of such indicators which distinguish both early and late stages in the erosion process. Many of them may be readily observed during the course of field inspection, and it is intended in Part II to describe these indicators in detail, so that their significance in the erosion process may be recognised and appreciated.

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(*To be continued.*)

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