4. This photo, taken in the Lower Belford district, shows the result of spreading by Soil Conservation Service bulldozers. This sand was left by the flood as a deep spit which the farmer could not handle. After spreading by 'dozers it is reduced to a depth which will allow the operation of ordinary farm machinery. The next stage was to get some vegetation growing on the sanded areas.

5. This photograph gives an idea of the height of the river over its banks near Jerry's Plains. Mr. Reynolds of the Soil Conservation Service is standing on land which is approximately the normal river bank level. The debris in the tree above his head would indicate a depth of 10-11 feet.

6. This photo was taken on the flats upstream of Jerry's Plains. This land previously carried an excellent stand of irrigated lucerne. The rocks and stones were deposited up to a depth of about 1 ft. 6 in. in what was the strongest part of the stream running across the flats. The stones were pushed into conical heaps so that they occupied as little ground as possible. Farm machinery has recently been able to work on this area.

FOREWORD

BY

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

An important step towards the restoration of eroded catchments was the undertaking of detailed surveys in the field. The Soil Conservation Service undertook during 1941-43 a reconnaissance survey of the erosion position in the whole of the Eastern and Central Divisions.

In addition to this survey of erosion in the Eastern and Central Divisions, detailed surveys have been made of Hume, Blowering, Jindabyne, Keepit, Glenbawn, Brushy Hill and Warkworth Catchment Areas. At the present time, surveys are in progress in the Wyangala, Burrendong, Warragamba and Burrinjuck Catchments.

These investigations have enabled an evaluation to be made of the causes of erosion in each area. Whilst the basic pattern is somewhat similar in each area, the direct causes of the deterioration vary in accordance with the land-use of the catchment.

To illustrate particular examples, consider the facts revealed by the detailed investigation of the Keepit Catchment Area. It embraces the Namoi River and its tributaries above the Keepit Dam. The area is approximately 1,408,000 acres. It includes part of the North-Western Slopes and Northern Tablelands, and is bounded by the Nandewar, Moonbi and the Great Dividing Ranges.

The catchment of Keepit Dam has been largely denuded of trees. The lower and intermediate slopes have been cleared for cultivation or to improve the growth of natural pasture for grazing. The eastern part of the catchment where steep slopes and rugged country is encountered has been over-cleared, with a resultant increase in erosion hazard.

Erosion throughout the Keepit Catchment was so serious that a warning was issued by the Soil Conservation Service of N.S.W. that the useful life of the dam would be endangered by siltation unless active steps were taken to reduce the erosion occurring on the catchment area.

The eroded condition of the catchment was a *result*. It was the result of a history of incorrect land-use.

Settlement first began in 1830 and holdings covered large areas which were used for grazing cattle. The natural vegetation of woodland savannah was little affected by this occupation.

In 1872 the majority of pastoral holdings came up for review and there was a rush for selection. The small areas of the selections, and the increase in stock numbers, particularly of sheep, caused the new settlers to kill the trees to improve growth of pastures. Steep slopes unsuitable for grazing were also cleared.

Between the time of subdivision of holdings and the year 1900, wheat production rose from 3,000 bushels to 300,000 bushels. This increased to 750,000 bushels by 1921. This period marks the beginning of the serious sheet erosion which paved the way for the spectacular and disastrous gullying that has followed in the last twenty years.

Everything points to the great necessity for protecting all the catchment areas. However, a clearly defined pattern of activity must be followed to achieve this protection. The pattern of activity falls into three broad fields—management, revegetation and mechanical treatment.

Good management firstly requires preservation of timber on the steepest and most dangerous portions to prevent severe erosion, and the planting of those areas which have been unwisely stripped of timber cover.

Destructive fires must not be allowed to destroy timber and scrub on high country.

The mechanical works installed by the Soil Conservation Service in many parts of this State by way of demonstration, together with the work undertaken on the Service's Research Stations, and the specialised activities carried out on the catchments of Keepit, Glenbawn and Burrendong Dams, have enabled us to develop an exact knowledge of the types of mechanical works best suited to New South Wales conditions.

The greatest portions of the catchments are, of course, alienated land held by private interests under freehold title. Education, inducement and example, therefore, are the most appropriate means to lead the way to proper land-use.

It is particularly gratifying to be able to record that in these catchment areas throughout N.S.W. there has been a wonderful response on the part of the landholders, many of whom are wholeheartedly engaging in soil conservation activities under the guidance of the Soil Conservation Service but at their own expense. In fact, I know of no other instance anywhere in the world where landowners are doing so much at their own expense to protect the nation's catchment areas.

The Soil Conservation Service has brought a better realisation of the value of wise land-use as well as introducing an ever-widening application of contour farming and safe disposal of run-off.

The Catchment Areas Protection Board, constituted in 1938, came into existence too late to prevent much of the erosion, for most of the vulnerable lands had already been alienated. There was, however, time to protect some of the remnant Crown lands that still remained in the catchments. These are inaccessible, steep, shallow, often rocky lands, not suited to settlement, at the headwaters of the streams. It is essential to safeguard them, either by withholding them from settlement or imposing conditions which will preserve their vegetative cover and prevent erosion.

Four to five hundred cases are dealt with each year by the Catchment Areas Protection Board which decides whether the lands should be settled or not. When settlement is permitted, the Board fixes the conditions under which the land is to be used with regard to clearing, cultivation, pasture improvement and general management. In this way the vegetative cover will be preserved and the soil protected from erosion.

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THE USE OF BANKS IN SOIL CONSERVATION

BY

G. R. Wiltshire, H.D.A., H.D.D., District Soil Conservationist.

In the field of erosion control, the Soil Conservationist has a number of recognised techniques and structures to aid him. It is his job to use the correct combination of these in designing a soil conservation programme. A soil conservation programme is a system of land use whereby maximum production is attained, consistent with permanent maintenance of the soil fertility.

Of all the mechanical structures that are used, banks are perhaps the most important, in that, if they are well designed, well constructed and correctly maintained, they can be highly effective and efficient in controlling run-off and erosion; and conversely, if they lack good design or correct construction or adequate maintenance, they can be the cause of damaging erosion.

There are various kinds of banks. Some are used singly; they are usually fairly large and may have a grade, or they may be level. These are called Diversion Banks and they are often used to divert water, which is coming from an uncontrolled source such as a rocky knob, away from an area on which damage could occur. Others are used in a series and are called Graded Banks, if they have a grade or fall from the point of origin to the point of outlet; they are called Level or Absorption-type Banks if they are level.

The object of this series of articles is to cover the various aspects of design, construction and maintenance of banks in a brief but concise way and, where applicable, to suggest ways of checking them to locate possible faults after construction.

WHERE BANKS ARE USED.

The amount of soil erosion which occurs on land is determined by the inter-action of the basic land characteristics, the forces of erosion and the land usage. All soil conservation measures aim at altering, in some way, one or more of these three factors. Banks and other mechanical controls alter the basic land characteristic, windbreaks provide the classic example of alteration of the forces of erosion and modifications of the agricultural or grazing policy constitute changed land usage.

It is a self-evident fact, that the land usage is at fault if land which has been built up and maintained for ages under natural conditions commences to erode rapidly when cultivated or grazed. This is the position over huge areas of undulating farm land in this State, and especially so in the wheat-growing areas of the Western Slopes.

The arrest and elimination of this erosion on sloping cultivation country can be effective and, in time, complete, by a change-over to permanent pasture and grazing, but this would not be economic, nor would it be acceptable to farmers who want to grow wheat, whose plant is designed for wheat-growing and whose land values are based on wheat production. Accordingly, it is necessary for soil conservation programmes to be designed which will enable cultivation to be carried out on slopes varying from 0-12 per cent. and it is in such programmes that banks are often necessary.

It is also important to note that although the use of banks enables cropping to be carried on, they do not themselves constitute a complete soil conservation programme. It is still necessary to adopt a fertility-building crop rotation and, when this has been done, the whole comprehensive plan enables land, which could not otherwise be maintained as arable land, to be cropped while fertility and stability are permanently maintained.

There is also an increasing tendency to use level absorption type banks on hilly grazing country for the control of erosion, and for the control of run-off waters which would otherwise course down and destroy more valuable lands below. These are highly effective, they are easier to lay out than pasture furrows, and are especially useful where stony outcrops are interspersed with better land, as they can be laid out between the outcrops. They can be designed

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so that access to all parts of the paddock is easy, and they can be built with farm plant, and especially by the use of the small type of dozer which many farmers have fitted to their wheel tractors.

Other uses of banks in soil conservation programmes are as Spreader Banks in water spreading schemes, as catch drains for dams and tanks in water-harvesting schemes, and as retaining banks to retain water on flat country, away from active gullies.

OUTLETS FROM BANKS.

The object of building banks on cultivation country is to break up a long slope into a series of short lengths of slope so that water in flowing from one bank to the next does not develop an erosive velocity. The velocity of flow in the channel of the bank is controlled by the grade in that channel, and the water is conveyed away at a non-erosive velocity to the outlet. Providing the outlet is safe and no erosion can occur at this point or below it, the whole design is sound. In most areas the location of a place where banks can discharge without causing damage is most difficult, and in fact it often determines whether banks are feasible on the area or not, but a study of the various ways of disposing of water, enumerated below, should in most cases provide a solution.

Well Grassed Natural Watercourses.

The most logical and suitable place for the discharge of water from graded banks is into a well-grassed natural watercourse. If natural watercourses are free from gullying they usually have an ideal cross-section for the safe transport of water and they usually have a deeper, richer soil than other areas and, in consequence, are capable of absorbing a higher proportion of the water than are other lands.

It is unusual, however, for a well-grassed natural water course to be found in or alongside cultivation paddocks; usually they have been cultivated and, as a result of this, are badly gullied. Quite often, however, a cultivated natural depression can be found which can be grassed up and then used. In this case it is essential that the process of grassing of the depression is complete and that a sound and adequate grass cover is established before the banks are built. It is also at times necessary to build a temporary diversion bank to keep water away from the watercourse until the grassing up is completed.

Every aid should be given to the area to ensure quick and adequate grassing and as the total area involved is small, usually less than one acre, the expense involved in extra superphosphate, some sulphate of ammonia and straw mulching, is well worth while, especially when the benefits of a good waterway are considered. Protection of the watercourse from stocking during the establishing period is essential, this can frequently be achieved by having the rest of the paddock under growing cereal crop during the period, but fencing off the depression to enable permanent control is recommended although in some cases it is not essential.

An important aspect to be considered when determining where to discharge water from banks is the stability of the watercourse, not only at the point of discharge of the water, but also its stability lower down. A gully head in a natural watercourse will usually work up-hill and it may, at some future date, completely undermine the whole design. It must be remembered that once a waterfall head reaches the outlet point of a bank, it will rapidly move back along the channel, even if the bank is a level one.

Grassed watercourses with such gully heads can often be rendered stable by some gullyfilling and grassing up prior to the building of the banks. Other methods which can be successful consist of the damming of the gully head and diversion of the water

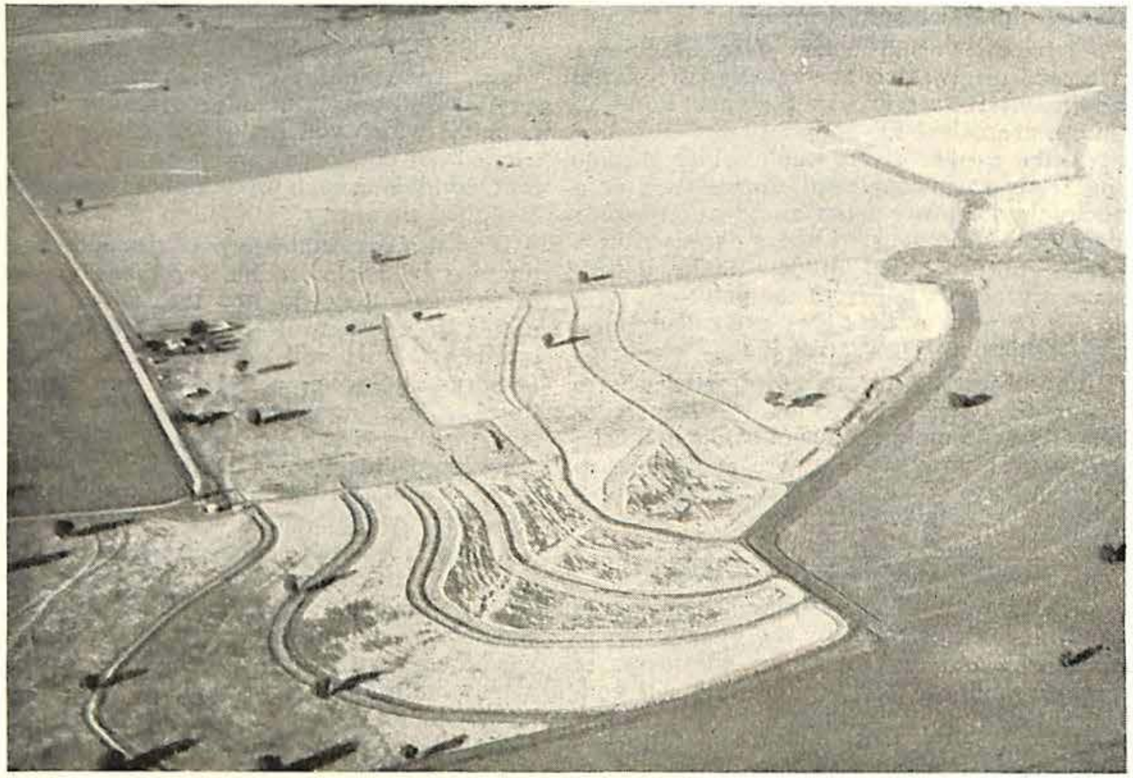

Fig. 1.—A Soil Conservation programme which includes banks, and soil saving management in the Greenthorpe district of New South Wales.

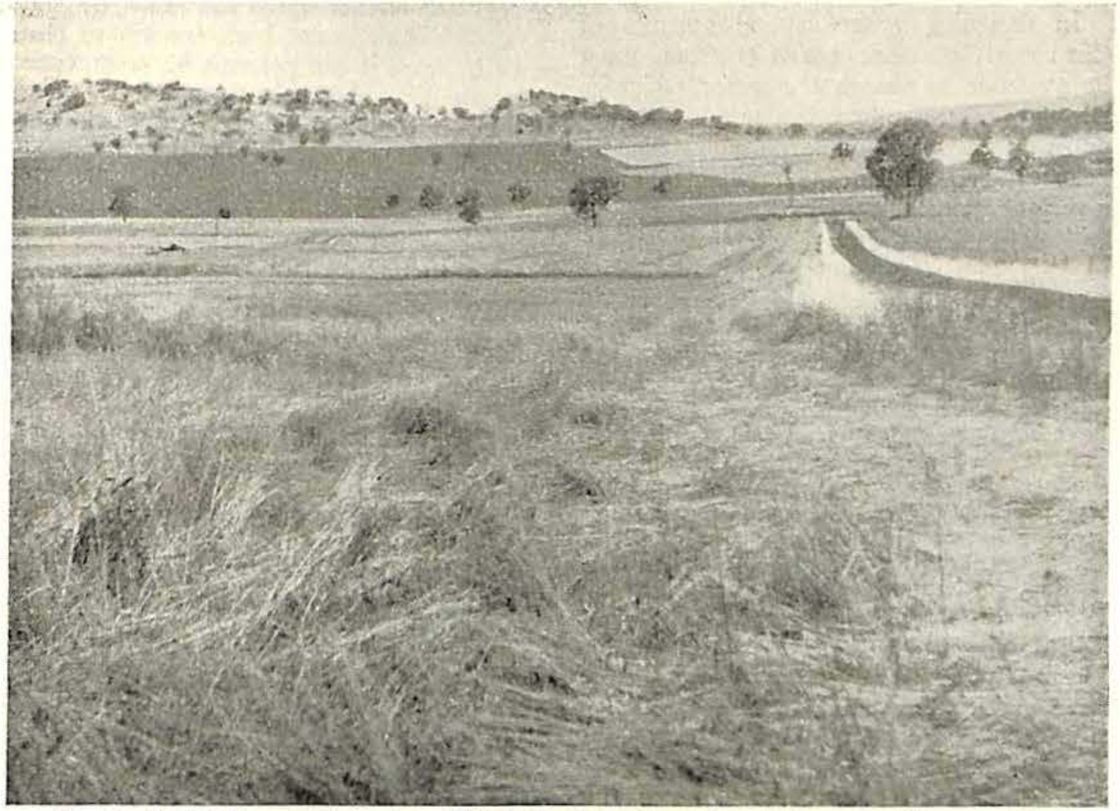

Fig. 2.—Undulating wheat country. This is the class of country which needs soil conservation works to maintain permanent productive capacity.

away from the gully head while still retaining it in the same watercourse but away from the gullied section, and the construction of a grassed waterway.

Disposal of Water on Grass or Timbered Country.

The discharge from banks can be taken into timbered country or grass where it can be dispersed to do good by increasing pasture growth. This is an ideal method of utilising surplus water from cultivation country and, provided the scheme is well designed so that the discharge from each bank disperses and does not quickly link up with that from other banks, excellent results should be obtained.

Here, as in the case when utilising natural watercourses, it is necessary to keep a continuous grass cover on the dispersal area. This is especially so during those times when the area shedding the run-off is clean-cultivated and liable to discharge maximum amounts.

In designing water-disposal schemes of this nature, sufficient area of grassland must be available to absorb the water which is run into it, unless there is a suitable natural or prepared get-away for surplus waters below such grassland. Grasslands having a very dense cover or extremely porous soils will naturally be more suitable than impervious soil types with sparse grass cover and, in the latter case, a greater area would be utilised. It is unusual for the dispersal area to be greater than one-third the area of the watershed area.

In many districts where large areas of land have been completely cleared for cultivation, and farmers are prepared to adopt the modern wide cropping rotations involving ley pastures between crops, considerable scope is left for the possibility of using level banks to discharge waters on to the leyland while the alternate paddocks are cropped. When the rotation reverses, the same banks, by reversing the end blocks, can be utilised to take the water in the opposite direction.

Dams and Tanks as Bank Outlets.

The use of dams and tanks as outlets for banks is most important, especially in small soil conservation schemes, and their value lies in their dual role of conserving both soil and water.

It would not be practical or economical to build a dam for the outlet of each bank and so it is usual for dams to be utilised in combination with other forms of water disposal. For example, a dam may be placed at the lower end of a natural watercourse, the upper reaches of which is used for bank outlets. It is not the purpose of this article to go into the general use of dams and tanks in soil conservation, but to discuss only their use as outlets for banks.

Where one bank only is required and an existing dam is suitably located for its outlet, to ensure that the bank comes in at the correct place, it is usual to lay the bank out commencing from the inlet to the dam. Slight manipulations of the grade of the bank are at times necessary for correct location. For example, if the bank is being laid out on 0.5 per cent. grade and it is going too high, perhaps into rocky country or timber, it can be recommenced and laid out level, in which case, it will be slightly farther down the hill. If, however, the bank is not high enough to clear a gully head, it can perhaps be commenced at a safe point above the dam, and the maximum permissible grade can be used to take the bank further up the hill. When the dam is built for the purpose of taking the run-off from such a bank, the bank is laid out in the correct place and the dam site is located at its outlet.

A major problem when bringing water into dams is to bring it in in such a way that scouring of the batter does not take place and, if some scouring does occur, to ensure that it does not work along the channel of the bank which is delivering the water. There are two solutions to the problem, one is to use correctly constructed inlets which are expensive, but are also most effective, the other is to design the inlet so that the scouring which takes place is minimised.

Inlet structures are many and varied, some constructed from hollow logs, do good service for many years, others are of concrete or grouted stone designed by engineers. They must be designed so that they will in fact carry the flow of water and deliver it to the bottom of the dam so that scouring is eliminated. If water by-passes them they will quickly be under-cut and can then be regarded as a complete loss. Once the dam is

Fig. 3.—A massive absorption-diversion bank constructed by the Soil Conservation Service in the West Wyalong district.

Fig. 4.—A well grassed natural watercourse on the Cowra Soil Conservation Research Station. Such a watercourse is an ideal outlet for water from banks.

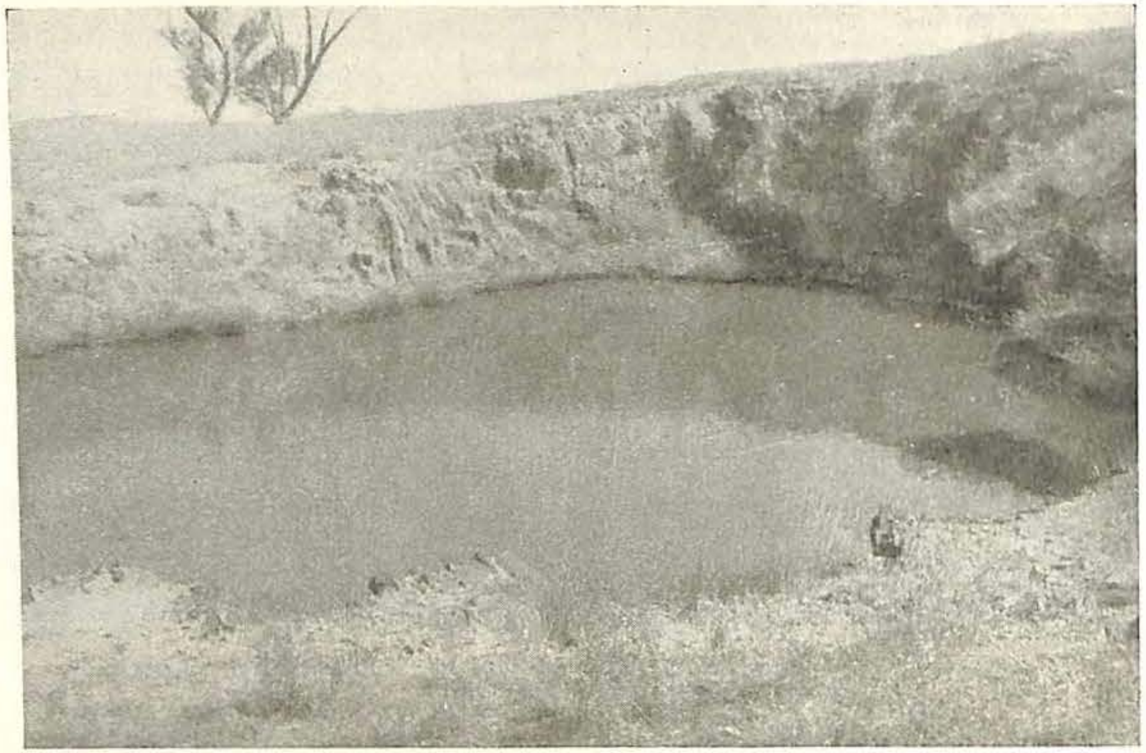

Fig. 5.—This quarry in the Canowindra District, with an estimated capacity of 15,000 cubic yards, has been used as an outlet for graded banks.

full there is no need for an inlet structure, and in fact by this time the structure is under water, and this is a good argument against their use.

If an inlet structure is not used, some scouring is sure to take place especially when the dam is empty and quick storm sends water coursing into it. Scouring will only take place while the dam is filling, provided the inlet point is lower than the outlet. If, on the other hand, the outlet is lower than the inlet, scouring will continue all the time water is running in.

From the foregoing, it can be seen that scouring will be reduced to the minimum if the inlet channel is continued around the berm of the dam to the lowest part of the natural land surface within the bank. This practice of running the channel around the berm is not used very often because of the inconvenience of construction, but it is quite effective.

In the case of tanks, which are usually built on almost flat sites, the inlet and the outlets are, for practical purposes, level. In this case, if the inlet channel is excavated, and the outlet channel is constructed from the bottom side so that the channel floor is on ground level, a ponding depth equal to the depth of the inlet channel is created. This is suffcient to prevent the water from cutting back along the channel.

The usual method of minimising the scouring effect, is to bring the run-off into the dam over a wide, level inlet, so that it does not enter in a concentrated, fast-flowing stream. If this wide, level inlet is well grassed with couch grass or water couch grass excellent results can be chieved. Both of the above species have a high degree of resistance to damage by flooding. Some other species such as lucerne and kikuyu grass are quickly killed by flooding.

Various other methods have been tried with differing success, one method is to cut the inlet channel down deeper and deeper as it nears the dam, so that it enters some four

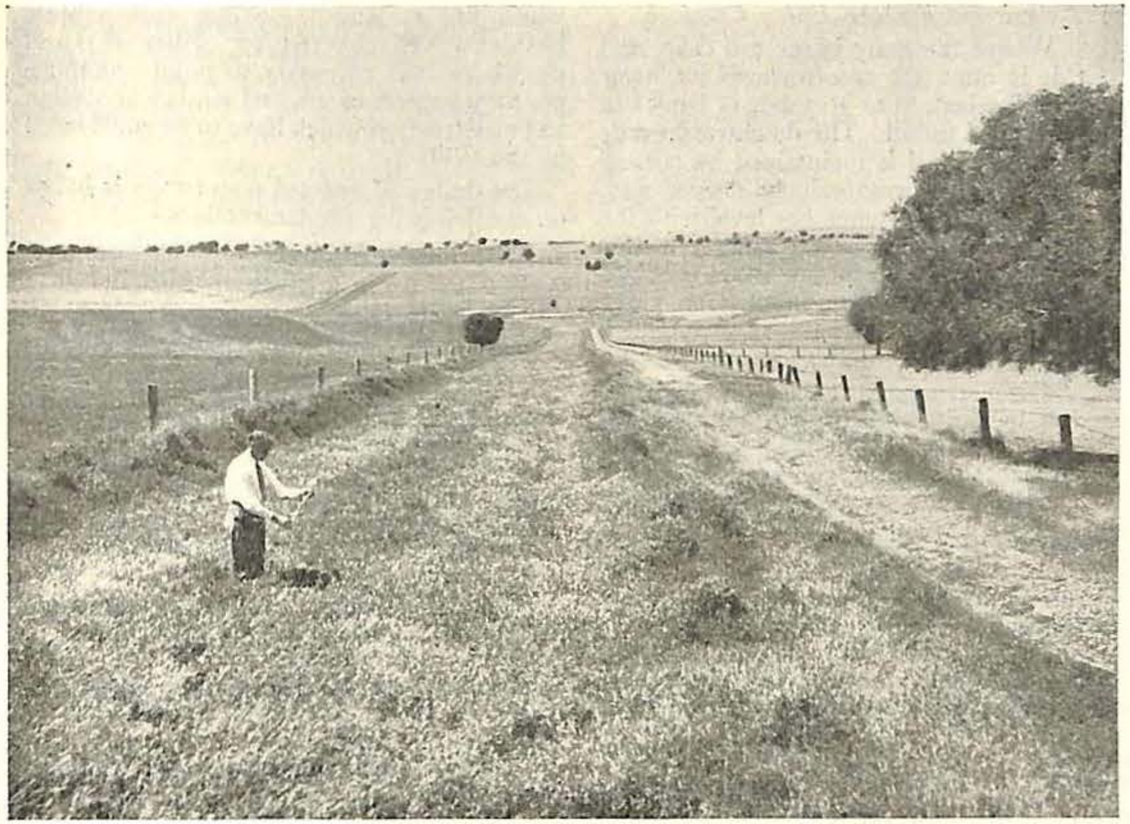

Fig. 6.—A grassed waterway. This waterway is a part of a comprehensive scheme of soil conservation in the Greenthorpe district of New South Wales.

or five feet below ground level. Construction of such a channel is difficult and consequently costly, but the method is quite effective. The use of pipe drop-inlet structures are costly and liable to blockages, but they are also quite effective.

Gullies as Outlets for Banks.

Gullies are not used as outlets for banks if the water can be disposed of in a more suitable way. There are times, however, when gullies can be utilised in this way to considerable advantage and without causing erosion.

A study of gullies reveals that they often consist of a vertical head at their highest point and have a long, tapering body which gradually comes out on the ground surface and immediately below this point there is a delta which has been built up from transported debris, much of which has been washed from the gully.

Narrow, deep gullies which have actively eroding floors are not suitable to carry water. Gullies with wide, flat, sandy floors are suitable. If a gully of this nature is 12 feet deep at its head, and 400 yards long, its floor has a grade which is 1.0 per cent. flatter than the natural ground surface, and providing the water can be brought in onto the floor of the gully, it can be effectively transported away without any significant erosion occuring. The problem is to get the flowing water to the gully floor without creating a vertical drop which will scour. The following are some practical ways by which this can be achieved:—

(*a*) *By the use of Rocky sections.*

Where reefs of rock occur they frequently present an opportunity for the water to be cascaded down over the rocky surface to the floor of the gully with no possibility of creating scour.

(*b*) *By cutting a Deep Entry Channel.*

Where the gully is not too deep, and this is often the case towards its lower end, the last 20 to 30 yards of bank can be turned uphill. The downward grade in the channel is maintained by cutting the channel progressively deeper and, in this way, it comes out level with the gully floor. When carrying out this method, very careful lay-out is required to ensure that a continuous fall along the channel of the bank is maintained.

(*c*) *By the use of Drop Structures.*

Drop structures at the head of a gully can be quite satisfactory, but they are expensive to build, difficult to design so that they do not undercut and they should only be used as a last resort. (1)

Prepared Grassed Waterways.

One of the main methods of disposing of the run-off from banks is by the use of prepared grassed waterways. A grassed waterway is a wide, flat-bottomed, well-grassed channel especially designed for the purpose of transporting a calculated maximum flow of water at a predetermined, non-erosive velocity.

While it is not the intention of this article to go into the subject of the design of grassed waterways at length, because this subject has been well covered by Miller (2) and elsewhere, it is necessary to point out those practical aspects of grassed waterway design and construction which have to be considered in the field.

The design of grassed waterways is based on the following fundamentals:—

1. They have a level cross-section.
2. Water flowing in them spreads out in a wide, flat sheet.
3. The velocity of flow of water is dependent mainly on the depth of flow.
4. A definite estimate is made of the amount of water which the waterway will have to carry.
5. The permissible velocity of flow for normal grassed surfaces in the N.S.W. 20-inch to 30-inch rainfall belt is 5 feet per second.

In the tables below the first two columns of Table 1 are taken direct from Table 1 in Miller's article, referred to above, the third column has been calculated and included for ease of work in the field. In the case of Table 2, the figures have been revised in the light of knowledge which has been acquired since Miller prepared his table some ten years ago.

TABLE 1.

Grade.	*Depth of Flow.*	*Capacity per foot of water way.*
2% or 1 in 50	1·10 ft. or 1 ft. 1¼ inches.	5·5 cusecs
3% or 1 in 33	0·82 ft. or 10 inches.	4·1 cusecs
4% or 1 in 25	0·65 ft. or 7¾ inches.	3·2 cusecs
5% or 1 in 20	0·56 ft. or 6¾ inches.	2·8 cusecs
6% or 1 in 16	0·49 ft. or 6 inches.	2·4 cusecs
7% or 1 in 14	0·44 ft. or 5¼ inches.	2·2 cusecs
8% or 1 in 12	0·39 ft. or 4¾ inches.	1·9 cusecs

TABLE 2.

Area.	Maximum Rate of Run-off to be Expected Once Each Five Years.
10 Acres	9 cubic Feet per Second.
20 ,, ...	18 ,, ,, ,, ,,
30 ,, ...	26 ,, ,, ,, ,,
40 ,, ...	34 ,, ,, ,, ,,
50 ,, ...	43 ,, ,, ,, ,,
60 ,, ...	50 ,, ,, ,, ,,
70 ,, ...	58 ,, ,, ,, ,,
80 ,, ...	66 ,, ,, ,, ,,
100 ,, ...	82 ,, ,, ,, ,,

Once the estimated maximum rate of flow has been determined, and the slope of the waterway is known, the width of the waterway is easily calculated by dividing the maximum rate of flow by the capacity per foot of waterway at that particular grade. For example, a 40-acre area where the waterway is on 5 per cent. grade will need a waterway which is $\frac{34}{2.8} = 12.2$ feet wide. In practice, waterways are not built narrower than 10 feet and it is usual to allow a safety factor of 5 feet width on all waterways, consequently, the example waterway would be built 17 feet wide.

The above calculations are based on the assumption that in any soil conservation programme a wide cropping rotation is used, and that a good cover is continuously maintained on the waterway. Sheep tracks down a waterway indicate unwise stocking, the necessity for fencing of the waterway and disaster should heavy rain fall while it is in this state.

The practice of ditching out the waterway and sowing the grass and clover mixture on sub-soil, after the top-soil has been removed to form the waterway banks is to be avoided. Wherever possible, a grassed area is selected which has a level cross-section, retaining banks are built from the outside leaving the natural surface inside undisturbed. This natural grassed surface is then improved by top-dressing, sowing and light scarifying and, where necessary, the waterway surface is fenced. Where the banks are to be built by a bulldozer, the fence is best if placed inside the waterway retaining banks, the dozer then can cut channels through them without touching the fence. This cannot be done if the waterway is enclosed by a wire-netting fence as the wire netting would deflect the water down between itself and the bank, causing considerable damage.

The grassing up of the waterway surface is to a considerable extent dependent on the care and attention given to it. Flowing water must be kept off it until it is grassed up and grazing control, even to the point of total exclusion of stock, is necessary in the early stages. Straw mulching is an excellent way of assisting quick establishment. Without straw mulching there may be a delay of an extra twelve months before sufficient cover has been developed for the waterway to carry water.

It is generally accepted that prepared grassed waterways cannot be considered as practical below an 18- to 20-inch rainfall as it is too difficult to develop a continuous grass sod in these areas. This is one of the reasons why absorption type banks are more frequently used in the drier areas.

Waterways are usually used in conjunction with dams and a natural watercourse. Wherever possible the waterway terminates in a stable section of the natural watercourse.

References.

(1) Taylor, T. P., 1945. *Gully Erosion,* Jour. S.C.S. of N.S.W., 1:2, p. 38.

(2) Miller, A. W., 1945. *Design and Construction of Grassed Waterways.* Jour. S.C.S. of N.S.W., 1:2, p. 9.

PROTECTION OF EARTHWORKS—KEEPIT CATCHMENT AREA

BY

A. W. Good, H.D.A., Resident Soil Conservationist.

In 1949 an article appeared in this Journal under the title of "Investigations Keepit Catchment Area" which indicated that a large proportion of the slopes section required earthworks to prevent soil erosion and silt movement to Keepit Dam.

At that time the Soil Conservation Service was carrying out demonstrations and minor demonstrations to show the value of soil-protecting earthworks.

Landholders were quick to realize the value of this work and, as a result, thousands of acres have been treated under the Soil Conservation Service Plant Hire Scheme. This has been the largest concentration of earthworks in the State. It is now possible to view earthworks at any point on any road leading from the Manilla centre. In many localities these works are continuous from property to property.

Whilst there are many paddocks which still require treatment most of the worst eroding areas have been treated.

The result has been a marked reduction in soil erosion and silt movement and landholders have applied improved methods of farm management.

Before soil conservation practices were introduced, production from the land was seasonal in the extreme. Rapid, short-lived pasture growth gave way to non-productive pastures and heavy storm rains eroded any bare land. Cereal cropping was the main practice giving wheat as a cash crop and oats for winter grazing. Upland grazing lucerne stands were a gamble to establish and often short-lived with bare areas losing soil on every rain. Wheat lands had to be cropped continuously because revegetation by native species was too slow to be economically sound. The soil texture was lost and erosion increased. Worn-out paddocks became heavily infested with black oats. It was considered to be "too risky" to try to establish improved pastures to give the land a spell after cereal cropping. Landholders often had difficulty in maintaining stock on the "off" season and many thought that the stock losses during the winter made cattle breeding a risky enterprise. Every effort was made to carry on without reducing the sheep numbers but it was a losing battle with soil erosion.

VALUE OF EARTHWORKS.

With the protection of the soil by absorption, diversion and graded banks, check dams, silt dams and specially constructed waterways, a marked change occurred in the district.

Land can now be safely and thoroughly worked at all times throughout the year to allow for safe establishment of improved pastures and highly productive lucerne stands which take their place in rotation to give better crops. Where stock were only fattened in short periods of flush pasture, there is regular vealer production and a more regular marketing of fat cattle. The same number of sheep are being run on part of the area and the reserve of feed is an assurance to the landholder and a protection for the soil. Other capital improvements have been possible so that extra fences and watering points have allowed for a better management of pastures through rotational grazing and an increase in returns and stability.

In this district, where returns increase immediately the soil is stabilized, soil conservation earthworks are as essential as any other farm capital improvement. Maintenance of these works is essential in the interests of farm economy.

EFFICIENCY OF EARTHWORKS.

The efficiency of any earthworks is determined by their ability to receive, hold, distribute or discharge run off water. In the initial design, allowances are made for normal variations such as settling of the soil and establishment of vegetation.

It is interesting to note that after the disastrous flood rains of February, 1955, when Soil Conservation Service plant was used in

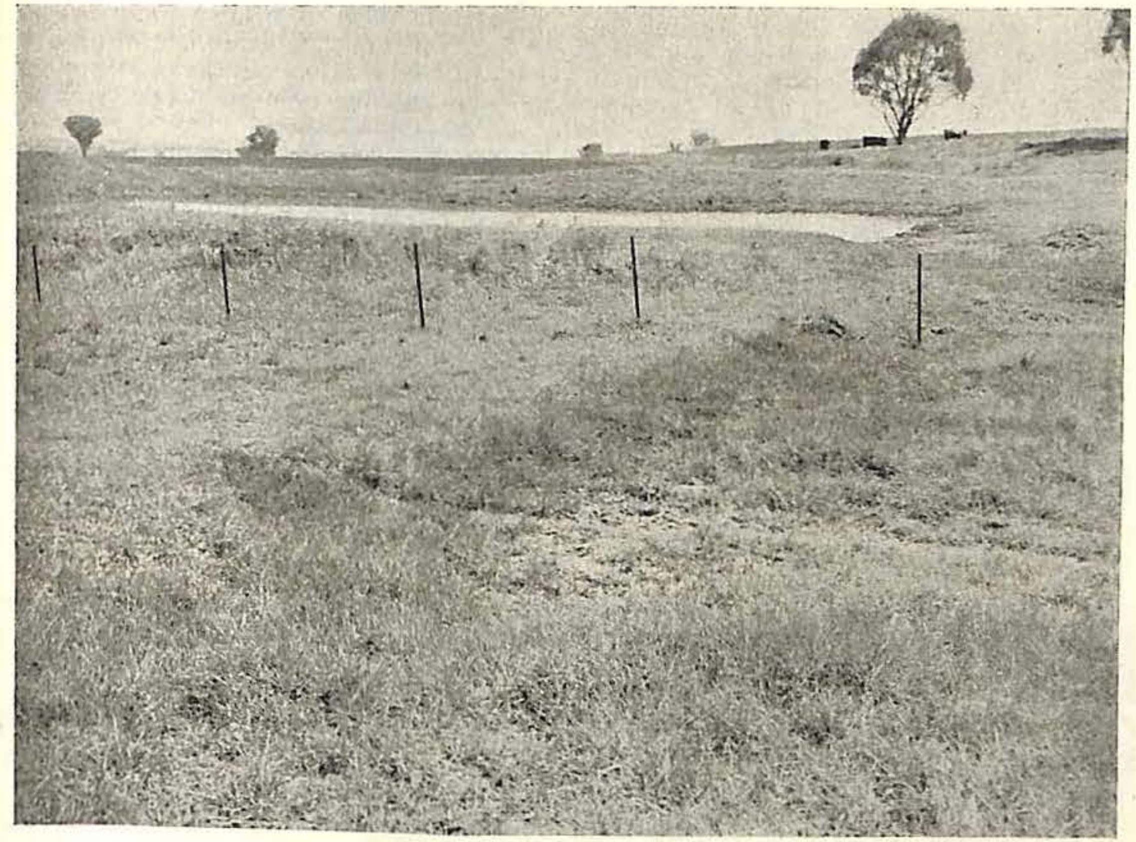

Fig. 1.—Graded banks, dam batters and spillway fully protected by grazed Kikuyu grass.

assisting to open damaged roads, very little damage occurred to the miles of conservation earthworks in the district.

However, capacities can be lost and the functions impaired if the work is neglected.

CAUSES OF FAILURE.

The most frequent causes of failure are:—

(1) Failure to give adequate protection by vegetative cover.

(2) Unusually vigorous growth of vegetation at discharge points.

(3) Badly planned fence lines causing stock tracks and collection of debris at discharge points.

(4) Overstocking, causing trampling and tracking of banks which reduce freeboard and inter-bank soil movement which silts up channels and reduces the water-holding capacity.

(5) Failure to provide suitable plant for topping up works if necessary.

PROTECTIVE MEASURES.

Vegetation.

Many landholders had the opinion that if they sowed new earthworks with pasture types, stock would trample and track over banks and cause rapid deterioration of the works. Actually, this is not the case when all points are considered. For best results, all new works should be sown immediately after construction so that the seed is covered as the soil is broken down by rain. Later sowings may be necessary if works are constructed at a time which is unsuitable for germination. Quite good results have been obtained from sowings on older works.

Grasses used for protecting earthworks in this area are:—Rhodes, Kikuyu, couch, Sudan, Buffel, green panic, Paspalum and Wimmera ryegrass.

With the exception of Kikuyu, the seed is usually broadcast as mixtures, including a medic, preferably barrel medic, which helps to maintain the nitrogen balance. An addition of either superphosphate or gypsum is usually advantageous, as most of the soils are deficient in phosphorus or sulphur or both.

Lucerne is not always recommended for sowing on earthworks because of the possibility of isolated succulent plants occurring when other grasses are less attractive; the stock may make tracks from plant to plant causing low spots.

The use of Kikuyu grass has been most successful in this district. A much wider use is recommended. When grown under paddock conditions, Kikuyu grass does not become a pest, as it may in gardens. Winter cultivation will prevent its spread to cropping areas.

The main value of Kikuyu grass lies in the fact that it gives a dense mat of growth which is weed free and capable of protecting soil from scouring even on slopes carrying water at high velocity. Once Kikuyu is established, fences are not required to protect the earthworks. Stock grazing tends to make this grass mat spread and develop a stronger soil-binding root system. The grazed Kikuyu does not build up a rank growth which could reduce the channel capacities.

Kikuyu grass is the outstanding grass for use on banks in black and self-mulching soils. It is most suitable on the steeper dam batters and at points where water may concentrate such as dam outlets, bank outlets and any natural channel which is used in an earthworks programme.

Fig. 2.—Back batter of dam wall completely stabilized with ungrazed Kikuyu grass. Note rilling on unplanted areas.

Dams should be sprig-planted around the top of the bank. This will succeed often when plantings fail on the sloped batters. However, if planted correctly, Kikuyu sprigged on the back batters and front batters above the water line will prevent rilling which invariably occurs on the bare earth.

Banks, especially settled banks, may be protected by sprig-planting along their length. The sprigs may be placed well apart in the initial planting and assisted to spread by dividing at a later date.

Artificial waterways are most successful in this district when the centre line of the cross section is 1 or 2 inches lower than the sides near the trainer banks. The centre line is sprigged with Kikuyu so that low flows actually irrigate the grass and promote its spread. Rilling which may occur before sown grasses are well established is directed to the centre line which is held by Kikuyu. This method also protects the trainer banks, which tend to break on waterways with flat cross-section.

Fully constructed artificial waterways are avoided whenever possible. This is because they are expensive to establish and also much time is lost in the completing of the earthworks scheme while waiting for the waterways to become established with grass cover. Very often it is found that native grassed land can be used by constructing trainer banks to keep expected flows of water spread over a fairly level cross-section. This type of waterway can be strengthened, at places which may tend to concentrate water, by introducing Kikuyu grass. Where better pasture types are sown on the paddock a native waterway need not be fenced as stock

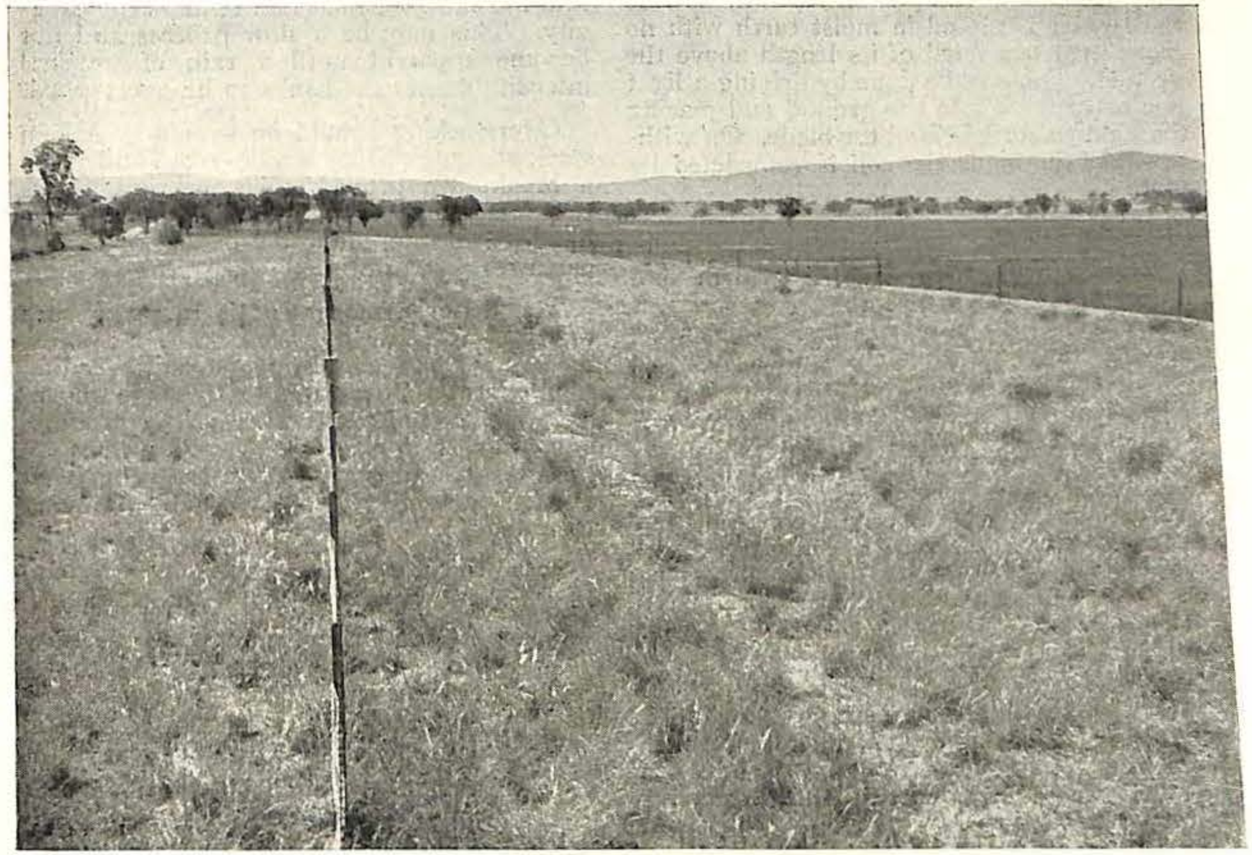

Fig. 3.—A Rhodes grass waterway correctly fenced. Note temporary fence within the paddock. This may be removed when the land use will ensure that the waterway is not denuded of cover.

will not overgraze them. By eliminating the need for fenced waterways a major cost is saved.

Kikuyu grass is most useful in reclaiming old gullies when the water has been diverted from them by earthworks. The grass arrests the earth as it frets down under natural weathering and this tends to level out the land.

Realizing the value of Kikuyu grass in protecting earthworks, some landholders have established a plot of Kikuyu at a favourable location near their operational centre. The practice is to take out a bag of runners from the plot and plant them with a small hoe whenever riding through the paddocks. The practice is worthy of consideration as Kikuyu grass is a highly nutritious grass which will stand adverse conditions well.

A point to note in planting is to make sure the runner is placed in moist earth with no more than one third of its length above the ground. This can be done by driving a light hoe or mattock into the ground and placing the Kikuyu sprig behind the blade. On withdrawing the blade the soil is compacted by foot.

Discharge Points.

Grasses with their tangled growth and fibrous root system are the greatest agent in arresting the run-off of water by checking the flow and allowing absorption into the soil. However, in bank channels and outlets from earthworks a heavy growth can cause a build-up of the water level, prevent discharge at a rate equal to intake and cause the banks to be overtopped. If one bank overtops causing a break the concentration of water may well ruin a complete earthworks scheme. Outlet points must be checked regularly and cleaned of heavy growth to avoid damage.

Fencing.

When fences are necessary to maintain protective cover they should be erected. However, temporary fencing will often achieve the requirements at a lower cost.

Fence lines can often be re-located to prevent stock tracking. Fences must not direct stock across banks at any one point, especially at dam outlets. Fences should follow contours wherever possible. If it is necessary to cross a bank with a fence the bank should be given additional freeboard and width of base so that stock following the fence will not wear the bank down and cause a danger of overtopping. Any fences crossing banks and bank channels should be provided with a safety apron or small flood gate so that debris will not collect on the wires and restrict the free flow of water. Fixed netting fences should never cross a discharge channel.

Stock Management.

Earthworks in paddocks which are overstocked are most likely to become ineffective. In planning an earthworks scheme for a paddock some allowance is usually made for vegetative protection between banks. If the land is kept constantly bare, soil is washed into the bank channels and reduces the capacity. This may be a slow process and not become apparent until a rain of unusual intensity causes the banks to be overtopped.

Overstocking should be avoided. When stock are hungry they tend to roam and cause a breakdown of works by wearing tracks over banks. In dry times stock should be hand-fed in safe, untreated paddocks so that earthworks are not affected.

The better management is to make sure that pastures are not grazed to a point where the soil can be seen. Supplementary feeding should be introduced at an early stage to prevent pasture deterioration from overgrazing. The practice of heavy rotational grazing and moving stock frequently so that only the tops of the grass is grazed has the following advantages:

(*a*) Pastures are quicker to respond and give a greater bulk of feed.

(*b*) The soil is protected from wash by rain and a maximum of water is absorbed.

(*c*) The soil dries out evenly at all depths so that the maximum of soil moisture is available to plants and the growing period is extended.

(*d*) Soil temperature is better regulated to keep an even growth of grass.

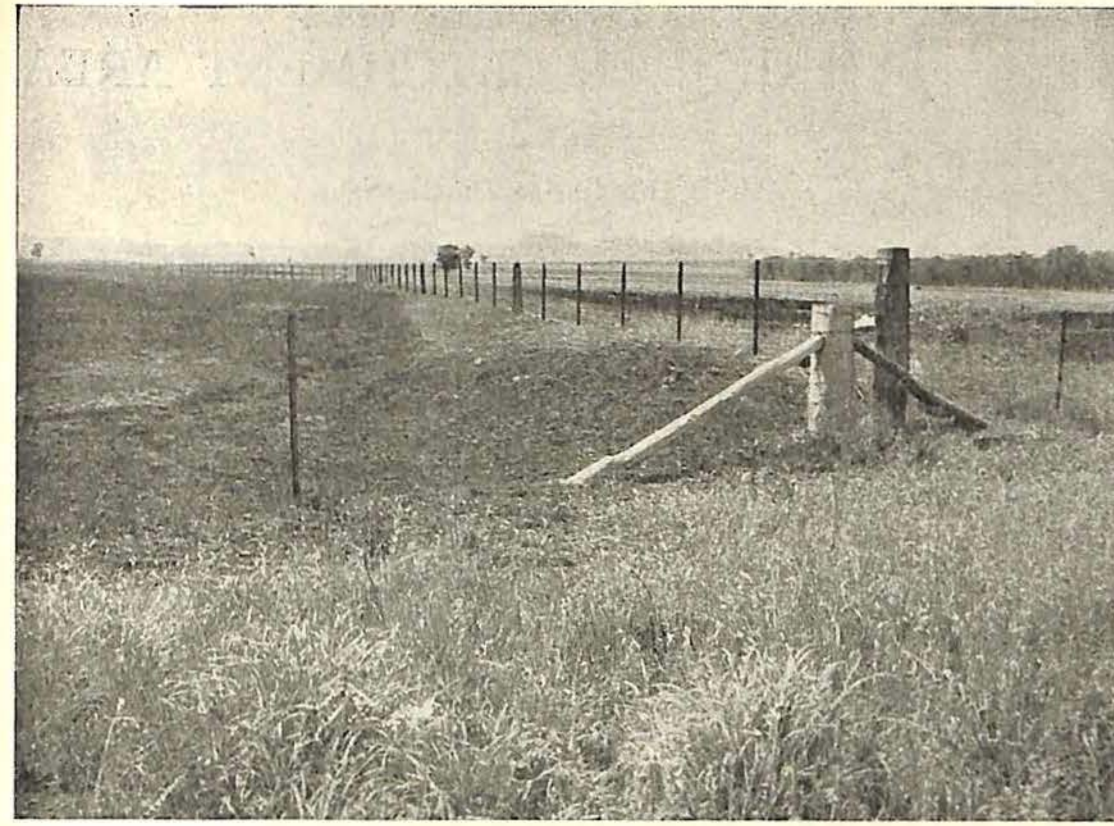

Fig. 4.—Paddock subdivision with fence along crest of broadbased graded bank in cultivation land. Outlet to Rhodes grass waterway in foreground.

Where these protective measures of vegetation, care of discharge points, fencing and grazing management are thoroughly applied, earthworks require practically no maintenance.

Provision of Suitable Plant.

In a district, such as this, where maximum safe production is based on conservation earthworks, all landholders should include some earthmoving equipment in their items of plant.

Timely topping up of a low spot, clearing of a silt deposit after an unusual storm, or clearing trash from channels may save costly repairs.

CONCLUSION.

The improved farming practices made possible by soil conservation earthworks has been a major factor in increasing prosperity and enhancing land value in this district.

Additional works together with proper maintenance of existing works will increase this prosperity.

The Soil Conservation Service is able to assist through its Plant Hire Scheme in the continuation of this work. Advising on conservation land use, including paddock rotation and pasture improvement, planning and designing earthworks schemes, checking the levels of works and assistance to landholders is done free of charge.

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SOIL CONSERVATION IN THE BURRINJUCK CATCHMENT AREA

BY

J. S. Harris, H.D.A., Soil Conservationist.

In May, 1954, a programme of Soil Conservation was commenced on the properties of Messrs. C. R. Southwell, "Brooklands", A. H. Curran, H. & D. Moore, "Glenmore", Kilby Bros., "Parkwood" and A. C. & K. K. Kilby, "Charnwood". These five properties all adjoin a few miles from the village of Hall. They lie near the boundary of the Australian Capital Territory and New South Wales, within Burrinjuck Catchment Area.

The control of erosion on properties such as these is of great importance in protecting the Burrinjuck Dam from siltation. This fact is realised by the landholders, who are in a position to help protect a national asset and at the same time safeguard their own properties. Fig. 1 shows the position of these properties relative to each other.

The country in this area is ideal for both sheep and cattle grazing and responds very readily to pasture improvement.

Erosion is mainly in the form of very deep gullies, many of them about 30 feet deep and up to 40 or 50 feet wide. The sides are steep to perpendicular and afford harbour for any rabbits which might escape eradication. Many of these gullies have formed on the sites of old roads and tracks which were used years ago by bullock and horse teams and which unfortunately were generally situated in hollows where water running off the hillsides concentrated to the greatest degree. As the roads became impassable others were made alongside, ultimately forming a network of gullies. These make access to various parts of the properties very difficult and unless checked would continue to spread up the depressions.

The danger of rapid siltation of a storage dam through erosion such as this needs no emphasis.

Unfortunately huge gullies can never be economically erased from the landscape. Filling them would involve the complete loss of surface soil from a greater area than would be reclaimed. Nor can most gullies be silted up by means of checks across them since this depends upon continued erosion of soil higher up the catchment, which itself should be conserved by suitable methods.

The most practical measure is to exclude water from each gully and stabilise it by encouraging a satisfactory cover of vegetation which will contribute towards the feeding of stock. In time the sides of a gully will usually fall in but this can often be accelerated by bulldozing the edges down to a batter. Sometimes the bottom of a gully is stabilised by bars of rock and the main consideration then becomes the prevention of subsidiary gullies running off the sides.

On the properties under discussion steps were taken to reduce the amount of run-off as much as possible and to dispose safely of the water which could not be absorbed into the soil. This was done by earthworks carried out under Plant Hire by the Soil Conservation Service in conjunction with pasture improvement and other conservation farming principles applied by the landholders.

MR. C. R. SOUTHWELL AND MR. A. H. CURRAN.

As these two works are complementary to each other they will be grouped together and discussed as one overall programme, although carried out as two distinct plant hires.

The main problem at Mr. Southwell's property was a number of large lateral gullies creeping back from a natural watercourse which had itself eroded to a great depth over a long period. Except for the head section, which was very actively eroding, the bed of the watercourse had stabilised itself but the offshoots would have cut the paddock into several sections within a few years.

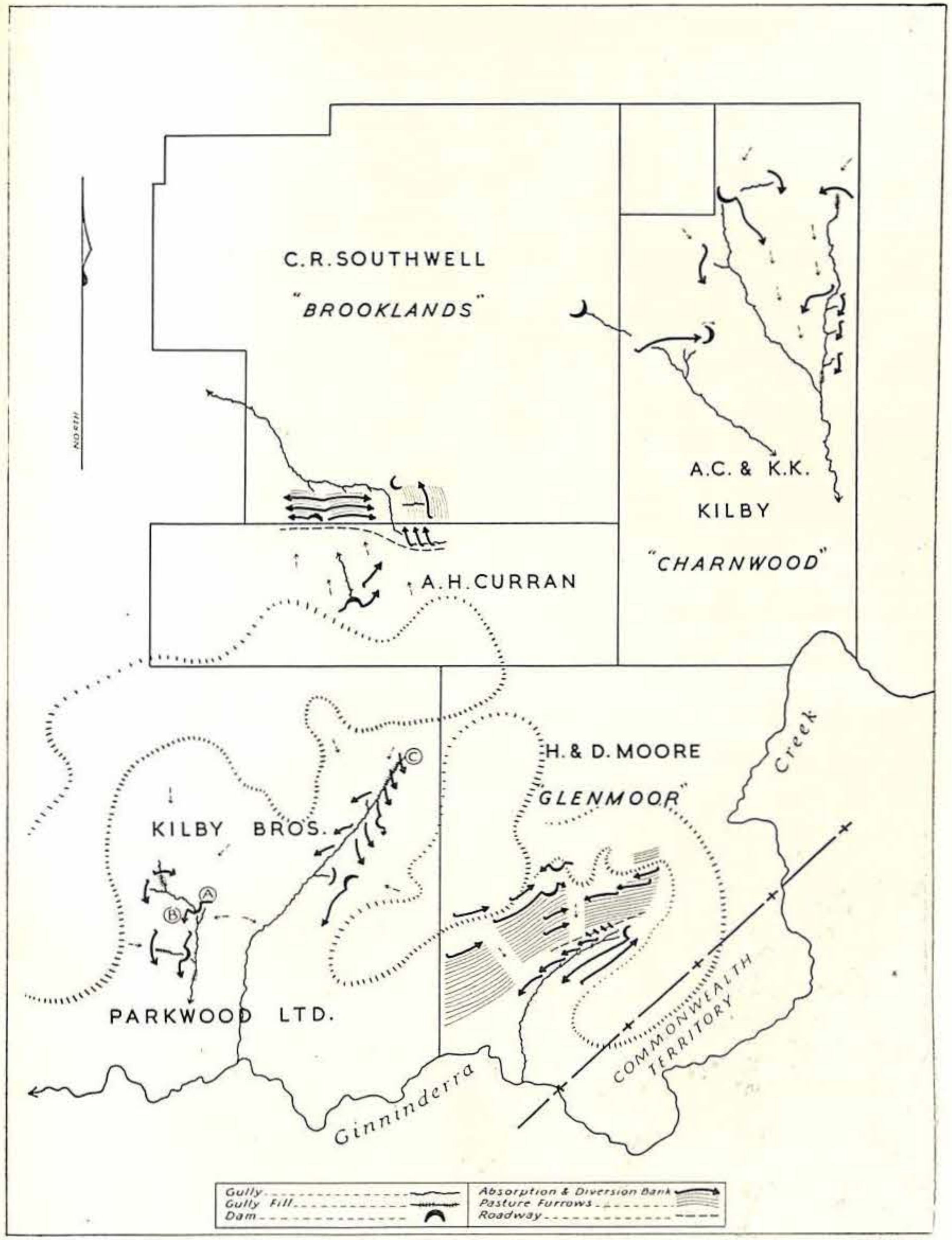

Fig. 1.—Sketch plan of location of properties showing boundaries.

To lessen the amount of water coming from the upper portion of the catchment in Mr. Curran's property a large dam was constructed at the head of a gully which had the dual effect of impounding several thousand cubic yards of water and also preventing the gully from cutting back any further. Provision was made for safe disposal of overflow by the construction of two banks which finally discharged the water on to a well-grassed even slope where it could spread out harmlessly.

Above the gully in Mr. Southwell's paddock and lower down the slope, a second smaller dam was constructed to impound more water. A number of absorption banks and pasture furrows were also constructed, the aim being to eliminate run-off from the area adjacent to the gully as completely as possible. The absorption banks were designed to hold any water overflowing from the pasture furrows, to a depth of 6-8 inches, and then to discharge any surplus into a natural grassed depression. However, the expected rainfall should seldom fill both banks and furrows to capacity. With the pressure on the gully relieved in this manner it is expected that extended time of concentration would result in much of the run-off from the higher land being absorbed before it reached the gully.

Surplus water which cannot be held will be discharged into grassed depressions at opposite ends of the work. This ensures that water can enter the gully in two selected places only and a large section of gully bank is completely protected from erosion. Several absorption banks were also constructed at the side of the road to check a gully which threatened it. To the east of the large gully, a small gully was levelled off and the hillside controlled by an absorption bank with pasture furrows above and below it. The bank was designed to overflow down a well-grassed slope into an existing dam.

It must be mentioned in passing that, in all the work under discussion, on this and other properties, absorption banks are generally used in preference to diversion banks. The function of a diversion bank is purely to guide the flow of excess water to a chosen place but an absorption bank will impound a certain quantity of water, like a long, shallow dam and when it overflows at the outlet, will then act as a diversion. This is achieved by constructing it on the true contour, blocking one end securely and turning the outlet end uphill a few vertical inches, sufficient to suit the purpose.

Fig. 2.—View from point B in Fig. 1, showing western arm of gully with a diversion bank at its head.

Fig. 3.—The gully check dam at A in Fig. 1, showing massive bank and overflow bank at right.

These banks may be pushed up from above or below the surveyed line. The former entails pushing soil down the slope which forms a channel with some water-holding capacity even without turning the end uphill. However, it also results in an increased slope on the batter of the channel which, while in a bare state, can erode to a moderate extent. To obviate this risk in some cases the soil may be pushed up the slope to form a bank without an excavated channel. This in turn involves some risk in certain soils, as for instance pipe clay, which is most unstable when wet and will often flow downhill like lava, thus destroying the bank. In the pipe-clay type of soil it is most important to preserve the comparatively firm crust of surface soil to ensure as firm a foundation as possible for the bank. The bank is therefore built by pushing down the slope and laying the soil partly on to the ripped soil and partly on the undisturbed surface. The bank will tend to bond in with the ripped surface and prevent seepage occurring between the bank and the ground on which it rests.

MESSRS. H. AND D. MOORE.

Figure 1 shows that this property adjoins both "Parkwood" and the property of Mr. A. H. Curran and the one range of hills is common to all three.

At "Glenmoor" the run-off from these hills made its way via several depressions down the lower slopes, its volume increased by water from these, until it reached a huge gully which in turn emptied into Ginninderra Creek. Wherever this run-off water poured into the gully the edge had collapsed causing offshoots to encroach into the paddock at intervals and these, if unchecked, would eventually have progressed right back to the hills and cut the paddock into sections. The position was further aggravated by a roadway which tended to concentrate water into the gully at certain spots.

It was decided to treat the whole catchment and endeavour to increase absorption to such a degree that there would seldom be any run-off and if water did at any time reach the vicinity of the gully it would be diverted onto a comparatively flat area. At one spot a spillway was battered down into one of the gully offshoots and one bank allowed to discharge so that the water would spread out and pass down this spillway. This was done in an effort to get rid of some water safely and reduce the quantity which would finally flow. The spillway was seeded and fertilised and should stabilize satisfactorily. However, if necessary, the bank, which is of the level absorption type, can quite easily be extended a few yards to overflow into the next one.

A small dam of about 200 cubic yards was constructed high up on the hillside to check a small active gullyhead. At the foot of the hills another dam of about 900 cubic yards capacity and a number of absorption-diversion type banks were constructed. As the hillside was too steep and rocky to work on, these level banks were intended to check the rush of water, hold a certain amount and divert the balance into either the dam or several well grassed depressions down which it could flow quite safely. It was then possible to cover the lower slopes completely with pasture furrows leaving the actual depressions untouched. Banks were constructed at the edge of the depression to confine the water to the desired course as it showed a tendency to spread out and over-run the ends of some furrows.

A number of short check banks were placed across the old roadway to turn the water out to the side and prevent rilling of the tracks.

Water overflowing from an existing dam had caused the gully to threaten the wall and this was overcome by constructing an overflow bank to take the surplus water well out on to a grassed slope. A bank above collects run-off from the slope and discharges it into a depression above the dam and so increases the effective catchment.

A feature of the absorption banks at the foot of the hills, above the pasture furrows, is the provision of a safe outlet from each. As these are on a comparatively steep slope there would be some possibility of water cutting a rill around the end of the bank where it overflowed. This was overcome by providing a sill or step 9 inches or 10 inches deep. The channel was continued 10-12 feet beyond the end of the bank to

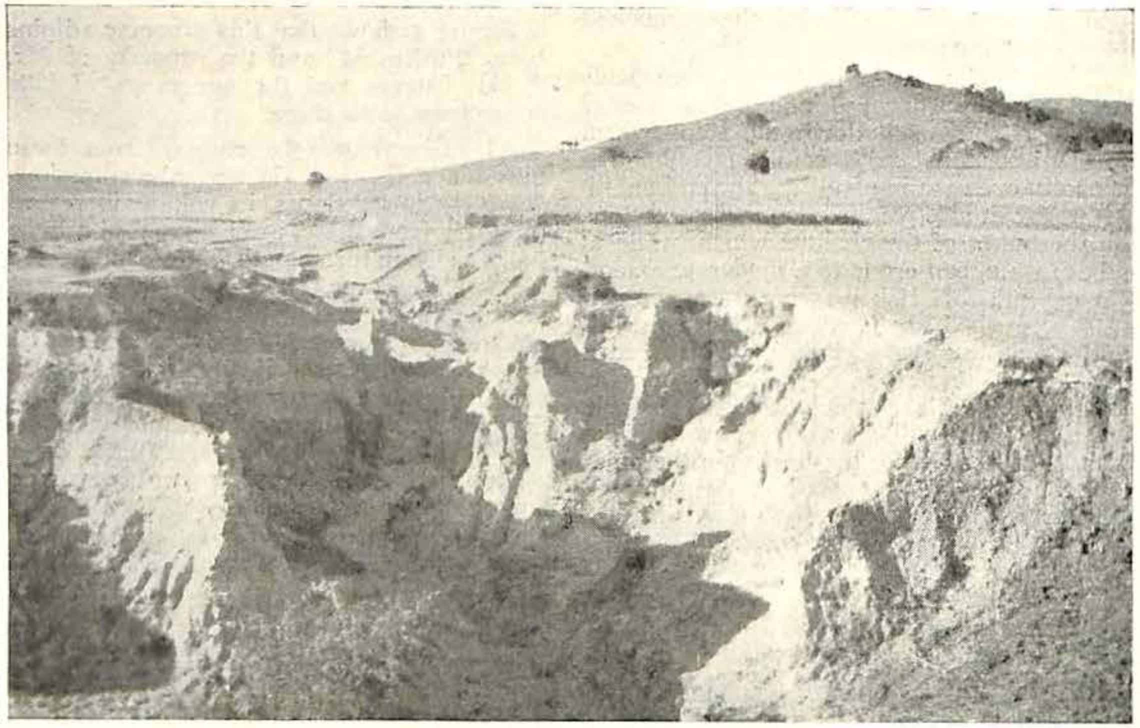

Fig. 4.—The head of the gully near Point B in Fig. 1, looking north and showing the diversion bank and battered sides of the gully head.

encourage the water to flow well out beyond the bank. Then as the level rose it would overflow evenly over the whole width of the sill.

Also, where stock tend to make tracks round the overflow end of a bank a short span of fencing may be used to keep them away from the critical spot.

MESSRS. KILBY BROS.

On this property there were two distinct problems. The first was a huge gully about 30 feet deep and in parts almost 40 feet wide. It extended along a valley almost to the top of the catchment. The gentle slopes on either side at the foot of the hills are periodically sown with wheat and then held in ley pasture for several years between crops. This is very effective in growing supplementary feed and at the same time improving the pasture. The gully was developing lateral offshoots on both sides and would eventually have encroached well into the cropping area.

A large level bank about 4 feet high was constructed above the head of the gully to divert water approaching from the slope above and this overflowed into a wide grassy depression well clear of the gully.

The top few chains of gully were then filled in and two level banks put across, blocked at one end and discharging well clear of the gully on the south-eastern side. Level banks were constructed along this same side, each one checking the run-off before it could reach the gully and turning it out onto a grassy slope again. In this way the water is guided down the slope to the lower section where it is eventually allowed to flow into a large dam. The overflow from this is conveyed by a diversion bank with a grade of 2 inches per 100 feet and allowed to spread out over a comparatively flat area.

Each of the banks was designed to hold several inches depth of water to a width of 12-15 feet before overflowing. In effect they are a series of long shallow dams with high absorption and evaporation as well as being diversion banks. In this manner a great deal of run-off is held and quite a small proportion finally flows into the dam.

On the north-western side the water was diverted into a slight depression running parallel to the gully and thus prevented from causing further damage. Three or four diversion banks sufficed to keep the water flowing in the desired direction.

The other major problem was a network of gullies with a catchment of several hundred acres. Fig. 1 shows the main gully split into two channels and there were three lateral offshoots advancing along slight depressions where the flow of water concentrated. There was an excellent cover of clover and rye grass over almost the whole of the catchment area, which was of such a size that a system of pasture furrows and absorption banks over the whole of it would have involved a great deal of work. It was not considered that such measures were warranted.

The gully was therefore blocked with a massive earth wall which dams water back to the head. The three active heads on the western side were dozed down to a batter and the water kept out by means of diversion banks. The main wall was extended to divert water away from the second arm of the main gully and the channel widened and formed into a gentle batter along which the bulk of run-off water would flow into the dam.

The overflow was conveyed by large banks across to another smaller dam and thence down a grassy slope into a gully which was stabilised by a dense growth of grass along its banks.

A potential spillway was formed below this second dam in case it should be desirable to use it in the future as a means of dispersing some of the water.

The area of several acres containing these works has been fenced off securely so that grazing may be controlled at all times and lucerne, clover and rye grass pasture has been established. A woodlot of trees has also been planted with the aim of beautifying and helping to stabilise the area.

MESSRS. A. C. AND K. K. KILBY.

In this property three gully systems in one paddock required controlling. On the western side of the paddock water running through the boundary fence from Mr. Southwell's property was excluded from a network

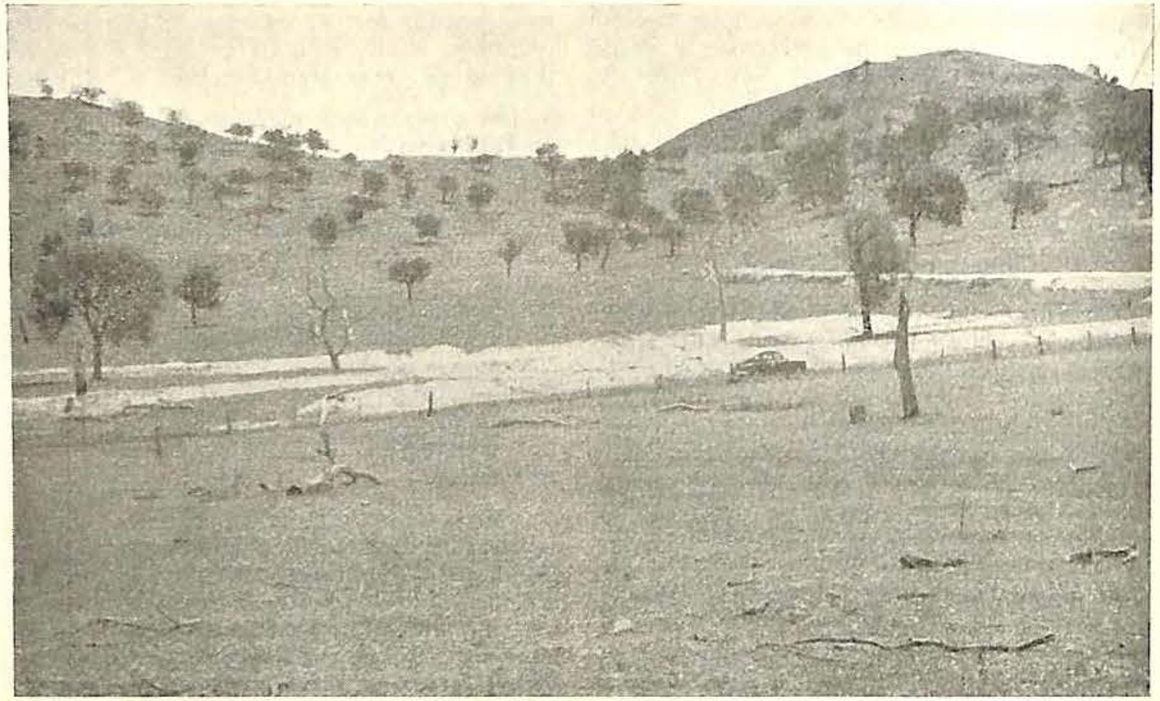

Fig. 5.—The system of absorption-diversion banks at the source of the gully at the point C in Fig. 1.

of gullies by means of absorption-diversion banks which hold up to 8 inches of water and then divert the flow into a dam. The overflow from this spreads out and flows gently down a grassy slope.

At the northern end of the paddock a large flow of water enters the paddock from a catchment of several hundred acres on an adjoining property. This has caused a large gully to form.

A large earth wall was built across the head of the gully to form a dam of more than 2,000 cubic yards capacity. This also caused water to bank up in a medium sized gully running off the main one.

A large diversion bank was constructed to convey the overflow from the dam out into a wide, well-grassed depression where it can spread out without causing harm.

On the eastern side of the paddock the run-off water from a large hillside and a travelling stock route was diverted away from a third gully by means of a large bank and allowed to flow down a wide, grassy depression for about 300 yards.

At a point where it would enter the gully again another diversion bank turns it away and conveys it around a slight ridge into another depression where it can spread out without causing harm.

On the opposite side of the gully several active offshoots of the gully have been checked by diverting the water in other directions.

CONCLUSION.

Erosion has been successfully checked on the properties under discussion, as on many others like them, by means of earthworks such as absorption banks, silt dams and pasture furrows which greatly increase absorption of water and decrease run-off, and by diversion banks which exclude water from existing gullies and turn it out on to suitable grassy areas where it will cause no harm.

Mechanical control measures must be supported by sound farming methods such as pasture improvement, eradication of rabbits, careful location of roads, woodlots and watering places, judicious stocking, and perhaps even permanent fencing off of some vital areas where it is essential to preserve a good grass sward and prevent stock trampling and overgrazing.

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SOIL EROSION PROBLEMS IN THE SNOWY MOUNTAINS AREA

BY

L. J. DURHAM, B.Sc.Agr., Soil Conservationist.

Part I.

SINCE the inception of the Snowy Mountains Hydro-Electric Authority in 1949, this area has been much publicised, resulting in a wider realisation of its potential capacity to increase power and water resources for industry and agriculture.

Prior to this, the area was mainly utilised for grazing and recreation, but it had been periodically studied by various organisations interested in particular aspects of its unique characteristics.

Following the initiation of the present engineering scheme certain of these studies have been intensified, while at the same time, actual operations have been responsible for an increasing awareness of problems associated with these works.

Erosion hazard and damage is probably the major problem now to be controlled. It is integrally bound up with the various activities which are liable to cause, and in many cases have caused, extensive damage to vital catchment areas in a unique portion of the Australian landscape.

Within the scope of this article it is not proposed to deal at length with the ecological aspects of the area, since these have been studied and recorded by Costin, Newman, Morland, Mueller and others. However, where certain of their findings are relevant to the problem they are restated.

It is proposed to set out the erosion problem, to consider the various characteristics and agencies contributing to it, and to discuss soil conservation measures undertaken to date.

THE PROBLEM.

Stated in simple terms, the problem is essentially the implementation of control of active erosion wherever it occurs, as entrusted to the Soil Conservation Service of New South Wales by statute.

As much of the area forms a unique unit of the New South Wales landscape and comprises the majority of the Kosciusko State Park, it should be preserved to the best of our ability and resources. That some serious erosion is to be found within these catchments will be demonstrated.

The Snowy Mountains hydro-electric project has been started and continued operation depends largely on a free and uninterrupted water flow from the various catchment areas concerned. Perhaps even more important is the safeguarding of the area as a source of domestic and irrigation water for the rapidly growing cities and rural areas of the Lower Murray and Murrumbidgee Valleys.

Three major catchments, the Murray, Snowy and Murrumbidgee, are included in the area. Whilst these major river valley catchments in themselves are important, it seems advisable to direct attention to the many minor catchments which go to make the whole.

Situated on many of these comparatively minor catchments, will be several of the lesser engineering structures, such as pondages of small capacity.

Inefficiency of these small catchment areas will not only jeopardise these smaller units, but could readily impair the function of a major section of the scheme.

PHYSICAL CHARACTERISTICS OF THE AREA.

These have been studied and recorded in detail by previous workers and it will be sufficient to state here the overall contribution to the problem by climatic, physiographic and soil characteristics.

CLIMATE.

Altitude is the dominant factor in the climatic environment of the area and three orographic tracts are recognised:—

Montane tract	: 3,000-5,000 feet.
Sub-alpine tract	: 5,000-6,000 feet.
Alpine tract	: 6,000-7,328 feet.

(maximum elevation at Mt. Kosciusko).

High winds are common in the area, Costin (1954) having recorded by field measurements in the tableland tract (below 3,000 feet) individual gusts of 60 miles per hour and velocities of 50 miles per hour sustained for as long as 90 seconds.* During part of the year it is certain that much greater velocities are recorded at higher altitudes. Recent anemograph recordings (May, 1955) by the Snowy Mountains Authority of individual gusts to 88 miles per hour at Spencers Creek support this.

*Measurements made with a portable air meter held 4 feet above ground level. (Costin).

Precipitation for the area ranges from a maximum of 90 inches per annum in the Kosciusko area to 22 inches at Jindabyne, and 63 inches at Kiandra on the northern fringe of the area. At the higher altitudes, snowfall probably represents 60-70 per cent. of the annual total.

Costin (1954) states that in the alpine tract, the mean monthly temperatures fall below 32°F. for four to six months of the year and in the sub-alpine tract from one to four months, but elsewhere exceed this value. The mean monthly minimum temperatures are 32°F. for six to eight months in the alpine tract, for about six months in the sub-alpine tract and from nought to six months in the montane tract, depending on altitude and aspect. Only in the alpine tract does the mean maximum temperature of any one month fall below 32°F.

SOILS.

While soil type determines the erosion pattern to some degree, it is evident that parent rock materials greatly influence the problem, particularly in regard to road building and other engineering works.

Fig. 1.—Part of the Summit area, taken from Mt. Kosciusko looking north along the main divide.

There are many parent rock materials throughout the area including intrusive igneous rocks, extrusive igneous rocks and various sedimentaries. It is in the first group, represented by the granites, gneissic granites and porphyries, that the major difficulties are encountered. Since the commencement of engineering operations, evidence of weathering to the extent of complete or almost complete decay of the rock on some granites, has been commonly found to depths of 50 feet. Shale and quartzite materials, on the other hand, are rarely strongly weathered below depths of 10 feet and the severity of erosion problems associated with works in these areas is far less than on the granites.

Soil type assumes greater importance when considering such factors as grazing, burning, and incidence of frost and ultimately remedial measures making use of available topsoil.

It is the opening of the continuous vegetative cover and exposure of the soil due to the destructive action of frost, wind and water, grazing, burning, roadmaking and other engineering activities, that causes concern at the present time.

THE EROSION PROCESS.

The importance of wind and water action in the process of sheet and gully erosion have long been recognised, and more recently their significance in this area has been better understood as a result of ecological and erosion surveys. These same studies have also demonstrated the effects of severe frost action on exposed soil and directed attention to the significance of mass movements of the soil by flowage and slippage.

Seldom, however, do the natural agencies of erosion become destructive until the balance between climate, soils and vegetation in a particular environment is upset by human interference. The natural process of geological erosion has occurred throughout the ages and is responsible for soil formation and many of the land-forms recognised today. Accelerated erosion, on the other hand, destroys the soil profile and hastens changes in the landscape to a point beyond that occurring under natural conditions.

The natural agencies of erosion in the area, may therefore be summarised as wind, water and frost action; the erosive effects

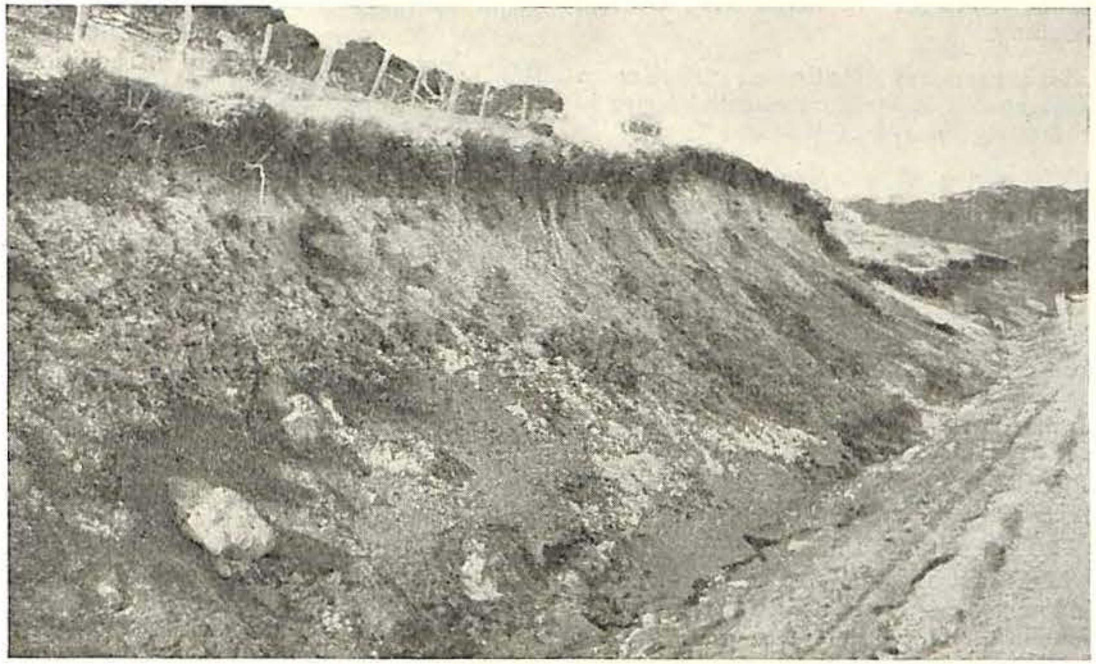

Fig. 2.—Needle ice on a road batter near Kiandra showing typical recession of the slope face.

of these natural agencies tend to become more extensive, following destruction of vegetative cover.

Soil movement by water action may be initiated by raindrop splash or surface and stream flow. In this area, in which many of the soils are derived from abrasive granitic materials, accelerated run-off due to over-grazing, burning and engineering activities has been responsible for serious rilling and gullying in many places.

Erosion by wind action may be brought about by soil movement in suspension, surface creep and a special form of soil creep known as saltation. Costin (1954) states that in areas of high wind velocity, particularly at alpine levels, the process of saltation is so active that stones of half-inch diameter may be moved.

Frost action on exposed soil is very severe, especially on those which are not protected from low winter temperatures by a prolonged cover of snow. The alpine humus soils in sub-alpine levels, on which winter snows do not persist for any length of time, are particularly subject to the effects of frost heave, leading to soil creep, characteristic solifluction, terracette formation and slumping.

Maintenance of a continuous surface cover of vegetation is again an essential factor in minimising the effects of frost action.

The action of frost both pulverises and desiccates the soil. As the soil freezes, fine needles of ice, commonly 1-2 inches in length, are forced from the surface and as the ice melts the soil is left in a loose and powdery condition. On sloping areas this loose soil falls to the base of the slope, so that over a period of time progressive recession of the slope face may lead to caving or slumping of the surface layers. On level areas the soil surface assumes a characteristic fluted appearance and may remain in its loose condition until removed by wind and water action.

Mass movements of the soil surface have undoubtedly occurred under natural conditions in the area over a long period of time. Whilst certain of these movements such as rock and talus creep have little influence on accelerated erosion, the action of soil creep, solifluction, slumping, caving and debris slides have been favoured by human interference.

Since soil creep, solifluction, slumping and caving are greatly influenced by frost action, the problem of their control reverts again to the need for protecting the whole surface, through rigid control of burning and grazing and early installation of appropriate mechanical and/or vegetative erosion control measures on seriously damaged areas.

To the erosion hazard and damage caused by the natural agencies under unfavourable human interference since early settlement must now be added the serious hazard being created by the present engineering works. Because of the need for heavy equipment and materials and the disposition of the various engineering structures throughout the area, road-building and other engineering works have been pushed into areas and onto slopes regarded as presenting an extreme erosion hazard if the vegetation is disturbed in any way.

Although the immediate problems of landslide and general instability are evident with many of these works, the problem goes further. Each new area denuded of vegetation and topsoil represents an additional hazard for the future in regard to one or more of the natural agencies of frost, wind and rain.

EROSION HAZARD AND DAMAGE.

The high mountain pastures were discovered in 1829 and it is probable that the practice of summer grazing in the snow country followed soon afterwards, since the contiguous tableland tract of the Monaro region has been essentially a pastoral district from its earliest days of settlement.

Prior to the Kosciusko State Park Act in 1943, the leasehold areas were much larger than now, with no restriction placed on the numbers of stock carried. Annual burning of coarse dry growth to promote palatable spring feed, and to a lesser extent to prevent summer bush fires, was widely practised as an adjunct to general grazing practices.

Fig. 3.—Needle ice commencing to thaw on a roadside batter.

Fig. 4.—Erosion damage in the Mt. Twynam-Carruthers Peak area as a result of high winds, frost and water action.

(Photo S.M.H.E.A.)

Under Kosciusko State Park regulations, burning-off is now prohibited between the period 1st December to the 15th March each year on all Snow Leases and Permissive Occupancies east of the divide, and prohibited between 1st October and 31st May on all Permissive Occupancies west of the divide. This has reduced the frequency of deliberate burning but the practice still occurs during the remaining period of the year, particularly on the open sub-alpine snowgrass (*Poa caespitosa*) country and snow-gum (*Eucalyptus pauciflora*) woodland.

While several reasons are put forward to justify burning, the weight of recent scientific opinion on deliberate and regular burning suggests that its effect is deleterious to the area, by placing emphasis on damage to the various species themselves, removal of surface cover and creation of extensive bare areas, and in a progressive lowering of the humus content of the soil. The most drastic effect of burning lies in the removal of surface cover and exposing extensive bare areas to frost, wind and water action.

Stock trampling has the additional effect of causing mechanical damage to any vegetative regeneration and in lowering infiltration capacity by soil compaction.

Extensive soil creep, solifluction, terracette formation, sheeting, rilling and gullying is therefore directly attributable to past grazing and burning practices.

One of the most seriously affected areas is to be found near Mt. Twynam (7,207 feet) on the main divide, 5 miles north of Mt. Kosciusko, where an area of approximately 200 acres is showing evidence of progressive deterioration owing to serious erosion by wind and water action which has occurred in recent years. Where wind action has been particularly active, 2-3 feet of soil has been removed and the parent rock material exposed. When this stage is reached, excess run-off further assists soil removal and results in rilling and gullying on lower areas.

Damage as a result of the above agencies is also clearly evident in the Happy Jacks Plain area at the head of the Rocky Plain and Valentine Rivers, the Tooma River basin and around Kiandra. The damage is therefore not confined to local areas but is widespread throughout the catchment.

TOURIST ACTIVITIES.

The area is a popular tourist venue and owing to recent wide publicity this activity has increased to a large extent.

The major development in recent years has been the establishment of a number of ski lodges. Eight of these have been built in close proximity to the Back Perisher Range and a further two in the vicinity of Mt. Northcote.

One of the main difficulties associated with this building, has been the necessary provision of access tracks since most of them lie some distance from the main road to Kosciusko.

Erosion damage on these tracks has followed a well-defined pattern. Since most of these are initially located over snow-grass cover on alpine humus soils, mechanical damage to this cover by vehicular traffic is the first effect. Very often only one or two trips over snow-grass is sufficient to damage individual tussocks which die out and disintegrate, leaving continuous stretches of bare soil. As the majority of these tracks are located over steeply sloping country, accumulated run-off quickly erodes the wheel tracks to considerable depths. When depth increases and the track becomes unserviceable for smaller vehicles, the common practice has been to select a new one, so that over a period of time, extensive areas on each slope become seriously scoured and gullied.

A similar practice has been adopted on areas which tend to become boggy and unserviceable during wet periods. Although these areas are generally flat and do not represent a hazard so far as gullying is concerned, extensive areas may be cut up and the vegetation destroyed.

Serious erosion has also occurred on steep sections of bridle tracks throughout the area, notably that which leaves the main road at Charlotte's Pass and traverses the high country via Blue Lake and Carruthers' Peak to the summit at Mt. Kosciusko. Frequent selection of a new track has been responsible for the formation of interlaced gully systems, creating a serious hazard on these steep slopes.

Fig. 5.—Erosion is widespread on many of the tracks in the area, like this section of the Blue Lake track. (Photo S.M.H.E.A.)

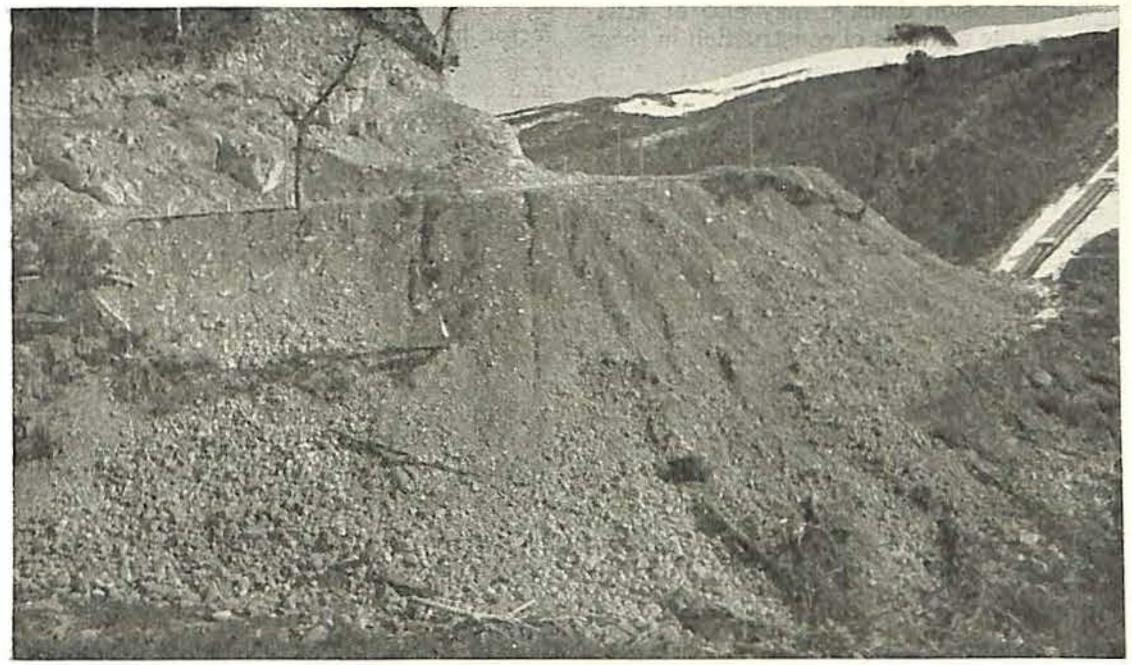

Fig. 6.—Vegetation destroyed by dumping excavated spoil downslope during road construction near Munyang.

ENGINEERING ACTIVITIES.

Access Roads.

To facilitate movement of heavy equipment to various sections of the engineering works, it has been necessary to widen and relocate large sections of existing main roads to the area and to undertake construction of a number of new ones.

The effects of renewed road-building has been twofold: a more extensive access system is now available throughout the area and extensive areas of erosion hazard have been created.

Whilst improved access will be of considerable value in such emergencies as a major fire, the possibilities of added erosion hazard and damage arising from extended human activities are most important if previous occurrences are accepted as criteria.

Immediate erosion damage arising directly from road-building is widespread and much of the erosion has been due to the very steep slopes and the deeply weathered highly erodible nature of much of the parent rock material.

Much erosion damage may also be attributed to the methods of construction in these highly erodible areas.

Until recently it was the practice to dump or cast all excavated material immediately downslope and since the widths of bench-cuts is around 20 feet, the majority of which must be placed on solid foundation to carry heavy loads, the quantities of spoil for disposal are quite large. The steeper the slope, the larger do these quantities become. It had been considered cheaper to overcast this material down slope than remove it back along the road. However, the effect of this was that the whole of the vegetation between road and river at the bottom of the slope was destroyed.

The Happy Valley Road from Cabramurra to T1 power station site provides extensive evidence of damage as a result of such operations. From Cabramurra this road descends some 2,000 feet to the Tumut River over an approximate distance of 2½ miles. Average land slope in the upper sections is 25°, grading to the order of 40° in the lower sections. Excavation to provide the necessary bench width on the steeper slopes resulted in the formation of cut batters of 60° or more. Where such excavations have been carried through areas of deeply weathered granite, serious instability of the batter face has resulted since the newly formed batter slope exceeds the natural angle of repose of the earth and rock material.

Dumping of excavated material immediately downslope has been responsible for major debris slides carrying huge quantities of earth and rubble to the Tumut River below, as shown in Fig. 7. Two of these slides, precipitated by blasting and dumping, swept 800 feet downslope carrying earth, rock and vegetation to the river, while others over a distance of 500 feet have recently occurred.

Although recent construction methods have been modified to provide for the haulage of a large percentage of excavated material to defined disposal areas, the remaining amounts which are unavoidably dumped downslope are still sufficient to cause serious damage. Apart from the initiation of additional rock and debris slides, permanent damage to and removal of vegetation is a major factor in the continuing instability of these slopes. Since the slopes involved are steep and the areas damaged usually quite extensive, the use of mechanical or vegetative control measures becomes exceedingly difficult, if not impossible in many cases. Areas denuded of vegetation and left in this unstable condition are open to further damage by water action causing gullying, slippage and mud flow.

Other problems associated with road construction have arisen by opening borrow areas on steep slopes, slumping of moist cut batters, accelerated table-drain and embankment erosion and the excessive destruction of vegetation with resultant exposure of bare unprotected soils.

Access Tracks.

In addition to main access roads, provision of access tracks to various points throughout the area has been one of the initial stages associated with the many activities being

undertaken. Access tracks have been provided to stream gauging sites, drilling sites, for aqueduct construction, transmission line construction and other activities incidental to the scheme as a whole.

The total mileage of these tracks is large; and much unnecessary damage has been caused by opening tracks beyond requirements.

One of the major difficulties has arisen from frequent attempts made to reach a given point by opening several tracks or extending one track by trial and error methods. To some extent, this has been occasioned by the nature of the slopes encountered but very often it can be directly attributed to the use of large earthmoving machines.

Upon completion of main access roads or with the cessation of activities in a given area, these tracks are abandoned and quickly fall into disrepair. Moreover, the erosion hazard due to each quickly assumes significance.

In addition to over-cast material which may already have seriously damaged the slope, severe gullying is evident on most of these tracks at the present time.

Aqueducts.

Some 16 miles of aqueducts are being constructed for the Guthega project alone and with successive extensions of the scheme the total mileage of these may be much more.

In the construction of these aqueducts, except for a small section of experimental open raceline, use has been made of concrete pipes for which it has been necessary to provide a bench cut around the slope on which to lay the pipes and for the purpose of transport. Problems associated with these operations again involve the removal of vegetation, cutting through scree slopes and natural drainage lines, and the dumping of excavated material down slope.

The majority of these pipes are covered by back-filling with previously excavated

Fig. 7.—Dumping spoil followed by debris slides has destroyed the stability of this slope below Happy Valley road.

(Photo S.M.H.E.A.)

Fig. 8.—Serious erosion hazard created during construction of the Snowy Valley road near Munyang.
(Photo S.M.H.E.A.)

material and recently some areas have been sown with pasture species. While awaiting revegetation of these areas which are largely composed of infertile sub-soil, erosion by water and frost action is allowed free rein and there is evidence of gullying and landslide activity.

Transmission Lines.

Construction of transmission lines forms a big part of the scheme and approximately 150 miles have been installed. Generally it has been the practice in timbered country to clear a strip 2 chains wide and to stack the fallen timber by bulldozer at the edge of the cleared area prior to burning. On very steep areas timber has been felled by hand and burnt. The areas cleared by bulldozer have been left in a loose and unstable condition and, in addition, provision of access tracks on steeply sloping sites has resulted in serious sheeting and gullying in many instances.

Some remedial measures, including use of absorption banks, sowing and many other techniques, have been undertaken on part of the affected areas. These will be described later.

Construction Sites and Township Areas.

To allow free access for major construction activities and to facilitate provision of camp and township amenities at various centres, considerable areas have been partially or totally denuded of vegetative cover.

Although destruction of soil-protecting vegetation is largely unavoidable in such operations, the use of heavy earthmoving machines has again been responsible for most of the damage.

At Cabramurra township site it was decided, owing to a high fire risk associated with the mountain ash forest (*Eucalyptus gigantea*) to clear some 400 acres of steeply

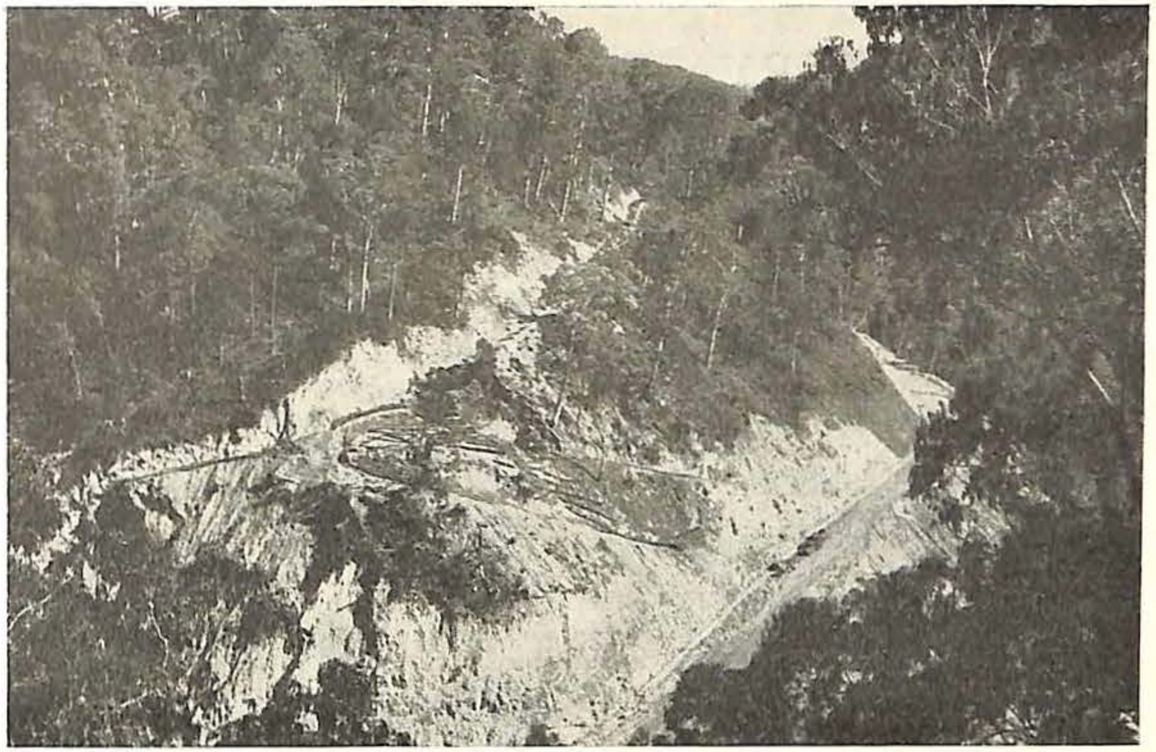

Fig. 9.—The lower leg of Happy Valley Road with the former access track above. The slopes have been seriously damaged by dumping spoil and opening the lower batter face.
(Photo S.M.H.E.A.)

sloping country. Not only was the tree cover removed, but in using heavy bulldozers to fell and stack the timber all vegetation was destroyed and the soil left in a loose and unstable condition.

In January, 1954, storm rainfall of 2½ inches in less than one hour, following previous rain which had thoroughly saturated the soil, yielded sufficient run-off from two adjacent catchments of approximately 20 acres each, to precipitate two landslides down the 2,000 feet slope and disgorge about 50,000 cubic yards of rubble and soil directly into the Tumut River. Soon after this occurrence the whole of the area, except the actual township site, was treated jointly by the New South Wales Conservation Service and the Snowy Mountains Authority using an extensive system of absorption banks to stabilise the area until it could be revegetated. Apart from some minor rilling and local sheeting the area has successfully withstood subsequent rain and snowfall.

Another instance of erosion hazard created by destruction of vegetative cover occurred during preliminary operations associated with the construction of the penstock leading to Guthega power station. During the initial stages a number of access tracks were opened up and finally an access road was provided. Together with clearing for the penstock, the slope was scarred throughout its length and all over-cast and denuded areas seriously gullied. Part of the area has now been stabilised by costly hand-installed structural control measures, followed by gradual revegetation of the area.

Similar occurrences are to be found in varying degree on all construction sites. To reclaim completely the areas already seriously eroded will necessitate expenditure on a large scale.

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SOIL CONSERVATION ON THE NORTH-WEST SLOPES AND PLAINS

BY

B. G. Warburton, H.D.A., Soil Conservationist.

THE development of conservation of the soil resources and control of soil erosion in this part of New South Wales began when a sub-district centre of the Soil Conservation Service was formed at Narrabri in 1949.

The Narrabri sub-district covers an area of approximately 5,400 square miles, and serves a large part of the North-west Slopes and Plains, providing advice to landholders on various aspects of soil conservation and erosion control.

Over this area there is a considerable contrast in the climate, soils, topography and vegetation generally.

RAINFALL.

On the average, summer is the wettest period of the year, during which storms of very high intensity are experienced, recording up to 7 inches of rainfall during one day.

Late winter and early spring is the driest period generally. August has the lowest rainfall, while December and January has the highest, usually.

Table I shows the average monthly and yearly rainfall for the various parts of the district, over a thirty-year period. The average rainfall ranges from 18 inches per annum on the western border to 36 inches per annum in isolated sections along the Nandewar Mountain Range at Mt. Kaputar and Mt. Lindsay. In Fig. 1 the distribution of the average annual rainfall, throughout the district, is shown by the isohyets.

SOILS.

There is an exceptional contrast of soil types over this area, and may be grouped generally as follows:—

Chernozem-like Soils.—The heavy black soil types are found generally on the treeless plains and in wide expanses of the northern and north-western portion of the district. The Chernozem soils form a large part of the district's soil types, being formed on the old alluvium and on the level areas of the basalt. These black soils are strongly alkaline with a pH ranging up to 8.3, and are fairly high in phosphates.

Gilgai Soils.—These are another group of Chernozem-like soils, merging from the Timbered Gilgai soils into the Brown Wavy Gilgai soils, which are distributed throughout the eastern section of the district, on the undulating country bordering the Nandewar foothills. In this area the Gilgai soils are found in a complex assortment of red-brown earths, Solodized Solonetz, Chocolate Basalt and Mountain soils associations. On the flatter country, generally south-east of Narrabri, these unusual puffy and hollow Gilgai formations form natural water absorption areas.

Table 1—Monthly rainfall averages (over 30 years period).

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Narrabri	2.39	2.04	2.20	1.43	1.54	2.40	2.14	1.28	1.43	1.77	2.21	3.31	24.14
Baan Baa	2.11	1.52	1.65	1.26	1.31	1.96	1.81	1.28	1.38	1.67	2.16	2.81	20.9
Boggabri	1.91	1.67	1.66	1.26	1.32	1.83	1.79	1.24	1.33	1.83	1.91	2.58	20.3
Pilliga	2.06	1.35	1.69	1.32	1.36	1.81	1.68	1.06	1.21	1.31	1.74	2.32	18.9
Wee Waa	2.31	1.63	1.83	1.43	1.50	2.09	1.90	1.16	1.31	1.50	1.77	2.72	21.1

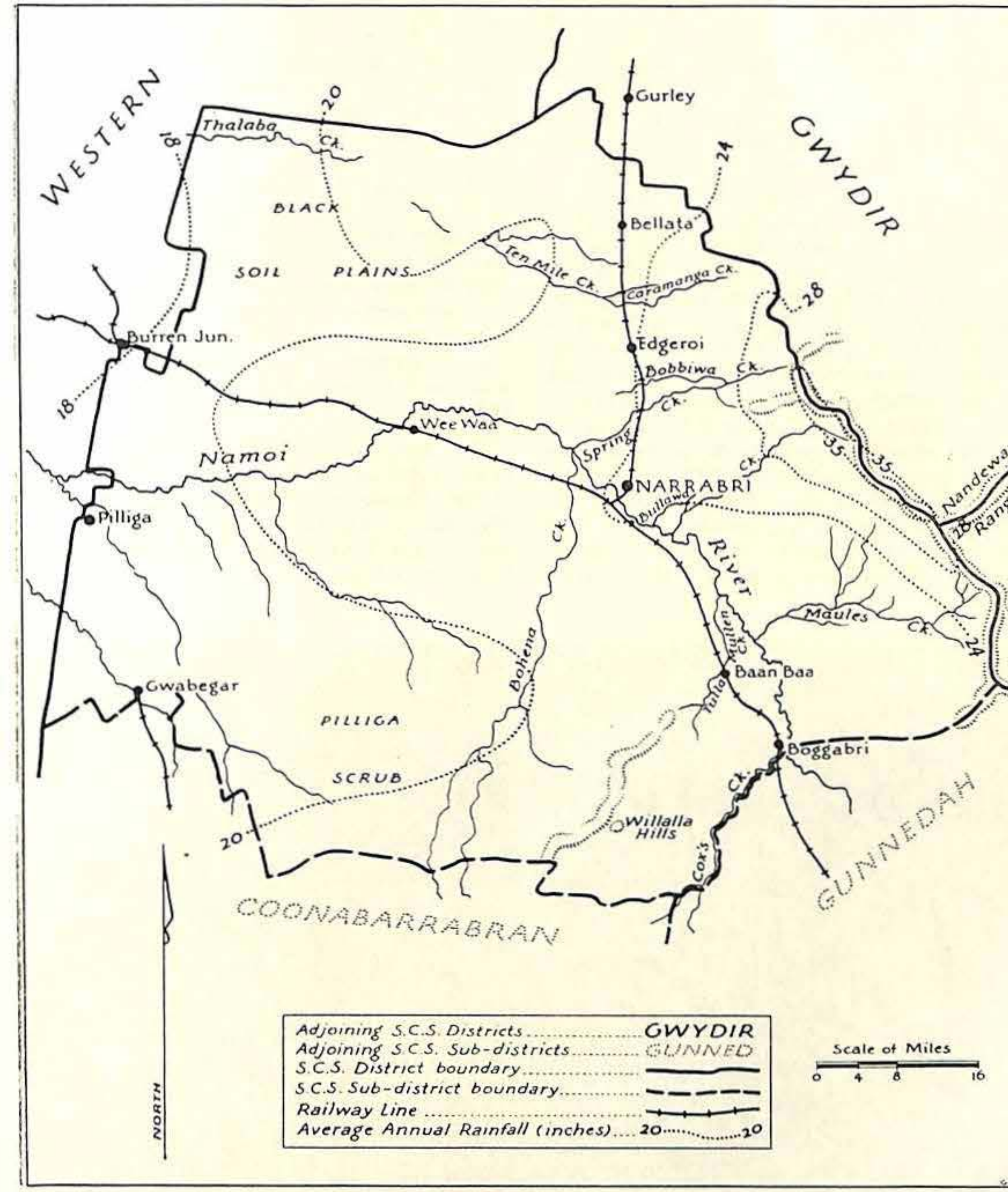

Fig. 1.—Narrabri Soil Conservation Sub-district.

Serozem-like Soils.—These soils are more alkaline, with a lower content of nitrogen and organic matter, and lighter in texture than the Chernozem soils. The Serozem association occurs in the western or drier areas, extending from the extreme western perimeter of the district to the Upper Darling or Barwon River, with an eastern extension along the south bank of the Naomi River, toward Narrabri.

Solodised Solonetz Soils.—These soils form another major soil type of the district. The soils of the Solodised Solonetz association represent the poorest soil in the district. They are low in nitrogen and phosphate, and particularly low in calcium and high in acidity, having a pH of from 4.0 to 5.0 and a shallow cemented hardpan in the sub-soil.

The Solodised Solonetz soil association covers a large area, running south of Narrabri and extending over the flat alluvial sandplains around the village of Pilliga. Together with the thin eroded skeletal soils of the sandstone ridges in the southern section of the Pilliga Scrub and the deep sands association in the western section of the district, they form the soil types of the Pilliga Scrub. Solodized Solonetz soils also occur along the eastern section of the district, together with the red-brown earth association.

Red-brown Earth Association.—These soils are developed from Lower Mesozoic or Jurassic and Cretaceous beds, mainly sandstones. They range in pH from 6.0 to 7.0 and are very rich in total phosphate. In this district the surface soils of this group are not very well supplied with nitrogen in the virgin state. As organic matter is largely confined to the surface, they have lost fertility by continuous wheat cropping, as well as losing topsoil by sheet erosion. These soils occur generally in the south-east and eastern section of the district, particularly south-west from Boggabri and in the Willalla Hills.

Chocolate Basalt Soils.—These are found along sections of the slopes and foothills of the Nandewar Range interspersed with Mountain soils, Brown Wavy Gilgai soils, Red-brown Earths and Solodized-Solonetz soils associations.

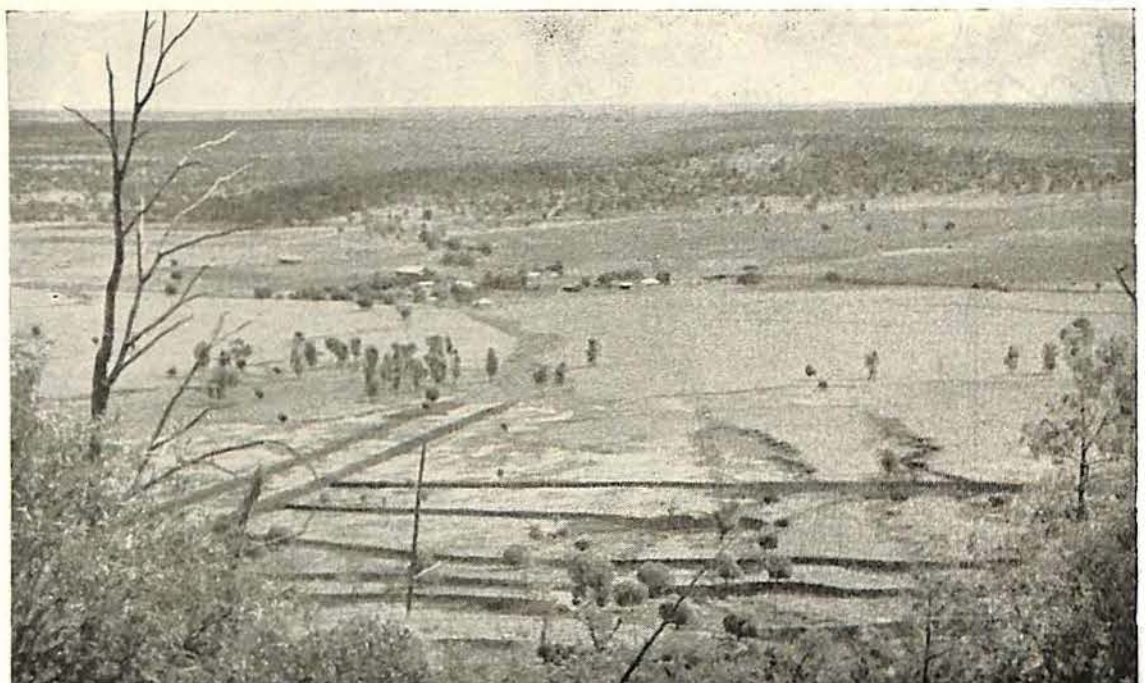

Fig. 2.—Typical country along the foothills of the Nandewar Range being reclaimed from soil erosion.

TOPOGRAPHY.

The Black Soil Plains extend away westward from the undulating country and foothills of the Nandewar Mountain Range. Such creeks as Bobbiwar, Curramanga and Ten Mile Creeks drain into the Black Soil Plains from the north-western section of the Nandewar Mountain Range.

The southern and south-western section of the district is flat to only slightly undulating in the Pilliga scrub area.

The eastern section of the district comprises the hilly and sloping country of the district, with the slopes ascending to the steep foothills of the Nandewar Range at the heads of the Spring, Horse Arm, Bullowa, Eulah and Maules Creek areas. The Nandewar Range is particularly rugged and rises to a height of 5,008 feet above sea level, at Mt. Kaputar.

In the south-eastern section, the Baan Baa, Willalla, and Boggabri area is undulating to hilly.

VEGETATION.

The types of vegetation vary, in the Narrabri district, according to the soil type and rainfall occurrence generally.

On the ridge tops of the Nandewar Range, the main types of trees found are: narrow leaf ironbark, forest red gum, black cypress pine, mountain stringybark. Along the undulating foothills of the Nandewar Range, tall woodlands occur in various communities of trees, consisting of narrow and silver leaf ironbarks, white box, kurrajong, bimble box, and Acacias.

Savannah and scrub woodlands occur on the less sloping areas of the district, running down on to the plains. Such woodlands consists of wilga, myall, belah, kurrajong, cattlebush, and brigalow. The pilliga scrub country, in the southern section of the district, consists of such vegetation as white cypress pine, brown bloodwood, blue leaved ironbark, various species of Acacia, and occasional black cypress pine and narrow-leaved ironbark, as well as bull oak. On the light

Fig. 3.—Same area as illustrated in Fig. 2, showing the use of small silt traps to reduce run-off from steep lands above contour banked cultivation country.

sandy soils of the Pilliga Scrub, grasses include common lovegrass (*Eragrostis elongata*), three-awned speargrass (*Aristrida vagans*), pitted bluegrass (*Bothriochloa decipiens*), while cotton bush (*Kochia* sp.) occurs particularly around Pilliga. There is a noticeable absence of medics and clovers on the Solodised Solonetz and Skeletal soils of the Pilliga Scrub, mainly due to high acid content of these soils.

Natural grasslands occur on the Black Soil Plains of the North-west. An unusual feature of these plains is that they are completely treeless, except for small clumps of trees on isolated low ridges or rises on the plains. On the plains the grasslands consist of two main associations:

The Plains Grass Association made up of plains grass (*Stipa aristiglumis*), wallaby grass (*Danthonia* sp.), barley grass (*Hordeum leporinum*) and burr medic (*Medicago denticulata*). The Mitchell Grass Association occurs alternatively to the plains grass association on the chernozem-like soils of the North-west Plains. It comprises curly Mitchell grass (*Astrebla lappacea*), love grass (*Eragrostis* spp.), small Flinders grass (*Iseilema membranaceum*), button grass (*Dactyloctenium* spp.). On the western section of the plains, on the Serozem-like soils, some saltbush (*Atriplex* spp.) occurs with the Mitchell grass association.

On the sloping savannah woodland country, naturally occurring grasses include wallaby grass (*Danthonia pallida*), Queensland blue grass (*Dichanthium sericeum*), barley grass, tall chloris grass (*Chrloris ventricosa*), windmill grass (*C. truncata*), small woolly bur medic (*Medicago minima*), burr medic and clustered clover (*Trifolium glomeratum*).

LAND USE.

Over this section of the North-west Slopes and Plains the land use varies to some extent. On the higher rainfall areas of the western slopes of the Nandewar Range, a great potential exists for pasture improvement, to increase production from this fertile country.

The main primary industries include sheep, for wool and meat production, and beef cattle raising is carried out extensively. Wheat production has been a most important primary industry, on the Slopes and extending westward into the marginal areas on the North-west Plains. Oats are grown to a less extent for hay, grain, and grazing crops. Lucerne is cultivated in small areas, along the Namoi River and creek flats, for hay, while on the sloping country it is used to some extent for pasture improvement.

On the Solodised Solonetz soils, in the southern portion of the district, running south of Narrabri into the Pilliga Scrub area, agricultural development has been limited, due to the low fertility of the soils. Grazing and timber-getting are the main occupation in this area, since large areas of the Pilliga Scrub are under the control of the Forestry Commission as State Forests and Timber Reserves.

The Effect of Land Use on Soil Erosion.

Due to the land usage now practised, accelerated erosion is taking place on lands which were originally quite safe under the protection of their natural cover.

Factors influencing the effect and occurrence of erosion in this district are:—

(1) Clearing of natural timber cover from the steeper slopes, particularly along the foothills of the Nandewar Range.

(2) Cultivation of excessively steep slopes, which should be established to permanent pastures.

(3) The general reduction of the humus content of the soil, by long summer fallowing, and stubble burning, particularly on the lighter soils of the district.

(4) Overstocking, and the depletion of natural grass cover.

Soil Erosion Survey.

The most serious erosion occurring in this district is on sections of sloping country, along the foothills of the Nandewar, north-east of Narrabri. The erosion is in the form of moderate to serious gullying of the cultivation and grazing lands mainly in the Chernozem and Red-brown Soil Associations.

On the lesser slopes, particularly on the Solodised Solonetz soils, sheet erosion and rilling is another serious form of erosion in this district.

Fig. 4.—Absorption banks on steep hillsides retain water and protect the fertile lower slopes.

In the lower rainfall areas of the district, moderate wind erosion occurs in a number of small scattered patches. This class of erosion is more serious, however, in a large latitudinal belt, extending from Narrabri westward to Pilliga, taking in much of the wheat-sheep area of the district.

The land which is not eroded to any appreciable degree, is the flat inland plain country, used for sheep grazing, together with the Pilliga country to the south.

EROSION CONTROL MEASURES.

The need for flood mitigation dams in the tributaries and on the Namoi River, and forestation on the steep lands draining into the catchment areas, has been stressed many times in recent years, but soil conservation and erosion control is an equally important aspect of flood control.

The results of the devastating flood in the Namoi Valley, in February, 1955, to be followed by another serious flood, only eight months later and a further flood in February, 1956, has impressed the community of this district.

Due to the more mechanised farming practised during the last twenty-five years, larger areas have been thrown open for agriculture. The insidious effects of soil erosion on these lands have greatly increased the amount of soil loss and run-off, resulting in erosional debris being deposited in the creeks and the Namoi River, and an increase in the amount of run-off that these gradually reducing flow lines have to carry.

One of the primary steps to be taken in flood mitigation measures has been the control of erosion and run-off on the catchment areas of the Namoi River. This can only be fully effective with the full co-operation of each and every landholder, to control the erosion and retain as much of the run-off as possible on his property. Such control can be achieved by adopting better farming methods, and quite often by the construction of contour earthworks to prevent run-off from rushing off the sloping lands.

In this district, among various types of earthworks used to control soil erosion, absorption banks and pasture furrows have

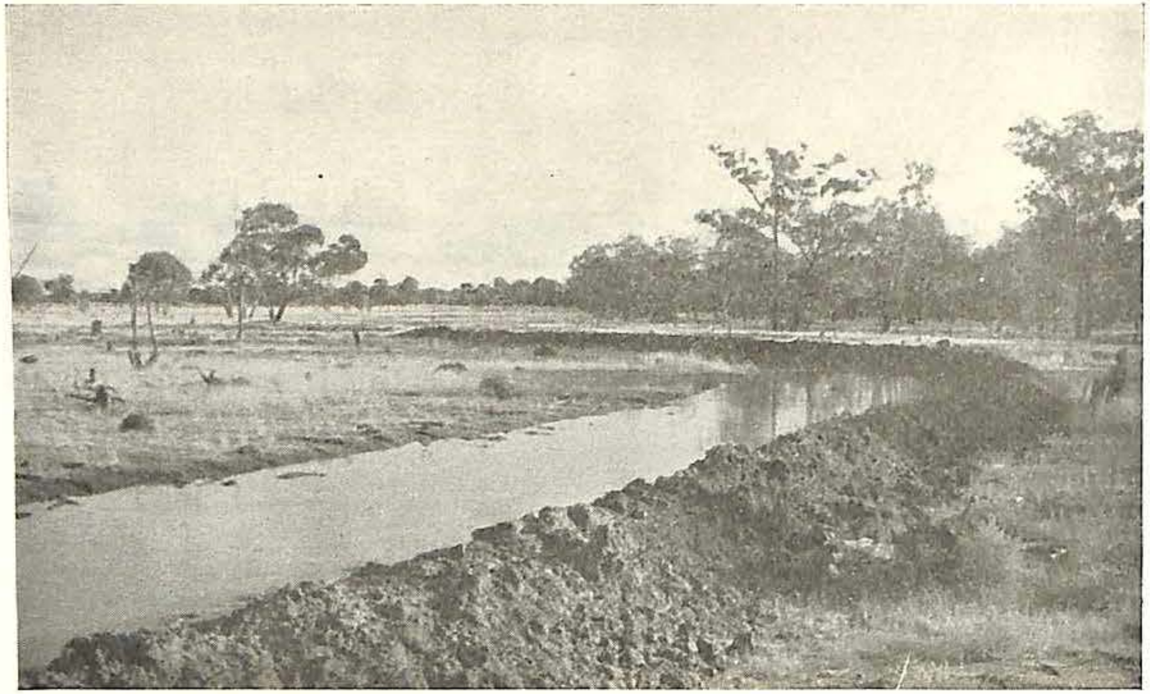

Fig. 5.—On the flatter grazing country, of the marginal areas of the Pilliga Scrub, absorption banks retain run-off during summer storms.

proved to be successful in controlling run-off. Above cultivation lands, along the foot-hills of the Nandewar Range, it has been necessary to protect such lands by the construction, usually, of a system of absorption or level banks, and silt traps or small dams. The run-off from such steep hills as these, can be slowed up, and reduced, eventually to be guided back into the main water courses.

On the cultivation country, graded banks, at spacings depending on the slope, have proved to be most efficient in protecting such lands against the effects of heavy rainfall during the summer months. The outlets of graded banks are designed to enter either a well grassed watercourse or a previously constructed grassed waterway.

Pasture furrows, consisting of a single furrow constructed on the contour with either a small grader or single furrow mould-board plough, have proved successful in controlling run-off and erosion on grazing country, on the lighter soils of the district. Such pasture furrows aid in retaining the run-off and increasing the absorption of the soil. On hilly grazing country, as well as the less sloping country there is an enormous scope for these pasture furrows together with absorption banks.

Another method of retaining and absorbing run-off on cultivation lands, and used by farmers in this district, particularly on the Solodised Solonetz soils, has been by contour cultivation with heavy scarifier or chisel type plough. Such ploughing is desirably done on the contour and, on steep slopes, between graded banks. This type of cultivation reduces the run-off reaching the channels of the banks and helps the more even distribution of moisture in the soil down the slope.

PASTURE IMPROVEMENT.

The establishment of permanent and long term improved pastures plays a very important part in the rotational farming programme, to reduce soil loss and run-off, on the higher rainfall areas of the district.

On the heavier soil of this district, ranging from the Chernozem-like soils to the Red-brown Earths, there is considerably less

Fig. 6.—Pasture furrows, constructed with farming equipment, retain run-off.

difficulty in establishing improved pastures than there is on the lighter Solodised Solonetz and sandy soils of the Pilliga Scrub. However, during the past two years much research into the lighter soils of the Pilliga Scrub has been carried out. It has been found by sowing pasture seed mixtures with superphosphate and lime, that the lighter and less fertile soils of the district are capable of producing good balanced pastures of legumes and grasses.

Improved pasture species found to be most suitable in the north-west district are, Rhodes grass (*Chloris gayana*), Wimmera ryegrass (*Lolium rigidum*), Guinea grass (green panic) (*Panicum maximum*), giant panic (*Panicum antidotale*), lucerne burr medic (*Medicago denticulata*), barrel medic (*M. tribuloides*).

Below the twenty-two inch per annum rainfall areas of the district, the valuable native grasses on Black Soil Plains, such as Mitchell, Flinders, hairy panic, brown top, early spring, plains and other species as previously mentioned, must be maintained by judicious stocking and rotational grazing. Good grasses should be encouraged in every way possible particularly by allowing them to seed and by collecing some seed and scattering it over denuded areas.

CONCLUSION.

Due to the wide variation in soils, slopes and rainfall over the Narrabri district each farm presents its own erosion problems, ranging from gully erosion on sections of the foothills of the Nandewar Range, to wind erosion on parts of the North-west Plains.

Increased interest is now being taken in this essential aspect of land management, and there is an increasing demand on the services offered by the Soil Conservation Service.

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THE USE OF FERTILIZERS IN THE IMPROVEMENT OF THE CATCHMENT OF GLENBAWN DAM

BY

A. L. MITCHELL, B.Sc.For., Soil Conservationist.

THE Glenbawn Dam, near Scone, is the first of a series of dams being constructed to alleviate damage caused by periodic floods along the lower reaches of the Hunter River. As this Dam is now nearing completion, it is necessary that its catchment be so improved that a maximum of water is detained on the area where it falls and a minimum of silt reaches the storage. Only then can the effective life of the dam be prolonged in meeting its flood control and irrigation requirements.

Although soil conservation measures such as silt traps, contour banks, and pasture furrows are effective on the lesser slopes, two-thirds of the entire catchment is too steep for mechanical treatment. It is necessary, therefore, to develop and maintain a dense, vigorous protective vegetation. The first step in the development of a vegetative cover is the correction in the soil of any mineral deficiencies which may be a limiting factor on plant growth. Further steps would include the selection and establishment of improved plant species and the maintenance of this vegetative cover through careful management of grazing.

EFFECTS OF LAND USE.

The entire catchment has been grazed by sheep, cattle and rabbits for many years. Although there are some remnants of forests left, these have little value in soil protection while they are being grazed. Such forests can develop into the ideal watershed cover if all grazing is excluded; however, as most of the catchment will probably continue to be grazed for many years, a cover must be developed under grazing conditions which will retain as much of the rainfall as possible and adequately protect the soil from erosion. Where grazing has not been too severe, it has thickened the ground vegetation and distributed valuable legumes throughout the area. These introduced clovers and medics are the basis of soil improvement and grass development. With these legumes already on the area, the problem is to stimulate their development so that they can utilise the free nitrogen of the air most efficiently and pass on this nitrogen in a form that can be utilised by plants and animals for increased soil fertility and plant growth.

FERTILIZER PRACTICES BY LANDHOLDERS.

The only fertilizer in general use by landholders of this area is superphosphate. It has been used for many years to increase the growth and productiveness of the legumes and, as the soil nitrogen is built up, there is a noticeable increase in growth and improvement in the grasses. In the Pages Creek area, "Oakleigh" has had a striking response with superphosphate for several years, and in 1954 this property and an adjoining property, "Poitrel", were aerially top-dressed. This latter property was top-dressed by air in 1955 with 300 tons of superphosphate. During this past winter and spring the hills in this area were covered with clovers and medics nearly a foot deep. In the summer the grasses form a thick continuous cover. Three years ago some of these hills were classified as erosion danger areas. Subterranean clover and ryegrasses, broadcast by plane at the time of top-dressing, are well established over much of the area. Superphosphate is being spread throughout most of the catchment in smaller quantities through broadcasters, spreaders, drills, and even by hand. Although the response is great, the areas treated are small because of the expense involved.

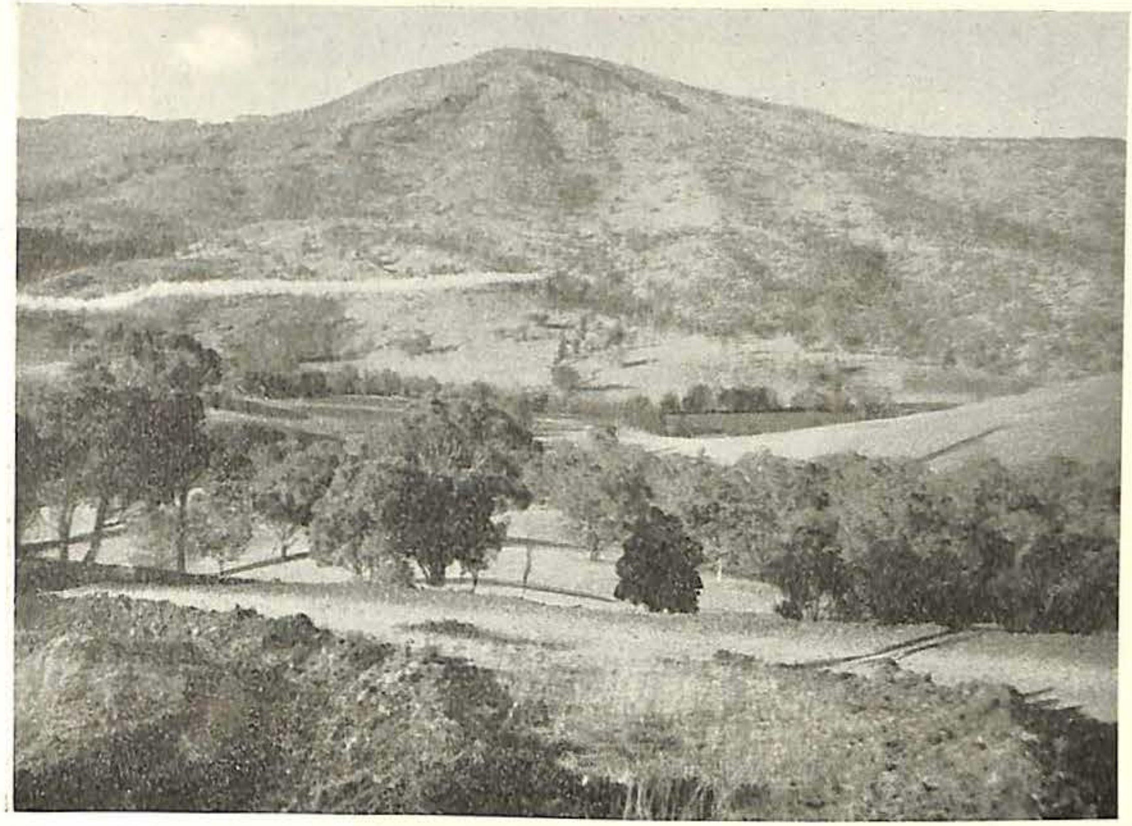

Fig. 1.—Aerial top-dressing at "Poitrel" in the Upper Glenbawn Catchment has promoted a dense protective ground cover.

AN EXPERIMENT WITH SUPERPHOSPHATES.

In September, 1954, N. H. Monteith, of the Scone S.C.S. Research Station, made up a trial to determine what it was in the superphosphate which was causing the response in legumes. As superphosphate contains phosphorus (phosphates), calcium (lime), and sulphur (gypsum), this trial consisted of plots containing these three elements, singly and in combination. These plots, replicated four times, were laid out on a natural pasture containing hop clover (*Trifolium campestre*) at "Bullarer", Woolooma, in an area known to respond to superphosphate. The response in several plots was outstanding in the much greater density and development of the hop clover and in the considerable darkening of colour of these plants. This response occurred only in the plots containing sulphur, whether in combination with phosphorus and calcium (as in superphosphate) at 4 cwt. per acre, in combination with calcium (as in gypsum) at 179 lb. per acre, or as elemental sulphur at about 40 lb. per acre. There was no response to either calcium or phosphorus. If this condition were widespread it would mean that about 6 acres could be treated with gypsum for the same cost and with the same results as obtained from treating 1 acre with superphosphate. The problem now was to find if this condition of sulphur deficiency was general throughout the catchment and at the same time to find if there were deficiencies of other minerals.

COMPLETE FERTILIZER TRIALS.

Fertilizer trials after the design of A. J. Anderson [5], which tested for the adequacy of all the major and minor elements (except nitrogen and sulphur), necessary for plant growth, were established in certain

Fig. 2.—Naturalised white clover increased in abundance and flowering in plots where gypsum or superphosphate has been applied.

representative areas. These trial kits were purchased by the landholders, who fenced and looked after the trials after assisting with the establishment. These trials are located at "Bullarer", Woolooma; "Stoney Creek", Belltrees; "Avoca", Moonan Flat; "Yannerlea", Branch Creek; and "Hunter Springs", Tomalla. The trial at "Hunter Springs" initially showed an apparent response to molybdenum, but this disappeared as the clovers became fully established, and has not reappeared. All trials showed there to be no deficiency which was not corrected by superphosphate. As there was no additional response to calcium, further trials were to be made comparing the effectiveness of sulphur to phosphorus with an occasional trial including lime, molybdenum, amonium sulphate (for effective nodulation), and the "complete fertilizer' (when there was no apparent response).

SUPERPHOSPHATE AND GYPSUM TRIALS.

If 2 cwt. per acre of gypsum gives the same response as 4 cwt. of superphosphate, it can be concluded that there is no apparent phosphorus deficiency at that time. Superphosphate contains about 50 per cent. gypsum. If, however, there is a response to both fertilisers, but superphosphate gives the greater response, there is then a deficiency of both sulphur and phosphorus.

On the basis of this reasoning a simple fertilizer trial was designed. Two adjacent plots were laid out 3 yards wide by 5 yards long. Superphosphate (about 2 lb.) at the rate of about 4 cwt. per acre was broadcast in one; gypsum (about 1 lb.) at 2 cwt. per acre in the other. In order to remember which plot was which, in all cases the gypsum plot was on the right-hand side looking uphill. A strip of molybdenum at 2 oz. per acre mixed with lime was spread through the middle of the two plots in many trials. Some of the trials were put on improved pastures, but most of them were spread over the natural pasture where there was evidence of a clover or medic being present.

In co-operation with forty-six landholders, 177 trials were established throughout the Glenbawn Catchment Area, attempting to test as much of the area as possible over a wide range of slope, rainfall, soil type, parent rock material and species of legume. Most of these plots were established during the

Fig. 3.—A corner of the gypsum plot showing increased growth of ladino white clover at "Oakleigh", near Pages Creek.

autumn and winter of 1955 and notations on plots were made whenever they could be visited. The maximum responses have been taken on 152 trials, the other twenty-five having been established too late for results this year.

As conditions vary so much in this catchment area of 300,000 acres from 1,000 feet to 5,000 feet elevation, and including a wide range of soil type and parent rock material, the results of the trials were summarised by locality.

Belltrees, Donalds Creek, Stoney Creek.

Of sixteen trials all showed a marked response to sulphur (gypsum), while one showed a slight additional response to phosphorus. The soils of this area are mainly derived from sedimentary material of shale, claystone, sandstone, and conglomerate laid down during the Carboniferous period. Responses were noted on white clover (*Trifolium repens*), hop clover (*Trifolium campestre*), clustered or ball clover (*Trifolium glomeratum*), burr medic (*Medicago denticulata*), small woolly burr medic (*M. minima*), button medic (*M. orbicularis*), and barrel medic (*M. tribuloides*). Gypsum at about 1 cwt. per acre would be the most economical fertilizer to use in this area. After a few years a strip, or plot, of superphosphate should be spread over the areas treated with gypsum to see if there is any additional response to phosphorus.

Woolooma.

Of thirty-seven trials, twenty-nine showed a marked response to sulphur, two showed an additional response to phosphorus, and eight showed no response to either element. One of these latter trials at "Bullarer" showed no response, even when the complete fertilizer was added. The soils of this area are derived from the same rock as at Belltrees, except that there are more frequent intrusions of contemporaneous felsitic lava flows of the Carboniferous period. There is a sulphur response on some of the colluvial soils derived from granite and porphyry of the Mt. Wooloma Permo-carboniferous period. Responses were noticed on lucerne (*Medicago sativa*), burr medic, small woolly burr medic, button medic, clustered clover, hop clover, haresfoot clover (*Trifolium* *arvense*) and white clover. Gypsum could be used over most of the area, while further trials are being carried out in places where no response has been obtained.

Stewarts Brook.

Of sixteen trials, two responded to sulphur, but gave an additional response to phosphorus. Three others responded to phosphorus only, while there was no response in eleven trials. There was no response to gypsum on the north or south arms of Stewarts Brook, and only a very slight response to superphosphate even when these trials were laid on old-established pastures of subterranean clover which had never been fertilized. All trials had a strip of molybdenum through them. Most of the area is quite steep and the soils are derived from felsite, rhyolite, andesite and, in the higher elevations, a Tertiary basalt. Six soils sampled in these trial plots had a pH of 5.0 to 6.0. It would not be advisable to use topdressing in this area until further trials outline deficiency areas. On the lower slopes and alluvial flats, the landholder should put out a superphosphate test plot before "supering" the whole area.

Moonan Flat, Moonan Brook.

Of twenty-nine trials twenty-seven gave a definite response to sulphur; two of these gave a slight additional response to phosphorus, and two gave no response. Impassable roads excluded trials at the headwaters of Moonan Brook and Brushy Hill Creek. Most of the soils are derived from shale, conglomerate, and contemporaneous lava flows of the Carboniferous period. The brown skeletal soils derived from the shale outcrops having a pH of 7.0 give about the same response to sulphur as the deeper podsolised red-brown earths of pH 6.0, and the grey-brown loam of the alluvial flats of pH 5.0. Responses were recorded from hop clover, clustered clover, haresfoot clover, subterranean clover, spotted medic (*Medicago arabica*), burr medic, small woolly burr medic, and lucerne. Gypsum could be used to advantage on all this country except on

Fig. 4.—A fertilizer trial on natural pasture showing increased density of clustered clover and decreased density of pitted blue grass and wire grass due to sulphur response of the clovers.

the untested areas of upper Moonan Brook which may be similar to upper Stewarts Brook.

Omadale Brook.

Of twelve trials in this area, all responded equally well to gypsum as to superphosphate, showing a general sulphur deficiency and no noticeable phosphorus deficiency. Molybdenum gave no additional response, nor did "complete fertilizer". Some trials were on alluvial flats on the Hunter River, others were on the shallow soils of the hillsides. With the present information, gypsum would be the most economical fertilizer.

Ellerston, Pages Creek, Branch Creek.

Of thirty trials all showed a response to sulphur, and one showed an additional response to phosphorus. Soils of the lower elevations are of sedimentary rock origin, whereas soils of the higher elevations are of Tertiary basalt. Some of the soils of this demarkation line contain free lime nodules, and the white scalds of these areas have a high lime content. The response to sulphur is particularly high in the transition area. Trials on black basalt soils showed a quicker response than trials put on light brown shallow shale-derived soils, but in most cases the responses were equal—the sulphur deficiency being very high in both. Responses were recorded on subterranean clover, clustered clover, white clover (naturalised), white clover (*Ladino strain*), hop clover, yellow suckling clover (*Trifolium dubium*), burr medic and small woolly burr medic. Conspicuous response was also noticed on the phalaris (*P. tuberosa*) at Ellerston in a subclover-phalaris paddock that had been established many years but never fertilized. Although the use of superphosphate has been heavy in much of this area, gypsum should give the same response at half the annual dressing.

HUNTER SPRINGS, TOMALLA.

Of twelve trials established, all responded to sulphur, and to sulphur only. The responses were very high in all plots, showing there to be a severe sulphur deficiency in

Fig. 5.—The increased growth of subterranean clover and white clover is noted on the fertilizer trail and on the superphosphate trail from a broadcaster at "Sempill's Rock" at head of Hunter River.

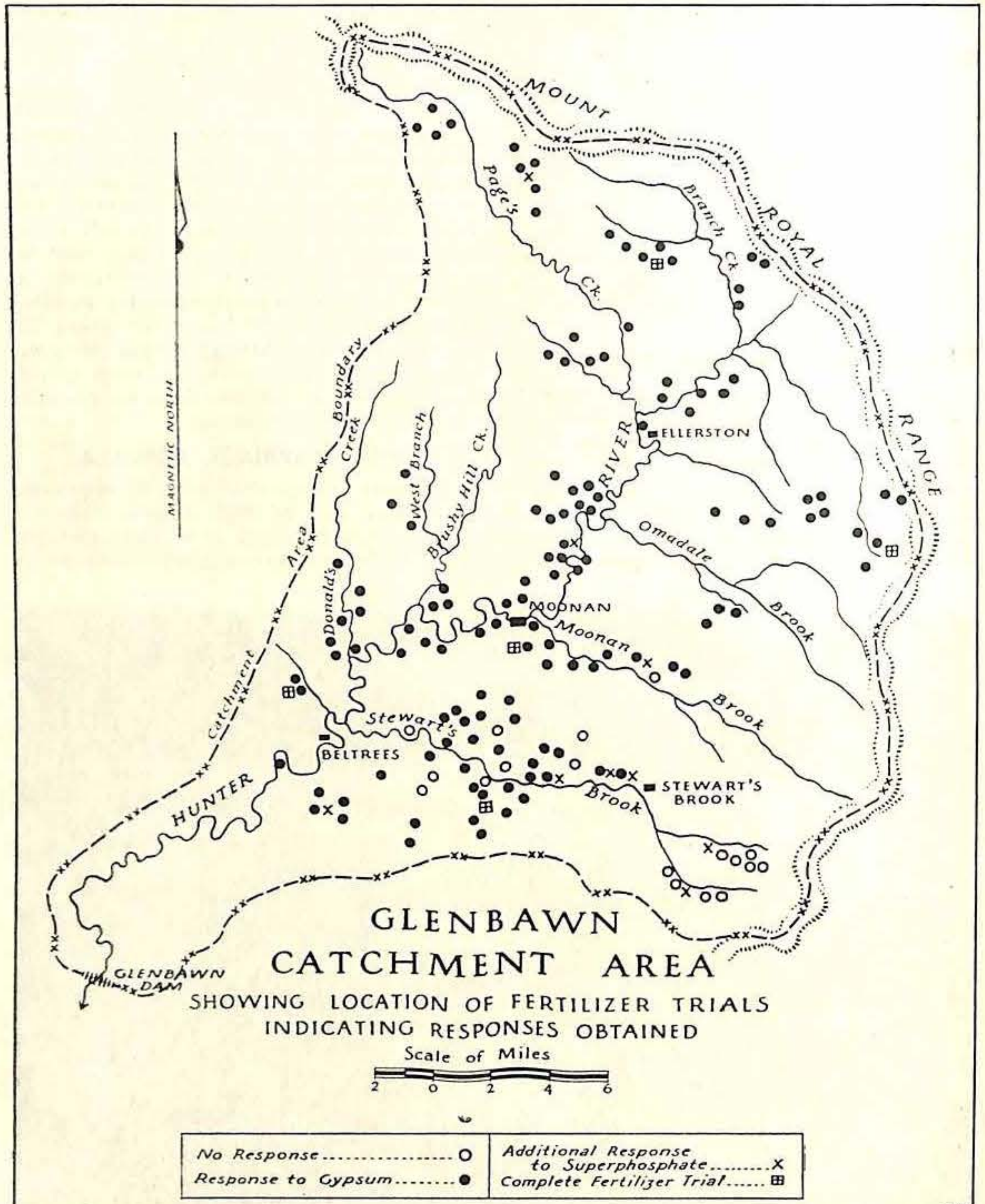

Fig. 6.—Location of fertilizer trials indicating responses obtained.

this area. Most were red, brown, and black basalt soils with a similar response to sulphur and no response to either molybdenum or lime applied singly or in combination with superphosphate. Ammonium sulphate gave the same response as calcium sulphate (gypsum), indicating there to be no additional response to calcium, and that nodulation of both naturalized and recently introduced legumes was effective. The soils in the Hunter Springs area are derived from Tertiary basalt and Devonian quartzite, whereas the soils on the Sempills Creek fall are mainly basalt. Further trials were established into the granite country in Tomalla as the much more abundant naturalized white clover indicated that there may be less severe sulphur deficiency there. Soil tests in this area showed a somewhat more acid soil. Responses were recorded on hop clover, clustered clover, subterranean clover, white clover (New Zealand Mother Strain), white clover (naturalized), and red clover (*Trifolium pratense*). The very high response to sulphur would make it economically sound to topdress this country with gypsum and at the same time broadcast Tallarook variety of subterranean clover and one of the improved strains of white clover. Clovers are sparse over most of the area, possibly because of the extreme sulphur deficiency. The cool climate and favourable rainfall would ensure the establishment of an excellent ground vegetation once the sulphur deficiency was met, and improved grass and clover seed introduced. This area is important as being the headwaters of the Hunter River, Sempills Creek, and Omadale Brook.

QUANTITATIVE RESPONSES TO SULPHUR AND PHOSPHORUS.

In every trial where there was a response to sulphur there was a conspicuous darkening in the colour of the legumes, a great increase in the number of plants and, in plots which were not heavily grazed, there was a great increase in the bulk of clovers and medics. Cuts were taken on some of these trials from which stock were excluded in order to get a better picture of the actual response due to the addition of sulphur as gypsum, and sulphur and phosphorus as superphosphate. These cuts were made on a ten-square link quadrat in each plot and converted on a tons-per-acre green weight basis. In order to measure responses on burr medic and button medic, cuttings were made on a fenced trial at Gundy on the Page River Catchment.

"Moonbria", Gundy, Pages River Catchment.

Soil: Sandy loam alluvial flat of pH-7 at 3-6 inch depth.

Date of etablishment: 8-7-55. Date of response: 4-10-55. Elev. 900 feet.

Response: Equal on burr medic (*M. denticulata*) and button medic (*M. orbicularis*).

	Tons per acre.
Control plot, no fertilizer added ..	0.5
Molybdenised Superphosphate at 4 cwt./acre	9.4
Superphosphate at 4 cwt./acre ..	9.4
Gypsum at 2 cwt./acre	5.5

The gypsum plot was not added until five weeks after the other plots were established. As the medics were further developed at this time, this may have a bearing on the gypsum response.

This trial was on a river bank which was subject to flooding. The very dense growth of green material, the increased root system, and the heavy residue of stems and leaves would be a considerable deterrent to streambank erosion.

"Oakleigh", Pages Creek, Ellerston.

Soil: Basalt soil of pH-6.5 at 3-6 inch depth.

Date of establishment: Mar. 1955. Date of response: 1-11-55. Elev.: 3,000 feet.

Response on Ladino strain of white clover planted June, 1954.

	Tons per acre.
Calcium phosphate at 138 lb. per acre	1.5
Calcium sulphate (gypsum) at 178 lb. per acre	8.5
Superphosphate at 4 cwt. per acre	15.8

A trial 50 feet away on clustered clover on apparently the same soil type and aspect showed an equal response to gypsum as to superphosphate.

Response on a natural pasture of clustered clover (*Trifolium glomeratum*) on a similar soil about 500 feet in elevation above the preceding plot.

Date established: April, 1955. Date of response: 1-11-55.

	Tons per acre.
Control plot, no fertilizer	1.2
Superphosphate at 4 cwt. per acre	8.5
Gypsum at 2 cwt. per acre	8.5

These trials are on fairly steep mountain slopes susceptible to landslips and erosion. An increase in plant growth of from five to ten times should be very effective in protecting the soil.

"Barrington Hut", Hunter Springs.

Soil: Brown soil containing basalt rocks and granite rocks. pH-6.0 at 3-6 inches.

Date established: 23-3-55. Date of response: 23-11-55. Elev. 4,600 feet.

Response on naturalised white clover.

	Tons per acre.
Control plot, no fertilizer	1.8
Superphosphate at 4 cwt. per acre	13.4
Gypsum at 2 cwt. per acre	12.2

Other plots contained lime at 2 cwt. and 4 cwt. molybdenum at 2 oz. per acre. These showed no response. "Complete fertilizer" and ammonium sulphate gave no additional response.

"Sempill's Rock", Tomalla-road.

Soil: Red-brown basalt soil of pH-6.5 at 3-6 inches.

Date Established: 23/3/55. Date Response: 23/11/55. Elev. 4,000 ft.

Response was equal on both subterranean clover and white clover in approximately equal densities.

	Tons per acre.
Control, no fertilizer	1.8
Superphosphate at 4 cwt per acre	20.7
Gypsum at 2 cwt. per acre	24.4
Lime at 2 cwt. per acre plus ammonium sulphate at 2 cwt. per acre	21.9

There was no additional response with lime at 2 cwt. over the superphosphate trial, indicating that the response in the ammonium sulphate trial was to sulphur, and that the clovers were effectively nodulated. The clovers in the control plot were too short to cut and the material taken was rattail fescue (*Vulpia myuros*). There was almost no grass in the fertilized plots. This pasture had been established several years previously but never fertilized.

These trials are on gentle slopes at the top of the catchment. Such high increases in plant growth should be effective in increasing the water holding capacity of these upper slopes and also in providing more intensive grazing, thereby relieving grazing pressure on the steeper country.

EVALUATION OF RESULTS.

There is a general deficiency of sulphur in soils of apparently adequate phosphorus status throughout most of the Glenbawn Catchment Area, with the exception of the upper part of Stewarts Brook and possibly upper Moonan Brook.

Estimates of responses were taken on all trials. The average for the entire area the first season showed that one application of gypsum on a natural pasture increased the bulk of legumes by 400 per cent. As the seed supply is thus increased, responses are expected to increase after next season's top-dressing with an increase also of grass cover due to increased soil nitrogen. As these legumes are at their best during the winter and spring when the natural pasture is generally at its poorest, soil loss and surface water run-off should be greatly lessened.

A deficiency of sulphur in the soil means a deficiency of protein in the plant.[2] Without sufficient sulphur, plants cannot manufacture the level of protein necessary for high quality pasture for animal production. The application of gypsum on soils deficient in sulphur not only greatly increases the quantity of vegetation available for the grazing animal, but also its quality in the protein content.

GYPSUM.

There are large deposits of gypsum in New South Wales which could supply the fertilizer demand at a fraction of the cost of superphosphate. Gypsum is now in the process of being marketed in a form suitable for aerial top-dressing and general agricultural use. E. J. Hilder[3] states that on experiments on pastures in the Northern Tablelands, 1 cwt. of gypsum gives 90 per cent. of the maximum yield. Although lesser amounts could be used, greater amounts may be wasted, as it is easily leached from the soil. Annual applications must be made—preferably during late summer or early autumn. In areas that are inaccessible by machinery or not available for aerial top-dressing, "Flowers" of sulphur mixed with sawdust can be scattered by hand on foot or from horseback at rates up to 20 lb. per acre. If clovers or medics are not present in the area, suitable legume seed inoculated with the appropriate bacteria must be sown or broadcast throughout the area. On properties in the Glenbawn Catchment Area now known to respond only to sulphur, it is estimated that 7,000 acres were top-dressed with superphosphate in 1955. Gypsum could have been used with equally satisfactory results over 40,000 acres for approximately the same cost for the material. With the advent of aerial top-dressing, the delineation of areas known to be seriously deficient in sulphur but not in phosphorus, and the availability of gypsum at low cost, it should be economical to top-dress a much larger portion of this watershed. Not only will the landholder be repaid by better grazing, but he will also retain more of the soil and water on his property.

The benefits of improving this catchment area will be many and far-reaching. The landholder will lose less soil by erosion and less rainfall by run-off; the greater bulk of better pasture will increase his income from cattle and sheep; flooding of the lower Hunter will be reduced and the life of Glenbawn Dam will be lengthened.

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FOREWORD

BY

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

THE associated catchments of the Snowy, Murray, Murrumbidgee and Tumut Rivers are considered the most important in Australia. They comprise the highest mountains in the Commonwealth, rising to 7,000 ft. altitude. The mountains are steep with slopes into gorges frequently in excess of 40 degrees. The higher slopes are covered with snow for five to six months of the year and sometimes snowdrifts remain for much longer periods. The rainfall ranges between 50 in. to 80 in. per annum.

The catchments were originally covered with vegetation with numerous peat moss and swampy areas. Vegetation is depended upon to hold the soil in position on the catchment.

The Soil Conservation Service of New South Wales has carried out very careful field investigations of this area for the past seventeen years and has advised the various Government Departments of the position and the need for safeguarding the catchments as a source of usable water. The Service has given specific information on how this protection should be achieved. This has also been done through the Catchment Areas Protection Board since it was constituted in 1938. Many actions of both practical and administrative nature were taken by the State Authorities in New South Wales to protect these catchments long before the Snowy Mountains Hydro-Electric Authority was constituted, particularly in the regulation of stocking, the exclusion of stock from the most vulnerable areas and the control of burning.

Since the advent of the Snowy Mountains Hydro-Electric Authority the importance of the catchment as a source of water has been more fully recognised by both officials and the public. However, by reason of the nature of the works of the S.M.H.E.A., the threat to the stability of the catchment has been vastly increased. The construction of roads, tracks and works, with their destruction of so much vegetative cover, surface soil, peat beds and swamp areas, has greatly increased the surface run-off and caused serious erosion.

The immense programme of works of the Snowy Mountains Scheme is being undertaken in a class of country and under conditions which are more difficult than ever before faced in any major work undertaken in Australia. It is obvious that the erosion hazards in the catchments are very great and very serious.

The theory has been advanced by some that only a small proportion of the catchment has been stripped of cover by the Snowy Mountains works and therefore the effect is not important. This theory is quite fallacious as it is the areas bordering the vital streams which are being injured. Also, the width of a road may not be great, but when that road runs for miles along the streams and is located at the bottom of unstable slopes, these slopes may be undermined and all the soil may slip off them, even up to the top of the slope. There are many such roads in the area affected, so the total area being injured is very significant and, unfortunately, it is the vital area. It would be as logical to claim that, as a disease only affected a small part of a man's body, it was not important to the whole. A disease in a small but important part may kill a man. The parts of the catchment affected by erosion-causing roads and works are the vital portions. They could prove fatal.

Along all roads built by the Snowy Mountains Authority in the Snowy River Valley, including the Digger's Creek road, from Rennix Gap to Island Bend, the Snowy Valley road, from Island Bend to Guthega, and the road from Smiggin's Holes to the Snowy

Valley road and along the Cabramurra T.1 road in the Tumut Valley, the prevalence of soil erosion has been noted. Frost action causes a steady recession of the batters of cuttings, while gullying of excessively steep catch drains and of the steep slopes of cuttings and fills is widespread. Landslides have also resulted from the slumping of undercut material on the faces of cuttings.

The numerous tracks made in the clearing and erection of transmission lines, and by investigation officers of the Authority, have also destroyed much vegetation. Where no provision has been made to control roadside drainage or prevent scouring, they are causing soil loss and stream pollution.

The erosion referred to in the previous paragraph will increase and aggravate the damage to the catchments and the siltation of the streams wherever steps are not quickly taken to stop it.

To reduce erosion damage it is essential that soil-conserving measures be incorporated in the design of the works and be carried out concurrently with the execution of those works, and this action is necessary not only in respect of the major works within the scheme but, also, in respect of all preliminary and ancillary works associated therewith.

In respect of all future roads, tracks and other works, which involve disturbance of the soil's surface, adequate preventive and control measures should be determined and incorporated in the overall plans for such works and carried out concurrently with such works.

In order to restore stability in these most vital N.S.W. catchment areas, permanent liaison has been established between the Soil Conservation Service of N.S.W. and the Snowy Mountains Hydro-Electric Authority. Local officers of both organisations have surveyed the whole field of the Authority's existing works, from the viewpoint of erosion damage associated therewith, and have worked out methods for stabilisation of hundreds of individual areas of erosion, in those cases where the damage is not irreparable.

A Soil Conservation Section has been set up within the Authority and regular quarterly meetings are held in Cooma of senior officers of both organisations, followed by extensive field examinations, so that plans proposed by investigating officers may be examined, together with stabilisation works already in progress; the widest soil conservation experience possible is brought to bear on the many difficult erosion problems resulting from these works.

Additionally, proposals and plans for the future engineering works of the Authority are studied with a view to ensuring that associated erosion-prevention measures are given top priority in design and construction of future works.

Much has now been done in these fields and, if the remedial and preventive measures are effectively and expeditiously implemented, I am hopeful that, although the damage has been substantial, stability may be regained in many affected areas and that, in future, erosional damage arising from engineering works will be reduced to a minimum

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SOIL EROSION PROBLEMS IN THE SNOWY MOUNTAINS AREA.

BY

L. J. DURHAM, B.Sc.Agr., Soil Conservationist.

PART II.

THE extent of erosion damage and the various factors contributing to the increased hazard in recent years have been discussed.

To conclude this article, it is proposed to discuss control measures carried out to date and to record briefly the need for future studies to overcome problems associated with long-term management of the catchment areas.

CONTROL MEASURES

A survey of the area reveals that the vegetation and erosion pattern at the present time is markedly different from that described for earlier times. Extensive areas of forest and woodland have been destroyed by fire; slopes which previously carried heavy vegetative cover are now reduced by regular burning and stocking to sparsely vegetated areas subject to erosion; and an extensive network of tracks and roads, on slopes previously regarded as relatively stable, add a further erosion hazard.

Fire Control

Whilst extensive bushfires have undoubtedly occurred in the area over a long period of time, it seems certain that they have become more frequent and of more drastic consequence since the entry of the white man.

The last major fire occurred in 1939 when many thousands of acres of forest and woodland were destroyed.

The greatest fire threat is from the west, where altitude falls much more sharply than to the east and the country is greatly dissected to form steep narrow gorges, carrying wet sclerophyll forest.

To meet the position created by the high fire hazard, the Hume-Snowy Fire Protection Scheme was inaugurated in 1952.

Some success has already been achieved through this scheme by provision of a nucleus fire-fighting force with fire-fighting equipment, better communications and co-ordination of activities of individual fire brigades on the western side of the range and by increased vigilance during the danger periods. This aid, together with better access now available, should materially assist in reducing the frequency of major bush fires and in removing one of the main hazards to the efficiency of catchment areas.

Considerable danger still lies in widespread deliberate burning in the snow-lease country, resulting in permanent damage to grassland, peat bog communities and forest.

Since 1943, when snow-lease conditions prohibited burning within certain periods, the frequency of these fires has been reduced, but the practice of burning is still carried to extremes in many cases during the unrestricted periods.

There seems no alternative to further cumulative damage unless all burning, other than on limited areas when required for essential fire control, is prohibited.

Controlled Stocking

As distinct from earlier times, snow-lease conditions also limit the numbers of stock to be carried. Additionally, some of the worst affected areas have been withdrawn from lease through decisions of the Catchment

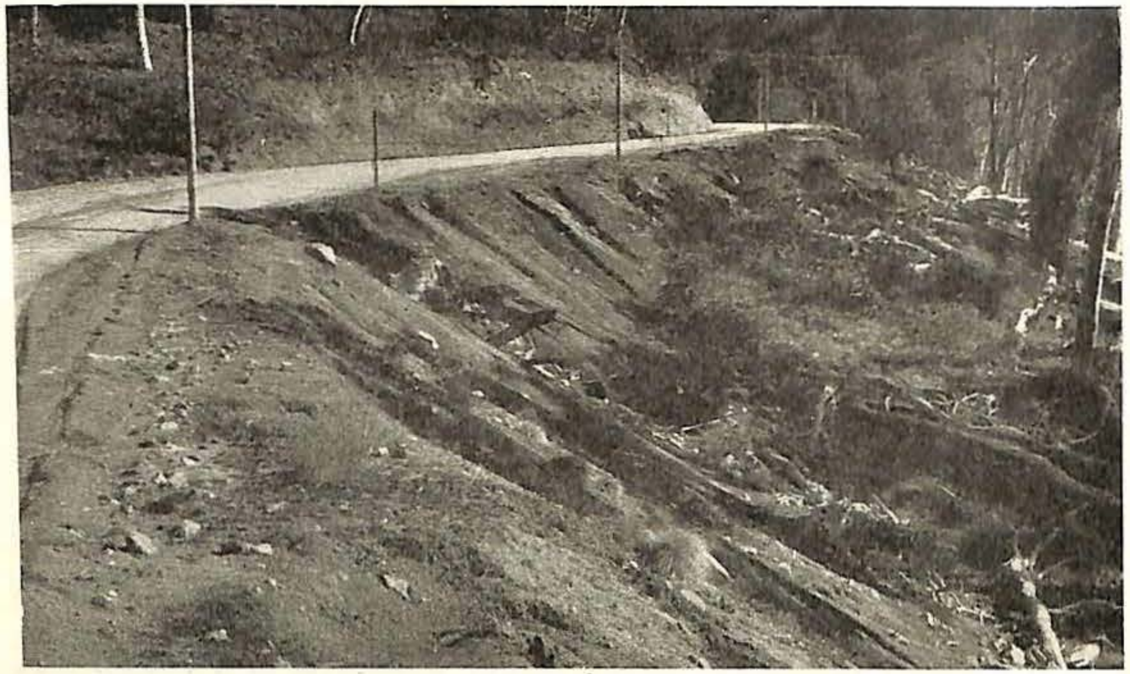

Fig. 10.—Typical erosion of an embankment on the Snowy Valley Road due to lack of adequate drainage.

Areas Protection Board. In 1943, approximately 10,000 acres in the Summit area were withdrawn, this being enlarged to 54,000 acres in 1950, together with a further 18,000 acres at the head of the Geehi River.

The actual rate of recovery of the vegetation following removal of stock is variable and will be subject to long-term studies before specific information is available for different areas.

Following past burning and grazing, studies are at present being undertaken by this Service to define the rate of regeneration and soil restoration. Selected areas have been withdrawn from use and fenced and periodic species counts are being made, using the quadrat and transect methods.

These observations, together with additional studies which have been initiated by the Snowy Mountains Authority, should provide valuable data as to the management of these catchment areas.

On the most seriously affected areas, recovery is slow, due to effects which have been cumulative for periods up to 100 years. It is extremely doubtful whether areas damaged to the extent of those found on Mt. Twynam would ever heal naturally, owing to the high winds causing a constant removal of soil and vegetation and a continual increase in the total area reduced to parent rock material. However, if stock are not excluded the rate of deterioration is very much accelerated.

In the light of present knowledge and until studies reveal the best methods of management for this country, exclusion of stock and fire from the more susceptible areas is necessary to assist the stabilisation of the whole area.

Recognition of the Problems

There is need for all who are associated with the area to be actively aware of the existing erosion damage and to understand fully the means by which the contributing agencies assume greater significance. In the multitude of ways in which human interference can act unfavourably to destroy the natural soil, water and vegetation relationships, lies one of the main hazards to the continuing stability of the area at the present time.

Since the area is becoming more widely known as a tourist centre and with an increasing network of access roads being constructed, an extension of human activities into previously inaccessible areas can be predicted.

Of greater significance, however, is the rate at which the present engineering activities can change the erosion pattern of the area. Whereas other human activities generally tend to have a detrimental effect over relatively long periods of time, the extensive damage due to engineering works can be of immediate consequence and may extend rapidly unless controlled.

It is necessary to understand then, that each new area on which the vegetation is destroyed, every fire which occurs, each additional peat bog which is drained or destroyed and every new track or road which is constructed will add to existing erosion damage and materially reduce the efficiency of the catchment areas.

SPECIFIC CONTROL MEASURES

Specific control measures have largely been directed towards controlling damage resulting from engineering works, but the withdrawal of areas from lease since 1943 has resulted in some improvement in vegetative cover.

Soil Conservation Service Activities

Although considerable work has been undertaken in the form of ecological and erosion surveys since 1948, mechanical control measures, as an addendum to the abovementioned vegetative improvement, have been initiated only over the past two years.

Prior to the commencement of the engineering works of the Authority, it was doubtful whether extensive mechanical measures would find application at these high elevations, due to the erosion problem being mainly one which could be stabilised natur-

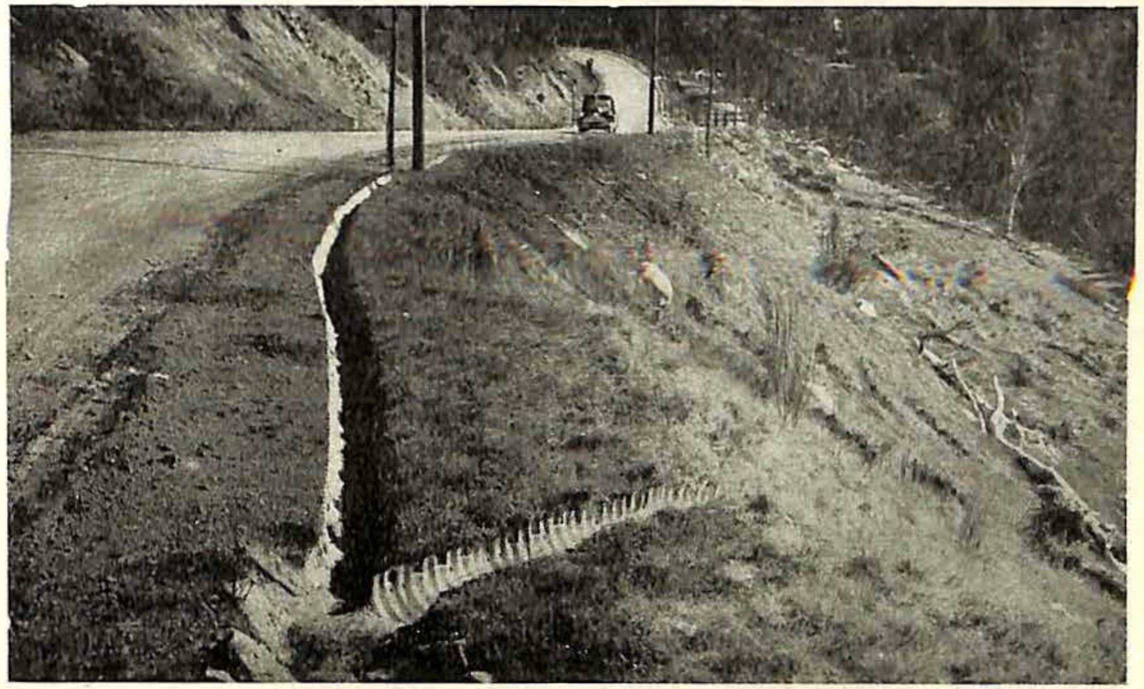

Fig. 11.—A similar embankment to that in Fig. 10, controlled by complete sodding and provision for safe disposal of road drainage.

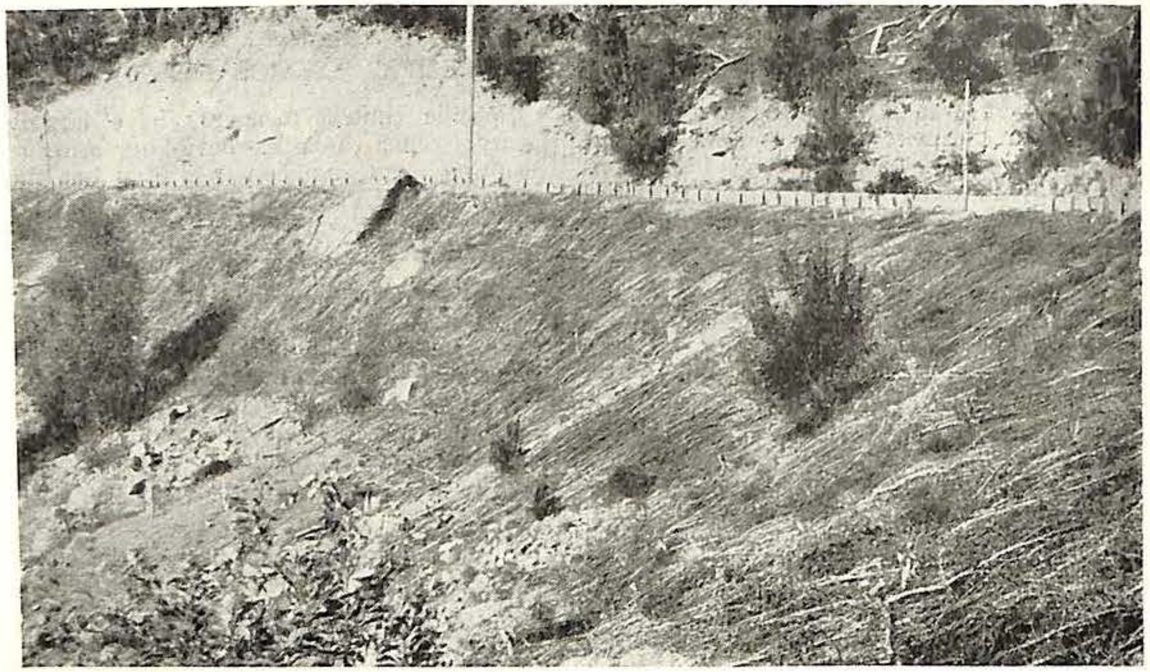

Fig. 12.—An embankment on the Snowy Valley Road treated with brush cover.

ally by vegetation, if the damaging effects of stock and fire were controlled, despite the severe effects of frost action and the lengthy periods of time necessary at these elevations.

With the occurrence of drastic landslides at Cabramurra at an elevation of 4,800 feet, it was found necessary to make use of an extensive system of absorption banks to help stabilise the area until it could be revegetated. The works were designed by the Soil Conservation Service and carried out by Snowy Mountains Authority plant.

These control measures have withstood snow and rainfall since February, 1954, in a satisfactory manner and, apart from minor sheeting and rilling, have greatly assisted in stabilising the area.

At the present time, studies are being made on the requirements for reclamation works on some of the seriously eroded country in the vicinity of Mt. Twynam. As the total area seriously damaged comprises some 200 acres altogether and the altitude is above 7,000 feet, the general conditions made the installation and satisfactory operation of extensive soil conservation measures difficult. Since the usual types of earthworks seem most unlikely to have any application at such altitudes, these works will probably comprise more intensive measures, such as stone pitching, brush cover, sowing of grasses and possibly use of bituminous seals. The likely effect of these measures is also uncertain at this stage and it may be necessary to allow one or two years experimentation before specific results can be recorded.

Under liaison arrangements between the Soil Conservation Service and the Snowy Mountains Authority, commenced in 1953, a number of erosion problems have been the subject of study to ensure future control measures to restore the area to a more stable condition.

Similar action has been initiated with Kosciusko State Park Trust to help overcome present damage and to obviate the need for future costly control measures, by

requesting the avoidance of certain practices which contribute to erosion.

Snowy Mountains Authority Activities

Much of the damage due to engineering works is of immediate consequence. In addition, remedial measures needed to control further erosion on many of the sites bared of vegetation and topsoil call for special techniques. Many of these techniques are new amongst erosion control measures in New South Wales.

A number of these methods have been applied on a demonstration basis, but in the past twelve months they have been widely used on seriously damaged and eroding areas.

Techniques in Use

It is essential that all drainage problems be properly controlled before full benefits can be obtained from these techniques. Complete grass sodding is of little benefit to an area if proper drainage facilities are lacking, or the stabilising effects of wattled fences of little value if sub-surface seepage or drainage is not first controlled by brush or rubble drains, to prevent gullying or slumping at a later date.

Where ample rock is available on the site, stone pitched drains have been constructed by the Authority with considerable success. Use has also been made of grass-sodded waterways and corrugated steel piping on other sites, each giving satisfactory results when correctly installed.

Sodding

The use of grass sods has not been possible to the extent desired, owing to the lack of suitable sod nursery areas in close proximity to the works and because of excessive costs involved in long haulage. Where suitable sods are available the method can be widely recommended, as a high degree of stability is obtained immediately following their use. This follows successful use of sod in the widest variety

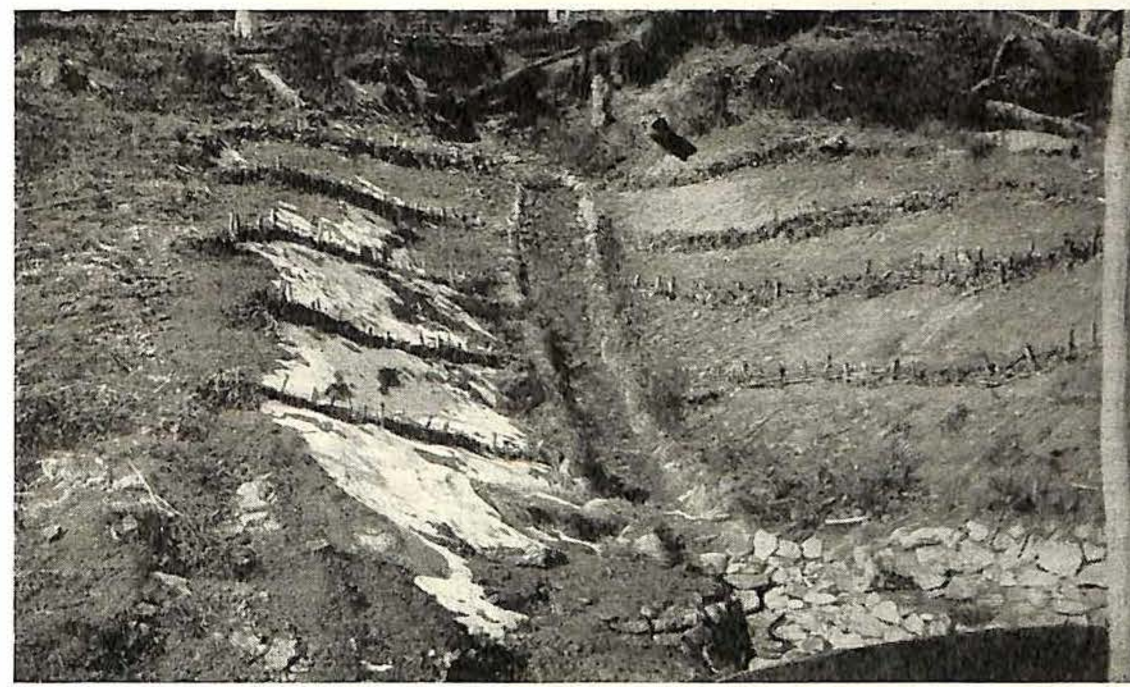

Fig. 13.—An excavated inlet to a culvert controlled by use of a stone-pitched drain and wattled fences. There are patches of snow lying between the fences on the left.

Fig. 14.—Wattled fences and a stone-pitched waterway in the early stage of revegetating a disused track. (Photo. S.M.H.E.A.)

of conditions throughout New South Wales by the Soil Conservation Service.

To facilitate ease of handling and to reduce labour costs, sods have been cut mechanically by means of a special blade attachment drawn by a light vehicle. Where good quality turf is available, sods measuring 9 feet by 1 foot and 1-2 inches thick have been found very suitable for ease of handling and transport. For transport purposes the sods are rolled lengthwise and then unrolled downslope at the site being treated. Sods 1-2 inches thick have been found to be the optimum size, since the root system is trimmed during cutting. This brings the roots in direct contact with the surface on which the sods are being laid and provides better growth conditions than with thicker sods which may dry out before the roots make contact with the surface below.

After initial preparation of the surface by raking down any rubble or boulders, sods are laid and pegged into place. The final operation is generally to cover lightly with topsoil to fill any spaces between sods and prevent drying out.

Continuous or block sodding has been found superior to trench or strip sodding. Areas which have been properly treated by block sodding rarely give any trouble and quickly transform bare eroding areas to complete stability at moderate altitudes.

Strip sodding has failed in many cases due to heavy frost action on the surface left bare. Immediately downslope of the sod strips, frost action may cause recession of the slope face and final slumping of the sods. Run-off and soil movement downslope quickly forms a gully at the point of slumping, thus menacing successive strips below. Sods which are not trenched properly and which are under-scoured by run off are affected in the same way.

Brush Matting

This consists of specially prepared brush fixed on a slope surface, with the stem bases facing downslope and the smaller branches directed upslope to filter soil particles carried down by run-off. The term brush refers to small branches, with or without the leaves, having a desired minimum length of 5 feet and a maximum diameter of 2 inches at the base.

The success of brush matting depends largely on its immediate use on completion of cut batters or wherever the technique is applicable. To gain positive control it is essential that the matting form a continuous cover and be securely pegged as close as possible to the surface, with the bigger branches slightly trenched. When these conditions are met, the action of the brush mat is that of a number of small dams formed by the forking branches.

These filter soil particles from upslope run-off or alternatively may be used to retain topsoil spread over the slope. From either source a relatively stable seed bed is maintained, so that vegetative growth from natural sources or sowing is given a better chance to stabilise the slope.

If very light material is used or if it is not pegged down against the surface correctly, benefits from this method of control are largely nullified.

Wattling

This method consists of building fences composed of fine brush interwoven horizontally between wooded pegs and fixed diagonally to the direction of the slope.

Their particular application is suited to sections of cut batter which are made unstable by sub-surface seepage or drainage, for the repair of gullies on slopes and embankments and on landslide areas.

By constructing these fences diagonally to the slope, better results have been obtained than when placed on the contour, since several problems have arisen with the latter method due to overtopping and under scouring by run-off.

If placed at a slight angle on the slope, time of concentration of run-off is still in-·ased, but flow is deflected sufficiently to allow only small amounts of water through the fence at any one point and so transported soil particles are more completely filtered.

To lessen the possibility of under-scouring, these fences are placed in trenches 4 inches deep so that one or two brush layers lie below the surface.

Spacing is dependent on the slope and the degree of permanency of water percolation, and it has generally been found that spacings from 5-8 feet are satisfactory.

As these structures are designed to prevent rilling and gullying and all intermediate areas are left bare, it is generally necessary to sow these areas to effect complete stabilisation.

Willow Wicker Work

This method is an extension of the use of wattled fences, where willow rods and pegs are used instead of the ordinary brush and saplings. The advantages in this method are twofold, in that the willow is capable of taking root and providing vegetative control as well as mechanical control, and thin pliable rods enable the wattling to be of a finer quality and thus increase the filtration and deposition of transported soil particles.

Sapling Retainers

Sapling retainers, placed diagonal to the direction of the slope, find application where slopes are to be revegetated by covering with a layer of topsoil and then sowing.

Their main use is in the provision of a footing for the placed soil and to assist in proper drainage at sub-surface levels until the area is stabilised by vegetation.

Saplings used are generally about 10 feet in length and 3-4 inches in diameter, with spacings again varying according to the degree of slope.

Replacement of Topsoil

On areas which have been bared of vegetation and topsoil during construction work, regeneration is difficult to accomplish. The longer a particular site is left before remedial measures are undertaken, the more necessary is topsoiling prior to sowing.

One of the major difficulties has been the failure to provide for removal and storage of topsoil before commencing actual engineering operations. The ideal method is to remove and store the topsoil while construction proceeds and to replace it immediately on completion of each section of work. On the few areas where this has recently been demonstrated, followed by early sowing, very satisfactory results have been obtained.

If replacement of topsoil and sowing, together with any other of the above techniques necessary, were to be carried out as part of each engineering work, much of the ensuing damage would be prevented.

Overall Management

From a study of the foregoing factors contributing to present erosion damage, it is evident that future stability of the various catchments depends largely on the integration of all activities in the area, so that the erosion hazards of each are known in advance and adequate preventative and remedial measures planned in respect of each *prior* to the undertaking of that operation.

Whilst satisfactory methods of control are known for many of the present problems, further studies will need to be made in protection and management of catchment areas.

Some important possibilities, in addition to the implementation of mechanical works, lie in the development of the better natural species for use in extensive regeneration, the improvement of present vegetation, the use of fertilisers and trace elements and re-afforestation of particular areas.

Considerable time may elapse before such problems can be fully solved, but, with erosion damage so widespread and the ever present hazards of frost, wind and water action progressively adding to this damage, the need for objective investigations in the area is imperative.

SUMMARY

The natural agencies of erosion in the area are frost, wind and water action. Without unfavourable influence from human activities, however, it is seldom that these agencies create problems, although natural or geological erosion occurs to some degree at all times.

Since present erosion hazard and damage can be readily traced to the various sources of human interference, it is essential that methods of control and stabilisation be fundamentally based on control of these unfavourable activities.

With the power and water potential of the area being exploited and the erosion pattern being markedly altered by engineering works, it is essential that all damage be quickly remedied to prevent further erosion occurring.

From previous studies it is evident that many minor catchments have deteriorated in recent years. Failure to observe the reasons for this decline and to adopt the means whereby future damage may be greatly reduced, would undoubtedly be reflected by further decreases in catchment area efficiency.

ACKNOWLEDGMENTS

My thanks are due to Dr. M. Mueller, Dr. J. Raeder-Roitzsch and Mr. J. Warren, Soil Conservation Section, Snowy Mountains Authority, for co-operation during preparation of this article; to the Snowy Mountains Authority for information regarding recent climatic studies and supply of photographs; and to Mr. A. Taylor, Soil Conservation Service of New South Wales, for assitance regarding surveys and studies being made in the area.

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CONTROL OF SAND DRIFT IN BEACH MINING.

BY

J. B. Sless, M.Sc., Soil Conservationist.

SINCE 1951 the Soil Conservation Service has been acting in an advisory capacity to the Mines Department of New South Wales on problems of control of sand drift associated with beach mining for rutile, zircon and other minerals in marine sands. The liaison stemmed from the fact that such operations render extensive areas on the coastal sand dunes susceptible to wind action, resulting in sand drift.

Much of the technical advice given by the Service has been incorporated in the special lease conditions imposed by the Mines Department on mining zircon and rutile, by which mining operators are obliged to carry out rehabilitation of mined areas in a progressive and systematic manner.

Investigations on the far north coast, where the majority of rutile mining operations are at present in progress, indicate that it is quite feasible to bring under control any sand movement that might be caused by the mining of coastal dunes. Furthermore, if control measures are fully implemented, the dunes on completion of mining could be left in as stable a condition as they were prior to mining.

The control methods used are based largely on the work carried out at the Service's sand-drift control experimental areas, which was reviewed in the October, 1955, issue of this Journal. However, many minor modifications have been necessary, to suit conditions which are peculiar to rutile mining areas. The ensuing description embodies the author's observations over a period of three years in these areas, as well as the results of much experimentation in the field.

RUTILE MINING

A description of a mining industry might seem out of place in a Journal of this nature. However, it is necessary to give a brief prefatory account of the zircon-rutile mining industry, to explain why sand-drift control techniques are, and must be, employed by rutile mining operators. The emphasis here is, of necessity, on the erosion control aspect of beach mining. For further information on the industry the reader is referred to a recent article by Gardner (1).

Distribution and Occurrence

Mineral-bearing sands are widespread on the beaches and dunes throughout the length of the New South Wales coast, particularly on the North Coast; rich deposits also occur on the south and central Queensland coasts. The minerals consist chiefly of rutile, zircon, ilmenite and garnet, with small quantities of monazite, tin, platinum and gold. All the constituent minerals are invariably admixed with pure siliceous sand, in varying proportions.

The greatest concentrations occur on the beaches proper, i.e., seawards of the frontal dune, and they appear to decrease progressivly with distance from the sea. Mineral deposits occur either in the form of wave-deposited seams from several feet above to several feet below mean sea level, or as wind-blown deposits in the dunes, which are then said to be "mineralised".

Economic Importance

Before the war, rutile was of little economic value, but it has recently assumed considerable prominence in the industrial

Fig. 1.—CUDGEN. Open cut mining of frontal dune.

sphere, because of its use in aircraft construction. The other minerals are used chiefly in the paints industry, ceramics and welding. The zircon and rutile industry now ranks third in the economic productivity of the mining industries of the State, the order, in terms of output being: silver-lead-zinc, coal and zircon-rutile.

History

Extensive mining operations have been in progress for over sixteen years, mainly on the coast between Byron Bay and Tweed Heads. Initially, mining activities were restricted to the beaches proper, but with the discovery that low-grade deposits of mineral sands could be worked economically, operations have extended inland so that, at the present time, sand dunes as far as three miles from the sea are being worked.

In the last ten years, operations have extended southwards from Byron Bay to embrace the Ballina, Port Macquarie, Laurieton, Swansea and Shellharbour districts. Prospecting, to locate mineral deposits, is currently being carried out on most parts of the central and north coasts. With the recent rapid expansion of the industry, and the commencement of operations on beaches and dunes close to well-populated settlements, satisfactory rehabilitation of mined areas has become vitally important.

In the early stages, the Mines Department issued mining leases to different interests in the form of long, narrow parallel strips—a factor which has complicated and often impeded rehabilitation of mined areas. The present practice in regard to allocation of leases favours the granting of leases in the form of wide blocks, so that rehabilitation can be carried out without hindering the activities of other operators.

Mining Methods

The mineral is extracted from the sand dunes and beaches by one of two methods—

open-cut mining, or sand pump dredging. In open-cut mining, which is used to extract high-grade deposits from the beach and frontal dunes, the existing vegetation is cleared and the overburden, that is the siliceous sand overlying the mineral seam, is stripped with draglines and bulldozers, and stacked in the vicinity of the excavation (see Figure 1). The exposed mineral is then scooped out, loaded on to trucks and carted to separation plants, where the constituent minerals are separated from the silica, and from each other. The overburden is then replaced in the excavation by bulldozing.

In the dredging process, which is used to extract low-grade deposits, vegetation is cleared, overburden stripped, and a deep excavation is made in the dune or on the beach. Water is then pumped into the cutting to form a pool of up to 6 feet in depth, the surface level of which corresponds to existing sea level. Mineral-bearing sands in the pool and the surrounding sand masses are then pumped from a sand pump mounted on a pontoon barge in the pool to a primary concentration plant located nearby (see Figure 2). In some cases, the concentration plant itself is mounted on a barge; this method is becoming increasingly common.

The primary concentration plants used in conjunction with dredging are portable, and carry out the primary separation of silica from rutile, zircon, etc., producing what is called a "rough concentrate", which is carted to the separation plant for further treatment. The tailings or residues from workings are pumped back into the dredge pool while mining is still in progress and, according as hollows are filled into the lee of the workings, the dredge works further into the sand masses, thus extending the pool.

EFFECT ON DUNES

A distinction should be drawn between erosion of coastal dunes caused by wave action and erosion caused by wind action, that is, sand drift. Mining of the open beaches does not predispose to sand drift, provided the vegetated frontal dune is left

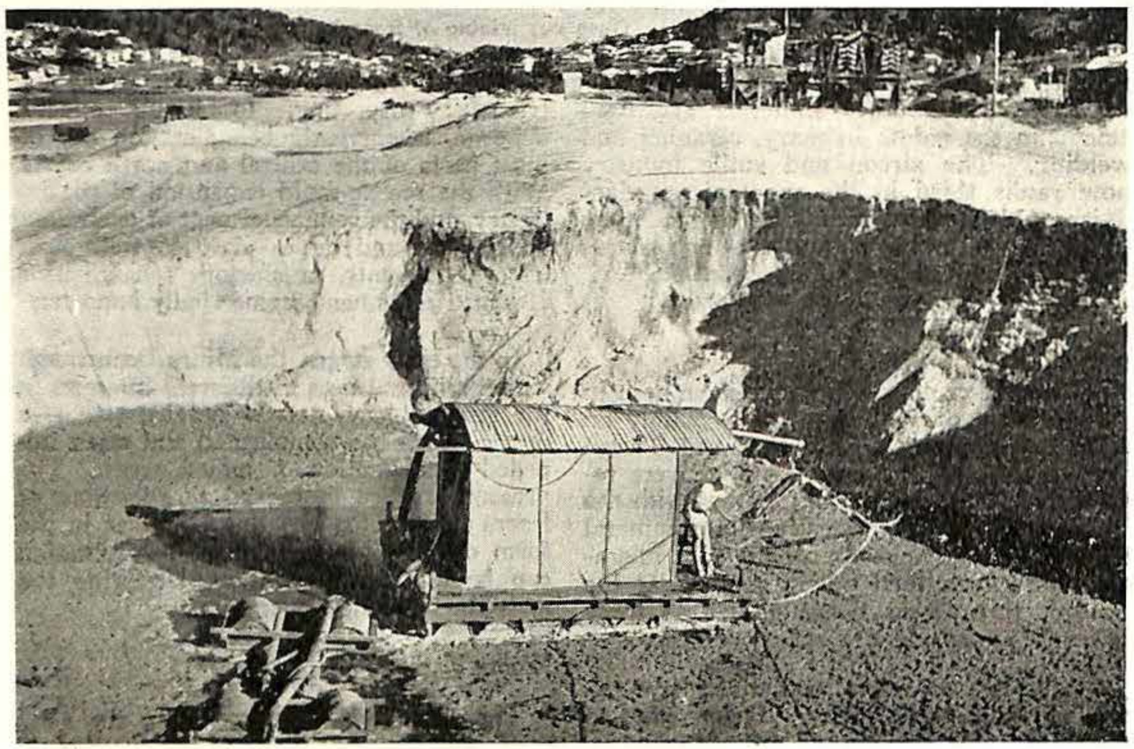

Fig. 2.—BURLEIGH HEADS. Sand-pump dredging in frontal dune.

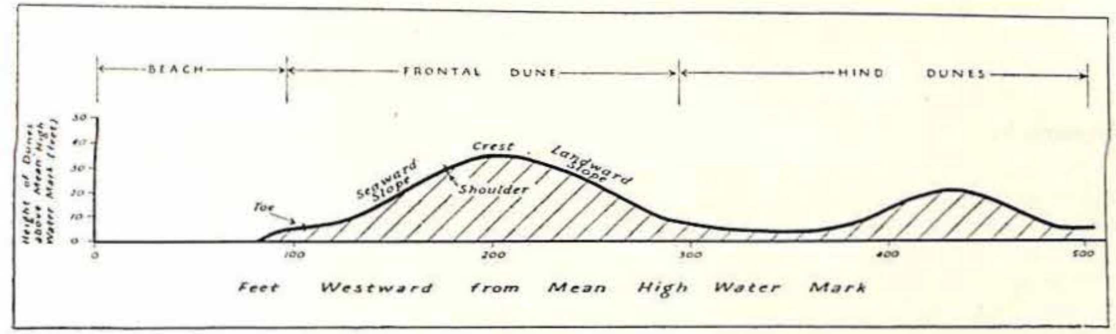

Fig. 3.—Cross-section of typical dune system on north coast.

intact. It is not known whether such mining affects the general configuration of the beach, or the near-coastal currents; very little is known of the normal beach changes, still less of the changes, if any, induced by mining. However, it seems that mining of the open beaches does not predispose to wave erosion, in view of the fact that in recent years, during which there has been an extensive cutting back of the dunes by wave action on many parts of the coast, far more serious wave erosion has taken place on unmined than on mined beaches.

Terminology

Throughout this article, the following terms are used to connote the physical features of the dunes:—

Frontal Dune (Foredune).—The main dune which fringes the beach. Three sections are distinguished, viz.: the seaward slope, the crest or top, and the landward slope.

Hinddunes (Back Areas).—The successive lines of dunes parallel to the beach, which occur on the landward side of the frontal dune.

Shoulder.—The point where the dune slopes seawards.

Crest.—The flat area on the top of the dune.

Toe—The seaward base of the dune which, on the frontal dune, usually marks the limit of vegetation.

The terms "seaward slopes" and "landward slopes" are used in preference to "windward side" and "leeward side", in view of the fact that on the New South Wales coast, although the prevailing winds are onshore, longshore and offshore winds are very common, so that the standard terms are apt to lead to confusion.

Figure 3 illustrates a profile of a well-developed dune system on the north coast.

Botany

The frontal dunes are stabilised by grasses and creepers on the seaward slope, small shrubs or stunted trees on the crest, and tall shrubs and small trees on the landward slopes. The hinddunes are, in their virgin state, held by various forms of tree growth.

The principal indigenous species on the north coast, proceeding landwards from the beach, are as follows:—

Frontal Dune. — Sand spinifex (*Spinifex hirsutus*), prickly couch (*Zoysia macrantha*), goatsfoot (*Ipomea pes-caprae*), pigface (*Carpobrotus aequilaterus*), scented fan flower (*Scaevola suaveolens*), coastal wattle (*Acacia sophorae*), coastal honeysuckle (*Banksia integrifolia*), heaths (*Leucopogon* spp.) and tuckeroo (*Cupaniopsis anacardioides*).

Hinddunes.—Heaths, coastal honeysuckle, tuckeroo and paper bark (*Melaleuca* spp.) in association: or eucalypt (*Eucalyptus* spp.)-she-oak (*Casuarina littoralis*) association; or climax of coastal honeysuckle, paper bark and various rain forest species, including lillipilli (*Acmaena smithii*), brush box (*Tristania conferta*) and brown pine

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(*Podocarpus elata*); or heaths, dominated by bottlebrush (*callistemon* sp.) and saw-toothed honeysuckle (*Banksia serrata*).

Topography

The topography of the hinddunes, as of the frontal dunes, is gently undulating, consisting usually of successive lines of low dunes parallel to the sea shore, each trough indicating the location of a former strand or shore line. In low-lying hollows, swamps often occur.

The extent and area of the dune systems vary widely, and range from a quarter of a mile to 5 miles in width, and from 10 to 70 feet in height. The best developed dune systems occur between creeks or rivers which run parallel to the sea shore and the beaches themselves. The creeks, particularly on the north coast, usually enter the sea at the northern ends of beaches, and at the point of entry, the dune system breaks down, giving way to sand spits.

Destruction of Vegetation

On the frontal dunes, clearing of sand-binding vegetation, particularly sand spinifex, automatically renders the exposed bare sand susceptible to wind action. Excavations are apt to give rise to blow-outs which, if permitted to extend, could result in the development of large drifts, augmented by fresh sand from the beach. Therefore it is essential to fill in all excavations, and to re-establish vegetation without delay, on completion of mining operations. Mining of formerly stable frontal dunes has, in the past, been responsible for minor sand drift inland, which has recently been brought under control.

In this connection, it is to be noted that many coastal dunes which have not been mined for rutile are highly unstable, or only

(Photo R. Anthony, Murwillumbah).

Fig. 4.—CUDGEN. Hinddune scrub cleared in rutile mining

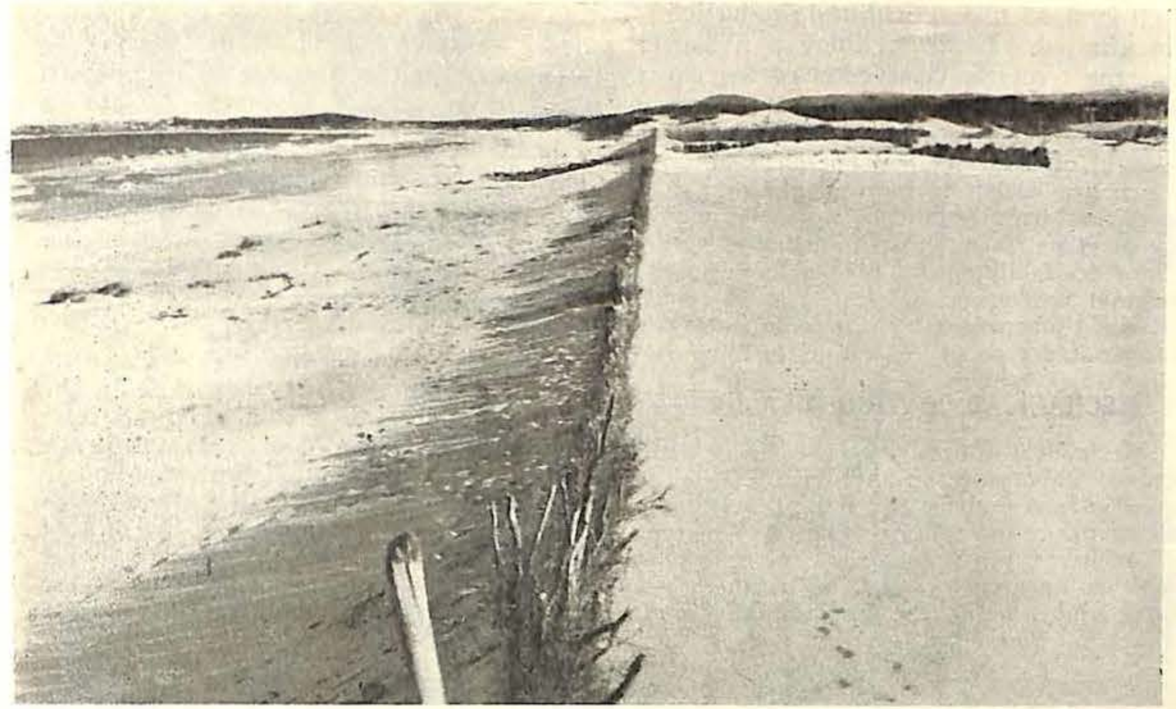

Fig. 5.—SOUTH FINGAL. Brush fences erected after frontal dune was re-shaped; March, 1953.

partially stable at the present time. Instability in such cases has invariably been brought about by uncontrolled grazing by stock, clearing of vegetation and excessive foot and vehicular traffic.

To date, no sand drift has arisen on hinddunes which have been mined for rutile, probably because such areas have been protected from the full force of onshore winds by a belt of vegetation on the seaward side. In consequence, no difficulty has been experienced in stabilising and revegetating the hinddunes. A typical belt of paper bark scrub, portion of which has been destroyed in the course of mining operations, is illustrated in Figure 4. Minor drift can be observed in the frontal dune; the white strips in the centre of the photograph constitute bare, but not drifting sand.

If, however, all tree growth between the hinddunes and the sea were cleared, sand drift over the entire area could very readily develop, unless special precautions were taken; in fact this has happened in rutile mining areas on the Queensland south coast,

Long-Term Effects

Experience at the Service's experimental centres and on rutile mining areas has shown that, provided mechanical and vegetational control measures are fully implemented, it is possible to rehabilitate mined areas so that the frontal dune should have a good cover of grasses and creepers within one year of completion of mining operations. Within two years, the seaward side of the frontal dune should be perfectly stable, and the landward side should have a good cover of young shrubs. Within four years, the frontal dune should be perfectly stable throughout, with grasses, creepers and shrubs of up to 5 feet in height. Back areas regenerate within a year or two, if protected by a windbreak; if not, complete regeneration may take as long as with the frontal dunes.

There are, however, other factors which might be considered, one being the effect on agricultural land adjoining the dunes; another being the effect on indigenous rain forest trees. Most rutile mining leases are far removed from good quality agricultural land, so that agricultural production is not affected. However, there is a danger that the complete destruction of the paper bark scrub and brush forests could result in the permanent loss of certain rain forest tree species of considerable botanical interest which are becoming increasingly rare. In fact, this feature has been observed on areas other than those mined for rutile. The desirability of re-establishing the original vegetation on cleared areas which adjoin timber country, or substituting a comparable type of vegetation, is obvious.

MECHANICAL CONTROL MEASURES

Mechanical control measures are of the utmost importance in the rehabilitation of mined areas, and usually must precede any attempt to re-introduce vegetation. The type of control measure varies according to whether open-cut or dredging methods are used, and whether the foredunes or hind-dunes are worked.

Disposal of Overburden

The objective should be to conserve as much pure sand as possible in its original location. Therefore, overburden should be pushed lengthwise along the beaches and dunes and not into the sea, as has often happened in the past. On completion of mining, whether by open-cut or dredging methods, the overburden should be pushed back into excavations.

Sometimes, dredge cuttings are made among the frontal dunes very close to the beach, so that only a thin ridge of sand separates the dredge pool from the beach (see Figure 2). To avoid the formation of blow-outs which could result in heavy seas washing into the dredge pools, the cutting should be made so that the ridge is as wide as possible; overburden, pushed against the seaward side of the ridge, can be used for this purpose.

Fig. 6.—SOUTH FINGAL. Same area as Fig. 5, after frontal dune was planted to marram grass; September, 1955.

Fig. 7.—CUDGEN. Brush fence and barriers protecting young marram grass plantation; seaward slope not yet treated.

Pumping of Tailings

In the dredging process, tailings are normally pumped back into the dredge pool while mining is still in progress. By extending the disposal pipes from the portable separation plants, tailings can be pumped for a distance of up to 500 feet into depressions or low-lying areas for the purpose of re-shaping damaged dunes.

Re-shaping Dunes

The most satisfactory results in re-establishing badly damaged frontal dunes have been achieved by re-forming the dune by dozing or pumping tailings, so that the reconstructed dune is at least 10 feet, but not more than 15 feet, above the level of the toe, which should conform with the general and normal configuration of the beach. The batter on the seaward and landward slopes should be fairly gentle—not exceeding 1 in 3—to avoid scouring by wind and undermining by wave action. The crest should be as wide as possible—at least 20 feet.

It is not necessary to reshape damaged dunes to the contours which existed prior to mining; in fact, sometimes such action would be inadvisable. Frequently, the angle of the seaward and landward slopes of a perfectly stable dune is as high as 60 degrees, which is far too sheer a slope for the re-introduction of vegetation on bare sand. Restoration of the frontal dune should be directed primarily to the formation of a fairly low, broad-topped dune.

Brush Fences

When the frontal dune has been reshaped to the desired conformation, a brush fence 4 to 6 feet in height and running parallel to the beach should be erected on the shoulder. In very exposed positions, brush fences at right angles to and on the landward side of this fence, and at a distance of 100 to 250 feet apart, may also be necessary. Figure 5 shows an area where both types of fence were used; Figure 6 shows the same area three years later, following the planting of marram grass (*Ammophila arenaria*), on the seaward slope and the natural spread of sand spinifex throughout the marram grass plantation. As can be seen, the brush fences, which were originally 5 feet above the surface of the sand, have been almost completely overtopped; the restored dune, which is now approximately 15 feet high, is quite stable—in fact, more stable than the adjoining sections of the dune which had never been disturbed.

Brush fences can also be used to build up hollows or seal off gaps in an otherwise stable dune. In rutile mining, cuttings are frequently made in the frontal dunes to provide access to the beach for machinery. Normally, they cause little trouble, but they should be avoided as far as practicable, since sand tends to blow through the gaps, forming troublesome blow-outs. For quicker results, gaps should be filled in by dozing.

The purpose of brush fences running parallel to the beach is to retard drift caused by onshore winds, usually easterly and north-easterly; brush fences running at right angles to the beach and to the main fence help to retard drift caused by longshore winds, usually southerly or south-easterly. Since most beaches generally face east, the fences on the shoulder of reconstructed dunes usually run north and south, and the angled fences run east and west.

Brush Barriers

Brush barriers, 1 to 2 feet in height, and at distances ranging from 15 to 30 feet apart, are used to supplement brush fences, and to protect initial grass plantings (see Figure 7). They prove highly effective when laid across any fairly level area of bare sand, and should be used particularly on the seaward and landward slopes of reconstructed frontal dunes. In most cases, they should run roughly east and west, to counteract the strong longshore winds.

Fig. 8.—CUDGEN. Natural regeneration of original shrub growth (*Duboisia* sp.) on hinddune area; two-and-half years after mining.

Fig. 9.—CUDGEN. Marram grass and creeping groundsel, fourteen months after planting among brush barriers in semi-exposed position.

Following erection of brush fences, and laying of brush barriers suitable grasses and creepers should be planted among the barriers.

Spreading of Brush

Frequently, scouring develops on the steeply sloping sides of dredge pools or similar cuttings. This trend can be quite easily overcome by spreading brush, in the form of young saplings, directly on the slopes. Usually, grasses and creepers will then appear by natural regeneration, but planting of grasses may be necessary.

Occasionally, funnelling or "dishing out" tends to develop on the landward side of reconstructed dunes where the slope is too steep. This tendency can be offset by dumping brush in hollows, so as to trap sand.

Brush may also be dumped in gaps or breaks on the frontal dune, so as to cause accumulation of sand. If funnelling or scouring still persists, bulldozing may be necessary.

Materials for Brushing

The most suitable material for brush fences is she-oak. For brush barriers, honeysuckle, particularly saw-toothed honeysuckle, is most effective. However, any fine-leaved brush which retains its leaves for a long period after cutting is satisfactory. Ample material for brush fences and barriers is usually available from the hinddune scrub.

Replacing of Topsoil

In the back areas, there is often an appreciable layer of blackish peaty humus overlying the pure sand, to within 150 feet of the frontal dune. Where a depth exceeding 3 inches of humus exists prior to mining, it is desirable to strip topsoil to a depth of 12 inches, and stockpile, pending completion of operations. Provided all excavations are filled in, the mined area levelled off, and the original topsoil replaced, there is no danger of drift arising. The original grasses and shrubs usually appear by natural regeneration within a few months and, within a year, a complete cover can be expected (see Figure 8).

However, where the existing topsoil has a low or negligible humus content, and where a protective belt of shrubs or trees seawards of the hinddunes is lacking, the hinddunes should be rehabilitated in the same way as the frontal dunes—that is, fences and barriers should be erected, and grasses and creepers planted.

Mulching Materials

Many early plantings of marram grass were blown out on rutile mining areas, due to movement of sand away from the plantings. This trend can be counteracted by spreading mulch, in the form of reed tops and small fragments of brush, throughout the grass plantations. Mulch should be used on all grass plantings, wherever practicable.

VEGETATIVE MEASURES

There are comparatively few native grasses and shrubs that can withstand sand blast, salt spray and strong salt-laden winds, all of which are common features on the New South Wales coastal sand dunes. Unfortunately, even the most hardy native species do not lend themselves readily to the usual methods of propagation. Accordingly, much use is made of exotic species such as marram grass and creeping groundsel.

A list of the more important grass, shrub and tree species, which have to date proved most dependable in rutile mining areas, is given on Tables 1, 2 and 3, together with instructions on methods of propagation. One species on Table 3, viz., she-oak, has not yet been tried out in rutile mining areas, but it is included because of its good performance at Iluka under conditions resembling those in rutile mining areas.

The planting seasons given are for the north coast only. On the central and south coasts the planting season for most species can be extended to cover all but the hottest months of the year. Some rutile mining operators practice watering of grass and creeper plantings on the dunes. In this way, planting can be undertaken throughout the year; nevertheless, the best results are invariably obtained by planting in the cooler months.

Revegetation of mined areas, as of any sand drift area, should be carried out in three successive stages, viz.: primary, secondary and tertiary stabilisation.

Primary Stabilisation

On frontal dunes, this consists of the planting of grasses, marram and sand spinifex, shortly after the surface of the dune has been reshaped and brushed. Excellent results have been obtained with marram grass planting at Cudgen, one of the most important rutile mining centres (see Figure 9). Sand spinifex has also given good results, although the initial strike and early growth are not as good as with marram grass planting. Both grasses require the protection of brush barriers, preferably laid some months prior to planting, and of mulch at the time of planting.

In fairly protected situations, or where the drift of sand is very slow, creepers such as pigface and creeping groundsel, which are normally regarded as secondary stabilisers, can be planted on their own, or concurrently with grass planting, but in most cases, creepers should not be planted until the drift has been stilled to some extent by grasses.

On exposed hinddune areas, that is, where all vegetation has been cleared between the hinddunes and the beach, sand spinifex should be planted among brush barriers. However, on protected hinddune areas, seeds or turves of couch grass can be planted after replacement of the original topsoil, where a layer of humus existed prior to mining. Good results have been obtained in this way, but planting on sand devoid of humus has given poor results.

To boost the growth of grasses and creepers, fertilisers—sulphate of ammonia, superphosphate and muriate of potash—can be

SAND STABILISING SPECIES.

TABLE I.—PRIMARY STABILISERS—GRASSES.

Species.	Seed Ripens.	Propagation. Method.	Propagation. Period.	Location.	Remarks.
Marram Grass (*Ammophila arenaria*).	Flowers: December–January. Does not set seed in N.S.W.	Roots: 4–6 rhizomes cut or pulled from vigorous parent plant and trimmed to 10-in.–15-in.; plant deeply.	June–August ...	Seaward slopes and crest of frontal dunes; also on hinddunes where slow drift of sand.	Do not plant too close to toe of frontal dune—cannot withstand submergence in salt water.
Sand spinifex (*Spinifex hirsutus*).	November–December	Seed with mulch ...	February–March ...	Landward slopes of frontal dune; all parts of hinddunes.	Soak seeds in fresh or salt water before planting. Withstands submergence in salt water. Runners (trailing stems) give poor results.
		Rooted cuttings, 6–8 leaves.	June–August ...	All parts of frontal dune and hinddunes.	
Couch grass (*Cynodon dactylon*).	January–March ...	Seed	April–May	Hinddunes only, where sand quite still.	Requires slight humus content. Turves or cuttings give best results.
		Rooted cuttings or turves.	May–September		

TABLE II.—SECONDARY STABILISERS—CREEPERS AND SHRUBS.

Species.	Seed Ripens.	Propogation. Method.	Propogation. Period.	Location.	Remarks.
Pigface (*Carpobrotus aequilaterus*).	October–January ...	Rooted cuttings, 6-in.-12-in. from vigorous growth. Spacing 3 ft. x 3 ft. or 4 ft. x 4 ft.	April–September ...	Crest and landward slope of frontal dune, anywhere on hinddunes; particularly among marram grass plantings.	Can be planted on its own where drift slow, but if too far apart, causes hummocking.
Creeping groundsel (*Senecio crassiflorus*).	October–November. (Apparently not viable).	Rooted cuttings about 12-in. long, preferably including terminal shoot. Spacing 3 ft. x 3 ft. or 4 ft. x 4 ft.	April–September ...	Crest and landward slope frontal dune all parts of hinddune.	As for pigface.
Running bean (*Canavalia maritima*).	March–June	Sow seed among grasses and creepers.	August–October ...	Crest and landward slopes of frontal dune; all parts of hinddunes. Protected situations.	Sow only after grasses well established.
Coastal wattle (*Acacia sophorae*).	October–November	Seedlings raised from seed in nursery.	Sow in spring or autumn, plant out autumn or following spring.	Crests and landward slope of dune, quite exposed situations, among grass plantings, to within 100 feet of toe of foredune.	Nursery plants highly susceptible to insect pests. Treat with gammexane.
		Seed. Sow direct among grasses and creepers where sand quite still.	Autumn or Spring ...		
Cyprus wattle (*Acacia cyanophylla*).	October–November	As for Coastal Wattle	As for Coastal Wattle	Hinddunes only, in protected situations.	As for Coastal Wattle.
Vitex (*Vitex trifolia*).	May–June	Rooted cuttings ...	May–September ...	Crest frontal dune, semi-exposed positions.	Suitable only for far North Coast.

TABLE III.—TERTIARY STABILISERS—TREES.

Species.	Seed Ripens.	Propogation. Method.	Propogation. Period.	Location.	Remarks.
Coastal honeysuckle (*Banksia integrifolia*).	September–November	Seedlings raised from seed in nursery.	Sow in spring, plant out following year.	Landward slopes of frontal dune; all parts of hinddunes. Semi-exposed positions.	Very slow growth in early stages. Transplants from scrub give only a fair strike. Suitable for all parts of coast.
		Seedlings to 12-in. transplanted from scrub with original soil surrounding roots.			
Coral tree (*Erythrina corallodendron*).	Early spring ...	Rooted cuttings ...	May to August ...	Hinddunes where well protected from salt spray and windblast.	Suitable for north and central coasts.
She-oak (*Casuarina equisetifolia*).	October–December ...	Seedlings raised from seed in nursery.	Sow April-May or August -September; plant out spring or following autumn.	Crest of frontal dune and hinddunes. Exposed situations to within 180 feet of toe of foredune.	Suitable for far north coast. Rapid growth in early stages.

broadcast among plantings. At the Service's experimental areas, grass and creeper plantings have shown an excellent response to a quarterly application of a mixture of fertilisers at the rate of 10 lb. sulphate of ammonia, 5 lb. superphosphate, 5 lb. potash to 100 square yards of planting. Similar results could presumably be anticipated on rutile mining areas.

Secondary Stabilisation

Several months after the satisfactory establishment of grasses on the frontal dune and exposed parts of the hinddune, creepers should be introduced among grass plantings (see Table 2). Within 12-18 months of grass planting, sand movement is usually sufficiently stilled to permit the planting of shrubs on protected parts of the frontal dune, and most parts of the hinddune. Seedlings of coastal wattle, raised in a nursery, should be planted out when 6-9 inches high; alternatively, seeds may be sown direct, but only where the sand is quite still. Except in protected situations, seedlings or seeds should not be planted closer than 100 feet from the toe of the frontal dune.

On protected back areas, seeds or seedlings of cyprus wattle should be planted, following satisfactory establishment of grasses or natural regeneration of the original shrub growth.

Tertiary Stabilisation

When grasses and shrubs are well established, trees may be planted (see Table 3). Coastal honeysuckle and she-oak may be planted to within 250 feet of the beach even without the prior protection of shrubs. The other species listed can grow in pure sand, but only in very protected situations. In most cases they should not be planted closer than 400 feet from the beach.

CONCLUSION

It is quite practicable to prevent sand drift arising out of rutile mining operations and to bring under control any drift that may develop. To avert the danger of drift, a great deal of bulldozing, brushing and a considerable amount of hand planting of grasses, creepers and shrubs is required. Investigations at the Service's sand drift control experiment centres and on the beach mining areas are continuing, with a view to improving present methods and techniques of brushing and planting.

In conclusion some guiding points are summarised:—

(1) Where gaps are cut through or developed in the foredune, fill in with bulldozer, or erect brush fence across gap, or dump brush; then plant to sand spinifex and/or pigface.

(2) Where scouring develops on steeply sloping dunes, spread young saplings of brush.

(3) To counteract furrowing and funnelling on the landward side, dump brush.

(4) To rehabilitate a badly damaged foredune, doze sand or pump tailings to reshape dune to 10-15 feet high, with a wide crest and gentle batter on the slopes. Erect brush fence on shoulder, parallel to beach, and lay brush barriers at right angles to the fence, 15-30 feet apart; where drift is severe, erect additional brush fences at right angles to the main fence, 100-250 feet apart. Then plant seaward face to marram grass and/or sand spinifex, crest to marram grass, pigface and creeping groundsel and follow up with shrub planting to within 100 feet of the toe of the dune.

(5) To restore a damaged hinddune area, where protected and a layer of humus in topsoil existed prior to mining, level, replace topsoil, plant to couch grass and follow up with shrub planting; where topsoil contains no humus, treat as for damaged foredune.

ACKNOWLEDGMENT

The advice given by Mr. B. A. Hadley, Senior Inspector of Mines, on mining techniques and terminology is gratefully acknowledged.

Reference.

(1) Gardner, D. E., 1955. *Beach-Sand Heavy-Mineral Deposits of Eastern Australia.* Bureau of Mineral Resources, Bull. No. 28.

PERENNIAL GRASSES TESTED FOR SOIL CONSERVATION.

BY

D. G. CAMERON, B.Sc., Agr., Soil Conservationist.

THE importance of using vegetative as well as mechanical soil conservation methods has been frequently stressed and since 1950 the Soil Conservation Service has been seeking new plants for the protection and reclamation of eroding land.

The plants collected to date have been tested mainly in the section of the State served by the six research stations, roughly the 19-26 in. rainfall belt in the south ranging to the 24-30 in. belt served by Inverell in the north, that is the Western Slopes and Hunter Valley.. Any conclusions stated in this article are only valid in the area indicated in Fig. 2.

The essential features of a grass for soil conservation uses may be listed as follows:

Establishment: Rapid establishment under adverse conditions of soil fertility and moisture is essential.

Habit: A rhizomatous or stoloniferous sward-forming habit, free from extreme weed potential and tolerant of associated legumes, is required.

Seeding Characters: Good production of seed that is easily harvested and handled is complementary to ease of establishment.

Vigour: A species capable of making vigorous growth all the year would be ideal.

Drought Tolerance: This area requires ability to grow well into a dry spell as well as persist through the severe droughts experienced.

Adaptation: Development of plants useful under narrow ranges of climate and soil is not warranted at this stage.

Persistence: Good perenniality is required for waterways and other points of permanent erosion hazard.

Pest and Disease Resistance: Freedom from parasites likely to kill or weaken the sward is vital.

Economic Utility: The grasses used must be capable of fitting into the general farm conservation programme, being reasonably palatable, non-poisonous and free from other weedy features.

Rhodes grass (*Chloris gayana*), and phalaris (*P. tuberosa*), are the main perennial grasses used for soil conservation purposes in this section of the State, although their successful use is, at present, confined mainly to the eastern half. It is against these species as controls that all perennial grasses have been tested, the essentially cooler season species against phalaris and the others against Rhodes grass.

A number of native and naturalized grasses, together with most available commercial lines, have been included in the programme. They serve as a guide to the potentials of the various introductions, especially those lines which are too numerous to establish in sward plots.

The introduced grasses in the main have been received from the C.S.I.R.O. Plant Introduction Section. The assistance and encouragement received from this section, especially Mr. W. Hartley, Mr. C. A. Neal-

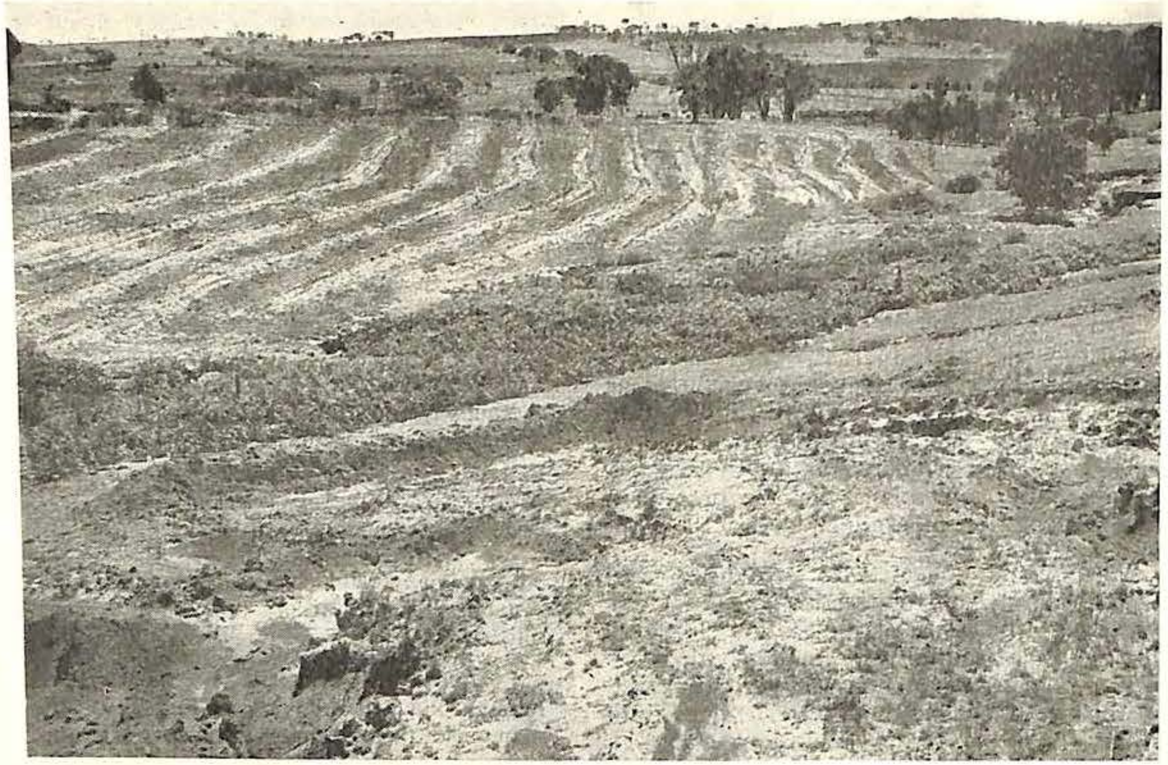

Fig. 1.—Mechanical soil conservation measures must be followed by vegetative cover to achieve complete stabilisation.

Smith and more recently Mr. J. F. Miles, is very much appreciated and gratefully acknowledged, as also is the assistance received from the N.S.W. Department of Agriculture and especially Mr. W. T. Atkinson.

Preliminary results of this work have been published by Cameron (1954) and conclusions relating to those grasses sufficiently tested for broad classification up to April, 1955, are given here. They are classed as:—

(*a*) Showing sufficient promise to warrant further testing.

(*b*) Have shown some promise but discarded because of certain features.

(*c*) Of no value.

WARRANTING FURTHER TRIAL

Panicum coloratum. Makarikari strains.

P. coloratum is a very variable summer-growing species of which only four accessions had been widely grown. These are CPI-7939 (SCS-162), N.S.W. Department of Agriculture accessions, Kx-19 (SCS-1408) and Kx-20 (SCS-555) and an unidentified C.S.I.R.O. line (SCS-2010). The first three are strains of the variety *makarikariensis* (Makarikari panic) given rating by some authors as a separate species. These are the only perennial grasses to show outstanding vigour and habit, but unfortunately they have poor seeding characters and it may be difficult to isolate a suitable seeding strain.

Until 1954-55, SCS-555 had been regarded as sterile, but under the recent wet conditions odd filled seeds were obtained. SCS-1408 seeds lightly while SCS-162, though its seeding habit is by no means ideal, is the best, but it is slightly inferior in vigour and habit. It may, however, be necessary to fall back on this line if better seeding types cannot be obtained. Poor seed yields are the result of two factors,

varying degrees of sterility combined with an extended flowering period and rapid shattering of ripe seed.

The Makarikari panics are vigorous, hardy and stoloniferous. They could prove useful in soils unsuited to Rhodes grass such as the heavy chernozemic soils of the North-west and Hunter Valley. The best strains may not be as vigorous as commercial Rhodes grass when the latter is at maximum vigour, but they have a longer growing season, starting earlier in the spring and growing later into the winter.

The habit is satisfactory for most soil conservation uses, being semi-prostrate, and capable of satisfactory spread if they are not grazed while growth is vigorous. The stolons grow more slowly than those of Rhodes grass but they are generally heavier and more leafy and root down better.

Drought tolerance and palatability, as reported by Van Rensburg (1948) and other African workers, are quite good. The mature stems are rather harsh in some lines.

Its ability to establish from seed when and if this can be obtained in suitable quantities will be the critical factor deciding the final value of Makarikari panic. Humphreys (Unpublished) has obtained an indication that SCS-162 has better final emergence than Rhodes grass on chernozem-like soils under pot conditions. Unfortunately, he also obtained an indication of slower emergence. Final establishment was not tested.

Ehrharta calycina. Perennial veldt grass.

This commercial species has shown two promising features, ease of establishment on lighter textured soils and drought resistance. On sandy granitic soils at Cowra it has been the easiest species to establish in autumn, but results on heavier soils have not been so good. Drought tolerance was also excellent at Cowra and Wellington in 1954.

It is used to some extent as a pasture plant in South and Western Australia, but it remains to be seen if it can be effectively utilized in any of the drier areas of this State for soil conservation. Persistence is reputedly rather poor and tussock type is not ideal being too compa t and erect, leaving bare ground between individual plants. Weakly rhizomatous forms are, however, being obtained for trial.

Cenchrus ciliaris. Buffel grass.

SCS-232 obtained from the Queensland Department of Agriculture and Stock as Type D (Q-2948) has shown some promise over the 1954-55 summer, when it proved a rapid growing, leafy plant with a tendency to sub-surface tillering in its first year. Commercial material has proved a weak, compact plant to date, easy to establish but of little use in this zone. If a plant can be obtained with the same ease of establishment and hardiness, but a better habit and vigour it could prove useful in the northern portions of the zone in Fig. 2.

SOME PROMISE BUT DISCARDED

These have shown some promise but have been discarded because of certain undesirable features or inferiority to the standard lines.

Agropyron glaucum and *A. obtusiusculum* (CPI-9352 and 9353).

These lines grow well for limited periods in flush seasons, but do not appear quite hardy enough for widespread use. Establishment has usually been slower than for phalaris and they are more sensitive to moisture and weed conditions. While these two lines are being discarded *A. intermedium* and *A. elongatum* which are very similar but slightly superior will be temporarily retained.

Agropyron semicostatum (CPI-11970). Drooping wheatgrass.

The promise in initial rows was not maintained in swards, establishment being poorer and vigour lower than expected. Persistence has been almost of an annual nature and regeneration from seed poor. Best performances were at Inverell.

Astrebla lappacea (various native selections). Curly Mitchell grass.

While much poorer than Rhodes grass they were the best of the summer-growing native species and did moderately well during moist summer periods. The habit is too compact and semi-erect for general use

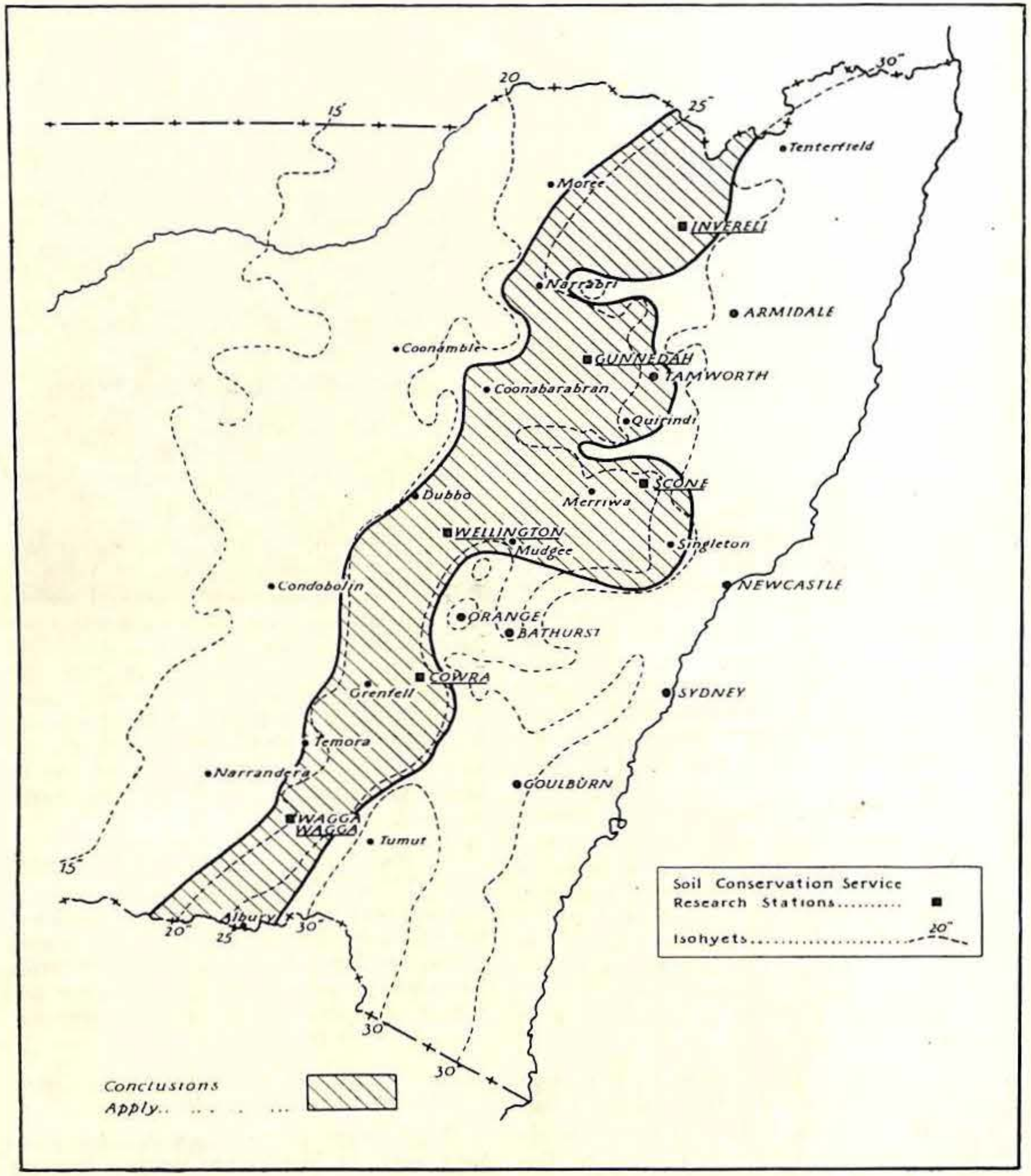

Fig. 2.—Map of New South Wales showing the area to which the results of these observations are applicable.

but it may be of value in the north-west margin of this zone.

Brachypodium pheniocoides (CPI-1719).

A most difficult species to establish and all sward plots have been disappointing. In rows, when established, foliage is harsh, but it is weakly rhizomatous and fairly vigorous.

Bromus carinatus (CPI-3455). California bromegrass.

It has died out during dry years but has done better in very good seasons. It is slightly inferior to better types of prairie grass.

Buchloe dactyloides (CPI-9513 and A-261). American buffalo grass.

While it has continued to show promise for sodding, where good soil binding is required without bulk, native couch grass has proved just as good. The only improvement over couch grass has been ready seed-setting. It is completely dormant in winter.

Cynodon dactylon (CPI-11360—Tifton Strain). Couch grass.

This has proved most useful for sodding purposes but its vigorous spread by both rhizome and stolon make it too dangerous for widespread use. Native couch grass is a serious weed of cultivation on lighter soils in areas of summer rainfall and Tifton strain would prove a greater problem.

Cynodon plectostachyum (CPI-17095, 16886, 16664 and 15893). African star grass.

A summer grower with most promising vigour and a prostrate bulky habit. Strongly stoloniferous, it spread up to 20 feet in one summer at Scone but Van Rensbury (1948) has indicated that no weed problem exists, it being easy to remove from cultivation land. A number of references were sighted to possible cyanide poisoning. The Queensland Poison Plants Committee (1950) considered it of sufficient value to warrant use in that State provided adequate care was taken, but as the cyanogenetic properties are most highly developed under the hot droughty conditions likely to be encountered in New South Wales it has been removed from all nurseries. Should a cyanide-free strain be identified then it should be immediately reconsidered.

Dactylis glomerata var. *hispanica* (CPI-2145). Spanish cocksfoot.

It has shown drought resistance superior to other cocksfoots being the only one to persist though 1954 in swards at Cowra. Vigour is excellent but is limited to autumn and spring. It has been quite easy to establish but the tussock is very compact and it is susceptible to both leaf and stem rust. More suitable lines are available.

Dactylis glomerata (N-71). Cocksfoot.

A more typical cocksfoot than the *hispanica* variety and has done better than commercial material. Peak vigour was not as good as *hispanica* but of a more extended duration. Drought resistance is poorer.

Eragrostis curvula (CPI-11471, SCS-809 and SCS-1406). Weeping lovegrass.

Ease of establishment has been its most promising feature and drought resistance is also very good but the tussock is too compact. Despite numerous references to the contrary, indications of extreme unpalatability have been obtained. While it will be tested in the Western Division it is being discarded elsewhere.

Panicum antidotale. Giant or blue panic.

This commercial species has been used to to a limited extent for waterways but is not an ideal type, being too erect and tussocky. A summer grower, it is quite vigorous in suitable areas but provides poor ground level protection because of its erect habit.

Pennisetum clandestinum (SCS-1704 Seeding strain). Kikuyu grass.

Because seed production could have increased the weed potential of this rhizomatous species in arable areas it has been discarded. Seed production would lead to more rapid spread and more difficult eradication of this strain than the common strain which does not set seed.

Setaria argentina (CPI-9726).

Although this species has shown some promise, *S. sphacelata* appears, from initial trials, to be superior. It has a fairly compact, erect tussock with moderate vigour and fair

Fig. 3.—The end of a row of Makarikari panic in its second season at Scone.

drought tolerance. Seed setting, while not ideal, would allow utilization.

Sorghum almum and *S. arundinaceum* (CPI-9840 and 12020).

These are essentially forage plants with little application to soil conservation practice only moderate ground level protection being provided although some rhizome spread akin to, but weaker than, that of Johnson grass (*S. halepense*) has been noted. Possibilities of cyanide poisoning have also been reported.

Stipa hyalina (CPI-9729).

A tussocky native of South America that is far the best of the *Stipa* spp. tested. It is not well suited to this zone but may be useful further west. Seed is set freely, but shatters readily, making harvesting difficult. Both awn and seed are softer than most native species and it is more leafy and bulky.

SPECIES OF NO VALUE

The following types are of no value in this zone, though some may have uses outside it. Some are now being tested in the Western Division.

Acroceras macrum (CPI-9358) Nile grass.

Requiring at least a 30 inch summer rainfall in South Africa and native to the 30-45 inch rainfall belt according to Botha (1944), it was not impressive, even in very wet summers. It flowered regularly but no seed was noted. No rhizomes and only very weak stolons were formed.

Agropyron cristatum, A. desertorum and *A. sibericum*. Wheat grasses.

Accessions tested included CPI-7656, 7580, Ki 65, of crested wheat grass, CPI-1775 of desert wheat grass and CPI-7667 and 7669 of Siberian wheat grass. All are very similar, being weak, of poor habit with

compact tussocks and no sign of vegetative spread. CPI-1775 was the best but despite their reputations (Hughes *et al* (1951)) for drought resistance in America they have shown no promise here. Establishment, especially in swards has been most difficult.

Agropyron dasystachyum (CPI-13312) Thickspike wheat grass.

A small, weak plant with fine but harsh foliage that has been very difficult to establish even in weed-free rows. Heavy leaf rust infection has been noted at Wagga, Scone, Gunnedah and Inverell. It has weak rhizomes but is too unthrifty for further trial.

Agropyron inerme (CPI-13313) Beardless wheatgrass.

A fine leaved, compact tussock, less vigorous than *A. dasystachyum* and most difficult to establish.

Agropyron riparium (CPI-13518) Stream bank wheatgrass.

Very similar to A. *dasystachyum*.

Agropyron scabrum (SCS-844) Common wheatgrass.

Collected on Cowra Research Station for comparative purposes, it proved a sparse stemmy type of this variable native species. It has erect flowering stems and poor persistence.

Agropyron smithii (CPI-8966). Western wheatgrass.

A vigorous rhizone that may have weed potential, especially as it lacks bulk and provides poor ground cover. Hefenrichter *et al* (1949) noted seed setting in the U.S.A. but it was very shy here.

Agrostis castellana (CPI-12398).

A fine, weak, densely leaved turf former that may be of use in flumes. Leaves are soft but stems harsh and wiry, and it was difficult to establish from the original seed. Best performance was at Inverell during the 1954-55 summer.

Andropogon furcatus (CPI-12773). Big bluestem.

Fairly leafy and dense with a tussocky habit, it was late maturing and shy seeding. A summer grower, drought tolerance is doubtful.

Andropogon hallii (CPI-12774). Sand bluestem.

Regarded by Wheeler (1950) as strongly rhizomatous, it has only shown weak spread here but was the best of the andropogons. It flowers readily but seed is hard to harvest and clean as it is light and fluffy. Much of the seed has also been of doubtful viability. Drought tolerance has been good.

Andropogon scoparius (CPI-12771). Little bluestem.

A fine, fairly short-leaved, dense summer grower with a compact tussock and little bulk. Establishment has been difficult and vigour and seed-setting poor. Best performances were at Gunnedah and Inverell.

Arrenatherum erianthum (CPI-2283).

Rather difficult to establish, it was weak with a low, dense, expanding tussock, erect flowering stems and poor persistence. It is probably more suited to cooler areas.

Bouteloua curtipendula (CPI-12772). Side-oats grama.

A summer growing type with good drought tolerance. It seeds well and is easily established but is weak and tussocky with a fairly harsh foliage. The best of the *Bouteloua* spp., as reported by McTaggart (1942). It may be useful to the west of this zone.

Bouteloua filiformis (CPI-12775). Slender grama.

A slender, weak, tussocky plant, smaller than side-oats grama, it grows further into the winter and has good drought tolerance.

Bouteloua gracilis (CPI-12776). Blue grama.

A very small, fine leaved, hardy type.

Bromus sp. (Possibly *B. erectus*). (CPI-7708.

Soft-leaved and dense with an expanding tussock, it was generally weak and quite inferior to *B. inermis*. Drought tolerance was its best feature.

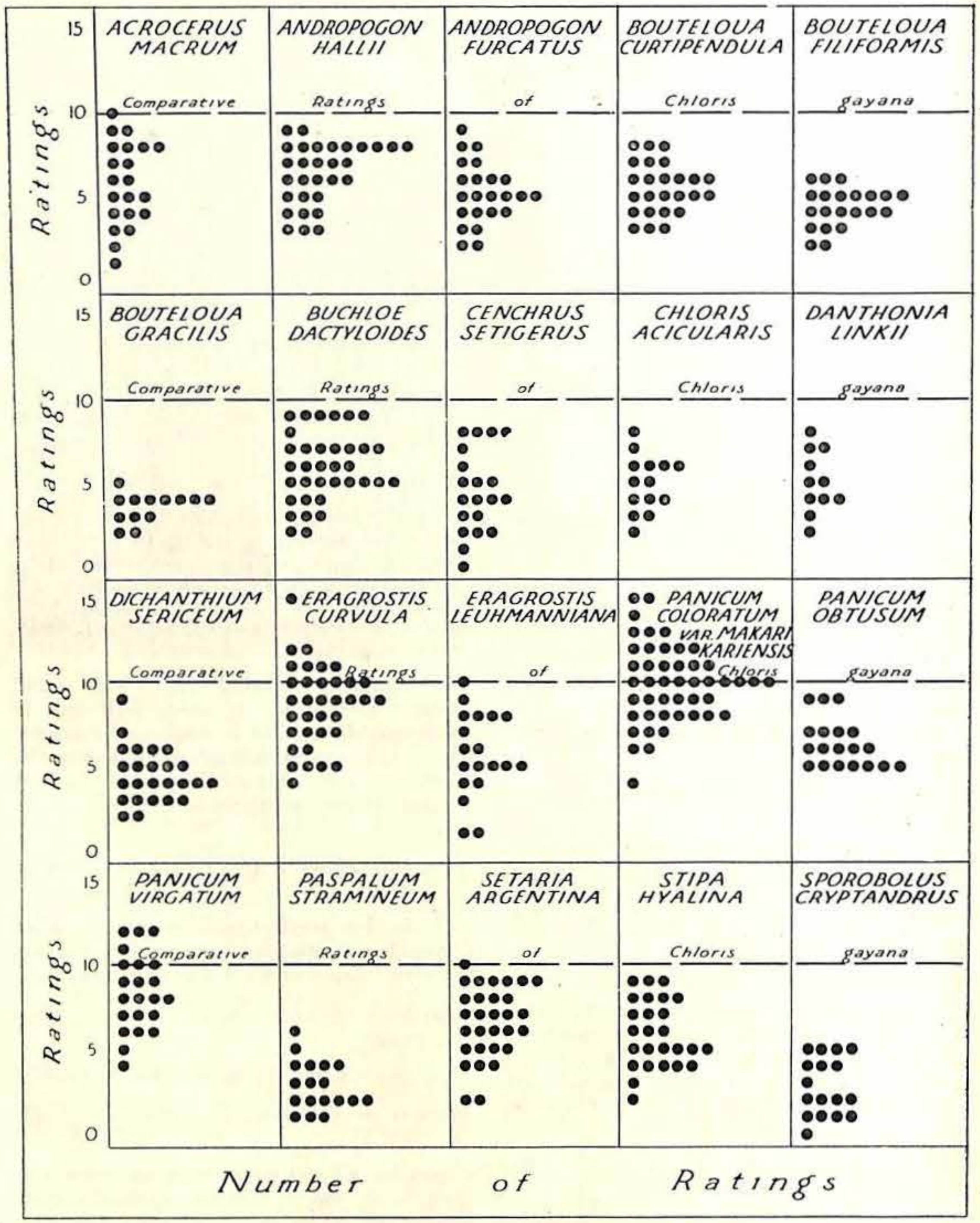

Fig. 4.—Comparative ratings of relative value of a number of warm season grasses and Rhodes grass at all Research Stations.

Bromus unioloides. Prairie grass.

Ease of establishment has given this commercial and naturalized material value for comparative purposes, but it is otherwise unsuited for soil conservation uses here. Its habit is too compact and vigour low after the first year with poor persistence.

Cenchrus setigerus (A376). Birdwood grass.

Reputedly very hardy, it only showed promise at Gunnedah. It seeds rapidly and heavily, maturing seed in six to eight weeks. Never taller than twelve inches it was generally only four to six inches high and lacked bulk and vigour. Persistence was poor, as it failed in most rows within three years.

Chloris acicularis (N-370 and local selections). Curly windmill grass.

Although highly regarded as a native pasture grass it was difficult to establish, weak and lacking bulk with a compact tussock and poor quality cover.

Chloris truncata. Windmill grass.

Similar but even poorer than *C. acicularis.*

Dactylis maritima (CPI-9003).

A fine-leaved cocksfoot of the *hispanica* type but weaker, not as hardy and never impressive.

Danthonia spp. Wallaby grasses.

All lines, including *D. caespitosa, D. linkii* and *D. richardsonii* failed to show any value, having compact tussock and poor vigour at all times.

Dichanthium annulatum (SCS-801).

A sparse stemmy summer grower with a basal leaf habit. Slightly later maturing but inferior to *D. sericeum* it seeds heavily but ripens unevenly and shatters readily.

Dichanthium sericeum. Queensland bluegrass.

While regarded as useful for soil conservation purposes in natural stands it cannot be considered useful for artificial sowings being tall, erect, fairly compact and rather coarse and stemmy. Some variation, especially in vigour, was noted in lines from different localities.

Elymus angustus (CPI-6805).

This was removed because of its weed potential in arable areas, which was also noted by Hafenrichter *et al* (1949). This is due to vigorous deep-seated rhizomes, while above-ground growth was below par, being harsh and open. It flowered but no viable seed was noted.

Elymus canadensis (CPI-10636). Canada wildrye.

A summer-growing short-lived perennial behaving as an annual here. Initial vigour was good but it apparently requires very mild summers, as it wilted quickly and died in hot weather.

Elymus giganteus (CPI-1824 and 13320). Siberian wildrye.

Essentially a hardy inland grass suited to sandy areas, although Glubokov (1939) states it is used for pasture in arid portions of the U.S.S.R. Very coarse and harsh but quite vigorous and bulky, it has a vigorous rhizome during wet summers and could be a weed in arable areas. It flowered readily and although the rows were established from seed originally, no viable seed has been collected here.

Elymus glaucus (CPI-7340). Blue wildrye.

It forms a compact tussock with dense basal leaves and erect seed heads. A summer-growing type, it lacks bulk and vigour, and persistence has been rather poor.

Elymus junceus (CPI-6793 and SCS-824). Russian wildrye.

A hardy plant with a compact tussock and basal leaves which has growth peaks in autumn and spring. It has done best at Wellington but has been difficult to establish especially in swards and SCS-824, at Cowra, was frequently affected by stem rust and failed to set seed.

Elymus mollis (CPI-15929).

A summer-growing grass with coarse, ascendant stemmy tussocks, generally weak with good seed set but a heavy awn.

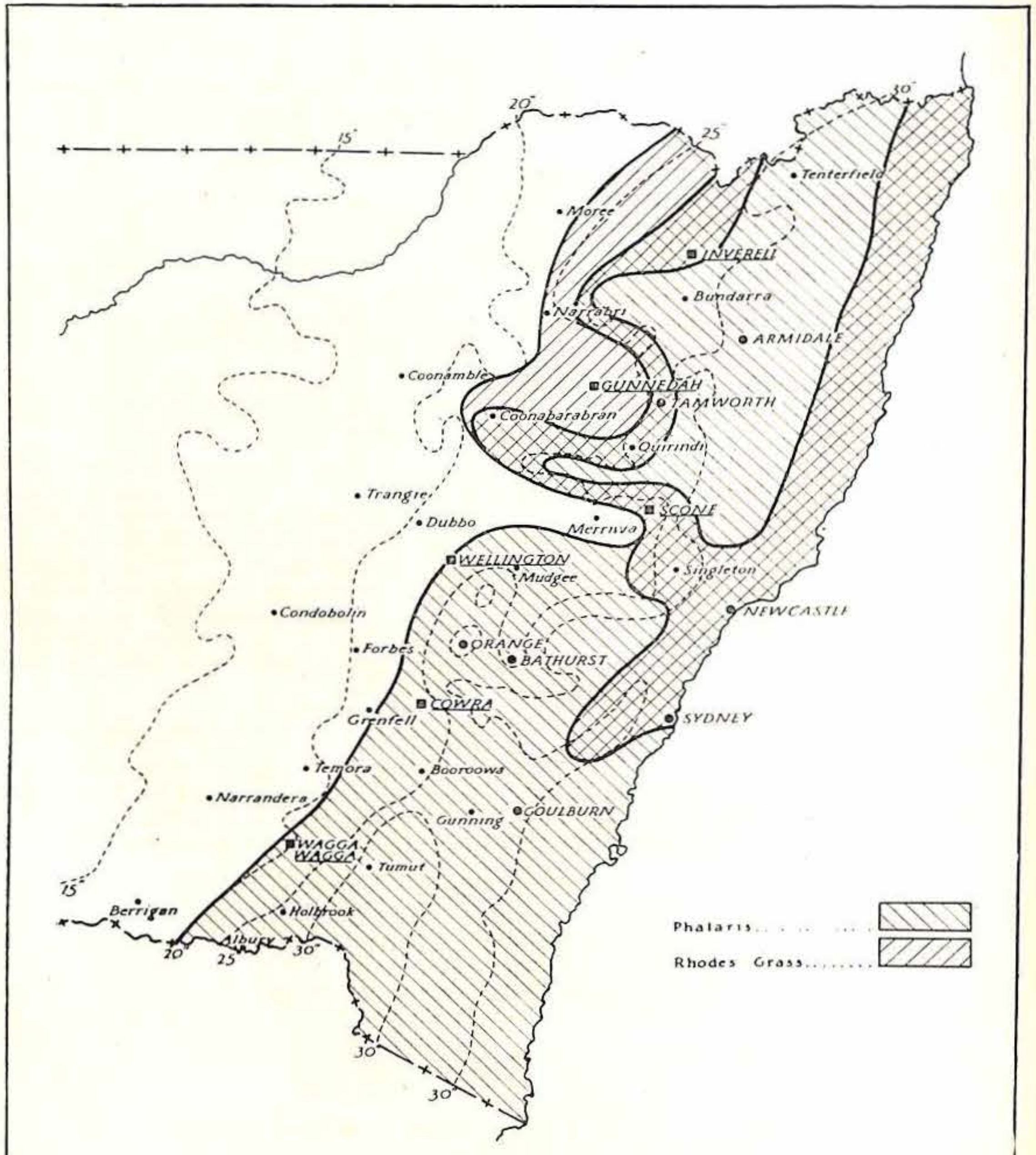

Fig. 5.—Zones of usefulness of Rhodes grass and phalaris for soil conservation purposes in New South Wales.

Elymus sp. (CPI-9355).

A sparsely-foliaged, erect type with medium-textured leaves giving poor ground cover. In some years, rising temperatures have stopped growth before seed was set in the spring.

Eragrostis lehmanniana (CPI-7341). Lehmann's lovegrass.

It is fairly hardy, only leafy when conditions are good, and has fine, wiry, stoloniferous stems. The seed is extremely small and shatters readily while establishment in swards has been poor.

Eragrostis superba (CPI-13723).

Has shown some promise and drought resistance is fair, but the tussocks are compact and vigour and bulk are only average.

Eragrostis trichoides (CPI-11015). Sand lovegrass.

It is a medium-sized and erect summer-growing type with fine but sparse leaves. Only grown to any extent at Wagga and Gunnedah but did not persist well.

Festuca rubra (CPI-12384). Red fescue.

It was quite out of its element here, dying out of all sowings in the following summer.

Festuca pratensis (CPI-5713). Meadow fescue.

Finer and less vigorous than *F. arundinacea*, it has a compact tussock with poor bulk and ground cover. It needs moister conditions.

Oryzopsis hymenoides (CPI-8281). Indian ricegrass.

Establishment was only obtained at Wagga where it proved very sparse and weak, with narrow harsh leaves, a compact tussock and no bulk. It is useful in arid areas according to Wheeler (1950).

Panicum decompositum. Native millet.

This summer grower is one of the best native species but the tussock is compact and vigour inferior to the Makarikari panics. It is fairly leafy and in natural stand provides quite fair protection.

Panicum obtusum (CPI-3652). Vine mesquite.

A summer-grower with vigorous stolons that do not root down very readily, possibly because they are light and not always in intimate contact with the ground. They generally die back to the parent crown in winter. Best results were in wet summers on heavier soils. Quite hardy but lacking in bulk with sparse leaves.

Paspalum scrobiculatum (from C.S.I.R.O., Queensland). Scrobic.

This summer-growing type, regarded by Paltridge *et al* (1943) as promising in Queensland, has only given occasional periods of satisfactory growth, vigour has, as a rule, been poor and habit is not ideal for soil conservation work. Seed setting has rarely occurred as the season is too short.

Paspalum stramineum (CPI-12492). Sand paspalum.

A small, weak, soft summer grower, with a tussocky habit and little bulk. Drought resistance has not been good, despite a typical rolling of the leaf which will completely enclose the seed head in dry weather.

Pennisetum villosum. Long-style feather grass.

A frequent volunteer around towns it showed some promise, being fairly hardy and moderately bulky with slight rhizome development. Seeding characters are poor, setting being variable and the florets, while easy to collect, would require hammer milling.

Poa ampla (CPI-12279). Big bluegrass.

A sparse, tussocky plant, growing slowly during winter and spring but burning off with the first hot weather. Establishment was difficult.

Poa nevadensis (CPI-13325). Nevada bluegrass.

Most difficult to establish, it is very weak, semi-erect with a compact tussock and sparse narrow leaves.

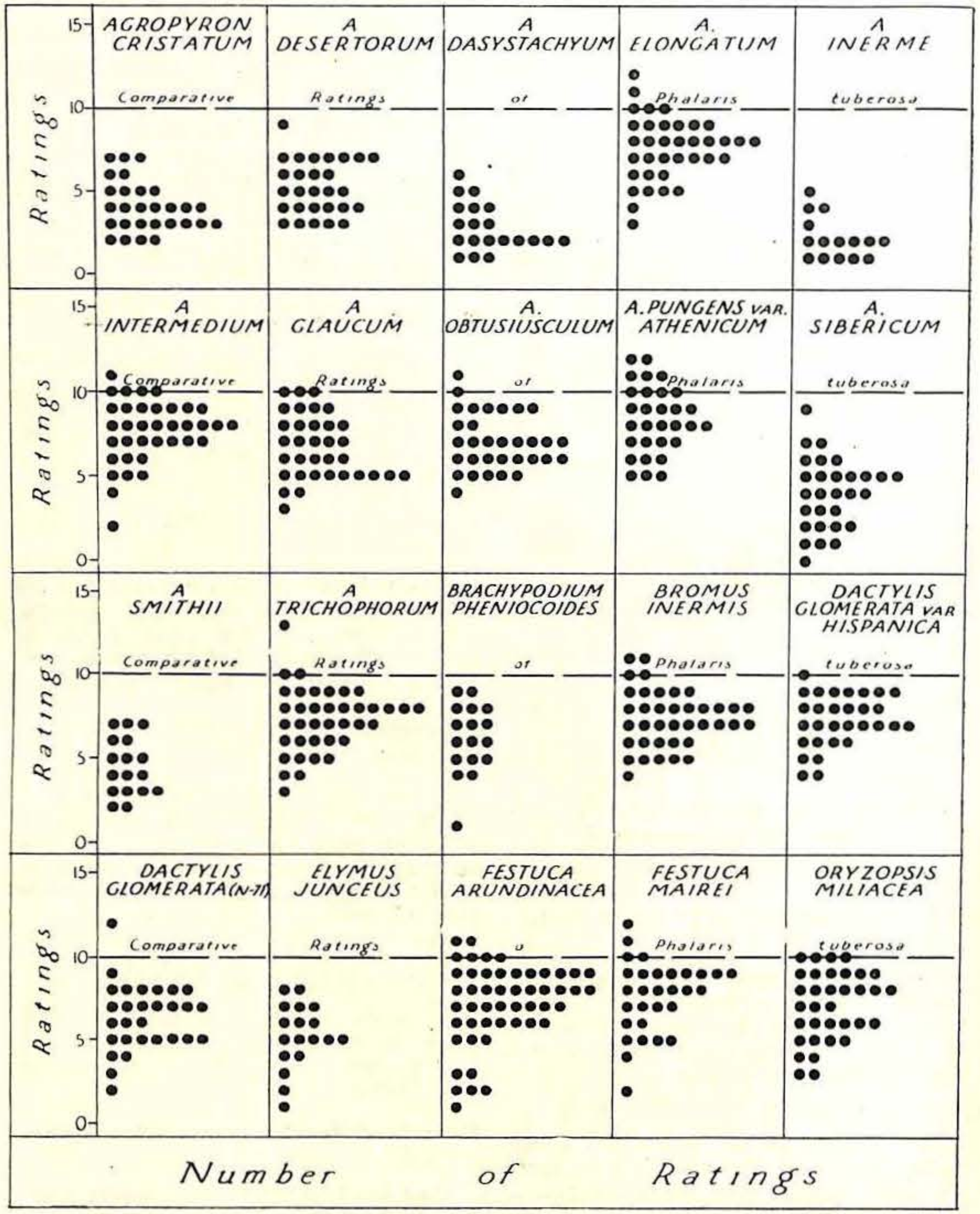

Fig. 6.—Comparative ratings of relative value of a number of cool season grasses and *Phalaris tuberosa* at all Research Stations.

Sporobolis airoides (CPI-13327). Alkali sacaton.

A similar tussock to *E. curvula* with less vigour and bulk and a harsh foliage. A summer-grower, it is a shy seeder and also shatters the seed set. Establishment has been difficult.

Sporobolus cryptandrus (CPI-9514). Sand dropseed.

It is fine, very sparse and useless with harsh stems almost lacking in foliage. Very weak, it gave poor cover. Seed is fine and hard to harvest, except in the dry late summer when the seed heads are held within rolled leaf blades.

Stipa aristiglumis. Plains grass.

While prized as a natural forage in many areas, this is not an ideal conservation type, being too compact, and not as vigorous as control species. In natural stands, carefully grazed, it can provide fair soil protection but is far from ideal.

Stipa spp. Spear grasses.

Lines, including *S. scabra, S. setacea* and *S. variabilis,* have been poorer in vigour and bulk than the controls, although generally superior to the *Danthonia* spp. The tussock is too compact and vegetative spread limited. Reputedly drought-resistant, they have not proved any more so than Rhodes grass or phalaris under row conditions. (Humphreys, 1955).

DISCUSSION

The major drawbacks with both phalaris and Rhodes grass as perennial grasses for soil conservation purposes within the zone shown in Fig. 2 are the difficulty and uncertainty of establishment. A ready establishment and rapid development of initial cover under quite harsh conditions are essential. While these species can be established along the eastern margin of their relative sections of the zone, this success is not always achieved very far west. The research stations are located near the western fringes of the areas of frequent use of Rhodes grass and phalaris. Satisfactory stands can be obtained further west in good seasons, but many failures are encountered. It is along the western margins of the area marked in Fig. 2 that new species are most vitally required.

Once they are established, both control species have the drought tolerance to persist and provide reasonable protection, but establishment is the major problem. Rhodes grass has also been hard to establish on some soils well within its zone of usefulness as indicated in Fig. 5. On the heavy self-mulching soils, such as those around Merriwa, on the Liverpool Plains and around Inverell, it has proved almost impossible to establish, despite ready establishment on the lighter soils nearby.

The ability to establish readily must be combined with suitable habit and reasonable vigour, especially rapid initial vigour, as the harsh conditions do not allow the use of mixtures that would include species to give initial cover. The eventual effectiveness of the major species is endangered if more than the essential legume component is included.

To date the majority of the more easily established species such as *Dactylis glomerata* var *hispanica,* perennial veldt grass and *Eragrostis curvula,* have all shown an unsatisfactory, compact tussock and, in the case of *E. curvula,* a lack of economic usefulness, as it is so unpalatable.

As all species under trial are being examined solely for their general usefulness in soil conservation practices, many of the native grasses, regarded as good forage plants, have not shown suitable features for this purpose. As well as having unsatisfactory growth habit, some species such as *C. acicularis, C. truncata* and various selections of *Stipa* and *Danthonia,* have also been rated well below most introduced lines for vigour and seeding characters under nursery row conditions. Only curly Mitchell grass, of other native species tested, appears moderately vigorous with satisfactory seed setting. Because of the difficulties of establishment of these native species in swards, it has not been possible to compare them with the introduction under sward conditions, but it is probable that the same relationship would have been found.

Fig. 7.—Vigorous growth of Rhodes grass stabilising a diversion bank at Scone.

It has also generally been found that species which are valuable for soil conservation purposes in the U.S.A. have shown only slight promise here. This particularly applies to native American species. Although some of the summer-growing types have done fairly well, the majority of them have proved inferior to Rhodes grass. The American species have been slow to establish and had short periods of vigorous growth. Usually they only grew satisfactorily in autumn and spring and lacked vigour under both hot and cold conditions.

Plants of African, Mediterranean and South American origin have, on the other hand, shown much more promise, especially the summer-growing species. Rhodes grass is an African species as also is Makarikari panic, which has the most promising vigour and habit so far tested. *Setaria sphacelata* and *Panicum* sp. (Kabulabula strain) from this region have also shown satisfactory vigour in initial trials.

It is an unfortunate, but unavoidable, feature of the testing procedure that establishment is one of the last features that can be critically tested. It is an added difficulty that the ideal habit of a plant for soil conservation purposes is an extremely vigorous spread, preferably by rhizomes, as this is the most binding form of growth. This habit makes a plant a potential weed and it becomes necessary to strike a happy medium between vegetative spread and weed potential. For this reason stoloniferous spread is safer, as these species are generally more easily controlled in arable areas, while giving a reasonable rate of spread. Short scaly rhizomes, such as those of *Paspalum dilatatum* and phalaris are suitable for soil binding, but a good initial establishment is necessary with this type of habit if good eventual protection is to be obtained. Also breaks in a sward of this type heal slowly.

CONCLUSIONS

No perennial grass, with a suitable habit and vigour, has been isolated that can be more readily established than the existing commercial lines of phalaris and Rhodes grass and these for the present must remain the major waterway grasses in the section of the State indicated. A more thorough study both of the species of phalaris and the strains of Rhodes grass is to be made in the hope of expanding their zones of usefulness as indicated in Fig. 5.

The Makarikari strains of *P. coloratum* have shown the most promising vigour and habit for northern areas but, unfortunately, strains tested to date have poor seeding characteristics. A comprehensive collection of this group is now being obtained in the hope of finding a strain that seeds freely.

The only plants that have yet been found superior to the sodding plants, Kikuyu grass and couch grass, already in use have some undesirable features which caused them to be rejected.

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EROSION IN WESTERN NEW SOUTH WALES.

BY

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and

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PART I. A GENERAL DESCRIPTION OF THE WESTERN DIVISION.

THE Soil Conservation Service of New South Wales, since its inception in 1938, has been conducting investigations into the erosion problems in the Western Division. These investigations have been directed mainly towards the reclamation of eroded country, study of the various factors involved in the loss of soil by erosion, and the natural regeneration of the eroded sursurfaces. Along with these investigations, officers of the service have been conducting an erosion survey from the various centres to which soil conservationists are appointed.

The purpose of this series of articles is to describe the various forms of erosion which are encountered in the Western Division, particular attention being paid to the factors causing erosion with a view to illustrating the basis for the classification of erosion and mapping of the erosion survey. However, it is proposed, firstly, to outline the general features of the region such as topography, landforms and vegetation, particularly in relation to erosion.

THE WESTERN DIVISION—GENERAL.

The Western Division of New South Wales covers an area of approximately 80 million acres, representing 40 per cent. of the area of the State. It is bounded on the north, west and south by the borders of the States of Queensland, South Australia and Victoria, respectively. The eastern boundary is an irregular line running from the Murray River in the south (from the point where it is joined by the Murrumbidgee), north-eastward to where the Barwon River meets the Queensland border.

The Western Division lies beyond the area considered suitable for agricultural pursuits and accordingly all country within this region is used almost solely for extensive grazing, principally of merino sheep for wool-growing, with occasional areas devoted to beef cattle. Cattle are more suited to country where sheep raising is hazardous by reason of wild dogs, or where the development and maintenance of improvements is rendered difficult, such as in barren sandhill country or ephemeral lake beds and "flooded" country.

By reason of the arid climate, grazing capacity is very low, ranging from 5 acres per sheep under the most favourable conditions in the south-eastern portion, to 35-40 acres per sheep in the far north-west. Throughout this area grazing capacity varies more or less directly with the amount of rainfall received. There are local variations due to marked changes in soil type and pastures or presence of dense scrub.

A very limited amount of irrigation for fodder production is practised along the rivers, apart from the extensive areas developed for fruit-growing in the Wentworth district.

The pastoral settlement of the Western Division began in the middle of the last century, and by 1880 the area carried 8 million sheep. Stock population increased

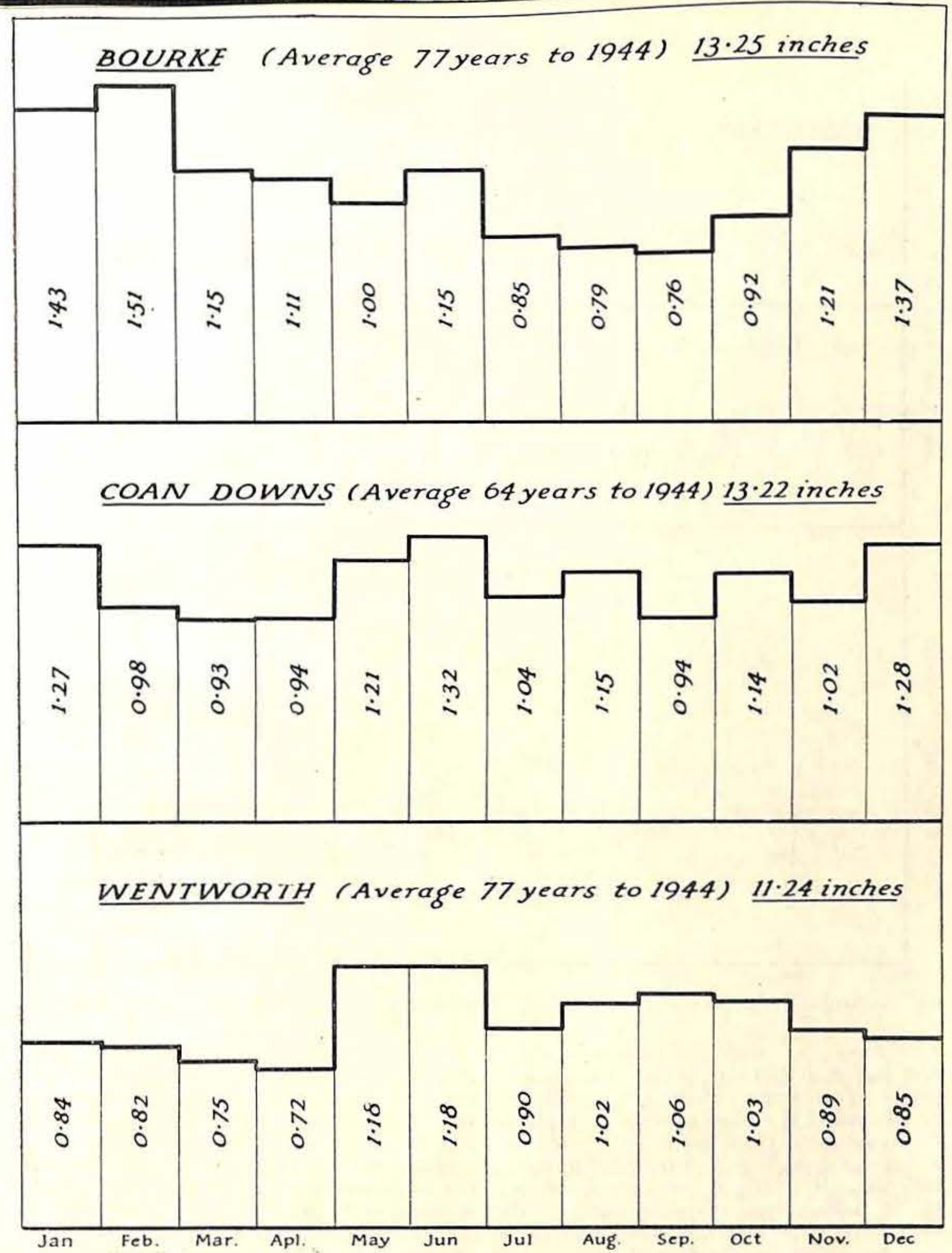

Fig. 1.—Monthly distribution of rainfall at three centres in the Western Division of New South Wales.