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FOREWORD

BY

E. S. CLAYTON, H.D.A., Commissioner.

THE expanding interest of land owners in soil conservation is causing them to seek more information on this comparatively new subject. There is now a definite trend in New South Wales towards conservation farming. Increasing interest is developing among farmers in the work being carried out on the Soil Conservation Stations.

In order to further assist land owners, the Service is commencing a scheme to use visual education methods at the Soil Conservation Stations throughout the country. We have a specially selected number of documentary films depicting in attractive form the principles and practice of soil conservation. Case histories of wise and unwise land use and farming methods on many different types of country are included. Both American and local Australian films are being used.

It is felt that these films, which present highly educational material in an attractive manner, will interest and instruct both adult and youth. In that way they will impart a further understanding of the land and its needs. Also, with the discussions that will follow these screenings there will be an interesting and useful exchange of ideas and experiences between farmer and farmer, and farmer and soil conservation officer, with inspections of practical soil conserving measures in the field both on the Station and on the co-operating private properties. The details of a practical pattern for conservation farming will gradually be evolved to suit particular needs of local districts.

It is thought that the provision of this additional educational facility in the form of documentary films at our Stations will be a useful addition to the main field activities of the S.C.S. on private lands.

To have problems visually presented showing what the other fellow is doing is an important stimulus. Improvements in soil conservation methods and techniques are constantly being achieved. They come from the close association of the soil conservation officers (both research and operational) and the farmer. The ingenuity and inventiveness of the country Australian is frequently responsible for important advances in knowledge and improvement in technique.

It is this harmonious co-operation between the Soil Conservation Service and the land user in New South Wales that is resulting in the rapid spread of what can be called "conservation farming." The prospect of achieving widespread and effective erosion mitigation is now very much brighter than it was a few years ago. If conservation farming continues to develop so that the farming and grazing lands of the State are used with an appreciative understanding of their requirements, their limitations and their potentialities, they will richly reward the good husbandry bestowed on them. The reward will be not only in immediate economy of production but the State-wide erosion threatening the very existence of our soil, and of course ourselves, will have been brought under control.

VEGETATION SURVEY OF THE MARINE SAND DRIFTS OF NEW SOUTH WALES

SOME REMARKS ON USEFUL STABILISING SPECIES

BY

G. W. MORT, H.D.A., Soil Conservationist.

PART 11.

IN an article published in the Journal of the Soil Conservation Service, Volume 5, Number 2, April, 1949, a detailed survey was made of the plant species occurring on the littoral sand drifts of New South Wales.

These were tabulated according to habit of growth, the climatic regions in which they occur, and finally to the successive zones of colonisation in which they appear to thrive.

In succeeding articles it is intended to describe in detail some of the more important sand-stilling species which constitute the basis of sand stabilisation procedure recommended by the Soil Conservation Service.

Recommendations embodied in these articles are the outcome of extensive study of the habits and characteristics of these species under the varying environmental conditions existing along the New South Wales seaboard.

These investigations, however, are by no means complete, but recommendations contained herein will provide a sound basis on which any stabilisation programme can be initiated.

MARRAM GRASS—*Ammophila arenaria (L.) Link.*

(Greek—ammos, sand; philos, loving.)

Synonyms and Vernacular Names.

Arundo arenaria L. (1753); *Calamagrostis arenaria* Roth (1788); *Ammophila arundinacea Host* (1809); *Psamma littoralis* Beauv. (1812); *Psamma arenaria* Roem and Schutt (1817); *Phalaris ammophila* Link (1821); *Arundo littoralis* Beauv (1840).

The name marram or murram is supposed to be derived from the Gaelic muram or the Danish marhalm meaning sea straw, but due to the world-wide distribution of this grass several other vernacular names have been given it from time to time, some of which are in regular use to-day. In America it is known as European Beach Grass; in France Gourbet or Oyat des Côtes du Nord; in Denmark Klittelag; in Holland Helm, and in the British Isles where a considerable amount of marram planting has been carried out for centuries it is known as bent, sea bent or starr grass. It is also known in some parts as sea matweed or matgrass.

Distribution.

Although a native of the Atlantic seaboard of Europe, this grass is now widely known throughout the world as a sand-binding or more correctly as a sand-stilling plant, and has been planted as such, both by seed and roots. Extensive plantings have been carried out in all the coastal areas of Europe and Britain, and in recent years trials have been carried out in the United States of America, South Africa, Palestine, New Zealand, Tasmania, and Australia.

It is not known accurately when marram was introduced into Australia but the first recorded introduction was made in 1883 when Baron Von Mueller obtained some seed, presumably from Europe. It was naturalised in Australia in 1893 and since that date has been used in all the southern States of Australia with varying success. Some extensive plantings have been made in Tasmania and Victoria but there are still many extensive drifts to be treated throughout this country and marram is undoubtedly the "king" of primary stabilisers for this work.

Botanical Description.

This is a perennial, which like other grasses of sand dunes produces a well-developed rhizome. The shoots are cylindrical, the leaves being long, narrow, and the apex needle-like. The blade is involute, glaucous and prominently ribbed on the upper side; glabrous but not keeled below. The ligule is thin, 1-3 c.m. long, and bifid; auricles absent. Spikelets, one-flowered, awnless, stalked, in a cylindrical straw-coloured panicle 10-20 c.m. long. Outer glumes 2, glabrous and scabrous on the keels, about 12 m.m. long; flowering glume shorter, stiff, 3-toothed at the top and with a basal tuft of hairs and a bristle at the base of the palea. Fig. 1 illustrates a healthy stand of marram grass at Port Kembla.

Climatic Requirements.

Marram grass, being a native of the north-west coast of Europe, favours a cool climate with a fair rainfall, however, it has been used with varying results under many different conditions. It has been planted on the Palestine coast, on the dunes of South Africa and even on the drier inland drifts of South Australia and Victoria and in the majority of cases has given satisfactory results, so its climatic limits are still a matter for further investigation. In New South Wales marram has been known for some years and a considerable amount of planting was carried out as far north as Yamba, where it was an unqualified success. In recent years this Service has conducted trials with this grass as far north as Tweed Heads, and some excellent results have been obtained when planted during the cooler winter months.

Fig. 1.—Marram grass—(*Ammophila arenaria*)—The best of our primary stabilising species.

Fig. 2.—Illustrates how marram grass causes accretion of wind-blown sand.

Habit of Growth.

This is a spring and summer growing perennial, about 3 feet high with an open, somewhat tussocky habit and long bowing leaves. It flowers in early summer but apparently does not set much seed under Australian conditions. On areas of sand drift this plant has been particularly valuable due to its habit of rapid growth vertically through comparatively large drifts and its ability to flourish only on areas of migrating sand, gradually dying out as the dune is stabilised. This is often due to exhaustion but sometimes due to competition from other plant species. Its life seldom exceeds ten years on areas not receiving regular additions of sand but this is usually sufficient for the establishment of plants of a more permanent nature. Fig. 2 shows how marram grass stills sand movement, accumulating sand in the lee of the plant.

Marram, like most other grasses of sand dunes, produces a well-developed system of rhizomes and a network of fibrous roots which sometimes grow to a length of 20-30 feet. Thus the plants are assured a large feeding area from which they can draw nourishment, a factor most important in all soils of low fertility, particularly coastal sand drifts of marine origin.

Although the rhizomes may reach great depths the culms push upward as the sand accumulates and roots develop from the new nodes as they reach maturity.

Economic Importance.

The long, tough, but flexible leaves enable marram to endure the action of the wind with little detriment, and, by reducing wind velocity near the sand surface, the plants cause accretion of the wind-borne debris in the lee of the plant. Thus, marram grass has been proved to be a sand-stilling species of the first order.

It has comparatively little value for hay or pasturage due to its coarse, wiry nature, but the leaves have been used, though not extensively, for mat and basket making.

Propagation.

(a) Time of Planting.

Very little investigation has been carried out in Australia to determine what is the best time to plant under our varying conditions, but it appears from trials carried out by this Service along the coast of New South Wales that, provided adequate moisture is available in the sand, quite satisfactory results can be obtained at almost any time from early autumn to early summer. However, our experience with marram grass indicates much more robust and rapid growth when planted during the late autumn and winter months, and this appears to be the case in other countries where this species has been used more extensively.

Rainfall during establishment and selection of suitable culms for planting are also factors which will determine the success or failure of planting. If sufficient moisture is available within easy reach of the plant and if strong, fresh culms are used there should be little difficulty in establishing a good stand of grass.

(b) Preparation of Culms for Planting.

Planting stock is harvested by cutting 4 to 6 inches under the surface with a flat-bladed garden spade, however, experience has shown that grass can be pulled by hand almost as easily as it can be dug when there has been no sand deposition during the current growing season. The most suitable material for planting is culms possessing 3-4 stems taken from vigorous growing, 2-3 year old tussocks relatively free from dead growth and trash, as strong nodes are usually present which in turn throw out vigorous shoots. If the plant has been inundated with sand during the growing period, long weak stems are formed which are usually devoid of mature nodes for 9-12 inches below the surface. This type of culm should be avoided when selecting planting material until strong mature nodes have developed closer to the surface.

Having cut the tussocks about 6 inches beneath the surface with a sharp spade they are then separated out by hand, the rhizomes being cut back to two or three strong nodes and the leaves trimmed, leaving the entire culm about 12 to 15 inches in length. The culms are then bundled, tied and heeled into the sand pending planting, but not so close as to cause overheating.

Fig. 3—A two-man team planting marram grass at Port Kembla.

Planting stock of marram grass and most other sand-stilling grasses can be stored during the cool winter months for several weeks without destroying the vigour of the plants. Storage, during early autumn or after growth begins in the spring, must be held to a minimum, and it is advisable to store less than a week in these seasons, as the bundles of roots may either heat, or, during dry weather, dry out and become of little value.

The grass should not be heeled in where water will lie, as this decomposes the basal buds of the stem, thus lowering potential survival and plant increase.

Planting stock has been shipped considerable distances during cool weather without apparent harm. The Soil Conservation Service has transported this grass as much as 300 miles by truck and even greater distances by rail during cool weather without any appreciable deterioration. However, the time the grass is out of the sand should be kept to a minimum for the most satisfactory results.

If grass has dried out during transit it is advisable to soak the bundles with water a few hours before planting out. This helps to replace lost moisture and ensures quicker establishment.

(c) Planting.

This is best carried out by two men-- one using an ordinary gardening spade to open the sand, the other carrying and inserting the culms and compacting the sand around the roots with his foot. Fig. 3 illustrates the speediest method of planting marram with a two-man team.

The number of culms used in each position or "hill" is determined by the prevailing circumstances. Initial plantings of sand-stilling grasses usually are made on non-vegetated areas in order to still the sand and prepare the site for secondary seedings and plantings. Site conditions will very greatly throughout the different areas of sand drift; consequently in order to control sand movement effectively on all these sites with the greatest economy, several different "hill" spacings and numbers of culms per "hill" are necessary, under varying conditions.

On most areas of moderate exposure a spacing of 18 inches to 2 feet, with 3 culms per "hill" will suffice, but on severe sites or on areas surrounding particularly valuable property, closer planting with spacing approximately 12 inches, is needed. Table I gives a summary of planting rates that have been found successful on the New South Wales coast.

TABLE I.

Site Conditions.	*For immediate stabilisation.* Spacing in inches.	*For deferred stabilisation.* Spacing in inches.
Steep slopes—		
Windward	12 × 12	18 × 18
Leeward	24 × 24	24 × 24
Flat areas—		
Exposed to high winds	18 × 18	24 × 24
Exposed to moderate winds	24 × 24	30 × 30
Valuable Property—		
Exposed to high winds	12 × 12	18 × 18
Exposed to moderate winds	18 × 18	24 × 24
Foredune—		
Windward face ...	18 × 18	...
Leeward face ...	24 × 24	...
Top	12 × 12	...

In exposed positions if the "hill" spacing is too wide, sand may be removed during heavy gales, thus exposing the roots and eventually destroying the entire plantation. Also, if the culm spacing is too close it has been found that sand is accumulated and the plants smothered before they are established.

If close spacing is necessary in order to build up a depression it is advisable to plant at double the distance required, planting the additional alternate culms after the original planting is well established.

In order to obtain rapid establishment of the grass it has been found advisable to plant the culms about 10-12 inches deep leaving about 2-3 inches above the surface. By this method the plant is kept fresh and does not dry out to the same extent as is the case when planted shallow.

On completion of planting any area it is further recommended to scatter the grass tops removed during the preparation of the culms, in amongst the new plantation. This will not only protect the surface during the early establishment period but, in addition, will provide a mulch which will assist in reducing excessive evaporation from the surface.

Recent Investigations.

On the three experimental sand stabilisation centres conducted by this Service at Port Kembla, North Entrance, Tuggerah Lakes, and Port Macquarie, trials have been carried out with this grass under varying climatic and site conditions.

At these centres marram grass is susceptible to inundation by sea water if covered for any lengthy period, but on occasions when grass in low-lying areas has been flooded for only brief periods recovery has been rapid. Figs. 4 and 5 illustrate an area at North Entrance, Tuggerah Lakes, before and 18 months after treatment with marram grass.

Fertiliser trials have also been carried out with sulphate of ammonia with excellent results. It has been proved beyond doubt that marram grass responds readily to this fertilizer and applications up to 40 lb. pei acre are recommended. In this way good stock for field planting can be produced in one year without much cleaning. Two and three year old stock under these conditions requires considerable cleaning prior to planting.

Due to the fact that most sand dunes along the coast are moist within a few inches of the surface during all but the most severe drought conditions, little difficulty has been experienced in establishing marram grass on these coastal dune areas regardless of their geographic location. However, on occasions, when other vegetation of a sparse nature is competing with it for the limited amount of available moisture, very little growth has been recorded until regular rains replenish the moisture.

SAND SPINIFEX—*Spinifex hirsutus. Labill.*

(Latin—"thornmaker," alluding to the pungent leaves.)

Synonyms and Vernacular Names.

Ixalum inerme Forst (1786); *Spinifex inermis* Banks and Sol.

This is not the species familiarly known as spinifex in the Western areas of New South Wales, that grass being a member of the genus Triodia, however, it has been recorded under several names of which silvery sand grass, spiny rolling grass, hairy spinifex, black grass and mat grass are those most frequently used.

Distribution.

Sand spinifex is common to all the coast of Australia with the possible exception of the extreme north. It is also widespread on the dune areas of the North Island of New Zealand but only on the northern shores of the South Island.

Botanical Description.

This is a perennial with long creeping stems which are usually soft and juicy for 3 or 4 apical internodes but elsewhere hard, smooth, woody and a pale brown or yellowish colour. Leaves are rather long with incurved margins and silvery silky, terminating in a fine tapering but usually dead tip. In texture they are flexible, coriaceous and thick, being covered on both surfaces with adpressed silky hairs. The leaf sheath is about 5 inches long, pale coloured, thick and fleshy especially at the base, and rather brittle. The flowers are dioecious, that is the male and female flowers are produced on different plants. The spikes of the male plant are arranged in terminal or axillary clusters subtended by long leafy bracts; the spikelets are two-flowered and about 1/3 inch long; the spikelets of the fertile plants are numerous but solitary, at the base of an awn-like rhachis 10-15 c.m. long, the whole forming a large, bristly, globose head which breaks away at maturity and is blown by the wind. Glumes 4, similar; flowering glume and palea hardened round the grain; ligule, a ring of hairs.

Climatic Requirements.

Sand spinifex appears to thrive under most conditions of rainfall and temperature in Australia and New Zealand and consequently, can be quite safely recommended for any coastal sand drift problems in New South Wales.

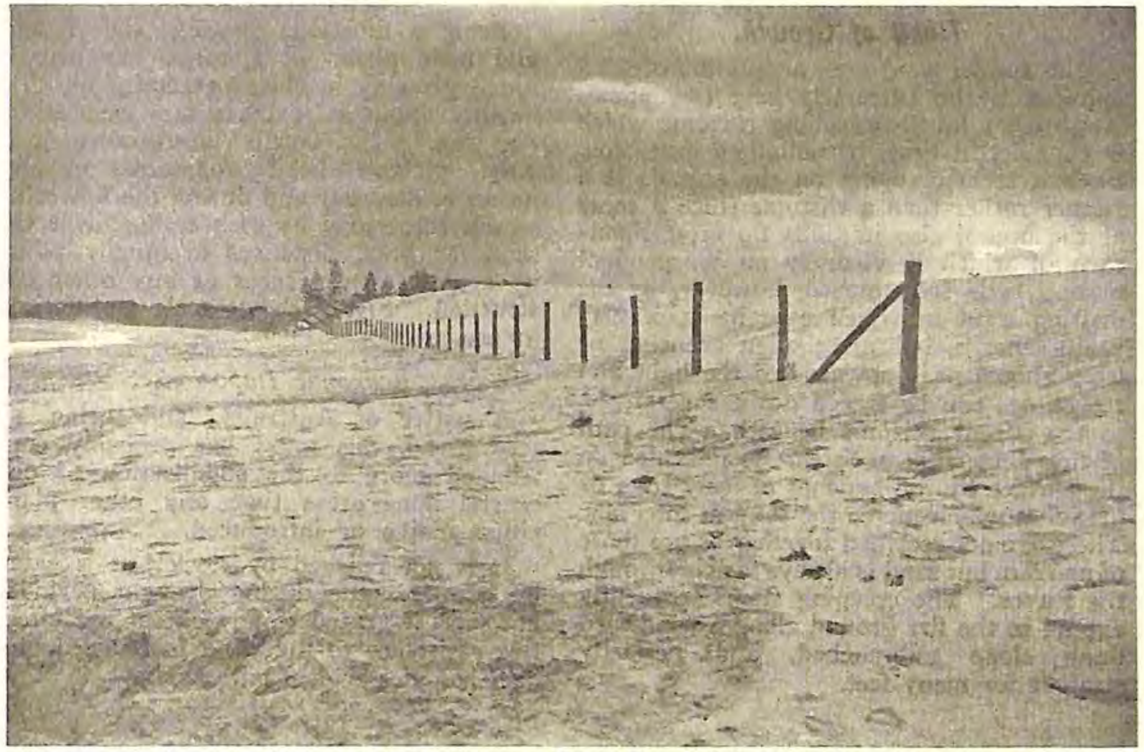

Fig. 4.—A dune area at The Entrance North, Tuggerah Lakes, before treatment.

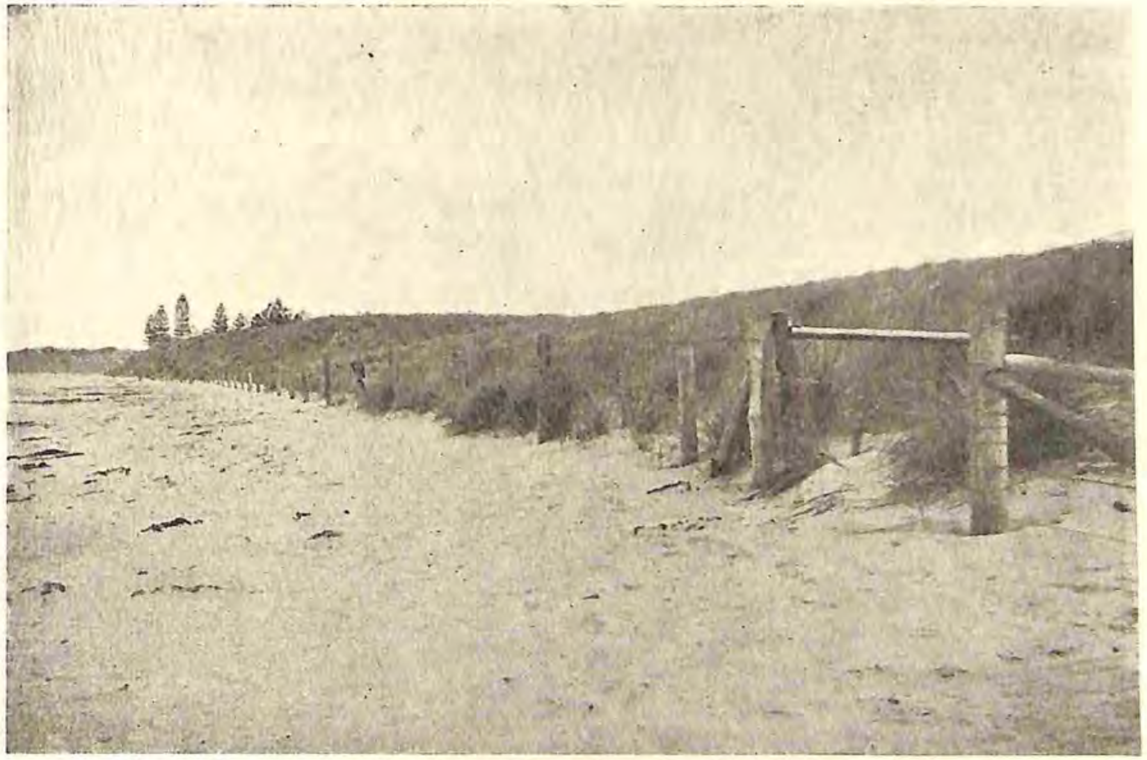

Fig. 5.—The same area illustrated in *Fig.* 4, 18 months after planting marram grass.

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Habit of Growth.

The special sand drift adaptation of sand spinifex is the extremely long (sometimes 20-30 feet) much-branching rhizome which is capable, in time, of unlimited extension. Such a stem creeping on the surface is a runner rather than a rhizome since it roots at the nodes, also it sends up erect shoots each of which is virtually an independent plant. It is soon buried, however, by the drifting sand in which case its apex may again emerge, but more often branches or leafy shoots pass upwards to the light and sometimes can be traced down several feet to the parent rhizome beneath. The path of this subterranean "stem" is indicated on the surface by the bunches of leafy tufts or branches which pierce the sand at intervals. These are not crowded together as are those of marram but sand is always visible through the leaves. The creeping stems frequently extend to the flat ground along a windward dune slope unbranched, and perfectly straight for many feet.

Being a dioecious species, the female and male plants of spinifex are usually found growing in close proximity but frequently extensive patches are seen all of one sex. The female inforescence is a large globose head sometimes twelve inches in diameter and during the flowering season these may be seen rolling over the sand for great distances eventually piling up against scrub, fences or any other obstruction. Fig. 6 shows male and female inflorescences.

Economic Importance.

A native of Australia, and being so widespread, this grass has probably contributed more to the stabilisation of our coastal dune areas than any other plant either native or introduced.

It is not relished by stock but is eaten by hungry cattle during drought periods; however, if grazed to any extent the effective resistance to the wind is reduced and drift becomes evident once again.

Fig. 6.—Samples of inflorescences taken from male and female plants of sand spinifex (*Spinifex hirsutus*).

Propagation.

Recent trials with this grass have consisted of propagation both by seed and cuttings with varying results. At Port Kembla seed was planted in drills without any surface protection in February and excellent germination resulted. However, strong onshore gales during the late autumn and winter destroyed many of the young seedlings leaving only just sufficient for a very sparse cover. During the ensuing summer months this grass showed excellent growth and is now spreading vigorously.

This method is considered quite satisfactory where the terrain is comparatively level, but on the more irregular drifts, where high winds often alter the dunes in a matter of hours, some form of protection against the cutting action of the sand, such as tea-tree brush, is required in order to establish a permanent stand of grass.

Natural regeneration from seed does take place on most of our beaches following periods of favourable conditions, but few of these seedlings survive unless they are favoured by the protection of other vegetation or rubbish on the beach.

Propagation by root cuttings has not been as successful as anticipated due to many factors, the chief being inundation by sand, but provided adequate protection is given either in the form of tea-tree brush or a thin planting of marram grass then reasonable success can be expected.

Root cuttings planted in the winter have given the best results to date but growth has been very slow until about January or February when runners are thrown out and new plants developed at the nodes as the runner accumulates sufficient sand. Fig. 7 illustrates a dense sward of sand spinifex in flower at Port Kembla.

Fig. 7.—A dense sward of sand spinifex in flower on the Port Kembla sand dunes.

Further tests are being carried out to ascertain whether it is possible to establish this grass more rapidly but meanwhile the major areas of drift are being planted to marram grass, spinifex being used only in areas adjacent to the high tide level subject to salt spray. In these areas an espacement of 2-3 ft. each way is considered quite satisfactory for most requirements, but where it is given ample protection this spacing could be considerably widened.

In conclusion, it is stressed that the two abovementioned species form the basis for the primary stabilisation of sand drifts in coastal areas of New South Wales and I consider that sand spinifex will always find a place in the permanent fixation of areas immediately adjacent to our beaches.

In succeeding articles it is the intention to discuss some of the more important secondary and tertiary species being utilised for the permanent stabilisation of our sand drift problems.

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MASS MOVEMENTS OF THE SOIL SURFACE

With Special Reference to the Monaro Region of New South Wales

BY

A. B. Costin, B.Sc.Agr., Soil Conservationist.

PART II.*

MASS movements of the soil surface are commonly encountered in the Monaro region, which may be divided into four well-defined altitudinal and climatic tracts: alpine, subalpine, montane and tableland. The movements are favoured by one or more of the following environmental conditions: heavy precipitation, strong winds, severe frost action, snow-falls, steep topography, rock jointing, prismatic and columnar soil structures, and unfavourable human interference with the vegetative cover.

Mass movements most commonly encountered are soil creep, solifluction, earth flow, rock creep, talus creep and rock glacier creep, all of which are flowage phenomena; slumping, caving, debris slide, debris fall, rock slide and rock fall, which are primarily slippage forms, and minor movements due to subsidence. Evidences of mudflows have not been observed, and although certain alpine and subalpine debris slides approach debris avalanches in some of their properties, typical avalanches are probably rare.

Where initiated by human interference, mass movements of the soil have almost invariably been followed by sheet and gully erosion.

FLOWAGE MOVEMENTS.

Soil Creep.

The almost universal process of soil creep operates in all areas of the Monaro from alpine levels with annual precipitations approaching 90 inches to lower tableland elevations with annual precipitations of less than 17 inches. In the alpine and subalpine tracts soil creep is always associated with solifluction, but in the montane and tableland tracts, where precipitations are lower and temperatures higher, soil creep is the dominant process.

Soil creep on the Monaro is assisted by a variety of influences, most important of which are rain drop splash, frost heaving, and the expansion and contraction of soil particles due to rapid temperature and moisture changes within the soil. The effects of these influences have been increased by the exposure of the soil surface by overgrazing, burning and clearing.

Soil texture is likewise an important consideration in frost heaving. Fine-textured soils such as those derived from basalt are more resistant to surface freezing than are the light-textured soils formed from coarser-grained rocks. The frost-heave danger of a soil also increases with its moisture content.

In areas of high wind velocity a special form of soil creep known as saltation is active on exposed surfaces. Although the larger soil particles such as coarse sand, gravel and small stones may be too heavy for direct wind transport, the bombardment by smaller, wind-borne particles and the consequent vibrations among the larger particles result in the slow mass movement of the latter. Saltation occurs on exposed windswept soil surfaces of the Monaro region, particularly at alpine levels where the process is so active that stones of half inch diameter are moved.

*Part I of the article appeared in this Journal, Vol. 6, No. 1, 1950.

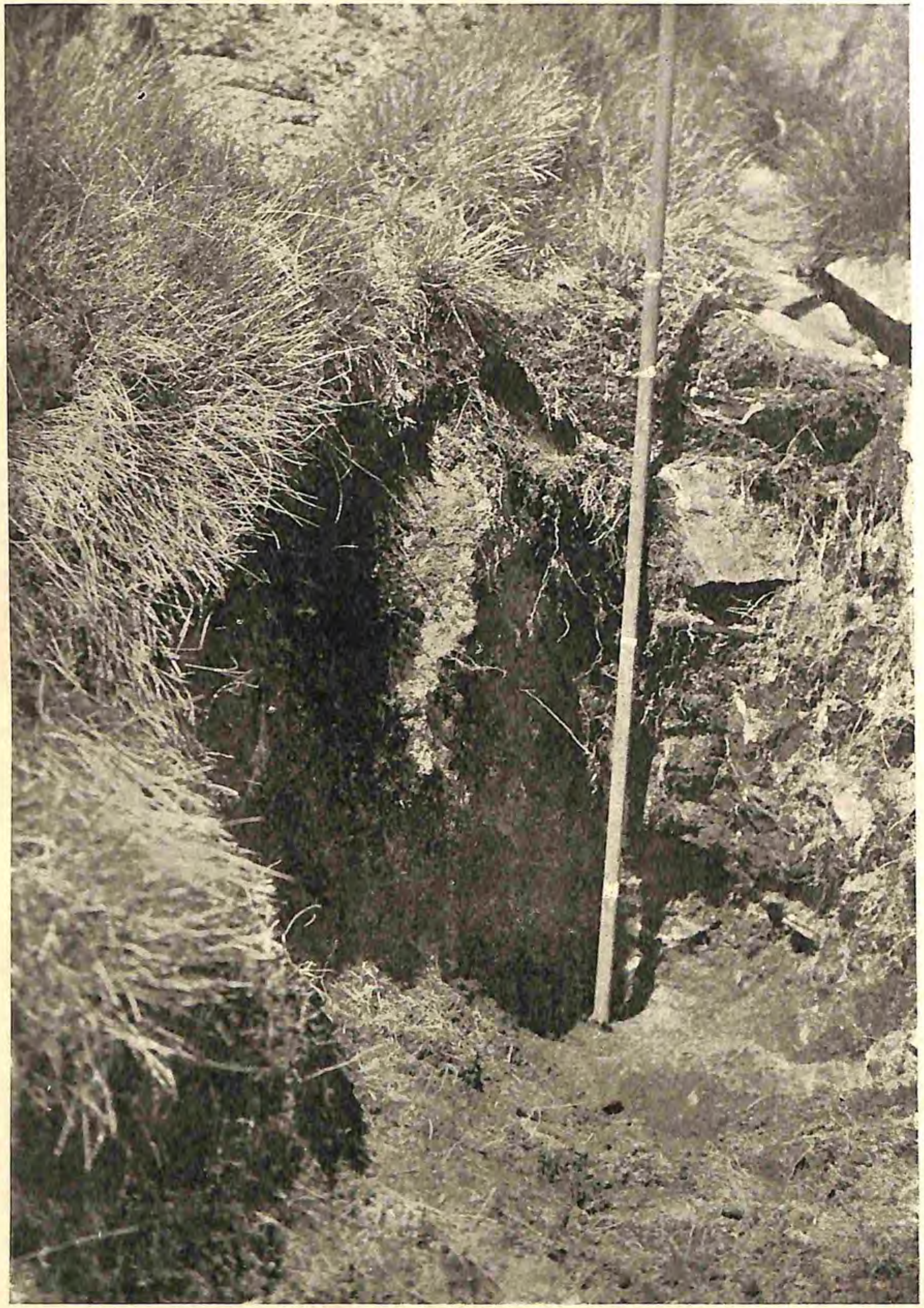

Fig. 1.—Alpine humus soil in the Alpine tract showing non-podsolised profile, gradual mergence of horizons and abundant rock skeleton. Soil creep, rock creep, and solifluction are important pedogenic processes.

Importance in Natural Processes.

Soil creep, probably operating more intensively in the warm, pluvial Pliocene period and assisted by more active solifluction processes in the cooler and wetter Pleistocene, is considered to have been largely responsible for the gently rounded hills so characteristic of the lower Monaro landscape.

As a factor of soil formation soil creep is of great importance. In the alpine and subalpine tracts soil creep, combined with solifluction, is responsible for some of the most characteristic properties of alpine humus soils (Fig. 1). The stone line of many soils in the montane, subalpine and alpine tracts is also due to soil creep and solifluction processes (Fig. 2). The colluvial brown earths of the montane and tableland tracts are essentially creep-determined soils; and the black, semi-colluvial chernozems and prairie soils of the latter tract are considered to have been accumulated largely by creep and solifluction in late Pliocene and Pleistocene time. The characteristic tors of the boulder-strewn Dalgety-Berridale area are thought to have been exposed at this time by removal of the surrounding soil by creep and solifluction. These tors form extensive boulder-fields or *Felsenmeere,* and are sometimes erroneously attributed to previous glacial action.

Importance in Accelerated Erosion.

Under natural conditions soil creep is not important in accelerated erosion, but its action is intensified on soil surfaces exposed by burning, clearing and overgrazing.

On certain steep slopes of the tableland tract the formation of stock terracettes is being hastened by accelerated creep movements, with the development at a later stage of serious sheet and gully erosion. The mechanism of terracette formation is discussed in connection with solifluction movements.

Fig. 2.—Stone line in alpine humus soil in subalpine tract, marking depth to which soil creep and solifluction are active.

Accelerated soil creep due to frost action on exposed soil surfaces is one of the most widespread erosion problems of the Monaro. Alternate freezing and thawing result in the frost-heaving, desiccation and pulverisation of moist, exposed soil surfaces by spew frost or needle ice (Figs. 3, 4). The soil thus affected, which commonly develops a fluted or striated appearance (Fig. 3), either falls downslope under the action of gravity or is subsequently removed by wind or water action.

The secondary plant succession on bare soil surfaces is also adversely affected by frost action. Seedling regeneration of pasture plants is checked by frost-heaving, and the only plants which can recolonise the bare areas successfully are mosses, lichens, annuals, rosette plants, mat plants, and certain dwarf shrubs. The mosses, lichens, and annuals afford little protection to the soil, but the perennial mat plants and dwarf shrubs are of considerable value in reducing further needle ice erosion. In the tableland and montane tracts* the most important of these perennial species are *Acrotriche serrulata, Bossiaea buxifolia, B. riparia, Dillurynia prostrata, D. sericea, Dodonaea procumbens, Mirbelia oxyloboides, Pultenaea styphelioides, P. subspicata*, and *Scleranthus biflorus*. The last-named species, a mat plant, is of additional value in providing a seed bed for the more delicate species which occupy later stages of the subsere.

High frequencies of the above-listed species in Monaro pastures thus indicate practices of overgrazing, burning, or clearing which have been accompanied by needle ice, water and wind erosion.

Control of Accelerated Soil Creep.

In marked contrast to the severe action of needle ice on exposed soil surfaces is the effectiveness of a continuous vegetative cover both in minimising soil freezing and in preventing needle ice erosion. The most obvious control measure is thus the maintenance of a protective cover on the surface soil. Exposed soils should be closed to grazing until this cover has been re-established by volunteer or hand-sown species.

On steep slopes, where terracette formation is being hastened by accelerated creep, protection of the exposed soils from grazing is also recommended. Contour banks and pasture furrows should not be used as in the control of sheet and gully erosion, because the impounding of additional moisture may so saturate the already unstable soil that solifluction and slippage movements are facilitated.

SOLIFLUCTION

Solifluction (which is also associated with soil creep in the tableland and montane tracts) is probably the dominant process of mass movement at alpine and subalpine levels. Optimum conditions for solifluction are provided by high soil moisture contents resulting from heavy falls of rain and snow, and by the daily alterations of soil freezing and thawing in the early spring and late autumn months.

Importance in Natural Processes.

Acting in conjunction with soil creep, solifluction is one of the dominant factors in pedogenic and geomorphological processes in the alpine and subalpine tracts.

Creep and solifluction are intimately concerned with the genesis of alpine humus soils and are responsible for some of their outstanding properties. The continuous movement of soil and rock materials from higher to lower levels helps maintain the non-podsolised properties of these soils, their usually clearly defined stone line representing the average depth to which creep and solifluction are effective. (Figs. 1, 2). It is noteworthy that the stone line is deeper in the subalpine than in the wetter alpine tract. This apparent anomaly is due to the greater duration of the alpine snow cover protecting the underlying soils from the severe autumn and spring frosts which affect the relatively snow-free alpine humus soils of the subalpine tract.

Importance in Accelerated Erosion.

Most of the soils of the alpine and subalpine tracts are naturally well protected by a dense herbaceous sward and in this condition are not subject to accelerated erosion. Exposure of the surface soil by overgrazing during the snow-free summer months, by burning of the vegetation to

*Secondary succession on exposed soil surface in the alpine and subalpine tracts is discussed in connection with solifluction.

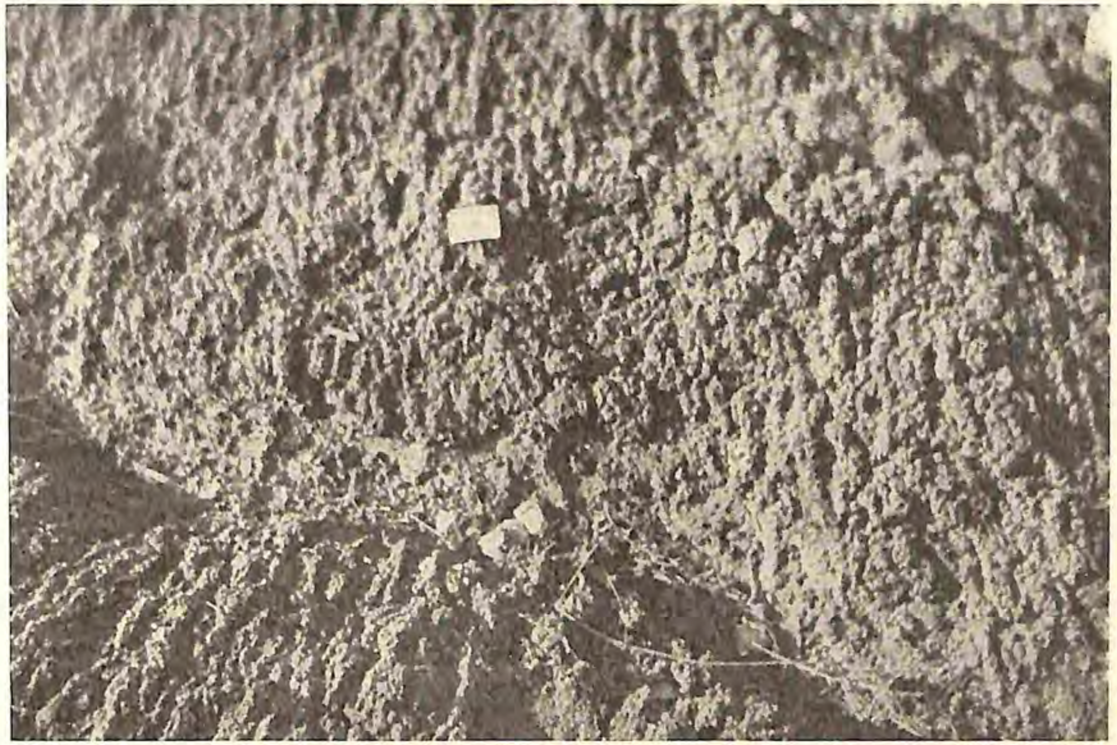

Fig. 3.—Needle-ice erosion of exposed soil surface in subalpine tract. Note development of surface fluting. (Matchbox near centre of photograph.)

Fig. 4.—A close-up view showing mechanism of needle-ice erosion of exposed soil surface. (*Photo* by U.S.D.A.)

Fig. 5.—Snow grass pastures being killed by case moth larvae in subalpine tract.

promote palatable spring growth, and by roadmaking operations, has greatly accelerated the processes of solifluction and wind and water erosion. In recent years this position has been further aggravated by the depredations of a small case moth, the gregarious larvae of which have killed large areas of snow grass pasture (*Poa caespitosa*) by attacking the buds at the crowns of the tussocks. Evidence has been obtained supporting the view that the recent increase in the case moth population is due partly to human interference with the virgin plant communities, the structures of many of which have been profoundly modified by burning and grazing. These case moth areas now constitute one of the major erosion hazards in the alpine and subalpine tracts, as the regeneration of the snow grass is being checked and in many cases prevented by selective grazing of the palatable grass seedlings (Fig. 5).

In the alpine and subalpine tracts unprotected soil surfaces are subject to extreme frost action in the spring and autumn months when alternate freezing and thawing, causing frost heaves of several inches, are often daily occurrences. (Figs. 3, 4). Soil movements in springtime are also favoured by the abundant water derived from rapidly melting winter snows.

As explained in the discussion of soil creep, the pulverized, desiccated soil particles are rapidly removed by wind and water erosion. For example, in recent years overgrazing and trampling of snow patch communities in the Kosciusko area have so accelerated solifluction and water erosion that some of the associated snow patch meadow soils have been buried beneath more than three feet of coarse detritus (Fig. 6). This burial is still progressing.

Needle ice erosion at alpine and subalpine levels is also responsible for the rapid lateral recession of gully walls and roadside cuttings. Erosion is usually most severe in the A_2 and B horizons of exposed soil profiles, as the A_1 horizon receives some slight protection from the abundant surface root development and the BC horizon from a usually high content of stones and gravel.

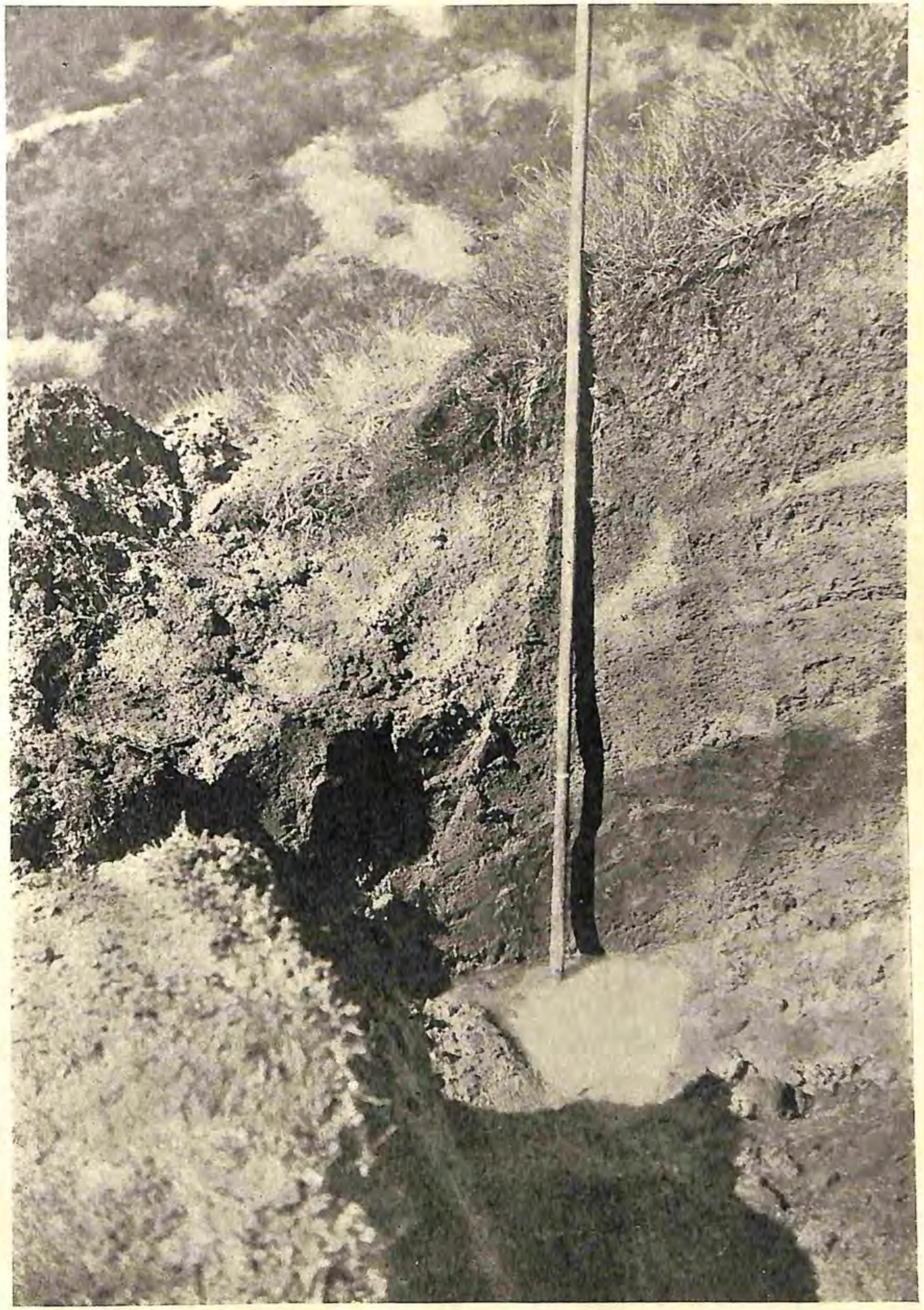

Fig. 6.—Dark peaty snow patch meadow soil buried beneath coarse detritus in the alpine tract. The causes of the burial are overgrazing and trampling leading to accelerated solifluction and water erosion.

In this way undermining of the gully or cutting occurs and caving movements result. Caving is discussed in greater detail at a later stage.

In the alpine and subalpine tracts, and to a lesser degree at montane levels, accelerated solifluction processes on sloping soils are intimately associated with so-called stock terracettes and often with various slippage forms. The formation of these terracettes is usually attributed to minor slumping, but on the Monaro it is considered that solifluction is also a major cause. Overgrazing and burning of pastures first result in localised exposures of the surface soil on which needle ice erosion commences. In this way numerous slightly depressed bare areas develop within the naturally continuous vegetative cover below which natural creep and solifluction still continue. Owing to the dense development of plant roots near the soil surface, solifluction in the A_1 is slower than in the A_2 and B horizons, with the result that there is a gradual backward movement of the ground sward at the base of each bare, depressed, frost-eroded pocket. In this way the so-called stock terracettes develop, which are better termed solifluction terracettes as stock are concerned only indirectly with their formation (Fig. 7). The features of solifluction terracettes may be intensified by slippage movements, and on steeper slopes terracettes are usually associated with larger slumps, minor debris slides, and sheet and gully erosion.

The solifluction terracettes of the Monaro are not to be confused with the developmental terraces often associated with silty bog and immature alpine humus soils as in the Kosciusko area. The latter terraces only occur on moist, gentle slopes and represent an intermediate stage in a natural hydrosere (Fig. 8).

Accelerated solifluction processes in the alpine and subalpine tracts render difficult plant regeneration on bare soil surfaces. Quadrat observations covering three successive years have shown that little regeneration can be expected on exposed steeply sloping soils unless grazing is discontinued. On gentler slopes the secondary succession may proceed slowly. The pioneer plants,

Fig. 7.—Solifluction terracettes in overgrazed, disclimax grassland of snow grass in subalpine tract.

Fig. 8.—Natural developmental terraces in alpine tract. These terraces represent an intermediate stage in a hydrosere and should not be confused with solifluction terracettes.

which are mainly annuals and small, freely seeding perennials, are of little value in preventing further soil movements. At a later stage a more effective soil protection is afforded by perennial rosette plants and particularly by mat plants and shrubs. Under favourable conditions snow grass and associated sedges appear in the final stage of the subsere, but as previously indicated their re-establishment may be severely retarded or prevented unless grazing is temporarily discontinued (Figs. 9, 10).

Control of Accelerated Solifluction.

The same control measures previously discussed in connection with accelerated soil creep are also recommended to control accelerated solifluction processes. Burning, and excessive grazing and clearing should be avoided, and plant regeneration should be encouraged by the exclusion of livestock from eroded areas.

It is believed that the restoration of the virgin structures of the alpine and subalpine plant communities by the elimination of undesirable practices associated with current grazing methods will ultimately reduce the case moth population to its formerly low level. Until the restoration of the virgin plant communities is achieved, however, the depredations of the case moth will probably initiate further serious soil movements and the problem of its immediate control is still largely unsolved.

EARTH FLOW.

Protracted rains or water from rapidly melting snow may so saturate the soil that earthflows may occur on sloping ground. Earthflows are invariably associated with solifluction, and as previously explained, with slumping at the head of the flow (Fig. 11).

Fig. 9.—An intermediate shrub stage showing *Olearia floribunda* in the secondary plant succession on frost-eroded soils associated with case moth aıeas in the subalpine tract.

Fig. 10.—Final stage in the secondary plant succession on frost-eroded soils of the case moth areas showing regeneration of snow grass.

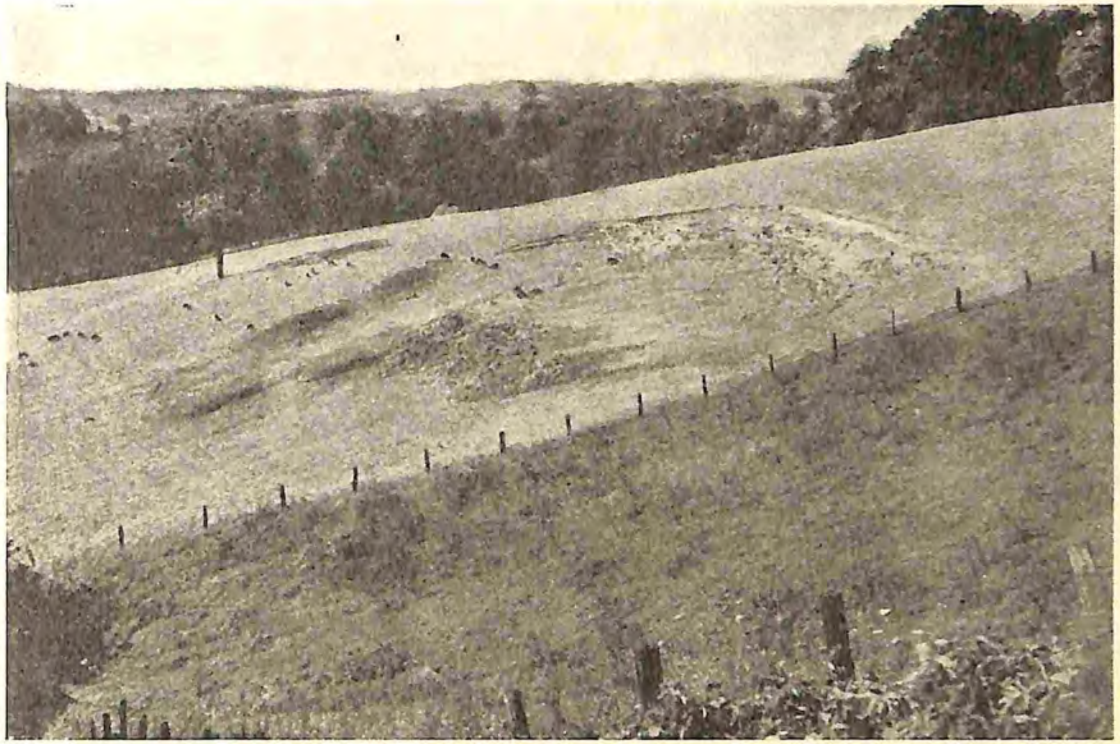

Fig. 11.—A typical earth flow showing slumping at head and bulging at base of flow. (*Photo* by U.S.D.A.)

Importance.

On the Monaro few indications of recent earthflows have been observed. On steep slopes of the alpine and subalpine tracts, however, small scarps occur which represent the slumps and basal bulges of previous flows. It is considered that most of these earthflows occurred naturally, as they have now been restabilised by vegetation.

It is significant, nevertheless, that the old earthflow scarps are commonly associated with the solifluction terracettes, slumping and debris slides induced by human interference. For this reason any area showing earthflow scarps should be regarded as one of erosion hazard, particularly if undesirable grazing methods are being practised.

Control of Earthflows.

Earthflows are not of great importance on the Monaro and only occasionally may remedial measures be necessary.

These measures should be aimed at preserving a protective vegetative cover on the soil, and also at the even distribution of snow in the alpine and subalpine tracts. In the U.S.A. attention has been drawn to the beneficial effect of planting trees and shrubs on sunless slopes to prevent locally deep accumulations of snow. Although this practice is not yet economically feasible on the Monaro, it is considered that the promotion of the natural regeneration of snow gum (*Eucalyptus niphophila*) *in* the subalpine tract would minimise the danger of earthflows on slopes where burning and grazing have caused the replacement of the climax snow gum woodland by a disclimax grassland of snow grass.

Fig. 12.—Semi-permanent snow patch in the alpine tract associated with which are snow patch meadow communities (dark areas on left hand side of photograph), and alpine detrital soils. In the latter soils talus creep is active, grading into rock glacier creep in the immediate vicinity of the snow patch.

ROCK CREEP.

Rock creep consists of the slow, down-slope movement of individual rock fragments, and like soil creep is of almost universal occurrence. Its rate is greatly accelerated on steep slopes and by sudden temperature fluctuations, and is consequently of greatest importance in the alpine and subalpine tracts.

Importance.

Rock creep operating in conjunction with soil creep and solifluction is of considerable importance in soil formation. The continual addition of rock fragments to the soil surface is most significant in offsetting the podsolising tendencies operating in alpine humus soils and colluvial brown earths, and in maintaining the high fertility of grey-chocolate, chocolate, and red-chocolate soils derived from basalt.

The rate of rock creep has not been greatly affected by human interference.

TALUS CREEP.

Talus creep is of widespread occurrence on the Monaro, being favoured by the same conditions which promote mechanical weathering, such as frost action, rapid temperature fluctuations, and strongly folded or jointed rocks.

In the tableland and montane tracts temperature fluctuations are mainly responsible for talus creep, but in the subalpine and alpine tracts frost action is at least of equal importance. At alpine levels near semi-permanent snow patches (Fig. 12) talus creep grades into rock glacier creep.

Importance.

Talus creep is of localised but widespread occurrence and operates in most of the lithosols or detrital soils on the Monaro (Fig. 12). These soils are so unfavourable for plant growth that only specially adapted species are able to develop and the resultant plant communities are usually open in structure.

Some of the larger screes in the montane and tableland tracts are considered to date from Pleistocene time when conditions for the accumulation of talus and for talus creep were even more favourable than at present.

Human interference has not affected talus creep.

ROCK GLACIER CREEP.

Many of the screes associated with the larger semi-permanent snow patches in the alpine tract (Fig. 12) are affected by rock glacier creep. On the Monaro, however, rock glacier creep is always associated with talus creep, and the latter process may operate exclusively during those summers through which the snow patches fail to persist.

Importance.

Rock glacier creep is one of the major pedogenic processes affecting certain alpine detrital soils, and the associated environmental conditions are so severe that only highly specialised shrub communities can develop.

Human interference has not affected rock glacier creep.

(To be concluded.)

THE CONTROL OF EROSION ON FARM ROADS

BY

G. R. Wiltshire, H.D.A., H.D.D., Officer-in-Charge.

Articles on "Roadside Erosion" have been published in previous issues of this journal, but, while those articles dealt with the problems of large scale erosion along main roads and highways, this one deals only with farm roads and the problems associated with them. It could be said that the same principles apply to both, but on close examination some basic differences are revealed.

Public roads and highways are generally narrow with defined boundaries, there being little scope for re-location, while many farm roads could and should be re-located quite easily. Further, the erosion on public roads is usually manifested in severe roadside gullying, while that on the farm roads takes the form of scouring of the road surface itself. Farm roads are essentially problems which must be dealt with by the farmers themselves.

PROBLEMS OF FARM ROADS

Every farmer who commences a soil conservation programme on his farm will, before long, become alarmed by the amount and frequency of erosion which occurs, both on, and as a result of the run-off from, farm roads. There are four main reasons for the occurrence of this erosion:—

1. Roads being hard and compacted by traffic, are impervious and in consequence shed water very rapidly, even when only light showers of rain are received.
2. Roads tend to cut diagonally across slopes, intercepting the normal courses of run-off.
3. Wheel tracks form into small channels which convey the diverted waters at velocities in excess of those required to cause erosion.
4. Where roads cross natural depressions, the water is discharged, where it may cause gullying of the natural watercourse, or, if the natural watercourse is well vegetated, the flow may be checked, in which case deposition of the erosional debris occurs, creating silt deltas; sometimes a combination of the delta formations with a gully lower down results.

CLASSIFICATION OF FARM ROADS

A classification of farm roads, based on the occurrence of erosion in relation to road location, reveals that these fall generally into one of the following four groups:—

1. Roads which are on the contour, or which have insufficient grade to carry a flow of water, are the least eroded, as the waters which they intercept flow across them, but do not flow along them. Similarly these roads do not tend to create concentrations of water to points where such may do damage.
2. Roads which run directly up and down the slope have a steep grade, but as they do not tend to intercept run-off from other areas, they do not carry large flows, and in consequence they erode only moderately.
3. Roads which run diagonally across slopes intercept and divert large amounts of run-off, and they are usually on such grades that this water flows at velocities in excess of those required for serious erosion to occur, and in consequence they erode severely. Unfortunately most farm roads fall into this latter category.
4. Various combinations of the above three locations occur, and these combinations usually favour the incidence of erosion. Probably the worst combination is that which has the higher portion of the road running diagonally across the slope, and the lower portion running directly down the slope; in this case a considerable flow of water is delivered by the higher portion to the steeply sloping lower portion, down which it flows at excessive velocities.

METHODS OF REDUCING FARM ROAD EROSION

From the above classification most of the logical methods of reducing the problems of erosion and siltation caused by farm roads may be deduced. These include:—

Road Re-location.

If all farm roads could be so located that they ran on the contour, the associated erosion problems would be reduced to negligible proportions. However, it is obviously impossible to connect two points which are on different levels by a road which runs on the contour, and so in practice it is necessary to lay out roads so that wherever practicable they run on the contour, and, where this is not practicable, to run them directly up and down the slope for short lengths.

A combination of the two layouts will give access to every point on any farm, and a study of farms indicates that a very large proportion of farm roads could be replaced by those which are laid out in this way.

Figures 1, 2 and 3 show practical examples of road re-location and in each case the roads which ran diagonally across sloping lands have been replaced by those which run either on the contour, directly up and down the slope, or by a combination of the two. It is of interest to note that in most cases the cultivation of farm lands on the contour is rendered more convenient by these new road locations.

An important point to be considered when designing roads according to the above principles, is that those roads which run directly up and down the slope should be located on areas where the slopes are moderate, as transport problems are associated with roads which run directly up steep slopes.

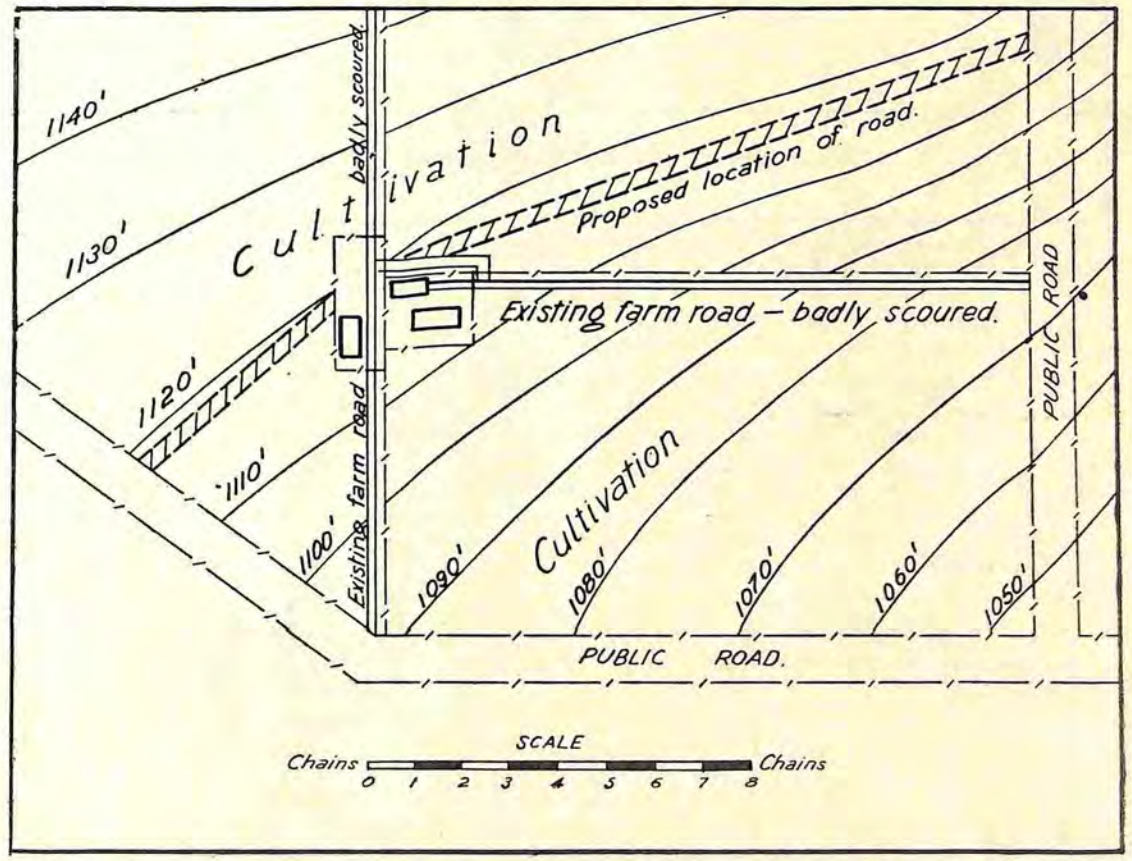

Fig. 1.—A farm road layout showing how re-location would alter the existing design. Note the re-location of the fences to the new road locations would alter the paddock shape and facilitate cultivation on the contour.

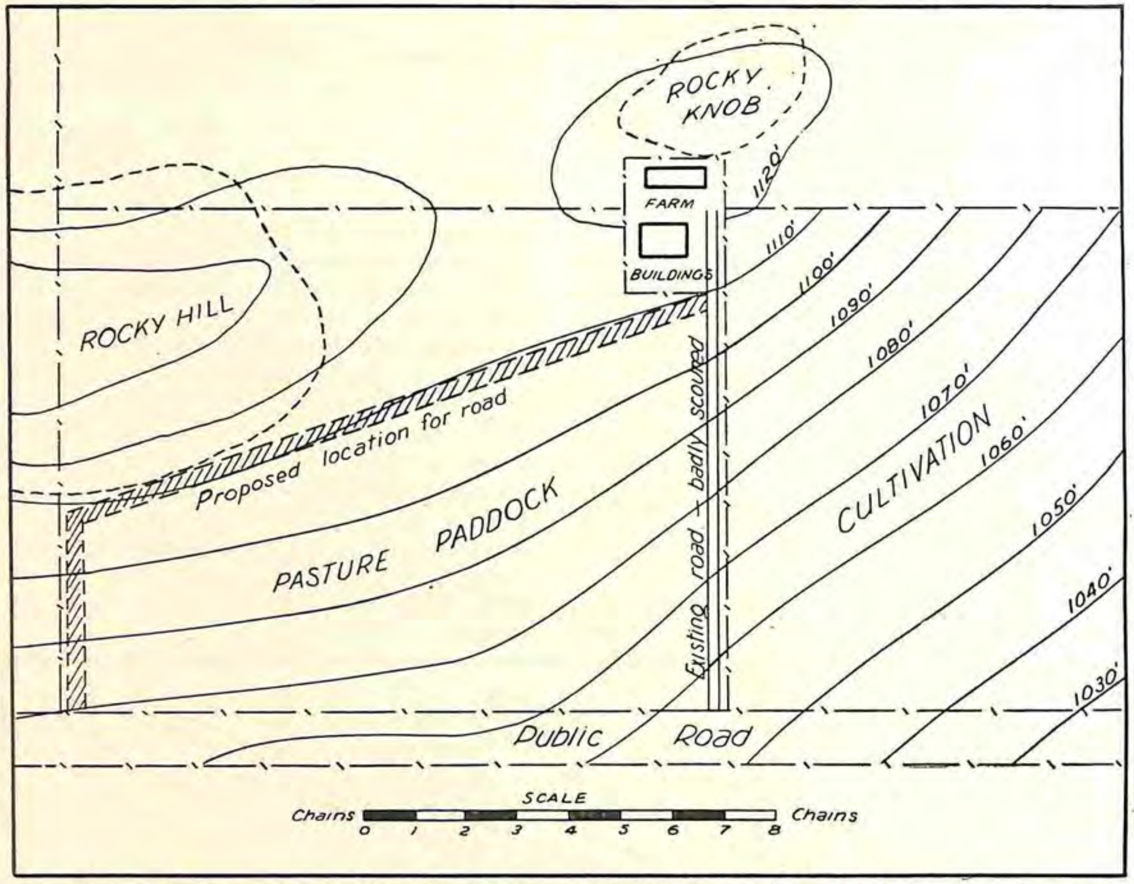

Fig. 2.—The existing road in this figure is being replaced by one which runs directly up the slope from the public road, and which then runs on the contour to the farmstead.

The Prevention of Extraneous Run-off from Reaching Roads.

As extraneous run-off, which is intercepted by roads, is responsible for the major part of the erosional damage occuring on them, any reduction in the amount of this run-off directly reduces the damage.

There are two ways of preventing this outside run-off from reaching roads, these being:—

(a) Increasing the absorption of water on the area from which the run-off is coming.

(b) Diversion of the water by means of diversion banks.

Where grazing lands are shedding the water, greater absorption can usually be effected by the building up of the pasture sward. This is accomplished by topdressing, control of rabbits, and by good grazing management. On most soil types a thick continuous pasture sward will absorb and retain all but the heaviest of downpours.

If such pasture management cannot be carried out, or if it is not adequate in controlling the run-off, it can be supplemented by pasture furrows; these pasture furrows running on the true contour, impound the run-off waters on the land surface and allow it to soak into the soil. If correctly designed, constructed and maintained, pasture furrows will give positive control of all surplus run-off in the area.

Diversion banks are utilised where run-off from the area cannot be controlled by absorption methods; it often happens that areas above the roads are stoney, or they may be cultivated, and in these cases pasture furrows are not usually used. A correctly placed diversion bank or system of diversion

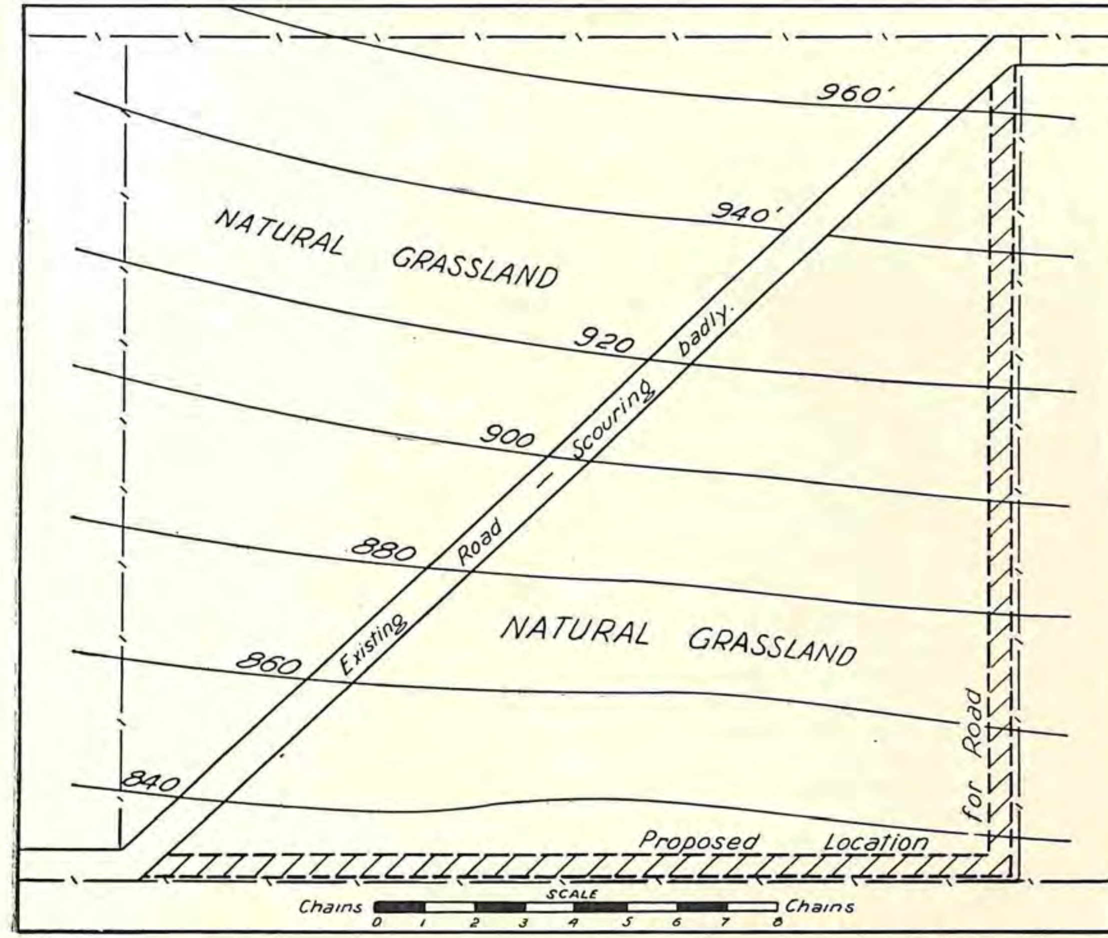

Fig. 3.—The proposed new road is slightly longer but it greatly reduces the erosion problem.

banks will give adequate protection, but care must be exercised to ensure that these diversion banks convey the water to safe disposal areas, such as grassed waterways, or to well grassed watercourses.

The Diversion of Run-off Waters from Roads.

The diversion of flowing waters from road surfaces onto neighbouring lands is effected by the use of small drains which are commonly called mitre drains.

These drains are extensively used, on both private and public roads, where they do very good service under some conditions. In theory they are excellent; they convey the water away to grasslands or to diversion ditches where it is safely disposed of, and thereby the erosion on the road is minimised. In practice great care must be exercised in their design and construction as they have some basic weaknesses, these being:—

(*a*) It is difficult to build and maintain mitre drains which run far enough out on to the road to prevent the water by-passing their ends, and continuing on its course down the road surface.

(*b*) There is a tendency for them to choke rapidly with erosional debris, which is deposited by the water when its velocity is checked at the point of entry into them.

In consequence of the above these should be built in such a way that they are sufficiently close to one another to prevent high velocity flows occurring on the road; they should have such a grade that the waters which they convey will flow at a velocity which will ensure that these waters will carry their silt load, while at the same time they will not cause scouring of the channels in the drains.

It is a practical impossibility to design and construct drains which comply completely with the above ideal; some siltation of the drains will occur, and this siltation is cumulative, so that ultimately the channel chokes sufficiently to cause by-passing. Once the drain chokes, the fast flowing water chokes the one immediately below it, and so the whole system becomes liable to failure.

Sufficient grade can be allowed in the channels to ensure that siltation does not occur, but in this case scouring of the channel would probably take place, and this scouring would work uphill by simple waterfall action on to the road surface itself.

Observation suggests that if these drains are put in with a vertical interval of 3 feet between drains, and a channel grade not exceeding a fall of 1 foot per 100 feet, they are very successful while well maintained; regular maintenance is the key to success providing the drains have been well designed in the first place.

.ng action of traffic, and the removal of soil by erosion tend to lower the level of roads, so that firstly the wheel tracks become channel shaped, and, later, the whole road surface is affected; the road develops into a broad, shallow depression to which waters run from neighbouring areas.

Gravelling of the road is one method of overcoming this effect, and on main entrance roads to the farm the gravelling of the whole road surface would often be advantageous. It has the effect of raising the centre of the road so that water runs off to the sides, from whence it can be conveyed away and disposed of safely.

Another very good reason for the gravelling of roads lies in the fact that it becomes increasingly difficult to convey water from roads by means of mitre drains as the road surface is lowered below the level of the surrounding land; the formation of a crown on the road is almost a necessity for the successful use of mitre drains.

On those farm roads which are not so frequently used, the gravelling of the wheel tracks only is in most cases ample. With the increasing use of motor vehicles for

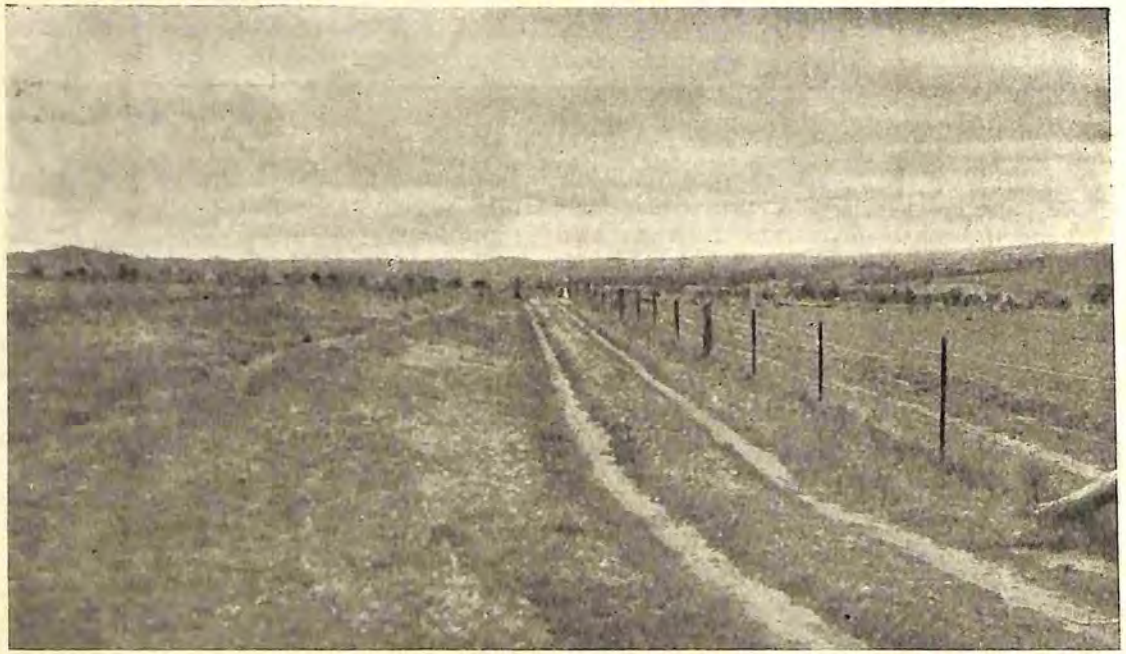

Fig. 4.—This farm road is running on the contour and the run-off water is prevented from reaching it by pasture furrows.

Fig. 5.—Farm road with the wheel tracks gravelled.

Fig. 6.—Road running along the top of a graded bank, almost a contour.

cartage, haulage and general farm work, the wheel tracks are fairly standard; two gravelled strips, each being approximately 15 inches wide, give ample bearing surface for most of the traffic.

By these means, farm roads can be kept convex in cross section, instead of concave, and farm run-off will not tend to run down them, but rather will run off to the roadsides.

Old roads which have been badly scoured on many occasions may have to be formed up by means of a grader prior to gravelling, otherwise an excessive amount of gravel is required. In some cases forming alone is sufficient, this depends on the suitability of the soil type as a road surface, and the availability of road gravel.

Farm Roads in Relation to Other Erosion Control Structures.

In the design of soil conservation programmes, it is necessary to consider roads and their locations in relation to the various other erosion control structures. A good example of this is seen in a paddock which requires a wind-break along one boundary, a grassed waterway to be used as a safe disposal for water from graded banks, and an entrance road.

The ideal location for the road is along the crop side of the windbreak, as it then occupies that area which is directly affected by the foraging action of the tree roots. Should the waterway have to be placed on the same side of the paddock as the windbreak, it should be placed so that the road is between it and the trees, it is then buffered from the effects of the tree roots by the road, and the run-off waters from the road can be taken directly on to the grassed waterway. In this way the road does not have to cross the banks, and the tree roots do not sap any area where crops have to be grown.

If a road has to traverse a paddock which is terraced with graded banks a most suitable site is that location where it can be drained by the origin end of each bank. Roads should not be laid out to cross the delivery end of the banks, as the banks are weakened by the road at that point where they need to have maximum capacity; in addition to this, the banks would be very dangerous and inconvenient for the road traffic.

Where roads cross grassed waterways they should do so at right angles to the direction of flow, in this way the water cannot course down the wheel tracks, and a minimum area of the waterway is denuded by road traffic.

In grazing paddocks, mitre drains from the roadside can be directed into pasture furrows, and in this way the run-off from the road can be utilised to advantage in the pasture improvement programme.

In conclusion it can be said that while farm roads should be designed, constructed and maintained according to the principles laid down in this article, they will still remain a constant source of trouble, and where possible one main road through the farm giving access to all paddocks should be used to replace a series of individual roads to separate paddocks, as the main road is easier to maintain, and there is less total length of road on the farm.

FACTORS WHICH MINIMISE SOIL EROSION IN GREAT BRITAIN

By

L. E. Humphries, N.D.A., Soil Conservationist.

QUITE recently an article appeared in a Sydney newspaper discussing the problem of soil erosion and suggesting that instead of studying the problem in countries where erosion had already occurred, such as in India and America, some of the older countries where erosion had not taken place might well be examined.

I have not yet been in any country which does not show signs of erosion in a greater or lesser degree. For instance, the view is sometimes expressed that in England there is no accelerated erosion problem.

EROSION SLIGHT IN ENGLAND.

Whilst England has quite an extensive coast line it is only in the south-western corner that it is washed by the ocean, but there is considerable erosion in parts of the coast elsewhere. Sandhills and dunes exist and such is the force of the wind, in parts of Lancashire, for example, that trees are windswept, growing some 8 degrees out of the perpendicular, and have all their branches growing to one side. In cultivated fields surface wash can be noted after heavy rain showers, and, on the brows of fields, sheet erosion has long since occurred.

This is illustrated in parts of the country where subdivision of the fields has been carried out by utilising the stones exposed on the surface to build the dividing walls. These walls are added to from time to time still.

Flooding by rivers takes place, sand bars exist in most estuaries, and dredging is carried out continuously in the River Mersey and others to maintain a free channel.

CLIMATE, SOILS AND SLOPES.

Apart from these remarks, erosion in England, however, is minimised by the following factors.

The most obvious factor is the favourable climate which is moist; the land mass is small and entirely surrounded by sea and extremes of temperature are largely obviated. The annual rainfall is fairly constant. The Southern Region receives 25 inches of rainfall, the Midlands between 35 inches and 45 inches, and Wales, the Lakes, and west of Scotland from 40 inches to 60 inches each year.

There is much mist and fog, the sun being frequently obscured; dry periods seldom exceed 4½ months and wells rarely fail. These factors together with sound farming practices are largely responsible for the excellent grass cover that exists both on the permanent and the temporary pastures.

All soil types exist from light sandy loams to the heaviest of clays. Most of the arable farming is carried out on the medium clay loams.

Soil texture is good generally, but deteriorated considerably during the intensive farming period of 1914-1921.

Slopes of most arable fields are moderate, since, in the past, tillage has been largely carried out by animal draft implements. Slopes of 1 per cent. to 4 per cent. are common, but many fields of 5 per cent. to 7 per cent. slopes are tilled one year in four in hill farming districts.

METHODS OF CULTIVATION.

Most of the tillage has been carried out by the use of mould board ploughs, either by animal or tractor draft, but ploughing has been done at a moderately slow pace.

Mechanisation rapidly increased during the 1916 to 1921 period, but fell away during the depression years only to increase again still more rapidly from 1936 onwards under the pressure of war demands. (It will be interesting to observe the effect of this fuller mechanisation in later years as field sizes are being increased.)

The use of mould board ploughs in the past appears to have been beneficial in limiting soil losses, for, on clays and clay loams, the bouts of ploughing are set up closer (Fig. 1), and open furrows, left by this type of plough, have acted as surface drains for many years past.

This is the case also on land later seeded to permanent pasture. The bed of the open furrow lies on, or below the plough pan, and as the last few furrows turned usually contain more grass roots there is little tendency to scour on slopes prior to the crop being planted (Figs. 1 and 2).

Where winter wheat is sown these open furrows still partly exist, though naturally smoothed out and seeded over, yet they still continue to act as surface drains to a slight extent.

For winter ploughing the furrows are more set up on edge than for spring ploughing when "digger" type mould boards are more often used. The set of the furrows permits rain to penetrate and allows any excess to seep below the furrow slice whilst minimising any soil movement. On a slope the open furrow may fill and overflow but it leads down to a headland which has been ploughed across. Here the excess water will pond and any soil wash is caught. Although flooding may occur there is seldom any discharge as most headlands have hedges with banks or ditches adjacent. Fields with any slope invariably contain richer soil at their lower boundaries.

These conditions do not exist to the same extent where disc ploughs are used, unless separate bouts are laid out and ploughed around. With discs the soil is more pulverised.

The depth of ploughing lies between 4 to 7 inches since root crops are usually grown in the rotation first, followed by grain.

DRAINAGE.

In England, of necessity, great attention has been given to efficient land drainage in all fields liable to saturation by the provision of a system of field drains of tile piping set in the subsoil. Once saturation has been reached, excess water percolates to the drains and is led away by main drains or discharges to open ditches along the hedgerows, replenishing farm ponds along its route. In summer as much as 20 per cent. of rain falling may be drained off by such field drains, and in winter between 40 per cent. and 70 per cent.

FIELD SIZE.

Sizes of arable fields are somewhat small, usually from 12 to 30 acres on undulating ground, and from 30 to 80 acres on level ground; field sizes in the past were decided by workable unit size for a family with the implements then available. The general length of furrow still approximates the "Furlong" (Fig. 3).

The small size of the fields has undoubtedly been a considerable factor in reducing the amount of run-off, whilst the "Jigsaw" layout partly follows the contours. Country roads twist and wind about similarly. Much can be said for the value of the hedge-rows which surround most fields: many are banked up, or have ditches and these frequently act in a manner similar to that of a grassed absorption bank. This is well illustrated in Fig. 3.

CROP ROTATION.

The rotation is both varied and extended. Basically it is first year roots, second year grain crop—later seeded, third and fourth year hay crops and grazing. Modifications may extend the sequence period of the root crop according to the cleanliness of the ground and seasons experienced.

The root crop is the soil builder; to it is given deeper tillage, heavy applications of dung and fertiliser. After the lifting of the root crop, at the beginning of the winter rains, the soil is in a somewhat friable state but the residue of topped leaves lying about partially protects the surface soil, whilst the remnants of the ridges from which the roots have been extracted permits the rain to penetrate deeply.

In the case of winter sown wheat, this is seeded almost immediately and the resulting "braird" helps in retaining the soil.

OTHER MANAGEMENT FACTORS.

Considerable quantities of farmyard manures are used since stock are yarded during most of the winter and much straw and fodder is available for litter and feeding. Dung handling has been facilitated to a great extent by the increasing use of mechanical loading grabs and trailer-spreading in more recent years.

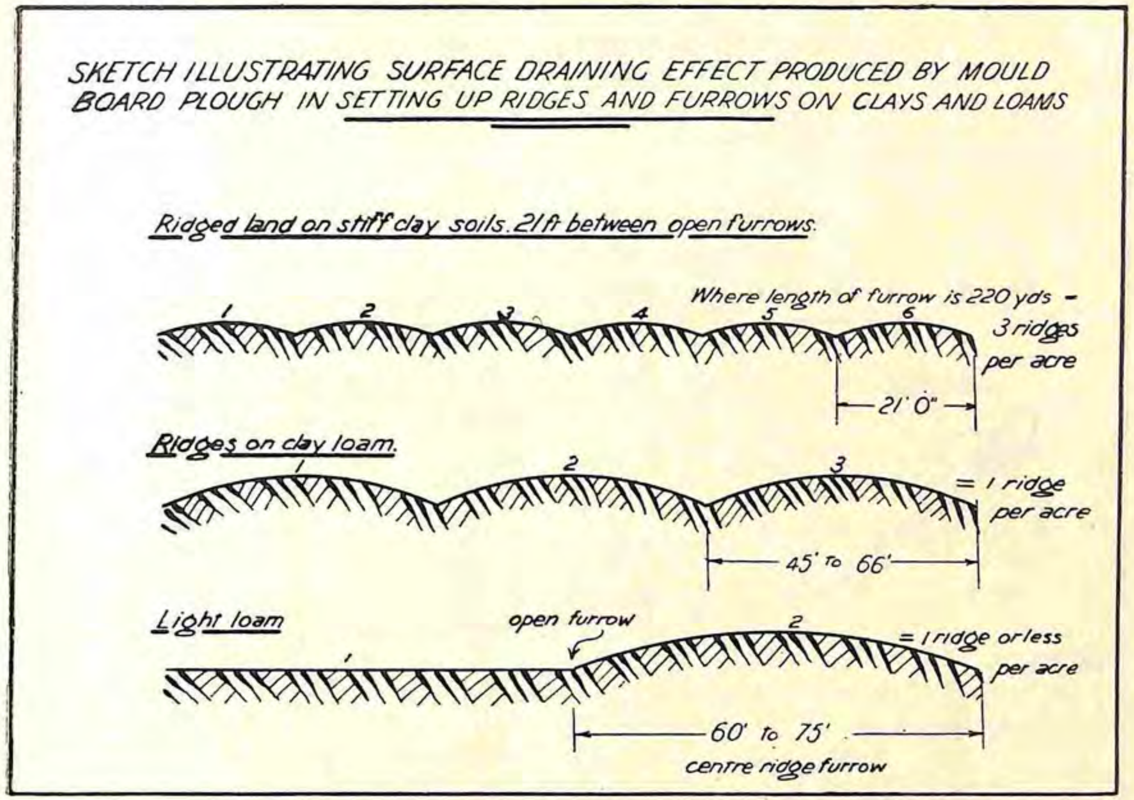

Fig. 1.

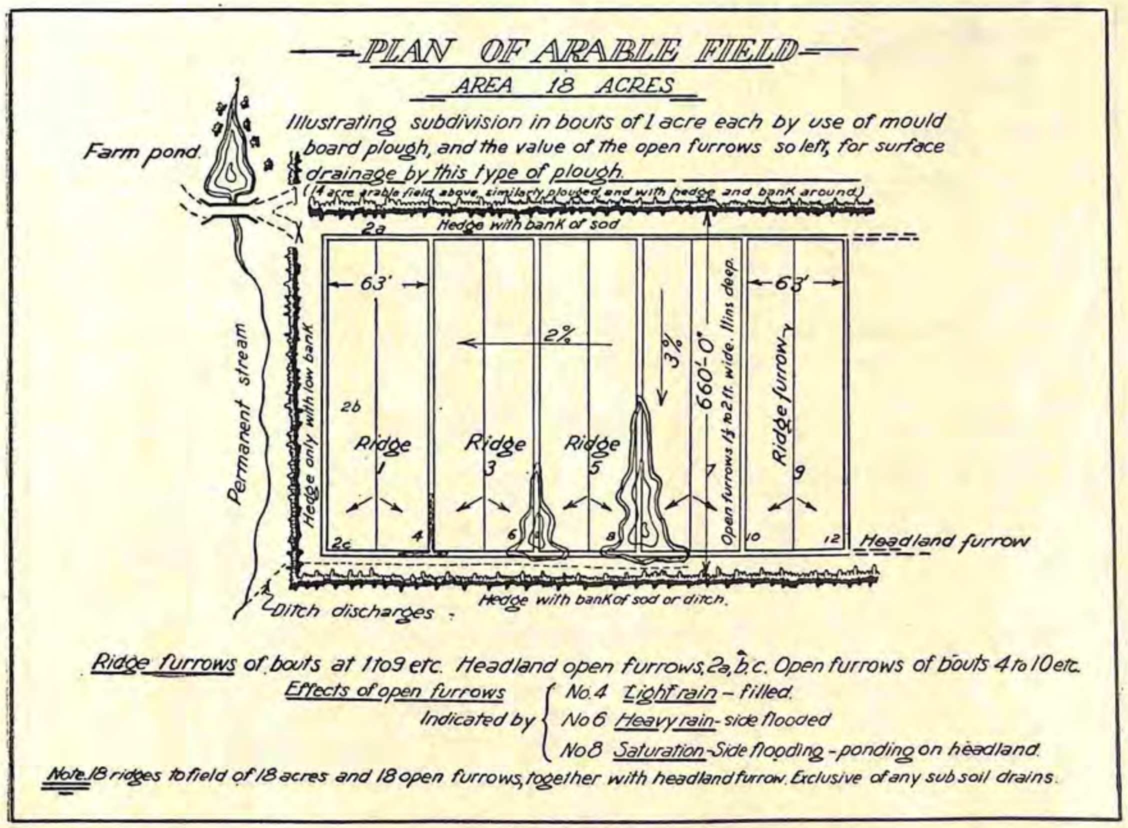

Fig. 2.

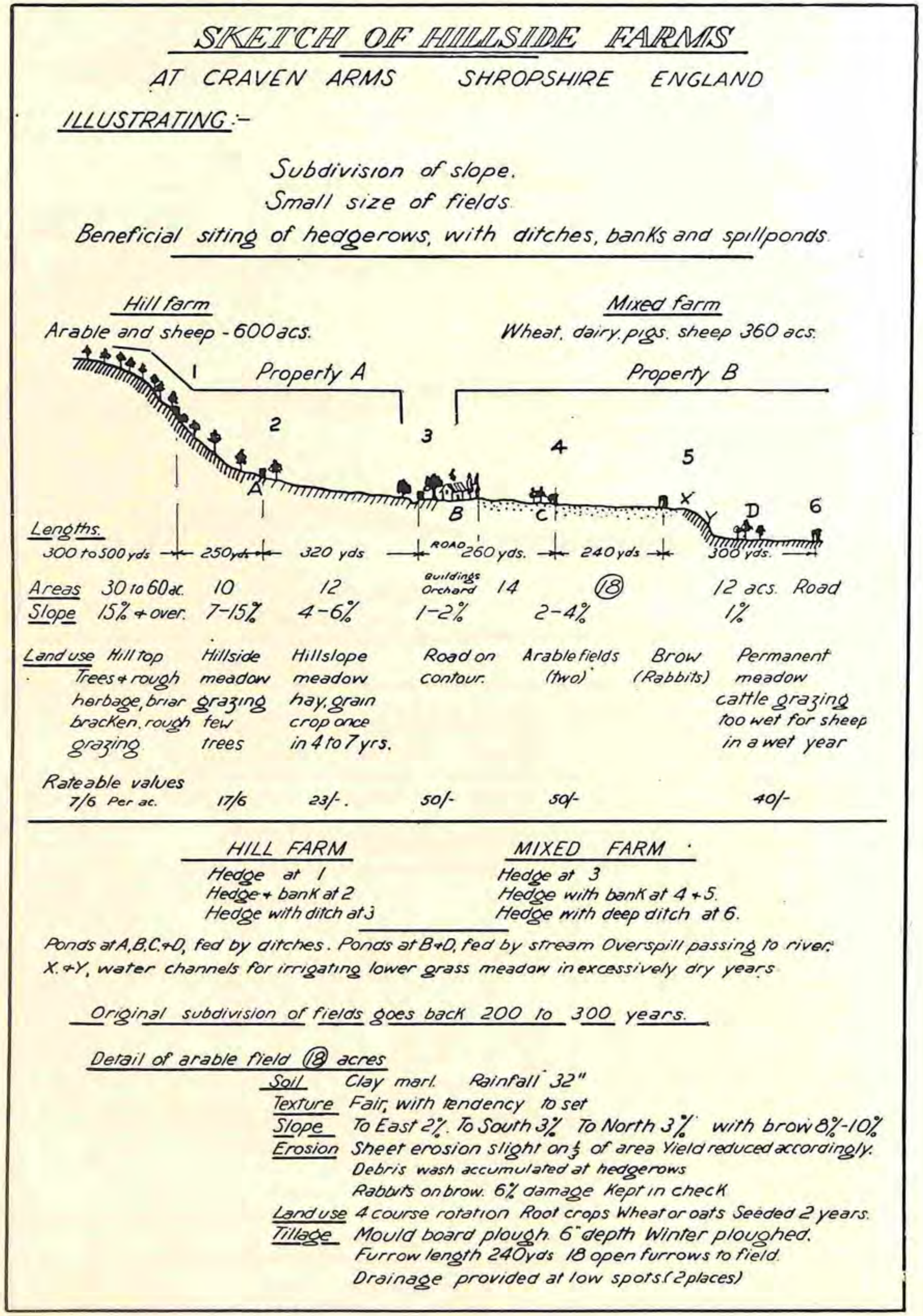

Fig. 3.

Since much permanent pasture exists, stocking is at a high rate. Cattle are followed by sheep. Stock are seldom allowed on arable lands except in the second or third year after seeding to grass, or, on the lighter soils when "folding off" on turnips. Sheep are kept off soils which have any tendency to run or set.

A great deal of care is given to meadows and pastures. Brush, chain, chopping and scratch harrows are used in renovation with rolling after frost periods. In meadows set apart for hay, brush or chain harrowing is done to spread animal droppings and the soil of molehills thus obtaining an even mowing swathe. Liming and topdressing are done when necessary.

Rabbits, although present, are few, providing both an article of diet for a human population more numerous, and a useful week-end sport for miners and others; the whole countryside co-operates in rabbit destruction at harvest time and trappers are active in all districts.

Tenancy agreements place first and foremost a clause for the maintenance of soil fertility on the holding. A rotation which is to be followed for the particular locality may be laid down, and a further clause stipulates that all dung produced on the holding will be utilised within its boundaries and not sold.

PROTECTED CATCHMENTS.

Catchment areas of water storages are well established, afforested, contain good grass cover and are closely controlled, whilst most streams and rivers have tree-lined banks and are well stabilised.

SUMMARY.

In Great Britain the climate is favourable for the maintenance of grass cover. There is freedom from long, dry periods and sun temperatures are not excessive. Rains occur mostly in winter, and are fairly constant. Excessive rains are disposed of by subsurface drainage. Moderate slopes are cultivated and field sizes are small. Stocking is heavy, but cover is seldom depleted since ample reserves of fodder are available. Rabbits are not a large problem. Land fertility is protected and maintained as high as possible. Catchment areas carry a good cover and are generally afforested.

APPENDIX I.

RAINFALL DATA FOR AN AREA OF MODERATELY LIGHT RAINS IN ENGLAND.

Comparison of Monthly Rainfall for Tamworth, N.S.W. and Rothampstead, England.

Month of	*Tamworth, N.S.W.*	*Rothampstead, England.*
January ...	2.6 inches	2.3 inches.
February ...	2.7 ,,	2.0 ,,
March ...	2.3 ,,	1.9 ,,
April ...	1.9 ,,	2.0 ,,
May ...	1.9 ,,	2.1 ,,
June ...	2.2 ,,	2.1 ,,
July ...	1.7 ,,	2.6 ,,
August ...	1.9 ,,	2.7 ,,
September ...	2.2 ,,	2.2 ,,
October ...	2.3 ,,	3.1 ,,
November ...	2.6 ,,	2.8 ,,
December ...	2.7 ,,	2.8 ,,
	27.0 inches	28.6 inches.

Amount of Rainfall in Summer—
Tamworth = 15.2 inches.
Rothampstead = 13.7 inches.

Amount of Rainfall in Winter—
Tamworth = 11.8 inches.
Rothampstead = 14.9 inches.

Amount of rainfall, in inches, passed to field drains at Rothampstead—

Average rainfall for year	= 28.6 ins.
Amount in inches passed to drains	= 15.1 ins.
Of this drainage in Summer	= 4.1 ins.
Of this drainage in Winter	= 11.0 ins.

Represents drainage average off fallow land over 54 years recorded. Soil moderately heavy clay, normally cropped to roots, wheat and oats.

APPENDIX II.

Illustration of Rainfall Intensities at Rothampstead.

Year.	*Number of storms over*—		
	0.4 *inches per hour.*	1.0 *inches per hour.*	2.0 *inches per hour.*
1944 ...	10	1	...
1945 ...	6	...	...
1946 ...	12	3	2
1947 ...	4	3	1
1948 ...	3	...	...

(1946—exceptional flooding at harvest time and much of crop ruined.)

Months of year receiving maximum storm intensities—
September.
July.
October.

Maximum intensity recorded at Rothampstead—
(1944 to 1948 only).
Date— July, 1947.
Duration— 5 minutes.
Amount— 2.1 inches.

SOIL CONSERVATION SERVICE PLANT HIRE

Application at Parklands, Scone.

BY

K. G. Secombe, H.D.A., Soil Conservationist.

SINCE the Plant Hire Scheme came into operation, a steadily increasing number of requests have been made in the Scone Soil Conservation District for work to be carried out. Some are for only small jobs and some are for work involving many hundreds of pounds.

One such request was made by Mr. F. A. King, of "Parklands," Parkville, and it is proposed to present some of the facts surrounding the project, for the interest of landholders considering availing themselves of the benefits of the scheme.

EROSION PROBLEM.

This property of 1,400 acres is situated adjacent to the New England Highway, about 7 miles north of Scone. The slopes vary from 3-10 per cent. for the larger part of the holding to mountainous country (over 20 per cent. slopes) on the eastern boundary. Approximately 600 acres have been under grazing lucerne for some years, and 200 acres are cropped to wheat.

Over the years the uncontrolled run-off from the mountainous country on the eastern boundary has produced gullies which, together with their silt loads, were damaging the lower country. The erosion was reaching the stage of rapid acceleration.

CONTROL MEASURES.

A control scheme was prepared by the Soil Conservation Service as indicated in Fig. 1.

The watercourse draining in on the north-eastern corner of the area was scouring in many places and depositing silt and rubble on the grazing lucerne paddock below. To achieve control of this water a large dam was constructed in the gully with a 300-yard long diversion bank to convey the overflow to a safe point of inlet to the main gully which flows through the centre of the area. This gully is quite stable and no trouble is anticipated as a result of the increased volume of water. The natural grassed inlet from the diversion bank to the gully has been Kikuyu sprigged and fenced to give further protection in times of high run-off.

As well as serving as a spillway for the dam, this diversion bank gives "top water" control to the paddock immediately below it. At a later date this paddock could be pasture furrowed or graded banked as necessary.

The southern half of the subject area has been cropped to wheat for a number of years and sheet erosion and minor gullying was developing. The 1947 crop was sown on the contour, but without any mechanical aids. This undoubtedly did serve some purpose, but now the whole area has been graded banked (0.25 per cent. fall) at intervals of approximately 2-4 chains. These banks discharge into a stable grassy watercourse along the southern boundary of the area. To give protection from drainage from the mountainous country on the east, a series of three graded banks were constructed above the cultivation, spilling to the main central watercourse.

All banks were constructed with a bulldozer and ripper, and one final run through the channel was made with the grader. Banks thus constructed cannot be worked across, but the saving in cost of construction more than compensated for ground lost to cultivation, and a vegetated bank is less susceptable to damage in times of high run-off than a bare one. Provision was made at the origin end of each bank for machinery to cross from one "land" to the next without difficulty.

It will be noted that only half of the paddock in the south-western corner has been banked. There were several reasons for this:—

(1) It is intended at a later date to construct a road along the ridge at the origin end of these banks. Then the balance of the paddock will be banked, discharging towards the north.

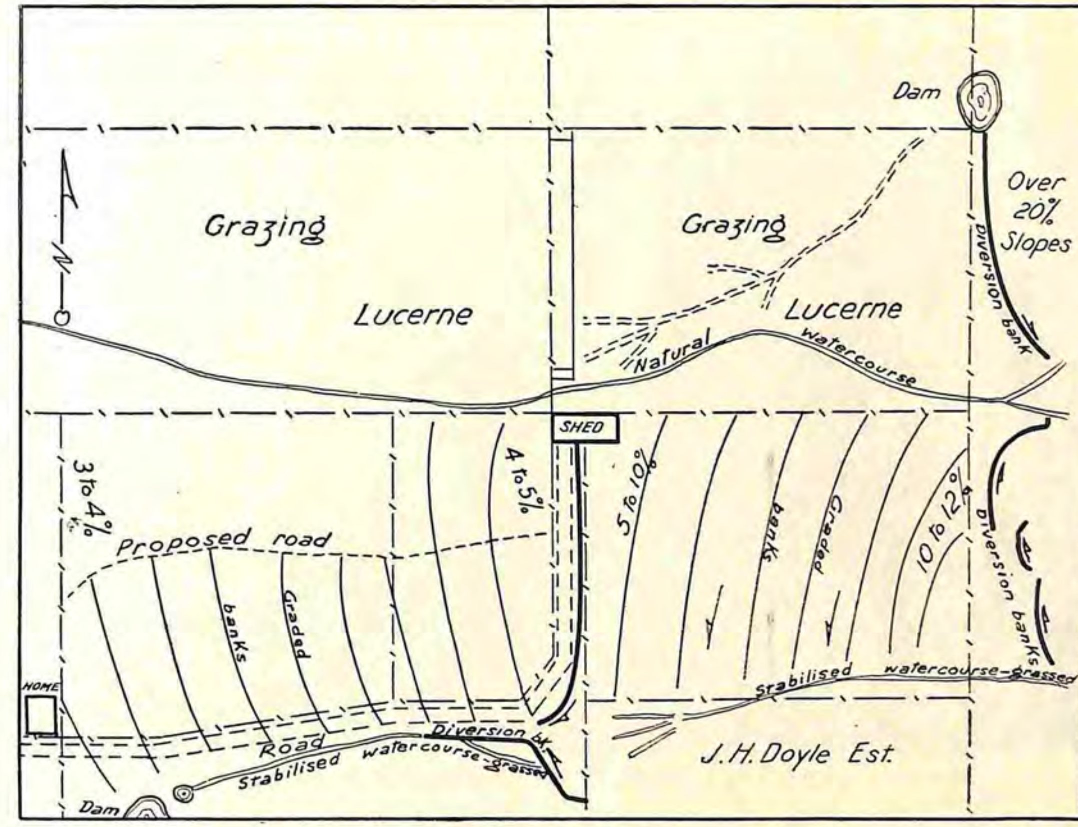

Fig. 1.—Parklands.

Fig. 2.—Erosion damaged lands prior to the adoption of soil conservation measures.

Fig. 3.—A newly constructed dam designed for the soil conservation programme. Note the steep nature of the catchment.

Fig. 4.—The overflow from the dam shown in Fig. 3 safely conducted along a grassed diversion bank.

Fig. 5.—A graded bank with dense cover of lucerne, Wimmera rye grass, Rhodes grass, and oats.

Fig. 6.—Graded banks on the arable land in the south-east corner of Fig. 1.

(2) In view of the fact that an alternative disposal area was available to the north of this paddock it was considered advantageous to avoid excessively long banks draining only to the south.

The banked paddocks have been sown to a mixture of:—

5 lb. lucerne per acre.
2 lb. Wimmera rye per acre.
2 lb. Rhodes per acre.
20 lb. oats per acre

and all banks were broadcast with the same mixture. An excellent germination and subsequent growth has been obtained.

Since this work has been completed, an unusually wet season has been experienced, and the work has proved most effective in arresting all soil movement in the treated areas.

For the information of any who may be of the opinion that contour cultivation and working between banks is an unsatisfactory and cumbersome procedure, Mr. King has offered to write his opinions of conservation farming now that he has had the experience of this modern form of farming. His comments, as follows, are worthy of serious consideration.

THE LANDHOLDER'S ANGLE.

BY

F. A. KING, "Parklands," Parkville.

For the benefit of any who may have any doubts as to the value and convenience of soil conservation farming, I quote here my experience.

Graded banks in the cultivation give quite good working conditions, particularly on the lesser slopes where banks are wider apart. Where the slope is greater and banks are consequently closer together (say, less than 2 chains apart) it is problematical whether country of this nature should be cultivated in any case.

Advantages associated with soil conservation farming are:—

(1) More economical working as the machinery is working on the contour. This obviates low gear work and the tractor is working under an even and constant load.

(2) All ridges left by cultivation are on the contour, thus tending to hold water and drive it into the ground, rather than encourage run-off and consequent erosion.

(3) The actual bank areas, whilst not being available for crop cannot be classed as waste. Apart from the protection the bank vegetation gives, this vegetation provides excellent feed and gives a more balanced ration at the time of feeding off the stubble.

(4) Prior to the work being carried out, the cultivation paddocks were all commencing to wash—minor rills were becoming more frequent, and gullies up to 1 foot deep developing. Since this system of graded banks was installed, one of the wettest years on record has been experienced but no soil movement has taken place in the treated areas. Had these banks not been constructed I feel sure that serious sheet and gully erosion would have taken place.

(5) The cost of the whole operation was very reasonable and quite within the scope of the average farmer.

Consequently, I have no hesitation in suggesting that any landholder who is experiencing soil erosion problems or can visualise any such problems as being likely to occur, should contact the District Soil Conservationist in whatever district he may happen to be and avail himself of the facilities available.

STOCKING AND STOCK MANAGEMENT IN THE CONDOBOLIN DISTRICT WITH A VIEW TO SOIL CONSERVATION

BY

D. D. H. GODFREY, H.D.A., Soil Conservationist.

OF the many factors contributing to soil erosion, overstocking and other injudicious stock-management practices are perhaps the most important in this district. It is also well for us to realise that by far the largest area of this State is used for grazing purposes and it is, therefore, essential that such grazing be of a wisely controlled nature if these vast grazing areas are to remain an asset for future generations rather than a liability. The principles outlined below apply not only to the Condobolin district but to grazing districts generally throughout the State, particularly in the drier areas.

Erosion on grazing properties is directly related to the question of stock management, and the basic cause of erosion can be attributed to overstocking, in one or more of its many aspects. These various aspects are dealt with in detail below.

SIGNS OF OVERSTOCKING.

The obvious signs of overstocking are:—

1. The disappearance of the more palatable grasses, especially perennials, coupled with an increase in the number of non-palatable species, often noxious weeds, such as roly poly, saffron thistle, galvanised burr, No. 9 (wire grass) and many minor grasses and weeds of little or no feed value for stock.
2. The appearance of small bare patches of ground with consequent further damage by wind and water and a gradual increase in the size of these bare patches until they reach sometimes the alarming size of hundreds of acres.

The above exposure of the soil surface results in the removal of the fertile top-soil by wind and/or water, leaving the familiar "scalded" plain or severely gullied areas in place of what was once a fertile plain or an even well grassed hillside. In addition, the replacement of our hardy, drought-resistant and palatable "root" grasses or perennials by the shorter lived annual grasses (even although they be palatable to stock) means an increase in the severity of each succeeding dry period because of the inability of these annual species to reproduce themselves or grow adequately under drought or semi-drought conditions. When the above signs of erosion are evident, the actual carrying capacity of the land has been reduced, more or less in proportion to the eroded areas and the disappearance of the perennial and palatable species. Land which previously carried one sheep to two acres, may now be able to carry only one sheep to four acres, and it must be realised that stock carried above this figure help to accelerate erosion, in turn reducing the actual carrying capacity still further.

STOCK MANAGEMENT.

1. *Carrying capacities and stocking figures.*

When we speak of stocking figures we are very inclined to accept the figures obtainable from the Pastures Protection Boards as the correct or most suitable carrying capacity for a particular property; this may or may not be so; generally it is the latter. These figures are not intended to be an indication or a recommendation of the number of stock that the Board concerned considers can be safely or economically carried on that property; they are, in fact, an average of the number of stock actually carried on the property over the last five-year period and are the occupiers' own figures as submitted by him on his yearly stock return to his Pastures Protection Board. These figures are, however, of considerable assistance in assessing the carrying capacities of

Fig. 1—Judicious stocking has maintained this dense sward of corkscrew grass under lightly cleared Bimble Box and Bulloak.—[*Photo*: N.C.W. Beadle.

properties in that, over a ten-year period or so, they may be used as a guide in relation to the present condition of the grass cover on the land as against the known seasonal conditions and market trends for the same period. This evidence may indicate only that the land in question was incapable of carrying safely that number of stock under the existing management and seasonal conditions. Any signs of land deterioration shows that the past land management has been too severe.

2. *Rabbits, Kangaroos and Emus.*

The number of rabbits on the property will, of course, temper the significance of the above figures. Kangaroos and emus are considered here more for the effect that any great numbers of them may have on rabbit-proof fences. In some areas where these animals are plentiful they have been known to invade a paddock which is being rested from stock and, in addition to what they actually eat, which may be quite considerable, they have done serious damage to fences, and so allowed the easy invasion of the area by rabbits, with obvious results. Many landholders have proved, over a period of years, that the rabbit can, by persistent and continuous action, be controlled, but, unfortunately, in very few cases completely eliminated. The damage done by rabbits, in addition to what they actually consume, is increased by the ringbarking of stems and roots of edible shrubs.

3. *Class of stock.*

As a general rule it may be stated that cattle do considerably less damage to pasture than do sheep. This is chiefly because of the more selective and close grazing habits of sheep. Also cattle generally run in smaller mobs and often graze and roam as individuals, while a flock of sheep usually graze an area on a face and often in one mob. It is generally accepted that one head of large stock is equivalent to ten sheep for grazing purposes.

4. *Breeding.*

If breeding is to be considered, it must be remembered that a weaner eats almost as much as a full-grown sheep, and that calves, lambs, etc., start eating grass very soon after

they are born. Extra allowance should therefore be made for stock which are carrying or suckling young.

5. *Domestic animals.*

Seldom is enough consideration given to the pasture for the odd milking cow and her calf, the half-dozen or so "killers," pigs, goats or saddle horses, etc. Often two or three cows, and perhaps a calf or two, a saddle horse and some half-dozen poddy lambs are running in the 30 to 40 acres house-paddock with very little supplementary feeding; this is the equivalent of a little better than one sheep to one acre and there is very little safe sheep per acre country in the State. The obvious result of this in the drier districts is a bare, eroded and unsightly area near the homestead.

6. *Subdivison and watering places.*

Generally, large paddocks and few watering places lower the overall carrying capacity of a property. With adequate subdivision and watering places stock may be rotationally grazed, and a portion of the property rested all the time. Large flocks of sheep watering from the one place continually wear "pads" (often 4 inches to 5 inches deep) to and from water. These pads are very liable to collect and run water and often become severe gullies, which help to drain the soil of much needed water and cause excessive silting of dams and tanks. Stock also tend to congregate round the watering place at some periods of the day, trampling and killing off more grass than they actually eat. The ideal practice is to have as few stock as possible using the one watering place, or small flocks with a choice of watering places.

7. *Conserved fodder.*

An adequate reserve of fodder has often been called "the grazier's best insurance against drought" and it is cheap insurance.

With a sufficient reserve of fodder, it is unnecessary to allow all paddocks to be eaten right down during drought or semi-drought periods. Successful fodder reserves in this district have consisted of hay (lucerne, oaten, wheaten or a mixture),

Fig. 2.—*Craspedia crysantha* (buttons) which, through overgrazing, has become the dominant pasture species in cleared country originally supporting *E. Woollsiana.* Near Barmedman. [*Photo*: N.C.W. Beadle.

Fig. 3.—" An example of sheet erosion caused by overgrazing near Micabil."—[*Photo*: N.C.W. Beadle.

preferably baled, grain (usually oats), silage (not much here), and of course fodder trees; some landholders are fortunate enough to have a supply of all the foregoing. The grazier fortunate enough to have a frontage to permanent water has the opportunity for irrigation—even 10 to 20 acres is considerable—and any irrigation, wisely used, will pay for itself in a remarkably short time.

Another way of conserving fodder in the drier areas is by stocking very lightly, or completely resting portions of the property in turn, especially during flush seasons. This allows an extra body of feed to develop and eventually seed, which generally means more feed and better soil protection, and so better pasture, in the future.

8. *Woolshed, yards, etc.*

The shearing shed is very often the focal point for serious erosion due to the extremely heavy stocking to which the shed holding paddock is subject; the damage is caused by excessive grazing and trampling during shearing, crutching, dipping and perhaps lambmarking and Mulesing, and the area is never given an opportunity of "catching up." For this reason it is important that the shed paddock be free of stock except when the shed and yards are being used, and then every effort should be made to move sheep to the outer paddocks as quickly as possible.

Consideration should be given to the erection of temporary yards for Mulesing, lambmarking and also, perhaps, for crutching and dipping away from the woolshed. Paddocks giving access to the woolshed are not then being flogged and severely trampled every time the more important sheep-work is taking place.

9. *Agistment.*

This practice may be a very big factor in causing erosion; agisted stock very often do untold damage to pasture and soil protection, in that, for the sake of an immediate cash return, the property is overstocked for a period beyond its safe carrying capacity; any extra feed is being removed from the property instead of providing an extra supply of seed to the soil, and extra protection to the soil in the form of dead and living vegetable matter not required by the normal stock carried.

Fig. 4.—An extreme case of scalding on a sandy loam soil overlying a clay. The original vegetation was a savannah woodland of bimble box (*Eucalytus populifolia*). Condobolin district. [*Photo*: N.C.W. Beadle

10. *Erosion control and Soil Conservation.*

There are very few grazing properties in the State on which soil erosion is not evident.

In the case of seriously eroded areas the first step in correcting soil erosion is the complete exclusion of all stock and rabbits. On some properties this is almost impossible and the owner has to be content with their partial exclusion, in which case final regeneration will be correspondingly slow. If further corrective action is required, then mechanical measures such as pasture furrows, absorption banks, diversion banks, gully structures, etc., and the application of artificial fertilisers and the sowing of seed may be necessary.

It is obvious that prevention is better than cure, and most sloping pasture land, eroded or non-eroded, is definitely improved by the construction of pasture furrows, the correction of possible past malpractices such as overstocking, and the realisation that "care of the soil" is paramount.

11. *Returns.*

Economics play a very important part in the stock and land management policy. When prices for primary products are high, every effort will be made by some primary producers to increase their output without consideration of the effect this increased production may have on their soil and its future productivity. On a grazing property this increase may mean serious overstocking.

Finally, it is well to observe the relation between the actual carrying capacity of a property and the returns. It will be agreed that the greater the number of stock carried per unit area, the greater will be the overhead expenses per unit area. This will be more easily understood by quoting an example in the case of wool-growing. A grazier in the New England Tablelands district had run one sheep per acre for many years with a handsome net profit. For experimental reasons he reduced this rate to three-quarters of a sheep per acre, with the result that, after a period, the net profit per acre was even greater than previously. This was due to the fact that the smaller number of sheep were able to produce the same amount of wool and lambs as the larger number, because of better feeding conditions. By this means the grazier was receiving the same gross returns but with a considerable decrease in his overhead expenses.

Fig. 5.—Grazing land badly gullied adjacent to Wallamundry Creek, near Condobolin.
[*Photo*: N.C.W. Beadle.

Many graziers, both in the Eastern districts and in the Western Division have also realised this tendency by dint of actual experience, and the sooner the realisation becomes universal the more profitable and productive will our grazing lands become. I consider that there are many thousands of properties in the State where a review of present stock numbers could be carried out with benefit both to the grazier's pocket and to the land.

CONCLUSION.

Listed hereunder are the most important causes of soil erosion on grazing land:—

1. Over assessed carrying capacities.
2. Rabbits.
3. Overclearing.
4. Large flocks and mobs and few watering places.
5. Unnecessary stocking of woolshed holding paddocks and the lack of temporary yards.
6. Agistment.
7. Exploitation.

It will be noted that the above are all closely related to overstocking and stock-management.

Before commencing any programme of land management, consider first and foremost "How will this affect my soil protection?" If the answer is even doubtful where the soil's stability is concerned then DON'T DO IT. The most important factor of all is the realisation of the land's correct carrying capacity with due regard to seasonal vagaries and practical application. For the assessment of this carrying capacity the paramount consideration should be the stability of the capital asset, the soil.

In the past, innumerable efforts have been made by Man to squeeze and abuse Nature but Nature cannot be abused in any way and at the same time satisfy Man's wants. If we do not in the future take more care of our grazing lands, and hence our soil, than we have in the past, our greatest asset will become our greatest liability.

FOREWORD

BY

E. S. CLAYTON, H.D.A., Commissioner.

THE need for water conservation in a country so poorly served as Australia in the matter of amount, distribution and reliability of rainfall has long been recognised. The community generally is also coming to a realisation that there can be no permanent and effective water conservation unless also there is effective soil conservation. Water conservation, in fact, begins by getting the rain-water into the soil of the catchment area, and in the absence of glaciers and permanent snow the basic reservoir is the soil itself or peat masses therein, which cover the parent rock. If it is deep, permeable and covered with vegetation, it retains amazing quantities of water which can be fed out to the streams by gravitation long after the rain has fallen. This action imparts some degree of continuity to the flow of a river.

Water storage dams and reservoirs for human consumption, stock use or irrigation, must be filled by run-off water from the associated catchment areas. This area may embrace all types of country from rough timbered mountains, hilly grazing, undulating arable lands to rich alluvial flats. If these lands are not used wisely and adequately protected by vegetation, there will be an excessive run-off of water, which will cause erosion. With an increased run-off more water reaches the storage dam, but it is muddy water and it carries great quantities of silt and soil and this is deposited in the dam, occupying the storage space which should be filled with water. Unless arrested this will continue until in time the dam is completely silted up and rendered useless, as dams have been in this as well as in other countries.

What is needed is that the surface run-off from the catchment area be clear water. Getting the water into the soil also ensures underground seepage which finally feeds into the streams after the rain has stopped. The only way to ensure this is to protect the catchment area from erosion by an understanding of wise land utilisation in the first place, to apportion lands to their appropriate use, and by preventing unwise cultivation on the steep slopes, over-grazing, over-clearing and burning. Anything which destroys the protection of cover of vegetation is a disadvantage in a catchment area.

Outside catchment areas the loss of surface soil by erosion is serious enough in itself, as it depletes the farm of inherent productivity; but in a catchment area, in addition to this loss, there is the serious effect on streams and storage reservoirs which are the lifeblood of the land.

One of the worst effects of denudation of forest cover in a catchment area is that it vastly increases the run-off during rainy periods with consequent diminution in the rainless periods; thus the continuity of flow of the streams is interfered with.

This brings us to the realisation of the need for protective forests in catchment areas in addition to the commercial forests. Where properly managed commercial forests are maintained it is possible to ensure practical protection to guard land against erosion and for safe water production. There are, however, large areas of rough and often inaccessible mountain country where the soils are too shallow, or the slope too steep, to produce satisfactory swards of grass. These should not under any circumstances be settled on account of their unsuitability. In a scheme of catchment area protection these areas should be dedicated as protective forests. Timber-getting and appropriate forest management for timber production would not be a practical proposition, though some timber may be removed. Such areas should not be grazed or burnt. and the vegetative cover should be preserved to ensure safe water production. Such areas are of greatest value for safe water production, and their value to the nation as grazing lands is negligible in comparison.

While there is still time in this country of scanty water resources, our thoughts should turn to the early complete protection of our vital catchment areas, remembering that the line between protection and restoration is subtle but important. Protection begins with wise land use and forestry; restoration ends with costly public works and expensive engineering structures.