FOWLERS GAP ARID ZONE RESEARCH STATION

LANDS OF FOWLERS GAP STATION NEW SOUTH WALES

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FOWLER'S GAP ARID ZONE RESEARCH STATION

UNIVERSITY OF NEW SOUTH WALES

This Field Station of 98,000 acres (39,200 hectares) is situated 70 miles (110 kilometres) north of Broken Hill in western New South Wales. It was leased to the University in 1966 to facilitate arid zone research, particularly into problems concerning the pastoral industry in the region. With an average rainfall of 8 inches (20 centimetres) distributed through the year, the Station is climatically representative of much of the southern Australian arid zone. The Station carries some 5,000 sheep, and has a small laboratory as well as residential facilities for scientists. Its policy is guided by a Consultative Committee which includes representatives of the pastoralists and of other local interests, of the New South Wales Departments of Lands and Conservation, and of C.S.I.R.O., as well as of the University. The Station is presently administered through the University's Robinson College at Broken Hill.

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Edited by J.A. Mabbutt, assisted by M.E. Sullivan

A survey of the environment on the Arid Zone Research Station of the University of New South Wales by staff of the University and of the Soil Conservation Service of New South Wales.

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PREFACE

On January 1st, 1966, the Hon. T. Lewis, Minister for Lands in the New South Wales Government, handed over Fowlers Gap Western Lands Lease No. 10194 of 38,889 ha to the University of New South Wales to undertake research pertinent to the pastoral industry of the West Darling area. This responsibility has been interpreted to include the study of the problems of the desert environment against which the industry operates, as well as applied research into pastoral management. An Arid Zone Research Station has been established, and during the past seven years many Schools of the University have carried out investigations there.

This report is an account of the natural environment at the Station and aims to provide a background to such research and a reference framework against which its findings can be set. It discusses the basic elements of the environment such as climate, geology, and landforms, and also defines environmental units or land systems on the Station in terms appropriate to an assessment of pastoral potential. Since many aspects of the physical and human geography of the region have been affected by more than a century of settlement and land use, the report is introduced by an historical survey.

Most of the authors are members of the staff of the University of New South Wales who have worked at the Station; however the chapter on Pastures and Pasture Lands was written by Mr. P. L. Milthorpe of the Soil Conservation Service of New South Wales partly on the basis of an assessment of carrying capacity at Fowlers Gap Station made for the Consultative Committee in 1968 by Mr. J. C. Newman, also of the Soil Conservation Service, assisted by Mr. Milthorpe.

The initial field survey of land types was carried out early in 1968 by staff of the School of Geography at the University and the findings of the survey have been supplemented by subsequent observations at the Station. The account of the climate at the Station by Mr. F. C. Bell has drawn partly on weather records from a climate station established at Fowlers Gap in 1968. The chapter on water resources largely originates from surveys conducted by the authors, as part of the planned development of the Station. The chapter on the fauna of the Station reflects research at Fowlers Gap by members of the School of Zoology throughout the period of the University's lease.

As editor of this volume, I express my gratitude to the Director, Soil Conservation Service of New South Wales, for agreeing to collaboration by his officers, and to Professor A. H. Willis, Pro-Vice-Chancellor of the University of New South Wales, for his support in the publication as part of the Fowlers Gap Research Series. The production of the report owes much to Mr. K. Maynard and Mrs. V. E. Threader of the School of Geography and to Mr. J. W. Brain of the Institute of Rural Technology. All those contributors to the report who have worked at Fowlers Gap will wish to acknowledge an indebtedness to Dr. I. L. Johnstone, formerly Director of Field Stations, the Manager Mr. R. I. Eglinton and his staff at the Station, to the former Director of the W.S. & L.B. Robinson College, Professor T. K. Hogan, and to Mr. R. Emes, the Administrative Officer.

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by J. A. Mabbutt

I. EXPLORATION AND EARLY SETTLEMENT

Patterns of exploration and early pastoral settlement in this area, as elsewhere in the Australian arid zone, were determined by the availability of natural waters, specifically the Darling River and the smaller and often ephemeral supplies along local drainage in the Barrier Range. These provided permanent bases from which activities could temporarily be extended into the adjacent plains after rains. The first European explorer in the area, Charles Sturt, who experienced drought conditions on his journey in 1844-5, followed the Darling River to the point that gave the shortest plains crossing to the southern end of the Barrier Range. He then moved northwards along the west side of the Range to Floods Creek, named after one of his party, where he camped for three weeks on a waterhole about 25 km WNW of Fowlers Gap.

From this point Sturt made a short journey across the plains to the east of the Barrier Range between December 13th and 16th 1844, and gave the first report on the condition of the country near Fowlers Gap. He wrote (Sturt, 1849) "immediately on the other side of the range, there was a plain of great width, and beyond, at a distance of between 50 and 60 miles, was a range of hills running parallel to those near the camp. The first portions of the plains were open, and we could trace several creeks winding along them, but the distant parts were apparently covered with dense and black scrub. Descending to the eastward towards the plain we rode down a little valley in which we found a small pool of water; at this we stopped for a short time, but as the valley turned too much to the north I left it". This may well have been Fowlers Creek. His general direction was ENE and at 12 miles out into the plains he "crossed the dry beds of several lagoons"; at 16 miles he "entered dense brush of pine trees, acacia and other shrubs in pure sand". This is consistent with a traverse from Fowlers Creek, across the line of claypans that includes Nucha Lake, and through the sand dunes in the east of the plains to the north end of the Bynguano Range, identified by Sturt with Mt. Lyell. The description of the plains country on the map that accompanies Sturt's journal is appropriate to the floodout of Fowlers Creek on The Selection across the northeastern boundary of Fowlers Gap Station," .... plains lower than those W fall of Wr to N - plains swampy in winter with pools of water, now dry - grass on the plains tho' barren soil". Periodically he referred to "barren" areas, or to areas with "some grass".

Sturt traversed the area at the onset of drought, and the periodic sparseness of vegetation in the area before European settlement is confirmed by the fact that when Sturt returned southwards a year later, when conditions were excessively dry, he found that all bird and animal life had gone, and his horses and bullocks could barely find enough fodder to sustain their emaciated bodies. It can be concluded that even before any pastoral occupation took place, the lower pasture layers were scanty on the hills, that on the plains there were grassy areas interspersed with claypans, and that little herbage of value persisted close to natural waters during dry periods. The tree cover was probably much denser than now.

In the interval between Sturt's return in 1845 and the departure of Burke and Wills from Menindee in 1860, a line of pastoral stations was established along the Darling River frontage, a pattern to be strengthened by the advent of river boats on the Darling after 1859. Under the Waste Lands

Occupation Act of 1846, the West Darling area formed part of the Unsettled Districts beyond the Nineteen Counties, in which squatting licences could be granted for "runs" capable of supporting 4000 sheep at an assessed stocking rate, but in 1851 the new land district of Albert was formed, comprising all of New South Wales beyond the Darling River north to the 30th parallel. Systematic surveys and allocation of runs began here in 1854 and grazing licences were apparently already being issued by 1850, but settlement continued to outrun the extension of administration in this remote area, and many of the early settlers who took up land west of the Darling did so without licences. The pastoral leases under the 1846 Act were mainly of 32,000 acres for up to 14 years, and there was no limit to the area that could be held by one man provided he held the land in runs of standard size and paid his assessment on the number of stock held on each. In the absence of proper surveys, this led to a good deal of land speculation by middlemen, and a tendency to occupy strategic sites such as waterholes and pockets of better-quality grazing land. Behind the river frontages, back blocks were taken up for temporary occupation after rains; for instance Kinchega Station near the present-day Menindee extended back towards the Barrier Range along Yancowinna Creek and its soakages.

It was in the decade after 1860 that the main movement west of the Darling took place. By this time most of the frontage country had been secured, there was the additional attraction of good reports of pastoral potential from the parties which followed Burke and Wills in 1861-2, and also the stimulus given by the threat of selection in areas further east under the 1861 Crown Lands Occupation Act, which allowed the taking up of pre-emptive leases and small freeholds on land held on pastoral runs. Already before 1860, pastoralists had been exploring the country west to the Barrier Range, which was itself an avenue for travel northwards. For instance when Crawford journeyed to the Grey Range in 1859, chiefly with a view to the discovery of minerals, he found evidence of journeys in the area south of Fowlers Gap by pastoralists from the Darling stations. Among these pastoralist explorers were Wright and Stone, who later accompanied Burke and Wills, and a Robert Gow who was engaged by the Victorian pastoral firm of Clough and Co. to look for pastoral lands west of the Darling, and who in 1861 travelled up Stephens Creek with local men and reported on the Corona area, where scrub cattle and wild horses were found.

The 1863-4 season was particularly favourable for pastoral expansion west of the Darling, for good local rains encouraged occupation of the back blocks at the same time as the exceptional flooding along the Darling frontage caused problems there. The first stocking of pastoral runs near Fowlers Gap dates from this time. In the south the Mt. Gipps run, close to the main Darling settlements and favoured by soakages and water-holes along Stephens and Yancowinna Creeks, was taken up and stocked. A Darling River squatter George Urquahart was the first to travel sheep into this area. Further north, Abraham Wallace brought 1400 sheep across the Barrier Range from South Australia and took up Sturts Meadows on Caloola Creek, probably the first pastoral utilisation of the Fowlers Gap country. At first Wallace's settlement was nomadic only, and in times of water shortage he had to leave the area and move to water at Bancannia or Cobham Lakes, or even further afield. It was not until 1871 that a homestead was built at Sturts Meadows, by which time a flock of 18,000 sheep occupied the run. To the west and north Corona was also occupied in 1863-4 on behalf of Clough and Co., with Robert Gow as manager. It can be assumed that all the easily-watered country in the area of Fowlers Gap had been taken up by 1870, even if not effectively occupied. At this time there were no man-made waters, and sheep were shepherded as protection against the dingo. There are many reports of attacks by aborigines on the first stations, including one on Corona in 1867.

II. EARLY PASTORAL DEVELOPMENT

The philosophy behind the 1861 Crown Lands Occupation Act and its subsequent amendments was that the "natural" carrying capacity of the land -already held over-optimistically as one sheep to between 9 and 10 acres - could be raised further through the provision of improvements such as fencing and watering points, and by "judicious stocking" and consequent trampling of the ground. The enormous areas of pastoral runs west of the Darling, large parts of them only temporarily occupied, represented a challenge to this view and its aim of establishing closer settlement by resident graziers on medium-sized holdings. Faced with the threat of selection, the pastoralists were also being pressed to introduce improvements - in expectation of increased returns - through increased rentals, which were raised from 0.15d per acre in 1861 to 0.37d per acre in 1880. In the event, few Homestead Leases were taken up in the arid area west of the Darling River by bona fide selectors. However the burden of higher rentals and the high costs of providing water and fencing for permanent occupation put the individual squatter without capital at a considerable disadvantage. Many of them left the newly-occupied areas in the dry years after 1865, particularly during the period of depressed wool prices in 1868-70, among them Wallace from Sturts Meadows. Their place was taken by the extension of large company holdings such as that of Corona Station, which early in the 1870's incorporated runs to the north and east to take in parts of Sturts Meadows and Cobham, and brought what is now Fowlers Gap Station within its area of more than one million acres.

The Fowlers Gap area was affected only indirectly by the wave of mineral prospecting and mining activity that followed in the region after 1870. In 1869-70 a gold strike occurred at Mt. Browne and subsequently one at Tibooburra. Traffic northwards increased as a result, and the bullock track from Umberumberka through Euriowie and Fowlers Gap to Bancannia and Packsaddle developed into a mail route. The mining episode was short-lived and was virtually over by 1885, but the route remained for coach traffic and for travelling stock. A stock route was gazetted in 1884, with a branch along the eastern foot of the ranges where it presumably used the natural soakages and waterholes. The Gap may well have received its name at this time. Hardy (1969) refers to a Fowler, "perhaps an early Murray squatter", who may have pioneered the Gap through the Ranges ,and an alternative suggestion is that Fowler was a bullock-train driver who located the Gap on his journeys northwards. However local reports identify Fowler as a surveyor with one of the early exploration parties (K. Conners, pers. comm.). Certainly the name already existed in 1892, when Fowlers Gap Hotel was built on the route, on the left bank of Fowlers Creek about 3 km downstream from the Gap itself.

Unlike the 1861 Act, which had tried to impose a general formula for closer settlement which could apply throughout central and western New South Wales, the Crown Lands Act of 1884 recognized the need for more flexible tenure arrangements to meet the special needs of the more arid western part which was now constituted as the Western Division. The Act attempted to provide security of tenure for the squatter appropriate to his investment in improvements, whilst yet furthering the cause of closer settlement. The large agglomerations of pastoral runs were now legally consolidated and divided into two approximately equal parts known as Leasehold Areas and Resumed Areas. The holder was granted a Pastoral Lease of the Leasehold Area for 15 years with an option of further extension of five years; he was entitled to an Occupation Licence of the Resumed Area, which was renewable annually, but this area and any vacant Crown Land were available for the selection of Homestead Leases with terms similar to those of Pastoral Leases. Subsequent amending Acts extended the terms of Pastoral Leases to 1918 and of Homestead Leases to 1930. The rent on both Pastoral and Homestead Leases was to be appraised for the first five years by a Local Land Board, the rents to be increased automatically by one-fourth for the second five-year period, and by one half for the remainder of the term, in the expectation of increasing returns following development.

Corona Pastoral Holding No. 195 was gazetted in July 1885, with a Leasehold Area of 828,820 acres in the south and a Resumed Area of 824,100 acres extending to the north. The holder was Dalgety and Co. Most of what is now Fowlers Gap Station was included in the northeast corner of the Leasehold Area, of which the eastern boundary is to be seen in the present eastern limit of Fowlers Gap Station; the old northern boundary survives in the present northern fences of North Mandleman and Sandstone Paddocks.

The improvement of pastoral leases proceeded during the 1870's and 1880's. Natural soakages had already been replaced by wells and earth tanks along stream courses, but after 1879 the mechanical drilling rig appeared. Bores could now be put down at a cost of about 11s. per foot compared with £4 per foot for well-sinking, and the increased range of depths allowed a more rational siting of waters. Sandy Creek No. 1 Bore near the stock route in the north of Fowlers Gap Station dates from 1893. The practice of shepherding disappeared, and the sheepfolds which had given rise to severe erosion and dust blowing were replaced by fenced enclosures. With the development of light-weight fencing costing as little as £5 per mile, the grid of five-mile paddocks began to extend across the country, and some of the oldest fences along the eastern and northern boundaries of Fowlers Gap probably date from the late 1880's. There was a general depletion of tree cover in the area to provide fence posts, both in the hills and along river frontages.

These investments were encouraged by an optimistic view of the carrying capacity of the country and by an official faith, expressed in sliding scales of increased rentals, that its potential could be more fully realized by station improvements. Fostered by high sheep prices during the early 1880's, and afterwards by good seasons, flocks of considerable size were built up. From less than 2 millions in 1880, sheep numbers west of the Darling rose to a peak of almost 8 millions in 1894. No figures are available for Corona Station at that period, but in 1877 Mt. Gipps carried 71,000 sheep on 540,000 acres, and Wonaminta Station, to the northeast of Fowlers Gap, sheared 92,000 sheep in 1892.

III. PASTORAL CRISIS OF THE LATE NINETEENTH CENTURY

The last 15 years of the 19th century brought increasing difficulties for the pastoral industry in the far west of New South Wales. The increase in sheep numbers had continued through and had in fact been provoked by a period of declining wool prices after 1884 and by the financial recession and further fall in wool revenues after 1890. This phenomenon of growing stock numbers combined with declining returns, whether from natural or economic causes, is so characteristic of the history of the pastoral industry in the Australian arid zone as to invalidate the use of stocking rates as an index either of grazing potential or of prosperity (Duncan, 1972).

The long drought that followed 1895 found the area severely overstocked at a time when there were few opportunities to transport sheep. Stock prices fell and a thriving boiling-down works was established at Menindee in 1891. Sheep numbers decreased sharply in the drought years after 1895, to less than 3 millions by 1901, but it is generally held that at this period much of the saltbush country and other perennial pastures underwent a deterioration from which they have not since recovered, particularly in holding paddocks, along stock routes, and near watering points. The southern part of Fowlers Gap Station, the frontages of Fowlers Creek, and much of the plains and foothill country to the east and north still reflect this degradation. Considerable soil erosion ensued, sand drifting was widespread, and dust storms were noted to be more common.

To this was added the problem of rabbit infestation from 1890 onwards. The rabbit had spread across the Darling River in 1884 and by 1886 had reached the Queensland and South Australian borders. Rabbits reached plague numbers several times in the following decades, and during drought they caused severe depletion of pasture grasses and widespread ringbarking of edible trees and shrubs. Damage was particularly extensive in the Resumed Areas, in which the pastoralists naturally took less interest and which therefore served as breeding grounds. The dingo population also increased, since the rabbit formed a new food supply. State Governments took action to construct netting fences along the border with South Australia in 1886 and with Queensland in 1887, but under the Rabbit Nuisance Act of 1883 much of the cost of rabbit control was levied on the pastoralist, particularly in the payment of bounties. After 1889 the landholder was faced with penalties for not controlling rabbits on Leaseholds. Rabbit depredation was particularly severe in areas of calcareous shale, as in much of the undulating country on Fowlers Gap Station; this may previously have carried perennial shrubs but no shrub cover survives today. In these areas some of the large warrens - now only periodically occupied - were originally those of the native bettong (Bettongia lesuri) which was driven from the area by the invading rabbit.

In its aim of bringing closer settlement, the Crown Lands Act of 1884 was as unsuccessful as that of 1861.

The Homestead Lease, initially of 5760 ac and increased to 10,240 ac in 1895, was entirely inadequate for most of the area, and only small parts of Resumed Areas were selected along the river frontages and near the market centres of the mining settlements. The Selection Station which borders Fowlers Gap on the northeast doubtless owes its name to the taking up of a Homestead Lease in the Resumed Area of Corona Station, on the favoured country of the Fowlers Creek floodout.

Although it did not serve the needs of the smaller grazier, the 1884 Act nevertheless succeeded in antagonising landholders, whose rentals were progressively increased from 2.23d per sheep in 1879 to 8.95d in 1900. Arrangements for compensation for improvements taken over by selectors were unsatisfactory, and led to the neglect of Resumed Areas at the cost of further overstocking of Leasehold Areas. Even on the Leaseholds, the conditions of tenure were not considered secure enough to justify the investments called for.

As in 1868-70, falling wool revenues after 1884 hit family squatters and smaller holdings hardest. The majority of family properties and many pastoral company leases passed into the hands of the foreclosing banks and mortgage companies at this time, among them Corona, which passed to Goldsbrough Mort and Co. Homestead Leases were even harder hit and Hardy (1969) reports that less than a quarter of the selectors who had taken up lands under the 1884 Act remained in the area by 1901. The critical situation led to the establishment of the Royal Commission of 1901 "to enquire into the position of Crown tenants in the Western Division". In its findings, the Royal Commission stressed the environmental problems of drought, rabbits, overstocking, and"sand storms" as principal factors in the depressed state of the pastoral industry; nevertheless it also named as contributory factors, lower wool prices, depressed values of properties, and the comparatively short terms of pastoral leases which made finance hard to obtain.

IV. GENERAL RECOVERY AND SUBDIVISION

Many of the recommendations of the Royal Commission were embodied in the Western Lands Act of 1902, which brought important changes to land tenure in the Western Division. It was now recognised that the harsh and unreliable climate and low productivity made the area unsuited for close settlement, as was apparent from the small extent of Homestead Leases taken up before 1901 (13.6 per cent of the Western Division) and the high rate of failure (Heathcote, 1964).

More realistic assessments of carrying capacity at one sheep to 15-25 ac were introduced for the far western country, based on inventories of land properties which took into account the degradation of the previous 20 years. Additional land was to be obtained by a withdrawal of up to one-eighth of the large pastoral leases. All leases were to continue to 30th June 1943 and there was to be no further alienation of land to freehold in the Western Division. Relief was also offered to a depressed pastoral industry in the form of lowered rentals, now based on the capacity of the land, on a sliding scale of 2d to a maximum of 7d per sheep area. The special problems of the Western District were recognised administratively, in that it was now removed from the Lands Department and placed under the control of a Western Lands Board.

In 1903 a new lease No. 243 of Corona of 827,738 ac, restricted to the former Leasehold Area, was granted to Goldsbrough Mort and Co. for a term of 40 years. An early pasture map of Fowlers Gap which may date from that time shows that four paddocks had been fenced off in the Station area, namely:

Gap Creek Paddock
Fowlers Gap Paddock (including Sandstone, South Sandstone and Holding Paddocks)
North Mandleman Paddock (Salt Paddocks Nos. 4-6, plus Mantappa, now part of Rowena Station)
Mandleman Paddock (remainder of Fowlers Gap Station area)

Gap Creek Paddock was described as "only annual saltbush" and North Mandleman as "saltbush". In Fowlers Gap and Mandleman Paddocks there was open saltbush on the flats and rolling country, scrubby mulga, belah and saltbush, chiefly annual, on the hills north of Fowlers Creek, and saltbush, a little mulga and scrubby belah on the hills to the south. The poor condition of the country between the hills and Fowlers Creek which formed part of the stock route was noted, it being badly wind-eroded and containing only sparse annual saltbush and grass. Signs of degradation were also apparent in the absence of perennial saltbush from Gap Creek Paddock, but there was as yet no mention of copperburr. The assessed stocking rate was stated to be one sheep to 15 ac, compared with the present estimate of one sheep to 20-25 ac.

The original outstation on Fowlers Gap, a three-roomed stone cottage, had been built in 1892 on the left bank of Fowlers Creek just above the confluence with Homestead Creek. In 1895 a small hut was built in Mandleman Paddock, and it is likely that Mandleman Tank (now Saloon Tank) was built about that time. Other improvements followed after the granting of the new lease in 1903, for instance Sandstone Tank (Schmidt's Tank) in 1905 and Warren's Tank in 1910. Two of the series of Public Watering Points established along the Stock Route at droving intervals of about 20 km were sited on or adjacent to the Station; Fowlers Gap Tank (PWP 577) was approved for construction near the south boundary in

1906, and it is likely that Bald Hills Tank in the north of the property was excavated at about the same time. By 1910 the original homestead had apparently fallen into disrepair and a three-roomed wood and iron cottage was built to replace it; this was eventually dismantled in 1940 when the stone cottage was repaired and again brought into use.

In 1911 the Corona lease was transferred to Thomas Brown and Henry Dutton, but in 1917, as the Corona Pastoral Co., it passed to Sir Sidney Kidman and became the headquarters of the belt of large leases owned by him, which extended north almost to Tibooburra. At that time, Corona was reported to carry 50,000 sheep (1 sheep to 16 ac) and 1,200 head of cattle.

The Royal Commission had recognised the need to combat overstocking and the degradation of pasture lands, but control of stocking was not enforced under the 1902 Act. Protective measures were confined to requirements to control vermin and remove noxious scrub, and restrictions on the removal of timber or edible shrubs. Rabbit numbers, which had fallen markedly towards the end of the long drought of 1895-1902, were a recurrent problem and the Corona records of 1905 include an order to destroy rabbits. In 1912 the north border of Corona was netted against the rabbit-infested former Resumed Area, including the northern fences of Mandleman and Sandstone Paddocks. Dingoes were also a perennial problem on the border stations and a Border Fence Trust was formed in 1912, by which the Queensland Government was recompensed to render the former rabbit fence dog-proof. Kidman earned local disapproval by standing out from this arrangement, and had his own protective fences erected, for instance the north-south fence along the western boundary of Fowlers Gap against Floods Creek Station was built in 1924. However, the Wild Dog Destruction Act of 1921 enforced dingo control through a general rate which is paid into a Fund and administered by a Wild Dog Destruction Board. The dingo is no longer a problem in the area, its place having been taken by the fox, which was introduced only too successfully into Victoria in the late 1870's. As with the dingo formerly, the number and range of foxes fluctuate with seasons in response to rabbit numbers.

The period from 1902 to 1924 was generally one of recovery following the severe droughts of 1895-1902. With better rainfall and more favourable leasehold conditions, the Western Lands Board reported in 1903 that the "pastoral industry in the Western Districts is now on a reasonably sound basis". Under the influence of rising wool prices sheep numbers in New South Wales west of the Darling recovered sharply to almost 4 millions in 1907. They continued to fluctuate about this figure, for the decade 1910-20 was also one of drought, but although they exceeded 5 millions in 1925 they never again attained the peak of the early 1890's. This is generally attributed to the deterioration of carrying capacity of the natural pastures following the heavy stocking which continued into the drought years after 1895, and it has been claimed that such stability as has been achieved has been the result of man-made improvements, particularly the provision of additional watering points which have brought more land within the reach of stock (Perry, 1970).

Wool prices slumped badly during the depression years 1928-32, yet sheep numbers were generally maintained until late in the long drought period of 1940-45, again demonstrating that the high stocking rates encouraged by good seasons and favourable prices are maintained with falling prices, as a counter to diminishing revenue.

The records of Corona Station during the 1920's and 1930's reflect the state of the pastoral industry in the region generally, with periods of drought and occasional better seasons, rabbit plagues, stock losses and strongly fluctuating sheep numbers, and repeated requests for relief from rentals on the basis of diminished carrying capacity.

Apart from lower or deferred rentals, another form of relief requested was extension of tenure to give greater financial manoeuvre. In 1930 existing pastoral leases were offered an extension of up to 25 years, but in return for withdrawals of up to half their Leasehold Areas for further subdivision. Under the Western Lands Amendment Acts of 1932 and 1934 this was redefined as "one quarter of their land immediately, an eighth in 1943, and an eighth in 1948" (King, 1957). These areas were to be used to establish new Western Lands Leases and to build up smaller holdings to economic size. However the Corona Pastoral Company did not fully exercise this option, and the lease as gazetted in June 1932 was to continue only until October 1947.

The Amendment Acts were in response to strong pressure for land in conditions of high enemployment. They emphasised the concept of the home maintenance area - a rural equivalent of the basic wage - capable of supporting 3-5000 sheep in the more accessible parts of the Western Division and up to a maximum of 10,000 in the more remote and arid areas. They introduced the right to extend existing leases to perpetuity and to grant new leases, subject to a restriction to a home maintenance area in both cases. The majority of the large landholders accepted the offer of extended leasehold in return for giving up part of their area, but there was some resistance west of the Darling, notably from the Kidman group of companies, which preferred to retain interim control over its entire areas with the intention of eventually transferring its interests to Queensland and South Australia. The Corona holding was thus to remain intact until the termination of the lease in 1947, when it would become due for complete subdivision.

The Act of 1934 also established the Western Lands Commission under the direction of a single Commissioner. The closer supervision of land use which now characterises Western Lease Holdings was instituted; Local Land Boards were set up to decide on lease allocations, and such allocations included for the first time a restriction on the numbers of stock that could be carried. The process of land subdivision, which had previously been relatively slow west of the Darling, began to speed up after the 1934 legislation, but it was to be significantly advanced by a wartime Labor Government which in 1943 directed the simultaneous withdrawal from pastoral leases of areas which under the 1934 Act were to be ceded separately in 1943 and 1948. Complete enforcement of subdivision followed with the 1949 Amendment Act, which in the face of new demands for land from returned ex-servicemen fixed the maximum holding of further leases in the Western Division at two living areas. Heathcote (1964) records that 96 per cent of the Western Division had been divided into living areas by 1956, and that all the large old pastoral leases had been broken up. The 1949 Act reinforced the control of land use, in that it empowered the Minister for Lands to order the de-stocking of leases to prevent undue deterioration and to allow regeneration of pastures. A 1945 Amendment had also made mandatory a review of sale prices on transfer, in order to prevent undue increases in the price of land and its use for speculative purposes.

The Pastoral Lease of Corona was due to terminate in 1947 and pastoral inspections were carried out in 1945 in anticipation of subdivision and give the following picture of Fowlers Gap Outstation at that time:

Fowlers Gap Paddock - mulga, dead-finish, black oak and berrigan, good saltbush and copperburr. Carrying capacity, one sheep to 25 ac, or 843 sheep

Mandleman Paddock - good saltbush and copperburr. One sheep to 22 ac, or 1230 sheep

North Mandleman Paddock - one sheep to 22 ac, or 588

Warrens Paddock - one sheep to 25 ac, or 660 sheep
Gap Creek Paddock - one sheep to 25 ac, or 242 sheep

This assessment makes the first mention of copperburr on Fowlers Gap, suggesting that deterioration of saltbush pastures had progressed since 1903. The average carrying capacity was rated as one sheep to 25 ac, which compared favourably with a number of other blocks in the area. Fowlers Gap block, Western Lands Holding No. 1236, with an area of 92,100 ac, was thus allocated a carrying capacity of 4100 sheep. No part of the block was indicated as showing severe erosion.

V. CONSERVATION AND RESEARCH IN THE WESTERN DIVISION

Although the 1901 Royal Commission had recognised the deterioration of pastures and consequent wind erosion as major problems of the region, there was no protective legislation until the Acts of 1934 and 1949. A visit in 1934 by E. A. Buttenshaw, New South Wales Minister for Lands, to the United States, then in the throes of the dustbowl years and in the early stages of its soil conservation measures, may have influenced the setting up of a New South Wales Erosion Committee in 1934, the passage of a Soil Erosion Bill in 1937, and the establishment of the Soil Conservation Service in 1938. The change towards a conservationist policy was certainly reinforced under the widespread move for planned postwar construction and development under the McKell Government, and a Department of Conservation was formed in 1946. Doubtless the need for soil conservation measures was given point by the drought that set in after the good seasons of the early 1930's and continued through the war years, again under the impact of rising sheep numbers, and which hindered considerably the progress of subdivision under the Western Lands Commission.

The problem of drought and soil erosion in arid Australia was surveyed scientifically for the first time in the late 1930's, notably by Ratcliffe for the CSIRO in South Australia and southwest Queensland (Ratcliffe, 1936, 1937). Morris successfully established a saltbush regeneration area around Broken Hill in 1937, to combat the nuisance of dust storms. However, the major contribution in the Western Division was the work of Dr. N. C. W. Beadle, who as an officer of the Soil Conservation Service carried out a wartime survey of vegetation and pastures in the Western Division with special reference to their deterioration under grazing and resultant soil erosion (Beadle, 1948).

Beadle's work underlined the necessity for field experiments by the Soil Conservation Service, and negotiations were begun for the transfer of one of the Corona leases that contained suitable country. As a result, Fowlers Gap Block No. 1236 of 92,100 ac, the smallest of the Corona blocks, was granted to the Conservation Authority of New South Wales* under Special Western Lands Lease No. 7318, for 20 years from January 1st, 1952, "for conservation purposes".

A first necessary step was to survey the pastures and conditions of soil erosion on the Fowlers Gap Rural Investigation Station, as it had now become. This was carried out later in 1952 by Dr. Beadle, who had moved to Sydney University in 1950, and his students. Their surveys show annual pastures with bassias and copperburrs on the plains country in the east of the Station and also along much of the eastern footslopes, as well as on the continuation of the stock route south of the Homestead, short grass-forb pastures along the river frontages, and ephemerals on the light calcareous soils in the southwestern sector of the property. Much of these areas was characterised by severe to moderate wind erosion. It was noted that between 75 and 90 per cent of all the mulga on the Station was dead, with no evidence of regeneration.

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* This consisted of the Commissioners of the various branches of the New South Wales Department of Conservation, together

Professor Beadle continued these studies from the University of New England, to which he moved in 1955. Seven kangaroo-proof enclosures were fenced off, across a characteristic range of country, and permanent quadrats were maintained in them to measure the progress of natural regeneration. Unfortunately their value was seriously diminished through their occasional use as holding pens for travelling stock! Postgraduate research from the Department of Botany, University of New England, continued into the 1960's and included the general ecology of the Station, patterns of soil salinity and vegetation and their modification by grazing, and studies of the root form and nodulation of <u>Acacia aneura</u> (mulga) and of the ecology of rhizobia of pasture and indigenous legumes in native vegetation communities. Unfortunately, some of the records of this work, including a small herbarium based on the Station, were destroyed in 1962 when the shearers' quarters, built in 1953, burned to the ground.

Officers of the New South Wales Conservation Service began experimental work on the Station in 1954, when a regeneration area of about 1300 ac, now known as Conservation Paddock, was fenced off in the northwest corner of Warrens Paddock. This was kept free from sheep but was open to grazing by feral animals. The studies included the effectiveness of ponding banks in conjunction with water spreading, for the reclamation of scalds (Newman, 1966), and effectiveness of ripping and checkerboard furrowing in scald reclamation; the effect of contour furrows and trenching on the regeneration of bladder saltbush (<u>Atriplex vesicaria</u>); the progress of regeneration of cotton bush (<u>Kochia aphylla</u>) and also of bladder saltbush in degraded sites as shown in repeated measurements along permanent transects; measurements of the extension of scalds; the effect of animal repellants as a counter to attacks on tree seedlings, particularly by rabbits; dung sampling to compare grazing intensity in an unstocked and an adjacent stocked paddock (Warren, 1971); and the role of stone in stabilising surface soil.

In 1953 a sublease of the Station, other than the experimental areas, had been granted to O. J. Hayes, at first for a period of five years and subsequently for a further seven years. These were years of recurrent drought, and the lease records indicate periodic plagues of kangaroos and rabbits, particularly in the dry year of 1957, when trees were ring-barked and pine seedlings were killed. This was particularly unfortunate as these represented the first regeneration of pine in the memory of pastoralists in the Western Division. Sheep numbers accordingly fluctuated strongly; for instance permission was granted to raise the stocking to 4200 sheep temporarily in 1956. Hayes was eventually extended Permissive Occupancy through the year of 1965 because of general drought conditions on other leases in the area. Nelia and Homestead Lake (Gum Creek) Dams were constructed during the period of this sublease.

Towards the end of 1965, the Station was inspected in connection with the termination of the sublease. The Pastoral Inspector's report indicates that the pastures were in poor condition at that time. North Mandleman Paddock carried practically no feed, Warrens and Mandleman Paddocks were also grazed out, the area around Mandleman Tank was completely bare, Sandstone Paddock contained bare areas with incipient sand drifting, and East Bald Hills Paddock was also bare. The only signs of regeneration were in South Sandstone and Bald Hills Paddocks. This condition appears to have resulted from drought periods of heavy grazing.

In the period since the lease was granted to the University of New South Wales, there has been considerable investment in the development of the Arid Zone Research Station. The rebuilt shearers' quarters have been extended, two cottages built for Station staff, a dormitory block has been constructed for use by visitors, including students and postgraduate workers on the Station, and a laboratory has also been created. On the Station itself, 90 miles of fencing has been renewed or newly erected, including subdivisions for experimental purposes. A second tank of 10,000 cu m has been constructed adjacent to the former Sandstone Tank, Planet Camp Bore, sunk in conjunction with the drilling of Bancannia No. 1 Oil Well in 1967-8 has been equipped, and an extensive system of water reticulation has been established in order to bring surface and groundwater to all parts of the property and to assure supplies to the Homestead complex. This investment was recognised when the University of New South Wales was granted a Lease in Perpetuity early in 1972.

In these developments, the University has benefited from the advice of its Consultative Committee, which contains representatives of local pastoralist organisations, and of the Pastoralist Advisory Group, a smaller body of local graziers, who meet frequently with executive officers of the University. Much of this initial development was guided by Associate Professor I. L. Johnstone as Director of Field Stations, and by Professor T. K. Hogan as Director of the University's W.S. & L.B. Robinson College, with which the administration of the Station is closely linked. The Minister for Lands, the Hon. T. Lewis, has maintained close personal interest in the development of the Station and the University has received considerable assistance from his Department, particularly in the provision of air photography and a topographic map of the Station.

It is a condition of the University's lease that the facilities of the Station be made available to other organisations concerned with arid zone investigations, and there has been close collaboration with the New South Wales Soil Conservation Service, which has recently stationed an officer at Broken Hill. This collaboration is reflected in the authorship of this volume, and of the following number in the Fowlers Gap Research Series.

VI. ACKNOWLEDGMENTS

Apart from the references cited, this history has drawn upon an unpublished manuscript "A short historical background of the Fowlers Gap area" by Dr. I. L. Johnstone, formerly Director of Field Stations, University of New South Wales, and on information from the files of the Western Lands Commission in Sydney which was kindly obtained by Dr. Juliet Burrell of the School of Geography, University of New South Wales. I am grateful to Mr. G. R. Woods, Western Lands Commissioner, for permission to quote from this source, to Messrs. R. W. Condon and H. A. Kilby, Assistant Commissioners, for their helpful advice, to Mr. J. C. Newman for information on work on Fowlers Gap Station carried out by the Soil Conservation Service, and to Mr. K. Conners for valuable local information. Professor N.C.W. Beadle kindly supplied information on earlier work on vegetation and pastures at Fowlers Gap.

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CHAPTER II. LAND SYSTEMS OF FOWLERS GAP STATION

By J.A. Mabbutt, Juliet P. Burrell,
Janice R. Corbett and M. E. Sullivan

I. INTRODUCTION

The land types on Fowlers Gap Station are here described as land systems, defined by Christian and Stewart (1953) as "an area or group of areas throughout which there is a recurring pattern of topography, soils, and vegetation". Maps and descriptions of land systems form a convenient synthesis of the natural environment and provide a basis for an assessment of land potential and for the study of land-use problems.

Land systems are distinguished on the basis of airphoto patterns, and their characteristics are identified by ground observations at sample sites chosen from airphotos. The survey team, consisting of the authors cited above, initially used the airphotos of the Fowlers Gap North One Mile Sheet at a scale of 1:63,360, flown in 1965, but were subsequently assisted by a special airphoto coverage of the Station at 1:25,000, flown in 1968 by the New South Wales Department of Lands. A contoured topographic map of the Station at 1:25,000, published by the New South Wales Department of Lands in 1971, has subsequently been used in the landform descriptions. An unpublished geologic map and account of the geology of the Station by C.R.Ward (since published in Ward _et al_., 1969) helped in the preliminary delineation of land types.

During the field survey, which was carried out early in 1968, 53 field sites were sampled, as shown in Fig. II-1, at which observations were made of the geology, landforms, soils, and vegetation. Fourteen land systems were recognized on the Station, their boundaries were mapped on airphotos, and their

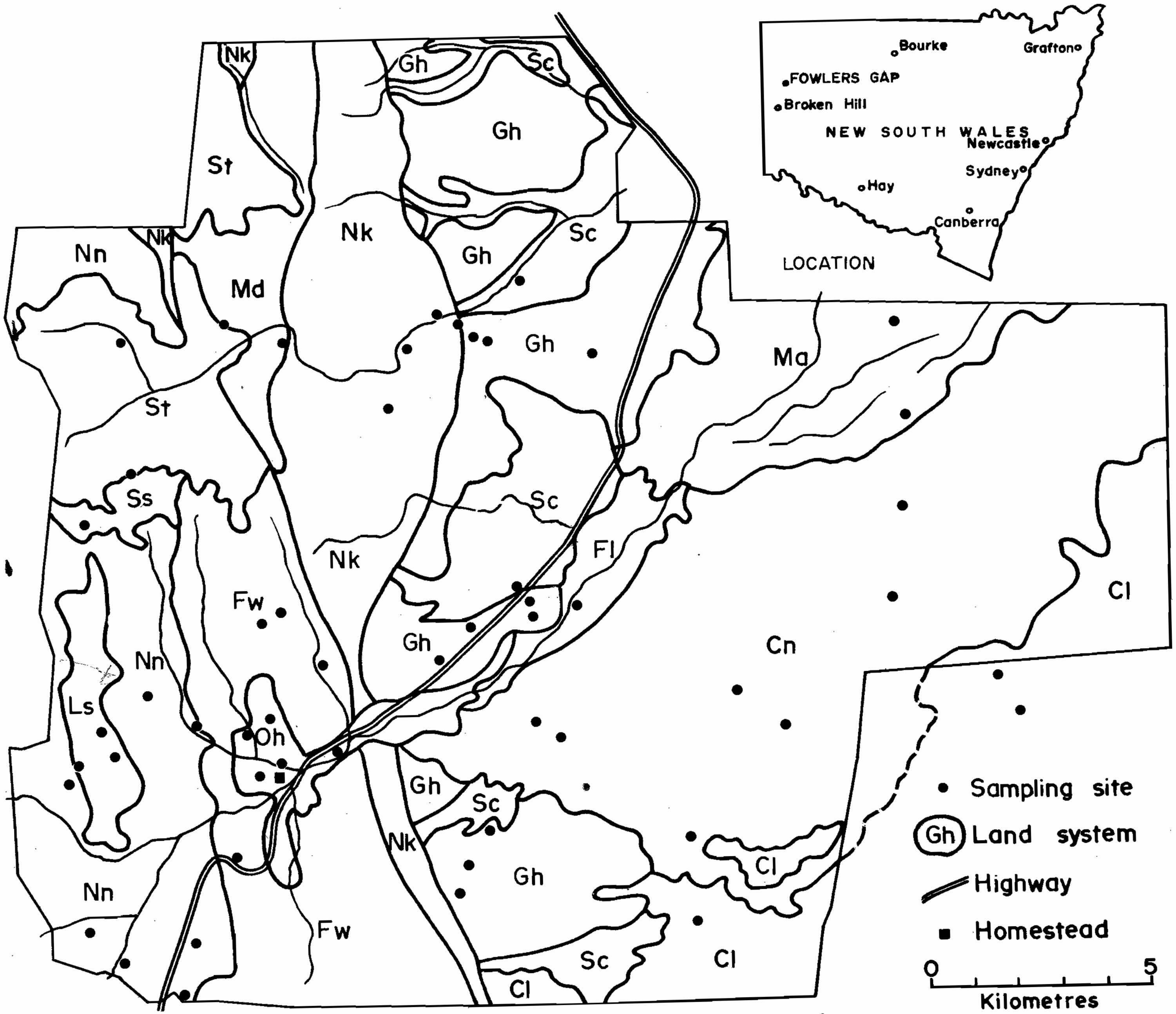

Fig. II-1 - Sampling sites in relation to land systems component units established. This data has since been supplemented through subsequent work on the Station by members of the survey team.

II. LAND SYSTEM TABLES

The land systems are here described in tabular form, in order of diminishing relief. The tables are headed by overall descriptions of geology and landforms and by a statement on land use which relates to the pastures and pasture lands defined in Chapter IX. Each land system is then described in its component land units, which are more homogeneous areas too small to be mapped. The relative extent of each land unit has been estimated from airphotos and is indicated in the tables as

VL	very large	more than 50 per cent of land system
L	large	30-50 per cent
M	moderate	15-30 per cent
S	small	5-15 per cent
VS	very small	less than 5 per cent

A block diagram or sketch plan accompanies each land system table and shows the relative positions of land units, although not necessarily in proportion. Generalised geological sections are shown in the block diagrams.

In the land unit descriptions, soils are described in terms of profile morphology, which is summarised in Tables VII-1 to 3. The vegetation of the land units is stated in terms of dominant species, including local common names where possible. The correlation between land systems and structural vegetation types is given in Table VIII-1.

Table II-1 summarises the characteristics of the land systems and indicates the bases of their definition. It also

TABLE II-1. SUMMARY OF CHARACTERISTICS OF LAND SYSTEMS

Relief Class	Predominant Lithology	Predominant Soil	Predominant Vegetation	Land System
Ranges	sandstone, quartzite	loamy sand	mulga and shrubs	Faraway
	sandstone			Nundooka
			mulga and bluebush	Mulga Dam
Lowlands with Minor Ridges	sandstone, shale, gravel	sandy loam	contour bands of saltbush	Gap Hills
	shale, dolomitic limestone			Limestone
		calcareous sandy loam	casuarinas and shrubs	South Sandstone
	shale	loam	contour bands of saltbush	Nuntherungie
	shale, gravel	calcareous loamy sand	sparse shrubs	Old Homestead
		loamy sand	contour bands of saltbush	Sandstone Tank
Plains	alluvium		scalds, sparse shrubs, bassias	Conservation
			scalds, sparse saltbush, perennial grasses	Fowlers
		sandy loam and sand		Sandy Creek
		sandy loam with some gilgai	copperburrs, sparse shrubs, perennial grasses	Caloola
		loamy sand with extensive gilgai	perennial grasses	Mandleman

shows relationships within groups of similar land systems.

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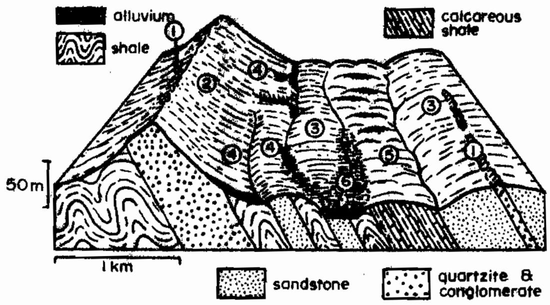
FARAWAY LAND SYSTEM Fw (3550 ha)

General Description: High sandstone ranges and low rounded hills

Geology and Geomorphology: Synclinal tract to 5 km wide with steeply-dipping Precambrian strata (Faraway Hills Quartzite and Fowlers Gap Formation) with prominent quartzite strike ridges, lower sandstone ridges, and belts of rounded hills on shale with calcareous horizons; relief to 150 m; dense trellis pattern of incising drainage

Land Use: Hilly shrubland country with areas of moderately close mulga and casuarinas on rockier slopes. Units 1 and 2, partly inacessible, support mulga with limited ephemeral growth after rain; Units 3-6 have moderately dense bladder saltbush or pearl bluebush pastures with high drought resistance and with abundant short grasses and copperburrs after rain. Gullying in Units 4 and 5, and locally in Unit 2

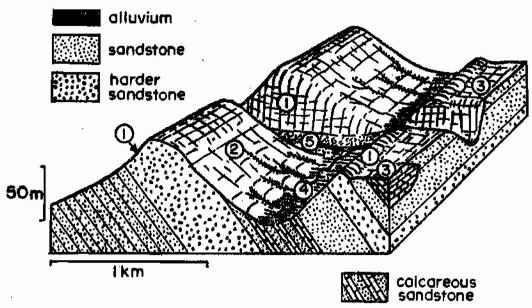
Estimated grazing rate: 12.9 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	S	Rocky crests and faces: slopes commonly above 30%	No soil	Bluebush (Kochia sedifolia, K. astrotricha) + mulga (Acacia aneura) and/or dead finish (Acacia tetragonophylla) and/or bladder saltbush (Atriplex vesicaria)
2	M	Higher ridges: partly bevelled narrow crests; slopes to 50% and to 300 m long	To 30 cm of yellowish-red massive stony neutral loamy sand on sandstone; locally calcareous	
3	M	Lower ridges and strike rises: to 15 m high; flattish crests; slopes to 15% and to 200 m long	Less calcareous sites: red massive loamy sand, pedal with clay skins from 10-30 cm, stony in upper 10 cm, calcareous and weakly saline below 30 cm Calcareous sites: about 40 cm of light-brown stony loose calcareous non-saline loamy sand on rock	
4	S	Footslopes and spurs: local relief to 6 m; slopes to 10% and to 200 m long; some gravel	Red stony massive loamy sand; pedal, calcareous and saline below 30 cm; less stony with depth	Casuarina sp. with mixed bluebush and bladder saltbush
5	S	Rounded hills: to 15 m high; short slopes to 50%; some leached cappings	To 30 cm of light-brown stony calcareous loamy sand on fresh rock; some soils leached of lime in upper 10 cm	Mallee (Eucalyptus gillii) + bluebush and other low shrubs; mallee absent from leached cappings
6	S	Drainage tracts: flats to 20 m wide, with small tributary fans; channels to 10 m wide and 3 m deep	To 30 cm of red pedal sand with clay skins, overlying 30 cm of gravelly calcareous sandy loam, overlying at least 120 cm of red calcareous saline loamy weathering shale with clay skins	Minor tracts with Casuarina sp. and mixed bluebush and bladder saltbush; major tracts with river red gum (Eucalyptus camaldulensis)

NUNDOOKA LAND SYSTEM Nk (4050 ha)

General Description:	Sandstone ranges witn some mulga or casuarinas
Geology and Geomorphology:	Strike belts to 6 km wide with moderately to steeply-dipping Devonian sandstone (Nundooka Sandstone and Coko Range Beds); massive cuestas and uplands with broadly rounded or bevelled crests and minor rocky faces; relief to 80 m; trellis drainage
Land Use:	Hilly shrubland country with areas of moderately close mulga on rocky slopes; bladder saltbush and pearl bluebush pastures with abundant short grasses and copperburrs after rain. Units 1 and 2 partly inaccessible. Drought resistance high. Minor gully erosion in Units 2 and 3
	Estimated grazing rate: 13.4 sheep per 100 ha



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	S	Rocky crests and faces: short slopes, 25-100%	To 40 cm of red pedal neutral loamy sand on sandstone; commonly with stones only in upper 20 cm; shallower and stonier throughout near outcrops	Mulga (Acacia aneura) and low shrubs, bladder saltbush (Atriplex vesicaria), bluebush (Kochia sedifolia) and Bassia spp.
2	VL	Cuestas of more massive sandstone in west of belt; escarpments to 45%, dip slopes 10-20%; relief to 80 m; stony surfaces with gullies		Bladder saltbush ± mulga
3	M	Uplands and bevelled ridges on more steeply dipping, thinner-bedded sandstone with some calcareous horizons: planed crests with slopes to 10%; marginal slopes to 45%; relief to 50 m	More calcareous areas: shallow reddish-brown stony loose calcareous weakly saline loamy sand, on calcareous sandstone Less calcareous areas: at stonier sites, about 40 cm of red pedal loamy sand on rock, becoming heavier and weakly calcareous with depth, and with stones only in upper 20 cm; at less stony sites, to 40 cm of red massive stone-free weakly calcareous loamy sand	Bluebush ± mulga Bladder saltbush and copperburrs ± Casuarina sp.
4	VS	Minor drainage tracts: to 20 m wide, with channels to 10 m wide; narrow adjoining flats and small tributary fans	Yellowish-red massive loamy sand on rock; pedal, with strong clay skins from 25-40 cm; calcareous and saline below 40 cm; some soils overlain by red layered sand to 20 cm	Bladder saltbush and copperburrs ± mulga and Casuarina sp.
5	VS	Major drainage tracts: floodplains to 100 m wide, with sandy or rocky channels to 80 m wide	Deep yellowish-red neutral layered sand	Either river red gum (Eucalyptus camaldulensis) or Casuarina sp. with prickly wattle (Acacia victoriae), and scented grass (Cympopogon exaltatus)

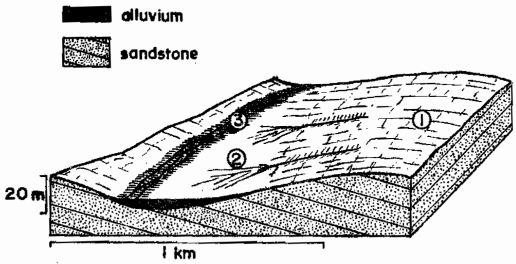
MULGA DAM LAND SYSTEM Md (1140 ha)

General Description: Broad low sandstone ridges with mulga and bluebush

Geology and Geomorphology: Strike belt to 2.5 km wide with moderately to gently-dipping sandstone (Nundooka Sandstone); partial cover of Quaternary sand; subdued foothill ridges and footslopes; relief to 30 m; ill-defined drainage, partly strike controlled, partly dendritic

Land Use: Hilly shrubland country with moderately close mulga; bladder saltbush and pearl bluebush pastures with abundant short grasses and copperburrs after rain. Drought resistance high

Estimated grazing rate: 14.7 sheep per 100 ha



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	VL	Rocky rises: low ridges and foothills with extensive outcrop; slopes mainly below 10%, locally to 15%, and to 200 m long	Calcareous sites: to 30 cm of red or reddish-brown loose calcareous stony weakly pedal loamy sand or sand on calcareous sandstone Non-calcareous sites: to 30 cm of red neutral bouldery massive loamy sand on sandstone	Bluebush (*Kochia astrotricha* and *K. sedifolia*) and mulga (*Acacia aneura*), and locally bladder saltbush (*Atriplex vesicaria*)
2	M	Alluvial slopes: wash surfaces to 500 m wide; slopes to 2% and to 500 m long; with irregular sandy channels	Red layered sand	Mulga groves; intergroves with bladder saltbush and copperburrs (*Bassia* spp.)
3	VS	Drainage tracts: to 75 m wide with variable braiding channels to 20 m wide	To 30 cm of red layered neutral sand overlying 50 cm of red massive loamy sand which is pedal with clay skins from 25-40 cm and calcareous below 40 cm	Bladder saltbush and copperburrs; mulga along minor channels; *Casuarina* sp. and isolated river red gums (*Eucalyptus camaldulensis*) along larger channels

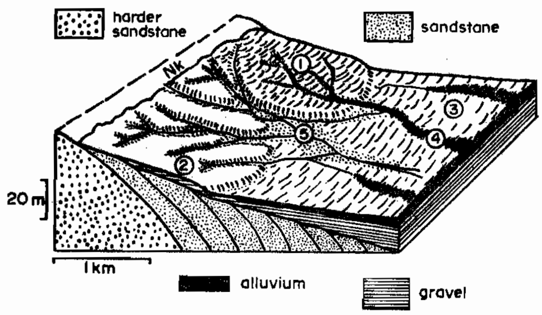
GAP HILLS LAND SYSTEM Gh (5920 ha)

General Description: Footslopes east of the ranges, with bands of saltbush and Mitchell grass and stony ground

Geology and Geomorphology: Eastern edge of strike belt of moderately to steeply-dipping Devonian sandstone, locally calcareous and with pebbly horizons (Nundooka Sandstone); overlain eastwards by Quaternary alluvial gravel to clay; planed spurs dissected to 15 m, with gravel cappings, passing downslope into gravelly alluvial lobes to 2.5 km long between larger drainage outlets; with prominent contour pattern of stonier and less stony bands; area of rounded hills in north of Station; through-going drainage

Land Use: Lowland shrubland country with dense bladder saltbush pastures in which shrub cover should be maintained by careful management. Local areas degraded and devoid of perennial shrub cover. High drought resistance in areas where shrub stands have been maintained, low elsewhere. Severe scalding and minor gullying in Unit 5 and local gullying in disturbed areas in Units 1 and 2

Estimated grazing rate: 16.3 sheep per 100 ha in areas with saltbush; 12.4 in northern area lacking shrub cover



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	M	Stable spur crests: planed smooth crests to 400 m wide, slopes to 1%; contour pattern of stonier risers and less stony steps	Stonier risers: deep red massive loamy sand with pedal sandy loam from 10-35 cm; calcareous below 10 cm, saline below 100 cm, stony below 180 cm Less stony steps: yellowish-red massive neutral loamy sand on stones at 100 cm	Very sparse short perennial grass or no perennial vegetation Bladder saltbush (Atriplex vesicaria) and copperburrs (Bassia spp.) ± caustic bush (Sarcostemma australe); or copperburrs and Eragrostis sp.
2	M	Stripped spur crests and slopes: narrower crests than Unit 1, with steeper slopes and minor outcrop; marginal slopes to 15%; relief to 15 m	Shallow light-brown calcareous loose fine sand	Bluebush(Kochia sedifolia) and Casuarina sp.
3	L	Alluvial lobes: to 5 km long and to 2.5 km wide, slopes to 1%; contour pattern of flatter, partly stone-covered steps and narrow risers with gilgai	Stone-free steps: deep yellowish massive loamy sand, with pedal sandy loam from 10-30 cm; calcareous below 40 cm, saline below 10 cm Stony steps: deep red massive silty loam, pedal from 10-45 cm, calcareous and saline below 45 cm Risers: deep red massive calcareous sandy loam, saline below 15 cm	Grading from no perennial vegetation to well-spaced short perennial grass No perennial vegetation Mitchell grass (Astrebla pectinata) bladder saltbush and copperburrs ± other perennial grasses
4	S	Shallow drainage tracts: to 100 m wide, with well-developed gilgai; discontinuous small trench-like channels	About 15 cm of yellowish-red layered sand overlying deep red massive loamy sand which is pedal for 30 cm and saline below	Sparse bladder saltbush and copperburrs ± Mitchell grass and/or neverfail (Eragrostis setifolia)
5	VS	Incised drainage tracts: alluvial flats to 50 m wide, with sandy channels to 20 m wide	Deep yellowish-red massive loamy sand, becoming heavier with depth; pedal from 15-40 cm, calcareous below 40 cm, saline below 15 cm in some areas, stones below 100 cm	Bladder saltbush and Mitchell grass on flats; Casuarina sp. ± mulga (Acacia aneura), tall and low shrubs and scented grass (Cymbopogon exaltatus), and locally tobacco tree (Nicotiana glauca) along smaller channels; river red gum (Eucalyptus camaldulensis), Acacia victoriae, low shrubs and scented grass along larger channels

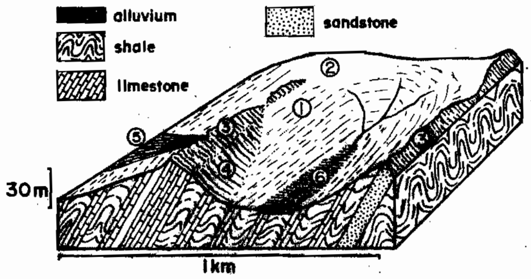
LIMESTONE LAND SYSTEM Ls (580 ha)

General Description: Rounded hills with bands of saltbush, crossed by limestone outcrop

Geology and Geomorphology: Strike belt to 1.5 km wide with steeply-dipping Precambrian shale with dolomite and limestone lenses (Teamsters Creek Subgroup); discontinuous low ridges and rounded footslopes; relief to 30 m; moderately close dendritic drainage

Land Use: Lowland shrubland country with bladder saltbush pastures and scattered leopardwood and casuarinas, with abundant short grasses and copperburrs after rain. Drought resistance high due to dense shrub stands. Local gullying in disturbed areas of Unit 1 and in Unit 5, and wind erosion following trampling in Unit 2

Estimated grazing rate: 16.7 sheep per 100 ha



UNIT	AREA	LANDFORM	SOIL	VEGETATION
1	L	More stable interfluves: to 250 m in extent, slopes to 10%; contour pattern of stony risers and partly stone-free steps with minor gilgai	Stony risers: deep red massive sandy loam; pedal with clay skins from 10-80 cm, stony in upper 10 cm, calcareous and saline below Less stony steps: deep red massive saline calcareous sandy loam, weakly pedal in upper 100 cm; locally leached to 10 cm	No perennial vegetation Bladder saltbush (Atriplex vesicaria) and copperburrs (Bassia spp.)
2	M	Less stable interfluves: to 250 m in extent; slopes to 10% and to 50 m long	Deep red massive calcareous saline sandy loam; weakly pedal from 10-25 cm	Bladder saltbush and copper-burrs and Bassia spp.
3	S	Rocky faces and crests	To 20 cm of red or reddish-brown neutral stony fine sand on dolomite or sandstone	Bladder saltbush ± bluebush (Kochia sedifolia) and Sida virgata; occasional tall shrubs
4	VS	Colluvial slopes below limestone outcrops: to 10% and to 50 m long	Deep brownish-red stony massive sandy loam; weakly pedal to 30 cm, calcareous and weakly saline below 30 cm	Bladder saltbush and bluebush ± Casuarina sp. and other tall shrubs
5	VS	Alluvial fans: slopes about 5% and to 150 m long	Deep red massive calcareous saline loamy sand, pedal with clay skins from 30-80 cm; weathered rock below 140 cm	Bladder saltbush and copperburrs
6	S	Drainage tracts: alluvial flats to 40 m wide; small incised channels	Valley between spurs: to 25 cm of red calcareous non-saline loose stony loamy sand on dolomite Open valleys: deep red saline massive sandy loam; calcareous and pedal below 10 cm, stony to 10 cm	Bladder saltbush and berry saltbush (Rhagodia spinescens)

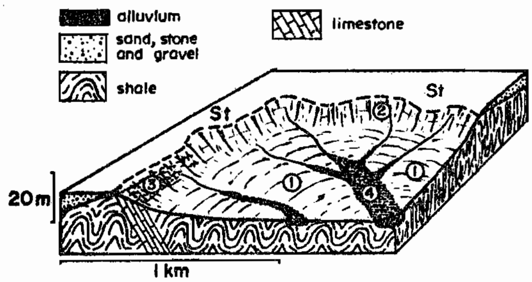
SOUTH SANDSTONE LAND SYSTEM Ss (260 ha)

General Description: Breakaway and slopes with saltbush and casuarinas

Geology and Geomorphology: Soft weathered, steeply-dipping, partly calcareous Precambrian shale and dolomitic limestone (Teamsters Creek Subgroup), with capping of sandstone and clayey gravel of Tertiary and Quaternary age; escarpment margin of perched plain of Sandstone Tank land system, and adjacent footslopes; relief to 15 m; dense, incising dendritic drainage

Land Use: Lowland shrubland country with bladder saltbush pastures, locally with moderately dense casuarinas and with abundant short grasses and forbs. Drought resistance high due to dense shrubs and trees. Gullying in Units 1, 2 and 3, and scalding on Unit 4

Estimated grazing rate: 15.2 sheep per 100 ha



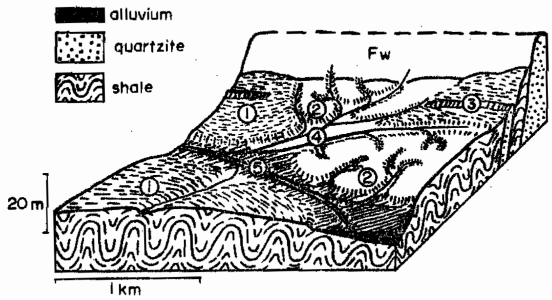
UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	VL	Footslopes: low gravel-mantled rises to 400 m wide, slopes to 5%	To 20 cm of reddish-brown stony calcareous saline sandy loam on shale; weakly pedal from 10-20 cm	Bladder saltbush (*Astriplex vesicaria*) with copperburrs (*Bassia* spp.), and bare stony areas
2	S	Escarpment on shale: slopes to 20% and to 50 m long	To 50 cm of reddish-brown sandy loam on shale; pedal to 30 cm, calcareous below 10 cm	Bladder saltbush
3	S	Escarpment on calcareous rocks: slopes to 20% and to 50 m long, with minor outcrops	To 30 cm of reddish-brown loose sandy loam; stony to 5 cm, calcareous below 5 cm	Bluebush (*Kochia sedifolia*) and scattered *Casuarina* sp.
4	S	Drainage tracts: flats to about 10 m wide, gradients about 1 in 50; small channels entrenched to 3 m	To 50 cm of reddish-brown weakly pedal calcareous saline loamy sand on about 60 cm of weathered calcareous shale on fresh rock	Bladder saltbush and copperburrs with patches of bluebush

NUNTHERUNGIE LAND SYSTEM Nn (3410 ha)

General Description: Rolling stony country with alternating bands of saltbush and stone, and some bare areas of light bulldust soils

Geology and Geomorphology: Belt of steeply-dipping Precambrian shale, partly calcareous, with bands of quartzite, quartz and dolomite (Teamsters Creek Subgroup); undulating lowlands with prominent contour patterns of stonier and less stony bands; relief to 15 m; minor low strike ridges; moderately close dendritic drainage

Land Use: Lowland shrubland country with bladder saltbush pastures, commonly with abundant short grasses and copperburrs after rain. Unit 2 dominated by bottlewasher-copperburr pastures of low drought tolerance. Drought resistance generally high, due to dense shrubs and trees. Severe gullying and sheet erosion in Unit 4, locally gullying in disturbed areas in Unit 1, and wind erosion following trampling in Unit 2



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	VL	More stable interfluves: to 600 m in extent; flat to rounded crests; slopes mainly less than 5% and to 300 m long; contour pattern of stony risers and mainly stone-free steps with minor gilgai, becoming more pronounced downslope	Stony risers: deep brownish-red massive loam; pedal with clay skins from 10-50 cm, calcareous and weakly saline below 50 cm, on weathering shale at 100 - 250 cm Stone-free steps: deep reddish-brown massive loam, weakly pedal with clay skins below 40 cm, on weathering shale at 100 - 250 cm	No perennial vegetation Bladder saltbush (*Atriplex vesicaria*) and copperburrs (*Bassia* spp.); neverfail (*Eragrostis setifolia*) around gilgai; *Casuarina* sp. locally on uppermost slopes
2	M	Less stable interfluves: more narrowly dissected than Unit 1 and lacking contour patterns	Deep light-brown loose calcareous saline loam with lime hardpan from 40-100 cm	Ranging from no perennial vegetation through copperburrs to bladder saltbush with copperburrs; *Acacia cana* locally
3	VS	Low rocky ridges and outcrops	Shallow reddish-yellow neutral massive stony loamy sand on rock	Scattered tall and low shrubs
4	S	Minor drainage tracts: alluvial flats to 50 m wide, commonly severely gullied; narrowly entrenched small channels	Reddish-brown calcareous saline massive loamy sand interbedded with pedal loamy sand and irregular stony layers	Bladder saltbush and copperburrs on flats
5	S	Major drainage tracts: alluvial flats to 200 m wide; trench-like channels to 3 m deep and 6-8 m wide, cut into bedrock or alluvium, with gravel and sand bed loads	To 20 cm of yellowish-red layered saline sand overlying deep reddish-brown calcareous saline massive loamy sand; weakly pedal from 30-60 cm, with irregular stony layers	Copperburrs on flats; prickly wattle (*Acacia victoriae*) and tall and low shrubs towards channels; river red gum (*Eucalyptus camaldulensis*) along channels

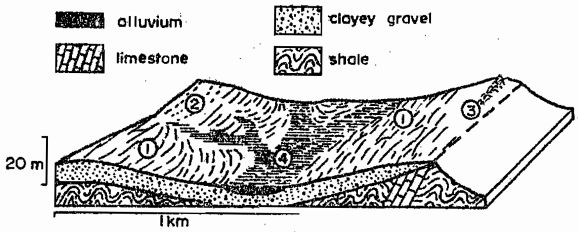
SANDSTONE TANK LAND SYSTEM St (2460 ha)

General Description: Broadly undulating stony country with bands of saltbush

Geology and Geomorphology: Soft-weathered, steeply-dipping Precambrian shale, calcareous in minor part, with a cover of Quaternary clayey gravels and minor outcrops of silcrete and Tertiary sand; broadly undulating perched plains with prominent contour patterns of stonier and less stony bands; relief to 15 m; shallowly incised dendritic drainage

Land Use: Lowland shrubland country with dense bladder saltbush pastures with local areas of short grasses and copperburrs. Drought resistance high. Gullying in Unit 4

Estimated grazing rate: 18.6 per sheep per 100 ha



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	VL	More stable interfluves: rounded, with slopes to 10% and to 400 m long; contour pattern of stonier risers and less stony steps with some gilgai	Stonier risers: red, loamy sand, pedal from 10-50 cm, calcareous below 10 cm, saline below 50 cm Less stony steps: red massive loamy sand, weakly pedal from 10-30 cm, calcareous and saline below 30 cm, rock at 140 cm	No perennial vegetation Bladder saltbush (Atriplex vesicaria) and copperburrs (Bassia spp.)
2	M	Less stable interfluves: as Unit 1, but locally higher, with less marked steps, and commonly stonier	Stonier risers: red loose calcareous loamy sand, weakly pedal from 10-25 cm, saline below 10 cm Less stony steps: as for stonier risers, but less saline and with minimal ped development	No perennial vegetation Bladder saltbush and copperburrs
3	VS	Minor outcrops: rocky and stony rises	No soils	Patches of bluebush (Kochia spp.)
4	S	Drainage tracts: flats to 200 m wide, gradients 1 in 50 to 1 in 100; discontinuous small head-channels and sandy shallow main channels to 20 m wide, locally braiding	To 30 cm of red layered sand overlying deep red massive sand; weakly pedal from 50 - 100 cm, with stony layers	Bladder saltbush and copperburrs; channels unvegetated

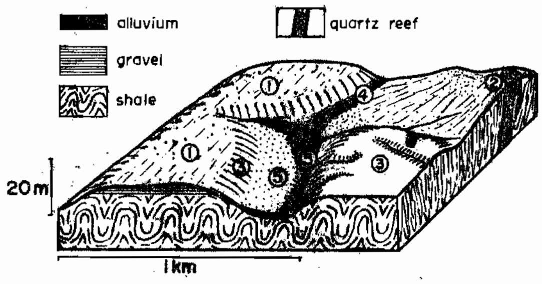
OLD HOMESTEAD LAND SYSTEM Oh (740 ha)

General Description: Stony terraces along Fowlers Creek near the Homestead

Geology and Geomorphology: Mainly within synclinal belt of steeply-dipping Precambrian shale, calcareous in part (Fowlers Gap Formation); cappings of Quaternary gravel; dissected terraces with relief to 10 m; dense dendritic incising drainage

Land Use: Lowland shrubland country with sparse bladder saltbush and pearl bluebush pastures, commonly replaced by short grasses and forbs which are abundant after rain. Drought resistance low due to absence of perennials. Moderate to strong gullying in Unit 3

Estimated grazing rate: 13.8 sheep per 100 ha



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	L	Stable crests: flattish, to 400 m in extent, and partly gravel-capped	Stony areas: to 30 cm of red neutral sandy loam, pedal from 10-30 cm, on weathered calcareous saline shale at 70 cm Less stony areas: to 30 cm of yellowish-red massive neutral sandy loam on weathered shale at 70 cm	No perennial vegetation except for an occasional bluebush (Kochia spp.)
2	VS	Stony rises: to 6 m high; rounded crests with minor rock outcrop; slopes to 5% and to 50 m long	To 40 cm of light-brown loose stony calcareous weakly saline loamy sand on rock	
3	L	Stripped crests and terrace margins: generally narrower, more sloping crests than Unit 1; convex marginal slopes to 15%	To 30 cm of light-brown calcareous stony loamy sand, weakly pedal in upper 10 cm; on shale	Bladder saltbush (Atriplex vesicaria) or bluebush, with copperburrs (Bassia spp.), small patches of perennial grasses, and bare areas
4	VS	Minor drainage tracts: flats to 30m wide, and small channels	Between outcrops, to 60 cm of light-brown neutral massive loamy sand on shale	Copperburrs on flats and bluebush along channels
5	S	Major drainage tracts: floodplains and low terraces to 50 m wide; generally uneven, with gravelly banks; trench-like channels to 5 m deep and 6-8 m wide, incised into bedrock or alluvium, with mixed bedloads, sand to gravel, and steep firm banks in silty alluvium; local waterholes	Floodplains: deep yellowish-brown loose sand; calcareous below 75 cm, saline below 120 cm Channel banks: as above, but calcareous below 30 cm and saline throughout	Bluebush and copperburrs River red gum (Eucalyptus camaldulensis)

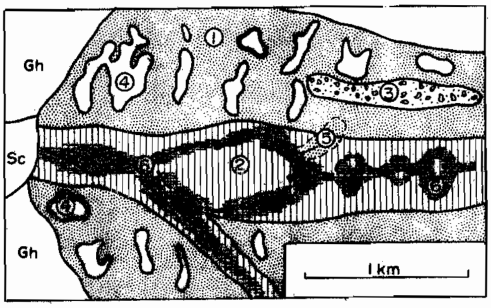
CONSERVATION LAND SYSTEM Cn (9260 ha)

General Description: Scalded flats between the main river floodouts

Geology and Geomorphology: Quaternary alluvium; relatively stable alluvial plains to 8 km wide, mainly between the terminal floodplains of Fowlers and Caloola Creeks; gradients 1 in 250 to 1 in 500; extensively scalded surfaces traversed by ill-defined depressed drainage zones

Land Use: Frontage country with short grass-forb and bottlewasher-copperburr pastures, with minor perennial shrubs; abundant ephemerals after rain. Low drought resistance. Units 1 and 4 subject to scalding and development of sand hummocks where overgrazed

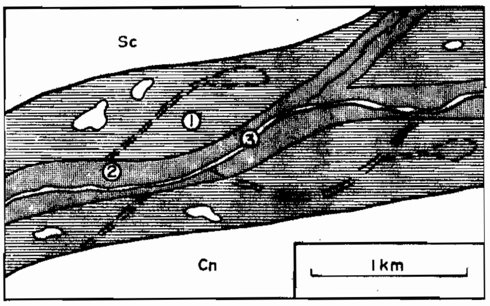
Estimated grazing rate: 10.9 sheep to 100 ha, with 12,2 sheep per 100 ha in lower eastern area supporting stands of shrubs



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	M	Higher-lying tracts: scalded plain tracts to 200 m wide and 800 m long, with many transverse scalds to 200 m in extent; sand accumulations ranging from sand hummocks about margins and scalds to elongate low sandy rises in lower part of land system	Deep yellow-red massive loamy sand; calcareous below 60 cm, saline below 20 cm; hummocks and rises of red loose leached sand	Copperburrs (Bassia spp.), otherwise little or no perennial vegetation, except on elongate sandy rises which carry Cassia spp. or mulga (Acacia aneura) or Casuarina sp.
2	M	Lower-lying tracts: to 800 m wide; uneven surfaces with weak gilgai	Deep yellowish-red massive loamy sand, becoming heavier with depth; calcareous below 30 cm; weakly saline at surface, becoming more saline with depth	Scattered shrubs, copperburrs, cottonbush (Kochia aphylla), berry saltbush (Rhagodia spinescens) ± bladder saltbush (Atriplex vesicaria). On the eastern part perennial grasses, Mitchell grass (Astrebla spp.) and neverfail (Eragrostis setifolia)
3	VS	Gravelly rises: elongate, to 100 m wide and 400 m long, and to 1 m above Unit 1; stony surfaces	No observations; probably red pedal loamy sand, calcareous and saline at depth	No perennial vegetation
4	L	Scalds and claypans: hard, bare surfaces to 500 m in extent, with some gravel	Claypans: deep yellowish-red massive sand, strongly pedal from 10-40 cm, calcareous below 40 cm, saline below 10 cm Scalds: as above, but calcareous below 10 cm	No vegetation
5	S	Sand splays: marginal to drainage lines with elongate low mounds of loose sand to 50 cm high	To 30 cm of yellowish-red layered neutral sand overlying deep yellowish-red massive loamy sand, becoming heavier with depth; calcareous below 40 cm, weakly saline below 100 cm	Perennial grasses (Chloris spp. and/or Sporobolus spp.) with copperburrs
6	S	Drainage zones: to 200 m wide, with discontinuous small channels in upper sectors and aligned circular depressions to 200 m across in lower sectors; some gilgai	About 30 cm of yellowish-red layered neutral sand overlying deep yellowish-red massive loamy sand; calcareous and saline below 100 cm	Neverfail and other perennial grasses with scattered shrubs ± prickly wattle (Acacia victoriae)

FOWLERS LAND SYSTEM Fl (650 ha)

General Description:	Main river frontage
Geology and Geomorphology:	Quaternary alluvium; floodplain of middle sector of Fowlers Creek; to 1.5 km wide; gradient 1 in 400; sinuous, locally braided channel
Land Use:	Frontage country; minor areas of lowland shrubland country with bladder saltbush and Mitchell grass pastures in Unit 2; with short grasses and copperburrs after rain or floods. Drought resistance low. Unit 2 subject to severe scalding Estimated grazing rate: 12.7 sheep per 100 ha



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	VL	Backplains: to 400 m wide, with flood channels and terminal depressions; moderately scalded, with some sand patches	Deep undifferentiated yellowish-red neutral loamy sand	Mitchell grass (Astrebla pectinata) and Chloris sp. ± scattered low shrubs (Kochia pyramidata and Bassia spp.) patches of prickly wattle (Acacia victoriae); occasional groups of sapling river red gum (Eucalyptus camaldulensis) in channels; sand patches with no perennial vegetation
2	L	Levees: discontinuous, to 200 m wide; sloping gently away from channels; locally severely scalded	Deep reddish-brown sand with gravelly bands; calcareous and weakly saline below about 100 cm	Scattered tall and low shrubs
3	S	Channel: trench-like, to 10 m wide and to 5 m deep, with some water holes; bed material unsorted sand to cobbles	Deep undifferentiated yellowish-brown sand	River red gum in channels and Chloris sp. on banks

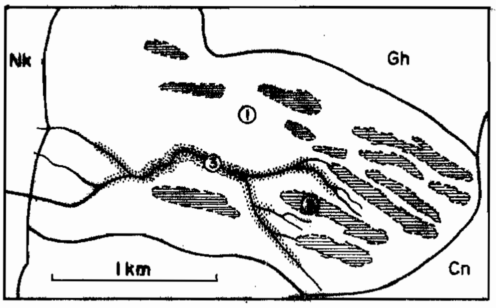
SANDY CREEK LAND SYSTEM Sc (2700 ha)

General Description: Scalded river flats with saltbush

Geology and Geomorphology: Quaternary alluvium; tributary floodplains to 4 km long with extensively scalded surfaces; gradients 1 in 200 to 1 in 350; braiding channels, commonly distributary or diffuse in lower sectors

Land Use: Tributary floodout country with dense bladder saltbush; Mitchell grass pastures, mainly in Unit 2, suited to cattle grazing. Units 1 and 3 subject to scalding and wind drift and to minor gullying

Estimated grazing rate: 18.1 sheep per 100 ha



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	L	Floodplains: scalded surfaces with some stony patches locally and low sandy hummocks about shrubs	Scalds: deep yellowish-red massive sandy loam with clay skins in upper 30 cm; calcareous and saline below 30 cm Sandy hummocks: red layered neutral sand overlying deep massive sandy loam; weakly calcareous throughout and saline from about 100 cm	No perennial vegetation Copperburrs (*Bassia* spp.), bladder saltbush (*Atriplex vesicaria*), *Eragrostis* sp.; *Salsola kali* locally
2	L	Backplains and terminal depressions: mainly to 100 m wide	Deep reddish-yellow calcareous massive sandy loam, becoming heavier with depth; saline in upper 10 cm, then non-saline to 200 cm; pedal from 10 to 60 cm	Perennial grasses (*Eragrostis* sp.) + Mitchell grass (*Astrebla pectinata*) with copperburrs and bladder saltbush
3	S	Channel tracts: levees to 75 m wide; shallowly entrenched sandy channels	Deep red weakly saline loamy sand, pedal in upper 30 cm; weakly calcareous below 35 cm	Levees: low shrubs Smaller channels: scattered low shrubs with dead river red gum (*Eucalyptus camaldulensis*) or treeless Larger channels: river red gum, low shrubs, scented grass (*Cymbopogon exaltatus*) and/or *Eragrostis* sp.

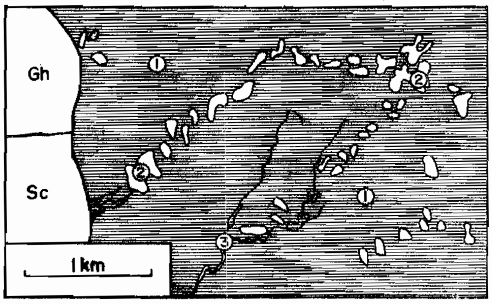
CALOOLA LAND SYSTEM Cl (2010 ha)

<u>General Description</u>: Caloola Creek floodout, with many crabholes and patches of Mitchell grass

<u>Geology and Geomorphology</u>: Quaternary alluvium; terminal floodplain of Caloola Creek system, with pronounced gilgai; to 3 km wide, gradients 1 in 250 to 1 in 500; sinuous distributary channels, gilgai nets and trains of scalds

<u>Land Use</u>: Main floodout country with bladder saltbush pastures; abundant ephemerals after floods allow heavy stocking. Well-suited to cattle grazing. Subject to scalding in Units 2, 3 and 4, and to gullying in Unit 2

Estimated grazing rate: variable depending on frequency of flooding, but generally above 16.6 sheep equivalents per 100 ha



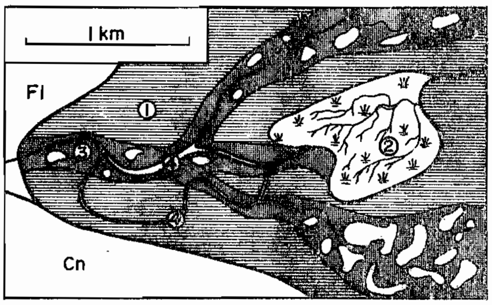
UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	VL	<u>Plain tracts</u>: surfaces subject to flooding, with extensive gilgai	Deep yellowish-red calcareous sandy loam, weakly pedal to 20 cm	Copperburrs (<u>Bassia</u> spp.) in gilgai; patches of Mitchell grass (<u>Astrebla pectinata</u> and <u>A. lappacea</u>) and other perennial grasses (<u>Chloris</u> spp., <u>Sporobolus</u> spp., <u>Eragrostis</u> spp.), grading through a zone of cottonbush (<u>Kochia aphylla</u>) on sandy hummocks to scalds with no perennial vegetation
2	M	<u>Scalds</u>: sealed surfaces with small sandy hummocks; elongate tracts to 150 m wide marginal to channels, and smaller transverse bands in Unit 1	<u>Scald margins</u>: deep yellowish-red massive sandy loam, calcareous and weakly saline below 60 cm <u>Scalds</u>: deep yellowish-red massive sandy loam, pedal with clay skins from 10-30 cm, calcareous and saline below	
3	S	<u>Channels</u>: small but deep channels and associated gilgai nets	Deeply-cracked yellowish-red calcareous saline massive loamy sand	Patches of perennial grasses (<u>Eragrostis</u> spp. and <u>Sporobolus</u> spp.)

MANDLEMAN LAND SYSTEM Ma (2570 ha)

General Description: Floodout of Fowlers Creek, with many crabholes

Geology and Geomorphology: Quaternary alluvium; terminal floodplain of Fowlers Creek; to 5 km wide, gradients 1 in 250 to 1 in 500; sinuous distributary channels, active and abandoned; linear gilgai and trains of scalds

Land Use: See Caloola Land System



UNIT	AREA	LANDFORM	SOILS	VEGETATION
1	L	Backplains: marginal zones to 1 km wide; with zones of minor channelling locally and pronounced gilgai	Deep reddish-yellow massive saline loamy sand, becoming heavier and more saline with depth; weakly pedal in upper 15 cm, calcareous below 60 cm	Occasional copperburrs (Bassia spp.) ± cottonbush (Kochia aphylla); otherwise without perennial vegetation
2	M	Flood-out basins: to 1 km wide; many channels and strong micro-relief with prominent linear gilgai	Flats: deep yellowish-red massive sandy loam; weakly pedal, weakly saline, and weakly calcareous below 60 cm Gilgai margins: deep light-brown massive saline loam, calcareous below 60 cm	No perennial vegetation Berry saltbush (Rhagodia spinescens)
3	M	Levees: active and prior, to 150 m wide, sloping gently away from channels; scalds to 200 m in extent	Levee crests: deep light-brown undifferentiated fine sand; lime in lenses throughout Scalds: deep reddish-yellow sandy loam; saline and calcareous below 60 cm, weakly pedal in upper 60 cm	Occasional bladder saltbush (Atriplex vesicaria) and copperburrs; otherwise without perennial vegetation No perennial vegetation
4	S	Channels: active and abandoned, to 10 m wide and 2-3 m deep; sandy bedloads	Deep light-brown calcareous layered loamy sand; weakly pedal in upper 20 cm, saline below 20 cm	River red gum (Eucalyptus camaldulensis) dead or alive, with scattered bluebush (K. pyramidata), berry saltbush and Mitchell grass (Astrebla pectinata)

CHAPTER III. CLIMATE OF FOWLERS GAP STATION

by F. C. Bell

I. INTRODUCTION

The climate at Fowlers Gap Station may be described in general terms as dry with hot summers and mild winters. In more precise terms it can be classified according to some of the main schemes as follows:

Köppen (1936)	warm arid (BWh)
Thornthwaite (1948)	arid mesothermal (EB')
Meigs (1953)	mild arid (Aa23)

The major climatic characteristics result essentially from the location of the Station in latitude 31°S, near the centre of the zone of migrating subtropical high pressure systems which are unfavourable for precipitation, and its remoteness from the moisture-bearing airstreams of the ocean, with its moderating effect on temperature. Thus rainfall is low, and both daily and seasonal ranges of temperature are relatively large, consistent with the continental climate of an inland area.

Detailed climatic records at Fowlers Gap Station have been kept only since November 1968, with the exception of some earlier years of daily rainfalls. Some of the data for this short period have been correlated with the corresponding data from other stations in the district with much longer records, namely White Cliffs, Sturts Meadows, Corona and Broken Hill. Such correlations have provided a basis for more reliable estimates of climatic variables at Fowlers Gap than could be obtained from the brief record alone. A more comprehensive regional climatic survey of the Fowlers Gap-Calindary area has been published elsewhere (Bell, 1972), and frequent reference will be made to that report.

II. SUNSHINE AND SOLAR RADIATION

Table III-1 shows the estimated mean number of sunshine hours, percentage cloudiness, incoming solar radiation and net radiation for each month at Fowlers Gap. The estimates of sunshine hours and cloudiness are based on the published data of Phillips (1951) and of the Department of National Development (1953); those of incoming solar radiation and net radiation have been obtained by interpolation from maps by Hounam (1963) of generalised values for the whole of Australia.

The mean number of sunshine hours per year, about 3,270, represents 75 percent of the maximum possible total of 4,380 hours per year. The mean annual cloudiness, expressed as percentage of sky covered, is about 23 percent, with little variation through the year. This relatively low cloudiness contributes to the very high receipts of solar radiation, especially in summer months. During December and January this part of Australia has about the highest incoming and net radiation in the world. During the winter months, however, receipts of solar radiation are only slightly greater than in Australian coastal areas of similar latitude.

III. TEMPERATURE

Long records of 9 a.m. temperatures are available for Broken Hill, Tibooburra, White Cliffs and Wilcannia, and the daily maxima and minima at these stations were compared with the corresponding readings at Fowlers Gap Station in the three-year period commencing Jan ary 1969. High correlations were found between Fowlers Gap and all the other stations, the best being with White Cliffs with a correlation coefficient of 0.95. The temperature difference between the two stations

TABLE III-1. SUNSHINE AND SOLAR RADIATION AT FOWLERS GAP STATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Sunshine Hours	320	270	270	260	240	225	235	265	270	290	305	320	3270
Mean % Cloudiness	23	25	24	20	22	24	22	20	21	23	23	25	23
Mean Incoming Solar Radiation (Langleys/Day)	680	610	520	405	305	250	270	350	460	555	650	675	5730
Mean Net Radiation[1] Langleys/Day	320	300	240	160	95	45	60	125	195	260	320	345	2465

[1] Estimated by Hounam (1963) assuming an albedo of 0.23

TABLE III-2. TEMPERATURES AT FOWLERS GAP STATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
<u>Daily Maxima</u> Mean (°C)	35.5	34.7	31.0	25.5	21.1	16.7	16.5	19.5	23.6	27.5	31.3	34.1	26.4
Coefficient of Variability[2] (%)	5.5	4.5	4.0	3.5	3.5	3.0	3.0	3.5	3.5	4.0	3.5	3.0	-
<u>Daily Minima</u> Mean (°C)	19.9	19.6	16.3	11.2	7.2	4.6	3.2	5.3	8.2	12.5	16.2	18.5	11.9
Coefficient of Variability[2] (%)	5.5	4.5	4.0	4.0	3.5	3.5	3.0	3.0	3.5	3.0	4.0	5.0	-

[2] The coefficients of variability adopted here are the standard deviations expressed as percentages of the means for each month

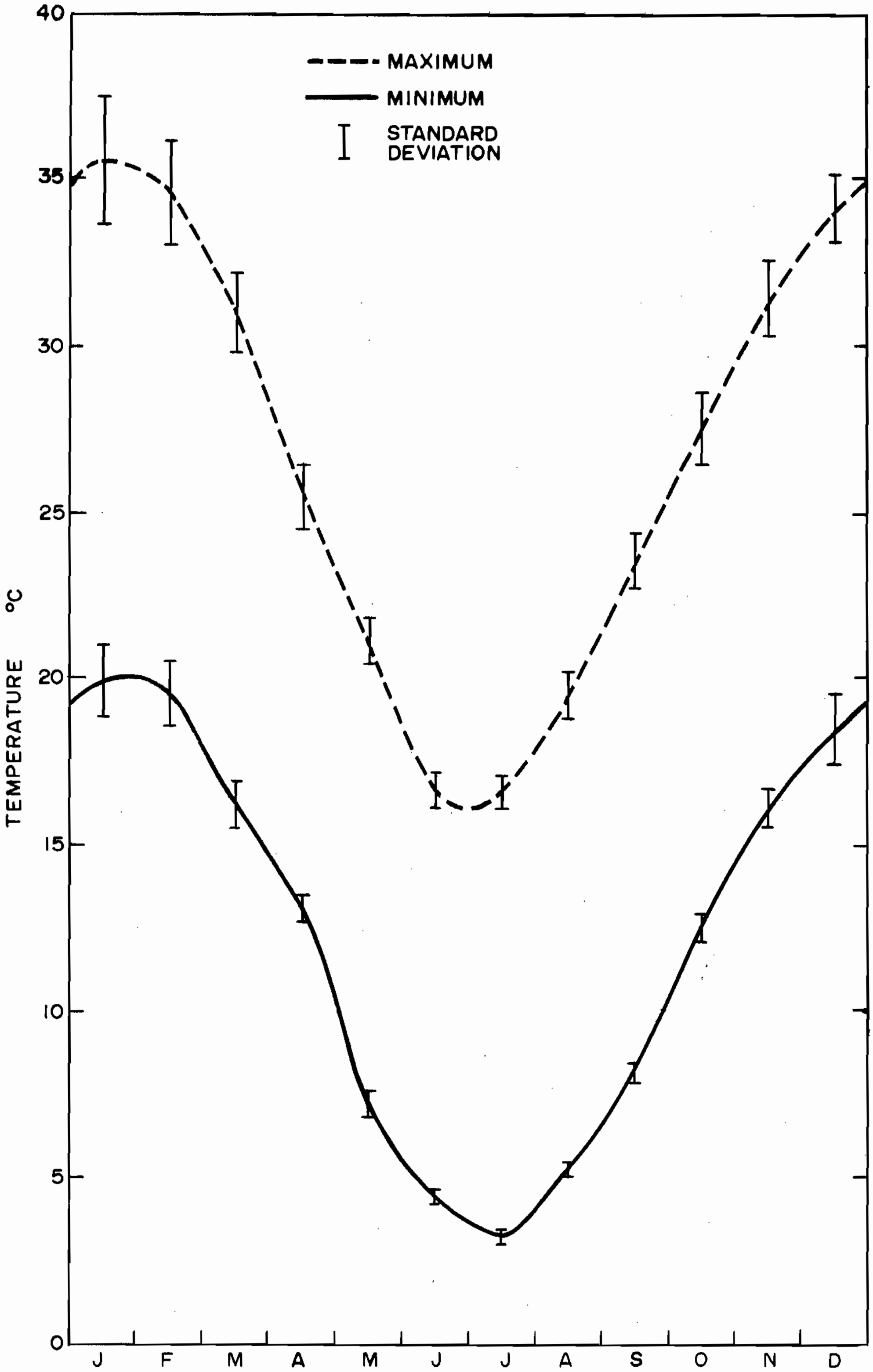


Fig. III-1. - Means and standard deviations of daily maximum and minimum temperatures at Fowlers Gap Station is therefore fairly consistent, being 0.6°C. higher at White Cliffs for maxima and minima, with no significant seasonal variations. Table III-2 and Fig. III-1 show the best available estimates of mean temperatures at Fowlers Gap based on this correlation.

The relationship between temperatures at Fowlers Gap and Broken Hill is less consistent, the correlation coefficient being 0.90. On the average, mid-day and afternoon conditions at Fowlers Gap, as indicated by the daily maxima are between 1° and 2°C hotter than at Broken Hill at all seasons; on the other hand, night-time and early morning temperatures as indicated by the daily minima are 1° - 2° higher at Fowlers Gap in summer and 3° - 4° lower in winter. It may therefore be concluded that somewhat greater extremes of temperature are experienced at Fowlers Gap than at Broken Hill. These differences are probably partly due to local factors such as differences in the exposures of the weather stations, and partly because Broken Hill is closer to the ocean.

As shown in Table III-2, and Fig. III-1, daytime temperatures in the summer months generally exceed 30°C at Fowlers Gap, which is regarded as hot by usual standards. On the average, approximately 40 days have maxima above 35°C, which may be significant for lambing rates as Farmer et al. (1947) have suggested that prolonged temperatures of this order reduce fertility in rams. More extreme "heatwave" conditions occur when 37.7°C (100°F) is reached, and as many as 24 consecutive days exceeding this level have been recorded in the district (Commonwealth Meteorological Bureau, 1966). In a typical year, heatwave temperatures may be expected at Fowlers Gap on about 35 days per year, most of these occurrences being associated with slowly-moving high pressure systems to the southeast of Fowlers Gap, with persistent weak to moderate air streams from the north or northwest. The highest official reading at White Cliffs was 51.5°Cin 1909, which is one of the highest temperatures recorded in Australia.

Temperatures approaching this can be expected at Fowlers Gap on very rare occasions, perhaps once in a hundred years.

In studies of human heat discomfort it is desirable to consider the "effective temperature", which makes some allowances for humidity and other factors influencing the sensation of warmth. According to the recommendations of Ashton (1964), a considerable number of people feel uncomfortably hot in effective temperatures above 24^{o}C, at which level air-conditioning is desirable. At Fowlers Gap Station this threshold is likely to be exceeded for at least three hours on an average of 85 days per year.

In contrast to daytime conditions, early morning and night-time temperatures throughout summer are generally quite mild, as shown by the daily minima in Table III-2. The large differences between day and night temperatures are evident throughout the year, being typical of diurnal ranges in most inland areas of Australia.

During winter months, daytime conditons are mild to warm and nights and early mornings are relatively cool. Screen temperatures below 0^{o}C are recorded 7 - 10 times per year, generally coinciding with heavy frost in susceptible gullies and hollows. Lighter frosts, when temperatures are between 0^{o}C and 2.5^{o}C, may be expected 10 - 20 times per year, all in the period from April to October inclusive. Frosts and cold snaps commonly occur under the influence of the leading edge of a high pressure system with an associated cold front and airstream from the southwest. The lowest temperature on record at White Cliffs is -6^{o}C (July 1940), and readings as low as this could be experienced at Fowlers Gap on rare occasions.

IV. RAINFALL

(a) Annual and Seasonal Rainfall

In the regional study of the Fowlers Gap-Calindary area (Bell, 1972), the mean annual rainfall at Fowlers Gap Station was estimated to be 195 mm with a coefficient of variability of 44 per cent. There is 20 per cent more rainfall in the summer half of the year (October to March, inclusive) than in the winter half, but the winter rainfall is more reliable than the summer rainfall, the respective coefficients of variability being 51 per cent and 59 per cent. A long-term trend towards an increasing proportion of summer rainfall over the past 60 or 70 years is evident from the long records of a number of stations in the area, some extending back before 1880. At Corona 34 km SW of Fowlers Gap for example, the proportion of summer rainfall has increased from 46 per cent in the period 1889-1918, to 58 per cent in the period 1939-68. However, the statistical significance of this trend is not very high because of the inherent large rainfall variability for both short and long periods.

The five years of daily rainfall records from Fowlers Gap have been correlated with the corresponding data from several nearby stations with long records, namely Corona, Sturts Meadows, Gnalta, Quinyanbie and Nuntherungie. The best correlation is with data from the adjacent Sturts Meadows (coefficients of 0.81 for daily and 0.84 for monthly rainfalls) and the record from this station may be regarded as statistically equivalent to the Fowlers Gap record as there is no significant systematic difference between the two. Therefore, the estimates in Table III-3 and Fig. III-2, which have been derived from the 60-year Sturts Meadows record, should be valid for Fowlers Gap.

December and February have the highest mean monthly rainfalls, and April and August have the lowest. It should

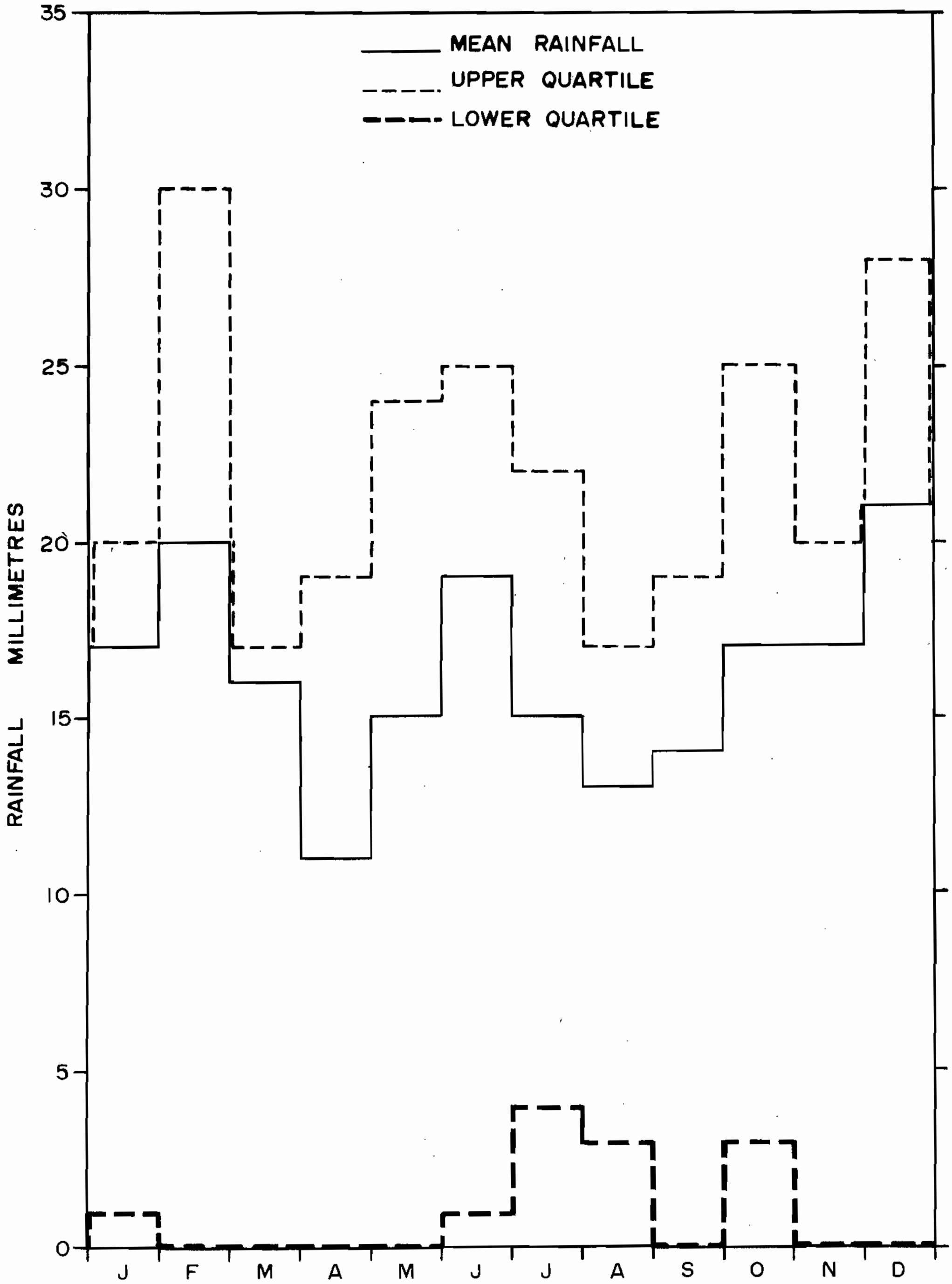


Fig. III-2. - Rainfall at Fowlers Gap Station be noted that the frequency distributions of monthly rainfall are so skewed that it is preferable to indicate the variability by upper and lower quartiles rather than by the more usual standard deviation or coefficient of variability (which exceeds 100 per cent). The upper quartile is a typically high value exceeded in only 25 per cent of months while the lower quartile is a typically low value exceeded in 75 per cent of months. The range between the two quartiles is a measure of variability and this is high in every month (Table III-3). December and February have the highest variabilities and August has the lowest.

(b) Wet Spells

Rainfall in the Fowlers Gap area tends to occur in wet spells, consisting of between one and six days of measured rain, interspersed with much longer dry spells which commonly vary from a few weeks up to two or three months. Brief wet spells of one day duration occur relatively frequently and are responsible for a large proportion of the total rainfall, averaging about 45 per cent of the summer rainfall and 65 per cent of the winter rainfall. In both seasons much of this rain is due to local convective storms of thunderstorm type, the significance of which is apparent in the two years of pluviograph data already available from the station. These consist of short bursts of high intensity rain lasting from a few minutes up to about an hour, and the probabilities of extreme magnitudes of such rainfall are important for the engineering design of roads, dams and water harvesting and soil conservation schemes. Estimates of these probabilities for the whole of Australia show that Fowlers Gap has about the same expectations of extreme short-duration rainfall as Adelaide, although the mean annual rainfall at Adelaide is much greater (Institution of Engineers, Australia, 1958; Bell, unpublished).

TABLE III-3. RAINFALL AND DROUGHT AT FOWLERS GAP STATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Rainfall (mm)	17	20	16	11	15	19	15	13	14	17	17	21	195
Mean Number of Wet Days	1	1	2	1	1	2	3	2	1	2	2	1	19
Upper Quartile of Monthly Rainfall (mm)	20	30	17	19	24	25	22	17	19	25	20	28	-
Lower Quartile of Monthly Rainfall (mm)	1	0	0	0	0	1	4	3	0	3	0	0	-
Duration of Dry Spell with 50% Probability*	52	25	44	40	26	33	40	46	45	30	30	35	-
Duration of Dry Spell with 10% Probability	130	80	140	135	80	107	132	150	147	90	94	136	-

* A dry spell commencing in the given month has a 50% probability of persisting for the indicated duration or longer

TABLE III-4. 9 AM WINDS AT FOWLERS GAP STATION*

	N	NE	E	SE	S	SW	W	NW	CALMS
Less than 20 kph Dec-Feb	4.6	12.6	8.5	23.0	8.5	7.3	0.8	3.6	7.4
Mar-May	3.0	10.3	7.0	21.5	7.0	10.8	1.5	4.8	23.0
Jun-Aug	3.8	4.6	2.7	10.5	6.2	15.5	8.5	14.7	32.0
Sep-Nov	3.1	14.0	4.7	22.0	7.8	16.0	3.0	9.4	10.7
20 kph and Over Dec-Feb	1.8	2.4	1.0	9.3	3.7	3.5	0.4	1.8	-
Mar-May	0.8	2.0	0.4	2.0	2.4	3.2	0	0	-
Jun-Aug	0.5	0	0	0.5	0.2	1.0	0	0.5	-
Sep-Nov	0.7	2.4	0	2.8	1.0	1.7	0.2	1.7	-

* Percentages of days with winds from the stated directions in the period Dec.1968-Nov.1971 inclusive

Wet spells of three days duration or longer are experienced on the average less than once per year, but these are responsible for the larger rainfalls, i.e. greater than 40 mm. Contributions from such falls average 22 per cent of the total rainfall in the summer half of the year and 12 per cent in the winter half. Short and long wet spells are both due to strong inflows of moist air, most commonly from an easterly to northeasterly direction but occasionally from the south and other directions. These airflows are associated with a variety of synoptic conditions, the most typical being:

1. intense tropical cyclones or depressions in the vicinity of Queensland during the summer months
2. extra-tropical depressions over southern inland Australia or the Great Australian Bight, generally during the winter months
3. strongly-developed low pressure systems in the upper atmosphere which can bring heavy falls of rain over wide areas of the inland in any season (Foley, 1956).

(c) Droughts

Probabilities of occurrence of dry spells of various durations have been estimated by Fitzpatrick (1953) for the whole of New South Wales. Based on this study, Table III-3 shows the lengths of dry spells with probabilities of 10 and 50 per cent commencing in any month. It can be seen that dry spells commencing in January, March, August and September are more likely to develop into long, severe droughts than those commencing in other months. Least favourable is January, when there is a 10 per cent probability of a dry spell commencing and persisting for six months or longer.

Gibbs and Maher (1967) have suggested that the lowest decile of annual rainfall is a useful and convenient index of drought. This is the annual rainfall that is exceeded in

90 per cent of years, or which may be regarded as having an average return period of ten years. It is about 100 mm at Fowlers Gap, and by this criterion severe droughts occurred in the area in 1938, 1940 and 1965 during the past 40 years. The lowest annual rainfalls recorded at Sturts Meadows are 44 mm in 1940 and 50 mm in 1922, amongst the lowest recorded anywhere in New South Wales.

V. WIND REGIME

An analysis has been made of the three available years of wind observations at 9.00 a.m. at Fowlers Gap from December 1968. The results as summarised in Table III-4 and Fig. III-3 are consistent with expectations based on similar analyses of longer records for Broken Hill and Tibooburra carried out for the Fowlers Gap-Calindary area (Bell, 1972). In general, prevailing wind characteristics at Fowlers Gap Station are directly related to the anti-clockwise atmospheric circulation about the eastward-moving subtropical high pressure systems. The seasonal locations of these high pressure systems impart a well-defined seasonal pattern to the wind directions and speeds.

In the December to February period, with the highs usually centred in the latitudes of the Great Australian Bight, Fowlers Gap is subject to winds with predominantly easterly components, particularly from the southeast. The circulation is also often strengthened by clockwise airflow around "heat lows" in the central and northern parts of Australia at that season.

During winter months, with the paths of the highs at their most northerly limits near 28°S, westerly airflows along the southern edges of the highs exert considerable

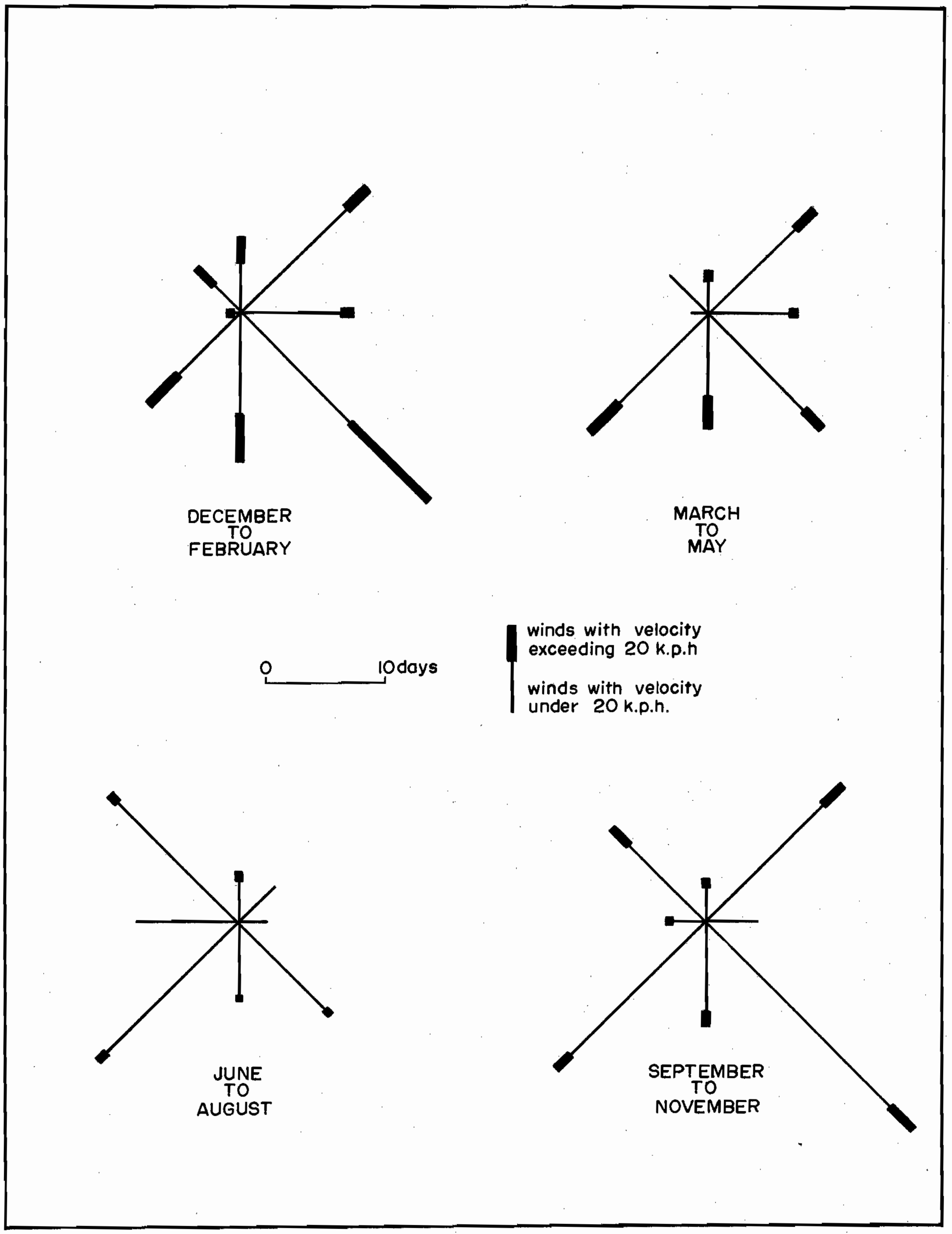


Fig. III-3. - 9 am wind observations at Fowlers Gap Station influence, as suggested by the prevailing frequencies of southwesterly and northwesterly winds at Fowlers Gap. In the autumn (March to May) and spring (September to November) periods, conditions are transitional between those of summer and winter, both easterly and westerly components being prominently represented. Southeasterlies are particularly frequent in autumn and spring, apparently due to vigorous airflows around the leading edges of highs which tend to stall over southern and central Australia.

As may be seen from Fig. III-3, the southerly component is more pronounced in stronger winds, with velocities exceeding 20 kph. These are mainly southeasterlies in summer and southwesterlies in winter. Their frequency patterns suggest that January and February are windier than other months, and that June and July are the least windy months. The frequency patterns of calms are also consistent with this, the number of calms in summer months being considerably less than in winter months. Calms appear to occur more often at Fowlers Gap than at Broken Hill or Tibbooburra, but it is uncertain whether this is due to local topographic effects or merely to differences in observer judgment.

The wind conditions at 9.00 a.m. would differ somewhat from conditions at other times of the day, for which at present no data are available for Fowlers Gap. The records at Broken Hill and Tibooburra suggest that there would be a lower frequency of easterlies and a higher frequency of westerlies in the afternoons in all seasons. Also, there would be fewer calms in the afternoons in all seasons. These differences between morning and afternoon conditions are associated with diurnal variations in horizontal thermal gradients, but such effects are subsidiary to those of the prevailing synoptic pressure systems.

VI. HUMIDITY, DEW AND EVAPORATION

(a) Relative Humidity

Relative humidities and dew points have been calculated from thermohygrograph and daily temperature readings at Fowlers Gap for the three years of records available. No large systematic differences have been detected between these and the corresponding values at Broken Hill, despite the temperature differences discussed previously. However, the correlation coefficient is only 0.84 for 9.00 a.m. relative humidities, and apparently random variation of 20 per cent or more may occur on individual days. Mean daily values of relative humidity in Table III-5 are from a long period of records at Broken Hill (Commonwealth Bureau of Meteorology, 1969), and these should provide the best estimates of conditions at Fowlers Gap Station.

It is evident from Table III-5 that low relative humidities prevail in summer months, but in winter months the 9.00 a.m. values are not much lower than those at Sydney and Adelaide for that time of the year. As relative humidities are inversely related to temperature it may be preferable for some purposes to remove the effects of temperature by considering absolute humidities or vapour pressures. At Fowlers Gap these do not vary greatly throughout the year, the highest mean daily vapour pressure being 12.5 mb in February and the lowest 8.0 mb in August. Again, the winter values are only slightly lower than those at Sydney and Adelaide for that time of the year.

(b) Dew

In some arid areas dew is an important element in the survival of xerophytic vegetation and desert fauna (Angus, 1958). Although it usually represents only very small quantities of water when compared with rainfall, its significance is due to its regularity of occurrence and also to the fact that evaporation of dew dissipates atmospheric energy that would otherwise cause loss of soil moisture through transpiration and direct evaporation. Standardised measurements of this element are not readily made and there is no record of its occurrence at Fowlers Gap; however, consideration of the available temperature and humidity data suggests that it is fairly frequent in the five months April to August inclusive. During this period the calculated 9.00 a.m. dew points are often equal to or higher than the observed minimum temperatures and the thermohygrograph charts show relative humidities above 95 per cent in the early mornings. Under such conditions some condensation from the atmosphere is to be expected in favourable locations, particularly as minimum ground temperatures are usually lower than screen temperatures. Dew is unlikely in summer months, however, because relative humidities are generally too low.

(c) Evaporation

Observed mean monthly values of pan evaporation at Fowlers Gap for the three years of available records are listed in Table III-5. Also listed are the corresponding estimates for the area by Hounam (1961), which are seen to be considerably lower in all months. The observed values were measured with a United States Type A Land Pan raised above the ground in accordance with standard specifications, whereas Hounam's estimates are based on observations made with the "Australian Sunken Tank", which is let into the ground and is therefore influenced by different heat storage effects. Good correlations have been found between the readings of the two instruments by Fleming (1964) and Hounam (1961), who suggest seasonal correction factors that enable the conversion of estimates from one type of instrument to equivalent estimates based on the other type. These correction

TABLE III-5. RELATIVE HUMIDITY AND EVAPORATION AT FOWLERS GAP STATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
9 am Relative Humidity (%)	38	42	45	55	65	74	71	60	50	41	38	38	51
3 pm Relative Humidity (%)	24	27	30	38	47	54	49	39	31	26	25	24	35
Observed Mean Pan Evaporation 1969-71 (mm)	582	424	338	214	133	90	92	148	230	352	472	537	3613
Estimated Mean Sunken Tank Evaporation[1] (mm)	320	255	220	150	100	71	70	105	150	205	250	285	2180
Coefficient of Variability of Sunken Tank Evaporation[2] (%)	9	10	11	13	15	17	19	17	15	13	11	10	9

1. Interpolated from maps prepared by Hounam (1961)
2. Standard deviation expressed as a percentage of mean

TABLE III-6. EFFECTIVE RAINFALL AND ITS PROBABILITY OF OCCURRENCE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Initial Effective Rainfall[1] (mm)	30	25	20	14	10	7	6	10	15	20	24	27
Probability of Initial Effective Rainfall (%)	18	27	21	28	42	55	50	47	26	28	21	25
Effective Carryover Rainfall[2] (mm)	63	50	41	30	20	14	13	20	29	39	49	54
Probability of Effective Carryover Rainfall (%)	7	14	14	15	32	40	40	23	13	15	10	7

1. Initial effective rainfall is equivalent to 40 per cent of the estimated (sunken) pan evaporation over a 7-day period
2. Effective carryover rainfall is equivalent to 20 per cent of the estimated (sunken) pan evaporation over a 28-day period, including the week of initial effective rainfall

factors should be comparable with the ratios of the observed to estimated values in Table III-5, but the agreement is in fact quite poor, and it seems likely that different factors apply to arid conditions such as those at Fowlers Gap. Probably the sunken tank estimates in Table III-5 are a better guide to the evaporation that would be expected from a reservoir or other large body of water than the actual measurements by the Type A Land Pan. In this regard it is worthy of note that the energy represented by the net radiation in Table III-1 is generally below that required to account for any of the monthly evaporation estimates of Table III-5.

Comparison between evaporation and rainfall throughout the year at Fowlers Gap shows that, even under very wet conditons as indicated by the upper quartiles of rainfall in Table III-3, monthly rainfall is never likely to exceed monthly evaporation.

VII. INDICES OF COMBINED CLIMATIC INFLUENCES

The concepts of "initial effective rainfall" and "effective carryover rainfall" attempt to specify the rainfall required to germinate annuals and to stimulate growth of perennials in arid and semiarid areas (Slatyer, 1962). Their values vary with seasonal conditions as expressed by pan evaporation. "Initial effective rainfall" is equivalent to 40 per cent of the pan evaporation over a 7-day period, and "effective carryover rainfall" is equivalent to 20 per cent of the pan evaporation for a 28-day period (including the week of initial effective rainfall). Table III-6 shows estimated required values of these effective rainfalls at Fowlers Gap and the probabilities of their occurrence based on calculations by Turner (1969) using Hounam's pan evaporation estimates. The higher probabilities for May to August inclusive indicate that these months are significantly more favourable for plant growth than the summer months, despite the higher mean rainfalls of the summer months.

Fitzpatrick and Nix (1970) have developed light, thermal and moisture indices for assessing the growth of pasture in response to a complex of climatic variables, and other work by CSIRO with similar objectives for desert vegetation has emphasised the moisture factor, adopting a simple water-balance model (WATBAL) for estimating the changes in available soil moisture in response to weekly inputs of rainfall and outgoing potential evapotranspiration (McAlpine, 1970). This approach has not yet been tested for the Fowlers Gap area, but it could play an important role in future applications of climatic data in land-use planning and for related purposes.

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CHAPTER IV. GEOLOGY OF FOWLERS GAP STATION

by C.R. Ward and M.E. Sullivan

I. INTRODUCTION

Fowlers Gap Station extends across the eastern edge of the Willyama Block, part of the ancient continental Basement, into the Bancannia Trough, a structural depression later filled with at least 2000 m of Devonian, Cretaceous and later deposits. At the contact of these two structural units, Upper Devonian rocks are exposed. Accordingly, the western part of the Station consists of rugged uplands or rolling lowlands on Upper Precambrian and Devonian sedimentary rocks and the eastern part of low-lying plains on Quaternary alluvium.

A number of geological investigations have been carried out in the region north of Broken Hill, but only those of Kenny (1934), Ward (1967), Wright-Smith (1967), Thompson (1969) and Ward, Wright-Smith, and Taylor (1969) have specifically treated the area of Fowlers Gap. Other more specialised studies have also been carried out on the property by Planet Oil N.L. and by several workers from the University of New South Wales.

II. STRATIGRAPHY

(a) Upper Precambrian Rocks

The oldest rocks exposed in the area are part of the Adelaidean System, a thick succession of non-fossiliferous sedimentary strata which south of the Station rest unconformably upon the high metamorphosed Willyama Complex. On Fowlers Gap Station only the middle and upper parts of the Torrowangee Group are represented, consisting of shale, dolomite, limestone and quartzite, all of which have suffered a moderate amount of folding accompanied by low-grade regional metamorphism.

This part of the sequence has been subdivided as shown in Table IV-1. These units crop out in the southern and western parts of the Station,with the Faraway Hills Quartzite member of the Farnell Group forming the ridge country of the Caloola Syncline on each side of the Homestead (See Fig. IV-1). The lithology of the various formations is described below.

(i) Teamsters Creek Subgroup - The Teamsters Creek Subgroup consists mainly of grey-green cleaved shale (slate) with numerous boldly outcropping dolomite lenses. Horizons with a number of erratic boulders, possibly of glacial origin, occur towards the base of the unit, but are more prominent in the underlying formations of the Upper Precambrian sequence. A few thin dark-grey limestone beds are also present in the upper part of the unit, but are subordinate to the dolomite both in size and abundance.

The shale consists of chlorite, mica, quartz and kaolinite, often with a small amount of feldspar, but some red-brown and pink varieties contain haematite and a few white friable phases occur in which calcite forms an abundant constituent. White quartz veins are present throughout, commonly running parallel to the NNW trend of the beds, and yield a cover of sub-angular fragments on weathered outcrops.

Most of the dolomite is light-brown to buff in colour, and like the shale is cut by numerous fine quartz veins. Microscopic examination suggests that a considerable proportion of quartz (up to 50 per cent) has also impregnated the carbonate rock itself, and in some cases complete replacement has occurred. The grey limestone, on the other hand, is largely free of quartz veins and contains very little material other than recrystallised calcite.

TABLE IV-1. STRATIGRAPHY OF FOWLERS GAP STATION

<table>
<tr><th>AGE</th><th colspan="3">ROCK UNITS</th><th>LITHOLOGY</th><th>THICKNESS (m)</th></tr>
<tr><td>Quaternary</td><td colspan="3">Undifferentiated alluvium</td><td>Clay, silt, sand, pebbles and cobbles</td><td>100 (min.)</td></tr>
<tr><td>? Upper Tertiary</td><td colspan="3">Duricrust</td><td>Silcrete</td><td>3</td></tr>
<tr><td>? Lower Tertiary</td><td colspan="3"></td><td>Sandstone and siltstone</td><td>70</td></tr>
<tr><td>Mesozoic</td><td colspan="3">Partly consolidated alluvium</td><td>Shale and sand-stone</td><td>100</td></tr>
<tr><td rowspan="2">Upper Devonian</td><td colspan="3">Nundooka Sandstone</td><td>Quartz sandstone and ortho-quartzite</td><td>1100</td></tr>
<tr><td colspan="3">Coco Range Beds</td><td>Quartz sandstone, pebbly sandstone, orthoquartzite: red and green shale</td><td>800</td></tr>
<tr><td rowspan="3">Upper Precambrian (Adelaidean System)</td><td colspan="2" rowspan="2">Farnell Group</td><td>Fowlers Gap Formation</td><td>Shale and quartz-ite with limestone lenses</td><td>3500</td></tr>
<tr><td>Faraway Hills Quartzite</td><td>Quartzite</td><td>100</td></tr>
<tr><td>Torrowangee Group</td><td>Teamsters Creek Sub-group</td><td>Not sub-divided on Fowlers Gap Station</td><td>Shale with dolo-mite lenses and some limestone</td><td>2000 (approx.)</td></tr>
</table>

Note: The Upper Precambrian Adelaidean System includes a number of rock units additional to those shown (Cooper and Tuckwell, 1971) but these do not crop out in the area of Fowlers Gap Station.

Two small outcrops of black, fine-grained chert occur in the lower part of the sequence. These consist of microcrystalline quartz and mica with one bed cut by thick quartz veins, and their origin is uncertain.

In addition to these beds, a thin, persistent horizon of white, fine-grained quartzite resembling chert occurs near the top of the unit. This material also consists of microcrystalline quartz, and appearance in the field suggests that it may represent a completely silicified dolomite bed.

(ii) Farnell Group - Conformably overlying the Teamsters Creek Subgroup is a succession of interbedded cleaved shale and massive quartzite, together with a few small limestone lenses. The abundance of quartzite distinguishes this upper part of the Adelaidean sequence from the underlying succession, and the change in lithology provides a useful marker for stratigraphic correlation with other areas (Ward, Wright-Smith and Taylor, 1969).

Only the lower part of the Farnell Group is exposed on Fowlers Gap Station, and two formations have been recognised as follows:-

(1) Faraway Hills Quartzite. At the base of the Farnell Group is a very prominent marker horizon consisting of medium-grained, somewhat metamorphosed orthoquartzite. This quartzite is up to 100 m thick and contains minor shale lenses up to 6 m thick and also a small dolerite intrusion. It crops out to the east and west of the Homestead, forming the highest of the series of paired ridges in the Caloola Syncline.

(2) Fowlers Gap Formation. The Fowlers Gap Formation is a sequence of interbedded quartzite and shale conformably overlying the Faraway Hills Quartzite and underlying a similar marker horizon, the Camels Humps Quartzite, which crops out further to the south. The quartzites are similar in appearance to those of the Faraway Hills unit, but usually

contain a small proportion (5-10 per cent) of microcline feldspar in addition to the interlocking recrystallised quartz grains. The shales are similar to those of the underlying Teamsters Creek Subgroup, commonly light grey-green in colour with some buff and white varieties. Small lenses of dolomite and limestone, generally less than one metre thick, occur throughout the shale, and one of these beds, just west of the Homestead, is seen to grade laterally through sandy material to quartzite.

The Fowlers Gap Formation crops out in an area of fairly straight parallel quartzite ridges and intervening valleys to the north and south of the Homestead. Further to the south on Sturts Meadows Station, the overlying beds of the Farnell Group are exposed, overlain unconformably by (?)Cambrian strata (Taylor,1967).

(b) Upper Devonian Rocks

Along the eastern edge of the Barrier Range and extending north of Fowlers Gap Station, the Farnell Group is unconformably overlain by quartzose sandstones with associated red-brown and grey-green shale of probable Upper Devonian age. This sequence has been separated by large-scale faulting into two separate blocks (see Fig. IV-1) such that the complete section is not exposed, but petroleum drilling on the property (Bancannia South No. 1) has indicated a total thickness of approximately 2000 m for these strata.

The sequence exposed on the upthrow (western) side of the fault shows some lithological differences from that on the downthrow side and these two units have been given separate names although they are probably part of a conformable succession. Fossils are rare in these beds, but a few Upper Devonian fish plates (cf. *Bothriolepis sp.*) have been found (M.J. Rickard, *pers. comm.*).

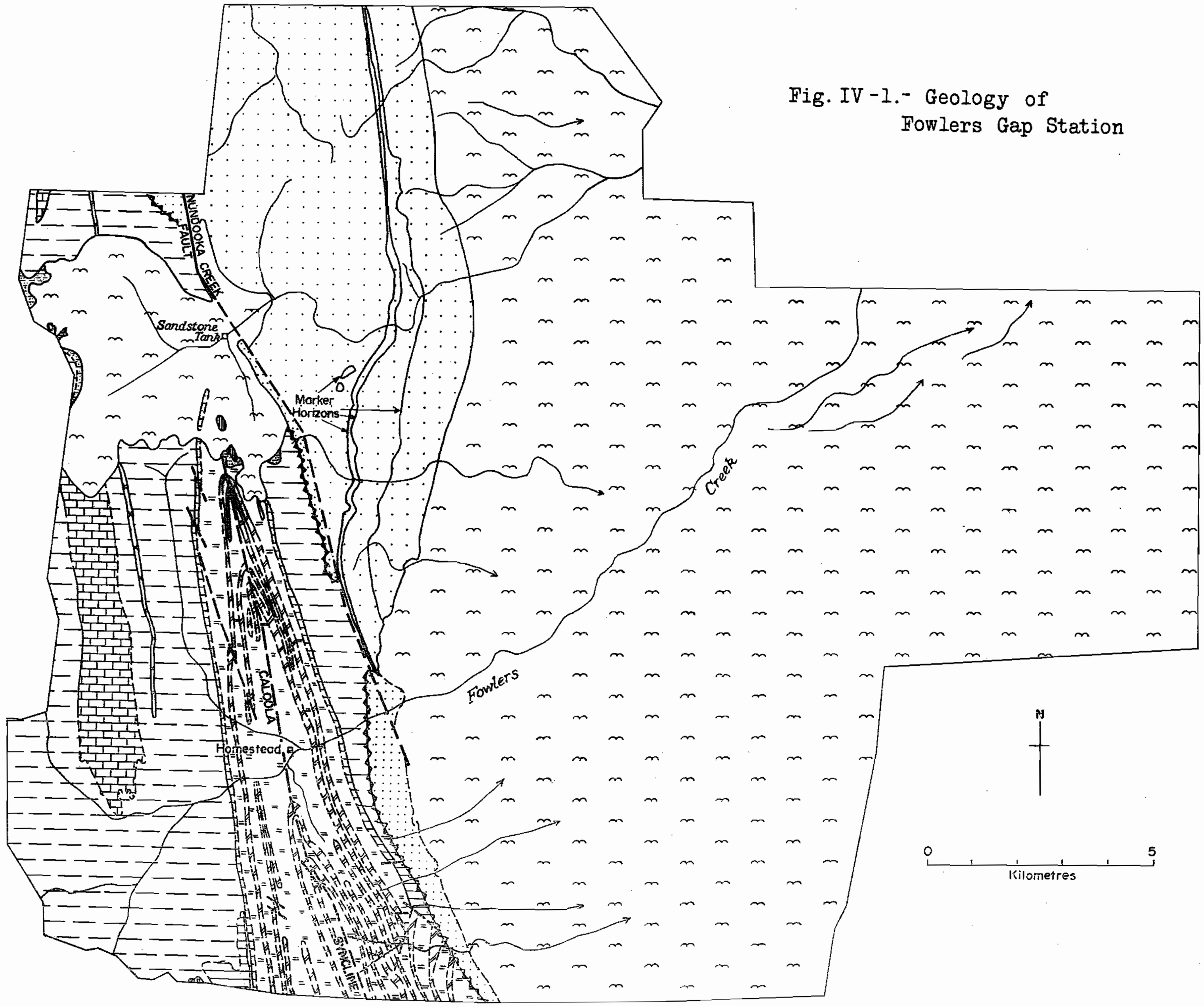

Fig. IV -1.- Geology of Fowlers Gap Station

LEGEND

QUATERNARY				Alluvium
TERTIARY				Silcrete
				Siltstone and sandstone
DEVONIAN		Nundooka Sandstone		Sandstone, orthoquartzite
		Coco Range Beds		Sandstone, pebbly sandstone, orthoquartzite, shale
PRECAMBRIAN	Farnell Group	Fowlers Gap Formation		Quartzite
				Shale
		Faraway Hills Quartzite		Quartzite
	Torrowangee Group	Teamsters Creek Subgroup		Fine grained quartzite
				Shale
				Dolomite

Fault

Established fault, position approximate

Inferred fault

Unconformable boundary

(i) Coco Range Beds - The Coco Range Beds rest with a marked angular unconformity upon the Adelaidean strata. The basal portion of the unit is exposed on the edge of the elevated country east of the Homestead, but a more complete section is preserved to the north of Nundooka Station (see Fig. IV-1), where the thickness of strata exceeds 800 m. Thin beds of red-brown silty shale occur at the base of the sequence in places, but in other localities quartzose sandstone rests directly on the metamorphosed basement. The remainder of the unit consists of quartzose sandstone, although as shown on the map (Fig.IV-1) conglomerate and thin shale beds crop out near the Station boundary north of Sandstone Tank.

(ii) Nundooka Sandstone - On the eastern, or downthrow side of the Nundooka Creek Fault is a sequence at least 1100 m consisting principally of quartzose sandstone and orthoquartzite. Unlike the Coco Range Beds, the unit does not contain a significant proportion of conglomerate and only a few thin beds of greenish-grey shale can be seen in outcrop. Several beds of orthoquartzite occur in the sequence, forming distinctive marker horizons. These beds consist of sandstone similar to that in the remainder of the unit, but with a strong secondary silica cement unlike the clayey cement of the other Devonian sandstones.

The base of the Nundooka Sandstone is not exposed, due to faulting, and the top of the unit is covered by the alluvium to the east. However, the results of petroleum drilling described above suggest that the sequence is conformable with the underlying Coco Range Beds.

(c) (?)Mesozoic and Lower Tertiary Deposits

Up to 60 m of friable micaceous siltstone, sandstone and pebble conglomerate, believed to be of Lower Tertiary age (R.L. Brunker, *pers. comm.*) is preserved in the northwestern part of Fowlers Gap Station, especially in the area west of Sandstone Tank. Although much of this material is covered by alluvium, and only sporadic occurrences can be seen, the complete succession crops out immediately west of the Station boundary, where it forms distinctive silcrete-capped mesas on Floods Creek Station. Recent excavations in connection with the deepening of Sandstone Tank have also encountered similar material beneath a cover of gravel (A.D.M. Bell, pers comm.).

Up to 30 m of the platey ferruginous sandstone, locally nodular, rests unconformably on weathered Devonian siltstone along the front of the Nundooka Ranges between Telephone and Sandy Creeks. In a creek section they are revealed over a distance of 300 m as dipping gently eastwards into the Bancannia Plains, and they also form adjoining low rounded hills, beneath a gravel mantle. Their age is not known, but it is remarkable that no silcrete clasts have been observed in them.

The middle layer of a succession of terrestrial sands and clays penetrated by Bancannia South No. 1 Oil Well (see Chapter VI) is probably also of similar age. This partly consolidated layer, which does not occur in outcrop, consists of 25 m of grey-brown shale, 36 m of white sand and 25 m of grey-green to brown shale. It is presumed to be lower Cretaceous and overlies a possibly post-Devonian layer of 23 m of red-brown shale above the red Devonian sandstone.

(d) Tertiary Duricrust

Several outcrops of silcrete, left as residuals by the present erosion patterns, are shown in Fig. IV-1. These are part of the widespread duricrust of western New South Wales and Queensland previously studied by Woolnough (1927) and by Langford-Smith and Dury (1965). The silcrete is mid- to - dark grey in colour and consists of quartz grains set in a microcrystalline silica cement. Some finer-grained phases with fewer visible granular constituents contain impressions of plant remains resembling the Tertiary to Recent Cinnamomum flora. Conglomeratic phases also exist, with rounded gravel, mainly quartz of apparent local derivation, strongly cemented by siliceous material. The silcrete rests on all the rock types described above including Upper Precambrian shale, Devonian sandstone, and (?)Lower Tertiary sediments. Detailed studies of these contacts have not yet been carried out.

Ferruginous hard cappings, presumably also part of a deep-weathering profile, are also found on dolomitic ridge crests southwest of Sandstone Tank and south of the exit from Sandy Creek gorge.

(e) Quaternary and Recent Deposits

In the east of the Station, the Mesozoic and Upper Devonian sedimentary rocks within the Bancannia Trough are overlain by an accumulation of alluvium. At the western edge of the plains the surface deposits include piedmont spreads of pebbles and cobbles, similar to the deposits which occur within the upper catchment of Sandy Creek in the area of Sandstone Tank. These consist of pebbles and cobbles of quartzite, sandstone, quartz and silcrete derived from what was probably a more extensive duricrusted surface. Further east, the alluvium is finer-textured, ranging from sand to clays.

At a distance of 6 km from the ranges Bancannia South No. 1 Oil Well penetrated 100 m of unconsolidated sediments indicating that deposition in the Bancannia Trough has persisted through the Cainozoic. This alluvium is made up of two units. The upper unit, to 75 m thick, consists of stiff clay with sandy or gravelley layers, and bands of swelling clay towards the base. The lower unit, which ranges to 20 m thick, consists of clay interbedded with quartz sand. The clay layers include lignitic materials and thin bands of dolomite. These units are described in relation to their properties as aquifers in Chapter VI.

Calcareous material or "kunkar" sometimes occurs in creek beds on the Station, and consists mainly of a whitish secondary deposit frequently cementing rock fragments together.

III. STRUCTURE

Fowlers Gap Station lies within an area which was tectonically active in Precambrian and Palaeozoic times. The Adelaidean System has suffered considerable folding in association with its regional metamorphism and thus forms distinctive outcrop patterns with converging paired ridges in the Homestead area. The dominant geological structure is the Caloola Syncline, the axis of which trends NNW through the Homestead (see Fig. IV-1). The fold plunges to the south and is outlined by quartzite horizons of the Farnell Group. On the flanks of the syncline, dips of up to 70 degrees have been recorded, but these lessen in the axial area. Minor faults also occur within the syncline, represented by off-setting of the marker quartzite beds; these faults appear to be closely related to the development of the fold itself.

A vertically dipping plane cleavage is developed in the Upper Precambrian strata. This cleavage is most apparent in the shales of the sequence, but is also present in the quartzites and carbonate rocks. The cleaved strata are intersected throughout by quartz-filled veins commonly more than 30 cm thick.

The Upper Devonian strata are also folded, although not as tightly as the Precambrian beds. An easterly plunging syncline is developed in the Coco Range, extending beyond the Station north of Sandstone Tank, and a broad east-west anticline occurs in the vicinity of Sandy Creek. In general, the Devonian sandstones dip at less than 20 degrees, and this is reflected in the broader ridges of the Nundooka Ranges, but a sudden increase in dip can be seen on the eastern edge of the ranges where values may exceed 60 degrees.

A major fault strikes generally north through the Station, separating the Upper Devonian strata into two blocks. This fault, the Nundooka Creek Fault, is downthrown to the east, but the amount of displacement cannot be fully determined. Steeply dipping strata are encountered near the fault plane, where dips to 70 degrees are noted. A marked flexing of the strata occurs just north of the Silver City Highway, where several orthoquartzite marker horizons swing abruptly into parallelism with the line of faulting.

Along a zone on each side of the fault the sandstones are intruded by an irregular network of veins of white recrystallised quartz, apparently the result of high stress conditons associated with the faulting. Similar but less intense veining is also found along the axes of the gentle folds in the Devonian strata.

IV. GEOLOGY AND LAND SYSTEMS

Geology affects the land systems in several ways Surface form is determined by bedrock structure and lithology, the nature and thickness of the soil is determined by the chemical composition of the rock and its resistance to weathering, and vegetation is affected directly by the environment produced by rock outcrop, and indirectly through soil properties. These effects are here considered in relation to the land systems on Fowlers Gap Station.

(a) Erosional Land Systems

Structure is most important in controlling gross relief, while lithology and consequent soil development control more detailed landform (see Table IV-2). In this, as in other arid areas where the transport of rock waste proceeds as rapidly as weathering itself, rock structure and composition are emphasised in relief and there is extensive exposure of bedrock in all upland areas. There is hence a close correspondence between geologic and erosional land system boundaries.

In Faraway land system, steeply dipping Precambrian quartzite in the Caloola Syncline forms spectacular paired ridges, giving rise to the maximum relief on the Station. Subsequent transverse faulting guides the main transverse drainage as in the water gaps of Fowlers Creek. In contrast, gently tilted massive Devonian sandstone forms the broad cuestas of Nundooka land system and the low ridges and hills of Mulga Dam land system. The transverse gorge of Sandy Creek through the Nundooka Ranges is probably related to a transverse anticlinal flexure. The high feldspar and clay content of these Nundooka and Coco Range sandstones has led to the formation of soil with sufficient swelling clay to allow the development of lobate steps on the hill slopes.

Steeply dipping Proterozoic sandstone also forms narrow ridges, lower than those formed of quartzite, as in Faraway, Limestone, and Nuntherungie land systems.

In this arid environment limestone is quite stable and thin dolostone beds form strike ridges through the shale lowlands of Nuntherungie and Limestone land systems. These outcrops are characterised by the growth of calcicolous plants such as bluebush, and by a general absence of soil.

Interbedded shale weathers more readily than quartzite, sandstone or dolostone, to form loamy soils, generally calcareous due to intercalated limestone lenses as in South Sandstone land system. This soil is often strongly leached on stable

TABLE IV-2. RELATIONSHIP BETWEEN LITHOLOGY, STRUCTURE AND EROSIONAL LAND SYSTEMS

LITHOLOGY	STRUCTURE			
	High Resistance		Moderate Resistance	Low Resistance
	Steep dips: narrow ridges	Moderate dips: cuestas	Steep dips: ridges and hills	Footslopes and rounded hills
Quartzite	Faraway (part)			
Quartz sandstone with feldspar laths		Nundooka Mulga Dam		
Calcareous slate and shale				Nuntherungie (part) South Sandstone Faraway (part)
Dolomitic limestone			Limestone Nuntherungie (part)	

hillcrests as in Nuntherungie and parts of Faraway and Old Homestead land systems.

On most surfaces on shale there is a considerable cover of quartz gravel derived from quartz veins in the Adelaidean beds and often recycled. There is a sufficient swelling clay constituent in these soils to allow gilgai development and consequent arrangement of this gravel in contour bands. The relatively deep soils and weathered rock facilitate severe gullying on steeper slopes, while the calcareous light clayey soils are subject to "bulldust" formation and severe wind erosion.

(b) Depositional Land Systems

Geology affects the depositional land systems chiefly through the composition and texture of derived sediments (see Table IV-3). On this basis the depositional land systems on Fowlers Gap Station fall into three main groups, consisting respectively of gravel, coarse-textured alluvium, and fine-textured alluvium.

Two land systems have extensive gravel deposits. In Sandstone Tank land system, gravel of silcrete, quartz, and quartzite, derived mainly from silcrete cappings and from (?)Tertiary pre-silcrete fills further west, are arranged in contour bands associated with gilgai activity. A similar surface pattern occurs on gravel-mantled piedmont slopes of Gap Hills land system east of the Faraway Hills and Nundooka Ranges. The gravels resemble those of Sandstone Tank land system but are doubtless in part derived from sandstones and conglomerates in the Precambrian and Devonian successions in the ranges. Old Homestead land system similarly has areas of terrace gravels deposited by Fowlers Creek, but these have been extensively stripped and dissected, locally exposing the underlying shale.

TABLE IV-3. RELATIONSHIP BETWEEN SUPERFICIAL MATERIAL AND DEPOSITIONAL LAND SYSTEMS

Deposited Material	Land System
Gravelly alluvium	Sandstone Tank
	Gap Hills
	Old Homestead
Sandy alluvium	Fowlers
	Sandy Creek
	Conservation
Fine-textured alluvium	Mandleman
	Caloola

Beyond the piedmont zone, Fowlers, Telephone and Sandy Creeks have carried sand derived mainly from sandstone and quartzite ranges and have deposited it in levees and channel fills in Fowlers land system and as sandy floodouts in Sandy Creek land system. Between and beyond these zones of active deposition are the stable plains of sandy alluvium mapped as Conservation land system. Some of this alluvial sand has been reworked by the wind, forming sand hummocks, particularly in Conservation land system.

In its floodout zone, Fowlers Creek finally deposits fine-textured alluvium in Mandleman land system, whilst Caloola Creek has also formed terminal plains of fine-textured alluvium mapped as Caloola land system. Both these creeks drain extensive areas of shale and limestone south and west of the Station and the fine-textured alluvium, calcareous at depth, in these land systems reflects this as well as its position in the landscape. These floodout areas have extensive gilgai microrelief, reflecting an element of swelling clay.

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CHAPTER V. GEOMORPHOLOGY OF FOWLERS GAP STATION

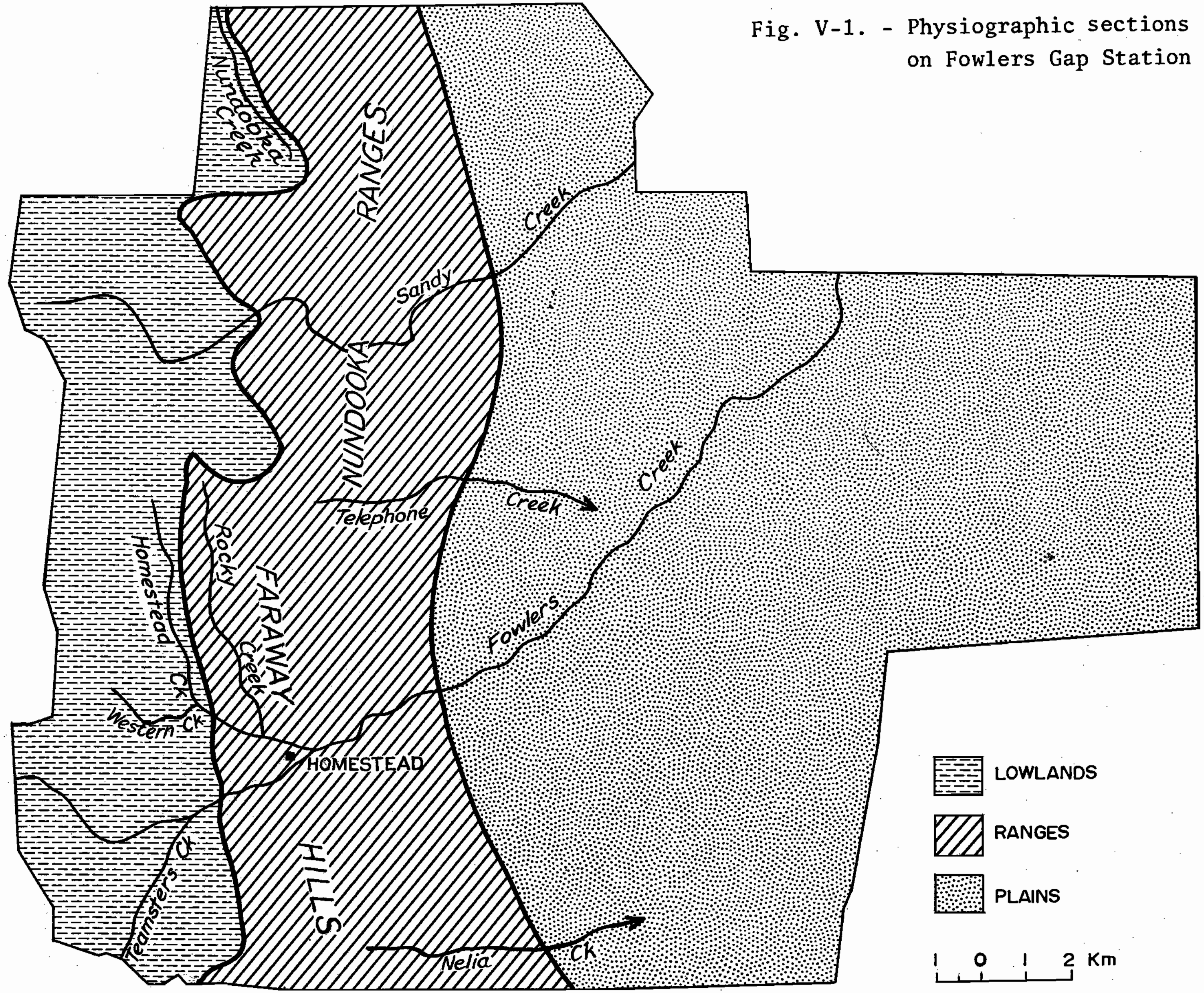
by J. A. Mabbutt

I. INTRODUCTION

Fowlers Gap Station comprises three physiographic sections (Fig.V-1) which trend north and south with the regional strike. In the west is an undulating lowland with low ridges, mainly between 180 and 240 m above sealevel and typically with between 10 and 30 m relief. There follows a central belt of ranges and foothills with up to 100 m relief locally and attaining 294 m above sealevel in the north; these are part of the Barrier Range, here declining towards its north end. In the absence of local names, Faraway Hills is used for the paired ridges and hills in the south and Nundooka Ranges for the broader cuestas in the north. The eastern section of the Station consists of alluvial plains which descend eastwards from about 170 m to 140 m above sealevel, flanking the lower course of Fowlers Creek.

With the exception of a very small area in the northwest, which drains towards Lake Frome, the Station falls entirely within the Lake Bancannia system, the smallest of the interior drainage basins defined by Tertiary earth movements in the south of the Great Artesian Basin. In the south, drainage is to Fowlers Creek, which rises to the southwest, traverses the ridges of the Faraway Hills in two water gaps, of which the downstream one has given the Station its name, and then floods out on the plains to the east and northeast. The drainage in the north of the Station has two components: Sandy Creek with its open upper catchment above Sandstone Tank drains eastwards in a gorge through the Nundooka Ranges, and north again is the upper part of the catchment of Nundooka Creek, which runs northwards beyond the Station boundary

Fig. V-1. - Physiographic sections
on Fowlers Gap Station



before swinging northeast through the Barrier Range to enter Lake Bancannia.

The Station occupies a transect from erosional uplands and lowlands into alluvial plains, characteristic of an arid region of interior drainage. The remainder of the geomorphic spectrum, the terminal salt lakes and sand dunes, lies beyond the boundaries of the Station to the east and north.

This account of the geomorphology of Fowlers Gap Station and its land systems first considers relict features of the landscape through an account of its land surface history. The present-day morphogenetic processes are reviewed and the dynamic status of erosional and depositional land surfaces in the area is then described. The geomorphology of the land systems is treated in the historical or later sections, according to whether the elements are considered to be inherited or related to the present regime.

II. GEOMORPHIC HISTORY AND INHERITED LAND SURFACE ELEMENTS

Many land surface and drainage elements on the Station originated in earlier periods when relief energy and climate differed from today, and some of their associated attributes, for instance weathering mantles, are similarly inherited. An understanding of such land system elements involves consideration of the history of the landscape, including past formative climates.

(a) Tertiary Land Surfaces

The oldest landforms are survivals from a former land surface which mainly stood above present base levels and which in the Station area takes two main forms, namely upland surface remnants in the ranges and duricrusted mesa summits above the lowlands.

(i) Upland Surface Remnants - The upland surface remnants comprise two elements. The higher element is an undulating summit plane, mainly between 280 and 300 m, in the Nundooka Ranges north of Sandy Creek gorge; the even crest lines of the paired quartzite hogback ridges in the Faraway Hills are probably an equivalent survival further south. A lower component is the more prominent bevel at approximately 220 m in the east of the Nundooka Ranges, across steeply dipping, little-resistant calcareous sandstone. This lower bevel is extended upstream along Sandy Creek in flat hill summits with gravel mantles, and as benches and perched valley plains. It rises eastwards and continues at 250 m along the west side of the Nundooka Ranges.

The two components appear to indicate two erosional stages preserved only on resistant rocks. At the later stage of the lower bevel, the upland surface would have been one of rounded crests and concave slopes with half the relief of the present ranges. The meridional strike grain of ridge and valley already existed as today, but in less pronounced form, for many cols and sloping bevels indicate that transverse drainage across the ranges may have been more developed than at present. This is also supported by the occurrence on some crestal slopes, especially north of Sandy Creek, of gravels originating from Proterozoic rocks or derived (?) Tertiary deposits to the west.

(ii) Duricrusted Mesa Summits - There are only minor summits on and near Fowlers Gap Station, for the main occurrences are to the northeast in the Great Artesian Basin. However, characteristic forms occur about 1 km west of the boundary, on Floods Creek Station, and lesser examples in the Nundooka Ranges where they establish a relationship with the upland surface. Since the mesas on Floods Creek Station yield evidence of the form of the Tertiary land surface in this area, they are briefly considered here. They have characteristic grey-brown silcrete cappings 1.5-3 m thick, locally conglomeratic with rounded quartz pebbles. The cappings, which show characteristic columnar jointing and give rise to breakaway forms, occur above a weathered profile in little-consolidated deposits up to 60 m thick, of presumed Lower Tertiary age (Ward, Wright-Smith, and Taylor, 1969). About 50 m of the deposits below the silcrete are weathered to a bleached grey, with some iron mottling in the uppermost 5-10 m below the duricrust. The silcrete is regarded as a near-surface indurated horizon, and if we accept the date of mid-Miocene obtained from the Great Artesian Basin (Dury, Langford-Smith, and McDougall, 1965) it marks a mid-Tertiary land surface which in this area was locally depositional.

Other tabular silcrete cappings occur at 250 m on a low sandstone ridge in the Faraway Hills 2.5 km south of Sandstone Tank and also at 210 m on the eastern foothills of the Nundooka Ranges between Sandy and Telephone Creeks. These occurrences are at the level of the lower elements of the upland surface and appear to link that element with the silcrete. Other silcrete remnants east of the Silver City Highway and about 1 km south of the Station boundary (Langford-Smith and Dury, 1965) cap a broad spur extending west from the Far-Away Hills at about 210 m and confirm that the ridge crests, here at 250-270 m, stood above the general silcrete level.

Some lowland ridge crests, although lacking silcrete cappings, apparently extended up into the zone of silicification. For instance, dolomitic crests at about 250 m beyond the head of Western Creek carry partly siliceous crusts with iron oxide which have previously been mapped as "ferricreted aggregates" (Ward, Wright-Smith, and Taylor, 1969).

Although silcrete in situ is restricted, widespread silcrete fragments indicate that the duricrust was formerly extensive across the lower parts of the area. It linked laterally with the lower elements of the upland surface and a thin mantle of silcrete also appears to have continued across much of the uplands; for example, there are scattered blocks of silcrete up to 10 cm thick on upper hillslopes in the Nundooka Ranges, on both elements of the upland surface, and thin silcrete skins have been observed adhering to sandstone outcrops.

There is a general descent of the silcrete eastwards, from the mesa remnants at about 275 m on Floods Creek Station towards the Nundooka Ranges, where the cappings are accordant with benches and perched valleys along Sandy Creek gorge. The mesas are on the drainage divide between the Lake Bancannia and Lake Frome drainage units, a topographic position incompatible with the alluvial deposits with which the silcrete is accordant. From evidence elsewhere in the region (Mabbutt, 1972) the Bancannia basin appears to have been defined by warping of the silcrete, and it is therefore assumed that the present drainage in this area originated through subsidence of the silcrete surface to the east and that the benches along Sandy Creek gorge were graded by this drainage.

East of the ranges the silcrete surface formed piedmont slopes towards the Bancannia Plains, but in the area of the Station it probably stood above the present base level and was removed by erosion before deposition occurred.

Evidence that the climate prevailing on the Tertiary land surfaces was effectively more humid than that of today consists of:

(1) Upland crests more rounded than younger, lower hillslopes.

(2) General deep weathering, including kaolinisation of soft rocks beneath the silcrete and selective weathering of harder rocks on the upland surface, for instance of feldspathic sandstone.

(3) Surface silicification, not only as silcrete cappings but including secondary silicification of resistant sandstone.

(4) On a regional scale, a predominance of erosional surfaces over depositional plans, indicative of a more competent out-going drainage than the present.

(b) <u>Surfaces Formed Below the Tertiary Land Surface</u>

Destruction of the Tertiary land surface in the southwest of the Great Artesian Basin generally followed doming and basining of the silcreted surface, causing dissection in peripheral uplifted zones and deposition in the basins. On Fowlers Gap Station it took two forms reflecting contrasts in geologic structure and relief.

(i) <u>Upper Valleys</u> - In the west, behind the protective barrier of the ranges, open valleys were formed below the silcrete level on weak Proterozoic shale. This is the land surface preserved in the upper catchment of Sandy Creek and described as Sandstone Tank land system, with moderate to gentle slopes of 1.5 to 3 per cent and with less than 25 m of relief. It is thickly mantled with gravel, including silcrete cobbles as well as more rounded gravel of quartz, quartzite and sandstone. Some of the gravel, which exceeds 5 m thick at Sandstone Tank, has been derived from the (?) Lower Tertiary fill described above. However, this fill extended eastwards only a short distance into the Station area and the catchment was mainly eroded into underlying shale before deposition of gravels occurred above the gorge outlet to the east. Palaeozoic conglomerate in the adjoining ranges also provided an important gravel source.

Stonier rises locally interrupt the smooth gravel-covered profiles near the perimeter of the catchment, and at these points the gravel mantle is coarser and richer in silcrete and also thinner, with weathered shale exposed locally. Since these rises occur at about 250 m, only a few metres below the projected original level of the silcrete, they may mark points at which the duricrust survived longest, possibly as cappings of low mesas.

In detail, the gravel-mantled slopes consist of alternating unvegetated stony bands and less stony shrub-covered bands. The bands are aligned along the contour and form the two components of a terraced profile in which the stony bands are the relatively steeper fronts and the less stony areas the flats. Gilgai depressions to 50 cm deep and 2 m across are aligned along the flats and impart a lobate element to the banding pattern, since the stone cover tends to extend concentrically around the depressions. The relationships are shown diagrammatically in Fig. V-2A. These microtopographic sequences are associated with alternations in soils and vegetation which are listed in the land system tables in Chapter II.

The features are commonly emphasised by the white quartz stone between the strips of dark green shrub and appear on the airphoto as alternate lighter (stony) and darker-toned (vegetated) bands. They are analagous to the sorted stone steps of desert gilgai (Ollier, 1966). The stony riser equates with the mound of stony gilgai terrain (Hallsworth, Robertson, and Gibbons, 1955) and the less stony flat with the shelf, but with distortion due to slope such that several shelves and included depressions are linked and extended along the contour, whilst the mounds on the upslope side are forced up as the stony riser and on the downslope side merge into the stony band below. The gilgai phenomena are associated with some upward extrusion of stone from the mound subsoil, adding to the stoniness of the mantle on the riser.

The bands form a series of repetitive hydrologic units, since the risers and flats are zones of runoff and run-on respectively, resulting in differential wetting and swelling. The pattern is a system in dynamic equilibrium in which the

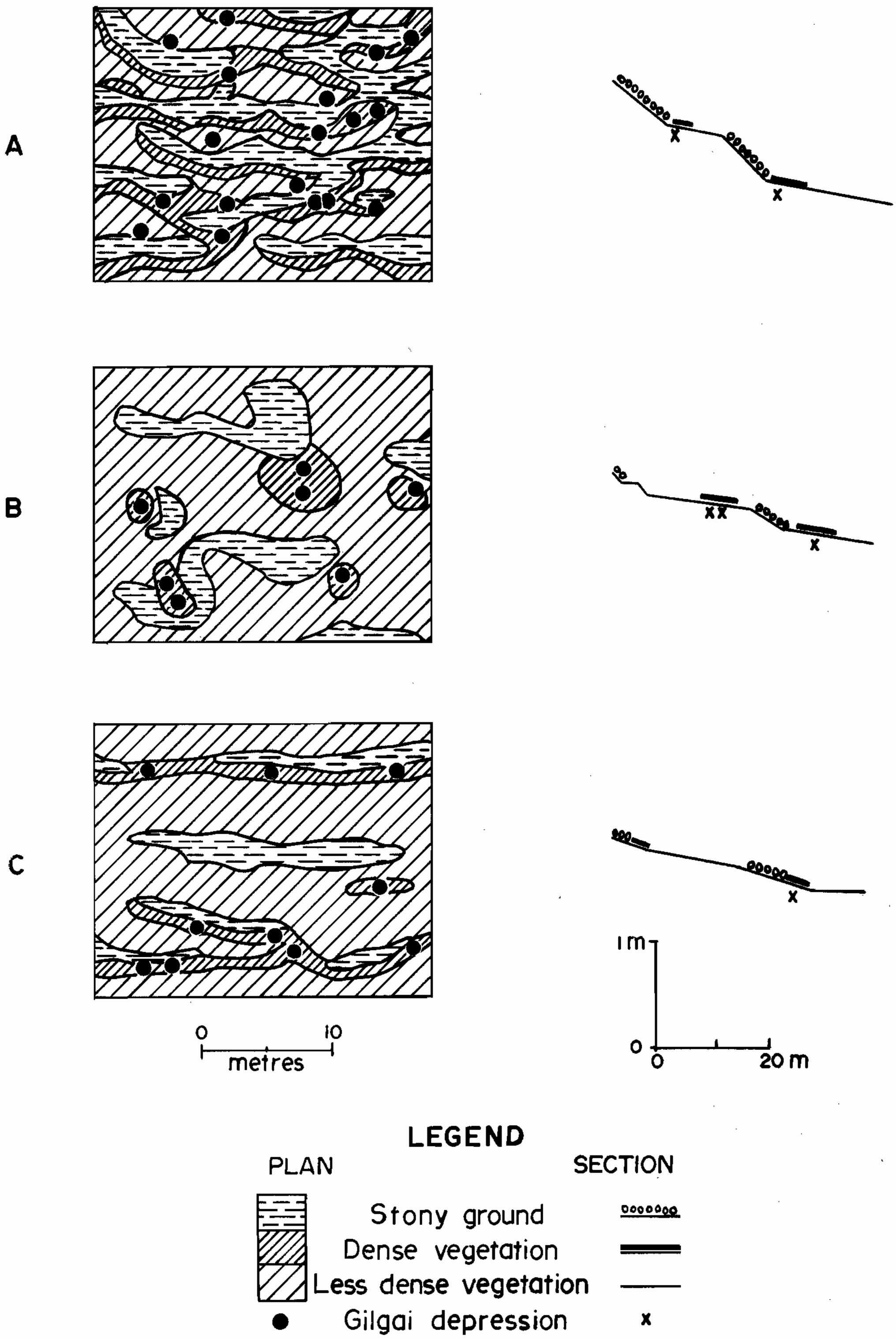


Fig. V-2. Microrelief of types of patterned ground independent factors are the slope mantle, with its element of swelling clay, and the sheet runoff; these generate a microrelief which is maintained by its own resultant hydrologic regime, resisting regrading through regressive erosion on the risers and deposition on the flats. The system naturally opposes the initiation of slope gullies and this is reflected in the low stream densities and bifurcation ratios of Sandstone Tank land system (Table V-1) and in scant channel development along the shallow valley floors.

A similar upper valley drained by Nundooka Creek survives to the north of the Sandy Creek catchment from which it is separated by a rounded gravel-mantled divide at about 250 m. Other such surfaces previously existed to the south, in the narrower catchment of Homestead Creek and more extensively in Fowlers Creek catchment, but have since been dissected by this more vigorous drainage and are restricted to accordant crests and footslopes in Nuntherungie and Limestone land systems.

(ii) Ranges, Intermont Valleys, and Footslopes - The equivalent surfaces formed in the belt of ranges show greater variety, reflecting the geologic diversity.

In the Faraway Hills, smooth lower hillslopes with moderately deep sandy colluvial mantles graded into intermont vales on shale, about 10 m above the present valley floors, which opened out southwards with the Caloola Syncline into undulating lowlands. The intermont valley floors were distinctly planed along Fowlers and Rocky Creeks and mantled with river gravels, as near the Homestead. Much of these intermont lowland surfaces bore a leached stony mantle. Beds of sandstone formed broad low rises within the vales, becoming more prominent in the north towards the nose of the plunging syncline. Their crests are below the general level of the silcrete remnants, indicating that erosion below the Tertiary land surface in this upland tract had led to an increase in the strike grain of relief and drainage that has continued to the present. The main survivals of the intermont lowland surface are footslope spurs and accordant interfluves with leached cappings which have escaped subsequent dissection and stripping. The river-planed surfaces have been mapped into Old Homestead land system and the remainder left in the complex Faraway land system.

In the Nundooka Ranges, mapped as Nundooka land system, there is greater survival of Tertiary surface elements. Drainage incision into the Tertiary surface has been vigorous along Sandy Creek gorge, leaving remnants of the Tertiary valley as gravel-mantled spurs, but otherwise only narrow tributary strike valleys like that east of Clancy Trig. Point were formed at this stage. Their age is shown by their accordance with the upper catchment of Sandy Creek, although they are now perched between 10 and 15 m above the present channels.

More extensively, there was regrading of the long dip slopes in the west and dissection of Tertiary summit bevels into accordant flat-crested ridges in the east of the Ranges. Parts of the regraded slopes bear colluvial mantles up to 50 cm thick, including fragments of silcrete and showing evidence of advanced weathering and some upward stone sorting. These rest abruptly on little-weathered rock, suggesting that slope mantles inherited from the Tertiary land surface may have been transported to lower levels.

East of the ranges, smooth concave footslopes were cut across soft Devonian sandstone and siltstone in a zone which widened northwards with the outcrop of the Nundooka Sandstone, reaching its maximum width of 4 km north of Sandy Creek. The slope was mantled with gravel to at least 3 m thick, including quartz and silcrete from west of the ranges as well as locally derived quartzite. This mantle was formed into a stepped contour pattern of stonier and less stony bands similar to that described from Sandstone Tank land system. However these footslopes are differentiated by greater subsequent dissection and have been distinguished as Gap Hills land system.

III. CURRENT MORPHOGENESIS

Present-day surfaces on Fowlers Gap Station have resulted from renewed incision of drainage in the western half of the Station, involving dissection and stripping of the inherited land surfaces described above and reworking of associated slope mantles. At the same time there has been a progressive adjustment to the present arid morphogenetic regime, involving the proliferation of minor drainage channels, limitation of weathering mantles on newly-eroded slopes, and increased adjustment of minor forms to lithology and geologic structure.

The current morphogenetic regime may be defined as "moderate desert", in which erosion by integrated stream systems predominates on sloping ground and deposition by disintegrating systems in piedmont zones. Wind action becomes increasingly important with distance from the uplands, but most aeolian landforms are now at least partially stabilised by vegetation. The main land-forming processes are described below.

(i) Weathering - Deep weathering profiles and leached slope mantles with evidence of clay weathering and translocation are fairly widespread on Fowlers Gap Station, but their association with relict land surfaces suggests their inheritance from past conditons. Under the prevailing regime, with potential evaporation about 10 times the average annual rainfall, current weathering can be partial and superficial only, save in favoured micro-climates. This is confirmed by extensive outcrop in which the rock remains structurally intact to the surface, and by widespread encrustation with oxides of iron and manganese, case-hardening beneath which carious weathering commonly proceeds in a relatively weakened horizon. Within the shallow weathering zone, disintegration generally forestalls decomposition and it is physical cohesion rather than chemical stability which determines rock resistance; for instance, hard dolomite stands out among cleaved shale or weakly cemented sandstone. In the absence of chemical weathering, structurally controlled physical disruption occurs at various scales, for instance the blocky disintegration of quartzite, the laminar cleaving of shale or flaggy sandstone, and thin exfoliation on massive sandstone surfaces. Much of this breakdown may be physico-chemical, the result of stress due to volume changes associated with encrustation from capillary solutions, but thermal expansion of strongly heated bare surfaces and the release of connate stresses may also contribute to the final breakdown.

Although topsoils are commonly leached of lime, possible pre-weathering makes it difficult to assess the current degree of leaching; however, secondary lime crusts are common on calcareous rocks and lime hardpan, nodules, or dispersed lime occur in associated soils. Powdery, lime-impregnated soils are among the most vulnerable to wind erosion on the Station.

Salt lakes occur in the region, and salt of possible cyclic origin is abundant in topsoils; it plays an indirect part in soil erosion by causing loose topsoils and strong textural contrasts.

Rates of rock disintegration, and particularly of secondary comminution appear to be slow, for although surface stone is widespread it is generally a superficial layer, and the fragments are commonly coated with desert varnish. On sloping ground, surface wash appears competent to remove weathering products as they form; there is generally little depth of accumulation and the rock is commonly exposed. Under such conditions, the smallest differences in lithology are exploited by weathering and expressed in the details of slope form.

(ii) Mass Movement - Generally, mass movement on hill slopes is not an important feature of arid areas, where slope mantles are usually thin and lacking in clay matrix. Loamy mantles of moderate depth do exist locally on Fowlers Gap however, for instance on felspathic sandstone in Nundooka land system, where stone-fronted lobes and tilted stone slabs indicate downslope movement of the mantle and its contained stone, possibly combined with gilgai activity. These phenomena are also associated with tunnelling and gullying. On gibber-mantled slopes of weathered shale below silcrete cappings there are smaller but straighter steps, probably of similar origin to the lobes of Nundooka land system.

The contour steps of Nuntherungie, Sandstone Tank, and Gap Hills land systems similarly represent a combination of mass movement with gilgai activitity in mantles weathered from shale. It is of course possible that these microforms, like the mantles in which they are developed, may have been inherited from past moister periods. Airphotos of the Station show a remarkable development of paterned ground, suggesting affinities with a periglacial regime with the periodic swelling of clays replacing freeze-thaw processes.

Small mud flows have occurred locally on shale slopes in Faraway land system, mainly in gully depressions, and are marked by parallel levees and terminal lobes. In these, saturated soft bedrock has presumably acted as a lubricant for the stony mantle.

(iii) Runoff and Stream Action - Bell (1972) has reviewed evidence of runoff in the region, indicating that this may range between 10 per cent of annual rainfall for small upland catchments and as little as 2 per cent from the plains, i.e. between 20 mm and 5 mm annually at Fowlers Gap. Drainage patterns on the Station reflect the control by relief and surface deposits over the local runoff response; essentially the ranges and lowlands in the western half are the only source of drainage, and they supply run-on to the eastern plains.

Overland flow has been observed to begin on moderate slopes after a sharp rainfall of 5 mm and to be maintained by falls of 1 cm per hour. Such runoff is effective in erosion and transport, particularly in its initial stages, since it is favoured by sparse vegetation and by a wisespread loose veneer of wind-blown sand. Sediment traps on upper slopes in Nundooka land system have demonstrated abundant silt and sand in runoff above gully heads, and the efficacy of hill wash in transport is indicated by the widespread steps or terracettes a few centimetres high formed as a result of trapping of sediment behind lines of boulders on hillslopes.

The zone of overland flow may be as narrow as 50 m on the ranges, as in Faraway land system, and increases to 75 m on the lowlands; it widens to 100 m on stepped slopes with gravel mantles, as in Sandstone Tank land system, and attains 140 m on the moderate sandy slopes of Mulga Dam land system. Parallel "shoe-string" gullies at the lower margin of the zone of overland flow in parts of Nundooka and Faraway land systems suggest that Horton overland flow predominates on open slopes with shallow soils. However, through-flow and saturation overland flow (Kirkby and Chorley, 1967) occur on less regular slopes and in areas of deeper soil, as indicated by tunnelling and percolines headwards of extending gullies.

A survey of surface water resources on the Station and a questionnaire to local landholders have yielded preliminary evidence of the regimen of the ephemeral stream channels on the Station. Floods of an hour or two's duration in third or fourth order channels, sufficient to cause recharge of surface tanks, occur with heavy falls in excess of 15 mm, that is about five times each year. These may not feed into the fifth and sixth order channels of the piedmont zones, which can be expected to flood only on two or three occasions annually, generally for periods of 24 hours and with heavy local falls of between 50 and 100 mm. Extensive flooding on the alluvial plains occurs at intervals of one to two years, with regional rainfalls exceeding 100 mm.

Drainage characteristics of erosional land systems on the Station are given in Table V-1. Drainage densities, measured as kilometres of channel per square kilometre, are moderate to high. The controls are steepness of slope and the presence of erodible, relatively impervious rock such as shale, and both of these are indicated in the relatively high densities of Faraway land system. The lower densities for Nundooka land system reflect the extensive outcrop of resistant sandstone. The suppression of gullying on gravel-mantled surfaces with contour steps has resulted in lower densities for Gap Hills and Sandstone Tank land systems, and particularly in reduced bifurcation ratios between first and second order channels. Stripping of the mantles by rejuvenated drainage has led to closer gullying in Nuntherungie land system, and particularly also in South Sandstone land system.

Accelerated extension of stream channels on shale slopes, for instance where the construction of Station roads has removed protective gravel mantles or where tracks and sheep walks have concentrated runoff, has resulted in severe gullying locally, as in the southwest of the Station in Nuntherungie land system.

Most stream channels in the western half of the Station are in or close to bedrock and the thickness of adjoining alluvial fills is generally less than 2 m, even along the main streams. Many channels in shale country show evidence of recent deepening however, with incision into formerly undissected

TABLE V-1. DRAINAGE CHARACTERISTICS OF EROSIONAL LAND SYSTEMS*

Land System	Drainage Density (km/km^2)	Constant of Channel Maintenance (km^2 per km of channel)	Average Length of Overland Flow (m)	Bifurcation Ratios First/Second Order Channels
Faraway	11 44	0.09	45	5
Gap Hills+	4.44	0.23	115	3
Limestone	5.77	0.17	85	5
Mulga Dam	3.50	0.29	145	2
Nundooka	5.94	0.17	85	4
Nuntherungie	6.63	0.15	75	4
Sandstone Tank	5.22	0.19	95	3
South Sandstone	9.22	0.11	55	4

* Old Homestead land system omitted because of small area; probably resembles Nuntherungie land system

\+ Upper sector only

alluvial or colluvial mantles with well-developed soils Deep subsoils with vertical columnar structures have locally favoured this process, which is probably due to increased runoff from degraded catchments. Associated changes in the larger drainage tracts include the shoaling and braiding of channels (a common expression of increased discharge), regressive gullying of alluvial floodplains, and widespread sheet erosion of alluvial soils down to the B horizons of texture-contrast profiles.

Beyond the piedmont zone the role of the stream systems is depositional. Channels progressively shoal and braid, particularly where, as along the east front of the Nundooka Ranges, they are fed with sandy alluvium. Most of the smaller channel systems die out within 2 km of the uplands, often passing into shallow depressions in which channels are discontinuous or lacking, associated with the transition to finer-textured alluvia. Sheet runoff may recur in these piedmont lowlands, presumably in the form of saturated overland flow. The disorganisation of lowland drainage is advanced by the backponding of minor systems by major depositing channels, as among the left bank tributaries of Fowlers Creek. Stages of breakdown of the main channel of Fowlers Creek are discussed in detail in the account of Fowlers and Mandleman land systems.

Accelerated runoff and erosion in upland catchments have led to increased shoaling of channels in the piedmont zone, as in Sandy Creek land system, to accelerated deposition of sands in some floodplains and to concomitant erosion in others.

(iv) <u>Wind Erosion</u> - Long rainless periods and a sparse vegetation favour wind erosion at Fowlers Gap. Aeolian and fluvial processes are not independent of each other however; many sand-moving winds occur in disturbed spells of rainy weather and the most severe dust storms are commonly associated with the passage of fronts. Further, sediments left by prior flooding are vulnerable to wind erosion, and severe dust storms often follow closely after light rains in times of general drought. Nevertheless, erosion and transport by wind, unlike stream action, can occur throughout the long dry periods between episodes of runoff. At Broken Hill for example, winds exceeding 16 km and hence effective in erosion occur on 50 days in the year on an average, and there is in addition the localised effect of "Willy willies" during the warm months, particularly across the plains. Wind erosion is also more widely-acting than stream erosion and its general effectiveness on the Station is indicated by the ubiquitous mounding of sand around the bases of shrubs.

Wind erosion constitutes a major problem to the pastoral industry, through the removal of topsoil and seed reservoirs, undermining of the roots of shrubs, the killing of seedlings through abrasion or desiccation, and also through the burial of pasture plants. Dust pollution of fleeces is equally of major concern.

There are important variations in the severity of wind erosion and dust blowing in different parts of Fowlers Gap as determined by relief, vegetation and stone cover, surface soil texture, and land use. The windiest areas are the open plains in the east of the Station and the lowlands in the west and south, where a general absence of trees reinforces exposure through lack of sheltering relief. In many parts of the lowlands however, the shrub cover effectively restricts wind erosion, particularly where it is associated with stone pavements as in Sandstone Tank, Gap Hills, and parts of Nuntherungie land systems; however, where this cover has deteriorated, as around watering points, in holding paddocks, or along stock routes, the shale country with its friable fine sandy and silty soils becomes subject to severe blowing. This is the case in the southwest of the Station, particularly in Old Homestead land system and near the present Homestead site. The most vulnerable surfaces in the lowland areas are the interfluves lacking stony mantles and with solonized calcareous soils, particularly in Nuntherungie and parts of Faraway land systems, where rabbit depredation has been severe and a former shrub cover destroyed.

Sandy alluvial soils are everywhere subject to wind erosion, and here wind and water erosion (sheeting) combine in the formation of scalds, which are particularly widespread in Conservation land system. The vulnerability of floodplain soils to wind erosion is increased in that channel frontage country, with temporary surface waters and short-lived feed after flooding, are subject to extensive trampling by stock. Fowlers and Sandy Creek land systems are among the most severely wind-eroded areas in the Station. Floodplains in the western half of the Station also form localised areas of strong wind erosion; for example sand has drifted extensively from Sandy Creek and its tributary floodplains eastwards to the slopes of Mulga Dam and Nundooka land systems.

On hill slopes and in areas subject to flooding, wind-formed sand accumulations tend to be reshaped or removed by subsequent water action; it is on the stable alluvial plains of Conservation land system that the wind-formed accumulations around shrubs are most marked, particularly in the lee of small floodouts, where mounds up to 60 cm high and sand drifts up to 5 m long have been observed. Along the margins of the zone of fluvial activity, wind-modified surfaces increase in importance as the frequency of flooding diminishes, and along the north-east margins of the Station one finds elongate sandy rises where Mandleman land system passes into Conservation land system, presaging the development of the linear dunes that occur some 20 km to the east.

The self-mulching heavier-textured alluvial soils of Mandleman and Caloola land systems are naturally less subject to wind erosion, but are nevertheless liable to dust-blowing where stock have overgrazed and trampled the surface.

There are no large-scale aeolian landforms on Fowlers Gap. A small claypan with a low lunette rim on its NNE margin occurs near the front of the Nundooka Ranges north of Telephone Creek, representing in miniature form the large lunette lakes which exist in the Bancannia Plains to the northeast of the Station. It also confirms that the dominant direction of sand movement is between east and northeast, as at the time of formation of the sand ridges of this region, and this is also indicated by the general drift of sand eastwards from source areas, as from Sandstone Tank into Nundooka and Mulga Dam land systems.

IV. EROSIONAL LAND SYSTEMS

The erosional land systems described in Chapter II are here discussed within the three physiographic sections of western lowlands, central ranges, and eastern piedmont.

(i) Western Lowlands - In the north, the perched catchments of Sandstone Tank land system have been protected and preserved virtually intact by the Nundooka Ranges. In the south, however, rejuvenation of Fowlers and Homestead Creek systems has regressed through the narrow water gaps in the Faraway Hills and caused dissection and extensive stripping in Nuntherungie land system. This contrast in drainage energy is expressed topographically in the low east-west escarpment of South Sandstone land system, where south-going first-order tributaries of Homestead Creek are undercutting the northerly and easterly system of Sandy Creek.

This southern tract of lowlands has been dissected into undulating surfaces with a local relief of up to 25 m, in which accordant broadly rounded interfluves mark a former plain. The associated proliferation of low-order drainage channels in these actively eroding land systems is shown by comparison of South Sandstone and Nuntherungie land systems with Sandstone Tank land system in Table V-1. The soft and partly weathered shale of the Teamsters Creek Beds is vulnerable to gullying, as are the overlying leached mantles. The latter, with their protective gravel, are stable under conditions of overland flow, but the well-structured subsoils are readily eroded once the gravel bands and the associated microrelief are breached by channels.

Rejuvenation and extension of linear drainage has been accompanied by stripping and re-working of the inherited stony mantles, particularly near the main drainage channels. Where stripping is complete, a calcareous surface has been exposed, lacking the banding pattern and associated microrelief. Such "bare" interfluves (Unit 2 of Nuntherungie land system) show some N-S alignment and may mark strike belts of more calcareous shale as indicated by the occurrence of a lime hardpan in the subsoil; however, it is noteworthy that where this strike belt passes into Sandstone Tank land system it <u>is</u> gravel-mantled, with banding and microrelief. Another factor contributing to the degree of stripping may have been differences in the original gravel supply with distance from bounding ridges or depositing river channels, for it is noted that a stripped zone runs along and west of Homestead Creek along the centre of the vale, where the detritus may originally have been thinner.

Since the mantles extend across lower slopes presumed to have been eroded below the original surface, the material must in part be transported. Consistent with this, stones from depths of up to 75 cm have included silcrete and quartzite as well as shale and quartz fragments from the bedrock below. Presumably gilgai activity associated with the banded microrelief has led to lateral as well as to vertical displacement of the mantle.

Nuntherungie land system illustrates topographic controls of the banding patterns. These do not occur on upper footslopes exceeding 5 per cent; then follows a downslope increase in the regularity and length of the bands until the pattern attains its clearest expression in mid-slope, where declivities are between 3 and 5 per cent and the band-interband spacing is about 15 m and where bands may extend between 50 and 100 m along the contour. On the upper slope sectors, particularly on footslopes below quartzite ridges, the patterns and microrelief resemble those of Sandstone Tank land system, but in their fuller development downslope they exhibit significant differences reflecting gentler slopes, less stone, and diminished gilgai. The treads of the stepped profiles are here broader, wider, and more parallel with the contour, and this is associated with the appearance of a third element in the pattern, namely flat surfaces around the aligned gilgai depressions, which are here set towards the inner parts of the steps. These surfaces are partly bare, adjacent to the depressions, and partly stone-mantled. The risers are lower, more gently sloping, and less stony than in Sandstone Tank land system.

Still further downslope the bands may widen to a repetition interval of more than 25 m, but on slopes of less than 2 per cent the pattern becomes irregular, with greater influence of the central gilgai depressions over the trends of the stony bands (Fig.V-2B). Length as well as degree of slope may be important in these variations, in that greater run-on in lower slope sectors might increase the influence of individual gilgai; however its control is not complete, since flattish interfluve crests with less than 2 per cent slopes also have irregular or strongly arcuate banding with prominent gilgai. Where the lower flanks of interfluves are being dissected, the banding is restricted to inter-gully sectors, for it is incompatible with linear runoff; on the other hand, where the pattern has become degraded through accelerated sheet erosion or excessive grazing it persists longest in shallow depressions receiving above-average overland flow.

Dissection and stripping in Nuntherungie land system and consequent breakdown of the contour steps have led to increased flooding, channelling, and alluviation in drainage tracts as shown by comparison of Sandstone Tank and Nuntherungie land systems. In the former the tracts remain stable and largely unchannelled, whereas the latter have actively extending alluvial tracts with well-developed channels. These contrasts have been emphasised by excessive grazing, destruction of shrub cover, and consequent increase in runoff and erosion in Nuntherungie land system, where floodplains are now undergoing sheet erosion and close gullying, while the main channels have shoaled and become braided.

The low dolomite ridges and hills of Limestone land system have proved less erodible, and although there has been an increase in the number of minor channels as indicated in Table V-1, flanking slopes have been less affected and the banding patterns here remain largely intact. The greater stability of this land system is also reflected in a restriction of alluviation and of sheet or gully erosion in main drainage tracts.

(ii) <u>Central Ranges</u> - In this physiographic section, incision of the main transverse drainage has led to dissection of lower hillslopes and strike valleys into spurs or rounded low hills, stripping of inherited slope mantles, extension of strike valleys, and proliferation of first-order channels.

This applies particularly to the Faraway Hills in the wide belt of low sandstone ridges and shale valleys in the south of the Station. Here, in Faraway land system, a dense pinnate or trellis drainage has been established as shown in Table V-1. Contour-banding patterns associated with leached gravelly mantles on formerly smooth footslopes are now restricted by valley incision to the crests of spurs and interfluves; in areas of close dissection even accordant hill crests have been stripped of their mantles. Nevertheless, the land system remains fairly stable due to the limited extent of soft rock and to the partial cover of protective stony mantles, such that erosion has been mainly linear. The limited alluviation in the valley floors of this land system reflects this stability and the competence of channels fed by run-off from steep bounding slopes.

Incision of Fowlers Creek as much as 10 m into its former plain has left the gravel-strewn terrace flats of Old Homestead land system. These probably had partial leached cappings originally, although with poorly developed banding on account of low gradient; however, these have since been stripped in many areas adjacent to incised channels, and the little-weathered calcareous bedrock exposed.

The contrasted setting of broad cuestiform ridges and narrow strike valleys has brought a different response to current dissection in Nundooka land system in the Nundooka Ranges. The latest phase of rejuvenation of the main transverse drainage has here regressed only halfway through Sandy Creek gorge, as shown in a distinct deepening and narrowing in its lower sector; the upper gorge sector still grades almost smoothly into the plains of Sandstone Tank land system. In consequence there has been limited drainage incision, and its erosional effects have been further restricted here by lack of the shale horizons of Faraway land system. Channelling is most evident on the steeply dipping softer calcareous sandstone in the east of the Ranges, where there has been renewed extension of strike drainage below the crest bevels of the Tertiary land surface.

Much of Nundooka land system remains relatively stable, preserving the well-developed and probably inherited slope mantles, and rocky outcrops are of limited extent. Long smooth slopes of between 15 and 25 per cent show features reminiscent of a periglacial regime, for instance stone-fronted lobes up to 10 m across and 50 cm high, tunnelling associated with lobe collapse and the extension of long straight gullies, tilted stone slabs, and terracettes. These features are associated with the well-developed slope mantles with moderate clay content, pedal subsoils and perhaps also with an element of swelling clay as indicated by the occurrence of stone-ringed gilgai on flattish crests.

Friable flaggy sandstones build the low fore-ridges of Mulga Dam land system along the west side of the Nundooka Ranges. A feature of this landscape is the sandiness of the thin slope mantles, due partly to the breakdown of the sandstone, but increased by sand blowing from the floodplains to the west. This is particularly marked south of the entrance to Sandy Creek gorge. The sandy cover limits the initiation of drainage channels, as seen in Table V-1. There are in consequence well-developed sandy alluvial aprons along the foot of the ridges; these are subject to alternate sheet wash and wind drift.

(iii) Eastern Piedmont - In Gap Hills land system the upper sectors of former gravel-mantled footslopes have been dissected into spurs and locally detached from the bevelled ridges behind, into which they formerly graded. A small strike vale has formed in this way between Telephone and Sandy Creeks. On spur crests, particularly south of Sandy Creek, the leached loamy gravel mantle survives and with it banded microrelief as in Sandstone Tank land system. However, in the salient along Gap Hills Creek there has been almost complete stripping over large areas and banding here is vestigial. This area has a close dendritic drainage, in contrast to the low channel frequency of stable slopes in this land system.

Only the upper slope sectors have been dissected in this way. South of Sandy Creek extensive stony alluvial lobes extend as much as 5 km from the ranges, and here the incised channels open out into scalded floodplains with numerous small channels, and may eventually feed into unchannelled linear depressions with relatively fine-textured alluvium. Such undissected lobes exhibit a banded pattern, on gradients of between 0.5 and 1 per cent, which differs from those described above. The bands here extend for considerable distances along the contour, with convex trend, and have a repetition interval of up to 30 m. There are two components, a broader flat with some stone only in its lower part, and a narrower steeper sector broken by small gilgai depressions, with scattered stone throughout. On these gentle slopes it is the gilgai and its adjacent mound which create the microrelief, between wide relatively stable areas which yield sheet runoff to the gilgai cells downslope (Fig. V-2C).

V. DEPOSITIONAL LAND SYSTEMS

The eastern half of Fowlers Gap Station consists of alluvial plains which vary in stability laterally with distance from active stream channels, and in alluvial texture and associated drainage patterns downslope with distance from the ranges. The active plains are dominated by Fowlers Creek and its left bank tributaries, which flood out at a distance of 6 km from the upland border, but there are also terminal alluvial deposits of Caloola Creek in the extreme south.

These depositional landscapes constitute a southwestern part of the Bancannia Plains, formed by streams draining into the Bancannia interior drainage system. A major factor controlling the extent and thickness of deposits has been subsidence in this part of the Bancannia Trough, a continuation of tectonic movements extending back into the Palaeozoic. These movements have established and maintained the fundamental contrast between a structurally higher, mainly erosional western half of the Station, and a structurally depressed eastern area of deposition. On Fowlers Gap Station this contrast between erosional uplands and depositional plains is unusually clear; there is remarkably little depth of alluvial fill in the upland tracts, even along the main floodplains, since rock barriers in the water gaps have prevented deep down-cutting at any stage. In comparison, Sandy Creek Government Bore, only 6 km from the ranges, penetrated 210 m of unconsolidated deposits of presumed Cainozoic age, while Bancannia No. 2 Oil Well, at a distance of 9 km into the plains, also traversed more than 215 m of fill to bedrock. Lignite and clay beds among the sandy alluvial horizons indicate that subsidence and deposition generally kept pace.

A second factor controlling alluviation through the competence of regional drainage has been increasing aridity since the mid-Tertiary period.

The superficial alluvial deposits of the depositional land systems range from gravel and grit in upper piedmont sectors, through sand in the floodplains,to fine sand, silt, and clay in the terminal floodouts. This is associated with a decline in gradient eastwards from more than 1 per cent in the piedmont zone to between 1 and 0.25 per cent in the floodplains, and to less than 0.25 per cent in terminal sectors. The piedmont deposits are older and more stable, as shown by weathering and soil formation, banded micro-relief patterns, and by considerable dissection in their upper parts. Since these have been treated as inherited and eroding landscapes under Sandstone Tank and Gap Hills land systems, they will not be considered further here. Among the remaining depositional systems there is a fundamental contrast between the alluvial plains with through-going drainage channels and the terminal floodouts.

(i) Alluvial Plains with Through-going Drainage - The more important of the active systems in this group is Fowlers land system, the floodplain of Fowlers Creek, which drains an area of 440 sq km extending south and west beyond the Station.

At its entry into the plains, Fowlers Creek is a bed-load channel, generally above 15 m wide and of low sinuosity (1.1-1.2) but with a moderate width-depth ratio (1:20). Gravel bars characteristic of the upland sector have here given place to bed deposits of coarse sand with minor pebble gravels. There is a tendency for channel scour at times of strong flooding, and scour pools to 3 m deep alternate with sandy tracts in a pool-and-riffle sequence having a wavelength of about 350-500 m within a channel sinuosity wavelength of 700-1000 m. These pools tend to be shallowed by sand filling at times of minor flooding.

Over a course of 10 km in Fowlers land system the channel narrows to less than 10 m and the width-depth ratio decreases to less than 7, indicating an increased relative importance of finer-textured, suspended-load. There is a corresponding decrease in meander wavelength and a tendency to increased sinuosity. However, this transition from a bed-load to a suspended-load channel is counteracted by the tributaries, notably Telephone Creek, which bring coarse load from the Nundooka Ranges; this conflict is evident in variations in channel habit between a deeper, meandering and a shallower, less sinuous form.

In this sector the channel is shallowly incised into the adjoining flats and lacks levees, although partly flanked by a narrow hummocky flood tract. Where its low banks are initially overtopped by floods, as along convex reaches, broad splays with aligned sandy hummocks extend directly down the floodplain and may feed into parallel systems of deep scour channels in depressed flood basins. These basins may lie adjacent to the channel but they also occur along the backplain margins of the land system, connected by winding floodways with few channels. The outer basins receive a tributary drainage which has been back-ponded through alluviation in the main floodplain and which tends to flood out, as exemplified by Telephone Creek. The flood basins have pronounced gilgai, both circular and linear, the latter commonly acting as sources of scour channels. Separating the flood basins are low linear rises up to 300 m wide which may be prior channel tracts.

The active regime of Fowlers land system is reflected in undifferentiated sandy alluvia which are extremely subject to erosion by wind and flood waters, and the surfaces are extensively scalded, a process accentuated by the overstocking of frontage country over a long period.

The tributary floodplains have been mapped as Sandy Creek land system and are characterised by coarse-textured alluvia reflecting a predominance of sandstone in their steep catchments. The channels are relatively shallow and wide, with width-depth ratios between 15 and 20; however they rapidly diminish on the plains and with the exception of Sandy Creek do not persist for more than 2 km. Some of these tributary floodplains, such as that of Nelia Creek in the south, are virtually alluvial trains with multiple braiding channels, indicating an extremely abundant coarse load.

The channels of tributaries to Fowlers land system pass into parallel shallow linear depressions with finer-textured alluvium, mainly unchannelled and commonly with gilgai, which connect with the backplain basins of Fowlers Creek. South of Fowlers Creek the channels end in small distributary systems feeding directly into the main terminal alluvial plains.

Flanking the floodplain of Fowlers land system on the south and again north of Sandy Creek are the older alluvial plains of Conservation land system, its stability indicated by better-developed soil profiles and also by its occurrence between the major active channels. The plains, which consist mainly of sandy alluvia, apex towards the upland exit of Fowlers Creek, indicating that they originated as alluvial tracts along its prior courses. They show a radial pattern of raised prior levee zones, often with low gravel ridges, separated by linear depressions occupied by small, sinuous, and commonly discontinuous channels. These depressions are still followed by flood waters from the backing ranges. Conservation land system extends eastwards far beyond the Station boundary, for as much as 20 km from the ranges and beyond the present-day terminal floodouts, denoting an earlier period of more widespread and coarser-textured alluvial deposition, presumably with greater runoff and erosion than today.

The open plains of Conservation land system are subject to increasing wind action eastwards, and the loose sandy topsoils drift readily. This is shown by sand hummocks about shrubs, particularly on the east sides of wind-eroded areas. Wind and water erosion have reinforced each other in the extensive sheet erosion or "scalding" which characterises Conservation land system. Almost 30 per cent of this area is scalded to a depth of 15 cm and there is even more severe scalding in about 5 per cent, with the development of true claypans locally where erosion has progressed to the heavier subsoil.

Scalding has been more severe on the sandier prior levee tracts than in the depressions, which have somewhat heavier locally self-mulching soils and which locally have slight gilgai. Where erosion has not progressed too far, the scalds have a characteristic transverse arrangement on the contour, with an interval of between 100 and 150 m. In this pattern the scalds occupy flats between narrower but slightly steeper sectors. These slope relations are indicated in flooding, when the floodwaters progress haltingly from scald to scald, where they are checked before advancing further. The scalds are connected by small channels and their upslope margins are often slightly gullied. It is not known whether this pattern reflects initial patterns of deposition and hence differences of alluvial texture and resistance to erosion, or whether it is in response to the rhythmic and localised action of the erosional processes involved. The pattern of scalds becomes confused where erosion has progressed to extremes, as where it has been accentuated by overstocking.

(ii) Plains with Terminal Drainage - Neither Fowlers Creek nor Caloola Creek reaches the topographic base level of Lake Bancannia; both flood out near the N-S axis of the Bancannia Plains as separate elements in a disorganised system of interior drainage.

In the northeast of the Station, Mandleman land system comprises the upper sector of the terminal plain of Fowlers Creek, which extends northeastwards with an average fall of 1 in 400. The land system exemplifies the way in which a desert drainage system terminates. There is a progressive narrowing downstream of the channel of Fowlers Creek to less than 5 m wide, an increase in depth to 2.5 m, and a concomitant increase in sinuosity to almost 2.0. The channel occupies a broadening levee zone up to 60 cm above the backplain. This zone attains its maximum width of 500 m where channel bifurcation appears most commonly to have occurred in the past, at which point the levee zone resembles an elongate fan front across which prior meanders can be distinguished. Beyond this point, several branching prior levee tracts can be traced, the youngest of which has a well-preserved abandoned channel which is still used by occasional floods. The levee tracts are distinguished by extensive scalding, in contrast to the more stable backplains.

Despite the prominence of the levees there are many signs of their being topped by floods which have formed sand splays as in Fowlers land system. Reinforced by the levee backslope these commonly develop into crevasses which eventually aid shifts of the stream; for instance at several points the channel meanders strongly out towards the levee margin, abandoning a former straighter course marked by parallel lines of river gums. Finally there occurs a major change where the channel breaks out northwards from the main levee tract into a flood basin, and the relative youthfulness of this course is shown in its incompletely moulded channel and poorly developed levees. The channel is incised into the former levee backslope where it leaves the older course, and has in turn caused dissection of the upstream levee margins of the basin which it now traverses. Abandonment of the former course has also deprived the associated backplains of floodwaters, and a number of such abandoned basins occur between prior levees. They are distinguished by well-marked linear gilgai, whereas the active flood basins are characterised by low-lying areas with circular gilgai and forking feeder channels.

The lowest sectors of Fowlers Creek consist of several meandering distributaries, both active and abandoned. Blockage by flood debris appears to be a major cause of abandonment of the smaller channels, and once relict they rapidly fill with sediment to become shallow winding depressions; however they may be reoccupied in part with further changes of course.

Tributary channels such as Sandy Creek have built small terminal fans and sandy trains into the backplain basins, but fail to connect with the main channel.

Towards the downstream margin of the floodout, near the northeastern border of the Station, reduced fluvial activity has allowed increasing reworking of alluvia by the wind, and low sand hummocks, locally with an E-W alignment, appear on old channel deposits and mark the transition towards Conservation land system.

Caloola land system, mapped in the southeast, is part of a series of floodouts associated with Caloola Creek and its left-bank tributaries, including Nelia Creek. Channels are restricted to the upslope margins of this land system, are mainly very small and sinuous, and are sometimes flanked or prolonged by scalded levee tracts; further downslope, in the extreme southeast of the Station, there is no linear surface drainage, merely a number of partly connected, elongate and branching scalds or shallow pans.

The deposits of Mandleman land system comprise fine sand, silt, and minor clay, but those of Caloola land system are generally finer-textured and there is more widespread, albeit less intense development of circular gilgai. This difference in texture may reflect the lesser amount of channel activity, for Caloola land system represents a more downstream stage in the fluvial depositional system; however, it may also denote a greater predominance of shale in the sediment source area compared with the sandstone which is an important contributor to Mandleman land system.

Caloola land system also passes northwards into Conservation land system with diminution in the frequency of flooding and alluviation and hence an increase in the wind erosion of alluvial soils which also become more vulnerable as they increase in maturity and hence in horizon differentiation.

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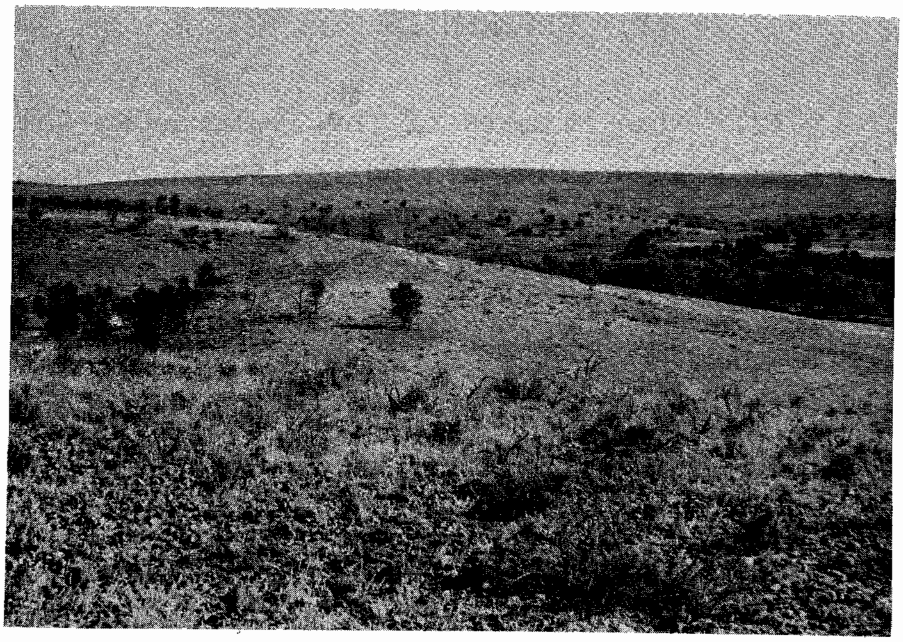
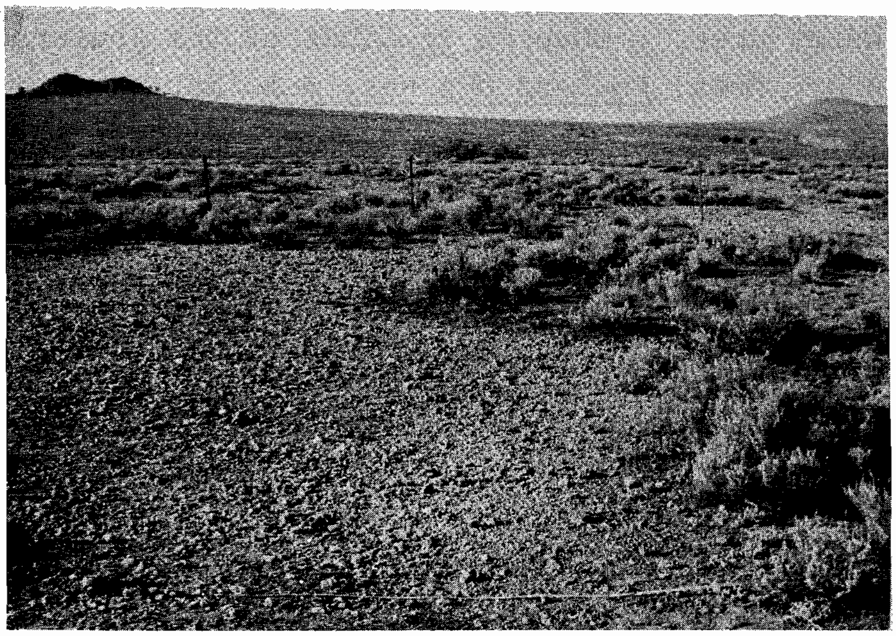


1. Broad bevelled cuestas of Nundooka land system, traversed by the incised valley of Sandy Creek; extensive cover of low shrubland, with tall shrubland along rocky outcrops



2. Lowlands and minor ridges of Nuntherungie land system in the west of the Station, with alternating bare stony risers and belts of low shrubland of bladder saltbush (*Atriplex vesicaria*)

3. An abandoned distributary of Fowlers Creek in Mandleman land system, showing lines of dead red river gum (Eucalyptus camaldulensis), mixed chenopods along the banks, and a general cover of ephemerals after rain

4. Margin of a scald in Conservation land system, with sparse mixed chenopods in gilgai depressions on the surrounds; bare areas between the shrubs will have a cover of ephemerals after rain

CHAPTER VI. WATER RESOURCES OF FOWLERS GAP STATION

By A.D.M. Bell, I. Cordery, D. T. Howell,
S. J. Perrens and D. H. Pilgrim

I. INTRODUCTION: DEMAND AND SUPPLY

The demand for water on a grazing property is for activities carried on at the homestead and in its vicinity and at yards, and for animals to drink where they graze. The location of watering points for grazing animals determines the area of pastures which can be exploited. The sources of supply are groundwater, surface runoff stored in natural water holes, in dams and in excavated tanks, and runoff from roofs, stored in covered steel or concrete tanks.

At the homestead there is a demand for high quality, biologically uncontaminated water for household purposes such as drinking and food preparation, as well as a demand for larger quantities of water of lower quality for other household purposes and for garden watering.

Indications are that grazing sheep require a maximum of approximately 5 litres per head per day of low-salinity water, but more if the water is saline. Water of high salinity causes sheep to drink more than once per day, thereby reducing the area of pasture commanded by one watering point. Turbidity and faecal contamination are not known to be harmful to sheep, except that faecal contamination can accelerate the spread of parasites. It appears that sheep are often unwilling to drink water at a high temperature.

At Fowlers Gap the demand for water differs from that on an ordinary sheep station because of needs imposed by research and by unusually large numbers of visitors. For experimental purposes both surface water and groundwater should be available in a large number of paddocks. At the homestead, water in part of good quality is needed in the laboratory for a variety of purposes.

Supply from groundwater is seldom turbid or biologically contaminated, but it is commonly saline. It is usually more reliable than surface-water supply; failure occurs only from the mechanical breakdown of pumps, motors or windmills, or from the malfunctioning of bore screens.

Surface waters have very low salinity and do not add to the salt load of grazing stock under dry conditions when they are on a diet of salty vegetation. However they are commonly turbid and often have considerable contamination. Their main drawback is unreliability, since runoff is infrequent and erratic, and since the rate of evaporation from surface storage is very high. Natural storages are ephemeral and man-made storages must be made deep at some expense if they are to contain water for reasonably long periods. Runoff collected from the roofs of buildings and stored in closed tanks has low turbidity, low biological contamination, and low salinity, but shares the unreliability of all surface supplies.

The techniques traditionally used in this region to meet the demand for water include excavated earth tanks, steel tanks, earth dams, catch drains, silt traps, wells, and bores with windmill-driven pumps. Engine-driven pumps are now often used. More recently, long pipelines of plastic material (usually polyethylene) have become common. The new technique of desalination remains to be exploited in this area.

The demand for stock watering on Fowlers Gap has been met by a combination of bores and excavated tanks with some long pipelines. The demand for water in the homestead area is met partly from surface-water storage and from pumped groundwater, supplemented by runoff from roofs collected in a covered concrete tank.

Costs of the provision of man-made water supplies are high and increments to the supply system such as additional dams or bores are very expensive (of the order of A$20,000 each, equipped). An overall evaluation of the water resources which are capable of being put to use on a pastoral station can assist in planning investment in watering facilities and in deciding what level of investment is reasonable. Such evaluation has been a continuing process at Fowlers Gap Station. A series of unpublished reports have appeared[1] and several additions to the water supply system have been based upon them. The following account of resources and supplies of groundwater and surface-water at Fowlers Gap Station draws extensively on those reports.

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1. Bell, A.D.M. (1969). Preliminary Report on Groundwater Resources at Fowlers Gap Station

   Perrens, S.J., Howell, D.T. (1969). Preliminary Evaluation of Surface Water Resources at Fowlers Gap.

   Johnstone, I.L. (1970). Fowlers Gap Arid Zone Research Station: Station Improvements and Management Survey.

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II. GROUNDWATER

(a) Introduction

Fowlers Gap Station is situated on the boundary of the Willyama Block with the structural depression of the Bancannia Trough. The latter contains alluvial and sandstone aquifers to a depth of at least 1200m and hence the groundwater resources of Fowlers Gap Station are above-average for this arid region. There is a marked difference in the groundwater potential of the three physiographic sections on the Station. The Eastern Plains has the greatest potential, being underlain by alluvial aquifers and by a deeper aquifer of Devonian age. In the north of the Central Ranges, the outcrop zone of the Devonian aquifer in Nundooka land system is an important groundwater zone. The outcrop of Upper Precambrian rocks forming the Western Lowlands and the southern part of the Central Ranges has limited groundwater potential as the bulk of the water is saline.

A regional groundwater survey by Kenny (1934) established the general groundwater pattern. Bancannia South No. 1 Oil Well drilled in 1967 by the Planet Exploration Company in the Eastern Plains penetrated some 3000m of basin sediments and sedimentary strata and produced a detailed record of the lithology of the sequence, together with information on porosity and permeability. An experimental geophysical survey was carried out in May 1969 by a joint team from the School of Applied Geology, University of New South Wales, and the New South Wales Geological Survey. Its aim was to determine the effectiveness of geophysical techniques in this environment, with particular reference to the depth of alluvium within the Bancannia Trough (Hawkins and Johnson, unpublished). Tests with a Gish-Rooney resistivity unit with a maximum voltage of 450 volts were ineffective as it was not possible to penetrate the dry surface layer of hard clay; however, a gravity profile across the Nundooka Creek Fault gave a marked decrease in readings, from which it would appear that gravimetric methods could be used to locate major faults along the margin of the Trough.

(b) Groundwater Provinces and Major Aquifers

Three groundwater provinces have been differentiated in Fig. VI-1: the outcrop of Upper Precambrian rocks, the area of Devonian outcrop, and the Bancannia Trough.

(i) Outcrop of Upper Precambrian Fractured Rock Aquifers - The Upper Precambrian rocks are tightly folded and dips are generally steep. The sequence is largely made up of metamorphosed argillite within which groundwater is limited and highly saline; however the thicker quartzite or calcareous members are potential sources of groundwater storage where they are intensely fractured. The narrow outcrop of these strata due to the steep dips and the absence of major fault zones limits the extent of aquifers of this type on the Station, although such rocks have been productive further south.

The blanket of lowland soils and the argillaceous nature of the bedrock facilitate runoff rather than infiltration in this province. Recharge is therefore limited and shallow groundwater layers are easily depleted. Bores drilled near Fowlers Gap Homestead which have been abandoned because of reduction in yield and quality with time are typical of many drilled in these rocks. Localised freshwater recharge may occur in beds of fractured brittle rock such as quartzite, slate, dolomite and limestone, particularly where they are covered by coarse alluvium in drainage channels.

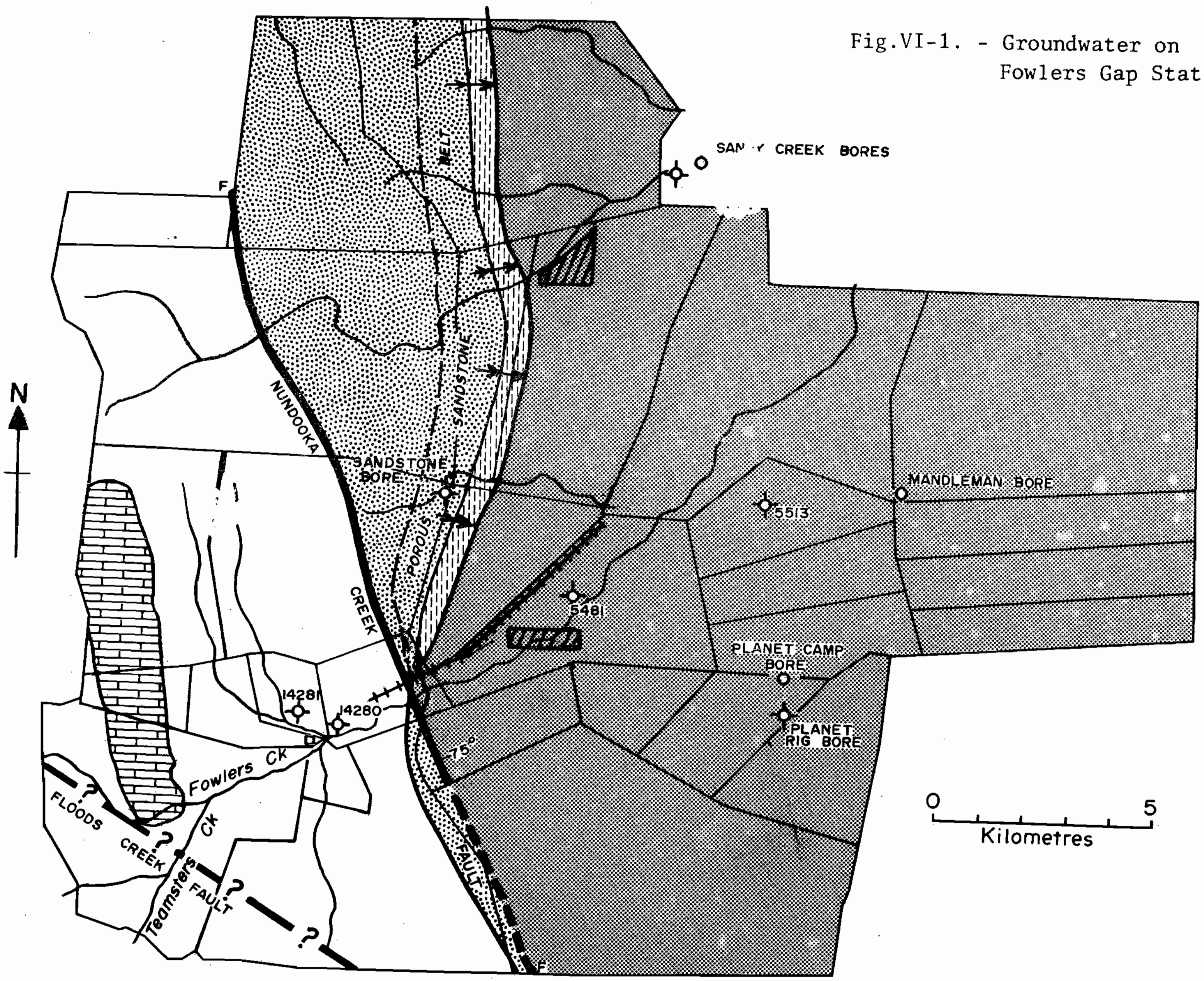
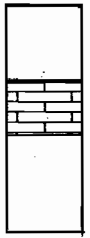


Fig.VI-1. - Groundwater on Fowlers Gap Station

UPPER PRECAMBRIAN FRACTURED - ROCK AQUIFERS

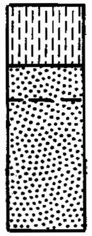


Shale, quartzite and limestone, with massive dolomite member

Yield : Highly variable and generally low

Quality: Saline, except for localised fracture zones with freshwater recharge

DEVONIAN OUTCROP



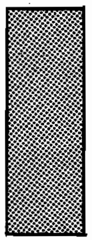
Shale-siltstone member

Quartz sandstone, minor shale, siltstone and conglomerate with upper zone of porous sandstone

Yield : Variable (1·8 – 4·5 cu. mph in porous sandstone belt)

Quality: C_4/C_5

BANCANNIA TROUGH



Aquifers:-
- Upper sands (Cainozoic)
- Lower sands ((?) Mesozoic)
- Quartz sandstone (Devonian)

Yield : Upper aquifer - 4·5 – 9·0 cu. mph

Quality: Upper aquifer C_3/C_4

Fault

Hidden Fault

Postulated Fault

Postulated Monocline

Gravity traverse (approx)

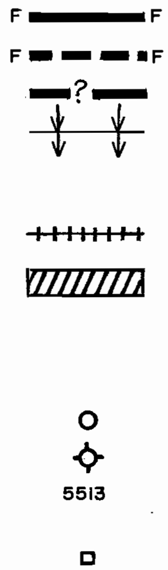
Area of seismic traverse (approx)

Bore equipped

Bore abandoned

Bore W.C. & I.C number

Fowlers Gap (Homestead) well



Successful bores have been drilled in fault-controlled valleys south of Fowlers Gap Station, and an area recommended for investigation is that west of the junction of Fowlers and Teamsters Creeks, where outcrops are masked by alluvium and where a possible transcurrent fault, shown as Fowlers Creek Fault in Fig. VI-1, may cut the fractured extension of massive dolomite of the Teamsters Creek beds which form Limestone land system to the north.

Water in the fine-grained formations is brackish or highly saline, but poor quality stock water (6000 - 10,000 ppm salts) has been obtained from more open strata.

(ii) Outcrop of Devonian Sedimentary Aquifers - The major lineament which now forms the western margin of the Bancannia Trough continued to move in post-Upper Devonian time and the regional geology is further complicated by the Nundooka Creek Fault, which trends between 20 and 30 degrees west of north and cuts the Central Ranges into two wedge-shaped zones (Fig. VI-1) of which the northern (Nundooka land system) is formed by the outcrop of gently dipping Devonian sandstone and shale.

This red-bed sequence of Devonian age, separated from the Upper Proterozoic sequence by a marked unconformity, comprises sandstones and pebble beds with intercalated shale and siltstone units. Many of the sandstones are friable, with an argillaceous cement, but thick beds of porous sandstone and orthoquartzite in the upper part of the sequence constitute a potentially useful aquifer. This aquifer crops out in a belt north of Fowlers Creek, as shown in Fig. VI-1, and extends at depth through the Bancannia Trough, where some 400 m of permeable strata were penetrated at this stratigraphic level in the Bancannia South No. 1 Well. Sandstone Bore has penetrated this unit in a zone of little fracture, and in a hill area with limited surface infiltration. Production from 18 m of sandstone is about 1.6 cu mph of good quality stock water (3600 ppm salts). Higher bore yields of better quality water can therefore be expected from thicker, more fractured zones with more favourable freshwater recharge conditions. As maximum recharge will occur from major drainage channels, two localities are recommended for further investigation, namely where the floodplain of Fowlers Creek crosses the Nundooka Creek Fault and where closely-jointed sandstone occurs near the exit from Sandy Creek gorge.

The youngest Devonian strata encountered in outcrop are a sequence of red shale, siltstone, and ferruginous sandstone which occurs downstream from Sandy Creek gorge. Their extent in outcrop, as mapped on airphotographs, is shown in Fig. VI-1. The beds are conformable with and grade into the sandstones of the upper part of the Nundooka Sandstone formation. These and possibly younger sediments lie at shallow depth in the piedmont zone east of the Ranges, where they form an aquiclude against the overlying deposits. Bancannia South No. 1 Well penetrated 600 m of similar strata before striking the uppermost massive sandstone unit.

(iii) Aquifers of the Bancannia Trough - The surface expression of the structural feature forming the western margin of the Bancannia Trough is not clear. North of Fowlers Creek it is probably a monocline within the Devonian strata, but at Fowlers Creek and for some distance to the south it is a narrow fault belt, the Nundooka Creek Fault. The main sources of evidence concerning the stratigraphy of the Trough are the Bancannia South No. 1 Oil Well, bore logs as of Sandy Creek Bore, and seismic traverses about 1.5 km east of Sandy Creek gorge. The Oil Well penetrated interbedded sand and clay of Cainozoic age to 130 m depth, 86 m of presumed Lower Cretaceous sediments, and about 3000 m of Upper Devonian strata. Results from the two seismic lines were encouraging in that three sub-surface layers were indicated. The top layer, between 60 and 90 m thick and with a velocity of about 1500 m per second, appears to represent slightly consolidated deposits, probably Cainozoic alluvium. This is underlain by a layer with a velocity of about 2000 m per second representing slightly more consolidated deposits. An approximate velocity of 3600 m per second was obtained from the lowest layers, which would appear to correlate with the Devonian sequence. The estimated depth of this high-velocity refractor near the outcrop at the eastern limit of the traverse was 150 m.

(1) Upper Devonian Aquifers - The upper sandstones of the Nundooka Sandstone formation were penetrated between 820 and 1200 m in Bancannia South No. 1 Oil Well. The favourable permeability was noted and the water quality was considered good, but as fresh water was used during drilling operations and considerable infiltration around the hole is to be anticipated, the actual water quality from this aquifer may be brackish (J.C. Cameron, pers. comm.).

The oil well also penetrated up to 600 m of the shale-siltstone member overlying the sandstones. Since these form an aquiclude between the sandstones and overlying deposits in the Bancannia Trough, freshwater recharge of the Devonian strata must largely be limited to infiltration from its outcrop.

(2) (?)Mesozoic Aquifers - The Bancannia South No. 1 Oil Well penetrated three units of presumed Mesozoic age, namely 25 m of grey-brown shale, 36 m of white sand, and 25 m of grey-green to brown shale. Between these horizons and the Upper Devonian sequence is a bed of red-brown shale 23 m thick, of possible post-Devonian age. These four units have not been identified in outcrop.

The sand bed is a potentially important aquifer. The log indicates this unit to consist of white to grey, medium to coarse, quartz sand. Sandy Creek No. 1 Bore, drilled in 1892-3, also records a thick sand unit at this level (Table VI-1). Its static water level was at 37 m depth, which is substantially higher than the level of the Cainozoic upper sand aquifer above.

TABLE VI-1. INVENTORY OF WATER WELLS AND BORES ON FOWLERS GAP STATION

Name or W.C.& I.C. Bore Number	Year Completed	Depth m	Cased to m	Static Water Level m	Draw-down Level m	Supply cu.mph	Water Quality (p.p.m. salts)	Depth to Water Feeds m	Aquifer
Sandy Creek No.1 Bore*	1893	207	207(?)	36.6	49/55	4.5	1350	90 111 137	Upper sand (Cainozoic) Lower sand (?) Mesozoic
Sandy Creek No.2 Bore*	1943	113	108	56.1	-	4.1	Fresh	85 94.5 104	Upper sand (Cainozoic)
Sandy Creek No.3 Bore	1952	101	99	61	61(?)	2.3	2544	89 101	Upper sand (Cainozoic)
Bore No. 5481*	1914	90	90	-	-	3.4	Stock?	84 89	Upper sand (Cainozoic)
Bore No. 5513*	1914	104	90(?)	64	67	4.1	Good stock	73 99	Upper sand (Cainozoic)
Mandleman Bore	1954	94	94.5(?)	57	57	2.0	2300	66 78 93	Upper sand (Cainozoic)
Planet Camp Bore	1967	110(?)	?	-	-	4.5+	1640	-	Upper sand (Cainozoic)
Planet Rig Bore*	1967	110(?)	?	-	-	9.1(?)	Fresh	-	Upper sand (Cainozoic)
Sandstone Bore	-	116	116(?)	97.5	97.5(?)	1.4(?)	3600	99 to 113	Upper Devonian porous sandstone
Bore No. 14280*	-	26.5	27(?)	12	20.5	0.5	?	19 26.5	Upper Precambrian slate and quartzite
Bore No. 14281*	-	54	24.7	18	34	0.8	3050	24.4 42 54	Upper Precambrian slate and quartzite
Fowlers Gap Well*	Before 1934	32	-	17	-	2.0	9000+	-	Upper Precambrian slate and quartzite

*Abandoned wells or bores

TABLE VI-2. ANALYSES OF GROUNDWATER ON FOWLERS GAP STATION*

Locality: pH: E.C.25[1]:	Planet Camp Bore 6.4 2520		Sandy Creek No.3 Bore 7.2 3960		Mandleman Bore 7.9 3492	
Analysis[2]	p.p.m.	e.p.m.	p.p.m.	e.p.m.	p.p.m.	e.p.m.
Carbonate	N.D.	N.D.	N.D.	N.D.	19	0.64
Bicarbonate	282	4.62	236	3.90	210	3.44
Chloride	558	15.75	1003	28.30	829	23.38
Sulphate	250	5.21	398	8.28	401	8.36
Nitrate	<0.5	-	N.D.	N.D.	N.D.	N.D.
Calcium plus Magnesium	133	7.41	222	12.34	140	7.80
Iron[3]	<0.02	-	<0.02	-	0.13	-
Potassium	8	0.19	12	0.31	8	0.20
Sodium	409	17.8	673	29.25	667	29.00
Total p.p.m.	1640		2544		2274	
p.p.m. .65 x EC	(1650)		(2575)		(2270)	
Hardness[4]	371		617		390	
Alkalinity	231		195		204	

* Carried out by New South Wales Department of Mines, October 1967

1 E.C.25 = electrical conductivity (micromhos/cm at 25°C)

2 p.p.m. = parts per million; e.p.m. = equivalents per million

3 Total iron as Fe++

4 As p.p.m. $CaCO_3$

The nature of these sediments indicates that they were deposited in a humid climate, and the quality of the connate water should be better than that of the Cainozoic aquifer which was deposited, at least in part, under more arid conditions. This is partly confirmed by the analysis of water obtained from Sandy Creek No. 1 Bore, the only bore to have tapped this aquifer. The salt content of water from this bore, which also penetrated two sand beds at higher levels, is given as 1350 ppm salts, compared with 2600 ppm salts from the higher aquifers in Sandy Creek No. 3 and Mandleman Bores. Because of the possibility that this Mesozoic sand bed contains higher-quality water, and as it apparently has a higher piezometric surface than the overlying Cainozoic aquifers, it may well be the most important aquifer in the Bancannia Trough, to be developed in preference to the shallower Cainozoic aquifers.

(3) Cainozoic Alluvial Aquifers - Continuing depression of the Bancannia Trough during Cainozoic times resulted in the further deposition of alluvia. Since the stream courses, like those of today, were of low gradient, and because of the prolonged weathering of rock outcrops in source areas, the occurrence of gravels in these alluvial deposits is restricted.

The Cainozoic alluvial deposits were found to extend about 130 m beneath the surface in Sandy Creek No. 1 Bore and Bancannia South No. 1 Oil Well. The sequence consists of clay and sand with thin beds of dolomite and lignitic clay, and from the drill records can be divided into two units.

The upper unit, about 75 m thick, consists of stiff brown clay with layers of sandy or gravelly material and thin bands of light-coloured and black swelling clays towards the base. The sand consists of red-brown quartz grains with flakes of mica or chlorite schist. Small feeds of water are associated with the sandy layers. The lower unit is a white, light-grey or black clay interbedded with bands of fine to coarse quartz sand. The latter are generally poorly graded but contain some well-sorted layers up to 7 m thick. The dark-coloured bands contain pyritic and lignitic material as well as thin bands of dolomite. The sand beds are situated between 70 and 110 m depth and are lenticular, since recorded thicknesses vary from a few metres to 20 m.

The lower Cainozoic sands are present producers within the Bancannia Trough; failures are few, and good quality stock water is usually obtained. Earlier records give the supplies as between 2.3 cu mph and 4.5 cu mph. However, there is an unconfirmed report of yields of 9.3 cu mph from a bed of coarse sand 6 m thick penetrated in water bores associated with the drilling of the Bancannia South No. 1 Oil Well. The general salinity is between 1000 and 3000 ppm with low bicarbonate content and a chloride:sulphate ratio of 3 to 1. At least four bores in this province on the Station have been abandoned, presumably due to corrosion of the casings and screens.

The recharge potential of this aquifer has not been established. The sands at some distance from the hills are overlain by about 55 m of stiff clay into which the present drainage has incised shallow channels. Recharge by infiltration from terminal floodouts on the open plains will hence be slow, and this will facilitate solution of salts from the overlying clay beds. Optimum conditions for freshwater recharge occur in the piedmont zone, particularly in the floodplains of Fowlers, Sandy and Caloola Creeks. Geophysical investigations indicate that the depth of the sequence is maintained to within 1 km of the margin of the Eastern Plains, and hence sand beds may occur below groundwater level in this area. This piedmont zone of maximum recharge is a potential producer of better quality water, possibly suitable for restricted irrigation.

(iv) Resources of the Bancannia Trough - Assuming the extent of the Cainozoic aquifer to be 25 sq km, its average thickness 12 m and its specific yield 5 per cent, the storage may be in the order of 15×10^6 cu m. The history of bores which have penetrated beds of fine sand associated with the lignitic clay indicates that bores utilising this aquifer should be carefully developed, with the use of non-corrosive screens and casings. The storage of the (?)Mesozoic aquifer is at least equal to the above, and the storage capacity of the deeper aquifer of the Upper Devonian sandstone is some ten times greater. Further investigation of the (?)Mesozoic aquifer is merited, for if the high piezometric surface and good quality water of this aquifer are confirmed it could be the most useful aquifer on the Station. Investigations are also required to ascertain the nature of the groundwater within the Devonian aquifer, but unfortunately the major area of storage is at uneconomic depth.

Stock-quality water is present in all three aquifers, with the probability that better-quality water suitable for restricted irrigation purposes may exist in aquifers near the western margin of the plains, where good freshwater recharge from surface drainage may be postulated.

III. SURFACE WATER

(a) Available Hydrologic Data

Climatic data available for Fowlers Gap Station are discussed in Chapter III of this Report, and for the broader region by Bell (1972). With minor exceptions, measurements of runoff and streamflow have not so far been made on the property, although the Station diary includes a few notes on flows into storages following known rainfalls.

(b) Estimates Based on Catchment Surveys

A preliminary estimate of potential runoff from selected catchments, in the context of an evaluation of storage sites, was carried out by S.J. Perrens in 1969. The boundaries of catchments supplying existing and potential storages were determined from airphotos and checked in the field where necessary. Catchment boundaries were marked on an overlay prepared from 1:25,000 airphoto maps, and catchment areas were measured by planimeter. Detailed topographic surveys were made of some existing and potential storage sites. The selected catchments were classified according to their predicted potential for useful runoff as judged from landforms, soil types, and vegetal cover. The categories were:

Good. - Undulating country with moderately fine-textured soils and little silt in creek beds, for example Sandstone Tank land system.

Fair. - Catchments with steep slopes and possessing much exposed rock and shallow soils; generally with distinctive close channel networks. Most of the hilly country on the Station comes under this classification.

Poor. - The plains area in the east of the Station largely falls into this category. The heavier-textured soils resist infiltration and are capable of producing runoff but there is insufficient slope to cause it to run together and form channels. As a result, most rainfall remains ponded on the surface.

This tentative classification, intended as a guide to the usefulness of water storages, has been found to be far from satisfactory and is not supported by comments relating rainfall and runoff in the Station diary in the period 1966-68. Nevertheless it was used in the preliminary evaluation of existing and potential storages.

(i) Existing Storages. - A summary of existing surface-water storages is given in Table VI-3. Apart from Warrens and Saloon Tanks, it does not seem to be feasible to enlarge the catchment areas supplying these storages by constructing channels and banks to pirate other streams. To make any

TABLE VI-3. EXISTING DAMS AND TANKS ON FOWLERS GAP STATION

Storage	Type	Volume ('000s of cu m)	Catchment Area (ha)	Catchment Runoff Potential	Remarks
Sandstone	Tank	15.4	1500	Good	Two linked adjacent tanks
	Tank	22.7	1500	Good	
The Lake	Dam	430.0	1100	Fair	Dam leaks at base
Nelia	Dam	37.0	400	Fair	
Warrens	Tank	15.4	*	Poor	Two catch drains north and south
Saloon	Tank	13.5	*	Poor	One catch drain
Gap Hills	Tank	15.4	1500**	Fair	Public Watering Place

* These areas on very flat country are difficult to estimate but are of the order of thousands of hectares

** 28% of which falls outside the Station significant increase in the catchment areas of The Lake, Nelia Dam, or Sandstone Tank would require earth works on too great a scale for the benefits to be obtained.

(ii) Potential Storages. - There are a number of additional sites suitable for storages along channels on the Station. Desirable characteristics for potential storages are in general

- a catchment with "good" or "fair" potential runoff
- a well-defined channel
- facilities for a natural by-wash spillway
- a steep-sided valley (for a dam)
- deep impervious soil (for a tank).

Details of a number of potential sites on the property, defined in these terms, are summarised in Table VI-4.

Tabulations such as those in Table VI-4 can assist in ranking storage sites in order of desirability, but there are limitations to these assessments. Not only is the ranking of catchments according to potential runoff quite subjective, but in an arid zone the area of catchment is not necessarily a guide to the runoff produced at any site. In any hydrologic event, the area contributing to runoff is always less than the total catchment and may vary depending on storm patterns and wind directions and also on the magnitude of the event.

(c) Estimates of Runoff Based on Channel Dimensions

There is evidence to indicate that where streams are neither actively eroding nor depositing, bankfull flows can be expected with approximately the same frequency of occurrence in all the channels of a region (Leopold et al., 1964). Bankfull discharge (Q_{bf}) can be estimated from the Manning equation:

$$Q_{bf} = \frac{AR^{2/3}S^{\frac{1}{2}}}{n}$$

where Q_{bf} is the discharge at bankfull stage measured in cumecs

TABLE VI-4. POTENTIAL SITES FOR DAMS AND TANKS ON FOWLERS GAP STATION.

Name and Map Reference*	Type	Volume ('000s of cu m)	Catchment Area (ha)	Runoff Potential	Damsite Potential	Remarks
Woolshed (Broken Homestead) (672605)	Dam	230	3000	Fair	Good	Enlarge northern spillway. Possible use of saddle to west of homestead
Rocky Creek (662613)	Dam	120	900	Fair	Good	Needs clay along faulted quartz zone
Picnic Creek (685619)	Dam	180	650	Fair	Good	
Airfield (657609)	Dam	2500	2000	Fair	Poor	Problem of leakage from fractured quartz at damsite. Airfield would be flooded to develop full potential
Western Creek (640626)	Dam	150	1000	Fair	Poor	Leakage problem with fractured quartzite.
Western Creek (639626)	Tank		1000	Fair	Fair	Alternative to dam on same creek. Underlying rock? Test drilling needed to check rock base
Floods Creek (642590)	Tank		2100	Fair	Good	
Fowlers Creek (635571)	Tank		40000+	Good	Good	Two possible sites. Off-stream tank to take off only part of flow down large creek. Utilise old creek bed?
Telephone Creek (710660) (720658)	Tank		460 or 730	Fair	Good	Alternative to Sandstone Bore. Could be extended to pirate nearby creeks
Mulga (687742)	Dam	12	140	Poor	Poor	Leakage problem with fractured sandstone. Spill-way inadequate. Small catchment
Nundooka Creek (661760) (665750)	Tank		360 and 760	Good	Poor	Two possible sites. Under-lying sandstone on main creek
Hotel (703622)	Tank		190	Fair	Fair	Old tank used by Hotel(?) now silted up.
Sandy Creek (710705)	Dam		4000 (approx.)	Fair	Poor	Dam at gorge on Sandy Creek would be a major work involving rock grouting etc.

*Note: Map references refer to 1:25,000 contour map of Fowlers Gap

A is the cross-sectional area of the channel in sq m

R is the "hydraulic radius" of the cross-section in metres, being equal to the cross-sectional area divided by the wetted perimeter

S is the energy gradient of water flow, which on the assumption that the flow is approximately uniform is the same as the longitudinal bedslope, and

n is the hydraulic roughness of the channel boundary.

The value of the coefficient n, which has the dimensions of the one-sixth power of length, can be estimated only with an accuracy of about 20 per cent, giving the same maximum order of accuracy to the estimate of bankfull discharge. However if all roughness estimates are made by the same person at a number of different sites, then the ratios of the discharges at these sites can be expected to have much less error. These estimated flows can then be used as a basis for comparing the runoff potential of the catchment upstream of the section with that for other sites on other channels.

This approach was put into practice in a field survey carried out in July, 1973. At five different sites, channel cross-sections and longitudinal bedslopes were measured and estimates of channel roughness were made. As is usually the case (Woodyer, 1968), several benches could be identified at most cross-sections examined and bankfull stage was there defined by taking outer or major banks. At each site the banks were also examined for flood debris to confirm the selection of appropriate bank levels. The results of these assessments are presented in Table VI-5.

This clearly represents a more objective evaluation than the preliminary assessment based on catchment classification. However the estimates are subject to a number of qualifications. Firstly, floods which reach a given peak flow will in general have shorter durations for smaller catchments, so that peak discharges are not directly proportional to the total volumes

TABLE VI-5. BANKFULL DISCHARGES AT SELECTED STORAGE SITES

Site	Catchment Area (ha)	Storage Volume ('000s of cu m)	Runoff Potential from Preliminary Assessment (as in Tables VI-3,VI-4)	Estimated Bankfull Channel Capacity (cumecs)	Ratio of Channel Capacity to Catchment (cumecs/ha)	Performance of Existing Storages since 1966 (from Station Diary)	
						No.Times By-washed	No.Times Emptied
The Lake	1100	430	Fair	18	.016	Many (2 since 1969)	3
Nelia Dam	400	37	Fair	10	.026	Many (2 since 1969)	4
Sandstone Tank	1500	15-23	Good	6.5	.004	1 since 1969	0
Gorge Tank Site (712704)	230	15-23	Fair	7.9	.034	-	-
Telephone Creek Tank Site	470	15-23	Fair	8.5	.018	-	-

of flows. Secondly, it is by no means a settled question that the postulated similarity of frequency of bankfull stage applies to the arid zone, where the form of a channel may have been determined by the most recent streamflood. Finally, the frequency of small to moderate discharges may well be more important than bankfull flow for the replenishment of storages.

(d) Proposals for Further Measurements of Rainfall and Runoff

In 1973 a broad-crested measuring weir, together with a V-notch weir for measuring small flows and with automatic recording, was installed on Homestead Creek near the airstrip, the latter having been selected as a representative basin under the Representative Basin Programme of the Australian Committee for the International Hydrological Decade. Rainfall estimates for this catchment will be made from pluviographs at the climate station near the homestead.

The area of this catchment is 20 sq km, which is many times larger than those of most interest for potential storages for stock-water supplies. What is needed in addition is the continuous measurement of runoff at selected sites on smaller catchments on the Station, by measuring volumetric changes in the contents of dams or by measuring depths over weirs, and simultaneous measurement of rainfall with pluviographs installed on their catchments. Results from about 3 to 5 years of measurement may well be sufficient to enable the catchments to be modelled mathematically, whereby long-run estimates of runoff could be made in conjunction with long-term records of daily rainfalls. Such estimates could be of general applicability throughout the region.

IV. PRESENT AND FUTURE SYSTEMS OF WATER SUPPLY

The water supply system on the Station at July 1973 is shown in Fig. VI-2.

The homestead area now has two alternative sources of water, besides roof-collected rainwater. Surface water is pumped from The Lake and groundwater is pumped from Planet Camp Bore; these supplies are gravitated to the homestead from storage tanks sited at the north end of the ridge about 1.5 km to the east. The tanks will permit the possibility of the mixing of surface and groundwater in varying proportions. Similarly, much of the eastern part of the property now has alternative supplies from Warrens Tank, Saloon Tank, Mandleman Bore and Planet Camp Bore. Clearly, the reliability of watering points has been much improved by this means, but there remain possibilities for further integration through linking by pipelines sources and watering points which are at present unconnected.

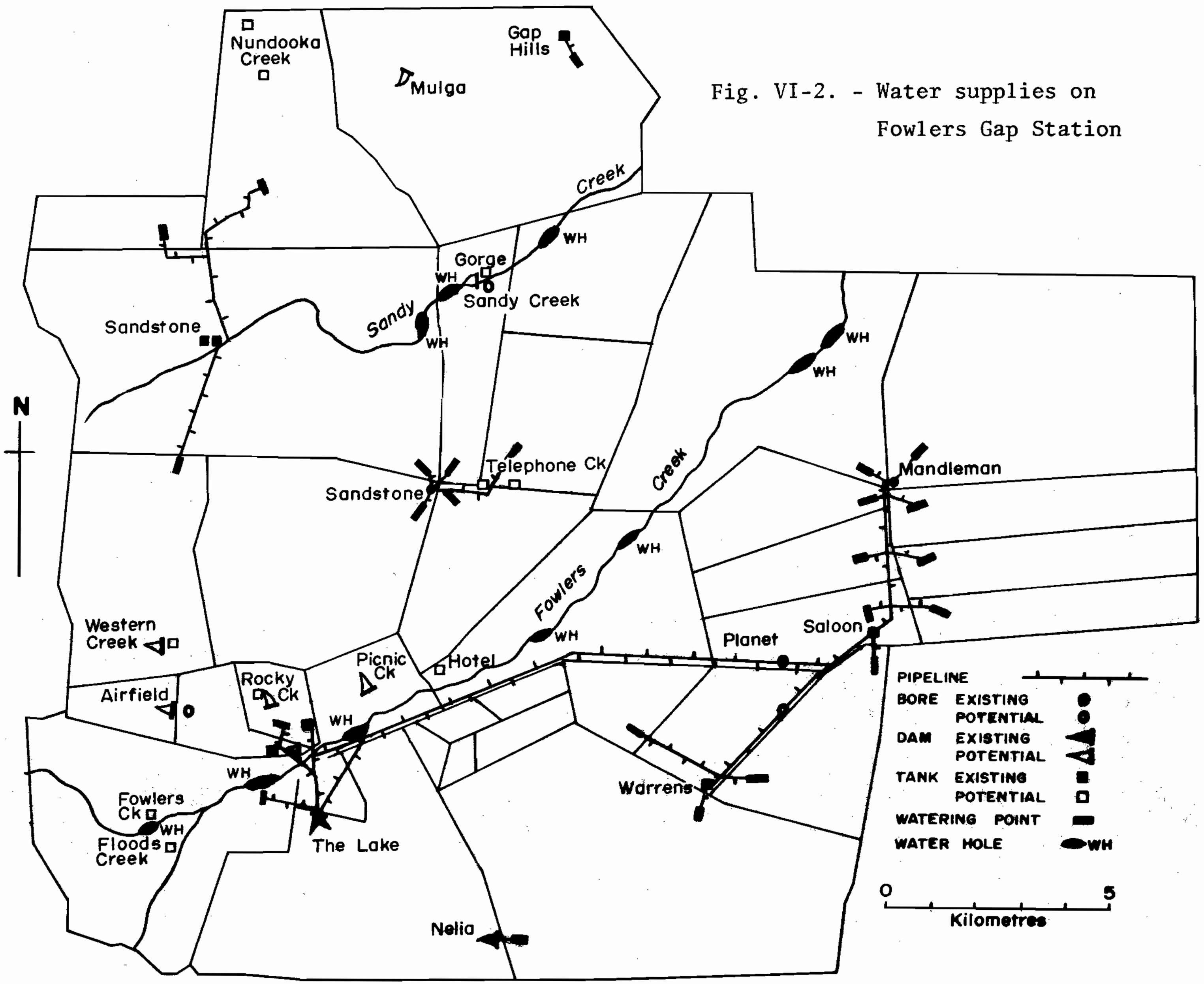
An increasing demand for water of low salinity at the homestead for domestic and laboratory purposes and for garden watering makes the use of some form of desalination of groundwater worth investigation. A further possible source of groundwater for the homestead from shallow wells nearby in Fowlers Creek may also be investigated.

V. RESEARCH NEEDS

There is much room for further data collection and research in connection with water resources at Fowlers Gap. Data collection in the following fields would be of benefit:

- measurement of precipitation rates, runoff, and sediment yields in a variety of catchments in different land systems

Fig. VI-2. - Water supplies on Fowlers Gap Station



- measurement of piezometric levels and water quality in aquifers for which information from borings is currently inadequate

- measurement of water use for different purposes at the homestead, and its correlation with work load and numbers of visitors.

The problems involved in using surface water also suggest a number of fields in which research could develop useful understanding:

(1) The sediment deposited in surface storages by runoff from sparsely vegetated catchments creates a need for periodic cleaning of storages of silt and has led to the practice of providing silt traps. Work by Hattersley and others (1969, 1972) suggests that silt traps are inefficient and has led to alternative proposals for the mitigation of silting, involving the design of formed channels leading into storages. Investigation of the applicability of this approach could be rewarding.

(2) Assumed relationships between rainfall and runoff based on the assumption that an entire catchment area contributes to the runoff are probably not valid for the arid zone. A detailed understanding of the partial contribution of arid zone catchments under different circumstances is required to aid future development in the modelling of such catchments. This could be assisted by installing detectors to provide information on runoff characteristics of different slopes and soil types on the Station as a function of combinations of rainfall and antecedent ground wettings.

(3) In a system where water of low salinity and low reliability is available together with water of high salinity and greater reliability, there exists the possibility of using desalination sporadically. An investigation into the economics of desalination at the homestead could indicate whether or not there are economic advantages in the conjunctive use of surface

water and groundwater and a desalination unit.

(4) The unreliability of surface water supplies is exacerbated by the very high rates of evaporation from surface water storages in this area. Investigations, both theoretical and experimental, into the efficacy of ways of reducing evaporation would be useful.

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CHAPTER VII. SOILS ON FOWLERS GAP STATION

By Janice R. Corbett

I. FIELD TECHNIQUES

The soils on Fowlers Gap Station were examined on two occasions for this survey. The first was with the survey team for two weeks in February 1968, when gradations between land units and between surface elements in areas of patterned ground were deliberately avoided. A second field visit in May 1968 enabled land units inadequately sampled on the first trip to be examined and the depth and continuity of soil horizons across other land units to be checked.

Exposure was mainly by bucket auger, but estimates of soil structure were checked in gully sections where possible. Field estimates of pH were made with Raupach's indicator and barium sulphate. Lime was tested for with 4N hydrochloric acid, and chlorides by adding silver nitrate to soil filtrate washed with distilled water. Samples were collected for carbonate determination and particle size analysis in the laboratory. The Munsell Colour Chart was used to estimate the colour of dry soil.

II. PROPERTIES OF THE SOILS

The soils on Fowlers Gap Station are in some respects typical of soils of the Australian arid zone in general, but also present three quite unexpected features which are not readily explained. Firstly, the best-developed profiles in terms of structure and horizon differentiation are found in areas devoid of vegetation, especially under stone cover; secondly, scalded claypan surfaces are areas of salt depletion rather than of accumulation; and thirdly, many crestal surfaces on resistant rocks bear relatively well-developed and locally deep soil profiles where one would normally expect only shallow lithosols.

(a) Depth

Upland soils on Fowlers Gap Station are generally shallow, although some are relatively deep, with well-developed profiles; on crestal bevels the deepest and best-developed profiles occur on sandstone and quartzite, whereas shallow lithosolic soils are commonly found on shale. On hillslopes and footslopes the position is reversed in that deeper soils generally occur on shale and shallower soils on sandstone. Crestal soils on sandstone and quartzite generally rest abruptly on fresh rock without a C-horizon, but hillslope and footslope soils on shale and limestone have a deeply-weathered C-horizon which in some soils could be augered to a depth of up to 2.50 m.

Many of the alluvial soils are quite deep, but in such localities more than one profile was usually found to be represented, in keeping with the earlier findings of Charley (1959).

(b) Colour

The soils are typical of the Australian arid zone in their colour which is mainly reddish. Most dry soils were located on the 10R 2.5 YR, 5 YR or 7.5 YR Munsell colour cards, with 2.5 YR 4/6 and 5 YR 5/6 by far the commonest colours. The strongly structured soils tend to be more intensely red, since both clay and sand fractions are usually red. During mechanical analysis the suspended clay was observed to be less red than the settled sand, indicating that the main colour pigment in the soil takes the form of iron oxide thinly coating sand grains. Concentrations of lime or other salts tend to mask the red colour in some soils, and some undifferentiated leached alluvial sands are also not very red, because they lack free colloids as well as sand-grain coatings. Organic matter is relatively unimportant as a colour pigment in the soils and only a few topsoils are naturally browner than their subsoils on this account. Black organic coatings were found on peds in some poorly drained alluvial soils and black manganese coatings were found on some peds in deep alluvial subsoils.

(c) Texture

The laboratory method of particle size analysis used was the hydrometer method with motor dispersion (Black, 1965). When these results were plotted on Marshall's (1947) triangle there was poor agreement with the field textures, in that many soils were super-plastic, that is they had appeared much heavier in field texturing. The greatest discrepancy was found in massive clay soils of Caloola and Mandleman land systems, which were "over-textured" in the field by one or two classes compared with the laboratory results.

Since carbonates had first been removed with dilute hydrochloric acid, the discrepancies could not have been caused by flocculation of clay due to excessive free calcium; further, the disagreements occurred in soils rich and poor in sodium and thus could not have been caused through lack of dispersion due to too high a sodium concentration. More severe grinding of the soils than the standard "hand-grinding with mortar and pestle" gave higher clay contents, suggesting that some of the recorded sand fractions consisted in reality of clay aggregates. (However, since particle size analysis should reflect how the soil particles behave in the profile, more severe grinding than the standard technique hardly seems justified; some clay aggregates undoubtedly behave as sand rather than as clay in the field soil, for example in lunettes).

It is noteworthy that the results of particle size analyses were very similar to those obtained for similar soils by Charley (1959) using a different technique, indicating that the method of analysis is not the main reason for the discrepancies. A contributing explanation could be the nature of the clay itself, in that swelling 2:1 lattice clays presumably dominate over the less expansive 1:1 lattice clays in this area, and it requires a lower content of the former to yield a given heaviness of field texture. In this report the textures stated are those determined in the laboratory except where there was considerable super-plasticity, when a compromise is given.

The heaviest-textured soils, with more than 30 per cent clay in some cases, were found on contour-stepped slopes on shale and in low-lying alluvial tracts. Some alluvial profiles and most profiles on contour-stepped slopes showed a degree of texture-contrast.

(d) Structure

Soil structure was estimated with some difficulty from augered samples because of inadequate gully exposures. Fortunately the most strongly pedal horizons commonly occur close to the surface and can be exposed by spade; however macrostructures such as the domed columns of solonetzic subsoils would have been missed in augering.

Loose, or apedal single-grain structure is confined to undifferentiated sands, to some alluvial soils, brown solonized soils, and to the deep dry subsoils of hillslopes; all other soils are massive or pedal. Pedal soils are most common beneath the unvegetated bands on contour-stepped slopes, particularly on the steeper facets with a stony surface. In these soils a thin pedal horizon is encountered a few centimetres beneath the surface, above a massive or loose subsoil. The pedal horizon contains well-developed red clay skins which suggest relatively strong soil-forming processes. The sparsely -vegetated bands without stone cover on such slopes commonly have pedal soils, particularly on stable interfluves, but here the pedal horizon is less prominent and concentrated than in the unvegetated areas. The more densely-vegetated bands generally have massive soils, and where there is some pedal development the peds are larger and weaker than those in the soils of the bare areas. This is perhaps because of a high return of salts to the topsoil by plants, which hinders flocculation as the salts are recycled through the soil. The pedal horizon in soils beneath bare areas usually has a much lower pH than the massive soil of nearby vegetated areas, suggesting that the former has been leached of dispersing salts, especially sodium.

(e) Consistence

Consistence estimates are not very helpful in describing the soils on Fowlers Gap since there is as much variation in consistence within single horizons as there is between horizons, especially in the force required to rupture soil fragments.

(f) Reaction, Lime and Chlorides

Soil reaction in the topsoil varies over short distances. It is closely related to plant cover, being particularly high (9.0-10.0) under saltbush whereas a similar unvegetated soil only a metre away may have a pH as low as 7.5 High pH values are also found in subsoils with salt illuviation, in association with lower values (6.5-7.5) in the eluviated topsoils.

Lime illuviation is a ubiquitous soil-forming process on Fowlers Gap Station and lime was encountered in all soil profiles except in some leached alluvial sands which did not contain lime for a depth of at least 4 metres. Greatest lime concentration is found in the brown solonised soils of stripped interfluves in Nuntherungie land system, where a thick cemented hardpan occurs. In other soils lime segregation takes the form of nodules or fine earth.

Chlorides commonly concentrate at a lower level than that at which lime begins to accumulate, but minor concentrations are found throughout many soils, especially in vegetated alluvial soils. Evidence of surface concentration of chlorides by capillary rise in bare areas such as scalds was very restricted; few surface crusts are saline, and in most soils of bare areas chlorides are illuviated. Scald surfaces are actually among the least saline environments.

(g) Stone Concentration

Stone concentration is one of the most interesting features of the soils, and yet one of the most difficult to interpret. Areas of dense surface stone usually have stone-free soils beneath, whereas areas of scattered stone usually have stone throughout the underlying soil. More detailed examination of the size, shape and nature of the stone in the soils is needed before the evidence can be interpreted, but it is significant to note that the most highly developed soils underlie the densest stone cover, on land surfaces classed as stable in Nuntherungie and Gap Hills land systems.

III. SOIL-FORMING FACTORS

Overall, soil properties are in keeping with the moderate effectiveness of leaching predictable under the regional climate, in that high pH values and accumulations of lime and chlorides are general. The lowest pH recorded was 6.5. However it is not an easy matter to account for local soil variations in terms of relief, parent material and vegetation; the time factor, expressed in surface stability, seems more important. With such a slow rate of leaching one must envisage long periods to bring about the high degree of organisation represented in some of the soils. Climatic change must also be considered when accounting for soil properties developed over a long time.

Parent material has exercised limited control over soil morphology in that quartzite, shale and alluvial sands may all be overlain by soils similar in colour, texture, reaction and structure; however the relationship between these soils and the rock or deposits beneath is difficult to determine. Some hillslope soils could have developed from the underlying rock, especially above shale where soil organisation decreases with depth and is gradually replaced by properties more closely related to the rock below, but many soils on hillslopes, especially those on sandstone and quartzite where the junction between soil and rock is abrupt, are probably derived from transported materials. Such soils are not noticeably sandier than those on shale. The sandy nature of much of the alluvium indicates that it contains a greater component from unstable stripped slopes with sandy lithosols than from the stable slopes with well-developed soils.

On Fowlers Gap Station the more developed soils are not associated with closer vegetation cover: in fact the situation is closer to the reverse. Highly organised soils are found beneath bareground and it seems that some vegetation, especially saltbush, limits the effectiveness of certain soil-forming processes, especially base illuviation and ped formation. Different processes appear to operate in bare and vegetated areas: for instance salts are illuviated beneath bare areas but in vegetated areas are re-cycled by plant uptake and return, with subsequent limited illuviation. Clay illuviation, however, operates best in the vegetated areas where salt re-cycling leads to sodium-dispersion of colloids.

IV. CLASSIFICATION OF THE SOILS

Although some of the soils on Fowlers Gap Station obviously fit into Great Soil Groups, for example the brown solonized soils, strong local development of profile features, especially peds, and haphazard patterns of calcareousness and salinity make soil classification difficult at this level. Better exposures of macrostructure might enable more soils to be named at the level of Great Soil Group; for instance if the deep pedal loams described below have a domed columnar structure they could be classified as solonetz.

Sheet 10 SE of the Atlas of Australian Soils (CSIRO, 1968) indicates four soil types on or near Fowlers Gap Station:

uniform textured shallow dense loamy soils with weak pedologic development (Um 5.41) in the Ranges

duplex textured crusted loamy soils with red clay sub-soils, sporadically bleached A_2 horizons, and alkaline reaction trend (Dr 1.33) in the Lowlands and Plains

gradational textured red earths with neutral reaction trend (Gn 2.13) on alluvium in the Plains

uniform textured brown self-mulching cracking clays (Ug 5.3) along through-going streams

The first type was found as indicated, but poorly-developed soils in the Ranges are sandy rather than loamy and well-developed soils are equally widespread there; the second type was found to occur in the alluvia of the Plains, but no bleached horizons were distinguished; the third type occurs on footslopes in the Ranges and in the Lowlands as well as on the alluvial Plains; the last type was not determined,* certainly not along the floodplains, which on Fowlers Gap Station are sandy.

Although detailed investigations of the morphology of the soils on Fowlers Gap have not previously been made, there have been studies of similar soils elsewhere. Charley (1959) reviews these, paying particular attention to the stone-covered soils which resemble the "stony desert tableland soils" well-known in Australian pedology (e.g. Jessup, 1960; Mabbutt, 1965). However, Charley's soil descriptions are concerned with evidence of periodicity rather than with naming the soils on the basis of morphology, as his work was done when soil-stratigraphical studies were receiving a great deal of attention in Australia. Although he gives quite detailed profile descriptions he does not classify them into Great Soil Groups.

Since no existing work classifies the soils of the area at a level suitable for this report, a new scheme is proposed as follows:

- Upland Soils
  - shallow soils
  - deep pedal loams
- Alluvial Soils
  - deep loose leached sands
  - texture-contrast soils
  - differentiated loamy soils

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* Subsequent analyses indicate this could have been due to incomplete dispersion.

Soils of Patterned Ground

reddish pedal soils
brownish-red less pedal soils

Brown Solonized Soils

The distribution of the first three of these groups of soils by site and by land unit is given in Tables VII-1 to VII-3.

V. DESCRIPTIONS OF THE SOILS

(a) Upland Soils

These soils occur on crests and slopes in the Ranges and in the strongly dissected parts of the Lowlands, on sites which lack contour-banding patterns by virtue of shallow cover and active erosion. They rest on a rock base which is mainly quartzite, sandstone, or calcareous sandstone, with minor areas of limestone. A useful subdivision can be made between shallow soils, generally less than 40 cm deep, which consist of a relatively uniform solum, and deeper pedal loamy soils with distinct horizonation. The latter mainly occupy sites with colluvial accession whereas the others occur in complex mosaics of varying texture, stoniness, and degree of profile development. The upland soils can be subdivided further according to structure, colour and degree of leaching as set out in Table VII-1.

(i) Shallow Soils - The term "lithosol" is not applicable to all the shallow soils, since some are stone-free; nor is "skeletal soil" generally adequate, in that some are markedly pedal and quite strongly leached.

Loose, (apedal single-grain) shallow soils are mainly lithosolic, that is they are also stony and unleached, particularly on calcareous rocks and on sites subject to strong

TABLE VII-1. UPLAND SOILS ON FOWLERS GAP STATION

Soil Type	Characteristics		Sites of Occurrence	Land System and Land Unit Numbers
Shallow soils (depth to rock less than 40 cm)	Loose-structured	Brownish unleached stony loamy sand	Upland surfaces and stony rises on calcareous rocks	Faraway 3, 5 Nundooka 3 Old Homestead 2
			Stripped spur crests and slopes	Gap Hills 2
		Reddish unleached stony loamy sand	Rocky rises on calcareous rocks	Mulga Dam 1
		Brownish unleached stony loam	Strongly dissected foot-slopes	South Sandstone 1
		Reddish leached stony loamy sand	Rocky faces and crests	Limestone 3
		Brownish leached stone-free loamy sand	Escarpment on calcareous rocks	South Sandstone 3
	Massive loamy sands	Brownish unleached and stony	Stripped crests and terrace margins	Old Homestead 3
		Reddish unleached and stone-free	Uplands and bevelled ridges on sandstone	Nundooka 3
		Reddish leached and stony	Higher ridges	Faraway 2 Mulga Dam 1
		Yellowish leached and stony	Low rocky ridges	Nuntherungie 3
	Pedal stone-free soils	Reddish leached loamy sand	Upland surfaces on sandstone and quartzite	Faraway 3 Nundooka 1, 2
		Reddish leached loam	Uplands on sandstone	Nundooka 3
Deep pedal loams	Unleached	Reddish	Less stable interfluves	Limestone 2
	Leached	Brownish	Escarpment on shale	South Sandstone 2
		Reddish	Colluvial slopes	Faraway 4 Limestone 4

stripping. Absence of stone from these soils locally is due to stone-free parent material, as on the shale of South Sandstone land system, which may also give rise to a loamy texture rather than to the more common loamy sand. The soils are mainly unleached, being calcareous and/or saline, but on limestone and calcareous shale they may locally constitute a shallow leached residue. Because of the masking effect of lime the unleached soils tend not to be as red as the leached soils.

Massive loamy sands are transitional to the deeper pedal soils, and also vary in texture, colour and stoniness according to parent material and degree of leaching.

Markedly pedal shallow soils are found on relatively stable crestal surfaces on resistant rocks in Faraway and Nundooka land systems. They are strongly red (2.5 YR 4/6 or 5/6), in part due to prominent clay skins on the peds. This strong degree of profile development is surprising in an environment of low soil-forming intensity, especially where the underlying rock is quartzite, and it suggests that the soils have undergone a long period of formation under fairly stable geomorphic conditions. The profiles are stone-free, although there is normally a stone cover, and the strongest development of profile features is found where the surface stone is densest. These better-developed shallow soils tend to be heavier-textured than the lithosols.

(ii) Deep Pedal Loams - These deeper upland soils have a definite profile development, but the pedal horizon does not occur at a consistent level, in contrast to similar soils on patterned ground, where it is always immediately below the surface. For example it occurs in topsoils on colluvial slopes in Limestone land system, but on the footslopes and spurs of Faraway land system it starts at 30 cm. This apparent haphazard location of the pedal horizon probably relates to accession to or stripping of surfaces, bringing the surface out of phase with profile formation.

(b) Alluvial Soils

These soils overlie unconsolidated alluvial deposits. They occupy the Plains and extend in drainage tracts through the Ranges and Lowlands. However, the category does not include alluvial soils in patterned ground as in Conservation and Gap Hills land systems. The alluvial soils may be grouped according to texture, colour, structure and degree of leaching as shown in Table VII-2 .

(i) Deep Loose Leached Sands - These soils lack profile differentiation but are non-calcareous and non-saline to depths of at least 100 cm and may have pH values as low as 6.5. Since some of the unconsolidated sands still show layering, it is difficult to imagine that this leaching is entirely post-depositional, for in this case one would expect the bedding to have been destroyed and salts to have accumulated at depth, which was not necessarily found to be the case. The sands in major drainage tracts of Old Homestead land system could have been leached *in situ*, since lime occurs as fine earth at depths of less than a metre, and chlorides below a metre. These soils can be considered transitional to the differentiated loamy soils described below.

The colour of the sands varies. The sand in the alluvial lobes of Mulga Dam land system appears to be derived primarily from the red-weathering sandstone and red upland soils and is one of the reddest soils on Fowlers Gap Station, namely 10R 5/8 or 2.5 YR 5/8. Other sands are less red, and the brownest ones (7.5 YR 5/4 to 5 YR 6/6) are found in the active parts of through-going drainage tracts, for example in Fowlers land system.

TABLE VII-2. ALLUVIAL SOILS ON FOWLERS GAP STATION

Soil Type	Characteristics		Sites of Occurrence	Land System and Land Unit Numbers
Deep loose leached layered sands	Reddish		Major drainage tracts Alluvial lobes Backplains	Nundooka 5 Mulga Dam 2 Fowlers 1
	Brownish		Major drainage tracts Levees and channels	Old Homestead 5 Fowlers 2, 3
Texture-contrast soils	Unleached	Reddish massive	Lower-lying tracts	Conservation 2
		Yellowish pedal	Backplains and depressions	Mandleman 1 Sandy Creek 2
	Leached to at least 10 cm	Reddish pedal	Incised drainage tracts	Gap Hills 5
		Reddish massive	Sand splays	Conservation 5
Differentiated loamy soils	Unleached	Reddish pedal	Alluvial fans and drainage tracts	Limestone 5, 6 Caloola 1
		Reddish massive	Channels	Caloola 3
		Brownish pedal	Drainage tracts and channels	Nuntherungie 4 South Sandstone 4 Mandleman 4
		Brownish pedal with loose sand cover	Major drainage tracts	Nuntherungie 5
	Leached to at least 20 cm	Reddish pedal	Drainage tracts	Faraway 6 Sandy Creek 3
		Reddish pedal with loose sand cover	Drainage tracts	Nundooka 4 Mulga Dam 3 Sandstone Tank 4 Gap Hills 4
		Reddish massive	Higher-lying tracts Drainage tracts	Conservation 1, 6
		Brownish massive	Minor drainage tracts	Old Homestead 4

Leached sands are by no means restricted to drainage tracts; for example they include hummocks and sheets of re-distributed sand covering developed soils in Conservation land system; these are non-calcareous and non-saline unless they have been vegetated by plants such as saltbush which return salts to the soil.

(ii) Texture-Contrast Soils - These soils become heavier with depth, changing from loamy sand or sandy loam near the surface to sandy loam, loam, or light clay at between 30 and 60 cm. The boundary between the light and heavy horizons is usually sharp. They occupy low-lying drainage tracts or backplains which remain wet for long periods after rain and which are accordingly among the better-grassed areas. This is one of the environments most conducive to soil formation, enabling clay illuviation to operate, and the subsoil has prominent clay skins in addition to the texture contrast.

Because of the low-lying sites and consequent high run-on and evaporation, salt concentration is high; some of the soils contain chlorides and carbonates throughout the profile, pH values at depths of between 30 and 60 cm were as high as 10, and strong positive reactions for chlorides were obtained. These conditions account for the massive structure of the soil, in that sodium-dispersion prevents ped formation despite an adequate clay content. It is possible that large domed subsoil columns of solonetzic type are present in these soils, but no exposures were available for this to be checked.

Where leaching has occurred it does not generally extend below 20 cm. The variable depth of such leached horizons is probably related to salt-cycling. After heavy rain and run-on the salts are temporarily illuviated, and they rise again through plant return or through capillary rise as the soil dries. Some of the thin crusts on these soils indicated the presence of chlorides, but others were non-saline with pH as low as 7.

The presence of free carbonates and some humus makes these soils less red (5 YR 5/6) than some other alluvial soils, and some are quite yellowish (7.5 YR 6/6), for example in the poorly drained backplains of Mandleman and Sandy Creek land systems.

(iii) Differentiated Loamy Soils - These soils also have strong profile development, but lack textural contrast. Their textures range from loamy sand through sandy loam to loam. Excellent exposures in Gap Hills land system enabled some of them to be examined in depth, and more than one alluvial soil layer was evident above the weathering rock in such sites. Auger holes deep into the alluvia of Caloola, Mandleman and Conservation land systems also revealed more than one pedogenic phase in a succession of leached, pedal and unleached massive horizons, but only the uppermost soils are described in the land system tables.

These soils are more freely drained than the texture-contrast soils and occupy drainage tracts in the Lowlands, or higher-lying parts of the alluvial plains. Their salinity is also generally lower, and perhaps for this reason most of these soils have a pedal horizon. Such horizons do not contain enough chlorides to react to silver nitrate, and if calcareous at all are usually not strongly so, but strong chloride reactions and high pH values (9.5-10) are encountered below the pedal horizons.

As with other soils on Fowlers Gap Station, the best ped development is associated with unvegetated areas, whether stony or stone-free, and massive soils with the vegetated areas where the return of dispersing salts by plants is higher. In less freely-drained areas, these massive soils grade towards texture-contrast soils.

These soils are also covered locally by splays or hummocks of loose leached sand.

(c) Soils of Patterned Ground

These soils occur in two widespread types of patterned ground, namely contour-stepped slopes in the Lowlands and on footslopes of the Ranges, and scalded alluvial flats in the east of the Station. The soils in these areas differ markedly in morphology over short distances, in keeping with rhythmic patterns of microrelief, surface stone, and vegetation cover. From the pedologic viewpoint there are two contrasting types of surface, namely vegetated and unvegetated, the latter being either stony or stone-free. On most contour-stepped slopes, as in Nuntherungie, Sandstone, Limestone, and Old Homestead land systems, as well as the upper part of Gap Hills land system, only the stony type of unvegetated surface is strongly represented, but on alluvial lobes in the lower part of Gap Hills land system stony and stone-free unvegetated bands alternate with the vegetated areas. On the alluvial plains, as in Conservation land system and also in parts of Sandy Creek, Mandleman, and Caloola land systems larger vegetated areas alternate with extensive bare scalds that are mainly stone-free. The first distinction, as set out in Table VII-2, is between soils of the vegetated and unvegetated areas, with further grouping according to texture and degree of leaching.

(i) Reddish Pedal Soils of Unvegetated Areas - The most strongly developed profiles are found under unvegetated stony surfaces. The soils are stony only to depths of between 5 and 12 cm, 8 cm being most common; the stones become less frequent with depth and cease at the top of a pedal horizon which is stone-free throughout. Stones recur in the profile only below the pedal horizon at depths of about 120 cm, where fragments of quartz and weathered rock are encountered, the latter increasing in frequency and size with depth.

The subsoil is distinctly red in colour (2.5 YR 4/6) and completely pedal; the peds are quite strong, considerable force

TABLE VII-3. SOILS OF PATTERNED GROUND ON FOWLERS GAP STATION

Soil Type	Characteristics		Areas of Occurrence	Land System and Land Unit Numbers
Reddish pedal soils of unvegetated areas	Stone-covered light textured	Pedal horizon calcareous and/or saline	Stony risers on crests and interfluves on sandstone	Gap Hills 1 Sandstone Tank 1, 2
	Stone-covered heavy textured	Pedal horizon calcareous and/or saline	Stony risers on stable interfluves on limestone	Limestone 1
		Leached to below pedal horizon	Stony areas on stable interfluves on sandstone	Nuntherungie 1 Gap Hills 1
			Stony steps in alluvial lobes	Old Homestead 1
	Stone-free light textured	Pedal horizon calcareous and saline	Scalds and claypans in older alluvial plains	Conservation 4
	Stone-free heavy textured	Pedal horizon calcareous and/or saline	Stone-free treads in stepped alluvial lobes	Gap Hills 3
		Leached to below pedal horizon	Scalds in floodplains	Mandleman 2, 3 Caloola 2 Sandy Creek 1
Brownish-red less pedal soils of adjacent vegetated areas	Light textured	Unleached	Scalded levee crests	Mandleman 3
		Leached to at least 20 cm	Less stony steps on crests and interfluves on sandstone	Gap Hills 1 Sandstone Tank 1, 2
	Heavy textured	Unleached	Less stony steps on stable interfluves on limestone	Limestone 1
			Risers in alluvial lobes	Gap Hills 3
			Gilgai margins and sandy hummocks	Mandleman 2 Sandy Creek 1
		Leached to at least 20 cm	Stone-free steps on stable crests and interfluves	Nuntherungie 1 Old Homestead 1
			Margins of scalds	Caloola 2

being needed to rupture them, and are angular blocky in shape, with prominent clay skins. On a slope transect, the pedal horizon starts beneath the densest stone cover and extends downslope into the adjoining vegetated area where it gives place to a less pedal soil. The peds are smallest (average diameter 0.5 - 1 cm) beneath the densest stone, and largest (1.5 - 2 cm) across the pattern boundary into the vegetated band. The thickness of the pedal horizon increases downslope from about 20 cm beneath the dense stone to more than 50 cm at the lower edge of the stony band.

Leached horizons, when present, are restricted to the areas of closest stone cover. Some soils are leached to below the peds, whereas others are weakly calcareous and/or weakly saline within as well as below the pedal horizon. The pH in the pedal horizon varies between 8.0 and 9.0, but usually rises to between 9.5 and 10.0 below, where lime and chlorides normally accumulate.

Most pedal soils are loamy in texture, with a quite high silt content which increases with depth. Clay content usually attains its maximum in the pedal horizon and decreases with depth below.

The soils of stone-free unvegetated areas are not quite as well developed as those beneath stony bands. Considerable stripping has occurred in some of them, especially on scalds as in Sandy Creek land system, where prominent clayskins and some angular blocky peds in the surface soil are reminiscent of better-developed subsoil in more stable areas. Most scalded soils are not strongly calcareous above the base of the pedal horizon but some are saline within it, for example in Conservation land system. The peds in soils under scalds are less stable in water, rounder, more irregular in size and easier to break than those of soils beneath a stone cover, suggesting a stronger influence of sodium salts.

(ii) Brownish-Red Less Pedal Soils of Vegetated Areas - These soils are not usually as red as soils in adjacent unvegetated areas, 5 YR 5/6 being the most common colour. They are less pedal and usually consist of about 40 per cent of easily broken, large (average diameter 2 cm), rounded blocky peds in an otherwise massive soil in the top metre, over an entirely massive subsoil. Clay skins are less prominent. Stones are not concentrated and may be encountered anywhere in the profile.

Salinity and calcareousness in these soils are closely related to the vegetation. Chlorides are found at the surface beneath saltbush, with pH values as high as 9.5, whereas surface lime is commonly encountered under dense grass; elsewhere the soil is usually leached to a shallow depth.

These soils are in general most similar to alluvial soils with texture contrast, and their micro-environment is similar, for they occupy steps and depressions which receive local run-on, either gilgai, including some melon holes, or drainage zones. For example, vegetated soils on stable interfluves of Nuntherungie land system have a maximum clay content at about 60 cm, with 10 per cent more clay than in the horizons above and below. In other soils of vegetated areas, for example in Gap Hills land system, texture contrast is less obvious.

(d) Brown Solonized Soils

On the less stable interfluves (Unit 2) of Nuntherungie land system a soil was encountered unlike that in any other land unit on Fowlers Gap Station. It is weakly saline and highly calcareous throughout, with lime concentrated in a hardpan between 40 and 100 cm depth containing up to 60 per cent carbonates.

The soil is reddish yellow (7.5 YR 6/4) at the surface and becomes less red (10 YR 7/3) with depth. The pH is highest (between 9.5 and 10) at the surface and decreases to 8.5 in the parent weathering calcareous shale which is encountered below 140 cm. Augering was still possible at 230 cm, so that the depth of weathering is as great as on stable surfaces of the land system.

Except for the massive lime hardpan the soil is soft and loose throughout and is locally referred to as "bull-dust soil". All horizons were found to contain more than 50 per cent fine sand after carbonate removal, and clay content reached its maximum of 10 per cent immediately above the hardpan.

The soil closely fits the description of a brown solonized soil, mallisol, or mallee soil by Stace et al. (1968), but in this case the lime hardpan could have originated by illuvial concentration of local material, since the parent material is calcareous, followed by stripping of the surface soil. The presence of only minor angular quartz gravel scattered throughout the soil lends support to its residual origin, since the parent shale contains quartz veinlets.

VI. SOIL ERODIBILITY

Like most soils of arid areas, the soils of Fowlers Gap Station are highly susceptible to erosion due to their internal properties as well as to external environmental factors. The soils are in the main poorly structured, and the aggregates, whether peds or the units of massive-structured soils are mainly unstable in water; on immersion or when wetted slowly by spraying, they either explode or slake quickly. In addition, the sparse vegetative cover affords little protection from erosion by wind and water or from the impact of raindrops. In Table VII-4 the soils are grouped according to erodibility, and corresponding land units are indicated.

The pedal and massive-structured soils tend to harden when dry and are accordingly not very susceptible to deflation in that

TABLE VII-4. SUSCEPTIBILITY OF SOILS TO WIND AND WATER EROSION

Erodibility	Soil	Land System and Land Unit
Very susceptible both to wind and water erosion	Loose shallow upland soils, deep loose leached layered alluvial sands, brown solonized soils	Faraway 3, 5 Nundooka 3, 5 Old Homestead 2, 5 Mulga Dam 1, 2 Limestone 3 South Sandstone 1, 3 Gap Hills 3 Nuntherungie 2
	Loose sand cover on other soils	Parts of Conservation 5 and Nuntherungie 5
Resistant to wind erosion, but susceptible to water erosion (gully and sheet)	Massive and pedal shallow soils and deep pedal loams on uplands, texture-contrast soils and differentiated loamy soils on alluvium	Old Homestead 3, 4 Nundooka 1, 2, 3, 4 Faraway 2, 3, 4, 6 Mulga Dam 1, 3 Nuntherungie 3, 4, 5 Limestone 2, 4, 5, 6 South Sandstone 2, 4 Conservation 1, 2, 5, 6 Mandleman 1, 4 Sandy Creek 2, 3 Gap Hills 4, 5 Caloola 1, 3 Sandstone Tank 4
	Brownish-red soils of vegetated areas in patterned ground	Parts of:- Gap Hills 1, 3 Sandstone Tank 1, 2 Limestone 1 Nuntherungie 1 Mandleman 2 Sandy Creek 1 Old Homestead 1 Caloola 2
Resistant to both wind and water erosion (peds are stable in water)	Reddish pedal soils in un-vegetated areas in patterned ground	Parts of:- Gap Hills 1, 3 Sandstone Tank 1, 2 Limestone 1 Nuntherungie 1 Mandleman 2 Sandy Creek 1 Old Homestead 1 Caloola 2

state. However a number of loose (apedal, single-grain) soils are liable to deflation when dry; these comprise sands, aggregates of silt or clay, and puffy clays. Loose sand moves fairly freely across the Station and all land systems are affected by it to a certain extent. Some of the finer-textured soils and the brown solonized soils undoubtedly contribute to the aeolian dust so characteristic of the area.

Some soils on Fowlers Gap have extremely low erodibility as they are pedal near the surface, with peds that are stable in water. Such peds are leached of lime and have pH from 6.5-8.0, indicating that sodium is probably only a minor component of the exchangeable cations. The well-developed red clay skins on these peds may contribute to their stability. These stable red pedal soils are found beneath steeper stone-covered sectors and adjacent unvegetated stone-free surfaces on contour-stepped slopes as in Nuntherungie land system. Water tends to flow across these soils rather than sink in, due to soil structure, stone cover, and microtopography.

In contrast, the brownish-red soils which underlie most of the vegetated stone-free surfaces in this type of patterned ground contain structural units that are not stable in water; they contain free lime and/or have pH greater than 8.0 and hence exchangeable sodium, and slake slowly or explode when immersed in water.

The remaining soils on Fowlers Gap are either weakly pedal or massive but are subject to water erosion because they disperse in water, again presumably due to free lime or exchangeable sodium, or a combination of these. Erosion of these soils takes different forms depending on soil texture and structure, and topography. The eluviated horizons of texture-contrast soils are very liable to sheet erosion above the arresting B horizon, particularly on gentle to moderate slopes. Gullying and tunnelling are more common on the steeper slopes of the ranges, where sheet erosion is restricted by stone cover.

Being highly erodible, most soils on the Station tend to gully badly where disturbed by stock, roads, or pipelines, and in practice the restricted extent of soils with low erodibility makes it impossible to avoid such disturbances.

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CHAPTER VIII. VEGETATION OF FOWLERS GAP STATION

By Juliet P. Burrell

I. INTRODUCTION

(a) Vegetation Classification and Nomenclature

The vegetation of the area is low woody and open and is representative of the shrub-steppe of southern arid Australia. Beadle (1948) sub-divided the vegetation in the region of Fowlers Gap Station into scrub and saltbush formations. He mapped the vegetation of the ranges as a mixture of the *Acacia aneura* association of the scrub formation and the *Kochia pyramidata* - *K. sedifolia* association of the saltbush formation, and the alluvial plains and lowlands as the *Atriplex vesicaria* association of the saltbush formation. Under the modified structural form classification of Specht (1970) used here, Beadle's scrub and saltbush formations fall into the categories of tall open-shrubland and low shrubland to low open-shrubland respectively. Small areas of low open-woodland and of tussock grassland are also present on the Station.

The botanical names used are according to Black (1943-57) and Eichler (1965), and the common names are those adopted by the New South Wales Soil Conservation Service.

(b) Environmental Controls of Vegetation

(i) Climate - The vegetation reflects the severity and nature of the climate in a number of respects. High evaporation and low rainfall have resulted in low and open communities and in a perennial vegetation which is floristically poor. Few communities contain more than ten perennial species, and these are predominantly low chenopod shrubs and tussock grasses. Of the taller perennial species, probably less than thirty fall into the category of tall shrubs, and of these only three are sufficiently abundant to be described as dominants of a community. In addition there are only three species which can be classed as trees.

That effective rains occur both in summer and in winter is reflected in the presence on the Station of shrub-steppe (saltbush), which is restricted to the southern half of arid Australia where between 30 and 50 per cent of the rain falls in winter (Perry, 1970), and tussock grasslands dominated by Mitchell grasses (Astrebla spp.) which grow only after summer rains.

Rainfall is sporadic in occurrence, and after wet periods the appearance of the vegetation changes with the germination and growth of ephemerals. The quantity of ephemeral growth depends on the amount of rain falling in a wet period and the accompanying evaporative conditions. Depending on the season, between 50 and 100 mm of rain is required to produce a closed canopy of ephemeral vegetation; however in the cooler months as little as 15 mm may yield a sparse cover. After wet periods ephemerals may outnumber perennials by five to one, even though the full range of ephemerals is not represented after any one rain as germination of many of them is dependant on temperature. Grasses are most abundant among the ephemerals that follow rain during the high temperatures of summer, and the more moderate temperatures accompanying winter rain result in a high proportion of forbs, especially daisies.

(ii) Landforms - The influence of landforms on vegetation, both in general and in detail, is exercised largely through control of runoff and infiltration. In the ranges, tall open-shrublands occur along rocky outcrop zones where crevices allow deeper water storage and root penetration, and also on some lower hillslopes receiving run-on, as in Faraway land system. The low shrublands of the lowlands and alluvial plains are broken into a mosaic of areas with and without perennial vegetation reflecting control of run-on and run-off by microtopography and the associated spatial variation in soil structure. Low open-woodlands are mainly restricted to the margins of large through-going channels, particularly where sporadic floods provide shallow groundwater, and tussock grasslands occur in the floodouts.

(iii) Soils - In this arid setting, the influence of soils on vegetation is exercised primarily through the effect of soil texture, structure and depth on infiltration and water storage capacity. Many of the coarser-textured and loose-structured soils support tall open-shrubland, as on sandstone in parts of the ranges and on rises of wind-blown sand in Conservation land system; the sandy alluvia of the large river channels support riparian woodland. Thin loose calcareous soils developed on limestone outcrop commonly have a low shrub canopy of bluebush (*Kochia sedifolia*; *K. astrotricha*). Variation in rock type and in residual soils on steeply dipping rocks can cause rapid alternations, for instance there are some interrupted lines of bluebush, often only one bush wide, following a strike band of calcareous sandstone, with the "normal" ecotype of bladder saltbush on either side. Even the calcicolous pearl and low bluebush and "lime" ecotype of bladder saltbush are segregated at some sites. The bladder saltbush (*Atriplex vesicaria*) low shrublands of the lowlands generally occur above subsoils which impede the downward movement of water, and the tussock grasslands are found on the heavier-textured soils of the lower alluvial plains. Some highly pedal soils that have low rates of infiltration or that are self-sealing do not even support ephemeral vegetation, as for instance on the stony risers of banded microrelief and on the scalds of the alluvial plains.

The general low phosphorus status of soils in Australia has long been known (Wild, 1958). Charley and Cowling (1968) confirmed the exceptionally low phosphorus status of Australian arid zone soils compared with soils of arid zones elsewhere, and soils of western New South Wales fall slightly below this Australian average in this respect (Cowling, 1969). This may in part account for the predominantly woody rather than grassy vegetation. Chenopod communities of the Australian arid zone show a preference for soils which are calcareous at least at depth, as is the case with almost all the soils on Fowlers Gap Station.

(c) Changes in Vegetation over Time

There have been changes in the vegetation on the Station with time. In part these reflect the variability of rainfall and sequences of dry and wet years. Other changes are due to the history of grazing, mainly in the direction of a decrease in the long-lived perennial chenopods and their replacement by semi-perennial chenopods or ephemeral species.

II. COMPOSITION, FORM AND DISTRIBUTION OF THE PLANT COMMUNITIES

(a) Subdivision and Classification of the Vegetation

Perry and Lazarides (1962) commented on the independence of upper and lower canopies in the vegetation of the Australian arid zone, and this applies to the vegetation on Fowlers Gap Station. To overcome the consequent problem of subdivision and classification of vegetation, a modification of the structural classification of Specht (1970) is used here. Specht's subdivisions are made on the height and growth form of the tallest canopy and the area covered by its foliage. Low shrublands, being the most extensive form on the Station, are discussed first, followed by tall open-shrubland and low open-woodland. Attention is then given to the perennial tussock grasslands. Finally the characteristics of areas lacking perennial vegetation are summarised.

The characteristics of plant communities in the various land systems are shown in Table VIII-1. The structural form is noted and below that the dominants of upper and second canopy only. Because the foliage cover of all canopies is sparse (10-30 per cent) to very sparse (less than 10 per cent), cover classes as defined by Specht (1970) have been omitted.

(b) Low Shrublands

(i) Bladder Saltbush Communities (*Atriplex vesicaria*) - There are two ecotypes of bladder saltbush on Fowlers Gap Station. The "normal" ecotype is the dominant in the bladder saltbush low shrublands. It has narrow-oblong to oblanceolate leaves and the fruit has large spongy bracteoles which when mature conceal the bracts. The "lime" or "hill" ecotype is frequently associated with bluebush shrublands but may occur as the sole dominant over small areas up to an eighth of a hectare in extent. It has orbicular leaves with strongly undulate margins; the fruit is variable, commonly having one small bracteole on the ventral bract, or bracteoles may be present on both bracts or absent.

The perennial components of the bladder saltbush low shrubland communities are the larger long-lived bladder saltbush in association with smaller short-lived copperburrs (*Bassia* spp.). The saltbushes are 30-75 cm high and of similar breadth; they normally provide a cover of between 10 and 20 per cent, but locally a cover of up to 50 per cent may be achieved. The copperburrs occupy the areas between the saltbush and range in height from 15 to 30 cm. Because of their variable but relatively short life span, the cover provided by the copperburrs changes with time, but it rarely exceeds 10 per cent and at the end of a drought may be reduced to an occasional plant. After rain, bladder saltbush shrubland supports a good stand of ephemerals.

This shrubland is the predominant community in the lowland land systems, where it occurs in a conspicuous patterned community of contour bands of vegetation separated by stony bands without vegetation, which generate run-off to the vegetated areas. These bands of saltbush are very well developed in Nuntherungie, Sandstone Tank, and Gap Hills land systems. The bladder saltbush is usually most dense in the upslope part of the band, between the lower margin of the stony riser and the line of gilgais which occur within the vegetated band, and thins out slightly downslope. Gilgai depressions around the small central crabholes may be occupied by bladder saltbush and copperburrs, or by neverfail (Eragrostis setifolia), or there may be no perennials.

Bladder saltbush low shrublands also occur as a dispersed community in other lowland land systems, for instance on less stable interfluves in Limestone land system, and in the land systems of the ranges, notably on the cuestas of Nundooka land system.

Most of the soils associated with bladder saltbush low shrubland show an increase in texture down the profile, whether this is gradational or texture-contrast. Carrodus and Specht (1965) considered that soils which impede the downward drainage of water through changes in texture or other factors favour the shallow-rooted bladder saltbush by retaining moisture within the rooting zone. By comparison, pearl bluebush (Kochia sedifolia) is deep-rooting and requires soils that are free-draining to a depth of 60 cm or more.

Soils under bladder saltbush communities are generally alkaline or sodic. The return of salt in the litter results in pH values of 9-10 in the surface soil beneath saltbush plants, but values may drop to slightly alkaline or neutral between

TABLE VIII-1. DISTRIBUTION OF PLANT COMMUNITIES IN THE LAND SYSTEMS OF FOWLERS GAP STATION SHOWING UPPER AND SECOND CANOPY ONLY AND AREA OF LAND SYSTEM COVERED BY EACH TYPE OF COMMUNITY

	LOW OPEN-WOODLAND			TALL OPEN-SHRUBLAND					LOW SHRUBLAND				TUSSOCK GRASSLAND	NO PERENNIAL VEGETATION	
TREES >5m	R*	C*	M												
TALL SHRUBS 2-5m				Mg	Mg	C	C	P							
LOW SHRUBS <2m			BS	S	BS	S	BS		S Cb	BS Cb	Cb	Ct Bs S / Cb			
TUSSOCK GRASSES								T				T	T		
NO PERENNIAL VEGETATION														E	–
Faraway		Very small		Moderate	Very large										
Nundooka	Very small	Very small		Very small	Small	Moderate			Large						
Mulga Dam	Very small		Small		Very large	Small			Very small	Small					
Gap Hills	Very small	Very small					Moderate		Small				Moderate		Moderate
South Sandstone						Small			Very large	Very small					
Limestone							Very small		Very large	Small		Very small			Small
Nuntherungie	Very small								Large					Moderate	Moderate
Sandstone Tank									Large	Very small					Large
Old Homestead	Small									Moderate				Moderate	Moderate
Conservation								Very small			Very large	Small	Small		Small
Caloola											Moderate	Small	Moderate		Moderate
Sandy Creek	Very small								Moderate				Large		Moderate
Fowlers	Small							Very small					Large	Moderate	
Mandleman	Small								Very small			Very small	Very small	Very large	Small

*Second canopy variable

DOMINANTS

- B Bluebush
- Bs Berry saltbush
- C Casuarinas
- Cb Copperburrs
- Ct Cottonbush
- E Ephemerals
- M Mallee
- Mg Mulga
- P Prickly acacia
- R River red gum
- S Bladder saltbush
- T Tussock grassland
- – No vegetation

AREA

- ● Very small <5per cent
- ● Small 5-15per cent
- ● Moderate 15-30per cent
- ● Large 30-50per cent
- ● Very large >50per cent

shrubs.

Charley (1959) has described the changes in bladder saltbush shrubland following overgrazing. Initially there is an increase in copperburrs, especially in the centres of gilgai depressions, where bladder saltbush becomes restricted to the outer edges. Eventually bladder saltbush is replaced by copperburrs leaving annual chenopods or bottlewashers (Enneapogon avenaceus) in the depressions. These changes are accompanied by a decline in surface soil pH and a redistribution of salinity levels with deeper illuviation in the vegetated areas and an increase in the non-vegetated areas.

One sequence of vegetation changes with increasing intensity of grazing pressure can be observed in a traverse from the western boundary of the Station towards the heavily grazed area around Sandstone Tank. The final stages of degradation can be observed on stable crests in Old Homestead land system, especially near Fowlers Gap Public Watering Place. They are without perennial vegetation, but after rains the less stony parts support ephemerals including annual chenopods.

Overgrazing of bladder saltbush communities may also result in an increase of Mitchell grasses (R.A. Caskey pers. comm.). The communities of Sandy Creek land system and the lower parts of Gap Hills land system contain varying proportions of bladder saltbush, copperburrs and Mitchell grasses. Since this area lies on a stock route it will have been overgrazed in the past and may represent a degraded bladder saltbush low shrubland.

There are however a number of observations which suggest that episodic changes occur naturally in bladder saltbush low shrublands. In southern Queensland, Blake (1938) noted an apparently stable system of alternes. The usual vegetation consisted of grasses, bladder saltbush and copperburrs around crabholes, but in some years there was only bladder saltbush and copperburrs or only Mitchell grass or no perennials.

Beadle (1952) considered that bladder saltbush established itself only after winter rains, whereas Mitchell grass only grows after summer rains. Therefore sequences of pronounced winter or summer rains could result in natural changes in dominance which would be enhanced if they had been preceded by reduction in competition through grazing into a drought period. That the vegetation of Sandy Creek land system has been described as grasses and saltbush or simply as saltbush by Agricultural Inspectors at different times suggests that it may belong to an alternating system.

In 1968 copperburrs were abundant in the bladder saltbush low shrublands of Nuntherungie and Limestone land system, but with the exception of the occasional plant of the truly perennial Bassia divaricata these copperburrs died during the dry summer of 1969-70. They failed to regenerate after the heavy rains of February-March 1970 and the follow-up rains extending into the winter, and in June 1972 these communities still lacked copperburrs. On the other hand, seedlings of bladder saltbush less than 10 cm in height survived the summer of 1969-70 and new seedlings have appeared since. However, in an exclosure on Nuntherungie land there is little evidence of bladder saltbush seedlings occupying the spaces left by the copperburrs. So it is possible that given the necessary rainfall sequence for their germination and establishment, copperburrs may re-occupy these sites.

(ii) Mixed Chenopod Communities

(1) Bluebush - Bladder saltbush (Kochia astrotricha, K. sedifolia - Atriplex vesicaria)- These communities consist of low bluebush (K. astrotricha) and/or pearl bluebush up to 100 cm high, with or without the "lime" ecotype of bladder saltbush, 25-75 cm high. They may also contain black bluebush (K. pyramidata) or Sida virgata. There is considerable variation in the proportions of these larger shrubs in the communities on different areas of the same unit within a land system.

Copperburrs, 25 cm high, provide the lower shrub component.

Cover is usually less than 10 per cent and only approaches this figure when bladder saltbush is present. After rains these communities support a light cover of ephemerals.

On the lowlands, these mixed chenopod communities occupy small areas of minor outcrop and rocky crests and faces on Sandstone and Limestone land systems, and more extensive areas on Old Homestead land system. On the ranges the areas of these communities are again small, being extensions of the lower canopy of tall open-shrublands into areas lacking tall shrubs.

Beadle (1948) considered low and pearl bluebush to be indicators of alkaline soils of light texture and in all cases tested on Fowlers Gap Station soils under bluebush contained free carbonate. These soils are normally loose-structured and frequently shallow.

Beadle also noted pearl bluebush as a valuable indicator of brown solonized soils. This soil type occurs on less stable interfluves (Unit 2) of Nuntherungie land system which are almost without perennial vegetation. There are a few pearl bluebush on this unit in Sandstone Tank Paddock and an occasional low bluebush in South Sandstone Paddock. The "lime" ecotype of bladder saltbush is invading the margins of this unit along the few minor hollows present. This suggests the land unit may have once carried bluebush-bladder saltbush low shrublands.

The reason for the collapse of this low shrubland is difficult to ascertain. Bluebush is more resistant to grazing than bladder saltbush,and bladder saltbush low shrublands have persisted in the same paddocks. However, the brown solonized soil is a favoured site for rabbit warrens. In addition the loose texture of the soils and the lack of microtopography suitable for locally concentrating run-on suggest that the water-storage capacity of the area is low.

The bluebush species are long-lived, and seedlings and dead plants are both infrequent on Fowlers Gap Station.

(2) Cottonbush-Berry Saltbush - Bladder Saltbush (*Kochia aphylla* - *Rhagodia spinescens* - *Atriplex vesicaria*) - Cottonbush is usually the most prominent of the larger shrubs in these mixed chenopod low shrublands, but may be replaced locally by berry saltbush. Both of these shrubs can attain a height and diameter of 100 cm or more. The bladder saltbush plants are smaller but may attain co-dominance by virtue of abundance or may be represented by only an occasional plant. The lower canopy is usually comprised of copperburrs and tussock grasses, but may be absent.

The cover of the perennial species ranges from 15 to 20 per cent, with the grasses and copperburrs contributing up to three quarters of the cover (Mrs. S.B. de Hall *pers. comm.*).

Cottonbush - berry saltbush - bladder saltbush low shrublands occur on the land systems of the alluvial plains. They frequently border and grade into tussock grassland or prickly wattle (*Acacia victoriae*) tall open-shrubland on one side, and to copperburrs, low shrubland or scalds on the other side. The surfaces are usually gilgaied and the larger shrubs tend to occupy the gilgai margins and also sandy hummocks if they are present.

The soils may be heavy-textured differentiated loams or texture-contrast, reflecting the ecotonal position of this community between tussock grassland and copperburr low shrubland.

(3) Copperburrs (*Bassia* spp.) - The main components of these low shrublands are the two perennial copperburrs, *Bassia divaricata* and *B. ventricosa*. Associated with these two species are semi-perennial copperburrs and the occasional larger shrub or tussock grass. The copperburrs reach a height of between 20 and 30 cm.

The total shrub cover is 10-15 per cent, between half and two thirds of which is provided by the two perennial copperburrs. After heavy rains the dense growth of ephemerals may raise the total cover to over 80 per cent (Mrs. S.B. de Hall, _pers. comm_.).

These low shrublands occur on the land systems of the alluvial plains. On Conservation land system they occupy the sandy hummock areas associated with the scalded areas of the higher-lying tracts, and part of the weakly gilgaid surfaces of lower-lying tracts; on Caloola land system they occupy part of the plains tracts with gilgai.

On sandy surfaces the perennial copperburrs occur on the sandy hummocks. In areas with gilgai almost every larger crabhole has a perennial copperburr growing at its margin; frequently there is also a tussock of neverfail or an annual saltbush growing at the crabhole margin. The soils are texture-contrast or differentiated loams.

The copperburr low shrublands probably represent over-grazed bladder saltbush or cotton bush - berry saltbush - bladder saltbush low shrublands. The proportion of larger shrubs in the copperburr communities increases in the eastern part of Conservation land system which is well removed from watering points.

The lack of copperburr low shrubland on the backplains of Mandleman land system suggests that this surface is too unstable due to gilgai activity to support a perennial vegetation. However, the type and abundance of ephemeral growth after rain at different seasons on this unit is the same as in the copperburr low shrublands which occupy other areas with gilgai.

(c) Tall Open-Shrublands

(1) Prickly Wattle (_Acacia victoriae_) - These are tall

shrubs about 4 m high, umbrella-shaped or fastigate. They commonly have berry saltbushes beneath them, but the cover between the tall shrubs is predominantly of tussock grasses including neverfail, windmill grasses (Chloris spp.), and fairy grass (Sporobolus caroli). The inter-tussock spaces may be filled by ephemerals after rain.

Prickly wattle tall open-shrublands reach their maximum development on Fowlers Gap in Conservation and Fowlers Land systems, where they are a feature of minor drainage tracts, but are never extensive and occur in discontinuous narrow strips and lines. They are also present along minor channels in Nundooka and Nuntherungie land systems.

It appears that prickly wattle may be fairly short-lived for a tall shrub, as a number of stands on the Station are dead or dying. Such stands contain no young plants, and only half the healthy stands are regenerating. The dead and dying shrubs may have established and grown during a sequence of years with heavier-than-normal falls of rain, with subsequent collapse and death during years of lighter rainfall.

Young seedlings of prickly wattle were observed in February 1968 after 105 mm of rain in the previous month.

(2) Mulga (Acacia aneura) - The mulga shrubs vary from 4 m to 7 m in height and the spacing ranges from between 1 and 2 canopy widths to 20 m. In most stands on the Station between 25 and 95 per cent of the mulga is dead.

The low shrub canopy under mulga consists of bladder saltbush and/or pearl bluebush and low bluebush with associated copperburrs, and Cassia spp. may also be present. This canopy is usually less than 50 cm high, with the low shrubs tending to be fairly evenly spaced, providing a sparse to moderate cover. The growth of ephemerals is rarely dense under mulga.

Mulga tall shrublands are almost entirely restricted to the land systems of the ranges, where they occupy rocky crests and faces and some colluvial slopes. They also occur along minor stream channels in the ranges and in the upper parts of foothills in Gap Hills land system. They are also found on elongate sandy rises in the eastern part of Conservation land system.

Whereas mulga grows on a range of shallow soils over rock, the distribution of species in the low shrub canopy is closely determined by rock type and the associated lithosols.

Adult mulga is resistant to normal browsing. The browse line on Fowlers Gap Station is about 2 m above the ground, suggesting that goats rather than sheep may be responsible. Reports to the Western Lands Commission on the 1957 drought, when the rabbit population was of plague proportions, listed mulga among the species being ring-barked by these animals. This may have contributed to the high proportion of dead mulga in many stands.

Preece (1971) considered that in Western New South Wales there have been nine occasions in the last eighty years with the correct sequence of rainfall to produce abundant mulga germination, but seedlings and young mulga plants have not been noted on Fowlers Gap Station with the exception of a few young plants on sandy rises of Conservation land system in the north-east of North Mandleman paddock. There are no rabbit warrens on these rises and the area is some 7 km from the nearest watering point on the Station. Elsewhere grazing by sheep and rabbits has doubtless prevented mulga regeneration.

(3) <u>Casuarina</u> (<u>Casuarina</u> spp.) - Although more than one species of <u>Casuarina</u> occurs on the Station, lack of cones has prevented positive identification. The casuarinas are usually about 7 m in height and may be single or multi-stemmed. They are normally relatively evenly spaced, although they can occur

as small groups of a few trees. The low shrub canopy is similar in structure and behaviour to that found under mulga.

Casuarina tall shrubland is found on footslopes in Faraway land system and on some rocky uplands in Nundooka land system, from where it also extends on to crests and slopes in the upper part of Gap Hills land system. It is also found on shallow calcareous soils in South Sandstone land system and on elongate sandy rises on the eastern part of Conservation land system.

(e) Low Open-Woodlands

(1) River Red Gum (*Eucalyptus camaldulensis*) - this is a riparian community occurring along the larger channels in which an alluvial fill provides a shallow ground water supply. There are two strains of *Eucalyptus camaldulensis* on Fowlers Gap Station, similar in form and both growing together, but one has distinctly more glaucous leaves.

In upper sectors of the main stream channels, where the alluvial fill is scanty, scattered trees alternate with groups of trees around water holes. The trees here are approximately 10 m high, with heavy branches and spreading habits. In such sites there is no general lower canopy, but a sparse cover of mixed chenopods may occur locally.

Further downstream, as the alluvial fill increases, the woodland becomes a continuous riparian strip which occupies both the channel and the banks, with the canopy extending back on the channelward slope of the levee. In such localities the lower canopies are patchy. The raised parts of the channel and the banks may carry tussock grasses, scent grass (*Cymbopogon exaltatus*) or *Digitaria* sp. The banks and levees commonly carry a sparse canopy of low shrubs, up to 100 cm high, including a wide range of chenopods such as bladder saltbush, black bluebush, low bluebush, berry saltbush, ruby saltbush

(Enchylaena tomentosa) and copperburrs. Taller shrubs 4-5 m high may occur at the top of low banks or on the levee, including Eremophila spp. Cassia spp., rose wood (Heterodendron oleifolium) and Pittosporum sp.

As the distributary zone of the channel is approached the trees become smaller and are restricted to the banks. The trees here are single-stemmed and often lightly branched, and form a discontinuous strip along the banks of the channels. Some channels may have saplings from 2 m upwards in height; other abandoned channels are flanked by dead trees. The lower canopy on the banks is made up of tussock grasses, and a fringe of prickly wattle 3-4 m high may locally be present at the top of the bank.

River red gum woodland occurs along through-going channels in a wide range of land systems but reaches its maximum development along the largest channels in Fowlers, Sandy Creek, Old Homestead, and Mandleman land systems.

Germination of river red gum seed occurs on the litter lines left after floods. The seedlings usually die within a few months, but on some occasions they have survived longer. On Fowlers and Mandleman land systems there are a few sapling hedges 1-4 m in height and up to 40 m long. Some of these sapling hedges are healthy, and others are dying or dead.

(2) Casuarina (Casuarina sp.) - this woodland never consists of more than small groves of up to a dozen trees, in bouldery channels that lack the depth of alluvium to support river red gums. The trees are single stemmed and lightly branched, and there is usually no lower canopy.

Most of the casuarina woodlands occur in the land systems of the ranges, but there are also a few areas in Sandstone Tank and Gap Hills land systems.

(3) Curly Mallee (Eucalyptus gillii) - these trees are 6-9 m high, either with a multi-stemmed mallee form or heavily

branched from a short trunk. The lower canopy consists of bluebushes in association with copperburrs and the "lime" ecotype of bladder saltbush. The trees are some 15 m apart and the lower canopy is variable, locally reaching 20 per cent cover.

Mallee is restricted to a single area on Fowlers Gap Station, on rounded hills of calcareous shale with calcareous soils between the ridges of Faraway land system. The mallee characteristically becomes more open on the crests of the hills. It is possible that the soils are chemically distinct, as other calcareous soils of similar structure and profile on the Station do not carry curly mallee.

There is no evidence of regeneration of curly mallee from seed.

(f) Tussock Grasslands

The tussock grassland communities on Fowlers Gap Station are composed of a mixture of larger perennial grasses, with neverfail, barley Mitchell grass (<u>Astrebla pectinata</u>) and curly Mitchell grass (<u>A. lappacea</u>) being most abundant. Other perennial grass species include fairy grass (<u>Sporobolus</u> spp.) and windmill grasses (<u>Chloris</u> spp.). Occasional shrubs including cottonbush, berry saltbush, bladder saltbush and copperburrs may also be present.

After heavy rain and flooding the perennial grasses may achieve a height of 50-70 cm and a cover of 20-30 per cent, with ephemerals, often of equal height, colonising the inter-tussock spaces as the area dries out. Whereas the changes in aspect with rainfall regime in the low shrubland and other communities are due to the appearance and disappearance of ephemerals, in the tussock grasslands such changes are due to differences of co-dominants with seasonal rains. After rains during the warm months of summer and early autumn, the Mitchell grasses dominate the aspect of those communities that contain these species, especially after heavy rains. Although neverfail grows after rains at any season at Fowlers Gap, it has a lower growth form than the Mitchell grasses and therefore only dominates the aspect of the community after winter rains or after summer rains that are too light to induce growth of Mitchell grasses. During dry periods the tussock grasses die back and are grazed to ground level, leaving a light scatter of shrubs to dominate the aspect.

Tussock grasslands occupy low-lying-areas of the alluvial plains subject to periodic flooding. Observations after rain indicate that Mitchell grasses occupy the positions of longest water lie within the grassland. Mitchell grass may be absent from narrow gilgai depressions in these areas. Windmill and fairy grass may then occupy the lowest part, and neverfail the margins, or neverfail may occur throughout.

Beadle (1948) notes that neverfail occupies clay soils regardless of soil pH and that Mitchell grasses are indicators of alkaline soils of heavy texture. On Fowlers Gap Station the tussock grasslands are generally found on moderately heavy soils, although in some sites the surface soil may be sandy and neutral, becoming heavier-textured and saline with depth.

Mitchell grass seedlings have not been observed on Fowlers Gap Station, but neverfail seedlings appeared after the April and light September-October rains in 1970.

(g) No Perennial Vegetation

Absence of perennial vegetation has been noted separately in Table VIII-1, to give an indication of the proportion of each land system in that category. Areas without perennial vegetation occur in the lowland and alluvial plain land systems, and can be separated into two categories.

(1) No Vegetation At All - this category does not even support ephemerals. It includes the stony areas in patterned ground in the lowland land systems and the scalds and clay pans in the alluvial plains land systems; both are part of the vegetated - non-vegetated mosaic of the low shrublands. The soils show limited water penetration compared with the contiguous vegetated areas and are usually highly pedal, saline and calcareous in depth. Some of the scalds have 1-2 cm of sand on parts of the surface, particularly around the margins. Ephemerals may germinate on these sandy surfaces after heavy rain but most of the seedlings die from water stress before reaching maturity.

(2) Ephemeral Vegetation Only - for the most part the areas which support only ephemerals appear to be the result of past overgrazing, the active surface of the backplains of Mandleman land system being a possible exception.

On the alluvial plains land systems the rains of January 1968 and February-March 1971 resulted in a dominance of button grass (*Dactyloctenium radulens*) which achieved a closed canopy and a height of 20-30 cm. After the rains of April 1970 the ephemeral vegetation consisted of mixed forbs, the conspicuous elements of which varied from place to place.

In the lowland land systems the ephemerals are most abundant in gilgai depressions. After the rains of January 1968 these depressions supported annual copperburrs and a mixture of grasses and forbs; after those of April 1970 and February-March 1971 they carried annual saltbush. Charley (1959) also reports bottle washers in depressions where the soil is calcareous and gives a photograph of part of Old Homestead land system as an example.

The brown solonized soils of less stable interfluves in Nuntherungie land system achieved a lawn-like appearance after the rains of January 1968. This was due to the bright green of pigweed (<u>Portulaca oleracea</u>) with other forbs. There was little ephemeral growth after the April 1970 rains and the February-March 1971 rains resulted in a dense stand of variable spear grass (<u>Stipa variabilis</u>) which persisted for more than twelve months after the rain. In 1952 this area was mapped as niggerheads (<u>Enneapogon</u> sp.) on the Soil Conservation N.S.W. Map S.C.S.909 (Vegetation of Fowlers Gap Rural Investigation Station).

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CHAPTER IX. PASTURE LANDS OF FOWLERS GAP STATION

by P.L. Milthorpe

I. INTRODUCTION

Fowlers Gap Station, like all other pastoral holdings in the area, relies on the native plants for forage. This vegetation consists of tree, shrub and ground layers. The tree and shrub layers comprise drought-resistant perennial species which are a useful source of drought forage, but the ground layer of perennial and ephemeral grasses and forbs is grazed preferentially. As this ground layer is mainly only present for relatively short periods following rain, the grazing animal has to depend for long periods on the less palatable vegetation of the upper layers for feed. Since droughts are frequent and often lengthy, it is important that these upper layers be maintained in the pastures, not only for their value as drought feed but also because they protect the soil from erosion, as well as sheltering the ephemeral pastures from drying winds during periods of growth.

There appears to be little scope for pasture improvement through the introduction of improved pasture species. Studies have not revealed any hardy, yet more palatable species to replace the existing plants of the tree and shrub layers. Some herbaceous ground-layer species have shown adaptability, but being herbaceous these would not contribute greatly during drought when feed is critically scarce; also, most introduced species require regular growing periods to flower and seed and therefore would not persist here where seasons are short, infrequent and unreliable. An exception may be in small areas where run-off could be spread or ponded to provide sufficient moisture for such plants to persist through drought. The role of these special habitats would be to establish a seed source of desirable species for natural spread into other areas, or for special-purpose grazing, and they would require protective management to prevent excessive grazing.

II. PASTURE PLANTS AND THEIR ATTRIBUTES

The native plant species can be grouped into three classes on the basis of survival mechanism and response to the arid environment. The attributes of these three classes and of some of the main species in each class are described below.

(a) Perennial Drought-Resistant Plants

This class comprises all plants in the tree and shrub layers. Most important on Fowlers Gap are the group of shrubs which includes bladder saltbush (Atriplex vesicaria), the bluebushes (Kochia pyramidata, K. astrotricha, K. sedifolia), and berry saltbush (Rhagodia spinescens). Bladder saltbush forms dense stands over large areas in the west of the Station, whereas the bluebushes and berry saltbush are generally restricted to areas near drainage channels. Bluebushes may also extend on to hillslopes and crests, particularly on calcareous rocks. The tree species, casuarinas (Casuarina spp.), mulga (Acacia aneura), and prickly wattle (A. victoriae) also contribute to forage, mainly by leaf-fall and seeds. Although not normally regarded as pasture, the tree layer must here be considered as such because of its potential contribution to the forage intake of stock during drought. There is an additional group of unpalatable species, the spiny copperburrs (Bassia divaricata, B. longicuspus), the eucalypts (Eucalyptus camaldulensis, E. gillii), and caustic bush (Sarcostemma australe), which contribute little forage.

Growth of plants in this group occurs during favourable periods of available soil moisture and continues for some time after such rainfall because the root systems are relatively extensive. During droughts these plants remain dormant, but carry leaf through all but the most severe droughts, when they may shed their leaves. This applies particularly to bladder saltbush, the most abundant and useful species of the group. Death of the plants may result if drought continues for long periods following leaf-fall, or if complete defoliation occurs through grazing during drought.

(b) Perennial Drought-Evading Plants

This small group consists of perennial grasses which although not abundant are widespread on Fowlers Gap Station, and which are important as forage plants. A characteristic of this group is that the plant dies above ground during drought and regrowth takes place from dormant basal buds after suitable rains. The main species include Mitchell grass (*Astrebla pectinata*, *A. lappacea*), neverfail (*Eragrostis setifolia*, *E. dielsii*), bottle washers (*Enneapogon spp.*), kerosene grass (*Aristida contorta*), native millet (*Panicum decompositum*), and windmill grasses (*Chloris truncata*, *C. acicularis*). They are most valuable during wet summer periods, as they respond quickly to summer storms and supply nutritious feed. However the nutritive value of the plant declines once the leaves have dried off, and although the fibrous butt persists well into drought periods it is not avidly grazed.

With the exception of bottle washers and kerosene grass, these species are mainly confined to fine-textured soils and may exist as almost pure stands on plains subject to frequent flooding. Mitchell grass, neverfail and bottle washers also grow in association with other ground-layer and shrub species in gilgai depressions of the stony lowlands, and bottle washers are very abundant on the calcareous soils of less stable interfluves in Nuntherungie land system, in association with the copperburrs (*Bassia obliquicuspis*, *B. eriacantha*, *B. biflora*, *B. limbata*).

(c) Ephemeral Drought-Evading Plants

Characteristics of this class are an ability to complete the life cycle in short favourable growing periods and to survive drought periods in the seed form. The plants begin to set seed at an early stage of growth and continue to do so while growing conditions continue. The main species include button grass (*Dactyloctenium radulans*), five-minute grass (*Tripogon loliiformus*), small burr grass (*Tragus racemosus*) and spear grass (*Stipa variabilis*) among the Gramineae, copperburrs (*Bassia uniflora*, *B. biflora*, *B. eriacantha*, *B. brachyptera*) and annual saltbushes (*Atriplex inflata*, *A. leptocarpa*, *A. spongiosa*) from the Chenopodiaceae, and everlasting daisies (*Helipterum spp.*, *Helichrysum spp.*) from the Compositae. This class of ephemeral drought evaders is ubiquitous, but the plant density varies with the presence or absence of an upper storey, with local microrelief insofar as it controls run-on or exposure to wind damage, and with grazing history. It contains those plant species most preferred by the grazing animal but which do not persist long into drought, and which therefore constitute the bulk of the forage for only short periods. When these plants are depleted, the woody, less palatable perennial species are grazed.

Differing response to seasonal conditions within this group leads to grass-dominant pastures following summer rainfall and forb-dominant pastures following winter rainfall periods.

III. PASTURE TYPES

(a) Pastures Characterised by Drought-Resisting Perennials

The abundance and ease of accessibility of perennial shrubs to grazing stock make them the most important plants in this group. Trees, which are also drought-resisting perennials, are less common and generally only supply drought forage as leaf-fall and seeds. Most shrubs are not very palatable due to their woodiness and high salt content, and are only utilized by stock in periods of drought.

(i) Bladder Saltbush Pastures - These are by far the most extensive pasture type on the Station, being found mainly in the western and central portions, on medium and fine-textured soils. Where this pasture exists on saline soils with gilgai microrelief, tree species are usually absent and bladder saltbush is the sole species; near watering places it is locally replaced by the shorter-lived, less palatable spiny copperburrs (*Bassia longicuspus* and *B. divaricata*). Black bluebush (*Kochia pyramidata*) is common along drainage lines.

On steeper hillslopes, scattered casuarinas (*Casuarina spp.*) are present in these pastures, and in more rocky areas mulga (*Acacia aneura*) is often dominant. Other shrub species are also commonly present with bladder saltbush in these steeper and rocky habitats, the main species being low bluebush (*Kochia astrotricha*), pearl bluebush (*K. sedifolia*) and berry saltbush (*Rhagodia spinescens*). The latter species, which has succulent fruit spread mainly by birds, is usually present only beneath trees or in drainage tracts.

Abundant short grasses and forbs are usually present beneath the shrub cover after favourable rains and supply the bulk of the forage to grazing stock in normal seasons. Areas of perennial drought-evading grasses such as Mitchell grass (*Astrebla lappacea*, *A. pectinata*) and neverfail (*Eragrostis setifolia*) are common with saltbush in areas with gilgai.

This pasture type is able to support medium stocking rates for long periods, as bladder saltbush is sufficiently palatable to maintain stock during drought provided good quality water is available.

Bladder saltbush pastures are dominant over most of Sandstone Tank, South Sandstone, Gap Hills, Nuntherungie, Limestone and Faraway land systems and are present to a lesser extent on the other land systems on the property.

(ii) Pearl Bluebush Pastures - These pastures are confined to areas of calcareous soils or limestone outcrop and are now found mainly in the hilly country. Scattered mulga often forms a tree cover associated with this pasture type on the Station. Pearl bluebush is usually openly spaced, generally at least between 2 and 3 m apart, and where it is sparse or absent poverty bush (*Bassia longicuspis*) may be present. There is evidence that pearl bluebush pastures once existed on the less stable interfluves of Nuntherungie land system with brown solonized soils; however these areas are now dominated by bottlewasher-copperburr pastures.

Pearl bluebush is unpalatable and is eaten only in times of extreme fodder shortage, most of the fodder of this pasture being supplied by the ephemeral ground-layer species.

This pasture type is found on Nundooka and Mulga Dam land systems, mainly in the north of the property.

(iii) Cottonbush Pastures - These pastures are found on alluvial texture-contrast soils or soils subject to occasional flooding. It is a degraded pasture type which appears formerly to have been dominated by bladder saltbush. Cottonbush itself is of little forage value due to the small size of the leaves and the fibrous nature of the stems, and most of the forage comes from the ground-layer species associated with it. This pasture type is able to withstand low to moderate stocking rates in favourable seasons, but the soils on which it occurs are highly susceptible to erosion and are prone to wind-drifting or scalding if stocking rates are maintained during droughts.

Cottonbush pastures are found in small areas of Conservation and Fowlers land systems, as well as on higher-lying units of Mandleman and Caloola land systems.

(b) Pastures Characterised by Perennial Drought-Evading Plants

Pastures in this group are confined to areas dominated by perennial grasses, most of which are summer-growing species. After growth periods they are characterised by the occurrence of dormant butts of dry material which respond to heavy summer rains by shooting from basal buds. They supply nutritious feed when young, but generally become fibrous and less nutritious as the plant ages.

(i) Mitchell Grass Pastures - These pastures occur on areas of fine-textured soil subject to flooding, as in the floodouts of Caloola and Fowlers Creeks. They are treeless, but scattered to dense perennial shrubs may occur locally, and neverfail (*Eragrostis setifolia*) is often a co-dominant. Numerous ephemerals follow favourable rains in the cooler months.

This pasture type is capable of supporting high stocking rates for extended periods following heavy rains or flooding during summer, but severe grazing into drought will reduce the response of the pasture to further rains. Mitchell grass pastures are the only pasture type really suited to cattle grazing on the property; however their limited extent would make it difficult to maintain a herd of economic size.

Mitchell grass pastures are mainly restricted to units of Caloola, Mandleman and Sandy Creek land systems, but small areas also occur in degraded bladder saltbush pastures, as in parts of Gap Hills land system.

(ii) Bottlewasher-Copperburr Pastures - These pastures are characterised by bottlewashers (*Enneapogon avenaceus*, *E. nigricans*, *E. polyphyllus*) and copperburrs (*Bassia obliquicuspis*, *B. patenticuspis*, *B. limbata*, *B. ericantha*, *B. uniflora*). These species, together with spear grass (*Stipa variabilis*), are perennials which react differently to seasonal conditions, which therefore determine the dominant species at any time.

Bottlewashers repond to summer rains, and spear grass dominates the pastures following favourable winter and spring conditions.

Bottlewasher-copperburr pastures are restricted to the highly calcareous, slightly saline loamy soils classed as brown solonized soils in the west of the Station.

All these species are nutritious and palatable when young; however, the copperburrs tend to become woody and spiny with age and spear grass presents grass-seed problems for a short period in its growth cycle, whilst its nutritive value is very low following maturity. This pasture type provides little drought reserve, and as the soils on which it grows are highly erodible it is capable of supporting only moderate stocking rates.

These pastures are to be found in a strip running north-south on the western side of the property, comprising the less stable interfluves of Nuntherungie land system.

(c) Pastures Characterised by Ephemeral Drought-Evaders

Pastures dominated by plants of this group are usually degraded pastures which at some time in their short history of grazing have been subjected to excessive stocking and have had the perennial species removed. Abundant growth and seed-set ensue following favourable rains, but in the absence of any physiological or morphological attributes for drought survival, death of this pasture follows with the onset of adverse conditions.

(i) Short Grass-Forb Pastures - These pastures are extensive on the open alluvial plains in the east of the property and in locally degraded areas surrounding some watering points. The composition varies greatly with soil type and seasonal conditions, as well as with grazing history. The greatest response of these pastures occurs following rains during the cooler months, but abundant grass species also appear following favourable summer rains. As the plants are herbaceous and generally weakly-rooted, they soon disintegrate and blow away in hot dry periods.

Several of the plants included in this pasture type are perennials, but due to the long dry periods they often do not survive from one growing period to the next; being herbaceous, even when they do survive only a small crown exists during these dry periods, and this supplies little or no drought feed.

Grazing rates on these pastures are low to moderate due to the absence of tree and shrub cover to protect them and because of the lack of drought fodder.

Conservation land system is the most extensive area of these pastures on the Station, and although there are small areas of perennial shrubs and grasses this land system becomes very dusty during dry periods. Minor areas of this pasture type exist in most of the land systems on the Station.

IV. PASTURE LANDS

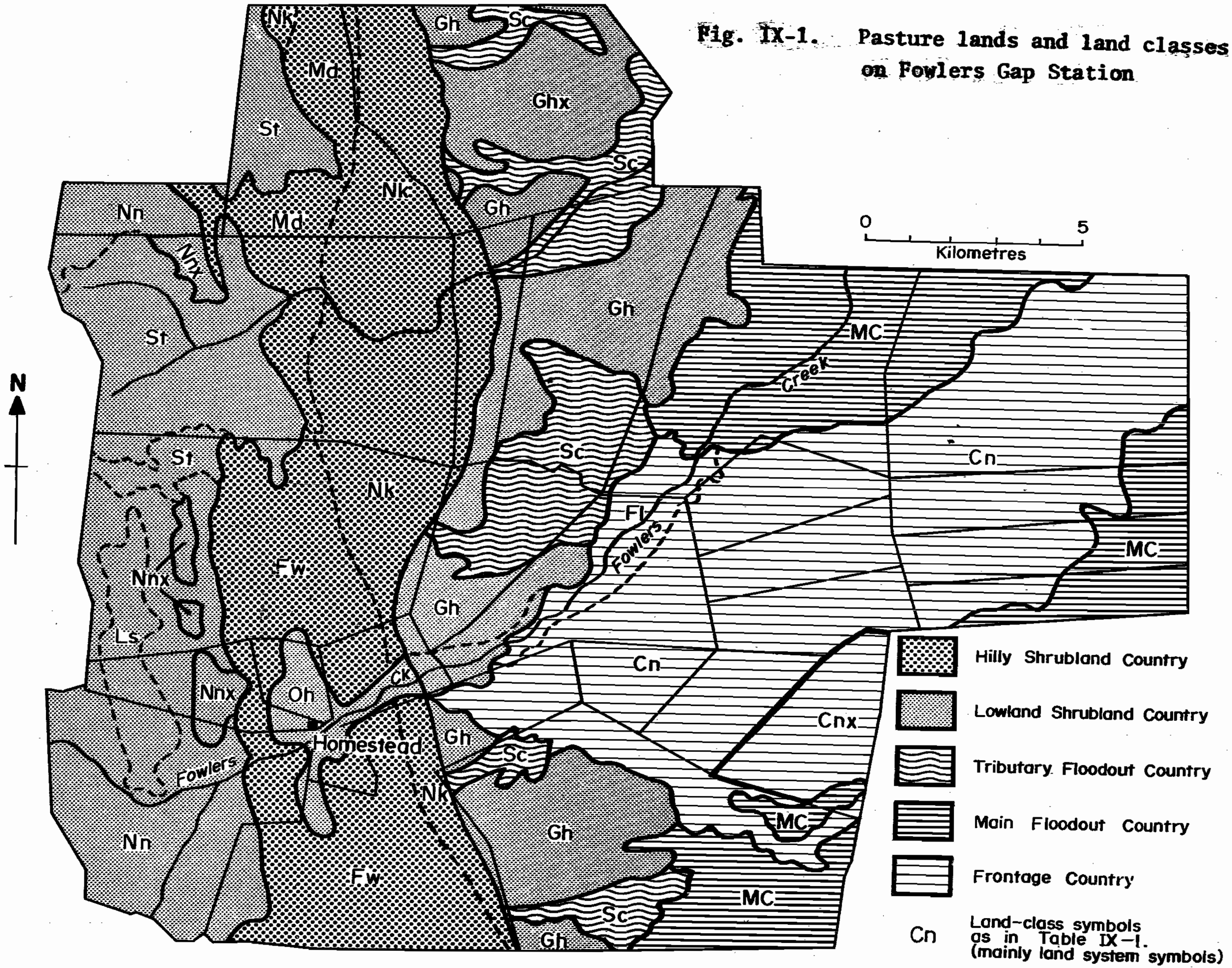
By grouping land systems with similar pasture types, landforms and soils, it is possible to define five pasture lands on Fowlers Gap Station (Fig.IX-1), each with distinctive features that are relevant to its productivity and management. All three classes of pasture types occur in each pasture land, but the overall pattern, composition and structure of the pastures differ greatly between pasture lands.

(a) Hilly Shrubland Country

(i) Area - 8,740 ha

(ii) Distribution - Comprises Faraway, Nundooka and Mulga Dam land systems, which form the central ranges of the Station.

Fig. IX-1. Pasture lands and land classes on Fowlers Gap Station



(iii) Environments - Sandstone ranges and uplands with much rock outcrop; belts of lower rounded hills with some calcareous soils; incised drainage channels.

(iv) Composition - The northern portion consists of dense bladder saltbush and pearl bluebush pastures under moderately close mulga or casuarinas; elsewhere there is sparse mulga or casuarinas over moderately dense bladder saltbush and pearl bluebush pastures with ephemeral pastures of grasses and forbs; mallee occurs on the calcareous soils on the low hills, and river red gum along the larger drainage channels.

(v) Productivity - This pasture land is moderately productive, but can be grazed continuously due to its component of drought-resistant species. Although steep and rocky in places, it is almost wholly accessible to the grazing animal and form valuable drought-relief country.

(vi) Present Use and Condition - Subdivision is difficult due to the steep and rocky nature of the ground and difficulty of vehicle access. Stock waters consist of two dams, one bore, and temporary water holes in rocky channels. There is scope for further bores and for small dams, and the area is an important source of run-off to adjacent pasture lands. The whole of this pasture land is within 5 km of a watering point. It is used for year-round grazing of mature wethers and dry sheep, and is a natural refuge for euros, kangaroos, and wild goats.

(b) Lowland Shrubland Country

(i) Area - 13,370 ha

(ii) Distribution - Comprises Limestone, Nuntherungie, Gap Hills, South Sandstone, Sandstone Tank, and Old Homestead land systems, mainly forming lowlands in the west of the Station and foothills and footslopes east of the Ranges.

(iii) Environment - Undulating lowlands and footslopes with a stony mantle which is generally arranged in prominent bare stony contour bands and alternate vegetated strips with gilgai depressions.

(iv) Composition - Dense to sparse bladder saltbush pastures, either treeless or with isolated clumps of belah. The saltbush is confined mainly to the contour bands with gilgai, between bare stony areas. Bladder saltbush pastures may be replaced by perennial drought-evading grasses or by ephemeral species depending on grazing pressure, as has occurred in parts of Gap Hills land system. Bottlewasher-copperburr pastures occur on calcareous soils. Bottlewashers are the dominant grass species of such pastures following summer rainfalls, and speargrass becomes the dominant grass after favourable winter conditions.

(v) Productivity - This pasture land is moderately to highly productive. The feed supply is intrinsically stable, with abundant ephemerals during good seasons and good reserves of saltbush during droughts, and hence the country is suited to year-round grazing by sheep. The small areas of calcareous soils are susceptible to powdering and wind erosion, the deeper fine-textured soils on lower slopes are liable to gullying where the stone mantle is disturbed, and the alluvial flats are subject to sheet and wind erosion. However, most of the area is stable and can produce good-quality wool relatively free from dust.

(vi) Present Use and Condition - Subdivision is generally easy because of gentle slopes, but is locally hampered by gullies, as along the western boundary of the Station. Watering is by earth tanks, which are favoured by the undulating terrain with broad valleys of moderate dimensions, by footslope situations, and also by the general abundance of excavatable materials. There are already two such storages (Sandstone

Tank and Bald Hills Tank) either in this country or adjacent to it, and there is scope for further constructions, particularly along the footslopes. All of this pasture land is within 5 km of a watering point.

Severe gullying has occurred where station tracks have disturbed the stone mantle on the more sloping country, and there has been severe scalding of alluvial flats, particularly in South Sandstone Paddock. There are also problems of wind erosion on the calcareous soils, particularly where the soil has been disturbed by stock or vehicle movements. In close proximity to watering points, along the stock routes, and in the holding paddocks there has been a serious depletion of the perennial shrubs. Although the perennial saltbush pastures are moderately drought-resistant, sheep should be excluded from them before they reach the stage of 50 per cent defoliation.

(c) Tributary Floodout Country

(i) Area - 2700 ha

(ii) Distribution - Comprises Sandy Creek land system in the centre of the Station, along the inner margin of the plains.

(iii) Environment - Floodplains and floodouts of smaller channels entering the plains, with scalded levees of texture-contrast soils and terminal basins of mainly fine-textured self-mulching soils.

(iv) Composition - Mitchell grass and bladder saltbush pastures on self-mulching soils, and mainly short grass-forb pastures on texture-contrast soils.

(v) Productivity - The perennial pastures are highly productive and persist, and following favourable seasons are capable of supporting high stocking rates without risk of erosion, provided they are spelled when feed is exhausted. The ephemeral pastures are capable of providing limited grazing for short periods, but the soils become highly susceptible to scalding and wind erosion with the onset of drought.

(vi) Present Use and Condition - This country is itself complex and does not occur in sufficiently large areas for separate utilisation. It is suited to the construction of earth tanks, and because of its foothill situation may be watered from dams and bores in adjacent upland country from which it receives run-on. The whole of this pasture land is within 5 km of a watering point and is fully utilised. Areas of texture-contrast soils are extensively scalded, and the more steeply sloping upper sectors of the channels are deeply entrenched and their margins strongly gullied.

(d) Main Floodout Country

(i) Area - 4580 ha

(ii) Distribution - Comprises Caloola and Mandleman land systems in the east of the Station.

(iii) Environment - Open alluvial plains of mainly fine-textured, often swelling and self-mulching soils associated with the main terminal floodouts, with discontinuous small channels. Slightly elevated tracts of more compacted scalded soils also occur locally.

(iv) Composition - Perennial drought-evading pastures such as Mitchell grass pastures occur in the lower, better-watered areas; elsewhere there may be bladder saltbush or cottonbush pastures, with short grasses and forbs. Ephemerals become abundant following heavy rain or flooding. Scalded areas are bare or have limited ephemeral vegetation.

(v) Productivity - This pasture land is highly productive after flooding or wet periods. In winter it produces an abundance of ephemerals to supplement the perennial species, and the perennial grasses respond to rains falling during the summer months. Because of the fine-textured soils this country does not respond to light falls of rain unless growth has been initiated by prior heavy rainfall. However, the soils allow the country to be stocked at a high rate without risk of erosion providing it is spelled when the feed is exhausted. The pasture land is capable of supporting cattle in good seasons.

(iv) Present Use and Condition - Subdivision of this pasture land is simple and the area is easily traversable by vehicles except after heavy rain, when the fine-textured soils may become impassable for several days; sheep may also be lost through bogging at such periods. The extensive fine-textured soils are stable, but the soils of the levee rises are subject to scalding. Stock water can be obtained from earth tanks provided they have extensive catch drains, and there is abundant alluvial ground water at about 100 m depth. Ninety per cent of this pasture land is within 5 km of a watering point.

(e) Frontage Country

(i) Area - 10,270 ha

(ii) Distribution - Comprises Conservation, Fowlers and part of Sandy Creek land systems, in the east of the Station.

(iii) Environment - Alluvial plains and floodplains, extensively scalded and with sandy hummocks and isolated gravelly rises, traversed by shallow drainage zones with weak gilgai and containing minor floodouts.

(iv) Composition - The main plain is treeless, with few shrubs except for isolated punty bushes (*Cassia eremophila*) on the sandy hummocks and prickly wattle on the gilgai and drainage tracts. The pastures consist principally of ephemeral drought-evaders such as copperburrs and grasses, with minor perennial grasses such as kerosene grass and neverfail on the sandy areas. The scalds are bare of vegetation. In the lower-lying drainage tracts, Mitchell grass pastures with fairy grass (*Sporobolus caroli*) and neverfail persist, with isolated cottonbush, berry saltbush and bladder saltbush.

(v) Productivity - This is the least productive country on the Station, mainly owing to the lack of perennial species and the low persistence of ephemeral species during drought periods. The soils are highly erodible by wind, particularly under heavy stocking, and the wool can become very dusty during dry summers and droughts.

(vi) Present Use and Condition - Subdivision is easy and the country is readily traversable by vehicle except after heavy rains, when low-lying tracts may become impassable for a few days. Water is from bores, with plentiful supplies of moderately good water at about 100 m depth, or from earth tanks fed by catch drains. There are three tanks and two bores in this pasture land, with an extensive reticulation by pipelines. Ninety per cent of this area is within 5 km of a watering point.

The present poor condition of this pasture land is due to excessive stocking, often during droughts at or prior to the beginning of the century. Degradation is seen in the extensive scalds and small clay pans and in the widespread occurrence of sandy hummocks about vegetation. Reclamation is difficult, requiring mechanical treatment of scalds by pitting, contour furrowing, and water-ponding structures, together with grazing control.

V. ASSESSMENT OF GRAZING CAPACITY

An assessment of the present and potential grazing capacity for Fowlers Gap Station was carried out by the Soil Conservation Service of New South Wales in 1968, as part of a regional survey of the district (Newman, unpublished).

The determinations of safe average carrying capacity are based on levels of stocking which have been shown to maintain country in good condition. The method used, as described by

Condon (1968), has been adopted as a standard procedure in assessing properties in the Western Division of New South Wales. Determinations are based on field assessments of soil characteristics, topography, drought forage availability, pasture types, and the existing degree of erosion, as well as climatic features such as average annual rainfall, rainfall variability and seasonal incidence of rainfall. For example, pastures able to provide drought forage such as bladder saltbush pastures are rated more highly than pastures characterised by ephemeral drought-evaders such as annual saltbushes and copperburrs. Likewise, provision is also made for areas receiving run-on to be rated highly depending upon its frequency of occurrence, whereas penalties are incurred for sloping country which sheds water.

This determination of carrying capacity takes into consideration that most country in western New South Wales, if stocked at a reasonable level, will carry sheep for approximately 12 months into a drought without experiencing permanent damage to soils and pasture. Were stocking to be at a level much above that recommended, this ability to carry stock into a drought would be reduced drastically and serious damage might be caused to erodible soils. Soils less susceptible to erosion would suffer loss of condition, and recovery to normal range condition would be delayed.

When the property was rated on this basis, the land system boundaries as described in Chapter II were generally acceptable as the boundaries of different land classes. Minor areas of some land systems were considered separately, mainly because of differences in vegetation from the remainder of the land system, and Caloola and Mandleman land systems were classed together. Several spot ratings of each land class were made, and calculations of carrying capacity were based on these field ratings. A summary of the pastoral characteristics and carrying capacity of the 16 land classes is given in Table IX-1.

TABLE IX-1. LAND CLASSES ON FOWLERS GAP STATION AND THEIR PASTORAL CHARACTERISTICS

Land Class Symbol[1]	Pasture Land and Land System	Soil[2]	Topography	Tree Cover	Pasture Type	Eroded or Bare Ground (per cent)	Grazing Rate $Sheep^3/100$ ha
Hilly Shrubland Country							
Fw	Faraway	brown gibber/skeletal	undulating	moderate mulga	bladder saltbush and pearl bluebush	30	12.92
Md	Mulga Dam	solonized brown	very gently undulating	moderate mulga	bladder saltbush and pearl bluebush	20	14.73
Nk	Nundooka	solonized brown/ skeletal	gently undulating	moderate mulga	bladder saltbush and pearl bluebush	20	13.37
Lowland Shrubland Country							
Gh	Gap Hills	brown gibber	slightly undulating	treeless	bladder saltbush	30	16.26
Nn	Nuntherungie	brown gibber	slightly undulating	sparse casuarina and nelia	bladder saltbush	20	17.22
Ss	South Sandstone	brown gibber	very gently undulating	casuarinas	bladder saltbush	20	15.17
Ls	Limestone	brown gibber	very gently undulating	sparse casuarina and leopardwood	bladder saltbush	10	16.65
St	Sandstone Tank	brown gibber	slightly undulating	treeless	bladder saltbush	5	18.56
Oh	Old Homestead	brown gibber	level to slightly undulating	sparse casuarina and nelia	bladder saltbush	30	13.84
Nnx	Pt.Nuntherungie	solonized brown	level to slightly undulating	sparse nelia	bottlewasher-copperburr	10	13.52
Ghx	Pt.Gap Hills	brown gibber	slightly to very gently undulating	treeless	bottlewasher-copperburr	30	12.40
Tributary Floodout Country							
Sc	Sandy Creek	alluvium/desert loam/ self mulching	level	treeless	Mitchell grass and bladder saltbush	20	18.14
Major Floodout Country							
MC	Caloola and Mandleman	self mulching	level	sparse prickly wattle	Mitchell grass, with sparse bladder saltbush and cottonbush	20	16.58
Frontage Country							
Fl	Fowlers	alluvium and brown gibber	level	sparse river red gum	sparse bladder saltbush and pearl bluebush	30	12.70
Cn	Conservation	texture contrast	level	sparse prickly wattle	sparse cottonbush and bladder saltbush	20-30	10.87
Cnx	Pt.Conservation	texture contrast, with some self mulching soils	level	sparse prickly wattle	cottonbush and bladder saltbush	20	12.21

1 As denoted in Figure IX-1

2 Soil and topography descriptions used in the above table are those used by the Soil Conservation Service of New South Wales in their classification of country when assessing grazing rates (Condon 1968)

3 Dry Sheep Equivalents

TABLE IX-2. ASSESSMENT OF PRESENT AND POTENTIAL CARRYING CAPACITY OF PADDOCKS ON FOWLERS GAP STATION

Paddock	Paddock Area ha	Area Within 5 km of water ha	Present Carrying Capacity[1]	Potential Carrying Capacity[1]
Bald Hills	1825	1825	286.9	286.9
Beadle	452	452	75.5	75.5
Sandstone	1764	1764	318.4	318.4
Sandstone Ridge	2201	2201	311.6	311.6
South Ridge	1975	1975	264.0	264.0
Holding	150	150	19.9	19.9
Gorge	676	676	99.0	99.0
Johnstones[2]	2059	2059	351.6	351.6
Mandleman	2879	2766	382.4	459.5
South Sandstone	1508	1508	246.4	246.4
Strip	586	586	89.2	89.2
Gap Creek	2330	2330	377.6	380.9
Lake	2190	2190	292.8	292.8
North Holding	260	260	35.3	35.3
Conners	497	497	68.4	68.4
Lane	37	37	5.1	5.1
North Mandleman	2987	1985	252.7	373.4
Salt 1	686	686	75.5	75.5
Salt 2	581	581	63.1	63.1
Salt 3	618	618	67.2	67.2
Salt 4	813	639	90.7	99.5
Salt 5	707	592	71.7	90.8
Salt 6	649	565	78.5	92.5
Saloon	1420	1420	183.6	183.6
Hotel	973	973	168.5	168.5
Gap Hills	2835	2819	401.7	404.0
Conservation	536	536	66.6	66.6
Warrens	3526	3526	545.6	545.6
Mating	415	415	45.1	45.1
Lambing	605	605	65.8	65.8
Ram	918	918	114.4	114.4
Property Total	39658	38154	5494.8	5760.1

1 Dry sheep equivalent

2 Now subdivided into Johnstones and South Johnstones

On the basis of the areas of land classes within it, the present average carrying capacity of each Paddock has been determined and is summarised in Table IX-2. Estimates of carrying capacity are based on the premise that sheep are able to utilise country reasonably within 5 km of watering points. The potential carrying capacity of each paddock is also listed, on the assumption that watering facilities will be extended to bring the total area into effective use.

The average safe grazing capacity for Fowlers Gap Station, based on existing watering points and subdivision as shown on the attached map, is 5,495 dry sheep equivalent. This includes provision for 66 sheep in Conservation Paddock which at present is ungrazed. It also includes allowance for areas grazed from temporary water holes along Fowlers Creek which usually provide water for portion of the year. During the winter these water-holes may persist for several months, but in summer they last only for a few weeks after being filled by storm rains. The potential average safe grazing capacity, assuming the whole of the lease to be adequately watered, is 5,760 dry sheep equivalent.

VI. REFERENCES

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CHAPTER X. MAMMALIAN FAUNA OF FOWLERS GAP STATION

By T.J. Dawson and Eleanor M. Russell

I. INTRODUCTION

Detailed studies of the fauna of Fowlers Gap Station have so far been limited to work on the biology of the large kangaroos. Initial observations have been made on the non-mammalian vertebrate fauna as part of the programme of the School of Zoology annual summer field camp, but these observations have extended only to the commencement of the compilation of check lists of the amphibians, reptiles and birds. Of these lists the most complete is probably that of the birds. This check list is similar to the annotated list of the birds of the Fowlers Gap-Calindary area provided by Hall (1972), and observations on Fowlers Gap have not yet produced any addition to Hall's extensive list.

II. MAMMALIAN SPECIES

The mammalian fauna of Fowlers Gap Station and of north-western New South Wales in general is limited. In this area there has occurred a drastic decline of the smaller marsupials due, apparently, to overstocking with sheep up to the 1890's, coupled with severe drought and the invasion by rabbits in the 1880's. The species extant on Fowlers Gap Station are now probably restricted to the echidna and several species of marsupials and native rodents, together with introduced species. A list of species that have been actually observed recently is given in Table X-1. In addition to these animals, it is possible that several other species may be present at times on Fowlers Gap. For instance the small jerboa marsupial mouse,

TABLE X-1 MAMMALIAN SPECIES OBSERVED
ON FOWLERS GAP STATION IN RECENT YEARS

MONOTREMES

Echidna (Tachyglossus aculeatus)

MARSUPIALS

Fat-tailed marsupial mouse (Sminthopsis crassicaudata)
Red kangaroo (Megaleia rufa)
Euro or hill kangaroo (Macropus robustus)
Western Grey kangaroo (Macropus fuliginosus)

EUTHERIAN MAMMALS

(a) Native (excluding bats)

Sandy inland mouse (Pseudomys hermannsburgensis)

(b) Introduced

House mouse (Mus musculus)
Fox (Vulpes vulpes)
Cat (Felis domesticus)
Goat (Capra hircus)
Rabbit (Oryctolagus cuniculus)

Antechinomys laniger, may be present on Fowlers Gap but has not been positively identified. On several occasions sightings have been made of a small agile mammal which may have been this marsupial or the native rodent counterpart, Mitchell's hopping mouse, *Notomys mitchellii*.

The yellow-footed rock-wallaby, *Petrogale xanthopus*, still occurs in small numbers in Faraway land system to the east of Fowlers Gap Station, but despite anecdotal reports this species does not appear to be present on Fowlers Gap, nor in its immediate vicinity.

III. BIOLOGY OF THE PRINCIPAL SPECIES

(a) Introduced Species

(i) Rabbits - The rabbit was introduced into Victoria in 1859 and entered northwestern New South Wales in the early 1880's. No studies have been carried out on the ecology of the rabbit on Fowlers Gap Station, but the findings of the extensive studies of Myers and his co-workers around Tero Creek, 150 km to the northeast, are probably applicable in general to Fowlers Gap (see Myers and Parker, 1972, for summary). These studies have shown that the rabbit population in northwestern New South Wales fluctuates violently and that patterns of distribution change significantly in relation to changes in climatic conditions. Rabbit numbers build up after several years of good rainfall. When drought intervenes, the population, which may have become widespread, collapses and rabbits become restricted to well-defined refuge areas principally along drainage channels. The importance of the rabbit as a herbivore on Fowlers Gap Station is well illustrated by the periodic complete devegetation of large areas, such as units of Nuntherungie land system west of Homestead Creek.

(ii) Foxes - The only significant mammalian scavenger and predator on Fowlers Gap Station is the European fox. Introduced successfully into Victoria in about 1870, soon after the rabbit (Rolls, 1969), the fox has adapted to the arid zone and now has a very wide distribution over the continent.

Most studies have shown that the fox is an omnivorous feeder, its diet ranging from berries and other fruit, insects, reptiles, and small birds to mammals and carrion, including dead and dying lambs (McIntosh, 1963; Alexander *et al.*, 1967; Rowley, 1970; Myers and Parker, 1972). Around Tero Creek, foxes feed mainly on carrion, on rabbits, both adult and nestlings, and on reptiles, frogs and insects. The number of foxes in the region fluctuates markedly with the nature of the seasons, and it has been suggested that this is related to the change in rabbit numbers (Myers and Parker, 1972).

(iii) Feral Goats - Goats were introduced into the north-west of New South Wales in the middle of the last century to provide milk and mohair to the pastoral stations and mining settlements. They range through the hills on Fowlers Gap Station, in Faraway and Nundooka land systems, in mobs varying in size upwards from between 3 and 5 individuals. One mob of approximately 150 goats was rounded up and sold by station staff in 1967 when it moved on to Fowlers Gap Station along the Barrier Range from the north. Occasionally the goats move out into the foothills on the Station, such as Gap Hills land system, usually along creeks which afford them some degree of protection.

Studies have been carried out into the watering and feeding patterns of the goats in comparison with those of kangaroos and sheep, and these are discussed below in the section comparing the data for all species of large herbivore.

(b) Kangaroos

Two species of large kangaroo normally occur on Fowlers Gap Station, namely the red kangaroo and the euro or hill kangaroo.

The western grey kangaroo occurs in small numbers in wooded country immediately to the east of the Station, but only occasionally have isolated individuals or small groups been sighted along the eastern boundary.

(i) Distribution - The red kangaroo and euro both occur widely in the arid areas of Australia. The red kangaroo is distributed over the whole of the interior of Australia, being found mainly in open grassland or shrub steppe. The euro is also widely distributed but normally occurs in areas with rocky hill country. On Fowlers Gap Station these basic patterns are largely maintained.

The major concentration of red kangaroos occurs on flat country in the eastern part of the Station, namely in Conservation, Caloola, Sandy Creek, Mandleman, and Gap Hills land systems. Other areas in which significant numbers of red kangaroos may be found are the broadly undulating lowlands west of the ranges, namely in Sandstone Tank land system in the north and Nunther-ungie land system in the south. The distribution of red kangaroos within these areas during daylight is largely influenced by the distribution of trees, particularly during summer when they rely on the sparse shade of acacia and casuarina trees for protection from the summer radiation heat load (Dawson and Denny, 1969a; Dawson,1972)

The overall distribution of the euro is determined by the availability of hilly country with suitable "lying up" sites such as caves and rock overhangs. These conditions are found along the ridges of Faraway and Nundooka land systems, and sizeable colonies of euros are present in them. The euro uses its selected microenvironments as heat refuges which enable it to avoid most of the strong heat load characteristic of the arid zone, thus effecting considerable water savings (Dawson and Denny 1969b). Russell (1969) has described many of the shelters used by euros and shown that the type of shelter varies with environmental conditions. During winter and in mild summer weather euros frequently shelter in vegetated gullies in undulating country, for example in Limestone land system, but during periods of high temperature most animals are found in rock shelters and caves.

(ii) Movement of Kangaroos - A trap constructed on Sandstone Tank in the summer of 1969-70 by the School of Zoology has enabled considerable information to be obtained concerning the movements of both species of kangaroo on Fowlers Gap Station. When animals were trapped they were tagged with numbered collars and released, each plastic collar being individually marked with a series of stripes of different coloured reflective tape.

Information so far analysed has confirmed findings made by other workers on these two species (Bailey ,1971; Ealey, 1967). Red kangaroos, as also observed by Bailey at Tero Creek, may move relatively long distances. Within 6 weeks of marking at Sandstone Tank the greatest movements by red kangaroos were by one animal seen 32 km to the northeast and another reported approximately 40 km to the south. The furthest movement to date is by a young red male found caught in a fence 64 km northwest, 7 months after release from the trap. Bailey (1971) reported a maximum movement of approximately 200 km in 5 months. However some red kangaroos appear to be relatively sedentary, since 8 of the 54 red kangaroos marked were still in the area one year later, and several individuals have been recorded after two years. Bailey (1971) also found that a proportion of the population remained sedentary.

The dispersal of euros from the trap has been much less widespread than that of the red kangaroos. Up to two years after trapping, no sightings of collared euros have been reported other than on the Station. These observations tend to support the findings of Ealey (1967), who reported that the euro in Western Australia had a limited home range, usually in the vicinity of a rocky outcrop or water or both.

(iii) Numbers - No attempt has as yet been made to obtain an accurate estimate of the number of kangaroos on Fowlers Gap. The difficulties in obtaining such an estimate have been pointed out by Bailey (1971). At Tero Creek Bailey obtained large differences between the densities of red kangaroos as estimated by ground and aerial surveys. Such difficulties would be much more severe in the case of the euro because of the nature of its habitat.

During the extensive programme of capturing and marking in the summer of 1969-70, at a time when Sandstone Tank was the only water source in the northwestern part of the Station, it was estimated that approximately 200 red kangaroos and 600 euros were watering on Sandstone Tank. Systematic ground observations indicated that a considerable number of the red kangaroos which watered at the Tank normally sheltered in shrubland in the parts of Floods Creek and Nundooka Stations adjacent to Fowlers Gap. Marked euros were found throughout the ranges north of the Homestead.

Extrapolation from these rough estimates to an estimate of the total number of kangaroos on Fowlers Gap Station obviously leads to still more imprecise figures. However, from observations in the various types of habitat in the remainder of the Station it appears possible that in the summer of 1969-70 there were of the order of between 1200 and 1500 kangaroos on Fowlers Gap Station, that is an approximate density of between 3 and 4 per square mile. Euros concentrated in the hills would have made up the majority of these animals.

Estimates of the numbers of red kangaroos and euros in a particular season, even if approximately correct, should not be taken to represent the usual situation. While the euro population appears much more sedentary than the red kangaroo population, its numbers as shown by age distribution studies may be severely affected by drought (Russell and Richardson, 1971).

(iv) Breeding - Breeding, both of red kangaroos and of euros, has been found to be continuous. In the red kangaroo there is no obvious seasonal variation in breeding, apart from the effects of long-term drought (Frith and Sharman ,1964; Newsome,1964). In drought, presumably because of poor nutrition, female red kangaroos enter anoestrus and cease breeding, and Newsome (1964) showed that the proportion of anoestrous females at any time was correlated with the severity of the drought.

The data on monthly distribution of births for the euro at Fowlers Gap (Russell and Richardson,1971) also show that breeding is continuous and that there is no obvious seasonal concentration. The low number of euros born at Fowlers Gap during the 1964-67 drought also demonstrated the effect of low rainfall on breeding.

Information obtained during the dry summer of 1969-70 suggests that the breeding of euros may be more influenced by poor seasonal conditions than that of red kangaroos. Of 38 mature female red kangaroos and 59 mature female euros examined during this summer, only 14 per cent of the red kangaroo females were not lactating compared with 49 per cent of euros. The reason for this may reside in the restricted range of the euros. Restriction to home ranges around heat refuges in rocky areas may be advantageous to the euros in respect of water conservation; however, this same pattern of behaviour may cause extensive overgrazing of these home ranges when seasonal conditions are poor.

(v) Drinking patterns and water usage - On Fowlers Gap Station investigations have been made into the frequency of drinking by red kangaroos and euros in summer and into their behaviour around water holes (Russell and Nicholls, 1972). Estimates have also been obtained of the actual usage of water by the two species of kangaroo and by sheep and goats. These studies indicate that during most of the year the red kangaroos

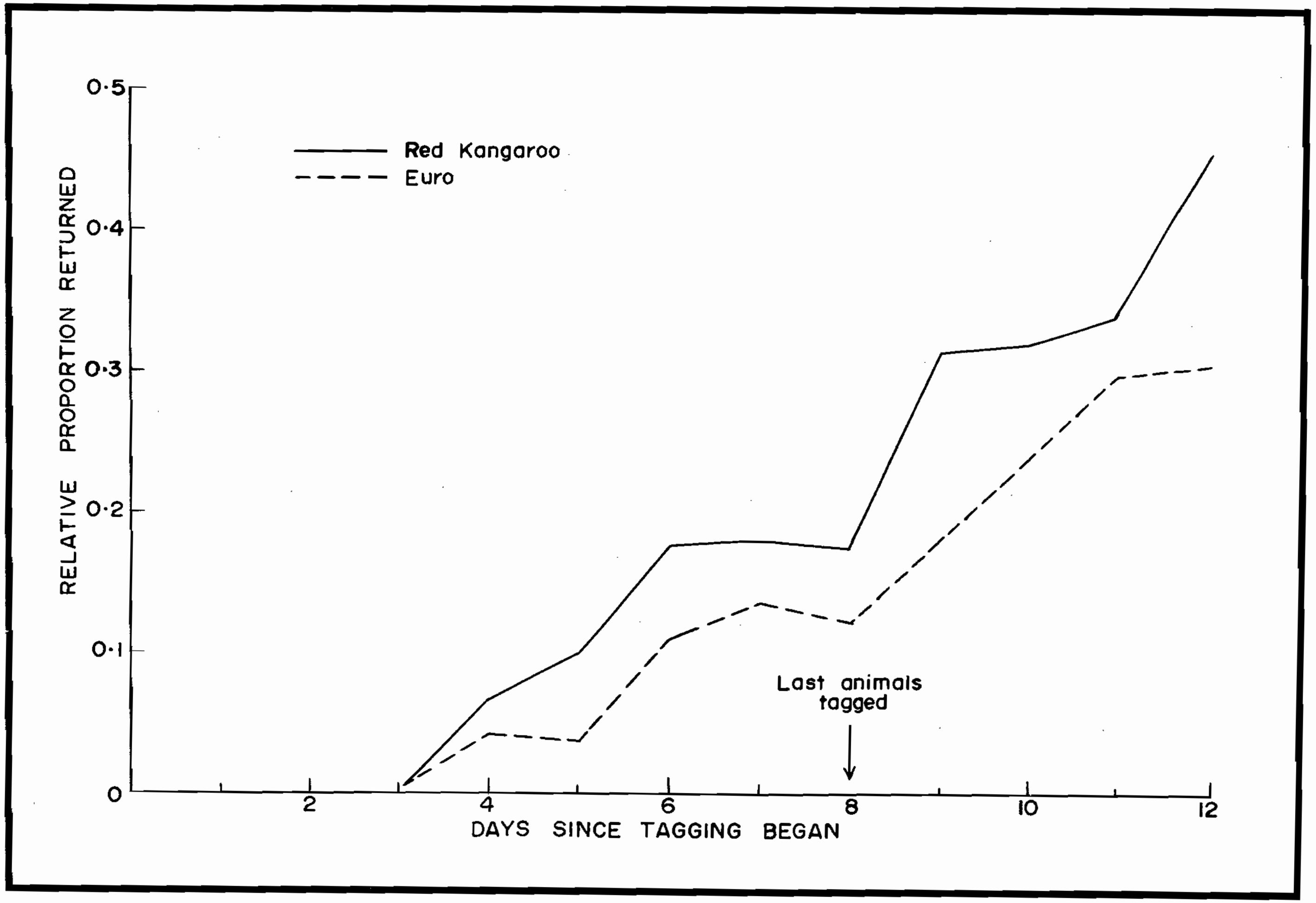

Fig. X-1. - Relative proportions of tagged red kangaroos and euros returning to the trap (only first returns included) and euros do not drink, or drink very infrequently. During hot dry summer conditions however, both species need to water.

The trapping study in January 1970 was carried out at Sandstone Tank to ascertain the drinking frequencies of the two species of kangaroo. Seasonal conditions before and during the trapping were dry and the daily temperature range was similar to the normal January average, the mean maximum and minimum for the trapping period being 36°C and 20°C respectively. Of the 106 euros and 54 red kangaroos marked and released, 32 euros and 24 red kangaroos were recaptured. The pattern of recaptures is shown in Fig. X-1, in which the cumulative proportion of tagged animals recaptured is plotted against time. These results suggest that red kangaroos drink more frequently than do euros during hot dry conditions, since 45 per cent of tagged reds had returned to water within the experimental period as against 30 per cent of euros. This tends to support the suggestion of Dawson and Denny (1969a) that in January red kangaroos should require more water for temperature regulation than euros. This suggestion was made on the basis of the higher radiation heat load on a red kangaroo resting in the sparse shade of a small tree compared with the heat load on a euro in a cave.

In the 1970 trapping study it was noted that no kangaroo of either species returned to water within 3 days, whereas sheep in the paddock were drinking at least daily and usually twice daily, in the early morning and evening. In January 1971 a comparison was made of the water usage of kangaroos, sheep and feral goats. The technique used was the estimate of water turnover using radioactive tritiated water. The values in Table X-2 indicate the very large difference between the two species of kangaroo and the sheep and goats, with sheep using four times as much water as the kangaroos.

TABLE X-2. WATER TURNOVER AND URINE NA/K RATIOS FROM LARGE HERBIVORES ON FOWLERS GAP STATION IN JANUARY 1970

Species	Water Usage ml/kg day[1]	Urine Na/K ratio
Red kangaroo	40 ± 1.2 (9)[2]	0.7
Euro	43 ± 2.6 (28)	1.1
Feral goat	115 ± 9.8 (12)	1.3
Sheep	168 ± 13.5 (27)	3.8

[1] Values for water usage are means ± standard error

[2] Values in parenthesis indicate number of observations

(vi) Diet selection of kangaroos, sheep and goats - Studies of the diets of kangaroos and sheep have been carried out in various regions of Australia, and their results are summarised by Frith and Calaby (1969) and by Newsome (1971). These studies have shown that in general the diets of red kangaroos and domestic stock overlap, but the degree of overlap varies considerably and extrapolation from these findings to what occurs on Fowlers Gap Station would be uncertain. A study is being undertaken of the diet preferences of the kangaroos, sheep and goats on Fowlers Gap Station and their variation with season and land system.

Evidence from studies on the electrolyte excretion patterns of red kangaroos and euros suggests that the proportion of the diet of these two species which comprises grasses as opposed to shrubs such as bladder saltbush (*Atriplex vesicaria*) and pearl bluebush (*Kochia sedifolia*) varies throughout the year. Grasses are rich in potassium relative to sodium, and saltbush and bluebush are rich in sodium relative to potassium. Because of this, the ratio of sodium to potassium excreted in the urine can be used to obtain a very rough estimate of changes in preference of diet.

The general tendency suggested by the work of Dawson and Denny (1969b) is that halophytic shrubs make up a larger percentage of the diet of kangaroos in winter than in summer. The sodium : potassium ratios in the urine of red kangaroos and euros respectively were 2.13 and 1.40 in July 1967, whereas 4 months later, in the absence of any rain and with rising air temperatures, the ratios were 0.80 and 0.33.

Preliminary results obtained in January 1970 show that the sheep utilize the high sodium plants to a much greater degree than either red kangaroos, euros or goats. Macroscopic observations of stomach contents have also confirmed field observations that goats tend to browse much more than the other species. A large quantity of bullock bush (*Heterodendron oleifolium*) was found in the stomachs of several goats.

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