The

Challenge of Landscape

THE DEVELOPMENT AND PRACTICE OF KEYLINE

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by P. A. YEOMANS

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DEDICATION

THIS BOOK is dedicated to the Trustees of the Keyline (Research) Foundation in appreciation of their willing co-operation and valuable support in the cause of Keyline.

The Trustees of the Foundation are:

SIR C. STANTON HICKS (Vice-President)
D. R. MCCAUGHEY (Vice-President)
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PROFESSOR J. R. A. MCMILLAN
DR. G. B. S. FALKINER
JOHN DARLING
MY WIFE AND MYSELF

On the formation of the Foundation I was appointed President, and Harold N. Sarina accepted the position of Honorary Secretary.

The real beginning of the work which led to Keyline was in 1944, our first full year on "Yobarnie", when my brother-in-law manager lost his life in the bush fire. So for my wife the early association with the whole project was one of deep bereavement, and but for her willingness to continue then, Keyline would not have originated.

* * *

SIR C. STANTON HICKS is Professor of Human Physiology and Pharmacology at the University of Adelaide; is widely known in England, the United States of America, as well as in Australasia for his interests in land development. He founded the Australian Catering Corps in the Second World War and is Scientific Food Consultant to the Australian Army. In 1950 Sir Stanton was invited to deliver the Sanderson-Wells lecture at the University of London ("Food and Folly"). This year (1958) Sir Stanton has received the honour of an invitation to deliver in London the Sir Albert Howard Memorial Lecture.

D. R. McCAUGHEY, C.M.G., of Borombola Park Beef Shorthorn Stud, Wagga (N.S.W.), and Coonong Merino Stud, Narrandera (N.S.W.), is also a director of land and wool companies. The name McCaughey has been famous for generations in Australian pastoral history.

C. R. McKERIHAN, C.B.E., is President of the Rural Bank of N.S.W., a position he has occupied for nearly 25 years. He has served on numerous committees and is known Australia-wide for the part he has played in charitable and philanthropic organisations, particularly his administration of the Australian Comforts Fund during the war. Prior to and during the war, he was Chairman of the Rural Advisory Council. Many Australians have been aided by his realistic summing-up of national problems.

PROFESSOR J. R. A. MCMILLAN is Dean of the Faculty of Agriculture at the University of Sydney. He was Plant Breeder at the Queensland Agricultural College and Lecturer, Faculty of Agriculture, University of Queensland. He has served with Australia's 'Commonwealth Scientific and Industrial Research Organisation' (CSIRO) as Principal Geneticist and was President of the Royal Society of Australia from 1941 to 1943.

DR. G. B. S. FALKINER'S name is inevitably coupled with his famous Merino Stud, "Haddon Rig", but also has other extensive properties, is Vice-President of the N.S.W. Sheep Breeders' Association, a member of the Council of the N.S.W. Bush Nursing Association, and a Director of several industrial companies. He is Chairman of the Industrial Committee of the Nuclear Research Foundation and was honoured recently by the University of Sydney for his work for this Foundation, on which he is also a Governor.

JOHN DARLING, another name famous in Australian national development, is a director of John Darling & Sons, flour milling firm founded originally by his great-grandfather. With his own grazing properties he maintains the same strong interest in rural matters as his father, who was a founder of the Waite Institute of South Australia.

H. N. SARINA, the Honorary Secretary of the Foundation, is widely known all over the Commonwealth for his interest in live stock and agricultural pursuits.

Each Trustee of the Foundation has expressed his views in support of the Keyline concept, but I may quote John Darling: "My father often said that Australia had everything except a good rainfall, and what the country needed was a high range of mountains down the centre of the continent, so that we would get the rain we needed. I regard Keyline as that range of mountains."

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THE DEVELOPMENT AND PRACTICE OF KEYLINE
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*NOTE FROM SOIL AND HEALTH LIBRARY:
These very interesting plates open in a "new windows".
They are rather substantial downloads; most are well worth viewing.

* * *

These 32 Plates contain 99 Photographs. (above)

Except where otherwise acknowledged, all photographs were taken by the author and are selected from his property records to tell pictorially the connected story of the Development and Practice of Keyline.

The Late Percival Alfred ("P.A.") Yeomans

A MAN BEFORE HIS TIME

By ALLAN YEOMANS

Percival Alfred Yeomans or "P.A" as he became known to all alike, changed Australian agriculture. It is doubtful that any man in this country's history has had such a profound influence on the thinking and methods used by the Australian agricultural community.

He was from the country, but grew up in a town. His father, James Yeomans was a train driver, and close friend of our World War Two Prime Minister, Ben Chifley.

When P.A. started farming he had already achieved considerable success in business. He applied the same thoughtful and common sense approach to agriculture that had proven so successful in his other ventures. He knew what Australian agriculture needed. He created a "sustainable agricultural" system before the term was even coined. A permanent agriculture, he believed, must materially benefit the farmer, it must benefit the land and it must benefit the soil.

His ideas of collecting and storing large quantities of run off water on the farm itself for subsequent irrigation was virtually unheard of, and quite opposed to state soil conservation departments then, and by some even now. His ideas to create within the soil a biological environment to actually increase fertility was unique, and totally opposed to the simplistic approach of the agricultural chemical industry. His ideas that using tyned tillage equipment and a unique concept of pattern cultivation could totally solve the ravages of erosion, was sacrilege in the eyes of extravagant and wasteful soil conservation services. They still are seen as a sacrilege to convention by many, even to this day. A quotation from the great German physicist; Max Planck, (1885 - 1947) seems so relevant to the concepts, the thoughts and the beliefs of P. A. Yeomans:

"A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die".

For how much longer must we say, "So let it be with Keyline"?

In retrospect, Yeomans' entry into the farming world appears almost inevitable. As a young, man after abandoning a possible career in banking, he tried several fields, including the then very new, plastics industry. At one stage he was a highly successful door to door "Fuller Brush Salesman". The wealth and excitement of mining however, fascinated him and during those hard depression years, and with a small family, he completed a correspondence course in mining geology. That course changed the direction of his life. In the wild and charlatan mining days of the 1930's, he established the rare reputation of being a reliable and trustworthy assayer, and valuer of gold and tin mining projects. A reputation he held throughout the mining fields of Eastern Australia and New Guinea.

The family was constantly on the move. It took less than half a day in the town of Snake Valley in south western Victoria to disprove the wild claims of riches of yet another gold strike.

He eventually established himself as an earth moving contractor in the early pre-war years. This business grew, and his company, P. A. Yeomans Pty Ltd became one of the major earth moving contractors supplying open cut coal to the war time Joint Coal Board.

The enormous war time taxes on company and personal income continued for many years after the close of the war. A tax incentive however had been established to encourage the introduction of soil conservation practices, and encourage a possible change to, what we now call sustainable agriculture. Food production would be enhanced and the terrible dust storms that ravaged the country, mitigated.

Income earned from non agricultural sources could be spent on saving the land. If farm dams, fences and contour drains could be constructed economically, and beneficially, this could result in a considerable capital gain. Capital Gains Tax itself did not exist. It came much later as yet another imposition on initiative. So was born the "Pitt Street Farmer" (or Collins Street, depending on your state capital city).

Consequently, in 1943 Yeomans bought two adjoining blocks of poor unproductive land, totalling a thousand acres, forty miles west of Sydney. The farm manager was his brother in law Jim Barnes. Conventional soil conservation practices then in vogue were commenced. These practices had been adopted by the newly formed state soil conservation services. They unfortunately originated from the agriculturally illogical practices, "invented" by the United States Corp of Engineers, guided and advised by U. S. Army construction officers. The doctrines of soil conservation departments, in Australia, have been fairly inflexible on these issues, and department after department adopted and promulgated these extravagant and useless practices. In those years that's all there was and these practices were tried by Yeomans and proved wanting.

A horrific grass fire, fanned by one hundred kilometres an hour winds, raced through the properties. It was the tenth day of December 1944. Jim Barnes was riding the horse "Ginger" that day, but they could not out run the speeding flame front. Only "Ginger" survived the ordeal, and was retired to become a family pet. After this tragic accident, it was some time before a family decision finally concluded that, the farms should not be sold.

All the experience gathered in those years of mining and earthmoving Yeomans then brought into play. The twin blocks became "Yobarnie", a combination of Yeomans and Barnes and "Nevallan", from his two sons Neville and Allan. Ken was born later in 1947.

The cheap storage and transportation of water, over long distances, are usually the life blood of a successful gold mine, and Yeomans became convinced it could be the life blood of a successful farm in Australia. Yeomans then became an avid reader and soon realised that conventional agricultural wisdom totally ignored the biological aspects of soil. The concept of totally inverting topsoil by using mouldboard and disc type ploughs was progressively destroying the fertility of world soils.

He applied the wisdom of T. J. Barrett, Edward Faulkner, Bertha Damon, Friend Sykes, Andre Voisin and many others, to Australian broadacre fanning. So for the first time in human history, techniques were developed that could produce rich fertile soil, thousands of times faster than that produced in the unassisted natural environment. This then became, after on farm water storage, the second major facet of Keyline which is also having a significant influence on Australian agriculture.

Being a mining geologist, and understanding the underling geological structures, gave him an appreciation of land form that is almost totally lacking in the farming world. With brilliant insight he combined the concept of the ever repeating weathering patterns of ridges and valleys, with contour cultivation. He was well aware that when cultivating parallel to a contour line, the cultivating pattern rapidly deviated from a true contour. He realised that this "off contour cultivation", could be used to selectively reverse the natural flow and concentration of water into valleys, and drift it out to the adjacent ridges. He discovered that a contour line, that ran through that point of a valley, where the steepness of the valley floor suddenly increased, had unique properties. Starting from this line, and cultivating parallel to it, both, above the line, and below the line, produced off contour furrows, which selectively drifted water out of the erosion vulnerable valley. He named this contour "The Keyline". The entire system became "The Keyline System".

The effects that P. A. Yeomans and The Keyline System have had on Australia and Australian agriculture are profound. His last book "The City Forest" Published in 1971 expanded the application of the principals. In it, the same Keyline concepts are used as a basis for the layout and design of urban and suburban communities. City effluent and waste are considered as valuable commodities. He proposed the creation of tropical and subtropical rain forests, within the city boundaries, as park lands, as sources of exotic timbers and as the means of economically utilising city effluent for the benefit of all. The City Forest has now become a textbook for landscape architects and urban designers.

The equipment and the practices of Keyline have become so well established as part of Australian agriculture, that it surprises many to realise this influence. In no other country in the world, have farm irrigation dams, contour strip forests, chisel ploughs, deep tillage cultivation, water harvesting almost become a nation's "conventional agriculture". P. A. Yeomans was constantly in conflict with bureaucratic orthodoxy. So no stone monuments, nor official recognition, have ever been accorded to his works. The changed and changing face of the Australian landscape however, is his immense and worthy memorial.

Allan J. Yeomans
Gold Coast City, Queensland Australia
January 1993

FOREWORD

THIS book of my husband's is the natural outcome of the results of "The Keyline Plan", published in 1954. So much has happened since then, both in public response and practical results, that he has been frequently asked when his next book will be published. His familiarity with Keyline makes it so simple to him that difficulty is experienced in realising this is not always so to others; now he is trying to remedy that in this book.

It is a narrative of practical experiments and experiences in a comprehensive approach to the planned use of land. He feels that no complete plan has been produced before and Keyline has got the merit of having been tried and proved successful.

Although this book, then, is chiefly for farmers and graziers, we both hope it will also assist to further enlighten public opinion to the extent of widely realising that when our land folk are enjoying a substantial measure of prosperity from high production, then many of our major national problems are on the way to being solved.

The interest shown in his efforts over the last four years has been outstanding, and visitors from all over the world have continued to visit our places.

His Keyline Plan has been admired, condemned, criticised, accepted in part and even pirated in part. Many have tried out sections of his plan on various types of properties and farms, and where faithfully carried out, have yielded results that have been more than satisfactory.

My experiences in the matter, too, have been interesting, sometimes exasperating, and often amusing. There was the woman who arrogantly demanded to be shown through the "Nevallan" home and became quite indignant when politely told it was private property. A charming old lady in her eighties tramped around the paddocks and her interest and enthusiasm were infectious. Another, a woman doctor, became so keen during a visit that she vowed on her return to the country practice her land-owning patients should receive large doses of Keyline with her course of treatment whenever she visited them. Others arrive for a quick inspection, checking their watches on arrival and allotting perhaps a fifteen-minutes "stay". These people usually are on their way from the city to their inland properties and the visit to our place is to be "just a passing look". They generally remain for hours. One couple had four young children and a long journey ahead of them. They arrived about lunch time, but it was dark before the husband finally agreed to leave. His wife had my sympathy that day.

Together with our loyal staff we have shared interviews, lecture tours and the making of moving pictures. These pictures were shown in theatres and lecture halls, and "Nevallan" has been seen on television both here and in London. So Keyline is steadily progressing.

On one occasion a 1600-miles Keyline lecture tour of Victoria in a period of ten days was undertaken. I generally go with my husband, and when given the itinerary which some of our staff executives had worked out I doubted our ability to cope. It was certainly a full programme, consisting of visits to one or two properties in the morning, then lunch, and an average drive of one hundred miles in the afternoon, dinner, and a lecture talk at night with Keyline films. My husband, whose speeches are impromptu, remarked that he had to speak on a different aspect of Keyline each time, if only to keep me from falling asleep.

Regretfully, we can no longer be available on Sunday afternoons at "Nevallan", as we have found ourselves unable to attend to this with the pressure of other events. However, "Nevallan" is now in the capable hands of our properties manager and his wife, who are carrying on our work there very successfully.

We go when possible to our properties, "Kencarley", at Orange, "The Campbelltown Place", and "Pakby", at Bathurst. Here the work can proceed much faster, as all those trial-and-error experiments of "Nevallan" and "Yobarnie" are eliminated and only normal problems can temporarily delay progress.

On first inspecting "Kencarley" as prospective buyers the weather was hot, the country dry, and the area altogether extremely discouraging and uninviting. I looked at its rundown, neglected appearance, heavily covered with scrub and trees, the barren soil, and broken fences--even the house was uninhabitable. My husband said to me, "Well, what do you think of it?" and my answer was, "If it wasn't for Keyline and tractors I wouldn't want to touch it." We know that many landholders and others considered the purchase a mistake, but so did several people when we first bought "Nevallan". The story there, of course, is different now and we expect similar results at these new areas, with the same increase in soil fertility and success that Keyline brought to "NevalIan".

The first year at "Kencarley" was unsatisfactory. Equipment and plant were constantly held up owing to bad weather, and consequently it would have to be transferred elsewhere and then brought back again. We had to content ourselves mainly with boundary fencing and line marking, and whenever a visit was made a feeling of disappointment pervaded us.

The second year was different. The drought began and, although this did not help with soil improvement, it did make possible the speeding up of the major development work, which now became fascinating to watch. I have stood with others and surveyed a scene I had never before witnessed. The timbered country, already marked according to Keyline, now showed rapid changes. One could see a strip of timber falling before the bulldozers, with a line of trees about thirty yards wide left standing. Next would be seen another strip with fallen timber already burning in heaps, while a fourth one was being chisel plowed and seeded down. The whole process, from virgin timber to cultivation strips sown with pasture seed, taking place in the one area, not just a few acres, but hundreds of them changing before our eyes.

This type of work, of course, is something made possible by the coming of the bulldozer era, and with Keyline as the guide, no qualms are aroused that such large projects may be a mistake.

With the clearing, commenced also the water storage section of the plan. Dam building started, and one farm dam, "Kencarley" Basin, we believe is the largest in the Commonwealth, covering forty acres of pasture-sown paddock and capable of holding over a hundred million gallons of water. Five dams are now completed here, with others still to follow. Water will be brought to them by carefully planned drains and released again *via* suitably large pipes through the wall to irrigate hundreds of acres below the walls on the Keyline flow pattern. When the rains come, it is gratifying to watch the water under man's control flowing along the drains to its allotted place. During the building of the largest dam, located in a wet, swampy valley, a sense of urgency had developed.

"Would it rain before it was finished?" Many were the anxious queries as to the weather. The rain did not come, however, and many months were to pass before the drought eventually broke.

The scene is changing constantly and we have to show people other areas not yet started to convince them of what has already happened.

As a contrast there is "Pakby", a 2,000-acre property nine miles from, Bathurst, on the Mid-Western Highway, where the soil is granite. Here the land has been subjected to the thoughtless tree destruction of earlier days and consequently suffers from strong winds. Like "Yobarnie", it endured the fate of a bushfire in our first year of occupancy, eight hundred acres of grass were burnt and minor buildings damaged. "Pakby" is badly eroded, too, in parts with huge erosion gullies, caused by road water, beginning at the boundary fence. Development work has now diverted the water to new irrigation dams, cultivation for soil improvement continues and strips of land are prepared for tree planting.

Occasionally we are asked why our properties are all westward of Sydney. Why not north or south, perhaps even some other region? Proximity to each other and to large centres we find is time saving both for ourselves and our staff. There have been such comments as "Aren't you lucky, they are all in the one direction when you want to go visiting." Time generally becomes such an important factor to us, that, when looking for land to buy, and being aware also of the fact that the city of Sydney is our main headquarters, travelling time and suitable access roads play an important part in our decisions.

To some the work may seem a major undertaking, and consequently beyond their consideration, yet they will find it just as possible on a small scale, the pattern is the same, and in the development of a property there is pleasure and satisfaction watching the plan unfold. One day recently I stopped the car to enjoy a view of "Yobarnie". How very different it was to the old days! Now I saw good green pastures on the gently sloping hills and valleys, dams of water correctly located and stock grazing contentedly. I don't think I have seen anywhere a view more beautiful. I know I felt very happy about it.

Finally, I would like to say that after four more years of observations, study and investigations, and having been given active support from scientists and many others, men whose main thought in the matter is the welfare of their nation and who are able to weigh the evidence of Keyline clearly with an unbiassed mind, my husband is more convinced than ever in the soundness of the theory and practices of Keyline. However, this book will help elucidate his ideas and beliefs and perhaps be of some value to our nation as a whole. I know that we are both hoping that it will be so.

RITA YEOMANS

Sydney, April 1958

PART ONE

CHAPTER I

Vision Ahead

WE are discovering a new Australia! As yet, few Australians have seen it. Even those of us who see it every day, who live with it and work for it and think about it continuously, only really see it occasionally in imagination. But we have seen it though only in glimpses; nevertheless, hundreds of Australians are trying to develop this picture on their own land.

Occasionally the farmer sees the picture develop suddenly in a good Spring season but it fades again and is not yet permanent. Excessive heat and the absence of rain bleaches the colour from his picture. The stock droop and lose the proud posture of health and the farmer worries; he talks about the weather; he is always talking about the weather--if only it would rain! The picture has gone. It can return and perhaps he will see glimpses of the picture in the moonlight, when the harsh lines of reality are softened as the film of soil covers and softens the rock formation below. The land scars are hidden in a velvety smoothness.

Our farmer thinks more about it now. The picture develops and improves in his imagination. Water! The creeks run clear and strong while ponds of water fit snugly into the valleys of his farm like jewels in a landscape of beauty and permanence. Permanence, with trees protecting the land from hot and cold winds alike; trees whose each leaf-fall creates a balance of soil fertility and good pasture, rich dark soil and waving crops.

Now it is raining! Wonderful, bountiful rain. Heavier now definitely and grass will be clean and fresh in the morning. It may be the reservoir will fill again, the big one. Clear, clean water, moving everywhere and flowing into the higher dams; cool, clean and clear. The reservoir being nearly full, it still has plenty of water in reserve, but none of the water will be lost-not 'til the big low dams at the bottom of the paddocks are filled.

The thin early morning light is harsh on the true scene; it is just a dream. But the hills are the same. They have maintained that smooth, strong look for thousands of years. There is beauty and promise in the valleys. Despite the immediate valley so badly eroded, he catches a glimpse of the form and usefulness hidden in the shape of the land he knows so well, but rarely "sees", a shape smoothed off by the climate that he lives with, a climate that is not always kind. Water and trees! That is what is missing--water, trees and good soil.

Another day has arrived. There is work to be done; but while the farmer works he thinks and uses his imagination, for this land will some day fit the picture that lies ahead and which he is now beginning to see more clearly.

* * *

No doubt the picture of this new Australia (which will develop rapidly now, in spite of the effects of drought, flood and bush fire) is different for different people.

I see it as a picture that looks right, and because it looks right it cannot help but be more beautiful. I see a beautiful and permanent landscape with trees that will hold it in balance, improve the living conditions of stock and humans and protect and form part of all pasture and crop lands.

In the picture the land will be cleared, but not as of old or so ruthlessly. Trees will be left in broad belts, or be planted to suit the land form, and in association with water storages they will give a new emphasis to the old and beautiful shapes of our hills and valleys.

Soil will improve until Australian soil everywhere is richer and deeper than nature has ever provided.

It is a broad picture I see covering quickly the million square miles (the 640,000,000 acres) of our better rainfall areas. It will be a country on which flood rains will fall as "money" to be banked in the richer soils and behind the walls of farm dams. It will be a land that fire cannot burn and in which drought will reveal only the sound efficiency of our farming and grazing methods.

I believe the general change about to take place will follow the pattern of older developments. It will move from the coast, continuously pushing farther inland the stability and the new permanence of its agriculture. There are such farms and grazing properties, but they are found usually in climatic conditions which are much better agriculturally than our own.

There is a task to be undertaken. Only the planning and work of our landmen, the farmer who is also a grazier, the grazier who is a good farmer, will produce this new picture and superimpose it on the age-old form of our land. Oils will not make this picture. It is a watercolour. And farm water will mix and spread the pigments of our picture, the delicate balance of many shades of green, the warmer tones of the improving soil dark with stored moisture.

Since the greatest potential water storage capacity is where the rain falls right where we want it on the soil to colour pastures, crops and trees, and since the greatest potential surface water storage is in the valleys of the farming and grazing properties, the prospects from planned development are immeasurable.

Though every part of agricultural land development, i.e., the planning, the day-to-day running and the management is important, to us in Australia no item is more vital than the control, conservation and use of water and our control and conservation of water on each separate farm for use on the farm could be the major influence on future agricultural development.

There is no doubt that the Australian landman is seeing a greater potential in his own land than he ever saw before. His own importance in the nation's development is becoming much more widely recognised. He has more authorities of the Government assisting him and offering advice than ever before.

He is ever conscious that there is sufficient knowledge, from accumulated experience, invention and science, to improve and increase agricultural production to any height to which national development could possibly aspire. Yet this knowledge is often difficult to apply. It has not been co-ordinated into practical application in the mind of the average landman. It is all too often presented by segment specialists with insufficient appreciation of basic agriculture. There is a natural tendency for the farmer, bombarded by too specialised knowledge from many quarters, to become confused, and in consequence he makes false starts as the popularity of one subject or another dominates agricultural publicity and thinking for a time. Is there any wonder that at times he sees it as a fascinating but nearly hopeless jigsaw puzzle?

All knowledge is based on simple fundamental truths. If these can be presented in a reasonable order and relationship to the farmer, he can learn quickly to employ the knowledge to the same extent as if he were master of all these sciences. However, there is-no authority suitably co-ordinating this new knowledge from the various sciences in agriculture to present it to our landmen. The extension work of all Agricultural Departments needs rethinking and recasting.

If there is need for scientists and new research in agricultural matters--and it is obvious there is--then these men should be presenting their work to our agricultural teachers so that they in turn can present or teach it practically to all the farmers. If some aspect of engineering is necessary or desirable in agriculture, then the engineering aspect should be imparted to all officers of agriculture who contact farmers. The few engineers involved can do little directly for the great number of farmers, but they can instruct a sufficient number of agricultural officers who, in their turn, can teach all the farmers they contact.

Likewise with soil conservation, if it is a necessary part of farming, then every agricultural officer should know the techniques and be able to advise the farmer. These techniques are very simple and not difficult to learn. If the construction of farm irrigation dams is necessary, then surely all agricultural officers should be fully capable of instructing farmers on how to design and build them.

All these matters can be fully covered in teaching for practical use in a very simple fashion, and covered, notwithstanding the expert's continuous tendency to preserve his standing by making simple things appear difficult. Or is it that too much has been asked of experts from other fields when agriculture itself should have kept the job in its own hands and closer to the farmer.

It seems to me that the divorcing of some agricultural matters from our Agricultural Departments is a retrograde step that has cost us an unknown but very great amount of progress, and that the continuance of this division will seriously and still further retard progress.

No specialist in a segment of agriculture is likely to do as much good for agriculture with his specialty as the general agricultural officer. It is this officer's duty to present the matter more practically to farmers and to ensure that each item of accumulated knowledge is seen in its proper perspective. If all this were done, then the picture of our development would have pattern and meaning and not be just a slowly improving yet formless thing. Our efforts must be the best possible, as nothing less can be tolerated.

Just as a picture needs a crayon sketch or a line drawing before the real colours are applied, so our farm work needs a planned simplicity of performance that will fix all the sections and pieces together in orderly and in coordinated design.

The object of this book is to present a basic design for a more stable and permanent agriculture which will fit into the background of our climate and our landscape, and a design which would have manifold applications beyond our shores. This is not so much a text book as it is a history and a working manual. It is a response to the challenge of our landscape.

CHAPTER II

The Aims of Keyline

THE Keyline plan is a plan for the development of agricultural land based, first, on my own conception of what soil is, how it developed naturally and how it can be further developed, and, secondly, on the climate and the land shape of each individual property on which the plan is applied.

It is based on a belief that the ordinary pursuits of farming and grazing are in themselves the means of inducing an ever-increasing fertility in the soil. The techniques of the Keyline plan have been developed to this end.

The aim of the Keyline plan then is to improve all farming and grazing lands by reversing the tendency of land to deteriorate under man's occupancy--making it stable and permanent in a generally improving landscape. Its aim is to improve any agricultural soil, from the poorer soils right through to the richest of soils, to far beyond that which originally developed naturally in the particular climatic environment. The development of soil in nature from dead earth and rock may have occupied considerable periods of time. Man, with little time, fortunately has many means or processes by which he can rapidly improve any natural soil. It. is considered that the most logical or fundamental approach to soil improvement is through processes which are aimed directly toward improving the effect which the general climate has on the soil climate. Every technique of the Keyline plan is designed to improve the soil's climate against the background of the general climatic conditions which affect it and which have largely created the soil.

The Keyline plan was developed in New South Wales, Australia, and its development has probably been influenced by the general conditions as they apply to most of our agricultural land. Since Keyline is based upon a study of climate and land shape, it therefore fits in a practical manner any type of agricultural land. However, its various techniques will be employed on a wider scale in the broader aspects of agriculture embraced in the cereal crop, sheep and cattle country in Australia and other lands.

While Keyline rejects the wholly or dominantly chemical or artificial fertiliser approach of generally orthodox agriculture, it finds great value in some artificials from a new or unorthodox approach. While Keyline is not classed as organic farming, it employs natural means of soil development with great benefit.

The orthodox methods of pasture improvement are not Keyline. Keyline obtains accelerated and greater pasture improvement by an emphasis on soil improvement, using pasture and improving pasture in the process.

It does not follow the approach or make use of the methods of soil conservation, because the Keyline technique has the effect of improving soil rapidly and curing and preventing soil erosion. It preserves and holds the natural shape of land by improving the climatic environment of the soil. It prevents fertility erosion of good soil by increasing soil fertility. Soil erosion then ceases to be a factor requiring special consideration.

The plan aims generally at conserving as much water in the soil from each rainfall as the soil can use for its own improvement according to its particular state of development. If all the rain that falls is needed, then all is conserved, and techniques are provided to this end for the economical storage and profitable use of this water. All surplus run-off is conserved in farm dams of various kinds and for particular usages.

When water flows beyond the conservation needs of the soil and the additional capacity of farm dams, it is allowed to follow natural flow lines. Waterflow which formed the valleys will not damage those valleys in a Keyline programme.

When water is the limiting factor, storages are designed against maximum run-offs, and not the minimum annual run-off of orthodox recommendation.

The Keyline plan, in common with many others, advocates tree planting, but provides a planned pattern for all plantings.

Again, the plan makes soil deepen. It has been said that it may have taken centuries to develop an inch of natural soil. But man can so control the factors involved that he can develop many inches of good soil from decomposed rock and subsoil in about three years, while in many instances he can produce grass on such earths in one year.

The Keyline plan stems primarily from an overall planning technique based on a new conception of land shape as a powerful aid to agricultural land development, and its planning background is the pattern taken by naturally flowing water. This can best be illustrated as follows: The farm headwater valleys of smooth, rounded shape, whether they are small, of a few acres, or large, of a few hundred acres, generally have two distinct slopes along the centre line of the valley; one, the first and steeper slope falling from the hill or ridge, and, second, a flatter slope below, which generally is constant to its junction with the watercourse below. The point of change between these two slopes--the point where the first steeper higher slope meets the flatter lower slope I named the keypoint of the valley in my earlier, book, "The Keyline Plan".

A line through this point, extending to left and right, which may be either a true contour line or a line with a slight grade, according to the circumstances of climate and land shape which will affect the planning of each property, is the keyline of the valley. Now, these two slopes of the valley are a constant feature of land shape, and the valley with its immediate environment is the first or primary water catchment to be considered.

The next and larger catchment area is that which includes two, three or many of these primary catchment areas. Within this second catchment area, in a region of uniform geological character, the keypoints of each primary valley have a relationship with each other; they have a rising relationship into the rising country. Therefore the general planning of Keyline is based, firstly, on these generally constant features of land shape, and, secondly, on the general subdivision of land that can be made according to these natural shapes and as disclosed by the various patterns of water flow. (*See Fig. 1.*)

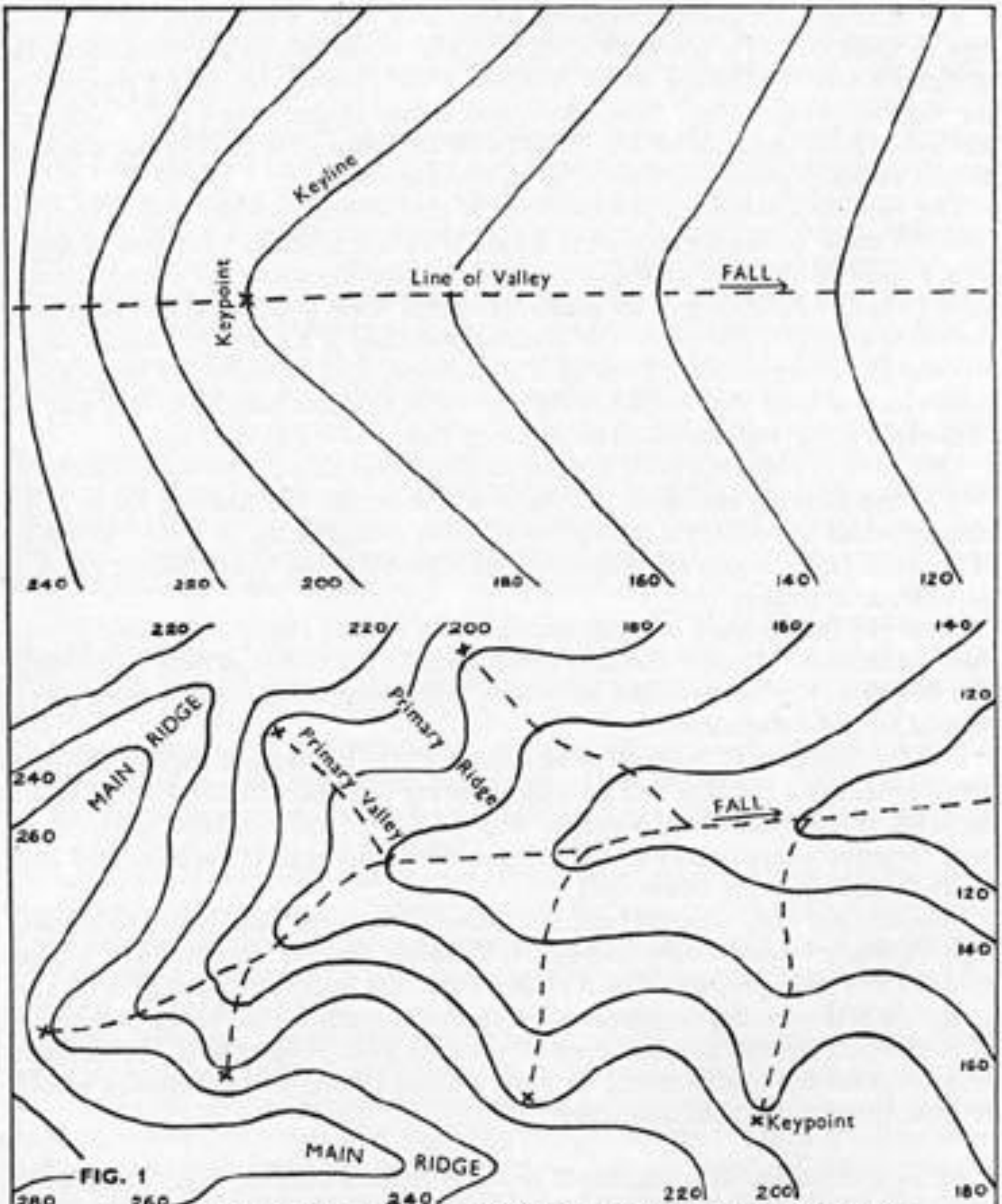

FIG. 1

Upper: A contour diagram of a primary valley, showing the position of the keypoint and the keyline; the Keyline relationship between the first steeper slope and the second flatter slope of the valley, and the relationship of the valley floor slope to the slope of the sides of the valley.

Lower: A contour map of a secondary land unit formed by the several primary valleys flowing into it.

This general planning takes further pattern according to the water relationship of the farming enterprise. If water is scarce and the limiting factor, the plan provides the ultimate in efficiency in the conservation of water. If water in abundance is the general problem, then it provides the most efficient general pattern for drainage.

From the background of a full appreciation of land shape and water movement, with other climatic features which include the effects of floods, droughts and bushfires, Keyline provides an orderly and symmetrical plan covering every item of land development.

The Keyline plan is designed to be economical. The result of the full Keyline development of a farming and grazing property is to increase the fertility of all the land, bring useless land together with all other land into high productiveness, improve every aspect of the environment and hold it permanently and safely as an improving landscape.

Planning not only protects land from floods, but turns flood water to advantage. Planning beats drought very easily. Planning protects land from fire. I have not seen any good property that Keyline would not improve threefold, with the exception of the smaller properties which sometimes reach close to the maximum of production by means other than the best or most economical. The general order of potential improvement on most grazing properties in Australia would be from three to ten fold and more.

* * *

All agricultural land is contained in watersheds of varying sizes. These start with the smallest or primary valleys which flow into other larger valleys. Several primary valleys may flow to one larger or secondary valley; several of the secondary valleys--each with its several primary valleys--then flow into a small creek valley. Several small creek valleys, each with its several secondary valleys and each of these in turn with its series of primary valleys, may flow into a larger creek valley, and so on until the final valley, and its watershed includes all the land that flows water to the mouth of the river at the sea coast.

The primary and secondary valleys are those of the farms and grazing properties. Of these two, the primary valley is of the greatest significance. If every problem of the primary valley can be solved, so too can every problem of the secondary valley. These two valleys make or solve all the problems of land; therefore, every major land problem can be approached and solved as a series of small agricultural problems.

If a full Keyline development and management plan were applied on all the farm and grazing lands within a catchment area where the climatic conditions are of the general Australian pattern, then any former drought or flood problem of that area would disappear. It would also wipe out the danger of a major fire hazard.

Any major flood danger is capable of being solved if there is sufficient will to do the job, coupled with the necessary finance, labour and materials; but no solution, based on flood damage as the problem, will pay. The cost will generally be greater than the accumulated flood damages of a century and more. The real problem in our Australian conditions is not flood damage, but the sheer waste of valuable water.

When this factor is accepted as the problem, we immediately move the location of our work to the primary and secondary valleys of our farms, grazing properties and forest areas. Here, water storage structures can generally provide low-cost storage. Here, only, can the greatest profit and land advantage be secured from the stored water. Here, too, is the land below the highwater level of the storage, not waste land. But as well as the vast surface water storage potential of these dams there is the great potential of extra capacity of the soil and land itself. If farming techniques are followed which enable all the land to absorb sufficient extra water from each rainfall only for the development of the soil itself, the increased capacity would be more than all the huge storages of the big projects. It would, furthermore, be the cheapest and the most profitable storage.

So the soil treatment techniques of the Keyline plan, including methods of cultivation, have just this effect on soil, namely, of storing and holding in the soil increased water for when and where it is needed.

Again, if Keyline was instituted as a national development programme for all agriculture and applied as it fits the land shape and climate of each farm, it would have a profound effect on our major disadvantage--the lack of water.

The flood waters from prolonged heavy rains, which now go to sea within a few days, would still be in the soil and in the farm dams months later. Some of the water would remain there for a year and more. During this time the increased soil moisture would be feeding ground water supplies which flow as springs to feed the creeks and rivers. Therefore, river flow would be more constant. Then the continuous but slow seepages from farm dams would be adding to these underground supplies. This water would be clean and clear, as well as constant. The present accelerated silting up of rivers would first cease and the constant flow of silt-free water would speedily regenerate them.

There are wonderful things happening in agricultural science and research, but there is as yet no Government plan of overall development, nor indeed is there in private enterprise. There is too big a gap between the results of research and the practice on the farm.

If six farmers or six agricultural scientists were to plan the agricultural development for the same enterprise of 1,000 acres of undeveloped land, it is certain that six different plans would emerge. They all would have differing .ideas on subdivision, house sites, trees, water conservation, soil treatment and pasture management. Again, if the same six men, with the experience of having developed such a property once, could be given the same job again, no doubt there would be a further six plans. But if such an area was handed over to six competent Keyline farmers they would independently look at the land in the same manner, have the same appreciation of land shape and climate, the same knowledge of the value of trees in relation to land shape, and the same ideas on water. The separate plan that each would produce would be identical. Further, if they were to do the job again after the experience of having done it once, the pattern and the development would be constant.

* * *

What has struck me over the last few years is the deep-rooted pessimism of most people regarding soil. Even when they examine our deep fertile soil on a hillside which they had seen previously as subsoil or even yellow shale, they are still apt to discuss agriculture shortly afterwards in such a way as to indicate that they have not really accepted the fact that such poor material can be changed quickly into rich soil. They have seen it, they have dug their hands into it, they have accepted it on an intellectual level, but they are still bound by the dogma of orthodox agriculture.

As Keyline is based on climate, on land shape and on this particular theory of soil development, the details of the planning and the development techniques of Keyline will be preceded by a discussion on soil.

CHAPTER III

Soil, its Life and its Climate

SOIL is the film of life which covers much of the land surface of this planet Earth. It is so thin that a light coat of paint on a large-scale model of the earth would be much too thick to represent to scale the thickness of the soil. But it is the home of all earthly life and the great raw material of agriculture. We will never know all there is to be known about soils, but if a farmer understands and has a feeling for soil life, he can manage his soil just as well as if he had all the accumulated knowledge of all the scientists who are concerned with soil and soil life.

Soil is composed of rock fragments of every size and variety, representing all or nearly all the minerals of the earth's crust, together with an infinite variety of chemical and organic compounds made up of its rock particles, liquids and gases, all reacted on by the life that lives and dies in the soil and on the surface of the soil.

Rock is broken down by all the agencies of climate, sunlight and heat, freezing and thawing, wind and rain, and by gases as in the oxidisation process, but the disintegrated material is not soil until it is invaded by life; until plant life grows in it and animal life lives on it, and until soil life develops and lives and dies in it and thus forms part of the earth itself. Once soil has started to form, the greatest influences on its ultimate development are always those factors that most influence these life forces of the soil. The higher the life forces within the soil, the greater is the fertility of the soil, and the maximum development that any form of life may attain depends on its living conditions and its food supply. This truth, therefore, is of vital importance in the management of soil.

Monumental examples of this natural law can be seen in geology; for example, to mention only two cases, in the huge limestone deposits formed from the skeletons of a prehistoric life that developed rapidly in a favourable environment; and in the extensive coal deposits found in many parts of the world which represent an ancient vegetable life that flourished in a suitable climate and was nourished by a constant food supply.

Soil has a climate of its own. It is composed of the three factors, moisture, warmth, and air in combination. Good soil climate produces the best in pastures and crops. The natural soil climate is dependent on the effect of general climate on the basic geological makeup of the soil. Climate is a dominating influence in agriculture as well as on soil quality.

Soil is not, then, something that is dead. It is teeming with a great variety of life forms ranging in size from the submicroscopic viruses, through bacteria, microbes, fungi, to the colossus of the various species of earthworms. A mere handful of warm, moist, fertile soil contains a life population that is astronomical. Some of the species of soil life multiply at fantastic rates when conditions are suitable. Some species which increase by the mature individual dividing to form two, multiply so rapidly that if one single cell could conceivably have an inexhaustible food supply in good living conditions it would increase to a mass the size of the earth in a week or so. Many fascinating examples of the rapid rate of development of various species of soil life are contained in books on soil microbiology.

Oddly enough, although many distinguished soil scientists have observed these phenomena and commented on them, none of them seem to have made the natural inference, namely, that soil development under optimum conditions can be very rapid indeed.

Just about everything is food for some form of this soil life. Some live on others. Many are dependent on organic matter and some break down mineral elements for their food. The processes of living and dying form a variety of gases, acids and compounds. Minerals are acted on and altered to forms suitable for plant nutrition.

Represented within the soil is probably every factor of health and disease of plant, animal and humans. This fact, somewhat clouded by magic, was appreciated instinctively by primitive man, and was incorporated in the pattern of tribal rites and cures. Civilised man for a long time forgot it, but this soil health factor has gained a new significance in recent years through the development of the antibiotics--all constituents of fertile soils. Nowadays many of the chemical processes of the soil are regulated and reproduced in the laboratories in medicine, chemistry and industry.

A wide variety of some of the species of soil life seems to have a counterpart in the glands, organs and secretions of all animal life.

While there are processes within the soil that may be detrimental to crops and animals and humans, there is always a heavy balance favouring the healthful nutrition of grasses, crops, animals and humans in all really fertile soils. These beneficial or benevolent factors operate at their best when the conditions of moisture, warmth and air are most suitable for the optimum production of the best pastures.

Soil is dynamic and complete, forming and producing its own food supply. In a good soil the continuous production of vegetable matter, particularly the newly dead roots of pasture grasses, supply the force for its continuing processes.

Good fertile natural soil was made or developed in a suitable climate by plants growing in the soil, by animals and birds feeding on the growth from the soil, and by the complex of soil life living in the soil and processing the necessary nutrients of plant growth. These same processes describe our agricultural pursuits. Therefore, soil controlled by the farmer and grazier should rapidly increase in fertility and not deteriorate as so much soil has been doing for so long.

The development of soil is greatly influenced by climate. In the past, in my opinion, natural soil quickly reached its optimum development. It would then probably have maintained that particular fertility stage, only fluctuating slightly according to the varying climates from year to year. It would have reached a state of balance with all the factors that affect it, and remain relatively stable.

This idea conflicts with the general impression that soil takes great ages to form. Some rocks, it is true, decompose very slowly, but the formation of the live soil from rock particles can be very rapid in a good environment.

The study of soil life and all the soil-life processes is covered in soil biology, and particularly soil microbiology. There is probably a lot more to be learned about these various processes of the soil life than we yet know. But provided it is realised that to increase the quantities of vegetable matter in an environment that supplies the best conditions of moisture, warmth and air for soil life, is the outstanding way to accelerate the dynamics of this life, then the landman has the basic knowledge to greatly improve and increase the fertility of his soil. An improved soil climate itself acts to produce greater quantities of suitable organic matter and especially from the valuable root systems of pastures.

Regionally, weather sets the course for the general agricultural pattern. Agriculture is dependent on soil, and soil is largely dependent on the climate that affects it.

Perfect agricultural weather or climate, if it were possible anywhere, would soon produce perfect agricultural soil. Any soil, cleared of its unwanted growth of scrub and trees and planted to the best species of grasses and clovers would also rapidly increase in depth and fertility. If the effect of climate on soil is fully understood, I believe we have a basic knowledge that will enable us to increase the fertility and productivity of any natural soil. We have a knowledge that will allow us to increase the fertility of soil far beyond that which was produced in nature; but we need a new soil technology based on this knowledge.

I am well aware of the influence of rocks and their mineral particles on the development of soil. Some rock types, for example the basalts which break down rapidly and release the essential mineral elements of fertility, will quickly produce a fertile or at least a productive soil in climatic conditions that would not produce a similar stage of fertility in another type of rock. There has always been a wide range in the fertility of natural soil produced under identical climatic conditions over a range of varying rock types. Some rocks have been reformed again after breakdown from original rocks and the disposition of, not only their mineral elements, but also the plant availability of these elements, have been widely changed. Some rocks will produce a complete soil with only one inch of decomposition from the hard rock; other rocks will need much deeper decomposition to supply all the mineral elements of fertility. Granites, apparently identical, may differ widely in fertility with only moderate variations in their general climatic influence.

Soil on earths formed by wind deposits may produce maximum productiveness from minimum climatic influence. On the other hand, former good soil can deteriorate into poor soil by a changed climate that may cause the leaching down of a particular necessary element. Clearing and cultivating have first of all made way for good grass and good crops. Then, almost dramatically at times, the land seems to collapse and will not grow a crop or feed a sheep. The changed environment has caused a loss to the soil of a necessary mineral element resulting from a deterioration of the soil climate. Missing or unavailable mineral elements of fertility will never be very far away, but unless they are within the zone of plant roots they are not a part of the soil.

A suitable climatic change could rapidly improve a soil and bring within range formerly missing elements of fertility.

Disregarding for the moment the experiments being conducted by our Commonwealth Scientific and Industrial Research Organisation (CSIRO) to produce rain, there is little we can do to improve climate. But as the critical factor is soil climate, are there ways and means of managing soil and land to improve the effect that the general climate has on soil climate?

It is most conclusive that some types of soil treatment and land management do deteriorate the beneficial climatic effect on soil climate. The evidence is there in a deteriorated and eroding landscape. Before what is called soil erosion has its effect on soils that were originally of even moderate fertility, another very serious form of erosion took place. This is fertility erosion, which is a pre-soil erosion, and paved the way to major soil losses. It is caused by a change for the worse in the soil's climate, and the villain here is man.

While there are numerous ways of worsening the soil climate to reduce the fertility of soil, and we have no doubt employed them all, there are, in my opinion, as many ways of improving the soil climate and increasing soil fertility.

Good living conditions and plenty of soil-life food produce a soil that becomes increasingly more fertile. Perfect living conditions, or what amounts to the same thing, perfect soil climate, never exists and probably cannot exist continuously, but may be a present factor for short or longer periods once or more each year, according to the particular general climate. During the time that good soil climate extends to the limit of the food zone, the soil-life communities develop very rapidly to climaxes. The climax period in these conditions is limited only by the available food supply.

As the various soil-life communities feed on each other, there has to be a continuous new source of food to balance the whole ecology and biology of soil. This continuous new source of food is some form of vegetable matter. All forms of vegetable life become part of soil by these processes, and, I believe, that the greatest source of best possible food supply is contained in the newly dead roots of the best clovers and grasses under a good pasture on which a variety of grazing animals have fed.

Perfect soil conditions or soil climate involve a soil condition in which there is ample moisture but not complete saturation, a degree of warmth that suits most of the life forms, plus sufficient air for the life that needs it but not enough to dissipate overmuch warmth and moisture. These conditions produce the climaxes of soil life. To have maximum benefit they obviously must extend to at least the depth of the major root zone of a pasture.

If these optimum conditions can be induced in the soil, even the recognised poorest of soil, once each year for three years, as in Keyline, then these poor soils, or any soil, can be improved to something beyond that which the natural climate produced. Further, once the greatly increased soil fertility has been produced and maintained for three years it has the ability within itself to improve its quality and depth without further treatment. Just how far or for how long this self-contained improvement will continue I have no way of knowing, but I am quite certain that the correct answer will reverse the present beliefs and that it takes much less time for man to build a bounteous fertility into his soil than it does for him to reduce, deteriorate and ruin that fertility.

The practices and agricultural methods that deteriorate soil climate and reduce soil fertility may take many years to produce a noticeably harmful effect on good soil, but only a few seasons to destroy the low fertility of a poor soil.

Altered practices that improve soil climate and fertility can create, because of the fantastically rapid response of soil life to better conditions and food supply, a highly fertile soil in a few short years; and it will always require a much longer time to destroy this fertility than it need take to build it.

Perhaps the most dramatic evidence that there are many things wrong in our agriculture is the effect that it has produced on the land in ever-increasing soil erosion. I regard soil erosion as the perfectly natural reaction of land to change its shape in keeping with changing conditions of environment. But the stable shape of land, with its cover of soil, before it is brought into the category of agricultural land, represents a balance of all the conditions that affect it. If a soil that supports plant life and animal life has been produced naturally, then that soil is in balance with all the conditions that formed it and are continuing to act on it.

The factors that have affected and produced natural land shape are very numerous, but those of its basic geology and climate are no doubt the dominating ones, since they produce or influence all the other factors that affect land shape and soil class.

The features of land that make it suitable for agriculture are its soil coverage and its stable rounded or smooth form. These forms may range from large and low, as in our flatter land, to small and high, as in our steeply undulating hills and to all shapes between. Valley and hills are of a rounded smooth form.

To produce the best agricultural shape and the deepest cover of soil requires a climate, not only agriculturally suitable but one that has been operating for a long period of time over stable geological conditions. The deeper rich soils formed and shaped under favourable climatic conditions are very stable. Fertile soil has within itself capacities that resist change, or, as it is called, soil erosion.

When these natural soils and their land shapes are brought under agriculture many conditions may be altered and produce a lack of the former balance. The soil will eventually change and the land reshape itself to a new balance with the new conditions affecting it. (*See Pictorial Section.*)

Fertile soil resists change or erosion, but changed conditions may reduce and destroy fertility, and then reshaping of the land form takes place. This is man-made soil erosion.

For illustration, we can take the extremes of two classes of soil, both in a similar natural undulating landscape, one highly fertile soil, the other a very poor soil, and consider the changed conditions that affect them when they are converted to agriculture.

Usually, the first thing to happen is that the land is surveyed and cut up into holdings or blocks with straight line boundaries which will be fenced. The fences cross hills, ridges, small and large valleys, watercourses and creeks with little regard to natural land divisions. Travelways, tracks and roads follow the fence lines and the first altered condition that may affect the land shape takes place. Water flowing over land has natural flow lines according to the land shape, and falls in curved lines to the valleys from the hills and ridges. It flows as a sheet, losing its natural flow path or pattern in the first depression. Roads and tracks cross these natural flow lines and cause water to concentrate earlier and in new places. The velocity of water moving on a hillside is greatly increased on a soil that did not develop in such conditions and is less able to support the flow without soil movement. When the velocity of water is doubled its power to move things is, theoretically, increased by about 60 times, and in the conditions as they affect soil movement in erosion, by about 30 times. The poor natural soil then may commence to erode immediately by the concentration of flow water caused by the road, but the highly fertile soil, because of its fertility, will easily withstand this first slight concentration. (*Fig. 4, Chapter VI.*)

The answer to this first problem of agriculture is the better planning of land subdivision, and it must be based on a knowledge of the natural flow movement of run-off rain so that the planning avoids causing unnecessary concentration of water flow. Rain falling on the limited land area of a farm is fairly uniform all over the farm, but when rain reaches heavy general run-off proportions, then the water moving over the land varies greatly in volume and depth. Water which has fallen somewhere else is flowing over every point of the land except the centre lines of the ridges and hills. The amount of flowing water is progressively greater from the ridge toward the centre of the valleys.

Now, once boundary fencing as above is completed, large-scale clearing may be undertaken; preparation made for further subdivision and the land made ready for plowing and planting to crops and grasses.

Every one of these operations in orthodox agriculture breaks the flow lines of water movement, causing new concentration of flow. The very poor soils show some erosion immediately; the highly fertile soil is completely unaffected.

Every plow furrow that crosses a valley, every vehicle that moves on the farm, crossing even the flatter gentle valleys, breaks the natural flow line of run-off rain water and steepens its path to the valley, causing new and increasing quantities of flow. Side by side with this mechanical change in the conditions that affect water movement on land march others that directly and progressively change the soil climate. All, or nearly all, the trees may have been cleared, allowing drying winds to have a worsening effect on the soil, which then does not hold its moisture so well between rains. And the period of time that optimum conditions for soil-life development and plant growth exist is lessened. The dynamic forces of the soil are at first slightly, but then progressively, reduced.

The poor soil shows the effect quickly; the highly fertile soil is apparently unaffected. It may show no positive soil erosion effect for many decades.

Reducing these damaging effects, general farming practices may be improving conditions in other ways. The growing of plants in the soil and the feeding of stock on the crops and pastures are in themselves the same processes that form and improve soil. If the balance of all factors generally has the effect of improving soil climate, then the soil will improve and remain stable.

A property may be overstocked; concentrations of stock may firm the soil and at first even improve it. Then a real compaction may set in restricting the former depth to which suitable aeration extended. Beneficial soil life is restricted to the top inch or so of soil. The dead roots of the pasture grasses cannot form the best food for the most beneficial soil life, because this life cannot live without air. The fertility factor of the dead root is largely wasted, the current formation of new products is lessened and the soil is then deteriorating by fertility erosion. Less, moisture is absorbed in the soil, more water runs off with increasing velocities, carrying soil with it. Apart from the erosion which is caused solely by the artificial concentration of water flow, fertile soil must always suffer this fertility erosion before widespread soil erosion can touch it.

Concentrated water flow will move almost anything, but fertile soil can be plowed badly, up and down hill, and everything wrong can be perpetrated on it, but it still will be little affected by soil erosion until the treatment has reduced its fertility, reduced drastically its life and the current formation of new food or humus. The forces tearing down its fertile structure must be greater than the forces building them before soil erosion can affect it.

Some soils that farmers may believe are very fertile erode badly. But always such soils have lost their former power to produce year by year new or current humus. Among the many products of fresh humus is the gum-like substance which forms the crumb structure of fertile soil and resists movement. The good crops which they may still produce in good seasons, and the seasons affect them more and more, come from readily available minerals inherent in the original rock or produced in the past by the soil's former biological fertility.

Land which once carried some of the most fertile soil on earth is now distinguished by its giant erosion gullies. It took decades of plowing, bad plowing and cropping or wrong management, to start the serious erosion. Many of the cultivating implements of agriculture are condemned by the terrible land destruction that followed their use, for example the mouldboard plow in the great corn belts of, North America, the disk plow in the drier wheat areas of America, Australia and Africa. It would, however, be just as logical to blame the destruction of land on a most popular tractor because it pulled the plow, destroying land much more quickly, as to blame this type of erosion entirely on the implements. The failure of agricultural education or the general attitude of some early farmers to the land, the mistaken belief that exploitative farming was good farming, the lack of farming experience and knowledge by the early settlers, the failure to adjust the best in European farming methods to the new conditions of the new lands, the cheapness and abundance of good land, the thoughtless and careless rush to produce for a profitable and expanding market--all these factors are causes of the erosion problems of soil that worry the nation and other nations today.

Cultivation equipment, to be effective, has to produce a mechanical condition in the soil that permits crops to be planted, controls unwanted growth and allows the crop to grow, mature and be harvested.

Cultivation according to how and when it is done can eventually destroy soil fertility and start serious erosion or stabilise, develop and improve soil far beyond its natural state.

Continuous year-by-year cultivation to an even depth with orthodox mouldboard and disk plows is likely to form quickly a new artificial soil horizon that changes the soil climate and reduces soil fertility. The smashing and pulverising effects of many types of cultivation, if continued, change the soil climate by gradually sealing more and more with the first following rain, which restricts both the intake of moisture and air. The most desirable type of cultivation at the wrong time of the year is still bad. It promotes the rapid loss of moisture in summer and on the light soils in winter reduces the temperature of the soil.

Cultivation that promotes the best conditions of moisture, warmth and air in the soil together improve soil climate and promote fertility.

Any straight line cultivation or round and round the paddock plowing is tending to break the flow path of run-off rain, steepening its path and concentrating its flow. Acting and compensating against this though, certain types of cultivation, notably chiselling and ripping, may increase the absorption of rain and reduce flow. Again, if the balance of the factors improves soil climate, the soil improves and its stability is preserved. If the balance deteriorates soil climate the reverse is true.

It is not so essential that soil never be treated in such a way as to deteriorate its climate as it is for the farmer to understand the process he is using, and its ultimate effect, if continued, so that he can keep the general balance always in favour of his soil.

Some soil treatments or management processes which work against soil fertility may be necessary at times in the course of farming operations, but always the more fertile the soil the better it is able to withstand damaging treatment for a time. Various types of cultivation are necessary in farming enterprises and many cultivation processes are damaging to soil fertility. But just as surely, in my opinion, cultivating processes can be a great aid in improving soil climate and soil fertility if the farmer understands just what he is doing.

* * *

It seems that the aim must be to redesign every mechanical agricultural process so that it has the effect of improving soil climate. Then every other useful art and science of agriculture and property management will have greater benefit because each is applied or used on a fertile and improving soil.

Soil climate is so vastly important because, apart from its influence on agricultural production, it is the dominating influence on the development of the soil-life communities. This life in turn is likewise very important, because its products, the products of its living and dying and reacting on the various components of soil, supplies the necessary nutriments for plant life. It is a necessary part or process of fertile soil. The more dynamically alive the better it is.

The farmer should know that as soil dries out so the soil life dies out, but will regenerate again rapidly from its vital forces and eggs and spores when soil climate is again suitable. He should know that cold soil reduces the forces of soil life to a lower ebb; that moisture, warmth and air produce the climaxes of soil life; and, finally, that soil life feeds on every type of food, including other organisms of soil life, minerals and organic matter.

When soil has been eroded and almost completely lost, soil life can be regenerated in the dead earth by cultivating and sowing grass and clovers with fertilizers to stimulate early growth, and by the introduction of stock. Some species of soil life are distributed by all classes of animals and birds from their rumen glands and organs, and the wider the variety of the stock the more complete and beneficial is the whole complex of soil life.

Even without appreciating or knowing much about the soil life he cannot see, the farmer will know that his soil is as it should be when he can see that it contains a large and vigorous population of earthworms.

During the early part of 1944 1 commenced to develop "Yobarnie". I was a well-informed and ardent follower of American soil conservation methods and these techniques soon dominated the appearance of the property. Many experiments were conducted on pasture and soil improvement, both with the strongly artificial fertiliser approach of our orthodox agriculture and the wholly organic methods. Both methods, when we irrigated, produced good-looking pastures, but we were never conscious of an earthworm population. I do not remember seeing earthworms or their casts in the paddocks at that time, but no doubt there were some present. Some years later adjacent land was purchased and "Nevallan" was established. After two years of Keyline on this property, which was much more eroded than "Yobarnie", earthworms and their casts became so evident they could not be ignored. We commenced to take a great deal of interest in this remarkable phenomena. We dug, counted, measured and weighed earthworms.

Suddenly they disappeared; there were no casts nor earthworms to be seen. We found the earthworms with the aid of a spade, deep down in the earth.

Towards November they were everywhere again and ten times as many were casting on the surface of the ground. They had again disappeared by December, but at the end of March the following year they were in their millions and were seen by some of our largest parties of agricultural scientists as well as by more and more landmen. Now the earthworms were much larger. There were many more of the smaller earthworms, but the large ones--which we believed must be the older worms--were now over fourteen inches long. Many visitors both from Australia and overseas told us we had the largest population of earthworms they had ever seen. Other visitors said that they knew of only one area, the fertile Nile valley, which had a greater earthworm population than "Nevallan".

However, the point is not the development of the earthworm population on "Nevallan", which could be another story, but their function in the development of soil. Visitors have said to me, "Oh, yes, the earthworms follow the good soil", and others just as positively, "Once the earthworms are introduced they make good soil". But we did not have any good soil on "Nevallan" when we started Keyline and we did not introduce earthworms there.

I believe that the earthworm is merely a part of the life process which is soil. When the soil climate is slightly improved a few more earthworms breed and stay alive and active a little longer. At the same time, this applies to many other species of soil life which, although we cannot see them, increase in numbers by countless millions in a week. The minute forms of this life have a very short life cycle, but the earthworm, truly the giant of the beneficial soil life, may live to a great age. I have not yet found a reliable reference to the age to which an earthworm may live, but I have concluded that the largest of our "Nevallan" earthworms must be up to four years old now. There are large numbers in all sizes (and size may be a reliable indication of age), up to fourteen inches long in their shrunken, not stretched, length, with many over twenty inches long.

Many species of soil life require no other food than the soil or earth particles themselves. All they require to perform their work of making soil is improved living conditions, i.e., improved soil climate.

CHAPTER IV

The Keyline Scale of Permanence

IN order to plan the development and management of land, the many factors that are involved should be related in some logical order. The planning of one aspect cuts across others, so some must have preference. Decisions have to be made on all sorts of apparently conflicting items of land planning. We need, also, to have an aim or an object, a basic plan.

If something is to be planned and built it needs a basis or a foundation. If it has a foundation, then it should be permanent, more permanent than the 'thing', whatever it is, that goes on the foundation.

Decisions on any aspect of planning have a relative importance which relates to the permanence of the effect of that decision. A man decides to buy a tie; this decision is not as important as the decision to buy a suit of clothes. It is unlikely that he buys the suit of clothes to match the tie, but logical to buy the tie to match the suit. The permanence of the effects of each decision indicates the relative importance of the decision in planning.

Every decision made on any aspect of land planning must be based on or fit in with all others that are more permanent, or more permanent in their effect than it is. Every decision should be based on adequate consideration of the whole plan of development.

If permanence and relative permanence are the guides on decisions which have to be made, then we need to determine these agriculturally in relation to all the factors involved.

For instance, farmers and graziers are advised to plant trees, but where should they be planted? What are the factors involved in this decision? They should not be planted along an old fence that will need to be replaced in ten years, particularly if the farmer can now see that the fence was erected originally in the wrong place. Many recommendations suggest the planting of trees to protect valleys. It would be surely a shame, when a few years later it became necessary to remove them to make way for a dam. Farm roads are sometimes an endless source of trouble. How can their most suitable positions be decided?

If a farm road clashes with a water conservation drain, and this will happen more frequently in the future, how is the issue decided? Is the water conservation drain made to suit the road or *vice versa?*

A subdivision fence is required to divide arable land from a grazing area. How is its best location determined? Certain gateways wash badly. Why were they put there in the first place? Is there a more suitable place for the fence or a better position for the gateways?

It is planned to have some irrigation; what factors determine the exact position of the dam, the size and shape of the irrigation paddock? When it is finished could it then be obvious that another site for the dam, another site or shape for the irrigation paddock would have been much better? A new building is to replace an old one. Will it be built in the same place? What are the main factors that affect the decision?

These are only a few of the questions that arise. Decisions are being made all the time, every day, and some of the most casual, thoughtlessly-made decisions, apparently of little importance at the time, may have bad permanent effects.

Then we have all had the experience of saying "That's good enough" about a job we are doing. We probably knew it was not quite good enough; it did not last long enough and had to be done all over again. More time, much more time, had to be spent later redoing the whole work. It may be much worse than just redoing the work. The original work may have affected something else, perhaps something quite important and permanent.

Errors of this type are constantly happening, but on farms their effects are magnified. It may be that a farmer without planning has decided quickly to clear a piece of land. He wanted to work an idle machine. Inadequate instructions were given to the operator about some trees that were to be left standing and the farmer hurries off to repair a gate a mile away. It may be that he did not fix the gate properly, but it will do, and he goes back to the clearing to find the trees he wanted have been removed. He can replace them, in fifteen or fifty years, but while he is adjusting himself to his loss a mob of cattle break through the "good enough" gate and ruin a crop he grew for winter feed. Six months later the effect is shortage of feed. Ten years later he is still without his trees.

The dam built without a plan is usually the one that washes out if there is heavy rain, and the dam constructed to plan as a thing of usefulness and considerable beauty will not wash out and will last indefinitely.

Every item of work a farmer does has its own life of usefulness or effectiveness--its degree of permanence. If he is planning for the stability and permanence of his farm he should be ever conscious of the relationship of these factors to what he is doing or planning. What effect will his plans have on other things that are more permanent? Still more questions.

Will something cause a water concentration that can cut an erosion gutter in his land? Soil erosion is an opposing force working against the permanence of his land which should be his most permanent possession. Is the general development of his property planned for permanence? I know a man who bought a dairy farm which he cursed every day. The house was at the top of a steep hill, the dairy buildings at the bottom. Maybe it is much worse to climb a steep hill after working all day than climbing a hill to work in the morning. To that man that hill got worse and worse until he sold the farm. It has probably changed hands a few times since. In this case, there was no planning for permanence in the locations of those buildings. No one wanted to make of it a permanent home. This type of farm is not handed down from generation to generation; it has no permanence.

Natural land or undeveloped land owes its permanence to its association with environment and time. It has reached a degree of balance and is stable. Agricultural land is, however, in a different category. Its degree of stability and permanence is a direct reflection of the people who control and occupy it.

Man makes his moves and Nature sooner or later signifies approval or disapproval. If it is approval, man can hold it permanently, but if it's disapproval, Nature reshapes the land again in a fashion that does not suit man.

Farmers of the stable agriculture of the old world are not so much affected by these problems of individual decision. They know the solutions very often, and act on them without even being aware of the problems which were ironed out for them centuries before. No doubt there were periods of trial and error, periods when changes were violent and often disastrous, but as farming lore and tribal laws were handed down from father to son for generations than ran into centuries, traditions hardened and origins became blurred. No doubt there were many failures worse in their effect than the droughts, flood and fires we know, and famine wiped out whole communities before agricultural man in Europe mastered his environment. And, looking back beyond the documented period of agricultural change, there must have been times when a farmer by his primitive experiments produced results as momentous to his community as the invention of the wheel; and the glittering cavalcade of history as we know it (the warriors, princes and prelates of medieval times; the monarchs, explorers and traders of later times; the technocrat, bureaucrat and capitalist of today), travelled down the road prepared by such geniuses.

We of the new world have had little time. We have had no such tradition of agricultural wisdom to guide us and there has been as yet no union of the techniques of the old world with the new conditions and horizons of the new world.

For all that, the impact of the industrial revolution on the traditional agriculture of Europe caused grave ills; in the new countries the effect was swifter, deeper, and in places disastrous. For better or for worse modern technology speeds things along enormously. It is, however, just this powerful tool of modern technology, a lever, as it were, on the fulcrum of all traditional agricultural knowledge, that can reverse the process of deterioration with equal speed.

The partnership of technology and tradition, with the exact sciences replacing much that was superstition, and almost infinite power replacing bullocking labour, these properly co-related, form a basis for a new type of permanent agriculture. With all due respect to the many who have made magnificent contributions to the sum of our knowledge, I submit that there has been as yet no clearly formulated pattern for permanence in modern agriculture!

Seven years ago, after eight years of trial and error experiments on my own properties, I felt I had stumbled on to something of real agricultural importance in my land experiments. Three years later it seemed appropriate to set my ideas down in print, and "The Keyline Plan", 1954, was the result.

There has been since a further four years of experiment and proving over a much wider range of conditions, plus the great benefit of innumerable discussions with some of the best agricultural brains in Australia. Looking back to my first inquisitive interest in the affairs of farmers and graziers from meeting them as a mining man, I realise now that I have had opportunities that few men have ever had for just the type of work and investigations that have absorbed me for so many years. When I first purchased land I bought also all the problems of poor climate, eroded, abandoned land and dead soil. Fire took the life of my brother-in-law manager the first year, a year of withering drought. Soon, freak rains were to test and destroy some of my first work. I had few problems of money that beset the first years of many of our best farmers, and no problems of equipment, since there were always plenty of bulldozers and giant scoops on my nearby jobs or mines. Then I had a fund of knowledge from my own work which I soon found was of greater value to me than any available help or advice. I knew water, earth and rocks, and enough of many branches of engineering. The rest I learned by doing it. Over and beyond all this I could do what I liked, there was no one to dictate. I had the supreme advantage and the great privilege of making my own mistakes in my own way. For fifteen years my experiments, mistakes and failures have pointed the way to the solution of each approach of the work and to the completion of a workable and successful plan. While aware still that there is much to be learned, I feel that my experience and conclusions are of definite value.

For these reasons then I offer the idea of the Keyline scale as a contribution to the development of a modem planned agriculture that will be stable and permanent.

The Keyline scale of permanence, or to give it a full explanatory title, "The Keyline scale of the relative permanence of things agricultural", is a further development of the Keyline Plan. It was developed for the purposes of providing a yard stick or guide to every type and kind of decision that has to be made in any aspect of overall planning in the development and management of agricultural land.

The Keyline scale of the relative permanence of things agricultural, for the planning, development and management of agricultural lands is set out in this way:

1. Climate
2. Land shape
3. Water supply
4. Farm roads
5. Trees
6. Permanent buildings
7. Subdivision fences
8. Soil

* * *

The most permanent agricultural factor is climate. The general overall climate which has produced the natural vegetation and has given the final smoothing and shaping to the land is first on the Keyline scale.

Land shape is intimately associated with the particular climate and is second in the Keyline scale of the relative permanence of things agricultural.

These first two factors of the scale form the environment into which we must first fit our agriculture.

Land shape under the Keyline plan is to be preserved. Fertility erosion, the forerunner of soil erosion which causes the reshaping of land, is completely prevented.

Climate and land shape head the Keyline scale of permanence and are very closely related in the time or age of their permanence.

Item number three on the Keyline scale must unquestionably be water supply. There can be no satisfactory or permanent agriculture without permanent water supply. Even dry agriculture must at least have permanent water for household and for stock. If water can be conserved in farm dams, then the structures themselves are planned as permanent structures. Such water may be used for irrigation, and some of the irrigation dams may be depleted but the structures themselves remain.

Under the general Australian conditions it is always desirable to conserve all the water that falls on the land. This desirable objective has not been attained in the past because of lack of study and of experiment that would make this approach profitable and practical. Whatever the source of water supply, be it creek, river, bores, farm storage in tanks and dams or even pumped or carted to the property, it forms an important background to all other planning and development. It may influence the pattern of clearing, the planting of trees, the selection of home and other building sites, the location of roads and subdivisions and cropping and grazing areas.

The water supply should be decided and planned first so that it will fit the two other more permanent factors, namely, climate and land shape.

The fourth factor on the Keyline scale is main farm roads.

On the gentler, easier country, the sites of permanent farm roads may offer alternatives, some of which may be suitable in general planning, but as the country becomes steeper and more difficult the siting of permanent farm roads depends more and more on climate and land shape.

Fifth on the scale are trees, the trees that are to be left in clearing of the land, or the trees that are to be planted. They are more permanent generally than homes but much less permanent than climate and land shape.

It may be thought that trees are more permanent than water supply when the supply depends on dams that may silt up, but dams are located according to the climate and land shape and are designed and built for permanence. Silting can be prevented. If trees can live in drought conditions on natural ground water, then, surely, water supply can be made to last, provided dams are deep enough.

The sixth item on the Keyline scale of permanence is homes and major farm buildings. Their sites should be selected having regard to all other more permanent features. Trees and buildings are closely related as to their age of usefulness. Some trees for beautification will be planted near the homestead.

The seventh factor is subdivision. The location of the subdivision fences is influenced by farm roads, which in turn are located in respect to climate, land shape and water supply.

As well as the main farm roads, reasonable access has to be provided all over the property. The most suitable sites for subsidiary roads influence the general subdivision fencing pattern.

Soil is eighth on the Keyline scale of the relative permanence of things agricultural.

With the dominating place that soil fertility occupies in our planning aims it may be thought that soil would rate higher, but the scale is in order of the relative permanence of things agricultural. If the soil is poor at the commencement of planning it would not do to class it as third or fourth on the scale of permanence. Soil is eighth or last, because the fertility of the soil can be lost in less time than a line of fence posts will rot. A poor soil may be converted into rich fertile soil in a tenth of this time.

There is, however, the other aspect of soil that is related to number two of the scale, *i.e.,* land shape. Land shape is really the shape of the soil covering on the subsoil and rock form below. According to plan, land shape must remain stable and permanent.

In repeating then, the Keyline scale of the relative permanence of things agricultural, for the planning, development and management of agricultural lands is:

1. Climate
2. Land shape
3. Water supply
4. Farm roads
5. Trees
6. Permanent buildings
7. Subdivision fences
8. Soil

But let it not be thought that these "eight" are the sole factors on the broad agricultural scale. Without, at least one other, the will, energy and ingenuity of our landmen, land improvement will not prosper.

Each factor on the Keyline scale of the relative permanence of things agricultural will be discussed individually as far as any one factor can be separated from the others.

Climate and land shape are intimately associated and are related in age.

In any discussion on water supply we must consider it in relation to climate and land shape. The storage of water in farm structures cannot be separated from either of these two factors.

Like climate and land shape, water supply and farm roads are associated in age, whereas the degree of permanence of the former relates to periods of time ranging from tens of thousands of years, the time association of water supply and farm roads, which are provided on the farm by man, is in the order of mere hundreds of years.

Trees, next on the scale, also relate to water supply and main farm roads. In most farming conditions, where trees are still a factor, they may now have a greater degree of permanence than farm roads and water supply.

Permanent buildings are sited in relation to, or with consideration of, all the more permanent features. Their degree of permanence is generally greater than but relates to the next item, i.e., subdivision and fencing.

Soil is life and life may die. So this last factor on the Keyline scale of permanence is to be developed to a much higher state of life and fertility than it attained naturally. The farmer and grazier may then be justified in considering it as his permanent possession.

When soil is held permanently in an improved condition we will have attained the objective, a stable and permanent agriculture. The full duration of permanence will always depend on the farmer who is not only manager but custodian of his re-created agricultural land.

CHAPTER V

Climate--The First Factor

CLIMATE, the first factor on the Keyline scale of permanence, governs our approach and guides all agricultural matters. Climate sets the pattern of farming and grazing. The traditionally independent man on the land is completely dependent on the weather.

* * *

For the sake of clarity and brevity in the following discussions it will be assumed that we are dealing with the fairly general type of poor agricultural climate so typical of Australia's farm and grazing lands of the mid-temperate zone. This area is not snowbound for months in each year, but the temperatures are often high. The rainfall is insufficient and unreliable and droughts of a few months occur every year; flooding, destructive rains occur about as often as the severe longer drought. The position of excessive run-off followed by rain shortage for pasture and crops is a more or less constant feature. Generally, if all the water that runs to waste was conserved it could be utilised in practically every year.

Life cannot get down to living, let alone developing fully, until it is adjusted satisfactorily to its environment. This is the climate that set the course which our agriculture is only now seeking to follow.

The natural soil of this climate would not generally be of the deep, highly fertile type. Its development would have been continuously retarded or restricted by the shorter period of good soil climate and the longer and more frequent dry soil periods. It would have reached a natural development of a low to medium fertility and would not now be improving. Its fertility is constantly ebbing and rising a little, according to the season's changing climate.

Our climate cannot be altered, but as soil climate is the critical factor, what can be done to improve the effect of our general climate on soil climate? Varying degrees of beneficial control may be exercised on moisture, warmth and air.

First, water must be used more effectively and none must be allowed to run to waste.

If the period in which adequate or improved amounts of moisture remain in the soil is extended, even a little, the improved soil climate quickly affects the whole of soil-life development and with it the fertility of the soil.

Planning, then, is designed to retard moisture loss in hot weather after more moisture from rain has been induced to enter the soil's depth. All run-off rain, conserved in farm storages, is to be made available as irrigation water and applied to the special irrigation areas immediately it can be used. It may be needed as early as six or eight days after rain in summer and surely must represent a very powerful instance where soil climate can be tremendously improved. Air, too, is to be kept in the best association with moisture and warmth.

The correct association of these three influences--moisture, warmth and air--provides the best conditions for pasture and crop growth, and also the optimum conditions for the development of soil-life climaxes which rapidly change the whole soil, its colour, structure, feel and smell.

Since roots are dying and new ones are developing continuously while there is growth above ground, lack of air to the full depth of this dead root zone restricts and wastes the benefit in fertility to the soil of this important organic soil food. Therefore, air is to be provided to the full depth of this zone when the other factors are suitably present. It can be done by the right type of cultivation at the correct timing for soil life and at the appropriate depth. All items are to suit the particular soil and the condition of the soil at the time of cultivation.

Climate--the first factor on the Keyline scale of the relative permanence of things agricultural--sets the approach to everything.

Adequate air is provided by means other than cultivation in a soil that has been developed to a high state of fertility. The teeming soil-life populations provide air by the strong and continuous formation of the crumb structure of this soil and the burrows of the soil life itself, the dominating and obvious ones being the larger forms, the earthworms. The large roots which on dying and being absorbed into soil leave channels in the soil. Good aeration, a constant factor of fertile soil, waits for moisture and warmth. The earthworm population, large and vigorous, continuously moves in the section or horizon of the soil, where for the time being it finds the most suitable living conditions. When these influences extend to the surface of the soil, the earthworms will break through and cast all over the land. They delve deep into the subsoil, casting as they go into underground passages and cavities. The effect on the factor of aeration by an immense earthworm population in a highly fertile soil must surely approach perfection.

When the soil we are developing, by first of all improving the effect of general climate on soil climate, approaches this state of high fertility, it can look after itself. It will provide its own air requirements, absorbing its full share of rain and continuing to improve. When it does eventually lose its moisture and dries out, which it does more rarely as it improves, its response to small amounts of rain is dramatic. On the other hand, on such a soil, a week of flooding rain will cause no damage. It holds its air and does not drown nor asphyxiate.

When irrigation water is applied to land it critically affects the soil. Poor natural soil developed in poor climate cannot withstand this new condition. Water is an essential part of the soil fertility process, but it can, and does, drown and destroy as well as develop and preserve soil fertility. Whenever irrigation water is applied to soil, then that soil needs air. It may need to be provided more drastically for a time than in any other circumstances of the soil's water and air relationship. The great improvement in soil climate which increased quantities of water make possible can only become real, valuable and permanent when air also is suitably present.

Only soils of the highest fertility other than coarse dead sands are capable of maintaining a suitable relationship of moisture and air when greatly increased quantities of water are applied. When this optimum relationship is maintained, then the poor soil under irrigation will be transformed into highly fertile soil in an incredibly short time. A summer season of the new soil climate that irrigation with adequate air can maintain will produce a complete transformation of poor clayey soil. This has been a consistent result on our "Nevallan" and "Yobarnie" properties each time we have applied irrigation water and maintained, with adequate cultivation, good soil aeration.

* * *

There is an almost infinite range in types of climate. There is great variety even in the general climatic condition that forms the background to these discussions. There is every type and variety relating to the one factor of precipitation--rain, snow, ice, dews and fogs. Then there is the wide variety of other climatic effects on the general pattern of precipitation, such as prevailing winds, seasonal winds and heat and cold.

A dominantly winter, but low annual rainfall area may still lose great quantities of water by run-off in the winter. Although generally a dry climate, the over-abundance of rain in the winter may be the most unpleasant and unmanageable aspect of the farming enterprise. An annual rainfall of 18 inches in this case would provide very significant run-off for valuable farm storages. Another climatic condition with the same rainfall but spread uniformly throughout the year may not provide any regular water for irrigation storages. This climate may produce no reliable annual run-off, but the condition is rare in a Keyline programme, where occasional run-off cannot be conserved profitably.

The dominantly summer rainfall region of north-eastern Australia often creates a problem of extreme water shortage in conditions where the annual rainfall is 50 and more inches. The greater part of the rain which falls in the three summer months goes and may leave the property in drought conditions a month later. In these circumstances, large farm storages could be constructed and would provide enough water for extensive irrigation. The impossible-to-grow grasses and clovers would immediately become highly valuable pasture. A wide variety of plant species prohibited by the natural incidence of rain would in the new circumstances quickly become part of the economy of the farm.

Cold and heat are powerful agricultural influences. However, the planning of tree belts and water supply can greatly improve the living conditions of soil life, crops, pastures and stock, where the conditions of heat are uncomfortable. Tree belts also retard the extreme influences of cold. The soil which improves and becomes darker is notably warmer than a light infertile earth. The darker soil will provide a better growth factor while at the same time improving and further darkening to add more warmth to the soil.

Two days of hot drying winds may draw much more moisture from the soil than a week of hot weather with no wind. Belts of trees, designed and located according to a Keyline appreciation of land form and climate, will reduce the wind velocity and the attendant loss of moisture to a very marked degree. The effect of trees on wind velocity is significant at a quarter of a mile from a good tree belt.

Very severe soil erosion by water is not a characteristic only of the medium to heavier rainfall lands. It is often a more dominating feature of our drier areas, both the flatter western slopes and gentle undulating country. It is just this type of country that lends itself to the construction of the largest farm water storages at the cheapest cost per water unit. While today water storage on such country is confined to stock tanks generally, tomorrow this country must be dotted with some of our most notable farm irrigation dams. All the advantageous means of managing irrigation water, which now apply to our large Government irrigation areas, will then apply in a more economical manner to these large farm irrigation dams.

Water conservation is rarely attempted on such land because the orthodox agricultural approach to farm dams for irrigation purposes is that they should be designed for real reliability against the minimum annual run-off. Just why a cheaply constructed large farm irrigation dam is regarded as of no value because it only fills once in two, three or more years, I have never been able to determine.

Every single factor of climate can have both a beneficial effect, or a detrimental effect, according to its degree and relationship to the agricultural enterprise. The frost which wipes out a valuable crop can at the same time have a markedly beneficial effect on the soil of a recently plowed paddock. Snow, pleasant to play in, but not so pleasant to work in, can have almost a magical effect on soil at times.

The purpose of Keyline technique and the Keyline scale of permanence in relation to climate is to take complete advantage of all weather and climatic phases that will enhance soil climate through maintenance in the soil of improved relationships in the factors of moisture, warmth and air, and, by contrast, minimise to the full the disadvantages of those climatic elements that destroy, namely, flood rains, drought and fire.

In this regard, Keyline climatic technique is the surest form of control of the effects of weather now in practice.

CHAPTER VI

Land Shape

THE complete understanding, classification and use of the shapes of land for agricultural advantage is, along with climate, the basic structure of Keyline.

The shape of our land as it is today has been determined by climate which moulded and modified it. The movement of water over land is a constant force. If this force with equal volume or power acts on land of uniform hardness and erodability, then it produces various shapes that possess constantly repeated and geometrically uniform patterns. But the differences in rainfall and run-off rate on the widely-differing basic geological shapes of land, and the degree of hardness and erodability of its structure, have produced, together with other climatic forces, what appears to be an infinite variety of land forms yet which lie within a few basic geometrical patterns.

The variety of these shapes and patterns as they are produced in areas of similar climate, but on different geological bases, displays distinctive forms according to the geological structure beneath the surface. The large low forms of the soft granite country are very distinctive. The land could be classified as granite from its shape or outline alone from as great a distance as can be seen by the eye.

Granite country often increases in hardness as it approaches an area of geological change and the gradually-changing form of the country may clearly indicate the approach of the major geological break. How often does one reach the top of a hill to see a complete change in the shape and form of the land. While granite country, with great rounded hard domes appearing, changes from the large low form to the small, steeper, harsher shape, it is succeeded by a new shape. It is wide, gentle, expansive, probably with a soft shale base. We look at the skyline--the profile of the hills--and see from their lines that it is a soft, sedimentary formation. At the same time we may note if it is lying horizontally or well off the horizontal plane. The profile of the hills may change again. They may be flat-topped, in line and the same height. Almost anyone may pick this as old basalt flow country.

There is no doubt that the broad, wide view of land could be classified with the various major shapes related to their geological form. Some mining men and geologists develop a facility for judging these matters, but this particular study of land shape could be extended to a new agricultural study. I have noticed that farmers with mining experience tend to think of the potential of the land against its mineral and geological background.

Our interest in land shape is agricultural. We are looking for agricultural advantage in this study. Can we find a unit area suitable for observation? Can we find a logical start or finish, or beginning and end, to a suitable land form? Now since water is a major factor in the final shape of land, we may reasonably begin by studying the behaviour of water flow on land surfaces.

Progressively more run-off water flows over land from the centre of the ridge or hill to the centre of the valley. This is true whether we refer to the watershed of the smallest valley or the valley of a major river. But agriculture is the intimate use of the land and the water which falls as rain on the land, with man in close partnership. Therefore our consideration should start with the smallest valley and not with the watershed of the river.

Run-off water caused by heavy rainfall has a path or a pattern of flow according to the shape of the land over which it flows. Every hill or ridge on which run-off water flows, directs by its shape the path of the run-off water to its first place of concentration, and here at this first concentration of water is found the first feature of land shape. It is the smallest valley and it is called "the primary valley" in Keyline. This valley is a rounded or grassed valley down which the first concentration of run-off water flows to join another valley or flowing stream. As water flow is the guide in this examination of land shape, then the area of land from which run-off flows to the primary valley is the first or primary catchment area, and it will be classed in these pages as the "primary land unit".

There is a definite boundary to the catchment area of the primary valley where rain falling only inches away will flow to another valley. This boundary line is the centre or high line of a ridge.

In this new approach I classify the centre line of the hill or ridge as a "neutral line of no flow" and the start, beginning or boundary of a land unit in relation to water. The "neutral line of no flow" has been referred to in the past as a water divide or water parting. Accepting run-off flow as the guide, then the bottom or end of this land unit is found where it meets another stream of flowing water. This second flow may also be in a valley of rounded shape or it may flow water in a confined stream with banks on either side such as a creek. This, then, is the end or finish of the primary land unit.

The lateral boundaries of the primary land unit are the neutral lines of no flow of the ridges on either side of the primary valley. These smaller ridges, sometimes referred to as spurs, differ from the main ridge which carries the steep heads of the primary valleys, and will be named "primary ridges".

We now have a land unit with both a start and a finish. Its upper limit is the main ridge, its sides are the primary ridges and it ends at the valley or stream course below.

A start and a finish indicate that land can have length, e.g., length of slope. There will be all lengths of land, but for convenience these may be classified into short, medium and long. Short-length land may indicate a distance of one quarter of a mile from the neutral line of the main ridge down the valley to the line of the watercourse below. This is the length of land at "Nevallan" where Keyline originated. Where the distance is one mile this is medium length. Long length land may be two or more miles. Again, the length of land agriculturally signifies the unbroken length of the primary land unit from the neutral line of its main ridge to the first valley or watercourse below.

The length of land as it exists now represents a balance of all the factors that have affected it from the past--climate, geology and vegetation.

If the top of the main ridge is the start of a land unit, and the stream course below the end of a land unit, we then have agricultural land units that may be small in area or very large. In some shapes of country, the primary valley area or the primary land unit may occupy only an acre or two; in other types of country this same land unit may comprise upwards of one thousand acres. In the smaller form several associated units within one larger watershed may need to be grouped together to make a satisfactory agricultural working area or paddock. The larger unit may itself have to be subdivided to form suitable-sized paddocks. Indeed, some primary valleys may be too small to consider, but as these land features are to be used as guides for the planning and the working of the farm, then the primary valley must be given another quality or grading which may be called "significance". A primary valley which is too small or unsuitably shaped for a dam therefore has no planning "significance" if the plan of development includes the maximum conservation of run-off. It may still, however, have "significance" in Keyline cultivation. Again, it may be too small to enable the farm tractor to follow a cultivation pattern, and so loses all "significance".

Within the area enclosed by the line of the top of the main ridge and the line of the stream course below, and bounded laterally by the neutral line of the primary ridges on either side, we have a section of land which may include all or many important agricultural shapes. Several primary valleys may fall from the one main ridge to the stream course below; for convenience two such adjacent valley areas or primary land units are included for examination. Our map then shows two complete primary land units, combining a part of the main ridge and including all the land in the watersheds of the two adjacent primary valleys. It is seen that the two primary land units now include two primary valley forms and a primary ridge form between them. Within this area of land, as seen depicted simply on the contour map, are typical shapes of ridge and valley: (1) the main ridge from which the two primary valleys form; (2) the primary ridge formed by the primary valleys on either side of it; and (3) the primary valleys themselves. (*See Fig. 2.*)

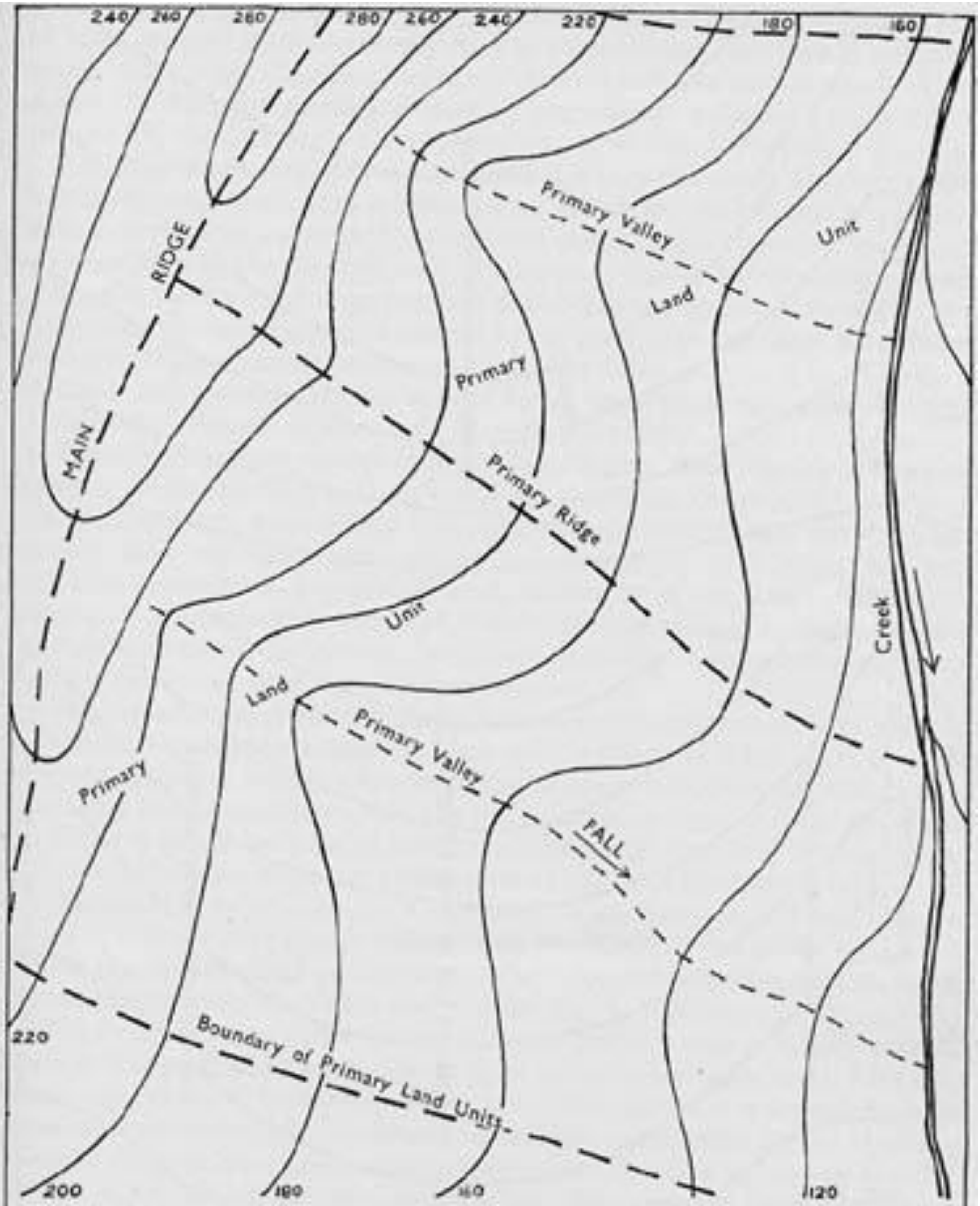

FIG. 2

A contour map, showing two primary land units, including two primary valleys flowing to a creek with a primary ridge between them, and part of the main ridge which forms the higher boundary of the primary land units.

The steep heads of the primary valleys fall or form from the main ridge shape; a primary ridge shape then is formed by and between the two primary valleys. The valleys have a standard geometrical pattern which can be seen in the contour lines of the contour map. The main ridge and the smaller primary ridge also have a regular geometrical pattern, again as seen in their contours. There is a typical geometrical pattern in the ridge form and there is a different but typical geometrical pattern in the valley form.

These two general patterns in land shape are of great agricultural importance in the ultimate development of land by Keyline.

There is an infinite variety of land shapes within these regular geometrical patterns of the contour of land, but if the significant features of the more or less regular forms depicted are fully appreciated, then all land shapes can be used to their best agricultural advantage.

These geometrical patterns of land, as illustrated by their contours, are markedly consistent in a region of uniform geological character. A geological change may break the pattern, but it will generally re-form below the break until it finally ceases at the watercourse below.

The primary valley form is probably the most important agricultural land shape. To repeat these points: It has a start in the main ridge where the steep head of the valley forms; it has its Keypoint in the valley bottom at the end of the steep head formation where the valley slope changes to form the second or flatter slope; it has a finish where the valley itself flows into a lower watercourse. It therefore has a top and bottom or high and low boundary.

The primary valley also has a boundary on each side of it. Looking at the contour form of the primary valley below the Keyline, the points or the area where the contour lines on the sides of the valley are closer together forms the lateral boundary of the valley shape. (*See Fig. 3.*)

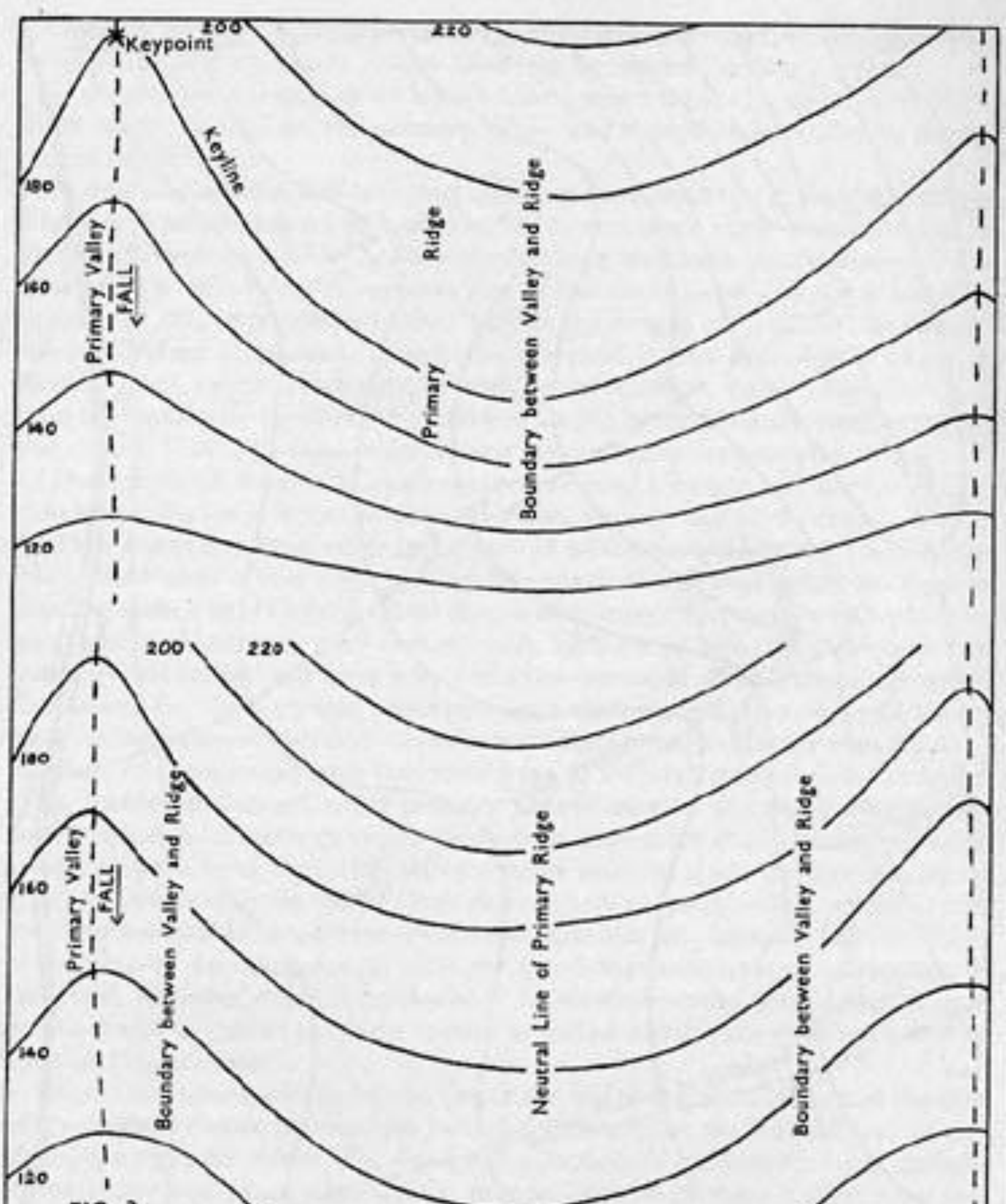

FIG. 3

Two contour diagrams of land shapes illustrating:
Upper: Valley-shaped land with the contours closest together along the neutral line of the ridge. In this land classification the neutral line is the steeper part.
Lower: Ridge-shaped land with the steeper portion close to the valleys and with the flatter area along the neutral line of the ridge.

The primary ridge shape between the two primary valleys in most circumstances is bounded by lines similar to those of the valley boundaries. This ridge has a top boundary at the top of the main ridge and a lower boundary at the stream course below. It has lateral boundaries represented by the boundary lines of the primary valleys on either side of it. The area of land on the sides of the valley where the contour lines are close together forms the line or boundary between the primary valley and primary ridge.

The varying relative positions of this boundary between the primary valley and primary ridge on differing land shapes enable us to make two further land shape classifications. These are "valley shaped" and "ridge shaped". Where the boundary is close to the valley the land is classified as "ridge shaped", and where the boundary is towards the neutral line of the primary ridge the land is "valley shaped". In a land form that is dominantly valley shaped the boundary up and down the ridge--where the contour lines are closest--will sometimes fall along the neutral line of no flow of the primary ridge. In this form the horizontal interval between the contour lines in the valley--below the Keyline--gradually become closer together as they leave the valley, reaching their narrowest point in the centre of the ridge; then the contour lines gradually widen out, reaching their greatest distance apart again in the next adjacent primary valley. In these circumstances of land shape the whole of the land is classified as valley shaped, with the neutral line of the primary ridge forming the boundary line between the valleys. (*Fig. 3, Upper.*)

In the variety of these forms the boundary of the primary valleys may be anywhere from the neutral line of the primary ridge to close against the valley.

These geometrical patterns, as displayed in the contour illustrations of land, will influence decisions on water conservation, farm roads, timber clearing, tree planting, cultivation procedures and much of the general working and management of the property.

As stated earlier, the land forms may be very large or very small. And again if one primary valley form is too small to be of significance for water conservation--too small for a dam--it may still be large enough to have significance in cultivation patterns. Valleys smaller again may have to be completely disregarded because their size is such that they are too small within their natural boundaries for a valley pattern of cultivation. In these last circumstances, the very small valleys are disregarded in planning, but, in the cultivation or the treatment of land, the operator may consider them by slightly altering a plowing pattern. Such a valley may be a small tributary valley to a slightly larger primary valley. The valley form that still has significance as far as a cultivation pattern is concerned may not have significance as a water conservation valley.

The man who puts in Keyline on his property may make many decisions of this nature in his early planning, but once he grasps the basic concept that the whole is more important than the part, these decisions will give him no difficulty. For instance, water supply is third on the Keyline scale. If this involves, in his circumstances, farm dams for irrigation, then his planning decisions are directed by his primary valleys which have water conservation significance.

Areas of land may be considered as dominantly valley shaped, that is in the circumstances where the boundary of the valley or the up and down hill line through the points where the contours closely approach each other, are well away from the valley towards the centre of the ridge.

Other areas of land may be considered as typically ridge shaped where the natural valley boundary is closer to the line of the bed of the valley. A very large ridge may be enclosed then by the boundary line of a valley on each side of it. The typical shape of this type of ridge has ridge sides which become steeper towards the valley floor. The sides progressively flatten out away from the valley to the neutral line of the ridge. Their typical contour pattern is illustrated by even-shaped sweeping curves in their contour lines, which are close together near the valley on either side of the ridge and gradually become further apart towards the neutral line of the ridge. This land shape is one of the basic geometrical patterns. It is of outstanding value as irrigation country in any circumstances where appreciable volumes of water can be made available near the middle length of the up-and-down slope.

* * *

This precise Keyline classification of land shape for agricultural purposes is my own. It has been necessary for me to apply suitable names to the various units. The names are therefore new in this application. New names were not selected for the sake of being different but because there were no land classifications or names suitable for my purposes. Land sciences, such as Geography in its various branches, Geology, Morphology, Geomorphology, Hydrology and others, cover wide fields all associated with land shapes, but they do not provide a suitable nomenclature for the intimate study of land in Keyline. These sciences are chiefly concerned with the origin and development of major land surfaces and continental structures. Rivers and their valleys are examined, measured and classified. Their slopes and thalwegs are related to major works for dams, roads and railways. But the more general the concept the less the description and descriptive name is applicable to the specific smaller unit which is a fundamental in the Keyline concept.

In my approach I have taken the smallest significant feature of land shape, which is the rounded, grassed or smooth valley of the farms, grazing lands and forests and called it the "primary valley". This unit includes the two slopes of the valley, the first steeper slope from the ridge in which it forms and the second flatter slope below to the watercourse where it ends. This primary valley is a gully to many, a re-entrant to others, a secondary valley, a headwater valley, and many other more picturesque names. But to take one of these names, headwater valley, which seems to be descriptively suitable, in many references it indicates the mountain catchment of rivers. This headwater valley then may have a catchment area of up to 1000 square miles and contain 10,000 to 20,000 primary valleys.

In Keyline the first land shape then is the primary valley.

This was considered from the point of view which is indicated by water flow. The area of land around the primary valley which sheds water to it then becomes the primary agricultural land unit, and it finishes at the stream course below, the lower boundary of the primary land unit. The primary land unit is synonymous with the primary valley area or primary valley watershed.

The purpose in selecting a primary land unit is to examine the wider aspects of agricultural land in a small representative unity.

The primary valleys of several primary land units may fall into the watercourse of a larger valley named a "secondary valley". The top boundaries of the watersheds of the primary valleys combine to form a catchment area whose boundary is that of the secondary valley area, and thus the secondary land unit. Every point in the secondary land unit is a point in a primary land unit. Other primary valleys flow from adjacent hills and ridges directly to the larger creeks and rivers, and to lakes. By summation all agricultural land is contained in primary land units; therefore all agricultural land is represented in our primary land unit with the exception of stream beds.

Every primary valley falls or flows from higher land--from the hill or the ridge. The ridge from which the primary valley falls is the most important ridge to that primary valley and generally of other adjacent or nearby primary valleys. It is therefore named the "main ridge". It may be large or small, high or low, and short or long, or any combinations of these, but it is still the main ridge of those primary valleys which fall from it.

Between two adjacent primary valleys lies a ridge having similar high and low boundaries to that of the primary land unit. This was named the "primary ridge".

The boundaries of watershed or catchment areas, whether they are of the smallest primary valley or the largest river valley, are ridge lines. These are generally called divides, water divides, or water partings. Such names do not indicate any particular size but will be used in this text in their general sense for the larger areas of land. The descriptive term, "neutral line of no flow" was used in describing these divides when they belong to the primary and secondary valleys of this study. The shorter term "neutral line" will generally be employed in relation to the divides of these two valley watersheds.

These are the new land classifications and the names of the agricultural land features. I hope they may be found suitable for general agricultural use.

The final significance of land shape will become increasingly apparent with the further description of the various Keyline techniques.

* * *

In farm planning, the natural length of land is to remain stable. It must not be shortened by planning or farming practices which would cause more water flow and higher velocities. These may break the land in a new place, forming an erosion gutter or gully.

The final shape of the primary valley itself, the rounded, grassed or timbered valley which the farmer can travel with his farming equipment, was formed by the balance of influences that collectively affected it, but most of all by water flow. It could be said to have been designed, constructed and developed with infinite care by a wide variety of natural forces, to perform the special function of draining the surrounding land and transporting the excess water to the watercourse below. It was built to transport the water which the climate and the surrounding land gave to it. If man, in his occupancy of the valley and the land about it, does not deteriorate the valley environment, then the valley will continue to perform its function and remain stable indefinitely. If, as is the aim in Keyline, the environment of the valley is improved by building the fertility of its soil and the soil of its surrounding catchment area, the valley continues stable and permanent; it is more capable of handling water and in even greater quantities than that supplied by the climate.

When land is cleared there is likely to be slower and less absorption of rain into the soil, thus causing water to concentrate quicker and flow faster in the valley. But there are two reasons why this must be prevented. One, the valley stability could be affected, and two, more and longer-lasting moisture is needed in the soil of the whole of the land unit for its development and for the growth of grass and crops. The object is for all the soil to improve in fertility. The extra moisture in the soil should be evenly spread throughout all the land of the valley area.

Now rainfall is uniform over the primary land unit, as it falls evenly enough to satisfy the desire for uniform moisture, but immediately rain reaches heavy run-off proportions the volume of water moving over various parts of this land unit varies. It follows its natural flow path, which is governed by the shape of the land. The volume of flowing water progressively increases from the neutral line of the ridge to the valley floor.

We have already seen that straight-line or round-the-paddock cultivation crosses the natural flow lines of water in such a way as to cause earlier concentration and faster movement of the water to the valley. We may disregard for the moment, the sometimes increased absorption of rain into the soil from special types of cultivation. It is apparent that the natural flow pattern of water should either be preserved by the furrows left by cultivation or controlled in such a way as to spread flow water more uniformly. That is also true in the immediate area of the valley floor, where the wider spread of water reduces destructive velocities. However, our approach to water is not the negative one of preventing destructive velocities because it may cause soil erosion, but from the positive aim of controlling water to provide all the soil with its full requirements from each rain for the continuous improvement of the soil's climate. By spreading moisture uniformly and so controlling the type of run-off flow, thus making its path broader in the valley, we are, incidentally, effectively protecting and preserving the shape of the land. (*See Fig. 4.*)

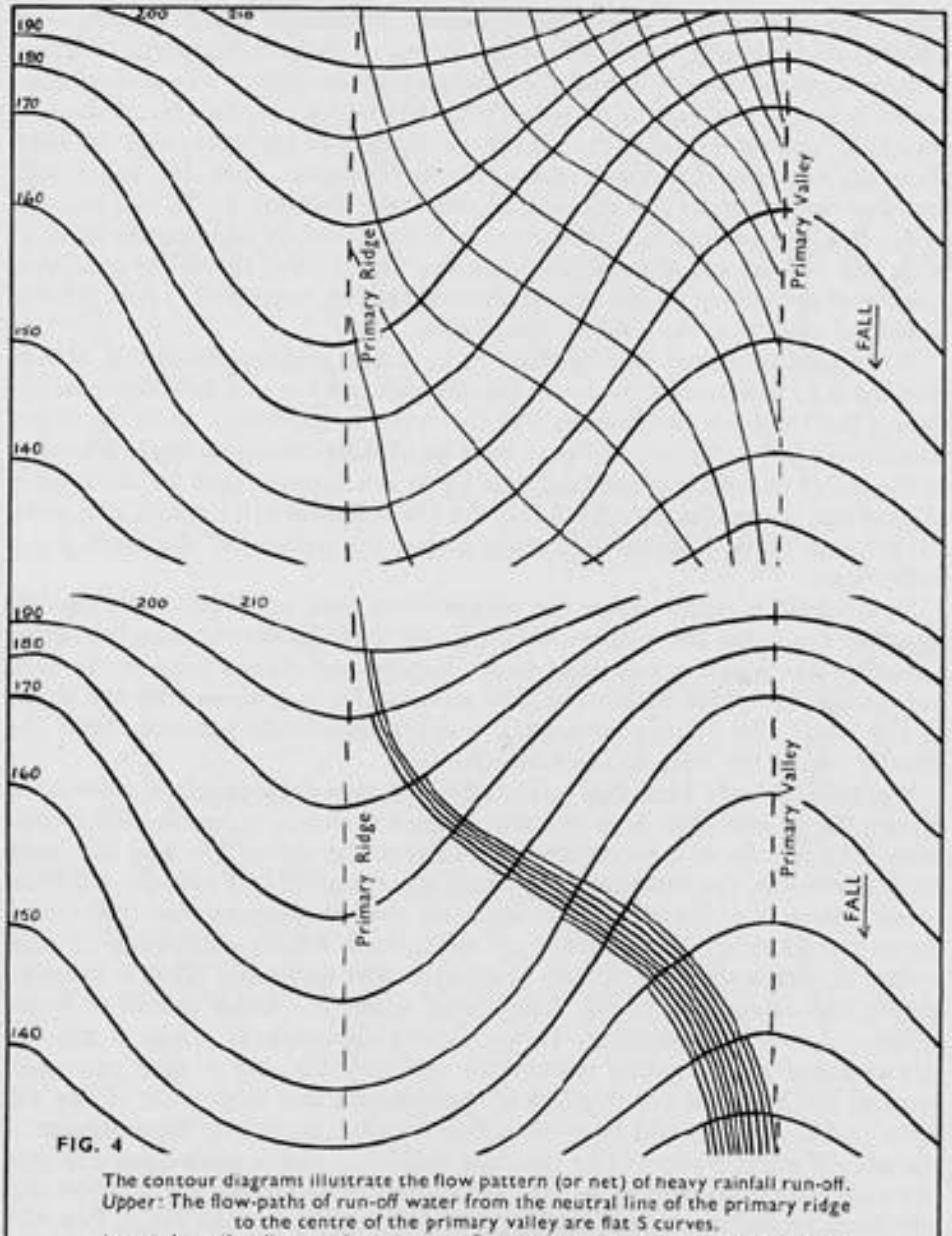

FIG. 4

The contour diagrams illustrate the flow pattern (or net) of heavy rainfall run-off.
Upper: The flow-paths of run-off water from the neutral line of the primary ridge to the centre of the primary valley are flat S curves.
Lower: A similar diagram depicting one flow path to show the increasing volume of flow from the ridge to the valley.

A diagram depicting the flow pattern of water on any shape of land can be produced on a suitable contour map by drawing lines outwards from points at equal distances along the neutral line of a ridge, and crossing each contour at right angles.

A little thought will demonstrate that this is sound reasoning. Water flows downhill by the easiest or steepest path until it reaches a depression or valley and then it concentrates as a stream. The steepest path from any point on one contour of the map to the next contour is the shortest line from that point to the lower contour. The flow lines on the contour diagram therefore represent the path of the sheet flow of water over that land surface. In my studies of the flow patterns of water over various land surfaces I have discovered that the complete pattern, i.e., the flow pattern from the neutral line of the primary ridge to the bottom of the primary valley, always forms a flat S curve. Whether or not this fact has been recorded earlier by others I do not know, but I have been unable to find any reference of it. If ordinary cultivation procedures are employed, the flow path is steepened, thus causing water to concentrate earlier and to flow faster. It is therefore desirable to seek some other plan of cultivation that will distribute flow water evenly. (*See Fig. 5.*) (*See Fig. 6.*)

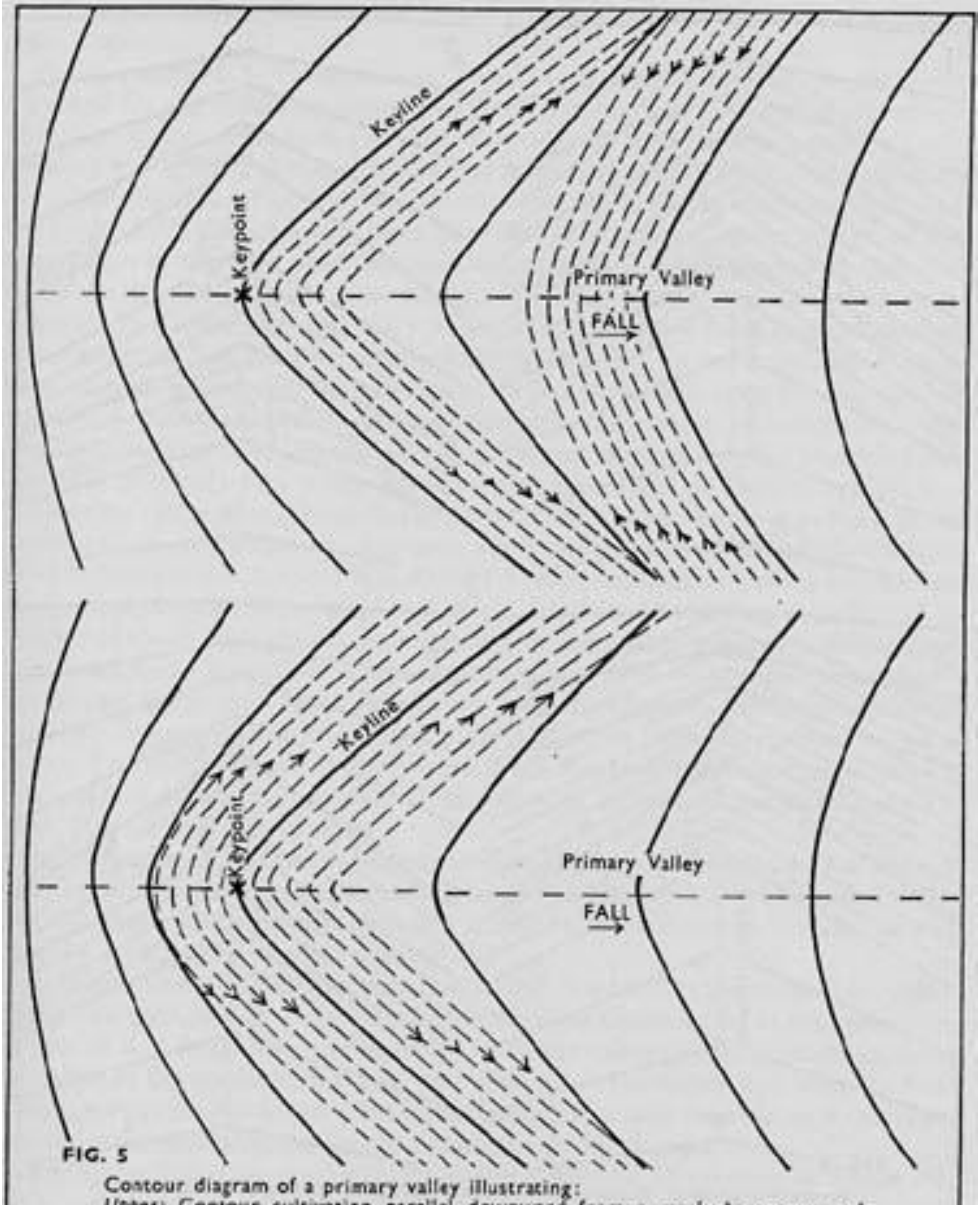

FIG. 5

Contour diagram of a primary valley illustrating:
Upper: Contour cultivation parallel downward from a marked contour and upward from a lower marked contour.
Lower: The effect of keyline cultivation working parallel to the keyline both up the slope and down the slope of the primary valley. The arrows in both diagrams show the downhill direction of the furrows.

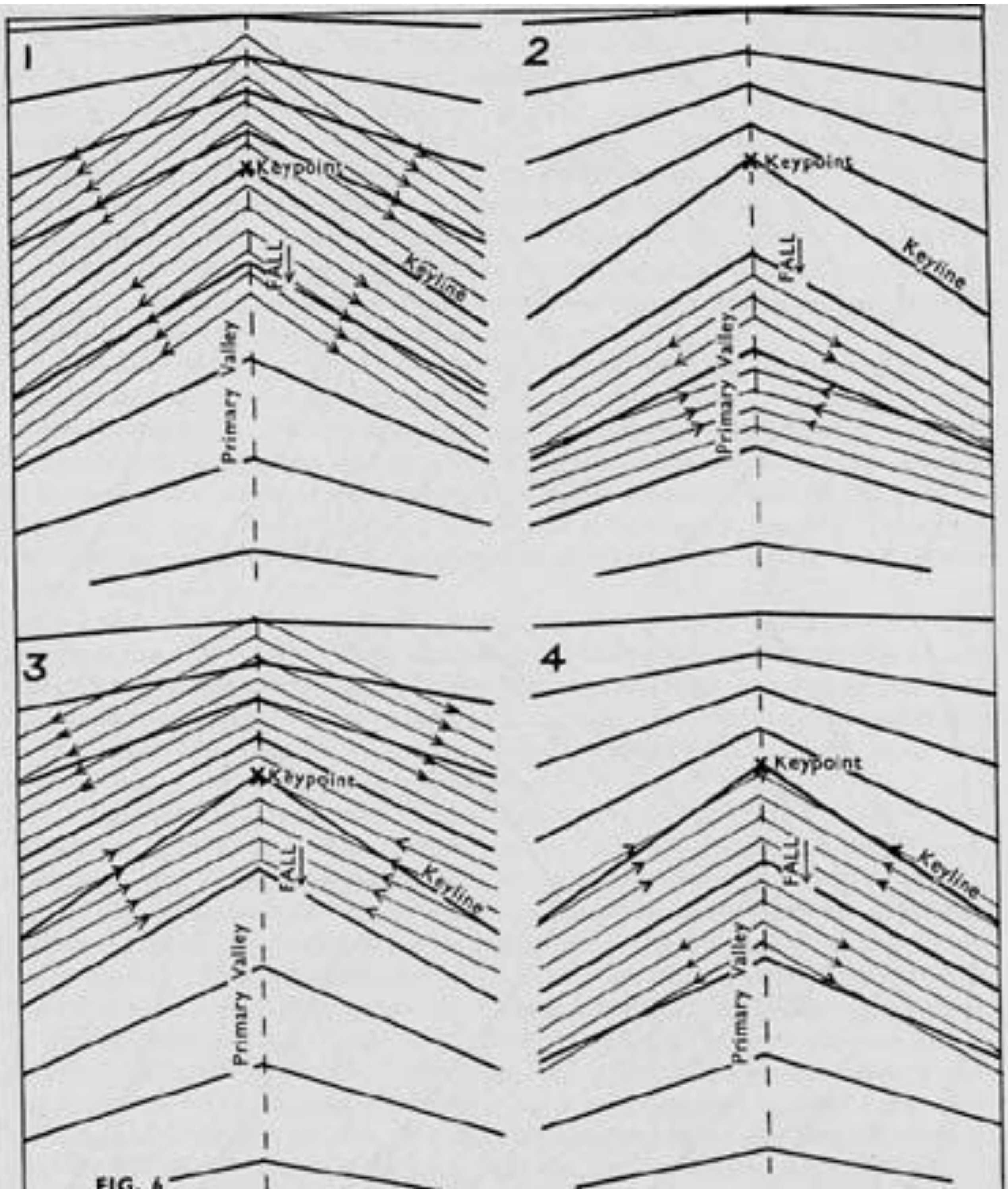

FIG. 6

Formalised contour diagrams of a primary valley illustrating: (1) Keyline cultivation; lines paralleling the keyline both up and down the slope of the land. (2) Contour cultivation; cutting out the area between contours marked on the land by working parallel upwards from the lower and downwards from the higher one. (3) Effect of cultivating parallel to a contour above the keyline. (4) Effect of working parallel to a contour below the keyline.

Contour cultivation, theoretically, is cultivation that leaves a pattern of all furrows on the true contour. However, every run of the tractor and plow would need to follow a true contour line marked on the land with a levelling instrument or the land must be of perfectly even slope. Contour cultivation, as practised, is neither of these. It is simply a cultivation in the spaces between contour lines that have been levelled-in and marked on the land by permanent or semi-permanent furrows or banks. It leaves a pattern of furrows half parallelling up from the lower contour and half parallelling down from the marked contour above. This pattern is illustrated on our map-diagram, which is a contour map of an actual land form, typical of country with a medium but not hard rock base. It is granite type country.

The pattern of practical contour cultivation is illustrated by the broken lines each representing many actual furrows on the land. Arrow heads on the lines illustrate the downhill direction of the furrows. Furrows without arrows may be accepted as contour lines.

It is seen that half the lines with arrows fall downhill in the general direction of the flow path and of the valley, thereby tending to cause earlier concentration of run-off and faster flow to the valley. An approximately equal number slope downhill in the opposite direction and away from the valley, opposing the flow lines, causing the run-off to spread as required. Contour cultivation is therefore much better than straight-line or round-the-paddock work.

Keyline cultivation, however, produces a pattern of furrows in which all, or a very large majority, break the natural flow pattern of water over land surfaces in such a way as to reverse the direction of flow. The result is a wider and uniform spread which prevents quick concentration of flow water. The natural valley flow is always reduced and widened.

As long as the influence of land shape on the flow path of flowing water is understood, it becomes a simple matter to control and evenly spread water by this Keyline technique. This knowledge influences many decisions.

If true contour cultivation were practical, each furrow would then cross the water flow path at right angles and there would be no tendency to alter the flow path. Water would be held on the land longer by the fact that it would have to surmount the obstruction of each furrow at right angles to the flow path, but when general flow occurs, it still follows the natural flow lines.

* * *

The Keyline conception of land shape is based on the fact that the consistent final force--flowing water--which shaped land, produced regular geometrical shapes in the land. The varieties of base hardness and the erodability of land and the varying amounts and times of water run-off produced infinite varieties within these geometrical patterns. The longer the shaping of land by water has continued the better are the shapes and the more valuable agriculturally. Since Australia is of great age geologically its land forms for a great period of time were very similar to its land forms today.

There is another primary valley shape in Keyline and it is closely related to the first shape already discussed and which with its surrounding land was classed as the most important unit for agricultural study. Reviewing the first type of primary valley we concluded that it starts from the main ridge and finishes where the rounded primary valley flows to a stream course below. This primary valley within a stabilised geological formation is one of the consistent geometrical forms as seen in its contour lines. The other type is the valley that flows from a saddle or low point in the ridge. (*See Fig. 7.*)

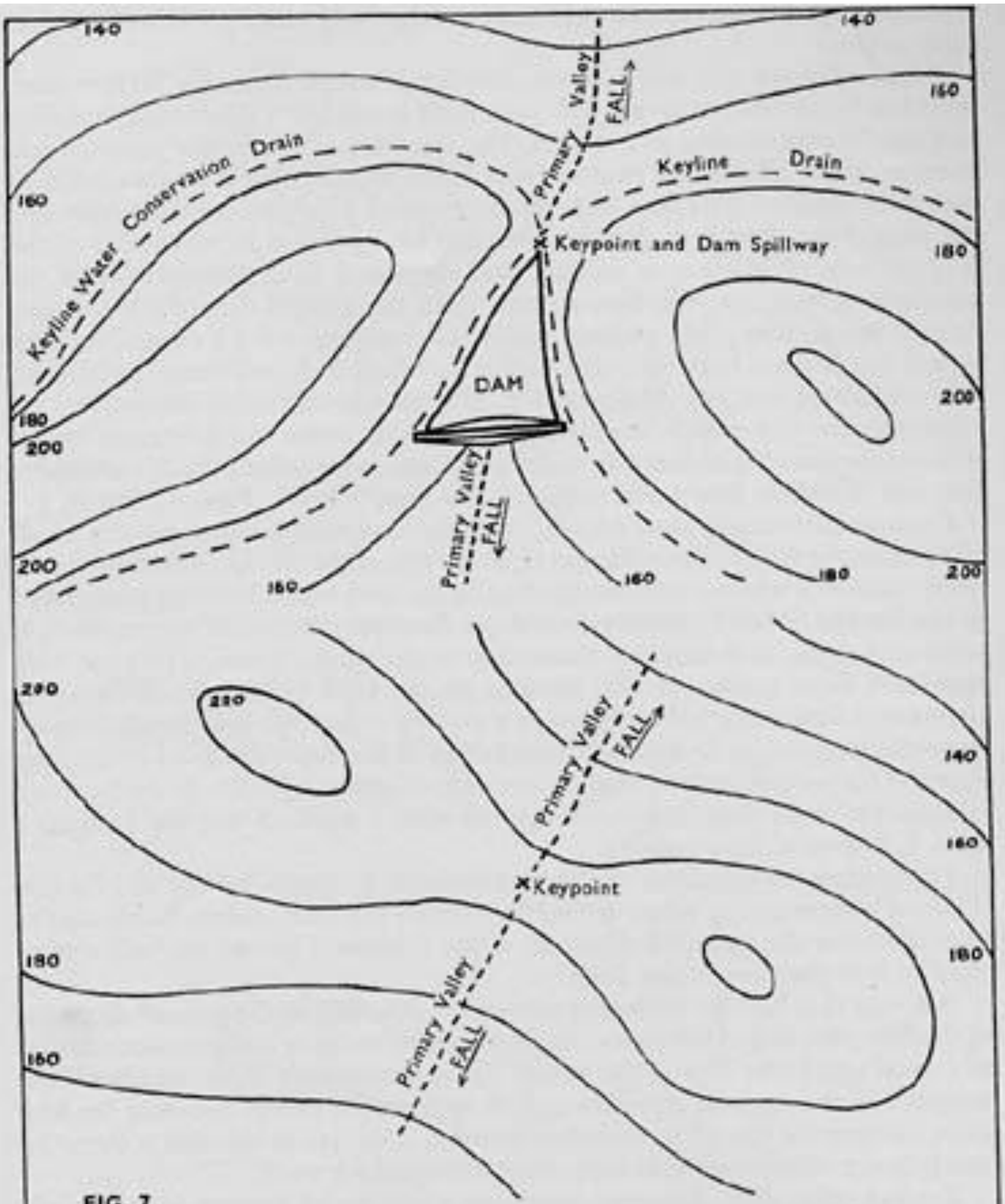

FIG. 7

Contour plan showing two saddle-formations and their associated primary valleys. Upper: The land shape similar to those on which dams have been constructed on our own properties, showing the position of the dam and the keyline water conservation drains.

Lower: A saddle-valley form without water conservation significance.

We have seen that the primary valley of the farms and grazing properties is a land form that transports run-off water over a rounded surface to a lower stream course, which may be a rounded valley or yet a creek or a river. The primary valley was formed and shaped by the work it does. For water to flow, the valley bottom must be lower than the land on each side of it at right angles to the direction of flow, or it would not be a valley and would not transport water. If the valley forms from a line of hills it must first lose height steeply, more steeply than the hillside. Then it flattens and flows more gently. The valley has a steep head, then a flatter bed. The steep head is generally of uniform slope until it flattens to form the flatter bed, which is the second slope of the valley. This second slope--more generally than otherwise--tends to continue as a uniform slope to the stream course below. This type of valley then has two slopes, one, the steep slope from the hill, and, two, the flatter valley floor slope below. The point of change between the steep head slope and the flatter valley floor slope is the keypoint of the valley, and the contour or grade line through this point is the keyline of the valley. However, the second type of primary valley forms from a saddle between two hills or a low point in a ridge. It does not have two slopes, but only the second slope, the flatter valley floor slope. This type of valley, by starting in the saddle, has already lost height. Its bed is already lower than the land on either side. It therefore may fall from the saddle as one continuous even slope. The saddle point is the keypoint of such a valley and the keyline is the contour or grade line through this point. (*Fig. 7.*)

This valley, the one slope or saddle valley, has its keypoint at the saddle, but this keypoint is also the keypoint of another valley falling on the other side of the saddle. It is therefore a dual valley formation, with the two valleys falling in opposite directions from the one saddle or keypoint. This natural land form, and it is by no means uncommon, can be of outstanding agricultural value.

It does not exist on either "Nevallan" or "Yobarnie", and was not mentioned in my earlier book, "The Keyline Plan". While I was aware of it then and saw in it the inevitable pattern of the land forms of Keyline, I had no opportunity to use it agriculturally. Of our three newly-acquired properties, two contain wonderful examples of these dual saddle-valleys in valuable agricultural form.

A dam in such a valley would have the minimum of natural catchment, but if it were located with the top water level right to the saddle keypoint and designed and constructed as discussed and illustrated in later chapters in this book, it could have as many as four Keyline water conservation drains, each falling from different directions to the saddle and spilling into the dam.

We have two such dams now on "Kencarley", Orange, N.S.W. One has a depth of twenty feet of water at the outlet valve of the dam. The wall of the dam provides three feet clear of freeboard but no spillway. The saddle itself is the natural spillway. When the dam overflows, the water runs out through the saddle into the other or second valley of this land formation and finishes up in a large reservoir in a valley a quarter of a mile away. The dam is of seven million gallons--28 acre feet-capacity, and although the reservoir nearby is nearly four times its size, our visitors all appear to be much more interested in this saddle Keyline dam.

There are also primary valleys which form from a saddle but still have the two slopes, a steeper head slope from the saddle down to a point of change (the keypoint), and then the flatter valley slope below. This latter valley is of the same class as the first of the two primary valley shapes.

To recapitulate: The particular geometrical form of the first type of primary valley, the commonest one in my experience, is seen in the contour map of the valley. Above the keyline of the valley the distances between contours in the valley are shorter than the distances between the same contours on each side of the valley, also the centre valley slope is steeper than the slopes on each side of the valley. Below the keyline of the valley this relationship is reversed. The distances between the contours in the valley then are greater than the distances between the same contours on each side of the valley, and the slope down the valley bottom is flatter than the slopes on each side of the valley. Again, above the keyline the centre slope is steeper than the slopes of the sides, and below the keyline the valley is flatter than the sides.

The saddle keypoint valley only possesses the second relationship, that of flatter valley bottom with steeper valley sides.

Keyline Cultivation and Valley Shape: In order to spread water and moisture wider in the first type of primary valley by a cultivation that produces furrows opposing the natural flow pattern of water to the valley, it is only necessary to plow parallel with the keyline up the slope of the land and parallel with the keyline down the slope of the land. This is Keyline cultivation as it applies to this valley.

All cultivating implements make a series of parallel lines or furrows on the land surface. Cultivation which parallels a line marked on the land as a contour remains, as cultivation proceeds, parallel to the contour on the surface plane of the land, but not to it on the vertical plane. Keyline cultivation uses this fact as a device and from a selected contour line previously marked out on the land plows in parallel formation in such a way that all furrows, or the great majority of furrows, oppose the natural flow paths of water on that particular piece or segment of land, thereby spreading the water or moisture more uniformly. Or more broadly still, Keyline cultivation is one that generally parallels a contour in such a way that water and moisture is caused to move as the farmer plans it for the good of his land.

Always the general effect of Keyline cultivation on rains which are fully taken in by the soil is that the moisture is more uniformly held in the soil; there is no pronounced drift of moisture to the valleys. With rain that produces run-off, moisture is uniformly held, run-off is wide and flat, and the first concentration that flows in the valley commences lower down the valley. The flow is very much wider and shallower, velocities are cut to the minimum and the valley stability is progressively improved. Erosion of fertility and of soil is therefore not a factor for special consideration in Keyline agriculture.

A Keyline appreciation of the various land shapes enables a farmer to control all aspects of water almost at will. The accumulation of power to control water which is provided by many hundreds of little furrows, all combining for one effect, is unbelievable until it is seen. For instance, following a very heavy storm which fell during the severe flood rains of 1956, one of our lower dams on "Yobarnie" overflowed with a stream two feet six inches deep by about fifteen feet wide through the flood spillway which emptied into a small flat valley. The valley was in a paddock which was Keyline cultivated three years earlier as a part of an experiment. The experiment, which included two other paddocks, was to determine the different effects on soil and pasture development of Keyline cultivation; one cultivation in the autumn for one year, one in each autumn for two years, and one each autumn for three years. This paddock, cultivated once only, had been stocked on and off about twenty-five times in the three years. There was no noticeable Keyline cultivation pattern left, as the stock had tramped it out. But within a few feet of the spillway's outflow in the valley the old Keyline cultivation patterns had completely controlled this large water flow. The powerful cumulative influence of what was left of the Keyline pattern spread the water well over three hundred feet wide. The water flowing in the valley centre was not noticeably deeper than that flowing on the sides of the valley where it extended laterally almost to the ridge between this valley and the next.

One place where water never flows naturally is down the middle of a ridge, the neutral line of no-flow, in even the heaviest run-off elsewhere. But a Keyline cultivation designed for the purpose of carrying water down the centre of a ridge will control the water and cause it to flow there. (*See Fig. 8.*)

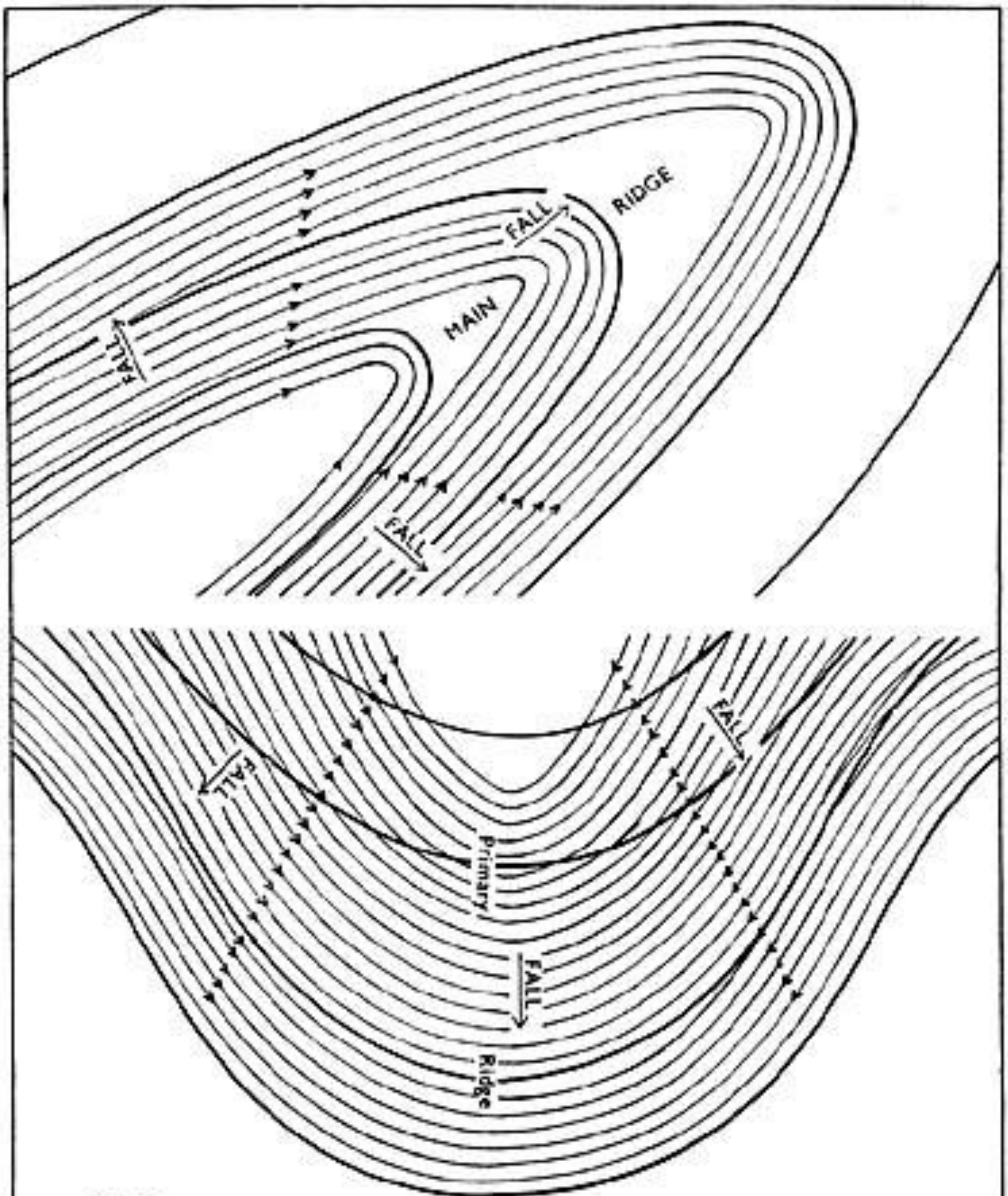

FIG. 8

The contour plans show two ridge shapes with keyline pattern cultivation designed to flow water down the centre of each ridge. The arrows on the furrow lines show the downhill direction of the furrows.

Upper: A typical main ridge shape. *Lower:* A typical primary ridge shape.

Water can be induced to flow where it is wanted and as it is wanted--except uphill--if our treatment and management of land is based on a full appreciation of land shapes. And if water is the critical factor by being in short supply or by unreliable rainfall, then the simple logical approach is not to waste it. However, there was, until Keyline, a serious drawback to this obvious approach. There has been no way of conserving all the run-off profitably. But in water we have our greatest primary commodity. Water, within itself, can be used for its own distribution. A sound knowledge of land shape, implicit in the complete study of Keyline, enables one to harness the force of flowing water for its uniform distribution over agricultural land.

We will assume for the moment that special Keyline techniques supply the cheapest means of distributing irrigation water in the manner most suitable for farms and grazing properties, and proceed to examine land shape as an aid in conserving all the run-off rain, but first consider briefly dam size and the possible cost of water storage.

Water can be conserved almost anywhere on agricultural land; it is just a matter of cost. The higher the storage the more valuable is the water. Just how much can a farmer profitably afford to pay for water storage capacity under conditions that permit economical use of the water for irrigation and in conditions where run-off is satisfactory? I do not know the limit of the amount he can afford to pay per acre foot of capacity, but the highest cost on any of my own farm irrigation dams is below £50 per acre foot, and this cost under the circumstances stated above is sufficiently attractive to warrant the outlay to conserve all the available run-off. By comparison the lowest cost of any of our dams was £6 per acre foot, on prices and values at time of writing.

The cost of water conservation in farm dams is the least of the consideration in most so-called supplemental irrigation projects. Other costs such as pumping and equipment and labour are the critical ones. This has been said often before, but it is worth repeating in this context.

If the cost of water storage capacity to hold all run-off and the cost of using the water returns a much higher profit than rain, or rain plus supplemental irrigation, then all water should be conserved.

To return to dam sites: The possible conservation sites should be examined starting from the highest to the lowest sites. Here again the land formation of the primary valleys is of major importance.

The highest valley water conservation site is generally just below the keypoint of the primary valley, thus leaving perhaps less than 20% of the slope above the keypoint. These sites were not considered for farm irrigation dams, because of their restricted natural catchment, until I started in 1944 building farm dams of from fifteen to forty acre feet capacity and providing special water conservation drains to fill them. The steep head of the valley above these sites--the true keyline dams--is usually short and collects only comparatively small quantities of flow water. Where the keypoint is a saddle point, the natural catchment of the true keyline dam would be still more restricted.

Now the keypoints of the adjacent primary valleys in a common watershed such as a secondary valley are higher as the land rises. The primary valleys themselves form in the main ridge, so that normally as the country rises the heads of adjacent valleys are higher and the keypoints of the valleys are higher. In a series of primary valleys flowing into a larger valley or into a creek, in undulating country of uniform geological formation, the keypoints of the valleys generally have this rising relationship to each other. But before going on, a definition of "general land slope" is necessary, and so in our primary agricultural land unit, with its lower limit at the stream course or the creek below, the slope of the land is the fall from the main ridge down the primary valley or primary ridge to the watercourse or creek. General land slope, however, is the direction of the rise of all the land--the hills and the stream course--and it is usually at right angles to the slope of the primary land unit. The general fall of land then is the direction of the drainage line which is the creek or the watercourse to which the primary valleys fall. This direction is down land. Up land is the opposite direction to this fall. (*See Fig. 9.*)

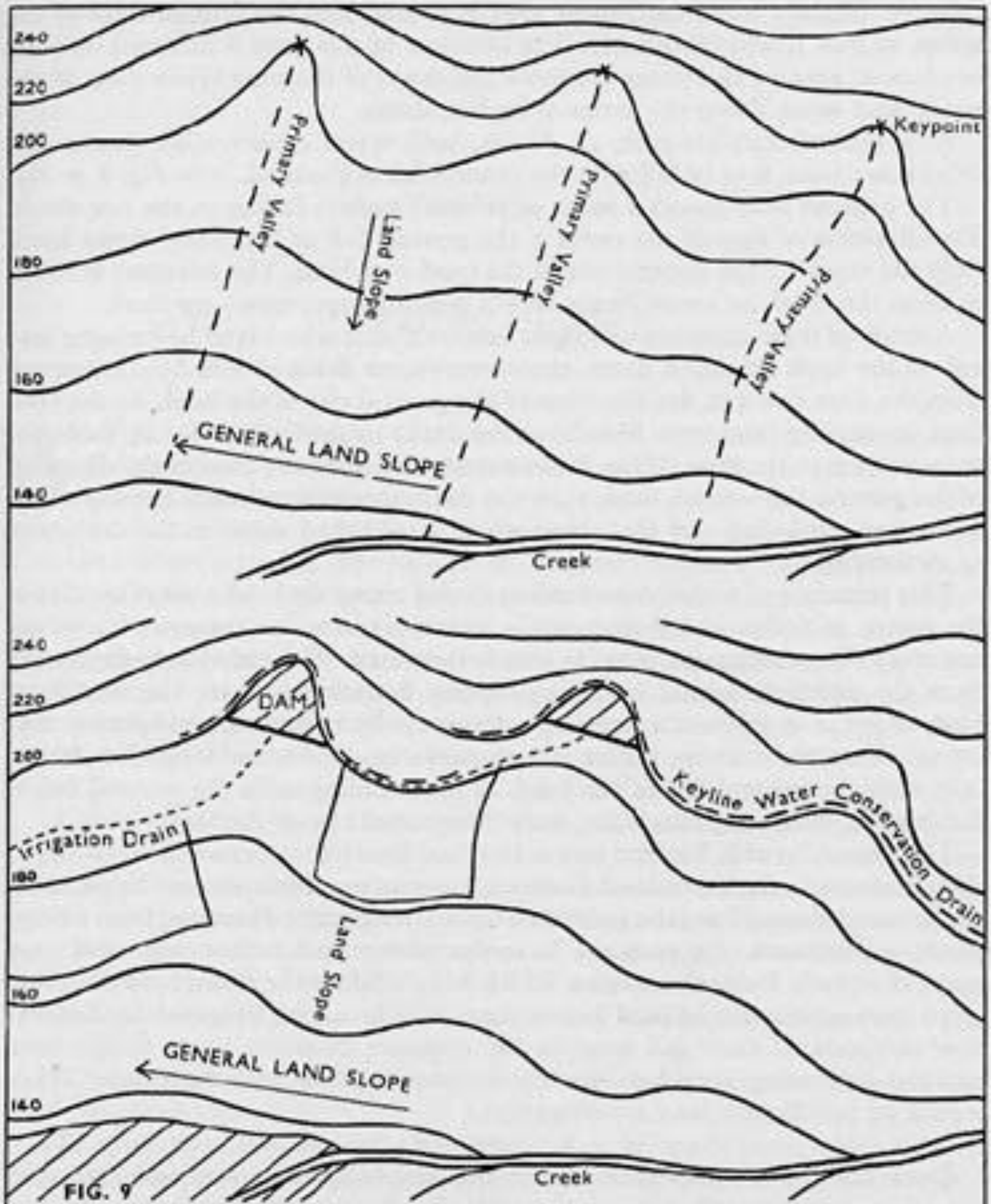

FIG. 9

Upper: A contour map of a series of primary valleys falling to a creek, showing the land slope in relation to "general land slope" as indicated by the fall of the creek and the arrow.

Lower: The same contour map, showing keyline dams, water conservation drains and irrigation drains.

A series of primary valleys flowing to a creek have a slope to the creek, but the creek itself indicates the general land slope.

These aspects of land have a very important significance in any circumstance where all the run-off water should be conserved in farm dams for irrigation purposes.

The rising relationship of the keypoints of the primary valleys within the one larger catchment area, and in converse a falling relationship, enables the siting of a higher series of dams in such a way that all these dams can be filled by the water conservation drains before any run-off water gets away from the higher country. Slightly more catchment area is turned into the highest dam of the series, so that it will fill quickly. The overflow of this dam is directed into the catchment area or the water conservation drain of the next lower dam of the series, and so on down the series of keyline dams.

As a general Keyline rule, all drains, both water conservation drains and irrigation drains, flow or fall with the general fall of the land. (*Fig. 9.*)

The contour map shows a series of primary valleys falling to the one creek. The direction of flow of the creek is the general fall of the land-down land. "Up the creek" is the general rise of the land-up land. The contours are seen to cross the creek as arrow heads or V's pointing upstream-up land.

A study of these contours will show further that if water is to be brought into any of the farm irrigation dams, the conservation drain should be constructed from the dam rising in the direction of the general rise of the land. As the land rises, increasing land area lies above the drain to shed water to the drain for conservation in the dam. If the drain were to rise from the dam in the direction of the general fall-down land, then the drain would soon reach the top of the watershed, enclosing very little land which would shed water to the drain and so to the dam.

This principle of water conservation drains rising up land always applies in the design of drains and their location in respect to water conservation where natural valley catchment is to be greatly increased. The only likely departure from the principle would be near property boundaries where the next land form is on a neighbour's property. Except where these interruptions may occur, all water in drains, both water conservation drains and irrigation drains, falls with the general fall of the land. A drain falling with the general fall of the land is, of course, also rising with the general rise of the land.

The reason for this Keyline rule is obvious. Study of the contour map shows that contours in the down land direction have increasing land area below them as they are followed from the watercourse; in the opposite direction, from a ridge to the watercourse, the contours have decreasing land below them and soon reach the creek. Irrigation drains, which have a fall in the down land direction have increasing areas of land below them which can be irrigated by Keyline flow methods. If their fall were in the opposite direction there would be a rapidly decreasing area between the irrigation drain and the creek. There would be insufficient land for irrigation.

* * *

Once the eye becomes trained to these simple land shapes, and the mind has selected and classified one or two of them, there is a fascination in the continuous broadening of one's understanding and appreciation of the landscape.

Every trip I have in the country becomes more enjoyable, because of this added interest, and I have had the pleasure of seeing a like interest develop in many others.

CHAPTER VII

Water Supply

WATER supply is third on the Keyline scale of the relative permanence of things agricultural. To nations as well as to farmers water supply is often a conflict and a dilemma.

In the discussions on climate the reader will have been conscious of the fact that land shape intruded. By the time the first two factors of the Keyline scale, namely climate and land shape, had been dealt with, water supply had already figured prominently. Throughout the discussions on the Keyline scale, the various factors show close interdependence upon one another and that many relationships exist between each and all. It has been clearly shown also that this relationship, so typical of agriculture, points to the need for a more practical approach or some basic guide in these matters which could prove or disprove the validity of such a concept as the Keyline scale of permanence.

Climate and land shape have their degree of permanence through no effort of man, but water, suitable agricultural water, is not always naturally permanent. It has to be made permanent for successful agriculture, and the supply has to be completely reliable. House water and stock water are naturally permanent in some circumstances, such as from springs and rivers, but under Australian agricultural conditions, in which water is always the critical factor, permanent natural water is seldom adequate or suitably distributed for basic planning.

"If water is critical none should be wasted" is the Keyline aim and the guide to planning.

The greatest environmental change that can be made even when there is sufficient rain water for agriculture, occurs in circumstances where there is a lack of long-lasting permanent water supply and when the incidence of rainfall is inadequate or wrongly timed. Where natural supplies are insufficient, dams that have been constructed for irrigation can also provide stock water, and the requirements may be satisfied by as little as one per cent of the total storage capacity. The location and the design of dams to conserve water are based firstly on climate and land shape. These two factors must always be studied together. Good physical sites for water storage are only suitable if they can be filled. It is the definite aim of our plan to convert what at first appears as an impermanent supply into a secure and permanently conserved supply. The water aims of the plan then are, firstly and in order of preference, to make provision for household and stock water supplies, then to prepare the land surface where necessary so as to get sufficient rain into the soil from each rainfall to promote the increased development of the soil. This procedure, and with other controllable conditions, will cause an improvement in soil climate. Again, all the run-off that comes from ordinary rain must flow into farm irrigation dams. Finally, all the flood rains that can possibly be held and be used profitably later must be diverted into all types of storages whose capacities have been planned to these ends. From my observations there are few areas in agricultural Australia where this cannot be done.

All high conservation sites where sufficient water can be brought into them by water conservation drains constitute the highest value in water storage. Such dams generally are to be used for irrigation immediately when irrigation would be beneficial. This could be as soon as seven or eight days after rain in the summer months. The next lower sites, there may be fewer of these and they are often larger, are to be held in reserve as "reservoirs" until the irrigation water of other sites is nearly depleted. And finally come the lowest or "lower dams" or series of dams, which generally have the largest storages per dam but which may be fewer in number. These last are usually pumping dams and are used for general irrigation water.

The picture then is of three types of dams--(1) the high series, which may be true "Keyline dams", in suitable undulating country; (2) intermediate dams, i.e., reservoirs; and (3) lower dams.

Some or all of these dams will be used for other than irrigation purposes. A suitably placed dam can be used as a house supply or to supply stock water *via* pipelines and troughs, and sufficient reserves will be held for these purposes. Generally speaking, the more efficient and complete the use of water on a farm the more it becomes necessary to increase the number of stock watering points. With full water control from Keyline planning, the farm environment improves, the soil improves; the pasture, crops and stock improve in health and condition and their numbers may increase many fold with the growing capacity of the property. Increased stock numbers calls for increased watering points and for good management. A property now served by six water points may require, and very profitably employ with better development, thirty watering points. Happily, the supply of such watering points is a very simple matter in the general water conservation planning of Keyline.

The whole question of the planning for farm water supply needs critical examination. There are recognised Government authorities on farm water conservation who are doing their best to educate farmers on these matters. Soil conservationists also consider water and advise the farmer on how to avoid the menace of soil erosion by water. And there are others, in fact many other sources of agricultural advice provided by Government agencies, but the advisory authorities are often at variance. The approach of the usual water conservation authority influenced by a concentration on his particular branch of the subject and often lacking a suitable background of agricultural knowledge, is on a somewhat different plane to the soil conservationist and the agriculturalist. Generally speaking, the Government soil conservationist may not touch the work of water conservation on the farms and grazing lands except and only insofar as it concerns his work of providing and advising on means designed solely to conserve soil, and so the provision of a small almost useless dam as a "gully block" to stop soil erosion is as far as he may go.

The water conservation authority in New South Wales who controls and designs dams and who advises farmers on farm water conservation may not have anything to do with soil conservation, and if the dam is likely to silt up, that is not his concern; it belongs with soil conservation. What is the upshot? Do we find the agricultural officer co-ordinating this frustrating division of authority? Indeed no; he is often careful not to mention either soil conservation or water conservation--it has nothing to do with him. But he is wrong. Both soil and water, indeed every agricultural aspect of soil and water, should be his concern. If he is not the prime authority on these basic agricultural matters, then why isn't he so?

My approach to the subject of water conservation and the use of water on farms does not follow that of the orthodox lines, and by inference, it could be taken that I am critical of such methods. Of course this is so. Many of the orthodox approaches to agricultural education, and particularly those concerning water on the farm, need criticism.

Now, water conservation and the use of water on farming and grazing land is essentially agricultural. Education on the matter should be controlled agriculturally. But the present water authority, namely the civil engineer, will immediately cry, "What do they know about the matter? This is a job for the engineer!"

Now, while it is agreed that the engineer comes into the farm water problem, isn't it also apparent that the job of providing the dams has not been done. As recently as last year, 1957, and the latter half of 1956, despite five years of abundant rainfall, drought again showed that we still need all the water which we can collect and store. Thus it is not helping matters very much when officers and administrators connected with agriculture agree with the cry of the engineer. It must be patent, too, that the engineers cannot greatly assist until agriculturalists themselves fully appreciate all that is involved and lay the whole problem before the engineer, who may then be able to advise with practical designs. However, if the work is partly an engineering job and the Government engineers were widely experienced in these very special matters, then of course the engineer should not be wasting his valuable time assisting the few farmers, but should be teaching every officer of agriculture, so that they, in their direct contacts with the farmer, could assist the thousand or ten thousand farmers.

The belief now that the engineer is the expert on these matters is based on the fact of his training as a civil engineer, which includes a study of earths (sands, clays, rocks, etc.) as structural materials for various works. He can design and build the giant dam, to him a relatively simple matter, since that is part of his education and experience, but his training does not include any particular study or experience nor has he carried out experiments on what must seem to him such an insignificant structure as merely a farm dam. Who can blame the engineer for being unimpressed with the agriculturalist's present conception of the farm dam?

While I am willing to concede that in the earlier days much attention was given to the big dam as a necessary public work, e.g., Burrinjuck and Hume Dams and their irrigation areas, there was certainly no proper attention given to what would have been the alternative effect if properly located and designed farm irrigation dams had been provided over large areas of eastern Australia.

Full investigations along these lines would not have cost a great deal of money, but if it had cost ten or twenty million pounds to get the answers it would have been little enough, since by now there would have been no problem of droughts because the effective conservation of the flood-type rains on the farms and grazing lands would have more than counterbalanced the overwhelming cost of drought and the high cost of floods. Furthermore, there could hardly have remained on agricultural land the hazards, still very much with us, of serious outbreaks of fires. Were a comparison of size of the water storages made between big dam schemes and the totality of farm dams, then it is worth saying that the conservation capacity of irrigation water that would be available if 30,000 farms and grazing properties in N.S.W., each one 1000 acres in area, were given the storage capacity they could hold, economically store and use profitably, then the amount of water would exceed that of the conservation capacity of the Snowy Scheme (the Adaminaby Dam alone will hold eight to nine times the water of Sydney Harbour), plus Burrinjuck Dam and plus a few other big dams. If each farm could hold 300 acre feet of irrigation water storage capacity there would be a combined capacity of nine million acre feet. Now, 300 acre feet is not an unreasonable figure for a thousand-acre area. For instance, it is much less than the capacity rate of "Nevallan" and "Yobarnie", and is not any more than the extra water that will be conserved at "Pakby", near Bathurst, when this new property is developed, and is much less than the capacity of one of the new farm irrigation dams so far completed at "Kencarley", our new property near Orange. There are hundreds of millions of acres of agricultural land in Australia that would have some profitable potential water storage capacity when compared with the thirty million acres of the 30,000 N.S.W. farms mentioned only by way of illustration.

The farm irrigation dam is a worthwhile structure. As part of the agricultural conservation and use of water on the farm, the farm dam is as completely a specialised structure as any of the giant works that the engineer loves so well. To me it is just as important a job as the "big" dam. It could be even more important and it requires proper principles of precise location based on an agricultural appreciation of the factors of land shape and climate. It has correct but specialised design based on the above factors and also on the depth of water, the foundation materials and the earth available for the wall, and on the particular use to be made of the dam. It needs set construction methods, based on all the foregoing and on the type of equipment that will be used in its construction. (*See also Chapter XVIII and Pictorial Section.*)

The engineer well knows that earths, unlike iron, steel, brick or concrete are not stable structural materials, the behaviour of which can be accurately predicted in all circumstances, as can be done for these other materials he knows so well. There is just no substitute for wide experience (particularly experimental or trial and error experience) and mature judgment in this specialised agricultural field of farm water control. Agricultural knowledge is a first essential. The scaled down model of the "big" dam, which is the civil engineer's usual offering to the agriculturalist as a solution to the problem, is not nearly good enough. There is as much art and achievement in a fine watch as there is in a giant locomotive. The fine watch represents the farm dam, but who would employ the locomotive engineer to design and make the watch? Yet the farm dam situation is analogous. But most of us are little people who love the colossus, the giant, the big job and the mammoth spectacle. We no doubt have an inferiority complex engendered perhaps by the insignificance of our life span against the evidence of great age in the geological forms with which we play. We are appalled by the immensity of the earth to our puny forms, and the insignificant size of the earth in the vast reaches of outer space, and are overawed by the fantastic precision of atomic movements against the clumsy efforts of our own hands. These feelings are related to the engineer's worship of the big job. He feels good if he can, just once, stand in the immensity of his own work. I know this feeling only too well.

This complex in many of us may explain the sometimes ridiculous perpetuation of bigness in engineering, as, for example, the big dam for flood control which does not control floods. These big dams never can control floods as effectively and cheaply as the many farm dams. This must soon be so obvious. However, works that are next to useless and costing millions are not the fault of the engineer. They are built because most of us approve, and as taxpayers we all pay for them. It is relatively easy for engineers to stampede on occasions even the wisest administrators into foolishness, if the foolishness is big enough.

There is, of course, this little complex which demands big things, but surely there is appreciation of the power of the little things, so many of them; for example, the power of catalytic change in the viruses or the forces in neuclei. Power and immense control comes from controlling the little things. Again, water on the rampage in a flood is uncontrollable, yet it is easy to control the smaller quantities of water where it falls as rain before its accumulation gets out of control. The latest flood control structure is Glenbawn Dam, on the Upper Hunter River in New South Wales, and it is now nearing completion. It is a multi-purpose dam. It has three "pools" with imaginary horizons; one is the lower or reserve pool to regulate river flow downstream; two is the middle pool for power, and it is sufficient for the water supply for a thermal (coal) power station but nationally insignificant for water-generated electric power; and three is the top or flood control pool. Although direct irrigation was a prime original purpose for constructing this dam, the cost of water reticulation, pipelines, canals, channels and drains is so high that it is unlikely that this original purpose will ever be followed. Of course, Glenbawn Dam is not a solitary example of this particular problem of reticulation cost. There are other big undertakings, and huge volumes of stored water will become available each year for the next ten years, yet without means being provided for its use for irrigation purposes. The reticulation works to make use of the water, which is more often than not twice the cost of the big dam, is in practically all instances several years behind the water supply.

Now, Glenbawn is a moderately large dam. The total height of the wall is 251 feet, the maximum depth of water at the wall is to be 245 feet, the width of the wall is 1800 feet at the base, and the length of the wall is 2700 feet; the quantity of earth and rock in the wall is 10,000,000 cubic yards. The total cost of the dam is to be £15,000,000, and the total cost against yardage is thirty shillings per cubic yard. Again, the total water storage capacity of Glenbawn Dam is 293,000 acre feet from a catchment area of 500 square miles, equal to 320,000 acres. The dam will require a total run-off of ten and a half inches from the whole of its catchment to fill it from the empty condition. What is there to be said?

In the first place, one would have expected some public reaction. But there has been no wide public criticism directed against Glenbawn as a national worthwhile project and no criticism of its cost, or the cost per yard of wall, or the cost of its water storage capacity, which will be about £50 per acre foot. The capacity of Glenbawn's theoretical flood pool in relation to its watershed area makes it a much more efficient flood control dam than many others, and if the whole of its capacity were used for flood control it would surely be a most effective flood control dam as far as retaining water from its own catchment area is concerned. I know of none other that would approach it, though, of course, it is not a big dam as big dams go. The cost problem can be further appraised.

The cost of Glenbawn Dam represents an expenditure of £47 for each acre of its entire catchment area, or £47,000 for each one thousand acre farm or grazing property or forest area. This money does not improve any of the catchment area, while it renders useless some of the best land in the vicinity by covering it with water. The catchment area has to be improved in other ways with more money if Glenbawn Dam is to be protected from siltation from its deteriorated catchment.

It is appropriate here to examine the purposes and aims behind Glenbawn as a project and to determine alternatively how far these could be satisfied by an agricultural development approach such as the Keyline Plan. Hence the first requirement of Glenbawn, and a laudable one, is to influence river flow by keeping the flow more constant. Pump irrigation along the river is assisted and the aquifers, beds of water-bearing, sands and gravels which are important sources of ground water and taken from wells for both agriculture and industry, are to be replenished. To the extent that Glenbawn may provide increased water in the river for pump irrigation from the river, it is providing for the costliest type of irrigation to those farmers affected but at the lowest reticulation cost to the Government. However, this requirement of controlling river flow would be much better satisfied as an incidental to land development, as will be seen before the end of this book.

The second purpose of the Glenbawn scheme is the provision of water supply for a thermal power station. This could not be met as an incidental in land improvement. The sole answer to this special problem is a dam located, designed and constructed for this special purpose. It is unlikely that the site selected for Glenbawn was entirely dictated by the power station water requirement, so a dam much smaller than Glenbawn and probably more suitably located for its special job, could be constructed at a very moderate cost.

The third purpose, flood control, is, in my opinion, not a logical one. Water should be conserved for use, and especially on the Hunter. But the water of Glenbawn is unlikely to be used for irrigation, other than from its effect on river flow, as the reticulation cost would be too high. The dam conserves roughly one foot of run-off from 300,000 acres; thus it could supply, disregarding evaporation and channel seepage losses, two feet of irrigation water to 150,000 acres at an extra cost of, maybe, twice the dam cost, £30,000,000, making a total capital cost of up to £45,000,000 for 150,000 irrigated acres, or a cost per acre of irrigated land of £300, plus the original value of the land. Glenbawn would lose effectiveness as a flood control dam if used in this manner for irrigation. For these reasons, Glenbawn is apparently not the best place to conserve this water, and at such a cost it may have been better to let the water go through to the ocean, although this water is wanted badly for agricultural uses.

Unfortunately, however, these direct irrigation costs cannot be verified now, but it is apparent that the whole matter is causing concern. The dam is nearly completed but no major works for the reticulation of the water have started. At the moment an inter-departmental committee of enquiry is investigating all these aspects of Glenbawn, and their findings, if published, should be of assistance in the assessment of the value of this major public work.

Glenbawn is only a suitable flood control dam if its entire capacity is available for that purpose, *i.e.*, if it is always emptied as soon as possible after a flood fills it. Yet it is a multi-purpose dam and is less effective in flood control according to the volume of water retained in it. It could still be classed as upward of 50% flood control effective, and that, by comparison with others, is very good.

The large multi-purpose dams for flood control and irrigation have always seemed to me to be a partnership of two completely irreconcilable fellows. The irrigationist wants all the water held. The flood-threatened want the dam kept empty. Very naturally these dams, which are always costly, have an unhappy history.

The final question is, can the water that would normally cause a damaging flood be conserved agriculturally in such a way that storage capacity would be available to catch the next flood? The answer to this query is in the affirmative when the best water conservation plans are combined with the most effective irrigation methods. And this is the meaning of Keyline.

The position is reviewed in this way:

The Keyline approach offers water conservation in different but special-purpose structures designed to conserve and use, but not to waste water or allow water to waste. If it succeeds in this there is no flood problem. In order to compare the different approaches it must be assumed that authority is equal. If one authority can do all the things necessary to build Glenbawn, then another must have equal authority to take the alternative measures necessary in the catchment area of the big dam. However, the catchment area of Glenbawn contains some of the steepest country in the Upper Hunter region, with over 60% of its catchment having slopes exceeding 15 degrees. As the conservation of water by improved agriculture and in farm dams in such a region would be hard to determine, the comparative figures below should be taken as applying to the more general class of country which is typical of our agricultural land. Moreover, we are interested in all the land of the Hunter Valley and not only the relatively small watershed of the Glenbawn Dam.

Water conservation costs in Glenbawn are £50 per acre foot. The cost of the conservation capacity on the farms in a catchment area of Glenbawn's size would be less than half of this cost, and I judge this on my own experience of many dams constructed to the designs in this book.

My costs of water conservation capacity on our farms range from £6 to under £50 per acre foot, disregarding purely experimental work. £6 per acre foot is low, but I have seen many sites on other properties where it would be even lower. The full capacity required then could be conserved generally at less than half the cost, and even this half provides or makes provision for an outlet system in all the farm dams and also includes the irrigation drain for the reticulation of the water. Approximately 50% of the water capacity would be flow water not requiring pumping and would be available for irrigation in the lowest cost manner possible. This would be as much or more water than Glenbawn can provide for irrigation. Of the balance which would be pumped, most of the water could be employed also in flow methods of irrigation. These methods are discussed in detail later.

Not only could there be a comparable capacity provided at less than half the cost, but included also there could be full irrigation provision for at least 50% of the water (more than Glenbawn flood pool) and partial irrigation provision for the remainder. To accomplish this under the present set-up, Glenbawn costs would be more than doubled. Under the alternative agricultural scheme which I advocate, the water is conserved on farms, on grazing land and forest land, in different kinds of dams each with a different and particular purpose. All the higher dams on each farming and grazing property would generally be used for irrigation. Within a week of rain they often could be profitably employed. The main method of irrigation would be by 8- or 10-inch outlets from each dam and distributed by the Keyline flow system. The lowest dams or series of dams on each property would also be used for irrigation as soon as weather conditions dictated. Keyline irrigation is designed to take the maximum advantage from this water in as short a time as possible. The reservoirs or "middle" dams or series of dams would not be used for irrigation at this time. They are reservoirs supplying perhaps stock troughs or holding water in reserve. They would be used for irrigation after the water in the high and the low storages had been used. Whenever heavy run-off rain occurred there always would be storage capacity in at least both the high dams and the low dams. Also, in a planned design of use, no run-off rain water would waste from the land until all dams were again filled.

There is also another great storage capacity available on the farming and grazing properties of such a five-hundred-square-mile area. A Keyline soil development programme would increase the general capacity of the soil to absorb at least two inches of additional rainfall, thus providing the lowest cost storage of all.

The money required for the project under this approach would not be spent with little return, but would produce directly a quick and certain return. If advanced to the farmers and graziers it would be repaid quickly and be available for further work. There is big profit to be made from water control in agriculture.

I have said that Glenbawn compares more than favourably with other flood control dams. It can hold a so much greater proportion of run-off from its own catchment that flood water from its catchment is, comparatively again, not likely to add to flood flow. Now, Glenbawn's catchment is only 500 square miles, a small area 20 by 25 miles, and its effect in controlling or even mitigating a major Hunter River flood is not of any moment. Glenbawn is what is often classed as a "head-water" flood control dam, and such dams drain areas up to one thousand square miles. Nevertheless, many such dams as Glenbawn would be needed to affect a really big Hunter River flood. But if £15,000,000, as spent on Glenbawn, was made available as loan money to the farmers and graziers for the development of their properties in the Hunter Valley, not only would the present shocking waste of water cease, but a lot of other wonderful changes would follow.

Another interesting cost comparison is that the cost of Glenbawn on a yardage of earth in the wall basis is at least eighteen times greater than my own recent costs of earth moving for farm dams.

The ratio of earth moved to water storage capacity in Glenbawn is in the order of one cubic yard of earth to forty-two cubic yards of water. The best ratio of any of my farm dams is one cubic yard of earth moved for a capacity of sixteen cubic yards of water. A more usual ratio for farm irrigation dams is one to five or six. The higher the ratio, other things being equal, the lower the water storage cost. So, while Glenbawn's earth-water ratio is perhaps eight times more favourable than many of the farm dams of Keyline, the earth-moving cost is eighteen times higher, and, as is seen, provides a heavy balance in favour of agriculture and for keeping the flood rain where it falls.

I have no personal interest in and particularly no animosity towards Glenbawn as a project, or towards the men who approved it or those who designed and built it. It is selected here for discussion because it is new, its construction costs are today's costs and are known and real. Glenbawn also presents the facts for this type of dam in a more favourable way (other than its high cost) than any other dam of the type I know or have read about, including those in other countries. I know Glenbawn's background, climate and its conditions. We all recognise the Hunter River flood hazard. Glenbawn Dam constitutes an excellent basis of comparison.

The Hunter River Flood Hazard.--It is not my purpose to minimise the Hunter River flood hazard. The dreadful loss of life, property and valuable surface soil of which we were witnesses in 1956 and which had a world-wide advertisement, has become such a holocaust that everyone is prompted to think in terms of flood prevention. All that the average citizen has is the scheme propounded by the Water Conservation Commission to build seven large dams, of which Glenbawn is by no means the largest, at the cost of countless millions, to do a job which experience now suggests they will not accomplish. If sufficient of the public think along the lines of seven big dams for the Hunter River district the parliamentarians will follow their lead and eventually build seven large dams. Who is likely to advise against it? Not the engineer. He insists that flood control is a big problem, a task only for the engineer, and who is not impressed and convinced of the size of the problem when watching a river on the rampage in a big flood. The official agriculturalist, then, what has he to say about the matter? Virtually nothing! He, most unfortunately, has been pushed out of the picture altogether, for even when a Government decides to do something to assist farm water conservation, and wherein lie the solution to these problems, the administration of the project is given to someone else. What has the official soil conservationist to tell the people? Only that, in certain instances, four to five and a half inches of heavy rain was held on the land of a farm or a grazing property where soil conservation methods and structures were used, but as the big floods are caused by twice this amount of rain he thinks big flood control dams are necessary. In fairness to those all-too-few soil conservationists who think differently, I must record that some do believe that continuous flood rains up to twelve inches or more in 48 hours can be controlled, conserved, and later used on farming and grazing properties. Some of these men in other countries wage a continuous fight to enlighten public opinion, but they have against them the policy which provides the truly fantastic money allocated to the big works for engineering control.

Australian floods differ in the amount of rain which causes the destructive flood. Total flood-period rain of twelve inches or less is the cause of most of our floods, but there are some small areas in the north along the easterly coastline where rains up to twenty inches occur over a short period. From my own experience of these matters (in the increased conservation of water in the soil for the development and improvement of soil, and in the location, design, construction and use of many farm irrigation dams), I know that the control of flood rains up to twelve inches is only a matter of water conservation for profit where the lowest cost and the greatest advantage comes from the control of water where it falls, namely, on the farm lands, grazing properties and forest areas. In these instances there is no flood problem but only the matter of preventing the illogical waste of needed water. In those few areas where the floods involve rain of up to 24 inches over a flood-period it is still logical to aim at the economical conservation of the largest amount of water which may be later used profitably on the farms and on the grazing lands before considering any other approach. The last approach of all should be the flood control dams, and then they should be planned only as many smaller dams located in forest areas where the water could be flowed over the forest land. Forests, when managed for the express purpose of disposing of excess water, can constitute the greatest absorption capacity of any type of land, and may also provide profitable use of the surplus water later in the trees themselves as a timber crop.

Big dams are justified only for purposes that require water for use for community or wide national advantage. Every city and town must, therefore, have an adequate and completely reliable water supply and so must plan storages of a capacity suitable for the projected increased population of future years. The large high mountain storages for electric power generation have been generally a prime factor in the development of many countries, although today other sources of power are often more economical and present technological development may tomorrow make such water-generated power completely uneconomical. Many fine large irrigation dams conserve water which cannot be used where it falls, for instance from snowfields, and these dams enable the establishment of flourishing irrigation districts in country that was virtually desert. Always, though, the bigness of the project is used too much as the most convincing measure of its success. While many large water schemes are justified by real success, the general large-scale irrigation project should always be more critically examined against the cost of the irrigation land which can be produced from the many farm-scale projects. The glowing success stories in words and pictures of some Government irrigation areas are not confirmed in the profit and loss account of the project, since the costs of irrigation are not directly assessed against the irrigated land. The capital costs, if disclosed against each acre of irrigated land, would be found in some instances to be so high that only the toll of tax on all the people of a State allow the schemes to exist at all. However, my quarrel is not with the concept of the big dam as such but with the viewpoint that fails to realise or even consider the comprehensive nature of, and the very wide national effect to be secured from, the many farm dam and irrigation projects.

At present we are in a position of serious lack of public thought as to what is correct in methods of water conservation. We must get our thinking right first, otherwise we are likely to impose a dreadful legacy in the form of continually wasting lands upon a beggared posterity. Education of public opinion on the basic importance of agricultural land as the foundation of the nation's very existence should begin in the schools.

The problem of floods becomes social and national as well as scientific and preventative. Following every flood, we need to concentrate our money on repairing damage and our sympathy for the victims of the flood. We read that the flood damage in a certain river valley reached one million pounds recently. (The damage from one Hunter River flood was assessed at £10,000,000.) Terrible! Of course it is terrible, and it is worse because human lives were lost or jeopardised.

The real problem, however, is not the £1,000,000 of flood damage but the sheer waste of more millions of pounds worth of water in a country that cannot afford the luxury of wasting any water.

Why is there not any real effort made to keep all our precious water? Because the job is too big for the nation? Because it requires a colossal amount of work and a hundred millions or more pounds, pounds which we do not have? On the contrary! The real job is not a series of big dams, while these will help, but simply thousands of farm dams which thousands of farmers are capable of making and who could have finished them ere this had our agricultural authorities been determined to retain overall control of matters affecting these wide aspects of water and land development.

There just must be a new approach to water. Can't we forget about the site for the giant dam on the river for a while and take a look at water where it falls, since it is here our greatest source of wealth originates?

In the discussions on land shape it has been conclusively shown that practically all land is contained in what I have called "primary land units". These units are the catchment areas of the primary valleys, and most of them flow to secondary valleys. These two types of valleys are the source of all flood water, but they also contain the most practical and economical sites for the storage of the precious water and as well contain in their catchment areas the land suitable for the most profitable use of the water for irrigation. All the problems and answers of water and land are contained in these lesser units of land.

To get back to the present inadequate advice on agricultural water which is not given by agriculturalists only. Farm water conservation for irrigation on the farm is widely spoken of as supplemental irrigation and sometimes insurance irrigation. Both could be more fittingly described as panic irrigation. The basis of too much of the official advice on supplemental irrigation is the complete conviction that such irrigation on the farm does not generally pay, but that a farmer should have a little irrigation land which he may use to supplement the general rain-only nature of the farm. By having only a small area of irrigation land and managing this efficiently he may then make it pay. In contrast to this and in circumstances where the production per acre from the type of farming is high enough, supplemental irrigation often pays handsomely. In circumstances where it does not pay, then it becomes "insurance irrigation". Like life assurance, there is no real profit in it for the assured, but it is a "good thing". It may save the farm in a drought, and many Australian farmers were glad of their insurance-type irrigation projects in the drought of the latter half of 1956 and all through 1957. It seems that the worst type of water scheme is better than no scheme at all. But what a dismal manner in which to regard such vital matters as water and irrigation. Expert advice says that a farm dam for irrigation should be planned against the minimum annual run-off of its catchment, so that the dam is sure to be filled each year. The water supply is therefore said to be reliable, but at the time of writing there has been no run-off for over eighteen months in nearly all the areas where this advice is given. While this type of advice must be scrapped, it is not quite as ridiculous as it seems. Again, the real trouble goes a little deeper, namely, to the orthodox farm irrigation dam. This structure is built usually in the valleys of the farm first--anywhere--and it frequently has land below it which could be cheaply irrigated were there an outlet. But is has no large outlet to enable water to flow from it and do at least part of its own distribution. Instead, the water has to be pumped up from the dam, and, in most instances, as the water level lowers from use, the pump and engine follows the receding water down into the mud of the dam. Invariably, such water is used for spray irrigation, which is generally the most expensive type of irrigation, both as to initial cost and running expenses. Spray irrigation is one of the methods of irrigation and has its own particular provinces and uses as well as many variations, but the method of irrigation used should always be the one that best fits the circumstances. If the farm irrigation dam is to be the basis for irrigation, then, if any dam is located wrongly or lacks design and is constructed badly without adequate outlet facilities what chances are there of efficient irrigation. Usually, then, one dam and a small supplemental irrigation scheme is all the farmer can tolerate. The rest of his run-off water can waste away, since he cannot afford to collect and conserve it.

Before all the run-off water can be conserved plans for the economical use of the water are needed.

The idea that a large farm dam filled in a good season is a failure if it becomes empty by irrigation is not sound. Water has to be used. Just storing water is not economical. There will be reserves of water elsewhere on the farm as described earlier. Water is a means to an end, and when all the water of a particular dam is used to this end, namely, the growing of crops or grasses, the dam is not a failure. The soil on which the water was used will be better; the crops and fodder were produced and both can be conserved, and this is successful use of water. However, a dam or a series of dams remaining full because the water cannot be used profitably is most assuredly plain failure.

A large farm storage that may fill only once in three years can be a fine investment for the farmer. The land below the water line of such a dam when emptied for irrigation is not waste land. When properly treated, as I have found, it can be used then for special crops and should be the highest value land on the farm, with the single exception of irrigation paddocks.

It is so much simpler and more natural to turn a tap to get water than pumping it. So the outlet through the wall and the turn-on valve are features never neglected in the big community dam. Any design for a farm dam that does not include a means to this end of turning on the tap is deficient.

Further, it should be realised that water storage on farms has many factors much more favourable than those of the "big" dams. Foundations are generally better, earth for walls is better, and hazards from heavy rains during building are negligible, while earth-moving costs are always very much lower.

There is this also to be said of water supply, the third factor on the Keyline scale. I believe that the overall planning techniques of Keyline provide the best possible methods for the location of farm dams and the best practical relationship between the high, medium and low types of dam. From my experience, I feel confident that the designs of the dams presented in this book will completely satisfy the requirements of the farmer and grazier, and that the construction methods and the various techniques for the use of the water will be so economical and profitable for the farmer that the ultimate aim of not wasting any water can logically be instituted as the best possible investment policy a farmer may make.

With Keyline planning and design the farmer and grazier will find that he can conserve just about all the water that would now run to waste from his property. He will certainly carry more stock and he will need more watering points and paddocks. If he has not yet, he will soon realise that farming is big business. The capital value of all farms can be increased enormously, and landmen, because of the favourable taxation provisions as they apply to his business, are in a position to finance the development of a very big capital asset returning good dividends and in the most advantageous conditions. And there is probably no country in the world where these conditions are more favourable for him than they are in Australia.

Water cannot be dismissed with the conclusion of this brief chapter on water supply, which is the third factor on the Keyline scale of permanence. The whole question of the simple and direct factors of storage cost and economical use of irrigation water as between these farm dams and the big dams is capable of a much wider comparison than I have illustrated. The largest and most economical storages in our vast Snowy Mountains Hydro Electric Authority scheme will not provide water for irrigation as cheaply per acre of irrigated land as many of the favourably located farm irrigation dams. Indeed, important as the scheme may be nationally, were it not for the electric power generating capacity involved, the whole Snowy scheme would not be even of secondary importance when compared to the work of providing farm water storage and irrigation as effectively as is envisaged in these pages.

A comparison of the farm dam and the great Adaminaby Dam of the Snowy Mountains Authority may seem ridiculous on the face of the gigantic size of the one to the minute nature of the other. Yet the number of farm dams that are needed throughout the agricultural lands and the capacity of water which they collectively could hold, would truly, as we have seen, be a huge scheme itself, albeit a scheme composed of innumerable smaller units.

The bigness and urgency of the full development of the farm dam and irrigation project is not fully realised by merely appreciating that they would have much more water storage capacity than all the big dams and would irrigate much more land extending over all the agricultural areas of the Commonwealth. There are these other important aspects. As always, there is the great question of transport. Water from any big scheme has to be transported great distances, which costs both large sums of money and big water losses in channel seepage and by evaporation, but from the farm dam the transport of the water is necessary for the shortest of distances, often only a few feet and rarely more than 300 feet before it comes into practical use, thus saving enormously on reticulation costs and water losses. Again, the question of transport becomes a powerful cost factor in the construction of these two types of dams, the big storage and the farm irrigation dam. Earth for the construction of farm dams usually is moved a distance of from a few feet to 200 feet, whereas for the big dam the transport of selected material involves many miles of cartage, cartage which generally increases with the size of the dam. There would appear to be a great asset in the concentrated nature of the water in the large dam, though there is some considerable risk of collapse, especially in war time, but with the innumerable small storages spread over the whole country there is presented no major risk.

Then there is the question of finance. In the big project there is never any expectation that the big outlay will ever be returned quickly, while with the farm storage project it is profitable in the way the landman and ordinary people understand profits. What is at stake? An amount of money is spent to start a farm irrigation project. The dam is constructed quickly in a few days or a week or two, the dam is successful, irrigation is profitable, and the capital cost of the work, be it loan money or farmer's capital, is paid back in a very short time. And there is in Australia not even any associated tax problem. The work is paid for from profits before the farmer's income is determined for tax assessment.

There is no doubt that we need all the water that we can conserve and that we need it where we can make best use of it, and this will always be on the farm and grazing lands of the Commonwealth.

As has been said, the undertaking is a vast one, but any great undertaking is made up of many parts as well as many people and much money, and to do the work quickly the undertaking must pay for itself as the work proceeds. Paying for itself simply means that a great number of people have to make a lot of money out of it, but as the people also have to pay for the work, then the scheme must be productive in the shortest time. If, as farm water conservation proceeds, the smaller parts of the whole scheme can be complete in themselves and be producers of good returns in a year or so, then the largest of projects can be undertaken with the minimum amount of money. As far as Government finance is concerned, no works approaching in size or importance that of the provision of adequate farm water supply could be undertaken so economically. A nationwide development worth literally thousands of millions of pounds could be projected and commenced with a comparatively small sum of money, a sum no more than has been considered lavish in the past for infinitely lesser public work, and which has been deemed to be well within our financial capacity.

The big dam for irrigation and the farm size project for irrigation are both necessary for the realistic development of this country, but one aspect of this development, the farm project, has been grossly neglected.

The true relative importance of the two water schemes, the big dam irrigation scheme and the farm-scale water project, may have been difficult for the reader to realise, yet I am hopeful, by the time I have reached the last reference to water, he will be in full agreement with me on the importance of farm water conservation, not only on account of its great value to the farmers and graziers, but because of its completely dominating influence on all national aspects of land use and water control.

CHAPTER VIII

Farm Roads

FOURTH on the Keyline scale of the relative permanence of things agricultural is farm roads. The main farm roads are influenced in their location by the climate and the land shape, since our study of the patterns of water movement over various land shapes provides a basis for determining the sites of the roads. Increasing volumes of flow water are hazards to roads, so that their trafficability in wet weather and their cost in maintenance are vitally affected. The centre of main ridges, which form part of the boundaries of the secondary valleys, are neutral lines of no flow, and being high and dry are very suitable sites for main roads.

The influence of the water conservation drains of Keyline and the position of irrigation drains and irrigation areas determine the sites and general patterns for work roads and are arranged as follows: Those roads which run across the land follow the water conservation drain either above or below it; others which follow the irrigation drain are located above it so that irrigation water will not flow across the road. Again, other roads may follow the lower boundary of an irrigation area and another road on either side of the breaks of the land, namely the watercourses.

Some of these considerations have always influenced the siting of farm roads, but the relationships of the factors of the Keyline scale of permanence and the appreciation of the new significance agriculturally of land shape provides a guide so positive that all road sites are selected to advantage because all factors in their siting are understood. Farm roads, while serving their purpose, change the natural drainage pattern either towards destruction or preservation of land profiles. From the general planning of Keyline it will be seen that the position or sites of farm roads become natural, obvious, and constructive.

CHAPTER IX

Trees

THERE is every indication from my own work in developing the Keyline plan on "Nevallan" that tree belts, where located in respect to land shape, are of tremendous benefit to land and have no disadvantages to the development and maintenance of a highly fertile soil in a stable and permanent landscape.

There has been a great new interest in the function of trees on the farm by all types of people and by many authorities recommending tree planting. In no instance do these recommendations include any logical method of placing trees and tree belts for their most beneficial effect on the land.

In New South Wales trees have been cleared from most land for all types of agriculture, but in no circumstances is the complete clearing of a property necessary or justified. Trees, even odd trees, by greatly restricting the area of grass growth, have caused farmers and graziers generally to aim at the complete destruction of all trees on grazing and farming land. But in clearing operations, when trees are left in properly located and designed belts, the land which they occupy will not reduce farm productiveness; rather they will add to it.

I have noticed on our own properties that tree belts which were left on country that had been badly eroded, abandoned and covered with only the poorest regrowth of trees, had the effect of restricting moisture and pasture growth near the tree belts. This was an effect only for the first two years of our Keyline development programme. From that time onwards the trees had a beneficial effect on the pasture, and the notably best pasture in a dry winter growing near the tree lines.

On much pasture land often it is only the old trees that are left, hence the concentration of stock around the trees causes bare patches of soil. But when the trees are left in properly-designed tree belts there is more than enough shade for all the stock.

There is a very marked improvement in the soil in the tree lines after the second year. On the edge of a tree belt on "Nevallan" there is left a larger than usual fallen tree, which was pushed down in 1951 as part of the clearing operation. It was left as it fell and not disposed of because it was too close to the trees. The operation of moving it would have destroyed the small trees in a place where there were too few in the tree belt. It has been lying there ever since, with the subsoil and shale in which it grew still firmly held in its turned-up roots. It has been a good illustration of the soil which we started to develop, with now a wonderful contrast of deep dark soil beneath the pasture nearby. Thousands of people have seen it. A wind storm in 1954 uprooted a tree a few yards away. The comparison of the deep rich soil held in the roots of this tree, almost incredible without having been seen, illustrates how rapidly soil can change and develop. The only factor influencing the development was the changed soil moisture of the treeline which was caused by the three years of Keyline soil management in the pasture area above the treeline. The longer-lasting moisture promoted in the tree belt by the work above it changed the soil of the tree belt. Formerly only subsoil and shale, it is now deep fertile soil. There was no cultivation in the tree belt, no fertilising and no grass planted.

Many people whom I have shown around "Nevallan" seem doubtful of my statements on the rate of growth and the increasing thickness of the foliage of our trees. Whenever I hear doubt expressed or sense a doubt I invariably glance around the group for a copy of "The Keyline Plan". Hundreds of copies of my book have been carried to "Nevallan" by visitors, who find great interest in identifying on the property the pictures in the book. Then we walk to the camera site of one of the book's pictures and everyone becomes interested in the convincing comparisons.

The healthy condition of stock is assisted by adequate shade in the summer. The tree lines have a beneficial effect on all the soil by retarding the drying effect of hot winds and ameliorating cold windy days.

Tree belts, since they are cooler in hot summers and warmer in winter, help to maintain the constitution of farm animals. There is little apparent benefit from trees for two years, but from the second year onwards the tree belts develop into moisture reserves and into great fertility reserves from the droppings of the animals. As moisture and fertility spread fast downhill, the belt of trees soon has a beneficial effect on much of the pasture land below it.

In wet weather the better conditions in the tree belt encourage stock to stay on pasture only a sufficient time to feed, thus keeping them for long periods in the tree belts and off the pasture, and preventing trampling damage caused by stock roaming on wet soil.

If a farm is to maintain an increasing fertility in its soil--a complete fertility in a progressively improving landscape--then trees will be necessary for their continuous turnover of the deeper elements of fertility. They may draw these from great depths in the earth and shower them back on to the surface as leaf fall. The deep minerals they supply soon become incorporated in and form part of the soil.

The selection of the tree species must logically be based on the climate, the type of trees that will grow in that climate and the progressively improving environment. The pattern of any tree planting is always based on the shape of the land. Farm roads and water supply features also influence their location.

It may be argued that a farm earth-wall dam is not as permanent in its life of usefulness as a tree belt, but the location, design and construction of farm irrigation dams in Keyline are such that they remain permanent agricultural features. The tree belts bordering the roads on "Nevallan" are not only beneficial but add to the beauty of the landscape.

Trees are placed in the Keyline scale ahead of permanent farm buildings because their lasting qualities exceed those of the buildings. How often does one see a group of trees in an area where a farm homestead once stood?

While the general design of clearing and tree planting is based on climate, land shape, water supply and farm roads, trees should be planted as part of the site planning for the whole farm.

The remainder of this chapter is substantially what I wrote on trees in "The Keyline Plan" published in 1954.

On uncleared land, where the initial trees had value as timber, all these trees were part of the environment which produced the soil. In no circumstances is the complete destruction of all timber trees and the associated smaller growth necessary or desirable for farming and grazing pursuits.

There is probably no other land development work that has been so completely unplanned and haphazard as that of timber killing and clearing and no factor of fertility so completely ignored.

In order to grow crops and pasture on forested country clearing of some timber is necessary. Gradually more and more timber is cleared because of the disadvantageous effect of trees on crop land. However, like some methods of cultivation, clearing has been overdone, with the result that soil fertility eventually suffered and crop and pasture yields were affected. Sufficient trees on a property may make, in some circumstances, all the difference between a good farm and abandonment. Grasses and timber do not usually grow well together. A large tree will all too often affect quite a sizeable area of crop or pasture land and the tendency is to get rid of the tree. On some farming lands trees are left scattered about. These trees, no longer living in forest conditions, tend to die out. It is often observed that the upper and outer branches are dead and groups of trees are slowly dying. On some farms they are already dead.

Properties containing some steep country have often been cleared to allow all the flatter country to be cropped. The steep land is left timbered and used for grazing purposes. The general practice of leaving all steep country in timber to protect it from erosion has not been successful. This is certainly true of Australia, and the practice has not improved the timber. Steep country left fully timbered is often the greatest bushfire hazard and the worst area for pests. One heavy rain following a fire in a timbered area moves the poor soil quickly and often to the stage of guttering.

To derive the greatest benefit from timber for soil fertility and better farm working and living conditions trees must be left to serve the whole of the property. Properly located trees cool a farm for stock in summer and warm it in winter. They protect the land from winds and in their widest aspect may be capable of some overall improvement in climate. Keyline timber clearing is planned to derive the greatest benefit from trees for the whole of the farm.

First, trees are left in strips or belts wide enough to keep some semblance of forest conditions in the timber for its normal healthy growth.

Steep country is not left in full timber but partially cleared to plan with timber strips left to serve as wind protection for the property.

The Keyline is again the planning guide for clearing. The first timber strip twenty to thirty yards wide is left immediately above or below the Keyline and forms a Keyline timber strip--our basis for planning in clearing operations. From the Keyline both up the slope and down the slope of the land timber strips are left (or planted) on the contour or on a slight grade to suit the overall Planning and at selected vertical intervals apart. The important guide for determining this vertical interval between timber strips is related to the height of the trees. If trees are forty feet high and the vertical height occupied by the land in the width of the tree belt is ten feet, the timber strips would be vertically fifty feet apart. This provides very effective overall wind protection for all the land and locates the timber strips closer together in the steep country and farther apart as the country flattens. Even in very flat country of low scrub or mallee only ten to fifteen feet high, a similar formula for clearing will provide greatly improved farm conditions.

Timber strips left as described are a valuable aid to soil fertility apart from the supply of the deep minerals which they bring to the surface. In wet weather cattle will only stay on soft pasture ground long enough to feed and then return to the firmer ground in the undisturbed soil of the timber belt.

The two most efficient land compacting implements are the sheepfoot roller and the multiple pneumatic-wheel roller. The farmer has to contend with his own efficient compactors which are his stock and wheeled farm implements. The comfortable conditions of the timber strips will, to a large extent, keep his stock off soft wet ground. The farmer, of course, should leave his wheel machinery in the machine shed when the land is wet. Thus compaction of the soil, one of the great destroyers of soil fertility, is minimised.

By clearing the steep country on this pattern more and better grass areas are available and better timber will grow in the timber strips. Very short steep slope country is always of greater value when cleared and Keyline developed. Suitable timber strips are left on the flatter top country above.

Keyline absorption-fertility methods above the timber strips, by the greatly increased moisture-holding capacity of this land, provide the timber with better moisture. Timber growth is considerably accelerated.

Timber strips are the only completely satisfactory means of preventing land slips on country that would tend normally to slip when fully cleared and saturated in heavy rains. The timber strip is a definite and effective anchor holding the land shape.

Land that has been Keyline cleared and subdivided into paddocks will have some shelter timber in all or most paddocks. Every paddock, whether in the steeper slopes or the flat country, can be rotated in turn to grasses and crops.

The only way to ensure perpetual timber is by providing conditions that allow trees of all ages to grow together. If each paddock in turn is closed to stock and cropped for three or more years, young trees develop in the timber strips and permanency of timber belts is assured.

If tree strips of even width are desirable, then a contour line, or grade line, forms the lower line of the strips above the Keyline. A line, parallel to this, forms the upper line. Below the Keyline the upper line of the strip is on the contour or grade line and the lower line is parallel to it. The exception is near the irrigation drain line where the timber strip is above the drainline.

A strip of trees is also left around the boundary of any suitable land area.

There are other considerations in maintaining tree belts. No land could be more spectacularly beautiful than the timbered undulating country of Australia when it has been cleared and developed by Keyline planning. However, large areas of land which will come up for Keyline development have had too much of their timber removed without plan. The growing of timber strips now will be a necessary part of the best Keyline development.

Generally a small Australian native tree will cost a little over one shilling to plant but may cost over one pound to maintain for a year. While the cost of planting is not so serious and can be reduced by growing the young trees on the farm, the cost of growing timber strips of thousands of trees is impracticable unless some cheaper and easier methods are devised. Keyline planning and development may permit the closing of paddocks from stock for three or more years while crops are grown. This amount of time will allow a planted or "induced" timber belt to develop to a stage where the trees will survive without attention.

In large or small paddocks without trees that are to be Keyline improved a timber strip five to ten tree-rows wide can be planned. After the paddock has been completely cultivated tree rows are marked, the first row by a deep single rip cultivation parallel to the Keyline or a guideline. The distances apart of the further rows of trees are gauged by the tractor that will later cultivate between these rows. The following procedure has produced good results:

After completing the full Keyline cultivation of the paddock, mark out by a single rip the first tree row position. A single shank is allowed to penetrate deeply through the plowed soil. On the return run with the tractor place the uphill side rear wheel in the lower wheel track of the first run and travel the tractor back without ripping. Turn around and again with the uphill side rear wheel in the lower track of the last run mark out by ripping deeply the second tree row. Repeat to the number of tree rows to be planted. This row spacing will allow the tractor later to cultivate satisfactorily between the tree rows and one or two cultivations are done during the first year after planting the young trees.

The preparatory cultivation takes place some months prior to the time for planting the young trees so as to collect, in the drier conditions, as much deep moisture into the earth as possible. The object is to improve the soil and to provide sufficient moisture in the soil before the planting of the young trees and so avoid entirely the necessity for watering later. A delay in planting for a year while the soil improves from a cultivation after each rain will be quickly offset by the faster growth of the trees.

Australian native trees should be planted when a few inches high and a few months old and planted directly from the tubes as used by the Forestry Nurseries. Plant the young trees well into the moisture zone without breaking the tubed soil in which the tree was raised. Press the soil firmly around the young trees. Trees can be planted very quickly into this deep moist soil with very few losses and without the addition of any water. The distance apart of the trees in the row may be closer than is intended for the developed trees. Spacings of eight feet are suitable for a variety of tree species. Planting time varies in different districts.

If watering and hand cultivation can be avoided, the chief cost of growing the trees is also avoided.

A tree strip may sometimes be satisfactorily grown by planting the tree seeds directly into the paddock.

Trees can be induced to grow by a variety of means without the actual planting of young trees or tree seeds by merely leaving a strip of unplowed country when the paddock is closed for cropping. Tree growth will often flourish on this strip and form a valuable tree belt.

Two interesting incidents of my own experience will serve to illustrate possible low cost means of growing valuable timber strips.

During the construction in 1944 of several water conservation drains all except one were harrowed and fertilised. A directive was given that this one drain was not to be treated or touched in any way in order to see just what would grow on it. A variety of vegetation rubbish grew quickly on this exposed subsoil. Three years later a row of trees twenty feet high and all of one species covered the drain.

In the drought of 1944 several runs with a heavy road plow were made to form a fire break. Later the dry grass of this fire-break strip was burned off. The paddock was not stocked heavily during the following two or three years. At the end of this time the fire-break strip alone was then well overgrown with trees, all of the one species. The trees here were a different species entirely from those which were growing in the drain less than a mile away.

From these events it can be seen that whenever a treeless paddock is to be closed up for cropping for two years or more a suitable marked and planned strip of land could be left untouched, or perhaps given some special attention, so as to allow a timber strip to develop of its own accord. Once the trees are three or four years old the majority will survive stock damage.

There is still another aspect of treed land and cleared land, and that is the bush fire and grass fire hazard. In Keyline this hazard is negligible for the following reasons: With farm roads in the right places for quick access, the tree belts widely spaced, the grass paddock rotationally grazed, and water at intervals to be distributed crosswise for long distances through the farm, a fire originating outside the property could not make headway.

The relation of tree belts to cleared strips and to soil and pasture development is well illustrated in many of the plates in the pictorial section at the end of this book.

CHAPTER X

Farm Buildings

THE five earlier factors on the Keyline scale will now have indicated clearly which one of the possible alternatives is the best site for the permanent farm buildings, the sixth factor on the Keyline scale of permanence.

The selection of sites for the permanent farm buildings may influence the pattern of clearing trees adjacent to the site; therefore the sites should be fixed early during the planned clearing of the land. However, deciding the location of permanent farm buildings does not affect the general planning of the trees that are to be left in the clearing of the property or grown on cleared country. Permanent farm buildings should be located in respect to climatic features and land shape so that the best living and working conditions are provided on the site. Consideration is also given in the planning to the general water conservation scheme and to the pattern of clearing as it affects living conditions at the site for the buildings.

Without the benefits of a full appreciation of the various factors of the Keyline scale it has often been difficult to decide the most suitable site for permanent farm buildings. There may be several sites, all of which could have a particular feature more favourable than on other possible sites. However, with full consideration of all the earlier factors of the Keyline scale, possible sites can be more realistically appraised. The positioning of water supply features guiding the location of farm roads in relation to land shape and climate will disclose all the suitable or possible sites of the access roads from the shire or council roads into the farm. The access road would follow perhaps along the top of a ridge or, from a suitable point on the public road, along a contour of the land high enough to avoid heavy run-off flow. The access road must be trafficable in all weathers and must be permanent. These relevant matters will be so obvious that the final consideration of possible sites can then be made.

Permanence in such matters on the farm relate strongly to family life and the final decision is made to suit the farmer's wife. The best aspect and view is more important than such matters as easiest sanitation, one time considered as the first in the order of importance. Modern methods and equipment can, with little trouble, provide perfection and permanence in such matters. Sometimes the final deciding factor on the location of buildings has been the availability of a particular water supply. Water supply is important, but, again, modern construction will provide the best of these facilities without the home being necessarily bound too closely to the locality of a suitable supply.

The Keyline planning of the land opens up and often creates beautiful vistas that make for pleasant home life. Farm homesteads may overlook the public road but need not be too close to the road when the farm access road is as good or better than the public road. Good views and appearance dominate the site selection.

The homestead takes precedence in site selection over the other buildings, which are sited so that they are overlooked from the kitchen or living area of the home. The old central courtyard with the various buildings grouped around it has much to commend it. The access road from the public highway should then lead directly into the central area and the main farm roads lead out of it. The work area should be of sufficient size at least to enable any vehicle working on the farm or one likely to carry goods to the farm, to turn and manoeuvre satisfactorily. Prevailing winds in relation to smell and dust are considered. Sufficient small paddocks are associated with the building area so that overnight horses and special or sick beasts may be kept under close supervision. Finally, no fire hazard can be permitted in this planning. The higher the development of a property the more fireproof it will become. The development at any time should therefore be greater near the homestead and permanent building sites. Improvement of land could logically start at the steps of the homestead and the first irrigation area to be developed could be the one closest to the buildings. There is no better fire break than paddocks which can be irrigated at the turn of the large water control valve on a dam.

All the various considerations that are taken into account in the siting of the homestead and permanent farm buildings are not contained in this brief summary under the heading of this chapter. Rather, as with other factors of the Keyline scale, all items higher on the scale form part of the present factor under discussion.

CHAPTER XI

Subdivision

THE subdivision or paddocking of land is seventh on the Keyline scale of the relative permanence of things agricultural. All the factors already considered relate to this seventh factor of the Keyline scale. Climate and land shapes, with their dominating influence, water supply and the uses of water on the farm, farm roads and their relationship to the boundaries of natural shapes of land areas, trees and their great value to agricultural land when located to suit the shapes and form of land, the homestead and permanent farm buildings; all these factors in aggregate have already clearly indicated the pattern of subdivision.

The main subdivisions on a farming property are usually closely associated with the roads. The roads in most instances take precedence over the fence line, the fences being made to follow the pattern of the farm roads.

The first main subdivision fences should enclose the large land forms, i.e., the large watershed areas that can be treated and developed as the larger complete land units. Fences may follow work roads along one or other side of the break of the land on a creek and again where there are big changes in land form due to a changing geological structure. The geological changes are usually along the centre of the hills or just to one side of the main ridges.

For subdivision purposes land can be classed in two main divisions: (1) All land that may be travelled by the farm tractor, or, in other words, land that can be developed mechanically by farm equipment. (2) Land that is too steep or too rocky for any farm equipment. A fence line can divide these two types of country in any large natural land division.

On any land form where the conservation of water in farm irrigation dams can play an important part in the general scheme of things, irrigation paddocks, large or small, may be fenced off as island paddocks which take their shape and form only from the line of the irrigation drain and the land strip below it which is to be irrigated. These areas have previously been decided upon against the background of climate, land shape and water supply, with some consideration given to the location of the trees and buildings.

With the land fenced off into its natural larger divisions, with island paddocks within these boundaries as irrigation areas, subdivision for smaller paddocks would quite logically be enclosed by fences running from the irrigation area straight up hill to the high boundary or straight down hill to the lower fence.

It has been pointed out that the better the development and improvement of a property the greater will be the number of stock watering points necessary, and, following the location of the paddocks mentioned earlier, the paddocking of any other particular area could largely depend on the most suitable dam for the provision of water to stock watering points. From the outlet valve beneath the wall of all farm dams, pipelines from I inch to 2 inches diameter may suitably supply stock troughs in a series of paddocks generally stretching across the slope of the land.

All subdivision paddocks should be located with the continuous possibility in mind of their further subdivision. The higher the fertility and productiveness of a property, the greater the number of paddocks that will be required to take the greatest advantage from increasing productiveness.

CHAPTER XII

Soil--The Eighth Factor

ALTHOUGH soil is of first importance in any agricultural development, it is the last or the eighth factor on the Keyline scale of permanence of any of these main factors of agriculture. The fertility of good soil can be destroyed before a line of fence posts will rot. A poor soil can be changed into a highly fertile soil in about a tenth of this time.

If almost any type of soil in a climate that makes a satisfactory agriculture possible can be converted quickly into highly fertile soil, then the orthodox practice of planning farm layouts with the emphasis always on the various soil types is an unsuitable approach and is not followed in Keyline planning. However, a particular highly valued crop that may be produced on a special piece of soil could be of sufficient importance to warrant a small localised departure from this principle.

We are interested in making permanent one class of soil only and that is the best soil possible in the particular natural environment when the environment, and with it the soil climate, is undergoing a continuous progressive improvement towards its most favourable agricultural peak and as a direct result of the techniques of our planning, development and management.

This brief mention of soil, the eighth factor on the Keyline scale of the relative permanence of things agricultural, serves only to give soil its proper place on the scale. As mentioned in Chapter IV, "The Keyline Scale of Permanence", the whole stability and permanence of our agriculture depends to a large extent on just what we do with our soil, the least permanent of the factors. Land shape, one of the most permanent natural features of land, owes its continued degree of permanence, once it is occupied and exploited agriculturally, to its covering of soil.

The Keyline scale of permanence does not need to be carried any further than this eighth factor--soil. The permanence of stock breeds and their continuous breed improvement depend firstly on the pastures and crops which in turn depend always on the soil.

Agriculture generally and of whatever kind can develop to its greatest heights only when every factor of the Keyline scale of the relative permanence of things agricultural has each been considered in its proper order and place in the development and management of the farm.

* * *

We have come to the end of our eight factors as introduced in Chapter IV and continued in Chapters V to XII. The discussions in these chapters have shown the Keyline scale of permanence to be a new conception and the eight factors have been placed in their true perspective.

But there is the further consideration of the landman. While he is not given a place on the Keyline scale, he does, by his control of land, dominate for good or ill the environment in which he works and makes his living. Firstly, consideration can be given to those farmers and graziers on good properties. Then in a subsequent chapter the Keyline scale will be applied to an undeveloped property of easily discernible landform and of low economic value.

The Keyline scale to be a workable tool for good farming and good grazing practices needs therefore to be good business for the landman, and so the Keyline scale of permanence must be shown both to be good business on established properties and as well a better basis for the planning of new land than any methods now in practice.

Farms and grazing properties have their water supply, farm roads and trees; they have their homestead and permanent buildings and their subdivision paddocks. They are also generally producing a satisfactory living from their soil and their people are happy and enjoy their mode of life as it is. Moreover, many farmers and graziers, as I have repeatedly found, have their plans for the further development of their properties. Will they want to adopt another plan, a plan which they may first consider is not their own? What therefore has the Keyline scale and the full land planning technique of Keyline to offer those of the good farms and grazing properties? How will the Keyline scale apply to them?

First of all, to the farmers and graziers with good properties and their own plans for the future, I say Keyline will fit your property in as completely an individual way as your own plan which it will extend and improve beyond your present hopes. The pattern and the picture that it will produce on your land is the ultimate and natural one for the particular shapes of your land. No other property will be like it because all land shapes, while following as it were natural rules and patterns, are different just as are finger prints; no two are alike, they are all individual.

But, leaving planning for a moment and getting back to the soil. I have found that many landmen and agricultural people in general and some scientists in particular do not have the kind of basic conception of soil which enables them to quickly accept my own view, which is that any soil can be improved beyond its best natural or original fertility and that the process is simple, rapid and economical. But I have not yet found any landman, who, accepting this view, does not desire to improve his own soil. Many farmers and graziers visiting "Nevallan" after reading "The Keyline Plan" have first considered that their soil was really good (they had come to investigate planning for timber clearing, or dam construction, or an irrigation system, or some other matter), but after digging into a foot of the soil on "Nevallan" they were then not so sure as to their own soils, and before leaving had the fixed intention of immediately starting a three-year Keyline soil development plan on their properties.

So Keyline has, I believe, this something which every landman wants, no matter how good his property, and that is better soil. But as soon as a greatly improved soil becomes a certainty or as soon as the landman accepts the fact of rapid soil improvement, things are changed. While there is little point in increasing the productiveness of a property to carry, for instance, an extra few hundred sheep in circumstances where the extra sheep would cause overwork for the farmer or make it necessary to employ an extra man for no extra profit or even at a loss, now there is a different story when the increased productiveness from just this one Keyline technique may quickly double carrying capacity and then continuously further improve it. No matter what the previous condition of the development of the property, the landman must then make new plans in order to obtain the best advantage from this new productiveness. It will be better now if the new planning and new work is done to suit his climate and individual land shape, and so Keyline can be his logical guide.

It follows therefore that the rapid effects of the soil improvement methods of Keyline quickly lead to a consideration of planning. But consider again the aspect of water supply. Whenever farmers and graziers see the water flow at the rate of over a hundred thousand gallons an hour from my keyline dams and reservoirs on "Yobarnie" they are immediately interested and intrigued. Then they follow the irrigation water along the drain to the drain-stop which causes the water to overflow the lip of the irrigation drain. But when they follow the pattern of the water flow and see the effective spread and the uniformity of the irrigation they then appreciate the significance of what they have seen and want the same set-up for their own properties. The next step is that they try with their mind's eye to pick suitable spots for a dam and an irrigation area on their own properties. They may decide they have one such place on their farms. But it is not easy for them to quickly interpret the new conception to their own circumstances and they may see one site when there could be six better ones. If these men are convinced that this Keyline idea is a good one and will be profitable for them they must also see that two or ten will be twice or ten times as profitable, and, further, that all their run-off should be so conserved. The limit of the effectiveness of water conservation and irrigation cannot be attained unless the planning of the scheme fits the landman's own land shapes, and so planning on this factor is seen to be a necessary first step. So we see that a conception of the overall planning of Keyline is an early step no matter what particular aspect of Keyline is the first one that attracts the interest. Then any work whether new or of a routine nature just naturally fits the land shape features of the farm.

Again, the present permanent buildings are the hub of the working farm and will remain that way. The influence that they will have on Keyline planning is simply that improvement in soil, water supply, trees and farm roads will commence here instead of further away. When a new subdivision fence becomes necessary, and only as a means of accepting the profits from improving land capacity, then the areas extending from the homestead are the first ones to be considered.

On many occasions farming folk start their farming life in a small temporary cottage. They have plans for their home, but may soon find that many other farm developments are competing with the home for the available money and the home building plans suffer and time goes on. But the Keyline planning of this property will decide, in a very positive manner, the site for the new home and enable a little to be done to improve the site. It could be that with the new home site fenced and perhaps used as a special paddock on which some attention continuously improves its soil and a few trees planted and suitably protected, the site will, when the home is completed, have the look of age and beauty that only the well-established trees can give. Trees, to whatever pattern the new home site indicates, can be planted and will grow well with the minimum of attention, as is shown in the chapter on trees.

The planning lines of Keyline do not change the fences on established properties. The lines of Keyline planning should be marked first with a furrow that will last two or three years, so that those parts of the work that are not to be proceeded with immediately may be lived with and better visualised and understood. And any work in the area, be it some type of cultivation or just driving across the paddocks on a farm tractor or car, can then be adapted to the lines already marked in. New fences when they are required are only for the purpose of obtaining the benefits of the increased productiveness of Keyline, and then their location is decided on the Keyline plan of the overall development.

However, it becomes a completely different matter when fences are considered in respect to new water supply structures. The dam or dams in Keyline are to be precisely located as dictated by climate and land shape; therefore those parts of present fences which are in the way are removed and the paddock area involved is adjusted with a little new fencing. And likewise with the new irrigation area, which soon will become so valuable to the property that it warrants fencing and as an island paddock if necessary. There is no doubt that this is the right approach. Now water conservation drains come into the picture. They follow the planning lines which may be located at this time or which may have been marked in perhaps two years earlier. The drain may cross one or more fences, but these fences remain. A panel or two of the fence will generally be worth moving for the easier construction of the drain, or on other occasions it is left standing and the section of the drain under the fence is put in by hand.

Keyline should always be followed in the most logical and practical manner by first gaining a complete appreciation of the overall plan as it applies to the property and according to the climate and the land shape of the property. The particular water relationship of the enterprise of the farm and grazing property affects all the work, both as to the short-term aspects of day-to-day working and to the long-term benefits of the ultimate in permanence and value from complete water control which follows the development of the plan. Always the Keyline scale of permanence will assist in this full, if gradual, development.

We can look now to lands that are flatter. Behind all the discussion of the Keyline scale, and in fact Keyline generally, with its precise definitions and ready classifications of land shape, is the picture of hills and ridges and valleys in definite and readily distinguishable forms. And so the impression may arise that Keyline is something only of the type of undulating country that emerges from these descriptions. This view has sometimes been expressed, and in fact some of our visitors at "Nevallan" and "Yobarnie" at first thought that Keyline was something for our own properties only and would not apply to their country which was of very different shape. Again some farmers who knew "Nevallan" and "Yobarnie" well had expressed the view that our newer property at Bathurst or at Orange would be a very different proposition, inferring that they were not suitable for the type of Keyline development as they pictured it. But, of course, it was not long before someone else was saying that "Kencarley", at Orange, or "Pakby", at Bathurst, was the ideal for Keyline development. And it is always this way. First, a property is thought not suitable for Keyline, and then when the lines are marked in and the work starts the same folk see just the opposite--it is then the "ideal". The reason is simply that they are looking for land suitable for Keyline when land itself makes its own individual pattern of Keyline, and that it is Keyline which emphasises the exclusive pattern that belongs to each farm or grazing property. And so it is with the flatter lands, where the broader and lower and less distinguishable shapes do not impress themselves on the eye. But for these lands the planning of Keyline is still based on the shape of the land as revealed by water movements.

The very gentle slopes will have all the land patterns in their contours that are seen in the country of more definite shape. These patterns of ridge and valley will be consistent-they are always so; and they can be clearly seen on their contour maps. But each land form and land unit may be much larger in area and are not seen so clearly unless the land areas or farms represented on the contour maps are also of larger size.

On our own properties the lands may range in slope from one foot fall in less than two, to one foot in forty-five feet. On the flatter lands the steepest slope may be as flat as one foot fall in forty feet and the flattest slopes of one in a hundred. And the discussion could go on. We could speak of country that is very dry and that that is all the more reason for conserving all run-off and for improving soil to hold its moisture and growth longer, and for tree belts to break the drying power of winds. But the evaporation rate is very high, and much water would be wasted from the dams, so why not use the trees to retard evaporation. Of course, evaporation can absorb large quantities of water. The rate may be five feet and more from open water surfaces in the summer months alone. But it would be hardly less logical to decide not to cook food because the heat lost or wasted is much greater than that actually used in cooking, than to discount the idea of conserving water because much may at times be lost by evaporation. Large low-cost water conservation capacity is a feature of these flatter lands and so long as there is run-off, reliable or unreliable, conservation of water on the plans of this book will be profitable. Water supply and all matters affecting water supply are planned from the background of the climate and the land shape. Wind then is a feature of this climate, and so is the evaporation rate, and thus evaporation affects the design of dams as a result. If the evaporation rate is five feet, dams are designed with a depth of ten feet or more up to an average depth of eight feet, which usually would be provided by making a dam of twenty feet maximum depth. Generally on flatter land the most economical depth may be somewhat less than twenty feet, fifteen feet of water being usually an economical as well as a practical figure. Further discussion on water storage on these land shapes is contained in a later chapter.

The flat land of the large irrigation district should be mentioned. Here, as much or more than anywhere else, the soil treatment techniques of Keyline are needed where generally the problem has been too much water and too little air. Good planning will also improve these lands.

On those lands that are really flat and in near desert country where run-off water is not a factor, the pattern of development may be then based on the prevailing winds. The same factors of soil climate, the improved association of moisture, warmth and air in the soil, still apply in soil improvement. Tree belts across the path of the prevailing winds are still important factors and water supply remains the basic planning guide whatever the source of water on which the land depends. Generally the more critical the climate agriculturally the greater is the need for planning and the wider is the improvement that good planning will bring.

While there are some lands which when fully planned and developed on Keyline will illustrate all the techniques of Keyline in ways easier to see and simpler than the plan on other lands, in the end all agricultural land has its climate and land shape, and therefore the planning of Keyline based on these factors will always apply to produce an improving property.

Full consideration of all the factors of the Keyline scale will ensure that development cannot do otherwise than follow the most suitable course.

PART TWO

CHAPTER XIII

The Keyline (Research) Foundation

THIS chapter is written to acquaint the reader with the challenge of events which led to the formation of the Keyline (Research) Foundation, the later changes in the policy of that Foundation, and the results and altered plans for Keyline that have now been made.

I published "The Keyline Plan" in 1954 after ten years of practical experience as a land owner and trying to develop a property in an area where the orthodox methods of pasture improvement had never been successful. If things had been otherwise, if the soil had been better or the climate a little less unfavourable and a modicum of soil improvement had followed my earlier efforts, Keyline would not now be a much-discussed and controversial agricultural subject.

I became intrigued and absorbed in the land and the soil, and could not keep it from my mind. Then some slight success convinced me that what I had envisaged for my land was not only possible, but that I could raise my aims to something much higher. I found the work which I was continuing to regard as failure was to others great success. My water storages built in 1944 and 1945, and to my mind only the start of things, were considered as something outstanding by our visitors. My irrigated pastures of those years were to me an undertaking far from successful because of cost and time factors. To others, however, the luxuriant-looking, and at that time spray-irrigated, pastures, growing with the aid of superphosphates on our impossible soils, were astounding. Then later, whenever I had occasion to open the valves of my dams (which to me had always been the only method of getting water out of a dam), most people were fascinated with the flowing water. I became more ambitious for the property and aimed at having over a thousand acres of the best soil, a water storage capacity that would hold all the run-off water on the property, and an irrigation set-up that could use the water almost as cheaply as when rain falls directly on the soil. I did not want a scheme which only paid in the production of highly valued special crops or special high value per acre enterprises. I was interested principally in the grazing of beef cattle and sheep.

With the first glimpses of Keyline I believed that 1 had happened on something of outstanding importance. Keyline became an absorbing subject in our home with my two elder sons, both of whom have scientifically trained minds, and their friends of like ilk, pounding the theories of Keyline with all the enthusiastic fervour and imagination of youth. Before I had given even my first talk on Keyline just about every possible attack and criticism had been introduced and talked into its proper place.

I spent a lot of time trying out every aspect of Keyline, dropping most other things that took much of my time, probing, testing and proving. Over two years went by and every aspect was proved, or so it appeared to me. One of the last things I ever expected to do was to write an agricultural book, but, convinced of the importance of my discoveries, I then wanted to write the book as quickly as possible.

"The Keyline Plan" was written, but when I discussed it with a publisher he said, "An agricultural book, eh! Sell about five hundred", and at my look of consternation he conceded, "Well, maybe seven hundred if it's any good". This number would have made the cost per copy very high and he suggested that only by printing ten thousand could such a book be sold at a reasonable price. Certainly he would not be the one to say that ten thousand copies of an agricultural book could ever be sold in Australia. It had not been done before.

However, I published the book myself, printing ten thousand copies. Many were given away to friends and other people, but the book did turn out to be an agricultural best seller, and few copies are available for sale anywhere now.

We, my family and I, awaited the first review with some trepidation. However, it was favourable and eventually we read forty other favourable reviews. Later, a few critical comments continued to promote and maintain interest in the book.

Events then took a new turn. Farmers, scientists and students had been visiting my property in considerable numbers since 1944; now the Keyline book brought them in thousands. The book was written for farmers, but the orthodox agriculturalist and the scientist did not ignore it. Groups of scientists of many interests in parties of a dozen or of a hundred, extension officers from all over the State, land surveyors, bank valuers, teachers, students, and many others came, and I have talked to them all.

I had known many in the professional and academic fields prior to Keyline, but when the first visit was arranged for twenty such gentlemen, all highly educated and experienced specialists in some branches of agriculture, I felt some diffidence. What I had to do was deliver them a lecture on agriculture! I just hoped for the best but hardly expected it. The visit, however, was a complete success. They were not only wonderful fellows but they treated my work with a great deal of respect. They praised the experimental work as original and very valuable. They praised my poor soil of three years earlier and described it as incredibly rich. They put their hands into it, examined it closely and got friendly with some of my earthworm population. They looked at everything, grass, roots of grasses, the nodulation of clovers and lucerne, and seemed to enjoy digging for the deeper roots with my spade. They washed their dirty hands in the big flow of water from the outlet valve of one or other of my dams and were just as interested as anyone else in seeing the water flow. They praised these dams, and liked the big supply of water, thoroughly approved of one at least of my ideas on irrigation where the outlet valve lets the water into an irrigation drain and the plow pattern on the land takes control and spreads the irrigation water evenly.

Each was interested to talk of his own special subject, asked what I had done about this and that, and wanted my opinions on the application of some of their particular work if it were applied in a Keyline way.

One special group later was made up of ten to twelve scientists from CSIRO, with one grazier whom they all knew, together with one of Australia's leading land valuers who had been my guest a little over two years earlier. At the conclusion of our walk and my talk the CSIRO scientists were much more interested to hear the grazier's opinion of what they had seen and heard than they were in first expressing their own. When one of the scientists, a notable soilsman, asked the grazier did he think my pastures might collapse as his improved pastures had done recently, after being highly productive for a few years, every scientist there stopped to listen to his reply. He replied, consciously addressing them all, "No! Not in your life, this is it, this is what I'll do at 'X'," naming his own property.

One of this group had earlier asked me what a certain paddock was like two years ago. I told them the valuer saw it then and asked him to repeat to them his opinion of the area as he gave it to me a little over two years previously. He said something like this, "I told Mr. Yeomans about two and a half years ago when first I saw his work here that this land was not worth two shillings an acre, but if he kept on with his work it could then be worth two shillings an acre." Then, with a smile, "You see, gentlemen, that I am right, as usual; it's now worth every penny of two shillings an acre. Speaking seriously, though, what has happened here in a little over two years is absolutely incredible. Where you have been digging into the good earth, all I could see then was yellow sand and sandstone!" (I have since paid £50 an acre for adjoining land to improve "Nevallan" and refused double this figure for my own property.)

The early reactions of farmers and the top-flight scientists to my Keyline approach to land confirmed my own view on its ultimate scope and importance. The fact that I personally had originated the idea and developed the plan was just one of those inexplicable quirks of chance that do happen. But having done so, then perhaps I should do something about it.

I considered the Keyline development of land something too big and important for me to tie it to, any commercial enterprise and decided to discuss its future development with men of sufficient stature to judge of its importance and work out its future. This I did. All those whom I approached had read my book. On more than one occasion they had also visited "Nevallan", where the plan developed.

They agreed that the Keyline Plan was of sufficient importance for us to make an effort to teach it widely, to apply it to farms and eventually to have it accepted as part of national agricultural policy. Thus was formed The Keyline (Research) Foundation. I have paid my tribute to its founders in the dedication of this book. Membership was invited. It was to be a research foundation, but, as the founders considered that the merits of Keyline had already been proved in my own work, they would also do something that was immediately practical and organise a Keyline service to farmers and graziers. These matters were embodied in the constitution and application was made to the proper authorities for the taxation considerations that apply to gifts of money allowed research organisations.

Membership fees were accepted but no large donations were sought pending approval of the Foundation as a research organisation.

I had been appointed President, and as it was somewhat my "baby", my family and I made a substantial donation initially to bring the foundation to immediate usefulness. A start was made with a service to farmer members and the foundation began to function. However, the Keyline Foundation was not approved in this manner as a research foundation for taxation purposes because the whole of the money was not intended to be used by an approved research organisation such as a University. This approval, we found, could not be given if we conducted any type of service to farmers.

Now, it should be realised just what a great disappointment this decision was to the founders of the Keyline (Research) Foundation. We then had in our minds the picture of a real national revival in agriculture and the concept of a service to farmers was in fact the selling of an "idea" with appropriate assistance to put the Keyline concept into wide practice. It had, of course, been fully realised that the work would have been very extensive and very costly to the Foundation when applied on a broad national scale, and that this could not be done merely with the donations of the few founders. The farmers and graziers were actually being asked to assist us financially and as well to conduct, on their own properties, Keyline experiments for the good of all. We also had plans that the Keyline (Research) Foundation would endow scholarships for special student and post-graduate study of land, so that the broadest aspects would be thus assisted. Manifestly, there were extremely wide areas for research embracing the different types of lands within the Commonwealth. The whole scheme then, solidly upheld by the founders, who are all patriotic Australians, was frustrated by the narrow interpretation of the meaning of the word "research" (strangely enough determined by taxation authorities). Personally I had offered the suggestion that I close my agricultural business and devote my time to Keyline work, but the point at issue was simply that we could not function as a research organisation. (with taxation benefits) unless all moneys were handed over to an "approved" organisation such as a University, and such official research would not only have been very costly but of necessity would need to duplicate all my earlier work and over a period of years. The Foundation was satisfied that Keyline was already sufficiently demonstrated in my work and that this long delay was unnecessary. It was considered, further, that wider research would be accomplished in a very practical way on the properties of the farmers who were anxious for our early assistance.

These matters are mentioned to show the difficulties which arose against something which we all hoped would quickly influence national agriculture. Instead of the work progressing on a rapidly accelerating scale as we had fully expected, we were forced now to approach things in a pedestrian fashion. However, time moves on, and with the elapse of time many more farmers, graziers and scientists connected with all aspects of agriculture have become more interested in Keyline. My own further experiments have widened its scope and confirmed its value, and the main aim of the Foundation, that of having Keyline accepted widely as national land development policy, has certainly not stagnated.

However, following the receipt of the information refusing recognition of the Foundation as a research organisation, it was decided not to seek donations which would not be free of tax to the donors, and to conduct the service to farmers at a profit margin if possible.

The farmer has so many sources of free agricultural advice from well-paid officers, in fact it is almost thrust at him, that we soon found ourselves in a very confused field. With agronomists, veterinary officers, soil conservationists, irrigation experts, forestry officers, and even road engineers discussing Keyline and expressing all sorts of views on the subject, there was naturally confusion in the minds of landmen. Even so, it soon became apparent that there was quite a large number who were willing and anxious to help and to pay for Keyline service, and especially if the service could include something more than advice. They were interested in the general planning of Keyline, the location and marking-in of the planning lines themselves, a start on the soil development programme, the siting, location, design and construction of our dams, the layout and planning of irrigation areas under Keyline, and even the management of the full development of a property.

Several meetings of the Founders of the Keyline Foundation discussed all aspects of these matters, including the very high cost of conducting the work in which we were all so interested. Eventually it was decided that my private agricultural business organisation be asked to consider, and, if approved, draw up plans for instituting a Keyline service to farmers and graziers, a service which would include every aspect that we were capable of handling. This service would then be run as a purely commercial undertaking.

It was fully realised that a certain stigma of "base commercialism" could attach itself to Keyline under these circumstances, but it was also considered that this straightforward practical business approach to farmers and graziers would be the best way to serve the majority of farmers.

The decision to accept the proposal of the Keyline Foundation was an easy one for me to make, but the big and significant decision was that which the other members then made. They decided, first of all, that the Keyline Foundation, with themselves as members, would continue; that its aims of doing all things to assist in scientific research on Keyline and the placing of Keyline before Governments would continue as its main aim and policy. Under the circumstances it would have been reasonable for them to consider that, even with their belief in the principles and practices of Keyline, they had done all that could reasonably be expected of them, and that at this stage the Foundation should close. Their decision, which was unanimous I am pleased to say, was more than I could have expected.

In deference to the members of the Keyline Foundation I have been at some pains in the past to avoid too close an association between Keyline and my agricultural business activities, but now that policy is reversed. Our agricultural business literally became a merchandising organisation to promote Keyline as a main business aim.

We had to move forward, and so commenced to explore every avenue of Keyline service that would provide revenue to do the job properly. We limited our activities somewhat to those matters which directly assisted the main task of providing education and instruction on the various aspects and techniques of the Keyline Plan. From the Foundation's earlier experience we knew without question that the most money consuming aspect of the whole work was that of education.

We had to examine the business of Keyline in the same way as any other business activity must be viewed. We knew always that we had a basis for such a business by our complete confidence in the fact that our work and services would always be very profitable to the farmers and graziers who use and employ them. But the presentation of the ideas in a manner that would provide revenue was a problem that had to be discussed and worked out in some detail. Apart from implements and services that we can provide and that will assist Keyline, we needed good men fully trained in the new work. We had a satisfactory manufacturing set-up backed by a merchandising organization with a good team of men all keen on the job they were doing, and they were capable of doing much more. One source of income from that business is the manufacture and sale of the Graham plow, which was my choice for one part of the Keyline development of my own properties and a new and revolutionary implement at the time I introduced the chisel plow to Australian farmers and graziers. I had made a chisel plow in 1945 and conducted many experiments with it, and while later the Graham plow had been in use in other countries, a completely different, or Keyline, approach to cultivation was now to be realised with the new implement. For one thing, from being merely an instrument of deeper cultivation, it now became a soil maker by being used precisely according to soil condition and climate. Then I had, from the basic overseas implement, redesigned our own make Graham plow to make it very strong and so resilient that it would work on any land where a tractor could travel. Keyline pays attention to all land, and the steeper and rougher hills are very important. There are now fifteen followers of this Keyline implement and eventually some of these manufacturers made very good chisel plows. The result now is that the best of the Australian chisel plows are superior, in my opinion, to those employed in other countries, and Australians have bought more of the new implements than the farmers overseas.

So our Graham plow has been successful. Following its initial introduction only a short time elapsed before the sales had reached the million pounds mark. We were satisfied that every farmer and grazier who uses the Graham plow is more likely to be improving his land than harming it. Still it is only an implement, and the important thing is that it be used according to the techniques that were developed in the Keyline plan. However, since it is an important implement for Keyline we will continue to offer it on its merits to all farmers and graziers. Next arose a host of problems and we were besieged for solutions.

First came the problem of supervision. Since many farmers and graziers are wanting a service that will provide supervision of their work of developing their properties on Keyline methods, we are establishing a service on a basis of three years' supervision for a fee determined on the size and condition of each property.

Next came the problem of marking out. I believe the most good can be achieved if the landman learns by doing things himself. He needs, as one of his items of equipment, a satisfactory level, which he or any of his work force can use without experience. I designed the "Bunyip Level" especially for the farmers and graziers' own personal use.

Then there had to be designs. Farmers have been interested in my dam designs since 1944, when they were first used agriculturally on "Yobarnie", but it is not easy, as they find, to follow the design and methods without proper plans and specifications. I have therefore drawn designs and plans for various standard farm irrigation dams and copyrighted them. They are straightforward and can be understood and used, in conjunction with instructions that have been prepared, by any farmer or grazier.

And now for lockpipe. One of the very important design features of all my dams has been the provision of pipes beneath and through the wall for the simple and economical distribution of stored water. This type of work, simplicity itself to me, had to be made equally simple for all to handle. There was no suitably developed engineering technique with clear instructions for the layman; moreover, there has never been any manufactured equipment available to farmers for the placing of a pipe line through the wall of a farm dam, although such means of water control are always included in the design of the big community type dam. So we had to develop and present the "lockpipe system" and include every necessary item of equipment to enable the work to be undertaken by any landman. This system includes heavy steel flanged pipes, the only type of pipe suitable, with baffle plates, gaskets, strainers, valves and take-off mechanisms, together with complete instructions, including suitable illustration.

Next we had to have maps. A Keyline map is a map of a farming or grazing property drawn to a workable scale with contour lines at a vertical interval that suitably illustrates the shape and form of the land. The Keyline map includes the keylines or guidelines marked in with all valuable water conservation sites, irrigation areas, and special or valuable land forms indicated.

I said earlier that the most difficult, time-consuming and costly job in any new agricultural development is the educational part of it. My own earlier contour maps produced by field surveys cost then the equivalent of from ten shillings to fourteen shillings per acre at today's values. They were slow to produce and too expensive for me to recommend them to farmers.

It is simple enough to show farmers the new Keyline agricultural values in his landforms if one can spend the time with the man on his own land, but lack of time is the difficulty. A farm contour map is one of the greatest though least used instruments for land development. But with a suitable Keyline map I could discuss with the farmer the full development of his property in under an hour, and both of us would know the property and the appropriate Keyline development. I have maps of this type for all my own properties and can explain them and their uses, but unless a farmer has a map of his own land the first discussion on Keyline may remain somewhat unreal to him.

We are now approaching a position when we can produce Keyline maps of the farmer's and grazier's property and will be able to teach those who do not understand them fully how to read and use them. In addition, the provision of aerial photographs on the same scale as the maps may be a later development of this particular service.

Still, maps were not enough. With the assistance of some of my academic friends we have succeeded in producing very fine models of farming properties. I believe these models will find their most valuable use in universities, agricultural colleges and schools, but I have been very interested to find that many farmers and graziers, after seeing my models, express the desire for a model of their own property.

In the educational and scientific field Keyline is not without recognition. It has appeared in the examination questions of agricultural colleges and is on the curriculum of at least one college. It was stated to have been the only subject chosen by more than one student as the subject of an agricultural talk which each student had to give as part of the fourth year Agricultural Science Course at Melbourne University in 1956. Queensland University has maintained a strong interest. Sydney University asked me to be guest of honour and deliver the address at the graduation dinner of the Faculty of Agriculture of Sydney University. Agricultural colleges have requested a text book on Keyline and thousands of students and their teachers visit "Nevallan", and many have returned each year. A goodly number of scientists have expressed a great interest in Keyline. Sir C. Stanton Hicks, Professor of Human Physiology and Pharmacology, Adelaide University, and a founder of the Keyline (Research) Foundation, has said, "After all the gloomy prognostications of the pioneers of soil erosion control--Jakes and Wyte, Bennett and others--it is with a feeling of relief and renewed hope in national development that I see the entry upon the scene of the realistic and practical optimism of Keyline", and, further, "I have seen soil similar to this (on "Nevallan") before, but it took over twenty years to make. The big thing with Keyline is that it only took three years". Sir Stanton, after two earlier short visits, spent ten days on "Nevallan" studying and investigating every aspect of my work. An agricultural scientist who had been engaged for many years in the academic teaching of agriculture, and who is now continuously occupied with the broad advisory field to farmers and graziers, said, "Yeomans has discovered in the Keyline concept itself something of great importance that has somehow eluded scientists all these years." The distinguished chief of a national research organisation said to me after a world trip, "Keyline in Australia is the most interesting development in world agriculture". He had also expressed interest and a further measure of approval of my work when he had earlier visited "Nevallan". Such opinions surely indicate something worthwhile. It must, therefore, be our aim to help in providing facilities for the teaching of Keyline in these most important institutions--the Universities and Agricultural Colleges--wherever such assistance is asked of us. For instance, the supply of a series of Keyline maps, aerial photographs and models would be a great aid in students' study of the land forms and shapes for the planning and development of land.

We needed more experiment and demonstration farms. Nothing is more convincing than the accomplished fact. Immediately the Foundation had made its decisions on my firm's function in Keyline I considered the acquisition of new properties, and it became necessary for us to control such ventures, and therefore we had to buy more land ourselves. But the decision to buy more land was an easy one for me, since many of my activities in recent years have been dictated by my great interest in land and in the development of the Keyline Plan. The whole wonderful consistency of the land forms that Keyline discloses are there to be discovered on every farming property, and the study and development of land could become much too easily an all-absorbing hobby. Of course, such work always involved considerable financial outlay if the work was to be done properly and also enjoyed. Fundamentally, both the farmer and myself have to make the work pay. Experimental farms are never expected to pay. Our farms must do so, because that is the meaning of development. For us now, happily the large and more costly experiments are finished. It is just a matter of applying the techniques of Keyline planning and development of which we are completely sure and to be varied only against the climate and the land shape of the newer properties. These new farms will be acceptable because they vary widely in land form, climate and soil types. But doubts have been expressed as to the success of Keyline soil development technique if applied to light soil such as poor granitic and then sandstone soils. Therefore, we bought 1,500 acres of sandstone shelf country at the back of Wedderburn, some few miles from Campbelltown, New South Wales. It appears all sand and sandstone. The land form consists of high flattish shelves, breaking out to sandstone gorges up to six hundred feet deep. The land was cheap and close to Sydney.

For similar reasons, a property, which we have named "Pakby", of 2,000 acres of the lowest-priced granitic country we could find close to a good town, was also acquired near Bathurst, New South Wales. Nine miles from Bathurst, on a main bitumen highway, it presents a typical picture of the deteriorated landscape of the poor granitics with big erosion gullies, with much surface soil removed, and it is an unfavoured property locally.

Then we ventured more ambitiously and bought "Kencarley", which is some seven miles from Orange, New South Wales. This property contains 3,000 acres of what was described to us by the Orange folk as "tiger" or "biddy-bush" country--poor country. Biddy-bush covers those parts of the property where the soil has all been lost by soil erosion, nevertheless biddy-bush does have roots and is much better to start with than nothing.

Now on "Kencarley" the land form is the most varied of our properties. There are high slates and schists, all "end-on", as it were, standing nearly upright and rising to 850 feet above the lowest point of the property. These metamorphic rocks contain intruded igneous rock formations. Although many kind friends were sympathetic toward us for our bad judgment and misfortune in acquiring the property, I am quite sure that it will not only be a rich, highly-productive area in the shortest time, but also one of the most beautiful farms.

These new farms, together with "Nevallan" and "Yobarnie" at North Richmond, New South Wales, give us five fair-sized experiment and demonstration properties. We intend to develop these farms fully on Keyline planning, and they should enable us to give the answer to any query the farmers might bring to us.

There was the question of an earth-moving equipment service, because now the development of the experiment and demonstration farms required the use of some big mechanical equipment. This became a personal problem, since I had disposed of all my heavy equipment of the type which would have been suitable and which was earlier available for my experimental work on "Yobarnie". Therefore, about this time I acquired the control of a reasonably-sized contracting business to do our major work and to undertake Keyline earthworks for farmers. It was expected that many farmers would be able to use these services, and learn the technique and methods of dam construction with lockpipe and irrigation and for them to use other contractors to continue our work. However, we found that very often a farmer would contract the firm for a job of a few days or a week, but having seen the manner of our work he wanted to have a lot more done. Jobs of a few days turned into months, and all our plant became tied up, with a bad effect on our own developments. What we require now is many contractors with good plants, and because we intend to teach farmers our methods we hope to be able to achieve greater results.

This also must be said--there is no question of our plant competing with other contractors, because there is so much financial advantage to the farmer in this work that if all available contractors were working with us there would be, in my opinion, more work for the next ten years or so than all of us combined could do.

Now the question arose of the insurance of farm dams. I have investigated the insurance of this most valuable asset, the farm irrigation dam, in various countries of the world, and farm dams seemed to be the most unpopular type of risk from the insurance company's point of view. Only one country was prepared to quote a rate that slightly approached what I consider to be a practical insurance premium to the farmer. A detailed study of our own registered design farm dams with the lockpipe system was made from the point of view of the risks involved in insurance. With the increased factors of safety automatically provided in our designs and construction we have been able to work out a practical insurance scheme at a low premium, and so it was decided to undertake the insurance of farm irrigation dams. Consequently, a new company is in process of formation for this purpose, so that we are now in the insurance business and can offer rates of premiums to farmers and graziers for the insurance of all their dams built to the design of those described in this book. This coverage by our insurance is a practical business proposition to the landmen.

Then, of course, we welcome new business associations. Because we need help in our work we will make new alliances with suitable business organisations who are closely associated with the farmers and graziers. This part of our work has recently been commenced, but it will entail the training of staffs before the alliances become effective. We believe that by undertaking the programme of Keyline as a straightforward business, and that by providing valuable services to agriculture, these allied organisations will reap a satisfactory business reward.

There is no doubt that the work will be influenced by the attitude of Government Departments to the Keyline Plan. If the Agricultural, Soil Conservation, or Water Supply Authorities oppose Keyline with outright condemnation, agricultural business firms who would otherwise be willing to assist would then be very reluctant to participate in our work. Their very business existence can often depend on the continued approval of these Government Departments. Agricultural businesses consistently accept or reject new implements and merchandise according to the approval or otherwise of these authorities.

On the other hand, if Keyline received a measure of endorsement from the appropriate State authorities new associations which we could make would soon have a widespread effect.

These various Government Departments have, up to this date, treated me and my work very well. They have gone to a great deal of trouble to organise visits by their various officers. For instance, the assembling of a large party of agronomists from widely scattered country districts for a visit of several hours at "Nevallan" calls for considerable organisation on their part.

There have now been dozens of such group visits to my properties, if one includes those also from universities, agricultural colleges, schools, many farmers' organisations, teachers, technical and church college societies, land valuers from banks, Lands Department staff surveyors and special touring 'bus parties from interstate. All have expressed their thanks to me, and I, in turn, appreciate the compliment to my Keyline work.

While some of the official groups have repeated their visits it is nearly impossible to obtain a full view of all that is involved in Keyline from these visits. Keyline work often impresses visitors according to that aspect most evident to them at the time of their visit. If the earthworm populations are casting on the surface, then earthworms and soil are likely to occupy a lot of discussion time. A visitor may ask the name of the trees in one of our planted tree belts. As a result, an hour or so later I am discussing, on the soil of the tree area, a fungi which someone says he has not seen outside a tropical rain forest. In a group, one who has been to "Nevallan" before wants to see a certain area he has been discussing with his friends in the group. So time passes and we do not see the spillway of a particular dam someone else wanted to inspect. We may be watering, so the course of the visit is dictated by the flowing water which everyone wants to follow as it flows slowly along the irrigation drain. It may have been decided that a group who arrived by special 'bus will visit vantage points by 'bus and at each stop a discussion will take place. The size of the conveyance may limit the inspection to four spots, but only two are seen. A famous trace-element expert with a group of soil scientists is anxious to see the paddocks on which I conducted my trace-elements experiments. The scientists see many soil samples, try to reconcile my results with their own experiments and experience, but do not see the Keyline land shapes, the pattern of the planning, the locations of dams or the reason for the trees.

Some people see Keyline as a Graham plow because I introduced the chisel plow to Australia, when what I really did was to introduce an implement to play only a part in the whole plan of Keyline. Other folk understand Keyline as a technique and manner of cultivating land to make it hold a lot more rainfall or as a way to clear land that makes land look well; again they may see it as a new way to build nice-looking dams, or a tap to turn water from a dam, but may not see that the water was there for the purpose of using it to the best advantage. Many folk, on their first visit, are amazed to see our large water storages and extensive irrigation areas and to learn that we have had some of the country's largest farm irrigation dams for fourteen years.

These impressions that miss the complete approach of Keyline are perhaps natural and understandable, but they do suggest that much more than one or two visits by agricultural authorities may be fully justified. There has been no instance as yet of any real attempt at a full investigation of Keyline by such authorities. But a committee or representative group could be detailed to investigate and study the work to report on Keyline as an effective or otherwise agricultural development plan.

It has always been an object of the Keyline (Research) Foundation to subject Keyline to such a test for the purpose of having the whole concept widely understood and then accepted. For my part, I have always been willing to give my time to such a project. The wide educational and agricultural background of the officers of our Departments of Agriculture ensure that any representative group would be fully competent for this task. I would suggest that such an investigation could start by the members spending one week with me, when a detailed study of the theory and technique of Keyline would be made. Chapter by chapter the Keyline publications could be read with every officer of the investigating Agricultural Committee attacking every smallest detail he did not understand or with which he did not agree. The films, maps, photographs and land models which I have could be studied and discussed in the same manner. When points were reached in these discussions where studies of land form or Keyline technique on the land itself was necessary we could go to our properties. The committee members must learn Keyline to be judges of Keyline, and part of this knowledge would be gained in performing the various operations themselves. And the members of the committee do not have to be engineers; it would be as well if they were not, but they must certainly be agriculturalists. There is engineering in Keyline, but it is quickly learned by the layman. The committee could do this part of the work as we suggest a farmer does it. They can follow the methods of location, design and construction of our farm dams by selecting locations, sketching and dimensioning the plans and designs, and then they could supervise the construction of a dam themselves. I can at least arrange this. Inspections could be made of all our dams. Farmers owning orthodox dams would no doubt permit inspections, and discussions would soon disclose the value of the different approaches. If any member of the committee held the view that such "engineering" matters were beyond him he would soon be convinced otherwise.

At this point visits to random farms and grazing properties where no Keyline work had been in progress could be made to enable the committee members to check their knowledge of Keyline by summing up the Keyline applications on each property, and to check its application on any type of property.

If the report of such an Agricultural Committee was completely favourable and was immediately acted on, the work of our State agricultural officers would soon transform the countryside.

I have met most of the agricultural officers of the New South Wales Department of Agriculture and many outside this State. Many of them are my personal friends and not antagonistic in any way to Keyline. They are, moreover, an outstanding body of men. The members of our proposed Agricultural Committee would, by the time they were ready to make their report, constitute a solid core of Keyline knowledge and be fully capable of quickly training all agricultural officers in this new facet of their work. The selection of the particular officers for such an investigating committee could logically be influenced by their suitability for the possible later teaching of the Keyline work. They could be maintained as instructors for some time at least, though not for the purpose of training farmers but to train all departmental officers and other agricultural educators, who in turn would be in contact with farmers on the new work.

The acceptance of this whole proposal for the investigation of Keyline appears to be a relatively easy matter. It would certainly be simple enough to the stage of the committee's report, and, if this was acceptable of Keyline, to the further stage of the training of all agricultural officers. Here, however, it must become a Cabinet matter for the rationalisation of the work of the other two authorities--Soil Conservation and Water Supply--who would be concerned.

As already mentioned some purely agricultural matters have been taken away from agricultural control. Agricultural water conservation on the farm could quite easily be placed under the control of the proper agricultural authorities. However, the soil conservation authorities, because of the strong agricultural background on which they insist for their officers, would be in a position to supply a very powerful force of men with an eminently suitable background for training to the new work. However, this authority has always fought to maintain its complete independence of Agricultural Department control in this State, and in Victoria the position is similar. Again, in another instance in Queensland, the Soil Conservation Department does very excellent work and lives happily under the control of the State Department of Agriculture. This in my opinion is the proper method of administration for as long as soil conservation is considered an important function of agriculture. When the various State Governments do not agree on the province of soil conservation in agriculture it is not much to wonder at that others are also confused.

As far as Keyline is concerned some soil conservation authorities alone have appeared to consider Keyline as cutting in on their preserves. Because of the fact that they generally may deal only with soil erosion problems and not water conservation, they suffer, in my opinion, an extreme disadvantage when they consider Keyline a rival doctrine to soil conservation. There have been occasions of mild arguments between Keyline supporters and soil conservation officers, when the soil conservationist, feeling the weight of argument a little heavy, has claimed that he tested Keyline and it didn't work. No doubt a very junior officer. The alleged secret test of Keyline must have been a major undertaking--if indeed such foolishness was ever even contemplated--and as such could only have as its purpose a petty condemning of Keyline. If tests were to be made genuinely of Keyline technique to produce a "right or wrong" verdict I would naturally be invited to participate. Keyline also has been damned with faint praise, and also included as "just another part of soil conservation". Some Government and educational authorities have borrowed descriptive terms and followed methods from "The Keyline Plan" and used ideas of my own without acknowledgment. It is said that imitation is the sincerest form of flattery, but I am not flattered by imitations that ignore principles or that copy engineering procedures and ignore vital life concepts. While our object always is to have farmers and graziers adopt Keyline on their properties, we do not wish to see some of its applications lose their usefulness and identity by being accepted wrongly into general agricultural methods.

We all view Keyline as a complete plan for agricultural land development based on wide new concepts and principles, and therefore it is the desire of the trustees of the Keyline (Research) Foundation that it should be fully investigated officially and accepted or rejected as such.

Any of these departments may condemn, belittle, praise, or ignore Keyline, but I, as the originator, cannot adopt any other attitude than the course I follow. I believe it is my right, privilege and proper function to report factually on all present agricultural methods (which include the soil conservation approach and the present farm water supply question) with which I am well conversed. I do not think that I should be influenced by the magnitude of any authority or opposition where I believe my experiments and experience discloses faults or misconception in orthodox methods and approaches. However, Keyline is now to be run as a business and we hope to stay in the business of Keyline until the principle aim of the Keyline (Research) Foundation is achieved.

Personally, my main interests lie in the wide implementations of the Keyline plan, in continuing with my experiments and in running our own properties. I am interested in Keyline as a business, only as a necessary stage to assist in its wide acceptance as part of official agricultural land development policy in Australia.

Many of the new business aspects of Keyline are protected by patents, copyrights and registered design and in the meantime these will be protected as our own. However, any farmer or grazier has permission to use, for his own purposes on his own land, any of the methods and techniques that are covered in this and other Keyline publications, and he can rest assured that I have thought this thing through and that I have worked it all out to a successful conclusion on my own properties. As far as I am concerned, the challenge of events of the last few years has been accepted.

CHAPTER XIV

Unfolding the Plan

ONE third of the continent of Australia has a climate which produces sufficient rainfall to warrant and support a highly-developed agriculture. Within this area there are great stretches of completely undeveloped land that are crying out and demanding attention and development.

If we are to produce a real Australian type of agriculture that is safe and permanent and which will preserve all that is best in our natural environment (an environment which in its totality is unlike that of any other country in the world and which contains everything except a good agricultural climate), then we must overcome this climatic drawback and regard it as offering our greatest opportunity. We could, by careful and realistic planning, produce in a few years on our undeveloped country, farms and grazing properties which would be permanent and safe from our present land troubles. They would also have more individuality than our best properties of today. Because this poor agricultural climate extends over so much of this land which is available for development, it is ever in the background of these discussions and it is therefore selected as the theme in the presentation of the planning techniques of Keyline.

These subsequent descriptions are typical of my actual experience but will be more readily appreciated if they are made to apply to a fictitious property under an assumed name. I have called it "Yonaroo".

In planning the agricultural development of any land, its climate (or weather), placed first on the Keyline scale, must be known. The general function of climate has been described in Chapter V, entitled "Climate", but to be more specific, the following paragraph completes the climatic picture chosen for the area of land we call "Yonaroo".

The average annual rainfall is assumed to be 24 inches. There is a little more rain in the winter months of June, July and August, though the flood rains do not usually occur at this time of the year. Heavy rainfalls are more likely to occur in the summer months of December, January and February. The summer can be extremely dry and hot. Good run-off occurs in practically every year, but on occasions the rainfall may vary from ten to nearly fifty inches, with consequently much greater run-off. There are frosts each winter but snow is never heavy enough to lie on the ground.

Land shape is second on the Keyline scale, and for our purposes is taken to include all the land forms that are likely to be present on land which is between 1400 to 1800 feet above sea level. The soil of the property is of two types, clays from slates and a lighter soil from a granitic area. The property must be described in some detail as the description proceeds to enable a clear picture to be seen of its development.

"Yonaroo" contains 1800 acres. Except for a small area all the land can be travelled with farm equipment. To describe the land further, it is assumed that there are two secondary valley systems which form small intermittently flowing creeks and which join on the property and flow to a larger creek. This larger creek, which rises several miles beyond the property, flows alongside and forms part of the property boundary. There is another secondary valley, but smaller than the other two, which forms on the property but flows away from the other drainage systems and is unconnected with them. The land is tree and brush covered but well cut over, with most of the good milling timber trees removed. Agriculturally this property would carry a few sheep or cattle in a good season and offers only a poor type of sheltered winter grazing. There is no permanent stock water, but holes in the creek retain water for most of the winter except in the droughts.

There are two general means of examining "Yonaroo" preparatory to planning. First, we may produce a suitable contour map of the property and develop from it a Keyline map with all planning lines and land shapes displayed. The map would have a scale of one inch equal to five chains (110 yards), with contours at 20-foot vertical intervals.

The second method of land examination for planning purposes is by visual means on the land itself.

The land divisions of "Yonaroo" are those already mentioned, namely, two secondary watershed areas each containing several primary valleys, and these two secondary valleys which, joining on the property, form a creek which, in turn, joins a larger creek and becomes part of the property boundary. Several primary valleys flow to this boundary creek and the combined land area of these latter primary valleys is the third land division. Another valley area, not associated with any of these three areas, forms on and flows from "Yonaroo" without joining the other systems. It is the fourth main division. To repeat, there are four main areas of land--the two secondary valley systems, the area of the group of primary valleys falling into the boundary creek, and the fourth valley or watershed division not associated with the other three.

The next step in planning is to select the land division which will be developed first and to determine the relationship between its various primary valleys. In order that the full pattern of the water supply scheme for the farm may be determined, it is necessary to know whether the keypoints of the primary valleys rise into the rising country.

Water supply is third on the Keyline scale of permanence, and it is designed according to the dictates of climate and land shape.

The rainfall feature of the climate of "Yonaroo" indicates that the plan of development should aim to conserve all the rain that falls. Land shape discloses that there is ample opportunity to do so in various types of storages.

Looking at the contour map we can spot almost at a glance the localities of all the most suitable dam sites. Where each contour line crosses a valley it could be the water line of a dam, and by drawing a line across the loop of a contour the dam can be "seen". On the map an examination is made of the primary valleys that fall to the secondary valley area which was selected for the start of the work. Beginning with the lowest primary valley falling on one side of the secondary valley, its keypoint is located, *i.e.,* the point of change in the slope of the primary valley at the bottom of the first steeper slope. Next on the map the nearest contour to the first keypoint is followed around to the next valley in the general direction of the rise of the land. If the keypoints of the valleys have the usual rising relationship into the rising country the contour followed will cross the next primary valley at a point lower than this valley's keypoint. Now the keypoint of the secondary primary valley is selected and the nearest contour on the map is followed in the rising land direction to the next valley, and so on until the highest primary valley in this system at the head of the secondary valley is reached. The primary valleys falling from the other side and into the secondary valley are examined in like manner.

These primary valleys vary in size. Therefore, they are appraised first from their significance in water conservation. The first or lowest primary valley flowing to the secondary valley is found to be too small a form to consider. The planning examination then considers the next primary valley, which is assumed to be of water conservation significance.

These matters are very simply determined on the contour map by examining the contour loop next below the keypoint of the valley against what is considered a suitable depth of water for effective water conservation. This latter matter, the suitable water depth of dams, must also be determined. Effective water conservation capacity for irrigation, or stock and irrigation, as distinct from purely stock water dams, should, in my opinion, be determined as a minimum of ten acre feet, approximately two and a half -million gallons. A twenty-foot depth of water should be accepted as a suitable depth for these Keyline dams. Confirmation of this figure will not be found in agricultural literature because it is a recommendation based on the results of my own experiences. By way of illustration, a dam with a depth of 24 feet of water at the lockpipe has generally been found to be double the cost of a dam on the same site but having a depth of 20 feet. If the contour loop immediately at or just below the keypoint of a valley can be joined by a straight line across the valley shape, thereby representing the wall of a dam, and just touches the top of the next lower contour loop, then a twenty-foot dam is represented. The capacity of the proposed dam is simply calculated by determining the acreage area bounded by the contour loop and the wall line, and multiplying by nought point four (0.4) times the depth. For instance, if the area of the dam is two acres and the depth of water is twenty feet at the lockpipe, the capacity of the dam is sixteen acre feet. The average depth of such a dam is thus generally 40% of the full depth of water at the lockpipe. In this manner the sizes can be determined against each valley and those valleys without value in water conservation potential in true keyline dams are disregarded in the first or general stage of the planning of "Yonaroo".

Now, there are two general approaches to the way in which the farm may be developed. Either it may be developed as a complete project in which all the work of the final plan is completed as one quick undertaking or, and much more usually, the work will be done over a longer period of time as finance becomes available from the results and profits of each stage of the development of the farm. Whichever approach is chosen the full final plan is prepared or at least understood before proceeding at all. On "Yonaroo" the design of the water supply sets the pattern for the whole of the development work.

While it may be assumed that the annual run-off is of the order of three to four inches there are occasions when the run-off in one year exceeds ten inches. There may be a run-off of even twelve inches in a short period in flood making rains.

In these circumstances of run-off all the better dam sites just below the keypoints of the primary valleys could be used. These dams will be filled by water conservation drains which follow the gently rising keylines of the land.

From prior knowledge of the uniform geological structure of the underlying rock of the secondary valley and from the examination of the contour map it will have been seen that the dam sites in each primary valley are progressively higher, permitting the use of keyline drains to feed water to each dam and to allow overflow water from each dam to flow into the keyline water conservation drain of the next lower dam or into the catchment above this keyline drain. Thus, all the water from the high country is controlled so that none escapes until all the keyline dams are filled. The keyline water conservation drains with the dams themselves are to become the most permanent structures of all the work that will be done on the property.

If the work is to proceed progressively there must first be permanent water. Under these circumstances the sites for all the projected dams and others to be discussed, are examined to select the dam that will best supply the early needs. Not only should the first dam be one that will fill quickly and provide low cost water, but it must be consistent with a site which will enable the water to be used for irrigation on a piece of land that can readily be cleared and developed for crops or pasture. Any one of the dam sites from the highest down may be chosen and built first so long as it is in its right place in relation to all other selected sites when the full plan finally emerges.

The capacity of all the true keyline dams will usually be filled frequently enough by the water conservation drains, but where there are many good capacity sites the average run-off rain for one and a half years from the areas above the dams and water conservation drain may be assumed as a limit to the capacity of the true keyline dams. A run-off of four inches per annum will be reduced, perhaps appreciably, by the soil developed in Keyline absorbing and holding more moisture, but the effect is less significant in periods of heavier run-off.

We have dealt with only the series of high-level dams, the true keyline dams. There are two further types of dams to be considered in this general climate and land form: they are *reservoirs* and *lower valley dams.* The reservoir site is looked for firstly in the area of the secondary valley below the highest dam of the keyline series. The reservoir or reservoirs may, in their height position in the secondary valley, lie below the level of the lowest of the keyline dams, but not necessarily so. A reservoir site could be just above the break of the land that marks the first formation of the small creek of the first secondary valley. The reservoir is kept high for preference and with some consideration being given to the area of its catchment excluding that of the keyline dams above it. The reservoir catchment is suitably related to its capacity if two years usual run-off will fill it. If a larger than necessary catchment is available two or more reservoirs are considered, the higher site being used before the others.

The lower valley dam or dams of this particular natural land area is sited at or near the point where the land form of the secondary valley finishes and becomes part of another division. In Keyline the lower valley dam is sited and designed to hold all the run-off from its catchment area for three years or more of average run-off.

This then is the general pattern of the water supply for the full development of the land in the area of the selected secondary valley.

While there is a pattern to the siting of dams, there is also a particular pattern developed in Keyline for the use of the conserved water. For instance, the pattern of use with all dams filled commences with irrigation from the true keyline dams immediately irrigation is advantageous or profitable. The lower dam also comes into use at this time to irrigate its own special irrigation area, but the reservoirs are left filled while there is ample water still in the true keyline and the lower dams.

There is one other aspect of the overall water supply on "Yonaroo" to be considered. This relates to the whole farm and to the creek which is formed and fed by the joining of the two smaller watercourses of the two secondary valleys and which in turn join the boundary creek. It will be assumed that each small creek has a water catchment area of approximately 400 acres.

Three different types of dams have been discussed: (1) The true keyline dams located at the head of the second slope of the primary valleys. (2) Reservoirs, lower in height, and located in the upper part of the secondary valley beneath the highest of a series of keyline dams or just below the junction of one of the highest of the primary valleys with the secondary valley or in the lower end of a larger primary valley before its junction with the secondary valley--there may be one or several reservoirs in a secondary valley area. (3) Lower valley dams, which are located in the secondary valley at a site located above the junction of the watercourse formed by the two secondary valleys. When the boundary of a property crosses a secondary valley, the site of a lower dam is chosen so as to ensure that it will catch all run-off from the land below the other dams and also the overflow of these dams. We have seen that these three types of dams are simple and obvious against the background of the undulating country of "Yonaroo". Where there is sufficient variation in height over a property, the factors which relate to these three types of dam generally apply.

Getting back to the creek formed by the junction of the flow of the two secondary valleys, conservation of water here is not entirely in the hands of the farmer. In Australia, Government authorities generally control or administer these matters. A dam constructed across a defined and confined watercourse requires the permission of such authorities, since consideration must be given to the rights of owners of land below through whose property the creek later flows. There is also something less than law but still of some consequence which says that a farmer has the inalienable right to as much as he can store of the rainfall which actually falls on his own land. Even if all the rainfall which formerly was lost in run-off is now conserved in the soil and in farm dams by the farmer, he is still not holding all the water. Quantities of water would be continuously moving into the earth below the farm and so replenish ground water supplies. Springs which thus form are the only constant flow water of the creeks and rivers. The more water the farmer conserves the more water moves underground as seepage from his soil and from his dams. More water will also evaporate over his land.

Generally then, before these dams on creeks may be built, application has to be made to the appropriate Government authority, who cause a notice to be inserted in a suitable daily newspaper giving information of the proposed dam to those who may be interested. Other farmers have the right to object to the dam if they consider it is detrimental to their own lands. If such objection be lodged the matter is heard by an authority but with the rights of appeal, if necessary, determined by such court as the Land and Valuation Court. When authority is given the farmer is not released in any way of responsibility for the dam. The deciding authority in permitting the construction of the dam does not assume any responsibility for the effectiveness of the dam. This general procedure, in instances which have concerned me, is a source of inconvenience and delay on a matter that should never be unnecessarily delayed.

Here again, it seems to me, is a purely agricultural matter that should be determined quickly by the agricultural officer on the spot. He may be the local agronomist, dairy officer, or any other. An alternative procedure could be that the farmer first contacts his neighbour below and acquaints him of the project as a matter of courtesy and expedition, and then informs the local agriculturalist who accepts the farmer's application by word of mouth or telephone and immediately calls to inspect the proposed site. The agricultural officer should not be in any way responsible for the site selection, design or construction of the dam, but should be capable of offering effective advice if requested to do so by the farmer. The officer, who in all probability knows the farm well, should merely appraise the creek flow, if any, and then decide if the dam would detrimentally affect the neighbour or neighbours in the next two-mile length of the creek. The creek may be a constant-flow type, which would flow to the same capacity after the construction of the dam for most of the time, but on the other hand if in his opinion it could cease to flow in a drought where formerly it did not, the agricultural officer may then suggest to the two or three concerned that the farmer owning the dam should release a certain specified flow in drought times when there was still water remaining in the dam. If this is agreed he could issue a notice to each recording his inspection of the creek and the stipulation referring to drought flow. The dam could then be built but it would remain the farmer's sole responsibility. He is responsible for damages, if any, if the dam fails, and while there is water in the dam above the level of the original bed of the creek at the site, the farmer in dry times would release the equivalent of the drought flow. There will be concern in the minds of only those with little knowledge of these matters at the possible loss of water caused by a dam on one farm to the land of the property below. Generally, the more water that is conserved and used on farms the more constant and reliable is the flow in the creeks below. However, the rights of neighbours must be fully protected, and indeed, Keyline enhances them.

A dam constructed below the junction of our two creeks of the secondary valleys may be of relatively large capacity and of low-cost storage. It would have a natural catchment on "Yonaroo" of 800 acres, including the catchment area of all the other dams. In the present planned water storage scheme it would appear to have little chance of filling even in substantial floods. Under usual circumstances, the influence of the greater water storages above, the constant use of the water on the irrigation areas, and the continuous partial and complete recharging from each rain of the dams of the primary and secondary valleys, would cause the natural and intermittent flow of the creek to become a considerable constant flow. This effect may take two years before it starts to function.

In my opinion the matter resolves itself into a somewhat optimistic appraisal of the circumstances relating to filling capacity, cost of construction and use of the water. As there are still areas of "Yonaroo" below the projected creek dam it may be possible to use the water from the creek dam by flow methods of irrigation. In these methods of water conservation all dams are constructed with lockpipe controls. In the construction of dams in flowing creeks in this type of country the lockpipe system makes what is with other methods always a difficult and costly job, now a simple and easy one.

A creek dam built recently on "Kencarley", at Orange, flowed the water of the creek, which carried a constant flow, through the wall *via* the lockpipe installation during the construction of the dam. As part of the general site preparation work, the lockpipe, 140 feet total length, was laid in a prepared bulldozer trench at the level of the creek bottom and a little to one side of the creek bed where the water originally flowed. Immediately a full bulldozer blade load of good wall material was pushed over the lockpipe near its inlet end and across the flow of the creek, the water entered the lockpipe and flowed there and right through the wall, where it continued to flow during the building of the wall. There was no water and mud to cause trouble and the work proceeded in the same orderly manner as though the construction was in a dry primary valley.

There are many circumstances, where, while there is no suitable land for flow irrigation below the lockpipe level of such a dam, there is suitable land for this purpose below the level of the high water of the dam. In these circumstances a pipe from the lockpipe outlet to a suitable higher point between the levels of the lockpipe outlet and the top-water line can discharge water into a suitable irrigation drain and may employ the lowest cost method of irrigation for half the depth of the water in the dam. Much more than half the water capacity of the dam is contained in the top section. In such circumstances the dam, as it were, has two levels, top water level and irrigation drain level. In a large dam of this type the land lying between these two levels and covered with water when the dam is filled and at other times dry, may be prepared for special crop production. This type of dam and other special purpose dams are discussed in later chapters.

There remains the smaller catchment area of the property, which is actually the small top section of a secondary valley and which is planned to its own particular development capacity. The only area on the property presumed to be too steep for mechanical clearing lies near the head of this valley. The flatter top section is cleared and the steep section is left for possible later hand work. The lower area is planned and developed as are the other secondary valley areas.

The creek flowing to the property from higher lands and forming a part of the boundary of "Yonaroo" may now be considered. Several land owners could have an interest in the part of this creek that is on the property.

In general, where creeks form property boundaries, the centre line of the creek is presumed to be the boundary. However, the fenced boundary is a give-and-take arrangement, which provides suitable exclusive access to the creek for each party. Apart from the right of owners lower down, a dam on this creek would cover part of the adjoining neighbour's land and therefore could be constructed only on a mutual basis. After satisfying the land-owner lower down, a dam may be considered in which all details, including proportions of cost and particular rights of water usage, would need to be embodied in a formal legal document acknowledging permanent right of each area of land on the other. Water may be taken from such a creek by the various owners provided the reasonable rights of all others are protected. The water that is most significant generally is that which is above normal flow and up to flood flow. Small inexpensive weirs may divert water to a water race or water conservation drain, which would follow the general fall of the land to provide irrigation by flow methods. However, the only time during which this water is readily available is when it is not likely to be critically needed. Good creek flow is a feature only of good seasons. So the best use of the available water may be by the conservation of the water from the creek when flow is good, *via* a suitable drain into an off-the-creek storage. It may be brought into dams already a part of a primary or secondary valley storage or into a dam to be constructed in a special new site. If the creek water can be diverted to a previously constructed reservoir the use pattern for the water of the reservoir could then be changed to suit its new faster and more frequent filling capacity. It could become a special purpose dam and all its water used by flow methods as soon as irrigation was advantageous. With this matter suitably decided the full water conservation capacity in surface storage sites available on "Yonaroo" is now finalised.

I have suggested that dams for farm irrigation be limited to those with a capacity of a minimum of 2-1/2 million gallons, or ten acre feet. The limiting of a farm irrigation dam to this minimum size should be consequential to site, limitations and represent the amount of the water storage capacity of the site with a wall 23 feet high and water depth at the lockpipe of 20 feet. Dams of ten-acre feet capacity are generally the highest cost water storage with costs running to £200 per million gallon, *i.e.*, £50 per acre foot, or the equivalent of four shillings per thousand gallons of storage capacity. In the past I had considered £30 per acre foot as a satisfactory cost figure, but now am not inclined to set any cost limit to the value of storage capacity. In Keyline the storage capacity of dams is a permanent asset. The cost of the water as distinct from the water storage capacity relates to the storage cost divided by the number of times the water of the storage capacity is used. If the water is used twice a year for twenty years the cost of water from the most unfavourably sited farm dams is very low. The smaller farm dam also costs relatively more for the reticulation of the water, and in flow irrigation the cost of the lockpipe system and the irrigation drain, which constitutes the full irrigation system, will add approximately 66% to the earth cost of the dam. In a large farm dam of, say, 400 acre feet the cost of the lockpipe and the reticulating drain and irrigation system may add only 10% to the earthworks cost of the wall. The three costs are: (1) earthworks on the site and in the wall; (2) lockpipe system; (3) conservation and irrigation drains.

It can be understood that while all these decisions on the overall planning and the water supply scheme can be determined very quickly with the aid of the special contour map, the absence of the map changes things considerably. Then the same decisions must be made from direct observations on the land, in which matters determined almost at a glance on the map, without the map now involve much walking and some measurements and levels. A start is made as before at the lower limit of the secondary valley above the point where it junctions with the creek of its companion secondary valley. The nearest primary valley is the first one inspected. The valley is tree covered and it is necessary to walk up the centre of this primary valley to locate the keypoint of the valley. This presents little difficulty. Then it must be decided whether or not the valley is of significance in the planning which is based on water supply. If there is some doubt on this matter a more thorough examination of the valley will be necessary. This is done with the aid of a level, and in tree covered country our Bunyip level provides the quickest means. The examination first ascertains the "valley floor slope". Over my twenty years of experience, experiments on the siting and the design and the construction of many dams, valley floor slope emerges as one of the important design considerations for all farm dams. My farms dams are described fully in later chapters, but some points may need to be mentioned briefly as the development of "Yonaroo" unfolds.

A valley floor slope of one in twelve is too steep a site generally for a dam unless the rest of the valleys are similar or steeper. One in twenty is a satisfactory slope and one in thirty or flatter is considered good for a true keyline dam site.

In the first primary valley a point is selected one to two feet lower than the keypoint of the valley and the first staff is stood up. From this point and another point fifty feet away (the full length of the water tube of the Bunyip level) and down the centre of the valley the readings on the two staffs of the level are taken to determine the height difference. The difference in the levels, as read off the two staffs of the Bunyip Level for the fifty feet distance apart, determines the valley floor slope. A difference of one foot in the reading of the staffs indicates a valley floor slope of one in fifty, which is better than may usually be expected for a true keyline dam. If the valley floor slope is too steep the valley is not considered any further at this stage. Apart from a satisfactory valley floor slope, the valley needs a suitable "shape", which again is determined with the level. From the point previously pegged just below the keypoint, the Bunyip level is used to run out a true contour in both directions, marking points along the contour as conspicuously as possible; and so is determined the shape of the top water line of the possible dam. Here again classifications and determinations of my own must be mentioned. The length of a dam is the distance from the water line at the middle of the wall up the valley to the top water line of the dam near the keypoint. If the length of the proposed wall (a line across the water level contour) and the length of the dam are equal, then the site satisfies what I consider minimum requirements. But if the wall length is longer than the length of the dam, then the site is rejected for water storage.

A dam length twice as long up the primary valley as the length of its wall is of good shape. It is assumed that the first primary valley has a valley floor slope of one in eleven and would require a wall of 300 feet long to contain a depth of twenty feet of water at the lockpipe. These figures indicate that the length of the dam would be the depth in feet multiplied by the slope (20 x 11 = 220 feet). This figure could be further checked by taking levels from the peg placed originally just below the keypoint, down the valley twenty feet vertically lower, and from this point measuring back to the original peg. The wall of the proposed dam is longer than the dam, so the site is abandoned. But this dam site also fails on minimum requirements in another direction, that of capacity, which can be quickly checked by the following means: The water surface area of the proposed dam can be calculated by taking two-thirds of the area found by multiplying the length of the water line at the wall and the length of the dam measured at right angles to the wall (300 x 200 x

2/3 = 44,000 square feet = 1 acre approximately). Again, assume that the average depth is nought point four (0.4) times the water depth of 20 feet, which is 8 feet. The capacity of the proposed dam is therefore approximately 8 acre feet, against our general minimum capacity recommendation for a farm irrigation dam of 10 acre feet.

Continuing the inspection from the first primary valley which is suitable for water conservation in a dam, it is then necessary to run a near contour or rising keyline to the next primary valley up land. As the country is tree covered, the line will need to be marked in a manner that will permit of being located again later. This type of work is continued on the land generally as done on the map, but it takes considerably longer to obtain an appreciation of the land shape and the valley relationships. For the real work to proceed and whether a contour map is available or not, the marking out of these keylines must eventually be completed on the ground. Without the map, trial lines will sometimes be necessary to obtain a first understanding of the primary valley inter-relationships.

To summarise these early planning points. First, obtain an overall picture of the relevant larger agricultural land units and, as seen so far on "Yonaroo", these are four. Second, select one as the first for development, considering perhaps accessibility and uniformity of shape. Third, as water conservation in farm dams is determined to be of prime importance (judging from the climate and the land shape), examine the primary valleys of this first development area and ascertain both their significance in water conservation and their relationships, *i.e.,* whether they possess the general "rising relationship".

In general land development such as at "Yonaroo", where the conservation of all run-off water is planned, the keylines are lines rising with the rising country. As soon as their positions are determined, and marked with suitable pegs, clearing of the trees and brush may commence.

The keylines themselves are first cleared by a bulldozer, following the pegged line and forming a definite cleared line which will represent also the boundary between cleared and uncleared land. A strip or tree belt is to be left along the keyline and may be either above the keyline or below it. In the conditions here where water conservation is vital it will be better for the tree strip to be left above the keyline. The first cleared run of the 'dozer along the keyline represents the top boundary of a strip of cleared land or land to be cleared which lies below the keyline. The timber belt itself is left standing above the keyline.

Any belts of trees left to form part of the permanent landscape should be wide enough for good forest condition to be pertinent. Strips which are too narrow tend to die out in about the same time that single trees take to die, but in conditions that resemble those in the natural forest, trees live longer and natural regeneration also takes place, thus preserving the tree belt in perpetuity. I have found that a width of twenty-five yards of trees in approximately these conditions appears to promote good conditions for timber-tree life and growth. This is the distance suggested as a minimum, and thirty yards as a general width. The first tree belt then is located by marking a strip of land twenty five yards wide in the trees above the keyline, a line uphill and parallel to the keyline.

The next permanent line of importance that may be preserved in a treed belt is the irrigation drain. Whether it is to be or not be used by the immediate construction of the dam, its site should be located at once if a strip of trees is to be left above the irrigation drain. The keyline tree strip works satisfactorily whether it is above or below the keyline drain. I prefer it above, so that in crossing the valley it does so above the dam, and thereby protects the dam from wind which causes wave erosion and the trees also retard evaporation; but the tree strip of an irrigation drain is located always above the drain, so that water does not flow through the trees when irrigating the paddock.

All the details of the water conservation and irrigation drains of Keyline, including their sites, designs, construction and uses, are explained in later chapters. However, to follow the course of the present development, it may be appropriate at this juncture to briefly discuss the drains used in Keyline. Many farmers know drains from the anti-soil erosion approach, but the drains of Keyline are totally different. There are only two classes of drains in Keyline. The first is the water conservation drain, which is for the express purpose of transporting run-off rainfall into farm dams. The second is the irrigation drain, which provides for the economical use of the irrigation water and generally, with the lockpipe, completes the irrigation equipment. The water conservation drains of Keyline may follow the keylines as we have discussed, or be located below the higher section of a property which does not include the complete land shapes of primary and secondary land units. Where these land forms are large, the land of a property may be of sizeable area and still only include a portion of one of these land systems. Again, the drains of the Keyline plan are permanent features while those of soil conservation are not, since they are designed purely to overcome soil erosion problems, when, if the drains are successful in their purpose, the problems no longer remain and the drains become superfluous.

The first irrigation drain on "Yonaroo" is located from the position of the lockpipe outlet of the first proposed dam. These lockpipe outlets are described in later chapters.

With the irrigation drain pegged in the down land direction from the outlet point the bulldozer clears the drain line. The tree strip is marked twenty-five yards wide in the trees above the line and again marked by the bulldozer pushing the trees down along this line. There is now an area ready for clearing with its upper limit marked by the pushed-down path of the keyline and its lower limit by the top of the irrigation drain tree strip.

The best means of getting the trees down is by using two large bulldozers with a 400-foot or longer length of six-inch wire rope (about two inches in diameter) or with a heavy chain. One bulldozer travels the top marked line, the keyline, the second 'dozer travels in the same direction about 100 feet lower down in the trees. The first run pulls down a large area of trees quickly. The second run should be made with one 'dozer on the line above the tree strip of the irrigation drain and the other in the trees 100 feet or so above it. After the first run, which pulls down a strip below the keyline, and the second run, which pulls down a strip above the irrigation drain tree belt, are both completed, the pattern of the work is clear. It is then a matter of pulling down the trees that are left in the centre of the land strip of what will be the first cleared paddock area. When pushing down and clearing are to be done with one bulldozer it should start by pushing down from the keyline into what will be the cleared strip and working right along the line. When this is done it pushes up into the area of clearing from the line above the trees of the irrigation drain tree strip. This part of the work when properly supervised, leaves the job in a condition where mistakes in pushing down trees in the wrong places are nearly impossible and supervision may be relaxed if necessary.

The keyline rising into the rising country from the keypoint of a primary valley in which a dam is planned, may, if extended, cross the next primary valley well below its keypoint and even below a keyline dam site in the second valley. There are sometimes very interesting planning possibilities in this feature which should not be missed. For instance the keyline water conservation drain feeding run-off to the lower keyline dam of a series of keyline dams may, as it approaches the next valley higher up land coincide with the irrigation drain from its keyline dam. It could, in some cases, be much lower than this irrigation drain and coincide with the extension of the irrigation drain of a keyline dam higher still. It may be suitable, in special circumstances, to continue the keyline tree strip of a lower primary valley right through the land area of the secondary valley. All drains, both irrigation and water conservation drains rise into the general rise of the country or, the same thing, fall with the general fall so that the slope of any drain line does not clash with any later work.

The tree belts to be left in the clearing of "Yonaroo" take their pattern from the first four factors of the Keyline scale, namely, climate, land shape, water supply and farm roads. So far, in considering trees in relation to the water supply features, dams and drains, the first two factors of the scale, climate and land shape, which govern water supply, therefore are interpreted also in the tree lines. We now must consider farm roads in fixing tree-belt sites other than those along the keyline water conservation drains and irrigation drains. Some of the work roads will take their pattern from the two drains already mentioned, but the roads of particular significance at this stage in the planning are those that travel the main divides, on the property and the others branch roads from these which lead down to the creek or the bottom of the secondary valley. Their preferred site is down the neutral line of a suitable primary ridge. The road would then leave the secondary watershed ridge, the main ridge, and turn down the neutral line of the primary ridge. Here it could have to cross a keyline drain and an irrigation drain. Since this road provides access to the work roads or travel ways along these drain features it will probably be necessary to provide from one to three such primary ridge roads on both sides of the secondary valley. They will cross through the tree lines, so far discussed, at approximately right angles. These first tree belts provide protection from wind blowing in the general uphill or downhill direction of the primary ridge and primary valley, but they provide less effective protection in the direction of the general rise of the secondary valley. This latter protection is provided by a strip of trees left in the clearing of the land on one or other side of the primary ridge roads. A fence may follow the road on one side with the uphill and downhill tree strip on the other side of the road.

Summing up as far as we have gone with the tree landscape, we have now a tree belt located by each of the keyline water conservation and the irrigation drains and by the main road which generally follows the boundaries of the watershed of the secondary valley, and also by the roads down the selected primary ridges. These tree belts set the particular pattern for the whole of the clearing to be undertaken in this secondary valley.

Above the keyline tree belts there will be further cleared paddock areas. These are located by deciding a suitable vertical height above the keyline for the lower line of the next tree strip. The most suitable minimum vertical height is estimated from the general approach that the tops of the highest trees of the lower tree strip, in this case the keyline strip, should be approximately on the same level as the ground at the lower side of the timber strip next above. This is not merely a matter of estimating the height of the highest trees. The average height gain in the tree strip from the keyline to the top ground line of the trees in the strip above it must be considered. For instance, if the taller trees are forty feet high, and the slope of the land generally in the keyline tree belt is one in eight--12-1/2% grade--the minimum vertical interval of fifty feet six inches is obtained. The calculation is as follows: The keyline, the actual line itself which forms the water conservation drain, needs to be ten feet clear of the tree belt above it so that equipment can build the drain without obstruction from trees; the tree belt is twenty-five yards (seventy-five feet) wide and the distance therefore is eighty-five feet minimum from the keyline to the higher edge of the timber belt just above it. The grade of the land--assumed one in eight--places the top edge of the keyline tree belt ten feet six inches vertically above the keyline and which, added to the height of the trees--forty feet--gives a vertical interval of fifty feet six inches,.

In retarding the drying effect of winds that blow across the clearing, tree belts at this vertical interval apart provide a very powerful influence on all the cleared land. The generally accepted relevant figure is that such a tree belt will appreciably retard wind velocity for a distance of 1,200 feet on the windward side of the tree-belt windbreak; therefore the cleared area is appreciably affected. But another favourable factor also operates. A tree belt or windbreak also retards the velocity of wind on the leeward side of the windbreak for a distance of approximately 200 feet under these conditions, and so provides greatly increased effect in the area approaching a second tree belt where the protection afforded from the lower tree belt would be petering out. In my opinion this influence on wind alone makes clearing on this pattern more than fully justified; it should be considered imperative on this type of land. It has been found also in all my experiences of these matters that the extra planning and supervision which is necessary in this method of planned clearing so increases the interest of all concerned that added efficiency results which in turn actually reduces clearing costs below those of other methods.

The position of the first tree belts above the keyline tree belt is determined by the foregoing methods and a strip of trees twenty-five yards wide is left as before. Generally the areas of cleared land above the keyline are above the highest dams, and so there will be no grade lines needed. The belt of trees may therefore follow a grade similar to the drains as before or be placed with the lower edge of the belt on a true contour. Whichever method is used, measurements which locate the tree line in reference to the lower belt are taken at near the middle point along the length of the keyline, the neutral line of the primary ridge. When the area of land above the keyline tree strip, or above the strip next above it, is below the height referred to, then all the area above is cleared with the exception of trees which may be left along a road or a boundary fence line.

The first tree strip to be left below the irrigation drain tree strip conveniently follows the lowest boundary of the irrigation area. Irrigation paddock boundaries are therefore considered and determined at this stage.

In Keyline flow irrigation which will be employed here, the irrigation area comprises a strip of land along and below the irrigation drain which is limited in depth down the slope by the distance that irrigation water will travel in one hour over the particular land fall. The distance downhill or the width of the irrigation area is influenced by another important fact, peculiar to a Keyline development, which also requires brief explanation at this stage. It involves a summary of a new approach to irrigation. Keyline techniques provide the widest control of water, including methods which control the movement of water over land surfaces for irrigation purposes. Low-cost irrigation is therefore eminently practical on land and land shapes and slopes that are seldom considered suitable for irrigation by orthodox methods where it is usually something which is considered with flatter and very flat lands, including, in the undulating country, the creek and river flats. Keyline irrigation principles and methods usually apply to all such land in a more effective manner than do orthodox methods, but it also brings another and extremely valuable and as yet unrecognised type of land into the class of high-value irrigation country. This form of land embraces the hill country which is not so steep that it is incapable of being cultivated on Keyline methods by the farm tractor and implements. It also can include country that is considered somewhat steep. Where water can be conserved and flowed on to hill country, such land will become the highest valued pasture and crop land, not excluding river flats. I realise that to most people such a statement will require a lot of proof. I trust it will be found in this book.

Drainage is one of the ever-present problems of flat land irrigation. So water, which is our main lack, then destroys land by being over supplied. This is strange, but true. Keyline hillside irrigation (the methods are covered in detail later), is designed for the highest efficiency in water use, which is in part accomplished by irrigating as high on the land as practical by Keyline flow methods, and leaving a strip or paddock of unirrigated land below the irrigation area. The unirrigated area lies between the lower boundary of the irrigation paddock and the bottom of the secondary valley below. This particular design in Keyline immediately eliminates drainage as a problem of irrigation. The surplus water, if any, from the irrigation area can only improve the dry or rain-only land below it. Therefore the bottom of the valley or flat land, the drainage problem land as normally irrigated, is segregated from the general irrigation water by a dry area. The dry or rain-only area is improved by the drainage, if any, of surplus irrigation water and improved by a moisture drift, which always develops later from the irrigated land. The secondary valley, often too wet naturally, is also improved by the protection thus afforded from excess water and further improved by Keyline soil development methods.

Consideration of these new factors, then, assists in determining the width of the irrigation paddock below the irrigation drain toward the bottom of the secondary valley. My own experience of these matters generally indicates that such an irrigation area should be at least twice the length along the irrigation drain as its width downhill from the drain. On short to medium length land, as defined in Chapter VI, "Land Shape", there will be sufficient space down the length of the land, *i.e.*, the length of the primary valleys and primary ridges, for only one such irrigation area from each irrigation dam. The width of the irrigation paddock could be such that half the land lying under the irrigation drain to the secondary valley bottom below is irrigation land and half rain-only pasture or crop land. The longer the irrigation areas, then, the larger generally will be the rain-only area below which will be improved by eventual moisture drift from the irrigation land. Circumstances applying in medium length land may provide a general width above the keyline water conservation drain of 230 to 300 yards to conserve water to an irrigation dam, and perhaps 400 yards width of land below the irrigation drain, of which half the width would be irrigated and the remainder comprise the rain-only area. However, these circumstances are determined only by the land shape as it exists. The farmer can, however, always do the best with what he has.

In longer-slope country it may be suitable to plan alternate strips of irrigated and rain-only land. For instance, on one section of "Kencarley", at Orange, the natural land shape and length of land permits flow-irrigated strips fairly high up on the land. Down the slope below the first strip of irrigated land there is a 25-yard-wide tree belt and a cleared rain-only area for pasture and crops. This is followed down the length of the land by two other tree belts, irrigated areas, and rain-only areas; in all three irrigated areas with, alternate rain-only areas below each of them.

There are other considerations which help to finalise the decision as to the most advantageous width for the irrigation area. These are discussed later.

We may assume that on "Yonaroo" this first area is a little longer than short slope land, and that the first irrigation area is twelve chains wide along and below the irrigation drain. The lower boundary of the irrigation area may be either planned from a true contour line or another grade line falling with the general fall of the land, as do all grade lines or drains. In this decision there are two factors to be considered. A grade line on the same fall as the irrigation drain will not generally enclose an area of uniform width below the irrigation drain. There is a tendency for such land as that of the irrigation area to flatten slightly with the general fall of the land (the fall of the secondary valley), causing the irrigation strip to widen in the down land direction. This is usually not a problem, since the area of rain-only land below the irrigation area always widens considerably by the fact that contours in the down land direction move away from the bottom of the secondary valley. If the possible increasing width of the irrigation area is a definite disadvantage (as the irrigation drain is followed down land), a lower irrigation area boundary on the contour has a compensating effect by the fact of the irrigation drain's slight fall approaching a little this lower contour.

However, in the circumstances on "Yonaroo" we will decide on "no contours" and mark the lower boundary of the irrigation area as a grade line falling down land.

We may now mark out the tree belt below the irrigation paddock and clear the timber from this area and from the land below it down to the bottom of the secondary valley.

Our discussion on clearing has been confined to only one of the primary land units with its primary ridge and primary valley form. The keylines of the remainder of the primary land units in the secondary valley area are marked and the clearing is completed for the whole of this first of the four distinct major land units of "Yonaroo".

We are now in a position to assess the progress of the work. The general situation may be that while all the future dam sites, their conservation drains, irrigation drains, and irrigation areas have been decided and, with the farm roads, influenced the plan of clearing, one dam site only has been determined for immediate construction. As the property cannot operate satisfactorily until permanent water supply has been obtained it is advisable that the first dam be constructed as soon as its site is selected and cleared.

The clearing down the length of any primary ridge at this stage discloses: (1) A keyline tree belt with cleared land above and below it. (2) A tree belt in the areas above the keyline trees with cleared land above it to the top of the watershed or main ridge. (3) A tree belt along the main road on the watershed divide or main ridge. (4) A tree belt along the upper side of the irrigation drain with rain-only pasture or crop land above it and irrigation land below. (5) A tree strip along the lower boundary of the irrigation area with the irrigation country above it and rain-only land below it to and including the bottom of the secondary valley. If the land above the keyline rises to legs than fifty feet six inches higher vertically than the keyline there will be no timber belt above the keyline trees other than trees which may be left along the main ridge road.

The line of the tree strip from the lower primary valley and ridge units are continued up land through the other land units according to how they work out in the planning of each unit in turn. Some reasonable adjustment may be made but otherwise each primary unit is designed individually. In my experience there are always lines which, when continued up land, fit the higher primary land units.

The lower tree strip, which approaches the bottom of the secondary valley is preserved as a tree strip crossing the valley into the primary land unit on the other side of the secondary valley. Other than the tree strip which crosses a valley when continued to plan, all trees should be cleared from both primary and secondary valley bottoms. Trees left in the valleys will always tend to limit the full development from the increased soil fertility and productiveness that rapidly follow the greatly improved environment from the Keyline planning and management. The secondary valley may be improved to such an extent that a portion of the broken land at the first formation of the confined stream bed may later be smoothed over to a form where cultivation may cross the old break.

There are many who recommend the leaving or planting of trees along a broken stream course or an erosion gully in the bottom of a primary or secondary valley to protect the land from soil erosion. In the great majority of cases in our climate and soil conditions, all that the trees "protect" is the permanence of the gully. They will prevent the easy smoothing over of the break when smoothing may be warranted. They will also screen the immediate area of the break in the land from the repairing effects of the improving environment.

Apart from the lines of the four of five tree belts running generally across the land, across the primary valleys and primary ridges, there are belts of trees along the roads down two of the primary ridges.

With both sides of the secondary valley area (secondary land unit), which includes the several primary valleys running into it, now completed and. one dam built with its water conservation drain installed, (a true keyline dam was selected as the first to be built), it is as well to go on immediately with work to develop the soil and pastures of the property. We begin with burning off and cultivation. This is the work of the next chapter.

CHAPTER XV

Completing the Landscape

LANGUAGE, like landscape, must change and grow, and men who work among trees call them "timber". Although this word originally belonged to the tree that would make a good log or to the sawn-up wood of the log, the Australian land folk at least will find the word timber as familiar as "trees".

Once the main timber pulling is completed on "Yonaroo", with the timber for fences already taken out, the remainder is pushed up for the first burn. Pushing up for the burn and burning is almost invariably a bigger task than roping the timber or pushing the timber down. On this job sound reasoning, planning and supervision pay good dividends, through greatly reduced time and money costs. It is important, by providing ground helpers continuously, to keep tractor operators on the tractor driving the tractor all the time. If a tractor is worth seven pounds an hour someone is paying seven pounds an hour for labour whenever the operator has to climb down from his machine to do something a ground man should be doing.

In the operation of pulling down timber with rope or chain and two large tractors, two men should usually be employed on the ground. On "Yonaroo" big stumps will on many occasions resist the combined power of the two tractors when the rope is close to the bottom of a tree stump. The ground man is the first to see the hold-up and can signal the tractors to back-up a few feet when the ground man lifts the rope to a higher position on the stump. With the greater leverage now exerted by the tractors the stump may be moved readily. Even so, stumps will on occasion defeat the pull of the tractors and then the ground man, after signalling the tractor operators to again back-up, moves the rope to a position where it will ride over the stump. An occasional big stump left is not serious. The heaping of timber over the stump may cause it to be burned out later.

I have had experience in the clearing of country similar to that described, where, in dry earth conditions, there were many large stumps and enough large trees to cause real hold-ups. A third tractor was then used to follow the rope behind the two tractors that were pulling down, and the third tractor pushed the tight trees and stumps while the two others pulled. It was well worthwhile. Still, ground men were needed more than ever to supervise and co-ordinate the three power units.

To get back to pushing up for the first burn. A roughly or haphazardly pushed-up heap of timber does not necessarily, or even generally, make for a satisfactory first burn. A good fire must be built. The first point is to burn only what should be burned. The heaps of timber therefore are kept at a suitable distance from the now very valuable standing tree belts.

There are two general patterns to pushing up for a burn. The timber may be pushed into a series of many suitably-sized heaps or it may be pushed into long windrows. Well built windrows, when the timber is of a type which burns well, may be the better of the two methods, but if the windrows are poorly made or the timber is difficult to burn there is then a lot more pushing-up time needed before the second burn than there is for suitably-sized heaps. Windrows should follow the land on the keyline or tree belt pattern with the first push made from the standing timber line in a downhill direction for seventy or eighty feet. The distance of the bulldozer movement is influenced by the thickness of the timber.

Big trees will burn only if their trunks are parallel and close together. It is then always necessary to preserve the main trees in line along the line of the windrow. "Magpies' nests" of big logs do not burn well.

The second push is from a distance of sixty to eighty feet below the partially-built windrow and pushes the timber together to form the complete windrow. The next windrow should be made similarly but by first pushing uphill from the lower tree belt a distance of sixty to seventy feet, and then pushing from above this line of the new partly-made windrow downhill from seventy to eighty feet above. If the windrows are too small they do not burn well.

Timber should not be pushed into the bottom of a valley. Heavy rain, before burning, may cause difficulties in slow drying-out, and after burning may wash out some of the soil which was killed below the fire area.

Pushing into heaps is done to a design based on the principle that the shorter and more consistent the length of the push the more efficient the operation. The push is to a selected spot for each heap, keeping the heap the full distance of the push from the tree belts. The area around each heap should be represented by a square with sides equal to twice the length of the push. The push distance is kept down to sixty to ninety feet if the timber is thick enough to make a good burning fire. All heaps should be as near as possible of the same size.

One of the very important rules in any burning operation is "burn the difficult one first"; therefore the area of fallen timber is examined for the difficult-to-burn stumps or trees, and these, preferably, are pushed up on top of the heaps. Burning is not a matter of throwing a match into a part of the heap or windrow and forgetting it. If done wrongly all the easy-to-burn material, which should be burning the hard-to-burn pieces, burns itself out. The tendency in unplanned and unsupervised work is for costs to be considerably increased by the loss of the easy-to-burn material, leaving only hard-to-burn pieces with nothing to help burn them right out.

When conditions are suitable and the equipment, bulldozers, etc., are available, all the heaps should be lighted from one end of the area, in turn, through to the finish. The fires are left to burn down to a point where, while there are still red-hot pieces in them, the main blaze and most of the heat are gone. This burning time may occupy anything from four to twelve or more hours, when the equipment should be ready for the second push-up. Although care is taken there will always be some soil and earth in the dying fire from the pushing-up operation. It is preferable then to push the unburned but still alight material to form a new heap just off the original heap. Ground men at this stage should place the unburned ends of logs and sticks where they will help burn the awkward pieces. Attention should always be concentrated on the big pieces.

There will be unburned material remaining after the second push-up and burn, but it does not usually pay to use a large bulldozer in a third push-up of this material. It is usually a hand job now and should be done before the fires of the second burn are dead. Again, the ground men concentrate on burning the bigger pieces. A big log can be simply burned in half with smaller wood piled under it. The two halves dragged together will then burn well. Small stuff should not be heaped and burned to "tidy up" while there are larger pieces unburned. Light material is always easy to burn, but once it is gone the bigger pieces may prevent the work from ever looking tidy. How, often does one see evidence of the point of this advice, in partly-burned big stumps and tree trunks lying around paddocks spoiling the appearance and reducing the usefulness of cleared land and with no small stuff in sight that would make a fire to burn them? Supervision of such work in land clearing will pay, as does the proper supervision of other types of work.

After the burning-off cultivation begins, and the land of the secondary valley area with its several primary valleys is now made ready for seeding. As the land is poor the method of quickest soil improvement is through a pasture stage. The final "picking-up", or "sticking", as it is often called, of the area may be designed to get rid of only those pieces remaining that are large enough to handicap cultivation and sowing operations. It is advisable to keyline cultivate the whole area with the chisel plow as soon as possible, so as to put the soil into a condition when it will absorb evenly a suitable rainfall. Newly-cleared land may need two and sometimes three cultivations to put it in shape for further work. The final of these cultivations--which are completed one after the other with no delay between--follows the Keyline pattern as discussed in Chapter II, "The Aims of Keyline", and mentioned in other references. As the soil is poor with less than an inch of the "colour" of fertility, the cultivation is kept shallow, perhaps two inches, or a little deeper if it is to help clean the land.

The irrigation area has the highest potential of the cleared area and should be cleared and cleaned to the extent necessary for this type of land. More complete cleaning is necessary if crops are to be harvested. Once the first irrigation dam is filled the irrigation paddock alone will often support the start of the new farming and grazing enterprise.

The final cleaning of a cleared paddock can be time-consuming and a suitable mechanical aid is a big advantage. I generally use a Graham plow with all the clamps and shanks placed on the back beam of the plow, as an effective power rake. Again the procedure is to examine the paddock for the larger unburned pieces and rake the smaller rubbish up to these to burn the big pieces first. Paddocks need to be well cleaned for such operations as mowing, and odd stumps or pieces may be thrown into a tree belt.

The water supply is designed from the factors of climate and land shape. Tree clearing, to leave standing timber in the most suitable place, is designed from the more permanent factors of the scale of permanence--climate, land shape, water supply and main farm roads. The first permanent building site, usually for a home, is selected. The subdivision fencing proceeds and follows the general pattern set by the other work.

The irrigation paddock, whether adequate run-off rain occurs early or not, is suitable for the first sowing of seed. The paddock is fenced as an island paddock after the necessary boundary fencing is finished. If any stock can be carried on the property during the early clearing they must be excluded now from the irrigation land until it is grassed with the most suitable pastures for the particular climate of "Yonaroo".

Sowing methods can follow any of the orthodox means according to the equipment available. The Keyline development of the soil of irrigation paddocks is discussed in detail elsewhere.

The course of the operations may now follow lines that suit the farmer. The clearing of the rest of the area or yet a second dam in the first main subdivision may follow. The second main subdivision of "Yonaroo", the number two secondary valley area, follows the lines of the first work.

The third and smaller secondary valley area is developed to a similar pattern by similar means. The remaining area, which comprises a series of primary valleys flowing to the creek which forms part of the property boundary, is examined and planned as was done on the one side of the first of the two secondary valley areas or secondary land units.

All the features of the land planning of "Yonaroo" have their effect on the ultimate aim of all planned land work--that of improving the fertility of the soil and adding stability and permanence to the developing landscape. The planned water supply and farm roads, trees, buildings and subdivision fences all are aids to these aims, and so now the next stage of the development is through methods and techniques concerned directly with the soil itself.

Keyline soil techniques for "Yonaroo" are employed to develop the soil to carry the best pastures for sheep and cattle. It is to be understood that the essential difference between the various orthodox methods of pasture improvement and those of Keyline is first of all one of approach. Keyline aims at the development of the highest fertility in the soil that is possible and practical in the particular climatic environment and on the relevant land shape and the type of earth on which the soil is based. It may be a good soil or a poor soil, or a subsoil of various types such as light, medium or heavy, but it is to be converted into a fertile soil.

The soil is improved in Keyline by exploiting the most appropriate means of improving the soil climate within the natural or general climate that affects it. The improved and improving soil climate is maintained until such time as the soil is improved far beyond its best natural state. Its new higher fertility then will maintain a greatly improved soil climate to further improve the fertility of the soil. While every technique of Keyline planning powerfully affects soil climate, the direct and particular means to discuss now are those of cultivation. Cultivation is done with suitable implements on the Keyline pattern for the optimum uniformity of moisture distribution and at the depth that is most suited to the soil's particular class or stage of development, and at the time of the year or the season when, following the cultivation, the best association of the factors of moisture, warmth, and air are likely to obtain in the soil. All the other means of improving pasture growth which are employed in general agriculture, and there are many valuable aids, are used only in such a way as to directly improve the soil. The natural fertility factors that are influenced in the improving soil climate are mainly those which promote the more efficient use in the soil of the organic matter available to the soil. The factor of prime importance in the development of high-fertility soil for the growing of crops and pastures, is to ensure the rapid incorporation into the soil of the newly dead roots of the pasture plants themselves and in such a manner that they become part of the soil itself.

This process, together with the resultant more efficient absorption by the soil of the droppings of stock, constitutes the permanent base of the new fertility.

The time that is required to improve and consolidate the improved soil climate is generally three years. The soil and with it the pasture will continue to improve for some, as yet, indefinite period of time beyond the three years with no further treatment beyond reasonably good management practices.

The soil and pasture of my own first Keyline-developed areas improved very satisfactorily during the three years of the development period, and on land where the orthodox methods of pasture improvement had never been successful. During the next three years, with no further work, soil deepened at a more rapid rate than during the three years of Keyline treatment. On some of this land a deliberate attempt was made over a second three-year period to ruin the fertility produced earlier by using cultivations at the wrong time and in wrong weather conditions. There resulted a noticeable deterioration in the light soils of sandstone base. There was also a definite loss of pasture production in the heavy soil, but a continued improvement in its structure and depth. The light soil, after the soil-destroying treatment, was still better than it had ever been before Keyline treatment. It appears that when soil has had three years of Keyline soil treatment it has greater stability than the best natural similar soil in its climatic area.

To start off the pasture of the irrigation area of "Yonaroo", the selection of the various species of the pasture for irrigation is of special import. Grasses that may be unsatisfactory on a larger grazing paddock basis for sheep, such as cocksfoot, which is sometimes killed out by sheep heavily grazing the crown, may be an outstanding species in the better-controlled stocking conditions applicable on the irrigation land. Special high-value types of white clover which will not grow at all, at least not until the soil is greatly improved in moisture holding capacity, in the rain-only area will be of maximum value in the irrigation land. Grasses in quantities that may be too expensive for the initial pasture sowing in the poor soil of the rain-only pasture paddocks may be a good proposition in irrigation. Once the irrigation water is available the expenditure warranted for the rapid establishment of irrigation pasture may be many times that which is reasonable and economical for the rain pasture.

The irrigation drain which was pegged in the planning, should be completely constructed before the cultivation and sowing of the irrigation paddock. In the circumstances applying on the property, the irrigation drain is below the surface of the land and water is flowed over the land below by controlled "stops" placed in the irrigation drain which cause the water to rise and spill over the lower lip of the drain.

There are many methods of sowing pasture seed that are suitable for the rain-only pasture area. In the soil conditions on "Yonaroo" it will be necessary to suitably inoculate the various clover and other legume species with their appropriate rhizobium and also to sow the seed into the soil with a neutralised artificial fertiliser, such as a half and half lime/superphosphate mixture. On poorer soil the sowing is much more critical than on good soil. The factor on which success or failure largely depends is the contact in the soil of the neutralised fertiliser with the seed mixture. Methods as broadcasting seed and fertiliser are not likely to be so satisfactory on the poor soil.

It is not a particular province of this book to go into all the details of pasture establishment and management, which may vary as widely as there are different soils and climate, but the general relationship of Keyline and orthodox views are set out throughout the book so that they may be applied in the way that will best suit the farmer's own conditions, and which he will probably understand as well or better than anyone else.

As already stated, the Keyline approach to pasture improvement is aimed primarily at rapidly improving the soil so that pasture is better under all conditions and will remain in a condition of high productiveness and continuous improvement. Keyline pastures, therefore, do not tend to run out as do most of the present improved pastures. The Keyline methods generally involve a special cultivation of the pasture area at a suitable time once each year for three years.

In the condition on "Yonaroo" the rain pasture may be sown in the early to late autumn. As soon as the growth is well enough established to resist the pull of the stock it should be grazed with a sufficient number to graze it to a stage when there is still about 20% of the leaf remaining. The paddock is best grazed on the all-on-all-off principle during the whole of the first twelve months, but to obtain best results, attention is required to prevent over grazing.

After the first year and assuming that autumn is the time of the year most suitable for the keyline cultivation, the cultivation should follow shortly after the pasture has been eaten off. The depth for the cultivation is ascertained by direct examination with a spade of the soil below the pasture. The depth of cultivation is then determined from the disclosed depth of the active soil. It may slightly exceed in its depth the depth of the main pasture root zone. If the root zone of any pasture is only two inches down, a very common depth, cultivation is limited generally to three inches. Only tined implements are used with a maximum tine width of two inches and with the spacing of the tines set generally at twelve inches apart. Soil conditions at the time of cultivation may be moist but never wet. Dry conditions are not generally a disadvantage, and when the right time of the year has arrived cultivation need not wait on rain. Stock are excluded from each area after it is keyline cultivated for at least fourteen days and a period of twenty-one to twenty-eight days without stock may be advisable where it is practical. Part of a paddock should not be cultivated and have stock left in the paddock to graze the remainder, since there is always such a quick response in improved palletability in the keyline-cultivated area that stock will mostly concentrate on to it within two days, and by avoiding the uncultivated area probably damage the pasture of the new work by their intense grazing.

Keyline cultivation at the end of the first year is designed to promote the best association of moisture, warmth and air in the soil to the full depth of the pasture rooting system so that a rapid climax development of the beneficial soil life takes place. All of the available vegetable matter including the valuable dead pasture root mass is quickly incorporated into the soil and so forms part of the soil itself. If the first-year keyline cultivation is affected by drought conditions preceding and following the work, there will be little, if any, apparent improvement in the soil, and pasture will be temporarily reduced. The nett result could be an actual loss of pasture growth for a period depending on the duration of the drought. The benefit would then be obtained later in the rapid response of both the soil, in the improvement of its fertility, and the pasture when moisture and warmth are again present. This condition was experienced in 1957 on our new properties. Where the second or third of the three yearly keyline cultivations were done there was a very noticeably lessened loss of pasture, the worst results being only on the first keyline cultivation--the one-year-old soil--and in 1956 the soil condition, at the time set for the keyline cultivation of some areas, was very wet, and in the new areas, soil asphyxiation was evident. It would probably have been better to cancel the keyline cultivation for all the areas but as our work is continuously experimental, the cultivation proceeded. Rain persisted and kept all the soil overwet right through to and past the middle of winter. Under these conditions, air which is so obviously essential, is excluded by excess water. The desirable balance of moisture, warmth and air in the soil had been destroyed.

"Yonaroo" may be left now since all the further work, such as the siting, the design and construction of the dams, including the details of the lockpipe installation, the design and making of the water conservation and irrigation drains, the cultivation and development of the soil and the place of artificial fertilisers in this work, all are dealt with elsewhere in this book.

As "Yonaroo" is a ficticious property perhaps the imagination could be called on further, and projected into the future some three or four years hence, the property would be seen as a rich grazing area carrying its large flocks of sheep and smaller numbers of cattle. The trees of the tree belts, which would have within two years started to show the effects of the Keyline-developed soil above them, have made remarkable growth and have greatly increased foliage. The dams would have been filled and used for irrigation and filled again. So the walls of the dams are well grassed and the drains are grassed. There is no raw earth to be seen, and the soil below the pasture is dark and deep. Though the homestead and buildings are new, trees which were left standing when the land was cleared, add to the landscape a vista of the beauty that grows from age.

A visitor to "Yonaroo", when told of the age of the property, would then point out that it could not be so, because the trees of the wide timber belts must have been planted forty years ago at least. This part of the story has been one of my experiences on "Nevallan", and it may soon repeat itself on our newer property, "Kencarley", at Orange.

CHAPTER XVI

Fertilisers and Fertility

NO artist or artisan ever has such broad control of the medium through which he expresses his own character and personality as does the farmer or grazier in the control he can exercise over his land. The landman can create his own landscape, but the artist gives only his impression of it, and few pictures can rival those scenes that are found on a farm which has been cared for by one family for generations. Age constantly improves the cultivated landscape; lakes, hills, and the flowing streams all gain in beauty and usefulness under the mellowing hand of time. This beauty is forever changing as it is continuously being reflected in the life of the streams, the ponds and the soil, as well as in grasses, crops and trees. There is nothing still or dead in this scene in which the farmer lives and continues to live with the other life that is the moving enterprise of his farm. Everything that has life in this scene draws its life from the sun and water and from the soil and air. The scene is composed of these things and developed by time.

Farming as we know it in Australia should produce scenes like these, but, unfortunately, there are very different landscapes which have been developed by man on which his hand has fallen as a destroying blight. There is a balance in nature which can be easily upset and the "rape of the earth" and the "violation of the landscape" describe a scene where this balance has been disturbed and which we know only too well. The two landscape pictures, the one that is all good and the other that is nearly all bad, may have started together on similar land and during the first decade or two may have remained very much alike. The factors that influenced them in the improvement of the one and the deterioration toward complete destruction of the other may have been very small or slight. Yet in the one case these factors produced a change in the balance of things which caused a movement in the downhill direction of ruin, while in the other the changed conditions of the environment resulted in an improvement.

All types of life (including man) are concerned greatly with the environment in which they live. No matter how small or apparently insignificant this life, it still must adjust itself to its environment, and in so doing has its effect on the environment and becomes part of it. Sometimes the introduction of a new life species into a stable environment may so completely upset the balance as to cause drastic and rapid changes, which in their turn affect other forms of life in the environment.

Human beings have a greater power than other life over material things and so may quickly change or modify the conditions to suit themselves. But there are some factors of the environment over which man has little or no control, and so he must adjust his pursuits accordingly. In the handling of land, for example, he must consider the effect of these uncontrollable factors on the new environment which he is trying to create. In agriculture, if the sum of all the factors that he can control, and those which he cannot control, add up to an imbalance against the soil, then the effect toward deterioration, which at first may only be slight, will ultimately result in the great damage to landscape now familiar to us as soil erosion. The giant erosion gullies, the multitude of erosion gutters, or the scene which discloses a great slice of the landscape stripped of its top soil, are all evidence of the final result of only this first slight but progressive, and later often accelerating, imbalance of the soil environment.

However, all farms do not belong to one or the other category of these two opposite types. Most lie somewhere in between, and it is with these that we are now concerned. But, first, whatever examinations we may make of the broad fields agriculturally, our approach and conclusions, whether rightly or wrongly, pessimistic or optimistic, will be influenced mainly by just how we regard the soil.

The science of soil has progressed to the stage of classifying and naming world soil groups. The structure of soil, its texture and chemical compositions, have become almost exact science and are of precise significance to those who so study them. The two great world soil groups are, first, the iron-aluminium soils--the pedalfers--and, secondly, the calcium soils--pedocals--and within these, all soils, varying with climatic effects, may be classified. On the other hand, and sometimes with little interest in these physical properties of soil, there is the soil biologist studying, identifying, classifying and naming the life species of the soil, which alone interests him. But a document must be looked at as a whole, and so soil as a field entity, with all its aspects taken together, should be seen as the basic factor in field agriculture.

Some of the wide classifications of soil science deal with materials which are suitable as the physical basis of soil, but which, owing to the climatic environment, are certainly not soil, and though they may not be varied much by the application of minute quantities of other material or agricultural chemicals, these initial soil materials may be so profoundly affected by the stimulation of the other properties of soil that the life properties may be affected in great degree.

So, always, the matters of greatest importance in the change and improvement of soil are those factors of soil life which are very responsive to the improvement or otherwise of soil climate. Therefore, the farmer, whether his land is a real soil or whether he is developing an agricultural soil from a physical material capable of being so converted to fertile soil, must consider always the effect on soil climate of all that he does on his land. In Australia, following each new development of chemical soil science, large areas of land constituting something which is less than soil are being transformed into agricultural soil which will support profitable farming and grazing businesses.

The application of chemical fertilisers to Australian soils has grown greatly in recent years with mixed success. An inorganic fertiliser is a good servant but a bad master. Following the wide response of superphosphate in improving some pastures, this fertiliser was tried out eventually on a wide and ever-widening range of soil and other material merely "earths". The scope of the use and usefulness of superphosphate was found to be limited, at least by itself. The older use of the various lime products had set a pattern, which in varying degrees was followed in the use of superphosphate. Later the failure of superphosphate to produce, on some land, its early success stories was found to be due to another factor which, when provided for, extended again the use of superphosphates on the pasture lands. The addition of lime with superphosphate to neutralise its acidity, which had prevented the early establishment of clover species on some lands, was a notable advance. There was still more than one class of soil which produced no response in improved pasture. On complete and fertile soils neither superphosphate nor any other chemical fertiliser could show results. The lack of response to these chemicals on such soil was then a measure of proof of their fertility.

After further work and scientific investigation on yet other soils, their lack of response to chemical treatment was said to indicate an absence of another and new mineral element or chemical, and so "trace elements" came into agriculture. While the quantity of the applications of superphosphate, which had so often produced amazing results, were extremely low, with as little as a mere hundredweight to the acre compared with 1000 tons of soil in only the top six inches of each acre, these new chemicals produced their also amazing results with minute applications of a few pounds down to an ounce to each acre of land. And so another new and fascinating advance was made in the science of soil, and Australian scientists were again, as they often have been in the past, world leaders in the discovery and successful use of trace elements. Following this basic chemical discovery, new scientific techniques were soon evolved for testing on all soils their response to the various trace elements. The result was, as with the story of superphosphates, another quick surge in the development of large tracts of land which until recently nobody wanted. Blocks of such land from a few thousand to over one million acres were rushed into project type development and on the basis of a major clement like 'super' and minor elements-the trace elements.

Always these new advances, which were the results of the discoveries of farmers, agricultural officers and soil scientists, were paralleled by advances in bigger, faster and better mechanical equipment with which to use and apply the new knowledge to the land, and thus the development of new country became almost an accelerating process.

Words of glowing praise and graphic "before and after" pictures, which often showed the "before" as arid nothingness to the "afters" utopian lushness, told and retold the story, and still on and on it goes. Can it be wondered at that the chemical science of soil has completely dominated agricultural thinking for a decade or so, and that those who would hesitatingly mention that there are as well other factors to this matter, are as a voice crying in a wilderness. But that there are very important other factors for consideration is proved and can be seen, and even on those parts of Australia where the chemical fertilisers have been in use longest and where they are now considered the main core of grazing and crop land management.

In passing, it may be as well to mention the use of artificial fertilisers for growing wheat. In the production of this and other cereals the artificial was almost exclusively superphosphate, and there is no doubt that over very considerable areas in all States of Australia the application of this artificial fertiliser made the whole difference between an unprofitable or a profitable crop. Along with the early tendency of those farmers living in the wheat-growing areas to be solely wheat farmers, marched a deterioration of their soils, which was at first seen in the changing and deteriorating structure of their soil and later in widespread soil erosion. There is no doubt in my mind that the increased prices of wool following the Second World War and the conversion of much badly erosion-damaged wheat land to sheep pasture, and coupled with a succession of better rainfall seasons, has done more to check the accelerated rate of soil erosion than has the combined efforts of all Soil Conservation Departments.

With the earlier increase in wheat production resulting from the use of superphosphate not only was there this loss of soil fertility as evidenced by deteriorating structure and soil erosion, but at the same time there was a notable and continuing drop in the quality and food value of the wheat. The grain was in many cases just not fit for human consumption, and on this being gradually realised, but called by some other name such as "poor baking quality" or "good biscuit wheat", those areas which were still producing good-quality wheat became of great importance to the whole wheat and flour industry simply because the poor-quality wheat could be used satisfactorily when mixed with a sufficient quantity of good grain. But this now scarcer good-quality wheat came from those areas already mentioned as fertile and on which superphosphate had no effect.

In New South Wales the north-western wheat area was in this general category, so it may be as well to examine the effect of wheat cropping on these soils where superphosphate was not in general use. Here again we find a general but less noticeable deterioration of the soil, which in its damaged condition still does not show a worthwhile result from superphosphates. Therefore, the lack of response is not a true indication of fertility on these north-western soils. The soils of Queensland's Darling Downs, where good-quality wheat is grown, as indicated by its relatively high protein content, are similar, since here also there is evidence of declining soil fertility in the march of soil erosion but no general lack of available phosphate in the deteriorating soil.

From this brief glance at soil in relation to the use or otherwise of superphosphate, there is no evidence that superphosphate has any material effect either way in destroying or maintaining soil structure or causing or mitigating soil erosion. The evidence suggests that the effect of superphosphate is governed solely by the condition of the natural phosphate in the soil. If the natural phosphate is readily available there is no response to the artificial product, and if it is not readily available then the response is very significant. It does not in any way indicate the actual content of phosphate in either of these soils. So it is generally with all artificial fertilisers, whether they be of the trace variety or the major elements. The apparent result merely discloses whether or not the soil, in its condition when the application of the artificials was made, contains or does not contain the added elements in a form or condition which is suitable and available for the nutrition of plants.

It is very important to realise the full implications of these factors, since there is no indication or otherwise that the results would be constant if other soil factors were changed. For instance, if these soils were improved as to their soil climate for two or three years only, would the results and responses be as before or would it be found that the apparent deficiency in the soil of all or some of the major or trace elements had disappeared?

As with the major elements, so the trace elements were found to be effective not only in bringing large new areas into the class of agricultural land, but in improving pasture production and enabling new and better grass and clover species to be grown successfully on land now deteriorated and which was occupied first in the earlier days of our history. Now some of these responsive soils had been greatly changed from their original condition prior to the successful application of trace elements and in no small measure many detrimental alterations had taken place during the use of the major elements. On large areas of old wheat land the soil had been cultivated in the orthodox fashion which insisted that cultivation produce a "fine seed bed" of often powder-like fineness, and causing each year an increasing tendency for the soil to surface puddle and seal in the rains after each cultivation. The entry of rainwater was thus increasingly retarded, and so one of the important three factors of soil climate, namely moisture, was restricted in a climatic environment which was short of moisture in the first place. The widespread belief in and the use of summer fallow, which left the soil in this finely cultivated condition, so that it could absorb a complement of moisture from any rains for the growth of the following crop, only damaged the soil further. On occasions following cultivation for summer fallow and prior to the first fall of rain but with some moisture present, the soil responds quickly to the better air conditions, and the organic matter present, notably the roots of previous crops and grasses, quickly becomes incorporated into the soil. This occurs only if and to the extent that moisture is present. If rain occurs before the existing moisture is used by the soil in this process or evaporated by the heat and winds of summer, then a stronger circle of soil improvement ensues. The result is two-fold--first, moisture is stored as was intended to result from the summer fallow, and, secondly, the soil itself is improved. Despite the fact that the cultivation is of the wrong type for storing rainwater in the soil, it still does usually allow more to enter than would be absorbed into the soil if it were left uncultivated in its settled and compacted or scaled condition. There had to be a reason why grain farmers continued to use summer fallow, and obviously that reason was simply that summer fallow was found to work. As some soils continued to deteriorate and by their sealed condition restrict further the absorption of rainfall, summer fallow became in many instances the measure of success of the following crop. Now, rain at the right time for the soil, and each time it needs it for only two years, will, without any effort on the part of the farmer, appreciably improve the soil. So the summer fallow, as we have seen, even with the worst type of overfine cultivation, can produce a similar but transitory soil improvement. But as appears to be the case in so many agricultural matters, few things are wholly good or wholly bad, and so the summer fallow, which provides generally a temporary condition of improved soil aeration, promotes at the same time the rapid loss of moisture from the soil. If the balance of the good and bad of these matters is against the soil even slightly, then, by the very nature of the process of soil deterioration, the end point of destruction that will result from the continuance of these methods will be the same as it would have been if the balance against the soil had been much greater.

Over the last few years many of those who earlier insisted on the fine-seedbed type of cultivation now have realised that as well as promoting the early germination and establishment of the grain or other crop, it also tipped the balance against the soil, thereby promoting its deterioration. Also it came to be realised that moisture in contact with the seed, and not the fine seed bed itself, is the critical factor in the germination of seed.

Without condemning either the use of superphosphate or the principle of the summer fallow (and, indeed, there is nothing in these discussions yet to condemn either), can the balance which is against the soil in these two techniques be influenced in favour of the soil? Obviously superphosphate, or something else, is still necessary, because without it on this soil there is little or no crop, be it cereals or grass. Superphosphate was in many cases the factor that first permitted profitable cropping, and while the soil remains as it was or continues to deteriorate and erode, superphosphate must be needed. Therefore, it is necessary to go to the soil itself and determine first whether it can be changed, and, secondly, what methods may be used to improve it. There appears to be little point in further investigating various other chemical fertilisers, for, if these have not already been tried, there is the direct evidence from long observation that these applications, while possibly not causing soil deterioration, certainly on their own have not prevented it. The first avenue of possible improvement lies in the field of cultivation, and the second may be through a pasture stage.

Inorganic fertilising of Australian soils may have helped the agricultural industries, but it is not their salvation. There are other avenues to be taken of which one is a new approach to cultivation methods. The following incident is illustrative:

One of my men in the course of his duties visited a client who had been notably successful in growing wheat by using cultivation procedures suggested by us with his Graham plow. Standing on the verandah of the farmer's home, they were looking over two adjoining paddocks which had recently been plowed in preparation for wheat crops. One paddock, the neighbour's, had been cultivated with a disk plow which had produced the fine seed bed thought necessary, and the other, the farmer's, had been cultivated with the Graham to our recommended depth, which, in this case, was about one inch deeper than the disk-cultivated land of the neighbour's adjoining paddock. Suddenly the farmer said, "Watch this". The "this" was a whirlwind, or willy-willy, in Queensland parlance, where the incident occurred, which entered the neighbour's paddock, whirling a dark thick column of his fine seed bed high into the sky. As they watched, it increased in size and blackness and moved across the neighbour's paddock and entered our farmer's paddock. Immediately it ceased to pick up dust so that the lower part of the column was practically clean air with only pieces of dry grass or stubble whirling about. These pieces indicated that the willy-willy was still twisting at its full speed, probably upwards of 50 miles per hour. All was soon over and an immediate examination of our farmer's paddock, initially left somewhat rough and cloddy, showed it contained considerable quantities of very fine soil particles or dust with the clods. The fact that the dust (or fine clay particles) did not rise indicates that the effective wind velocity of the willy-willy at the fine dust zone had been reduced by the special cultivation to less than ten miles per hour.

Now the fact that our farmer friend did not lose any soil under his method of cultivation and the neighbour did from his fine seed bed is not the really significant point to the story What appears to me to be so very important is the fact that a method of cultivation reduced wind velocity very drastically; wind which, on other occasions, may continue for days to draw critical quantities of moisture out of the soil and to its great detriment.

The results of soil cultivation depending on the methods used can be beneficial or detrimental, especially in regard to increasing or decreasing soil moisture content.

All farmers are familiar enough with this fine-seed-bed type of cultivation, the continuous year-by-year pulverising of the soil, with its very serious deteriorating effect. Similarly, this constant depth plowing method produces a compacted subsoil layer and a plow-sole.

These compacted horizons, plow-soles or hardpans, as they are variously named, are produced by such cultivation methods in as short a time as three years to my knowledge. They always have the effect of restricting the activity of the many important movements in the soil such as moisture, air and soil life. The active or vital depth of a soil, formerly six inches deep, may be reduced to only two inches, and, as always, when the practices that cause soil deterioration are continued, the process of destruction is progressive. So also is the process of soil improvement. On these partly-destroyed soils, or on any soil for that matter, a period during which improved cultivation (as far as soil itself is concerned) is practised, may so swing the scales in favour of the soil as to promote and maintain for a considerable number of years an improved and improving soil. A cultivation such as that produced by our Graham plow and regulated as to a depth that penetrates an inch only into the compacted layer will have a markedly beneficial effect immediately soil moisture requirements are supplied by the first following rain. But always no one soil treatment, be it through the various chemicals that may be applied or a particularly beneficial cultivation or any other matter, will produce a fertile soil. The critical factors are (1) improved soil climate and (2) the necessarily progressive nature of all soil improvements. It seems to me, from my own experiences and experiments in these matters, that a truly beneficial influence, whatever it may be, needs to be maintained generally for three years in order to produce a condition of new fertility in the soil which will then enable the soil to continue its own improvement.

The problem is how to get the most benefit from cultivation and other practices, including the use of chemical fertilisers. If special types of cultivation (embracing the correct control of depth according to the present condition of the soil and, as far as may be, done at the appropriate time of the year in relation to the continuously important factors of moisture, warmth and air in the soil) will greatly improve the fertility of soil, can this improvement then affect the question as to the most beneficial function of both the major and the trace elements? All my work supplies a definite affirmative to this question.

Agricultural practices should be designed to accelerate nature's beneficial processes. I propose to put a number of questions and give what I believe to be the answers and finally to give my opinion on what is the main basis of the production of healthy crops and pastures.

Superphosphate has assumed such a dominating influence in the agricultural views of some soil scientists and great numbers of farmers and graziers that many apparently believe that the whole agricultural development of this continent, both past, present and future, was and is vitally tied up with the chance occurrence of large phosphate supplies easily available on neighbouring islands. But it is extremely unlikely that the actual overall phosphatic content of our soils has been increased by one ton with all the countless tons of our imports of this still very important artificial fertiliser. What, for instance, was the weight of phosphate, including the plant available and unavailable types, that was carried to sea in a period of five weeks when six major floods occurred in the Hawkesbury River of New South Wales. As I saw it then, the floods were not water, but soup, its ingredients the finest and most valuable constituents of soil. At the same time other rivers were likewise transporting to the ocean not only phosphates but every other valuable soil element. While it is a mere matter of conjecture as to what our phosphatic profit and loss account does show, and while it is not perhaps of any real importance to know the answer, it is vitally important to have the answer to the question as to what is the correct inference to be drawn from the varying results of all artificials and what is their proper or most beneficial function in Australian agriculture generally.

The answer, I believe, is to be found in the reactions to these artificials when they are applied on soils which are being improved by other means. I refer to the control and improvement of soil climate. Certain trace elements applied to soil have certain very desirable results. What would be the results if at the same time Keyline soil development techniques were applied, methods which are designed to improve the soil climate by means already discussed? Again, what would be the results if the trace elements found to be of outstanding benefit to this soil were applied after the soil had undergone a Keyline programme of soil improvement for the previous two or three years?

It is fairly certain that the successful application and satisfactory results from particular trace elements is directly related to the actual condition of the soil at the time of the application. The results could be completely different if a poor, sealed and compacted soil was first considerably changed by using methods of cultivation or treatments that improved the soil by first improving the soil climate.

Again, if the soil is one that the artificial chemical has been solely responsible for bringing into the category of agricultural land, would these soil climate control methods accomplish a similar improvement without the critical element?

I believe that the answer to these questions in at least the majority of cases is that the methods involving, firstly, a direct improvement in soil climate, would produce results on their own far superior to the results of the trace elements on their own. If this were so, would the trace element be abandoned as a method of soil improvement? The answer to this question is simply no, and the reason is a direct one concerning time and money. The results from trace elements are very rapid, and they would almost always have the great advantage of promoting quicker initial growth, when compared with root organic accumulation, the main basis of the high development of soil in Keyline. The releasing of trace elements that are initially in the soil and not available in their present state to plants, is much slower than this almost immediate response of the applied trace elements. The controls or influences of soil climate do not operate to release mineral elements until the new cycle of improvement is well under way. From my own observation the period that must elapse before any effect is strongly evident is from twelve to fifteen months, but our experiments do not yet cover a sufficiently wide field for me to be sure whether this time is relatively constant or otherwise. In climatic conditions similar to those on my own farms this time factor appears to be relatively constant, but reports on these matters from dryer areas are conflicting, some suggesting the apparent release of a trace element within a few months of the first rain on the new cultivation, and others, that two years or a little more brings the desirable release. No doubt the actual chemical association of the element is a factor also with climate and weather conditions. The very important effect though to the landman who is developing a pasture and strictly following a Keyline programme, is that the application of the trace element saves valuable time, and therefore should be used as a "trigger" element to quickly get a stronger fertility cycle under way. With the new soil programme I am now advocating it is my belief that it is generally unlikely that there will ever be any need for a second application of trace elements.

In these discussions there is no indication of a case against the use of trace elements where they are at present recommended by our Agricultural Departments, but there is this new view as to just what these results mean.

The very small quantities involved in the application of trace elements against the weight of the soil which they so profoundly influence is a very strong argument against those who maintain that all such soils are completely deficient in these chemical elements. Considering soil six inches deep, some of these effective applications are in the proportion of one part in ten to twenty million. Surely the chemist, who with the finest laboratory at his disposal must still employ all his skill to produce any metal or chemical in an absolutely pure state, should not credit nature with such freak accidental "purity" as would be involved if such absolute-deficiency theory were true. All these trace elements which have been found to be so necessary on some soil or soil materials are quite evidently also widely and in many places liberally distributed throughout all soil and soil materials that do not require their application. It is from the evidence of these latter soils, producing as they do much dust to the atmosphere, the dust which housewives generally find in sufficient quantities inside the house to warrant removal each day, that of itself make such a general theory untenable and indicate that such absolute trace element deficiencies are rare.

What is to be said for the major elements? Is there anything relevant as to their true province in agriculture indicated in these discussions on trace elements?

It was stated earlier that little changes in their present orthodox use could be contemplated unless soil was first considered in a changed and improved condition. As with the trace elements, it seems likely that the major elements are generally present in those soils also which show the best responses to their use. But on these soils the elements are again in an unavailable condition as far as plants are concerned, or alternatively, the rate at which they naturally become available is too slow.

So it may be asked again, is there anything wrong with these chemical fertilisers in themselves, and then are they being used generally in the best possible way? Before directly answering these questions, some materials not yet soil and described as soil materials are at present being improved into agricultural soils by many farmers and graziers and can be included in this survey.

The methods being employed in making this soil are either through various procedures of cultivation in conjunction with the sowing of clovers and grasses and adding chemical fertiliser, or, alternatively, through the application of these without any cultivation of the original material. This soil material is being converted to something better than it was *via* a pasture stage, although seldom does the grazier think directly about it in this way. But it should be the general approach to all soil. Whatever the type of fertility of the soil with which the landman deals, he should consider his main task one of improving his soil by the processes of farming and grazing. And now for the question: Is there anything wrong with the chemical fertilisers themselves? This is a controversial topic that has been going on for a long time. Unfortunately, no judges of the matter have been found and appointed whose verdicts are acceptable to both sides, but in the final analysis the landmen, given the advantage of time, will determine the correct answer. There were originally two extreme schools of thought on the matter; one, the exponents of chemical fertilisers as almost the be all and end all of agriculture, and, two, the "organic school", which just as wholeheartedly condemned every artificial as injurious to the soil, to the health of plant and animal life, and, finally, to the health, well-being and long life of the human population.

Now the chemical school could show wonderful results which never lost in the before and after pictures with which they continuously supported their claims. Furthermore, because chemical fertilisers are very big business, and big business, very sensibly, always allocates appropriate moneys for special advertising and public relations generally, the chemicals had the advantages of the big money. On the other hand, there is little or no money to be made in the advocacy of the organics in farming. When organic fertilisers such as composts and farmyard manure were claimed, and more often than not, in my opinion, proved to be superior and in fact something more than superior in that they were right, logical and natural, it became a simple matter for the chemical adherent to analyse the organic fertilisers and show that on the chemical analysis they offered less in value of the basic chemical known to be plant foods than did the artificial fertilisers. Then the organic school believed in the "cycle of life" and that everything that came from the soil should be returned to the soil to complete the cycle and continuously improve the soil. The adherents of the chemicals then could show that in the modern world, with its various waste disposals, including water-borne sewage, the cycle of complete return was impossible in a general way, even if possible in some instances by concentrating the waste of other lands on to the organics farms. Therefore, they argued that the chemicals taken by the plant and animals from the land must still be returned by artificial fertilisers. It is my view that eventually all agricultural land should be capable of supporting its own fertility without the additions of outside chemical fertilisers or organic materials other than those produced by the land itself; but more of this later.

There is no doubt that each school of thought not only had its effect on the landmen, but on each other as well. Nowadays there is wide publicity given to the value of humus and organic matter in the soil by the actual makers of artificial fertilisers. When artificials on their own completely failed to hold even the original fertility of the soil and widespread erosion marched always with the use of these chemicals, then the artificial fertiliser people had to borrow from the organic adherents.

The organic school, by excluding the uses of artificial chemicals from their agriculture were able to prove, again in my opinion, that the use of these exclusively organic methods produces a fertile soil that reflects itself in the health of plants and animals which were almost completely immune to the diseases and pests which were the curse of chemical farming methods. The adherent of the organic school did not encounter the erosion problems of the chemical school.

In organic farming various minerals in the natural form but suitably crushed may be added to the soil, so that there are processes common to each school. The addition of the natural lime products and various other rock products are advocated by both.

Generally any of these materials that are in a more or less natural form may be applied to the soil and not disturb unduly the complex of the soil life. If chemicals which could not naturally come into soil in its original conditions are applied, then it is next to impossible to predict all the consequences that may follow. There is no doubt that the excess application of such chemical fertilisers has a very definite effect on the soil-life populations. One fertiliser will destroy a certain species and accelerate the development of another, and the reverse could be true of yet other chemicals, and in the whole complex of soil life gradual changes may take place with the repeated applications of specific chemicals. These changes could then affect plants, animals and people in a very positive and detrimental manner. There is not sufficient knowledge of their direct results on health, because the issues are always clouded by other factors. For instance, if it were proven that certain maladies of people were common to those areas using artificial fertilisers, it would also be found that those same countries so refine and denature their foods that this factor could cause their illnesses.

These, then, and very briefly are the considerations which have exercised my own mind, and no doubt many other farmers, in the approach to soil improvement through the use or otherwise of artificial fertilisers.

It is my firm conviction that any system of farming and grazing which will create conditions in soil which increase its organic life is creating simultaneously a sound and sure basis for healthy pastures and crops.

I have decided in my own case to assume that any chemical not a natural ingredient of soil should be considered as probably very harmful to soil and the general health of all life which comes from the soil. Artificial fertilisers that can be observed to destroy the earthworm, for instance, could be a real danger, and for this reason would play little or no part in my own work. Again, fertilisers that noticeably spoil the flavour of fruits and vegetables will probably be injurious to the cattle or pasture so treated. While vegetables, produced in my own yard from soil treated by composts, were of excellent flavour, I have often noted both the unpleasant smell in cooking and the taste of vegetables raised on artificials. I believe that some artificials are very harmful to soil and to everything that depends on soil and that their use should be very carefully controlled. But all artificial fertilisers do not have the same degree of harmful effects. While sulphate of ammonia quickly affects the earthworm population, continuous applications of superphosphate had no noticeable effects on these indicators of good soil until after the third year. This last experiment was conducted on my own property, where two similar-sized paddocks were treated identically as to keyline cultivation and stocking control, except that one paddock had an initial dressing of one hundredweight of superphosphate while the other had three hundredweights applied each year. The stock reactions were watched, but there was none until after the end of the third year, when it was found that the cattle concentrated unduly on the one hundredweight paddock. The two paddocks adjoined and with the common gate left open for free movement the stock at this time very definitely favoured the one hundredweight paddock. After the third year they were often driven back into the heavy -superphosphate dressed paddock but would not eat it down, so that the one paddock was nearly bare while the second carried plenty of grass which the stock refused. At the same time there were then fewer earthworms in evidence in the second paddock. In 1956 number one paddock yielded a good crop of mushrooms and number two, with the heavy application of superphosphate, had no mushrooms.

On the other hand, an experiment to improve soil and develop pasture without the use of superphosphate or any other fertiliser as compared with the initial use of one hundredweight of the superphosphate showed two things very clearly. One, that my own soil can be developed by Keyline methods without superphosphate, and two, that then it takes longer. The conclusion is that where superphosphate is effective in an orthodox manner on certain soil, then Keyline methods are much faster if an initial application of the artificial is used. Further, in good seasons soil development in Keyline proceeds very satisfactorily with a one hundredweight initial application, but if the season is dry and no climax development takes place in the soil after the first application, then a second application is an appreciable advantage. Many other experiments of our own tend to confirm the belief that superphosphate is much more valuable when used in Keyline methods to directly improve the soil by providing the initial "kick" for the rapid development of the pasture root system, which then is the real basis for soil and pasture development, than it is when used simply to stimulate pasture growth. There is quite a lot of evidence then that superphosphate is much more valuable to the poorer agricultural land than even the present methods of use indicate. While formerly it marched with soil erosion it should now be a powerful factor in excluding soil erosion by assisting in the most important work of soil development.

There are many other pointers to the use and results of the various methods of superphosphate applications, and I have for many years been very interested to hear farmers, with many more years of experience than myself, speak of their experiences. I have now met and talked at length with a group of farmers and graziers who have had approximately thirty years of experience with the use of superphosphates. They all have a similar story to tell, a story of outstanding importance that should be told again and again in every newspaper and periodical that caters for the landman.

Each of them told me that he was considered a crank by other farmers when he started the use of superphosphate to develop improved pasture, but, on the other hand, was considered a progressive farmer by soil scientists and, of course, by himself. They all applied superphosphate generally each year and saw their poor pasture develop a higher and higher carrying capacity. The top dressing, with various added pasture seeds, was spread by similar means by each of them. Then, after some years, the period varied with each farmer, something went wrong. With some the higher carrying capacity was followed by higher and higher lamb mortality rates, more disease, and, as one put it, queer behaviours in the flock. There was more need to be a progressive farmer to keep up with the newest cures for the newest diseases and troubles. Pastures that had been their pride and pleasure later collapsed and some of the farmers faced disaster. Great efforts were made to determine the cause of the troubles with every help being given from the various sciences of agriculture. There was a consistent pattern to the various accounts, although the causes and cures were not the same. The pasture which was developed with the aid of the superphosphates had gradually become shallower rooted, and so the plant nutrients other than the applied phosphate, were progressively extracted from a very shallow horizon of the soil. Eventually one or other of these elements was gone, and the collapse of the pasture resulted. In some instances it required twelve months to determine what element deficiency had caused the trouble, but whatever it was or how it had happened, each farmer had had a very bad shock. With the application of the missing element some sort of recovery took place, and each was able to carry on again, some with the help of bank finance. But while the pasture recovered, the health of stock and survival rates were not good. Often the pasture was plowed up in some paddocks and a crop grown. On this land the following pasture was better, with notably less health troubles. This is explained by the fact that a very considerable mass of old and dead pasture roots, aerated by the plowing, became more or less rapidly incorporated into the soil by the quick development of the soil-life species and a new surge of biological fertility developed with an almost immediate if perhaps short-lived response in the healthy pasture and stock. Always with these farmers was the fear of another collapse and they commenced to look for other means of safely holding their pastures. It seemed to me that the length of time their pasture lasted in apparently flourishing conditions was very closely related to their climate. The better the climate the longer the period before the collapse. One farmer opined that the continuous dressing of superphosphate had made the pasture lazy. It simply took the line of least resistance and grew only shallow roots in the very surface of the soil where the superphosphate was applied.

Another compared his pasture failure to feeding a jackass (Kookaburra) at the doorstep. Eventually, so he said, the bird becomes completely dependent and if not given the food he needs he forgets to hunt his own and will be found dead on the doorstep if the householder is away for any length of time. The pasture roots, when the deficiency becomes critical, cannot go down into the soil below, which has probably become dead because roots and the full soil life do not live there.

With the long experiences of these farmers in mind, I formed the habit of looking for the answer, or rather the explanation of any wide successes based solely on the applications of artificial fertilisers. Once it was claimed that a very famous stud bred all its stock on pasture dressed with a continuous yearly application of superphosphate, it being inferred that the quality of the stud was indeed dependant on this "improvement". Later a man who had worked there, on being asked somewhat casually on the running of the stud, disclosed the real facts. The stud animals were really pampered with the best food purchased from outside the area and the farm pastures played a very minor part. Other famous sheep studs with the finest of animals are fed almost entirely on the natural pasture, but slightly improved, and take their real breeding from the complete quality of the natural soil.

Then I had the rather wonderful experience of visiting, with two of my own men, an area of pasture which had received a yearly application of three to four hundredweights of superphosphate per acre for thirty years, and, we were told, never been dry or even short of water. It was irrigated land. Under such circumstances it is difficult not to ask pointed questions which often, by the mere perversity of human nature, are countered in a manner to disguise the real truths which one wants to know. However, I signalled my men, whom I could see were anxious to ask the questions, to wait for the story to unfold itself; and a very interesting and informative story it was.

On this area carrying capacity ranged from nine sheep per acre in the winter to thirty-three per acre in the summer, with an average of seventeen sheep to the acre all the year round. Immediately lambs were born on the pasture both the lambs and their ewes were moved to dry, undeveloped, unirrigated land, where they remained to rear them. Older sheep were then placed in the pasture paddock. But no lamb could be raised on this wonderful irrigated pasture; it seemed that they just died. Other sheep could not be kept too long on the pasture because they did not do well. No lamb had ever been born and survived to a ewe born on the irrigated pasture paddock.

In other words, this pasture was not capable of breeding anything. It was manifestly well supplied with some of the growth factors, but what about the others? Would this pasture affect hereditary factors in the sheep that were fed there for a time after they were raised to a suitable age on the completely undeveloped land?

We asked to be permitted to examine the soil of the pasture area with a spade. This was readily assented to but caused a surprise. We dug down into the soil for perhaps a foot, disclosing a near perfect moisture condition to this depth. The bulk of the pasture roots were confined to the top two inches of soil, but there was more root growth, although little enough, below this depth than I have ever found in a heavily superphosphate-dressed pasture without irrigation. The continuous but slow movement of water through the clayey soil probably carried superphosphate with it, encouraging a few roots of cocksfoot to go down. The soil itself in the top inches had a pleasant smell, but below the top there was no smell whatever. There were earthworms present in the soil of a size which to me indicated an age of up to two months, but of this I cannot be sure. However, the largest were about two inches long and of a thickness near eight-gauge fencing wire.

The pasture itself appeared to be almost entirely composed of cocksfoot and white clover, but the cocksfoot, although evidently a profuse growth, was so small and narrow of leaf that it was necessary to examine it near the crown to realise that it was really cocksfoot. The leaf of the white clover was extremely small, a leaf being of the size of the half of a little finger nail. The nodules (rhizobium) on the roots were very white and clustered tightly under the crown in perhaps half an inch of soil.

Apart from a very shallow "renovation" at infrequent intervals over the years our spade work was probably the only time the soil had been disturbed.

One subdivision of the pasture area, which was without stock at the moment, appeared to have a good sward of grass ready for stock. We enquired as to how long since it was eaten off and were told it was both eaten off and watered fourteen days earlier. On our comment that the irrigation water had produced a very quick growth we were told that the growth following irrigation had been very slow but that a shower of rain only four days prior to our visit had produced the main result.

Here then was a soil never short of water and with all the advantages of regular and adequate dressings of superphosphate producing evidently a great bulk of pasture to carry its heavy stocking rate yet incapable of providing the necessary unknown factors or ingredients of health which would enable it to breed stock or even carry the same sheep for any lengthy period. On similar adjacent soil but with no extra water on the 17-inch or 18-inch rainfall country and with no added artificials, sheep could live, maintain good health and propagate their species. Surely there can be little doubt that the methods of irrigation and pasture management followed are very much at fault. The fact that the pasture is still high producing after so many years would be of little consequence if it was not supported by the natural unirrigated unfertilised land available, which, after all, does supply the unknown health factors that enables the sheep to live.

A totally different but equally interesting area came under my notice where exceptionally heavy cattle stocking rates had been carried on deep river silts. No superphosphate dressings were employed earlier, but when carrying capacity declined seriously superphosphate was applied without success. However, an examination with a spade disclosed the story. Although the rich black river silt soil was many feet deep, the spade showed that only the top inch or two was being used by the roots of the pasture species. Indeed, the main root of white clover had penetrated to two inches only and had then rotted off to an inch below the soil surface and produced laterals which grew out horizontally and just below the soil surface.

Here in this instance is soil deterioration on a soil formerly of completely outstanding productiveness, that is unassociated with any artificial fertiliser and on which the later application of superphosphate and other additives had no effect in either improving or worsening the deteriorating condition of the soil. It can be seen therefore that factors other than heavy dressings of artificial fertilisers can cause a soil to lose its fertility depth and restrict pasture roots to the top inch or two of a formerly very deep and exceedingly fertile soil. The deep silts are generally good irrigation land, as they have good drainage and therefore satisfactory aeration, but irrigation water applied without due consideration to the maintenance of good aeration and coupled with the compacting effect on soil occasioned by the very heavy stocking rates can eventually have this effect. Our recommendation on the occasion of the black river silts was the simple and obvious one of Keyline. The soil was first cultivated to a depth of three inches with the chisel plow immediately stock were moved off and before the land was again irrigated. Irrigation was applied after one day and produced a result in rapid growth better than anyone remembered having noted before. This land was just about as flat as land can be, so it was further recommended that a second cultivation at an angle to the first be undertaken during the same irrigation season and under the same conditions as the first cultivation. It was expected that this very simple procedure of Keyline would quickly restore the soil to its former effective depth, and with the farmer watching his soil as much as he usually watches his pastures and stock he would know what it needed in the future.

Also in relation to the flat land irrigation pastures, last year I spoke to a meeting of farmers and graziers in a Victorian irrigation district and made comments on a similar strain in regard to the management of irrigated pasture. Following my talk, questions and discussions led to my, making a recommendation of a definite procedure which I am sure was at first not in accordance with the ideas of all present. However, a few months later one of the farmers present at the meeting called at my Sydney office to inform me of his spectacular success which followed this treatment on his irrigated pastures. In this instance again artificials had not played a part.

In another instance a notable and long-established pasture which resulted from the yearly application of artificial fertilisers caused grave concern to the owner, as the lamb mortality rate gradually increased until it reached 40% of marked lambs. The pasture was not supplying a complete and healthy diet, but a single cultivation which aerated the soil to the depth of the pasture root zone evidently caused the rapid change which at the next lambing produced a very satisfying result in reduced mortality in his lambs. A further year of due consideration of the soil climate which will promote the healthful change in the soil will largely solve this problem.

Similar stories come from other countries as well. A report from the last Grasslands Conference in New Zealand recorded that it was now generally impossible to breed from year-old heifers in a certain New Zealand district. The course of the district's pasture development had followed that of almost complete reliance on heavy applications of superphosphates which produced very large returns of butter fat. The conference seemed very concerned with the development of a proper system for the reporting by farmers of these infertility records and then handed the problem to the veterinary scientists. But it seems again a clear case for the soil scientists with the condition of the animals clearly reflecting the unhealthy soil condition. Along with the dependance on artificials for the production of grass there appears to march these conditions of animal ill heath, a condition which is generally a reflection of the soil's loss of balance. If it is accepted that a completely fertile soil naturally produces healthy plants and animals then no other inference can be drawn in these cases.

In my opinion the answer to the question--is there anything wrong with the artificials themselves?--is generally in the negative, but with notable instances where there are some which could better be excluded altogether. The answer to the query is there anything wrong with the present and orthodox uses of artificial fertilisers must be a positive. I believe that there is something very wrong, and that it is occasioned in the first place by a generally too narrow approach to all factors of soil fertility. Certain growth factors of plants have been discovered, identified and manufactured and applied to soil as artificial fertilisers to directly increase the growth of plants. But not all growth factors in the soil are understood, and we certainly know very little of other factors at least as important. These unknowns operating through the soil affect the plant, its health, and constitution, and its susceptibility to disease and pests. Through the plant an effect is produced in animals later, and in humans eventually. Artificial fertilisers are relied on too much and oversupplied in man cases. They can, however, be an extremely important factor in the totality of soil fertility when they are properly considered in relationship to the important factors of soil climate.

The intensive use of the year-by-year applications of artificial fertilisers (generally superphosphate) to pastures is, in my opinion, wasteful of both the superphosphates and the real potential fertility of the soil. Poor soils can be turned into highly fertile soil and carry very productive pastures, and superphosphates, as an initial application at the start of a three-year programme of soil development, can be of great value in speeding up the soil's improvement. More superphosphates than is now used could be applied in this manner over a greatly widened area of

Australia. But there is danger in the general overuse of artificial fertilisers. I believe it should be used somewhat sparingly on the procedure suggested, and more in the manner of a drug which will cure disease (the disease of infertility), and promote health when good plant food produced by the improved soil itself, and not drugs become the normal healthy cycle.

CHAPTER XVII

Why Soil Conservation?

THROUGHOUT agricultural history the landman has forever needed to concentrate his attention on the little things, on the daily chores and the weekly task, and on the differing work of the changing seasons. He has not had the time generally to see or understand the wide and the basic things of agriculture or know the real background of his endeavours. He was too busy just eking out a living. The agricultural development and use of land may cause tremendous changes in the natural environment, and man, with his attention focused on the things which from day to day directly concern him, has at times been overwhelmed by the sudden realisation of the deterioration which he had caused in his environment. Soil erosion, the final result of this deterioration, had become so widespread that it forced him from the land.

There are examples in history where, under good climatic conditions of gentle and reliable rainfall and land shape not harsh or steep, a stable agriculture was developed, and there are other occasions where in poor or less favourable conditions man has controlled and improved land and founded a permanent agriculture. Still there are many more instances where his agriculture caused wide land deterioration, which, by forcing huge population declines and mass movements, changed the whole course of the history of nations.

Even in modern times during which the various sciences have more greatly increased their scope as well as their knowledge than during the previous thousand years, agricultural science, like the early farmers, has still concentrated on the things of their special field, and the day-to-day work, and have tended to become even more remote from the broad environmental fields with which they should be most vitally concerned.

The wide agricultural problem that has to be solved before modern agriculture is safe and permanent is, I believe, the one I have expounded in this book. Agricultural pursuits must be adjusted to become methods which improve the soil so that the stability of the environment is preserved.

In man's attack on his problems he usually fights the obvious, the results rather than the causes, and through failure progresses to these causes and later to the real solutions. No doubt in the fight against soil erosion the results of erosion were fought and not the causes which he may have little understood.

All of us are aware that soil erosion has been a problem of ancient civilisations. Since this book and the practical experiments that lie behind it advocate a new approach to land problems, it is desirable that I should set out my views and a little of my experience with soil erosion.

There are two completely distinct types of man-made soil erosion and they have two different causes.

The first type is the erosion or washing away of soil and earths and decomposed rock and which is caused by the concentration of water flow. This type of soil erosion is a veritable land erosion and may start anywhere and at anytime. It is generally the result of public and private works that, in breaking both the small and major pattern of water flowing over land, cause new and unnatural concentration of water flow.

The second type is the soil erosion resulting from an agriculture which is not adjusted to its environment and is caused by the general change and deterioration of the soil's climate. This type of erosion may be local to one farm or regional and widespread. Its direct cause is from farming and grazing methods and practices that cause a loss of soil fertility. The agency which removes the soil is water or wind or both.

The first type of soil erosion is seen widely in the erosion that has resulted from road building. Wherever roads stretch out to conquer new land great erosion problems have followed. These are caused by diverted drainage, and where the two types of soil erosion affects the one property, then it becomes the most spectacular part of agricultural erosion. It is manifested in the greatly deteriorated landscape and the consequential very large gullies.

The methods that cure soil erosion depend on the degree to which it has broken the original land forms and profiles. The type of soil erosion that is most widespread in Australia's general agricultural areas still permits reasonable land management and can be cured by methods of land improvement and soil development that need not treat the erosion directly but cures and prevents it as incidental to better farm planning and soil and water management. I believe I have proved in my own work that the Keyline planning and development of land and its soil care is not only the economic and most effective method of preventing or controlling this type of erosion, but also the most profitable and logical.

Where the degree of soil erosion has reached the stage of gullies and gutters making the more intimate treatment of soil and the satisfactory management of land impossible, then the work is not so much erosion control or soil conservation but becomes land reclamation. This type of destruction is fortunately not extensive in Australia, yet it is seen on some stock routes and other places not directly the responsibility of the landman; however, quite a number of farms are affected by it. The work of reclamation here is a type of land reshaping more in keeping with such construction work as the reshaping of land for an aerodrome than it is erosion control in agriculture.

If such a deteriorated landscape problem were put forward for Keyline management, then reclamation would proceed as follows: Disregarding the damage, the land shape would be first appraised in the same manner as would be done on a good farm, and, of course, backed up with a knowledge of the climate. Water supply for the farm to be reclaimed would next be studied and determined. If the erosion was such that the general shape could be recovered, the highest planning lines would be marked in, again disregarding the gullies. Next, the area above these lines would be reconstructed as cheaply as possible and preserving in the treated land natural land shapes as disclosed in Chapter VI. This area would be fertilised and planted. The water conservation drain and keyline or highest dam would then be planned and built. The work of land reshaping would continue by proceeding downward with the appropriate Keyline methods, which would be followed throughout the development of the property until a stable fertility was reached.

There are very many instances where the destruction of land has proceeded to the stage where economic recovery is now considered impossible, and there are two reasons for this view, namely the high cost of recovery and the very limited value of the land when it is stabilised again. However, there may be wider implications than the value of the land, and so on occasions much more money than the land is worth in its recovered state is spent on saving it. Nevertheless, in the Keyline approach to the cost of the actual reconstruction of the land forms (and the cheapest-to-make natural shapes is all that is required) there is the aim that the land will rapidly become more fertile and valuable than previously. While there is earth or decomposed rock material to work with, and in this type of land destruction there usually is, then the recovered land will soon reach its highest development and value.

Leaving all these aspects of soil erosion, the proposition in farming and grazing is simply to maintain the natural shape and form of land permanently, so that soil erosion is not a factor.

Prior to the conversion of any land to agriculture, the land was in a certain state of balance. Geological erosion, the very slow movement-of-material *via* the streams towards the ocean, is generally more than balanced by the decomposition of rocks and the continuous development of new soil. If the hills and primary (and often secondary) valleys were rounded, then the valley transported the water without new rapid erosion. If, in the occupation of the land agriculturally, the environment is not deteriorated, then the land remains stable and the valleys transport the run-off water safely. The land is made quite secure by improving the fertility of the soil in the new farming environment, and by avoiding the uncontrolled concentration of water flow. In Australian conditions farmers usually require more water, and particularly at those times when the natural environment does not provide it, so they should control and conserve the water. This also makes certain that the valley will have less run-off to handle and even at the same time increase its capacity to handle more than it could initially. Farming and grazing, as practices for the management of the environment, will produce a soil more fertile than the original soil and improve the environment beyond its best natural condition. If this does not follow, then farm planning and management are at fault and the farming landscape will not be stable or permanent. However, the stability of farming land is often subject to influences from other land, influences not a factor of the natural landscape, and so, on occasions, unnatural concentration of flow water may enter the land. Such water flow can affect the best of agricultural land. If these inflows are not treated specifically, then wide destruction of the land form may occur. But water is a most valuable primary asset, and so it should be controlled at the immediate point of entry and transported by water conservation drains to a specially constructed storage. If the circumstances are such that water is never in short supply and therefore the inflow cannot be used, then, and only then, should consideration be given to its safe disposal. The first approach may still be one of control at the place where it enters the land.

Where an erosion gully enters from a road and continues through a property, causing active damage, then an earth dam is planned to first control the water, and in conjunction with a drain on a slight grade, transport the water to a disposal area. The dam and drain may be a very modest structure. A ridge of reasonably uniform shape and one that is suitably pattern-cultivated to transport the water down the ridge centre, is a suitable area, as is also a good valley. Water disposal *via* a ridge has the great advantage that increasing amounts of water flow down the slope do not cause increasing velocities as other forms of natural or prepared disposal channels may do. The factor that causes water to flow down the centre of a ridge is the reversal of the natural flow path occasioned by the furrows of the special Keyline cultivation pattern. The natural flow path is always away from the neutral line of the ridge and towards the valley, so that water flowing down the neutral line of the ridge is directed there only by the pattern of cultivation. If the pattern has furrows two inches deep, then water cannot flow, for example, four inches deep. This is because the water above the pattern would lose the influence of the pattern and commence to follow its natural flow path as dictated by the shape of the ridge and consequently, by spreading wider and shallower, becomes again influenced by the Keyline pattern of furrows further out from the neutral line of the ridge. Therefore, if a given quantity of water is flowing, it will form a general path down the Keyline pattern-cultivated ridge, and if the volume of water flow is doubled or quadrupled the effect is that the width of the shallow stream increases accordingly. Yet there is not, as in most other methods of water disposal, an increase in the velocity of flow. (*See Figs. 4 and 8, Chapter VI.*)

A general loss of fertility, which has been described as a pre-soil erosion, is not manifested by active and visible soil erosion, but can be seen in the examination of the soil of pasture land by the change in the soil's structure and generally by the decreasing depth at which the main pasture root system lies. This loss of fertility often first discloses itself in declining health of stock and lower stocking capacity with reduced yields. This type of erosion, the very serious forerunner to active soil erosion, can only be cured permanently by, methods which directly improve the fertility, the structure and the depth of the soil. This, however, becomes automatic with the start of the Keyline management of the soil of pasture land. Here again the important effect to be produced is an improvement in the soil climate. While there are other procedures which will assist, the most natural basis for lasting benefit relates to the improvement in the soil when moisture, warmth and air are in better relationship and when they are combined into one single factor.

There is no further need to discuss the Keyline approach or its solutions to the problems of land or water, as they are seen to be simple and directly effective. Now, if these soil-erosion problems are so simply disposed of as in Keyline, why, then, is there such an emphasis in the minds of so many on the problem of soil erosion, and why have we spent in the Federal and the various State Government departments such a considerable amount of money on soil erosion control or soil conservation? The subject is lightly discussed and dismissed with little comment in Keyline because it has been found that Keyline is quite effective in both curing and preventing soil erosion, and that in this type of development and management of land, soil erosion is not a factor that requires any special consideration. These claims are not made lightly or without realising the earlier seriousness of soil erosion, but from the background of long study and wide experience of both soil erosion itself as a land menace and of soil conservation with its approaches, methods and techniques as a cure of soil erosion. It might be well to review why we had come to be so preoccupied with soil erosion problems.

To start at the beginning of modern-day soil conservation, wide land surveys were conducted in America to investigate the losses from soil erosion there, and determine the course that events would take if the problem was not attacked in a practical way. Prior to 1930 these reports indicated that about one hundred million acres of once productive land were seriously affected by soil erosion, and even half of it to the stage of complete abandonment. The continuing rate of loss exceeded the equivalent of a million acres of fertile topsoil each year and the rate of loss was sure to increase. However, despite these facts and the lessons of history, there seems to have been no widespread awareness of the march of soil erosion in the new world until what are known as the depression years of the early nineteen thirties. Then in America there started probably the greatest campaign to educate public opinion on the menace of soil erosion than ever had happened before in all agricultural history. No mad scrambling land boom ever approached in publicity the course of the "sale" of the great land menace of soil erosion. No other land subject ever received such wide and popular press support. Then later, when the wonderful press co-operation and response started to die down somewhat there grew up association after association, formed by public-spirited people, who, themselves "sold" on the reality of the menace of soil erosion and the need for action in the matter, wanted to keep it continuously in the public eye.

America, like the rest of the world, was suffering from the shocking and repeated blows dealt out by the great depression and their unemployment figures ran into many millions. Consequently the great "soil erosion menace" became a boon to many unemployed as the Federal Government, fighting the two national menaces of unemployment and soil erosion, started project after project, all of which had their impetus from these dual menaces to the nation. Agricultural officers were taken from their work in departments and became soil erosion experts as vast sums of money were poured into the battle. For a start the new experts seemed to forget agriculture, but in keeping with the virile spirit with which America tackles her problems when her people are really aroused, many of these officers became instead of agriculturalists, enthusiastic amateur engineers. But the American people were told that she was losing by soil erosion the equivalent of a million acres of fertile top soil every year, and there does not seem much doubt that this figure may have reflected the true position. The new experts therefore were going to fight this great battle and win it, and where should they concentrate their major efforts but on the biggest and best soil erosion gullies. So their requirements in plant and equipment got bigger and bigger until the new experts had tasted to the full the thrill of the direction of huge accumulations of big equipment.

However, like everything else, these matters were gradually moved to better perspective, and the new soil erosion theorists and their departments commenced to grow up. "Soil erosion" was dropped for "erosion control" and then became "soil conservation". In 1934 authority on these matters of soil conservation was vested in the United States Departments of Agriculture, a saner outlook was restored and soil conservation grew up further, and the panic pessimism that gave it birth has now been almost forgotten. In parts of America the work of the soil conservationist dominated the rural scene, as I have observed in flying over the country; also on another flight I saw more of the devastation of soil erosion than I have noted through the years in Australia.

The early American campaign against the menace of soil erosion aroused similar action in other countries, and it was not too long before appropriate legislation was enacted in Australian States, with New South Wales in the van.

Here in Australia, however, we did not have the spending at that time of even reasonable sums of money, and little, if any, equipment was forthcoming. By contrast in 1957 the Soil Conservation Department of N.S.W. spent the large sum of half a million pounds. Shortly afterwards Australia was in the Second World War and it was not until 1946 that our soil conservation departments really got under way. In the meantime books on the subject became available for study and Australians had been sent to America to learn the American methods and become soil erosion experts.

This type of critical review is only possible after the event, but the "selling" of soil erosion as a great national menace had its effect on myself as well as hundreds of thousands of other Australians. In earlier times other nations, even whole civilisations, had experienced the same problem as America, and the march of soil erosion had won. Now for the first time in history a great nation was organising its forces to win the battle against soil destruction, and it was a battle with the outcome deadly serious. These matters are covered widely in other books, so they need not be pursued here. However, like so many others at that time, I read these books and many articles and references to soil erosion which were contained in the press and in magazines. I looked for the signs of soil erosion wherever I travelled on my mining work and talked about the subject to those whom I met who were interested.

In Australia there were evidences everywhere of the real truth of the menace of soil erosion. The menace was indeed very real, and farmers and graziers, too, were convinced and worried by the great problem of soil loss. Two outstanding impressions of those days remain. One was the first almost hopeless type of pessimism of the soil conservation concept, which in Australia extended among many classes of people, including landmen, the new soil conservationists and the higher official or Government administrative officer.

The other impression was of my own query then, and it has not been forgotten. This related to the almost complete disregard for the run-off water which was generally the instrument of the final removal of the soil in this soil erosion menace to which we were newly awakened. On the one hand I was very familiar with the practice of the mining man conserving every drop of water in order to create his own type of soil erosion in his sluicing operations, for instance, so that he could recover the "values" in gold or tin. On the other hand, the agricultural land of the farmer and grazier was allowed to sluice away in soil erosion with no values being recovered by anyone. Then along came the soil conservationist to tell the farmer how to get rid of the water "safely". Here is seen also, an instance of this illogical division of authorities in purely agricultural matters which I have previously mentioned. If the Government agriculturalist or the soil conservationist, or any other authority then had the full control of the two aspects of the problem, namely land and water, our agriculture must have gained considerably. Surely the farmers and graziers needed the water that was washing away their soil. There was as much positive evidence of the need for the water, in the many poor crops and dried-out pastures to be seen, as there was of the accelerating march of soil erosion, and I asked myself this question, "Why wasn't all the water conserved?" However, I had to buy land, build many more dams, not for mining but now for agriculture, make use of many of the practices of soil erosion control and spend a lot of money on experiments before I had the final answer to just this one question, "Why wasn't all the water conserved?" I had become a farmer and grazier and a land owner and made my first practical use of the methods of soil erosion control although it was by no means my first experiences in the conservation and control of water.

Like many another practical man and farmer at that time, I was prepared to be shown and told how to apply the methods of erosion control. I was told, too, but certainly not what I expected or wanted to hear. The first Government Soil Conservationists visited my property at my request in 1944 and some months before a bushfire swept through the area. It was the worst fire in the district's history. Now at that time I was not only a very enthusiastic believer in the need for some planned and positive action against the menace of land deterioration, but I was in a position to do something about it, at least on my own property. I had plenty of equipment of the type needed and which was then generally not available to the official soil conservationist, and I knew how to use it. I thought, of course, that the bulldozer was the most powerful implement for soil erosion control. Now I know that the powerful factor that will cure and prevent soil erosion is the little, the very little and at that time neglected things that should be just part of all good farming and grazing practice, and not the big bulldozer, which, of course, is a wonderful aid to the large-scale development of land. However, I was a practical mining man and knew, as I have said, earth, rock and water, and it seemed to me that this experience and my less powerful equipment was just what was needed. Also, as a mining man, I was somewhat of an optimist and in keeping with my profession. But imagine my reaction on being told by the soil conservationists that there was little that could be done for my property. True, they said, contour drains could be put in to stop the further erosion of the soil and the erosion gullies in all the valleys could be filled up, and probably would wash out again. No! The land could not be plowed, with the exception of an area which they pointed out of about 40 acres. The rest was too steep and would wash away if broken with the plow. The land was not any good and never would be and it was not worth doing much about it; that was their general attitude. But what about the water I could save in dams? It seemed that water was no good for irrigation unless the land was river flats. However, the pessimism of those days to the problems of land did not affect me much, and, of course, not all soil conservationists were quite so pessimistic. However, these soil conservationists were almost right and they were only reflecting this hopeless and generally pessimistic feeling of the times about soil erosion. Had not the greatest name in American soil conservation said more than once in the first few pages of his text, book (almost the bible of soil conservation) that once the fertile top soil is gone it is gone forever, and that there is nothing that can be done about it, "so we must save the soil that is left". Again, that it is just as impossible to remake a farm once the soil has washed away as it is to make a motor car without the necessary steel and rubber and wood. On top of this attitude, the shale soils of the County of Cumberland, it was said, had never been, good enough for pasture improvement, which fact was not known to me at the time I bought the land. These things are mentioned to show the general background at the time.

The next few years were busy ones for me, and I persisted in my belief that I could eventually make a thousand acres of fertile soil on my property. I put in the usual structures and devices of soil conservation all over the farm, but there was this notable difference in my application of the methods, namely, some of the drains of soil conservation were constructed as water conservation drains to carry the run-off water into dams for irrigation. The first dams with their water conservation drains were built before the fire of December, 1944. This early idea, a basic approach and feature of Keyline planning, received some publicity as water harvesting nine years later, when it was adopted at a farm belonging to Sydney University and following a visit to my farm by its manager. For the next few years, even with some successes, it still appeared that the soil conservationists' idea that my soil would never be good may have been correct.

I still believed in the concept of soil conservation and concentrated on improving its methods and trying to devise ideas for better land planning. I did make some progress in this direction. This only led to my abandonment of the whole concept of soil conservation and I filled in miles of my soil conservation drains. I had spent a substantial amount of money and made many experiments, but, like some mistakes, these were valuable lessons. I had tried out soil conservation thoroughly and probably learned much, and now I had abandoned the whole concept.

While I was moving from experiments to failure and away from soil conservation the work of soil conservation departments continued to spread in Australia. The emphasis was still too much on water flow as a menace; water had to be got away from the farm land safely, was the general attitude of soil conservationists. Contour drains, contour banks, absorption banks, pasture furrows, grassed waterways became widely-known terms and the use of these structures spread slowly. Likewise, the soil conservation departments grew and spread as large amounts of money were allotted to them.

On occasions rather amazing things began to happen on some properties on which soil conservation methods were used. While the extra water held in some of the structures prevented erosion and increased production, it also caused an improvement in the fertility of the soil, yet there appeared to be a reluctance to appreciate this fact. It was not recognised on the part of the soil conservationists generally. Perhaps the phenomena was too strange against the views expressed in their textbooks, which said that soil lost to erosion was land destroyed permanently. Even today this attitude persists, and an article on soil conservation, recently published, repeats the belief of the earlier days of soil conservation, that soil lost can never be recovered.

There could be little doubt of the fact that soil conservation generally worked and that it did stop soil erosion where the methods were applied properly. When some of the earlier attempts of soil conservationists made matters a lot worse it was not of any importance but for the fact that mistakes are very valuable teachers to those who will learn. I do not want to belittle any of the successes of soil conservation. So many of them were more wonderful than the official soil conservationist seemed to appreciate. In my experience the official soil conservationist has never taken sufficient notice of the actual soil changes that often took place beneath his feet where soil conservation practices were applied. He has his book and a few techniques and the tendency was to apply these almost willy nilly to any type of eroded land. However, experience of soil conservation work is not always a happy one, and every farm is a separate problem. A farmer and his wife visited my farm and with my wife we walked to the eight-inch lockpipe valve below a dam and, turning it on, commenced irrigating. When the farmer saw the water spread he asked how many such dams we had and their cost. He told me he had spent more money on a similar area of his property in similar rainfall conditions, on soil conservation work, and could not turn on a one-inch tap. Again, very recently, a grazier with a large property said he put in "soil conservation" in one large paddock a few years ago. He called it the unpopular paddock, because no one wanted to work there or even ride there; it was too uncomfortable, with its big banks and drains. In learning anything, mistakes are always made, and so the costs of improved farming practices are paid for by many landmen.

In America, under the guidance of agriculture, the methods of soil conservation fell into better perspective.

Gone is the reliance on the contour bank and the pasture furrow; and the large absorption bank, with its associated channel, once nearly as great a desecration of land as the erosion gully itself, is almost outlawed and rarely in evidence. Now better farming is practised with more complete fertilisation, including the wider use of green manures; with alternate strips of cleanly cultivated and close-growing crops and grasses, stretching across the land, and often dominating the landscape for many hundreds of miles; and the rotation of grass and crops go hand in hand with improved grazing management. Soil conservation, as in its original conception, has largely disappeared, although part of the name lingers still in the newer term "conservation farming".

Many Australians realise now that "wise land use" is not much use to a farmer if it means growing only grass when he wants crops as well as grass. Agriculture was faulty, but now it has improved and it is still improving, and that is the simple answer to what is wise in land use. "Plowing grasslands to grow cereals", once a widely publicised soil erosion cause, does not now obtain. Again, it is how the plowing is done and how the farm is managed, and so it becomes just another matter of agricultural practice. "Grass and trees to replace plowland", another early soil conservationist catchcry, is no answer to soil erosion nowadays when it does not suit the farmer. Good plowing and good farming enters into the picture and are here to stay. Forests are not the answer to soil erosion when we see forest land eroding; good management is the only way here also, and "hill country left timbered to protect the land" is no use to the farmer who wants grass for cattle, especially, also, if the trees are not of any value. No longer is it recommended that the farm be adjusted to suit the early ideas of soil conservation, but rather the profession of the land is adjusting itself better in its environment.

Soil conservation as an approach was never really necessary. Indeed, the accumulations of its mechanical procedures are not its own, but are borrowed from agriculture, ancient and modern irrigation systems, and from mining. To many laymen the use of the contour in agriculture is the invention, even the great inspiration, of soil conservation, but nothing could be further from the truth. In the study of aerial photography of Great Britain parallel contour lines were found, lines unseen from ground observation, which are interpreted to mean that contour working of land must have been practised in early Roman times, and the contour as a means of illustrating topography is not new. No! Soil conservation was certainly not born of invention or inspiration, but rather of such forces as panic and pessimism; and perhaps most of all as far as America was concerned it was seen as an aid to the spending of large sums of Government money to fight unemployment and depression. It may be considered that my rejection of the term "soil conservation" is just a matter of words only, but it is more to the associations which the term raises that I object than to the words themselves.

My desire is to eliminate entirely from our thinking the memory of the battle to save the soil, the thought of large sums of money used and the general air of depression, all of which we now know to have been completely unrealistic.

So soil conservation has performed this great service to land. Because of its mistakes, failures and misconceptions, as well as some successes, but most of all by the wide publicity which it gave to the menace of soil erosion, it not only made the landman aware of the danger and the need that something should be done about it, but widely disturbed the general public as well. This constitutes, in my opinion, its great achievement and at the same time cancels out the need for "soil conservation". But so unrealistic, pessimistic and exaggerated were some of the early statements on soil erosion that soil conservation agencies moved into a place at one time where they regarded themselves, and were considered by some others, as more important than the whole of agriculture itself. There has been a tendency also at times for some soil conservationists to use their position and their popular publicity to exaggerate land problems in order to show a need for the soil conservationists and to try to make a permanent place for themselves even in such matters as national land policy. However, in a country like Australia it is not the inherent pessimism latent in old-time soil conservation theories that should influence policy in such directions. The more practical developmental approach of the experienced agriculturalist should be followed in the broad aspects of land policy. Surely there is now no cause for pessimism in our agricultural outlook! Soon it will be realised more fully that while it is right and proper to conserve water and to conserve fodder, the landman's job is not so much to conserve soil as it is to develop soil, to improve his soil and to make it more fertile than it ever was. Soil is not dead, inert matter; it is alive and vital. It must be so managed as to improve its life so that the soil will deepen. Then the farming landscape will develop as it should do. But this also will have been some measure of achievement for soil conservation itself. In the meantime, again in my opinion, there is a great deal of money now being largely wasted in Soil Conservation Departments and too many excellent men being employed less effectively and beneath their true capacities by being designated merely soil conservationists. There are all too few of such excellent men concerned in the broader fields of agriculture, where they are sorely needed, and their talents and their usefulness should not be, even in small part, wasted to the nation.

"Soil erosion", as represented by land administration and sponsored farm practices and reclamation, was over publicised, became much too pre-occupied with the mechanical side and was too wasteful of public money. The social problem of the great depression in America, which "soil erosion" was expected to cure, no longer obtains. The newer form of "soil conservation" likewise has outlived its usefulness, s since, quite apart from the improvements in farming and grazing, the successful soil conservationist naturally works himself out of a job; and this is equally true of Soil Conservation Departments.

What is the alternative? In Australia it is not desirable that Soil Conservation Departments be eliminated, but that they should be given a new orientation and a new attachment.

Agriculture is growing up and extending, and it must take a wider and more comprehensive view of all its own functions. If Keyline or any other equally good and broad environmental approach to land and water can automatically control soil erosion, eliminate the disastrous effects of droughts by preventing the waste of water and floods, and increase productivity, then the large staffs of Soil Conservation Departments could be very profitably employed on expounding the new approach and teaching it to farmers and graziers, and thereby adding greatly to the national benefit. Such staffs, however, will require to return eventually to the agricultural fold, since the new approach to land and water and with which this book is particularly concerned, makes it abundantly clear that land and its problems must be seen as a whole and not as separate unrelated and often antagonistic aspects of public administration.

As for the farmer and grazier, they are already on the way to the new agriculture and bid fair to take advantage of every new opportunity which is offered to them.

PART THREE

CHAPTER XVIII

Design and Construction of a Farm Dam

I HAVE endeavoured to present in Parts I and II of this book a planned agricultural landscape as the permanent background to Australian farming and grazing enterprises. My own efforts were not just to improve land a trifle or to improve it a great deal, but to get the best result that is possible and consistent with our natural environment. It is a moving optimum rising higher as time goes on.

There are ways and means outside the considerations of this book which produce great improvements in farming and grazing lands; means and procedures that in some countries have operated for centuries. Yet all of these must depend on the association of land and water and the life forces that depend on them. In these writings I have tried to avoid the customary fault of describing any one thing or aspect as "the most important" in agriculture, because I see agriculture as composed of many factors, and all, in their respective ways, are important, since each is a necessary part and without one the rest mean nothing, or, at any rate, nothing that is permanent and stable. Nevertheless, there is an order of importance, an order of permanence which when taken to its logical conclusion in planning does bring the optimum of these combined agricultural things into view, and it is from the advantages to be gained by combining prevailing climate and land shape in planning our agriculture that we obtain our optimum.

Any farmer will admit that he does not know sufficient about his local climate, and all of us would believe he would be much better off if he could know the weather for a month ahead. At present he is without that aid, but, in regard to our second factor, land shape, this he can know well and is thus able to make the most of his climate in association with his land.

Behind all our thoughts on these matters we have the general Australian condition of water waste and water shortage, so that water becomes a dominating climatic influence on our land and in our agriculture as a whole.

There is little doubt that we could use all the water we now let go to waste, and so the question of water use and water storage is the next problem--a problem that remains wherever water wastage occurs. Now, if we are aiming at the optimum in the development of agricultural land, it is quite obvious that we cannot approach it until this dilemma of water wastage is resolved. Though this is a widespread and national problem, it is also local and intimate to almost every farm and grazing property, and so the custodians of our land and water are vitally concerned. It is their particular problem as well as the nation's.

The landman on his own property has two good ways of preventing wastage of our precious water, and each of these can individually have more influence than the widest use of national water control structures. This is because methods and places for water storage available to the farmer and grazier will not only hold in the aggregate more water, but the water is held where the farmer needs it most.

The first of these two ways is to make the soil itself hold a large storage, and the means of accomplishing this are widely applicable, greatly economic and highly productive. These conditions can be achieved generally on all pasture land by a three-year programme of soil development designed to improve the soil climate and promote a rapid and lasting increased fertility in the soil. Fertile soil will absorb the first two or three inches of rainfall rapidly before heavy run-off can start, and the increased moisture induced in the soil promotes a gradually improving underground storage that is valuable and extremely reliable for both agriculture and industry. The same type of valuable storage can be secured also on crop lands, as well as in the crop phases of pasture land, by improved methods of cultivation and soil management. Although this extra water-holding potential of the improving and improved soil could be very profitable for the landman (and soil could hold more water than all the huge 'big' dam storages built and projected), there would still be heavy water wastage.

Since both this chapter and the next two deal with farm dams and irrigation some repetition in order to keep the subject intact is necessary.

If the problem of water storage on farm and grazing lands had been solved in the past and all waste water had been conserved economically and used profitably, then there would not now be any problem of water wastage nor could there be any great flood problem left.

The fact that we have both flood wastage and shortage of water illustrates the need for a solution of the problem of rain run-off. Could the failure to find a solution be in faulty design and poor construction of our present farm storages and the wrong method of using farm-stored water? This brings us to the second type of storage, the farm dam or the farm irrigation dam.

Sources of Information.--Since present methods have failed to solve the problem of water wastage, and since information on existing methods is widely known and freely available, there is little need for me to discuss them further here. I think it is better for me to seek new approaches and bring other sources of information to bear on the problem.

In my own attempts to improve land by, among other things, using water more effectively, I had the same problems earlier that many landmen have had, and, as has been acknowledged, I also had many unusual advantages in my own work and equipment. While it is generally impossible to say how, why or what causes the occasional good idea to be forthcoming or inspiration arise, such things do happen if one is very interested and there is the opportunity to do things and then do them over again in a different way when they are at first not satisfactory. I have built dams, filled them in again and remade them. I have deliberately broken the walls of dams to improve them and had failures and also some successes. On other occasions and in completely unrelated projects there are experiences which later were helpful. It is often an advantage to look outside the confined field of our endeavours for sources of inspiration.

Years ago I built a dam for mining purposes, not a big one but somewhat larger than an adequate farm irrigation dam. It was in a creek which extended about five miles upwards and it had a big catchment. I did not know much about the climate or run-off but I met an old man who remembered a kind of legendary flood that had occurred late in the last century and he was able to point out the height that the flood water then reached. I built the dam with a spillway capable of carrying twice the volume of water of this former flood, but within four months I saw the spillway, which discharged the water away from the wall of the dam around a rocky nob, become a roaring torrent of water and racing almost to its maximum capacity. As with many another crisis, this one finally occurred in the early hours of the morning during torrential rain when the spillway reached full capacity and the flood water started to creep across the crest of the earth wall of the dam.

Two of us had been keeping watch all night, and when this overflow started we began placing earth with hand shovels on the advancing lip of the water. We worked for an hour or two holding back the peak of the flood with this small bank of wet earth which we maintained. This little bank saved the dam. I said there were two of us. The other man was our present business manager, Mr. R. H. Barnes.

This incident illustrates two important points in our problem of water wastage. First, that a dam spillway large enough to take twice the amount of water of the previous greatest known flood rains may be none too large, and, secondly, that a very little work and a small quantity of earth can give a disproportionate measure of control over water.

This same dam has a further agricultural interest. It was constructed like the usual farm dam, without a pipe outlet. A four-inch syphon was used to deliver water from the dam (actually our reservoir) to a working dam near the mine. The syphon consisted of a metal pipeline over the wall of the dam with one end, the outlet end, discharging into the creek below and the other end in the dam water. In order that a syphon will work it has to be first filled with water, so there is always a footvalve on the water end that will stay closed while the syphon is being filled and a tap or valve on the outlet end which can be closed for the filling of the syphon and opened when the water is to be used. There must also be an opening in the syphon line on the wall of the dam through which the syphon is filled, which must then be closed and remain airtight. Our syphon worked satisfactorily, though on occasions the foot valve beneath the water did not close properly. Thus the syphon could not be primed and someone had to go down the pipe under water to clear the footvalve. One has only to do this a few times in the cold of winter to decide that a pipeline under the wall, and not over it, is quite an advantage. Ever since then I have not built a dam of even modest capacity without an outlet pipe. One wonders to what extent this experience influenced my development of our own farm dam designs and the Keyline flow system of irrigation?

During the early years on "Yobarnie" we were building a moderately large dam on a creek. A 24-inch pipeline was placed in position on a rock shelf on the creekside and about 12 feet below the top water level of the dam. A 24-inch hinge-type valve was fitted and, with the wall approaching its finished height, the valve was held in the open position in case of heavy rain. Unfortunately, the man who placed the valve in position left it held open with a piece of wire tied to a peg which he pushed into the earth of the wall. During the night and early morning many inches of rain fell and the dam was washed away by daylight. The rainfall had softened the earth of the wall, the peg, now loose, was pulled over by the weight of the valve door and the valve shut. At the time the dam wall had not been built up to spillway level, so the flood went over the top of the unfinished wall. There was not enough earth left to rebuild the wall again.

This early happening probably influenced the design of our present lockpipe valve which cannot close of its own accord and cannot be closed too quickly in any circumstances. Another direct result of this dam failure was a more detailed appraisal of run-off in relation to a whole complex of dam types, while still not neglecting the creek dams. Our latest creek dam on "Kencarley", at Orange, was constructed while the flow of the creek continued, and heavy rain would have had little effect after the first few days of wall construction. The dams and their drains above it would have reduced the greatest run-off to manageable proportions. (*Fig. 18, Chapter XX.*)

There is much information, useful in connection with farm water storage, to be obtained in other mining activities and not only from the mining engineer.

In circumstances where tin or gold prospectors are attempting to develop a water supply for their workings, much may be learned. The various arts, techniques and dodges that the prospector employs, often far distant from the best of facilities, can be very valuable. The trained mining engineer may not have had the opportunity of learning them or had the necessity of knowing them. The prospector may attempt to build a dam by discharging his tailing across a valley to form a wall. The tailings themselves, classified and separated with the earth broken down in the sluicing process, sometimes make a poor wall which quickly washes away, but they can also make a good wall. Often these walls leak badly, so the miner tries to devise a way to save the dam. He will strip off his clothes and get down under water to rake the wall where he thinks the leak starts and so promote a sealing effect, and very often these methods are effective. He may try explosives. Although there was recent discussion in some agricultural papers in N.S.W. on the alleged new use of explosives for sealing leaking dams, explosives have probably been used for this purpose ever since there was an explosive and a fuse which could be lighted above water and explode under water. Certainly mining men have used explosives for this purpose for many years, as I have done also.

On other occasions a miner may want a pipeline beneath the wall of his dam, and lacking experience may simply lay the pipes and build the wall over the pipeline with little thought that this could cause the failure of his dam. Water will tend to flow along the outside of a smooth pipe and make a tunnel of increasing size until the wall collapses and all the water is lost. However, the same man is likely to be more careful next time and so will use some kind of baffles that will prevent or retard seepage and flow. One such man will mix rotted grass, chaff or horse manure with the earth around the pipe on the theory that if water movement should occur the lightweight material will also move and tend to block up the porous area and automatically seal the leak. Surely this dodge is the invention of some hard-pressed mining man, and while it is difficult to prove that the practice works, it is known that when it is employed pipelines do not usually fail, and that they often do when no such care is taken. Just being aware of the danger is often all that is required for the hazard to be averted. This type of knowledge and the further ideas suggested from it are embodied in my own methods in the lockpipe system where several anti-seep techniques, all simple and inexpensive, are employed as standard practice. The combination of the techniques now make it sure that if a dam wall does tend to leak and allow heavy seepage the one place where it is least likely to occur is in the immediate vicinity of the lockpipe equipment. There have been no failures with the lockpipe system, but I have had failures when I have used brittle pipes, and so also have some of my friends. Only sufficiently heavy steel lockpipe is, in my opinion, universally successful.

Often with little money, the prospector in the worst of conditions employs successfully the cheapest methods of water control, and such methods are not always known even to the mining profession generally. On one occasion I inspected an alleged alluvial gold mine which was owned by three prospectors who had very little money but they did have a large flow of water from their own water source, namely a dam made of logs. The dam site was such that most engineers would have considered that only a concrete wall would be suitable, but the log dam, a real work of art, was successful. The water entered a pipeline on a rise above the mine and served both as a jet to break down the face of the alluvial deposit, and as a jet elevator to carry the "wash" to the gold boxes for the recovery of the gold. The pipeline carrying the water under pressure to the mine was made up of pipes not all of the one size, and they were coupled together by every imaginable means. There were plugs and patches in the holes in the old pipes and water was spraying from the line. In spite of the responsibility that the men felt towards each other to make a success of the undertaking, there just was not enough gold to keep it going for long. The whole point of this story is that wealthy farmers in the area were suffering from an acute drought and water shortage while the prospectors had a water race flowing a large volume of water which as an agricultural asset was almost beyond price.

This practice of water control and transport, almost as old as time, has an agricultural significance on the individual farm or grazing property which has been almost entirely overlooked.

There are many failures that have turned out to be successes, and many of them go unrecorded, but the solution of the problem of water wastage is important enough for a landman to pursue every avenue that may be of assistance, and worth any amount of effort on the part of the Government authorities.

The conserving of all the run-off in the manner discussed in this book, and the very low-cost irrigation that is thus available, is so valuable that in my own circumstances it would still be worthwhile building our present storages if we had good rivers instead of dry creeks in our lower areas. But the farm dam in Keyline is a very different matter to the usual conception of a dam, and so a general review of this aspect is now made before the details of the methods of design, construction and use are set out. (*See Diagrams and Plates.*)

Definitions: To begin with, a farm dam is defined as an artificial or man-made water conservation structure that holds or "backs-up" the stored water by means of a wall constructed of earth obtained on the site. The water of the dam is held above the land adjacently below. An earth tank, on the other hand, is an excavated water-holding structure which holds its water in the excavated hole and below the level of all the immediately surrounding land. The tank is generally a stock-water storage only and is not a part of these discussions.

There are many types of dams and shapes of dams in Keyline, but they all hold water above the level of at least some of the surrounding land; they a possess some kind of a constructed wall or bank, and they all have a water outlet or "tap" under the wall.

The word "dam" refers to and means the whole thing, including the valley or basin area below top water level, the water and the wall. This is a different meaning for the word to that generally employed for the "big" dam, where "dam" applies to the wall itself. In the farm dam the back of the dam is behind the wall or the side away from the water. The inside of the dam is the water side. Parts of the wall are its top or crest, which is the roadway along the top of the wall. The wall has an inside and an outside or front and rear batter (or slope), the rear batter in behind the dam-the downstream batter. The particular slope of the wall is described in figures such as 1 : 2, which mean that a vertical fall of 1 occurs in a horizontal distance of 2. The wall has a foundation or foundation area which is the bottom of the wall shape on the prepared earth of the valley below it, but the bottom of the dam itself is the land of the site which is or will be below the water level of the dam when it is filled with water. In preparing a site for a wall, the foundation area of the wall has two trenches, both usually of the same width, called first the cut-off trench and second the lockpipe trench. The cut-off trench runs the full length of the wall from end to end and in the finished dam is usually directly beneath the crest or roadway which is along the top of the wall. The lockpipe trench crosses the wall foundation area from front to back at right angles to the cut-off trench. The lockpipe trench then runs in the same direction as the bottom of the valley but is located to one side of the valley centreline. The water line of the dam, when filled, is also referred to as the water-level contour. The dam has a spillway (overflow, or by-pass), and freeboard, which relates to the minimum height along the wall about the level of the bottom of the spillway. The spillway is usually on the down land side of a keyline dam and overflow or flood water leaves the dam *via* the spillway.

The natural catchment area of a keyline dam is usually restricted so this natural catchment area is augmented by a water conservation drain or feeder drain which falls to the spillway of the dam from the upland direction (see Chapter VI.). The water conservation drain actually is located for the greater part of its length in the immediate valley area near the dam, above the water level of the dam. Falling at a grade right around the dam, it reaches the top water level when it meets the spillway. It should be particularly noted that the water conservation drain does not feed water directly into the dam. Some farm dams, not on our properties, which have been constructed with a drain falling directly into the dam, missed this important feature of our dams. The reason for this and other design features will be discussed later in this chapter.

The two diagrams illustrate the various features of the keyline dam. Both diagrams are in the plan, one showing a completed structure and the other showing only the "site-and-wall-foundation-area-preparations" at the time when construction of the wall begins. (*See Fig. 10.*)

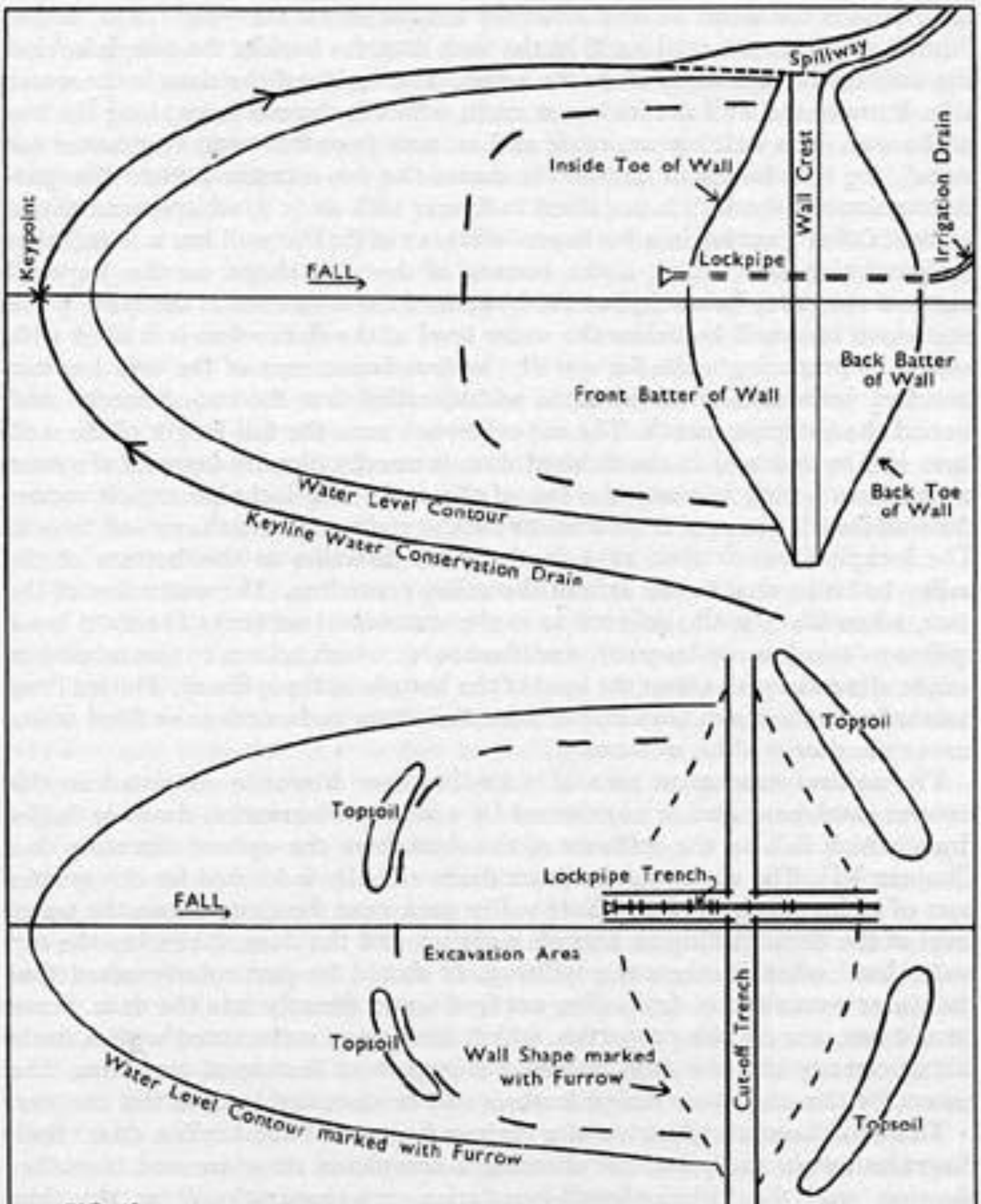

FIG. 10

Upper: Plan of a keyline dam, illustrating the names and the relationships of the various features.
Lower: Plan depicting the marking out and site preparation for a keyline dam.

These same names and features apply generally to most valley-type farm dams except that lower valley dams, and on occasions reservoirs, may not have water conservation drains. (*See Chapter VII.*)

A notable difference between the dams of Keyline and the usual farm dam is that in Keyline the whole of the dam is designed and constructed and not just the wall. The bottom of the dam, from which the wall material is generally taken, is finished off in such a way that a natural valley shape remains. The larger the farm dam the more important this may be, since the area of the bottom of the dam when the dam is emptied could be used as a very valuable special crop area.

Apart from Keyline construction, there are two other types of farm dams being made these days; one is the more or less haphazard type of structure constructed by bulldozer operators and which is lacking in design and for the most part poorly located, badly constructed and often unsightly. The second type of farm dam is that built by perhaps the same means but from a design supplied by water authority engineers. The design is too often a scaled-down model of the "big" earth wall. For the most part it is not followed in construction details because it is largely impractical and uneconomical in its application to farm water supply. Furthermore, a farm dam should be a lot more than just an earth wall.

"Big" Earth Wall Dams and the Farm Dam: The structures necessary for the walls of farm irrigation dams should not be a scaled-down model of anything. As I have said earlier, farm irrigation dams are completely specialised dams and should be studied and designed as such.

The engineering problems associated with the two types of dams, the "big" earth wall and the farm irrigation dam, are totally different. A farm irrigation dam is generally sited in or near the primary and secondary valleys. Almost any type of residual earth (earth in the place where it was formed from the decomposition, etc., of rocks) is nearly perfect for farm dam construction. These residual earths, which are characteristic of most dam sites with their decomposed rock above the harder rock below, are nearly perfect foundations for dams. But the "big" earth dam rarely, if ever, has such favourable conditions of site, foundation and wall material, and it is situated well down the fall of the land on a large creek or river several miles or even hundreds of miles from the headwater valleys of that river. The foundation materials below the wall may be layers and layers of sand and clay and decomposed rock and all its advantages and disadvantages hidden and often not capable of being inspected thoroughly even during the work. The wall material available may form a continuous construction problem and a huge volume of water often has to be brought under control before real work starts. There may be difficulties in procuring the large volume of materials of uniform type. Great expense could be incurred on site examination. The problems of river control, materials and foundations may be such that complete design and plans cannot be produced before the work starts and must be finally determined only by constant study of the behaviour of the materials and site as the work proceeds.

The "big" dam must never, under any circumstances, fail, because it could cause great property damage and heavy loss of life. The amount of water conserved is so large that if released suddenly it would cause enormous havoc. Many "big" dams have failed in the past, with loss of life and great property damage. On the other hand, the farm irrigation dam, by comparison, conserves manageable amounts of water; a farm dam conserving 400 acre feet of water would be considered a very large farm irrigation dam, but a "big" dam more than one thousand times that size conserving 500,000 acre feet of water is considered of moderate size.

For these reasons the design and construction features that are necessary in the "big" dam to secure adequate margins of safety bear little relationship to those involved in the farm irrigation dam. The same high factors of safety can be achieved in the farm irrigation dam without many of the expensive features of design and construction that are necessary in the "big" dam.

The farm irrigation dam is a specialised dam, and although the design is different to the "big" dam, correct design is just as important. It must be designed in relation to the nature of the foundation, the type of material, the depth of the water, and its future purpose, and also with adequate consideration given in the design to the type of equipment that will build the dam.

A "big" dam may require very flat batters of more than I in 3 to satisfy safety requirements, but on occasions farm dams carrying 16 feet of water may be just as permanent and safe with batters of 1 in 1-1/2. Farm dams with batters as steep as this, with walls formed of a mixture of shale and the clay of its own decomposition, have remained quite stable, but whether it be batters 1 in 1-1/2 or 1 in 3 entirely depends on the foundation sites, the wall material and the depth of water.

The farm irrigation dam, as outlined in this book, will be, in my opinion, as safe from floods, collapse and destruction as the "big" earth dam. There have been many failures of "big" dams in other parts of the world, and there are bound to be many failures of farm dams before all problems are overcome. However, the consequences of failure in the two types of dams are not comparable. If a dam of the design under discussion does fail, its repair will usually be a simple matter. If the farmer is on hand to open the lockpipe valve, a threatened failure may be averted, and if it did occur it should only be partial. There is, however, not much anyone can do in the failure of a "big" dam except get the whole endangered population out of the way in time.

In this connection, then, the farm irrigation dam in a Keyline development project has a great advantage over the "big" dam.

The majority of these farm irrigation dams will be constructed in or near the primary and secondary valleys, which, unless they are eroded, flow water over a rounded grassed bottom. Many are built in the solid land before the country breaks. This break of the land is seen in any watercourse, where stream water flows over raw earth of some kind, sand, clay, gravel, etc., and not over grass, as in a rounded unbroken valley.

Water will be brought to many farm irrigation dams by water conservation drains having an even grade, and is directed into the dam from the drain over the most suitable and stable area. The only silt, as can be seen in the colour of the water, that is likely to reach the dam would enter it during the first flows of water to the new dam. In a short time these drains and raw earth, which are always under the control of the farmer, become stabilised and grassed and will flow clear water. After this has taken place the greatest accumulation of silt likely would be such dust as comes from the atmosphere.

The "big" dam is built across a stream or, more often, a large river. According to the condition of the catchment area, flood rains carry varying amounts of silt to the dam. Immediately the fast-moving water, with its silt load, reaches the still water of the dam its velocity drops and it deposits its load into the dam. This is a continuing process and often an accelerating one. Then there is the ground load made up of material that the flowing water moves along the bottom of the stream but does not actually carry. This type of sediment, while it increases in floods, is continuously on the move, even in clear flowing water. Particles in size from sand up to large boulders are rolled along the river and creek bottoms by stream action.

Since siltation is almost negligible in a farm dam, there is no reason why a good farm irrigation dam managed by generations of good farmers on a good farm should not last longer than the average life of the "big" dams.

The control that a farmer can exercise over all the factors that influence the permanent usefulness and good appearance of his farm irrigation dams is not matched by the care or control that is possible in the "big" earth dam. In fact, the greatest influence that can be brought to bear in preserving the life and usefulness of the "big" dam would occur if all the farmers in its hundreds of square miles of catchment area were all looking after their own property and their farm irrigation dams. There is no force comparable to the farmers and graziers as custodian of land and water.

The essential design features that are to be provided for in the farm irrigation dams are listed below:

1. Site selection.
2. Constructional practicability of design.
3. Study of materials available to determine:
    - (a) Texture-whether uniform or not.
    - (b) Degree of compaction necessary for stabilising.
    - (c) Correct shrinkage allowance.
    - (d) Foundation area.
4. Height of freeboard.
5. Spillway size.

The design should also provide that the top width of the wall crest is wide enough to allow farm equipment to travel safely so that the dam can be always properly maintained. A good minimum workable width is 10 feet.

Site Selection: In selecting the site for a dam for irrigation purposes, full consideration should be given to the ultimate development of the property from the point of view of complete water conservation. The water from the first dam should provide profitable irrigation against its capital cost. The ultimate plan then should envisage a coordinated plan of dam lay-out and siting that will provide storage capacity for every drop of water that flows on the farm, and, because of this, the siting of the first dam becomes a very important task indeed.

In planning the full layout of dams for complete water conservation it is not by any means necessary that the lowest or the highest or any particular site should be used first, but it is important to consider the general location of all the dams so that the dam constructed first will fit in perfectly with the full plan if and when it is developed. For instance, there may be three excellent Keyline dam sites contained in a series of five primary valleys which flow into the same larger valley. There may be also two good reservoir sites and one lower valley dam site. Any one of these sites can be used first, provided it is located in such a way that when the other dams are built, it will receive their overflow water or alternately discharge its overflow water into the others, and fit in with the whole development.

It is not necessary to use the keyline sites first. Generally, the site should be one that will provide low water storage cost in conjunction with an adjacent area that is suitably developed or can be quickly developed for irrigation from this first selected site.

In this, the general order on undulating country, there are four distinct types of valley dams, including the creek dam:

1. The keyline dams (just below the keypoint of the primary valleys) or the high dams.
2. Reservoirs, often suitably located immediately below the highest dam in a series of keyline dams.
3. Lower valley dams, located near the point where water flows from the property or in the lower reaches of the secondary valleys.
4. Creek dams.

The keyline dam represents the first highest storage of run-off, whereas the lower valley dam (or the creek dam) represents the last chance of conserving water before it finally leaves the property.

The reservoir is an "intermediate" type of dam between these two. If there is not a suitable site below the highest keyline dam, then the highest other suitable site is selected and where it will receive the overflow from the high dams.

The first dam can quickly prove its effectiveness and profit potential and enable the landman to determine in the shortest possible time that he will institute a full programme aimed at conserving all the water that now goes to waste from his property.

It is usually assumed that dam site selection is a relatively easy matter and can be done by eye. While this is sometimes true, it is not necessarily always so. The critical factors in site selection are: (1) sufficient catchment available; (2) the contour shape of the valley at the proposed water line; (3) the valley floor slope; (4) suitability of earths for construction; and (5) suitable adjacent area for irrigation land.

It is very difficult to obtain an adequate appreciation of the shape of a farming property from the point of view of complete water conservation by simply studying it by eye. A good contour map is of outstanding value by enabling a quick study of all the land forms and suitable dam sites. Good contour maps of farming properties are unfortunately as rare as they are valuable.

An alternative and completely satisfactory means of determining land shape for farm water conservation can be obtained by laying in the keylines of the property. As discussed in earlier chapters, a keyline should be laid in from the keypoint of the first valley as a line rising with the general rise of the country, and then, after selecting the next valley keypoint, marking in a rising line there and so on for each valley in turn. These lines immediately disclose the relationship in height between all the suitable high conservation sites so that they can be arranged in such a way that no water leaves the high country until all the proposed high dams are filled. Suitable reservoir sites that would catch most of the overflow water from the high series can also be determined. Lower valley sites are usually obvious to the eye.

When investigating alternative sites for a first dam, the valley floor slope is checked with a levelling instrument over the proposed site of the dam and then compared with the valley floor slope of alternative sites. Other things being equal, the flatter valley floor slope is preferable. For instance, the conservation of water in a valley with a valley floor slope of 1 in 12 will cost more per unit of conservation area than a site in a valley with a 1 in 30 slope.

The contour shape of the valleys are then studied. This is done by choosing a contour to represent the water level of the dam and marking it on the ground with such an implement as a lister attached on a chisel plow. By standing on the marked contour line on one side of the valley and looking across at the contour line on the opposite side, a mental picture of the dam when filled with water may be visualised.

If the keylines have already been marked in (rising into country as they do in undulating land on which water is to be conserved), a satisfactory picture of the dam can be obtained by standing at various points along the keyline on the downland side of the valley and imagine the wall in place from that point across to the keyline on the opposite side of the valley. The keyline then will be just above the actual water level of the dam.

In marking out a selected dam site the depth of water is first determined. Where the contour shape of the valley is suitable, it is suggested that greater depths of water be considered than at present used on farm dams. A 20-foot depth of water is suitable if the shape is suitable and generally provides a worthwhile quantity of water for irrigation purposes. Where the site is large and greater storage is desired, it should be borne in mind that a depth of water of 24 feet as against a depth of 20 feet will in many circumstances double the cost of the wall. It should also be understood that in considering a dam of this size, the extra four feet of water may double the conservation capacity of the dam, and for this reason the larger undertaking may become well worthwhile.

The Design of the Dam: Before a good farm dam can be built it needs to be designed. To assist in the construction of our own dams and to help some of our friends and clients, we have produced an information sheet from which, when it is filled in, a complete design for a particular dam site is determined. It has been found by actual trial that an inexperienced man can control and supervise the construction of a farm dam from our plans and instructions and produce a good dam that will be valuable and permanent. After the experience of having built a dam to the designs I have prepared, the same man then can usually design as well as build a second dam. (*See Fig. 11.*)

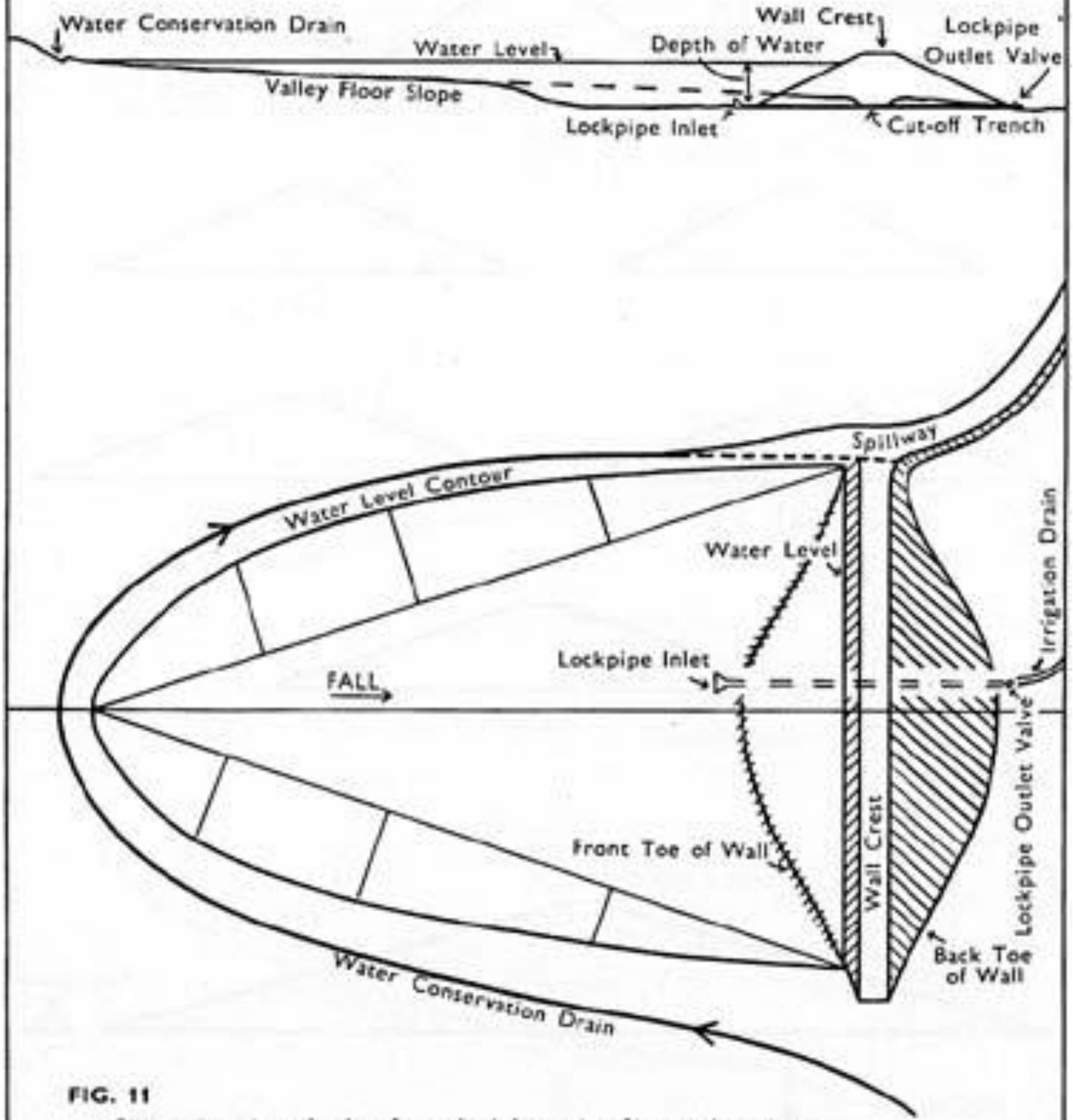

FIG. 11

Plan and section of a dam from the Information Sheet referred to.
Upper: Section along the length of the dam, which also shows cross sections of the excavation area and the wall, and the relationship of the lockpipe to the excavation area and to the valley floor slope.
Lower: Plan of the dam, illustrating the lines from which offsets are taken to determine the contour shape of the dam.

The information sheet referred to sets out what is required and defines precisely what is meant by such things as (1) depth of dam; (2) length of dam; (3) width of dam; (4) under wall valley floor slope; (5) excavation area valley floor slope; (6) total valley floor slope; (7) contour shape of dam; (8) natural catchment area; (9) induced catchment area; and asks for details of each and for rainfall information, earth type, etc. From this information the value of the site is assessed and the water storage capacity, wall yardage and cost are readily determined. It is also not difficult for any farmer or grazier to follow the sheet and supply the information.

There is such a wide field to the study, design and use of farm dams that a large volume would be needed to cover the subject fully, and so the object here is to present the simple fundamentals of the design and construction methods of those of our farm dams which I believe will have the widest application in Australia. To this end we may assume that we are building a keyline dam to the design illustrated. The instruction sheet which we use in Keyline work is designed to produce proficiency in the man as well as produce a good dam. Therefore, the first diagram shows the various batters or slopes for a selection of cross sectional shapes through the wall of a dam. The horizontal and vertical scale are the same, and so anyone using the sheet can soon visualise just what the various batters look like. These diagrams are marked A. (*See Fig. 12.*)

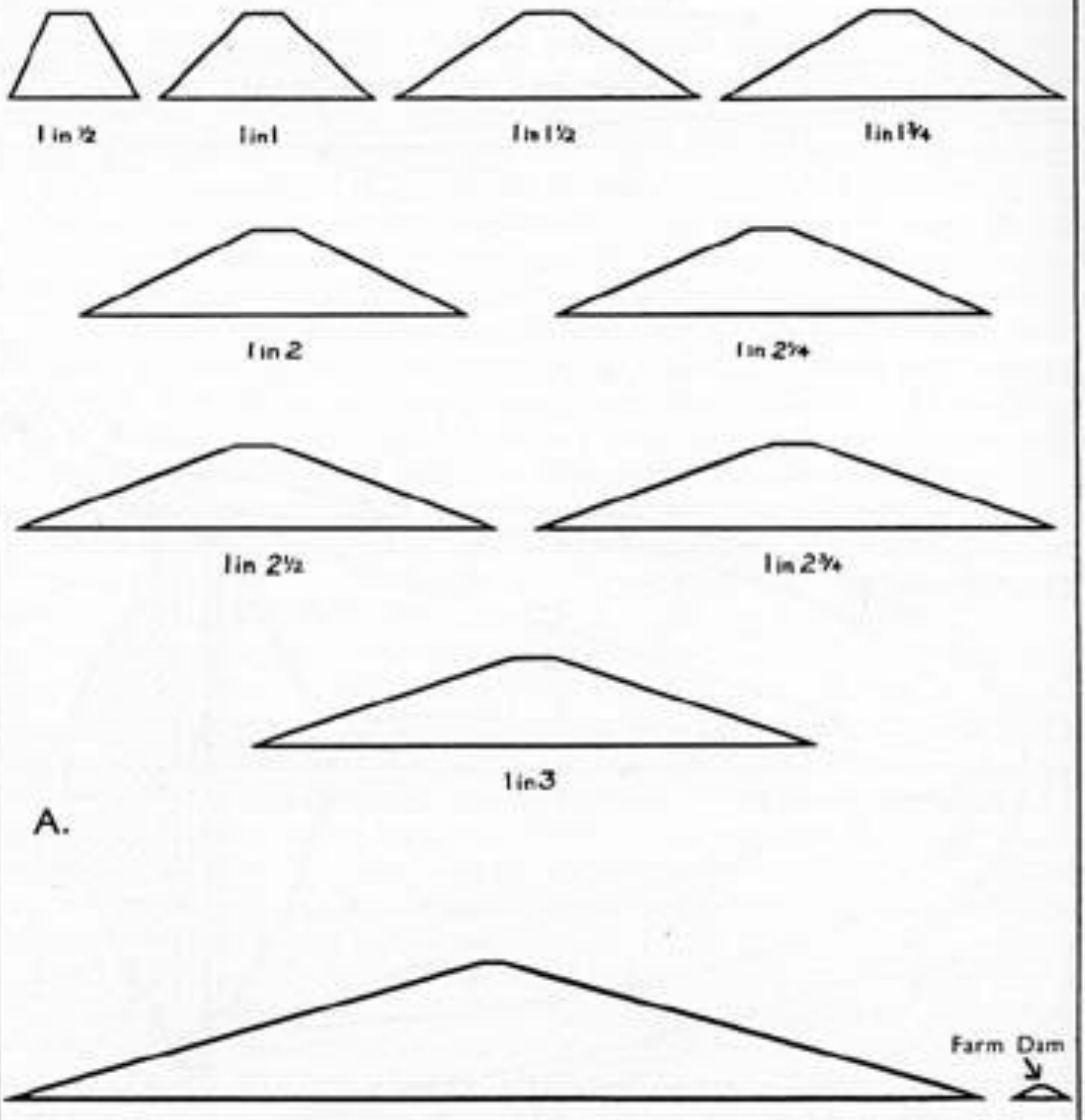

FIG. 12

Upper A: Nine wall sections illustrating various batter slopes. The horizontal and vertical scales are the same.
Lower: A cross section through the wall of a moderate-sized "big" dam and the small comparative size of a very large farm irrigation dam.

The second diagram, B, shows a section to scale down the valley floor, representing the relationships between keypoint, valley floor slope, water level and cross sections of the excavation area and of the wall of the dam. The third diagram, C, is a keyline dam in plan showing the general relationships of all features; water level to wall, conservation drain and spillway; excavation area to wall plan and lockpipe and irrigation drain. (See *Fig. 13.*)

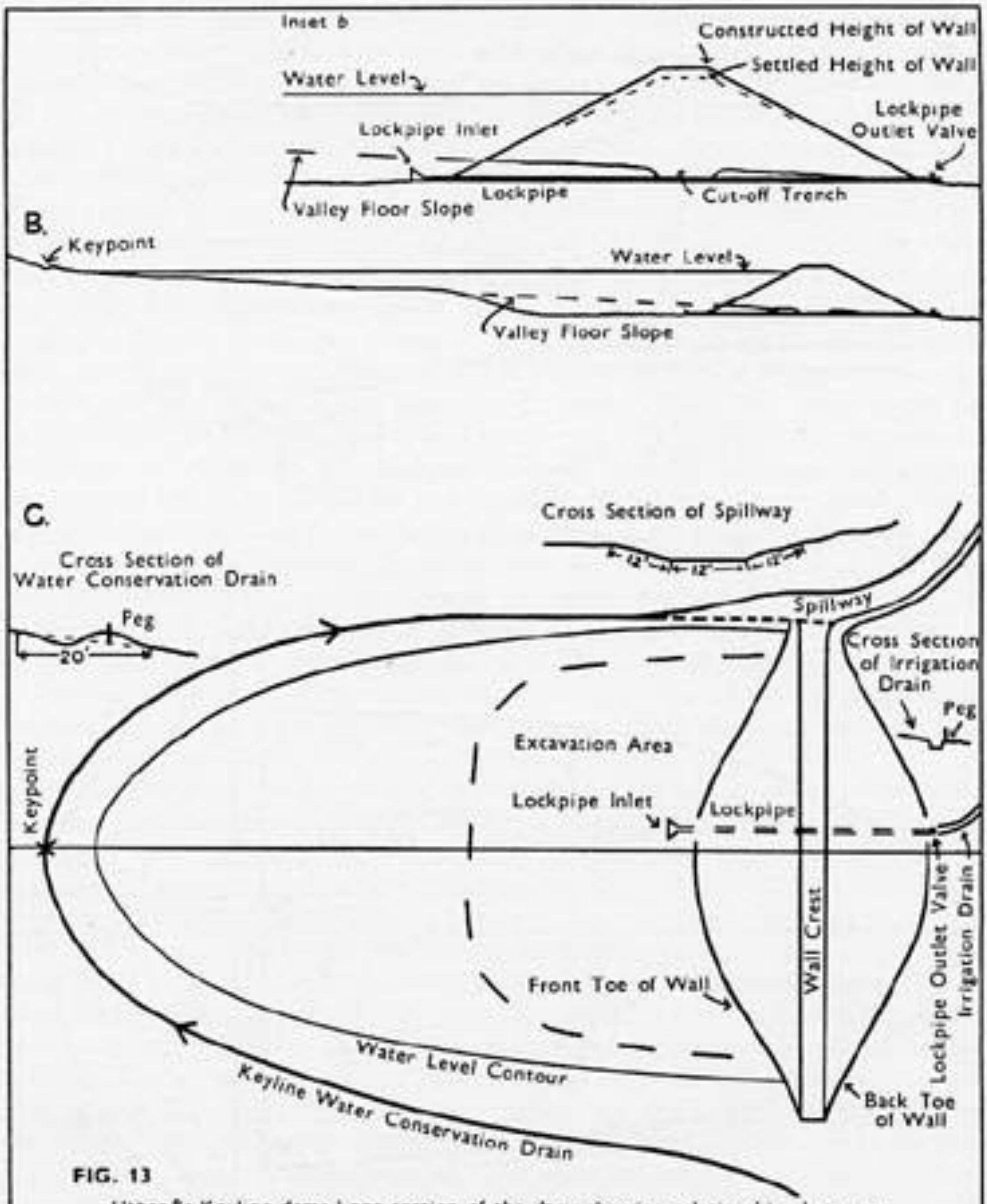

FIG. 13

Upper B: Keyline dam: Long section of the dam, showing relationships between keypoint, valley floor slope and water level; and inset (b) cross-sections of excavation area and wall.

Lower C: Keyline dam in plan, showing the general relationship of all features; water level to wall, conservation drain and spillway; excavation area to wall plan, lockpipe, and irrigation drain.

Then D is a section across the valley looking upstream from behind the wall, showing again the relationships of the water conservation drain to the spillway and the water level to the freeboard and settlement allowance. E is a plan of the site preparation and marking out of the dam, illustrating similar layout relationships. These diagrams are produced in this particular order, A to E, so that a study of each in turn leads to the marking-out diagram when the whole layout should be clearly understood and work on the dam can proceed. There are many dams to be built on farms that need them and which can very profitably employ them; therefore the diagrams are directed towards making all those who have constructed one dam proficient and capable of designing many more dams. There are also included in the design sheet two insets. Inset (b) illustrates the precise relationship between the valley floor slope under the wall of the dam and the location of the lockpipe to these two and to the cut-off trench. Inset (d) shows the detail of the relationship between the centre or low point of the valley and the lockpipe and outlet positions. (*See Fig. 14.*) (*See Plates.*)

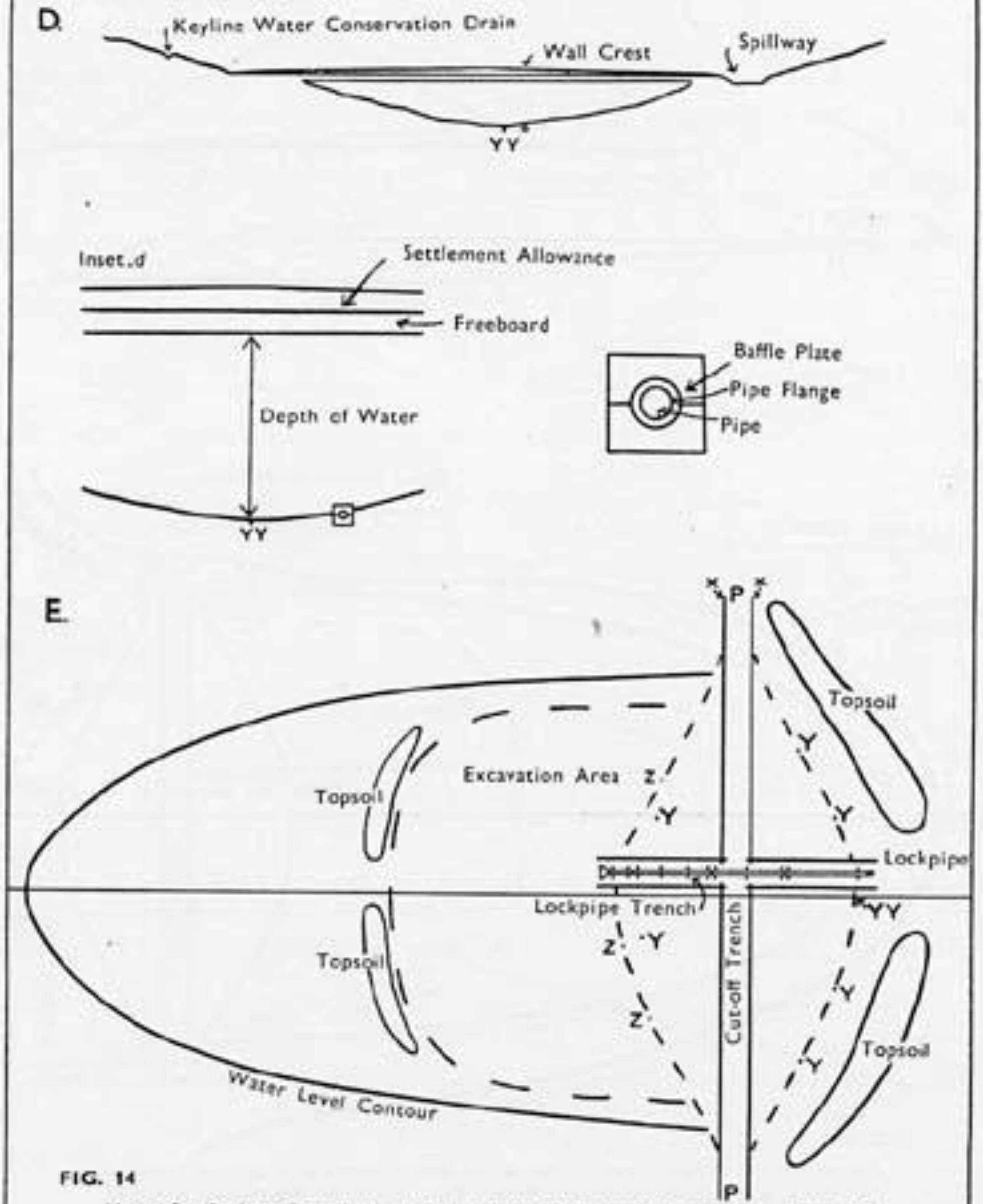

FIG. 14

Upper D: Keyline dam: Long section of the wall across the valley. Inset (d) illustrates depth of water in relation to freeboard and settlement allowance and the position and detail of the lockpipe and baffle plates.
Lower E: Plan of marking out and site preparation of a keyline dam.

Marking Out: In marking out the site of a dam some particular point must be selected as the main control point and to which all other construction features relate.

In a keyline dam the keypoint of the valley and the water conservation drain may serve as controls or points used to locate a main control point. For instance, the water conservation drain of a keyline dam has a fall right around the top water level contour of the dam, meeting the water level at the floor of the spillway. Therefore, a line of levels falling in the downland direction from the selected keypoint of the valley will represent the water conservation drain, and, somewhere along it, also the position of the spillway of the dam. If the dam is to be 20 feet deep, then along this drain line where the line is 20 feet vertically above the valley bottom opposite lies the point of the spillway overflow, and the low point in the valley can be selected as the main control point. In practice the approximate length of the water conservation drain from the keypoint of the valley to the spillway is obvious. Therefore, the location of this main control point is determined from the position of the keypoint and is done in the following manner. Assume this part of the length of the drain to be 200 yards (from the keypoint to the spillway) and the slope of the drain 0.5 feet per cent. (6 inches fall in each 100 feet), then the spillway height at the point of overflow will be three feet lower than the peg at the keypoint of the valley (0.5 per, cent. fall for 200 yards is equal to a fall of three feet). Therefore, the dam being 20 feet deep, it is necessary to find a point down the valley 23 feet below the keypoint. This point, as well as serving as the main control during the building of the dam, also represents the level at the bottom of the lockpipe outlet behind the wall. It is, as well, on the same level as the bottom of the lockpipe on the water side of the dam, since the lockpipe lies on a horizontal line, as is seen in the diagrams. The point in the centre of the valley 23 feet below the keypoint of the valley is now the main control point for the marking out and construction of the dam. The main control point should now be marked with a small solid peg driven well into the earth and a longer peg, such as a steel post, driven into the ground alongside. Next, a point the same height and 50 feet down on one side of the valley is marked with a similar peg, and a flag or marker is placed on it. This marker is away from the work area, so that it will not get lost in the latter work of dam building. The main control peg is called the "double Y" peg and marked YY on the diagrams.

The full marking out of the dam is not completed for the site clearing work, but the water level contour should be pegged and marked with a furrow. The site is then cleared of timber to a little beyond the water level contour (10 feet clear above this line is suitable) and down valley about 30 feet minimum from the YY peg. The timber is pushed into heaps outside the area of the dam site.

Now the dam may be marked out. The dam is to be 20 feet deep, therefore the height of the finished wall above the main control YY peg is 20 feet plus a freeboard of three feet and plus the shrinkage allowance. This is assumed to be 8-1/2%, or one inch for each foot of height, which is 23 inches, making the total height of the wall above the YY peg a maximum of 25 feet (24 feet 11 inches). The batter will be fixed as 1 in 2 for the two batters of the wall, and the crest width will be 12 feet, a width I often use for a wall of this height. In order to work out the dimensions of the wall the calculations are made against its height as planned, after shrinkage and settlement has taken place. The dimensions are as shown in the diagram. The maximum width of the wall shape is 104 feet. However, this width does not represent the width of the placed wall, but the width of the wall shape after the dam is completed, when it then includes a section of the original valley floor below the wall. This feature of the dam promotes a new efficiency in design affecting aspects of control, safety, efficient use of water and economy of construction.

The marking out and site preparation for a farm dam should be from plans and specifications already prepared. However, to illustrate the details of the design features the marking out will proceed from considerations on the site of this proposed dam. The dimensions of the centre cross section of the wall of the dam are known. From the YY or main control peg another peg is placed in the centre of the valley and well upstream from the control peg to clearly show the line of the valley itself. The centre line of the long section of the wall is to fall at right angles to this valley line. Then the centre point of the wall is determined. The section through the wall is 104 feet, so a point half this distance, 52 feet, is marked upstream from the YY peg and is placed in line with the two pegs indicating the valley centre line. From this centre wall peg and at right angles to the centre valley line is the actual centre line of the wall. Pegs are placed on this line to indicate the two ends of the wall on the sides of the valley, and two other pegs 50 feet up the side of the valley beyond the end of the wall. These last two pegs on the line of P pegs outside the work area should be marked clearly and so that they are not disturbed or lost in the work.

From the centre line of the wall further pegs are now placed on the back toe of the wall line Y pegs, so that this wall line can be determined and clearly marked. Points marked on the back toe of the wall for each 5-foot vertical rise from the centre of the valley up the sides are sufficient for this purpose. So the next Y peg will be placed at a distance from the centre wall line (P pegs), which is calculated for the first one in the centre of the valley in the following manner: There is a vertical rise from the YY peg of five feet, therefore the settled wall height at that point is 23 less 5, which leaves 18 feet. As the batter is 1 in 2, this figure is multiplied by two, and half the width of the crest (which has been determined at 12 feet), six feet added, so the first Y peg on each side of the YY peg will be 42 feet from the centre line of the wall (P line) at the 5-foot vertically higher point.

The next 5-foot vertical rise peg worked out in a similar manner will be 32 feet and the next is 22 feet, and the final distance of the fourth of these intermediate wall toe pegs will be 12 feet. (These various wall sections are shown on the diagram by the dotted lines.) (*See Fig. 15.*)

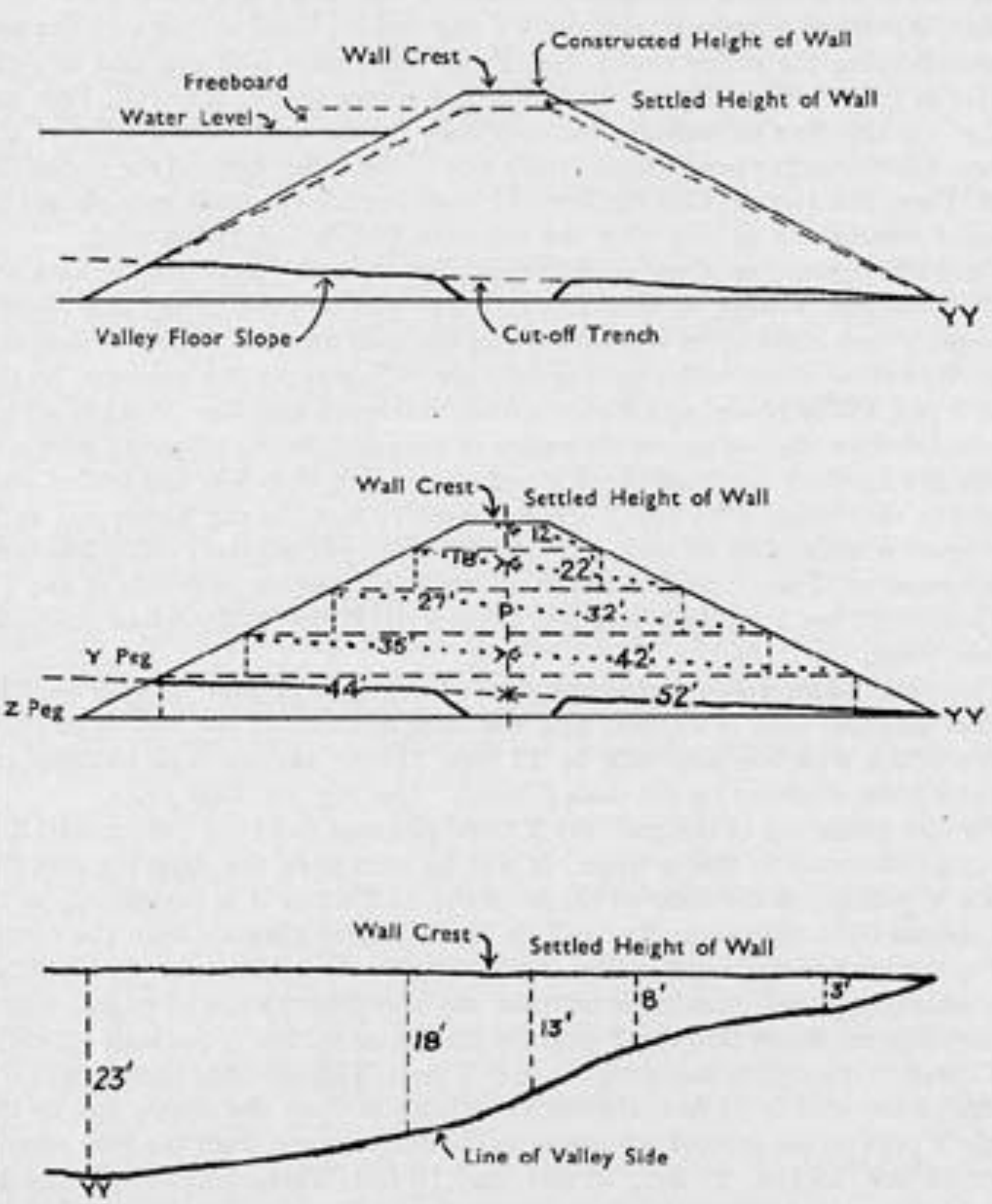

FIG. 15

Upper: Maximum cross section of wall of a dam having a depth of water of 20-ft. with 3-ft. of freeboard and 2-ft. settlement allowance.

Middle: The same wall with the dotted lines illustrating the various other sections of the wall for each five feet vertical rise towards the ends of the wall on the valley sides.

Lower: Half of the long section of the wall, showing the various height measurements (from the centre to the side) for each five feet vertical rise of the valley bank.

For the inside toe of the wall the Y pegs' distance from the centre wall line are not calculated in this manner. It will be seen from the diagram that the inside Y peg is not the finished shape of the wall when it is completed, so its dimensions from the centre line will be less than the distance from the centre line to the back of the wall-toe pegs. For designs in the field the simplest manner for determining their position is with the aid of ordinary squared paper, which in our diagram shows that the Y pegs for the centre section of the wall are eight feet closer to the centre line than the rear Y pegs. This distance therefore in the centre of the wall is 44 feet, the various distances from the centre line to the inside Y pegs on the ground according to the diagram are, from the wall centreline: 44 feet, 35 feet, 27 feet, 18 feet, and 10 feet. These lengths will not be strictly accurate, because the slope across the wall of the dam at the various positions will not be completely uniform. It is, therefore, advisable to make the Z pegs, indicating the front toe of the finished wall shape, the same distance from the centre line as the rear toe Y pegs. Steel fence posts make very suitable markers. From the P Pegs, on each side of the wall, the width of the cut-off trench (10 feet) is marked and the excavation area of the trench is defined by two or three pegs, as illustrated in the diagram.

The design and marking out of the dam will be left now for a moment while other matters are considered.

Study of Materials Available: As already mentioned, the materials available on dam sites are usually good. Practically any residual soil on farms in undulating country will make dam walls.

The requirements of a farm dam, as far as its construction is concerned, is simply that its works and is permanent. No amount of laboratory testing and classifications of earth for a farm irrigation dam wall will give as much practical information to the farmer as he can get by visiting a number of earth dams in his own area (even if they are small) which have been constructed with the same type of materials and built by the same methods as those that he would be using himself.

During the course of construction of a wall, fill material, particularly when moved by bulldozer operation, needs to be flattened out or levelled off by the bulldozer travelling along the progressive top of the wall. The material should be travelled over each time as the bulldozer places it, and, together with frequent smoothing off, a uniform texture is produced throughout the whole of the wall material.

The compaction of the wall of a farm dam is often unduly stressed and is frequently misunderstood. Some wall materials for farm dams do need the maximum of compaction, and where this applies implements such as the sheepsfoot roller or the multi-tyres pneumatic roller can be used. However, most earths used in farm dam construction do not require this costly process of complete compaction.

Some farm dams have been constructed very badly in that they are just mere masses of loose earth, untrimmed, unpacked, and with no uniformity of texture whatever, yet on settlement and shrinkage they develop into impervious and quite stable structures. However, such methods are inadvisable because dams so built often fail at the first rain. In areas where poorly constructed dams do hold well, no special compaction as such need be aimed at, providing that the suggested precautions are taken to ensure the uniformity of texture of the material as it is laid down in the wall. There are (as well as a general suitability of most materials on farms for dam construction) some areas where the problem of dam construction has not been solved. An instance is found in the deep cracking black clay soils which, when soaked, swell greatly. While I have not had direct experience on these earths, I believe serious investigations of the problem may be worthwhile, particularly now that the value of adequate farm water supplies is being better appreciated. While it has been my experience that the best dam building materials on a farm or grazing property are to be found at the site of the keyline dams, it is advisable to check the materials available. If the proposed dam is to be the first on the area, the dam should be dimensioned in a design and then an examination of the materials should be made to a depth of two feet below the deepest excavation area indicated in the design. A few small holes made with hand tools or even a small auger may be sufficient. The material is to be examined for cohesion, stability and water-holding capacity. If the dampened material will roll into a small bar or sausage three-eighths to half an inch diameter three inches long and can then be bent without breaking into a curve nearly a half circle, cohesion is satisfactory, and so generally is the water-holding capacity. If this earth is very fine with no sand or larger particles it may lack stability, and so wall batters would be designed flatter than in circumstances of good stability. Very fine and uniform particle clays and very fine silt are the less stable earths. Silts generally also lack cohesion, so silt earth walls generally need the flattest batters. Water-holding capacity is low in sand and high in clays, so that if there is in the earth a little more of the clay fraction than is necessary to fill all the interstitial spaces between the coarser particles, water-holding capacity will be suitable, but where this condition is not met the earth will not hold water well and often not at all. In these cases special sealer blankets are employed. Generally they are of two types; selected clay is used to cover the whole of the inside of the dam and inside wall batter with up to two feet thickness of clay or, alternatively, bitumen emulsion products incorporated with the earths of the structure itself form the blanket. Of other methods sometimes suggested I have found none yet that are sufficiently effective and economically priced.

Most residual granite earths and the decomposed granite rocks below them form very satisfactory walls for farm irrigation dams on a batter of 1 in 1-3/4 for water depths of 16 feet and batters of 1 in 2 for 20 feet of water. On the other hand, the same type of earths may have lost most of the felspar and mica that forms the clay fraction of such material and require flatter batters in order to hold water satisfactorily. The less stable materials always require batters that are less steep and perhaps greater supervision in their construction than the general material available on farms.

Shrinkage allowance in dam building simply means constructing a wall to such finished height and shape that shrinkage and settlement will reduce it to the planned or designed height and shape. The same relative shrinkage is assumed to take place along the wall at its various heights and a uniform allowance of 10% is adequate for most farm earths. It has been found on many of the dams constructed on these principles that an allowance for shrinkage of 8-1/2% is satisfactory. Generally, clay material shrinks more than mixtures of clay and sand.

*Freeboar*d is the minimum height of the bank above water level when the dam is filled to the point of overflowing. A freeboard of three feet is suitable on most farm dams.

A spillway is the channel prepared for the purpose of disposing of excess water from a dam when the dam is overflowing. Its size depends on the natural catchment area of the dam and on the run-off intensity. A spillway needs to be wide enough so that the maximum storm run-off likely when the dam is filled will flow through the spillway as a stream not much more than one foot deep.

In keyline dams, the spillway is situated on the downland side of the dam and it is constructed with the bulldozer which builds the dam. From the point of the spillway at maximum water level of the dam the spillway is given a drop of 0.5% and the spillway section carried far enough around the land so that overflow water from the spillway cannot flow on to the back toe of the wall.

In Keyline layout, the section of the spillway at a suitable distance from the dam usually changes to the smaller section of a water conservation drain which carries the normal overflow from the dam and the normal catchment above the water conservation drain into another dam. The main requirements of the spillway are that it carries all the overflow water from the dam and if it does overflow the country it does so at a place where water cannot reach the back toe of the wall or cause loss of soil anywhere.

It is not necessary that the whole of the water from heavy flood rains flowing out of the spillway should be transported by the water conservation drain to the next dam. Provision is made so that it can overflow at a suitable place.

* * *

To return to the construction of our keyline dam-the topsoil is now removed. The soil from the wall site is pushed down valley to a point 15 feet below the Y pegs by removing about three to four inches of soil and working at exact right angles to the centre line of the wall. (*Fig. 14.*)

The topsoil from the marked excavation area is moved upstream 15 feet beyond the limit line of this area. (On the completion of the structure, the topsoil from behind the wall will be pushed up over the back and crest of the wall, and the soil previously pushed up valley from the excavation area will be pushed down over the excavation area, after it has been plowed with a chisel plow, and up over the inside batter of the wall.) As the soil is moved from the area at a peg, the supervisor should remove the peg, stepping three or four yards away and lining up the peg position with some other mark. He replaces the peg in its original position when the bulldozer has finished for the time being.

A main control peg (YY) has been placed at the back or downstream side on the toe of the wall and a peg 50 feet away and exactly level with this point has been fixed. Two pegs have been placed on each side of the valley from and in line with the P peg, so that if the P pegs are lost these offsets will allow the centre line of the wall to be relocated. Another control peg 50 feet from the P pegs and at the same height and on the downland side of the peg should also be established, so that the wall height cannot be lost during the work. Care should be exercised to see that these pegs are not disturbed.

With the removal of the topsoil from the wall site and excavation area site, further earth is moved from the wall site if it still contains unsuitable material which can be used to form the line of the pegged toe of the wall represented by the Y pegs. Care is taken to maintain the pegs in position, and the material is pushed to the line of pegs and not beyond them.

Progressively more of this material is placed on the line from the sides of the valley towards the centre of the valley, but no more is placed at this stage than is necessary to remove the unsuitable earth.

Cut-off Trench: At this point, the centre line of the wall P pegs are checked, also the Z pegs, and the bulldozer starts the cut-off trench by pushing straight down the centre line (P pegs) from the sides of the valley. The earth from the cut-off trench is placed to form part of the back toe of the wall.

If the material below the wall is stable, as it usually is, and contains no excess of gravel or sand or other unstable or porous material, the cut-off trench need only be eight inches to one foot deep on the valley sides but increasing in depth towards the bottom of the valley, where it will be the same depth as the lockpipe trench, which is to be constructed next. (*Fig. 14.*)

The sides of the cut-off trench have a batter of about 1 in 1.

Lockpipe Trench: The lockpipe trench is located at right angles to the cut-off trench and parallel to the valley centre line on the downland side of the valley.

From the level of the low spot of the valley at the toe of the wall (the main control peg YY, previously placed), a spot is selected on the Y line, on the downland side of the valley one foot higher than the centre bottom of the valley. The lockpipe trench crosses the wall line, including the cut-off trench, at right angles from this point. The lockpipe trench is cut in one foot deep from the Y line at the back of the wall and constructed under the wall site right through to the inside of the wall, and must be dead level (a horizontal line). The level of the trench throughout is the same as that of the low point of the valley on the YY peg. The lockpipe trench will then be one foot into the solid ground on the Y line at the back of the wall, but, according to the valley floor slope, may be four to seven or eight feet deep at the inflow end of the pipe on the water side of the wall. In this dam we are describing it is five feet deep. A right-angle cross is thus formed at the junction of the lockpipe trench and cut-off trench and at this point both trenches are the same depth. The level along the lockpipe trench is checked during the excavation as the tractor works, until it reaches the correct depth throughout.

The construction of the pipeline trench is best cut by the bulldozer working first along the length of the trench to clearly locate it and then backwards and forwards at right angles across the trench.

Filling the Cut-off Trench: With the completion of the lockpipe trench and the cut-off trench, a chisel plow is brought in to cultivate to about four inches deep the bottom of the two trenches and the whole of the area of the wall site, particularly from the cut-off trench to the Z pegs, working parallel to the centre line of the wall. The roughing-up of this material, which is now the prepared foundation of the wall, aids the better bonding of the wall into the site.

The bulldozer then places good uniform material in the cut-off trench, material free of stumps, sticks, rubbish or organic matter, which is obtained from the excavation area but never from within the Z pegs defining the upstream edge of the under-wall site.

Laying Lockpipe: The length of lockpipe necessary for the dam is decided according to the maximum width of the wall plus an extra six feet of length, so that each end of the lockpipe protrudes three feet from the wall shape on each side. There is now a total of 110 feet. The lengths of the individual pipes making up the full lockpipe may not exactly equal the lockpipe length required, so on occasions a slightly greater total length may have to be used. This dam has even batters, i.e., the same batters on both the front and back of the wall, so the centre point of the lockpipe trench is selected from the centre line P pegs and checked by measuring a distance from this centre point half the total length of the lockpipe to the dam side of the wall. The number of baffle plates to be used and their distance apart depend on the designed depth of water for the dam. Their distance apart from the inside toe is determined as approximately one-third the depth of water and seven feet apart in this case.

The bottom half of each baffle plate is now placed in its correct position according to the measurement from the centre point of the wall site. The lower baffle plate of each pair is let into the ground or hammered in so that the half circle of the plate is clear of the bottom of the lockpipe trench by three inches. All the baffle plates are lined up and levelled-in with a levelling instrument from the reference point level already established, the YY peg, and the bottom of the lower half circle of each baffle is fixed at this level.

If both long and shorter lengths of lockpipe are used, the shorter lengths can be placed at the outlet end of the lockpipe and the long lengths at the inlet end. The pipes can be dragged to the side of the trench with a small tractor or carried by any other means and rolled into the trench. All the pipes that will form the full length of lockpipe should be lined up in their correct position beside the standing baffle plates before any are lifted into position on the cradle formed by the half baffle plates. (*See pictorial section.*).

"U" section rubber is used between baffle plates and pipe as an anti-seep and these gaskets are next fitted onto the lower half of the baffle plates and the pipes lifted carefully into place. Care should be taken to see that the holes in the flanges of the pipe are in such a position that when the valve is coupled, it will be sitting upright. One hole should not be positioned at the centre top; two top holes should be at the same height. The flange end of the pipes are inspected and cleaned and one rubber pipe gasket inserted between the flange junction and the bolts and nuts placed in and firmed up. It is better to place all lockpipe sections, gaskets and bolts and nuts in position before tightening any of the bolts. When they are in position, all nuts should be tightened uniformly around the pipe. Each nut should be tightened a little in turn right round the pipe two or three times. The final turn must be very tight and the pipe gasket quite clearly show a squeezed effect.

It is suggested that the farmer who is supervising the work should check the tightness at each junction of the full lockpipe. One loose joint could endanger the stability of the dam.

The top half of each baffle plate is now coupled with each U-shaped gasket around the pipe and the two sections of all the baffle plates bolted firmly together. The volume strainer, which fits on the inside end of the lockpipe or water side of the wall, and the valve which fits on the outlet or downstream side of the wall, are not coupled at this time, but are left until the dam construction is completed.

Filling the Lockpipe Trench: The lockpipe equipment, when laid and tightened, is held by the baffle plates a little above the bottom of the lockpipe trench. The earth that goes beneath the lockpipe is to be compacted by hand work particularly from the inflow end to the centre line of the wall. First the bulldozer travels parallel along each side of the lockpipe trench in turn, pushing a load of earth so that a sufficient quantity spills into the trench to be hand rammed beneath the pipe, but not sufficient to cover the pipe to any extent.

An anti-seep material is now placed. We use an inert, lightweight material ranging in size from very fine particles up to about the size of large sand grains, which is made by heat expanding a special volcanic rock. Its weight is about one-tenth the weight of sand. At each flanged junction of the pipe and each baffle plate from the inflow end of the pipe to the centre line of the wall a mixture of this material and the wall material is placed, so that if water does move, the lightweight anti-seep material will move with it to form a seal around it and so automatically seal a leak. The mixture is to contain about 20% by bulk of anti-seep material and the balance, wall material, mixed and placed at the flange junctions and baffle plates points during the filling-in of the earth around the lockpipe.

Commencing from the inlet end of the pipe, two men with crowbars ram the earth, which has been brought in by the bulldozer and spread by hand shovels beneath the pipe. The first ramming with a crowbar should be from an oblique angle on each side of the pipe, so that the material is firmed well beneath the pipe. One firm stroke with the ramming end of the crowbar every two inches along the pipe is usually adequate for this ramming operation.

Now more earth is brought in by the 'dozer or shovelled in. The level of this earth is brought up to the centre line of the lockpipe. Another careful row of ramming on the same lines as the first and from the inside end to the centre with less emphasis on the downstream half of the lockpipe will ensure suitable compaction below the pipe. A little work with a shovel and further general ramming around the area of the pipe will complete the hand work necessary. Loose earth in the wall of a dam may settle and consolidate, but not so the earth below the lockpipe, since there is no weight from the earth in the wall above. Hence the necessity for this procedure.

The bulldozer is then brought in as before to place material in the lockpipe trench from each side and just sufficient to cover the whole pipeline but leaving the top edge of the baffle plates showing so that they form a guide for the next bulldozer operation. The top edge of the baffle plates is left exposed to view, and the earth on each side of the lockpipe should be of sufficient height to carry the bulldozer, which next straddles the baffle plates and lockpipe from end to end. In this operation the bulldozer is carefully signalled forward so that each track straddles the lockpipe. Care is necessary to see that at no time can the undercarriage or sump of the tractor come in contact with the top of the baffle plates, and therefore sufficient earth on each side of the lockpipe is necessary to keep the tractor clear of the plates. One run up and back along the full length of the lockpipe is all that is required with the bulldozer straddling the lockpipe. The bulldozer next stands off at right angles to the lockpipe and positioned in such a way that each individual baffle plate will be straddled. The operator is now signalled forward with a load of earth, which he drops progressively in the lockpipe trench and over the baffle plate and pipeline (covering the pipe with at least 15 inches of earth), and continues the tractor movement forward until the front of the two tracks of the tractor have just crossed the pipeline, which, in the process, has become covered with more earth. He is then signalled back and does the next baffle plate in the same manner, and so on until this operation is complete. The bulldozer can then travel up and down each side of the lockpipe trench (but not straddling the lockpipe), to produce some compaction and uniformity of texture in the rest of the trench. The vibration of the tractor aids this work.

Next, a mound with a minimum of two feet six inches higher than the top of the baffle plates is pushed in over the lockpipe at right angles to the lockpipe.

The fill material in the wall on either side of the lockpipe is brought up to the height of the earth on the lockpipe and the whole area is travelled by the bulldozer from now on in the general course of the construction of the wall.

Immediately the operation of placing the lockpipe and filling the lockpipe trench is completed, markers are placed at each end of the line, so that it will not be lost by the bulldozer covering the ends with earth in the course of the dam construction. A 44-gallon drum placed at each end of the lockpipe with two steel posts driven in the earth on each side of each drum are excellent markers for the purpose.

Maintenance of Wall Shape: Throughout the whole of the construction of the wall of the dam the downstream batter of the wall should be maintained at its finished batter and line (Y pegs). The back batter is 1 in 2 and should be kept at this batter whether the wall is only five feet high or ten feet high; this batter should be maintained throughout the work.

The inside batter of the wall during construction is not treated in this manner. It starts off as a very flat batter, gradually increasing in steepness until it finally reaches the correct batter on the completion of the wall.

As the cut-off trench is filled with good material, this material is spread and levelled off by the action of the bulldozer travelling occasionally along the length of the cut-off trench. Once the trench is filled, material is taken from the excavation area just beyond the site of the Z pegs and spread across the wall and travelling towards the back line of the wall which was already marked with earth placed prior to the completion of the excavation of the two trenches.

Supervision is necessary to see that the bulldozer operator does not dig earth from below the site of the wall, i.e., within the boundary marked by the Z pegs. This is of particular importance in overcoming one of the general faults in dam construction. It is to be remembered that an irrigation dam will sometimes be filled with water and sometimes empty. The period of greatest stability for the inside of the wall is during the time when the dam is completely filled. The water helps to hold the inside of the wall stable. Its period of greatest instability occurs when the water is drawn from the dam and the dam becomes empty. Inside slumping and slipping of the earth of the wall towards the bottom of the dam is the manifestation of this instability. If earth is removed from inside the Z pegs, i.e., from below the inside toe of the wall (a universal fault in farm dam construction) during the early stage of wall construction, then fill material will later have to replace it. The result is that a greater length of material that will settle and shrink occurs at the most vulnerable inside point of the wall. If, however, the shape of the land below the wall is preserved in its original form (less the stripping of topsoil), then there will be a very much smaller length and total area of shrinkage surface and the wall is improved at what is usually a point of weakness. (*Fig. 14.*)

This feature of my design is of relatively greater importance in all valley dams, as the valley floor slope is steeper. Generally the orthodox farm dam design provides a flatter batter for the inside of the wall and a steeper back batter, and this arrangement acts as a compensation against inside slumping. However, the Keyline design adds stability and allows the construction of the inside wall batter to be as steep as the rear batter. As well as reducing yardage, it simplifies both design and construction. The effect is lessened as the the valley floor slope is flatter, but it is still of significant importance in design. To be fully effective, good design features should be preserved in the construction of the dam by equally good supervision.

Methods of Bulldozer Operation: Many operators can drive a bulldozer well by performing accurately all the tasks of cutting and filling required, and though working hard all the time, still move earth at double what it should cost. I have frequently made tests and conducted trials on such matters and always, good supervision and the techniques which follow reduce earth-moving costs by a large percentage. In the construction of farm dams we are concerned with placing the right material in position as quickly and cheaply as possible, and every technique that aids this end is worthy of consideration. First of all, the speed of the engine of a bulldozer is governed to a maximum speed. It cannot overwork or strain itself, so the bulldozer should be worked with the throttle fully open always. Then windrows in bulldozer operation are the parallel banks of earth left on each side of the bulldozer blade as it moves the earth forward. The action of pushing a bulldozer load forward occasions continuous spill of material from each side of the blade. With a large load in front of a bulldozer, the movement of the load forward over a distance of, say, 80 feet, without further digging as the bulldozer progresses, will result in a much smaller load at the end of the distance; earth will have been lost in spill which forms windrows. But windrows can be used as an aid to shifting earth faster and cheaper.

The bulldozer should start its run by grabbing a big load as quickly as possible, and in low gear if necessary, pushing the load in a straight line and at right angles towards the wall. As soon as the load starts to reduce by spilling in the formation of windrows, then it stops and backs up and grabs another full load. This load is pushed forward towards the wall, forming a larger and longer windrow until such time as the load is reduced below the full load capacity of the blade when it rips back and grabs another full load. (Modern bulldozers can be equipped with "back rippers", which tear up the earth as the 'dozer moves back empty.) The bulldozer proceeds in this manner until windrows sufficiently high are formed, which will enable a full load to be transported forward to its final position. The operation of the bulldozer is now confined between these windrows pushing up from six to twelve full-capacity blade loads to the fill site. Grabbing the load simply means loading the bulldozer blade to maximum capacity as quickly as possible and using low gear if necessary, so that the rest of the trip to transport the full load into the new wall can be travelled in a faster gear. If the full load is not obtained in the first pass over, say, a 20 to 25-feet run, the operator rips back and grabs a load again until the full blade load is obtained. After six to twelve full passes have been made in this pair of windrows the tractor is moved to form a new path and new windrows, with one windrow of the new path partially formed by the windrow of one side of the first pass. This windrow site is worked as before. Windrows may be approximately three feet high.

The windrows should be formed at the centre of the excavating site and moving out first on one side and then the other, so that after all windrows have been formed and used there is a series of parallel equidistance lines of windrows lying at right angles to the wall of the dam.

The next operation involves the destruction of all the windrows of the first series of passes. The bulldozer commences the second series by travelling with one of the old windrows in the centre of the blade pushing a maximum load of the old windrow material forward at right angles to the wall. This pass will form new windrows very rapidly and the 'dozer continues operations in this newly formed pair of windrows for a suitable number of passes, generally from six to twelve full-blade loads. The next movement of the bulldozer pushes the next windrow of the first series out on either side of the new pass and continues the operation until all the old windrows are dozed out, new windrows have been formed and the requisite number of full loads taken between them. This type of operation is followed throughout the whole of the construction of the dam.

Systematic working and following these procedures will often shift earth as mentioned for less than half the cost of another type of operation, which, though it may appear quite satisfactory and economical to both farmer and bulldozer operator, is much more costly. It is therefore very important that the full use of windrows is maintained throughout the whole of the work. The bulldozer, except in the final finishing-off of a job, should not travel to the wall site with less than its full load. A bulldozer travelling onto the wall site with half a blade of earth is shifting earth expensively.

Supervision in the construction of a dam is not provided by a man merely watching the bulldozer work. I have seen men set to work as supervisors stand idly by and watch while a bulldozer operator did almost everything wrong, added a hundred or so pounds to a job of modest size, and finish up with a blot on the landscape which both operator and supervisor mistakenly thought was a good farm dam. That is not the sort of supervision that is required.

A supervisor, whether a farmer or anyone else, must know first what he wants, and as most people have not seen a good farm irrigation dam, then he should really have a plan. The plan should be first studied so that the farmer may be convinced of the logic and necessity of every detail of the design, of the methods of work, of the construction details, and of the final finish and the use of the dam.

He then should see that the operator follows his instructions. A farmer may be somewhat reluctant to instruct a bulldozer operator of wide experience, and think that he should not be told or should not be stopped when he is not performing the operations according to plan. However, a bulldozer operator, in almost all other circumstances outside farm work, does work to a plan and under a supervisor, because such methods of operation have been found to produce lower costs and efficient work. Moreover, it is quite unfair to a bulldozer operator to expect him to design and construct a good dam from the seat of his tractor as he goes along. Also, the bulldozer operator is only on the farm for a short while, but the farmer has to live with this work, whether it is good or bad, for very many years. He should, therefore, get the dam that he wants and which he will only get if the manner of his supervision carries out effectively the design of the dam. It is also a good idea for the farmer when his first dam is finished to again study his plan perhaps quite critically, and maybe talk to someone about it. As long as the person to whom he talks is interested, the talking will probably line up his own ideas and plans, and he may even find that he can greatly improve the manner of the building of his next dam.

Travelling Forward Over all Earth as Placed: A bulldozer is not a completely efficient compacting machine. A farmer contemplating the purchase of a heavy crawler tractor for the purposes of farm work will be assured by the tractor salesman that the track-type tractor places less weight on his soil than the smallest wheel-type tractor. He may offer to place an egg a few inches below the surface and show that this will not be broken by the weight of the tractor on its tracks unless a growser bar on the track plates happens to hit it. Nevertheless, the travelling of the bulldozer over the earth as placed does give a measure of consolidation and stability to the loose earth and can produce a very desirable uniformity of texture in the material. Uniformity of texture is important, as it assures that shrinkage, when it does take place, is also uniform, while cross cracking and longitudinal cracking of the wall will be lessened. During the construction of a dam, continuous waves of earth in the wall site are to be avoided by the means suggested previously, e.g., the bulldozer travelling forward over the earth as it progressively drops its load and as the operator raises the blade. This fill material must be continuously smoothed off and shaped up.

Levelling-off at the End of Each Day's Work: The construction of a farm irrigation dam may occupy as little as two days, or may take several weeks, depending on its size, the implements used, and digging conditions and weather.

In dam sites with valley floor slopes that permit all the excavation material to be taken from above the level of the lockpipe, as in the keyline dam of this design, care should be taken to see that the bulldozers do not dig below this level. Those spots above the level of the lockpipe which would trap rain water are also to be avoided. The full depth is to be maintained only in the lockpipe area, so that rain water will drain to and through the lockpipe. Before finishing work for the day, the windrows left in the excavation area from the day's operation should be pushed into the wall area and trimmed. The whole area, including the wall, then will carry the minimum of loose earth and provide good drainage from the work to the lockpipe. Preparation made at the end of each day's work should provide against the possibility of damage by heavy rain falling during night time. Some inches of rain could fall on the construction then and not prevent work on the following day. However, loose earth on the walls and excavation site would, under the same conditions, absorb much water, create ponds, and possibly hold up the work for days. Trimmed earth will absorb the minimum amount of rainfall water and then the rest of the water will be shed off. The lockpipe should also be maintained in an open, free and operating condition at all stages of the construction, and should be checked each day before work ceases.

Rain: If rain has fallen on the work area the whole of the wall section should be travelled and ripped up if necessary before starting again, so that continuous bonding of the earth as it is placed in the wall occurs satisfactorily. Windrows are then formed again as usual, when the deeper, drier earth will become well mixed with the smaller amount of wet material, so that a uniformity of moisture content and texture is still maintained. In many types of earth work, moisture conditions are maintained within precise limits, but generally the only occasions that may be troublesome in the construction of a farm dam are when the earth is very dry and does not bond properly, or is in an overwet condition, causing clays to ball-up and leave air pockets in the wall.

Progress of Work: During the construction of the dam, all 'dozer paths should be at right angles to the wall and be particularly so in the early stages of the work. After the task of laying, tamping and filling the lockpipe trench is completed, the formation of the wall should continue with the bank at the highest level over the central low area of the valley bottom. From this stage onward right through to the time when finished levels are being considered, the central area of the wall should be maintained as the highest point, with a slope of about 10% (1 in 10) along the length of the wall from the centre to each side. When this wall line is maintained during construction the low portion of the wall is always well away from the area where the maximum earth has been deposited. In a valley of uneven section, i.e., where the one bank of the valley at the wall is steeper than the other, then the lowest point of the rising wall at any time will be the end of the wall on the flatter side of the valley and at the greatest distance from the main earth fill. Water would flow over the wall here if the partially built dam were flooded. The low spot acts as a safety fuse (the name for a weak or low spot), thus protecting the main fill area of the earth wall.

In a sudden heavy downpour the lockpipe would also be flowing a full bore of water and as soon as heavy rain ceased would quickly reduce the water level to below the overflow height and then empty the dam. Damage would be of the minimum, even though no expensive safety precautions had been employed.

Dams with only small natural catchments such as this keyline dam, though, would hardly be affected by heavy rain. The lockpipe provides full safety and water would only rise a few feet of depth for a short time. This safety factor is aided by the fact that the water conservation drain, which will later help to fill in dam, is not constructed until the wall is completed, so that run-off is restricted to the small natural catchment. It can, however, be even further restricted, if need be, by constructing that part of the water conservation drain only that is around the dam. Provision is then made for the disposal of the small natural catchment run-off through the spillway area of the site.

A well-planned and supervised job looks right all the time. Some bulldozer operators like to concentrate on one spot to bring it up to its finished height, but this is bad practice, since it tends to work against uniformity of texture and proper bonding of the earths in the wall. Furthermore, areas of compacted stabilised earth are likely to be placed adjacent to areas of very loose earth. Shrinkage later would form large cracks between the different textured materials. There is a tendency also for bulldozer operators to push all the earth of the blade-load into the wall and leave it as a loose mound. This is avoided by the operators starting to lift the blade at the correct position on the wall so that the earth is distributed evenly. Again, there is a likelihood of earth being carried forward too far onto the wall site, the result being that much loose material is spilt over the back of the wall. This loose material in a finished wall tends to absorb a lot more rain than the rest of the wall, which, by increasing its weight, could cause sliding and slumping of the rear of the wall. The back batter of the wall should be maintained throughout by trimming with the bulldozer when it becomes necessary.

Sometimes a bulldozer operator "rushes-for-height", which often results in a concave line up the wall. The line up the wall should always be a straight line. A concave line encourages slumping of the high point on the edge of the crest of the wall, and once this has started the extra weight on the material below causes a movement of earth which in the worst circumstances could result in a later partial failure of the wall.

Throughout the building of the dam the marking pegs should be maintained in their proper position by lifting them out of the bulldozer path when it is necessary for it to travel there and by the farmer stepping three or four paces out and lining up the position of the peg between himself and another peg, so that after the work in that area has for the time been completed then the old peg can be put back in its correct position.

The spillway of a dam, like all other features of good farm irrigation dam construction, has to be right for the dam to be a good one. For relatively small dams, the wall can be constructed to the completed height, which includes freeboard and shrinkage allowance, right through from one side to the other. Then the spillway, which outflows at the downland side of the wall, can be constructed by pushing through the placed earth at one end of the wall down to solid ground at the top water level contour and maintaining the flat bottom of the spillway on the side of the valley away from the water line. By constructing the spillway through the finished bank a considerable quantity of extra earth is available to strengthen the spillway at its critical point, *i.e.*, where the bank of the spillway merges with the wall of the dam. On other occasions, the construction of the spillway may produce a surplus of earth, which is then used in the building of that end of the wall.

The batter between the bottom level of the spillway and the wall of the dam is about 1 in 4, so that in the grassing of the dam site, wall and excavation area, convenient travel with cultivating equipment is possible. A section of the spillway therefore will show a batter slope of 1 in 4 falling from the end of the dam wall to a dead level spillway bottom of a given width, with a similar batter rising from the spillway bottom to the rising land on the high side of the spillway and away from the wall of the dam.

Shrinkage allowance, freeboard height and spillway size therefore provide than on the completion of the dam and its subsequent settlement, there will be three feet of wall everywhere above top water level at the point where water commences to flow out of the dam and through the spillway. The design of the spillway is such that the type of flood likely to occur any time in 50 years would be by-passed, with the spillway carrying little more than one foot of water across its full width, and when this happened there would still be a further freeboard of two feet to compensate as a safety measure for bigger floods and to provide for wave action erosion during high flood.

Larger spillways are necessary in farm dams such as reservoirs or lower valley dams, since they have considerably more catchment area than this keyline dam. To secure the necessary width of spillway with a dead flat floor, considerable material may have to be excavated into the rising country near the wall of the dam. In these circumstances, an appreciable amount of earth may have to be moved, that is, earth greatly in excess of the needs of the spillway bank. The construction of the wall of such a dam, then is designed so that the earth of the spillway is used in the construction of that part of the wall adjacent to the spillway. It is advisable to construct the spillway before the earth in the centre of the wall approaches its finished height, and when there is still plenty of wall area unfilled and available for the use of the spillway material. On occasions where the spillway of a dam involves very considerable earth moving, the construction of the spillway may be completed by placing the excavated material into the wall site immediately the site preparation is completed.

In spillway construction earth has to be excavated down to a specific level and supervision should ensure that the earth is not excavated too deeply, necessitating the filling of areas of the spillway with earth that would not be in as good condition as the stable undisturbed material.

Final Batters: With the earth for the wall being constantly moved in properly designed windrows at right angles to the wall, the site is in a condition to be examined continuously in order to ensure that the cheapest digging earths go into the wall. As the work proceeds, areas of material somewhat harder than that of the general digging conditions may be encountered. These areas are then studied to determine whether cheaper earth can be obtained by going back another 15 feet or 20 feet for earth or whether cheaper earth is obtained by persevering with the cutting and digging of the harder materials. Outcropping hard rock may be encountered, and it should not exceed 30% of the earth in any blade load. Bulldozers operating with back rippers are capable of making fairly light work of reasonably tough materials, and once the job is well opened up, continuous consideration should be given to the work to ensure that the cheapest material is being used throughout.

The cost of moving a particular quantity of earth is related to the distance it has to be moved, so length of movement of earth should be considered as the work proceeds.

Finishing Stages: With the back wall batters strictly maintained on a straight line and at the correct slope, the front wall will gradually steepen from very flat batters towards the final finished angle. Centre line pegs lined up with the P pegs on either bank of the valley should be placed at intervals during the final stages of construction, and measurements should be taken and marked with temporary pegs to show the finished width as well as the final height of the wall. A continuous check with a level and measurements ensures that the right amount of material is in the right place and excavated from the correct position in the excavation area. The centre area of the wall is first finished off to its final height, crest width and batters. The construction of the finished batters, the heights and top width of the remainder of the wall is maintained towards the sides. Final batters should be even and continuous throughout, with straight lines up the wall. A slightly steeper slope in part of the wall always has a tendency to be more unstable than the rest of the wall. Slight movement of earth may take place, the parting on either side of the movement being represented by a steep crack, which tends to allow movement of the flatter battered earths on each side of the steep area and thereby assisting the movement of the steep material and progressively worsening. Such movements tend to reach a point where they stabilise themselves, although not necessarily so.

Finishing Off: When the material has all been placed and the wall trimmed to its proper top width, height and batters, the final finishing-off commences. The windrows left in the bottom of the cut may be flattened out, but it is not necessary or advisable to move all loose material from the excavation area. However, it is important that the excavation area be smoothed into a natural shape to conform to the valley area of the whole dam. When this is finished, the raw earth is cultivated with a chisel plow and then covered with the soil, which was previously moved from the surface of the excavation area. Some of the soil should be used also to cover the batter on the inside of the wall. The soil which was stripped from the wall area and pushed behind the wall is now brought up over the wall to cover the back or downstream side of the wall and the top of the wall, where an inch or two of soil cover is all that is required.

If two tractors were used to build the wall and a big rope or cable of the type used for the roping down of trees is available, a good finish to the work can be obtained by the two tractors hauling the rope across the inside and then across the outside of the wall. In this operation one tractor with a cable attached travels along the top of the wall and the other tractor travels along the bottom of the dam near the wall, with the other end of the cable attached and slightly in advance of the tractor on the wall. The rope dragging over the top and side of the wall smoothes the work. The top of the wall should be finished with slightly rounded top edges. If it is finished off haphazardly with a bulldozer there is likely to be a small windrow effect left by the blade. When rain falls this could cause little ponding areas, which eventually break in one particular spot and flow down the wall in a concentrated stream. Further rain falling on the wall takes the same path, and sufficient erosion could take place with an inch or two of rain to spoil the appearance of the new wall and necessitate some repair work.

The area of the dam is cultivated with a chisel plow in a single-run cultivation about three inches deep. The cultivation parallels the water level contour downwards (keyline cultivation), so that flow water later spreads as it flows into the empty dam. Next, the wall and the whole of the site is sown with the regular pasture seed mixture and combined with a dressing of fertiliser.

Hand finishing of the top of the wall to leave a good shape and to aid the germination and growth of the grasses is well worthwhile. Slight ridges can be raked out and slightly rounded edges left on the top edges of the wall.

Finishing Off Lockpipe: The volume strainer is coupled up to the cleaned surface of the flange of the pipe on the inside of the wall with a rubber gasket between and with the straight edge of the volume strainer downwards.

The inclined section of the lockpipe is made to point upwards in the upstream direction. The upward tilt acts as an additional safety to preserve a free and full flow of water in case there is a slight slip of wall material through any cause. The volume strainer should be coupled up tightly.

Our strainer has an opening nine times the lockpipe size, and screened by heavy mesh. The rate of flow of water into the volume strainer when the lockpipe valve is open is therefore very much slower than the rate of flow through the lockpipe, so that any matter which can enter the strainer will flow out through the pipe. The outlet valve should be coupled in the same manner as the strainer, but on the downstream end of the lockpipe and tightened up and closed. All surfaces, gaskets and flanges should be clean and no earth left in the end of the lockpipe. As care has already been taken in the laying of the lockpipe to ensure that two holes are level on top of the flanges of the lockpipe, the valve will fit in an upright position.

Our own valves are provided with a 2-inch constant-flow outlet on the water side of the valve closure, so that water is always available for such items of smaller supply as stock troughs, etc.

The building of the dam is not completed until the working drains are provided. These are discussed in the following chapter.

CHAPTER XIX

Drains and Irrigation

THIS chapter will discuss how water conservation drains are designed and used to fill the keyline dam described in Chapter XVIII. This project is now to be completed to the stage of watering and the managing of irrigation land.

The line of the water conservation drain may have been pegged prior to the construction of the dam during the marking out or site preparation. The keyline dam water conservation drain starts from water level at the overflow point of the spillway, which is on the line of the centre of the wall. Preferably a line is pegged rising at 0.5% right round the dam in the direction of the general rise of the country. (NOTE: The spillway is usually on the downland side of a keyline dam.) Where the land shape has smooth contours, pegs 50 feet apart may be suitable for the construction of a drain, but it is preferable that Pegs be placed at closer intervals around the inside bends of valleys or the outside curves of ridges. When a peg intermediate between two 50-feet pegs is to be placed, it is not necessary to level in the peg 1-1/2-inch fall in 25 feet. The intermediate peg can take its height from the last preceding level.

The section of a water conservation drain provides that the centre line of the drain bank is over the pegs. The pegs, when placed, represent the centre line of the embankment of the drain, so that when digging commences in the construction of the drain, earth is moved from a line some feet above the pegs, so that the centre line of the finished bank will coincide with the pegs.

Various implements can be used for the construction of the drain, from 3-point linkage attached-farm-graders through to the angle-blade large bulldozer. If a farm implement is to be used, a chisel plow should first cultivate the area above and below the pegs, and by just missing the line of pegs and leave them undisturbed. From two to four runs of the plow may be necessary, according to the size of the drain. The plowing of the land below the pegs assists the bonding of the subsequent bank material.

A single deep rip furrow made with a small tractor, travelling so that the downhill wheels leave the pegs undisturbed, is a further aid to the construction of the drain with the smaller type of equipment. The farm grader can then be operated, digging the earth from a regular distance above the pegs and throwing it towards the pegs; in this way half a dozen or more runs may be necessary to form the drain, including its bank. Throughout the operation the pegs should be preserved in their true position. Pegs are preferably about two feet high.

The size of the drain depends on the slope of the country and the amount of catchment area above the drain. The conservation drain section illustrated is the one I generally employ for our own keyline dams. Its capacity range is upward of 350,000 gallons per hour. (*Fig. 13, Chapter XVIII.*)

There is a tendency for all equipment to "pull down" on the inside curve when the implement is travelling around a valley, and to do the opposite, i.e., climb-up when the implement travels on the outside curve around a hill or ridge. It is convenient and good practice to put in marker pegs one foot to three feet above the line-pegs in the valleys to compensate for this tendency to pull down. After the first couple of runs with the implement the obvious corrections can be made. Similarly, but in a reverse manner, compensation is provided against the tendency of equipment to climb on the outside curve of a ridge.

An angling bulldozer (angle 'dozer) provides a very efficient implement for constructing water conservation drains. The angle 'dozer should be operated with the heel of the blade against the lower or downhill track of the tractor, and working in such a manner that the lower track is in the cut of the drain as it is formed and the uphill track above the cut. The pushing forward and sideways of the earth with the angle blade tends then to throw the rear of the tractor uphill, but the weight of the tractor compensates for this and permits high-speed accurate drain construction. Again, some allowances must be made for a tendency to move downhill on the inside curve around a valley and to move uphill on the outside curve round a hill or a ridge. The line of the cut of the drain is again uphill from the line of pegs, the first pass being made in such a manner that the earth from the blade falls on the uphill side of the peg.

The angle 'dozer operating this way works like a giant mouldboard and can be operated efficiently by maintaining as big a bite as the tractor will cut and push evenly in second gear. It is advisable for a man to walk ahead of the tractor with a 6-foot pole, which he holds on the line peg and ahead of the 'dozer, so that the operator can see his line of travel clearly. The operator on his own cannot sight the pegs of the line quickly enough to maintain the generally smooth even curves that are desirable in these drains.

After the first run the full length of the drain, the tractor makes another pass. The tilt of the angle blade needs to be readjusted, so that it cuts a drain to its pre-determined shape. Two rapid passes will often shift sufficient earth to form the drain illustrated by the section diagram, but in harder conditions three or four passes may be necessary. Feeder drain sections, notably the shorter-length drains (under 900 feet), when newly constructed, are a flat V section with the uphill line and the bottom point of the V represented by the cut of the angle blade and the downhill shape of the V represented by the slope from the deep point of the drain to the centre line of the earth bank and the pegged line.

For longer drains with larger capacities, their section is represented by a flat centre section of the drain equal to the width of a 'dozer blade, a long sloping uphill cut on the topside, a long slope to the centre or high point of the bank on the downhill side to the pegged line, and a further earth slope behind the bank. Where the length of a feeder drain exceeds 900 feet, it requires theoretically a progressively larger section of drain to carry the quantity of water which in effect increases throughout its length from its beginning through to the dam. This can be achieved by constructing the drain from the end near the dam, and after completing the necessary number of runs to form the drain to the section required at the end away from the dam, make two more runs from the dam-the first one travelling three-quarters of the distance of the drain and the last run half the distance of the drain from the dam end. This provides a larger section of drain where the water flow will be greater. One extra run in a drain considerably increases its carrying capacity. (*See Pictorial Section.*)

Water carrying capacity, increasing as the length of the drain increases, may also be affected by planning the feeder drain with increasing rates of fall towards the dam. A steeper rate of fall is therefore to be made in the section near the dam and the flatter fall in the end section furthest from the dam. However, the drain of uniform fall, but increasing in size, if necessary, as it approaches the dam, is the type preferred.

The angle 'dozer constructed drain, while being the cheapest and fastest method I have employed, leaves the bank somewhat lumpy and uneven. Farm equipment can then finish off the drain quite smoothly. The upper wheel of a farm wheel-tractor with an attached chisel plow is placed in the bottom of the drain with the downhill wheel on the drain bank. One light run with the implement will smooth off the shape of the bank. A farm tractor and attached grader can also be used to trim up both the inside and outside of the drain bank.

As soon as the water conservation drain is completed, the hard, newly-cut surfaces should be cultivated to a depth of 2-1/2 inches or three inches with the tractor and implement and working on its first run with the downhill tractor wheel in the bottom of the drain and its upper wheel higher on the cut section of the drain. The whole area of the drain is cultivated once and parallel with the drain. The drain should be immediately sown down to the usual pasture mixture, together with an application of fertiliser.

It is desirable in the interests of the efficiency of the drain and the working of the property to have the pasture in the drain area of as good or better quality than the rest of the paddock, so that stock will keep this area eaten off. To this end, it may be as well to double the application rate of superphosphate on the soil of the drain area which, after all, by virtue of the topsoil being removed, may be very poor.

The feeder drain is designed as above, commencing from the centre of the spillway at the centre line of the wall, so that complete control over water can be exercised at all times. For instance, with the drain starting from this point and rising steadily right around the water line of the dam, the drain is above the end of the wall at the opposite end from its starting point. There is no interference with the wall. With the drain in this position, water can be let into the dam from any part of it around the dam. If there is an eroded area within the top water line of the dam, run-off water can be flowed into the dam over another area, avoiding the eroded area altogether. In order to by-pass water over the safe area into the dam it is only necessary to block the drain at the desired place and trim its bank for a short distance.

If required, run-off water can be by-passed right around the dam into the spillway and on to the water conservation drain or catchment area of another dam. If the overall plan envisages the maximum possible conservation of all run-off water no other design which embodies a different association of the feeder drain and dam to this layout will serve as efficiently or be as satisfactory.

A feeder drain should never be constructed to discharge water directly into the dam near the wall, although this has been the procedure on the farm dams where feeder drains are used other than those of our own design.

In Keyline there are usually only two drains down the land slope, one being the feeder or water conservation drain now discussed, and the other the irrigation drain. Heavy run-off water can pass over an irrigation drain without damage, so that there is no vital necessity that a feeder drain be constructed to such size and in such a manner that it never fails to hold and transport all the water that runs into it. If a feeder drain is sufficient for its purpose of filling the dam, but not large enough to transport the largest flood rains, then it is desirable that the area where water will overtop the drain should be deliberately located. A slightly lower bank produced by levelling off by hand on a suitable ridge section which has been Keyline pattern-cultivated provides a perfect safety against the heavy flood rain. The maximum amount of control should always be exercised over water on the farm.

Marking Irrigation Drain: The purpose of the irrigation drain is to transport water from the outlet valve along the higher boundary of an irrigation area. Marking out or levelling in with a level should commence at the valve.

A fall or grade similar to that employed for the feeder drain is suitable where the land is not too flat. In our own irrigation drains we generally provide a steeper fall (up to 1% grade) for the first 50 feet of drain from the lockpipe in order to counter an occasional tendency for a wet area to form near the outlet.

A high degree of accuracy in the construction of a feeder drain is desirable, so intermediate levelling pegs as close as 12 feet 6 inches or less apart may be placed to preserve the generally even-curved line of the drain.

On even-shaped land this procedure imparts perfect curved shapes to the drain and preserves a very desirable accuracy of line in the finished drain. As water is to flow over the edge of the irrigation drain for distances of up to 50 feet, some effort should be made to get considerable accuracy in the layout of an irrigation drain.

Constructing Irrigation Drain: The irrigation drain serves a totally different purpose to the feeder drain, and it is of different design and construction. It is designed (in undulating country) so that water flows within the excavated drain entirely, and no assistance being provided by a bank formed from the excavated material, as in the feeder drain. (In flatter country the design may be different.)

The irrigation drain is constructed with the lower edge of the excavated drain on the line of the levelled marker pegs, so that the water it transports, on being blocked in the drain with the blocks, spills over solid unexcavated material. Preferably the drain should be constructed with the excavated material thrown uphill to be spread out there, but in practice there is no farm equipment that will do this operation properly. On land with any slope, earth does not throw uphill readily, and the construction of an irrigation drain inevitably requires some hand work. (*Fig. 13, Chapter XVIII.*)

There is no suitable implement that will construct an irrigation drain to the desired sections in country of different slopes. An implement could be made that would be suitable for certain slopes of land, but its range of uses would probably be very limited. However, it is suggested that the drain be constructed with the use of one or more implements such as a delver, ridger, lister, or even a large single furrow plow. The first run with a farm tractor and any of the above implements should be made in such a way that the ground broken by the implement should not extend downhill to the pegs. Some implements will throw a measure of earth uphill, but there will always be a spill of earth onto the lower side of the drain which, if only a small amount, can be levelled off there by spreading, or preferably thrown uphill to the top side of the drain by hand shovel work.

The implement used should break the ground above the pegs and within the finished section size of the drain. When the soil is broken to the desired depth and a little under the finished width, the drain can best be finished by hand shovel operation by spreading the loose earth uphill and preserving the exact width and depth of the drain throughout and working in such a way that the pegs are still in position and an inch or two from the lower edge of the drain when this is completed. As soon as the drain is completed a small quantity of water should be let into it from the outlet valve of the dam to check the drain. The final finishing can then be done very accurately. Another larger flow of water could then be turned on for a short time as a final check.

Irrigation: When irrigating from the dam and employing Keyline flow methods, the water is first turned on at the outlet valve and allowed to flow to the end of the drain on the downland limit of the irrigation area. A block made of sheet metal or earth or any other suitable material is placed in the drain at this point, and by blocking the water, ponds it back and forces it to spill over the lower lip of the drain and run down over the land.

(NOTE: After irrigating, the drain stops are placed at intervals along the drain, so as to distribute any run-off rainfall.)

In order to preserve the correct water spread, proper time of complete wetting and for continuous soil and pasture improvement of the paddock we have employed certain specified procedures.

Pattern Plowing of Areas: The even spread of water is obtained by the pattern impressed on the land by the design of the appropriate keyline cultivation.

Keyline cultivation is simply cultivation with a chisel plow which parallels a selected contour line in such a way that when the parallel cultivation inevitably moves off the contour, the furrows oppose the natural flow pattern of the run-off water. The irrigation water then spreads evenly over the surface. The main art in keyline cultivation, when it is used in this manner as a positive control for the spread of irrigation water, lies in an understanding of the actual contour shape of the irrigation area, and in being able to select the line which is to guide the parallel cultivation, and then to determine the correct paralleling of this line, whether above or below it.

While this is simple enough in its cause and effect, it is not always at the outset fully understood to the extent that an inexperienced landman can put it into operation effectively on his own without first studying the land shape. He can, however, by the following procedure, illustrate the contour shape of the area and so determine the methods which will control the irrigation water effectively. The contour shape of an irrigation paddock can be determined and transferred to paper in the following manner: First, a line is drawn on a sheet of paper representing the approximate curve of the irrigation drain. Next, in the paddock, step a distance from the centre point of the irrigation drain and downhill at right angles from it about 90 feet and place a peg. From this peg run a true contour line in both directions with a levelling instrument, placing pegs at 50-feet intervals across the irrigation area. Next, place another peg 90 feet downhill at right angles to this contour line and peg another contour in the same manner as before. Measure and mark on the paper the distance of the two contour lines below the irrigation drain, marking first the distance stepped or measured at right angles from the irrigation drain to the two contour lines below. Then about three distances from the irrigation drain to the first and second contour line and each side of the centre are measured and marked in on the paper. These measurements are taken from even distances along the drain line (at right angles to the drain) to the first contour; and again at right angles to the first contour down to the second contour and marked in on the sketch. The contour shape of the area is disclosed by joining the points to form the two contours below the drain, and the appropriate guide for the cultivation can be selected.

The irrigation area watered from the dam should quickly become of high productive value, so it should be suitably fenced. If the area is already carrying a good pasture, it would be as well to feed it off quickly, and then, if the weather is dry and the land likewise, cultivate to the particular pattern which was selected.

Cultivation Procedure: The cultivation depth should be carefully determined beforehand by the following means: The soil is examined with a spade to determine the depth where, by the appearance and smell, the soil could be considered to be in reasonable condition, namely, fertile. It may be only one inch deep and will rarely be more than 2-1/2 inches. If it is the minimum of one inch and the pasture is fairly tight, a cultivation should not be more than two inches deep. Such cultivation need not disturb much of the pasture.

The first watering of a new area is preferably given in the morning, so that, with the mistakes and delays that may occur, the irrigating can be at least completed on the day it is started. In watering, certain relevant details have to be determined, and, first of all, is the width of the strip of land below the irrigation drain. This width should be narrow enough to enable a full flow of water from each overflow position on the drain to extend across 90% of the distance within a period of one hour. The reason is simply that land thoroughly immersed or saturated in water for any period of time longer than one hour may suffer "drowning". The beneficial soil life, which, after all, produces the various factors which we call fertility in soil, require oxygen. The whole complex of this life can be seriously disturbed and changed if water is continuously left too long flowing over land. The ideal length of time is somewhat less than one hour.

Irrigation is designed to produce abundant pastures or crops in the best seasons as well as the worst of seasons, and this is the basis or the reason for its use. However, fertile soil will produce more under irrigation conditions than infertile soil, and it is a deliberate function of irrigation to control water and air in relation to warmth in such a way that the fertility of any soil, fertile or otherwise, is rapidly increased. An inch of fertile soil under controlled irrigation conditions as in Keyline, can be converted into a foot or more of depth in two seasons of irrigation. This depth and degree of fertility can not only be maintained but increased.

Irrigation of the new area is accomplished in the following manner. The valve at the dam is opened and the water is allowed to flow to the far end of the irrigation drain. Here the first drain block has been placed. The drain block or dam may be a piece of sheet metal cut to the shape of the drain and pushed into the earth. A few shovelfuls of soil on the water side of the block may be necessary in order to make the block effective. The water thus held back overflows the lower lip of the drain and spreads down the slope of the irrigation paddock. Before the foremost edge of the flowing water reaches the lower limit of the paddock a second drain block is placed to spill the water again at a new site fifty to one hundred and fifty feet away and towards the dam. The distance from the first block to the second may be gauged approximately as 2-1/2 times the distance to which the water of the first block has spread laterally from the overflow position. Irrigation continues until the end of the area nearest the dam is watered and the watering is completed.

The first irrigation of a new area should provide the information for future watering procedures. The length of time that it takes flow water to reach the lower side of the irrigation paddock is determined and it should be less than one hour. Later irrigation of the area would simply mean that the farmer controlling the watering would come back to the area every half to one hour period, according to this time of flow, and with experience after a few waterings it is a simple matter for one man to control three or four dams contained in an area of, say, 600 acres.

On good, even-shaped land we have found that the first watering generally produces a good distribution, but on occasions there will be small areas unirrigated. The paddock should be examined twenty-four hours after watering to determine the effectiveness of the spread, and unless sizeable areas have been missed, it would be unnecessary to especially irrigate a dry area. Thirty-six hours after watering the condition of the land should be such that all is moist but none is wet and none is dry. Dry spots should be marked and studied in relation to drain block positions, so that on the following watering more effective spread would be secured.

Not all land takes water in the same way, because the shapes all differ, even a little, and the shape of the land and the cultivation pattern are the controlling factors. A good spread of water does not at first occur where the land is without a sufficiently uniform contour shape. Small local depressions or rises that are unrelated to the general shape of the land can cause too much moisture in the hollows and too little moisture on the rises. A corrected plowing pattern determined on inspection may be the suitable answer. On other occasions, the non-uniform areas may be too small in size to enable a plowing change to be implemented, since the distance of movement and change of movement in the plowing may be too short to be practical. In this case, "border checks" can be used to direct water to the awkward spot.

Border checks are one of the means of controlling water in flatter-land, flood-irrigation systems usually associated with the large irrigation areas. Generally with this method water is carried along the higher border of the irrigation country, which may be very flat, and water flows from the irrigation drain through various outlets along the length of the drain. The uniform spread of the water over the country is controlled by the border checks, which are small banks of earth 18 to 24 inches wide by as little as three inches high, which are thrown up by a "crowder" at right angles to the drain. The border checks parallel each other down the slight slope of the land at intervals of about 30 feet and provide an efficient means of spreading water uniformly over the land. It is sometimes called border strip irrigation. This check or bank is used where necessary in Keyline pattern irrigation to take water to the unwatered area, but whereas in conventional border check or border bank or strip irrigation numerous border checks are used, one to three banks is all that is likely on a reasonably-sized irrigation paddock in Keyline pattern irrigation. However, a study of the pattern of water movement and of areas not watered 24 hours after watering ceases will indicate quite clearly whether one or two border checks will assist the even distribution of water.

"Crowders" are the regular implements used for constructing border checks and consist essentially of two blades six feet long similar to those on small graders. They are arranged in an open V with the forward ends of the blades six feet apart and the rear end of the two blades around about two feet apart. The blades have various means of control, and, by travelling forward over land that has been lightly cultivated, in one run crowd sufficient material from the wide open end of the blades to the narrower end to form a satisfactory small bank without leaving a notable depression in the areas from whence the soil is taken. The same effect can be achieved quite satisfactorily in two runs with a small farm grader.

Distance of Water Flow in Irrigation: In considering the distance of water flow, it must be realised that soil will change by developing improved fertility and structure under good irrigation conditions and will be changed by deterioration if the soil is not managed properly during increased water application. Clay soils may allow water to flow at the first irrigation a relatively long distance rapidly. With the improvement in soil fertility due to well-managed irrigation, the distance water will flow then may be considerably reduced.

Soils that are poor and porous, such as some low-quality loams or sandstone soils and some granitic soils, will, by seepage, limit the distance of water flow in the hour, but with rapid fertility improvement the distance will increase. Where circumstances permit, it is preferable that the water for the irrigation area be supplied by the one drain, and that the distance downhill across the irrigation area be limited to a distance that water will travel within an hour, and at the same time provide a strip of unirrigated land below the irrigation paddock, and at least as wide as the irrigation country itself. This strip lies between the irrigation area and the valley below. For instance, if a dam provides sufficient water for the full irrigation of ten acres of land, it is preferable that the shape of the land be rectangular along the irrigation drain; 14 chains long by 7 chains wide, instead of square, 10 chains by 10 chains.

Where, by the shape of the land, such arrangement is not possible and a square block has to be irrigated, then watering could be by two drains, one at the top of the irrigation paddock and one across the centre, both falling in the same direction at the same rate of fall. The irrigation procedure then would be to commence at the end of the top drain away from the dam and watering the top strip progressively back towards the dam, and then by flowing the water over a specially prepared path, as between two border checks, allow the whole of the water to run into the second drain and complete this area by watering from the end of this drain away from the dam, and proceeding, as usual, back towards the dam.

Management of the Soil in Irrigation Land: The treatment that a soil may need varies widely according to the present state of development of the soil and to weather conditions. There is no exact theoretical method of determining the water requirements of a particular soil that will equal the practical examination of soils on the spot by the farmer with a spade. Many factors affect the development and fertility of the soil, but probably the overpowering influence is that of soil climate. The aim is always to provide the best condition of moisture, warmth and air in the soil for soil life and plant growth.

An examination by the farmer of the soil in an irrigation paddock is made by digging a spit of soil with a spade to the full depth where any pasture root penetrates.

Examination takes place by the look and feel of the soil to determine whether it is friable and crumbly with the unmistakable appearance of fertile soil. The fertility or otherwise is checked by the smell of the soil. Almost everyone, even without experience, knows the typical delightful smell of fertile soil. Below the zone of fertility determined on these lines, which may be only an inch or two, the soil will appear either close and compacted in clay soils, or loose, clean and sandy in light soils. The top zone of compacted soils is apparent to the eye and feel, and usually has no smell whatsoever. It could be called the neutral zone. Below this zone, there will be a change in the soil again, obvious both through sight and feel, and there may be on occasions a very definite change of smell to sour and perhaps objectionable.

The best means of improving soil is the right type of cultivation at the right time. Cultivation with a chisel plow and on the pattern decided for the irrigation area, should be undertaken when, from this examination, the soil needs it. The soil of the irrigation area should be closer to its drier condition than to a good moist condition. Cultivation can be best undertaken immediately stock has moved off the area. In warm weather irrigation is done on the following day. Cultivation time and depth should always be decided strictly on the condition of the soil at the time. Penetration that is too shallow will usually do some good, but a depth of penetration that is much too deep provides only the minimum benefit from the maximum water application. The penetration should just exceed the main pasture root zone and enter the neutral zone of the soil. With a soil in dryish condition, the resultant cracking coupled with the correct depth of penetration provides the air requirements and the space for the continued development of the soil without waste of water. With experience, cultivation can be used to control very precisely the amount of irrigation water taken in by the soil.

The response of the pasture and the soil to this planned procedure will be that the major root zone will deepen and at the same time, where warmth conditions are suitable, a rapid development or even a climax of development of soil life takes place by the provision of well nigh perfect living conditions for that life. These good living conditions, extending, as they do, just through the maximum root zone, allow the soil life to develop rapidly from the abundance of its food, the best food of all, the dead roots of pastures.

The improved conditions in the soil, both for soil life and pasture growth, continued for a period of only a few weeks, will, on examination again by the farmer with his spade, disclose that a rapid development of the depth and quality of fertility has taken place.

On clay or heavy soils resulting from the break-down of mudstones, slates, schists, etc., experiments in the cultivation of irrigation land have been conducted on our own properties six times during the warm and hot weather, with a resultant continuous improvement in soil development and pasture growth.

It is not known how many cultivations a pasture in this type of soil, coupled with good irrigation, will stand during, say, the hottest seven months of the year before the cultivations end in a detrimental way by destroying too many pasture plants, or in other ways by restricting soil development. Obviously, there is a stage where too much tillage would be damaging, even under the best irrigation procedures.

It is suggested that. the pasture soil be examined by inspection with a spade every month during the first year of irrigation, and that cultivation during this first year be as frequent as is indicated by the condition of the soil.

Of the two types of soil, heavy and light, the depth of cultivation is somewhat more critical in the light sandy soil, and, as a general rule, the cultivation depth of these soils should only be allowed to penetrate just enough through the major root zone. The factors of cultivation are again more critical during the first year of irrigation. During the second year, the irrigated land will be totally different from the original soil. It will then hold a condition of better balance than previously of the factors of moisture, warmth and air. It will require less treatment for its continued development. Earthworms will have come in, whether they were previously apparent or not. The earthworm life should develop rapidly and probably by the end of the second year of irrigation the depth of fertility and the structure of the soil may be such that it will look after itself, continuing its further development automatically.

While it is quite certain that this rapid soil development with its consequent beneficial effect on pasture and stock does take place in this manner in a short time, it is not certain yet how long the fertility developed in a year or two will continue to improve without further work (keyline cultivation) or whether or when this process will stop and a decline set in.

On "Nevallan", our experiment farm at North Richmond, we had country of very varied earth types. In one part it ranged from the shallowest grey soil through to yellow clay subsoil; others from yellow subsoil to soft yellow shales, even to medium hard blue shale, and all to be seen on the surface. There were other areas of sandy soil, with places where the sand was dean enough, and we used it in cement work for our buildings. On all these earths and under natural rainfall conditions, eight inches of highly fertile soil had developed in three years of Keyline treatment. During the next two years, the depth of this fertile soil had increased to two feet, with the roots of the pasture grasses well in evidence at that depth. Some green growth was continuous through the recent drought, the worst since 1944. A dramatic soil development during the fourth and fifth years had taken place naturally from the fertility that had been developed through the first three years of Keyline work.

How long this process, which increases the fertility and extends the depth of the fertile soil, will continue is not known. The ability of the developed soil to look after itself has been shown by the fact that it was apparently unaffected by the long-term saturation of the soil which extended from early in 1956 right through to the winter months, and by the fact that during the drought referred to it was able to maintain a green growth of grass where no other neighbouring rain pasture could. The earthworm population, which became apparent for the first time in March, 1954, has developed rapidly in numbers and size. Earthworms larger than those ever seen in the district can be obtained in every shovelful of earth during the casting seasons for earthworms when the moisture conditions are suitable.

These facts indicate that the state of the soil should be watched continuously even after the second year of irrigation, and if there is any falling away of condition, as evidenced by compaction, loss of structure, or the absence of a noticeable increase in the earthworm population over the previous year, or evidence that the neutral zone (zone of no smell) is higher, then keyline cultivation should again be introduced.

Cultivation of the soil in its condition after two years of development by irrigation and keyline cultivation will be a different matter to the cultivation of the first year. It will now be practically impossible to cultivate too deeply, because of the depth of the developed soil. From then on the soil can be worked, when cultivation is needed, to as deep as the logical maximum that is suitable to the chisel plow and the particular farm tractor, with, however, the effect kept in mind that it will have on irrigation water.

Experiments have shown that as progressively deeper cultivation is followed in the first year of irrigation, the improved structure and fertility of the soil develops beyond the depth of the work. It is therefore not necessary for cultivation towards the end of the second year to reach the full depth of the new soil.

The recompaction of a fertile soil that has been developed by these methods if and when it does take place, affects only a limited depth from the surface. Compaction does not seem to take place below five inches. A cultivation maximum depth of five or six inches may be all that is necessary to treat quite effectively a depth of 24 inches of developed soil.

Sowing Seed into Irrigation Areas: On occasions it may become advisable or desirable to introduce new species of grasses into an irrigation area. Sowing should be done as accurately as possible and the condition of the ground is preferably just moist or even slightly drier than would be considered good sowing conditions. The area may then be watered immediately and closed up for about two weeks before stock are brought in.

The reader having come so far will appreciate that the methods and procedures discussed above are not those now in general application for the management of irrigation pasture. Official recommendations do not cover the Keyline cultivation pattern as a control for water distribution. Continuous year-by-year applications of artificial fertilisers, and particularly on irrigated pasture, is the usual orthodox view. It is quite clear that the controlled application of water, plus artificial fertilisers, plus lime on occasions, will produce lush and abundant pasture growth with high carrying capacities. The assumption, which I do not accept, is that the important factor is to keep the top inch of the soil in a good pasture-growing moisture condition and replace the loss of nutrients from this thin band of soil by regular applications of the appropriate artificial fertiliser. It is assumed that, in general, phosphates are deficient in soils and need to be replaced by regular applications of superphosphate. Continuous application of water under these conditions induces soil deficiencies of other mineral elements of fertility, which have then to be added artificially on appropriate occasions.

The Keyline methods, however, assume generally that there are adequate minerals of all varieties present in the soil, but not necessarily in available forms or states, and it is good practice to make the unavailable minerals (phosphates generally being the critical one) available immediately by an appropriate application of superphosphate at the start of the development of the soil of an irrigation area. However, the rapid climax development of soil life due to the improved condition of the soil climate act on the existing but unavailable minerals and breaks them down rapidly into forms readily available to plant life. Chemicals, such as superphosphate, are, with advantage, used once or twice in the initial stages of soil development. Their purpose in Keyline is to provide rapid development of pasture root growth as well as pasture, so that -a basic food of soil life, dead roots of grasses, is in abundant supply as soon as possible. The continuous development of soil by the maintenance of the best possible soil climate right through to the depth of the zone of maximum root development during the first two seasons, continuously and progressively makes available the mineral elements of fertility and processed to their most perfect form by the natural factors operating on them. The effect is that in irrigation in Keyline the pasture is soon produced from some feet depth of fertile soil instead of from an inch or two of a very artificial growth medium.

I have proved, to my own satisfaction, that this conception of soil and pasture development, now commended to others, is a satisfactory and practical one.

CHAPTER XX

The Choice of Farm Dam Designs

NOW that I have described fully the design, construction and use of one type of farm dam, this chapter will, in less detail, consider the design and construction of other dams. A full appreciation of these dams can be obtained, however, from comparisons with the keyline dam of Chapter XVIII.

In Chapter VII, I have classified farm valley dams into three types--the high or keyline dam, the reservoir, and the lower valley dam. Both the reservoir and the lower valley dam are larger usually than the high or keyline dam. The larger capacity farm dam water storages are generally not so much larger construction jobs as their capacities would suggest. The sections of the wall, as described for the keyline dam, are, with some exceptions, the same as these for the bigger storages. For instance, the same wall section may, in different circumstances of land shape, impound quantities of water varying from 2-1/2 million gallons to 150 million gallons (10 acre feet to 600 acre feet).

A dam with a 20-foot depth of water at the inflow end of the lockpipe could be a keyline dam, or, alternatively, a reservoir, and have a capacity range of 21 to 100 million gallons. The maximum range of dam capacities varies widely, but there is a closer comparison in the minimum ranges of the various types of dam. The minimum capacity of a dam that is worthwhile for regular and effective irrigation is 2-1/2 million gallons, and this should be a limitation imposed only by land shape and run-off. The minimum size for a reservoir may be eight million gallons, and for a lower valley dam perhaps twelve million gallons.

A keyline dam on one farm or grazing property may have a greater capacity than the largest practical lower valley dam on another property. There is a general tendency for the capacity range of dams, all with the same depth of water, to be much wider as the country slope is longer. This length of land was defined in Chapter VI as the distance from the main ridge to the watercourse below.

Reservoir Sites: The reservoir in Keyline is classified as a reserve water storage located at an intermediate elevation between the high or keyline dams and the lower valley dams. A reservoir may be located at the low end of a large primary valley and just above the point where the primary valley joins a secondary valley; or where a primary valley flows into a creek, a river, a lake, or flows to a flat plain. A reservoir is also suitably located in the upper area of a secondary valley and in height somewhere below one or all of the keyline dams in the primary valleys which flow to and together form the secondary valley. Circumstances of climate, land shape and the association of other storages, or sites for other storages, dictate the location of reservoirs.

A reservoir (or several reservoirs), as part of a complete Keyline water conservation scheme, is designed to remain full during the time the higher and lower dams are used for irrigation. When these storages have been used, the reservoir is still full, despite some evaporation which may have taken place, and so the farmer or grazier in a dry time has at least one or more large reservoirs filled with water. He can plan his irrigation now from the reservoir and regulate stocking and management accordingly.

A reservoir is seen then as the largest body of longest lasting water on the farm or grazing property. It may serve as the basis for the planning for such lesser but permanent water requirements as stock troughs supplied *via* pipelines directly from a constant flow take-off on the outlet equipment. It is also the one type of dam that is most suitable for fish stocking, and one on which other forms of pleasurable water activities may be planned. Dams, such as keyline dams, in which the water level is constantly changing, are not so suitable for fish stocking or as pleasure resorts.

The design-for-use suggested for the various types of dams in Keyline (e.g., keyline dams and lower valley dams as general irrigation water and to be put into use at the same time, with reservoirs as reserve water during the use of these other dams), may be altered to suit individual requirements and convenience of management. However, the use-pattern for the stored water should be such that when some of the dams have storage capacity available by having been in use for irrigation, and run-off rain occurs, then no water will leave the property until all dams are again filled.

The design of reservoirs follows very closely the general design features of the keyline dam already discussed. It is assumed that the reservoir is on the same property as our keyline dam. The wall height may be the same or less according to land shape and run-off conditions. Water capacity will be cheaper, the storage will be larger, and the valley floor slope will generally be flatter. The relationship between storage capacity and annual run-off can be up to double that for the keyline dam.

I have suggested that the keyline dam should be designed to hold 1-1/2 times the annual run-off of its total catchment area, and this capacity is considered more a minimum than a maximum. Where the climate has a very uniform or regular rainfall characteristic the capacity should be somewhat less than this recommendation. The relationship of the reservoir size to its catchment area, other than in the climatic conditions just mentioned, should be from two to more than three times the average annual run-off. The actual ratio of storage to run-off should be related also to the cost of storage. For instance, if the storage cost in the keyline dam, which may range from under £20 to over £40 per acre foot, is double that obtainable in the reservoir site, then it could be good business to build reservoir capacity of double the storage capacity to run-off ratio of the keyline dam. If the storage capacity cost in the reservoir is more favourably related to the other dams, then it could be made even larger. In this case the reservoir's natural catchment may be increased by the use of a special water conservation drain. By keeping such points in mind, the circumstances of climate and land shape applying to each individual reservoir will clearly indicate the answers to these various questions.

For purposes of illustrating design and construction features, one of my own reservoirs may form a background. The design of the reservoir is illustrated in the plan and section immediately following, and titled accordingly. (*See Fig. 16.*)

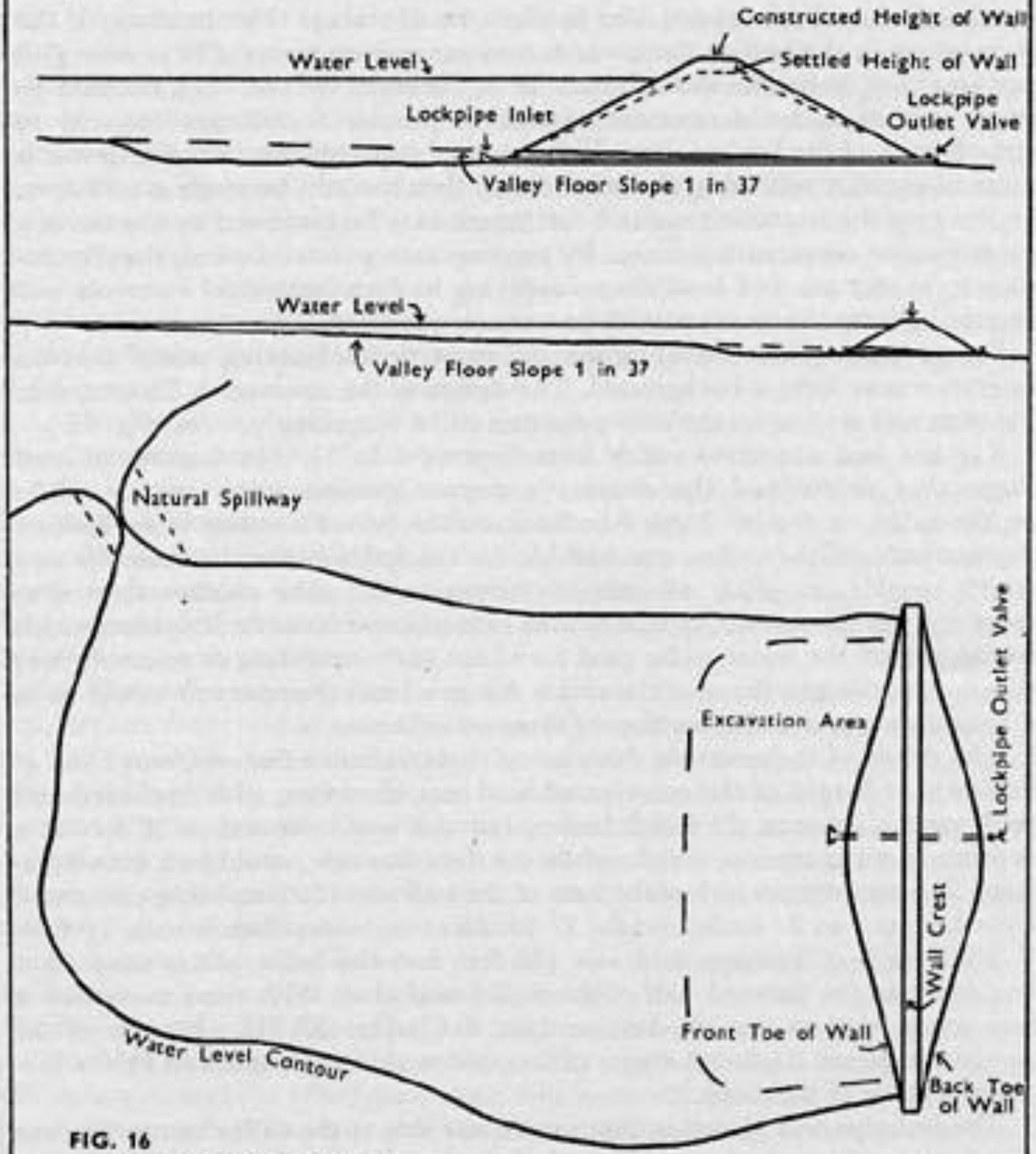

FIG. 16

The Design of a Reservoir.

Upper: Cross section of wall and excavation area. Broken line of wall represents the wall shape after settlement and shrinkage have taken place.

Middle: Long section of reservoir.

Lower: Plan of reservoir, showing natural spillway through the saddle in the ridge on the left bank of the valley.

The site had a general valley floor slope of 1 in 37. The features of land shape that determined the reservoir's precise location were, first, a saddle on the ridge on the left bank (the bank on the left of a valley when looking downstream) of the valley was suitable for the spillway for the reservoir and which would also allow all overflow water to fall into another dam site; secondly, the site was above a large area of land convenient for irrigation which would permit the water to be used for either early irrigation or reservoir use; thirdly, the contour shape of the valley was good and the reservoir would be in a position to receive the overflow of three other dams.

The depth of the reservoir, because of these valuable features, was fixed at 24 feet; the height of the constructed wall was, therefore, with freeboard and settlement allowance, 29 feet 3 inches, but this was increased to 30 feet as a counter to wave erosion, which, while the dam was new, could be a consideration. The maximum width of the base of the wall was 122 feet, being calculated from batters I in 2; settled height 27 feet, a crest (wider than usual), 14 feet.

The length of lockpipe laid was 130 feet and the baffle plates were eight feet apart in the forward half of the wall foundation. With these variations it was constructed as was the keyline dam of Chapter XVIII. (Pictures of the newly completed dam and stages of its construction are contained in the Pictorial section of this book.)

The lockpipe was placed in position on one side of the valley centre line one foot below solid ground, and the end of the lockpipe on the inside of the dam was four feet six inches below the solid bottom of the valley. The whole of the earth for the wall was obtained within the dam site and at a satisfactory close distance to the wall, and also without excavating earth below the level of the lockpipe inlet.

This reservoir has nine acres within its top water line. In addition, there is another acre or more of wall crest, back wall batter, drains and generally disturbed ground, which were all covered with the top soil we were able to strip from the original area. The land within the top water line was keyline cultivated and together with all areas of disturbed earth was sown with grass seed and superphosphate. The first flow of water into the dam did not move the newly-placed, sown and cultivated soil.

The average depth of the reservoir is approximately 10 feet, and storage capacity is 90 acre feet. The cost of water storage was under £17 per acre foot, allowing £6 per hour for the 100-horse-power bulldozers which built it, and 20% of this cost represents the lockpipe equipment and drains for irrigation. The reservoir has a rather special asset value worth many times its cost, yet such is the variations of these factors in farm dams that the nearest dam to it on the same property was much less than half this storage price, while another adjacent dam has a storage capacity which cost double that of the reservoir. All three dams, however, are very much more valuable than their costs, particularly so since they include the whole of the equipment and drains for effective irrigation, at the lowest of all operating expenses.

It will be seen that this reservoir has some special features, and this is so with most reservoirs. The recognition and the successful use of the individual and special features of each site depend largely on an appreciation of the relationship of climatic conditions to the shapes of the land. A facility in judging these matters is a great asset to the farmer and grazier. To give another instance of this individual value-of-site feature, we have a reservoir on another property which gains in usefulness by being precisely located according to the above principles. The effect of this location is that the spillway of the reservoir was made to coincide with the irrigation drain of a keyline dam located in the head or highest primary valley of the secondary valley formation in which the reservoir is located. Now we are able to turn water from the keyline dam into the reservoir, or we can direct the run-off past the keyline dam into the reservoir, or past the reservoir *via* its spillway into a lower keyline dam, or we may irrigate from the drain between the reservoir and the second dam. Flood overflow from the first or highest keyline dam can be controlled to flow either into the reservoir or into the second keyline dam, or, still further, if need be, into other lower keyline dams, or even the lower valley dam near the boundary of the whole region. Again, under drought conditions, after the top keyline dam is emptied by irrigating and its irrigation area. is requiring more water, this can be supplied by pumping water for the short distance from the outlet of the reservoir into its own spillway and thence it would flow along the irrigation drain of the first keyline dam.

A reservoir is seen to be a very valuable and versatile type of dam in Keyline. It is usually a permanent supply, and the best type of dam for a pleasure resort. In a secondary land unit, one or more reservoirs may be employed according to climate, land shape and the layout of the rest of the dams. Reservoirs, then, are the best farm insurance for dry times, in that a drought would be well advanced by the time other water storages were depleted, and with stock held in top condition, there would still be a large supply of water remaining. At the stage of the drought where it would be necessary to commence the use of a reservoir for irrigation the landholder would be in an excellent position from which to view the prospects of continuing drought. If a farmer or grazier can sell when most others have nothing fit for sale he can profit considerably. If he is also in a position to buy when others must sell, he is even better off.

Lower valley dams, in conjunction with the keyline dams and reservoirs, complete the series of valley dams that are available for construction on much of the undulating country. On the one property the lower valley dam will usually be the largest of the three types, although on occasions the reservoir may equal or exceed the storage capacity of the lower valley dam.

In planning for the complete conservation of all run-off water, the lower valley dam is designed to hold the overflow of all dams above it in the secondary land unit as well as all the run-off from areas below these keyline dams and reservoirs. It represents the last opportunity of conserving all such run-off before it leaves the secondary land unit.

The design of a lower valley dam is similar to that of the reservoir already described, but differing in that usually the lower dam is of larger capacity and has a flatter valley floor slope. Its capacity range on land of widely differing shapes may be from under 12 million to 100 million gallons or more. To illustrate its design and construction it may be assumed that a lower valley dam site has a valley floor slope of 1 in 55, and that it is to have a depth of water of 20 feet at the inlet into the lockpipe. Here the flatter valley floor slope necessitates a different design to that of the reservoir discussed. Such a lower valley dam is illustrated opposite this page, where both a plan and section of the dam are shown. The batters for the wall will be assumed to be 1 in 2, therefore, with a 20 foot depth of water, the final dimensions for the cross section shape of the finished wall will be the same as that of the Keyline dam construction of Chapter XVIII. The maximum width of the wall is 104 feet, and, with the flatter valley floor slope of 1 in 55, the variation in level of the valley floor inside the dam will be only two feet above that of the back or downstream toe. Therefore, after allowing for the lockpipe being positioned on one side of the valley and a foot into the solid valley floor, its depth below the valley on the inside of the dam will be three feet. The earth for the construction of the wall cannot be obtained from the valley down to this level, as was done in the construction of both the keyline dam of Chapter XVIII and the reservoir recently described. The distance away from the wall where some of the earth required would have to be secured would be too far for efficient bulldozer operation, so earth will need to be excavated from the inside area of the dam near the wall and below the lockpipe level. Other than the changed design of the excavation area occasioned by the flatter valley floor slope, the design and the construction are similar to that of the dams earlier described. (*See Fig. 17.*)

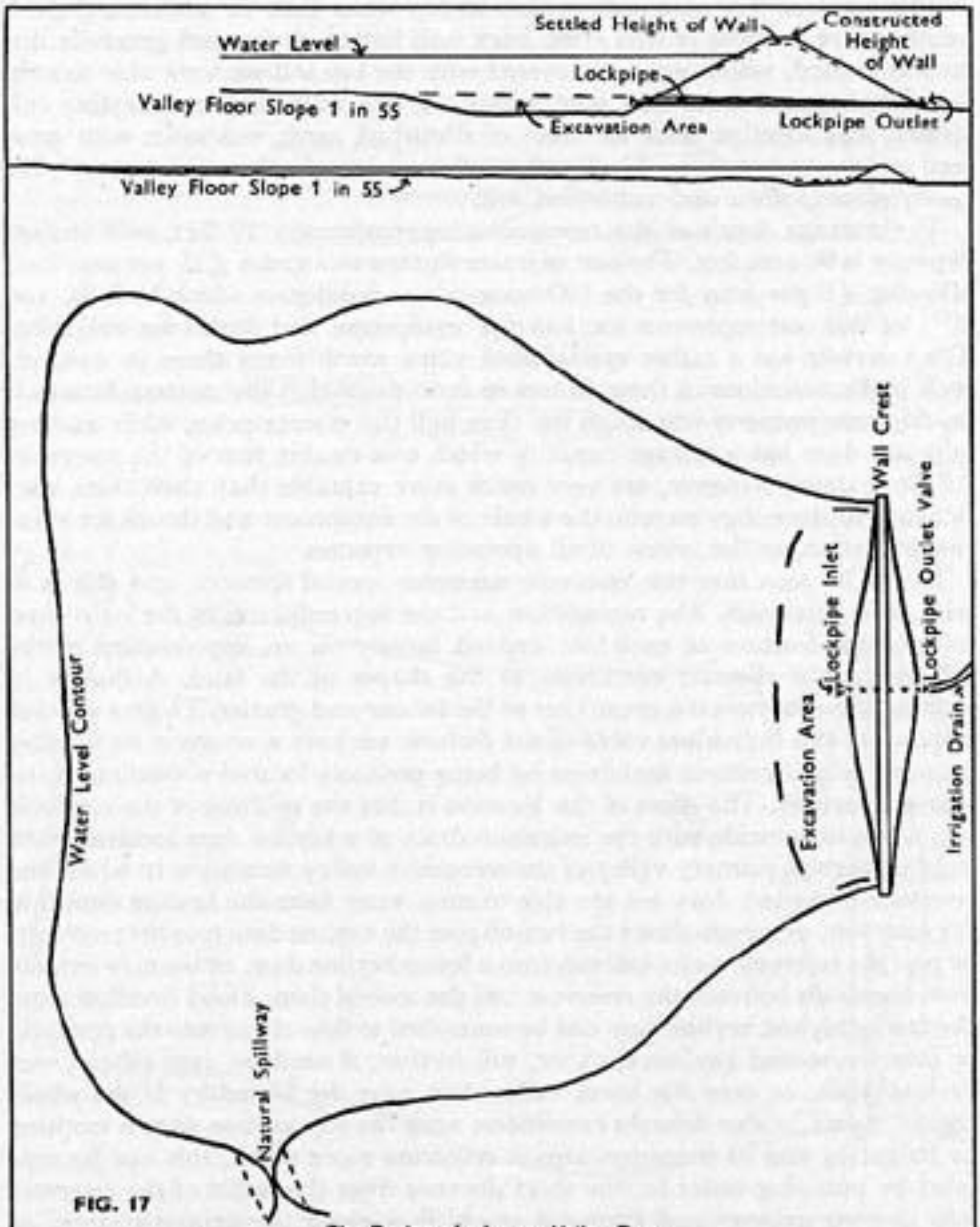

FIG. 17

The Design of a Lower Valley Dam.
Upper: Cross section of the wall and excavated area, showing the excavation area extending in depth below the lockpipe inlet.
Middle: Long section of the dam. *Lower*: Plan of lower valley dam.

The length of the wall of a lower valley dam may be considerably longer than the wall of a keyline dam having a similar depth of water, and so the construction may take a relatively longer time. The excavation of the material for the wall should be planned in two stages. In the first stage the earth is excavated only down to the level of the lockpipe and extending back from the wall toe at this level for approximately 100 feet. In this size dam and valley floor slope, earth down to four feet below the lockpipe level will need to be used, so an excavation is now made to this depth, and, to begin with, in the immediate vicinity of the inlet of the lockpipe. If heavy rain falls it would pond near the lockpipe in the most convenient position to be pumped out through the lockpipe. Also, if the area excavated to provide wall material is taken down to the full depth at this point and then extended outward from the lockpipe, water ponding in this area may be left there and will not hamper the completion of the wall.

The spillway of a lower valley dam, because of its generally larger catchment area, needs to be wider than those of the other two types of dams. Even though the dams above will hold large capacity from heavy run-off, there may be rare occasions when the lower dams will, when all others in the same land unit are filled, be required to take all the run-off from the whole catchment area. Where water conservation drains augment the catchment area these can be blocked and breached to reduce the excess inflow. There are different means of calculating spillway size in relation to catchment area, but as these are based on other factors which themselves are difficult to determine, a more reliable guide is local or farmer information as to the height that previous floods reached in the valley under consideration. Against this type of information one method often quoted may serve as a check. The spillway, according to this method, should be a width in feet equal to the figure obtained from the square root of four times the catchment area in acres. Using simple figures, the spillway of a dam having a catchment area of 36 acres is equal to the square root of four times 36, which is 12 feet, and the spillway of a dam having a catchment area of 400 acres is equal to the square root of four times 400, which is equal to 40 feet.

On my own properties there has been one occasion when these widths of spillway may have been inadequate, and the occasion was not during heavy general flood rains. However, subject to local knowledge, and also considering the greatly improved safety factors provided by an adequate outlet system, it is my opinion that this formula should serve as a satisfactory guide.

Therefore, if the lower valley dam under discussion has a total natural catchment of 400 acres, including the catchments of the dams which would overflow into it, then the spillway will be 40 feet wide on the floor of the spillway. The section of the spillway is 40 feet wide on the level floor, with a slope to the wall of the dam of 1 in 3-1/2 to 1 in 4 and with a similar slope on the side away from the wall of the dam.

Whenever a dam is flowing a large discharge through its spillway the lockpipe valve can be opened. "Sour" water, which sometimes lies at the bottom of a dam, is thus removed, and there is also an additional safeguard from this practice.

The use of the lower valley storage is similar to that of the keyline dam, it being a continuous-working and quick-profit dam. Whenever it contains water above the level of the lockpipe the dam is used continuously if irrigation is needed and can be put to advantage. Lower valley dam storage is not a supplementary system but is part of the regular farming and grazing enterprise.

The methods of irrigation from the lower valley dam depend on the circumstances of land shape and the type of pasture and crop to be grown. Although the dam is low in elevation in its situation in a secondary land unit, there may be much land below it on some properties, and on others it will be near the farm's lowest boundary. Our own lower dams illustrate these varying conditions. On one property The Pond, or lower valley dam (16 million gallons) is within a few yards of our lower boundary fence, so in this case the water of the dam is pumped up to an irrigation drain directly from the lockpipe outlet *via* a pipeline to a point nearly 200 yards away and twenty-five feet vertically above the top water level of the dam. The pump delivers a little over 1,000 gallons a minute (60,000 gallons per hour), and the method of irrigation is again keyline pattern suited to our purpose, which is generally pasture growing, but on occasions may be the growing of other fodder crops. A lower valley dam on another property is near the lower limit of the land unit and very like the reservoir mentioned in the construction details except that it is somewhat larger. Whilst it is low in its own land unit, it is high above a large area of our own property, and so its utilisation follows the lines of those for the keyline dam of Chapter XVIII. In this particular dam, when all the water that will flow from the outlet for irrigating is used, there will still remain an acre and a half of water six feet deep which lies in the excavation area below the lockpipe, and from which it was necessary to dig earth for the wall construction. Although this water represents only 2% of the capacity of the dam, it also represents a large stock water reserve but one which we will rarely need.

A lower valley dam, as I have said, is a real money-making dam. Apart from keyline pattern irrigation, the dam in various circumstances of climate, land shape and property management can supply water for almost any type of irrigation. In gently to steeply undulating country, the lower dam is usually adjacent to the flattest areas of the farm, and any type of watering now characteristic of the large irrigation district can be adopted here. These include border checks and bays (small crop and pasture), contour furrows (pasture), contour bays (rice, etc.), furrow irrigation (vegetable and orchards), and the basin system of irrigation (crops and pastures). All these systems and methods of irrigation are dealt with satisfactorily in official publications, so it is not necessary to include them here. Our lower valley type dam is ideal for any of the methods of spray irrigation (these also are described in official books), which may be suitable for particular purposes of cropping. It is suggested that the outlet of the dam is the most suitable point for a permanent or casual pumping set-up. Since the outlet is situated to one side of the low point of the valley behind the dam and with the water of the dam always above the level of the pump, pumping would not require a foot valve or any pump priming. The pump always works when the engine is started. It is also the best position for a permanent installation. Now-a-days, permanent pump and engine irrigation set-ups are placed on the wall of the dam, and after initial troubles have been ironed out, they operate satisfactorily. Personally, I much prefer to have the wall of a dam kept clear, so that it can be travelled and its soil and pasture aspects improved at the same time as adjoining paddocks are being worked. The arrangement whereby a pump and engine are placed somewhere around a dam, and, after pumping for a few hours the outfit has to be reset and often put down in the soft muddy area of the dam, is not a money-making arrangement, although in drought times the worst layout is better than nothing. Often after a dam has been constructed and has filled with run-off water and irrigating has been undertaken, the trouble of chasing the receding water into the mud begins; and it is a frustrating, time-consuming and money-wasting effort. Sometimes, too, a bulldozer is brought in to cut a trench from the deep part of a dam back to a spot on the water line to get at the deep water, so as to avoid changing the pump position. A small drag line excavator may be used for the same purpose. However, these things are evidence of not only inexperience, because the inexperienced can make a very good dam from a good plan, but the lack of proper forethought.

The relatively large volume of water available from most lower valley dams of this Keyline layout are so valuable that the most economical working set-up for the use of the water becomes very good business. One method which I have used, and which in other instances may prove suitable, is the use of a pump-sump for the permanent site position of the pump and engine. In this arrangement a sump or hole two feet six inches square and three feet deep is excavated adjacent to the lockpipe outlet, a few inches lower in level and on one side of the valley. The sump is lined with wood, brick or concrete and a permanent pipe from the lockpipe enters the sump and a smaller pipe drains surplus water from the top of the sump. The larger pipe from the lockpipe includes a valve. In operation, the valve on the pipe is opened, the sump filled, and the pump started up. The water inlet control is then adjusted so that there is a continuous small flow of water out through the overflow from the sump.

Some years ago I adopted a system which involved a series of lidded sumps 400 feet apart and located in a drain fed from the outlet valve of a high dam. Spray irrigation of pasture was the object and a readily portable pump and engine pumped the water from the sump adjacent to the land to be irrigated. Associated with the set-up was a mechanical means of moving the spray lines, which proved very successful. There were two dams, a larger one high enough for water to flow from it to a second and smaller dam. To use the system, irrigating commenced by using any water in the smaller dam first and then irrigating from the last sump (the one nearest the second dam) and moving towards the larger dam, using each sump in turn. For the sump to operate successfully there had to be a small overflow of water, which flowed *via* the drain to the smaller dam. Pumping from each sump only involved a lift of two feet and there was little trouble in pump priming. Although I did not continue with the use of this system, as our keyline flow method for pasture irrigating was very much quicker and cost almost nothing, the system may be of some value to others. However, the method applies more to the higher dams, and it could be valuable as a drought method of using water from reservoirs. It is mentioned here by way of illustrating the effectiveness of sump-pumping, but the obvious and best method of pumping is the direct one from the outlet of the dam.

A lower valley dam may be constructed with a capacity equal to several years of the average annual run-off and still conserve water at low cost, because of its favourable site characteristics. It may remain empty, or nearly so in some instances, and therefore during this time its land area should not be wasted. On occasions two such dams, the second located in the same valley and immediately above the first, may fill, but then remain empty for a year or two, after using all the water for irrigation. So the valley shape below such dams should be considered during dam construction and a good natural shape made or preserved. If old washouts or eroded gullies lie below top water line, these should be reshaped to a suitable natural valley form, so that keyline cultivation (parallel downward from the top water line) when the dam is empty will be effective to the maximum extent. With a good draining shape so provided, the area of the dam when empty can be sown down to special pasture or other crops. When the area of such a dam is dry enough for cultivation it should be worked up quickly and sown as soon as the soil has sweetened. The empty condition of the dam will usually occur in a dry summer, and so can be sown and made to produce its special crop.

I have cultivated this type of land and have found that a deep cultivation to gain quick aeration of the soil brings a rapid change and creates admirably suitable growing conditions; but the soil must not be touched while it is too wet.

The art of land utilisation is largely a matter of making the best use of water, and these larger lower valley dams offer wonderful opportunities in this connection over a very wide range of climates and land types.

Creek dams are classified as farm dams that are constructed in a natural watercourse in which the water flows over raw earth and between confined and defined banks. The stream may be flowing either permanently or intermittently. (*See Fig. 18.*)

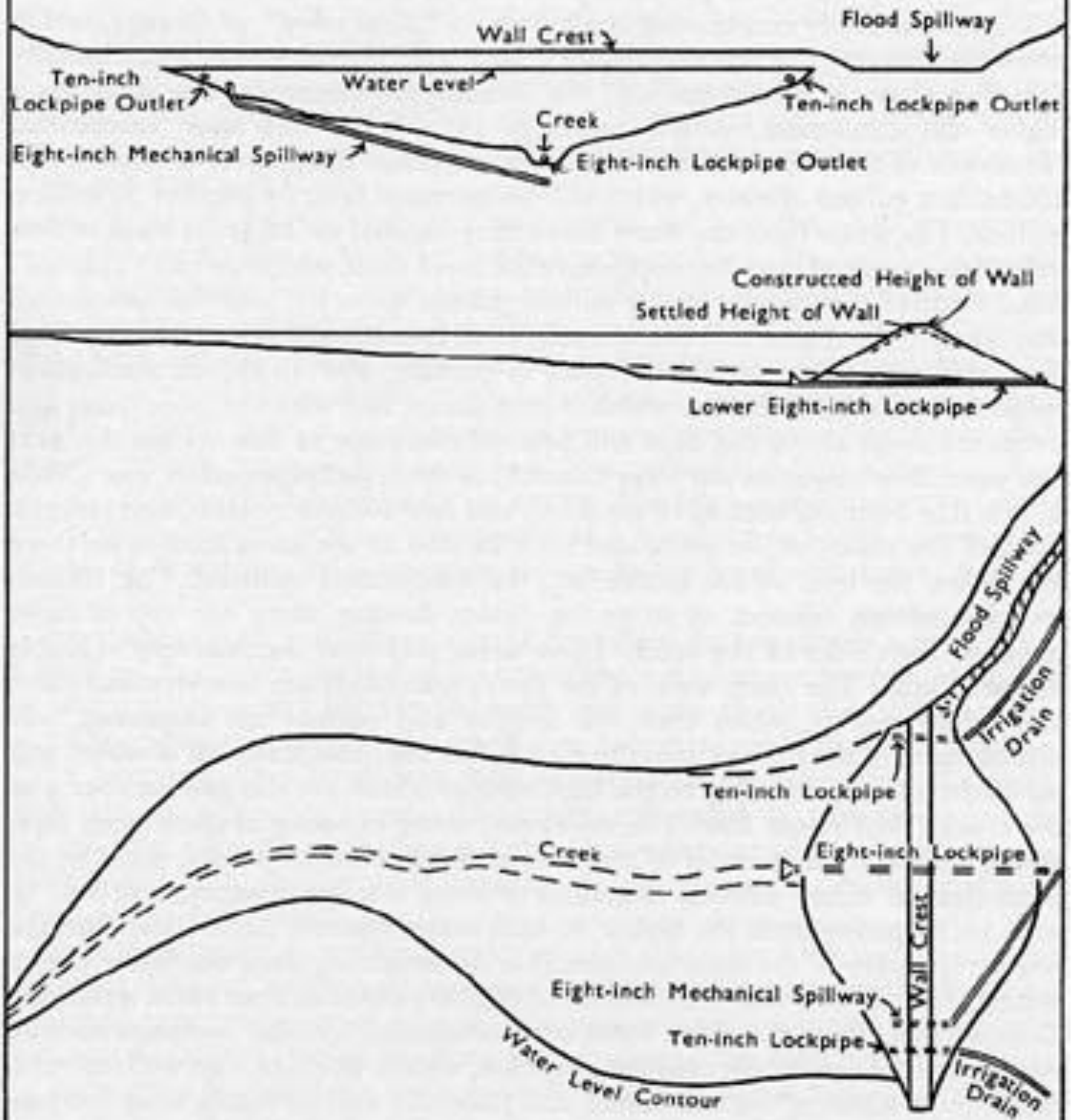

FIG. 18

Design of Creek Dam on "Kencarley", at Orange (Control Dam).
Upper: Long section of the wall across the creek, showing the four pipe outlets and the flood spillway.
Middle: Long section of the dam. *Lower*: Plan of "Control Dam".

As the distance down the land from the keypoints of the primary valley is increased for the various types of dams, so will the construction problems that may be encountered become greater. In the secondary land unit mentioned earlier, of the three types of dams that can be constructed, the highest or keyline dam is usually associated with the best construction conditions. The earth and the foundations are often better and the stability of the structure can be obtained with the minimum of effort. The reservoir site may have a deeper built-up earth and require a deeper cut-off trench into the more stable materials below. The cut-off trench may have to be excavated and filled with good earths as an independent job before the lockpipe trench is made. The cut-off trench of a lower valley dam in the same secondary valley may have further problems. However, the purpose of the cut-off trench and its filling with good material is always to prevent the water within a dam from seeping and then possibly later flowing under the wall of the dam. If this should happen the wall could collapse, and in any case the effectiveness of the dam is inevitably reduced. The creek dams, by being sited further down the land, may have these problems accentuated, and so not all creeks are suitable for farm dam construction. While there are ways and means of solving any of these problems, given the necessary finance, this discussion is concerned only with those dams whose construction is within the capacity of farmers and graziers generally, and with dams which will be very profitable to them. In the main, creeks with very large catchment areas are usually not so suitable for farm dams, as are likewise those with deep beds of loose sand below them and also the creeks of the very flat lands.

If I had continued my classification of valleys in Chapter VI from the primary and secondary valley to the next larger system, then this valley would be the one with the most suitable creeks for the farm creek dams.

The particular circumstances of the land shape and the characteristic of the creek itself should be studied before building any creek dam. For instance, the full benefit of the flow of the creek may often be obtained more economically by diverting the flow to an off-the-creek storage, which may be a dam of the type of the reservoir or lower valley dam, or possibly the contour dam to be later discussed. The kinds of diversion weirs that are suitable for such a purpose vary almost as widely as the circumstances of their use, but they have one common feature; they all must be able to take high flood flow of water over the top of the weir.

Good natural sites for creek dams have to be searched for, and not only for their largest water-storage capacities, but also for their absence of construction and management problems. On our new property at Orange we have a site for a creek dam which has a drainage area of under 600 acres, but if the drainage area was 4,000 acres the site would still be suitable and there would be no difficulties in providing cheaply the large spillway capacity that would be required. On the other hand we have a creek dam on the same property with less than 600 acres of catchment area, but the spillway for it had to be excavated, partly with explosives, into rock. A large creek dam may be constructed in some circumstances very cheaply, yet in almost similar conditions in the same area it could be an uneconomical task.

The design and construction factors that apply in the construction of a *keyline* dam, *reservoir* and *lower valley* dam govern the construction of the creek dam. If the materials are similar, then wall batters may be the same as for these other dams. Site preparations are the same as set down for the keyline dam.

The creek site is often associated with two features not generally encountered in the other dams; the creek may flow over rock and the earths adjacent may contain gravel and sands where the creek in earlier times flowed in a different course. It is then the examination of the material available for wan construction becomes more important; the cut-off trench in places may need to be deeper to get below the loose material, and there is more likelihood that some of the earth for the wall may need to be obtained outside the area of the dam.

Where water is flowing continuously the whole of the marking-out and site preparation should be completed as far as possible before commencing in the water. If the bottom of the creek is on solid ground or firm rock the next stage would be to bulldoze the loose rock and sand straight downstream along the creek bed through the wall site, depositing it a little higher than the creek bottom and on one bank of the creek. Ripping and 'dozing out in the creek bed will form a suitable channel for laying the lockpipe, which is set with the baffle plates sunk into the creek bottom. With the lockpipe in position (see Chapter XVIII.) and completely bolted up, a small earth dam is quickly pushed up with the bulldozer, using the earth near the upstream ends of the line. The purpose of this small dam is to hold back the flow of the creek and to force all the flow water through the lockpipe. With the water under control, the forward half of the lockpipe channel (the creek bed) can be cleared by hand of rock and excess loose material, which may be deposited in the lower part of the channel towards the back of the wall. In the construction of any farm dam it is intended that the seal against the movement of water through the wall is effected in the upstream section of the wall foundation down to the outside (lower side) of the cut-off trench, and that if water reaches beyond this point it is allowed to get away. If this water were sealed in the wall it could build up enough pressure to blow-out or cause the collapse of a section of the back wall. Therefore, the forward end of the lockpipe channel is cleaned to back behind the cut-off trench and some loose rock beyond this point is not a disadvantage. The laying of the lockpipe and the filling of the trench proceeds as in Chapter XVIII.

In a creek where flow is liable to continue for long periods a dam should have two spillways provided in the design of the dam. There should never be any question of the capacity of the main or flood spillway to dispose safely of the water. However, it is undesirable that any spillway constructed in earth and covered with soil and pasture should flow for long periods. The continuous flow eventually damages the pasture and soil. If damage is to be avoided where flow is prolonged, then provision should be made for the second spillway, a so-called mechanical spillway.

The mechanical spillway, then, is simply a pipe through the wall, and it may be placed some three or four feet below top water level (flood spillway level), with a right-angle bend standing up vertically and having the inlet from six to twelve inches below the main spillway overflow level. The capacity of the mechanical spillway should be from three to six times normal creek flow. The inlet into it should be approximately three times the diameter of the pipe itself and be covered with a heavy-gauge one-inch wire mesh. The pipe, after coming through the wall, is turned down the wall of the dam and discharges directly into the creek onto a heap of stones. The pipe of the mechanical spillway is set in the wall in the same manner as a length or two of the heavy pipe sections of lockpipe. The down-pipe section to the creek bed below may be a pipe of lighter gauge.

The main or flood spillway of a creek dam must be completely adequate for its purpose, that is the disposal of the run-off from the largest flood rains, so that the excess water cannot overtop the earth wall of the dam. The disposal area where flood run-off re-enters the creek then becomes one of the considerations of site selection. Very large quantities of water can be returned to the creek *via* a pasture ridge developed and pattern cultivated as already described. An adjacent valley form may be suitable, but whatever means is chosen, the development and preparation of the area should proceed as an essential part of the dam construction.

No land adjacent to a dam should be kept solely for dam purposes, since the larger the flood spillway of a creek dam the more important it is that it be developed as a good pasture area. Flood overflow does not last long, while the mechanical spillway, which has been flowing during the flood, will then divert the decreasing flow and the main spillway flow will cease. Whenever work is being done in the paddock near any dam, improvement of the dam itself can always be given first preference.

So we can see that again with creek dams, as with these other dams, they offer almost limitless possibilities for widespread improvement of the whole farming and grazing landscape, and, in addition, they yield those high monetary returns which are always a necessary final proof of good farming and grazing practices.

I know of a farm dam so valuable that were its real worth assessed, and allowing for the deduction of its cost, the value of the dam would greatly exceed the purchase price of the property on which it is situated.

We have a newly constructed creek dam on "Kencarley", at Orange, which serves to illustrate the possibilities associated with planning that is realistically based on climate, land shape and the farming requirements. The dam has a higher flat catchment, which continues to a lower but steep catchment. Hundreds of feet above this creek dam are other dams with a capacity of 150 million gallons of water, which will be increased later by another 50 million gallons. The water from the dams above may be used on adjacent areas in flow irrigation or turned into the creek above the creek dam, which we call "Control" dam. Control itself is of over 10 million gallons capacity, and full advantage was taken in the design and construction of all its natural features. It has a large flood spillway, soil covered and sown to pasture, also an 8-inch mechanical spillway to handle creek flow which is continuous, and with the large dams and irrigation areas above the dam will probably increase in flow within the next two years. For irrigation purposes Control has three lockpipe outlets, one a little to one side from the bottom of the dam, and two 10-inch systems, one on each bank of the valley of the creek and each located at the same level some three feet below the level of the intake into the mechanical spillway. The 10-inch lockpipe outlets connect to irrigation drains flowing along the top of large areas on both sides of the creek. These areas will soon become very valuable irrigated land. The steep areas of the dam's watershed are near-vertical slates and schists, which, when their soil fertility and pasture are improved, will absorb more of the rainfall into the rock below and practically all of which will no doubt add considerably to the high springs which are the present source of the creek's continuous flow. The developed water capacity of these steep hills, which will be consequential to the normal Keyline development, must be the equivalent of many millions of gallons of extra storage capacity, and will be used for irrigating from the higher 10-inch outlet systems. Lesser flows and the reserve capacity of the dam are available for irrigating from the lower 8-inch system. Any time we wish we could turn 300,000 gallons an hour extra water into Control dam. Since the entire water of its catchment is under complete control, we can use the catchment area for irrigation, which, in effect, also will replenish the ground water of the catchment and maintain and probably soon increase the normal flow of the creek below Control. The two 10-inch systems, apart from the irrigation, could be employed to fill dams which may later be constructed three-quarters of a mile away from the creek itself. (*Fig. 18.*)

In the foregoing discussions it will have been noted that each type of dam in turn has come further and lower down the landscape and from the keyline dam at the head of the primary valleys to the generally lesser slope land of the creek dam. In the flatter country, too, all valley dams can be useful if the valleys possess sufficient shape. A dam hereabouts will usually follow the design and construction methods of the previous ones, but the walls will not be as high and the dams themselves will have larger surfaces and be shallower in average depth. They will generally be more affected by evaporation, but this factor is offset by the lower cost storage capacities. If a keyline dam costing £120 per million gallons of storage capacity is a good business proposition, then a dam in flat country costing £30 per million and only filling once in two years and losing half its water by evaporation, can still be an equally good or even better proposition for the farmer and grazier. Apart from valley sites for dams, with their very wide suitability over all shapes of land, water can be conserved very economically on gentle or flattish slopes.

A contour dam may be used to advantage on slopes which contain no valley form. This dam is essentially a long earth wall of medium height constructed from earth which is excavated from immediately above the dam, and with wing-walls made to taper up land to above the water level.

In the flat lands all design features of the dams are flatter; the dams themselves are shallower; the water conservation and the irrigation drains are both flatter, but the irrigation drains are built up to flow water slightly above the level of the land. The land to be used for irrigation is also flatter and all the flat land methods of irrigation, already mentioned, can be used from the supply held in contour dams.

The critical design feature of this type dam, other than the all-important one of climate and its associated run-off, is always that of slope. Contour dams can be constructed on slopes ranging from 1 in 25 (4% slope) to 1 in 100 (1% slope). They may be classed or named "straight", "inside", and "outside", according to their general contour shape. A straight contour dam is one whose wall follows a contour line which is reasonably straight; an inside contour dam follows a contour curving round a flat ridge shape, the dam being on the inside of the curved shape; and an outside contour dam is one associated with a flat valley formation where the water lies on the outside of the curve of the wall.

Features similarly associated with the location of the first valley dam are to be looked for in the site selection of a first contour dam for a property. It should be as high on the property as convenient; there must be run-off and sufficient catchment area above the water conservation drain to fill the dam. As to size, it may range from five million gallons (20 acre feet approximately) to 25 million gallons or more. To bring the matter to practical consideration, we may assume a contour dam is to be designed with a capacity of 80 acre feet of water; that the slope of the land is 1 in 50 (2% slope); that the depth of water at the inlet to the lockpipe is 12 feet; that the land shape contains large low forms only, and that the contour shape of the dam is "straight". This capacity would require a wall 900 feet long approximately. Water 12 feet deep on a 1 in 50 slope would place the water line up this slope 12 x 50 or 600 feet, and the dam would therefore have an area of a little over 12 acres. The average depth of a contour dam is somewhat over 50% of its full depth, or about seven feet in this case, so that the required capacity is satisfied by this general size.

In the medium-size farm dam, a suitable freeboard height is three feet, but the circumstances of design in a contour dam suggest that this figure be reduced to two feet. There is no part of the wall of a contour dam that represents the main bulk of the earth, as is the case in the valley dam, and a failure of part of the wall is not nearly so serious a matter as in the valley dam; moreover, the inflow of water to the dam is readily controllable. These facts also suggest that the minimum or cheapest construction methods may be used in building the wall, and also with the lower wall height the wall batters may be nearly as steep as the most economical slope that the bulldozer equipment can construct.

Wall height will then be 12 feet depth of water plus two feet freeboard, and as minimum construction methods are to be employed, an allowance for settlement and shrinkage will be increased to 10%. The constructed wall height is therefore 15.4 feet. The dimensions of the wall section are as shown on the plan and section opposite. The constructed height is 15.4 feet, the settled height 14 feet, the width of wall shape at the base is 52 feet, and the crest width is 10 feet. The lockpipe will be placed into solid ground and there will be approximately two feet of earth above the lockpipe level on the inside of the dam. At distances of 80 and 100 feet from the inside toe of the wall there will be four and five feet of earth respectively above this level and more than sufficient for the wall without digging earth below the inlet level of the lockpipe. (*See Fig. 19.*)

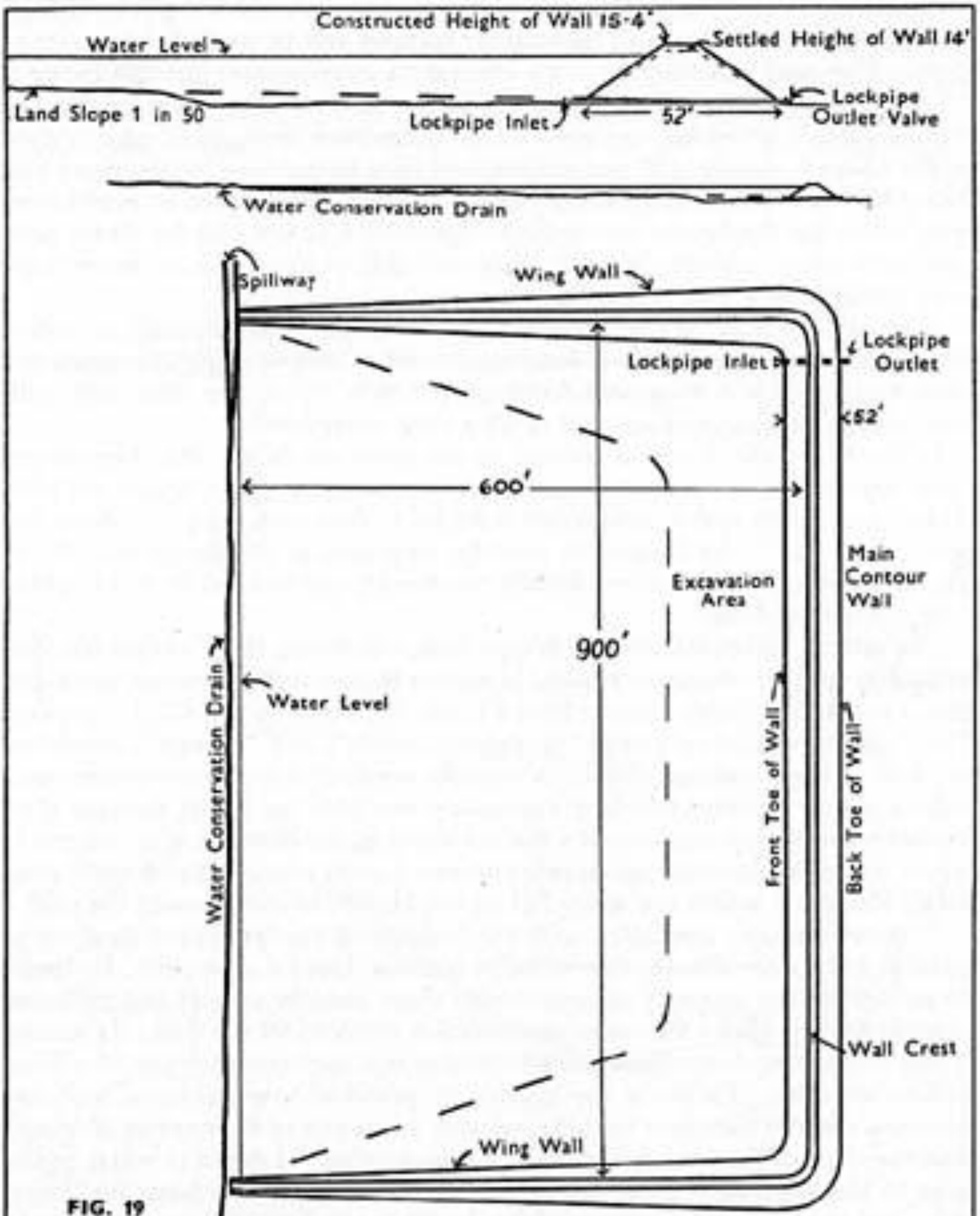

FIG. 19

Design of a Contour Dam of "Straight" Shape.
Upper: Cross section of excavation area and wall with 1 in 1½ batters.
Middle: Section across the dam. *Lower*: Plan of a contour dam, showing contour wall, water conservation drain, water level, excavation area and wing walls.

The water conservation drain of a contour dam, like those of all these dams, does not fall directly into the dam, but is constructed right along and above the dam, and reaching water level height at the spillway of the dam. As mentioned, the drain may be flatter than the 0.5 % fall generally employed for the other dams. A flatter drain has less capacity, so that the drain needs to be of larger section. The drain should fall in the down land direction, *vide* Chapter VI.

The position of the lockpipe may be in any portion of the length of the wall according to where the water is to be used. If the area of the gentle slope immediately below the dam is to be irrigated, the lockpipe is placed in the main wall at the end where the conservation drain first reaches the dam; in other circumstances it will be placed in the opposite end.

The price per yard of earth moved in a contour dam of this wall height will be considerably less than in the higher wall dams. The average haul will be less, the push up the batter of the wall is shorter, and more of the operation, which is only shallow digging, can be performed in second gear. A reduction of 40% in earth-moving costs is to be expected.

Marking-out and site preparation should proceed as for a keyline dam, with the clear marking-in of the wall shape on the ground with a furrow line. Top water line for the dam should also be marked. That part of the water conservation drain which is along the top of the dam could be first constructed to prevent any run-off into the area of the dam during construction. This drain may have a slope of from 0.2% to 0.5%, according to features of the land.

A cut-off trench for the full length of the main wall and the two wing walls should be used, but may need to be only a few inches deep. Even where it may be considered that the cut-off trench is not required, it is still advisable to use a shallow trench, since it helps appreciably in controlling the job and in supervision. The area of the wall site is chiselled along the line of the walls to assist bonding as before.

The cross section of the wall as illustrated (and it is not the minimum that could be used) represents an area of 48 square yards and (accepting the two wing walls as containing the equivalent of 200 yards of full wall section), the yardage in the walls is 24,000 cubic yards. The yardage of water storage capacity, with water depth an average of seven feet, is 135,500, or an earth to water ratio of 5.65. In other words, one cubic yard of very cheaply-moved earth creates about six cubic yards of water-storage capacity. The excavation area should be battered back into the land slope and covered with soil, cultivated and sown as suggested for the other dams. A contour dam of this or a larger size contains an area which, when uncovered, could be very valuable land.

The particular purposes for which the water may be used from such a dam are legion and the value of the dam is considerable. We can consider a particular case by way of example. The rainfall conditions may have been such that with the augmented catchment provided by the water conservation drain, the dam will be filled each year from winter rains. The dam then could be the basis of the production of a special spring or summer crop on which an extra 12 inches of water from the contour dam would ensure a successful crop every year. A crop area of 60 acres may be used for the purpose or a series of three paddocks each of similar size and irrigated in rotation. The requirements for the lowest cost irrigation are thus provided and any of several methods already discussed for the other dams may be used, according to land form and slopes. If the dam will fill each winter, then the dam water should be used fully each spring or summer.

We may suppose now that the water is all used in producing a spring crop and consider the empty dam. The dam area, which was provided during the construction with good draining slopes to the outlet, can then be cultivated, when dry enough, and sown to a summer crop. Because of the deep moisture of the dam area, a good summer crop could be produced in the driest of years. If, when this crop is nearly ready, heavy summer rains occur, the water conservation drain along the higher side of the dam, which filled the dam, can be used effectively to prevent run-off reaching the dam. The water conservation drain is blocked or breached before it reaches the dam and the section of the drain along the dam is put in order, so that run-off from the area immediately above the dam is made to flow out through the spillway. Only rain actually falling in the area of the dam would reach it, and, with the outlet open, even this water would drain away. On the other hand, the landholder may prefer to retain the water and so will allow the dam to fill up normally.

Under the same climatic conditions, a grazier may decide to use the conserved water for flood or flow irrigation of a smaller area of pasture, say 20 to 30 acres, so as to enable him to have ample water available throughout the season. Likewise, the dam is specially advantageous for spray irrigation of valuable crops, such as vegetables.

The costs of contour dams will vary considerably, but if I had such a suitable contour dam site on my own property I would expect my construction costs to be less than £1,800, including all the irrigation controls and drains. Under the climatic conditions of Richmond or Orange about 60 acres of irrigation could be provided and the area of the dam when emptied would be so much additional worth. Contour dams may be much smaller or larger than the one illustrated, but it seems from my own experience that the larger dam will return the higher capital cost just as quickly as the smaller dam returns the lower cost.

We may consider now the storage of water on land that is flatter than those gentle slopes suitable for the contour dam. As our water conservation structures are to hold water above the level of some of the immediately adjacent land, then the only way this can be accomplished on land with slopes of only a few feet fall in a mile is by completely surrounding the water with a constructed earth wall. In these circumstances, also, the only way to get the water for storage into the dam is by lifting it into the storage area. This pumped type of storage is always the last to be considered for storing appreciable volumes of water, so before dealing with this new type, consideration will be given to slopes intermediate between those suitable for the various contour dams and those where water must be pumped for storage.

It has been seen that a contour dam is an efficient water conservation structure where the land slope is 1 in 50. What changes are necessary where slopes are 1 in 100? A contour wall as described would, if employed on this slope, back water up to 12 feet (depth of water at outlet) multiplied by a slope of 100, *i.e.,* 1200 feet, so that the main contour wall would be 900 feet long as before and each of the two wing walls would be 1400 feet long, after allowing for two feet of freeboard. The approximate relationship between the two contour dams, one on 1 in 50 slope and the other on 1 in 100 slope, is that for the same length of main wall the area and capacity of the second is double that on the 1 in 50 slope. Though the quantity of earth of the wing walls has been increased, the extra yardage of earth required has only increased by less than 50%. The ratio of earth moved to storage capacity now approaches 1 for 8 instead of the other 1 in 50 slope dam, which is 1 for 5.65.

The second contour dam provides most efficient water storage capacity on this slope of land. The question now is, can any other type of structure be used satisfactorily for the same slope conditions? Of the various shapes which may be used to completely enclose a storage area, the ring shape is the most efficient in yardage of earth moved to capacity enclosed, so a *ring dam* may be considered for the above slope.

Some confusion has arisen as to the names of these dams, so they are given the general descriptive name of "closed wall" dams, which indicates that a constructed wall completely surrounds the water storage area. In this text they will be given individual names based on the particular shape of the closed wall. Thus, the closed wall dam of ring shape is the "ring dam". This is sometimes incorrectly referred to as the turkey's nest dam. However, the turkey's nest dam, as is "the overshot", is a dam of long-established use in Queensland's country areas. It is constructed in the same manner as the nest of the scrub turkey, from which it takes its name. The turkey's nest dam is built with earth obtained outside the structure, which forms a circular wall, and it is filled from flowing or pumping bores. By being above ground level the water of the dam can be led into stock troughs equipped with automatic float valves, which replenishes the trough water as it is used. The ring dam, on the other hand, is constructed by digging earth from the inside to form a wall. The dam then is a larger diameter earth-wall ring with a channel just inside the wall, the earth excavated from which forms the wall. Inside the ring-shaped channel there is usually a circle of unexcavated material or natural land surface. According to the depth of the dam, which may be from 11 to 16 feet in the channel, there will be from 8 to 12 feet of water over the land surface in the central area of the ring dam.

A ring dam of the same maximum depth of water above ground on this slope and having a diameter of 900 feet would have the following characteristics. The wall at its maximum dimension would be identical to the cross section of the contour dam on the same slope. At the opposite side of the dam, 900 feet up the 1 in 100 slope, the ground level would be nine feet higher, so at this point the ring dam would hold three feet of water above ground level. The average depth of the ring dam, and disregarding the excavation, would then be the approximate average between its deepest depth of 12 feet and shallowest depth of three feet, or an average of seven feet six inches deep above natural ground level. The section of the wall at the shallowest part of the dam would be five feet high (three feet of water plus two feet of freeboard), 10 feet wide at the crest and 25 feet wide at the base. Calculations for both dams show that the ratio of earth moved to storage capacity is somewhat better in the contour dam when compared with the ring dam, but the ring shape provides more water per acre of land under top water level, its average depth is a little greater and it has a smaller area of shallow water. Both dams appear almost equally advantageous except when it comes to filling the dam with water. If the ring dam on this slope had to be pump filled it would not be chosen for the site and a contour dam would then be the only logical choice. However, a ring dam on such a site can be filled as can the contour dam on the same site, namely, by flow water. For the ring dam to fill, the flow water must enter the dam (or a part of the dam or a closed inlet to the dam) at or just above top water level. Top water level would be represented by a position 300 feet further up the slight slope and beyond the dam near its smallest wall section. Water will then need to flow to the dam from this point. There are two satisfactory ways of getting this done. One is by extending a pipe of suitable diameter through the shallow wall of the dam and continuing it up the incline to the height of top water level. A water conservation drain (as for the contour dam) would deliver run-off water to this point, whence it would flow *via* the large pipe (about 18 inches diameter) through the low wall into the dam. The pipe line, which would be a little over 300 feet long, would be underground and a small bank or bay at the height of top water level would need to be formed around the higher end of the open pipe. The alternative method of filling the ring dam from the same water conservation drain is by extending a pair of parallel walls from the shallow wall section of the dam up to the water conservation drain. The walls are to be 30 feet apart and join the shallow wall side of the dam where a 30 feet section of the wall would not have been built to open into the waterway formed by the two parallel walls. The height of these little walls would be on the same level as the wall crest of the dam. This is now a "broken ring" dam or "pan-handle" dam, and the pan-handle walls at their water conservation drain end would be so arranged that when the dam reached its full planned depth no more water could flow in or overtop the dam. Spillway area for the disposal of excess water would be required and could be arranged on the lines already discussed for the other dams.

Of the two methods of filling the dam, the pan-handle walls method would be the more economical and generally the one to be preferred. This type of dam, the "broken ring", may be of any suitable shape, because the full ring shape may be influenced by other features, such as a watercourse or a property boundary. The ring shape is depicted here, as it is the most efficient of all the closed wall types of dam. (*See Fig. 20.*)

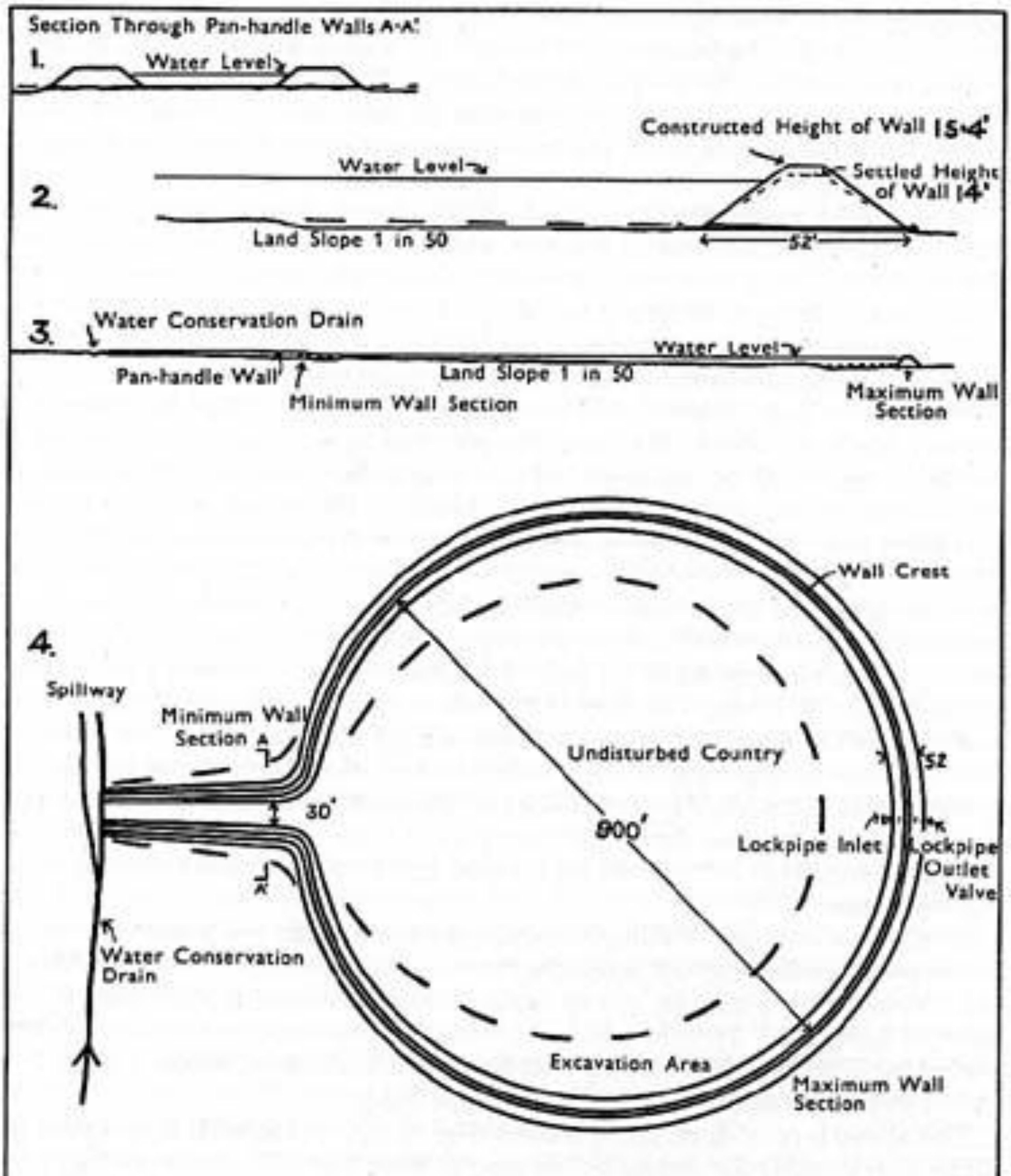

FIG. 20

Design of a broken ring or pan-handle dam, showing:
(1) Section through the pan-handle walls.
(2) Section through maximum wall size.
(3) Section across the dam.
(4) Plan of the dam.

The above type of dam, i.e., a broken ring dam, coupled with the method of filling it, is suitable for slopes slightly steeper than 1 in 100, but is not likely to be preferred to the contour dam. While it may also be used on slightly flatter slopes than 1 in 100, obviously it eventually reaches its flat limit of slope where the pan-handle walls arrangement becomes too long and later completely impractical. The specially critical factor of these designs is the slope, and in designing a dam in these, or, for that matter, in any circumstances, no attempt should be made without first knowing the exact land slopes.

Where the slopes are so flat that the contour dam and the broken ring become unsuitable and not worth consideration there is no way to store water above ground level other than with the closed wall dam and pump filling. All other dams may be filled by natural catchment, by water conservation drains, or by weir-diverted creek flows, but where a ring or other closed wall dam is the only choice the site should be near a watercourse of a particular type. The most usual source of water supply is an intermittently flowing stream, or, more often, one which flows only after heavy rainfall. The dam may need to be filled during heavy rainfall, therefore the above facts should be noted when locating the dam and when making the design of the dam and its related filling structures. In some circumstances, though a dam must be filled from a certain watercourse, it may be a disadvantage or even an impossible hazard to construct the dam close to the watercourse. In other circumstances and for the sake of efficiency and economy, it may be worthwhile to depart from the ring shape by having part of the wall following a section of the bank of a watercourse. (*See Fig. 21.*)

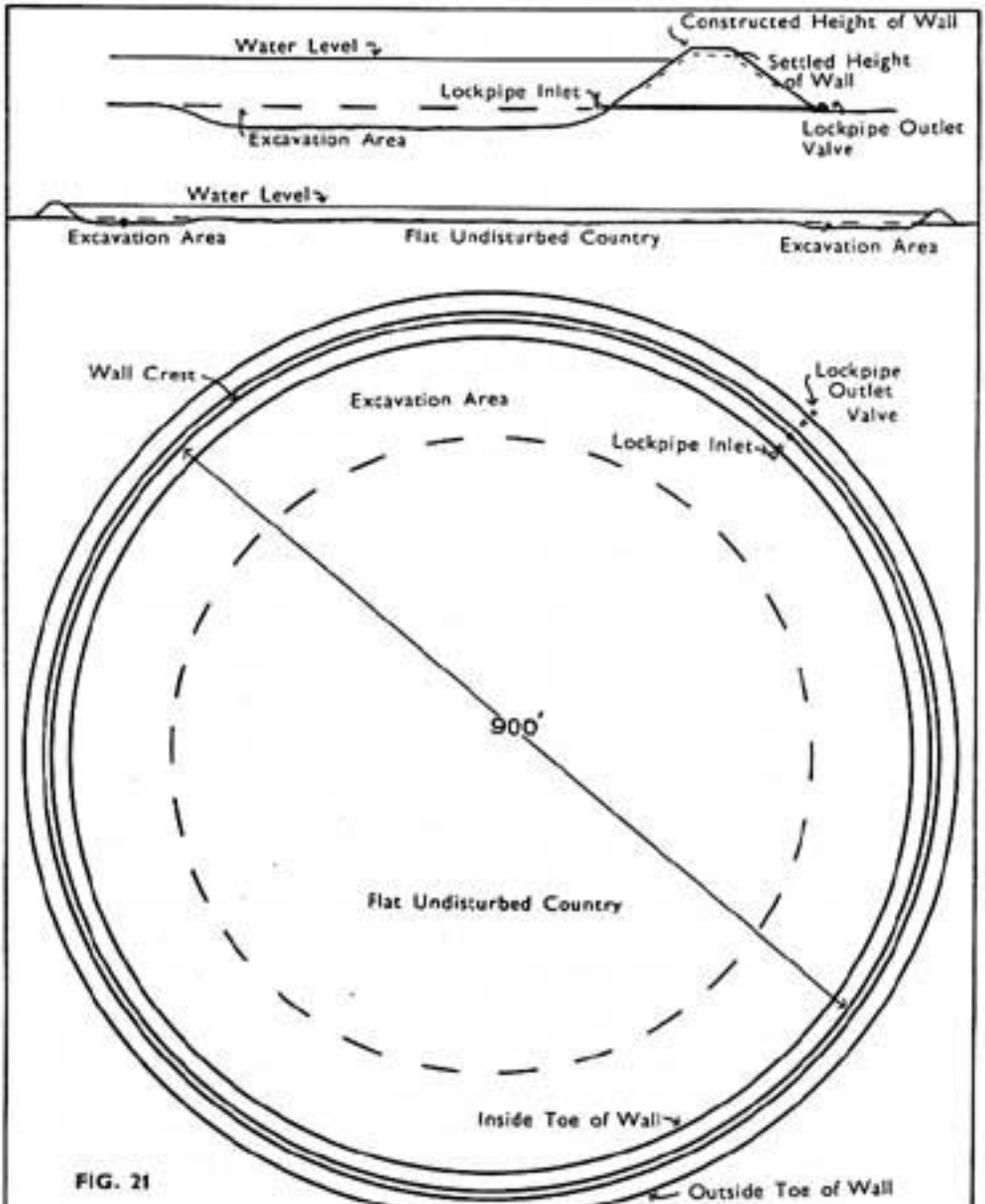

FIG. 21

Design of a Ring Dam.
Upper: Cross section of excavation area and wall, showing the position of the lockpipe control. *Middle*: Section of a ring dam 900 feet diameter and 12 feet depth of water above ground level. *Lower*: Plan of the ring dam.

However, only after carefully studying the possible locations for the closed wall dam and the filling site should the dam site be finally determined.

The most satisfactory filling arrangement is that the dam can be filled through the lockpipe outlet, and to this end a bay from the watercourse could be excavated to a suitable common filling and outlet point. A small permanent flood weir in the watercourse may be arranged in such a way that during flow periods the weir causes the drain and bay to fill for pumping into the dam, but at the same time allows flood water to flow over the weir, with no inconvenience to the site and structure if pumping is not required from certain flood flows.

There is an idea in the minds of some that water has to be pumped "over the top" of the wall of such a dam. On the contrary, this is a disadvantage against pumping through a suitable pipe beneath the wall. The higher water has to be lifted the greater is the power required, or, alternatively, less water will be delivered for a given power.

The construction of the ring or other closed wall dam follows the general procedures already given. The size of the lockpipe may be increased according to the capacity of the pump which is to fill the dam, but generally a size of 10 inches is suitable in nearly all circumstances.

The importance of making proper arrangements for the filling of ring dams (or any closed wall dam) cannot be overstressed. The full layout should be decided and included in the design of the dam itself; and the creek weir, the drain and bay, from which the water is to be pumped, should all be constructed and completed as part of the dam construction. Again, the elevation to which water has to be raised in the dam, the pump capacity and power requirement, must be logically determined in relation to the capacity of the dam. Generally, where water has to be pumped into a dam, time is so limited that large capacity low head pumps are invariably required. The dam for these reasons should be close to the level of creek flow, so that pumping will take place from only slightly below ground level. The likely length of time available after storm rains for pumping should be calculated against the capacity of the dam, that is to say, when the rate per hour of water delivery required has been estimated, a pump capable of this performance against the height of the total lift should be acquired. (*Fig. 21.*)

The most suitable dam filling arrangement is a permanent set-up of pump and engine that can be operated under the worst possible weather conditions. A lower initial cost method would be to arrange a permanent pump set-up so that the power of a farm tractor could be quickly coupled to the pump. With the pump in a permanent position and the suction line in place, the set-up is always ready for operation, *i.e.*, the delivery pipe from the pump is left coupled permanently to the lockpipe at its outlet end. There is also coupled to the larger size lockpipe a Y piece which has a control valve on each leg of the Y piece. One leg is the permanent inflow or dam filling side, and the other the irrigation water outlet. Whenever there is water in the dam at the lockpipe level the pump may be primed very quickly by partly opening the valve on the pump delivery line, then the engine is started up and the valve opened fully. A large low-head high-capacity centrifugal pump selected to exactly suit the requirement is inexpensive and will have low running costs.

The water from a closed wall dam may be used for many different irrigation systems and varying from flood to any type of spray irrigation.

Generally these dams of the flatter lands are uneconomical when attempts are made to employ them outside their proper land suitability. One practical experience of the ring dam was in 1947, when I constructed one for the purpose of maintaining a head of water in a long underground irrigation main which was laid along a high boundary on "Yobarnie". An intended use for the water was the spray irrigation of a new orchard. The orchard idea was abandoned and the dam then was used only for pasture irrigation, which included the giant monitor type of spray irrigation just introduced for the first time into this country. The ring dam was filled by pumping, which involved a considerable lift, *via* a six-inch underground pipe line that included a crosspiece and thence under the wall of the dam. The crosspiece was fitted with valves, one of which opened for dam filling, and at other times it was used to flow water from the dam back along the delivery line, which in turn was equipped with numerous take-offs for irrigating along its length. Other valves on the crosspiece directed water to underground pipe lines in two different directions. The mechanics of the whole set-up worked admirably and the scheme might have been successful in other directions also if the orchard project had been continued successfully. However, as a pasture spray irrigation project for beef cattle production there was little likelihood that it could be economical or ever really profitable, and so was abandoned. A ring dam was constructed on a farm in N.S.W. as recently as last year, and in circumstances unsuitable for its use, although adjacent to this particular ring dam (which has a pump lift of about 100 feet), there are well-nigh perfect sites for keyline dams. If these were utilised similarly to our dams and irrigation system, they would be highly profitable. The mistakes that have been made, and are continuing to be made, in all aspects of farm water storage and water use, would be very educational to farmers and graziers if they were made known. Many branches of agricultural science have been improved considerably by utilising knowledge gained from mistakes, and it is hardly an exaggeration to say that science generally is largely the accumulated knowledge gained from innumerable mistakes.

All dams of whatever type or kind and for any purpose must fit in with and became part of the landscape. They all must have a means of getting water into them, but they also need the best and cheapest means of getting water out of them and into effective use.

The foregoing discussion will have been most successful if it draws attention, much-needed attention, to the need and great value of farm dams of these various types and usages in their application to the development of the whole Australian landscape. It is a development that is not only beneficial to the individual farm and grazing property but one which adds merit to the work of every Australian landman.

The problems of farm dams do not end with their design and construction, so these dams we have been describing need proper care and attention, and this aspect, along with some associated problems, will now be considered.

After Care of Farm Dams: All newly-constructed farm dams, including those described in this book, are subject to change, The covering of all raw earth with soil and the sowing of grasses on every part of the dam and its immediate surroundings must be considered a part of the construction of the dam itself. Grass may grow and quickly cover the wall and the surroundings, but, even so, the wall will shrink and crack, and so needs inspection, and especially so during the first year of its useful life.

The earliest and best check on the general performance and accuracy of the newly completed dam takes place with the first occurrence of heavy rainfall. If it is heavy enough to promote considerable run-off, so much the better. To learn all that rain can teach, the farmer should get out in the rain with a long-handled shovel. He should walk the wall of the dam and look for little ponding areas on the wall crest, ponds which will later break out in one particular spot and flow water in a small but concentrated stream down one or other batter of the wall, and cutting little gutters. These first little gutters, if they are left, will form real flow paths for the continuing rain and so increase quite rapidly in size. It is therefore necessary to fill up the little ponds on the crest of the wall with earth from higher spots. The shape of the wall preserved at this very early stage ensures an even and harmless flow of water in the heaviest of rainfalls. Next, the four areas should be inspected where the constructed wall joins the banks or sides of the valley. Often water may flow along these junctions in small concentrated streams, and so should be diverted and spread away from the wall. The water flowing into the dam will not cause even a slight movement if the cultivation pattern below the waterline is properly done. A small soil movement is not of much consequence, but an inspection is a good check on the work, since it will illustrate, as nothing else can, the effectiveness of keyline cultivation. Now the water conservation drain should be inspected. If there are low spots where water is threatening to overflow or is likely to overflow with heavier rain, the low places should be repaired. A low section in a drain indicates that the drain at that place is slightly downhill and off its proper line. The low place is therefore repaired in such a way that the drain position is moved slightly uphill to its correct position. This is done very simply by shovelling earth from the uphill batter of the drain and placing it, not on the very top line of the bank of the drain, but just inside this line, so that the bank line is moved uphill slightly. If the low place is merely raised by the placing of new earth on the top of the drain bank, the slightly incorrect position of the drain is preserved and more earth will be needed to raise it to the appropriate height. Since the water conservation drain is to be one of the really permanent man-made structures on the property, earth should not be shovelled indiscriminately in adjusting the section of the new drain; the cross section shape of the drain should be preserved in the shovelling and repair work.

When water is beginning to break out of a water conservation drain, first, a high spot is looked for on the dam side of the break, which may be directly causing water to pond back and overflow. The high place should be fixed before the low spot. A high place in a drain indicates that the whole drain position at that point is slightly uphill and off its true position. Repairing the high place is done by digging earth at the downhill edge of the stream of water and spreading the earth either well uphill or down behind the drain bank, whichever is indicated by the circumstances. With the high spot adjusted, the overflow can be treated. Sometimes a bad break in a water conservation drain cannot be controlled directly. A suitable spot should then be selected upstream where the drain is in strong section. Here the drain is blocked with earth, and so, by causing water to overflow, relieves the bad break, which may then be repaired to its full section. The block is then removed and the drain adjusted.

When heavy dam-filling rain occurs a new dam is worth watching from many points of view. I have watched a man who, seeing a new and larger dam than he had experienced before filling rapidly, rush to break the water conservation drain to stop the flow into the dam and to open the outlet valve to let water out of the dam. But the larger dam is built only to hold more water and so should be allowed to fill as quickly as it can. If the dam was built reasonably well, and wall weight and shrinkage properly allowed for and with a suitable spillway, there is little cause for apprehension. If anything should go wrong, then the measures suggested in this book can be taken to correct matters. However, the new wall of a dam constructed of earth which was too dry should be controlled to fill more slowly, since the material of such a wall often lacks cohesion until it becomes slightly moist right through. If the first cracks on the water side of the wall of a new dam discloses dry, powdery earth in the wall, the water level may need to be lowered immediately. The very wet earth can slip off the dry, deeper material into the dam, and in doing so fracture the full section of the wall and result in the loss of a large part of it.

After or during the first heavy rain on a new dam, the first notable shrinking and cracking of the wall may take place. These movements are normal in a farm dam. They are a part of the design and construction of the dam, since the wall costs have been reduced by about half, because, instead of going to the expense of using sheepfoot rollers or pneumatic-tyred rollers to get complete compaction of the wall material, the natural compacting forces of settlement and shrinkage are allowed to operate. There are two types of wall cracking, and they are named according to their mode of occurrence--longitudinal cracking and cross cracking. The early longitudinal cracks usually occur near the outer edge of the crest of the wall and are often associated with the paths the tractor made along the wall. The looser earth on the outside of the path will pull away or shrink away from the more settled earth where the weight of the tractor compressed it. Such cracks are rarely a hazard, but they should be treated by raking earth to fill them a day or two after rain, when the wall dries out a little. Just sufficient earth is raked to fill the crack. Neglected longitudinal cracks become larger and could, after further heavy rain, hold water in such quantities, which, in finding its way out through the wall, could cause a slip in the wall.

Cross cracking or cross-the-wall cracking is not usually associated with early settlement and shrinkage of a new wall. It may occur only after a dam has been first filled, and then all the water used and the wall has started to dry out. Though rarer, it is a more serious form of cracking if neglected or overlooked. These cracks may form a continuous split across the wall or be in the form of short cracks from the front and back of the wall to a longitudinal crack, and so form a crooked path through the wall. The cross cracks never or very rarely reach down the wall to the water level. Danger lies in cross cracks forming when the water level is reduced and the crack reaching down near to water level. Should flow water cause the dam to rise above the cracks, water will flow through the wall. If this flow occurs below spillway level, and is undetected, quite considerable damage to the wall can occur. Prevention of damage lies in filling in the cracks as with longitudinal cracks, but paying particular attention to the crack on the inside of the wall where it appears above the present water line of the dam. Here the crack should be rammed after filling, then filled again after ramming. Dry, more so than moist earth, is always to be used for filling cracks. Fine dry earth is probably the best.

I have experienced occasions where the cracks, by first flowing as a very small stream, have become closed on the surface by stock walking the wall in wet conditions and the leak later developing into a pipe-type of flow. To repair such a flow after it has occurred, adjacent earth is shovelled into and around the opening under water, and no attempt is made to fill the full break across the wall until water flow has been stopped. Later the crack is filled with dry earth.

The ordinary settlement and shrinkage cracking of a new wall may be effectively filled by a 2-inch to 3-inch cultivation with a chisel plow. The cultivation may be a part of the soil and pasture development of the area. However, occasional inspection of the wall will ensure that all is well.

The often-recommended procedure of planting special wall-binding grasses can act against the safety of a wall. The generally coarse nature of such vegetation may hide dangerous cracks. Personally, I favour planting only the usual pasture mixture on the wall and fencing the dam off, or, alternatively, fencing the dam into a smaller paddock. Stock can be put on to graze the wall and the surroundings of the dam as part of the improvement programme, and the grazing should be controlled properly to these ends.

A well-designed and constructed dam such as any of those discussed is a very safe and permanent asset. The methods of construction are low cost, and these after-care considerations are for the purpose of seeing that natural forces in compacting and consolidating the dam do their work without creating damage.

Although things do not go wrong when all the above methods and procedures are adopted with good supervision, we may, however, consider some of the problems that are the result of less effective design and construction methods or that arise out of the use of the less suitable earths.

Failures in farm dams are generally presumed to arise from three main causes. The first cause is inadequate spillway size, which fails to convey the overflow water and forces the water over the wall of the dam. Soon a channel will be cut in the wall by the water, which, once it has got down below the spillway height, causes all the water entering the dam to flow through the break in the wall. The second presumed cause is from a low spot near the central area of the wall crest caused by inadequate or no allowance for shrinkage in the construction of the wall. The effect is the same as before; water flows over the low place in the wall, cutting a channel and destroying the wall. The third cause is presumed to be inadequate compaction of the wall, material, which allows heavy seepage to build up into a strong flow through the wall. All the water may be lost and the wall remain in position, or the flow through the wall may cause the wall above the hole to collapse into the flow and leave a break in the wall from the bottom to the top. Overtopping may destroy a new wall in 20 minutes and an older wall in two hours or more.

Many wall breaks resulting from the first two causes, and inspected after the failure, are attributed to the latter cause, because the material inside the now broken wall does not appear to be well compacted. The breaking of the wall itself often makes this aspect appear bad, but in my opinion the failures resulting from this cause are very few when compared to the other two causes of failure. I have inspected broken walls of dams that were said to have failed because of poor compaction, but in each case the breached wall remaining and the obviously inadequate spillway provisions clearly showed that overtopping of the wall had occurred. Many of these failures were in dams of some age which were holding water previously and had been washed out in later flood rains.

Dams may fail as mentioned earlier by cross cracking in the wall. Faulty dam construction or a batter design that may be too steep in relation to the stability of the wall material, may cause slumping or slipping of the wall and reduce the wall height and so overtopping may then breach the wall. Of all the failures in farm dams, the large majority are caused by faulty design. The earth of the shale area of the County of Cumberland--Sydney and hinterland area of N.S.W.--holds water well even with the most unsound construction methods, yet in one day during the heavy rains of 1956 between 40 and 50 dams were stated to have breached. Although the rain was heavy, the fault in all or at least the large majority of cases must have been poor design, since none of the new dams were constructed in drought conditions when earth walls could be too dry to stand sudden filling. No doubt many of these failures were due to the type of advice given to farmers on farm dams, which invariably emphasises good construction as "most important", when, quite obviously, good construction can only follow better design. All aspects must be given their rightful attention, and then good construction becomes a counterpart of good design.

We had one leaky dam on "Yobarnie" and another recently reconstructed dam that still could leak. As we are discussing problems in dams, the story of these two dams may serve as practical illustrations.

The first of these two dams was constructed in an unfavourable site in that the valley was small and steep and the available material for the wall was a medium hard blue shale. The site was chosen for a variety of reasons; it fitted in well with the other dams, and there was a very good-shaped piece of land adjacent at the right height and suitable for pattern flow irrigation. Also, I wanted, to build a dam wall with the hard blue shale as a test of this material under the worst possible conditions, namely, to construct a high wall as steeply as the bulldozers could operate. The planned depth of water at the lockpipe was 34 feet, freeboard was three feet and shrinkage allowance three feet, giving a total height of 40 feet to the new wall at its largest section. The wall was built, but before the feeder drain could be made very heavy rain filled the dam and a large flow of water was running out through the spillway. There was also a considerable flow from five different places through the back of the wall. We raked up and down the inside of the wall with a rake attached to a pole and found one leak by the simple process of walking along the wall batter in the water in gum boots and finding oneself suddenly sinking into a semi-fluid hole. Earth shovelled from the crest of the wall was tramped into the hole with the boots and closed this high leak. However, the raking had no apparent effect on the rest of the considerable flow, although this method of stopping seepage is often successful. The leaking areas were evidently too deep below water. So I prepared explosives. Six plugs of 60% gelignite were cut in half and each fused. I decided to explode the charges in the water about 20 feet from the wall water line and two feet above the bottom, which was a part of the underwater batter of the wall. A piece of board was tied as a floater to each half plug with a length of string about 12 feet long, and then, holding the plug, string and board together, each fuse was lit in turn, and together with the charges and floater, thrown out into the water about 10 feet apart. There was a series of dull thumps and rather convincing vibrations through the wall on which I was standing, as the charges exploded about 10 seconds apart. The result was a considerable reduction in the flow of all but the deepest leak. Two more shots were used, each a full plug, and thrown further out and attached with a longer piece of string to a floater. (The length of string and floater checks the depth to which the charge sinks.) The dam was still leaking a little but held the water, which was used in the summer for irrigating. There had been also some slumping of the back batter of the wall, and as the leaks were not completely stopped, a bulldozer was put into the dam when it was empty to work on the leaking area and to trim the job up. By this time there had been a considerable breakdown of the shale material with now sufficient clay to make the wall impervious.

Explosives are often valuable for farm purposes and are simple to use, but no one lacking experience should touch them without first studying the instruction book issued by the suppliers of explosives.

The recently reconstructed dam mentioned was built in 1945 and had a four-inch outlet under the wall. The dam held about seven million gallons (28 acre feet or 42,000 cubic yards) and had been used for various types of flow, flood and spray irrigation for many years.

After the first three years of the development of Keyline as a planning guide for, among other things, the siting and location of farm irrigation dams, it was decided that a keyline dam would be built above it. This old one would be reconstructed and enlarged with an eight-inch lockpipe placed under the wall and the enlarged dam would then become a reservoir and be kept filled as a reserve while the water of the three keyline dams and the large lower valley dam in this one catchment area was used first for irrigation.

The wall of the dam was cut with a big V-shaped excavation after all the water had been used and the dam stood empty. The keyline dam was then constructed higher up the valley. The eight-inch lockpipe, 120 feet long, was placed in dead level in the V cut of the old wall and the closing of the V and the enlargement of the wall started. A height of nine feet was reached above the lockpipe when continuous and heavy flood rains commenced.

I saw the work a week later and realised that a lot of trouble and waste of time confronted us. The bulldozer operator had left the job with waves of loose earth everywhere when he finished for the day. Rain was not expected, but now ponds of water were in the waves of loose earth and the work became super saturated. Fortunately, the lockpipe was left open, and this prevented the flood water from filling the dam to the point where it could overflow the unfinished V cut fill. Some millions of gallons flowed out the lockpipe in the flood rains which continued, yet no earth was washed away and lost.

Months later, anxious to finish the wall and seeing the surface of the earth dry and cracking, the bulldozer operator started work again. The whole wall was like jelly underneath and all he succeeded in doing was pushing a few yards of earth on to the wall at one part, which promptly settled back to its original height, and blocking the lockpipe with a fluid mud. Lengths of two-inch pipe were joined together and pushed through the lockpipe from the back of the wall to clear it. Again it rained, and once more the lockpipe carried more millions of gallons of water away, saving the earth and preventing a bigger mess. Later again, with the wall dried out somewhat, although still too wet, the bulldozer operators with a lot of perseverance succeeded in raising the wall to its planned height. Sticking to the bulldozer blade, the clay material would not spread evenly and went into the wall in lumps. Everyone by now was tired of the dam; however, it was completed. The operator relaxed for lunch before moving off, then when he looked at the wall again there was a great bulge on the inside batter; the whole wall section had slumped about five feet. Work was delayed while it dried out further, and eventually the wall was raised again to the finished level. The lumpy clay material which was placed in this wall looked bad enough for us to prophesy that the wall was likely to leak.

The sad story of this dam's troubles arose from the fact that the construction was not supervised. By neglecting to trim the wall, water got into and jellied the clay. The story adds point to my suggestions on supervision and the trimming of work before finishing each day. Yet it could have been even worse. If the lockpipe had not been used, the partly constructed dam would have been lost and the whole valley floor for 800 yards below would have been covered with the washed-out mud and earth which would have resulted from the heavy and continuous overflow of the loose bank. Instead, we now had a good dam and during the dry period which followed the final work the wall had shrunk, settled and cracked. The wall crest was cultivated on three occasions to fill the cracks, and no doubt the long dry spell helped the wall a great deal by allowing settlement to take place before much water entered the dam.

With regard to heavy rainfall on a new dam, it is to be remembered that a new dam, when filled rapidly in continuous heavy rain, imposes the worst conditions on the back (downstream) batter of the wall. The front wall batter is safe, being assisted by the water in the dam, but with the dam filled and the back saturated, the critical condition for the back batter of the wall occurs. Slips may follow. Small slips that start on the crest, well away from the water line, usually reach a stage where they stabilise or balance themselves. They present no particularly urgent problem, for they can be repaired later by filling the slump-hollow with earth. The bulge formed by the slip near its lower end down the batter of the wall can be left, as it acts as a wedge against further movement. Such smaller slips are repaired from above and not by pushing up from below with a 'dozer. The opposite extreme of a back-of-the-wall slip is the major one and the worst possible. Here the slips start from under water inside the dam, moving a section of earth right across the crest of the wall and bulging out lower down the back of the wall. Pushing earth onto the wall crest and down into the water is dangerous. The earth falling in the water stands up very straight, and when the water level drops, or even before, the concentrated weight of the new earth on the saturated wall below water will invariably start a slip of the material inside the dam. Earth that is pushed into the water must be spread out under water. In the large back-of-the-wall slip or slump water can immediately flow around one or both edges of the break, and, because the material in the path of the water is loose and fractured from the movement of the slip, the earth moves rapidly down the wall. This most serious of all slips is treated by immediately opening the lockpipe and then breaching the feeder drain. The lockpipe flow is continued until the water level drops below the break. When the wall and slip area dries out, the slip may stabilise itself and not move any further. If the slip is never as soft again as it was when the slip occurred, it will usually remain stable. Repairs are done in dry weather by filling the cavity of the slip area back to the original wall profile. The bulge area of the slip, if it is not too unsightly, could be left undisturbed.

While the critical stage in the back batter occurs in heavy rain with the dam filled, the same stage for the front batter occurs when the dam has been filled and is later emptied. The inside batter of the wall can slump or slip even before the dam is quite empty. Usually, inside slumping is a slower process. The first signs may show up as a series of little slumps and cracks over a sizeable area about as much as one-third of the whole inside batter of the wall above water. The little cliffs formed by the movement may be only an inch or two high, but in the following week or two can become cliffs three or more feet high.

The prospect of serious inside slumping is greatly increased if, during the construction of the dam, material has been excavated from under the inside toe of the wall, as mentioned in the discussion on dam design in Chapter XVIII.

The complete repair of a serious inside slump can only be made satisfactorily when the dam is empty and the slump area has dried out. The earth under the slump is usually very wet, even jellied and unstable, though it may appear dry on the surface. A pole should be pushed into the deeper earth through the cracks to test the material below. If it is wet and sloppy it will need further time to dry out properly. All the water of the dam should be released as irrigation water, and, if there is a pond below lockpipe level, this will need to be pumped out. A bulldozer will be required if the slump is large and serious. The wet sloppy material on the bottom of the dam should be pushed back and away from the inside toe of the wall and an area of more stable material selected in the bottom of the dam that is suitable for pushing up into the slump area of the wall. The bulldozer operator should test the slump area by backing the tractor from the solid bottom of the dam straight up the wall and moving slowly and carefully while watching for excess sinking of the tracks. It is very easy to bog a bulldozer in the slump, so the effect of the tracks should be inspected to see if the slump is stable enough for safety. If there is any doubt as to the stability of the wall supporting the weight of the bulldozer, a load of drier earth should be pushed forward up the wall and the blade raised gradually to spill earth under the tracks as the machine travels. If the slump area is at all boggy, constant care is necessary to see that there is always new earth being dropped ahead of the tracks of the bulldozer. The path of travel up the wall is constantly changed slightly, so that a uniform compaction of all the unstable material of the slump is produced.

The repair of an inside slump should produce the planned profile of the wall with a finished height of the crest about 5% higher to allow for settlement.

An inside slump may be repaired by smaller equipment or by hand work and working from the crest of the wall. This type of repair aims at using the bulge of the slump as a stabiliser. The slump is allowed to dry out as much as possible and the cracks and cliffs of the slump filled with new earth. The bulge is not cut down, but is left as it is, only being covered with earth where it is cracked. The bulge at the bottom of the slump acts against further movement. Such a repair may slump a little further after the dam has been filled and then emptied again. However, the slump will be much smaller and may soon become stable. It is important in hand repair work to allow the bulge to act against further slumping, and not to place any more earth than is necessary to reform the wall profile by filling the hollow of the slump.

Throughout these discussions the bulldozer has been considered as the type of equipment most suitable for farm dam construction. Although I believe this to be so, contrary opinions are often expressed which favour the use of large scoops or scrapers. The reasons given in preference for the latter machines are that this equipment imparts better compaction to the wall material. In my own experience of building dams of the type and size of the useful farm dam with both scoops and bulldozers, I believe the only worthwhile advantage of one over the other depends on the length of haul. Where the earth has to be transported distances beyond 200 feet the advantage lies with the scoop and continues so as this distance is increased. As for the scoop providing the best compaction, there is little significance to this view. What generally happens is that the use of the scoop allows the earth to be spread in thin layers (also a feature of good bulldozer operation), which aids uniformity of texture in the material; but the path of travel, being longitudinal along the wall, provides compaction from the tracks and scoop wheels only in this direction. In the early stages of building a dam wall the scoop and tractor equipment is working on a wide and rising wall crest and compaction can be made uniform by regulating the various paths of travel of the equipment. As the wall approaches its full height it becomes impossible to travel the material uniformly, and in the final stages, with the wall crest 10 to 14 feet wide, only narrow bands of earth across the long section of the wall are affected by the wheels. Hard compacted earth then is adjacent to loose fill and the contact between the different textured material forms larger longitudinal cracks. Later, the wall will still be satisfactory, but not because of the type of equipment or for the reasons given in its favour.

I have seen the loosest walls settle into good impervious walls and I believe that in the relatively small earth wall what is called proper compaction is necessary only on comparatively rare occasions. However, this aspect of farm dam building will be further tested over a range of different materials, as we propose shortly to build experimental farm dam walls with loose earth "thrown" into the site. In these experiments no equipment will travel over the earth wall except possibly to trim the wall to shape after all the earth has been placed. We have now a special machine for the tests. Another aim of this new series of experiments is to devise ways of building large farm dams efficiently with smaller equipment. Even now smaller equipment can build sizeable farm dams by using the designs of this book and the lockpipe system to prevent constant flooding by providing good drainage for the much longer period of construction. Our experiments with the new piece of small equipment which will operate in conjunction with on-the-farm machines, should, if successful, extend the scope and expedite the work of building farm dams.

With the coming of the large bulldozer many men are unaware or have forgotten what they can do without the bulldozer. While the bulldozer is a wonderful tool, farmers, by becoming too bulldozer conscious, tend to let a job wait, when the smaller equipment already available on the farm or even their own hand work can be used cheaper and more profitably. There is too great a tendency for farm workers to let a job or an earth works repair await the arrival of a bulldozer, a job which, considering the high hourly cost of a £10,000 to £15,000 bulldozer, they can do cheaper without it.

Wave erosion in the larger farm dam is yet another problem of maintenance; that is, if it has not been allowed for as a factor of design. Wave erosion does not operate evenly along the length of a wall of a dam filled with water, but tends to concentrate its larger waves on smaller sections of the wall. Wave action can destroy a wall on occasions by this larger wave concentration cutting right through the crest, or, with the waves breaking across the wall, causing a flow of water over it. Wind and heavy rainfall together would accentuate the danger. Then the continuous flow of water across the wall would have the same effects as any other destructive overtopping. The dam could now be lost unless effective action is taken. However, preventative action is simple and requires only the opening of the outlet valve fully and the blocking or breaking of the water conservation drain to prevent further inflow into the dam. With farm dams of the designs of this book this action would quickly reduce the water level below the breach, when it can be repaired later. A temporary repair in such a breach, once the earth is brought to the full height of the wall, will hold back all the water of the dam even if the repaired section of the wall is only one or two feet wide at the top.

However, the best cure for destruction from wave erosion lies in preventing it or providing effective counter measures in the original design and construction of the dam. Wave erosion as a serious and destructive force in the larger farm storages is reasonably predictable and can be duly considered and planned for in the design of the dam.

The accepted engineering counter to wave erosion is the provision of a riprap (heavy loose stone or rock) covering over the inside batter of the wall. However, the provision of riprap for a farm dam is usually an expensive item and more often than not it would cost more than the earth wall itself. This cost would no doubt be fully justifiable if no less expensive counter to wave erosion could be obtained.

In our own case, in designing the larger farm irrigation dams, we counteract wave erosion by quite simple and effective measures. There are three main considerations. One, the prevailing winds in relation to the shape and lie of the dam will indicate the portion of the wall where the highest waves will strike. The wave crests do not usually advance as a straight line or as a wave line with all parts at the same height, but rather as a curved line, curved according to the drag on the ends of the wave caused by the shallow bottom near the shores of the dam in relation to the wind direction. Winds from various points over a 90-degree are of the compass, will drive the high crest of the waves over a relatively short length of the wall and rarely more than one-third of its total length. It is possible to estimate approximately the length of wall that will be affected by wave erosion and to provide for it in design. In the earth wall farm dam the material that is most readily available and cheapest to handle is earth, not rock; therefore, earth in suitable quantities at the right place becomes the obvious counter to wave erosion. If a large farm dam built without considering wave action in the design, is being damaged by wave erosion, no doubt the farmer would repair the damage, which we may assume is reducing the effective width of the wall, by placing further earth at the reduced section. The cheapest means of providing extra earth is surely placing it there during the building of the wall. The design should therefore include an allowance of extra earth in the wall as an increased wall section to counter wave erosion. While there is a great deal known about the action of waves, there does not seem to have been any experiments conducted to determine effective counter measures to wave erosion of farm dams by the use of earth.

We built a farm dam which had a water surface of 350 yards extending out in front of the wall, and we made an arbitrary adjustment to our design to counter wave erosion. The width and height of the wall crest was increased by one foot along that section of the wall where, from the shape and lie of the dam in relation to winds, we considered wave erosion would be most damaging. The wall of the dam was treated by covering the crest and rear batter, but not the waterside batter, with soil and planting the ordinary pasture mixture. Wind shortly after the dam filled caused waves, which soon cut into the wall and formed perpendicular cliffs of earth with a long, almost flat, terrace on and just below the water line. Meanwhile, the grass was growing on the crest and back batter of the wall. Later, the level of the dam was reduced by about three feet in irrigating, and waves again formed the perpendicular cliff and the nearly flat terrace below on the new water line. This time the wave erosion was moving primarily some of the earth of the first terrace formed by the earth eroded in the formation of the highest cliff. Again the water level was reduced by irrigating and a new line of cliff with its associated line of terrace was formed. By this time grass had started to cover the highest terrace and soon appeared on the next lower terrace.

Many people had seen the experiments, and although its purpose had been explained, some sent special grasses to us to help stabilise the wall. However, we made no attempt to influence the course of the development of the cliffs and terraces, and the use of the water and the consequent lowering of the water level was dictated only by our irrigation requirements.

It was quite obvious to us from this experiment that we could, by releasing water *via* the lockpipe, determine the course of the development of the cliffs and terraces. However, a definite stability formed naturally against the damaging action of the waves, and as seen in the grassing of the terraces. It is now apparent that, even without attention, wave erosion would have to act for a very long time before it could affect the efficiency of the wall. There would be a gradual movement of earth from the crest of the wall down towards the bottom of the dam, which would occur each time the water of the dam was reduced from the filled to the nearly empty stage.

A recommendation in the design of dams that are of a size where wind erosion is likely to be a factor is to design the wall with an extra foot of height and an extra foot of width for the one-third distance of the wall where the waves are most likely to affect the wall. Thereafter, cover over, as, with all dams, the crest and both the front and rear batters with a couple of inches of soil and sow down with pasture grass seeds with fertilisers. The first cliff should be allowed to form, but when the level of the water is next reduced, the cliff is smoothed off by hand work, allowing the earth to fall on the terrace below, where more fertiliser and grass seed are then scattered. When further earth is required to maintain a good top section of wall, earth would be taken from the extra foot of wall height provided in the design for this purpose. Only the top cliff and terrace will need to be so treated.

These suggestions should be effective in dams with a water surface 400 yards in front of the wall; and the allowance of extra width and height could be doubled for those very rare occasions of a farm dam having half a mile of water surface extending out in front of the wall.

In bringing these discussions to a close, it is not to be assumed that the subject of suitable structures for the farm conservation of water has by any means been exhausted. Indeed, there are so many opportunities in farm dam construction it is a marvel that we have not taken more advantage of them. There are other interesting types and kinds of structures, for instance the log dams mentioned earlier, which will be suitable for particular occasions. There will no doubt be other problems of materials and sites and circumstances which are not touched on here. Yet it is hoped and expected that a study of the shapes of land in relation to agricultural pursuits generally and to the efficient conservation of water on rural properties in particular, together with the detailed design and construction methods of Chapter XVIII and this present chapter, will assist the farmers and graziers in doing this work for themselves. I hope my experiences will lead to many farmers attacking these problems more confidently and that my mistakes and experiments will obviate mistakes in their own work. I hope also I have said enough to justify my earlier contention that the farm dam is a job worthy of as specialised attention for its own sake as that of the "big" dam.

In agricultural areas where there are no existing farm dams, or farm dams have a reputation for failing to hold water, then I would suggest that the best procedure for the landman would be to construct his first dam high up on the property or at the keypoint of a valley where, I have found, the best dam-building materials are likely to be discovered. When it becomes necessary to employ special anti-seepage techniques the method known as mechanical stabilisation could be investigated first. It is generally desirable that the design of a dam in which these methods are to be used should provide for flatter batters, so that all the area of the inside of the dam can be worked with suitable equipment. Mechanical stabilisation involves several cultivations of the inside of the dam with chisel implements to fine-up the material. Several such workings should be followed by harrowing and rolling. The fine materials tend to move with seepage water to seal the leaking areas. The solution of the problem of the first dam may quickly lead to a wide use of other sites and a wonderful development of valuable land. But before all this farm development can take place on a wide and national scale there is this further aspect to be considered. It is quite certain that if the work of providing all the farm dams which the country needs is not to be done largely by our landman himself as the chief supervisor and expert, then the job will not be done soon enough. When one realises that the farmers and graziers are the largest force of executives in the nation, employing a huge and capable army of helpers who work always closely with them, and that the land of these directors of our rural industries is the nation's greatest capital, then one may be confident that the great challenge of the Australian landscape--the need for more water--will have many acceptors; and, moreover, in accepting this individual challenge, no farmer or grazier needing help, whether from governmental or private sources, should ever have it denied him.

CHAPTER XXI

Rewards of the Balanced Landscape

THE old order changes, of this there can be no doubt, and these changes are rapidly taking us away from the older, unplanned, haphazard use of land, with its emphasis on the next crop or the next wool clip. The mining of the fertility of the soil will soon have no part in Australian agriculture; and if the changes on my own properties are a glimpse of the future ahead, then the vision is indeed splendid. In contrast to the former yellow dead earth, poor grasses and sparse trees, we have now the darkening soil, the longer-lasting, all-pervading green of the pastures and the new luxuriance of the trees as striking evidence of the influence which the new design can have on the whole landscape.

Convincing the skeptics is usually an easy matter if the skeptics will come back again, and those whose interests in the land brought them back to "Nevallan" two or three times are now the most enthusiastic expounders of the principles and techniques of Keyline.

For myself, the whole development of Keyline, of which the first experiments had no real point until the problem of producing good soil from almost nothing had been solved, has been a fairly long task. In every way it was much more difficult than an ordinary manufacturing or construction project where, after the planning, there follows the "tooling-up" for the job. But originally there were no plans, only the search for a plan; and there were no tools to tool-up for the job; and until the plan started to emerge there was no way of really knowing just the type of tools that were needed.

I was always interested in water control, and whether experimenting with "wild flood" or contour furrow irrigation or getting oneself saturated watching run-off in heavy rainfall, the flowing water seemed to hold many of the answers to the questions of land.

There was so much trial-and-error work to be done which in the first place involved miles of levelling work, and usually I did myself, in order that we could determine where water would flow and where it would not, that a simple levelling device which could be used by anyone became an absolute essential. The development of our own level was a big step forward, as it put into the hands of the farmer himself, as well as our own men, an important necessary tool. Then, after my own earlier and somewhat heavy implements, the redesigned chisel plow was of outstanding assistance for the more intimate control of the soil climate, an essential approach in Keyline. Our early contour map must surely have been of great assistance in the final understanding of the agricultural land shapes of Keyline, and the application of aerial photographs and solid models, made the teaching of Keyline, which was not quite the simple task I had at first imagined, an easier matter. There were many designs which were developed and tried in the construction of farm irrigation dams, and long and sometimes costly experiments were completed before I finally decided upon the cheapest and fastest method of constructing them, together with their water conservation and irrigation drains., Since the water conservation drain and the dams of Keyline were to be the most permanent man-made structures on the land, these designs were of outstanding importance.

Good soil is the secret, and everything that is planned and everything that is done on the farm, the sowing or the cultivation of the soil, or even just the moving of stock from paddock to paddock, all have to be planned and carried out, always bearing in mind the effect that these things can have on the soil. The cultivation of the soil in such a way that the pasture is not destroyed and the best conditions of moisture, warmth and air, are created, became a precise Study, since cultivation can destroy as well as improve the soil. But when all these things were put right, everything looked just fit and proper, with the trees in their wide belts appearing as sentinels guarding the soil and pasture which they are sometimes thought to destroy.

The voice of the visitor (usually men and women from the land and also including many from other walks of life) has been one of acclaim for Keyline, and the Sunday afternoon farm walks, which became a special feature at "Nevallan", have been a source of pleasure to me and to many others, and also led to the discovery of new knowledge.

The vindication of the whole work has been in the test of time. At the moment, there is a sense of pleasure and great relief being felt over much of eastern Australia occasioned by the breaking of a drought (end of January, 1958) and an 18 months' absence of run-off, but there is something very much more than this in our own farm people. There is an infectious feeling of excitement and achievement about them that could hardly have been greater if each one had been directly responsible for the recent beneficial rains.

When our manager returned to "Kencarley" in January from his holidays he found the place somewhat of a disappointment. He had expected a big improvement from over an inch of rain which fell just after Christmas and while he was away, but there was only the dust previously churned up by the machines and the heat of high summer and the general look of drought. Still, the seeming miracle of soil change does not take place in one year, particularly when it is a drought year. By contrast, the picture at "Nevallan" from brief rain at the end of December was a different one altogether. There, the rich, deep, but now dry soil absorbed the rain and almost immediately the place responded with a remarkable new growth. However, back in the middle of the recent short yet severe drought, I had insisted on carrying out our programmes despite the dry conditions. We continued to sell fat cattle and replaced them with a new breeding herd, and the flock of sheep at "Nevallan" were kept there throughout the whole of the drought. I had planned also that the old dams which had been originally equipped with four-inch outlets through the wall, would be emptied and the small pipes replaced with eight-inch lockpipes. It had been found that the large lockpipes greatly speeded up the work of irrigating and the big flow of water had improved the even distribution of the irrigation water. The cutting of the big V-shaped excavations through the old walls, which were about 24 feet high, appeared to be quite a big job; however, it was accomplished very simply, but now four large dams in the main valley of "Yobarnie" stood empty, and we did not know, of course, that there were ten further months of drought to come. Following the floods in the early part of 1956, the succeeding twelve months from June, 1956, to June, 1957, provided only seven inches of rain, and we were to go on for over eighteen months without any run-off. However, "Nevallan", in its first drought, had come through well and our many visitors remarked on its excellent condition. It produced an immediate response from the rain at the end of the year, and with the coming of heavy rain at the end of January, the effect in a few days had been a complete vindication of our belief in the overpowering influence of good soil. In the last week of January there was over six inches of rainfall, and, exactly as expected, three inches were promptly absorbed into the soil before water started to flow in the water conservation drains.

At "Kencarley", near Orange, the depressing effect of the dry spell has gone. There, after 2-1/2 inches of rainfall, the drains began to flow. A large water conservation drain carries the water from higher country through a low saddle into the valley of "Kencarley" Basin, which is our largest dam. The drain is over ten feet wide at the bottom with flat sloping sides and it is three feet deep. It, like the pasture paddocks and the walls of all the dams, had been cultivated and sown to grasses with a dressing of superphosphate. "Kencarley" Basin was still empty, but after 2-1/2 inches of rain the biggest drain started to flow, and with the rain continuing, everyone on the property was watching the rather impressive sight. Although with three million gallons now in the Basin, it is little enough compared to the size of the dam which will hold 120 million gallons when filled, but it must have been exciting for the men responsible to see their work tested and proved by the big stream of flowing water. This large drain empties water, as I have mentioned, through a saddle to flow into the valley of "Kencarley" Basin. The valley floor of the Basin, formerly a wet marshy place of almost useless land, had dried out in the drought and had been cleared, keyline cultivated and sown to pasture grasses right to the wall of the dam. Yet the large volume of flowing water spread widely in the cultivated land of the valley and moved into the area of the dam as a broad, flat and shallow sheet. There was no movement of the plowed soil. The water now in this dam covers less than two acres of the dam's 40 acres of water line area, so that until there is further run-off rainfall the rest of the 40 acres of the floor of the dam will probably be our best new pasture paddock. Of course, "Kencarley" Basin could fill in a few days if we get rains of the type we had in early 1956, before work on the dam had started, or we could go two years without seeing it filled. It has been an experience of ours over the years for someone to always predict that each large dam, as we built it, would never fill. So more than one person has predicted that the Basin will not fill. "Kencarley" Basin is our latest experimental dam and our largest farm dam. It is built with steeper batters to the wall than any wall we have built as large and as high as this one; and as part of the experiment there are other features under test. So while it may do any number of things, we feel certain about one thing, namely, that this large dam will fill up with water.

There is a dam at the bottom end of the gorge on "Kencarley" which is probably the most interesting farm dam we have yet built. It has a capacity of 12 million gallons, and, aided by its steep catchment, is fairly well filled at present. It is holding our first irrigation water, but 800 acres of irrigated land on "Kencarley" is our minimum target. Now, the big change will be in the soil where this rain, the first soaking rainfall that the new work has received, will start the real cycle of soil improvement. There have been very big changes this year in the landscape, with the dam building and the clearing on the Keyline pattern, and the cultivating and sowing of the pasture areas, so that soon the real soil improvement should start.

The rewards (and there are great rewards in land work that result from seeing the plans of development unfold so rapidly) are well worthwhile. The plan of the work that has been laid down is like a trustworthy and successful friend. The plan seems to promise that if the work is done according to the design, then the results will be very rewarding, not only in themselves, but to the farmer, who feels satisfaction and pleasure in work well done, but knows also that there w ill be the monetary profits that must be the proof of all successful working of land.

I realised a year or two ago that another book on Keyline would become necessary, but it was not until three months ago that I felt any urgency about the matter. I was talking to a farmer on his own land, a fine and highly productive property. His home was comfortable, with the gracious and secure look from trees planted years ago, and altogether with his wife and family this was a man whom many people would envy. Inevitably, we talked of land and soil; of hills, ridges and valleys, and soon I was interpreting the shapes and forms of Keyline on his own land and probably producing in his mind a picture that he found good. Then he said, "If I did not own this land, I'd buy it." He told me he had read "The Keyline Plan", indeed several times, but that what I had just said was not in that book and he wanted to read it in a book. Like everything that is alive and vital, Keyline had to grow and expand, and, if in Chapter VI, by setting out the shapes of land in better sequence than in my earlier book, "The Keyline Plan", I am able to make the farmer see the value, and interest him in, the shapes and form of his land, then my farmer friend, I hope, will be answered and satisfied.

There has been this sense of urgency in the writing of the book now, as 1958 is rapidly unfolding glimpses of successes to come for Keyline. There have been enquiries from official sources in Australia and other countries, advice sought on broad important national aspects of land and water, and there have been more visits from overseas agriculturalists. One overseas agriculturalist spent weeks studying Keyline and left convinced that his own country must adopt it widely. Innumerable suggestions have come from our many new friends. Some have been practical, some impractical, others very simple if they had only included the money with which to carry them out, but all indicating great enthusiasm for what should be done now about Keyline. I have recently learned that Keyline will be the subject of an important agricultural lecture to be delivered in England this year by a visiting Australian scientist who will present it as a discovery of some value. This is probably one of those once-in-a-lifetime happenings, and, quite apart from the fact that a trip I had proposed to make was planned from the middle of last year, I feel I should not miss such an event.

Although the work of developing and improving land, which constitutes really the building of a new landscape, is never done, yet with this book now finished I do feel that the development of Keyline as a theory and practice is completed. I suppose one could say that the whole scheme has constituted years of hard work, although I have never felt that way about it, as the improving of land always involved the proving of men too, and so the making of new and genuine friendships has made the work one of pleasure as well as all-absorbing satisfaction.

Yet there is something more to go on with. Although I do not want to emphasise any one aspect in the overall planning of land on Keyline, there should be a further mention of the farm dam. Over the recent years there has been a tendency on the part of many farmers to regard the possibilities in these structures more seriously. Since 1944, many thousands of people have seen our farm irrigation dams, and no doubt much of this awakening interest in the farm dam has been occasioned by our own work and by those who, having seen the work, have commenced their own, water conservation schemes on the larger scale which we have always employed. There have been also increasing suggestions that something more should be done officially on farm water conservation. In N.S.W. there was enacted in 1946 a farm water supply bill aimed at assisting farmers. At that time the whole matter consisted in providing financial assistance to farmers to build dams, and it was assumed that everything was known about the matter and that the farmer only needed financial assistance. The usual stereotyped plan was issued but has not greatly encouraged any rapid increase in dam construction, although the few engineers employed have more work than they can handle. In 1946 there was need for something more embracing and which would involve the whole agricultural outlook, so that the farm dam could fit into the picture in its most valuable form. At that time, also, as has been mentioned, the matter was almost completely divorced from agriculture, and this alone was a tremendous handicap; and then the whole scheme depended for success on a few engineers, but the task was so big that only good designs, which would have enabled the farmers to effectively control the main work themselves, could have succeeded as broadly as the scheme merited.

Without being too emphatic about the matter, I do point out that the type of wide investigations that were necessary then have now been largely completed by my own experiments in this work, and that if Governments do follow the line now developing in public opinion and do decide to fully investigate the almost limitless possibilities of the farm dam, then I suggest that in the first instance a full investigation of our own experiments and development methods be undertaken. These cover a somewhat broader field than is presented in this book. For instance, we have repaired broken dams which have failed, after being constructed by others, for farmers on their own properties and investigated the reasons and the cause of failure. In the occasional cutting of the wall of an old dam which we had constructed ourselves, experience has been gained on the effect that various construction methods produce in the dam wall after ten years or more. As farmers sometimes react to large dams by thinking that they are on occasions waste of land, this aspect of the matter has been studied and investigated to determine the most practical uses of such a dam in a general farm water conservation scheme and to determine also the methods of construction that will leave the dam in a position when empty to be used as very valuable country for the growing of special crops. As mentioned earlier, explosives have been used in various ways to cure dam seepage, and we have been able to determine within reasonable bounds just where they are suitable for certain purposes. While there are further investigations that I believe should be made, it is also apparent that our own work will indicate where these investigations should lie. In the first place, a critical examination of the basic designs for dams as set out in this book should indicate whether there is any merit in my suggestions.

If my own view is accepted that the present approach and use of farm conserved water is completely inadequate, then it would also be apparent that the wide investigations, many of a trial-and-error nature, that would otherwise have to be made would involve the expenditure by the Government of a very large amount of money and many years of work to cover the experiences that we have had over about twenty years, fifteen of which were in the agricultural field and all connected with farm water supply. However, the full results of our work are freely available to our Governments and could be put into effect at once. It is to be hoped that in recommending action, however, any investigation committee would do so, not as the result of a casual inspection of a few hours or a day, but only after thorough study had proved the outstanding worth and value of this wide new approach to the problem of farm water supply.

The work of providing the farm dams that are necessary is a grandiose enough scheme for any of our planners, and if the dams are required, then nothing should be permitted to stop rapid progress in the work. As for money, if the amount spent in one week in wartime were made available to finance the initiation of a scheme, then its completion would be definitely assured.

Even as this is being written, very good rains are continuing to fall on our properties and over much of N.S.W. Everywhere around us great quantities of valuable water are being wasted as run-off, and destruction by river floods is again taking place. Although this is not the big flood with wide overflow of rivers, water is not only running to waste, but much soil is being swept away with the flood waters.

From the effect of the heavy rainfall anyone who has vision may see that Keyline has readily achieved on our own land complete agricultural water control, and that it can not only do this on any farm, but it will also produce and maintain its fertile soil in good heart indefinitely.

Addendum

THE DEVELOPMENT OF NARROW TYNED PLOWS FOR KEYLINE

The basic principles used in Keyline of increasing the fertility of soils has not changed since they were first described in The Keyline Plan published in 1954. What has changed is the design of the cultivating equipment and the modification of the techniques for soil building that the newer designs have permitted.

The production of fertile soil from biologically inactive subsoil is not difficult and one technique is well known. We know that if sufficient quantities of dead vegetation and animal manures are available for composting, and the composted materials are blended into inert subsoils, rapid fertility can occur.

For broadacre farming however, there is never sufficient waste materials available. The soil and the soil life must be managed to produce its own composting material. Keyline techniques do just that and do it extremely well.

The Keyline processes for the enrichment of soil were actually well developed before suitable implements were found that would handle the job. Earth moving rippers were often used because of my father's familiarity with such equipment. Results with this equipment were sometimes spectacular, sometimes disastrous. Rapid changes and improvements in soil fertility levels were, however, being achieved with ever increasing success. At that time a Graeme Hoeme Chisel plow was imported into the country by a long time friend. This design looked very promising and the implement was tried out. It worked well and was commercially available.

In June of 1952 my father and I were in the United States on another matter. While there, we called in at Louis Bromfield's well documented "Malabar Farm". The techniques of Keyline had, in my opinion, progressed well ahead of what was being done by Bromfield.

In Amarillo Texas we met Bill Graeme of the Graeme Hoeme Chisel Plow Co. A deal was struck where by we made the plow under their patent in Australia. The words and the concept "chisel plow" were unknown in Australia in 1952. The patent was found to be unenforceable in this country and so anybody could copy the designs. This inevitably occurred as Keyline ideas spread, so we were forced to go our own way. The plow was strengthened considerably until it "could go any where the farmer was game to take his tractor". That was my father's design requirements and consequentially, mine too.

Keyline soil building techniques were then slightly restricted by the limitations imposed by the plow itself and these are the techniques described in the Keyline books.

The plow business was sold in April 1964, with a proviso that P. A. Yeomans, and myself as the design engineer, had to keep out of the agricultural machinery business for a minimum of five years. The designs for a deep working, low disturbance chisel plow with the strength characteristics of earth moving rippers, a "sub soiler chisel plow" were moth balled.

They re-emerged, after this enforced hibernation, as the "Bunyip Slipper Imp" with "Shakaerator". This implement won the Prince Phillip Award for Australian Design in 1974.

The plow has an extremely strong, solid, rigid frame. The tynes or shanks are made from cast tool steel. They are narrow with a tapered leading edge. They travel through the soil with very little resistance, like a sail boats fin. The separate digging point is shaped like a long flat arrow head, tapering out to about 4" (100 mm) wide at the rear. The digging angle is very flat, only 8 degrees. A vertical "splitter fin" is incorporated on the top face, and becomes a vertical blade to the arrow head. In use, and in deep cultivation, the splitter fin initiates a vertical crack through the soil above, up to the surface. The side blades lift and loosen the earth between the shanks, and then allow it to re-settle. No mixing occurs between soil profiles and root disturbance is insignificant and gentle. After cultivation, the ground surface often appears as if undisturbed, yet is strangely spongy to walk on.

The Shakaerator is an off set heavy fly wheel, bolted to the plow frame, that assists soil shattering and reduces tractor horse power requirements in most soil types.

By then I had my own independent engineering business, and by constraint, not in agriculture. This was where the new plow prototypes were built. After my father's death in 1984, my company took over the complete manufacture of the plow. Improvements continued and six new patents have subsequently been issued. Three of which have won implement design awards at the Australian National Field Days.

The rapid soil building processes of Keyline were no longer restricted by the use of chisel plows, and the techniques were streamlined.

In addition, the use of this new plow enables the soil to absorb high quantities of run off from storms, and heavy downpours. This is the runoff that normally fills dams, and can often cause erosion. These effects have been catered for in the design of whole farm layouts. Greater emphasis is now placed on the location and size of the first dam constructed. This first dam now tends to be of greater capacity than previous designs called for. Fewer and larger farm dams now prove to be economically more viable. This first dam is sized and placed to so enhance the returns to the farm that future dams can become self financing by the farm itself. My brother Ken has developed computer simulation design techniques by which such decisions can be idealised. Design errors are virtually eliminated in the process, and financial and ecological viability can be assured.

The Keyline soil building process is now much more rapid with the use of this plow. Many clones of the plow have now been produced, often with interchangeable components, and if used correctly these plows can be equally effective.

The real value, almost one might say, the cash value of a soil is determined, firstly by the basic mineralisation within the soil. This is ordained by its geological history and formation. The farmer is not able to change this, outside the addition of some exotic trace elements. And the second determining factor, is the amount of humic acids within the soil, their age and their stability. The fulvic acids are here considered as subvarieties of the humic acids. If both abundant minerals and abundant humic acid is present, the soil is acknowledged as basically rich. Farming can, and does, change the content of humic acid within the soil. Most classic current farming practices in the Western World decrease the humic acid content of soils. The resulting soil deterioration manifests itself as, increasing dependency on chemical inputs, increased erosion and rising salinity levels.

To produce good crops in rich soils it is generally only necessary to maintain, within the soil, reasonable levels of biological activity.

Humic acid is not a simple acid, like hydrochloric acid or sulphuric acid. Humic acid is hardly an acid at all. When organic matter has been through all the biological processes within the soil, very large, relatively stable organic molecules are the ultimate result. Their formation is extremely haphazard and their actual chemical composition can have millions of variations. They are mildly acidic and so collectively they are described as "humic acid". Individual molecules can contain thousands of carbon atoms. They are so big that they can be acidic on one side and alkaline a little further around the same molecule.

For the farmer they have two very important characteristics. For a plant to take up an element for its growth, it must be in an available form. However, if the elements in the soil were in soluble form, they would have long since been washed, or leached away. Something else therefore, must occur for plants to exist at all. When acids break down basic geological minerals, nutritious soluble chemical elements become available, and these, fortunately, attach themselves loosely to the highly variable outer surface of the humic acid molecules. The element is no longer soluble, but it is readily available to the tiny root structures of plants and fungi. As far as a plant is concerned, the humic acid molecule is a supermarket, and its outer surface is the richly stocked shelves.

Carbon dioxide dissolved in rainwater forms carbonic acid. This carbonic acid breaks down the fine rock particles, replenishing the shelves in the supermarket. Also, biological activity within the soil can produce tiny quantities of acids, a thousand times stronger than the carbonic acid of rain water. These acids make available to the surface of the humic acid molecule, elements that would otherwise be totally inaccessible or unavailable.

If the soil is devoid of biological activity, and the minerals in the soil have been used up by growing crops, re-mineralisation of the soil can only be achieved by the much slower use of carbonic acid derived from rain water. I believe this to be a considerable, although unrecognised, justification for the "long fallow". It takes a long fallow, or simply a long time, to re-stock the shelves in the supermarket. When only minimum biological activity can occur, then the concept of "resting the soil", starts to make sense.

Humic acid molecules can last thousands of years, and these were described in German literature as "Dauerhumus" (dauer - German and endure - English). The long lived dauerhumus does not itself form part of soil biological activity. Other humic acid molecules however, do form that are much less stable. They can last anywhere from minutes to months. These molecules can, and do, get involved in biological activity. They contain, within themselves, protein and other similar structures containing nitrogen, as also do the long lived variety. Soil biological activity breaks down the short lived molecules and release a constant, and harmless trickle of ammonia to the fine plant roots, invigorating plant growth. This is "Nahrhumus", (nahr to nourish). Almost all of the nitrogen supplied to plants in healthy soil, is derived from this organic material within the soil.

It is well known that total soil organic matter constantly decreases with mono-cropping, and by the use of soluble chemical fertilisers, almost all of which kill earthworms and destroy microbiological soil life. The organic matter content decreases over periods, usually in excess of thirty years, and up to one hundred years, to a level of about half that in the original soil. Then a stability seems to be attained. This, it is claimed, proves that chemical agriculture does not continue to decrease soil fertility. I tend to believe that most biological activity has already ceased, and the organic matter, still in evidence by high temperature soil testing, exists only in the form of dauerhumus. These then are the extremely stable, but now empty, supermarket shelves.

So many problems are solved simply by increasing soil's natural fertility. And it all starts with dead plant material, air and water. Activity then starts, bacteria, fungi, actinomycetes and worms devour the dead plant material, die, and in turn devour each other. In the process, concentrated acids are produced that break down tiny rock structures, making available crucial elements in the life cycle. Complex humic acid molecules are ultimately formed. Some are broken down by more biological activity, producing ammonia for plant growth. Around others, the soluble newly released element become attached, but still available for healthy plant growth. Long chains of sugar like chemicals, polysaccharides, food stores for bacteria, are formed that bind the soil together. The tiny root like structures of fungi bind the soil particles in the same way. Small aggregates of these soil particles and sand and clays accumulate. In our hand we feel the whole thing as good soil structure.

Pieces of the less stable humic materials reform, and reform again until ultimately, relatively stable humic acid molecules are created. As the total organic content rises, earthworms move in and establish themselves. Their casts are a rich source of humus and their slimes and glues enhance soil structure. The soils ability to retain moisture, its "field capacity", rises dramatically and, to the farmer, rainfall patterns become less critical. This intense biological activity is the necessary "bio" in "biodegradable". Soluble heavy metals, poisons, become attached to the humic acid molecule and are no longer in solution and a threat. They won't be selected by the plants' discerning fine root structures.

Food producing plants grown on such soils are healthy, mineral rich and nutritious, and extremely resistant to insect attack. Weeds and non-food producing plants cannot compete in rich soils. This is not just accidental but logically inevitable.

For this all to happen, we must first structure an ideal soil environment, and then, if we can, we should water it.

The most rapid increase in soil fertility, and soil organic content in broadacre farming, is obtained by the utilisation, and the growth manipulation, of the legumes and grasses. The current model of Yeomans Plow was designed specifically, so that its use would create this idealised environment.

If conventional chisel plows are used to an excessive depth, for subsoil aeration and rain water retention, destructive mixing of soil layers results. For this reason, chisel plow use in Keyline required a program in which cultivation was only progressively deepened. Depth of cultivation was determined by taking a spade, and checking the depth of the root structures resulting from the previous cultivation. Tyne spacings were kept at 12" (300 mm).

Because of the resultant damage to existing pastures, it was often risky, and it was not advised to cultivate when pasture grasses were in short supply, or when approaching a period of, possibly, hot dry conditions.

Using these new implements we can now recommend an initial cultivation depth of 8" (200 mm) or more. Any less than 6" deep the cultivating effect is similar to a chisel plow, with a typical V shaped rip mark of loose earth being formed. If a hard pan exists, and conditions are dry, large clods can still be turned up. By increasing the depth of cultivation, a point will be reached where clods are not produced at all. Horizontal fracturing spreads sideways from the plough point and surface disturbance is minimal.

Tyne spacings should be much wider than would be recommended for chisel plows. 24" (600 mm) spacings are perfectly reasonable. 18" to 20" (about half a metre) would be a good general guide. If horsepower is limited, it is wiser to maintain the cultivation depth, and, if necessary, decrease the number of tynes being used. In this way little pasture damage occurs, good deep aeration has been achieved, and enormous quantities of storm rains can be absorbed before any run off occurs. Even with no following rain, very little soil moisture will be lost. In many instances plant roots will gain access to otherwise unavailable subsoil moisture.

The subsequent grass growth should be mown, or heavily grazed by overstocking to achieve the same effect. Stock should be removed promptly to permit rapid unhindered regrowth of the more nourishing pasture grasses. Subsequent cultivation should be repeated at or about the same depth. These Keyline stocking techniques are detailed elsewhere.

Within weeks of the first cultivation the decomposition of cast off root structures, following mowing or grazing, can promote soil colour changes from biological activity deep in the subsoil. This is quite impossible using a conventional chisel plow.

Cultivation, prior to cropping, using this plow at these depths invariably and dramatically increases crop yields. These dramatic increases are not always permanent. I believe that the dramatic increases result from exploiting soil layers, that have been "fallowing" for hundreds or even thousands of years. The minerals having accumulated on clay particles, as they do on the humic acid molecules. The dramatic increase in crop yields can only be maintained, by the inclusion of grasses and legumes into the cropping programs. This is to promote biological activity, and thus maintain the supply of minerals and elements.

Again; so many problems are solved simply by increasing soil fertility.

Allan I. Yeomans

THE CHALLENGE OF LANDSCAPE

* * *

THE DEVELOPMENT AND PRACTICE OF KEYLINE

PICTORIAL HISTORY

Plate 1

The Lemon-scented Gums of "Yobarnie" (*Eucalyptus citriodora*)

A Characteristic Scene

Plate 1 (above)

The Lemon-scented Gums of "Yobarnie" *(Eucalyptus Citriodora)*

A Characteristic Scene

Plates 2 (above) and 3 (right)

LANDSCAPES ON "NEVALLAN" AND "YOBARNIE"

Land once eroded and impoverished, supporting only suckered tree growth, has, by virtue of Keyline development, now become rich in soil and pasture framed by the growth of improving trees. Such landscapes are stable, since they are designed to withstand the vagaries of weather and climate, the long periods without rain, the devastating cyclonic storm, the destructive floods and the long soak of protracted rains.

Plates 2 (above) and 3 (right) (NOTE: The following Plate 3 page is unavailable, even via *the Soil and Health Library link.)*

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AND "YOBARNIE"

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Plates 4 (first above) and 5 (second above)

WATER STORAGE IN FARM DAMS

Keyline does not waste water. Full effort should be made to hold all rain water that falls on the property, so water storages, designed and fitted to the climate and the land shape, become permanent features. These farm irrigation dams, with their low-cost water readily available for quick irrigation, make property improvement continuous and repeatedly profitable. All the dams are constructed with lockpipe control ("Yobarnie" and "Nevallan").

The full development of farm water storage, together with the further improvement of all Australian soils, are our greatest sources of potential wealth.

Since the additional capital potential runs into the thousands of millions of pounds from farm water storage alone, expansion of this work dwarfs into insignificance all other schemes for the immediate development of our national economy. Not only is the scope for this type of development so very considerable, but it is also the easiest to finance.

Plate 6

AGRICULTURAL WATER CONTROL

It is not sufficient merely to conserve water; water must be controlled for effective use. Lockpipe valves (see also Plates 22 and 23) and drains for water conservation and irrigation (see also Plates 8 and 9) provide this control and facilitate the movement of large quantities of water both economically and profitably. Pictures are of irrigation drains on "Yobarnie". Each is flowing at the rate of over 100,000 gallons an hour.

Plate 6 (above)

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Plate 1

A STUDY OF CLIMATIC INFLUENCE

When climate is right, soil continuously improves, but our Australian climate is not everywhere good, and so man must reinforce natural processes.

Left: During thirteen consecutive months, rainfall conditions were such that the earth of the sand and sandstone footpath (Sydney—eastern suburb) did not once dry out, and there developed this remarkable change, with its growth of white clover, including some plantain. The effect of good soil climate, without clover inoculants, superphosphate or lime, produced this spring growth in 1955.

Middle: A year later, with less favourable climate, the pasture had deteriorated, and (right) by 1957 it had further changed into a dominantly poor couch grass cover.

Plate 7 (above)

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Middle: A year later, with less favourable climate, the pasture had deteriorated.

Right: By 1957 it had further changed into a dominantly poor couch grass cover.

Plate 6

KEYLINE-PATTERN FLOW IRRIGATION AND ITS RESULTS

Upper left: Over 100,000 gallons an hour flowing and watering evenly from a newly-constructed drain on to first-time-irrigated hill country planted the previous day.

Middle: The lesser amount of water, 25,000 gallons, effectively irrigates moderate slopes but does not have sufficient volume for quickly irrigating flatter slopes. The result of this irrigation in sandstone country on "Nevallan" quickly produced the growth of white clover. For identification, note the same tree in the middle and lower pictures.

We have found that Keyline-pattern is more efficient in water use than furrow irrigation, which in turn generally provides more effective water use than spray irrigation.

Plate 8 (above)

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Middle: The lesser amount of water, 25,000 gallons, effectively irrigates moderate slopes but does not have sufficient volume for quickly irrigating flatter slopes.

Lower right: The result of this irrigation in sandstone country on "Nevallan" quickly produced the growth of white clover. For identification, note the same tree in the middle and lower pictures.

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Plate 9

IRRIGATED HILL COUNTRY AND PASTURE GROWTH

This hill country does not become affected by the typical irrigation-land problems. As much good farm land is being put out of production by house building and roads, irrigated hill land is becoming the most valuable land in Australia. Lower left shows an area on "Nevallan" where Keyline-pattern irrigation was employed using the smaller flow of water. This land was in process of being irrigated when the picture was taken. Note the water in the furrows at the bottom left of the picture; 48 hours later there were no wet or unwatered spots to be found, only properly moistened soil. At lower right the man is standing at the advancing edge of the water, with the dog drinking the clear water as it flows over the newly pattern-cultivated land.

Over the very wide areas and the range of crops suitable for its use, Keyline-pattern irrigation is claimed to be second only to correctly timed natural rainfall in its low-cost effectiveness.

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Upper: Thick growth of white clover.

Lower left shows an area on "Nevallan" where Keyline-pattern irrigation was employed using the smaller flow of water. This land was in process of being irrigated when the picture was taken. Note the water in the furrows at the bottom left of the picture; 48 hours later there were no wet or unwatered spots to be found, only properly moistened soil.

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Over the very wide areas and the range of crops suitable for its use, Keyline-pattern irrigation is claimed to be second only to correctly timed natural rainfall in its low-cost effectiveness.

Plate 10 (above)

THE SPILLWAY OF A LARGE FARM DAM

Drains of various types are used for the control of water. First, spillways are the largest drains, so that they by-pass the flood overflow from the farm irrigation dams.

Upper: The spillway under construction.

Lower: The spillway completed.

This size spillway is necessary for the "lower valley dam" it serves, which has a catchment area of 350 acres ("Yobarnie" Pond).

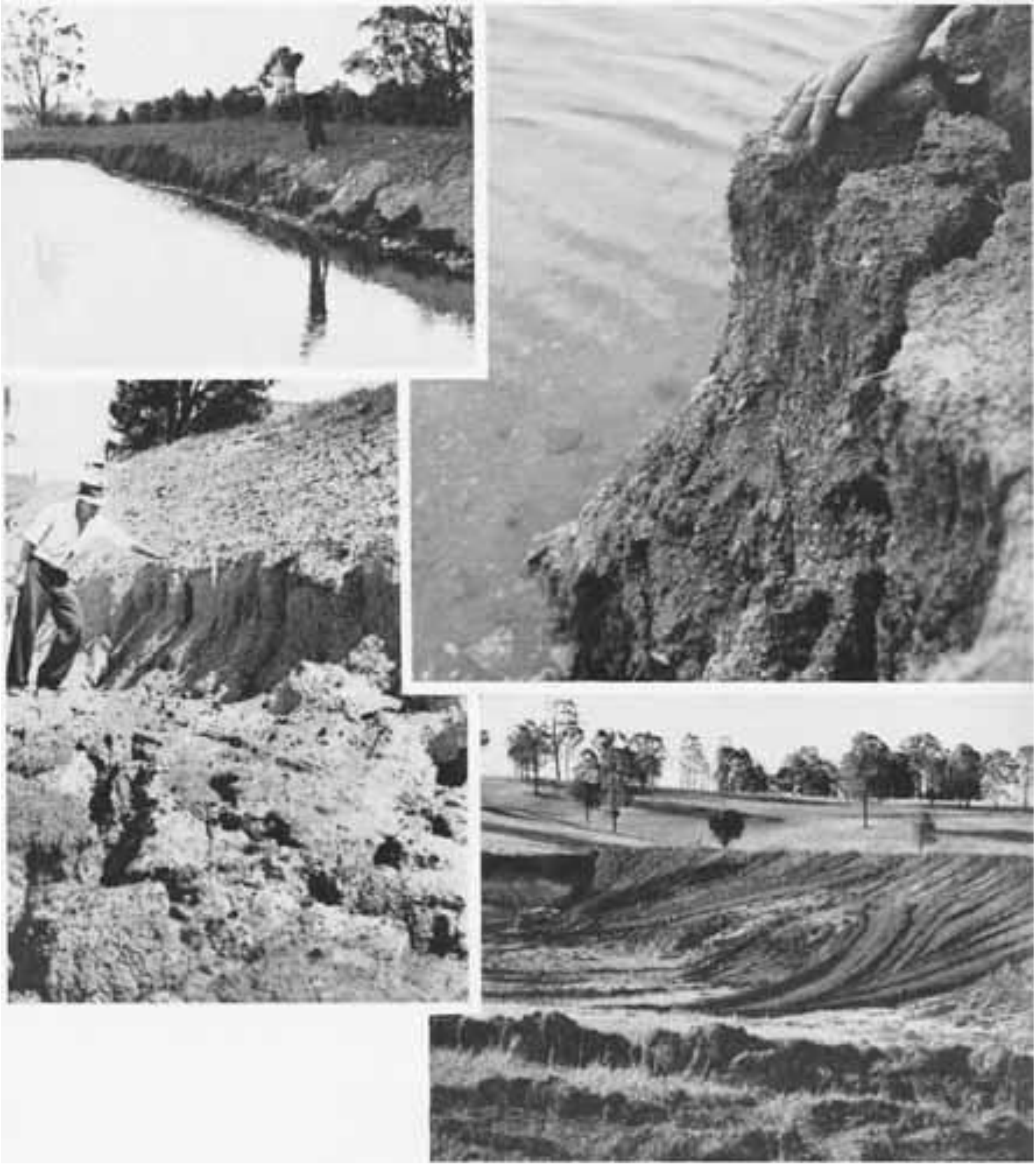
Plate 11 (above)

THE DRAINS OF KEYLINE

Upper: A large water conservation or feeder drain formed with a 100 horse-power bulldozer. It was next trimmed with farm equipment and sown with pasture grasses and superphosphate. After heavy rainfall it transported into a dam a large volume of water flowing twelve inches deep ("Kencarley", Orange).

Middle: A recently formed water conservation or feeder drain of the size and section suitable to transfer the run-off rainfall to a farm dam from a catchment area of 50 acres ("Kencarley").

Lower: The smallest drain in Keyline is the irrigation drain (lower picture). The drain stops are left in the irrigation drain after a watering, so that possible heavy runoff rainfall will not be concentrated, but distributed evenly for the benefit of all the area ("Yobarnie", North Richmond).



Plates 12 (above)

DAM TROUBLES AND STUDIES

Upper left: Wave erosion affects part of the wall of a large farm irrigation dam, forming cliffs of earth with a flat terrace below.

Upper right: Note the terrace just below water level.

Middle left (*as described in Chapter XX.*): Inside slumping of a dam wall may start with little cliffs of an inch or so after a full dam has become empty in irrigation. In a fortnight cliffs three feet high develop.

Lower right: The "wet" dam at "Yobarnie" which caused all the trouble as described in Chapter XX.

Plate 13 (above)

DAM TROUBLES AND STUDIES (continued)

Upper: A "fuse" or low spot in a wall under construction which protected this dam when sudden heavy flood rains occurred before it was completed to full height and broke the wall where it was only six feet high above natural ground surface. Ten million gallons of water flowed out through the "fuse" in half an hour. The earth lost could be replaced in an hour or two. (*See Chapters XVIII, XIX, and XX.*)

Middle: Damage caused by heavy flood to a large uncompleted dam wall when the water broke over the middle of the wall. The section of wall left standing was only a few feet thick and there was insufficient suitable earth left to reconstruct this dam. (*See Chapter XVIII.*)

Lower left: Slip scars on the back of a dam wall 40 feet high where heavy flow through the wall was stopped by the use of explosives as described in Chapter XX.

Lower right: Merino wethers near Homestead Ridge Dam on "Yobarnie".

Plate 14 (above)

THE CALCULATED RISK

The calculated risk in providing farm water supply by building dams in drought times with earths too dry for effective cohesion was taken when we built forty farm dams in the latter stages of the recent drought.

Plate 14 illustrates three such dams.

A large lower valley dam, with a maximum wall height over 30 feet and built of fine dry clays near the end of the drought of 1957, failed when it filled rapidly. The cost of the earth works was £1,200, but if the earth of the wall had been wetted and completely compacted, the cost would have exceeded £3,200. Effective repair will be £300 and is covered by our insurance.

Top: Shows the size of this dam (capacity 40 million gallons) and the broken wall.

Upper middle left: Shows the water line with the grass above, which had commenced to grow before the sudden filling.

Upper middle right: The shape and finish of the back of the wall.

Lower middle left: Shows part of the broken wall section standing almost vertical. The floor of the break was a filled large erosion gully which, being slightly moist, did not wash out again. The design and site preparation, including cut-off trench and the cleaning and cultivation of the foundation area for bonding, were all good. The rise in the water level in the dam was much faster than the rising moist zone in the wall, so the topmost dry earth first carried away.

Lower middle right: Shows the site preparation of another dam, but built of dry granitic earths at "Pakby". In this instance, the cost of adequate wetting of the wall material would have doubled the cost of the dam, which is stable to date but has not yet overflowed through the spillway.

A third dam, built of dry, fine clay, which failed above the first water line, is illustrated (bottom).

Bottom left: The two holes inside the wall where water channelled through when the dam filled quickly.

Bottom right: The condition of the back wall after failure.

The opening of the lockpipe valve prevented further damage. When this dam emptied there was an earth bridge over the hole which later broke when a beast walked on it. (The pictures of the two clay-wall dams were taken after the text of this book was printed.) Many dam walls constructed with fine, dry clays are stable, although this material is the most vulnerable to this class of dam failure. No instability has yet developed in walls which we built during the drought with other earths such as the dry granitics, earths containing sand or clays mixed with sand, shale or stone particles.

The calculated risk is part of the problem of farm water supply and this risk is accepted when considered as a worthwhile business proposition.

Plate 15 (above)

A DISTINGUISHED VISITOR

His Excellency, the Governor-General of Australia, Field-Marshall Sir William Slim, G.C.B., G.C.N.G., G.C.U.L., G.B.E., D.S.O., M.C., is welcomed to "Nevallan". Left to right: Professor McMillan, the author, author's son (Allan J. Yeomans), Mr. C. R. McKerihan, C.B.E., His Excellency, the Governor-General, author's son (Dr. Neville Yeomans), and Mr. John Darling.

Plate 16 (above)

PEOPLE AND KEYLINE

Our visitors come from all walks of life and include many groups of experts connected with the land.

Upper: Section of two groups, which included members of the Australian and New Zealand Association for the Advancement of Science meeting in Sydney and members of the Rural Group of the New South Wales Liberal Party. (*"Country Life" photo*).

Middle left: Scene at a farm walk on "Nevallan".

Middle right: A group of scientists and a grazier.

Lower: Party of country valuers from the Rural Bank of N.S.W. at "Yobarnie" (1957).

Plate 17 (above)

FARM WALKS OF "NEVALLAN"

Upper: Party of Queensland farmers arrive by two specially chartered 'buses making a 1500-mile trip specially to see Keyline development on "Nevallan". There have been a number of such visits.

Lower left (from left to right): The author, Lady Hicks, the author's wife, and Sir C. Stanton Hicks, at "Nevallan".

Lower right: Graduates in Agriculture from the Sydney University visit "Nevallan" following the author's address at their Graduation Ceremony mentioned in Chapter XIII.

Plate 18 (above)

RESERVOIR UNDER CONSTRUCTION

Upper: Following marking out and site preparation, the construction stage has reached the point where the lockpipe has been laid and earth is being placed to cover it. The width of the wall extends right across the picture, the forward bulldozer is over the centre of the wall and on the left is seen the topsoil which is to be pushed up over the wall on the completion of the work. Note the end of the cut-off trench on the right of the men.

Lower: Nearing the final formation of the wall, bulldozers trim-up prior to finishing work for the day. (Plate 22, upper, shows part of the site work of this reservoir.)

Plate 19 (above)

THE NEWLY-COMPLETED RESERVOIR

This reservoir, although not yet filled with water, is fitted to the climate and land shape and becomes a part of the new and continuously improving landscape. The whole of the water area of the dam, together with the rest of the paddock, was cultivated and sown with pasture grasses, which developed into a fair stand before the dam filled.

This reservoir is on "Kencarley" at Orange and is called Number 2 Basin. Its construction date was put forward by some weeks to enable our Queensland field officer, then visiting "Kencarley", to participate in its design and construction, including the laying of the large lockpipe controls.

Reservoirs are built to hold back run-off water not immediately required. Nevertheless, they are part of the assets of the farm, with their large water storage kept readily available for any demands. Their costs therefore become part of the ordinary working capital of the farm. There is this further point: Reserve storages hold back water for some planned future use or for an emergency, and so for these two reasons alone they are not only good income producers, but become of considerable insurance value to the whole property.

Plate 20 (above)

TWO STORIES FROM THE AUTHOR'S EXPERIENCE

Upper left: The most recent creek dam, "Control" Dam on "Kencarley", then nearing completion, now grassing up and well filled with water. (*See Chapter XXIII.*)

Upper right: The creek dam, mentioned in the text, was constructed nearly twenty years ago. It was probably the first earth dam built in Australia with large bulldozer and giant scoops. (*See Chapter XVIII.*)

Lower left: The first giant scoop built in Australia and designed and constructed by the author for mining purposes, is seen at work building a creek dam.

Lower right: A smaller scoop (six yards capacity), designed and constructed by the author. Picture was taken at the Battle of Sattelburg, our first victory of the Pacific War. (*Photo from Department of Information Film*)

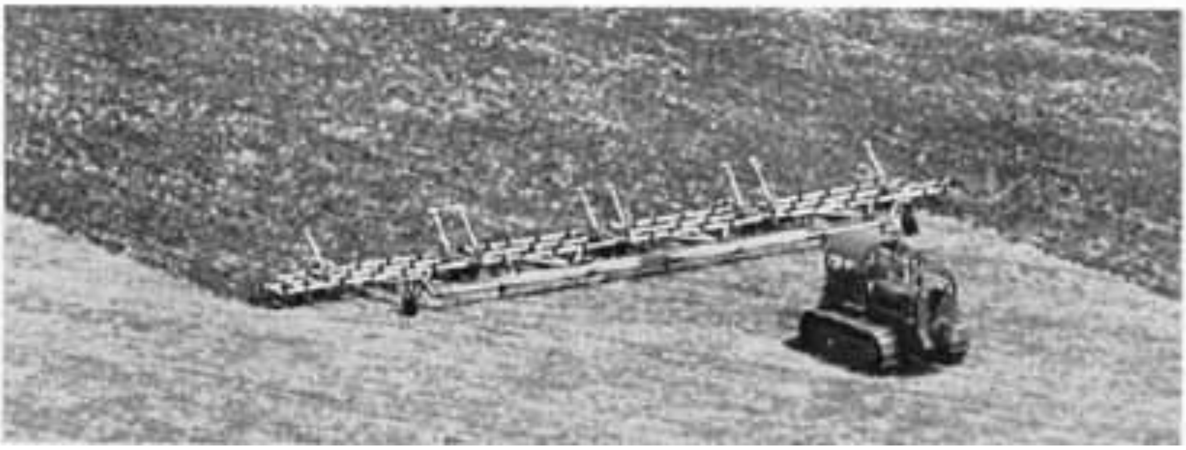


Plate 21 (above)

CULTIVATION AND IMPLEMENTS

Cultivation can either destroy or enhance and tremendously improve the fertility of any soil.

Upper left: Nearly three years of Keyline, which, by cultivation techniques and other means, greatly improved the soil climate and produced rapidly deepening soil and high quality pasture. This picture shows non-irrigated rain-only pasture.

Upper right: A popular-sized Graham plow of a type used on our own properties.

Lower: A 69-foot Graham plow specially produced for a Queensland farmer, believed to be the largest plow in the world (1955). The Graham plow is a useful implement for cultivating the top of the wall of farm dams, and all other areas of exposed earth. (See also Plates 24, 25, 26, 27 and 29 lower.) (*Professional photograph*)


KD83
KD83
BAFFLE PLATE

Plate 22 (above)

INSTALLING THE LOCKPIPE SYSTEM

It is essential that a farm dam have an outlet. A most significant aspect of Keyline is the type of outlet provided by the lockpipe system.

Upper: Two men level-in with our Bunyip Level the lower half of the baffle plates in the lockpipe trench. The picture is taken looking up to the inside of the dam. The baffle plates on the inside portion of the wall are closer together than towards the rear of the wall near the men. (*See Chapter XVIII.*)

Lower left: The U section rubber gaskets being fitted to the lower half of the baffle plate. This rubber gasket encircles the pipe between the two coupled-up sections of the baffle plate.

Lower right: The lockpipe equipment in position ready for the filling of the trench.


KD811

Plate 23 (above)

KEYLINE CONTROL OF WATER

It is important that the earth be placed and rammed under the pipe of the lockpipe, as satisfactory natural settlement will not take place below the pipe.

Upper left: The second row of ramming from an oblique angle, so that the earth is forced under the lockpipe. From now on very little hand work and only carefully supervised bulldozer operation is necessary.

Upper right: Water from rain (during the construction of a medium-sized farm dam) drains out through the lockpipe. The oil drum and posts are placed at the two open ends of the lockpipe to prevent it from being covered and lost during the construction of the dam.

Lower left: The volume-cone strainer in position on the inside of a newly completed dam.

Lower middle: The lockpipe valve with eight-inch lockpipes.

Lower right: The large volume of water from the opening up of an eight-inch lockpipe valve.

The lockpipe system is our own. The system, together with many items of the equipment, are protected by various patents and registered designs. (*See Chapter XIII.*)

Plate 24 (above)

"KENCARLEY" SCENES

The landscape of our 3,000-acre property "Kencarley" is changing rapidly.

Upper: In the foreground, land once tree covered had been cleared in this manner. The untidy grass was considered "pasture improved", but is land of obviously low carrying capacity. In the background is the initial tree-covered landscape.

Lower left: A strip of land in process of being cleared to the keyline plan as laid down for the development of the property.

Lower right: Formerly cleared and greatly deteriorated land, showing regeneration of low value trees and poorly nourishing tussock grass.

Plate 24 (left)

Plate 25 (above)

THE CHANGING LANDSCAPE

Upper: A cleared strip with timber pushed up ready for burning.

Middle: The heaps of timber burning.

Lower: A tree belt between two cleared strips of country on the high hills of "Kencarley".

Plate 26 (above)

"THE CAMPBELLTOWN PLACE"

While "The Campbelltown Place" is all sand and sandstone with poor trees and scrub, it has a better climate than "Nevallan", being favoured by more summer storms. Keyline soil improvement, including superphosphate, with clovers, inoculents and grass seeds, were all that were necessary to start off the cycle of soil improvement. This is a special soil-making experiment worth watching.

Upper left: Some of the rocky country cleared and keyline cultivated with a Graham plow.

Upper right: An aerial view of the scope of operations.

Middle and lower left: Partly cleared land, showing tree belts left in the clearing.

Lower right: Pastures commencing to hide the stone-, on parts of the property.

Plate 27 (above)

A KEYLINE EXPERIMENT

Upper left: The main farm road (as seen in aerial photograph, Plate 26) crossing through one of the tree belts.

Upper right: The road and year-old pastures with a tree belt in the background.

Lower left: Mixtures of pasture grasses eighteen months old, and now producing good food for fattening cattle.

Lower right: Newly planted pastures, with trees and rock outcrops in the background.

There are large areas of such virtually untouched land which, with Keyline planning for landscape control, can be developed quickly and economically into highly productive and extremely beautiful farms and grazing properties.

Plate 28 (above)

"PAKBY", BATHURST

Soil erosion is not a problem for special consideration on Keyline-planned properties, because soil is improved and all run-off rainfall is conserved for economical use. Gullies which were eroding badly have had their destructive water supply directed to farm irrigation dams, where it is utilised for flow irrigation.

Top photo: A general view of the early deteriorated landscape when we purchased the property.

Main photo: A close-up view of an erosion gully caused by the run-off from a small catchment, plus road water.


Lockpipe Outlet
Valve
Lockpipe Inlet

Plate 29 (above)

WATER CONTROL AND SOIL EROSION

Top left: Shows how the water is controlled and the problem of the big gully forgotten. The big eroded gully is in the line of trees. The run-off which cut the gully was re-directed across the recent keyline cultivation (at right of the picture), and though flowing across it, no movement of the sandy earth took place. The water reaching the drain was then under full control and flowed to the dam.

Top right: The typical erosion pattern on the front of a dam wall built with granitic earths and soil covered on the back and top only.

Upper middle: A dam on "Pakby" with the typical erosion pattern of granitic earths when there is no soil covering.

Lower middle: Son Ken standing on the front wall of the dam (Top right), which was covered with an inch or so of soil and received the same rainfall but has no erosion.

Bottom: An important finish to a dam wall is to cover all the wall with the soil removed from the site at the initial stages and recultivate it. Note also the two ends of the lockpipe through the bottom of this new dam.

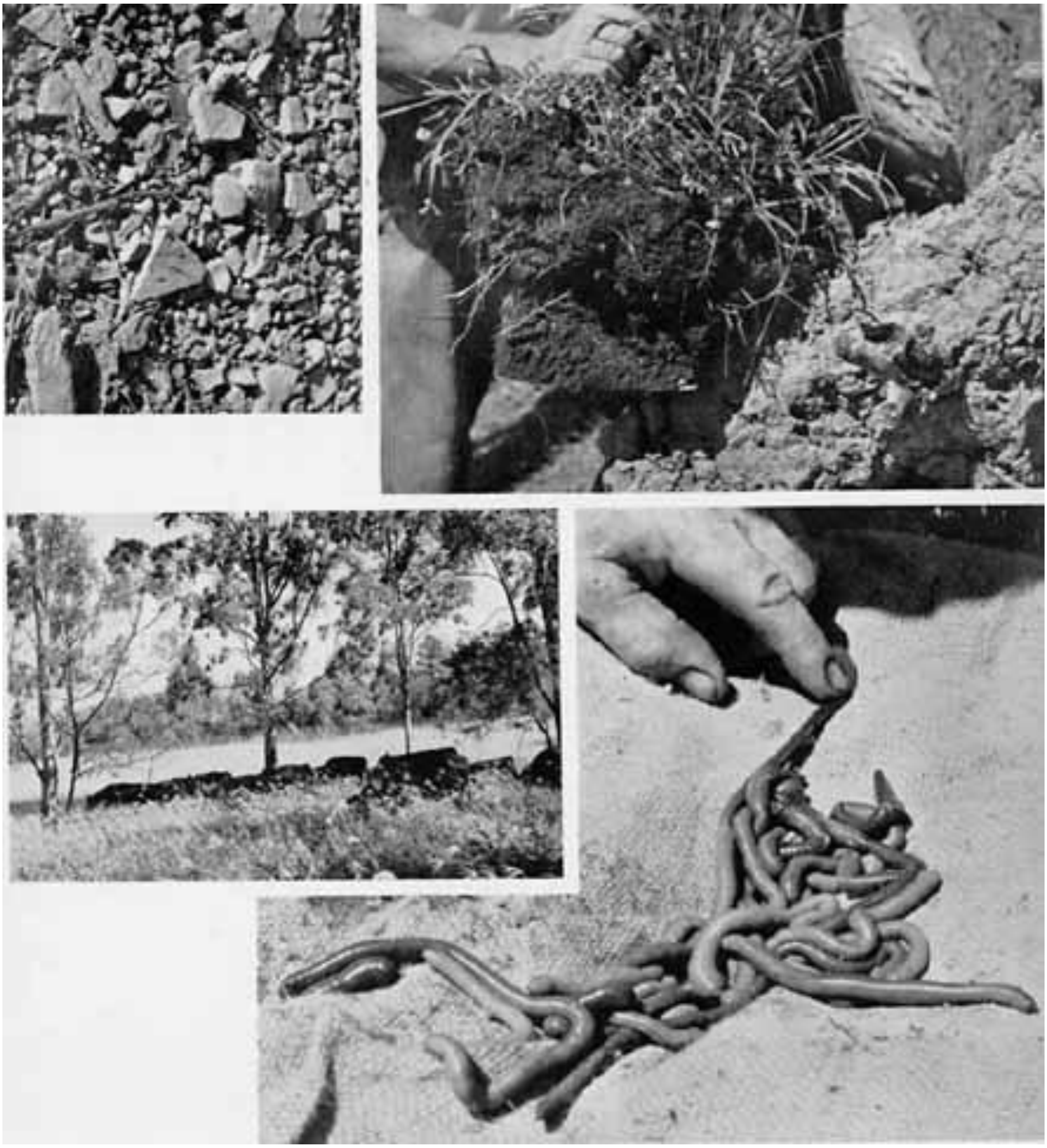


Plate 30 (above)

SOIL--THE FOUNDATION OF LANDSCAPE

Almost any earths, with the exception of extremely hard rock, can be transformed into fertile soil in a very short space of time. The best association of the factors of moisture, warmth and air rapidly break down these materials, allowing soil to form.

Upper left shows the condition of large areas of "Nevallan", which had lost the soil and subsoil with shale showing on the surface.

Upper right: The development of soil which took place in three years from the material seen as on the upturned tree roots. The agency of the improvement was again the better association of moisture, warmth and air in the soil.

Lower left: The new landscape, on the worst soil-eroded area of any of our properties, is founded on the improving soil.

Lower right: Earthworms commenced to multiply rapidly after the end of the second year of Keyline on "Nevallan".

Plate 31 (above)

TREES AND THE PERMANENT LANDSCAPE

Native Australian trees grow rapidly or slowly according to the condition of their soil climate.

On a property being Keyline improved, the growth of the trees will reflect the development of the improving soil and play an important part in the new landscape.

Upper left: Spotted gums planted as six-leaf seedlings in 1955, photographed March, 1958. The taller man is six feet two inches high.

Upper right: "Nevallan", the naturally short-lived black wattles, seen between the planted belts, have reached their peak and are dying off and will be removed this year. Our planted tree belts replace them, becoming effective wind breaks. They are long-living and produce valuable timber.

Lower left: Author's sons illustrating eighteen-months growth of a tree belt containing one thousand Tallowwoods.

Lower right: A spotted gum of one of our planted five-row tree belts, four and a half years after planting.

Plate 32

THE NEW "NEVALLAN"

Plate 32 (above)

THE NEW "NEVALLAN"